Chapter 6. Environmental Factors Affecting Project Viability

This chapter summarizes information on various environmental issues that could affect project viability. Some of this information was derived from a workshop held on July 26-27, 2005, to evaluate risks from proposed alternatives with respect to eutrophication, dissolved oxygen, and selenium issues. Several reports (Amrhein, 2005; Amrhein and Anderson, 2005; Anderson, 2005; Horn and Holdren, 2005; Robertson, 2005 [see also Robertson and Schladow, in review; Robertson et al., in review]; Schladow, 2005; Setmire, 2005), were produced for the workshop and are included as appendices to this report.

Additional information impacting the viability of various alternatives was also considered by Reclamation. This information addresses dissolved oxygen demands, (Ruane, 2006), the Salton Sea Authority Plan for Revitalization of the Salton Sea (Walker, 2006), and three dimensional hydrodynamic modeling (S.G. Schladow, in preparation). Papers that include this information are included as appendices to this report.

All of the alternatives currently under consideration, including the No-Project Alternative, have potentially serious environmental consequences with respect to eutrophication, dissolved oxygen, selenium, and fish and bird health. It is likely that some combination of treatment, mitigation, and/or active management will be required to minimize adverse environmental impacts of the project, regardless of which alternative is selected.

With all of the alternatives, a salinity spike to at least 93,000 to 123,000 mg/L is projected to occur during the transition period (2006 to 2023) from the current Sea to a new equilibrium state. This salinity spike will primarily occur due to the anticipated termination of mitigation water to the Sea in year 2017. This salinity increase will eliminate the existing fishery and will require re-establishment of a new fishery. The loss of the fishery is also likely to cause at least a temporary relocation of fish-eating birds.

All configurations of a smaller Sea are projected to be more eutrophic than the current Sea, as existing nutrient loads enter smaller bodies of water. Water conservation and transfer efforts will further increase concentrations of nutrients and other pollutants entering the Sea. As a result, the remaining Salton Sea and created habitat features are likely to face problems with high algal productivity and subsequent low dissolved oxygen levels.

Selenium would be of increasing concern, regardless of the alternative chosen. All options would expose currently-buried sediments, which increases selenium solubility and mobility and the risk of bioaccumulation in food chains. Like phosphorus (P), selenium concentrations are expected to increase as result of shrinking receiving waters and rising concentrations in inflow waters resulting from water conservation measures. All of the alternatives, except for the No-Project Alternative, would create extensive brackish water impoundments (i.e., sediment detention ponds and habitat ponds) that are of concern with respect to selenium. The conveyance channels required for the alternatives would further increase risks due to selenium exposure.

Another area of significant concern with respect to the viability of each of the restoration alternatives is fugitive dust and exhaust emissions from construction and maintenance equipment and vehicles. It is expected that all alternatives (not including the No-Project Alternative) would result in emissions that exceed thresholds established by regulatory agencies. Both Imperial and Riverside Counties already hold status designations of “non-attainment” related to Federal and State of California PM_{10} air quality standards (DWR, 2006). Reclamation acknowledges that construction emissions could affect the timing and duration of construction and maintenance of any restoration alternative.

However, for the purposes of this study, it was assumed that the construction and maintenance of all the restoration projects could be permitted such that the timing and duration would not be affected.

Future Inflows

The viability of each alternative is dependent upon whether or not there would be enough inflow to the Salton Sea to sustain that alternative. The Salton Sea has no assured water supply for the future. As a result, each restoration alternative would be exposed to risks associated with the uncertainty of future inflows. Each of the restoration alternatives included in this study was modeled using a risk-based approach to inflows. In this approach, the full ranges of uncertainty in each of the major inflow sources were considered without assigning specific probabilities of occurrence or specific actions that might contribute to the uncertainty. This method was developed and coordinated with modeling studies currently ongoing within the California Department of Water Resources. The same type of approach to future inflows and alternative modeling is being used by DWR. More complete descriptions of the risk-based approach to inflows and results of that modeling were included in Chapter 4. The viability of each of the restoration alternatives, with respect to inflows, is also discussed in Chapter 4.

Eutrophication

The Salton Sea has been eutrophic for many years. The high productivity was responsible for the very high fish populations that were found during extensive surveys in 1999 and 2000 (Reidel et al., 2002), but it also leads to adverse consequences. The most obvious problems related to eutrophication are the periodic low dissolved oxygen concentrations caused by the decomposition of organic matter in the Sea, and high sulfide levels created by bacterial sulfate reduction when oxygen levels drop.

Nutrient ratios indicate that phosphorus is the nutrient limiting algal growth in the Sea, and efforts to control eutrophication should concentrate on reducing P inputs (Holdren and Montaño, 2002). Phosphorus concentrations in the Sea changed very little between 1968 and 1999, in spite of an increase in P loading of about 55 percent (Holdren and Montaño, 2002; Robertson et al., in review). Co-precipitation with calcite represents a permanent removal mechanism for P (Amrhein, 2005), so the Sea may respond positively to P reductions. Because the Sea did not respond to loading increases between 1968 and 1999, possibly as a result of internal P loading, reductions of more than 60 percent may be necessary to improve the existing eutrophic conditions. This also indicates that proposed TMDLs and other treatment options could have little impact unless P loads are drastically reduced by 60 percent or more. The response of a modified Salton Sea to changes in P loading is a major uncertainty for the restoration effort.

Recent monitoring indicates that the Salton Sea may have already passed a critical point with respect to eutrophication. Corvina and pile worm numbers have been drastically reduced in the last few years (Crayon et al., 2005; Hurlbert, 2005), and those organisms may already be disappearing from the Sea most likely due to salinity increases and dissolved oxygen problems.

