Drought and Water Quality in Lake Mead

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Large size has buffered impacts but signals suggest change can come

Lake Mead, the largest reservoir in the United States on the basis of storage volume, has been in a drought since the year 2000 (Figure 1). This drought encompasses much of the Western United States, the entire Colorado River Basin, and areas outside of the basin that are supplied with Colorado River water through various conveyance projects. As has been widely reported by the media in the western states the Colorado River is likely over apportioned, more water is allocated to the states than the river carries on average, and the combination of conditions has resulted in significant decreases in storage in the Colorado River reservoirs. This extended drought and ongoing decrease in stored water has had little impact on water quality thus far, but significant changes in the tributary confluences and deltas, the ability of the lake to dilute discharges, and changes to upstream reservoirs suggest areas of concern moving forward.

Figure 1. Lake Mead outline from July 6 2000 and July 24 2015. The Colorado River, accounting for >95% of the inflow, enters the lake from the east, the Muddy and Virgin Rivers enters from the north, and the Las Vegas Wash enters from the west. The Colorado River leaves Lake Mead through Hoover Dam to the south. Source: http://earthobservatory.nasa.gov/IOTD/view.php?id=86426

Recent history of drought and lake "plumbing"

Since its construction, Lake Mead's maximum measured surface elevation was 1226 ft. msl. Since the year 2000 the maximum level has been 1214 ft. msl, a level reached in January of 2000 and not since (Figure 2). From 2000 to the end of 2005 surface elevations fell almost 100 ft. until a small improvement allowed the lake surface to increase ~20 ft. From 2005 to the present day seasonal patterns of rising and falling elevations can be seen most years, but the trend is overwhelmingly in a downward direction. 2011 was the obvious exception to this when a combination of water storage policies and improved precipitation in the basin allowed for a ~45 ft. increase. Most recently, 2014 and 2015, the rate of decrease has been reduced through a combination of conservation and storage strategies. Under the Colorado River Compact, the agreement between the basin states that allocates water, the surface elevation of 1075 ft. is critical as it is the first level at which mandatory shortages occur. Avoiding these shortages has encouraged this revised management approach.

Figure 2 also shows a variety of critical levels in Lake Mead for Southern Nevada and the operation of Hoover Dam. The blue lines show the depths of drinking water intakes serving the Greater Las Vegas Area. Intakes 1 and 2, 1050 and 1000 ft. msl respectively, were used to supply water to Las Vegas until mid-2015, when Intake 3 was completed (Figure 3). As expected the surface of the lake has moved closer to the depth of the intakes during this period of drought, but of greater concern to the quality of the drinking water is the associated increase in temperature entering the treatment stream. The depth of the summer thermocline has reached the depth of the intakes frequently during recent years. The Las Vegas Valley drinking water treatment plants have been optimized to treat cold, hypolimnetic water. While the seasonal warming that comes with autumn mixing of the water column has been accommodated, since 2008 the frequency

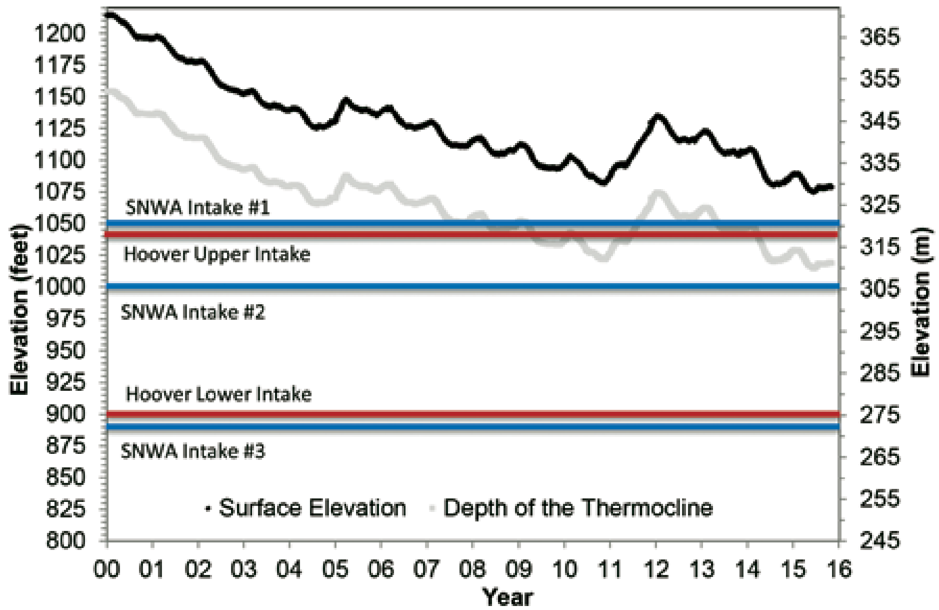

Figure 2. Surface elevations from 2000-2015. The black line shows the elevation of the surface of the lake while the gray line shows the approximate depth of the thermocline late in the stratified period.

