Nutrient Dynamics in the Salton Basin--Implications from Calcium, Uranium, Molybdenum, and Selenium

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H31B-02

ABSTRACT: The Salton Sea has been accumulating chemical constituents delivered by its tributary streams for nearly 100 years because it has no outlet. The buildup of chemicals that are highly soluble and unreactive, such as chloride, has resulted in the development of a quasi-marine lake. In contrast, chemicals that react to form insoluble phases ultimately enter the sediment that accumulates on the floor of the Sea. Solubility properties are especially relevant for two important contaminants, selenium and nitrogen. The selenium is contained in Colorado River water used for irrigation, and nitrogen is derived mostly from chemical fertilizer in agricultural runoff. Both are delivered to the Salton Sea as highly soluble oxyanions by the Alamo and New Rivers, which are relatively high in dissolved oxygen at their outlets to the Salton Sea, but are removed as reduced species in anoxic sediment on the Sea's floor. Without this removal mechanism, selenium concentration would presently be about 400 micrograms per liter and nitrogen would be about 100 milligrams per liter in the Salton Sea's water, rather than the observed concentrations of only about 1 microgram per liter and 5 milligrams per liter, respectively. Ironically, anoxic conditions responsible for producing the noxious odors and low oxygen conditions that lead to periodic dieoffs of large numbers of fish in the Salton Sea have prevented aqueous selenium and nitrogen from reaching levels that could indeed pose an extreme environmental hazard.

Does all the selenium and nitrogen ever discharged to the Salton Sea still reside in its sediment, or has some been lost? It is well known that certain bacteria are capable of converting both elements into gases that can then be volatilized to the atmosphere. By comparing concentrations of selenium and nitrogen with those of molybdenum and uranium, elements with similar geochemical properties, this study concludes that there is now little, if any, selenium and nitrogen loss to the atmosphere. It is important that any engineering changes made to the Salton Sea that are intended to remediate for environmental effects do not result in reintroduction of these contaminants from sediment into the overlying water.

Dissolved nitrogen concentration in the Salton Sea is apparently several times higher today than it was in the mid-1950's; yet dissolved phosphorus concentration has changed little, if at all. Why have phosphorus levels not seen a similar increase? One possible explanation is that phosphate is efficiently removed from the water column by incorporation with calcium as apatite minerals--the material that composes bone. If so, attempts to slow or reverse excessive biological productivity (eutrophication) through large-scale harvesting of fish may not result in lowering the dissolved phosphorus concentration that would thereby improve the trophic status of the Salton Sea.

The selenium profile in a core from the Salton Sea was found to increase from about 9 at the sediment-water interface to as high as 15 micrograms per kilogram, before decreasing with increasing depth to the sub-microgram-per-gram level in material believed to predate the formation of the Salton Sea. The low concentrations in sediment that predates the lake are about the same as those for clay-rich soils in the Imperial Valley at the south end of the Sea. A possible explanation for the maximum at mid-depth is that the highest concentration corresponds to a period when agricultural development in the upper basin was resulting in greater input to the Colorado River from leaching of selenium-rich soluble salts than today.

USGS
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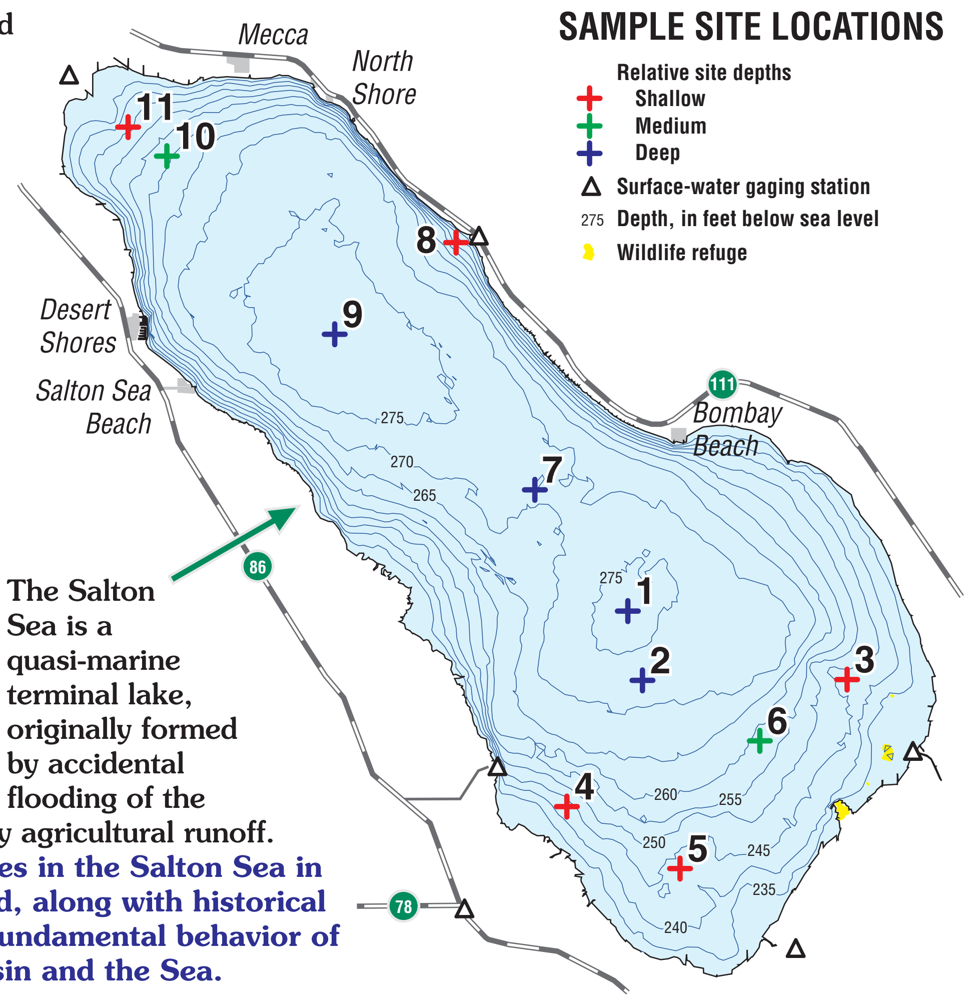
Presented at Spring 2000 Annual Meeting, American Geophysical Union, Washington, D.C.