Results of Reclamation monitoring in 2004 and early 2005 may also provide an indication that Tilapia populations are collapsing. Chlorophyll a concentrations, a measure of primary productivity, have increased dramatically. Chlorophyll a concentrations increased from about 40 micrograms per liter (µg/L) in 1999 to an average of 102 µg/L from 2004-2006, which may be an indication that grazing by Tilapia has been greatly reduced. Total phosphorus concentrations also increased from an average of 69 µg/L in 1999 to 114 µg/L from 2004-06. A decline in populations of fish and other macro-organisms, such as pile worms and barnacles, provides an explanation for this increase. Phosphorus that was previously locked up in fish tissue may now be present as algal biomass. Unlike phosphorus in macro-organisms, phosphorus in algal cells would be included in total phosphorus analyses. It should be noted that the 2004-2006 averages are based on quarterly sampling instead of the more intensive sampling that took place in 1999.

Water will be conserved and inflows to the Sea will decrease under the Quantification Settlement Agreement (QSA), but most of the existing pollutant load will still enter the Sea in a more concentrated form because water reductions are expected to be much more significant than pollutant reductions. As a result, significant reductions in P loading are not expected as water inputs to the Sea decrease. Modeling results (Robertson, 2005; Robertson and Schladow, in review) indicate that phosphorus levels in the Sea are expected to increase under all proposed alternatives, as most of the existing P load enters a much smaller volume of water, and that eutrophication will be as bad, if not worse, than under existing conditions as high P loads enter smaller volumes of water.

Walker (2006) proposed target inflow concentrations of 80-200 µg/L to meet an in-lake phosphorus concentration of 35 µg/L that is consistent with the goals of a proposed phosphorus TMDL. Achieving these targets would require reductions in total phosphorus inflows of 75-90 percent. The technology exists for reducing phosphorus by these amounts, but implementation of best management practices (BMPs), treatment wetlands, and other watershed measures are unlikely to meet TMDL goals in the absence of other, more advanced treatment methods.

Evidence indicates that TMDLs/BMPs are unlikely to reverse eutrophication or to have measurable impacts on in-lake phosphorus concentrations in large systems such as the Salton Sea (Personal communication, Roger Bachmann, University of Florida). Additional evidence is provided by projects that have already been implemented in the Imperial Valley. A silt/sedimentation TMDL was implemented (in 2003) to control particulate runoff, and presumably phosphorus, along with various agricultural BMPs to control phosphorus. While these projects should have theoretically reduced the amount of silt and phosphorus in the New and Alamo Rivers, Reclamation's monitoring has not shown significant reductions in either phosphorus or suspended solids loadings to the Salton Sea. In fact, phosphorus and suspended solids concentrations from Reclamation's monitoring of the New and Alamo Rivers from 2004-2006 (sample size: n=11) are not statistically different from those measured in 1999 (n=18). Alamo River orthophosphate and total suspended solids concentrations were slightly lower in 2004-2006 than in 1999, but Alamo River total phosphorus concentrations and New River orthophosphate, total phosphorus, and total suspended solids concentrations were all higher in 2004-2006 than in 1999. All differences were within one standard deviation of mean values and the differences are not viewed as significant. This supports the argument that implementation of BMPs alone will not likely have a measurable impact on eutrophication.

Even if watershed projects are able to reduce phosphorus loadings to the Sea, the addition of treatment plants to remove phosphorus is likely to be required to reduce P loadings to the point where eutrophication is no longer a problem. Because of the volume of water involved, such treatment plants would need to be on the scale of the largest existing treatment plants in the United States. As a result, construction and operational costs and associated benefits would need to be carefully evaluated.

The trophic state of a lake is a relative expression of the biological productivity of a lake. The Trophic State Index (TSI) developed by Carlson (1977) is among the most commonly used indicators of lake trophic state. Use of the TSI permits comparisons among different lakes and also allows managers to track progress of restoration projects. The TSI can be calculated from total phosphorus and chlorophyll a concentrations and from Secchi depth. The TSI is calculated on a logarithmic scale of relative trophic state, with most values ranging from 1 to 100. Increasing values for the Trophic State Index are indicative of increasing productivity. A TSI of less than 35 indicates oligotrophic conditions, a TSI between 35 and 50 indicates mesotrophic conditions, and a TSI greater than 50 indicates eutrophic conditions. Hypereutrophic, or excessively productive, lakes have TSI values greater than 70.

Total phosphorus was used for this analysis because phosphorus is the limiting nutrient in the Salton Sea and because phosphorus models are more advanced than models for most other water quality variables. The TSI for total phosphorus in the Salton Sea was calculated for existing conditions based on 1999 data from Holdren and Montaño (2002) and for the proposed alternatives from phosphorus modeling conducted by Robertson (2005).

Results for the Salton Sea summarized in **Table 6.1** indicate the Sea will progress from its current eutrophic state to a hypereutrophic state (TSI $\geq$ 70) for all alternatives, except for Alternative No. 3 at the high inflows, under the expected range of inflow volumes and resulting depths. Note that all phosphorus concentrations listed in **Table 6.1** are within the range of concentrations already observed at the Sea.

