USDI 1970 REPORT

Based on the Report-

"Salton Sea Project California, Federal-State Reconnaissance Report",

October 1969

The Department of the Interior and the Resources Agency of California

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Introduction

Background

The Salton Sea lies in a low-lying desert sink area approximately 85 miles east of San Diego, California. Formed in 1905-06, the 320,000 acre sea is threatened with rapidly rising salinity levels which if uncontrolled are expected to eliminate the currently valuable sport fishery within the next decade. Fluctuating water levels and eutrophication symptoms, such as dissolved oxygen deficiencies in deeper waters, discoloration and turbidity of the water and offensive odors caused by dense phytoplankton populations, are also major Salton sea problems.

An annual inflow of approximately 1.2 million acre feet principally from the new and Alamo Rivers brings salt, nutrients, pesticides, and fecal bacteria to the Sea. Much of this water is agricultural drainage from the Imperial Valley and sewage from Valley Communities and from Mexico. Figure 1 is a topographic and hydrographic map of the area.

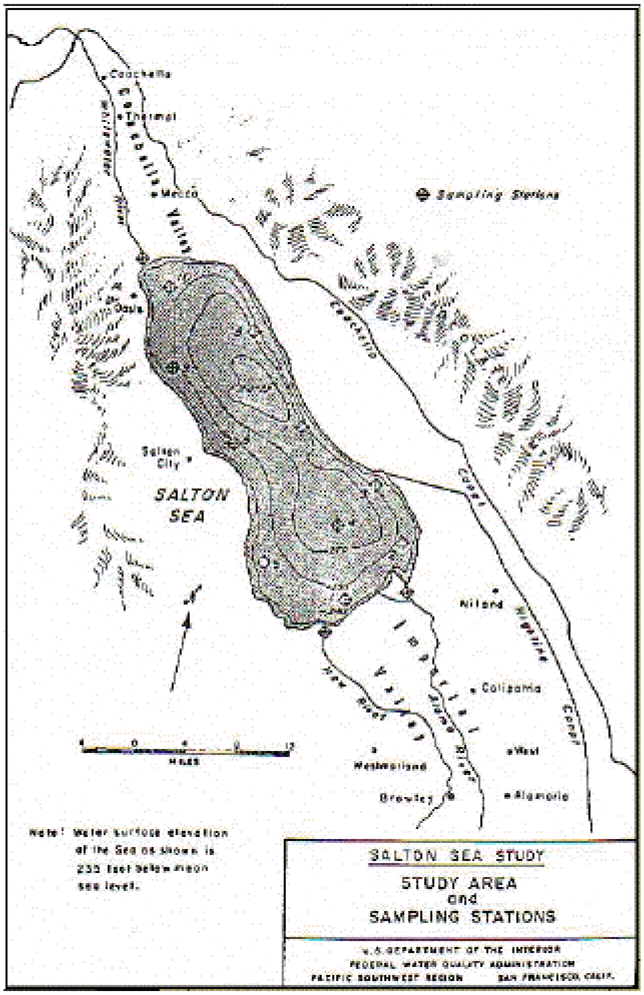


Figure 1

The Department of the Interior and the Resources Agency of California joined in a reconnaissance investigation of these problems in Fiscal year 1969. The general objectives of the investigation were to seek means of optimizing the uses of the Salton Sea. The report of this investigation, "Salton Sea Project California, Federal-State Reconnaissance Report" was published in October, 1969.

Purpose and Scope

The purpose of this report is to present data related to salinity and nutrient related problems and control measures to alleviate adverse water quality conditions in the Salton Sea. The development of this information was the Federal Water Quality administration’s contribution to the aforementioned reconnaissance investigation and is contained, in less detail, in the Federal-State Reconnaissance Report.

Acknowledgements

Salinity control methods herein discussed include contributions from the Bureau of Reclamation and U.S. Geological Survey. The section on fish salinity tolerance is based on studies by the California department of Fish and Game. This report was prepared by the Federal Water Quality Administration employees: R.C. Bain, A.M. Caldwell, R.H. Clawson, H.L. Scotten, and R.G. Wills.

II. Summary and Conclusions

Summary

The Salton Sea is an inland sink in a low lying desert area south and east of Los Angeles, California. See Figure 1. The 230,000 acre sea is threatened with rapidly rising salinity levels which, if uncontrolled, are expected to eliminate the currently valuable sport fishery within the next decade. The Sea has a volume of 6.0 million acre feet at ist present water surface elevation of about 232 feet below mean sea level. Fluctuation water levels and eutrophication symptoms such as dissolved oxygen deficiencies in deeper waters, discoloration, turbidity and odors caused by dense phytoplankton populations are also major Salton Sea problems.

Studies were conducted in the Salton Sea area, to determine the present water quality of the Salton Sea, its tributaries and major waste discharges in the basin. Water quality studies emphasized the nutrient and biological aspects of the eutrophic Salton Sea but also included some work on mineral salts, sediments and bacteriological indicators.

Most of the drainage to the Salton Sea comes originally from the Colorado River near Yuma, Arizona, where waters containing about 820 mg/l salt are diverted through a series of canals westward to the Imperial Valley and Coachella Valley for irrigation use. Of the annual 5 million acre feet imported from the Colorado River for use in the Imperial and Coachella Valleys and in Mexico, about 1.2 million acre feet is drained to the Salton Sea. Evaporation losses within the Salton Sea approximate this annual inflow. Thus a hydrodynamic balance exists.

The "modern" Salton Sea was formed by floods in 1905-07 which cut through a channel which carried irrigation water from the Colorado River to the Imperial Valley. The break in the channel was repaired by 1907 and since that time the Sea inflow has been controlled by irrigation practice. The salinity of the Sea has increased from less than 4,000 mg/l in 1907 to about 37 mg/l at the present time. Salinity levels approaching ocean values have persisted for nearly 50 years while water levels were rising. Slightly higher salinities, up to 40,000 mg/l, were observed during the late 1940’s due to reduced inflow. Salinity is increasing in the Sea now that water levels are more stabilized. Recent data show salt levels are approximately equal to oceanic salinity although ionic composition is somewhat different.

The Salton Sea currently supports a valuable sport fishery including Corvina, Sargo and Bairdiella (Croaker) which were introduced in 1948 from the Gulf of California. These oceanic species have thrived in the Sea but are not expected to tolerate salinity levels above 40,000 mg/l. Physiology studies conducted by the California Department of Fish and Game indicate survival of eggs and larvae is unlikely above that salinity. Adults may be more tolerant. Food chain organisms, of which there are very few species in the Sea, are not expected to tolerate any substantial salinity rise.

The Salton Sea is objectionably eutrophic and is characterized by an overabundance of mineral nutrients, mainly compounds of nitrogen and phosphorus, which produce intensive "blooms" of floating, microscopic plants (phytoplankton) in the upper levels of the water mass. Wind, wave action and currents distribute these planktonic algae throughout the Sea. The immediate visible results are discoloration and reduction of clarity of the water. In addition, although phytoplankton are essential to the ecological system of the Salton Sea, death and decomposition of large populations of these algae often result in temporary anoxic conditions, particularly in the deeper waters, and subsequent production of obnoxious odors over extensive areas of the Sea. Mats of decomposing benthic blue green algae which are torn loose from the bottom occasionally form rafts of unsightly and odiferous scum on the surface of the Sea, particularly near shore.

Eutrophication symptoms have reduced the aesthetic appeal of the Salton Sea and have limited water contact recreation such as swimming, although fishing activity has probably been stimulated by the productivity of the Sea. Health and safety aspects of the Salton Sea were also considered in the study including pesticide levels in fish tissue, bacterial contamination indices and air resource data.

