The Salton Sea: An Uncertain Future for California's Largest Lake

G. Chris Holdren

The Salton Sea, the largest inland waterbody in the state of California, is facing an uncertain and increasingly grim future. A previous *LakeLine* article (Barry and Anderson 2008) covered the history and some other characteristics of the Sea. This article will provide additional details on recent activity and conditions at the Salton Sea.

The Past

Located in Imperial and Riverside Counties, the Salton Sea was once an important recreational resource. In the 1960s, the Salton Sea state recreation area drew more annual visitors than Yosemite National Park. Unfortunately, recreation began to fade following two tropical storms in the 1970s that damaged recreational facilities.

Salinity, which had been near the level of 35 g/L found in seawater for much of the period from the 1920s through the mid-1980s, began to increase and reached 44 g/L by 1999 (Holdren and Montaño 2002). Fish kills and outbreaks of avian disease in the 1990s were also signs of degradation, but those events did increase scientific interest in the Sea.

This renewed interest in the Salton Sea led to the Reclamation Act of 1998 (Public Law 105-372), which directed the Secretary of the Interior, through the Bureau of Reclamation (Reclamation), to study options for managing the Sea. The Salton Sea Authority (SSA) was designated as co-lead for the State of California for the project. The overall goals of the Salton Sea Restoration Project were to:

- maintain the Sea as a repository of agricultural drainage;
- provide a safe, productive environment at the Sea for resident and migratory birds and endangered species;
- restore recreational uses at the Sea;
- maintain a viable sport fishery at the Sea; and
- enhance the Sea to provide economic development activities.

An intensive scientific effort initiated in January 1998, led to a series of reconnaissance investigations that were conducted beginning in 1999 to provide the scientific basis for the restoration effort. The results of many of those reconnaissance studies were reported in special editions of *Lake and Reservoir Management* 23(5) (2007), *Hydrobiologia* 473 (2002) and 604 (2008), and *Studies in Avian Biology* 27 (2004)

Reclamation and the State of California examined dozens of alternatives in an attempt to find one that would meet all of the objectives of the Reclamation Act, but finding a viable alternative was elusive. The immense size of the Salton Sea (349 mi^2), seismic activity in the area, uncertainty over future water supply, and other considerations drastically limited restoration alternatives. As a result of the size and complexity of the system, estimated costs for restoration measures that would meet all of the goals of the Salton Sea Restoration Project were in the billions of dollars.

The Salton Basin, which contains the present-day Salton Sea, is located in a highly active tectonic region with frequent earthquakes. The area is dominated by the San Andreas, Imperial, San Jacinto, and Elsinore fault systems, and many moderate to large earthquakes occurred in the Salton Basin over the last 150 years. All of the alternatives that would have stabilized the Sea surface at 1999 levels required construction of extensive levee systems. Estimated construction costs for structures that could withstand projected earthquakes were in the billions of dollars largely because of the numerous faults in the area.

The uncertainty of future water supplies is also problematic. For many years California had been using more water than the amount they were allowed by the Colorado River compact signed by all seven states in the Colorado River basin and the federal government in 1922. Water demand has continued to grow in other basin states, resulting in signing of the Quantification Settlement Agreement (QSA) in 2003. The QSA restricted California's use of Colorado River water to the 4.4 million acre-ft /yr allowed under the Colorado River compact, but also allowed for water transfers out of the Salton Basin. The main impact of the QSA on the Sea will result from reduced inflows as water is transferred from the Imperial Valley to San Diego, Los Angeles, and other coastal cities to meet the needs of their growing populations.

Reporting requirements of the Reclamation Act of 1998 were met in January 2000, when the Department of the Interior forwarded a draft EIS/EIR and several other documents to Congress. The Salton Sea also continues to collect agricultural drainage from extensive agricultural operations in the Coachella and Imperial Valleys. Although a major restoration project for the Salton Sea has not been implemented, seven different Total Maximum Daily Load (TMDL) projects were initiated to improve water quality by addressing sediment, trash, bacteria, and dissolved oxygen in the drains and rivers entering the Salton Sea. Additional information on these TMDLs is available on the State of California, Colorado River Basin Regional Water Quality Control Board web site at: http://www.waterboards.ca.gov/coloradoriver/water_issues/programs/tmdl/tmdl_projects.shtml. An additional TMDL to address nutrient loadings to the Sea is under development.