1 The Salton Basin is an important economic, environmental, and international resource located in an arid area that receives less than 70 mm of rainfall annually. The basin contains almost 400,000 hectares of intensively irrigated farmland, located mostly south of the Salton Sea; the city of Mexicali, a large urban area of 1 million people, also is located in the basin.



The Salton Sea is a quasi-marine terminal lake, originally formed by accidental flooding of the Colorado River nearly 100 years ago, now largely sustained by agricultural runoff. **Sediment grab samples were collected from 11 diverse sites in the Salton Sea in July 1998, and chemical data from these samples are used, along with historical aqueous data from the two major rivers, to ascertain the fundamental behavior of nutrients and selenium, important contaminants in the basin and the Sea.**

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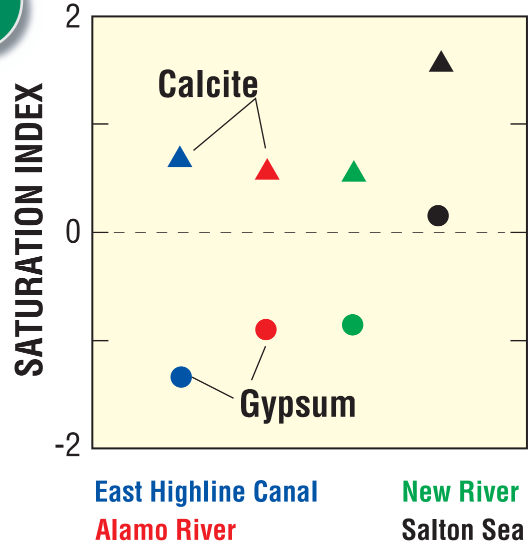
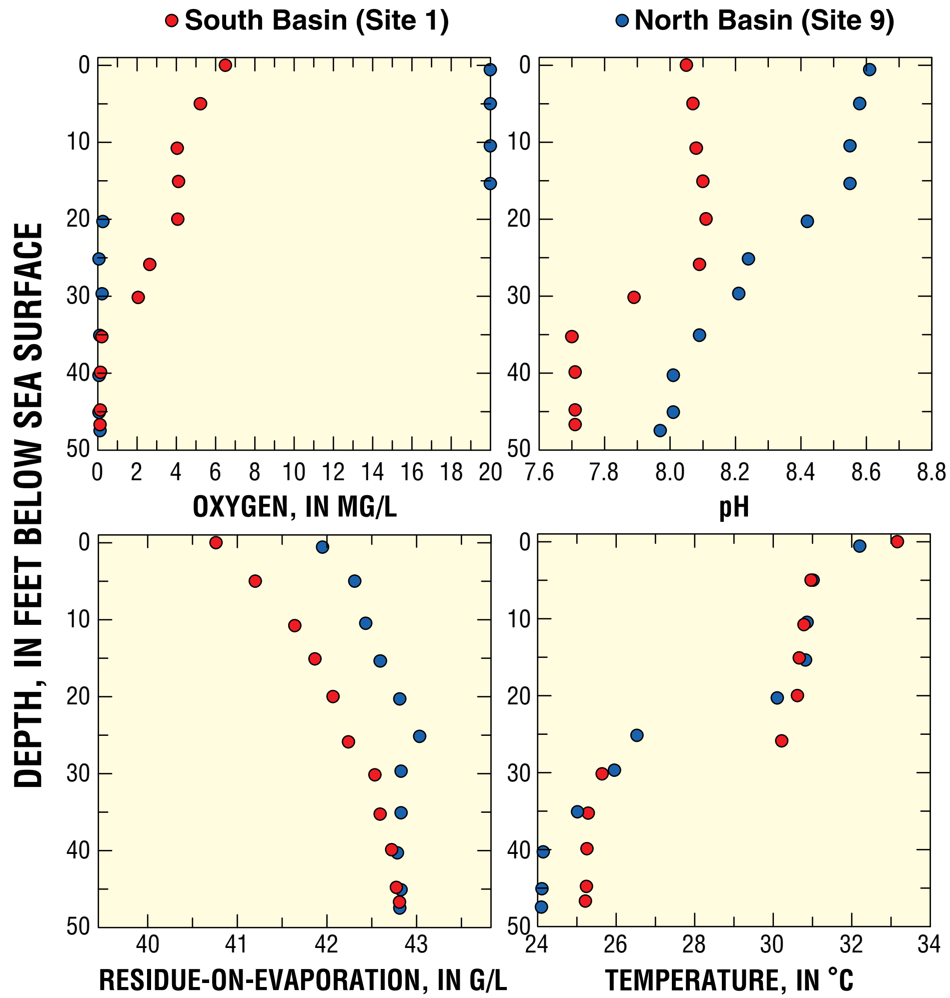


Saturation index, defined as the logarithm of measured activity ("concentration") product divided by the solubility product, illustrates the high hardness in irrigation water (East Highline Canal) supplied by diversion of the Colorado River and in discharge from the two major rivers. A calculated index that is much greater than zero (the value above which thermodynamic equilibrium predicts that precipitation can occur) indicates that deposition of calcium carbonate is very likely in the Salton Sea, whereas a value very close to zero suggests that formation of calcium sulfate may be taking place.