Conclusions

1. The Salton sea is a popular recreational facility with potential for considerably expanded use. The

demand for water-oriented recreational facilities in Southern California insures use of the sea if its environmental problems can be salved.

2. The waste waters which sustain the Sea and stabilize it at the present level carry with them quantities of mineral and nutrient salts creating two major problems, hypersalinity and eutrophication, the effects of which can ruin the Sea's appeal to recreationists.
3. Increased salinity to levels above ocean water concentrations will destroy the Sea's important fishery. Water contact sports are also curtailed by hypersalinity.
4. Salinity control can be effected by diking off a portion of the Sea to create a pond for evaporation and for storage of accumulate salts. Feasibility of such a scheme has been investigate jointly at a reconnaissance level by the Department of the Interior and the Resources Agency of California.
5. Some evidence has been accumulated which suggests that the environmental symptoms of eutrophication of the Salton Sea have reached their maximal level and will not appreciably worsen even if not controlled. This conclusion suggests that nutrient control should have a lower priority than salinity control. However, it must be pointed out that nuisance conditions already exist in the Sea which have already appreciably diminished its aesthetic appeal.
6. Control of the major nutrient inputs to the Salton sea can be effected through removal of the nitrogen and phosphorus contained in the three major tributary inflows. Nitrate nitrogen by anaerobic denitrification, phosphorus control by land disposal of treated sewage, and control of both nitrogen and phosphorus through algal culturing and harvesting techniques are among the possible methods. The economics and efficacy of such schemes are not yet defined, particularly the effects of inflow nutrient control on Sea nutrient concentrations.
7. Salinity control efforts could be coordinated with nutrient removal schemes so as to optimize utilization of physical control structures for both purposes. An example of this could be creation of a marsh area between the mouth of the major southern tributaries and salinity control dikes. This area could promote nutrient trapping and serve as a fish and waterfowl habitat.
8. Very few macroinvertebrates live in the Salton Sea; establishment of additional species may be necessary to assure the continued maintenance of a productive fishery.
9. Considering the extensive use of pesticides on the lands tributary to the Sea, a pesticide monitoring program appears warranted, including measurement of pesticides in water, plankton, sediment and fish flesh samples.

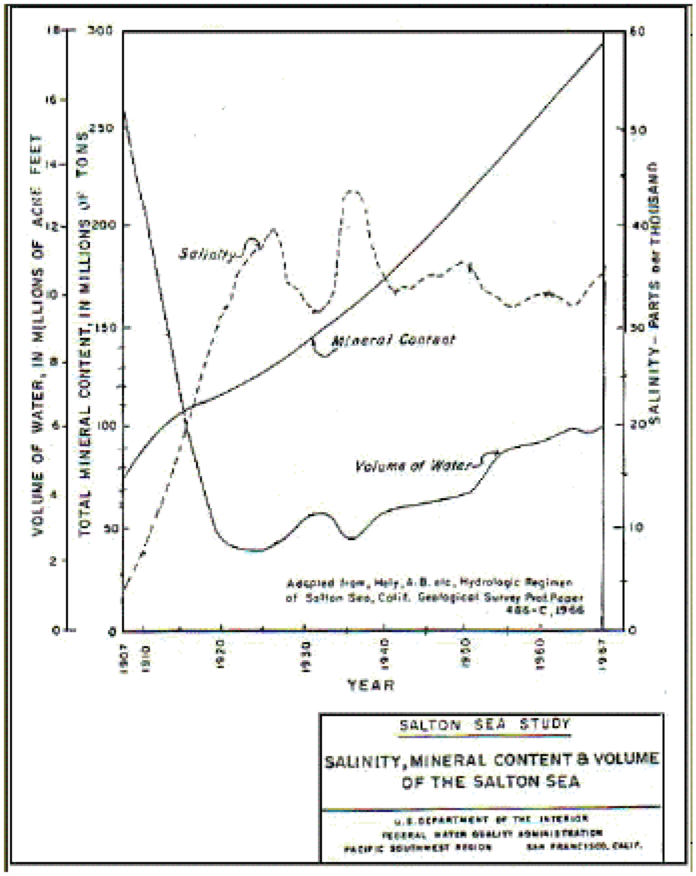


Figure 2

Salinity

Salinity Sources

Colorado River water containing about 810 mg/l salt is diverted at Imperial Dam near Yuma, Arizona. The diverted waters flow through a series of canals westward to the Imperial Valley and Coachella Valley for irrigation use. Drainage from irrigated land collected in open field drains and subsurface tile drains is channeled to the Salton Sea. Of the annual 5 million acre-feet import from the Colorado River for use in the Imperial and Coachella Valleys and in Mexico, about 1.2 million acre-feet of brackish drainage waters are discharged th the Salton Sea. Evaporation losses within the Salton sea approximate this annual inflow. Thus a hydrodynamic balance exists.

Chemically a much different condition exists as a direct result of the hydrodynamic balance. The effects of evaporation, transpiration and vegetative uptake of water applied to the land concentrate the salts in the water remaining in the field soils. The resulting drainage is often 3 to 5 times as saline as the irrigation supply and may be much higher if excess salts have accumulated in the soil. Leached materials carried in open field or buried tile drain systems are channeled to the rivers and ditches which discharge into the Salton Sea. This drainage usually is of a sodium-chloride-sulfate character in contrast to the sodium-calcium-sulfate character supply. Mineral quality data for the major surface water sources are shown in Table 1.

Groundwater infow to the Salton Sea is about 50,000 acre-feet per year. Of this total, about 30,000 acre-feet are contributed by Coachella Valley and 2,000 acre-feet by Imperial Valley. About 10,000 acre-feet enter through the alluvium bordering San Felipe Creek and the remaining 8,000 acre-feet enter through the alluvium in other peripheral areas. The remaining 8,000 acre-feet was assumed to enter from east of the Sea. Groundwater quality data are shown in Table 2.

Salton Sea Salinity

Th Salton Sea was formed by a summer flood in Colorado River in 1905 which cut through an irrigation channel damaged by a flood the previous winter. The break in the channel was repaired by 1907 and since that time the Sea inflow has been controlled by irrigation practice. The salinity of the Sea has increased form less than 4,000 mg/l in 1907 to about 37,000 at the present time. Slightly higher salinities were observed during the late 1940's due to reduced inflow. See Figure 2 for historical salinity observations.

The increase in dissolved minerals as defined by salinity observations since 1962 is estimated to be 5.59×10^6 tons annually. This rate was the basis for estimates of salt inflow values in the operation studies described in the Federal-State Salton Sea Study. Previous salt balance studies, while incomplete, tend to support figures indicated by the observed historic trend in dissolved solids within the Sea. A 20-year record of monthly patterns of salt inflows from data gathered by Imperial Irrigation and Coachella Valley County water District's salt balance studies indicate an annual salinity rise of 3.9×10^6 tons. Monthly salt loads to the Salton sea are not uniform, being lower November through February.

Published data are available on the chemistry of Salton Sea waters, including a review of ionic composition from 1907 to 1955 included in the California Fish and Game Bulletin edited by Walker and of 1964 sampling efforts described by Pomeroy (1,2). Recent data show salt levels are approximately equal to oceanic salinity although ionic composition is somewhat different. Sulfates and calcium are higher and chlorides lower than typical ocean water values.

Salinity Related Problems

Salt accumulates in confined water bodies such as the Salton Sea unless man or geological forces provide an outlet. Examples of the salinity found in other inland sinks within the Southwestern states are shown in Figure 3. Hypersaline (relative to the oceans) lakes such as Mono Lake and the Great Salt Lake are dvoid of fish and provide suitable habitat for only a few specialized organisms such as brine shrimp and certain of the more primitive algae. Oceanic fish, barnacles and algal species now thrive in the Salton Sea which has a salinity nearly comparable with the ocean.