The Present

Water levels from October 1, 1987, when the USGS started to collect daily elevation levels at the Sea, through 2013 are shown in Figure 1. Water levels remained relatively stable through the 1990s but have been dropping steadily since that time. Mitigation water coming from land fallowed by the Imperial Irrigation District as part of the QSA has helped to slow the decrease, but water levels will soon begin to fall at a faster rate.

Most monitoring at the Sea was curtailed as funding decreased following the intense scientific effort in the late 1990s. The Imperial Irrigation District continued to collect salinity data and the California Department of Fish and Game conducted quarterly net sampling from 2003-2008 to monitor the status and trends of the Salton Sea fisheries.

In response to requests for additional water quality information, Reclamation initiated quarterly monitoring in 2004 to provide information on changes in water quality that are occurring as a result of water conservation measures and other projects intended to improve or maintain water quality in the Sea. Monitoring includes profiles for temperature, dissolved oxygen, pH, conductivity, and oxidation-reduction potential; major ion concentrations; nutrients; chlorophyll-*a*; Secchi depth; and total and dissolved organic carbon.

Low dissolved oxygen concentrations continue to be a significant problem, with oxygen levels occasionally dropping to < 1 mg/L throughout the entire water column during the summer months. Local residents have long associated fish kills with mixing events referred to as "green tides." A previous reconnaissance study (Marti-Cardona et al. 2008) found that these events were the result of mixing events that brought sulfide from the hypolimnion to the surface, where it reacts with dissolved oxygen to form sulfate, stripping oxygen from the water. The sulfate then reacts with calcium to form gypsum ($CaSO_4 \cdot 2H_2O$). The gypsum crystals give the water a greenish tint that can be seen through satellite imagery, clearly showing the extent of the anoxic area (Figure 2). The oxygen loss during some of the green tide events had led to the death of millions of fish on single days.

Other key findings of Reclamation's monitoring program include:

- Salinity in the Salton Sea increased from about 44 g/L in 1999 to over 55 g/L today (Figure 3).

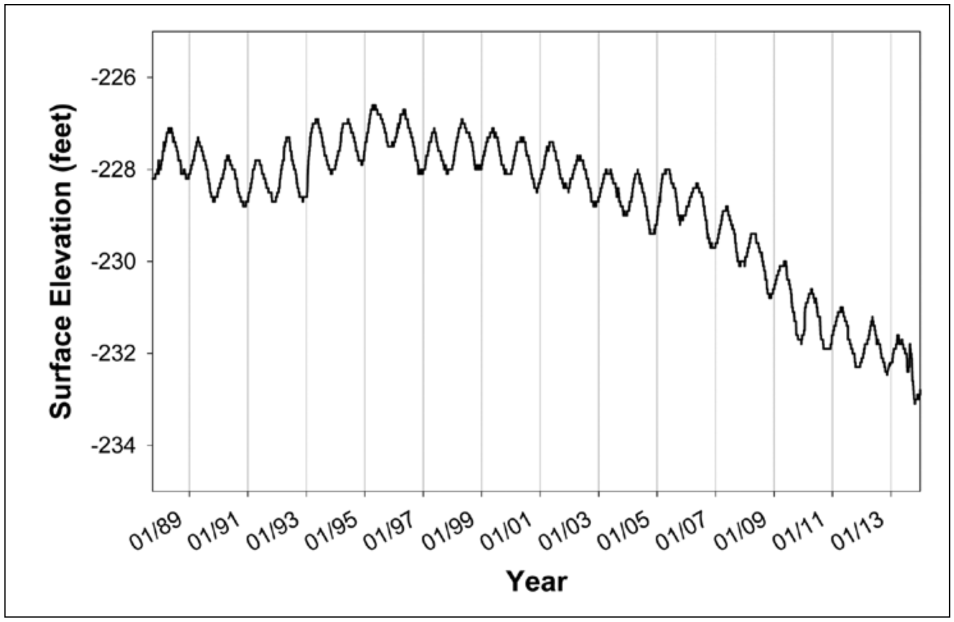


Figure 1. Salton Sea daily surface elevations, 1 October 1987 - 31 December 2013.

