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INFLUENCE OF LAS VEGAS WASH DENSITY CURRENT ON
NUTRIENT AVAILABILITY AND PHYTOPLANKTON GROWTH IN LAKE MEAD

by

John R. Baker¹⁾ and Larry J. Paulson²⁾

INTRODUCTION

Density currents are commonly formed in reservoirs because of temperature or salinity induced density differences between inflowing and receiving waters. Anderson and Pritchard (1951) were among the first to demonstrate this in their investigations of density currents in Lake Mead. They found that the Colorado River formed an underflow in Lake Mead during the winter, an overflow in the spring and an interflow in the summer and fall. Wunderlich and Elder (1973) have since described the hydromechanics of these types of flow patterns, and density currents have been reported for several other large reservoirs (Carmack et al. 1979, Johnson and Merritt 1979).

The importance of density currents in determining circulation patterns in reservoirs has long been known (Anderson and Pritchard 1951), but only recently have studies demonstrated their significance as mechanisms for transport of heat (Carmack et al. 1979) and nutrients (Gloss, Mayer and Kidd 1980). The vertical distribution and degree of mixing of a density current can directly influence nutrient availability to phytoplankton in the euphotic zone. In this paper, we describe how another density current in Lake Mead, the saline, nutrient rich Las Vegas Wash inflow, affects nutrient availability and phytoplankton growth in Las Vegas Bay.

DESCRIPTION OF THE STUDY AREA

Lake Mead was formed in 1935 by the construction of Hoover Dam and occupies a 183 km reach of the Colorado River on the Nevada-Arizona border (Fig. 1). Lake Mead is now the second in a series of reservoirs on the Colorado River after the formation of Lake Powell upstream in 1963. Major reaches in Lake Mead consist of Gregg, Temple, Virgin and Boulder Basins. At full capacity, Lake Mead has a maximum

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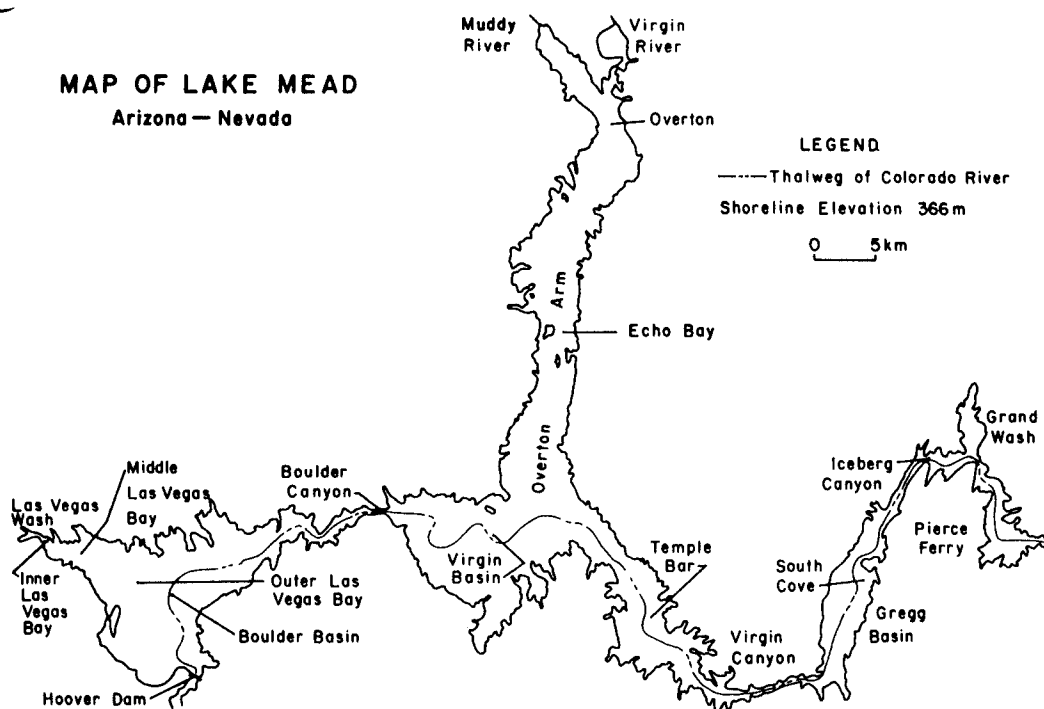


Figure 1. Map of Lake Mead

depth of 180 m and a volume of $36 \times 10^9 \text{ m}^3$ (Hoffman and Jonez 1973) making it the largest reservoir in terms of volume in the United States. For further morphometric characteristics, see Paulson, Baker and Deacon (1980).

