Physical and Chemical Limnology of the Salton Sea

Physical and chemical limnology essentially involves all parameters concerning the water quality of the Salton Sea. These include a number of physical characteristics, such as turbidity, suspended sediment load, Secchi depth (a measure of water clarity), circulation or current patterns, stratification, salinity gradients if present, temperature, etc. Chemical limnology, on the other hand, involves parameters relating to the chemistry, composition or distribution of components within the water, such as salinity and other dissolved solids, nutrient content (including chiefly phosphorus and nitrogen), contaminants or pollutants (like selenium and sulfides), dissolved oxygen, pH, major dissolved ions, and others.

Temperature

The minimum temperature for the Sea is usually reached in December or January, with the annual low ranging from 13 to 15 degrees Centigrade. The maximum annual temperature is generally attained between July and September, ranging from 31 (Watts, 1999) to 36 degrees Centigrade (Holdren and Montano, 2000). The temperature of the water in the lake varies from 1 to 3 degrees Centigrade during the cooler months, and 3 to 9 degrees in the summer. The water temperature of the inflowing streams, however, is slightly lower than that of the surface water of the Sea, reaching a collective maximum of 30.5 degrees Centigrade and a minimum of 11.4 degrees (Holdren and Montano, 2000).

The temperature of the Sea is directly responsive to ambient weather conditions, just as the mixing regime is to the wind, as noted in the circulation section of this atlas. Watts and others (2000) found that the low monthly air temperature is approximately 13.5 degrees Centigrade, and is achieved in January, whereas the monthly high of 33.5 degrees is attained between June and August, which correlates well to surface water temperature patterns. Solar radiation, which is directly responsible for heating of the Sea, generally reaches it's maximum a month earlier, but otherwise correlates well to the temperature patterns of both the air and surface waters of the lake.

Watts and others (1999) observed that the Sea displays surprising variability in temperature between different parts of the Sea. These spatial differences are likely due to the large size, bathymetry, circulation patterns and possible salinity gradients in the Sea, especially in the southern basin. Some days the Sea displays little variation in water temperature, but other days, either basin can be significantly hotter or cooler. Holdren and Montano (2000) noted that lake warming was greater on the berm than in either of the two basins of the Sea, which may assist in separating the two gyres. The berm and south basin also show more springtime fluctuation in temperature prior to the general summertime increase, which is probably due to the large influx of freshwater coming into the lake via the New and Alamo Rivers, which both empty into the south basin.

The conditions that control warming versus cooling of the lake can change anytime from July to September, which drives many of the seasonal chemical and physical variations in the Sea. During the cooling period for the lake, daytime warming affects only the top two or three meters of the lake, but frequent mixing during the cooling period also helps the lake maintain a fairly uniform temperature throughout the water column (Watts, et al., 1999).

Salinity and Salinity Gradients

→ move to circulation page.

Salinity and lake elevation both vary seasonally, but are inversely related. Salinity ranges from 41.0 to 44.7 g/l (Watts, et al., 2000), with salinity values peaking in late autumn or early winter when the lake is generally at its lowest elevation. The highest elevation for the lake occurs in early summer when the evaporation rate is at its highest, but this occurs because agricultural runoff is highest during the spring. **[Lake elevation and salinity issues are more extensively discussed in their own sections elsewhere within this atlas].**

The New River delivers the highest concentration of total dissolved solids (TDS) to the Sea of the three primary inflow streams, but also shows the greatest seasonal variation (40%). The Alamo also delivers a considerable TDS load to the Sea, but the Alamo and Whitewater show little seasonal variability in TDS, except perhaps in response to thunderstorm or similar events in the surrounding mountains. The Alamo and Whitewater Rivers, and the Sea itself display only a 10% seasonal variation in TDS content during the year (Holdren and Montano, 2000).

