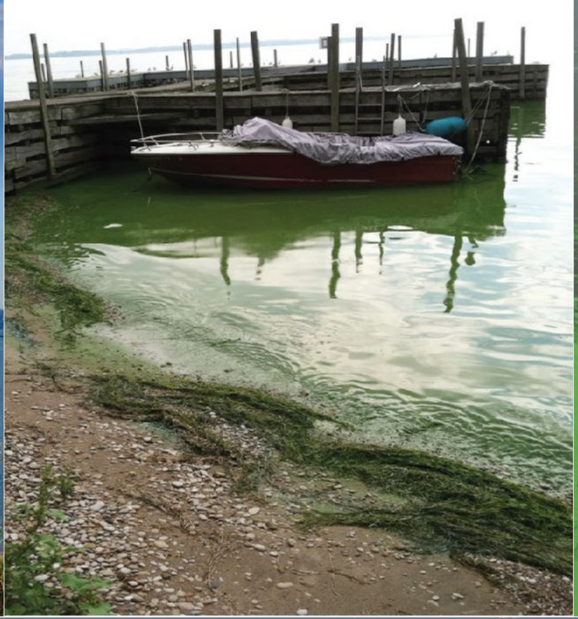
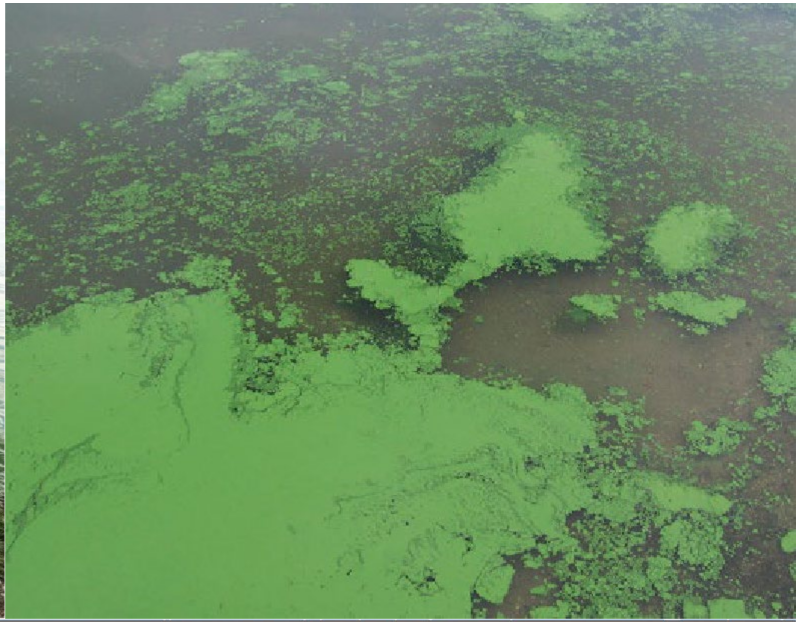
Utah Lake Water Quality Study (ULWQS)
Atmospheric Deposition Subgroup
Meeting Presentations
August 18, 2022, to February 2, 2023

The Utah Lake Water Quality Study Atmospheric Deposition Subgroup met from August 18, 2022, to February 2, 2023, to develop atmospheric deposition loading recommendations for the ULWQS. During meetings, the Subgroup provided direction to Tetra Tech on different analyses to conduct to inform the development of a atmospheric deposition nutrient loading recommendation. Following the direction of the Subgroup, Tetra Tech provided informational updates during Subgroup meetings. All the slide decks presented by Tetra Tech are included within this document. Please note that not all meetings had an associated slide deck. Please use the following links to quickly access meeting slide decks:

Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | September 8, 2022





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Updates on Data Processing & Analysis

- **Data processing**
  - ❑ Impute nondetects
  - ✓ For each site and sampling date, convert raw data to areal flux
  - ✓ Flag outliers
- **Data exploration**
  - ✓ Description of sampling locations, sample size, and period of record for each dataset and site
  - ✓ Summary statistics for each site
  - ✓ Summarize location, date, and constituent for flagged outliers
- **Visualization**
  - ✓ Boxplots of flux at each site
  - ✓ Time series plots of flux at each site
  - ✓ Cumulative flux plots at each site

Notes on Data Processing

- **Data processed only for Williams (BYU) dataset so far**
  - Processed data are unchanged from the raw data, except data are compiled into a single spreadsheet, conversions were calculated for fluxes, and outliers were flagged.
  - Raw data include measurements listed as 0 mg/m^2. If these samples were below detection limit and were assigned as zero deposition, the group may consider assigning 1/2 minimum detection or reporting limit rather than zero.
- **Data were mostly collected on weekly timescales, but not always. Fluxes have been calculated as daily and weekly fluxes, with the former calculated based on interval between samples (number of days) and the latter calculated based on fractional week interval between samples.**
- **Samples from Central Davis and Ambassador were compiled but not included in analysis (Salt Lake City area)**

Outliers

- Flagged if data exceeded the 75th percentile + 1.5*IQR from the whole dataset
- IQR = interquartile range (span between the 25th and 75th percentiles)
- Percentiles do not carry distributional assumptions, but the dataset has a wide range
  - Threshold for outliers is therefore high
  - Large deposition events may not be flagged if they are not extreme enough
  - Alternative approach: use extreme value analysis
- Note: no data were removed at this stage, just flagged for further exploration

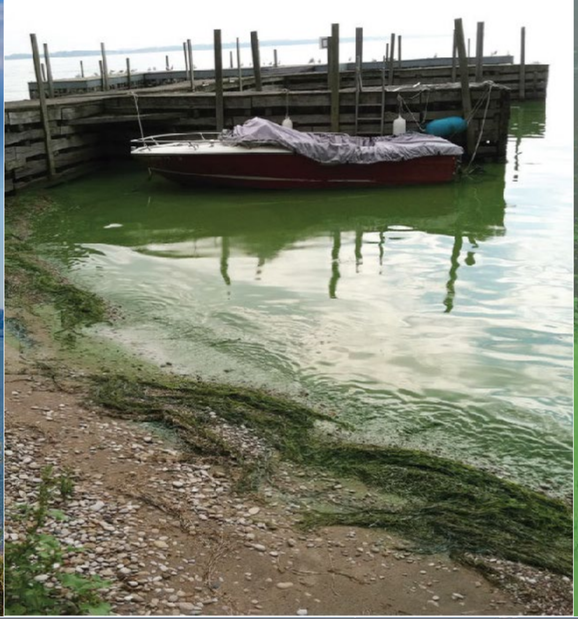
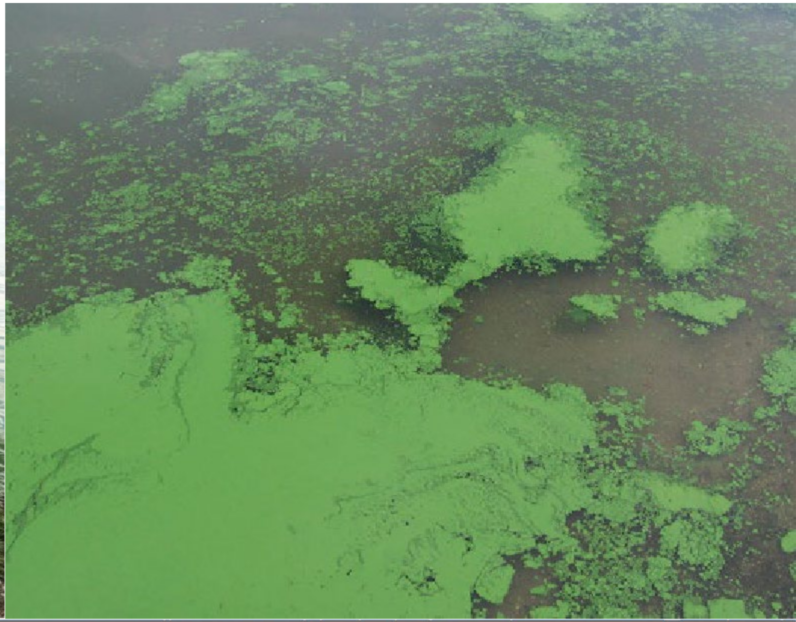
[View Visualizations from knitted PDF]

Outlier Analysis: Next Steps

- **Decide if IQR approach is the right one to ID outliers**
- **For outliers: do these represent contamination, weather events, or local sources?**
  - Contamination (specifically insects)
    - Publications noted insect presence led to higher AD estimates (Olsen et al. 2018, Barrus et al. 2021)
    - Previous SP recommendation was to consider insect sources separately from atmospheric deposition
    - Papers indicate insect metadata/field notes exist. Can the group get access to those notes for the dates specified as outliers?
  - Weather: do high flux events co-occur with precipitation and/or wind events?
  - Local Sources: are high flux events at certain sites explained by a proximity to a local source?
- **How to treat outliers, after diagnosis**
  - Exclude vs. include vs. include with implications for spatial interpolation
  - What to do if we cannot confirm insect presence/absence?

Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | September 15, 2022

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Analysis Plan Steps

Task 1: Review and summarize raw data from G. Williams and W. Miller datasets

Task 2.1: Review & discuss previous SP and David Gay recommendations

Task 2.2: Evaluate outlier samples

Task 3: Evaluate spatial interpolation among sites and attenuation of fluxes

Task 4: Evaluate speciation

Task 5: Evaluate constraining analyses

Task 6: Determine loading

Data Processing Updates: Williams Dataset

- **Follow up from Theron on detection limit to assign 0 mg/m^2?**
- **Feedback from SP members on outlier assignment**
  - IQR approach vs. other approaches (extreme value analysis, specific flux cutoff)
  - Dataset-wide outlier determination vs. site-specific outlier analysis
  - Flagging low outliers
- **Any other feedback/questions from summarized dataset and visualizations?**

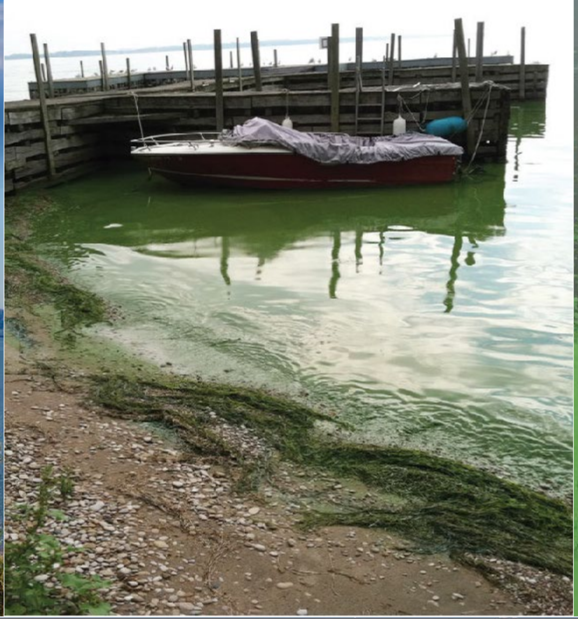
Data Processing Updates: W. Miller Dataset

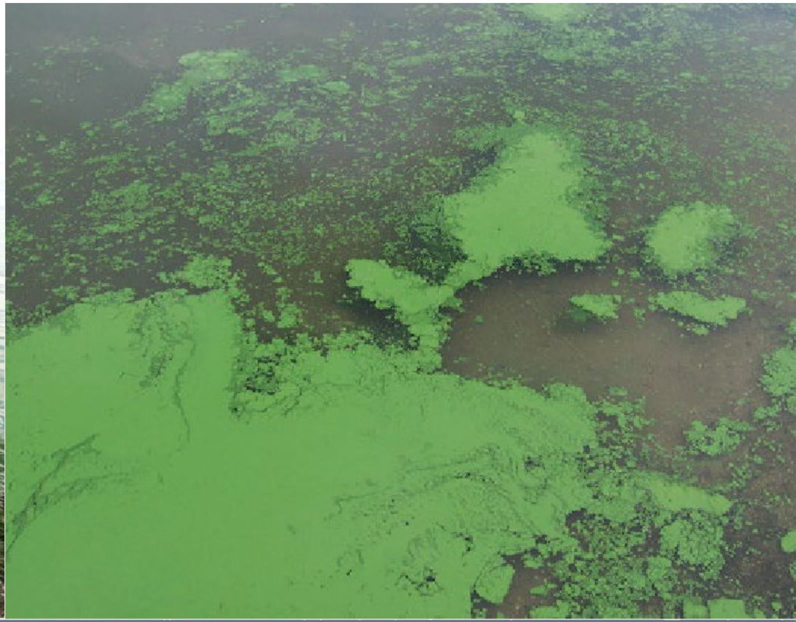
- **Different sampling design than Williams dataset**
- **Raw data reported in mg/L, not mg/m² → convert datasets to comparable units**
- **Original load calculated from single precipitation station across samplers**
- **New proposed approach:**
  - Weather can be patchy → assign precipitation from gauge closest to sampler
  - Sampler volume unknown → multiply concentration by depth of precipitation to get areal flux
  - Create similar explorations and plots as Williams dataset for direct comparisons

[Discussion about outlier decision flow chart]

Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | September 22, 2022





Data Processing Updates: Williams Dataset

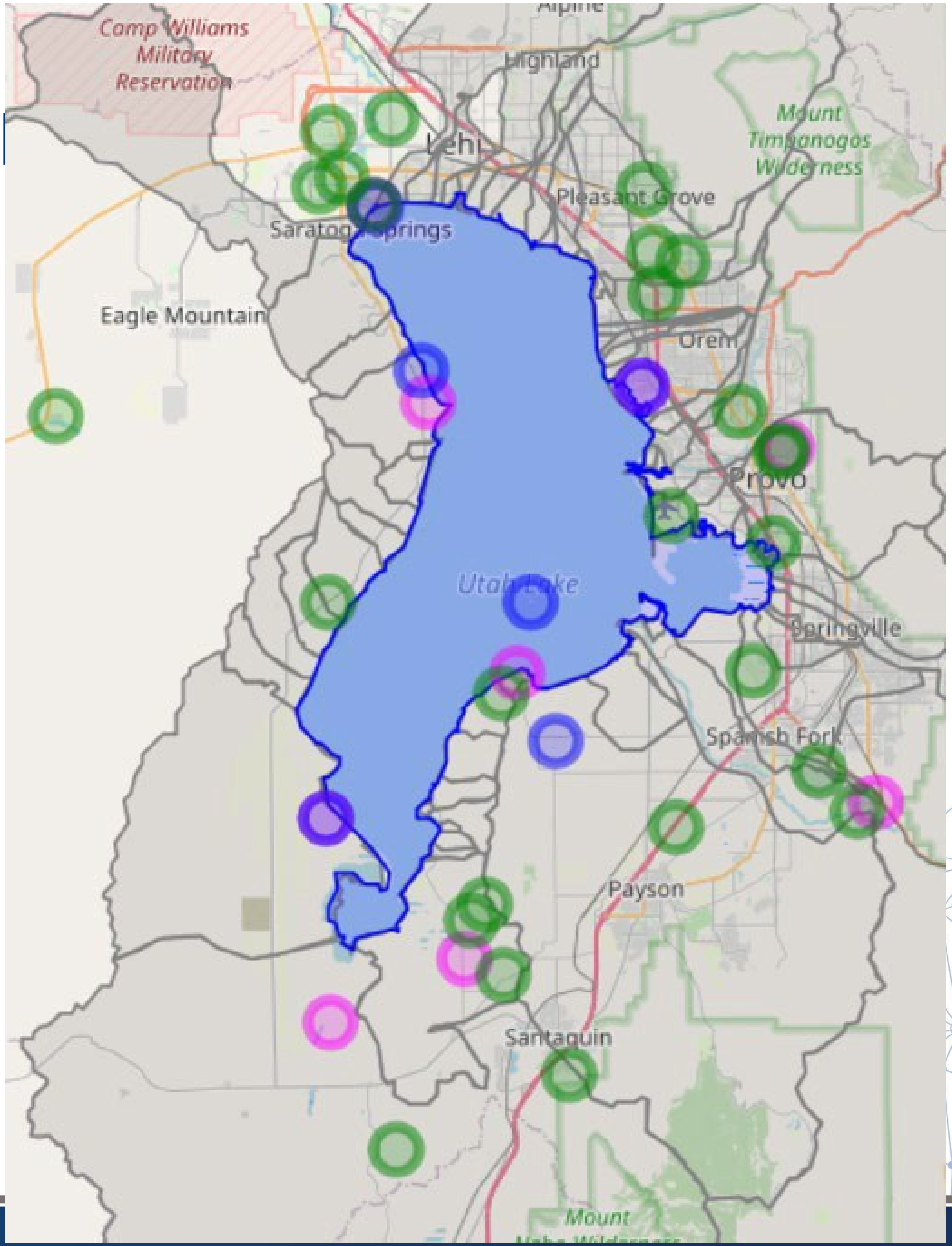
- **Follow up from Theron on detection limit? If no limit provided will retain non-detects as 0 mg/m2 as supplied**
- **Feedback from SP members on outlier assignment**
  - IQR approach deemed acceptable, can always revisit certain observations/sites
  - Identified low as well as high outliers → no low outliers exist