Figure 2. MODIS satellite imagery showing the location of the Salton Sea and the extent of a "green tide." Also visible is smoke from wildfires. Figure courtesy of Douglas Barnum, USGS.

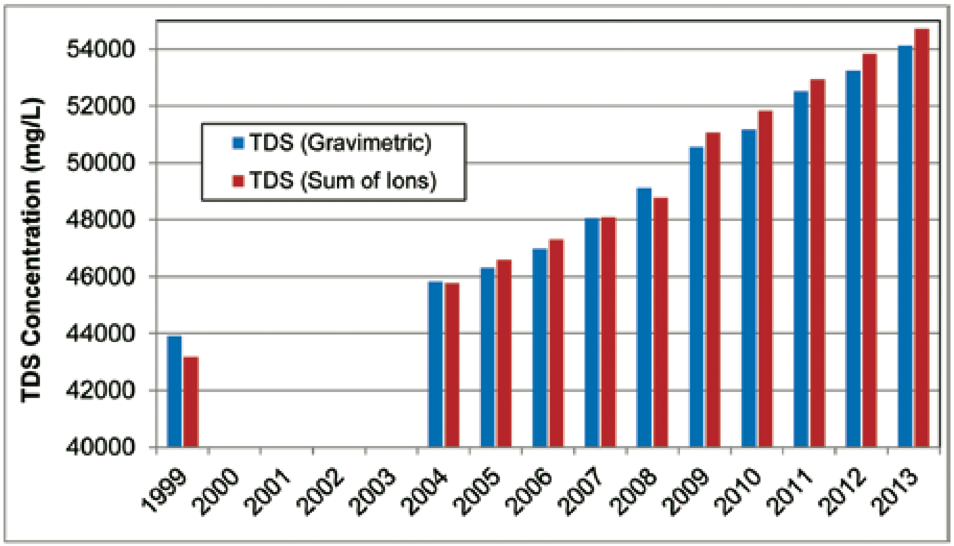


Figure 3. Salton Sea whole lake total dissolved solids concentrations, 1999-2013.

- Suspended solids concentrations appear to have decreased in the Alamo and Whitewater Rivers but remained unchanged in the New River (Figure 4). Because of changes in sampling frequency between the 1999 study and the current study, it is hard to tell if the differences were the result of the TMDLs that were initiated in the watershed.
- Phosphorus concentrations in the Salton Sea appear to have increased since 1999 while nitrogen concentrations remain relatively unchanged (Figure 5), although concentrations have varied widely from year-to-year.
- Selenium concentrations, which are of particular concern to wildlife health, continue to remain low (1-2 µg/L) in the Salton Sea. Selenium concentrations in both the Alamo and New Rivers have changed little since 1999, while Se concentrations in the Whitewater River have decreased. Average concentrations for all years are 5.4 µg/L, 3.3 µg/L, and 2.0 µg/L for the Alamo, New, and Whitewater Rivers, respectively.
- Chlorophyll-*a* concentrations have varied widely (Figure 6), with an individual station reading as high as 648 µg/L in 2007. Variations in chlorophyll *a* concentrations are possibly related to drastic changes in Tilapia (*Oreochromis mozambicus* x *O. urolepis hornorum*) populations. Unfortunately, no chlorophyll-*a* data are available from 2000-2003.

As recently as 1999, the Salton Sea was one of the most productive fisheries in the world (Reidel et al. 2002). A series of fish kills and increases in salinity decimated fish populations between 1999 and 2003. Monitoring conducted by the California Department of Fish and Game found that Tilapia populations reached a minimum in 2003 but increased significantly since that time. The other game fish, orangemouth corvina (*Cynoscion xanthulus*), croaker (*Bairdiella icistia*), and sargo (*Anisotremus davidsoni*) all appear to be extinct in the Sea. None of these species have been captured in net samples, totaling 9,449 net hours of effort, since mid-May 2003. In addition, none of these species have been detected in fish kills or presented by anglers since 2004 (Jack Crayon, California Department of Fish and Game, unpublished data).