Lake Mead is located in the arid Mohave Desert where annual precipitation is less than 12.7 cm (Hoffman and Jonez 1973). The Colorado River contributes 98% of the inflow to the reservoir. The Muddy and Virgin Rivers which discharge into the Overton Arm, a long embayment of Virgin Basin, and Las Vegas Wash which discharges into Las Vegas Bay, an embayment of Boulder Basin, comprise the remaining inflows.

Las Vegas Wash is a natural drainage system for the Las Vegas Valley to the Colorado River (Lake Mead). Two secondary sewage treatment plants, located approximately 17 km from Lake Mead contribute over 95% of the flow ($2.26 \text{ m}^3 \cdot \text{sec}^{-1}$) to Las Vegas Wash (Kaufman, Peckham and Sanders 1971) accounting for the high nutrient concentrations (Table 1). Ammonia concentrations measured at North Shore Road (1.6 km from Lake Mead) are low for sewage effluent because of ammonia stripping in Las Vegas Wash. To date, the mechanism for this is not completely understood (Baker and Paulson 1979). High nitrate and total dissolved solids concentrations, ranging to over $100 \text{ mg} \cdot \text{l}^{-1}$ and $20,000 \text{ mg} \cdot \text{l}^{-1}$, respectively, are derived from groundwater inputs in the Wash (Kaufman et al. 1971, Bateman 1976). The contaminated groundwater originates from large underground salt mounds that were formed

SURFACE WATER IMPOUNDMENTS

Table 1. Nutrient and total dissolved solids concentration ($\text{mg}\cdot\text{l}^{-1}$) in Las Vegas at North Shore Road (1.6 km from Las Vegas Bay).

	Total Phosphorus	Phosphate	Nitrate	Ammonia	Total Dissolved Solids*
Mean	3.52	1.9	4.95	3.7	2623
Range	2.53-5.98	1.29-3.08	2.43-6.57	0.21-6.73	2120-3040

*USGS Data

from discharged industrial effluent into unlined evaporation ponds up until 1978.

Las Vegas Wash contributes less than 1% of the total inflow to Lake Mead; however, a substantial portion of the phosphorus and nitrogen loads to Lake Mead is derived from Las Vegas Wash (Table 2).

Table 2. Total dissolved solids and nutrient budget for Lake Mead.

	Input		Output
	Colorado River	Las Vegas Wash	Hoover Dam
Flow ($\text{m}^3\cdot\text{yr}^{-1}$)	1.077×10^{10}	7.23×10^3	1.03×10^{10}
TDS ($\text{kg}\cdot\text{yr}^{-1}$)	6.79×10^9	2.38×10^8	7.21×10^9
Total Phosphorus ($\text{kg}\cdot\text{yr}^{-1}$)	198.7×10^3	263.1×10^3	123.1×10^3
Phosphate ($\text{kg}\cdot\text{yr}^{-1}$)	56.8×10^3	136.6×10^3	110.6×10^3
Inorganic Nitrogen ($\text{kg}\cdot\text{yr}^{-1}$)	47.0×10^5	6.7×10^5	31.0×10^5
Inorganic Nitrogen:	82.8	4.9	28.1
Inorganic Phosphorus Ratio	1	1	1

Phosphorus loading is greater than that from the Colorado River. Inorganic nitrogen loading is about 15% of the total load. The Colorado River inflow is poor in phosphorus as indicated by the very high inorganic nitrogen: phosphorus ratio ($\text{N:P} = 82.8:1$), whereas, Las Vegas Wash is rich in phosphorus ($\text{N:P} = 4.9:1$).

TDS loading is also high (Table 2) and Las Vegas Wash has been identified as a major source of salinity to the lower Colorado River by the U.S. Water and Power Resources Service. They plan to reduce the salinity in Las Vegas Wash by approximately 50%.

MATERIAL AND METHODS

The location of sampling stations are shown in Figure 1. Each station was sampled approximately monthly over a 3-4 day period from October 1977-September 1978.

Water samples for chemical analyses were collected with a 3-liter van Dorn from the surface and 1-7 other depths depending on the depth of the station. Samples were held in acid-rinsed, plastic bottles and placed on ice immediately after collection. Samples for ammonia analysis were analyzed within a few hours of collection. Samples for nitrate, phosphate and total phosphorus were frozen and analyzed within 1-2 weeks after collection. Ammonia, nitrate and phosphate analyses were run on samples filtered through glass filters (GFC). Ammonia analysis was made with the phenol-hypochlorite method of Solorzano (1969) as modified by Liddicoat et al. (1975). Nitrate was analyzed by the hydrazine reduction method described by Mullin and Riley (1955) and updated by Kamphake et al. (1967). Phosphate

and total phosphorus were determined using the ascorbic acid method described by Strickland and Parsons (1968) as modified by Goldman (1974). Total phosphorus was determined on unfiltered samples treated by acid hydrolysis (10.8 N H₂SO₄). All chemical results are reported as the elemental form.