Figure 3. Third intake structure being prepared for placement in Lake Mead. Drought conditions were a significant factor in driving the construction of a new drinking water intake despite the significant cost. Photo: Southern Nevada Water Authority Engineering.

of encountering warmer water has increased significantly. While this higher temperature water is treated to the highest levels to ensure the safety of the water supply, the higher temperatures increase the cost of treatment. In 2015 construction of Intake 3 was completed and moving forward the supply of cold, hypolimnetic water has returned.

Figure 2 also shows the depth of the two intake structures on Hoover Dam. These intakes supply water to the Nevada and Arizona hydroelectric plants in addition to being the only means to release water to the downstream Colorado River. As with the drinking water intakes the drought has not significantly impacted water quality thus far, but the depth of the thermocline data clearly demonstrates that increasingly warmer water will be released downstream. This has the potential to alter the downstream environment; Lakes Mohave and Havasu in particular. Under historical conditions the cold Colorado River water has flowed along the bottom of these lakes, reducing the occurrence and likelihood of anaerobic conditions developing. If the downstream water warms and transitions to a surface flow through the downstream reservoirs, the oxygen concentrations at the sediment water interface are expected to decrease, triggering the range of deleterious water quality and environmental impacts associated with anoxia.

Changes to the Las Vegas Wash Delta

The decrease in lake surface elevations has necessarily changed the interface between the lake and the various tributaries. While the Colorado River is the most significant source of water to Lake Mead, more information is collected on the Las Vegas Wash given its role in draining water; treated effluent, groundwater, and urban runoff from the Las Vegas Valley. Over the drought period the Las Vegas Wash delta has been extended over an additional mile. This extension of the delta has had significant impacts on recreation, note the boat ramp and marina in 1999 (Figure 4a) that are landlocked in 2015 (Figure 4b), but the water quality impacts thus far have been limited. The Las Vegas Wash flow is dominated by highly treated wastewater effluent from the region and the drought period has corresponded with increased levels of wastewater treatment, reducing the water quality impact in the lake.

The extended delta has significantly increased the wetland area encountered as the water flows to the lake. While this would be expected to increase the removal of nutrients and other compounds by wetland plants and soils, to date we have not been able to quantify this removal. What is obvious from field observations and the aerial photography is that the delta area has been colonized by wetland plants. When or if, lake surface elevations re-inundate this area, it is expected that this plant material will provide both benefits and potential water quality problems. As with newly inundated reservoirs we expect to see increases in fish and invertebrate biomass as the previously terrestrial material is brought into the water column. Unfortunately this increased organic material, combined