Data Processing Updates: W. Miller Dataset

- Different sampling design than Williams dataset
- Raw data reported in mg/L, not mg/m^2 → convert datasets to comparable units
- Original load calculated from single precipitation station across samplers
- New approach: match samplers with closest precipitation gage to calculate flux

Data Processing Updates: W. Miller

- Identified local weather stations via MesoWest, NOAA, USU (green)
- Matched AD stations from Miller and Williams to weather stations
- Each AD station matched to a primary and secondary weather station in case of data gaps

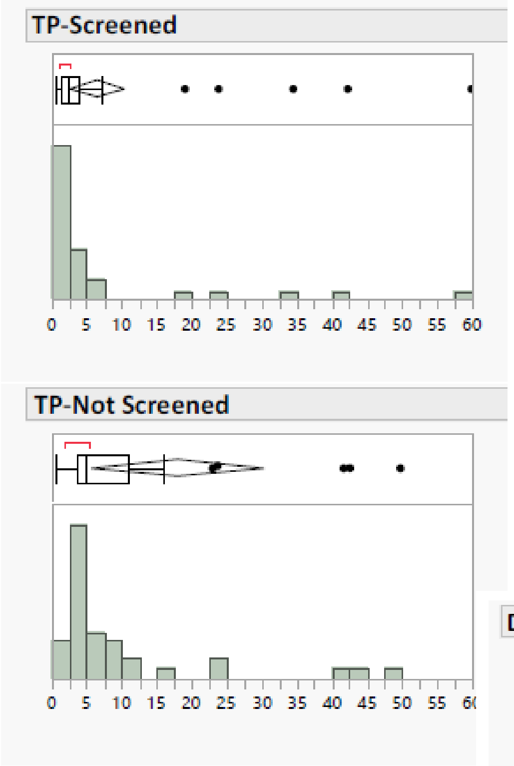


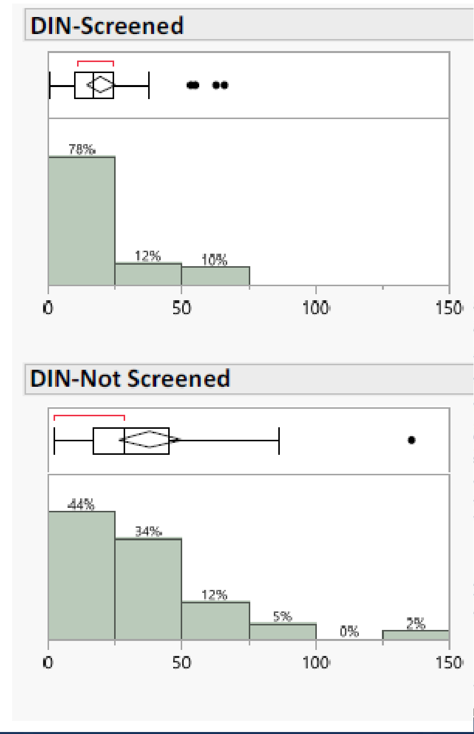
Influence of Insects

- **Olsen et al. 2018**
  - We labeled a sample as contaminated (i.e., “contaminated sample”) if any of the following conditions occurred: overlapped samples (dry buckets that collected some rainwater), bulk deposition samples (a combined wet and dry deposition sample, due to sampler malfunction), samples with visible contamination (bird droppings, insects, obvious algal growth), and samples that were collected longer than a week.”
  - “For the higher value (computed using all the samples), we estimated that the total deposition loading of TP and DIN were 350 Mg (tons) and 460 Mg (tons), respectively, over the 8-month period. For the lower value (contaminated samples excluded), the total deposition loading of TP and DIN were 8 Mg (tons) and 46 Mg (tons), respectively, for the 8-month period.”
  - “The largest dry deposition rates occurred at Saratoga Springs during the summer months with rates significantly higher than any of the other sites (see Figure 4). We attribute some of these high values to a terrestrial bee, Halictidae Lasioglossum. During the summer period, sample buckets had numerous bee bodies in the water. As noted above, these bodies were removed before sample analysis, but having been present in the water during the week, they significant raise the amount of nutrients in the samples.”

Influence of Insects

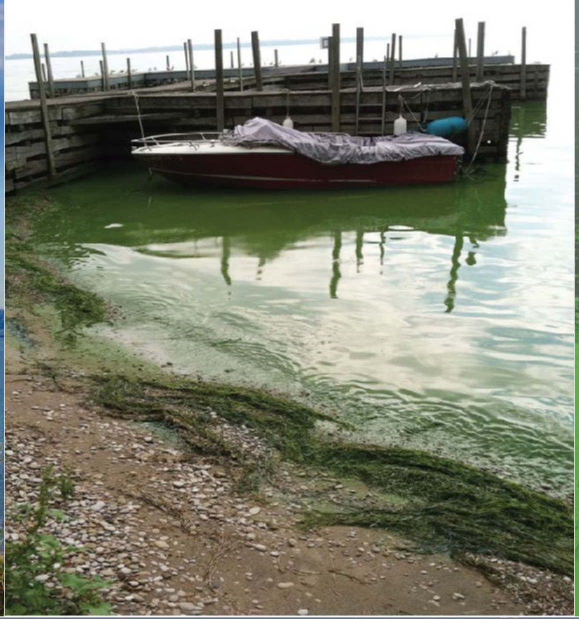
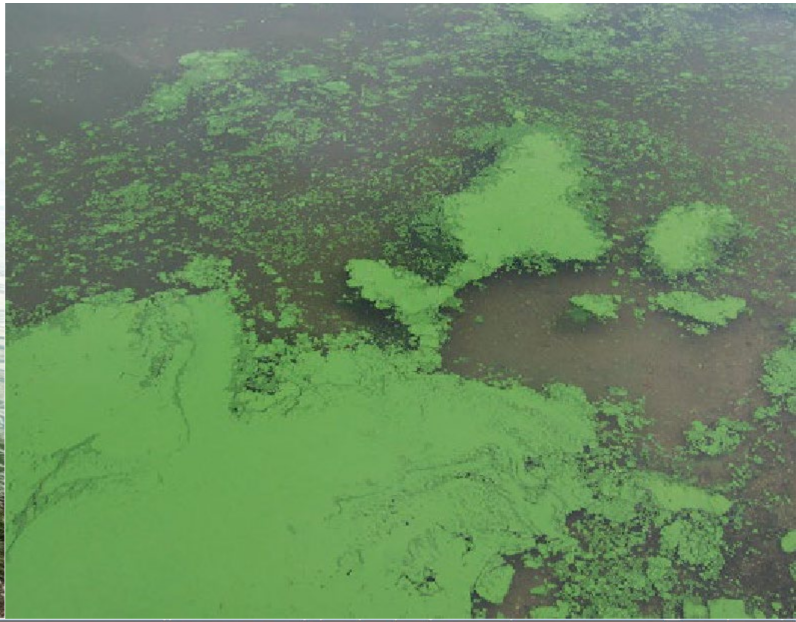
- Barrus et al. 2021
  - “For example, during the 2019 sampling year, from July to August, we counted approximately 100+ bugs per sample at the Mosida location in samples taken over a 4 week period.”
  - “Table 2 shows that the majority of outliers occur at the Mosida site and are typically associated with large numbers of visible insects in the samples. The other outliers occur at the Lakeshore site and are also associated with insects.”
  - Screen experiment w/paired samplers: 1-sided paired t-test
    - TP: avg difference in means = 2.488 mg/m^2/wk ($p < 0.0018$)
    - DIN: avg difference in means = 1.816 mg/m^2/wk ($p < 0.0116$)





Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | October 6, 2022

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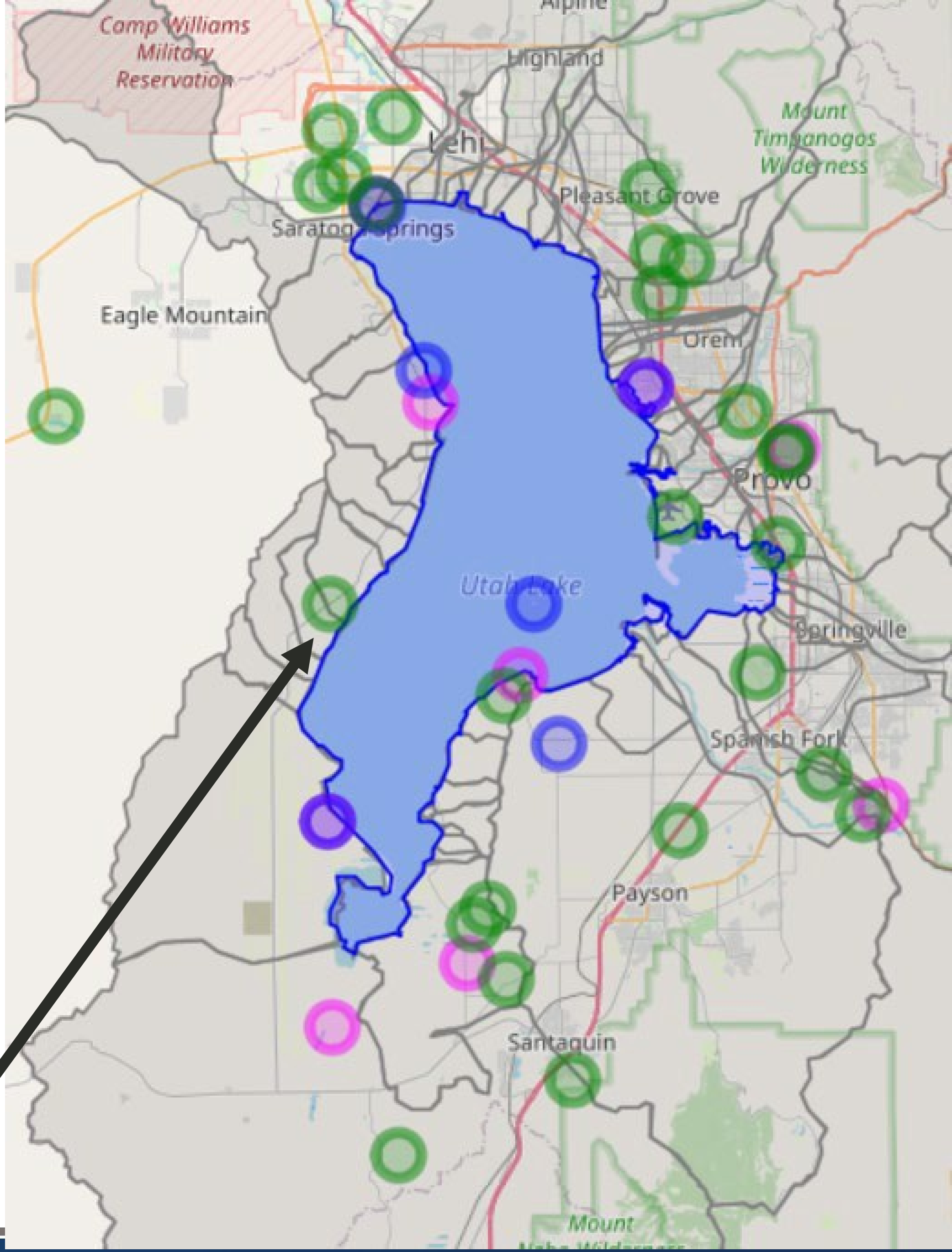
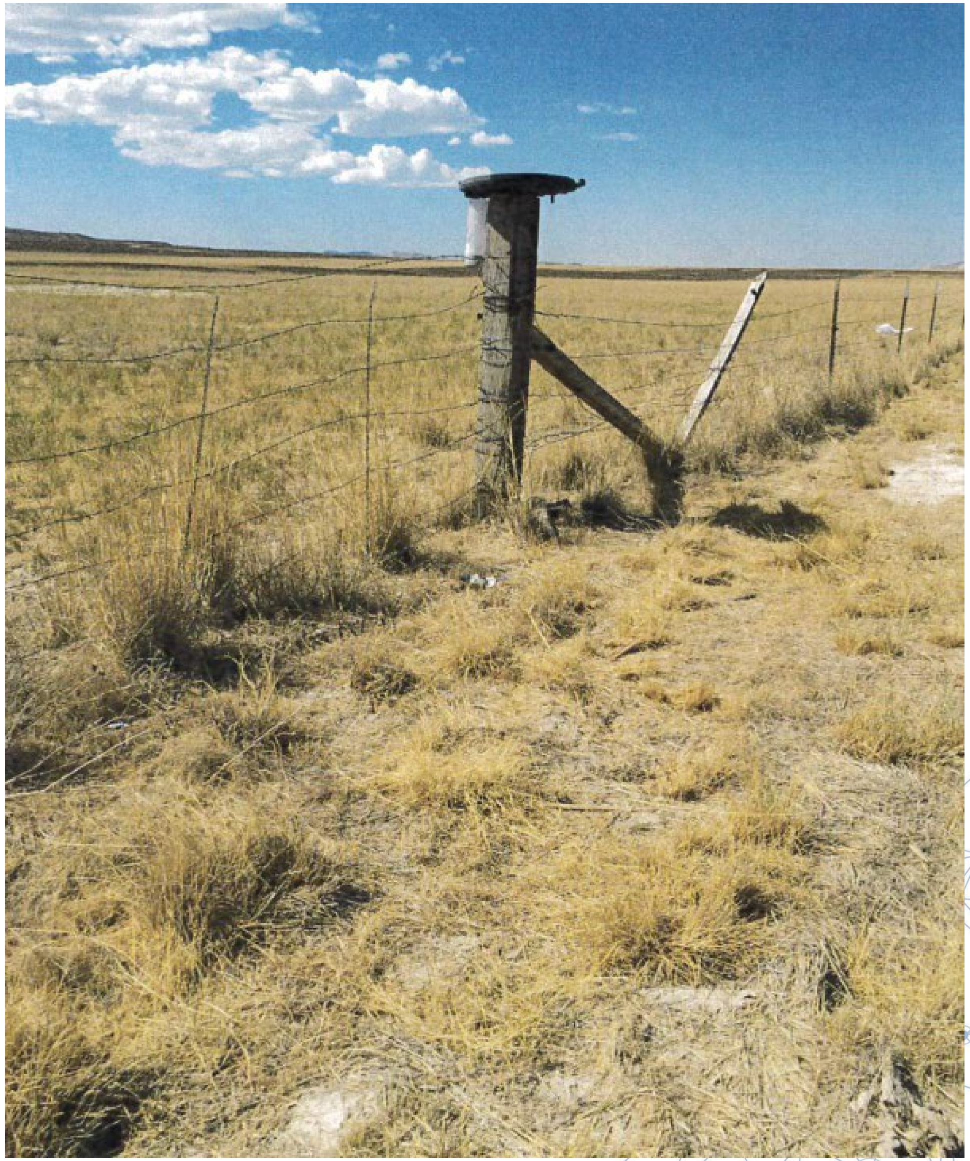
Data Processing: W. Miller Dataset