The USGS, with funding from Reclamation, operated an experimental Species Habitat Pond complex from 2005 through 2010 to evaluate the effectiveness of created habitat for wildlife. The primary goals of the SHP project were to conduct an ecological risk assessment, particularly for selenium; to evaluate avian numerical abundance, species diversity, nesting success, recruitment, and use patterns; to evaluate water, sediments, and aquatic invertebrate response to blended water; and to evaluate construction techniques and the durability of levees and islands.

The SHP complex, consisting of four ponds each with four islands, was initially flooded in January 2006 and birds began using the pond by May 2006 (Figure 7). Water was delivered to the ponds from the Alamo River and Salton Sea and flowed by gravity through the complex, increasing in salinity as it flowed through the ponds. Results showed that created ponds were capable of creating viable habitat with minimal environmental risks.

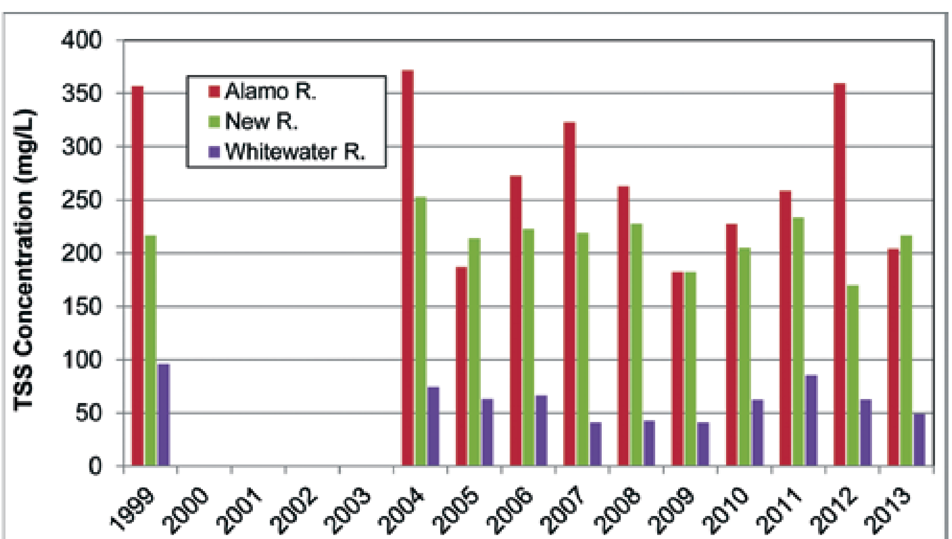


Figure 4. Total suspended solids concentrations in rivers entering the Salton Sea, 1999-2013.

The Future

Under all options currently being considered, there are three outcomes for the Salton Sea that seem certain: (1) water levels will continue to fall, (2) salinity will continue to increase, which will greatly alter aquatic life in the Sea,