Table 6.1 Calculated TSI for Salton Sea Alternatives

Alternative	Total P (µg/L)		TSI	
	Low Flow[1]	High Flow[2]	Low Flow[1]	High Flow[2]
Current Salton Sea (1999)	69		65	
Alternative No. 1 – Mid-Sea Dam with North Marine Lake	94	95	70	70
Alternative No. 2 – Mid-Sea Barrier with South Marine Lake	152	147	77	76
Alternative No. 3 – Concentric Lakes	131	91	74	69
Alternative No. 4 – North Marine Dam with Marine Lake	145	141	76	76
Alternative No. 5 – Habitat Enhancement without Marine Lake[3]	131	98	74	70
Alternative No. 6 – No-Project	N/A			

[1]Assumes lower 95 percent of volumes, inflow = mean - one standard deviation
[2]Assumes upper 5 percent of volumes, inflow = mean + one standard deviation
[3]Conditions in habitat ponds

The results in **Table 6.1** do not include any as yet unquantified reductions in phosphorus loadings that may occur through implementation of agricultural BMPs or construction of treatment plants to remove P from water flowing into the Sea.

Selenium

Selenium is an important consideration in aquatic fish and wildlife studies because of bioaccumulation. Bioaccumulation is a process involving the biological sequestering of a substance within an organism. Sequestering results in the organism having a higher concentration of the substance than the concentrations in the organism's surroundings. Although selenium can be acquired through the gills or skin, dietary exposure is the dominant uptake pathway in animals. The largest "step" in the bioaccumulation process occurs when selenium concentrations go from parts per billion (ppb) in water to parts per million (ppm) in plants and invertebrates. As additional layers, or trophic levels, of fish and wildlife feed on the levels below, selenium can reach concentrations resulting in reproductive impairment or death.

Selenium Risk to Aquatic Birds

Selenium can bioaccumulate in aquatic food chains until it reaches levels that can adversely affect fish-eating and invertebrate-eating birds. For example, reproductive toxicity is exposure responsive, meaning the higher the concentration, the greater the effect. Because a great many variables interact on the food chain, it is difficult to predict a response given various selenium concentrations in water, sediments, primary and secondary producer, etc. The embryo is the most selenium-sensitive stage in a bird's life cycle, and egg concentrations have become the assessment standard for risk. Egg concentrations avoid the uncertainties mentioned above for various environmental concentrations and permit the identification of a reproductive toxicity threshold.

The reproductive toxicity threshold for bird eggs is about 10 micrograms per gram (µg/g) dry weight (Heinz, 1996). At this concentration, the most sensitive indicator of reproductive toxicity—reduced egg viability (hatchability)—begins to appear and can be measured. The 10 µg/g is a general value for all birds, with some species exhibiting reduced egg viability at lower concentrations. For example, the threshold (EC_{10}) for reduced egg viability for black-necked stilts is 6 µg/g (Skorupa, 1998). Skorupa (1998) evaluated data from evaporation ponds in the Tulare Basin, California, and estimated that the reduced egg viability threshold for black-necked stilts can occur for birds associated with about 4 µg/L selenium in impounded water. Deformed embryos (teratogenesis) do not usually appear until higher egg selenium concentrations occur. For example, Skorupa (1998) estimates the egg threshold (EC_{10}) selenium concentration for teratogenic effects in stilts at about 37µg/g . Sensitivities to selenium are species specific with black-necked stilts generally considered a moderately sensitive species. Other species are less sensitive to selenium (e.g., American avocet), while some species are more sensitive (e.g., mallard duck).

The Risk Standard

This assessment attempts to characterize, to the extent possible, the risk of increased bioaccumulation of selenium in both fish-eating and invertebrate-eating birds from various components of the six evaluated restoration alternatives. The negative impacts of interest from increased bioaccumulation of selenium deal with egg viability. Egg viability is the most sensitive measure of reproductive impairment and can be determined from statistical studies of egg clutch viability and selenium levels within the eggs. Reduced viability reduces potential recruitment into local and regional populations. Although not as dramatic a response as teratogenesis, reduced egg viability also results in fewer young produced.

A potential increase in bioaccumulation is important because aquatic birds using the Salton Sea may be on the threshold of reproductive toxicity from selenium levels. Bird eggs from the Salton Sea had selenium concentration of 1.6-35 µg/g (Setmire et al., 1993), and black-necked stilts—a species moderately sensitive to selenium—experienced an estimated 5-percent reduction in egg viability linked to selenium in 1993 (Bennet, 1998; Skorupa, 1998).

This assessment attempts to qualitatively identify the status (i.e., stable versus increasing from present conditions) of selenium concentrations based on estimates of anticipated concentrations in water and sediments of individual restoration features. The estimated selenium status is then translated into the risk of reduced egg viability for birds likely to use restoration features. It is assumed that selenium concentrations in water and sediments would be reflected in selenium bioaccumulation in area food chains and, ultimately, in aquatic bird eggs. While this approach permits an assessment of alternatives, it is a generalized approach and lacks predictive precision. Too many uncertainties surround future selenium concentrations to permit a more quantitative approach at this time. Reclamation and USGS are currently studying a 100 acre shallow habitat complex and selenium bioaccumulation issues. This complex is located at the south end of the Salton Sea

The foregoing information is used to assess potential effects to aquatic birds feeding on fish and/or invertebrates produced in alternative features. Assessing these effects is a difficult task in light of the uncertainty that surrounds current alternatives. The assessment is based on the potential ability of alternative components to increase the selenium risk level above existing levels. Existing selenium levels in area food chains appear to be at a threshold for causing negative impacts to selenium-sensitive and moderately-sensitive species (Setmire et al., 1993). Any increase above these levels would be cause for concern.

Alternative Assessment: Assumptions

The cycling of selenium within the Salton Sea system involves a number of complex interactions among physical, chemical, and biological components. Some of these interactions are understood, and others are not. Thus, in order to conduct a viability assessment on the selenium risk to aquatic birds, it is first necessary to define a series of assumptions that would serve to establish boundaries for the Salton Sea system and its components of the future.

