Atmospheric deposition of total phosphorus to Utah Lake

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The total P deposition rates presented by Miller (2022) are an order of magnitude higher than rates estimated by Brahney (2019) (Figure 1). Here, I present some arguments for why I think the loads from Miller (2022) and his group may be overestimated. For comparison, I have made some P deposition estimates based on published dust flux data from Goodman et al. (2019) and unpublished P concentrations in dust, as I describe below.

A summary of my points:

- A back-of-the-envelope calculation applying the Wasatch Front urban dust deposition rate (from Goodman et al. 2019) over the full lake basin, gives an annual TP load of 57.5 tons per year to Utah Lake.
- Estimates of TP deposition from Reidhead 2019 and Barrus et al. 2020 seem unrealistically high compared with my calculation.
- The method used by Brahney (2019) for interpolating P fluxes across the Utah Lake using a decay equation may underestimate P deposition.
- Measurements of TP fluxes likely overestimate the influence of atmospheric deposition because only a fraction of the P is "bioavailable".

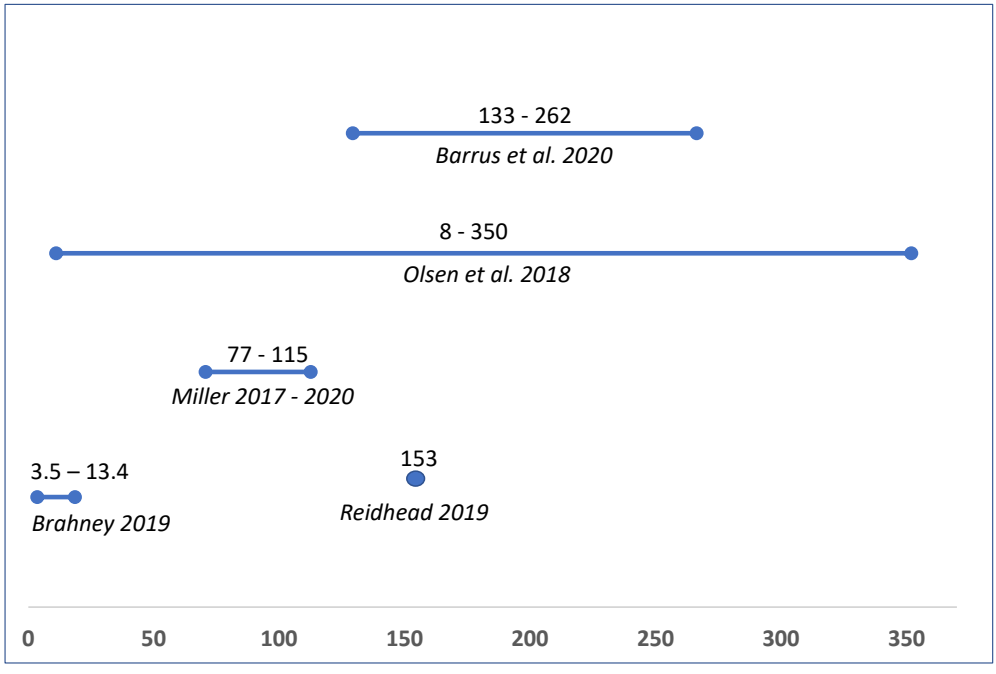

Figure 1. Estimated ranges of atmospheric deposition of total P on Utah Lake from various studies (figure from Miller, 2022).

In Goodman et al. (2019), we sampled bulk atmospheric deposition with marble collectors in Provo, Salt Lake City, Ogden, and Logan. The collectors were deployed for two-month periods during fall 2015, spring 2016 and from June 2017 through September 2018, for a total of nine sampling seasons. The collectors were placed on the rooftops of four-story university buildings where they were "less likely to be impacted by local dust or disturbed by people relative to locations near ground level". In the lab, samples were dried in a laminar flow hood at 50°C and treated with 30% hydrogen peroxide to remove organic matter. Dust deposition flux rates were calculated by dividing the dust mass (g) by the sample collection area (0.2624 m^2) and deployment time (two months), expressed as g/m^2/month. Dust deposition fluxes are shown in Table 1. Dust deposition fluxes ranged from 0.5 to 3.8 g/m^2/month. The annual flux rates calculated for the period of August 2017 through September 2018 (normalized to 365 days) were 28.7, 34.9, 33.8, and 24.7 g/m^2/yr for Provo, SLC, Ogden, and Logan, respectively. These calculated rates were within the range of an independent parallel study by Jessica Scholz (USU), who found similar deposition rates in Provo, Ogden, and SLC (Brahney 2019).