Water-quality profiles indicate strong thermal stratification and bottom water devoid of dissolved oxygen (DO) in July 1998, except at shallow depths. **Such conditions favor the deposition and permanent sequestration of redox-sensitive contaminants, such as nitrogen and selenium, in bottom sediment.**

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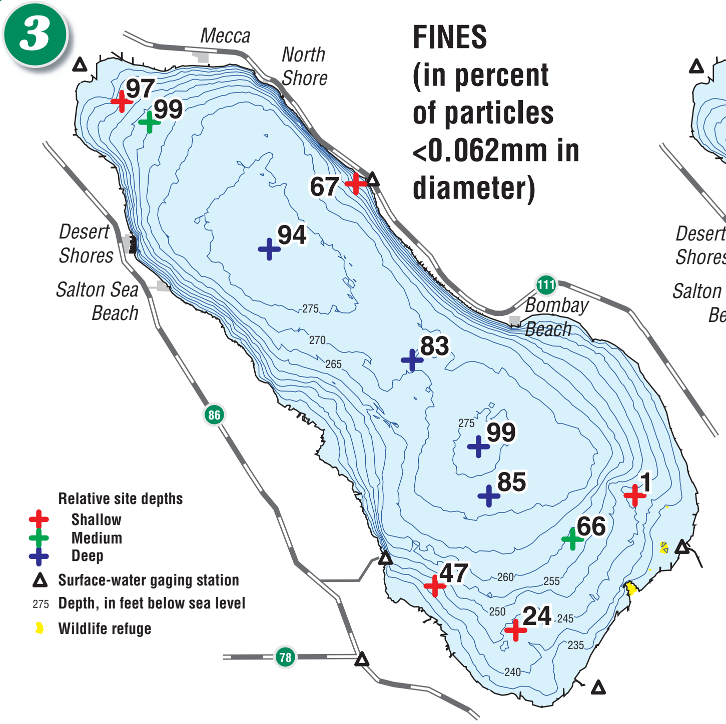
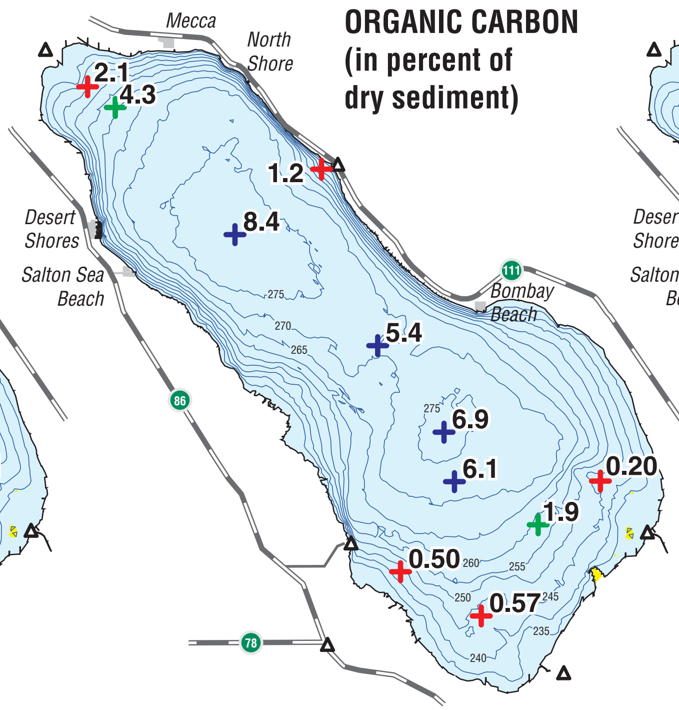
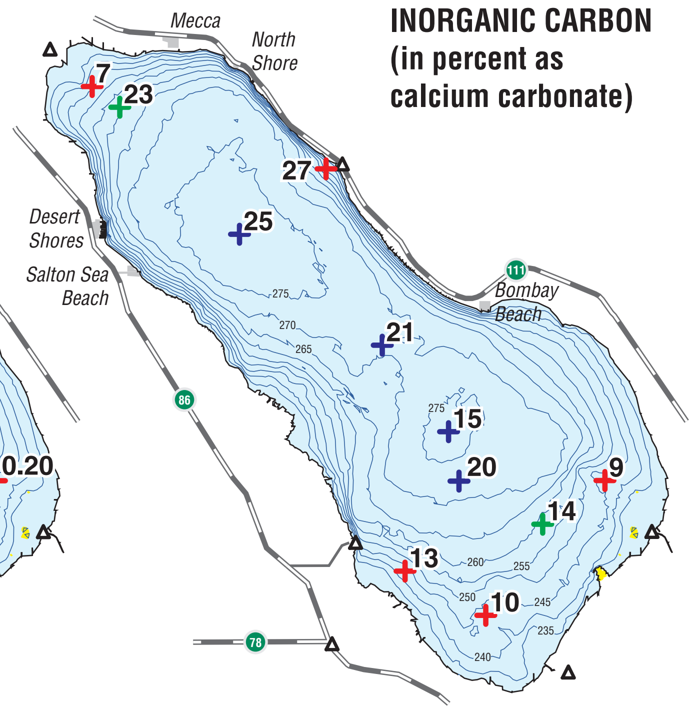


As expected, sand content increases toward the shore and in the deltas formed from deposition by large rivers and silt plus clay content increases in deeper parts of the Salton Sea.



Total organic carbon in sediment shows a strong correlation with grain size, as do many trace elements and organic compounds.



High calcium carbonate content in deeper parts of the Salton Sea confirms expectations of deposition based on saturation calculations.