These assumptions attempt to characterize, to the extent possible, parameters that may affect the concentrations of selenium in future alternative components. Given the above uncertainties, the following assumptions are identified for the purposes of this analysis:

- Selenium levels would increase in rivers and drains empting into the Salton Sea (or future restoration features) as dilution water (tailwater) is reduced.
- Shallower marine lakes—because of a smaller-cross sectional area and shorter fetch—would be less prone to sediment re-suspension and wind/wave mixing.
- A marine lake could experience extensive stratification.
- Bacterial reduction in the bottom sediments would continue for some time.
- Salinity concentrations would continue to increase until they reach a level that negatively affects existing primary producers.
- Phosphorus would continue to increase under any alternative from present conditions until a state of very low inflow is reached (Robertson, 2005; Robertson and Schladow, in review).
- Primary producers would continue to remove selenium from the water column to a level of 1-2 µg/L, or somewhat higher until salinity levels reach a level that disrupts and/or reduces the current assemblage of micro-organisms (including bacteria). This disruption would likely continue until salinity levels stabilize at a lower level.

Although the above assumptions define a system in which selenium is trapped in bottom sediments of deep eutrophic marine lakes, the uptake and bioaccumulation of selenium by primary producers would likely increase because of higher concentrations entering the system from tributaries and drains. Cohen and Hyun (2006) predicted that expected changes in hydrodynamics and sediment resuspension could also dramatically reduce, or even eliminate, the Sea's current ability to sequester incoming Se, which would result in increases in Se concentrations in the Sea, in aquatic organisms, and in birds.

In addition, it is reasonable to assume that increasing salinity would act to reduce the current assemblage of micro-organisms that play a key role in selenium cycling in the Salton Sea. Such a disruption may lead to higher selenium levels in marine lakes and brine basins until salinity levels stabilize. If such situations develop, they could translate into a high-risk level of increased selenium bioaccumulation for aquatic birds.

Se concentrations in the Alamo, New, and Whitewater Rivers are currently in the range of 2 to 6 µg/L (Holdren and Montaño, 2002), a level generally believed to represent a toxicity threshold (**Table 6.2**). These concentrations will increase in the future as conservation measures are implemented. IID (2002) projected that Se concentrations in river inflows could increase by up to 46 percent as a result of reductions in tailwater drainage and operational losses. A panel of experts convened by the Salton Sea Science Office in 2003 (Selenium and the Salton Sea, undated) projected that conservation, water transfers, and desalination could result in Se concentrations in the New and Alamo Rivers of 12 to 36 µg/L. Furthermore, concentrations in puddles on exposed playa could exceed 1,000 µg/L, a level far exceeding the concentrations found at Kesterson Reservoir. Finally, Setmire (2005) suggested that the flow in the New and Alamo Rivers would be composed almost entirely of subsurface drainwater after all tailwater and operational loss is eliminated and flow from Mexicali is significantly reduced. Under those conditions, Se concentrations in the Alamo River are expected to approach the median concentration of 28 µg/L found in sumps and gravity tile outlets throughout the Imperial Valley (Setmire et al., 1993; Setmire and Schroeder, 1998).

Table 6.2 Selenium effect levels (U.S. Department of the Interior, 1998)

Medium	No Effect	Level of Concern	Toxicity Threshold
Water (parts per billion, total recoverable)	<1	1-2	>2
Sediment (ppm, dry weight)	<1	1-4	>4
Dietary (ppm, dry weight)	<2	2-3	>3
Waterbird eggs (ppm, dry weight)	<3	3-6	>6
Warmwater fish (parts per million, whole body dry weight)	<3	3-4	>4
Coldwater fish (ppm, whole body dry weight)	<2	2-4	>4

Although the magnitude of the increase in selenium concentrations may be open to debate, there is no argument that flows to the Salton Sea will be reduced. As a result of those reductions in inflow, less dilution water will be available and selenium concentrations in surface waters in the Imperial Valley will increase. Selenium concentrations are already at or above the 5 µg/L level that the Environmental Protection Agency (EPA) recommends for protection of aquatic life and will almost certainly be well above that level following the planned diversions and water conservation measures. Furthermore, EPA may be reducing this level to 2 µg/L in the near future. Reclamation believes that it is reasonable to assume that selenium concentrations could present a health risk to aquatic life.

Several authors have published similar guidance with minor variations in values. All indicate a small range of values between "no effect" and "toxicity threshold" levels.

It appears that biological uptake, with subsequent deposition, is currently sequestering most Se entering the Sea, resulting in Se concentrations <2 µg/L, and the anoxic conditions in the sediments prevent this Se from being oxidized and mobilized through the food chain. Although Se concentrations are expected to increase in water entering the Sea as water conservation measures are implemented, Se should remain low in the low-oxygen marine environments created.

For the shallower, SHC and concentric lakes with higher concentrations of DO created under Alternative Nos. 1, 2, 3, 4, and 5, the uptake and bioaccumulation of Se by primary producers would likely increase because of higher Se concentrations entering the system from tributaries and drains. In addition, it is reasonable to assume that increasing salinity in downstream SHC areas and concentric lakes would act to reduce the current assemblage of micro-organisms that play a key role in Se cycling in the Salton Sea. Such a disruption may lead to higher Se levels until salinity levels stabilize. This same disruption may occur in the marine lakes and brine pools. If such situations develop, they would translate into a high-risk level of increased Se bioaccumulation for aquatic birds.