Physiological studies were conducted by the California Department of Fish and Game to determine levels of salinity critical for the survival of Salton Sea fishes. Results of these studies, described in Chapter V, provide criteria for use in design of salinity control schemes.

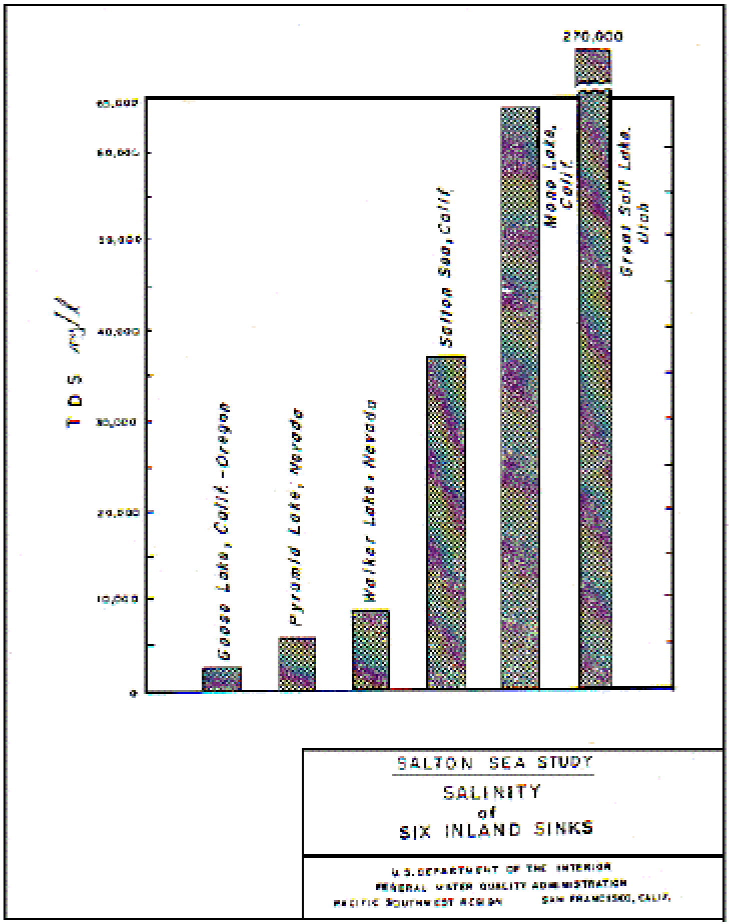


Figure 3

Salinity Control

Salts accumulate in the water of inland seas and lakes with no outlet for water other than evaporation. Control of salt buildup is achievable by salt removal either through transport mechanism such as diverted outflows to other basins or through extractive processes such as desalinization.

The Salton Sea lies in a deep sink area: the present water surface elevation is about 232 feet below mean sea level. Diversion of Sea water to another basin would require extensive pumping costs. The lack of any substantial fresh water inflow in this arid region precludes reliance on flushing of sea salts through any outlet which might be devised. Imported waters from northern California rivers or a connection with the ocean through a tidal canal are intriguing possibilities but do not appear worthy of consideration for technical, economic and political reasons.

Control through desalinization is technically possible and several methods are available. Processes such as distillation, reverse osmosis or other similar treatment methods are available but may not warrant serious consideration owing to their cost. Desalinization through solar evaporation from diked areas within the Sea itself has been proposed and is considered a likely possibility for feasibility study.

Maximal efficiency of solar evaporation ponds requires shallow water depth: evaporation ponds one or two feet deep are about 10 times as efficient as areas 30 feet deep of comparable salinity. As brines within the ponds concentrate evaporation rates decrease. At 36,000 mg/l TDS a rate of approximately 6 feet per year is expected to decline to about 4 feet per year at 405,000 mg/l.

Estimates of pond service life depend on the volumes available for salt precipitate and evaporate storage. Compaction also is a factor and is expected to vary from a specific gravity of 1.8 in a shallow (one foot) pond to

2.1 in a 16-foot-deep area. Service life estimates exceed 100 years in calculations for diked areas of 50 square miles.

IV Salton Sea Nutrients

Salton Sea Nutrients

Field measurements and water samples were collected between July 1968 and May 1969. The data obtained were used to describe the present nutrient context of the Sea and the nature of nutrient-related problems. Sampling stations were located within each of the ten sectors shown on Figure 1. Samples and field data collected at these stations include nutrient samples at several depths; profiles of dissolved oxygen, pH and temperature; observations of color, odor and transparency; light penetration profiles; chlorophyll concentrations; measurements of productivity and algal growth potential; biological collections including planktonic and benthic life; bacterial densities, and pesticides.

The mean total phosphorus and total nitrogen concentrations for the study period were 0.10 and 3.30 mg/l respectively. A nutrient budget of the Sea indicates that, on the average, about 53 million pounds of nitrogen and 1.6 million pounds of phosphorus* are present within the Sea waters. This estimate assumes a Sea volume of 6.0 million acre-feet which corresponds to a surface area of about 230,000 acres.

Nitrogen forms within the Sea are predominantly organic in contrast to the inorganically rich tributaries. Inorganic nutrients entering the Sea are converted to organic matter through photosynthetic processes. Depressed dissolved oxygen concentrations in the deeper waters and elevated DO and pH near the surface during the day reflect photosynthetic and respiratory activity of the dense phytoplankton populations and decay of other organic present in the Sea water and sediments. These data and other physical measurements such as transparency, pH and temperature are shown in Table 6.

Nutrient levels in Salton Sea bottom sediments reflect the high organic content of the sea waters. Sediment samples collected by dredge and corring devices contained about 5% organic carbon, 0.3% organic nitrogen and 0.1% total phosphorus (dry wt). The results of one series of analyses of sediments are shown in Table 7.

*Phosphorus values may be low since analytical method does not digest all the organic matter present and some analytical difficulties arose in the highly mineralized sea water due to interference with $HgCl_2$ preservative used.

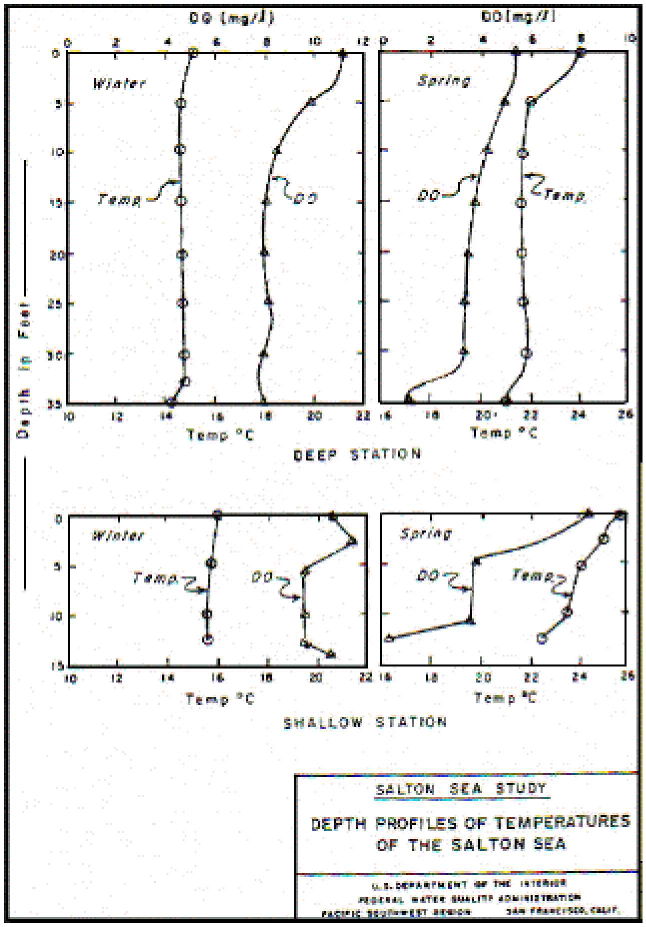


Figure 4

Nutrient Related Problems

Eutrophic waters by definition are endowed with nutrients and support rich organic production often typified as algal blooms (3). The Salton sea is objectionably eutrophic and is characterized by an overabundance of mineral nutrients, mainly compounds of nitrogen and phosphorus, which permit intensive "blooms" of floating, microscopic plants (phytoplankton") to occur in the upper levels of the water mass. Wind, wave action and currents distribute these planktonic algae throughout the Sea. The immediate visible results are discoloration and reduction of clarity of the water.