Historical values for salinity and/or TDS are probably up to 4% higher than they would be if measured today due to the lower temperatures previously used for drying samples, which allowed the "occlusion" of water with sediments. This is a typical phenomenon that happens in water with a high sulfate content, such as that of the Salton Sea (Holdren & Montano, 2000).

As noted in the lake circulation section of this atlas, most of the inflowing freshwater streams mix rapidly with ambient salt water, with little or no development of freshwater wedges. In the southern basin of the Salton Sea, however, inflows from the New and Alamo Rivers do form a freshwater wedge in the Sea whose extent is a function of wind conditions and the strength of the lake current. This effect is enhanced by the close proximity and volume of the two inflow sources relative to the other sources (Watts, et al., 2000).

Under windy conditions, the gyre pushes this freshwater "wedge" from the mouths of the New and Alamo Rivers northeastward along the shoreline of the Sea towards Mullet Island and sometimes even to the Wister Unit. This salinity wedge is often two to eight kilometers wide, but stronger winds induce more mixing, reducing the spatial extent of this feature. The strength of the currents in the Sea is also generally at its minimum during periods of low wind activity, just when a strong vertical salinity gradient is likely to be present. Hence, the size and extent of the freshwater "wedge" is variable, with distance from the source requiring more wind, and yet, more wind induces further mixing, which shrinks the size of the "wedge" (Watts, et al., 2000).

Saline stratification is more effective at resisting vertical mixing than thermal stratification, making the south basin more resistant to mixing during periods with calmer winds. Salinity gradients inhibit the flow of oxygen and heat from surface water to bottom water, affecting the distribution of biota and nutrients in the Sea. The majority of nutrients enter the Sea via the New and Alamo Rivers, placing most of the nutrients initially in the south basin. Phytoplankton density is higher and light penetration is lower throughout the year in the area occupied by this fresher water (Watts, et al., 2000).

Total Suspended Solids, Secchi Depth, and Light Penetration

Water in motion can transport material either in suspension, when the solid is dispersed but not dissolved into a liquid medium, or by dissolution, in which the substance is actually broken down and dispersed into the liquid medium. Materials in water remain in suspension as long as the liquid sustains sufficient momentum to keep particles from settling out of suspension. Sediments are generally too heavy to remain in suspension once an inflowing stream loses momentum upon entering a water body in which the velocity of the current is significantly slower. Hence, the sediment load is typically deposited right at the mouths of the inflowing streams, often forming a deltaic structure.

The total volume of sediments and detritus that a stream transports is referred to as Total Suspended Solids (TSS), and the greater the load, the more "turbid" the water is considered to be. Secchi Depth is a scientific measurement of water clarity by measuring the depth at which a white-colored plate can no longer be seen. Light transparency tests are similar, but are actually a measurement of what percentage of light penetrates the water at several pre-defined depths.

The TSS content is very high in the three major tributary streams, as expected, but significantly lower in the Sea itself, which is expected since suspended sediments settle out quickly as the streams empty into the lake. The Alamo and New Rivers remain turbid much of the year, and show little seasonal change, except for a reduction of 15-25% in the fall. This pattern is probably reflective of agricultural practices, which are the source of most of the water for these streams. TSS values vary widely in the Sea, however, because algal cells become a major component of the suspended load. In addition, TSS values in the Sea show more seasonal (higher in winter, lower in summer) and depth-related variations (higher in surface waters, lower in bottom water), also probably due to the additional algal cell content (Holdren and Montano, 2000).

In the Salton Sea, water transparency is a function of distance from inflow sources (which determines remaining sediment load), local plankton density, as indicated by chlorophyll-a concentration, and the quantity of dissolved organic and inorganic matter produced from algal secretions or decomposition (Watts, et al., 1999). Light penetration in the Salton Sea is low, yielding a thin photic zone for the Sea. Light penetration is greatest in the fall, when phytoplankton are at their lowest numbers, and lowest in the spring, when the population is most numerous.