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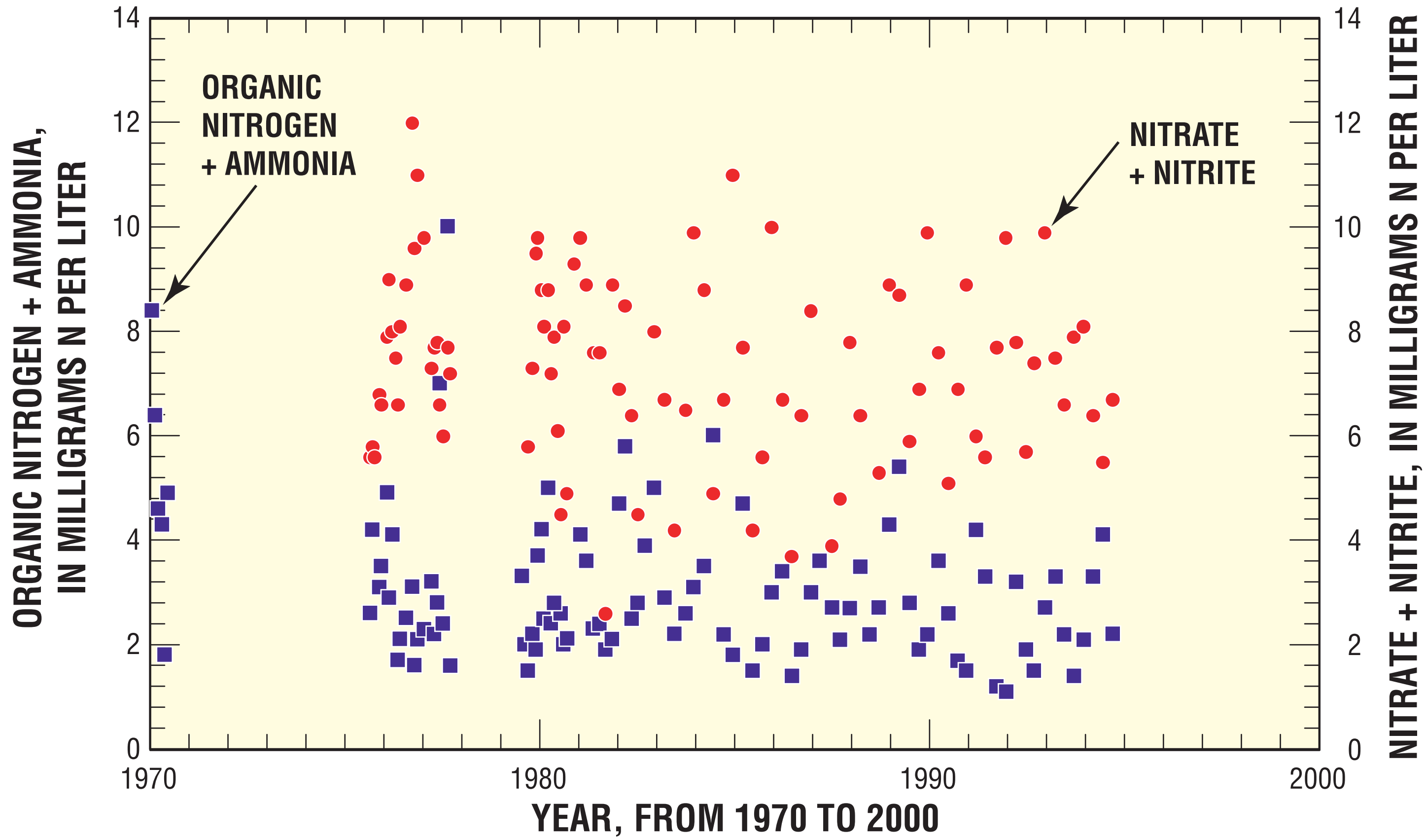
REDUCED NITROGEN AND OXIDIZED NITROGEN IN ALAMO RIVER AT DROP 3



The USGS monitored a broad suite of constituents at the New and Alamo River outlets to the Salton Sea monthly for a period of 1 year in 1988-89. Monitoring on the Alamo River at Drop 3, a few miles upstream from the river's outlet, since about 1970 shows that **the 1988-89 period used in subsequent calculations is representative of longer term concentrations for many constituents.** (Only data for nitrogen, which exhibits much greater variation than most constituents, are illustrated herein.) Nitrogen delivered to the Salton Sea is mostly in the form of nitrate, although virtually all of the nitrogen in the Salton Sea itself consists of the reduced species, ammonia and organic nitrogen.

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CONCENTRATIONS IN NEW AND ALAMO RIVERS (1988-89)

CONSTITUENT	ALAMO	NEW	n
Discharge	60%	40%	
Uranium	17	14	1
Molybdenum	13.3±1.9	10.8±2.5	10
Selenium	7.6±2.0	4.3±0.5	15
$NO_2 + NO_3$-N	8.1±1.6	4.9±0.8	15
NH_4-N	1.5±1.3	2.3±0.9	15
Organic-N	1.0	0.2	1
Total N	10.6	7.6	
Total Organic Carbon	9.3	12	1

MEAN RIVER CONCENTRATIONS (discharge weighted)

Nitrogen	9.3 mg/L
Selenium	6.3 µg/L
Uranium	15.8 µg/L
Molybdenum	12.3 µg/L
Organic Carbon	10.4 mg/L

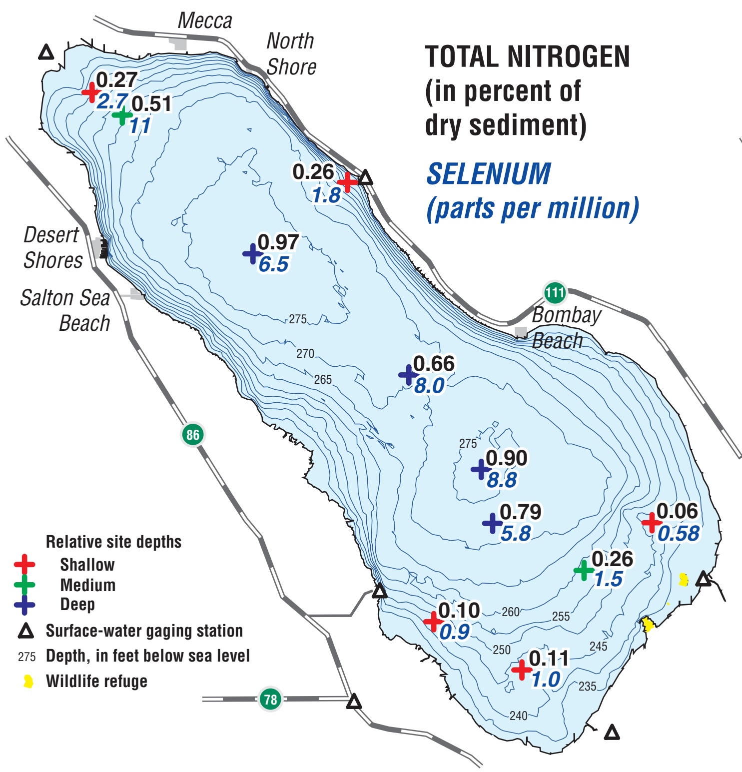
ELEMENT MASS RATIOS (parts per million)