Goodman et al. (2019) describes trace element chemistry of dust deposition in comparison to dust emissions from regional playas. However, the study did not include P concentrations. We made total P measurements on a limited set of samples (Fig. 2) and plan to publish these data in a forthcoming paper. The data in Figure 2 show that P concentrations were high in playa dust (1344 – 4340 mg/kg) and even higher in urban dust (3598 – 6608 mg/kg). Like other "anthropogenic" elements, urban P deposition to the Wasatch Front is a mixture of playa dust, agricultural dust, and urban aerosols.

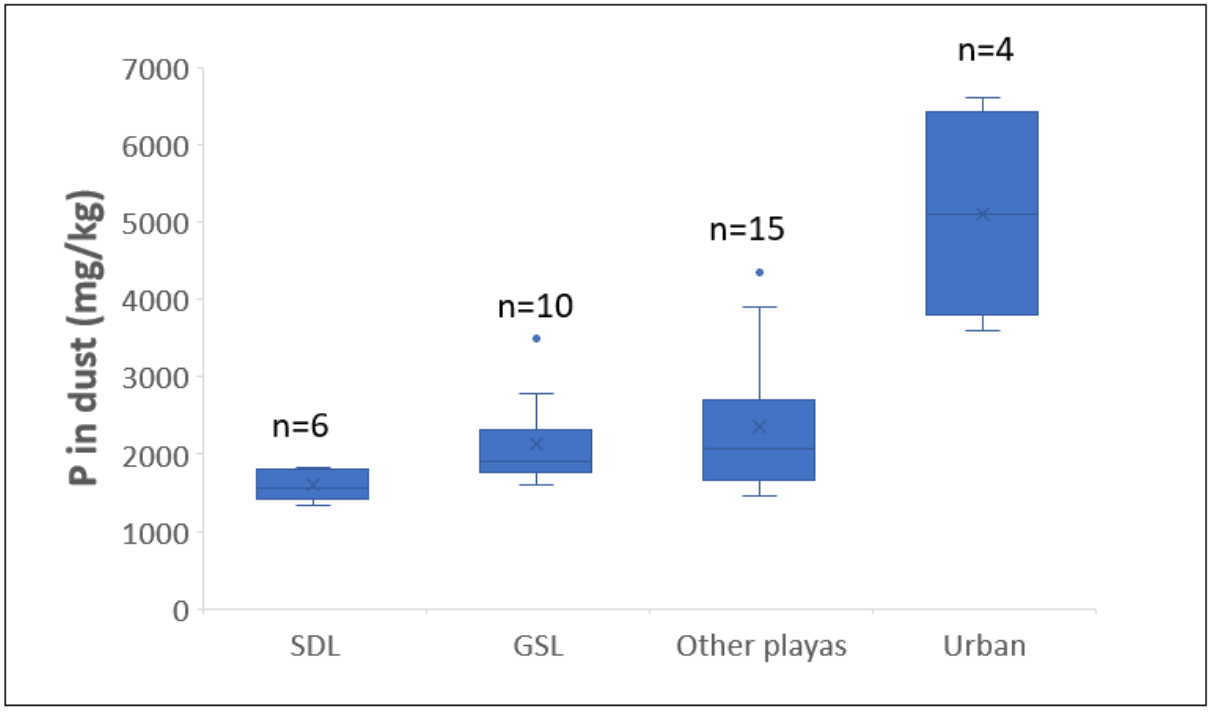

Figure 2. Total P concentrations in dust emission samples from Sevier Dry Lake, Great Salt Lake, and other regional playas, and urban dust deposition (including Provo, Logan, and two samples from Salt Lake City).

Our urban TP dataset is limited (only 4 samples) and we only have dust fluxes for one year. However, for the sake of argument, I will use these values to calculate potential TP loads to Utah Lake as a

comparison to values provided in Miller (2022). Using an annual dust flux of 30 g/m^2/yr and a TP concentration of 5000 mg/kg, annual TP deposition to Utah Lake (148 square miles or $3.83x10^8$ m^2) is **57.5 metric tons**. (Note: TP concentrations and dust fluxes in the urban area are likely higher than concentrations/fluxes to Utah Lake, so this is a "high" estimate). A dust deposition rate of 57.5 tons is slightly lower than the low-end estimate from Miller 2017-2020, 43% of the low-end estimate from Reidhead 2019, and 38% of the estimate from Barrus et al. 2020. In other words, even if I doubled the dust deposition flux to 60 g/m^2/yr, the TP deposition rate would still be lower than Reidhead 2019 or Barrus et al. 2020. Moreover, TP concentrations in dust derived primarily from playas without urban influence would be lower than 5000 mg/kg (Fig. 2), meaning the dust flux to the lake would need to be even higher than 60 g/m^2/yr to equal the loads calculated by Reidhead and Barrus. The reasons behind the high estimates from Reidhead 2019 and Barrus et al. 2020 should be closely examined.