Opportunities for bioaccumulation of selenium would increase under those options that create extensive amounts of fresh to brackish water with higher concentrations of dissolved oxygen, and these impacts are discussed in other sections of this chapter. Alternative Nos. 1, 2, 4, and 5 all include creation of habitat ponds. Unless adequate mitigation can be provided, water entering SHC and concentric lakes may need to be treated to remove Se to make those areas safe for wildlife. Unfortunately, no current, proven technologies are available that are capable of treating the large volumes of water that will continue to enter the Sea.

More research is needed to determine whether or not the Kent SeaTech, ABMet, or other processes are capable of providing the necessary treatment. As an alternative, additional mitigation habitat could be created to help compensate for damages to wildlife resulting from increase selenium concentrations. Additional research will be needed in this area.

Fishery Sustainability

Maintaining a marine fishery is a goal of all alternatives except Alternative No. 6. As noted previously, all alternatives are expected to reach salinities of at least 93,000 to 123,000 mg/L during the transition from the current Sea to a new equilibrium state. This salinity spike is primarily due to cessation of mitigation inflows in year 2017. This salinity spike would eliminate the existing sport fishery and require the establishment of a new fishery once equilibrium was achieved.

Under existing conditions, low dissolved oxygen concentrations appear to be the major factor adversely impacting the Salton Sea fishery. The low dissolved oxygen levels have led to massive, periodic fish kills resulting in the loss of millions of fish during major episodes. With eutrophication expected to increase, dissolved oxygen will continue to be of major concern under all alternatives.

Increasing salinity, temperature fluctuations, and increases in selenium concentrations may also have adverse impacts the Salton Sea fishery in the future. In fact, recent, unpublished reports from the California Department of Fish and Game indicate that *Tilapia* may already be the only sport fish remaining in the Sea at the current salinity level of 48,000 mg/L. No corvina, croaker, or sargo have been captured during routine fish sampling events for the past two years, and increases in salinity have been suggested as a possible explanation for this observation.

Dissolved Oxygen

A dissolved oxygen risk assessment model (Horn and Holdren, 2005) shows that there is a potential for dissolved oxygen levels to drop below 4 mg/L in the upper 3 meters (m) of the water column over 60 percent of the Sea's surface on any given night during the summer under current conditions. Similar results were predicted under most of the alternatives, indicating that low dissolved oxygen concentrations would continue to be a problem for fish in the Sea.

UC Davis Hydrodynamic Modeling Results

Because of the importance of dissolved oxygen concentrations on maintaining a marine fishery, the one-dimensional hydrodynamic model, DLM-WQ, was used to evaluate the hydrodynamics of the Salton Sea under various alternatives (Schladow, 2005). This model was recently used to model the eutrophic state of the current Salton Sea on behalf of the Regional Water Quality Control Board. The extent of thermal stratification predicted by the model allows informed decisions about the likelihood and extent of anoxia, hydrogen sulfide (H_2S) and ammonia (NH_3) formation.

Two sets of simulations were run to examine the Sea's response under modified flow conditions. In both sets of simulations, the inflow to the Sea was assumed to be 800,000 acre-feet per year. In the first set of simulations, the geometry of the Sea was preserved, but the initial water depth was altered to five depths of 14.9 meters, 14 meters, 12 meters, 10 meters, and 8 meters. The results indicated extensive stratification at depths of 14.9 meters and 14 meters, but only a weak and short stratification period for the 12-meter depth. Thermal stratification was virtually eliminated throughout the year for the 10 meter and 8 meter cases, implying that there would be very limited episodes of hypoxia and the production of H_2S and NH_3 for full Sea depths less than 10-12 meters.

In the second set of simulations, the effect of dividing the Sea with a dam or barrier was explored by reducing the lake volume by 50 percent at all depths. While particular Reclamation scenarios are a little different than this, the difference to the physics of the Sea is expected to be small. The results are expected to be similar whether the residual Sea was in the north or the south.

Within the model, the effect of halving the area of the Sea was dramatic. The model showed that thermal stratification was intense and persistent, with the formation of a very sharp and intense thermocline commencing at a depth of about 4 meters below the surface. Depending upon the selected inflows and water clarity, model projections indicate that the water column in a divided Sea will be homogeneous for only 13 to 47 days per year, compared to 206 to 265 days for the full-sized Sea. The primary explanation for these modeling results is that the primary mixing mechanism for the current Sea, turbulent kinetic energy due to shear production, is greatly reduced with the smaller fetches and surface areas for the divided Sea alternatives.

A main consequence of this type of stable stratification, as predicted by the model, is that the Sea will switch from a polymictic system, with several mixing event per year, to a monomictic system, which is mixed for a relatively brief period in the winter. As a result of this model predicted stability and the expected continuing eutrophication, the hypolimnium of the Sea will be anoxic for most of the year. With extensive anoxia (as predicted by the model), H_2S and NH_3 could build up to unprecedented levels because there could be little opportunity for venting during the stratification period.

If the breakdown of stratification was rapid, it would lead to a sudden redistribution of anoxia, H_2S and NH_3 throughout the water column and to gaseous NH_3 and H_2S to the air. The effect of this could be an annual die off of most fish in the Sea and serious odor problems. There are also potential human health impacts, including headache and nausea, as well as more serious problems for sensitive individuals. While no other depths were examined, this result should be the same for all depths greater than 10 m. Sediment re-suspension studies (Anderson, 2005) supported the results of the hydrodynamic model. Mixing is affected by lake morphometry, and a sediment transport model developed by

Hakanson (1982) indicated sediment transport and resuspension would be curtailed by those alternatives that divide the current Salton Sea.

