Review comments on documents related to Utah Lake nutrient loading

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Olsen, J. M. 2018. Measuring and Calculating Current Atmospheric Phosphorous and Nitrogen Loadings on Utah Lake Using Field Samples, Laboratory Methods, and Statistical Analysis: Implication for Water Quality Issues. Master of Science Thesis, Department of Civil and Environmental Engineering, Brigham Young University. All Theses and Dissertations. 6765. https://scholarsarchive.byu.edu/etd/6765 *(Filename: Jacob Olsen Measuring and Calculating Current Atmospheric Deposition.pdf)*

This thesis report by Olsen describes a study aimed at quantifying total phosphorus (TP) and dissolved inorganic nitrogen (DIN) loading to Utah Lake from atmospheric deposition. Our review of this research effort focused on the content included in the associated peer-reviewed publication (Olsen et al. 2018 article in *Hydrology*; discussed in subsequent sections), which we assumed to have a greater contribution from established researchers. However, the master's thesis report includes results from an interlaboratory comparison between ChemTech and Brigham Young Universities' Environmental Analytical Laboratory (EAL), which were not included in the peer-reviewed publication, and are reviewed here.

Interlaboratory comparisons to document consistency in analytical results are appropriate, given that the quality of results can vary considerably among laboratories. Although no details on the type of license ChemTech has, the thesis reports that ChemTech is a "licensed" laboratory. An interlab comparison between ChemTech and EAL was conducted. It is assumed that EAL is not a "licensed" laboratory. EAL is the location where the chemistry used as the basis for the study was analyzed. The thesis report identifies the existence of the interlaboratory comparison in the Results section with:

> "The comparative values for the analytical results between the licensed laboratory and Brigham Young Universities' Environmental Analytical Laboratory (EAL) for TP are shown in Table A-2 in Appendix A. Analysis on the DIN is not reported due to the samples not having been acidified and the samples being stored for several months before the analysis."

Other than this vague statement, the report makes no other mention of the interlaboratory comparison and provides no description of the results. Although this may have been an oversight by the report author, several sample results showed large discrepancies between results generated by the two laboratories. For example, TP from dry deposition sample at Saratoga Springs was 0.5 mg/L from ChemTech and 11.8 mg/L from EAL. The other major difference for TP was a dry deposition sample from Lake Shore with 38 mg/L from ChemTech and 0.5 mg/L from EAL. Overall, the performance expressed as a comparison between the two laboratories was poor (average relative percent difference = 115.7%; Table 1), which calls into question the validity of the foundational chemical concentrations used for the thesis report and associated peer-reviewed publication. The fact that these interlaboratory comparison data were not reported in the peer-reviewed publication is questionable. Furthermore, the statement in the thesis report regarding improper sample preservation and extended hold times that led to the lack of available interlaboratory comparison results for DIN suggests potential mishandling of the other project related samples prior to laboratory analysis.

We caution the users of the data presented in this thesis and associated journal article that these data may not be sufficiently robust to use in making management decisions.

Table 1. Reproduction of Table A-2 from the Olsen thesis report. The original column labeled “error” was removed because the metric was not defined and was uninterpretable. The error metric reported here is the relative percent difference (RPD) and is calculated by subtracting the two reported values, dividing the absolute value of this result by the mean of the two values, then multiplying by 100.

Date Sampled	Site	Wet or Dry	ChemTech Total Phosphorus (mg/L)	EAL Total Phosphorus (mg/L)	Relative Percent Difference (RPD; %)
7/13/2017	Saratoga Springs	Dry	42	39.2	6.9
7/13/2017	Saratoga Springs	Wet	0.03	1.2	190.2
8/3/2017	Saratoga Springs	Dry	0.5	11.8	183.7
8/10/2017	Pump Station	Dry	0.11	0.1	9.5
8/10/2017	Pump Station	Wet	0.18	0.7	118.2
8/24/2017	Lake Shore	Dry	38	0.5	194.8
8/24/2017	Lake Shore	Wet	0.02	1.4	194.4
8/24/2017	Central Davis	Dry	0.01	0	200.0
7/27/2017	Saratoga Springs	Wet	0.45	0.6	28.6
9/21/2017	Mosida	Dry	3	2.2	30.8

Olsen, J.M., G.P. Williams, A.W. Miller, and L. Merritt. 2018. Measuring and Calculating Current Atmospheric Phosphorous and Nitrogen Loadings to Utah Lake Using Field Samples and Geostatistical Analysis. Hydrology 5(3):45. *(Filename: hydrology-05-00045.pdf)*