Chlorophyll-a analysis was made on composite samples collected from surface, 3 and 5 m. Samples were stored in the dark in an ice chest immediately after collection. A 500-1000 ml subsample was filtered through a pretreated (2 drops magnesium carbonate solution) glass fiber filter (GFC). The filters were then ground in 90% acetone followed by a 3 hour extraction period in the dark. Chlorophyll-a concentrations were calculated according to the trichromatic equations of Strickland and Parsons (1968).

Phytoplankton productivity was measured in situ using the ¹⁴C method (Steeman-Nielsen 1952, Goldman 1963). Samples were collected and incubated (3-6 hr) at 0, 1, 3, 5, 7, 10 and 15 m. One light and one dark 125 ml glass-stoppered reagent bottle were filled with lake water spiked with 0.96 µC·ml⁻¹ NaH¹⁴CO₃ solution, and returned to each depth. Upon retrieval, the bottles were placed in the dark until filtered (1-3 hours later). The entire contents of each bottle were filtered through 0.45µ membrane filters. Filters were rinsed with 0.005 N HCL, placed in scintillation vials, allowed to dry and then filled with 20 ml scintillation cocktail (2 parts PCS: 1 part xylene). Radioactivity was measured with a Beckman LS-100 scintillation counter. Solar radiation during the incubation period was recorded with a pyroheliometer (Weather Master) near the vicinity of the sampling stations. Total daily solar radiation was obtained from the University of Nevada, Las Vegas, Physics Department.

Temperature, oxygen, pH and conductivity were measured with a Hydrolab Model 11A Water Quality Analyzer.

Additional data were obtained from U.S. Geological Survey "Water Resources Data for Nevada".

RESULTS

The location of the density current in Las Vegas Bay was easily traced with conductivity measurements because of the high TDS in the inflowing wash water. The vertical distribution of the density current in Las Vegas Bay changed seasonally in relation to thermal conditions. In the winter when the lake was isothermal, the wash water, which had greater density than the lake water because of its cooler temperature and higher TDS formed an underflow throughout Las Vegas Bay. With the development of thermal stratification, an interflow was established along the steep density gradient of the thermocline. At this time, the wash water was warmer than the water in the hypolimnion and even with the higher TDS was less dense than the cooler hypolimnetic water; it therefore was maintained in the metalimnion.

The conductivity isopleths in Figure 2 show the seasonal distribution of the density current in Las Vegas Bay. In the fall (October), the density current flowed along the bottom in the inner bay until it encountered and flowed out along the thermocline at 22 m. At this time, the thermocline was very sharp because of the onset of full overturn. This, plus the fact that the wash water was cooling faster than the lake, resulted in a very narrow, well defined, interflow out to

Conductivity isopleths ($\mu\text{mhos}\cdot\text{cm}^{-1}$)
Las Vegas Bay, Lake Mead