Although phytoplankton are essential to the ecological system of the Salton Sea, death and decomposition of large populations of these algae often result in temporary anoxic conditions, particularly in deeper waters, and subsequent production of obnoxious odors over extensive areas of the sea. This often occurs in the Salton Sea during the summer months and is linked to fish kills and disappearance of other animals that are intermediate links in the biological food chain of the Sea. Mats of decomposing benthic blue-green algae which are torn loose from the bottom occasionally form rafts of unsightly and odiferous scum on the surface of the Sea, particularly near shore.

Symptoms such as these which are characteristic of eutrophication were described earlier by Walker and co-workers (1961) as being prevalent in the years 1954. 1955, and 1956, the period of their study of the Sea, and have been regularly observed since. They have reduced the aesthetic appeal of the Salton Sea and limited water contact recreation such as swimming and water skiing. Fishing activity, although dependent on the productivity of the Sea, has most likely been adversely affected also.

Data from field and laboratory studies of the Sea in 1968-69 provide further documentation as to the seriousness of problems now present. Extensive fish kills of species such as corvina and gulf croaker were observed in the

Sea near the Whitewater River inlet on two separate occasions and dead mullet were seen near the Alamo River on one occasion. Observations of dead fish were commonplace throughout the sea. Extremely unpleasant odors were also encountered; these were especially prevalent near shore, often at the sites of marinas or popular fishing rounds. Strong odors, especially the rotten eggs smell characteristic of hydrogen sulfide (H_2S) were often noted and were nearly overpowering in the Whitewater River area at the time when one of the extensive fish kills was observed. A level of H_2S lethal to fish or other animals could very well have been present in the water on that occasion. High H_2S levels were also reported in May 1969.

The density of algal populations in the Salton Sea at times was so great that the water was highly discolored, varying in hue from a brick red in some areas to brown and light green in others. Examination of these water samples indicates that the brick red color was probably due to dinoflagellates, the brown to diatoms or ciliates and the green to green flagellates. The sea water was always somewhat colored and turbid. Secchi disc readings averaged about one meter varying from about .5M to 2M.

Dissolved oxygen (DO) concentrations in the euphotic zone* were generally supersaturated, sometimes by a factor of 200%, reflecting the intensive photosynthesis activity of the massive phytoplankton population. Dissolved oxygen measurements in the Sea at depths below the euphotic zone (15 feet and below) for the months of July-November show that the DO concentrations often drops to dangerously low levels, at times near zero. See Figure 4. Extensive regions of the deep water during these months often contained less than 3.5 mg/l of oxygen during daylight hours. Lower concentrations could occur at night when oxygen inputs from photosynthetic oxygenation are absent.

Data available from 1968-69 water quality surveys indicate that the nutrient content of the Sea (expressed as total nitrogen and total phosphorus) is not greatly different from the computed annual inflow; yet comparable annual loads of nutrients have been entering the Sea for decades. They also show thqat the Sea’s nutrient-laden tributaries carry greater loads of inorganic nutrients (such as nitrate) as contrasted with high organic content of the Sea. Soluble forms such as nitrate have not built up in the Sea over the past decades but rather have been converted to phytoplankton in the warm, shallow sea to be deposited late as dead organic matter on the sea bottom or consumed by predators within the Sea. An equilibrium has been established wherein entering nutrients are assimilated by the Sea’s ecological system or deposited into the rich bottom sediments. Only a relatively small fraction of nutrients which have entered the Sea of the years has been retained in the aqueous phase.

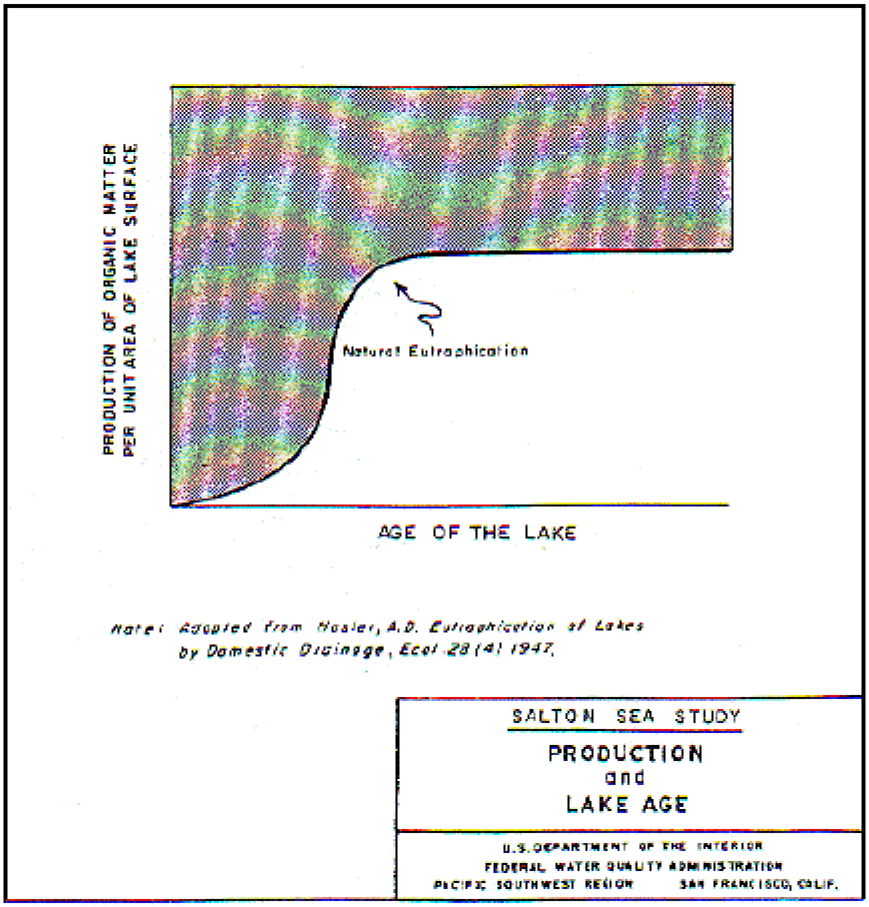


Figure 5

The rate of primary productivity, or synthesis of organic matter, varies with habitat type (ecosystem). Odum (4) has classified ecosystems on the basis of nutrient levels and relative productivity. Nutrient-poor lakes and oceanic areas, classified as oligotrophic, achieve maximal rates of carbon fixed per square meter of water column per day ($gmC/m^2/day$) of 1.0 or less. By comparison shallow eutrophic lakes may fix up to 5.0 $gmC/m^2/day$ although values over 3.0 are considered high for aquatic systems. Rates for the Salton sea during 1968-69 averaged about 4.4 $gmC/m^2/day$ and exceeded 5.0 on several occasions.

Measurements of primary productivity in other fertile waters have shown that, due to light limitations, there is a maximum achievable rate of photosynthesis regardless of other environmental factors. In other words, the amount of light per unit area available to phytoplankton for photosynthesis is the same whether in a 100-foot-deep euphotic zone in clear, oceanic water or in a 5-foot-deep zone of highly turbid bay water containing large concentrations of algae. As a result even in highly eutrophic waters a plateau of maximal rate of primary productivity is reached. This is illustrated in Figure 5. Values observed in the Salton Sea are probably at or near the plateau level.

