

Comments on the white paper:

Estimating total and bioavailable nutrient loading to Utah Lake from the atmosphere

By Theron Miller

The use of Lake Tahoe as a reasonable analogue to Utah Lake by the author of the white paper is problematic and unfounded. While it is about 20% larger than Utah Lake, this is the only comparable metric. At 1600+ ft deep it is the 2nd deepest lake in the US. Utah Lake is the shallowest lake of anything near its size in the US, with a mean depth at 6 ft or less. The population surrounding Lake Tahoe is about 30,000. The population of Utah Valley is about 575,000. There are no agricultural areas around Lake Tahoe while about 30% of the surrounding land use of Utah Lake is agricultural. The Lake Tahoe surface elevation is at about 6225 ft and occupies the entirety of its alpine valley. The surface elevation of Utah Lake is about 4490 ft and occupies a tiny portion of the ancient Lake Bonneville footprint. The only other analogue is that the prevailing wind comes out of the Southwest. In addition, one of the most important differences between Lake Tahoe and Utah Lake is that directly upwind of Lake Tahoe is the >9000-ft backbone of the high Sierra mountains that separate it from the agricultural areas of California's Central Valley, about 100 miles away with an average elevation of about 100 ft above sea level. Thus, any dust deposition on Lake Tahoe has to surmount mountains that are 9,000 feet higher than the dust source. Moreover, temperature inversions aloft inhibit vertical mixing between air that may transport material over the Sierra Nevada and the surface air within the Tahoe Basin (Dolislager et al. 2014). In contrast, the prevailing southwesterly winds cross Utah Lake and hit the "wall" of the Wasatch mountains that are 9,000 to >11,000 ft high. This may serve to trap and circulate airborne material within Utah and Salt Lake valleys, facilitating particle deposition. In addition, at only 200 ft above the elevation of Great Salt Lake, Utah Lake is a tiny remnant of prehistoric Lake Bonneville, which was also a terminal lake for several thousand years – enriching the sediments with nutrients throughout its 20,000 square mile (52,000 square km) surface area. Moreover, much of the geology in the watershed of lake Bonneville/Utah Lake/Great Salt Lake was and is sedimentary, rich in P deposits, much of which now sits in the sediments of the Lake Bonneville footprint. This area was also an ancient shallow sea several million years prior to Lake Bonneville with sea bed sediments rich in nutrients accumulating several hundreds of meters, if not thicker. Presently, for thousands of square hectares and 50 miles directly west of Utah Lake, lies the Great Salt Lake Desert. This vast playa, along with several other large P-rich playas, still remain in the lake Bonneville footprint and are experiencing active wind erosion, one of which is Severe Lake, which is 1.5 times the size of Utah Lake and located only 100 miles upwind and 200 ft above the elevation of Utah Lake. For comparison, Lake Tahoe sits in a granitic basin, very poor in adjacent geologic phosphorus and other than relatively minor urban development around the lake, the surrounding landscape of Lake Tahoe is forested with no agricultural disturbances.

Total P in recent soil samples from the Severe Lake are near or above 2000 mg/kg. These are near the P concentrations in soils around Utah Lake and Great Salt Lake as well as in sediment core samples (unpublished data; see Abu-Hmeidan et al. 2018). While we are currently confirming P concentrations and solubility in various chemical extractions in these samples, they

are likely to be much greater than the 10.9 ug of other dust samples collected in the wet depositional samples cited in the white paper.

The four NADP sites identified in Utah in the white paper are all downwind and up-elevation from Utah Lake and the Great Basin in general and do not represent dust samples entering or being produced in Utah Valley. This ignores or contradicts introductory information in the white paper that states: “*At a global scale, dust deposition rates range from 0 to 450 g m⁻² y⁻¹ with the highest deposition rates influenced by proximal (<10 km) sources (Lawrence and Neff 2009)*”. Thus, to ignore local sources, particularly when it is recognized that soil disturbance from agriculture and urban development are key sources of local AD is likely ignoring important sources to Utah Lake.