This peer-reviewed publication (based on the master's thesis reviewed above) describes a study aimed at quantifying TP and DIN loading to Utah Lake from atmospheric deposition. This paper includes many instances of improper use of tense, missing words, improper grammar, ambiguous statements, and other typographic errors, which calls into the question the extent of input from senior co-authors and thoroughness of peer-reviewers. A lengthy introduction provides the motivation for the study and other background information regarding water quality conditions of Utah Lake. Based on results from previous studies described in the introduction, the authors suggest that reductions in nutrient loading to Utah Lake from tributaries, including wastewater treatment plant (WWTP) effluent, may be insufficient to allow the trophic state of the lake to shift from its current moderately eutrophic level. Quantification of atmospheric nutrient deposition to the lake is assumed to help improve the effectiveness of potential future reductions in tributary nutrient loading.

Whether or not control of watershed nutrient sources (such as WWTPs) would cause a change in trophic state from eutrophic to other than eutrophic is not a useful criterion. Utah Lake has likely been eutrophic for a very long time. Changing the flux of P from the watershed to the lake, regardless of the effect on trophic category, might influence the occurrence of harmful algal blooms (HABs) depending on the lake N:P ratio, the availability of other nutrients, turbidity, warming temperatures, wind-induced mixing, and other factors. Management efforts should focus on reducing the occurrence, duration, and intensity of HABs and other adverse impacts of high nutrient loading, not on the (unlikely) transition in trophic state from one category to another.

The study is largely based on measurements from five sites surrounding Utah Lake located between approximately 235 and 5,000 meters from the lake shoreline. The authors state that the deposition samplers located at the sites were designed to "operate similar to the Aerochem Metrics (ACM) bucket collectors used by the NADP" and "placement of each sampler follow protocols similar to those established by the NADP". These statements could be interpreted to suggest that the overall sampling methods are endorsed by the National Atmospheric Deposition Program (NADP). Although the design of the samplers used in this study are similar to the samplers used for measuring wet deposition by the NADP, the methods used for estimating dry deposition by Olsen et al. (2018) study are dramatically different from those used by the NADP and partnering organizations. Olsen et al. (2018) estimate dry deposition using the "dry bucket" technique modified by filling the dry-side bucket with water in an attempt to simulate the properties of lake surface within the bucket. Although Olsen et al. (2018) cite two studies that, presumably, used an analogous method, this approach for estimating dry deposition is not used by the NADP. Furthermore, Olsen et al. (2018) makes this false statement in the conclusions:

> "We collected both wet and dry nutrient deposition using methods and samplers following recommendations from the National Atmospheric Deposition Program (NADP) [24]."

The NADP does not measure dry deposition in any of its monitoring networks and does not have any published methods for *measuring* dry deposition, in large part due to contamination by birds, insects, and other sources that can confound measurements of atmospherically deposited constituents. Dry deposition estimates used in total (wet + dry) deposition data products produced by the NADP and partnering organizations, are developed from measured or modeled air concentrations in conjunction with deposition velocities from the Community Multi-scale Air Quality (CMAQ) model (https://www.cmascenter.org/cmaq/) as implemented by the US Environmental Protection Agency. Although samples purported to have been "contaminated" were identified and removed from the analysis by Olsen at al. (2018), it is difficult to ascertain the reliability of dry deposition estimates based on the modified "dry bucket" approach used by Olsen et al. (2018). Development of methods to estimate dry deposition at local scales remains an active area of research.. Additional measurement data will be needed to develop more accurate estimates of dry nutrient loading to Utah Lake.

The study attempts to interpolate between the five measurement sites with kriging based on an exponential variogram. In addition to the five measurement sites surrounding the lake, the kriging method also used six "dummy" sites located along the center of the lake and applied "background" deposition rates of 0.019 mg TP/m^2/week and 0.112 mg DIN/m^2/week to these sites. These weekly rates of deposition correspond with annual deposition rates of 0.0099 kg TP/ha/yr and 0.0582 kg DIN/ha/yr. Although TP deposition is not measured by NADP or estimated by TDep, the very low rates of DIN deposition are not corroborated by total N (wet + dry) deposition estimates generated by TDep (3-year average centered on 2017), which indicates the lake surface received approximately 4 kg N/ha/yr (i.e., more than 60 times more than the "background" estimate used by Olsen et al. [2018]). This large discrepancy between the Olsen et al. (2018) DIN deposition estimates and total (wet + dry) N deposition from TDep renders foundational data used by Olsen et al. (2018) questionable. Even if the authors were attempting to estimate N deposition reflective of pre-European conditions at the six "dummy" sites, the values used appear to be at least 10 times too low.