- **Paired samplers with precipitation gages**
  - *Orem*: UTORM, filled in gaps with Provo Municipal Airport
  - *BYU*: NOAA Provo
  - *Spanish Fork*: NOAA Spanish Fork
  - *Lincoln*: Lincoln Point
  - *Genola*: Genola South, filled in gaps with Genola
  - *Elberta*: Genola South, filled in gaps with Goshen
  - *Mosida*: Genola
  - *Saratoga Springs (Pelican Point)*: NOAA Lehi
  - *Pump Station (Lehi)*: NOAA Lehi
- **Note: Mosida weather station established in 2018, but precipitation was not recorded until late 2020**



W. Miller Data Interpretation Caveats

- **Evaporation**
  - Intent was to sample following precipitation events, but this was not always accomplished
  - If evaporation occurred between sampling events, flux would be overestimated (calculation relies on depth of net precipitation)
- **Dry Deposition**
  - Sampler is a shallow black pan that funnels into a collection tube
  - If dry deposition blew off between sampling events, flux would be underestimated
  - But, cannot guarantee no dry deposition made it into the collection tube
- **How much of this should be analyzed further vs. inform interpretations/confidence?**

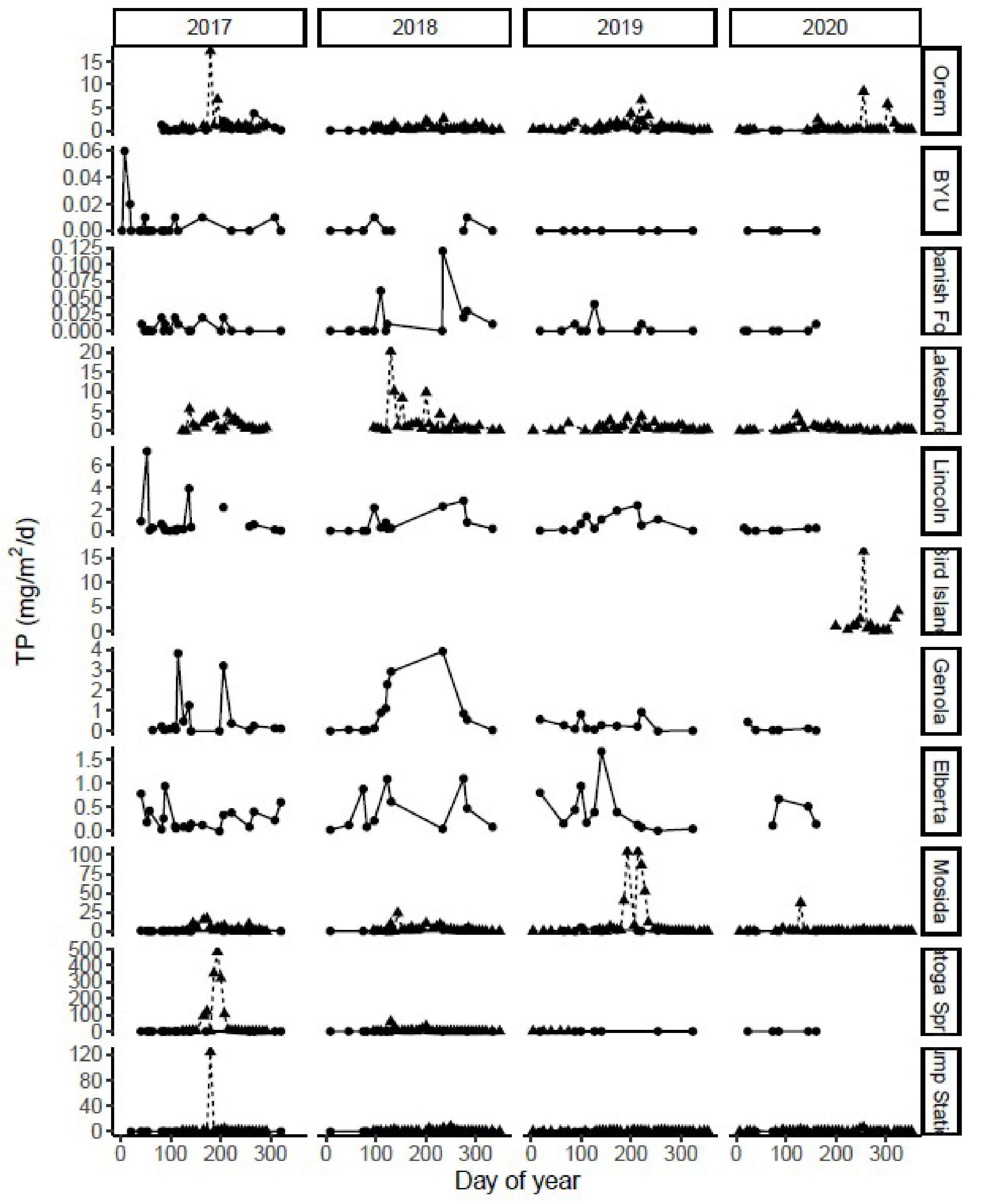


Williams & W. Miller Flux Comparisons

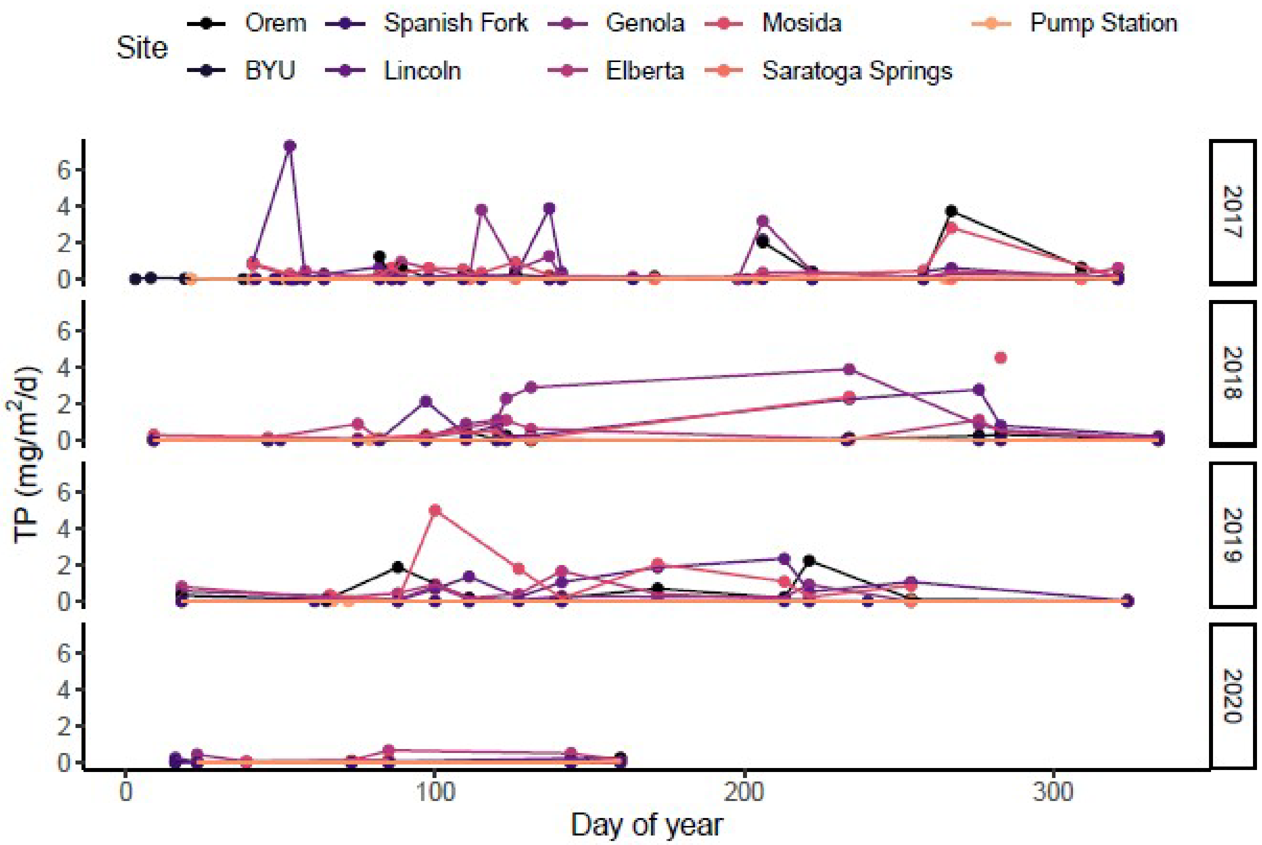
- **Common constituent: TP**
- **Other constituents:**
  - Williams: DIN, SRP, NO_{3^-}, NH_{4^+}
  - W. Miller: TN, OP
  - Suggest comparing DIN and TN. Not an exact match but we wouldn’t anticipate much organic or particulate N.
- **Some locations are an exact or close match spatially**

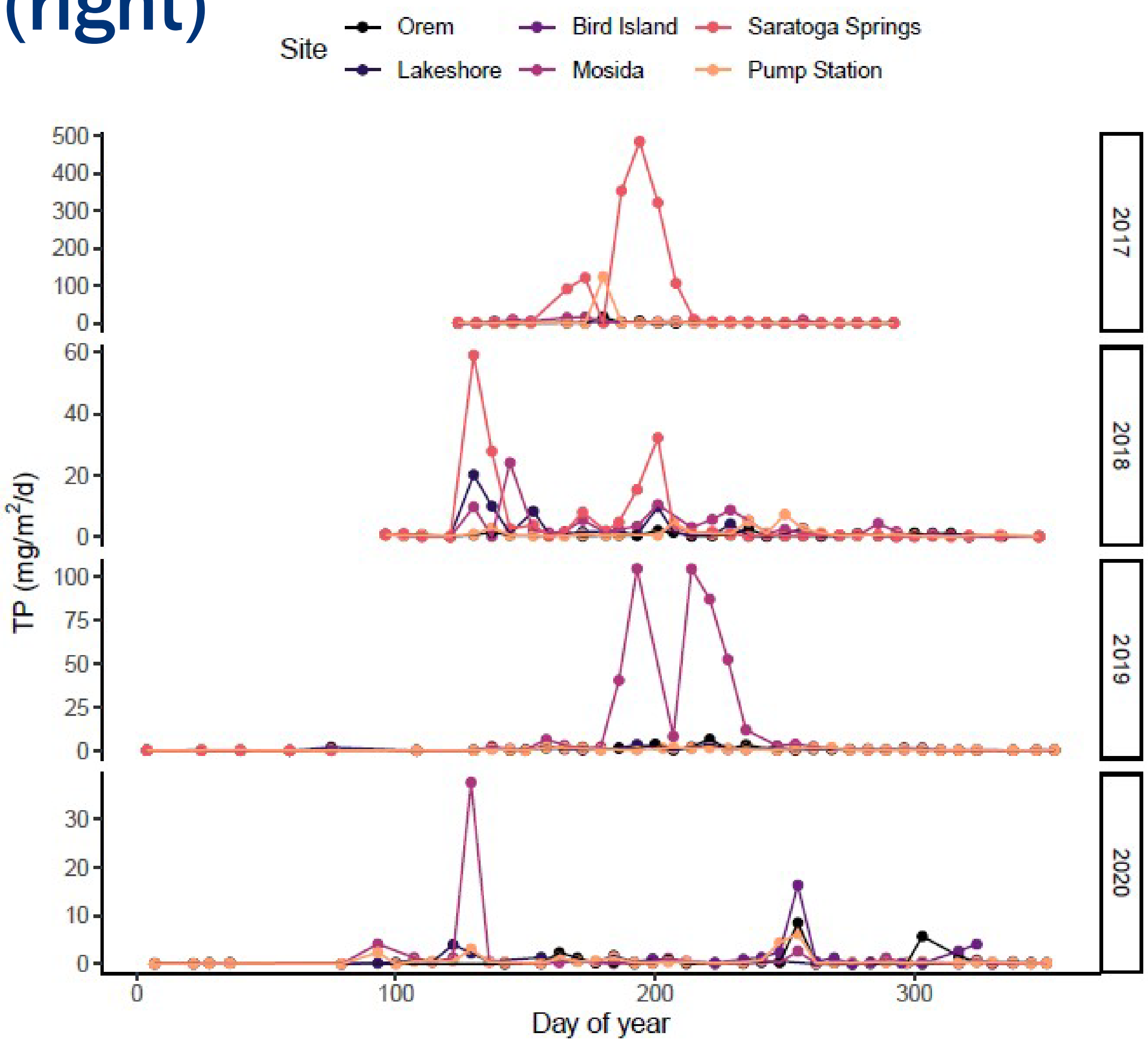
Comparing TP

- Large dataset in time and space → likely will work best to make comparisons in interactive format

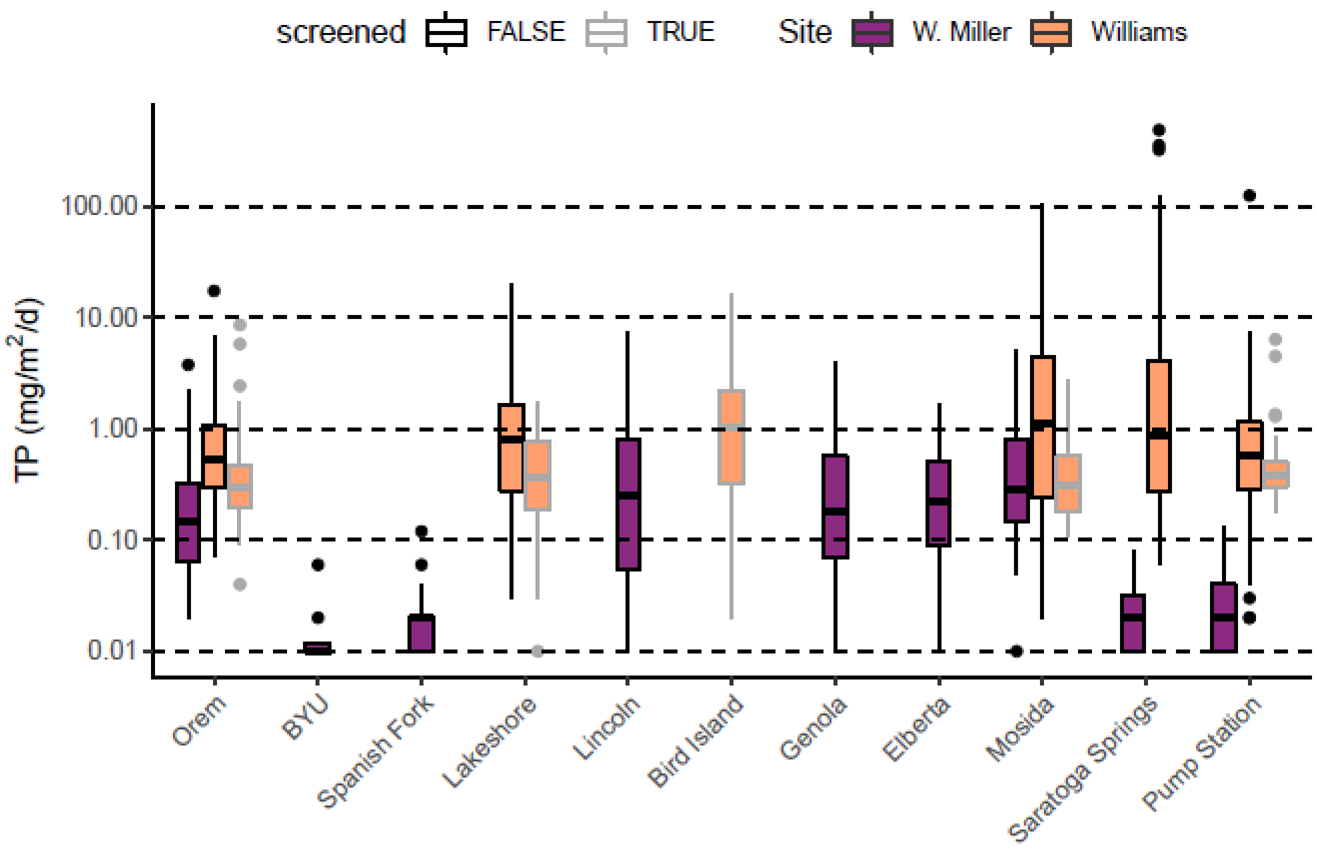


TP: W. Miller (left) and Williams (right)