An interesting phenomenon is that the nutrient-rich flows of the New and Alamo Rivers also produce a nutrient-rich wedge, just as they do a freshwater gradient, as noted earlier in this discussion. This gradient shows lesser Secchi Disk readings, but higher phytoplankton density, which is expected since phytoplankton feed on these nutrients (Watts, et al., 2000). An analysis of the Dissolved Organic Carbon in the lake reveals that most of the carbon (78%) is produced in the Sea, and at most, only 22% is generated outside of the Sea (Holdren and Montano, 2000), showing that most biotic organic material is recycling through the food chain.

"pH" Value

This chemical parameter is a measurement of the concentration of free hydrogen ions in a solution, which simultaneously expresses both the acidity and alkalinity of that solution. Values of "pH" range from 0 to 14, 7 being neutral, with numbers descending from 7 indicating increasing acidity, and those greater than 7 denoting increasing alkalinity.

In the Salton Sea, pH values range from 7.3 to 8.8, with the norm being 8.0 to 8.8 (Watts, et al., 1999) whereas the rivers flowing into the Sea show a range from 7.5 to 7.65 (Holdren and Montano, 2001). The pH value in the surface water of the Sea is approximately 8.2, and 8.0 or less in the bottom water. Values of pH tend to be even lower in the bottom water of the Sea when the lake is stratified, and comparable to that of surface water during periods of mixing (Watts, et al., 1999), which is typical of eutrophic systems.

The factors that drive pH variability in the Sea are thermal stratification, and both the photosynthetic and respiration rates, which also affect the dissolved oxygen content. ~~The real importance~~ One factor of pH ~~is that it affects~~ that is the conversion of ammonia ions to ammonia gas, which is one mechanism by which the lake could be relieved of much of its nitrogen load, or denitrified.

Dissolved Oxygen

A critical factor in the ecology of the Salton Sea is the amount of dissolved oxygen available in the water column at any given time, season or depth. The solubility of oxygen is a function of pressure, temperature, and salinity. Dissolved oxygen enters the water through biotic photosynthesis, and spreads throughout the water column by diffusion, but is removed by biotic respiration and reactions with reducing substances, such as hydrogen sulfide (Watts, et al., 1999). Decomposition removes dissolved oxygen, whereas photosynthesis eliminates carbon dioxide.

Temperature and pressure are inversely related to the concentration of dissolved oxygen. As the temperature of water increases, dissolved oxygen levels decline, and as the temperature decreases, more dissolved oxygen becomes available. Similarly, as pressure increases with depth, the dissolved oxygen concentration decreases since the solubility of oxygen also decreases, leaving less dissolved oxygen available. As thermal stratification develops in the water column, an oxygen gradient is often formed, in which there is little or no oxygen available on the lake floor, and yet adequate oxygen to support life at the surface. Mixing events reduce the oxygen content of the entire water column by blending oxygen-rich surface water with oxygen-poor, sulfide-rich bottom water.

Salinity and dissolved oxygen content are also inversely related. As salinity increases, oxygen solubility is reduced. Hence, as the salinity of the Sea has built up since the 1950's, hypoxic (little oxygen present) and anoxic (no oxygen present) events have increased dramatically in frequency, intensity, and duration. In the 1950's, bottom water of the Sea was usually oxic, with anoxic events generally occurring only in August or September, and lasting for a few days at most. Today, such events occur much more frequently at almost any time of year, and are of longer duration with a greater depletion of oxygen.

Each year, during the warming period of the lake, dissolved oxygen content varies greatly, due to limited vertical mixing of the water, removal of oxygen from bottom waters through respiration, and addition of oxygen to surface waters through photosynthesis and diffusion of atmospheric oxygen, the amount of which depends on the degree of wind turbulence. During the cooling period of the lake, dissolved oxygen is better distributed throughout the water column because there is more frequent wind-driven mixing and virtually constant convection. Photosynthesis can also cause peaks of oxygen enrichment in the surface waters of the Sea at any time of year (Watts, et al., 1999).