My estimate of 57.5 metric tons is higher than the estimated range of 3.5 – 13.4 metric tons from Brahney (2019). To reach these estimates, Brahney (2019) used a decay equation to calculate the urban and agricultural influence around the edges of the lake. The method for interpolating values across the lake without representative measurements of the decay, and deciding which decay equation to use, is up for debate. How representative are dust samples collected in Provo or samples collected around the edge of the lake? The sample at Bird Island (Miller, 2022) is helpful in this regard if it can be shown that there is no influence from birds.

Finally, the estimates shown in Figure 1 and my estimate of 57.5 tons/year likely overestimate the impact of atmospheric deposition because the calculations do not account for the bioavailable P fraction. As described in Brahney (2019), the bioavailable fraction of P may only be a small fraction of TP. The bioavailable fraction of Utah Lake dust deposition should be further examined.

To summarize, atmospheric deposition is a significant source of nutrients to Utah Lake but there is still a high degree of uncertainty in calculating TP loads from dust. My estimate of 57.5 metric tons of annual TP loading to the lake is higher than values provided by Brahney (2019) but lower than values from Miller (2022). I am not suggesting that my back-of-the-envelope calculation is the correct value, but it does call into question the unusually high loads estimated by Reidhead 2019 and Barrus et al. 2020. Methods for field sampling and data interpolation are potential sources of error.

Table 1. Dust deposition fluxes from Goodman et al. (2019).

Location	Period	Number of days	Total dust weight (g)	Monthly dust flux (g/m^2/month)
Provo	Sep-Nov 2015	63	0.27	0.50
SLC	Sep-Nov 2015	63	0.53	0.97
Ogden	Sep-Nov 2015	63	0.41	0.74
Logan	Sep-Nov 2015	63	0.35	0.63
Provo	Feb-May 2016	75	0.97	1.48
SLC	Feb-May 2016	75	1.53	2.33
Ogden	Feb-May 2016			
Logan	Feb-May 2016	75	1.24	1.89
Provo	Jun-Aug 2017			
SLC	Jun-Aug 2017			
Ogden	Jun-Aug 2017	61	0.80	1.50
Logan	Jun-Aug 2017	61	0.72	1.35
Provo	Aug-Oct 2017	59	0.94	1.82
SLC	Aug-Oct 2017	59	1.35	2.61
Ogden	Aug-Oct 2017	59	1.21	2.34
Logan	Aug-Oct 2017	59	0.97	1.87
Provo	Oct-Jan 2017-2018	77	0.97	1.45
SLC	Oct-Jan 2017-2018	77	1.75	2.59
Ogden	Oct-Jan 2017-2018	77	1.85	2.75
Logan	Oct-Jan 2017-2018	77	1.01	1.50
Provo	Jan-Mar 2018	60	1.40	2.66
SLC	Jan-Mar 2018	60	1.77	3.38
Ogden	Jan-Mar 2018	60	1.37	2.62
Logan	Jan-Mar 2018	60	1.16	2.21
Provo	Mar-May 2018	62	1.67	3.07
SLC	Mar-May 2018	62	1.45	2.67
Ogden	Mar-May 2018	62	2.09	3.85
Logan	Mar-May 2018	62	1.07	1.98
Provo	May-July 2018	61	1.09	2.04
SLC	May-July 2018	61	1.93	3.62
Ogden	May-July 2018	61	1.74	3.26
Logan	May-July 2018	61	1.22	2.29
Provo	Jul-Sep 2018	63	1.81	3.29
SLC	Jul-Sep 2018	63	1.35	2.45
Ogden	Jul-Sep 2018	63	1.01	1.84
Logan	Jul-Sep 2018	63	1.37	2.48

References

Brahney, J 2019. Estimating total and bioavailable nutrient loading to Utah Lake from the atmosphere. A report produced for the Utah Lake Science Panel and the Utah Division of Water Quality, June 30, 2019.

Goodman MM, Carling GT, Fernandez DP, Rey KA, Hale CA, Bickmore BR, Nelson ST, Munroe JS. 2019. Trace element chemistry of atmospheric deposition along the Wasatch Front (Utah, USA) reflects regional playa dust and local urban aerosols. *Chemical Geology* **530**: 119317. DOI: https://doi.org/10.1016/j.chemgeo.2019.119317.

Miller T, 2022. Review, chronology and summary of the atmospheric deposition program sponsored by the Wasatch Front Water Quality Council.