Because of the serious implications of the prolonged stratification predicted for a smaller Salton Sea, three-dimensional modeling was performed for the California DWR (Schladow et al., 2006). The three-dimensional modeling generally confirmed the results of the one-dimensional model. Prolonged stratification still occurred for smaller Sea configurations. Wind direction had a larger impact that expected, however, and results indicated a need for additional climatological data to provide an understanding of yearly variability in mixing events. This may provide an indication of the frequency of catastrophic mixing events following prolonged stratification periods. This three-dimensional modeling work is currently being documented in a paper being prepared for California DWR by S.G. Schladow, W. Fleenor, and E. Chung.

Oxygen Demands

Results presented by Amrhein (2005) indicate that the Sea currently generates about 75,000-78,000 metric tons of sulfide per year. Of this, about 7,000 tons of sulfide is precipitating as iron minerals, based on input of readily reducible iron on the suspended solids. Dividing the difference of about 70,000 metric tons of H_2S by the current volume of the Sea of 7.6 million acre-feet of water results in a sulfide concentration of 7.5 mg/L. Since 2 moles of O_2 are required to oxidize 1 mole of H_2S, sulfide oxidation alone could consume 14.5 mg/L of dissolved oxygen when the Sea mixes each year. This concentration is far higher than dissolved oxygen saturation levels in the Sea. Although this calculation is based on limited information, the results indicate the possibility that all oxygen could be eliminated by the predicted annual mixing events.

An analysis by Ruane (2006) found that oxygen demands in the Salton Sea were the largest reported in that author’s experience, which includes study of more than 110 large reservoirs. Oxygen demands in the Sea originate from the decomposition of organic matter (algae) in the water column. When there is sufficient organic matter to consume all available oxygen during the decomposition process, bacterial processes then consume sulfate and nitrate, producing hydrogen sulfide and ammonia. In addition to oxygen demands in the water column, Salton Sea sediments contribute additional oxygen demand. That sediment oxygen demand could continue to be exerted even if algal growth was reduced in the future by controlling nutrient loadings to the Sea. Sediment oxygen demand could decrease over time in the absence of additional inputs of organic material.

Ruane (2006) calculated the total oxygen demands for the hypolimnion of a south marine lake alternative using the assumptions that the hypolimnetic volume was 1,600,000 acre-feet. This value corresponds to a thermocline originating at 4 meters, which is typical of levels observed during the monitoring program and is also consistent with the thermocline depth predicted by Schladow (2005). The calculated total daily dissolved oxygen demands for the hypolimnion of the Sea ranged from 6.9-9.5 mg/L per day over the ranges of observed data and assumptions made, which equates to a daily oxygen demand of 15,000-21,000 tons that would have to be satisfied by external means to prevent the possibility of fish kills under future conditions.

Because of the concerns over eutrophication and stratification, all alternatives were rated as at least serious with respect to fishery sustainability (**Table 6.4**). Serious risk implies that problems create significant threats that may be tolerable with significant mitigation measures in place.

Methods for Increasing Dissolved Oxygen Concentrations

Five conceptual approaches could be used to reduce risks associated with low DO levels in the Salton Sea: (1) reduce nutrient inputs to a level that would lower algal productivity to acceptable levels, (2) avoid deep water to improve the efficiency of wind mixing, (3) mechanically circulate Sea water to improve reoxygenation, (4) use aeration/oxygenation/ozonation to directly increase DO concentrations, and (5) pump water out of the Sea and treat it by ozonation/oxygenation before returning the treated water to the Sea. Each of these approaches potentially has serious limitations and flaws.

The current (2000) phosphorus loading to the Salton Sea is estimated at 1,450,000 kilograms per year (kg/yr) (Robertson et al., 2006). Although a significant amount of this loading (30-40 percent, depending upon the loading numbers used) can be attributed to wastewater treatment discharges from Mexicali and Imperial County, the majority of the phosphorus loading to the Sea comes from nonpoint sources. As noted previously, Walker (2006) proposed a 35-µg/L goal for in-lake phosphorus concentrations, which would require reductions of 75-90 percent for current phosphorus inputs to the Sea. It would be extremely difficult to achieve reductions of this magnitude. The Salton Sea Authority (2006) recognizes these needs for significant reductions in phosphorus loadings and they have proposed including agricultural BMPs, treatment wetlands, removal of wastewater treatment plant effluents, and a 380 million gallon per day (MGD) chemical treatment followed by solids separation (CTSS) plant in their proposed alternative (Alternative No. 1). There is uncertainty that this treatment may or may not produce the desired results.

The thermodynamic modeling conducted by UC-Davis (Schladow, 2005; Schladow et al., 2006) indicated persistent stratification might be expected for residual Seas with reduced areas at depths greater than 10-12 meters. With the exception of Alternative No.1, all other alternatives have maximum water depths that would be less than this level. While these shallower depths reduce the possibility of extended stratification, increased mixing alone would not prevent oxygen depletion in eutrophic systems, as evidenced by current conditions in the Salton Sea. Unless phosphorus loading is adequately controlled, eutrophic conditions are still expected under all alternatives (**Table 6.1**), even with shallower water bodies.

One method that was considered involved the installation of 200-300 Solar Bee circulators to circulate 15,000 acres of deep water (> 30 feet) to solve the problem associated with low dissolved oxygen and high sulfide concentrations. The largest existing Solar Bee units will treat about 50 surface acres. Based on this, up to 1,700 Solar Bees would be needed to cover the entire surface of the north marine lake. This number of Solar Bees may not be sufficient to meet high oxygen demands and is not likely to circulate the water column. The amount of energy that would be required to overcome thermal stratification would be enormous and likely beyond the capabilities of Solar Bees.