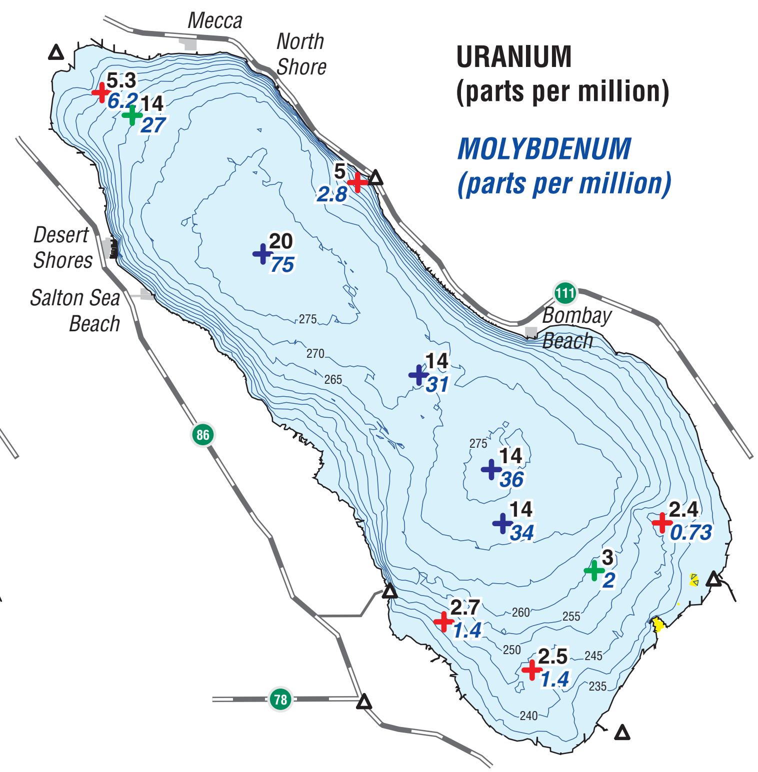
RIVER (1988-89)		SEDIMENT (1988-89)
1,476	N/Se	1,153±334
2.51	U/Se	2.43±0.8
1.95	Mo/Se	2.51±1.6
1,651	TOC/Se	7,522±2,984

CONCLUSIONS:

Nitrogen Reduction within the Sea = 22%
Autochthonous Organic Production is >78%

Element concentrations and mass ratios are from the 1988-89 river data and from the 1998 Salton Sea sediment data. Nonvolatile elements, such as molybdenum (Mo) and uranium (U), also exist as soluble oxyanions in the oxygenated river water and as insoluble species in reducing bottom sediment beneath the Salton Sea. Nitrogen (N) and selenium (Se) have geochemical properties similar to those of U and Mo, except that Se and N can potentially be lost as gases. The fact that relative proportions (mass ratios) for all four of the above elements are about the same in river water and in lake sediment indicates that **nearly all the N and Se discharged by the rivers is retained within the sediment accumulating beneath the Salton Sea.** Extending similar calculation methods reveals that at least 78% of organic carbon is derived from autochthonous (within lake) production and that no more than 22% is derived from outside the Sea.