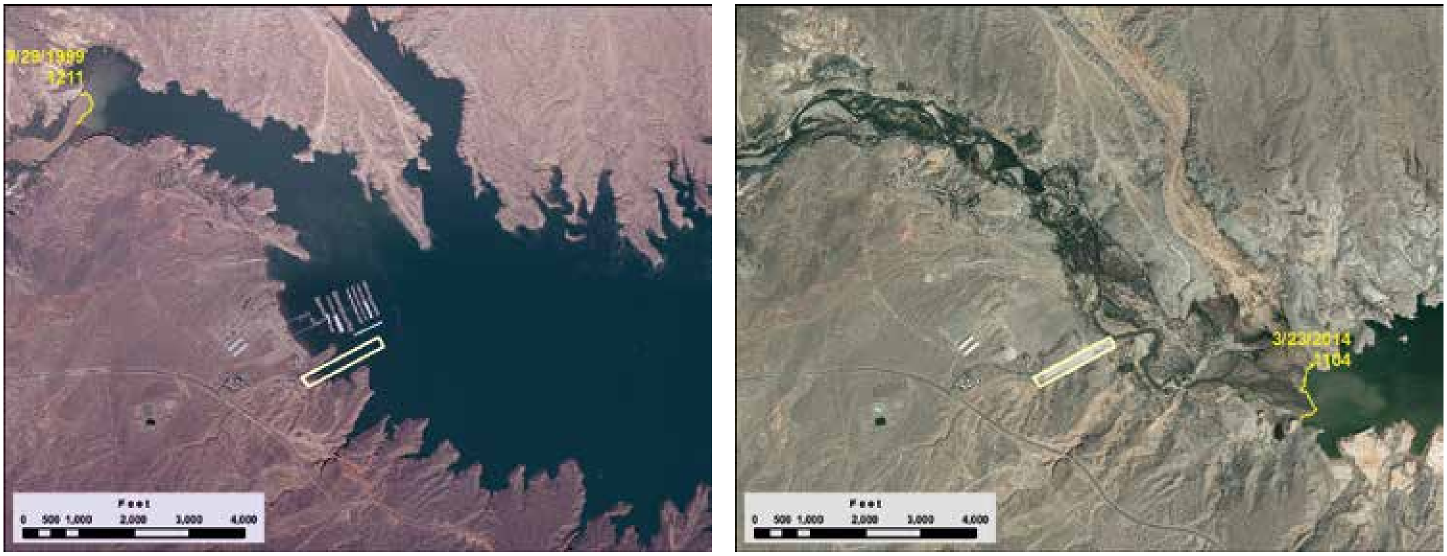

Figure 4. The confluence of the Las Vegas Wash and Lake Mead showing the extension of the delta as lake surface elevations have fallen from 1221 ft. ASL to 1087 ft. ASL. Source: Southern Nevada Water Authority Spatial Technologies Workgroup.

with plant bound nutrients and nutrients in the delta sediments, will then be leached to the lake water. Lake Mead is strongly phosphorus limited and loading of additional nutrients from previously dry areas would be expected to increase water column production. Prior to strict controls on phosphorus loading, Lake Mead had periodically experienced algal blooms, most recently in 2001 that degraded the recreation experience and increased the level of treatment needed for the drinking water.

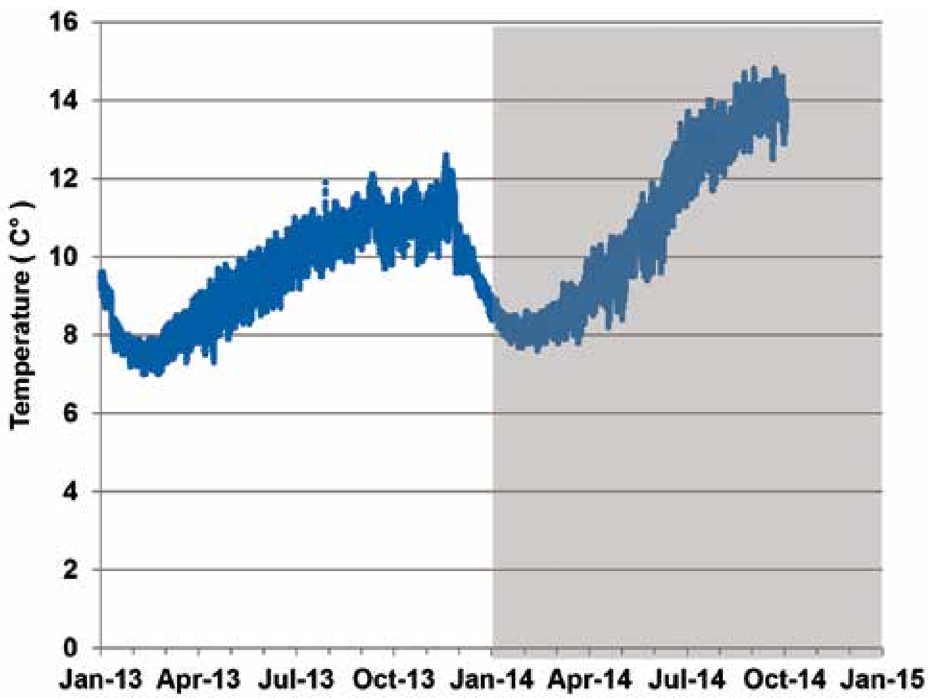

Figure 5. Water temperatures entering Lake Mead through the Colorado River leaving Grand Canyon in 2013 and 2014. Temperatures increased more rapidly during 2014 than during 2013 resulting in earlier warming and higher temperatures overall.