Nutrient trapping in lakes and impoundments has been discussed by Mackenthun, Ingram and Porges, in which they expressed efficiency in terms of detention time (3). Since the Salton Sea has no outlet, and detention is complete, the efficiency of its sediments as a nutrient trap is apparent from comparisons of nutrient levels in the Sea water with those from tributaries and bottom sediments. Fish harvests, although respectable, are not a significant factor in computing a nutrient balance. An annual harvest of 100 pounds of nitrogen or about 2% of the annual nitrogen load (based on 2.5% nitrogen in fish flesh by wet weight). The estimated Salton Sea harvest rate was only about six pounds per acre in 1966, or about 0.1% of the annual load.

In conclusion the nutrient-related problems of the Salton Sea are those expected in highly eutrophic waters. The enrichment of the water has possibly advanced as far as is likely in this inland sink where nutrient trapping and the dynamics of the eutrophic ecosystem have countered the fertilization effects of the rich tributaries.

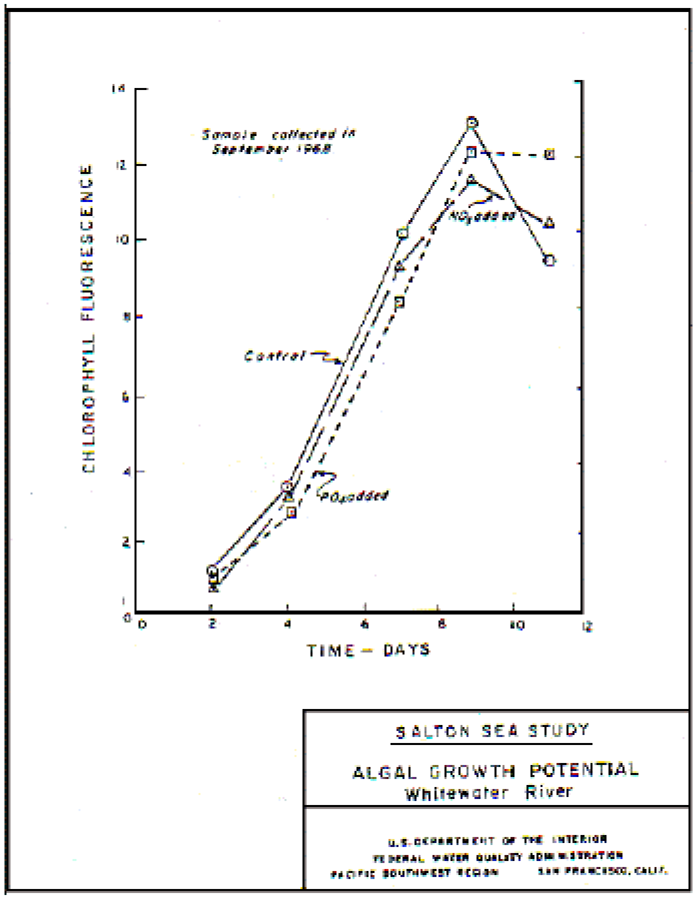


Figure 6

Eutrophication Control

The problems associated with removal of nutrients from agricultural waste waters resulting from irrigation are high volume and low nutrient concentrations. In addition varying flows and nutrient concentrations due to seasonal agricultural practices would also create problems of design in any nutrient removal system.

Removal of nitrogen and/or phosphorus I possible by many methods &endash; ion exchange, chemical denitrification, chemical precipitation of phosphorus, reverse osmosis, electrodialysis, algae stripping, and pond or filter anaerobic denitrification. State-Federal cooperative studies at Firebaugh, California have indicated that algae stripping and anaerobic denitrification are the two least expensive methods for removal of nitrogen from San Joaquin Valley agricultural waste waters. Estimates have been made that 95 percent of the nitrate-nitrogen can be removed by the anaerobic denitrification method. While such a removal percentage may be approached by the algae stripping method in summer months, it appears that, even with extended detention times, in winter nitrate-nitrogen removal would be less efficient.

The algae stripping method utilizes shallow ponds with detention times of 5-15 days, depending on the season, with the longer detention times used in colder weather. An advantage of this method as compared to anaerobic denitrification is that phosphorus removal is also accomplished. To create optimum growth the alage and removal of concentration of 10-20 mg/l nitrate-nitrogen, the relatively low levels of phosphorus in the San Joaquin valley waste waters (0.2-0.3 mg/l) was supplemented by the addition of 2.0 mg/l P. An iron deficiency was overcome by the addition of 6 mg/l Fe, greatly increasing efficiency. Advantages of the algae stripping method include in the Salton sea area availability of large land areas required by the shallow ponds and the warm, sunny climate.

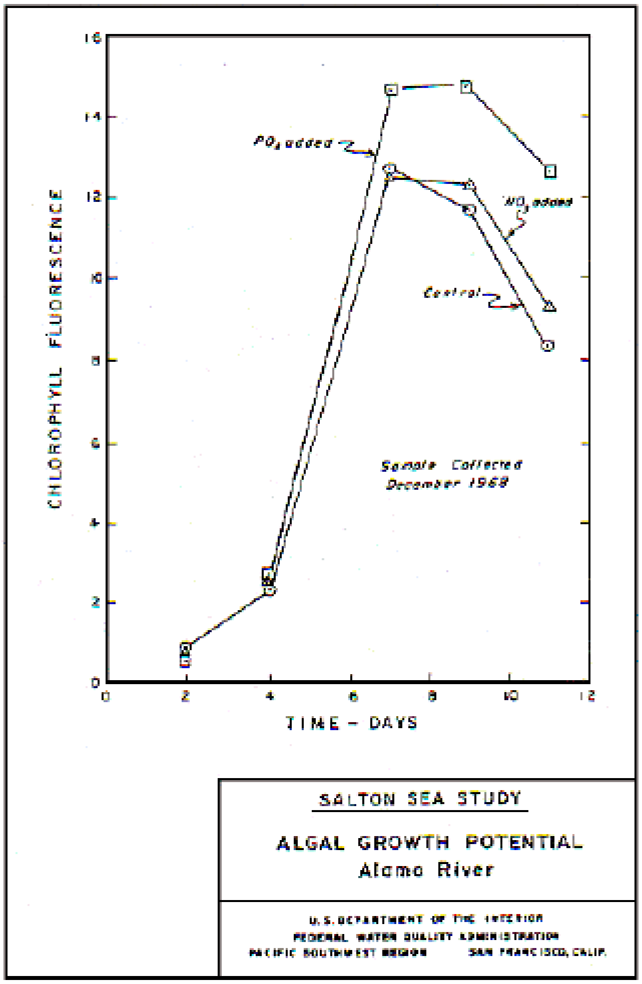


Figure 7

The algal growth potential for waters from the three river drainages was determined under Salton Sea environmental conditions. Typical results of these tests are shown in figures 6, 7, and 8. All tests indicate that the waters will produced heavy algal crops without any pretreatment or nutrient additions. Toxicity or micronutrient limitations do not appear to be a problem. Maximum growth was attained in seven to ten days.

The test system for the algal growth potential studies involved static culture and small containers and for this reason are not indicative of the extent to which algae will grow under actual ponding conditions. Figure 9 shows several cultures being incubated in situ. To determine the ultimate efficiency for nutrient removal by algal growth a pilot scale pond system should be tested.

Algal harvesting could be accomplished by chemical flocculation and either sedimentation, flotation or screening. Disposal of algae could be by digestion, incineration, use as a livestock feed or as an adhesive ingredient.