The mean atmospheric deposition of DIN measured at the five sample sites surrounding the lake was approximately 37 kg DIN/ha/yr (estimated from 10.23 mg DIN/m^2/day shown in Table 4 of Olsen et al. [2018]). Based on TDep total N deposition representative of 2017, there are no areas in the western U.S. and only one very small (16 km^2) area near New Orleans with total N deposition as high as 37 kg N/ha/yr. The highest rates of total N deposition in the western U.S. based on TDep are mostly in close proximity to Los Angeles and are between 20 and 25 kg N/ha/yr, which is approximately 40% lower than the average annual DIN deposition rates extrapolated from the average daily fluxes from among the five samplers surrounding Utah Lake. Based on these discrepancies, and other potential sources of uncertainty highlighted above, additional estimates of deposition directly to the near shore environment and lake center are needed to validate or replace the Olsen et al. (2018) interpolations of TP and DIN across the lake surface.

Also of note, Olsen et al. (2018) states:

> “We compared our DIN data to the NADP wet deposition data for 2014 in Utah. NADP-reported rates ranged from 2.14 to 8.42 mg/m^2/yr [24] while our measured rates ranged from 0.04 to 24.82 mg/m^2/yr.”

There are several problems with this statement:

1) It is not clear which NADP site “in Utah” was used.
2) Citation [24] is an NADP site selection and installation manual, which is not an appropriate citation for measured NADP data.
3) Rates of 2.14 to 8.42 mg N/m^2/yr correspond to 0.0214 to 0.842 kg N/ha/yr. These low rates of wet N deposition are not plausible. Data from NADP site

> UT01 (near Logan, UT) shows total inorganic N deposition of 4.36 kg N/ha/yr in year 2014. This discrepancy indicates calculation errors by Olsen et al. that may extend into other areas of the paper, including the estimates of atmospheric TP loading to Utah Lake.

Given the potential for mischaracterization of atmospheric nutrient loading rates to Utah Lake reported by Olsen et al. (2018), results from this study are not recommended to be used for management decisions related to water quality concerns in the Utah Lake watershed.

Reidhead, J. G. 2019. Significance of the Rates of Atmospheric Deposition Around Utah Lake and Phosphorus-Fractionation of Local Soils. Master of Science Thesis, Department of Civil and Environmental Engineering, Brigham Young University. *(Filename: Josh Reidhead Significance of the Rates of Atmospheric Deposition Around Utah Lake.pdf)*

This thesis report by Reidhead extends the deposition monitoring at five sites surrounding Utah Lake reported by Olsen et al. (2018), applies an alternative interpolation technique for estimating P and N loading to the surface of Utah Lake, and characterizes soil P fractionation at ~40 sites surrounding Utah Lake. This thesis report includes several examples of poor sentence structure, vague statements, missing words, and other typos. The content of the tables and figures is often not well described. Because this thesis report relies heavily on methods, and perhaps calculations, used by Olsen et al. (2018) for developing atmospheric deposition loading rates at the site level, the relevant methodological concerns previously described for the Olsen study may be applicable to this Reidhead thesis report. Of note with respect to methods, the following statement is made in the Reidhead thesis:

> "Measurements of AD were taken using the same methods as the sampling done in 2017 (Olsen et al., 2018) from the "Review of deposition monitoring methods" (Erisman et al. 2017)."

This seems to imply that the atmospheric deposition (AD) sampling used the same methods as Olsen et al. (2018), which were based on Erisman et al. (2017). However, Olsen et al. (2018) does not cite Erisman et al. (2017), so there appears to be a discrepancy or a misunderstanding by Reidhead with respect to the source of methods used by Olsen et al. (2018); or, it may be that Olsen et al. (2018) failed to properly cite the source of deposition monitoring methods used.

Although total (wet + dry) atmospheric deposition of various forms of P and N are included in Tables 2 and 3, the raw data and detailed calculations used to develop the P and N loading rates are not provided. Including such information would allow for evaluating the extent to which these calculations were performed with accuracy.