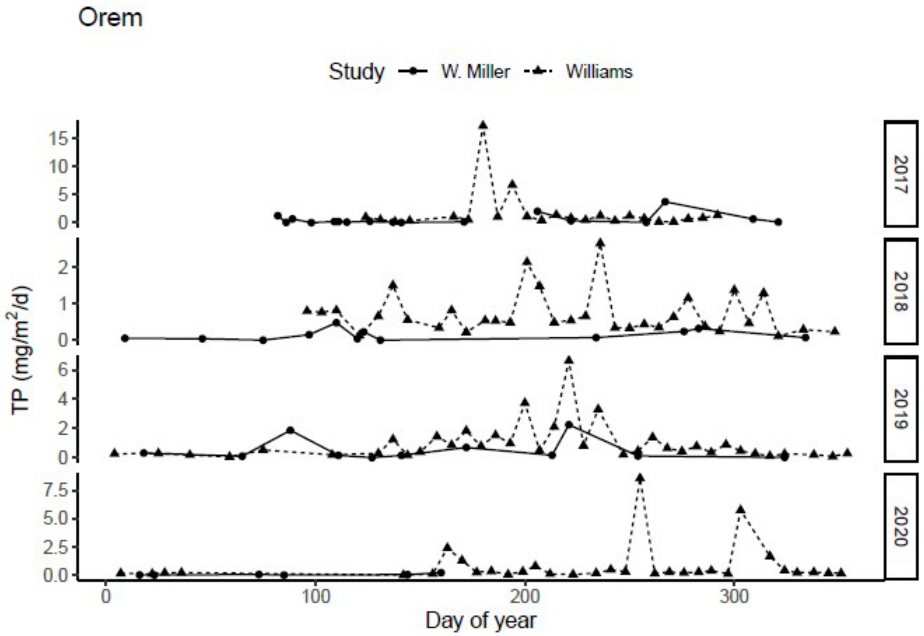


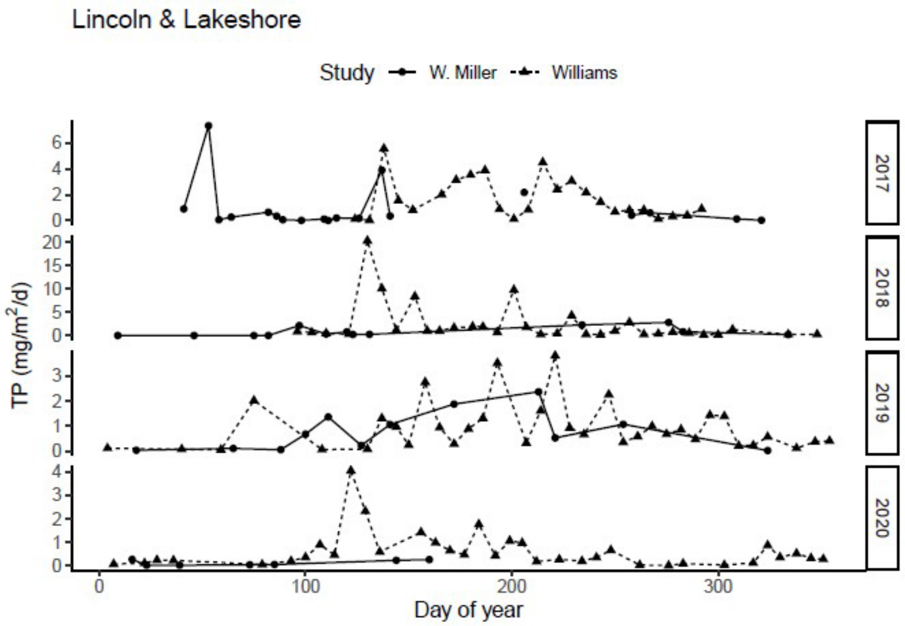
TP: W. Miller vs. Williams (screened & unscreened)

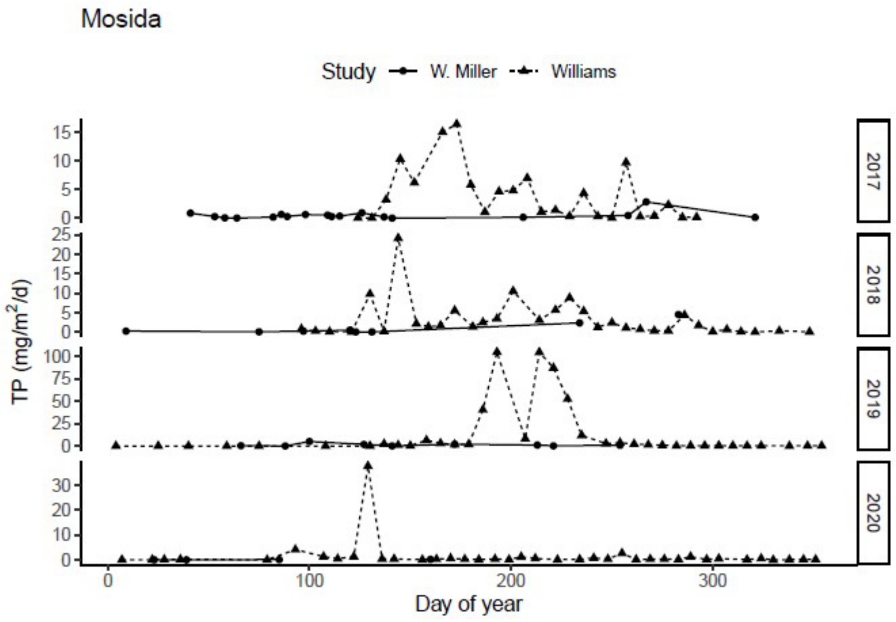


(note logged y axis)

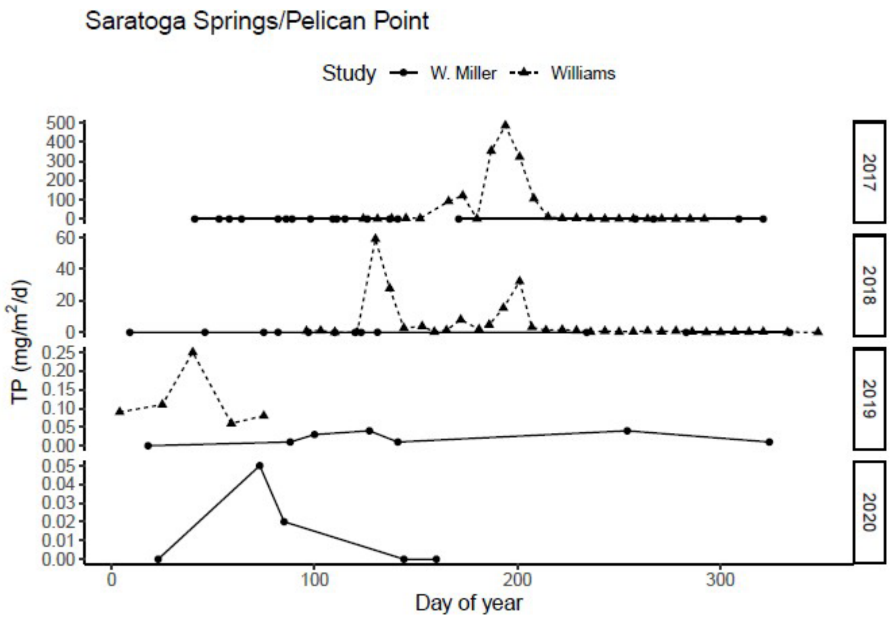
Individual Station Comparisons

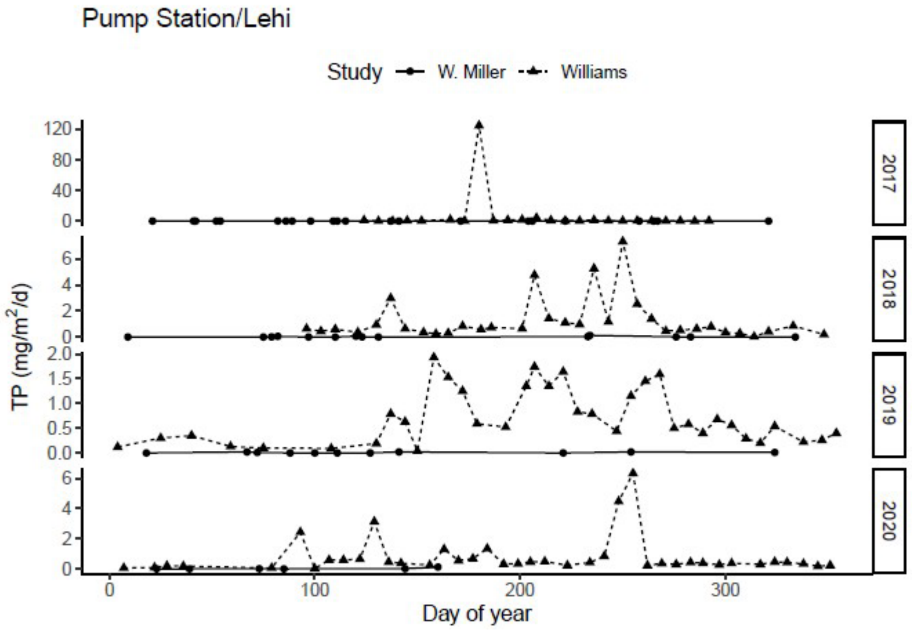






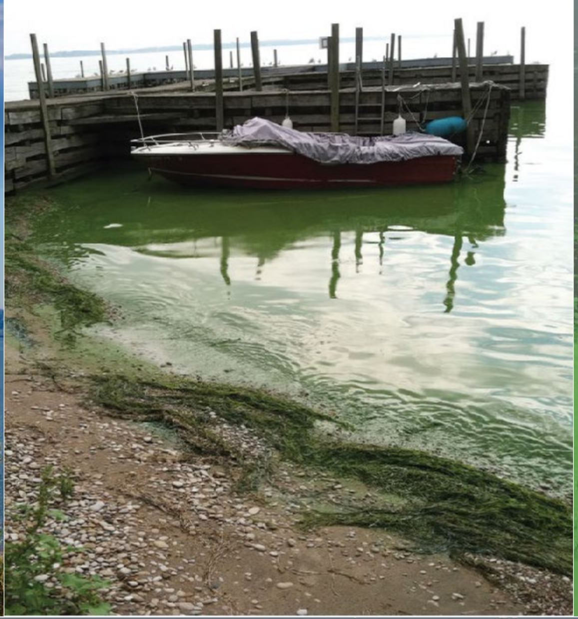
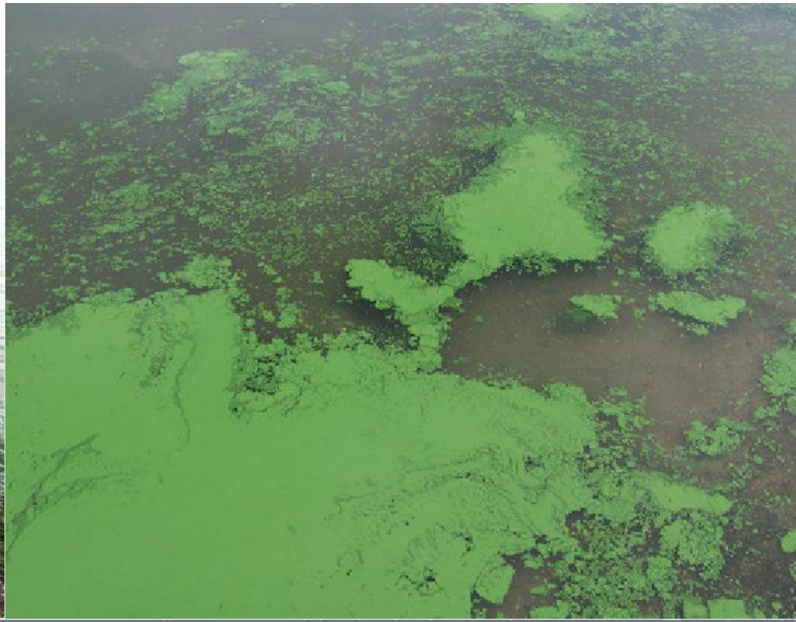
Individual Station Comparisons