The white paper states:

Samplers should not be located near point sources of atmospheric pollution including but not limited to open pit mining and housing developments on the western shores of Utah Lake (Figure 2), agricultural areas where either soils (Figure 4b) or irrigation spray can reach the sampler, construction sites or roads in urban areas (Figure 2, Figure 4c,d). Point sampling methods do not allow one to determine the zone of influence and thus contamination of samples by point sources can lead to erroneous extrapolation and inflation of actual deposition rates.

As cited above (Lawrence and Neff 2009), excluding these proximal (<10 km) are ignoring potentially important sources to Utah Lake. For example, the NADP Guidelines are focused exclusively on region-wide deposition. As such, guideline methods are only specific to wet deposition and the objective is to evaluate regional/national deposition – not local targets such as Utah Lake. As such, there are no guidelines for dry deposition other than that for the AMoN (atmospheric ammonia) samplers and there are no guidelines for phosphorus AD sampling. This suggests that dry deposition methods are in their infancy. This further suggests that there are additional variables or questions or even study objectives encountered in dry deposition sampling projects that were not dealt with in the previous methods developed for wet deposition, mercury or ammonia deposition. More specifically, this indicates that specific questions, such as deposition on single targeted sites, such as Utah Lake need to be uniquely developed to answer these specific questions. Such questions revolve around local/near-field vs far-field/regional vs global sources. Moreover, there may be near-field important sources such as continued development as well as emissions from existing urban zones, intense agriculture or a local gravel quarry. Because these anthropogenic activities disturb high P soils immediately adjacent to Utah Lake, they need to be considered, not ignored. The only challenge that we face is agreement on methods used and selection of placement sites, including sites out on the lake to measure transport distance and attenuation equations.

The white paper also states:

“I note that Olsen et al. 2019 measured TP deposition on the shores of Utah Lake and found deposition rates between 1.26 and 31.38 (average 8.1) mg P m⁻² day⁻¹, up to two orders of magnitude

higher than has been measured anywhere else in the world (Tipping et al. 2014, Brahney et al. 2015b)”.

This is highly misleading. While the high estimate of Olsen is approximately 2 orders of magnitude higher than the lowest worldwide estimate, the lower (and uncontaminated) estimate reported by Olsen was only 15% higher than the highest estimate reported by Brahney et al. (2015). Because the entire range of worldwide estimates is 2 orders of magnitude, a 15% difference from a measured value does NOT invalidate an estimate of AD on Utah Lake. Moreover, the white paper claims that the 400 mg/m²/yr estimate was from an area near biomass burning. However, this burning may not be the source of the high P as Dolislager et al. (2012) noted that wood smoke near Lake Tahoe was very low in phosphorus content.

The white paper also states:

“I calculate a range of bioavailable P deposition between 1.1 and 7.9 metric tons per year (Table 10). If we assume an urban deposition rate throughout the entire lake during inversions, which may occur 10 to 25 days of the year, this may add 1 to 2.5 metric tons per year. Option 1 below in the recommendations provides a mechanism for determining the actual potential deposition associated with an inversion”.

I raise the question as why it was assumed that the deposition of urban sources of P only goes 400 to 600 m from shore whether or not the wind is blowing, but when the wind is calm (during an inversion), the atmospheric deposition values are extended across the entire lake. Common sense suggests that urban sources emit similar loads of nutrients continuously throughout the year (and probably higher during the more active summer months), regardless of whether the wind is calm or not. In reality, in view of the wind roses in Figure 3 in the white paper, I suggest that urban emissions are drifting directly over the lake 365 days of the year. Moreover, the turbulence of both wind and surface water exponentially increases exposure and surface transfer of gasses and aerosols. Thus, I suggest that urban sources and deposition of these contaminants be applied for 365 days of the year.

Table 1. of the white paper estimates the range of nitrogen deposition on Utah Lake. Total N (nitrate plus ammonium) ranges from 400 to 700 mg N m⁻² yr⁻¹ or 153 to 288 metric tons per year on the lake.