The Reidhead thesis highlights the potential for events such as large dust storms and fires to contribute local nutrient deposition to Utah Lake. Although nationally available products such as TDep incorporate fire emissions of N, it is likely that large dust storms extending across the surface of Utah Lake are not represented in N deposition estimates from TDep. However, it would be surprising if these dust storms were able to account for the above stated deviation between total (wet + dry) DIN deposition reported by Olsen et al. (2018), which are analogous to N deposition rates reported in the Reidhead thesis, and total (wet + dry) N deposition reported by TDep. Furthermore, the extent to which "hyperlocal" (i.e, hundreds of meters in proximity) emissions of N (and P) that are contributed to the five sample collectors surrounding Utah Lake are also deposited to the surface of Utah Lake is uncertain.

Brahney, J. 2019. Estimating total and bioavailable nutrient loading to Utah Lake from the atmosphere. Report prepared for the Utah Lake Science Panel and the Utah Division of Water Quality. Department of Watershed Sciences, Utah State University, Logan, UT.
(Filename: Estimating Total and Bioavailable Nutrient Loading to Utah Lake FINAL.pdf)

This white paper was developed to 1) summarize rates of atmospheric deposition of P and N from existing studies in Utah and the Great Basin, among other data, and 2) apply this information to estimate wet and dry atmospheric P and N loading rates to Utah Lake. The writing style and content are generally commensurate with an experienced senior level researcher. However, there are some ambiguities and inconsistencies, which will be further described below.

The introduction highlights several studies focused on dust transport of nutrients in general, including transport to lakes. The report considers all atmospheric particulates as "dust". Table 1 includes a summary of nutrient deposition measurements from various global locations. It is not clear if these measurements include both wet and dry deposition. Also, each continental subsection of the table includes what appears to be an aggregation of the measurements (e.g., "All Europe") in bold print. Although it might be assumed that these aggregations represent averages, they do not. As such, it is not clear what these bold values represent. Also, it is not clear why bold values are not included to aggregate the N deposition measurements shown in the table.

The methods section is relatively short and could include additional detail (some of which can be found in the results section), particularly with respect to the "bootstrap method" to generate a frequency distribution for representing potential deposition rates to Utah Lake. In general, the author relied on data from the published literature and unpublished studies on 1) dust deposition rates in Utah and the surrounding region, 2) fractionation of P associated with dusts in Utah in comparison with other regions, 3) dust N measurements from the US southwest, 4) wet P deposition in Utah and elsewhere, and 5) wet reactive N deposition near Utah Lake. The author also relied heavily on a study from Lake Tahoe to estimate the zone of windblown dust influence on Lake Utah and expanded this from 200 m (used for Lake Tahoe) to 400 and 600 m in an attempt to accommodate the potential for dust to extend further across Utah Lake. We note that Lake Tahoe and Utah Lake are not at all similar. The shoreline and near-lake landscape of Utah Lake includes substantial urban and agricultural development. The Lake Tahoe shoreline is mostly forested. Utah Lake drains high-P former lake bed soils. Utah Lake is very shallow and eutrophic; Lake Tahoe is very deep and oligotrophic. The near-lake environment at Utah Lake generates much more wind-blown dust than the environment near Lake Tahoe. This issue of the extent to which windblown dust from the margins of Utah Lake is transported towards the center of Utah Lake is one of the largest uncertainties in understanding nutrient loading from atmospheric deposition to Utah Lake.

With respect to dry TP deposition from urban dusts, the white paper used two methods: 1) the average of unpublished observed data from urban centers in northern Utah (G. Carling, personal communication), which produced an estimate of 152.3 mg TP/m^2/yr and 2) average concentrations of P in urban dust “from multiple regions” (note: it is not clear which regions were included) applied to average urban dust deposition rates measured in northern Utah (and other data), which resulted in 93.6 mg TP/m^2/yr.

With respect to dry TP deposition from regional sources (i.e., not urban influenced), the white paper reported an average regional TP deposition rate of 5.6 mg TP/m^2/yr (end of first paragraph on page 14). Of note, this is inconsistent with the mean TP deposition rate of 4.8 mg/m^2/yr reported in Table 8.

With respect to wet TP deposition in urban environments, the white paper reported wet TP deposition rates between 5 and 15 mg/m^2/yr, based on measurements from 4 different datasets collected in Singapore; China; New Jersey; and Logan, UT.