Strong wind-driven mixing events can produce major fluctuations in the level of dissolved oxygen present in the water column. In some situations, the entire water column can become anoxic or hypoxic from dilution with anoxic, organic detritus-rich bottom water, or from contact with reducing agents like hydrogen sulfide, or by the introduction of "microbial heterotrophs" that consume large volumes of nutrients and oxygen and produce carbon dioxide from respiration. During the summer, 60-100% of the lake bottom has low dissolved oxygen, but in winter, when the water temperature is lower and mixing more frequent, most of the water column has an adequate supply of oxygen to support all biota (Watts, et al., 1999).

The oxygenated layer is usually thicker near the shore of the Sea, probably due to wind-driven turbulence and wave action, friction along the water-sediment interface (on the floor of the Sea) caused by wind-driven currents, convection along the shore from quicker cooling of shallow waters of the Sea at night, and less frequent mixing with sulfide-rich, oxygen-poor bottom water. In fact, these shallower areas of the Sea are less likely to develop an anoxic, sulfide-rich bottom water layer than mid-lake areas. During the warming period of the lake, wind speeds are lower between major wind events, but are still sufficient to generate wave action, surface currents, and nocturnal cooling, but insufficient to induce mid-lake mixing. Hence, shallow water (less than 8 meters in depth) in the nearshore areas can act as a refuge for fish and benthic invertebrates during deoxygenation events. Mixing of the water column often does not affect the shallower parts of the lake, but under the right conditions, currents in the Sea can carry the mixed mid-lake water in towards shore.

All of the inflowing streams show high dissolved oxygen levels as they drain into the Sea, but the best oxygen levels in the Sea itself are found only in the top 5 meters at any given time of year. Bottom water of the Sea can display hypoxic to anoxic conditions anytime from spring to fall, but a windier spring can delay the onset of lake stratification and the resulting anoxic events. The zone of oxygen depletion can also extend to the surface in August and September. Massive fish die-offs often accompany these deoxygenation events, although they are not exclusively caused by anoxia. Dissolved oxygen has been observed at 200% saturation on the surface of the Sea at various times, while simultaneously, no oxygen is present in the bottom water. This vast difference in oxygen availability is typical of a eutrophic system (Holdren and Montano, 2001). **[Please refer to the Biological Geography section for a more complete treatment of the effects of eutrophication and dissolved oxygen depletion on the biota of the Sea.]**

Sulfides

Deoxygenation events consistently occur from July to September, when the water of the Sea achieves its highest temperatures, but occur most frequently in September. Sulfides are usually present when the Sea is thermally stratified, often in concentrations high enough, at least in the mid-lake area (greater than 8 meters depth), to use up all the available dissolved oxygen in the water column without any other reducing agent present. The chemistry and kinetics of sulfide production and oxidation are the true keys to these deoxygenation events at the Salton Sea (Watts, et al., 2000).

Under anaerobic conditions, bacteria use nitrate, metal oxides, carbon dioxide, or sulfates to decompose organic matter. In the Salton Sea, high concentrations of sulfates virtually insure that bacteria use sulfates to decompose organic matter, generating large amounts of sulfides in the process. Thermal stratification assists in accumulating organic matter in the bottom water where anaerobic decomposition can continue to generate sulfides in preparation for future mixing events. Photosynthetic bacteria normally oxidize sulfides produced by decomposition, but these bacteria are restricted to the photic zone, so sulfides continue to accumulate in the bottom water. Wind-driven mixing and convection currents blend bottom and surface water, leaving surface water hypoxic and sulfide-rich. Sulfides have a half-life of 10-50 hours in the laboratory, and when brought to the surface of the Sea, have been observed to remain at levels toxic to mid-lake fish and metazoans for three days or longer.