A pilot program evaluated Solar Bee circulators to control odors and improve dissolved oxygen concentrations in confined harbors at the Salton Sea. Installation of three Solar Bees appeared to control odors and improve oxygen in a 32-acre harbor at desert shores, but one Solar Bee was less successful at Varner Harbor. The Varner Harbor installation may have been hampered by lack of circulation within the harbor, as well as other factors. The use of Solar Bees at the Salton Sea would appear to be better suited to smaller installations in protected areas than to larger areas in the main body of the Sea.

Aeration/oxygenation of deeper water is a proven method for increasing dissolved oxygen concentrations in lakes. Because of the size of the Salton Sea, this method was also not expected to be practical, but Reclamation commissioned a preliminary study (Ruane, 2006) to evaluate this method.

As noted previously, Ruane (2006) calculated total daily dissolved oxygen demands for the 1,600,000 acre-foot hypolimnion of a south sea ranging from 6.9-9.5 milligrams per liter per day (mg/L/day). Treating this demand would require 15,000-20,600 tons of oxygen per day and hundreds of miles of porous diffuser line. The estimated present worth of capital and O&M costs ranged from $3.1-5.3 billion for an operation period of 120 days per year. While it is likely that these costs could be reduced by generating oxygen on-site and optimizing the system with respect to treatment periods and volumes, costs for this option would still be extremely high. Other aeration methods are likely to be even more expensive.

The SSA has included a treatment plant using sand filtration and ozonation to remove ammonia, hydrogen sulfide, and organics, and increase dissolved oxygen concentrations in the north marine lake for Alternative No. 1. Ozone is a more effective oxidant than oxygen and would be generated onsite to take advantage of the relatively low power cost from geothermal energy in the area, although pilot testing is ongoing to evaluate this option. A preliminary assessment indicates that the proposed full-scale ozonation plant is significantly undersized. The proposed full scale 400 MGD plant would treat 66 percent of the 700,000 acre-feet per year circulation stream from the north lake to the south lake. The 5-10 tons of ozone per day used in this plant is equivalent to less than 0.1 percent of the daily oxygen demand created in the hypolimnion of the north marine lake. A plant of this size is not expected to significantly increase hypolimnetic dissolved oxygen concentrations in the north marine lake, especially given its proposed location. Additional evaluations could be conducted to optimize treatment times and volumes for aeration/oxygenation systems for the Salton Sea.

Viability of Alternatives Relative to Environmental Factors

None of the current alternatives appear to be free of environmental concerns. In general, environmental conditions are likely to deteriorate, regardless of which alternative is selected. There are significant concerns for all alternatives with respect to increasing Se concentrations and requirements for dust abatement.

In addition to loss of the Sea's fishery during the transition period when salinities will spike at 80,000 to 100,000 mg/L, the new equilibrium state for all alternatives including marine lakes (Alternatives Nos. 1, 2, and 4) is expected to be hypereutrophic, and low DO concentrations are expected without significant, and possibly unattainable, nutrient reductions from the watershed. Eutrophication and low DO levels, high Se concentrations, and fluctuating temperatures and salinities are potential problems in the SHC and concentric lakes created under Alternatives Nos. 1 thru 5.

Establishment of a viable fishery would be difficult under all alternatives with open water. All of the alternatives have significant adverse viability impacts. A progressive strategy that could adapt to changing conditions and new information as the restoration proceeds should be considered. **Table 6.3** summarizes alternative viability study results. This table identifies variability in these results where appropriate. Each viability issue is rated according to the following future risk categories:

- *Fatal*: Nothing can be done to alleviate the problems and issues
- *High risk*: Problems can be dealt with by taking extreme measures that would likely result in other significant problems
- *Serious risk*: Problems create significant threats that may be tolerable with significant mitigation measures in place
- *Moderate risk*: Problems are evident and potentially significant and may require mitigation measures
- *Low risk*: Problems are evident but would not require immediate mitigation measures

A summary of potential viability concerns for each alternative follows.

Table 6.3 Alternative viability assessment summary[1]

Alternative	Se Risk to Fish-eating Breeding Birds	Se Risk to Invertebrate-eating Breeding Birds	Hydrodynamic/ Stratification Risk	Eutrophication Risk	Fishery Sustainability Risk
Alternative No. 1: Mid-Sea Dam with North Marine Lake	Moderate risk	Serious risk	Serious to high risk	Moderate risk	In Sea –Serious to High Risk: Salinity, DO, H_2S, NH_3 In Ponds – Moderate to Serious Risk: DO, temperature extremes
Alternative No. 2: Mid-Sea Barrier with South Marine Lake	Moderate risk	Serious risk	Low risk	Moderate to serious risk	In Sea –Serious to High Risk: DO, temperature extremes, salinity variations In Ponds – Moderate to Serious Risk: DO, temperature extremes
Alternative No. 3: Concentric Lakes	Serious risk	Serious risk	Low risk	Low to moderate risk	Moderate to Serious Risk: DO, temperature extremes
Alternative No. 4: North Sea Dam with Marine Lake	Moderate risk	Serious risk	Low risk	Moderate to serious risk	In Sea – Moderate to Serious Risk: DO, temperature extremes In Ponds – Moderate to Serious Risk: DO, temperature extremes
Alternative No. 5: Habitat Enhancement w/o Marine Lake	Moderate risk	Serious risk	Low risk	In ponds moderate risk	In Ponds – Moderate to Serious Risk: DO, temperature extremes
Alternative No. 6: No-Project	Low risk	Serious risk	Low risk	Low risk	Fatal: Salinity