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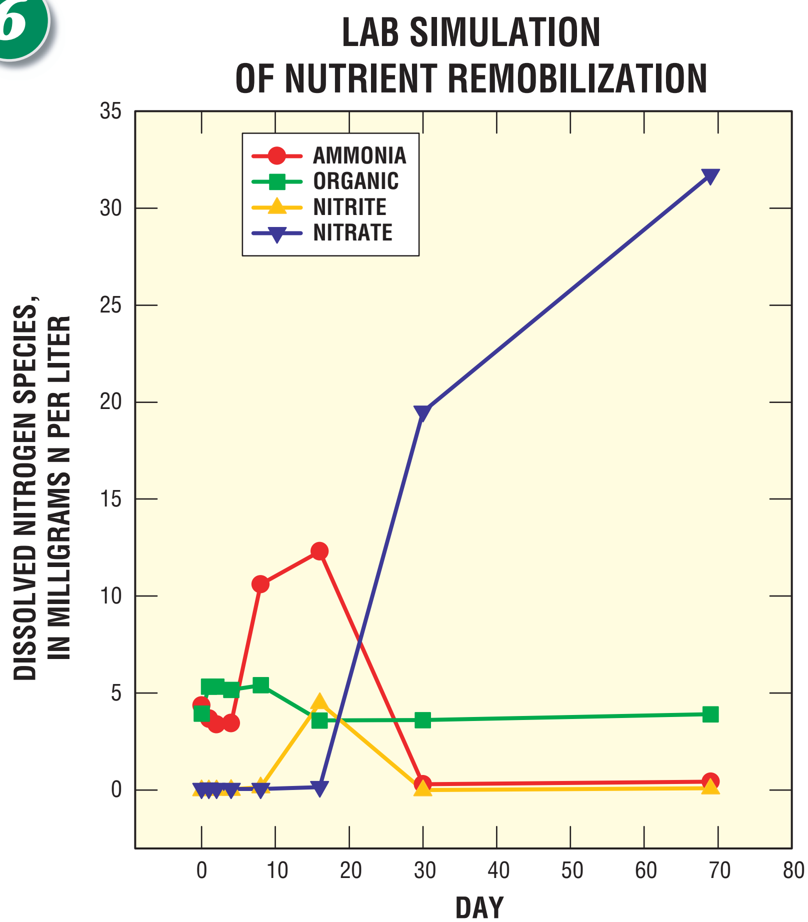
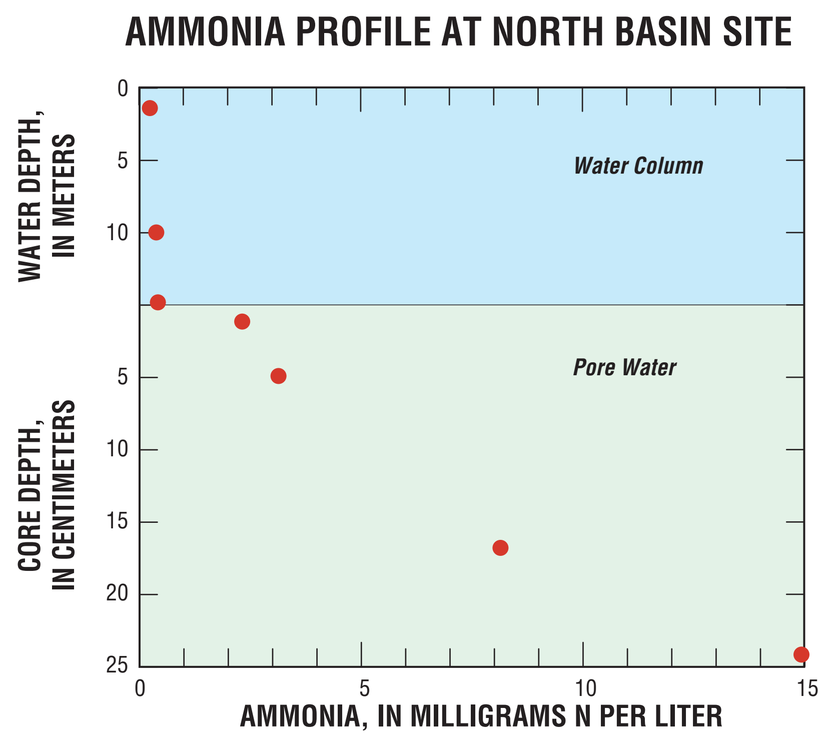
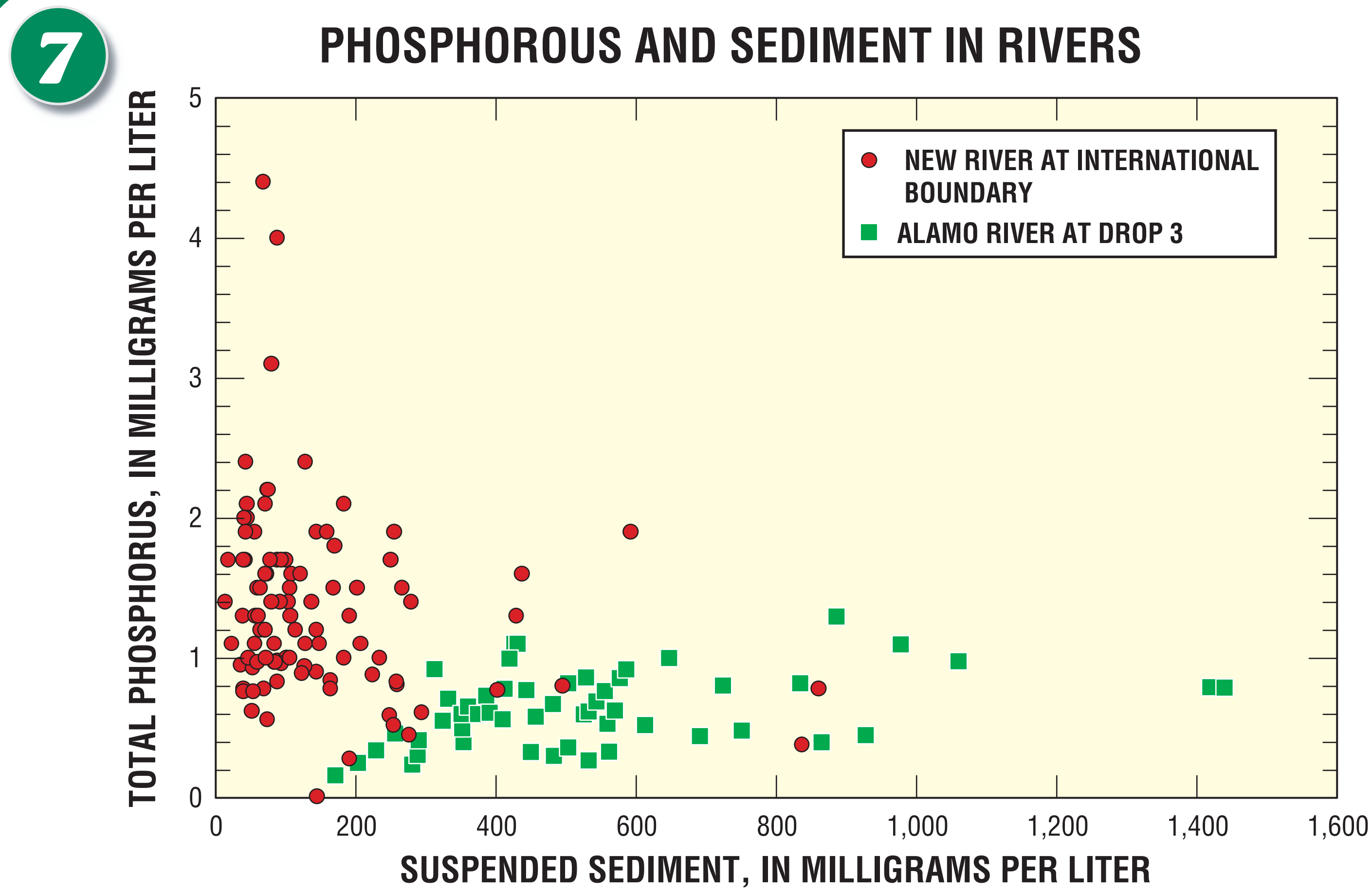


Potential mechanisms for reintroduction of sedimentary N into the overlying water column include mineralization (oxidation to nitrate) in areas where high-DO bottom water is present, and diffusion of ammonia from sediment into the overlying water. Results from a laboratory simulation, using a mixture of sediment and water from the Salton Sea infused with oxygen by bubbling air into the mixture, indicates that potential for oxidative mineralization exists.