Sulfide-related odors are one of the most noticeable problems inhibiting recreational uses of the Salton Sea. For example, hydrogen sulfide is the culprit for the smell of "rotten eggs" that permeates the air wherever there is decay. Sulfide concentrations have risen tremendously over the past 50 years, which is probably a result of an increase in the quantity of sulfates coming into the lake and a huge increase in the standing biomass of the Sea. **[Please refer to the Biogeography Section of this atlas for a more complete treatment of the biological productivity of the Sea, and a discussion of nutrient loading in the lake later in this section of the atlas.]**

Major Ions

Total ion concentrations continue to increase at the Salton Sea, but the concentrations of several major ions has not. As the waters of the Sea become saturated with a specific ion, that particular ion begins to be precipitated out of solution as some sort of mineral salt, but only if the other requisite ions are available to create that salt. If the other ions are not available, the ion in question can become supersaturated with respect to Salton Sea water. Sodium, chloride and sulfate are the most abundant free ions available in the Salton Sea, which comes as no surprise, since two of the major chemical problems of the Sea are an overabundance of salt, and the presence of too much sulfate, as we've already discussed in the Salt Story and earlier in the Chemical Limnology of the Sea sections of this atlas, respectively.

Tostrud (1997) reported that the Sea became saturated with bicarbonate ions within one year of the formation of the Sea, calcium ions around 1950, and sodium ions around 1980, resulting in the precipitation of minerals on the floor of the Sea that removed some portion of these ions from solution. Some of the minerals precipitated out of solution are halite (sodium chloride), calcite (calcium carbonate), gypsum (hydrous calcium sulfate), and apatite (a complex calcium phosphate). Carbonate ions are quite low in concentration in the Sea, and are probably the limiting factor in the precipitation of calcium as calcite from the waters of the lake. This means that calcium ions remain available, and since sulfate ions are also abundant, calcium sulfates and calcium phosphates are expected to be precipitated from solution.

At present, the Salton Sea differs from other similar saline lakes in its higher concentration of sulfate ions. From 1907 to 1999, sulfate increased from 13.7 to 24.4% of all ions present in the Sea, but chloride decreased from 48.9 to 40.1% in the same time frame. These changes are attributable to the composition of "hard" Colorado River water used for irrigation in the Salton basin, which contributed 2.5 times more sulfate than chloride to the Salton basin during the lifetime of the Sea. The rate of increase in sulfate concentrations will likely now decline if the Sea has reached a point of saturation with respect to sulfate, which some researchers suspect it has. If the Sea has reached saturation, the increase in the salinity of the Sea will be less than what has been projected because the precipitation of sulfates should begin in earnest, which will reverse the previous observed trends of increasing sulfate and decreasing chloride (Holdren and Montano, 2001).

Heavy Metals, Pollutant Loading

The concentrations of all trace or heavy metals in the Sea was found to be quite low, which is not surprising due to the high concentrations of sulfide, and the low solubility of all heavy metal sulfides. Selenium is an important consideration for all lakes in the southwestern United States, but was found to be well below the level of concern for the aquatic wildlife of the Salton Sea. Nearly all pesticides have been found to be below detection limits in the lake, but this is also expected due to their low solubility in water and the high salt content of the Sea (Holdren and Montano, 2001).

Of the pesticides found in the Sea, most are indicative of historical practices in the region. DDT is one such substance, and it has been identified in many locations around the lake, even though it has not been used in the United States for decades. This may be due to its protracted half-life, and the continued use of such substances in Mexico. Although nowhere in excess, pesticide residues appear to be found in higher concentrations in the south basin of the Sea, which is expected since the south basin is where the majority of agricultural runoff enters the Sea (Holdren and Montano, 2001).

Pollutant loading was calculated to be 3.434 million tonnes per year, which is only 73% of what was reported in the Salton Sea Restoration Plan EIS/EIR (2000). Of that volume, salt loading totaled 3.29 million tonnes per year (Weghorst, 2001). Nutrients comprise the bulk of the remaining pollutant load, and will be discussed in the following section of this atlas.