[1]Risk classified according to the following categories:
Fatal: Nothing can be done to alleviate the problems and issues
High risk: Problems can be dealt with by taking extreme measures that would likely result in other significant problems
Serious risk: Problems create significant threats that may be tolerable with significant mitigation measures in place
Moderate risk: Problems are evident and potentially significant and may require mitigation measures
Low risk: Problems are evident but would not require immediate mitigation measures

Alternative No. 1: Mid-Sea Dam with North Marine Lake

Under Alternative No. 1, the possibility of prolonged stratification, major die-offs of aquatic life, and salinity levels that would be too high to support a viable fishery could exist under the risk-based inflow approach. Eutrophication and hypolimnetic oxygen depletion are expected. Although the exact level of risk is uncertain, Reclamation estimates the risk (as shown in **Table 6.3**) of stratification to vary from serious to high. Existing modeling studies indicate that this risk could be reduced if operating water depths in the marine lake were reduced below 10 m (33 feet) (Schladow, 2005) which would correspond to an operating water surface elevation of -245 feet. Temperature fluctuations in the SHC also would be greater than those currently experienced, which could further limit the establishment of a viable fishery. Areas of potential concern with respect to Se for Alternative No. 1 include conveyance channels, 16,000 acres of created SHC, and the brine pool. The 4,000 acres of treatment wetlands on the New and Alamo Rivers included for P removal are also of concern, as the same processes that remove P could also concentrate Se. Reclamation is currently studying Se issues at existing New and Alamo Rivers wetlands projects. These studies will provide additional insight into potential concerns relative to the concentration of Se in SHCs.

Approximately 103,800 acres of lake playa could be exposed under Alternative No. 1, and it is estimated that 70 percent of this acreage would require dust mitigation by 2040. Reclamation modeling indicates that there may not be sufficient quantities of brine available to use for the treatment method proposed under Alternative No. 1 for AQM.

Alternative No. 1 includes treatment plants to remove P if watershed measures do not remove enough P to reduce eutrophication. The SSA proposed this alternative and the treatment plant but has not provided designs. There is uncertainty that this treatment may or may not produce the desired results and, as such, there exists significant risk of eutrophication.

While Alternative No. 1 also includes ozonation to address DO problems, the amount of treatment proposed may be several orders of magnitude too low to solve the problem. Therefore, there is uncertainty that the ozonation process would be effective.

The treatment plants proposed by the SSA in Alternative No. 1 have not been proven for conditions existing at the Salton Sea. Even if they were to work, the plants would be as large as the biggest treatment plants in the United States.

Alternative No. 2: Mid-Sea Barrier with South Marine Lake

The marine lake in Alternative No. 2 is expected to have hypereutrophic conditions with occasional, severe oxygen depletion. Temperature fluctuations also would be greater than those currently experienced, which could further limit the establishment of a viable fishery. Furthermore, it is expected that it would be difficult to maintain a constant salinity under low inflow conditions in the south Sea formed by the barrier, which could create additional challenges for establishing a viable fishery. Areas of potential concern with respect to Se for Alternative No. 2 include conveyance channels, 21,700 acres of created saline habitat, and the brine pool. Under mean risk-based inflows, approximately 73,600 acres of lake playa could be exposed under Alternative No. 2, and it is estimated that 70 percent of this acreage would require dust mitigation by 2040.

Alternative No. 3: Concentric Lakes

The concentric lakes in Alternative No. 3 are expected to be shallow enough to be subjected to frequent mixing, but some oxygen depletion could still occur during the summer months as a result of the expected hypereutrophic conditions. Temperature fluctuations also would be high under this alternative, creating additional problems for establishment of viable fishery. Se is of particular concern for Alternative No. 3 because each of the lakes would form large shallow water habitats directly receiving and concentrating New and Alamo River water. Se concentrations are expected to be greater than 5 µg /L in each lake. These levels would create significant threats that may be tolerable with significant mitigation measures in place. Under mean risk-based inflows, approximately 65,000 acres of lake playa would be exposed under Alternative No. 3, and it is estimated that 70 percent for this acreage would require dust mitigation by 2040.

Alternative No. 4: North-Sea Dam with Marine Lake

Hypereutrophic conditions with occasional, severe oxygen depletion are also expected to occur under Alternative No. 4. Temperature fluctuations also would be greater than those currently experienced, which could further limit the establishment of a viable fishery. Areas of potential concern with respect to Se for Alternative No. 4 include conveyance channels, 37,200 acres of created saline habitat, and the brine pool. Under mean risk-based inflows, approximately 91,800 acres of lake playa could be exposed under Alternative No. 4, and it is estimated that 70 percent of this acreage would require dust mitigation by 2040.

Alternative No. 5: Habitat Enhancement Without Marine Lake

No marine lake is associated with Alternative No. 5, and any fishery would be restricted to rivers, conveyance channels, and deep pools within the SHC. The shallow depths, expected eutrophic conditions, and fluctuating temperatures in these complexes would further limit creating a fishery. Areas of potential concern with respect to Se for Alternative No. 5 include conveyance channels, 42,200 acres of created saline habitat, and the brine pool. Under mean risk-based inflows, approximately 81,200 acres of lake playa could be exposed under Alternative No. 5, and it is estimated that 70 percent of this acreage would require dust mitigation by 2040.

Alternative No. 6: No-Project

Alternative No. 6, the No-Project Alternative, has no marine lake or created habitat, and has significant environmental concerns. Areas of potential concern with respect to Se for Alternative No. 6 include exposed sediments, river channels, and the brine pool. Under mean risk-based inflows, approximately 92,200 acres of lake playa could be exposed under Alternative No. 6, and it is estimated that 70 percent of this acreage would require dust mitigation by 2040.