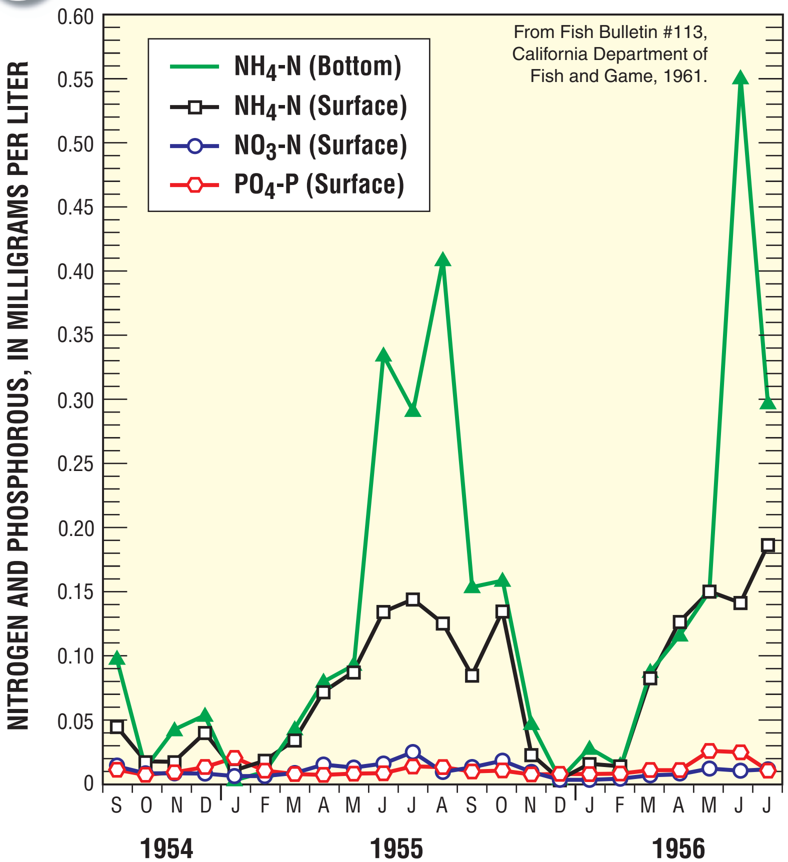


Much higher ammonia concentrations in sediment pore water than in the overlying bottom water at site 9 also confirm the potential importance of the diffusive mechanism. **These results for N hint at similar possibilities for Se remobilization under suitable environmental conditions.**

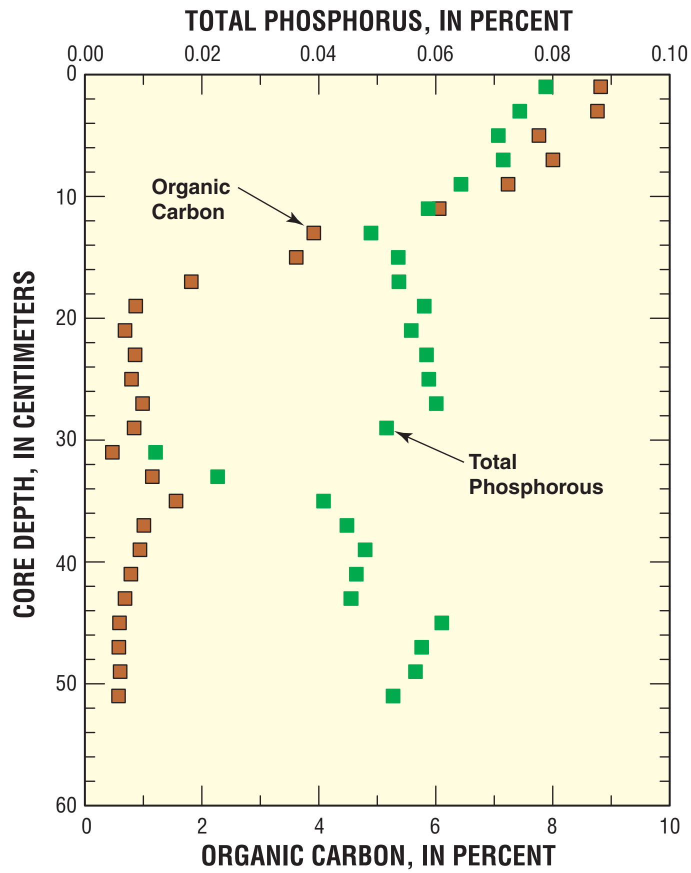


Phosphorus (P) differs from the above redox-sensitive elements in that a significant proportion of its transport to the Salton Sea is associated with attachment to suspended sediment. Agricultural tail water and resuspension from the riverbed are sources of suspended sediment in the rivers. Positive correlation between P and suspended sediment is illustrated by data for the Alamo River at Drop 3. Discharge of wastewater from Mexicali, immediately upstream from Calexico, results in a negative correlation (decrease in P with increase in suspended sediment) indicative of dilution from the point source. However, as the New River traverses the Imperial Valley to its outlet at the Salton Sea, it increasingly acquires characteristics similar to those of the Alamo River.

8 SALTON SEA NUTRIENT CONCENTRATIONS



ORGANIC CARBON AND TOTAL PHOSPHORUS IN CORES



Comparison with historical dissolved-nutrient concentrations in the Salton Sea is difficult to interpret because of strong seasonal variation, and because most of the nitrogen (50 to 75% today) is present as organic nitrogen.

Nevertheless, analysis of bottom water (not shown) suggests that dissolved-nitrogen concentration in the Sea has increased several-fold since the mid-1950's, while there has been no discernable increase in phosphorus.

The organic carbon profile in a core collected from the center of the north basin (site 9) in 1999 exhibits a large 10-fold increase in concentration for younger sediment near the surface, as does the profile for N (not shown). **These results contrast sharply with those of P, which shows only a modest 30% increase in concentration near the surface,** consistent with this element's com-paratively high natural occurrence in basin soil and in river-suspended sediment.