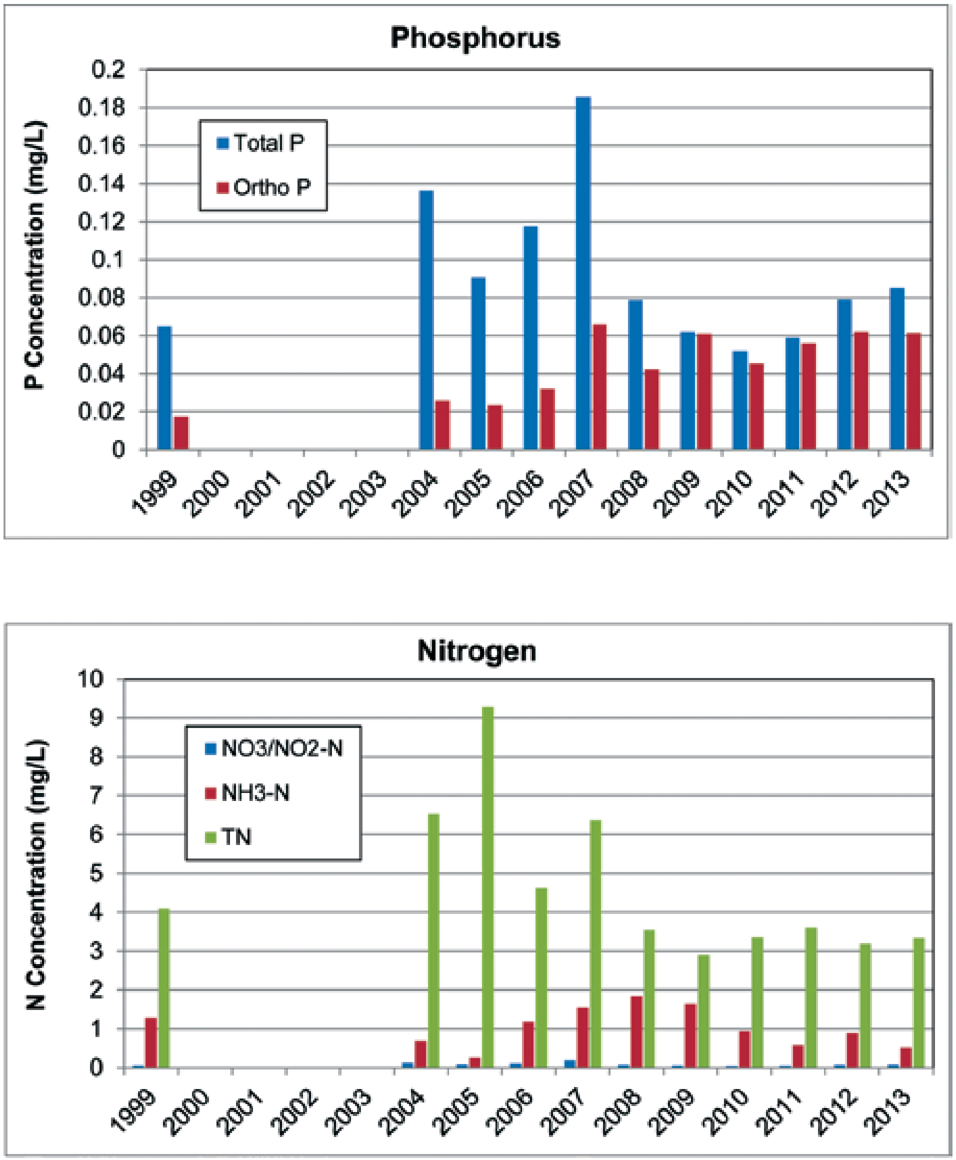


Figure 5. Salton Sea whole lake nutrient concentrations, 1999-2013.

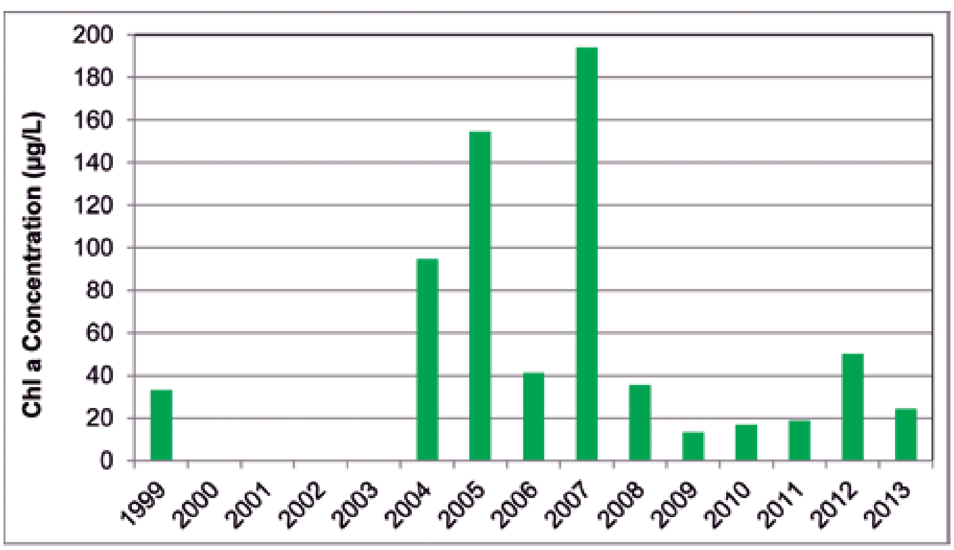


*Figure 6. Salton Sea whole lake chlorophyll-*a *concentrations, 1999-2013.*

and (3) dust emissions will become an increasing problem as more and more of the current Sea floor is exposed by falling water levels.