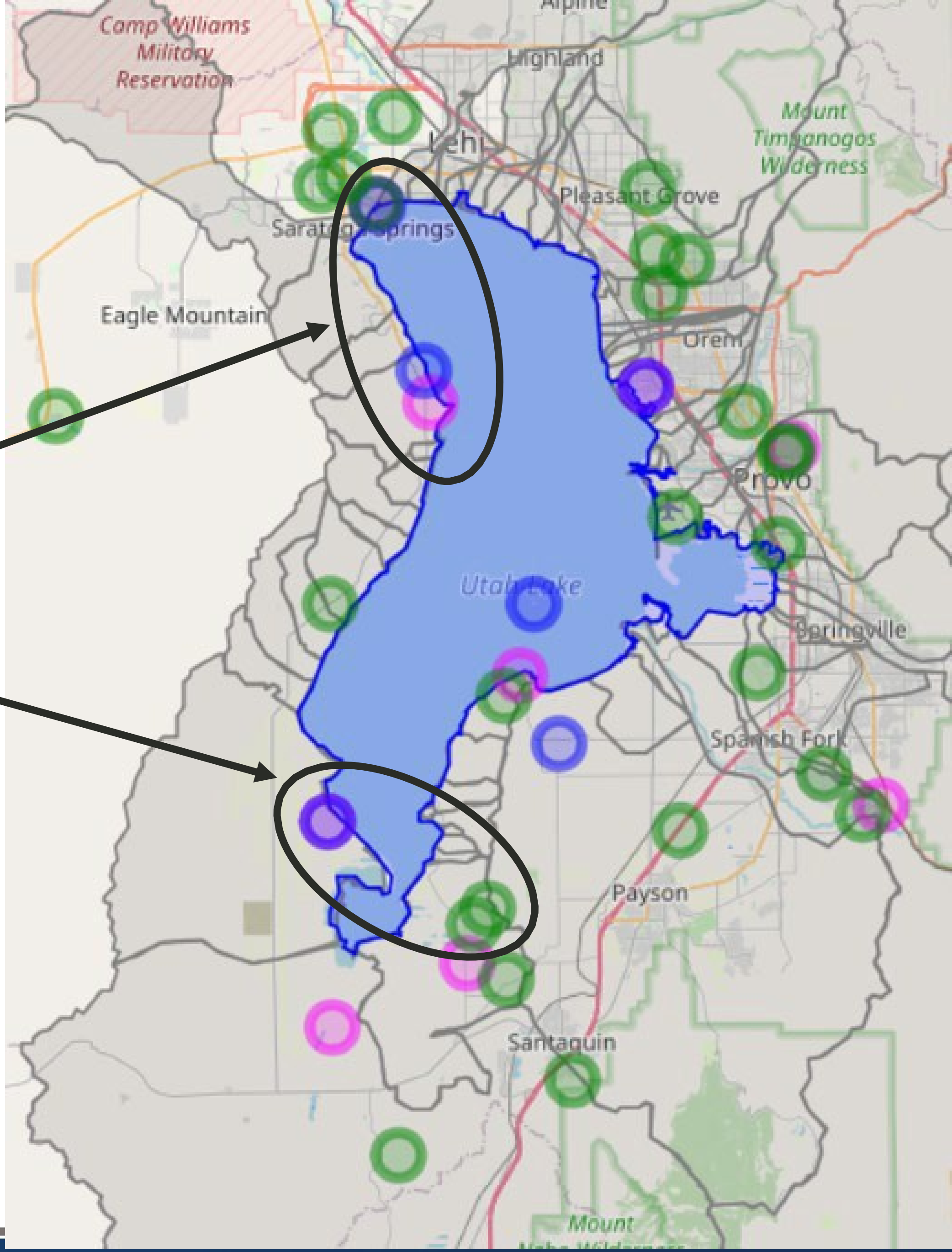
Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | October 20, 2022

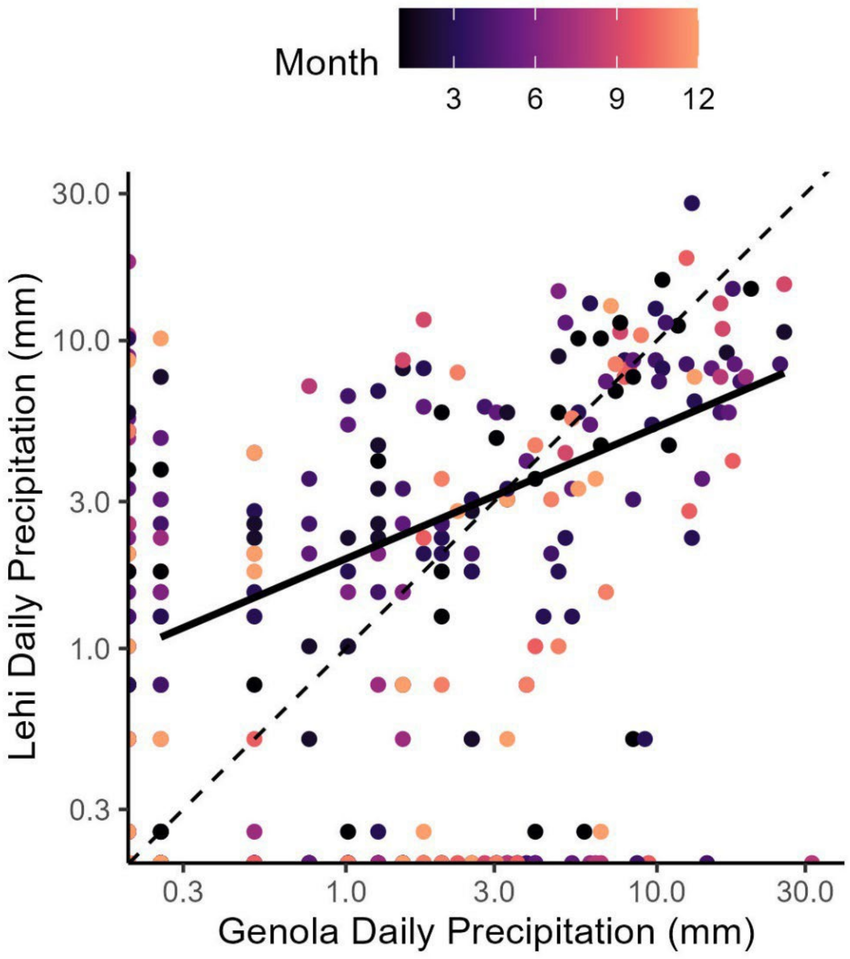




Precipitation Data Analysis

- **West side of lake has no precipitation samplers**
  - Mosida station has no precipitation data until late 2020
  - Saratoga Springs/Pelican Point uses Lehi precip
  - Mosida Station uses Genola precip
- **How different are Lehi and Genola precipitation measurements?**



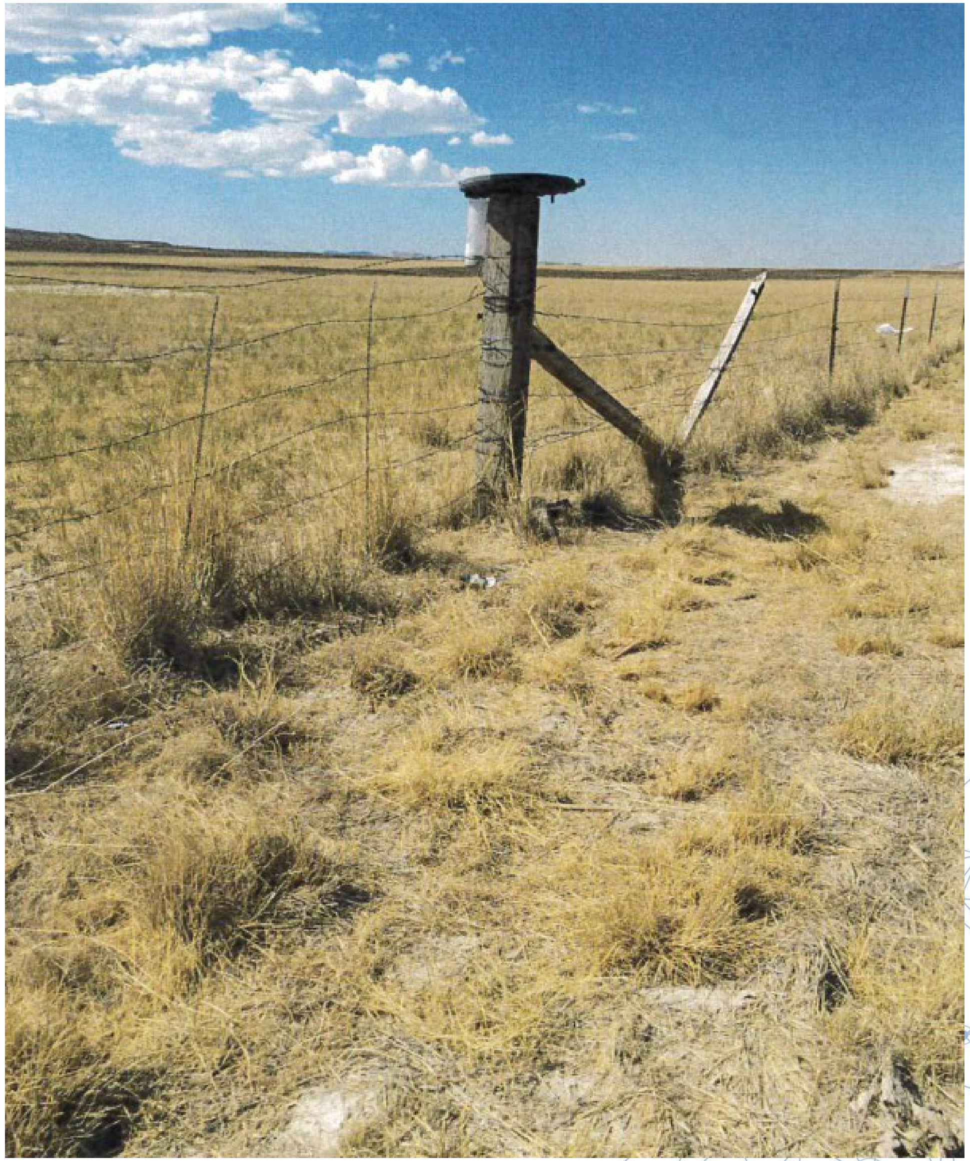
Lehi vs. Genola Daily Precipitation



- Dotted line is 1:1 relationship
- Solid line is least squares regression line
- Lehi tends to exceed Genola at low precip
- Genola tends to exceed Lehi at high precip
- Differences don't appear to have a strong seasonal component
- Paired Wilcoxon test: $p = 0.88$ → no significant difference between sites

W. Miller sampler: Overflow events?

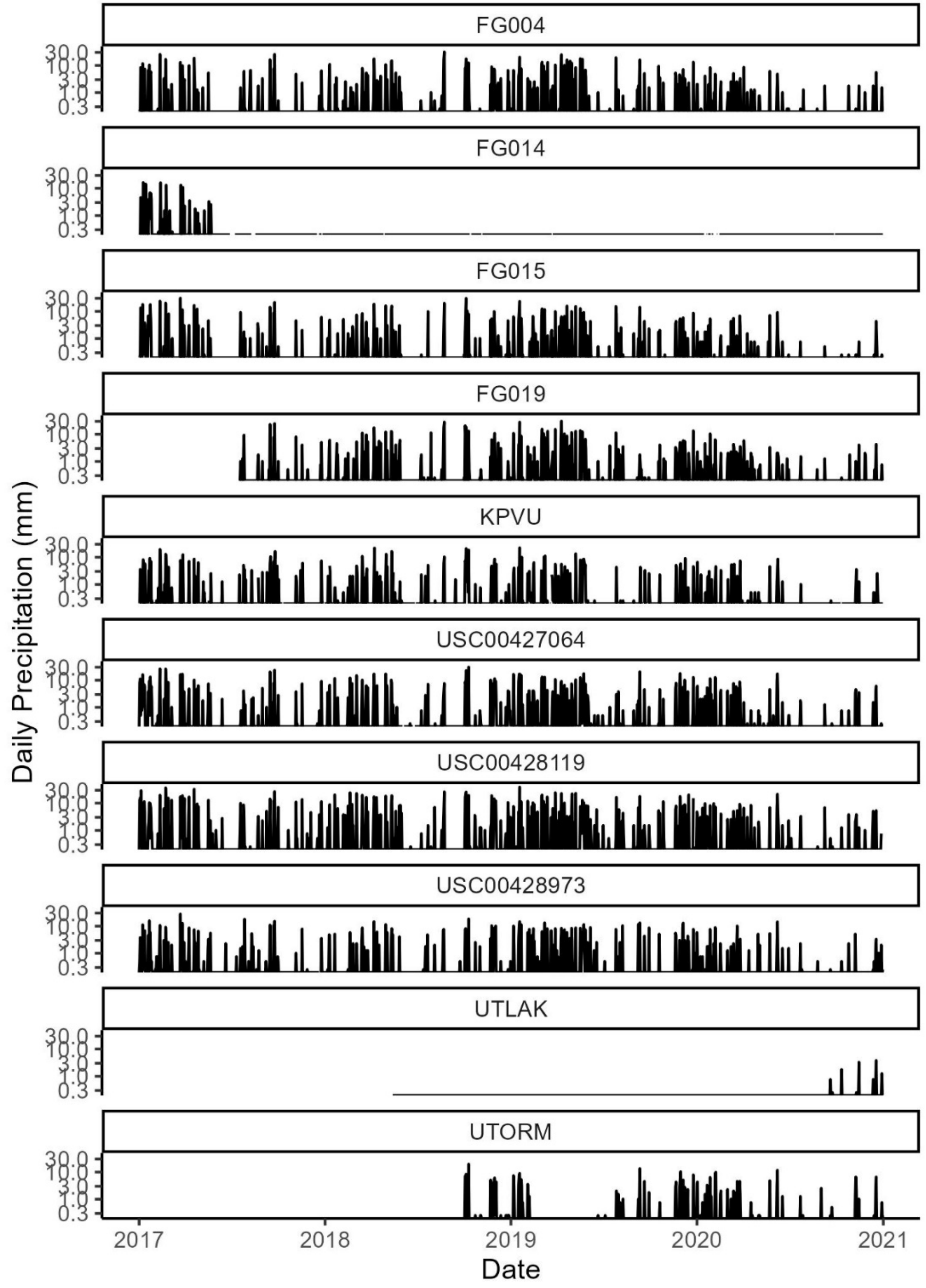
- **Sampler measurements**
  - Collector: 20 in diameter, 314.16 in^2 area
  - Container: 4 in diameter, 12 in depth, 12.57 in^2 area
  - Container: 150.84 in^3 volume
  - Precipitation event >0.48 in would exceed container volume
- **How often does daily precipitation exceed 0.48 in (12.2 mm)?**
- **How often would cumulative precipitation between sampling events exceed 0.48 in?**



How often does daily precipitation exceed 12.2 mm?

0.1-3.2% of days across stations

Station	# days with precip >12.2 mm	% days with precip >12.2 mm
FG004	26	1.8
FG014	5	0.4
FG015	21	1.5
FG019	20	1.6
KVPU	11	0.8
USC00427064	26	1.8
USC00428119	47	3.2
USC00428973	12	0.8
UTLAK	0	0
UTORM	2	0.1



How often does cumulative precipitation between sampling events exceed 12.2 mm?