Biologically productive lakes commonly display a "feed-back mechanism" that recycles P from highly reducing sediment back into the overlying water, thereby enhancing the lake's rate of eutrophication. Is it possible that skeletal material from dead fish is sequestering P within sediment beneath the Salton Sea as highly insoluble apatite (calcium phosphate) minerals, and has thereby kept dissolved P levels nearly constant for several decades?

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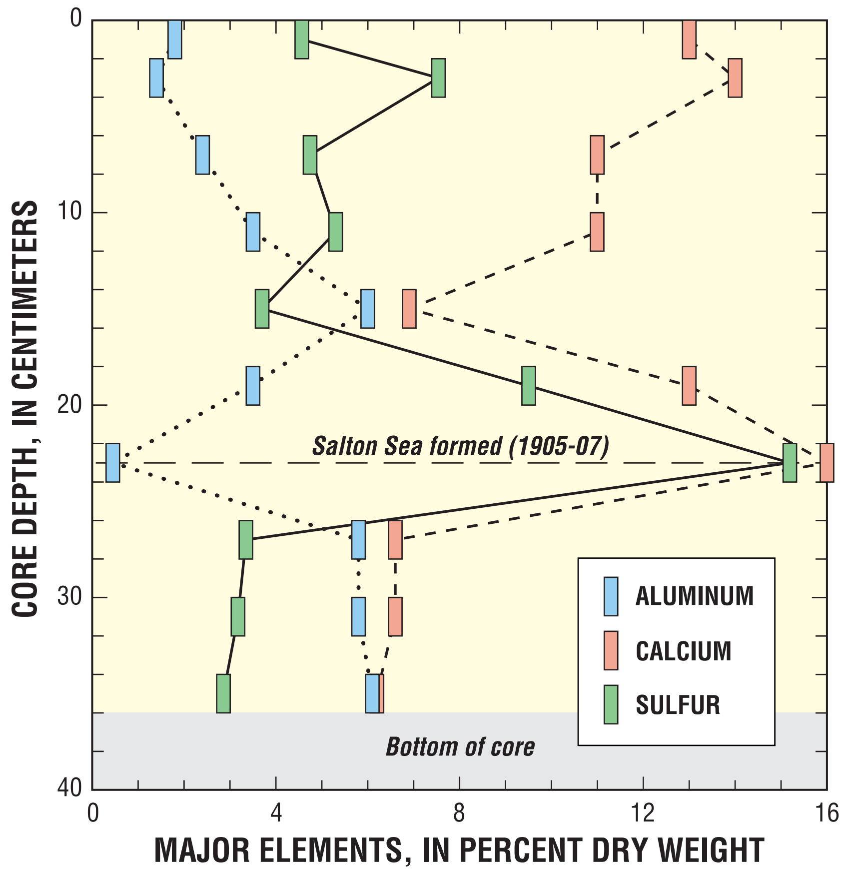
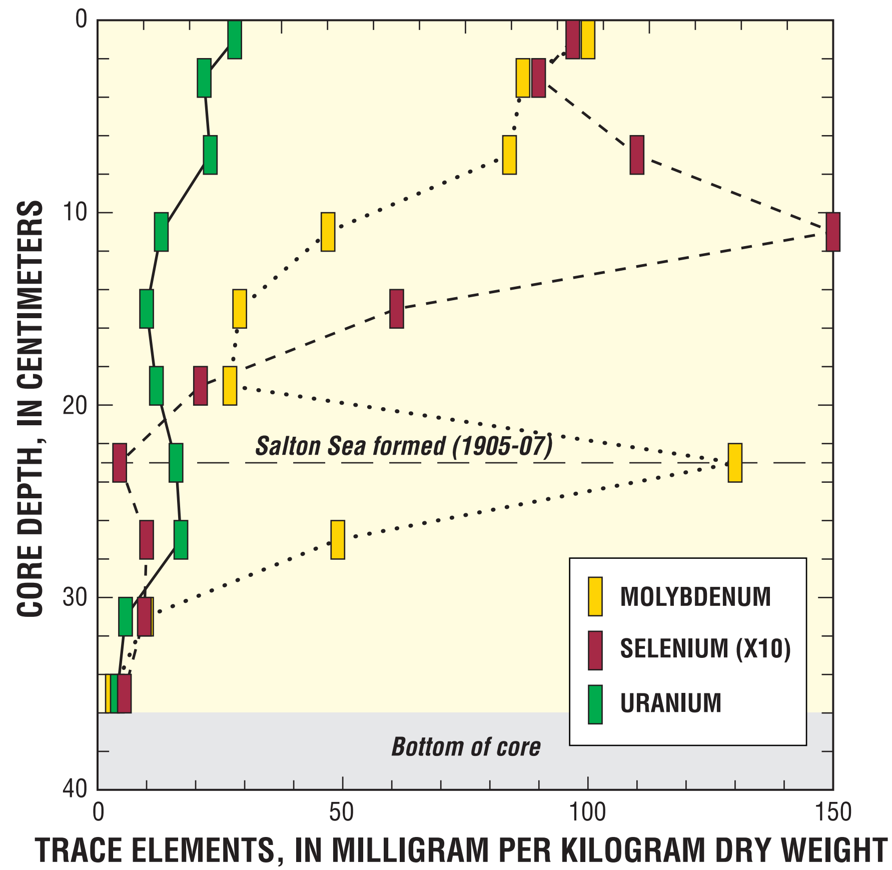
GEOCHEMICAL RECORD OF SEA'S FORMATION



Geochemical trends for other elements also are revealed by additional cores from site 9. Efflorescent minerals that accumulated on the dry lakebed prior to flooding in 1905-07 cause the enrichment in calcium sulfate and depletion in aluminosilicate content at 22-24 cm.

SELENIUM PROFILE



The Se profile rises through a maximum at 10-12 cm, and then declines with increasing depth to levels found in Imperial Valley soils. **The maximum might indicate dissolved Se in the Lower Colorado River was about 50 percent higher in 1940 than today.** Post depositional diagenesis and historical shifts in redox character of the Salton Sea are other possible explanations for the profile.