Geochemical Modeling

Geochemical predictions from modeling indicate the Sea should be supersaturated with respect to calcite, gypsum, magnesite (magnesium carbonate), dolomite (calcium-magnesium carbonate), celestite, huntite and others, and saturated with hydroxyapatite (calcium phosphate hydroxide) as well as fluorapatite (calcium fluorite hydroxide). Precipitation of hydroxyapatite and fluorapatite is considered likely under the current conditions in the Salton Sea, which would be a mechanism by which phosphate could be sequestered in the bottom sediments of the Sea. The importance of such a mechanism will be explained in the Nutrient Loading discussion in the next part of the atlas. Precipitation of calcite and gypsum is expected, but dolomite is not since dolomite deposition is known to occur only under the most saline of conditions. The other minerals are limited by other factors, including the availability and abundance of various ions.

Since sodium, magnesium, potassium and chloride salts are water-soluble, precipitation is expected to be dominated by calcium, sulfate, carbonate, calcite or gypsum. Because of the quantities of ions present, carbonate ions control the formation of calcite and several other minerals, calcium ions control the formation of gypsum, and excess sulfates remain in the water, eventually oxidizing to the sulfides, which act as reducing agents that can deoxygenate the water of the Sea. Assuming all incoming bicarbonate and calcium are precipitated, 39% of the annual salt load is expected to be deposited upon entering the Sea. As a result, the rise in salinity may be blunted due to geochemical constrains (Holdren and Montano, 2001).

Nutrient Loading

Arguably, the second major problem for the Sea after salinity is nutrient loading, which is the accumulation of nitrogen and phosphorus in a variety of forms, most or all of which are generated from agricultural sources which use Colorado River water to irrigate and flush the fields on which chemical fertilizers have been spread. Agricultural wastewater concentrates these nutrients and transports them to the lake for further concentration and interaction in the chemical environment of the Sea. In the last 30 years, nitrogen loading has slowly risen (between 0 and 25%), but total nitrogen has risen dramatically (70-140%). In the same time frame, phosphorus loading at least doubled, but total phosphorus concentrations actually declined.

Nitrogen and phosphorus are the nutrients that limit algal growth under natural conditions, but the relative concentrations of nitrogen versus phosphorus is actually more important than the absolute concentrations of either substance in the growth of phytoplankton communities. Both the inflowing streams and the Sea itself show a high ratio of nitrogen to phosphorus, called the "N:P" ratio. The average N:P ratio for healthy, growing cells is 7:1 by weight. A large N:P ratio (greater than seven) indicates that growth will be limited by the amount of phosphorus present, but a low N:P ratio signifies that growth will be curbed by nitrogen availability. The waters of the Salton Sea shows an N:P ratio ranging from 250-400, showing that, by far, phosphorus is the limiting nutrient to growth in the Sea. However, the ratio of inorganic nitrogen (nitrate, nitrite and ammonia) to soluble phosphate is actually a more effective ratio to measure than total nitrogen versus total phosphorus, because inorganic nutrients are easier to obtain and use by aquatic organisms (Holdren and Montano, 2001).

The Alamo and Whitewater Rivers display higher nitrogen to phosphorus ratios since they are more the product of agricultural return flows than the New River and the other incoming streams. Irwin (1971) reported nutrient concentrations were higher in both the New and Alamo Rivers, but lower in the canals, demonstrating that the nutrients are added to the water through flushing of the agricultural fields. Nitrate and nitrite, which are oxidized nitrogen, are the major forms of nitrogen in the Alamo and Whitewater Rivers (greater than 70%), but ammonia is a much more abundant species than either form of oxidized nitrogen in the New River, possibly as a result of the waters of the New River originating as municipal wastewater. In the Sea itself, oxidized nitrogen is present in concentrations less than 1% of what is found in the rivers, yet ammonia comprises more than one-third of the nitrogen content (Holdren and Montano, 2001). The effects of ammonia will be discussed in the following section.