With respect to dry TP deposition in remote locations in Utah, the white paper reported an average PO_4^{3-} deposition rate of 2.9 mg P/m^2/yr.

All of the above estimates of TP deposition rates described in the white paper are much lower than the value of 1,927.8 mg TP/m^2/238 days reported by Olsen et al. (2018), which is based on the daily average reported in Table 3 of Olsen et al. (2018) of 8.1 mg TP/m^2/day multiplied the number of days of the Olsen study (n = 238). Analogously large differences in the rates of N deposition reported by Olsen et al. (2018) and the Brahney white paper also exist.

There are differences in interpolation techniques to determine total annual nutrient loading from atmospheric deposition to the ***total surface area*** of Utah Lake used in the studies described just above. Given that the deposition rates in the Brahney white paper were summarized and developed from a variety of literature sources, including local studies, the major discrepancies in P and N deposition rates ***per unit area*** between the Olsen/Reidhead study and the Brahney white paper casts additional doubt on the validity of the nutrient deposition rates reported in the Olsen and Reidhead studies and/or the applicability of the methods used in the white paper to the near Utah Lake setting. Although results reported in the Olsen study based on “uncontaminated” samples significantly closes this gap, discrepancies between the Olsen/Reidhead and Brahney reports suggest major uncertainties with respect to the actual P and N loading rates to the surface of Utah Lake. We believe that additional studies will be needed to elucidate these loading rates. This need is also suggested in the Brahney white paper and in the Miller comments on the white paper (discussed below).

Miller, T. Comments on the white paper: Estimating total and bioavailable nutrient loading to Utah Lake from the atmosphere *(Filename: Miller Comments on Atmospheric Deposition White Paper V3.pdf)*

The first paragraph of comments by Miller focuses on the uncertainty introduced to the Brahney white paper estimates of nutrient loading from atmospheric deposition across the ***total surface area*** of Utah Lake by using attenuation equations based on a study from Lake Tahoe. We believe that this uncertainty is a valid concern with respect to estimation of total nutrient loading to Utah Lake. It is not particularly relevant to the very large discrepancies in ***per unit area*** deposition between the Olsen/Reidhead study and the Brahney white paper described above.

In general, the remainder of the Miller comments reflects the uncertainty in understanding nutrient loading to Utah Lake via atmospheric deposition that is not explained by either the Olsen/Reidhead study or the Brahney white paper. We believe that the suggestion by Miller that results from neither paper is ready for "prime time" is accurate. The additional suggestion that additional evaluations are needed is also accurate.

Brahney, J. 2017. Response to LaVere Merritt's Utah Lake deposition study. Memo to Senator J. Dayton and Representative K. Stratton. Department of Watershed Sciences, Utah State University, Logan, UT. *(Filename: BrahneyNRAEC.pdf)*

Under the assumption that the study referred to in this letter is the Olsen study (i.e., the thesis and journal article reviewed above), the following comments are offered with respect to the numbered comments listed in this letter from Brahney:

1. Statements with respect to the placement of samplers surrounding Utah Lake and consistency with NADP protocols are generally accurate. However, the issue of the extent to which deposition from the sources described here indicate "contamination" with respect to the topic of nutrient loading to the surface of Utah Lake has not been determined by any of the studies included in this review.
2. Indeed, the NADP does not measure dry deposition using the "open bucket method". Furthermore, the NADP does not "measure" dry deposition using any method in any of their networks. The NADP and partnering organizations estimate dry deposition based on measured or modeled air concentrations and modeled deposition velocities.
3. Extrapolation across the surface of Utah Lake is an issue, details of which have been described above.
4. The literature review on nutrient deposition rates elsewhere in the western U.S. and Utah has been more recently summarized and applied in the Brahney white paper, which has been reviewed above.