The anaerobic denitrification process being studied at Firebaugh utilizes methanol as a carbon source for the heterotrophic anaerobic bacteria. The pond denitrification method requires uses of a floating cover or other device to maintain anaerobic conditions which would otherwise be prevented by algal photosynthesis. High wind conditions which arise in the Salton Sea area would limit applicability of this method.

Filter anaerobic denitrification method offers many advantages. Detention times are relatively short, as low as one-half hours; land use is minimal, and there are no disposal problems, since harmless gases are the only products. Capital and operational costs would be higher than with algal ponds, since filter columns would have to be constructed and chemical costs are a major part of the treatment costs. Methanol is added at a rate of 3:1

by weight of nitrate-nitrogen.

Only the nitrate-nitrogen and nitrite-nitrogen would be affected by this process. Costs estimated by Firebaugh researchers of about $10 per acre foot are based on 20 mg/l NO_3-N inflowing drainage and methanol costs of 30 cents/gallon. By 1970 methanol costs are estimated to be down to 10-15 cents/gallon. A crude estimate of the cost to denitrify Salton Sea inflows which average about one-third the NO_3-N of the San Joaquin Valley Project would be from $2.5-$5.0 per acre foot.

Of the major inflows listed in Table 4, only the Alamo, New and Whitewater Rivers could be treated without an extensive collection system. The direct drains in Imperial and Coachella Irrigation Districts would require an extensive collection system if treatment were required. In addition, the high suspended solids in the New, Alamo and Whitewater Rivers would probably require sedimentation prior to treatment if anaerobic denitrification by the filter method were to be used with treatment costs being increased accordingly. The heavy turbidity in these waters might also cause problems in algae stripping due to reduction of transparency, although the majority of the solids settle rapidly. A one-foot-deep pond would be filled with silt in 50-75 years, and would require cleaning at that time or construction of new ponds.

The sources of phosphorus are primarily municipal and industrial wastes (see Table 5). These effluents could be utilized as irrigation waters for nonedible crops such as cotton or grazing land for sheep. The phosphorus not utilized by the crops would be reduced to minimal concentrations by the adsorptive capacity of the soil before reaching drain systems. The State of California and its regional water quality control board encourage use of sewage effluents for irrigation or other reclamation process. Water is at a premium in the area.

Nitrogen control would require different measures wince the major source is agricultural drainage. Treatment of the new and Alamo Rivers by algal stripping or filter denitrification would reduce the inflow of nitrogen to the Sea by about 60 percent. Similar treatment to include the Whitewater River would only increase the efficiency to 68 percent. The nitrogen additions by municipal and industrial sources are minor and probably represent less than 5% of the total input. Further work is required to assess the importance and impact of nitrogen or phosphorus control as opposed to control of all algal growth factors.

Other eutrophication control methods include increasing the rate of removal of phytoplankton by grazers. Additional zooplankters have been mentioned as being a desirable addition to the Sea but even more effective would be plankton feeding fish which could be utilized as second food link between the algae and the corvina. Some reduction of plankton blooms could conceivably be accomplished by harvesting fish at a greatly increased rate although harvest rates would necessitate commercial fishing techniques. Sealing of the bottom might lessen nutrient exchange, but even if effective periodic sealing would be required since organic material would continually settle within the sea. The effect of such a program on the bottom dwelling, detritus-eating pileworm *Neanthes* would have to be evaluated.

The effectiveness of the Sea as a nutrient trap is evident. If effective nutrient trapping did not occur the Sea waters would have nutrient concentrations far higher than found in the rich tributaries. Control of nutrient inflows may be expected to reduce sea nutrient levels.

Eutrophication control and forecasting is an infant science, although successful reversals of eutrophication through nutrient control are documented. Forecasting will require interdisciplinary efforts where engineers create models of the lake environment and chemists, biologists and limnologist provide rate inputs and other relationships. Such efforts have begun, and several comprehensive ecological models have been proposed for consideration for research grants. Future use of such tools will aid decision makers in evaluating effectiveness of eutrophication control schemes.

*The euphotic zone is often defined by the depth which sunlight sufficient for photosynthesis occurs &endash; often this is approximated by the depth at which light energy equals 1% of surface light intensity.

Sediment Inflow

Sediment inflow to the Salton Sea does not appear to be a problem in the conventional sense that reservoirs sedimentation is usually considered. The estimated sediment inflow volume is small as compared to the total storage volume of the Salton Sea.

Th reconnaissance estimate of the future long-term average sediment inflow volume to the Salton Sea is 4,000 acre-feet per year. The 50-year sediment volume of 200,000 acre-feet would be less than 4% of the gross water storage volume of the Sea (at a water-surface elevation of 232 feet below mean sea level). Since the anticipated effect of sediment inflow on the future storage capacity of the Sea is so small, no adjustments were made in the Sea's present area-capacity relationship for future condition operation study use.

The computation of the overall sediment inflow volume was based on suspended sediment sampling data where available and upon measured historical sediment inflow rates that were observed for other major reservoirs in the southern California-Arizona region. This approach was taken because of the lack of complete data pertaining to resurvey of the Salton Sea itself.

The relationship that has been observed for those resurveyed regional reservoirs was that the unit sediment yield rate was related to the size of the drainage area which contributes sediment to the reservoir. This relationship is approximated by the empirical equation:

$Qs = 2.4 A^{-0.229}$, where

"Qs" is the sediment yield rate to the reservoir, in acre-feet per square mile per year, and

"A" is the size of the individual drainage area in square miles.

The total drainage area of the Salton Sea is approximately 8.360 square miles. The surface are of the Sea is about 360 square miles (at an elevation of 232 feet below mean sea level) and, since this portion can be considered to be noncontributing, the net drainage are is 8,000 square miles. By sue of the above equation the sediment yields of the individual drainage areas (with the exception of the Alamo and New Rivers) were computed.

Periodic sampling of both the Alamo and new Rivers to determine their sediment concentrations has been accomplished by the Imperial Irrigation District. This sampling program has been carried out on a quarterly basis from 1952 to the present and as far as it known is the only sediment sampling that has been made of the two streams. Determination of the rate of streamflow was made at the time of sampling. It is seen that the largest discharge in the Alamo River ("Alamo River at Outlet") that was sampled for sediment content was 1,508 cfs and the lowest 385 cfs. The largest flow in the New River ("New River at Outlet") was 964 cfs and the lowest 315 cfs.

At an average Alamo River discharge of approximately 1000 cfs, a calculated sediment concentration of 0.0475 percent indicates a suspended sediment load of approximately 476,000 tons per year. At 70 pounds per cubic foot the annual suspended sediment volume from the Alamo River would be 310 acre-feet. Allowing for an estimated 10 percent bedload pickup, the total average annual sediment contribution fro the Alamo River is 340 acre-feet.

By similar means the sediment yield from the New River was computed, using suspended sediment data for the period 1952-1969. The average sediment concentration at the sampling point during that time was 0.0795 percent. At an average annual discharge of 660 cfs (W.Y. 1961-1967), this amounts to 519,000 tons per year, or 340 acre-feet per year at a unit weight of 70 pounds per cubic foot. By adding 10 percent bedload pickup the average annual sediment contribution for the New River is 370 acre-feet.

The combined recent sediment volume is 710 acre-feet per year. However, the total annual water inflow to the Salton Sea for the future condition has been previously determined to average 1.25 million acre-feet. Since this is about 95 percent of what it was during the 1961-1967 water period, the future average sediment inflow volume is adjusted downward to 680 acre-feet per year.

It should be recognized that while the overall quantitative effect of sediment inflow on the Sea is considered to be small, there may be certain local sedimentation problems relative to a future diked control area.