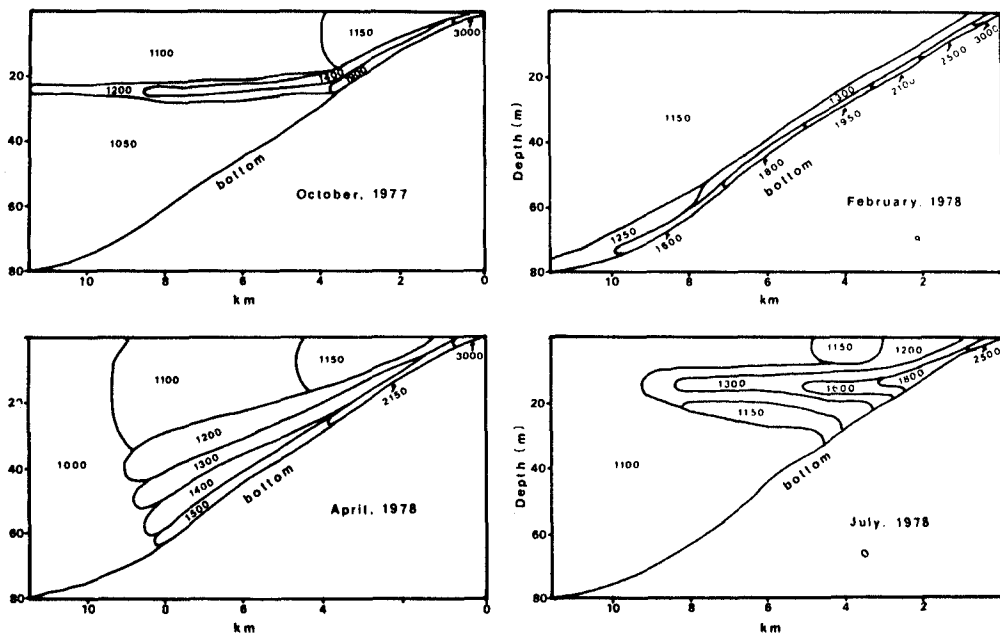


Figure 2. Conductivity isopleths in Las Vegas Bay, Lake Mead.

the mouth of Las Vegas Bay. The depth of the density current declined throughout the fall in the middle and outer bay with the progressive decay of the thermocline. In January and February, the lake was nearly isothermal and the density current extended out into Boulder Basin as an underflow along the old stream channel. Although there was partial mixing of the density current in Las Vegas Bay during the fall-winter mixing period, mixing did not disrupt the current until it reached Boulder Basin.

There was substantial mixing of the current in the spring as illustrated by the series of conductivity tongues that extended out near the middle bay in April (Fig. 2). In the spring, the wash inflow was increasing in temperature faster than the lake. This reduced the density difference, and therefore increased mixing between the wash and lake water. However, the high TDS of the wash inflow was sufficient to confine the density current primarily to the bottom of the inner bay. If the TDS in the wash were substantially reduced, overflows would occur during the spring and result in greater mixing of the inflow in the inner bay.

In the summer, the density current again flowed along the bottom of the inner bay and formed an interflow along the thermocline out into middle bay. Summer thermal stratification was broad resulting in a broad distribution of the density current. Mixing was still high in the inner bay as indicated by the higher conductivity ($1200 \mu\text{mhos}$) (Fig. 2).

Seasonal changes in the distribution and mixing of the density

current had a direct influence on the availability of phosphorus and nitrogen for phytoplankton growth in Las Vegas Bay and Boulder Basin. Phosphate concentrations were always high in the inner bay and declined in the middle and outer bay (Fig. 3). Phosphate concentrations rose to $57 \mu\text{g}\cdot\text{l}^{-1}$ in the inner bay during the summer because of the greater rate of mixing, which was also evident as higher conductivity in the inner bay (Fig. 2). In the winter, phosphate concentrations increased in the middle-outer bay and Boulder Basin as did conductivity (Fig. 2), reflecting the greater mixing rate at this time.

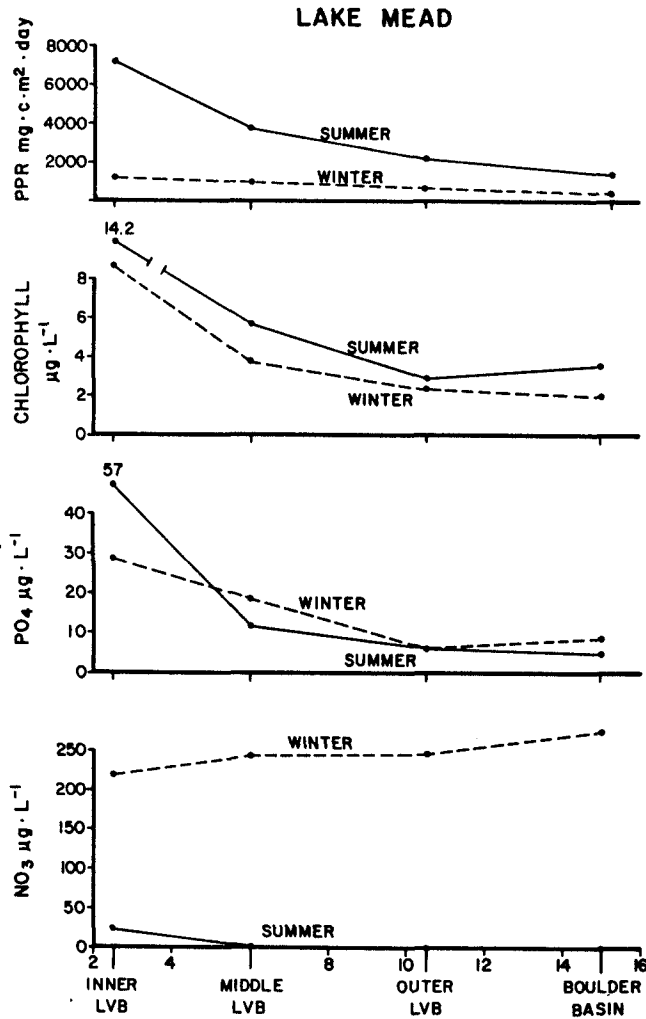


Figure 3. Phytoplankton productivity, chlorophyll-*a*, and nutrients in Las Vegas Bay and Boulder Basin, Lake Mead.