The impact of upstream conditions

The most pronounced water quality impact we have measured in Lake Mead during this drought has been the influence of water surface elevations in Lake Powell. As with Lake Mead, Colorado River water released from Lake Powell is influenced by the surface elevation. As the drought is impacting the entire Colorado River Basin, Lake Powell surface elevations have also been declining, bringing the warm surface waters closer to the intake depths. In 2014 the water released from Lake Powell was several degrees warmer than in 2013. Figure 5 shows that water released from Lake Powell entered Lake Mead at 10° C in May of 2013 and April of 2014. This warming trend accelerated and 12° C water entered Lake Mead in June of 2014 but only for a few dates in September and December of 2013.

As noted earlier for Lake Mohave, the cold Colorado River inflows travel along the sediment water interface and maintain high dissolved oxygen concentrations, this process is also important in Lake Mead. With the increased inflow temperatures of 2014 the river ceased entering as an underflow at the bottom of the water column and transitioned to an interflow that entered the middle of the water column (Figure 6). This interflow, or more accurately the lack of re-oxygenation at the sediment water interface, produced hypoxic and anoxic conditions. These low oxygen conditions were then carried down lake more than 25 miles. The extensive low oxygen region did not have any lasting impacts, nutrient concentrations remained low and there were no observed fish kills. However, if warmer Colorado River waters continue to enter the lake it will result in a major shift in the limnology of the lake with the potential to alter nutrient dynamics,