For comparison, nitrate and ammonium have also been measured for more than 2 years of weekly sampling during our Utah Lake AD program. Using his total (including contaminated) data set, Olsen reported 529 metric tons N per year depositing on the lake and, discarding the contaminated data set, Olsen reported 97 metric tons of total N. Notably, the white paper estimate falls midway between Olsen’s contaminated and uncontaminated data sets. In a more recent 2018 data set where insects were removed from the dry deposition buckets, the average of weekly samples = 928 mg N m⁻² yr⁻¹ for total nitrogen deposition or 382 metric tons per year on Utah Lake. Notably, this is only 33% higher than the higher modelled estimates reported in the white paper - even when the bugs were sitting in the water for up to 7 days. However we may have disagreed with treatment of bug contamination, considering that the white paper only applied urban source estimates to the first 400 to 600 meters extending from the shoreline needs to be equally scrutinized. Moreover, with such similar estimates of N deposition between the

Olsen data set and the white paper calculations, equal credibility should be granted to Olsen's phosphorus estimates.

There are four conclusions here:

- 1) the P estimates in the Olsen thesis are clearly comparable to the white paper estimates and, because they are based on empirical data, should be considered at least as valid as the white paper estimates;
- 2) the N estimates of both the Olsen data set and the other BYU measurements are clearly in the range of the white paper estimates – even though the white paper estimates may have significantly underestimated urban-sourced deposition for about 95% of the year;
- 3) If Dr. Brahney and the TDep workgroup had applied their modelled number over the entire surface for the whole year, as they did for inversion periods, the estimate for N would have been much higher – perhaps greater than Olsen's estimate that included the contaminated samples and;
- 4) These data suggest that P loading is somewhere between Olsen's high estimate, including contaminated samples (373 metric tons total P per year) and Olsen's low estimates, discarding contaminated data (including excluding samples with any single piece of debris; 17 metric tons per year).

It appears that the modeling decisions used in the white paper are questionable, and the Olsen and other BYU data are certainly useful and indeed, valid. I also suggest that empirical evidence (i.e. Olsen and other BYU data) is almost always more valid than modeled results, especially when model assumptions are questionable.

Due to questionable model assumptions and the exclusions of data or sites that are proximal to the lake, the white paper, with its recommendations, is far too narrow and is oversimplifying and may well lead to a severe underestimation of AD values. While there is a paucity of local data, and which is controversial, it is far too early to ignore or exclude the data, simply because it does not meet current objectives of the national NADP program or the modeling assumptions used in the white paper.

Undoubtedly, this is one of the biggest disputes in this discussion. I continue to postulate (presented as a testable hypothesis) that Utah Lake, with its surrounding landscape, is far too different physically, geographically and ecologically from lakes currently described in the white paper. To extrapolate, from a single dirt road or highway winding through the forest next to Lake Tahoe or from plant and animal debris from an adjacent hardwood forest surrounding 15-ha Mirror Lake, New Hampshire (Cole 1999), that 90% of dust or debris only travels 200 m, which was undoubtedly measured on a calm day; that dust or debris reaching Utah Lake behaves similarly, is unfounded. In addition, as acknowledged in the white paper the local agricultural and urban sources (such as building on and continually disturbing Lake Bonneville sediments), can be important sources and, depending on particle size and wind velocity, they may very well spread across a large portion or most of Utah Lake as there is no wind protection incurred from adjacent forest. Whether the dust settles within 200 m or 200 miles is a function of particle size and wind velocity and, on calm days, the influence of diffusion physics and temperature

stratification on dispersal characteristics and particularly across the lake. Utah Lake's location, obviously in the bottom of Utah valley, attracts urban emissions through the effects of gravity on colder, denser masses of air. I suggest the notion that while we may conjecture and hypothesize how far particles will travel and what the elemental composition is, all current estimates, whether local or regional extrapolations, are barely one step above an educated guess. Moreover, to think one can specify what SRP is from these different sources, is also merely an educated guess—particularly with regard to Fe and Al-bound P. While oxidized forms, or high pH forms of these minerals are insoluble, when they hit the bottom of the lake “all bets are off” as everything from bioturbation (or lack thereof), (e.g. Molot et al. 2014; Holker et al. 2015), to redox chemistry, to pH will dictate how much P is soluble; we simply don't know. But certainly, these are testable hypotheses that warrant investigation.