The State of California released their Final Environmental Impact Statement/ Environmental Impact Report (EIS/ EIR) for the Salton Sea project in 2013 (California DWR/California DFW 2013) in cooperation with the U.S. Army Corps of Engineers (ACOE). The preferred alternative calls for 3,770 acres of ponds constructed on either side of the New River, with pumped diversion of river water and cascading pond units.

The intent of the Species Conservation Habitat (SCH) Project is intended to provide in-kind replacement for near-term habitat losses and to serve as a proof of concept for the restoration of shallow water habitat that supports fish and wildlife currently dependent upon the Sea. The information obtained would be used to measure project effectiveness, to refine operation and management of the ponds, to reduce uncertainties about key issues related to the project, and to serve as a guide for subsequent stages of habitat restoration at the Sea. The SCH Project is not intended to restore the entire Salton Sea, although information obtained from the initial project will guide future restoration efforts.

A report by the Pacific Institute (Cohen and Hyun 2006) provided extensive descriptions of the changes that might occur in the Salton Sea in the absence of a restoration project. Interested readers can consult that report for more details.

Beginning in 2017 when the mitigation water is lost, annual inflows to the Salton Sea will decrease by over 400,000 acre-ft/year compared to pre-QSA levels. This represents a loss of nearly one-third of the current inflow. Water levels will begin to drop dramatically and salinity levels will rapidly increase at that time. To date, actual changes in both elevation (Figure 1) and salinity (Figure 3) have closely tracked the predicted values (Figure 8).

Water levels in the remnant Sea are expected to stabilize at about 255' below sea level and salinity could increase to 250 g/L or more. At that point, any further evaporation will be limited by the high salt content and viscosity of the brine

Figure 7. USGS Experimental habitat pond. Photo courtesy of Douglas Barnum, USGS.

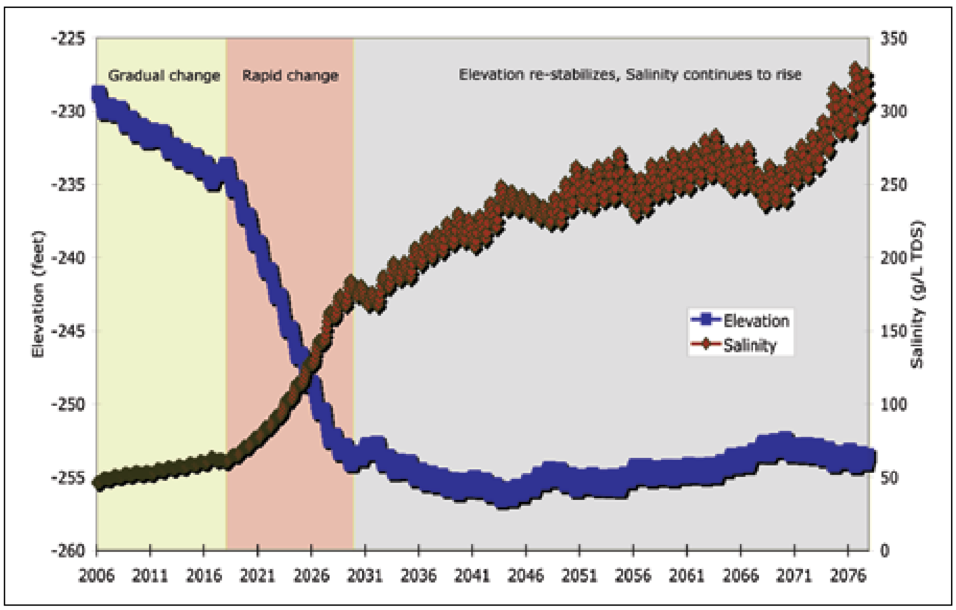


Figure 8. Future elevation and salinity trends at the Salton Sea (reprinted from Cohen and Byum 2006, courtesy of Michael Cohen, The Pacific Institute).

pool. The only remaining aquatic life is expected to be algae and bacteria. Table 1 shows the surface area of the Sea at water levels found in 1999, 2013, and levels projected for 2050. If these projections are correct, over 120 square miles of the Sea floor will become exposed as water levels fall. Mitigation of the expected dust problems will be a major expense for future restoration activities.