Gustavious Williams, Ph.D., Comments

Dr. Carling and I discussed the AD estimates computed below. We generally agreed (I think) that the difference in estimates is due to local dust sources (< 25 – 50 km).

I do not have any significant comments on the technical approach or computations presented here and agree with his calculations.

I have a significant disagreement with the decision to exclude all of the field data that has been collected over the last 5 years from the analysis.

There is no technical reason to exclude Utah Lake shore samples.

- It seems that the only reason to exclude the field data is that the data to not provide results consistent with a predetermined conclusion.
- That is not a sufficient or supportable reason to exclude the results.

I hold the main difference between the estimates is that the Carling/Brahney estimates do not capture local (< 25 – 50 km) sources.

- Local sources are important based on:
    - Measured data at the lake shore
    - Anecdotal evidence of watching dust clouds over the lake that do not reach campus
    - Most important justification, we have significant measured data at the Lake shore
        - These data are self-consistent and consistent with data from Farmington Bay

Comments specific to Dr. Carling's summary (Carling statements in italics:

- *A back-of-the-envelope calculation applying the Wasatch Front urban dust deposition rate (from Goodman et al. 2019) over the full lake basin, gives an annual TP load of 57.5 tons per year to Utah Lake*.
    - These estimates are based on bulk samplers deployed at elevations significantly above the lake level
        - These data are not necessarily representative of AD on the Lake
            - They are measured at locations at distances and elevations that are significantly different from the Lake.
        - **We have measurements at the Lake** – these should take precedence over remote samples.
        - **All local samples were analyzed for P,**
            - only a small subset of roof-top samplers were anlyaze for P and the rest estimated
        - Local sources (< 25 km or so) do not generally reach the BYU campus
        - The Salt Lake valley (UofU, and Weber) and Cache Valley (USU) have different land use than Utah Valley. This is especially true of Cache Valley which does not have as much exposed, non-irrigated soils.
    - We have over 1500 data measurements at the Lake shore on in the Lake.
        - These data are remarkably consistent, with the only outliers at Saratoga Springs, which are explained by bugs – this issue has been addressed
        - Lakeshore/Valley-bottom collections near Farmington Bay are consistent with those from Utah Lake

        - We have addressed all the technical concerns raised by the Science Panel and updated procedures and processes.
        - T**here needs to be a technical reason to exclude these data from an analysis**
    - Data show that bulk samplers, such as those from Goodman and Miller, underrepresent total AD as some dry deposition is not collected.
    - We hold that local dust sources (< 25 – 50 km) provide a significant contribution to AD.
        - If we use the estimates from this paper to represent medium range and long range transport (e.g., Sevier Dry Lake, West Desert, and remote sources), it appears that local sources (< 25 – 50 km) are anywhere from 3x (Miller bulk samples) to 10x (Barrus total AD), higher
            - This indicates local sources provide from 60% to 90% of the AD
            - The 60% is probably a better estimate, Goodman/Brahney estimates are from bulk samplers, more similar to Miller so they can be compared.
            - Total AD should be based on Barrus because bulk samplers underrepresent total AD
- *Estimates of TP deposition from Reidhead 2019 and Barrus et al. 2020 seem unrealistically high compared with my calculation.*
    - These estimates are based on measured data.
    - There must be a scientific reason to exclude these measurements.
        - Stating that the results do not meet a predetermined result are not a technical reason to exclude the data.
    - We hold these measurements result in a higher estimate because they include dust from local sources (< 25 km), that are not included in the bulk samples on university roofs.
        - In addition, these bulk samplers are known to underrepresent total deposition (Dr. Gay comments – I didn't look up a citation)
        - This is shown by comparing bulk data from Miller to Barrus
            - Rates are similar with bulk being lower
            - These both measure deposition near the lake, not at a more distance point higher in elevation
- *The method used by Brahney (2019) for interpolating P fluxes across the Utah Lake using a decay equation may underestimate P deposition.*
    - We agree with this statement.
    - To address this concern, we placed a sampling location in Utah Lake at Bird Island.
        - This sampler showed rates comparable to shore samples – no drop-off
        - In many cases samples in the Lake were near the high end of the measurements on shore
            - We attribute this to wind patterns from Spanish Fork canyon
            - We don't have shoreline location that would measure this deposition
- *Measurements of TP fluxes likely overestimate the influence of atmospheric deposition because only a fraction of the P is "bioavailable".*
    - While this is a valid statement, it is changing the stated goals and objectives of the study because the results do not confirm a predetermined result
    - We have always stated we are measuring Total-P
    - TMDLs are most often based on Total P