It is anticipated that water could be released to a salinity control pond from the "seward" side only; therefore, no appreciable sediments should accumulate within the diked area itself. However, the sediment contribution o f the Alamo and New Rivers could be significant to any area between the dikes and the shore. The area between the salinity control pond and the southern shore of the Sea could in effect act as a settling basin for New and Alamo River sediments.

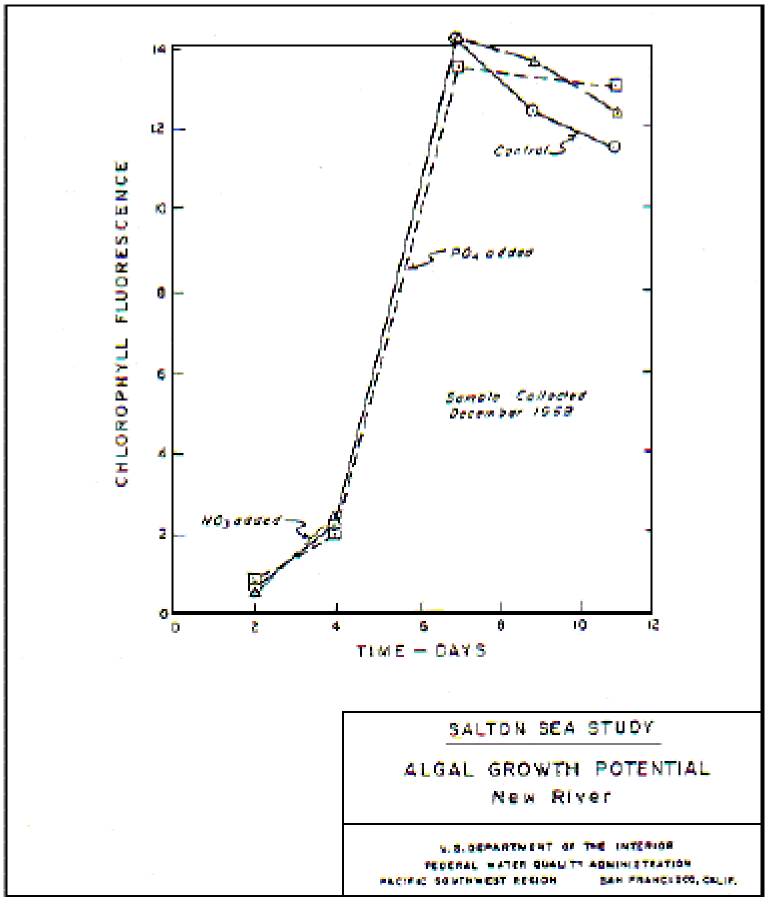


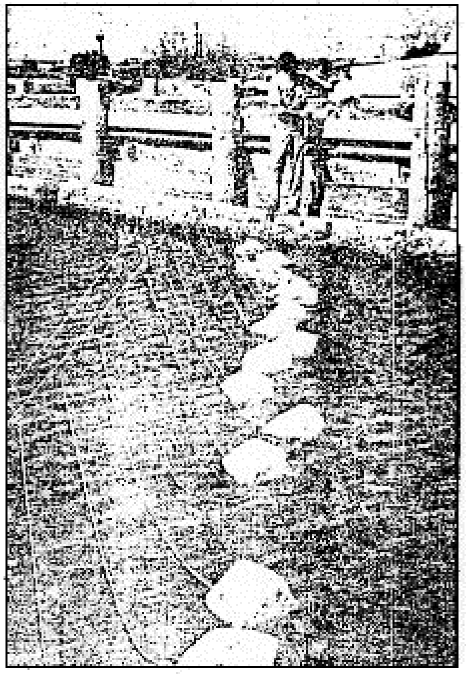
Figure 8

Ecology

Any consideration of the Salton Sea's ecology must be tempered with the knowledge of its completely artificial nature. The present ecosystem was primarily developed and is maintained by the activities of man. The praise for its continuance or the blame for its demise will rightfully fall on these same hands.

Although the sea itself is an historical accident, the story of its very successful and highly esteemed fishery is not (6). This valuable resource was the result of carefully planned introductions of both fish and invertebrates which now form the basis of the very simple food chain in the Sea (1). Briefly, this chain is formed by five links: Phytoplankton, zooplankton; benthic invertebrates; invertebrate-eating fish' and fish-eating fish. In general, each link is composed of one or two dominant species which can be considered to occupy a separate trophic level and each trophic level is dependent on the success of the next lower level in the system. In theory the ultimate productivity of the system is determined by the amount of energy input from the sun and is usually limited by the availability in organic nutrients (phosphates and nitrates) to the primary producers (phytoplankton) which form the base of the food chain. In practice the consistent success of anglers attests to the high productivity of the Sea.

However, in light of current ecological theory and practice, it is quite clear that the simplified ecosystem of the Salton Sea is endangered because its characteristic high productivity is gained at the risk of an inherent instability. The loss of one of the few food chain organisms in the Sea could greatly alter the present sport fishery.



In Situ
Algal Growth Potential Test in Progress

Figure 9

Fishes

The original fish fauna of the Sea came in from the Colorado River and was a freshwater fish stock. The fish found in the Sea today are the results of saltwater transplants from the Gulf of California except for the threadfin shad and striped mullet. The sportfishery is dependent on three fish: the orangemouth covina, *Cynoscion xanthulus*; sargo, *Anisotremus davidsoni*, and croaker, *Bairdiella icistius*. The threadfin shad and striped mullet are common throughout the Sea but are not caught. Other fishes from the Gulf of California such as totuava, *Cynoscion macdonaldi* and short fin corvina, *Cynoscion parvipinnis* were introduced but did ot become established. Today the orangemouth corvina is the chief gamefish and the sargo and second gamefish. Croaker are caught but are not fully utilized.

Earlier predictions that the Salton Sea sport fishery would deteriorate if salinities crept much above 40‰ (1,6) are strongly supported by the results of recent studies sponsored by the California Department of fish and Game (7). As a general rule pelagic fish eggs and larvae are more sensitivethan adults to adverse environmental conditions such as high salinity. Accordingly, experiments with these early life stages received high priority during 1968.

Lasker and Tenaza (1968) stripped eggs and sperm from living bairdiella and sargo, fertilizing them in various concentrations of Salton Sea water, and followed their subsequent development (7). In the case of bairdiella, 84% hatched in 35‰, 15% in 40‰, and 7% in 45‰. Embryos in 40 and 45‰, developed more slowly than those in 35‰, and all died as larvae within 60 hours. The control larvae in 35‰ developed normally. Sargo gave similar results, with 90% of 10-hour survivors still alive after 96 hours in 35‰, compared to 8% in 40‰ and none in 45‰and higher. So these two species will probably stop reproducing in the Sea at or near the 40‰ point. All efforts to catch corvina in spawning condition have failed so far. When some are taken it will be surprising if they do not give similar results.

In a second series of experiments fish several inches long were exposed to various concentrations of Salton Sea water for 96 hours (8). They survived much better than the larvae. For example, 100% of the bairdiella survived in 52.5‰, and 43.8% at 57‰. The pattern in young sargo was similar, although they may be more sensitive. Corvina were more resistant, with 100% survival at 52.5‰, 90% at 57.5‰, and no survival at 62‰. It must be emphasized that these tests lasted only four days and that they only tested the fishes ability to withstand the shock of a sudden transfer to the higher salinity. It is therefore difficult to apply results to anticipated conditions in the Sea as salinity incases. However they confirm the ability of larger fish to tolerate higher salinities than eggs and larvae.

In that connection an interim artifical rearing program might be developed to support the fishery if a salinity control program is delayed. The more sensitive young fish could perhaps be reared in nearby ponds for release into the Sea when large enough to tolerate higher salinities. However some preliminary feeding experiments during 1968 showed that salinities above 40‰ inhibit the growth of small bairdiella. This could rule out a hatchery program. Additional tests are planned to clarify this issue.