Miller, T. 2019. Proposal to Measure Atmospheric Deposition in Utah Lake. Prepared for the Utah Lake Science Panel. Wasatch Front Water Quality Council. *(Filename: Atmospheric Deposition Proposal-Workplan-2019-Version4.pdf)*

The Theron Miller proposal outlines an effort to refine estimates of wet and dry P deposition to Utah Lake. Although the approach seems reasonable, the uncertainties in the resulting data are expected to be very large. The following general comments are offered with respect to the Proposed Methods outlined:

1. It is true that NADP does not measure dry deposition. However, CASTNET estimates dry N deposition from measured air concentrations of N species and assumed deposition velocities. The model TDep, developed in part by the NADP, uses measured air concentration data and modeled deposition velocities to “estimate” (but not measure) dry deposition. Although the TDep model estimates do not include P, they are probably the best source of regional total N deposition. Total (wet plus dry) N deposition to Utah Lake over the period of TDep research is given in Figure 1 and mapped for the three-year average centered on 2017 in Figure 2. Total (wet plus dry) N deposition to Utah Lake has varied between about 4 to 5 kg N/ha/yr (Figure 1). The urban influence on N deposition to the northern and eastern portions to Utah Lake (Figure 2). Based on average total (wet + dry) N deposition of 4.43 kg N/ha/yr across Utah Lake and a lake area of 364 km2, approximately 161 tons per year . TDep would not be expected to well capture the influence of local P-rich wind-blown dust.
2. The wet deposition estimated cited by Theron Miller are at best very rough first-cut estimates of wet deposition, in part because they are based on bulk deposition collection.

Given the extended dry periods between rain events, an unknown amount of dry deposition is entrained in the samplers.

3. The methods suggested appear reasonable for expanding on the Olsen/Reidhead study to estimate dry deposition to Utah Lake. That being said, given that standard protocols for measuring dry deposition to a lake surface are not currently available, the uncertainty around estimates based on experimental methods will remain high, perhaps more than a factor of 3. In addition, much of the dust-transported P in the Utah Lake basin is undoubtedly associated with dust particles in forms that are not readily bioavailable. The effort described here will provide numbers that might well be considered “educated guesses”. Nevertheless, many of the likely conclusions of the work might well be robust, even with a very wide margin of error. This is because both the P loadings (atmospheric and WWTP effluent) and the P sequestered in the lake sediment are probably very high. Therefore, a conclusion concerning the likelihood of eutrophic conditions in the absence of WWTP effluent or atmospheric deposition might be robust regardless of substantial uncertainty in the deposition numbers.

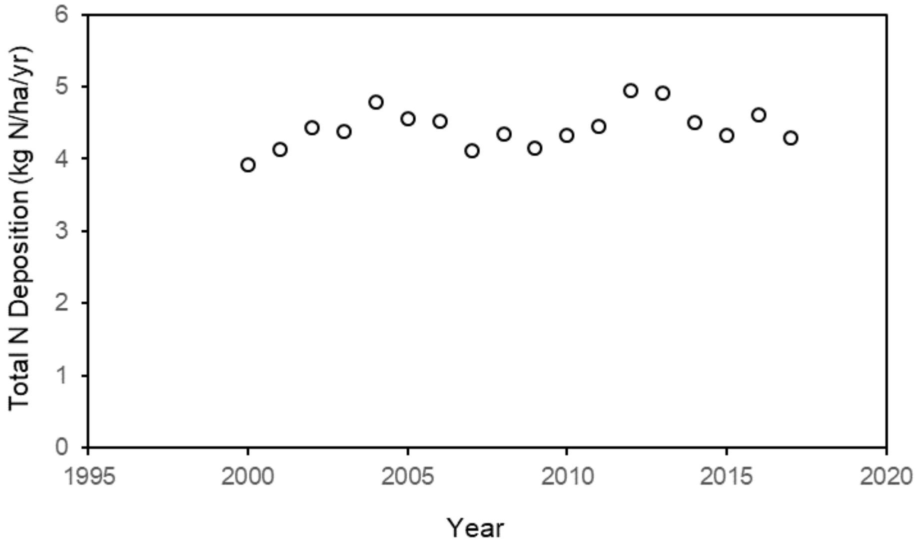

Figure 1. TDep estimates of total (wet plus dry) nitrogen (N) deposition to Utah Lake over the period of TDep record..