Nitrate was completely stripped from the epilimnion during the summer due to phytoplankton uptake, thus no gradient was present in the bay. Winter nitrate concentrations were greater than $200 \mu\text{g}\cdot\text{l}^{-1}$ as a result of fall overturn and decreased phytoplankton growth. Nitrate

was slightly lower in the inner bay during the winter, probably due to higher winter phytoplankton growth.

Phytoplankton productivity and chlorophyll-*a* concentrations were highest in the inner bay and progressively decreased from there to Boulder Basin (Fig. 3). This would be expected with the high nutrient loading and mixing patterns of the Las Vegas Wash inflow. Phytoplankton growth in Las Vegas Bay was nitrogen-limited based on low N:P ratios (Table 3) which were, except for a few winter months, below the approximate 10N:1P required for phytoplankton growth (Golterman 1975).

Table 3. Inorganic nitrogen to phosphorus ratios in Lake Mead.

	Inner Las Vegas Bay	Middle Las Vegas Bay	Outer Las Vegas Bay	Boulder Basin	Virgin Basin
Oct	13	3	4	6	26
Nov	8	5	10	8	74
Jan	9	17	16	19	152
Feb	12	20	30	38	82
Mar	25	51	153	37	107
Apr	5	10	30	53	83
May	4	22	30	35	44
June	4	3	4	7	50
July	5	2	6	5	35
Aug	2	1	2	3	69
Sept	3	2	2	5	84

This has also been substantiated with bioassay experiments. (C.R. Goldman unpubl. data). The nitrogen deficiency resulted in accumulation of excess phosphorus in the inner bay and produced the apparent, although spurious, correlation between phosphate concentrations and productivity and chlorophyll-*a* in Las Vegas Bay. The overall effect of the high phosphorus load from Las Vegas Wash is that Boulder Basin has become more nitrogen limited compared to the less productive, phosphorus limited upper basins (Virgin, Temple and Gregg Basins).

DISCUSSION

Phytoplankton growth in Las Vegas Bay and Boulder Basin was enhanced by nutrient loading from Las Vegas Wash. However, this growth was not nearly as great as expected based on the high rate of phosphorus loading. Goldman (1976), using Vollenweider and Dillon's (1974) phosphorus model, calculated phosphorus loading in Las Vegas Bay to be 34 times greater than the model's "dangerous" loading rate. Actual conditions do not reflect this high phosphorus loading. The trophic status of inner Las Vegas Bay has been classified as being slightly eutrophic with the rest of Las Vegas Bay and Boulder Basin mesotrophic-oligotrophic (Paulson et al. 1980). The lower trophic status of Las Vegas Bay and Boulder Basin is in part due to nitrogen limitation and to hypolimnetic discharge at Hoover Dam which greatly reduces nutrient retention (Paulson, Baker and Deacon 1979). However, the major factor operating in Las Vegas Bay to minimize the effects of the high nutrient loading from Las Vegas Wash is the density current. The underflow of the density current in the inner bay functions

as a natural diffuser of the nutrients. This reduces nutrient availability in an area where point source problems would exist if there were complete mixing of the Las Vegas Wash inflow.

Planned desalination of the Las Vegas Wash inflow entails bypassing the sewage effluent around the Las Vegas Wash system via a pipeline to facilitate the collection and removal of the highly saline groundwater. The bypass pipeline could increase the temperature of the inflow going into Las Vegas Bay by as much as 2-6°C. Under present conditions, the average decrease in temperature from the confluence of the treatment plants to 1.6 km above Lake Mead is about 3°C in the spring (18.6-15.5°C) and summer (25.4-22.0°C). A bypass pipeline will eliminate the cooling process in the Las Vegas Wash, and the effluent entering Las Vegas Bay will be warmer. This, plus the reduction in density due to desalination will enhance mixing of the inflow in the inner bay because of the decreased difference in density. If there is a 3°C increase in temperature, and a 50% reduction in salinity, surface flows would occur in the spring. Nutrient availability for phytoplankton growth will be greater as a result of the changes from desalination of the Las Vegas Wash. Nuisance algal conditions in Las Vegas Bay could potentially develop with the higher nutrient availability. The desalination of Las Vegas Wash, therefore, may have a detrimental effect on water quality in Las Vegas Bay.

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