Air quality is already a problem in the area surrounding the Salton Sea, with Imperial County having some of the highest concentrations of PM_{10} particulates (dust particles with a diameter of <10 µm that are a major cause of health problems) in the state of California. PM_{10} particulates can increase the number and severity of asthma cases and other health problems, particularly among sensitive populations, which include children and the elderly.

The future of the Salton Sea is not promising. Falling water levels have already caused most private docks to literally be left in the dust (Figure 9), and local residents have seen their dreams of living at the Sea shore recede along with the water levels. Whatever restoration methods are ultimately used, they promise to be expensive and the environmental impacts of the shrinking Sea will not be fully known for many years.

References

Barry, B. and M.A. Anderson. 2008. The Salton Sea. *LakeLine* (4):54-60.

California DWR/California DFW. 2013. Salton Sea Species Conservation Habitat Project, Final Environmental Impact Statement/Environmental Impact Report, U.S. Army Corps of Engineers Application No. SPL-2010-

Table 1. Salton Sea Surface Area at Various Elevations.

Elevation, ft (Year)	-228 (1999)	-232 (2013)	-255 (2050)
Surface Area, acres (sq. miles)	231,973 (362.5)	223,336 (349.0)	151,497 (236.7)

Figure 9. Residential docks in Salton City, California, 2014. Photo courtesy of Norm Niver, Salton City, CA.

00142-LLC, State Clearinghoiuse No. 2010061062. Prepared by the California Department of Water Resources and California Department of Fish and Wildlife for the California Nations Resources Agency. Available at: http://www.water.ca.gov/saltonsea/docs/eir2013/FinalEIS_EIR_complete.pdf, accessed 4 August 2014.

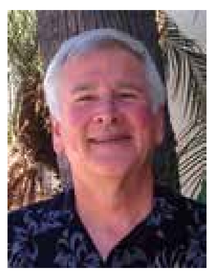
Cohen, M.J. and K.H. Hyun. 2006. Hazard: The future of the Salton Sea with no restoration project. Pacific Institute. Available at: http://www.pacinst.org/wp-content/uploads/2013/02/report15.pdf, accessed 4 August 2014.

Holdren, G.C. and A. Montaño. 2002. Chemical and Physical Characteristics of the Salton Sea, California. *Hydrobiologia,* 473:1-21.

Marti-Cardona, B., T.E. Streissberg, S.G. Schladow and S.J. Hook. 2008. Relating fish kills to upwellings and wind patterns at the Salton Sea. *Hydrobiologia,* 604:85-95.

Reidel, R., L. Caskey and B.A. Costa-Pierce. 2002. Fish Biology and fisheries ecology of the Salton Sea, California. *Hydrobiologia,* 473:229-244.

Tiffany, M.A., S.L. Ustin and S.H. Hurlbert. 2007. Sulfide irruptions and gypsum blooms in the Salton Sea as detected by satellite imagery, 1979-2006. *Lake Reserv Manage,* 23:637-652.



G. Chris Holdren, Ph.D., CLM, is the manager of the Environmental Applications and Research Group at the Bureau of Reclamation in Denver, CO. He has over 40 years of experience with lake and reservoir management. Chris has been an active member of NALMS and its affiliates. He is a past president of NALMS and the Pennsylvania Lake Management Society, a former director of the Colorado Lake and Reservoir Management Association, and a former associate director of the Virginia Lakes and Watersheds Association.

LAKE and RESERVOIR MANAGEMENT

A scientific publication of NALMS published up to four times per year solicits articles of a scientific nature, including case studies.

If you have been thinking about publishing the results of a recent study, or you have been hanging on to an old manuscript that just needs a little more polishing, now is the time to get those articles into your journal. There is room for your article in the next volume. Don't delay sending your draft article. Let the editorial staff work with you to get your article ready for publishing. You will have a great feeling of achievement, and you will be contributing to the science of managing our precious lakes and reservoirs.

Anyone who has made or plans to make presentations at any of the NALMS conferences, consider writing your talk and submitting it to the journal. It is much easier to do when it is fresh in your mind.

Send those articles or, if you have any questions at all, contact: Al Sosiak, Editor, *Lake and Reservoir Management*.

If there is anyone who would like to read articles for scientific content, please contact Al Sosiak. The journal can use your help in helping the editorial staff in editing articles.