The key form of phosphate is soluble orthophosphate. The concentration of total phosphorus is approximately 10 times greater in the rivers than in the Sea, but in the rivers, the primary form of phosphorus is soluble orthophosphate. In the Salton Sea, the concentration of soluble orthophosphate is lowest in spring and summer, and highest in winter, while total phosphate concentration is lowest in the fall, and highest in winter, demonstrating that soluble phosphate is critical in feeding the algal blooms that are a major part of the dissolved oxygen and eutrophication problems in the Sea (Holdren and Montano, 2001).

The peak N:P ratios are found during the summer throughout the Sea when algal growth is at its maximum. Within the Sea itself, the central berm between the two basins has the highest N:P ratio, with the south basin retaining a lower ratio compared to the berm and north basin, perhaps due to the greater volume of freshwater inflow into the south basin. The bottom waters of the Sea also retain higher concentrations of ammonia and phosphate than surface waters, indicating the Sea probably has a high rate of internal nutrient loading, which signifies that nutrients are being reactivated from the floor of the Sea, reentering the water column, and thereby are being contributed to support the abundant biotic production of the lake (Holdren and Montano, 2001).

Some mechanism in the Salton Sea is tying up the phosphorus and limiting the usage of nitrogen in the Sea. The currently favored scenario is that phosphorus is precipitated out of solution as hydroxyapatite and a suite of similar apatite minerals, which typically crystallize on the surface of existing calcite crystals. Phosphorus may also be incorporated into fish bones and tissue and in the shells of aquatic invertebrates, which remains in the bone or shell material following the death of the organisms due to the insolubility of hydroxyapatite, permanently removing phosphorus from the water column of the lake.

Ammonia

Watts, and others (1999), report that total ammonia content in the Sea has increased threefold since the late 1960's, although the data from that time is suspect. Regardless, ammonia levels in the Sea exceed water quality standards, and are considered toxic to some freshwater aquatic life. Although the toxicological effects of ammonia on marine life are unknown, it has been suggested that the high level of ammonia at the Sea may contribute to fish mortality along with high temperature and low dissolved oxygen that accompanies algal blooms. Ammonia levels at the Sea vary widely, but the highest values occur in the bottom waters of the Sea during stratification events (Holdren and Montano, 2001).

Ammonia in the Sea occurs as one of two species, ammonia (a dissolved gas), or ammonium ion (the ionic form). Dissolved ammonia is the more toxic species, but the precise level at which it becomes toxic depends on temperature, dissolved oxygen levels, and the relative buffering effects to pH increases that the abundant salts in the waters of the Sea have. Which species of ammonia is present depends on pH, temperature, and salinity, with ammonium ion being the dominant form. As pH values decline, ammonium ion concentration decreases, and dissolved ammonia content climbs, heightening toxicity of the water. The EPA has also indicated that toxicity of un-ionized ammonia increases with rising salinity (Holdren and Montano, 2001).

Conclusions

All of these characteristics indicate that the Salton Sea is part of a eutrophic system, characterized by periodic low oxygen concentrations and high sulfide levels, that eventually lead to fish mortality events and wildlife health problems. Algal growth in the Sea is probably limited by phosphorus availability, and lake management scenarios should focus on phosphorus removal as well as salinity reduction. Although phosphorus loading has doubled over the last 30 years, phosphorus content in the lake water is decreasing, suggesting that phosphorus is being sequestered at the Sea, probably via biotic means through incorporation into tissue and bone, and abiotic means by mineralization as insoluble hydroxyapatite. Nitrate concentrations are high in the rivers, but low in the Sea itself, so denitrification must be happening one way or another. Ammonia shows little or no reduction, and remains above regulatory limits, probably representing a significant source of stress on biota. Future increases in salinity may be slowed by the presence of calcium and gypsum, which have arguably reached saturation in the Sea. The water in the Sea is actually relatively clean, aside from high salinity and over-nutrification.