- **48.9-76.7% of events across sampling sites**
- **This assumes no evaporation, which would reduce the volume over time**
- **Potential impact on fluxes:**
  - This approach relies on concentration * precip depth
  - Precip depth would be accurate in this case since we are using gages rather than volume in container
  - However, concentration may not be accurate if not all precip makes it into the container
    - First flush expected to be higher concentration
    - Overflow water would be lower concentration
    - Would result in overestimate of flux

Site	# sampling events with precip >12.2 mm	% sampling events with precip >12.2 mm
BYU	33	76.7
Elberta	28	60.9
Genola	30	61.2
Lehi	29	54.7
Lincoln	30	56.6
Mosida	26	63.4
Orem	24	51.1
Pelican	22	48.9
Spanish Fork	38	73.1

W. Miller Constituent Fractions

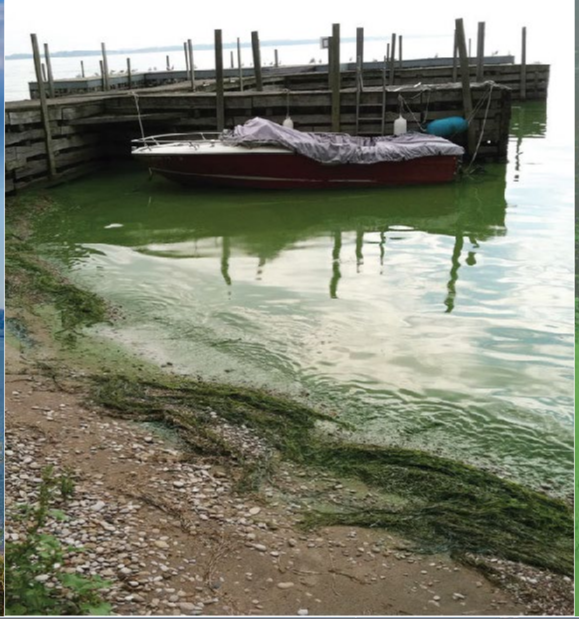
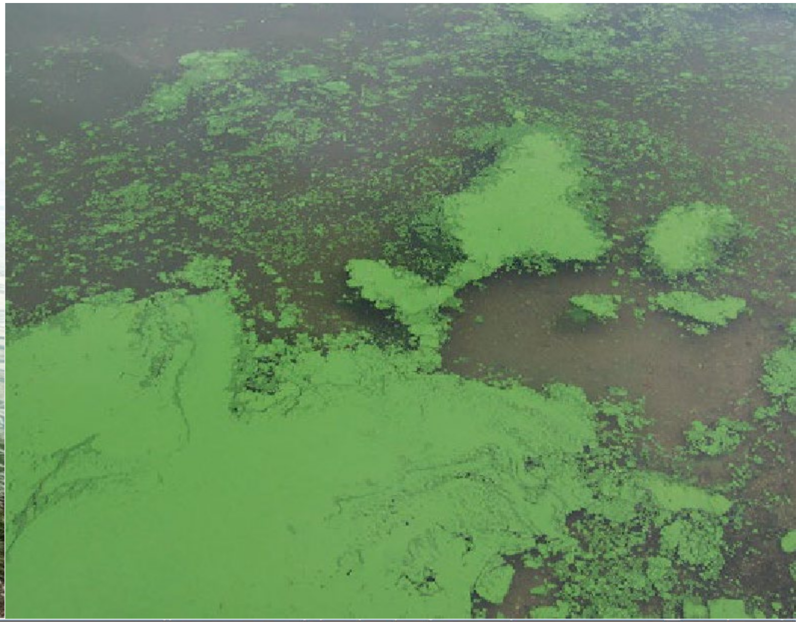
- **Samples analyzed at Chemtech-Ford Lab**
- **No analytical method details provided**
- **TP**
  - Total phosphorus
  - Unfiltered
  - Directly comparable to Williams dataset
- **OP**
  - Orthophosphate (not organic P)
  - Unfiltered
  - May assume this is comparable to SRP in Williams dataset
- **TN**
  - Total nitrogen
  - Unfiltered
  - Can we compare this to DIN in the Williams dataset? Expect TN $\geq$ DIN

W. Miller Dataset Analysis Summary

- **Precipitation gage stations are as close an approximation as we can get (in the absence of precip sampling at the sampling sites)**
- **Precipitation events that would overflow sampling containers**
  - Rare for daily events
  - Common for time between sampling events
- **Potential impacts on flux accuracy**
  - Precipitation overflow: overestimation
  - Evaporation: overestimation
  - Dry deposition blowing off sampler: underestimation
  - Sampler cleaning: W. Miller “quite well” (BYU, SF, Lehi), NWS observers “now and then”
  - May be difficult to constrain these sources of error

Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | November 3, 2022

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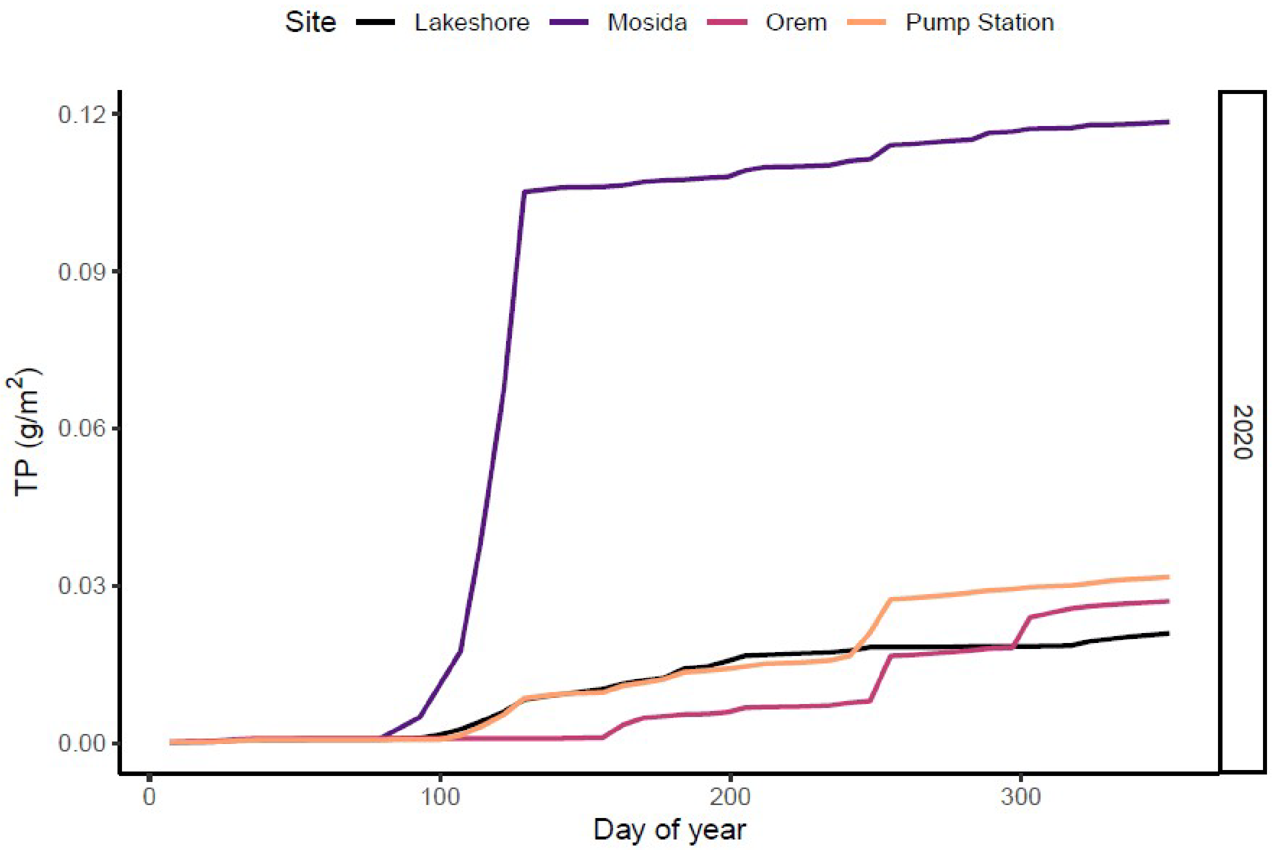
Action Items From Last Meeting

- ✓ Linear interpolation to impute sampling events removed due to contamination
- ✓ Explore relationships between weather conditions and AD fluxes
  - ✓ Precipitation
  - ❑ Wind
  - ✓ PM2.5 and PM10
- ❑ Evaluate potential impact of evaporation on Wood Miller samples

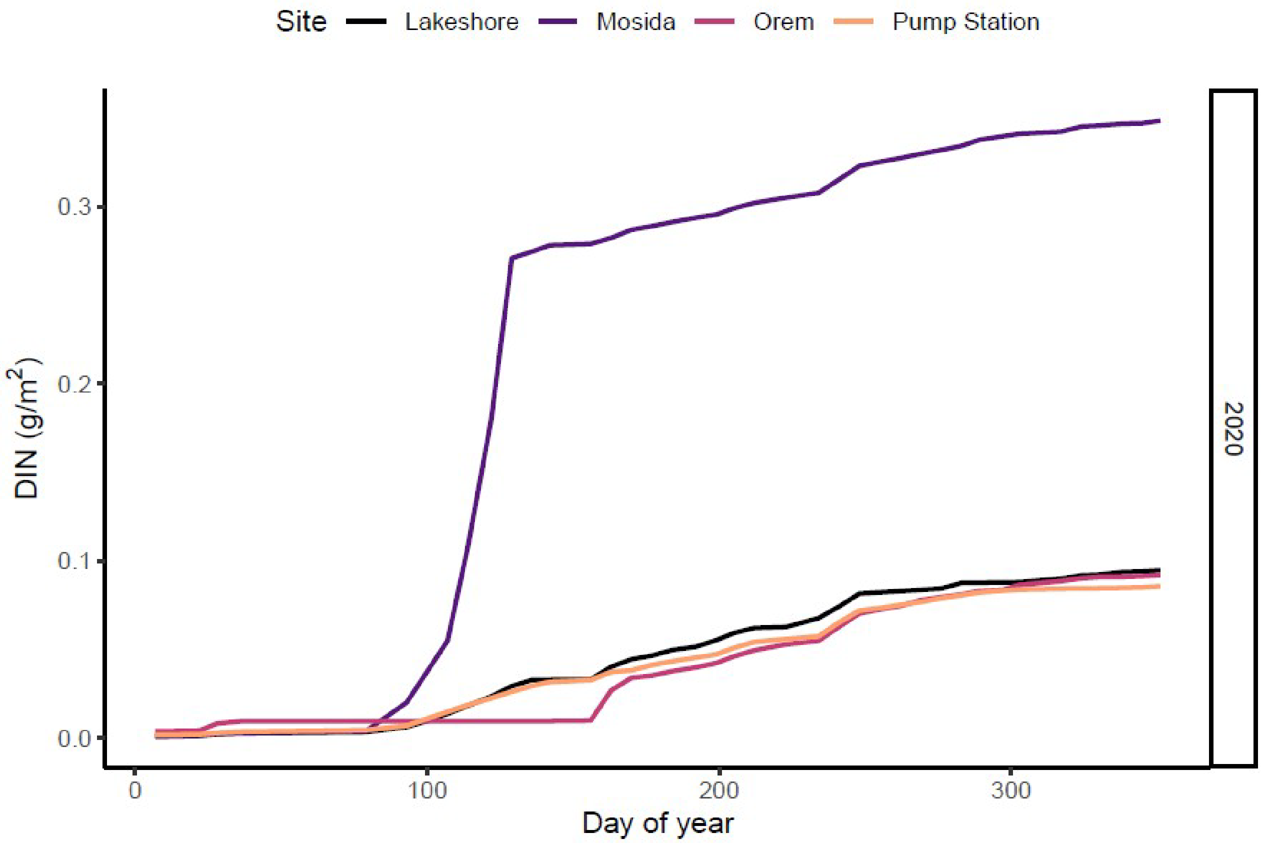
TP Cumulative Flux

- **Sampling events removed due to contamination were interpolated linearly**
- **Cumulative flux is lower than previous calculations**
- **Annual flux at each site:**
  - Orem: 27.0 mg/m²/y
  - Lakeshore: 20.9 mg/m²/y
  - Mosida: 118.4 mg/m²/y
  - Pump St.: 31.6 mg/m²/y



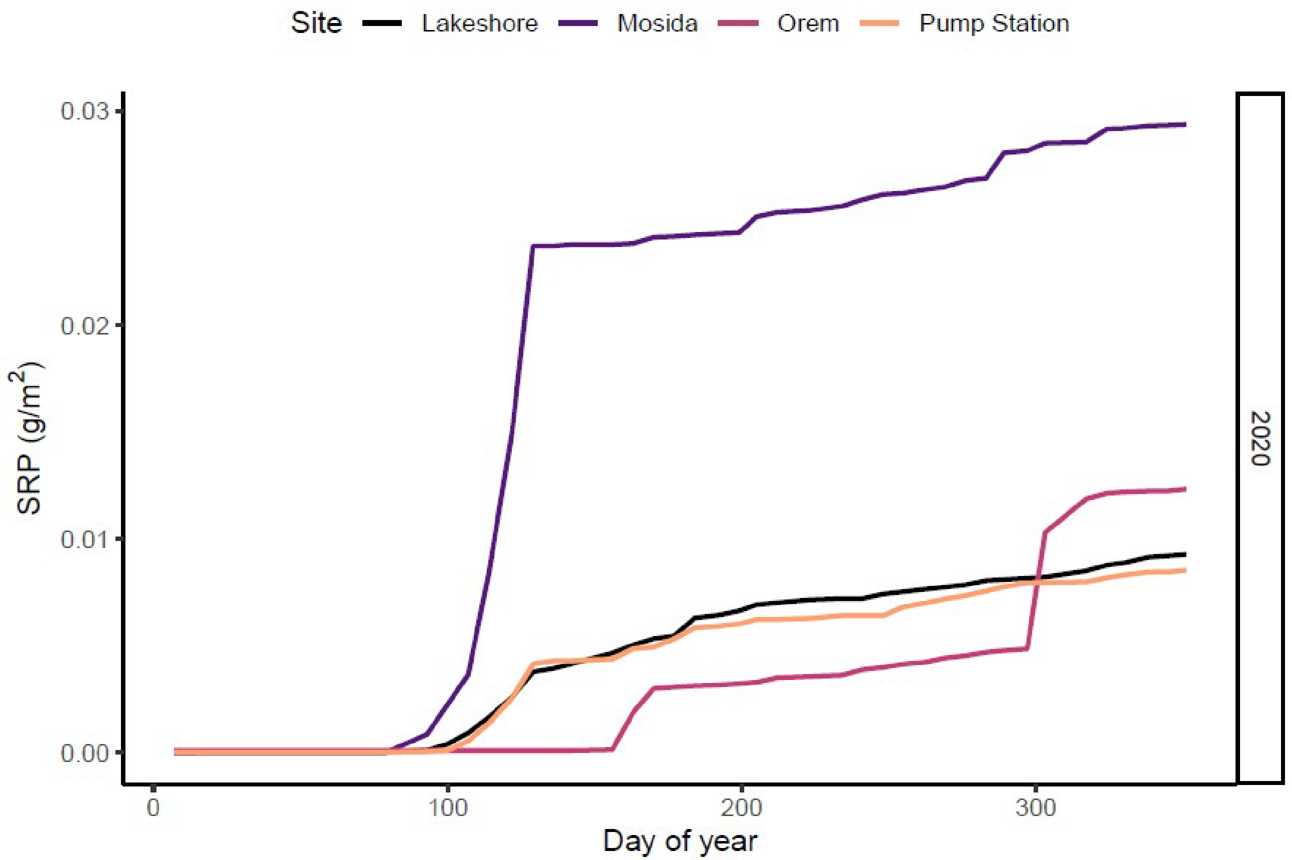
DIN Cumulative Flux

- **Sampling events removed due to contamination were interpolated linearly**
- **Cumulative flux is lower than previous calculations**
- **Annual flux at each site:**
  - Orem: 92.0 $mg/m^2/y$
  - Lakeshore: 94.7 $mg/m^2/y$
  - Mosida: 348.3 $mg/m^2/y$
  - Pump St.: 85.7 $mg/m^2/y$



SRP Cumulative Flux

- Sampling events removed due to contamination were interpolated linearly
- Cumulative flux is lower than previous calculations
- Annual flux at each site:
  - Orem: 12.3 $mg/m^2/y$
  - Lakeshore: 9.3 $mg/m^2/y$
  - Mosida: 29.4 $mg/m^2/y$
  - Pump St.: 8.5 $mg/m^2/y$