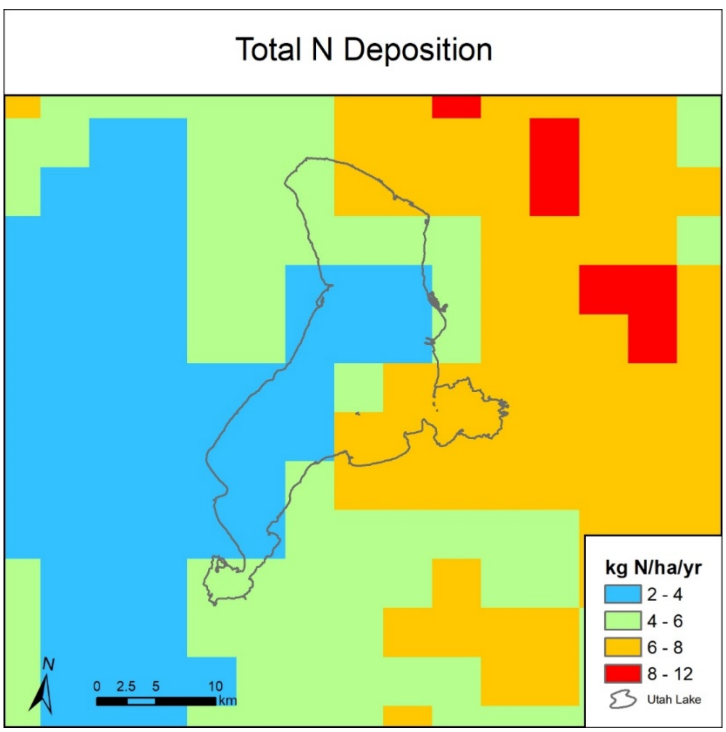

Figure 2. Total nitrogen (N) deposition in and around Utah Lake reported by TDep, shown as a three-year average centered on 2017.

Miller, W. 2019. Updated Interim Report on Nutrients in Precipitation from Utah Lake.
(Filename: Utah Lake PrecipInterim Report 3a.pdf)

Wood Miller reports nutrient wet deposition (measured as “bulk” deposition) to Utah Lake over a period of about two years. Wet deposition is much easier to quantify than dry deposition and has less uncertainty. At Utah Lake, the wet depositions of N and P are almost certainly lower than the dry deposition values, especially for P. Nevertheless, Miller concluded that the wet P deposition alone is *likely* high enough to keep the lake eutrophic and produce algae blooms; this conclusion is not surprising. The methods of Wood Miller seem reasonable. As Wood Miller points out, these estimates of wet deposition are probably biased high because some (unknown amount) of dry deposition is undoubtedly also collected in the sampling containers. Results are sensitive to assumptions about outliers that likely include the contribution of nutrients from insects or bird feces contamination. The outlier analysis seems reasonable, but uncertain. This study probably gives a good first-approximation of wet nutrient deposition loading to Utah Lake.

Conclusions and Recommendations

The debate described in the above reviewed documents is focused on the extent to which atmospherically deposited N and P would allow Utah Lake to remain as “moderately eutrophic” even with the absence of N and P loadings from WWTP effluent. This is not a particularly useful metric. Reductions in N and P loading to Utah Lake from any source type may, in fact, reduce the severity of harmful algal blooms (HABs), but not change the trophic characterization. The above reviewed information is insufficient to establish the extent to which reductions in nutrient loadings from WWTPs would be expected to impact the eutrophic state of the lake and the potential for HABs. We note, however, that it is plausible, if not likely, that N and P loading from atmospheric deposition alone may be adequate for Utah Lake to remain moderately eutrophic, especially given the high P content of the lake sediment.

Total P input to Utah Lake is clearly very high, due to:

- prevalence of windy conditions and dust storms
- P-rich soils/sediments from ancient Lake Bonneville
- semi-arid environment, with extensive exposed soils
- proximity of ongoing extensive urban development
- agricultural land near the lake
- WWTPs
- frequent temperature inversions

This is a “perfect storm” of conditions that would be conducive to localized P inputs to Utah Lake.

Robust estimates of the extent to which atmospherically deposited TP results in bioavailable, as opposed to total, P for supporting algal growth in Utah Lake are not currently available. Some of the above reviewed documents describe high concentrations of P in Utah lake sediments likely derived from windblown dust, which indicates that a potentially large fraction of TP deposited to Utah Lake is sequestered in lake sediments. Sediment P release studies can provide an indication of the extent to which bioavailable P associated with lake sediments is released to the water column. Future research activities should focus on determination of the atmospheric loading of DIN, TP, and bioavailable P to Utah Lake based on measurements at sites located on/above the lake surface. Ideally, these sites would be located at the lake center and at multiple locations near the lake shoreline. Locating measurement sites on the lake surface would provide the most relevant basis for extrapolating site-level measurements across the lake surface. Methods for estimating deposition at these sites should be carefully considered. Available methods all include considerable uncertainty. Implementation of multiple methods at a given location can assist with uncertainty assessment.