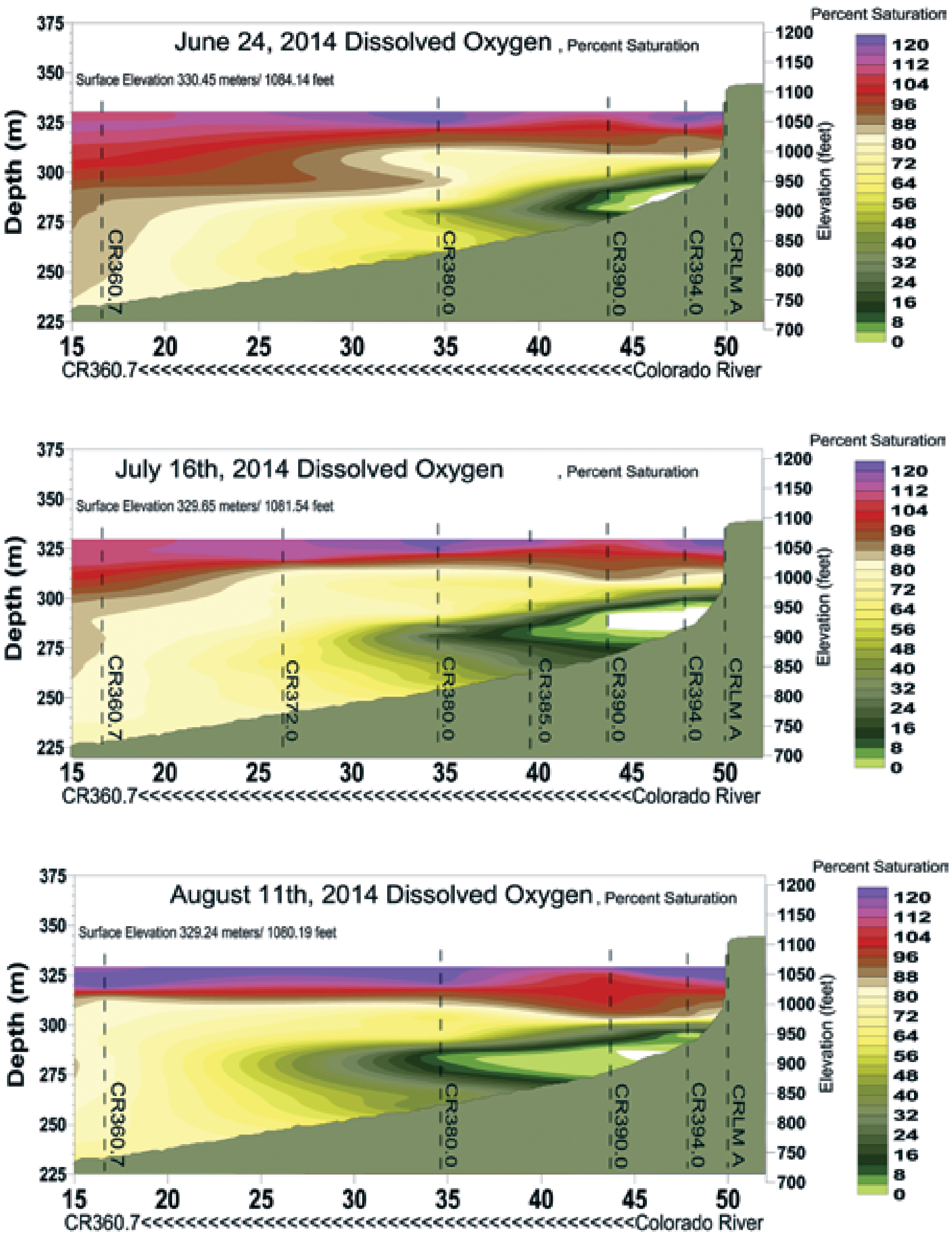

Figure 6. Dissolved oxygen (percent saturation) data for Lake Mead near the Colorado River confluence. Low values are shown in white, green, and gray. The dissolved oxygen data show the impact of warm Colorado River water entering the middle of the water column.

habitat suitability (including suitability for two endangered fish species), and ultimately the management of lake inflows and outflows.

Microcystis: Could it be related to the drought?

The most pronounced change observed in Lake Mead since the initiation of the drought occurred in 2015 with the first measurement of the algal toxin microcystin accompanying localized blooms of *Microcystis* (Figure 7). *Microcystis* has been observed in the lake in the past, generally becoming apparent during the fall and early winter months before declining in the early spring. In 2015 the fall and winter appearance did not lead to a die-off during the spring. Instead, localized blooms were seen in the lake throughout most of the summer months. As a water supply agency, the Southern Nevada Water Authority has been attempting to measure microcystin at 18 locations around Lake Mead for several years. Until the spring of 2015 none of these measurements had yielded a positive result. This pattern continued for the majority of the lake. Measurements at these routine monitoring locations continue to primarily yield non-detect results. *Microcystis* has been seen in algal samples from drinking water intake locations, but microcystin has never been detected at the lake sampling location, in the raw water transported to the treatment plants, or in the finished drinking water.

Where *Microcystis* has been seen and microcystin detected the small blooms have generally followed the same course. The blooms have most frequently been seen where the wind has produced surface aggregations of algae-marinas and shoreline coves. Where these aggregations appear high concentrations of chlorophyll, high numbers of *Microcystis* colonies, and moderate to high levels of microcystin are measured. In all cases the blooms have dissipated within one week, occasionally with microcystin being detected after the disappearance of the colonies. Nutrient concentrations in the bloom areas, when timely samples could be collected, have not shown elevated concentrations of nitrogen or phosphorus. It appears that the blooms become nutrient limited shortly after developing and cannot be sustained.

What remains unclear is if drought conditions have played a role in this change. Initial measurements of nutrients and other water quality parameters have not suggested a significant change; additionally the algal blooms have most frequently occurred in areas of the lake far removed from tributary nutrient inputs. While it is too early to rule out drought as a causative factor, the case appears to be merely coincidental.

While the drought in the Colorado River system has caused extensive thinking and action to conserve water and prolong the availability of water, the impacts to water quality have been limited thus far. Even at its current low level, Lake Mead is still a very large reservoir with a fairly short water residence time. The combination of reservoir attributes and sustained actions to improve water re-entering the lake from the Las Vegas Valley have worked thus far to limit water quality changes. If the lake continues to shrink it is likely that these water quality impacts will manifest themselves. Throughout the arid Western United States there has been a philosophy that water quantity trumps water quality,

continuation of this drought will likely increase considerations of water quality in the reduced supply.

Todd Tietjen has worked in reservoir limnology for the past 25 years is currently the Regional Water Quality Manager for the Southern Nevada Water Authority, working on water quality issues in the Lower Colorado River. He is a Certified Lake Manager and is serving as the NALMS Region 9 Director and CALMS Southern Region Co-Director.

< Figure 7. Microcystis in the Lake Mead Marina during March of 2015. This localized algal bloom released the algal toxin microcystin to the water column. The algae dissipated in less than 1 week but the toxin could be detected for several days after the disappearance of the algae. Photo: Southern Nevada Regional Water Quality

Next Issue – Spring 2016 *LakeLine*

The theme for our next issue is "Internal Loading."

In it we will explore the mechanisms and consequences of this "hidden" source of lake problems.