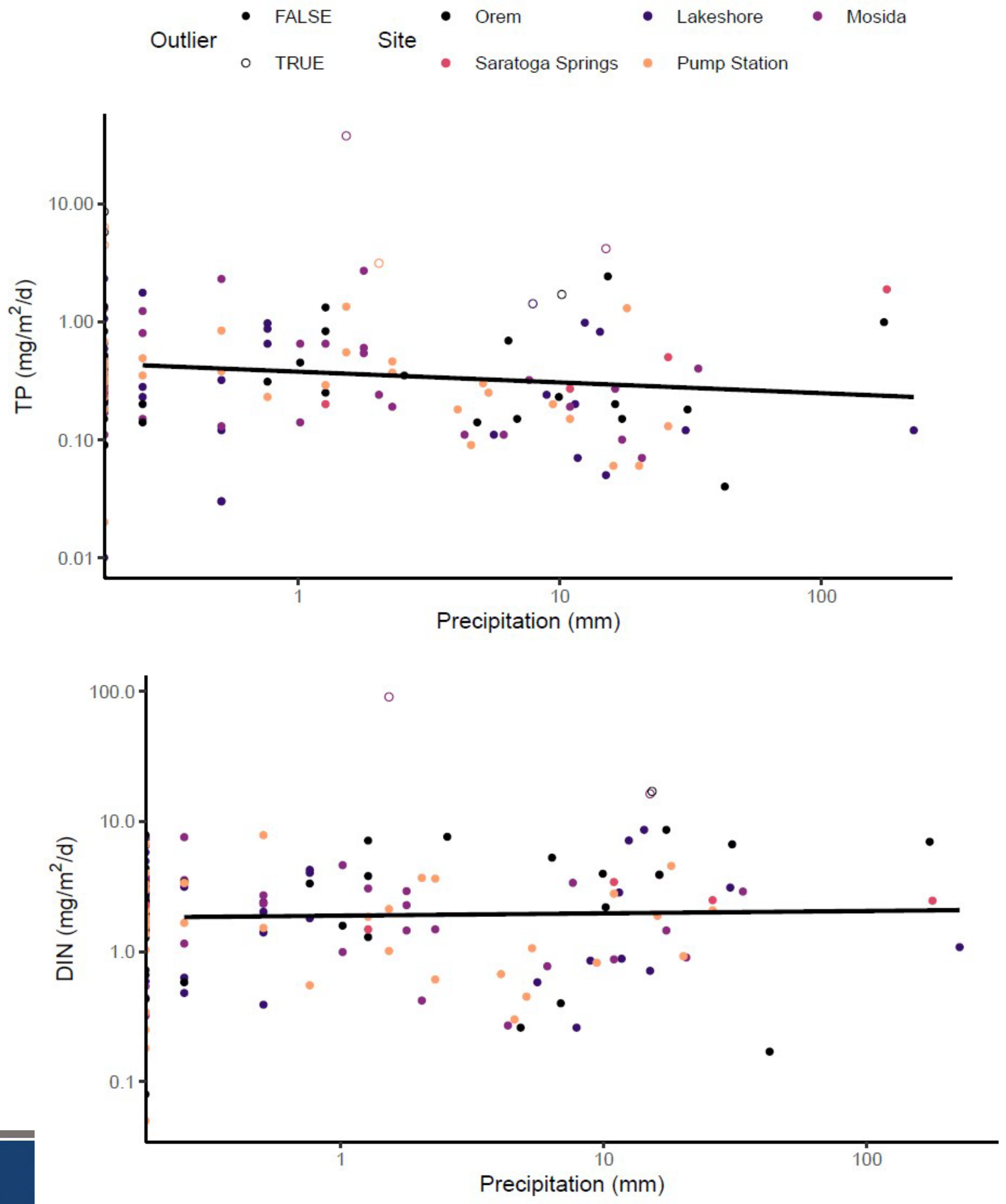


Exploring AD Flux in relation to weather

- **Precipitation**
  - Sum of precipitation throughout sampling period
- **PM2.5 and PM10 (Lindon)**
  - Average concentration throughout sampling period
  - Could try maximum concentration throughout sampling period?
  - Utah County includes North Provo in 2017 and Spanish Fork for PM2.5 2017-2020
- **Wind**
  - 1st exploratory attempt: average wind speed & maximum wind gust throughout sampling period
  - Variables we have access to: average daily wind speed, peak daily wind gust, wind direction
  - Follow-up from Theron on other wind indicators?
  - Challenge: must create a summary condition representing a whole sampling period

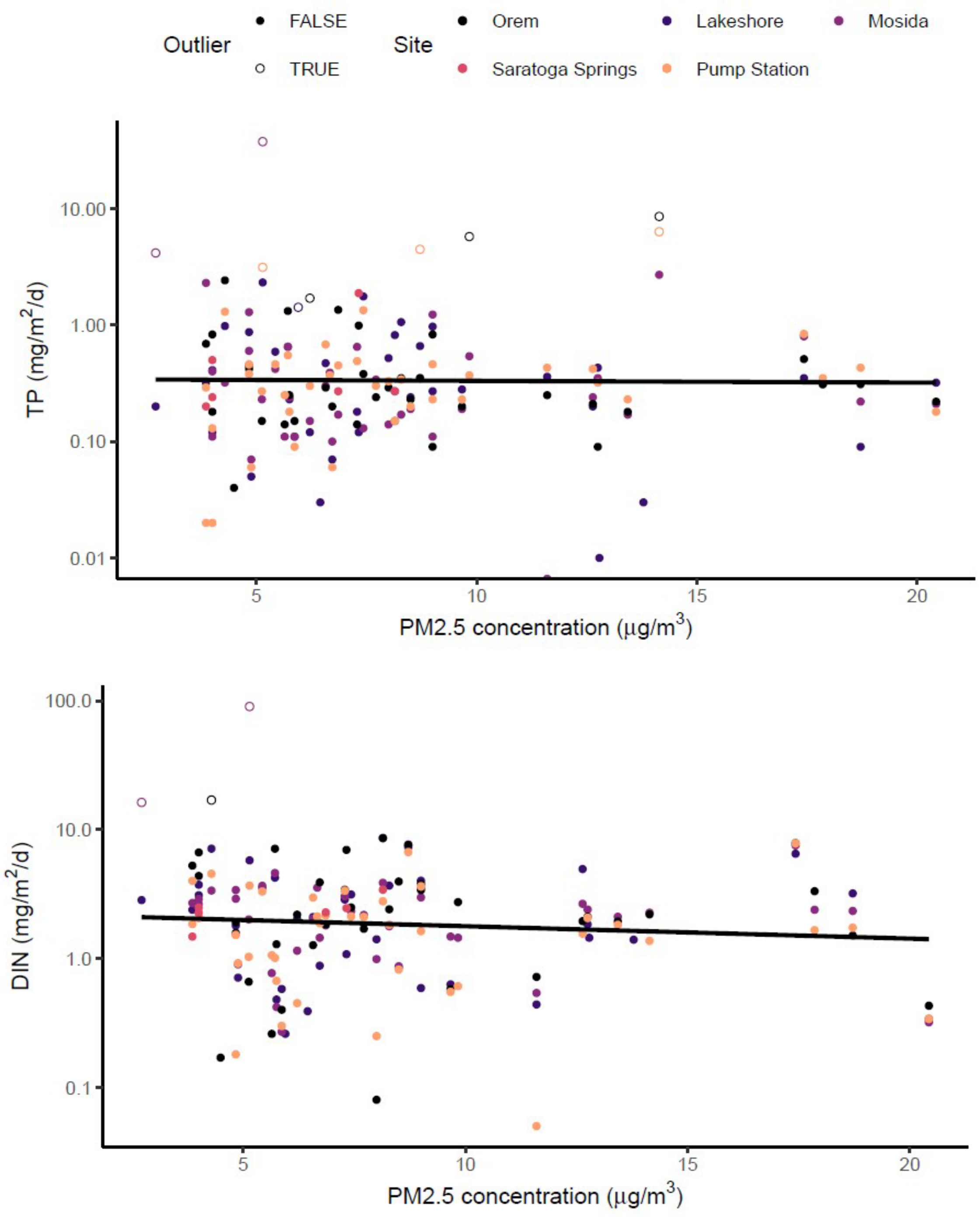
AD Flux vs. Precipitation

- Fairly flat relationship
- Outliers occur across various precipitation amounts



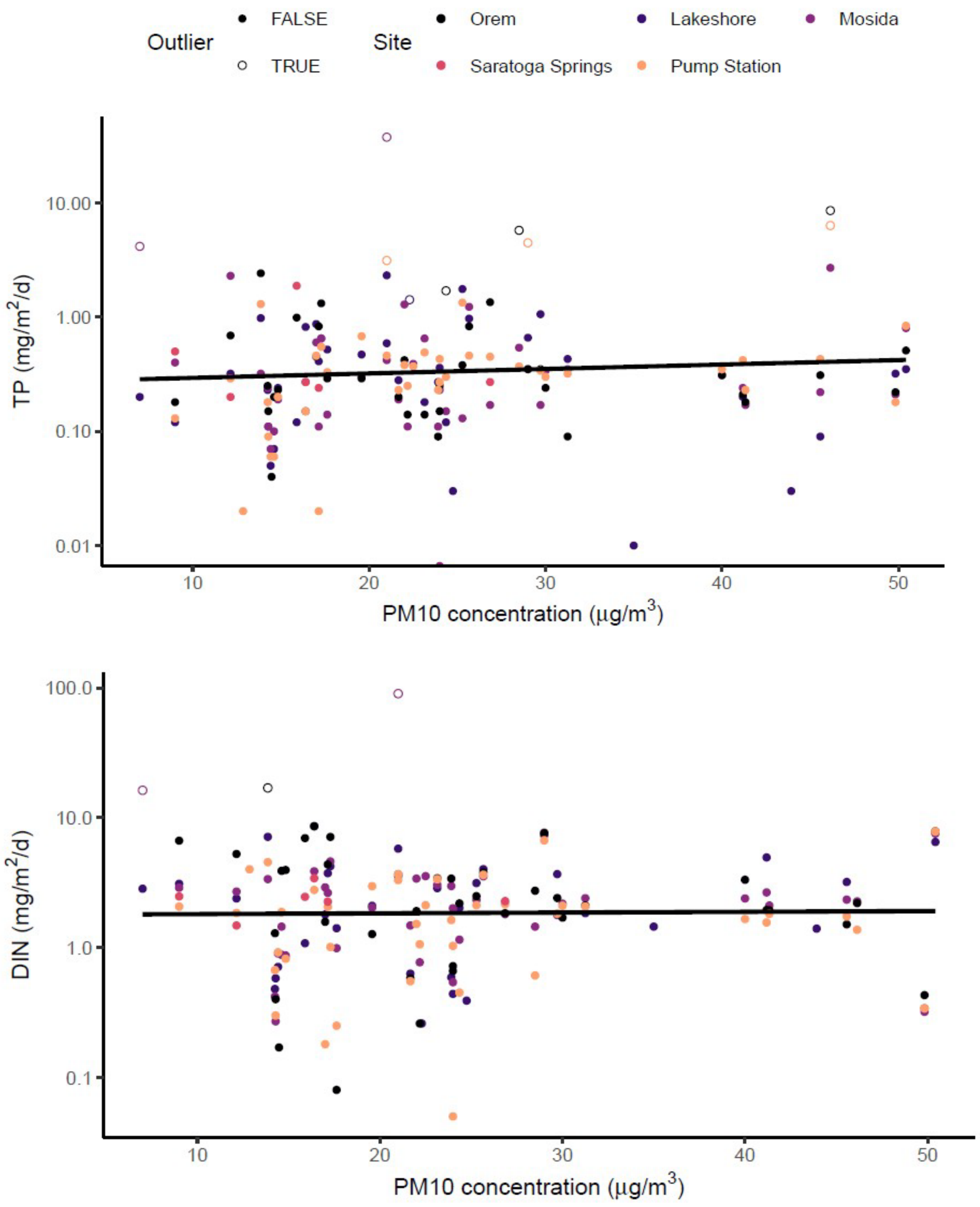
AD Flux vs. PM 2.5

- Fairly flat relationship
- Outliers occur across PM2.5 concentrations
- Explore peak PM2.5 concentration in addition to average across sampling period?



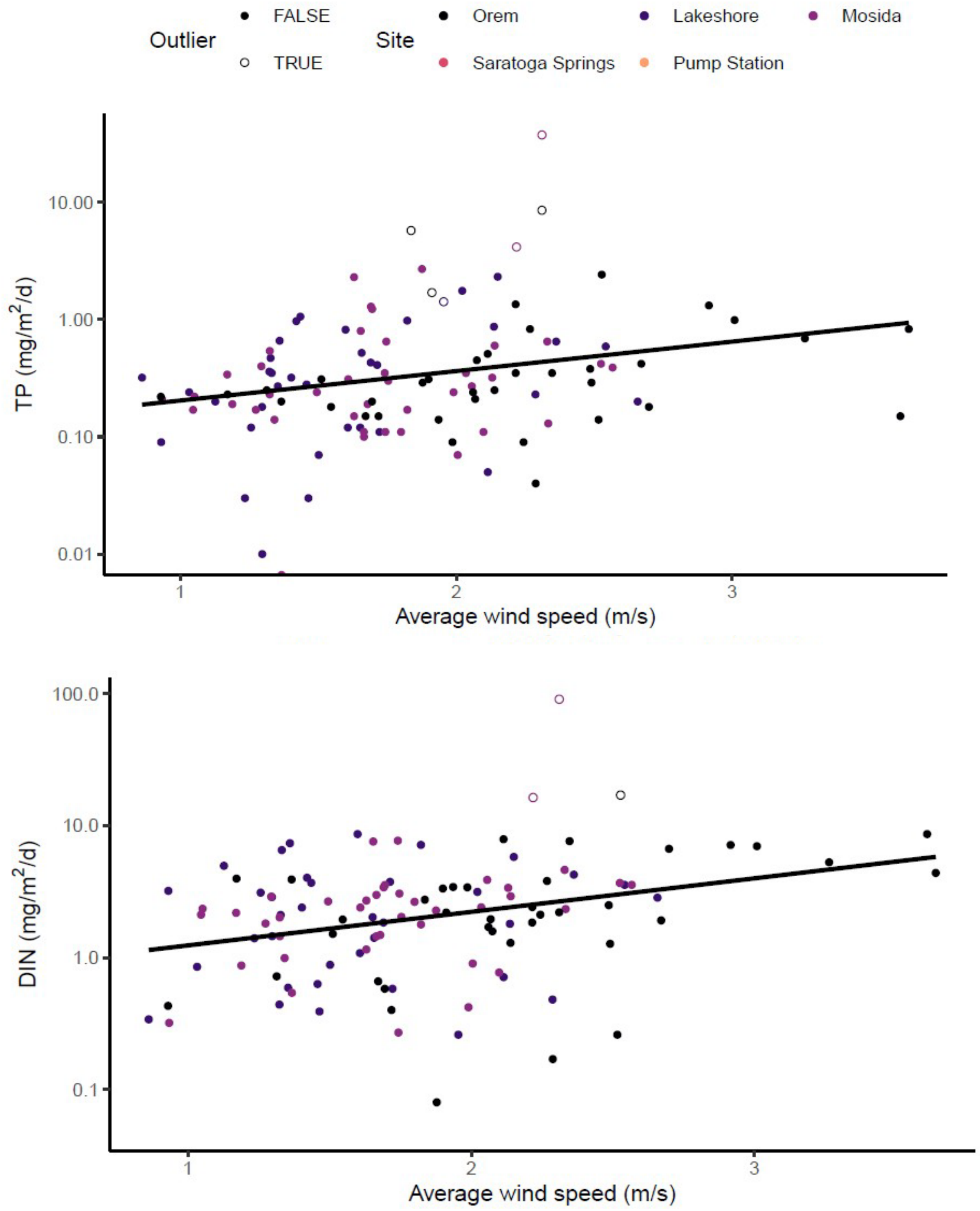
AD Flux vs. PM 10

- Fairly flat relationship
- High TP fluxes generally occur only when PM10 is >20 μg/m³
- High DIN fluxes are rare and occur when PM10 <25 μg/m³
- Explore peak PM2.5 concentration in addition to average across sampling period?