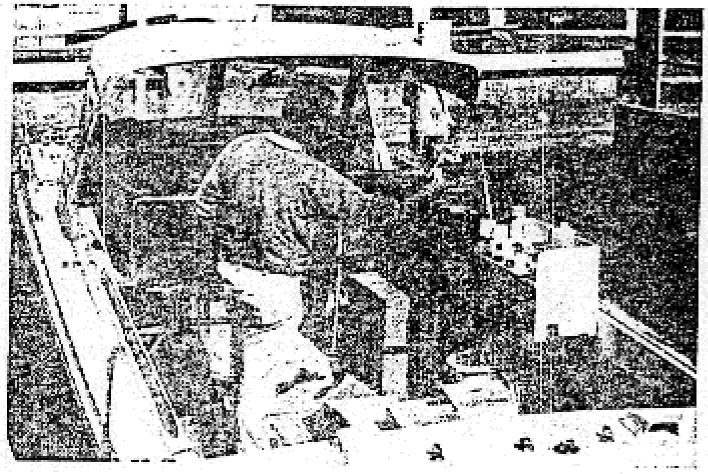
The California Department of Fish and Game can now predict with some assurance that the fishery at the Salton Sea will probably decline if salinity is not controlled near the present levels of 37‰. At or near 40‰, reproduction of the game fishes will probably declined as a result of eff and larval mortality. If, for a period of years, the salinity fluctuates around the 40‰ level the fish may spawn successfully in some years but not in others, providing a rather unstable fishery. Limited spawning may also occur within or near the mouths of major tributaries. Older fish will continue to live long after spawning ceases. However, they will grow more slowly and become thinner and less desirable as the salinity rises. Should salinity rist to levels comparable with Mono Lake (60‰) no fin fish will live in the Sea.

The results described above are still preliminary, based mainly on a single spawning season during which the biologists had to develop techniques as they experimented. However, in spite of these limiations, they provide a much better basis for prediction than has hitherto been available. All the available evidence indicates that salinities above 40 ‰ will be detrimental to the fishery. The Sea is already precariously near this level.

Invertebrates

There are only three known kinds of macroinvertebrates in the Sea but numerous microscopic forms including protozoa, a rotifer, byrozoans, nematoes, ostracods and copepods have been reported. The environment is limited to specialized organisms because of high summer water temperatures (up to 36û C), low dissolved oxygen tension during the summer, a shifting sand shoreline bottom and salt composition similar in concentration but different in ionic composition from ocean water.

The Sea was relatively fresh as late as 1916. Most invertebrates were introduced later from marine waters. Today the known macroinvertebrates consist of the pile worm, *Neanthes succinea*; a barnacle, *Balanus amphitrate*, and an amphipod, *Carinogammarus* sp. The *Neanthes* is the most important food of the forage fish in the Sea; adults are found in the mud bottom and immature forms are present throughout the water column. Barnacles are extremely abundant and are found attached in almost solid colonies to rock, sticks, piles, boats and any other hard substrate in the Sea. The amphipod is a newcomer to the Sea; first reported in May 1961, it is found on rocks along the shoreline as well as in the open water. The microscopic invertebrates such as protozoans and small crustaceans like copepods graze on phytoplankton and provide additional support to the food cycle of the Sea.



Sampling boat and biologist, Ron Clawson testing water samples.

Figure 10

Aquatic and Near Shore Vegetation

Only one submerged aquatic vascular plant actually grows in the Sea. The Fish and Wildlife Service and California Department of Fish and Game introduced shoal grass, *Diplanthera wrightii*, in the early 1960's at several locations. This exotic has become established at the southwest part of the Sea but has not developed as planned. It was introduced as duck food to reduce waterfowl depredation on lettuce growth in the Imperial Valley.

Vegetation contiguous to the Sea is characteristic of the environs, associated with low humidiy, low rainfall (0 to 5 inches annual precipitation), high summer temperatures (90ûFto 130ûF), and drying winds of gale force.

The vegetation is sparse along the shore except for salt brush, *Atriples* sp., and salt grass, *Distichlis* sp. Rooted aquatic plants such as cattails, *Typha* sp., nutgrass, *Carex* sp., and other associated sedges are common at the confluence of freshwater drainages into the Sea. Near freshwater drainages are dense stands of slat cedar, *Tamarix* sp. And cane, *Phragmites* sp. The bulrush, *Scirpus* sp., grows in marsh areas and is found submerged at the mouth of the Whitewater River. Salt grass, *Distichlis spicata*, grows partially submerged in the water. Another grass, ditch grass, *Ruppia* sp., has also been reported (USDA) to extend into the salty water at Salt creek by North Shore, California.

Finally, on levees of the Alamo and New River, above the influence of salt water, two species are found in abundance: arrow-weed, *Pluchea servicea*, which forms dense thickets, and a small berb, heliotrope, *Heliotropium* sp.

Algae

Plankton samples were taken on an approximately monthly basis from each station shown in Figure 1. Figure 10 shows the sampling boat and gear used.

The average number of planktonic algae present in each sampling period is shown in Table 8. No striking seasonal trends in total populations were apparent. However, the highest populations were found in January and February as was observed by Walker (1).

The planktonic algal flora of the Salton sea is comprised of more than twenty-two species representing four divisions: the green algae, euglenoid algae, dinoflagellates, and diatoms. The most prevalent forms were greeen algae, diatoms and dinoglagellates, liste din order of their abundance. The species found in greatest numbers in the period of this study, July 1968 through June 1969, are listed in Table 9. Maximum counts of dominant species and the volumes of cellular material they represent are shown in Table 10. The species composition of the flora does not appear to have change greatly since Walker's (1961) ecological investigation of the Salton Sea. One notable exception is *Gyrodinium resplendens*, a species of dinoflagellate, not described by Walker, but now abundant, with counts to 9400 per ml.

Blue-green algae also live in the Sea but appear to be restricted to the benthic habitat. Mixtures of *Oscillatoria*, *Phormidium* and other benthic blue greens grow on the bottom in shallow areas and at times float to the surface in mats. The blue-green algal genera which create the most objectionable pea soup discoloration and extensive rafts in freshwater lakes, such as *Anabaena*, *Microcystis* and *Aphanizomenon*, were not found in the Salton Sea.

The predominant species of algae in the Salton Sea populations may be divided into two groups: (1) those that demonstrated distinct seasonal peaks in numbers, and (2) those that were relatively constant in numbers throughout the year. Of the first group, the best example is a dinoflagellate, *Cachonia niei* (Loeblich), reported by Walker as *Glenodinium* sp., which was rare in July &endash; December 1968, but increased in January 1969 to counts of nearly 90,000/ml in areas of intensively brick-red-colored waters. A pennate diatom, *Thalassionema nitzschioides*, rose from an average of 130 per mel in July to 12,500 per ml in August. (The highest single count for August was 22,000 per ml.) By the end of September, this diatom had disappeared. A similar trend was noted for an euglenoid alga, an unidentified *Eutreptia* sp. Two unidentified motil green flagellates, species A and B, dominated plankton populations from September through November. The highest individual count for species A was 6,800 per ml and for B, 10,400 per ml.

These two algae began to decline in numbers in November although they were still present in significant numbers in December. In the second group, *Cyclotella caspia*, a *Peridinium* sp. And *Gyrodinium resplendens* maintained significant and fairly stable populations throughout the study period.

In both composition and level the phytoplankton populations in the Salton Sea during 1968-1969 were surprisingly similar to those observed by Walker (1961) in 1954-1956. The average population calculated for 1968-1969 is approximately 11,400 individuals per ml, while our estimates form Walker's data is 10,800. Most of the dominant species of algae appear in both FWPCA and Walker's samples.

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