In addition, the white paper references “Deposition Velocity models”, that, if used in concert with more-easily sampled dust concentrations using HVAC followed by digestions for nutrient content, can be used to accurately predict AD on Utah Lake or anywhere. If such is the case, the white paper should describe the functionality and data requirements for calibration so that the Science Panel can determine whether such a model can or should be used on Utah Lake. In the absence of data, however, there may be too many assumptions to deliver usable results (e.g. see Raymond et al. 2004). Moreover, while sampling boat cruises appear to be useful for HVAC sample collection, the author of the white paper has clearly not been on Utah Lake when the wind is blowing 20 to 50 miles per hour, creating waves 2-4 feet high and visibility is less than a half mile because of the sediment-derived dust blowing across the lake. During these all too often events, the enhanced deposition events cannot safely and carefully be sampled by even the most experienced boat crew and captain.

In short, I propose that the regional data from 4 NADP sites, using only wet deposition samples, have far too few data points, in too far proximity from Utah Lake and which may only estimate a small percentage of the AD sourced in arid central Utah to make any accurate predictions of AD on Utah Lake. Rather, the white paper serves as an exercise in hypothesis development, nothing more, that clearly needs to be tested with local proximal data that can be collected and verified with carefully constructed control practices and sample collection that includes at least one mid-lake location.

The white paper states the following guidelines (as cited from the NADP installation manual)

Samples must not be placed

- Where there is potential for contamination from irrigation;
- Where there is potential for contamination by fugitive dusts;
- <100 m from roads, paved or unpaved;
- <10 meters from access roads, though in Utah I recommend this be increased to at least 30 m (Figure 4c,d);
- <5 m from objects greater than 1 m tall (including a solar panel);
- Within a 5 m radius of vegetation.

The guidelines specify that the vegetation within the 5 m radius should be less than 0.6 m in height (NOT that there should be no vegetation within 5 m: This vegetation should actually help secure soils in place). Nevertheless, we are currently making adjustments to comply with the current guidelines. As well, we are maintaining three samplers in current configuration (1.5 m above ground level), to provide a side by side comparison with the configuration used during the last three years. In addition, we are inserting 250 um screens to prevent plant and animal parts from contaminating the sample. In addition, we are developing an alternative regression analysis method, similar to Blake and Downing (2009) to determine the influence of contaminated samples.

In addition, while the potential for contamination of some of the BYU samples has received criticism from the Utah Lake Science Panel, ironically, this contamination reveals the importance of nutrient recycling from insect carcasses that fall back on the lake surface (e.g. after egg laying; as described in the Miller AD proposal and workplan). Clearly, this “contamination” is significant. Blake and Downing (2009) found high levels of insect contamination (soaking as many as 185 mayfly carcasses in 2 L of distilled water) and decomposition can increase atmospheric deposition estimates by an order of magnitude. But to be clear, this still constitutes a considerable degree of recycling of nutrients – similar to recycling of sediment nutrients by diagenesis and redox chemistry. For example, it has been estimated that only about 10% of aquatic insect carcasses actually fall back on the lake surface, but peak deposition occurred in very close proximity (20-25 m) inland from the shoreline (Dreyer et al. 2015). Yet, of the up to 6000 tons of midges (estimated from quantitative sampling by Dr. David Richards) that are generated annually (some species may be multivoltine), the conservative 10% still constitutes 600 tons per year. At 1% P in body mass, this still constitutes 6 tons of dissolved P recycled into the water column. But this may still be a conservative estimate. For example, if the high end of Olsen’s estimates of P AD (373 tons per year) are primarily due to insect contamination, then reducing this by an order of magnitude still results in an estimate of 37 tons per year. For comparison, this is nearly an order of magnitude higher than the white paper estimates.

The take-home message from this exercise is that no current estimates, either from current BYU estimates, nor from the white paper, are ready for “prime time.” What is clear is that while sampling methods may vary, phosphorus AD may be a substantial contribution to Utah Lake’s nutrient budget, or it may not. The two greatest variables that need investigation are; 1) continued and improved methods to estimate local contributions (agricultural disturbance, urban emissions and mobilization from nearby Severe Lake and Great Salt Lake playas and the degree to which they deposit across the lake (i.e. what is the proper decay equation; and 2) the phosphorus and nitrogen content of mobilized particles, including total P and serial extractions to more accurately describe to degree to which the P content is soluble and biologically available in the Utah Lake environment. This process needs to recognize and include the lake variables such as pH, calcium carbonate species and concentrations, as well as sediment transformations as a result of redox chemistry and bioturbation.

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