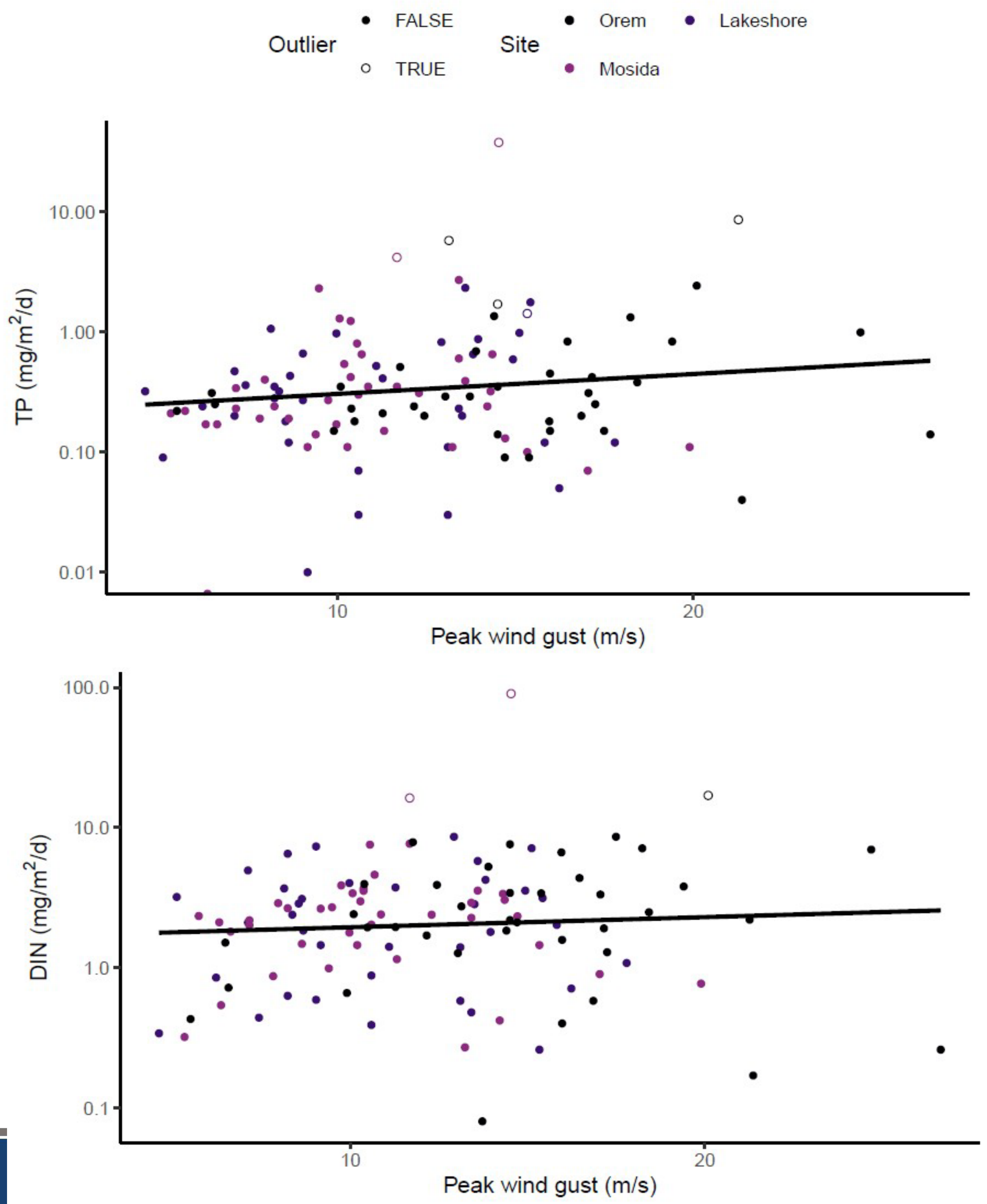
AD Flux vs. average of average daily wind speeds

- Positive relationship
- High TP and DIN fluxes typically only occur when average daily wind >2 m/s
- Initial take: promising indicator



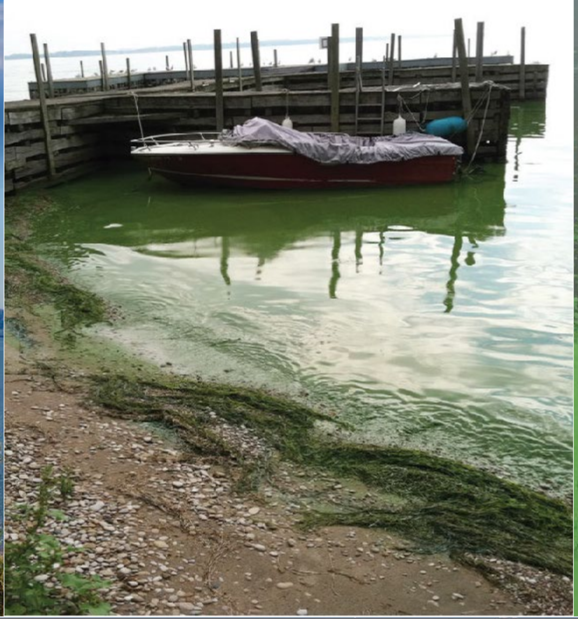
AD Flux vs. max of daily peak wind gust

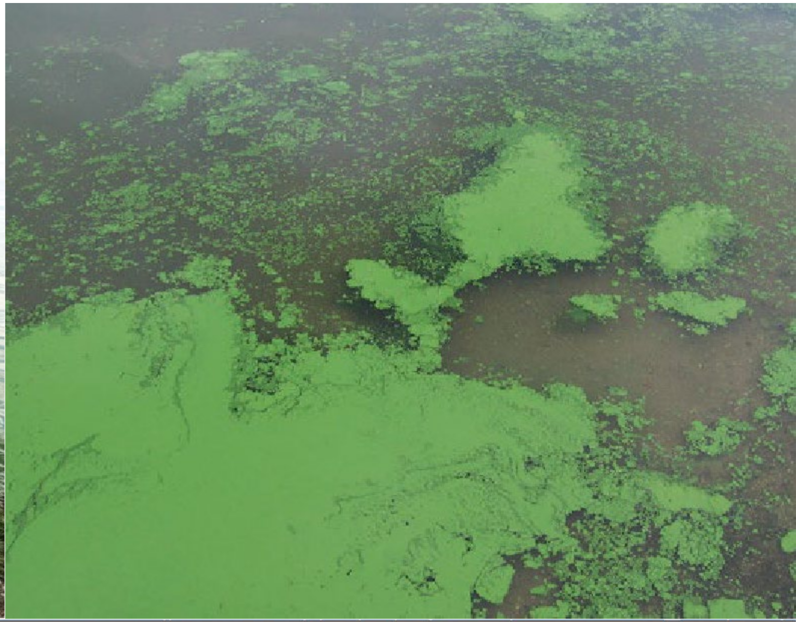
- Fairly flat relationship
- High TP and DIN fluxes typically only occur when peak wind gust >10 m/s
- Initial take: perhaps not a promising indicator (represents what may be a very short period of time)



Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | November 10, 2022





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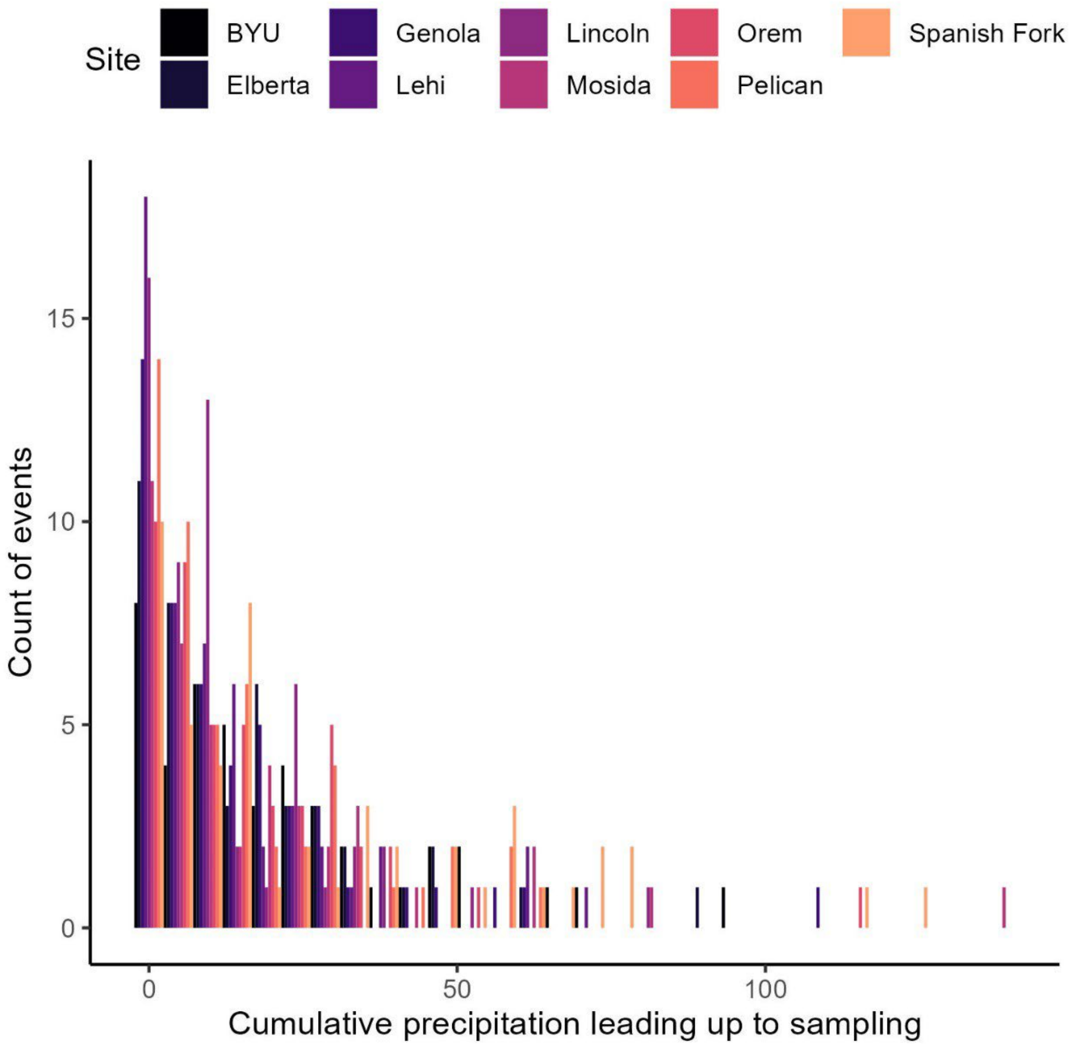
Action Items From Last Meeting

- ✓ **Wood Miller Dataset**
  - ✓ Incidence of gap between precipitation event and sampling date
  - ✓ Calculate evaporation loss
  - ✓ Share processed dataset
- ✓ **Further explore potential relationships between weather and flux**
  - ✓ Seasonality
  - ✓ Updates to PM2.5 and PM10 datasets (Purple Air)
  - ✓ Refinements to wind parameters
- ✓ **Cumulative flux including Bird Island**

Wood Miller Precipitation

- **Usually, sampling immediately followed large precipitation events. But,**
  - sometimes certain samplers got rain and not others
  - several rain events may have occurred within a sampling period
- **48/434 sampling events had zero rain except on sampling day**
- **There was often rain in samplers for >1 day before being sampled → explore potential for evaporation**

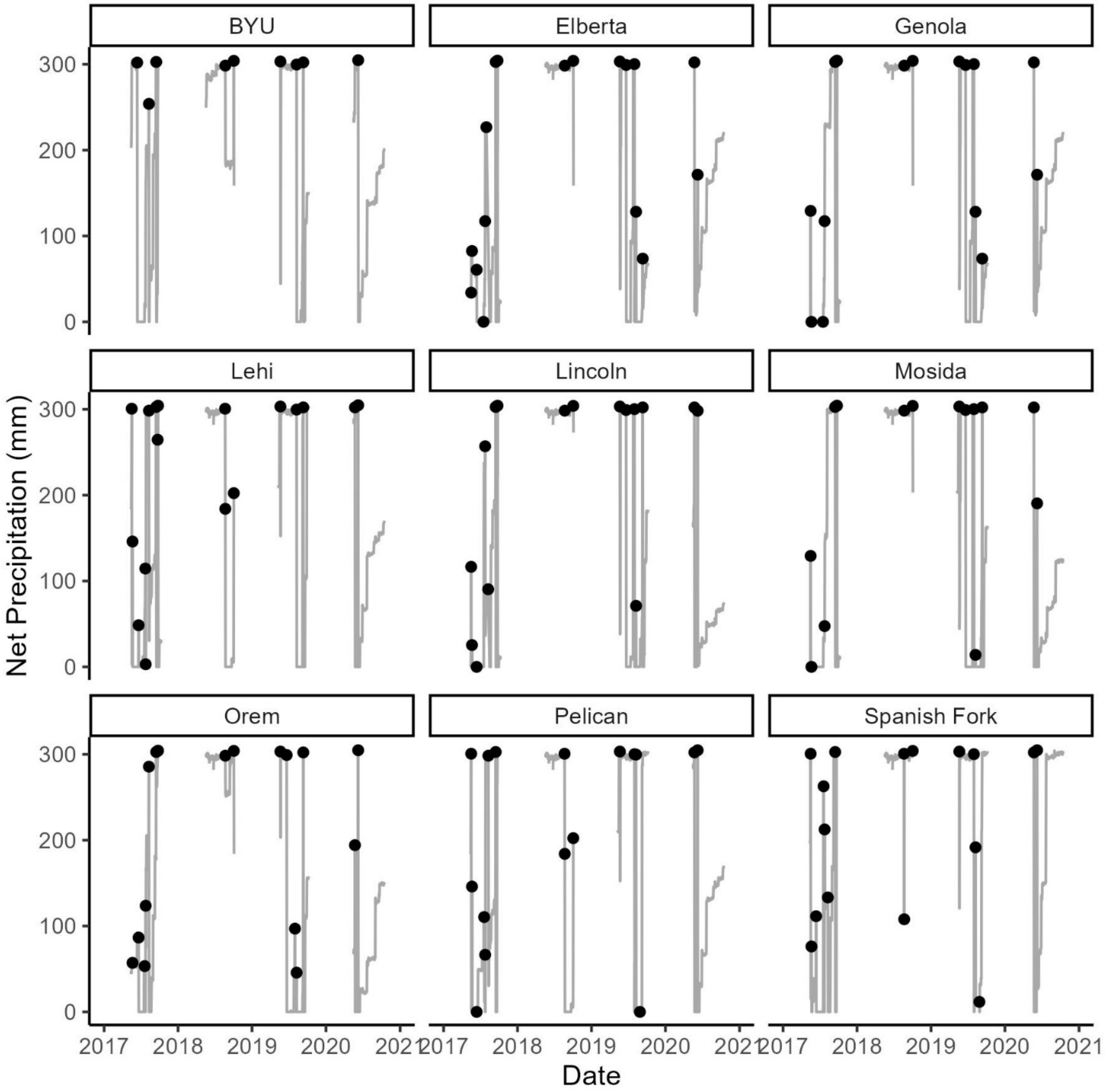


Wood Miller Evaporation Analysis

- **Calculated depth of precipitation in each sampler daily**
  - Used the conversion from funnel area (20 in diameter) to sampler area (4 in diameter)
  - Maxed out the depth if the sampler overflowed
  - Precipitation depth was reset to zero with each sampling event
- **Then, used BYU evaporation data to subtract depth, if depth >0**
  - BYU was only gage from originally identified weather sites with evaporation data
  - Evaporation data not available yearround
  - Evaporation data available from some fruitgrower sites
  - Evaporation is much more spatially consistent than precipitation

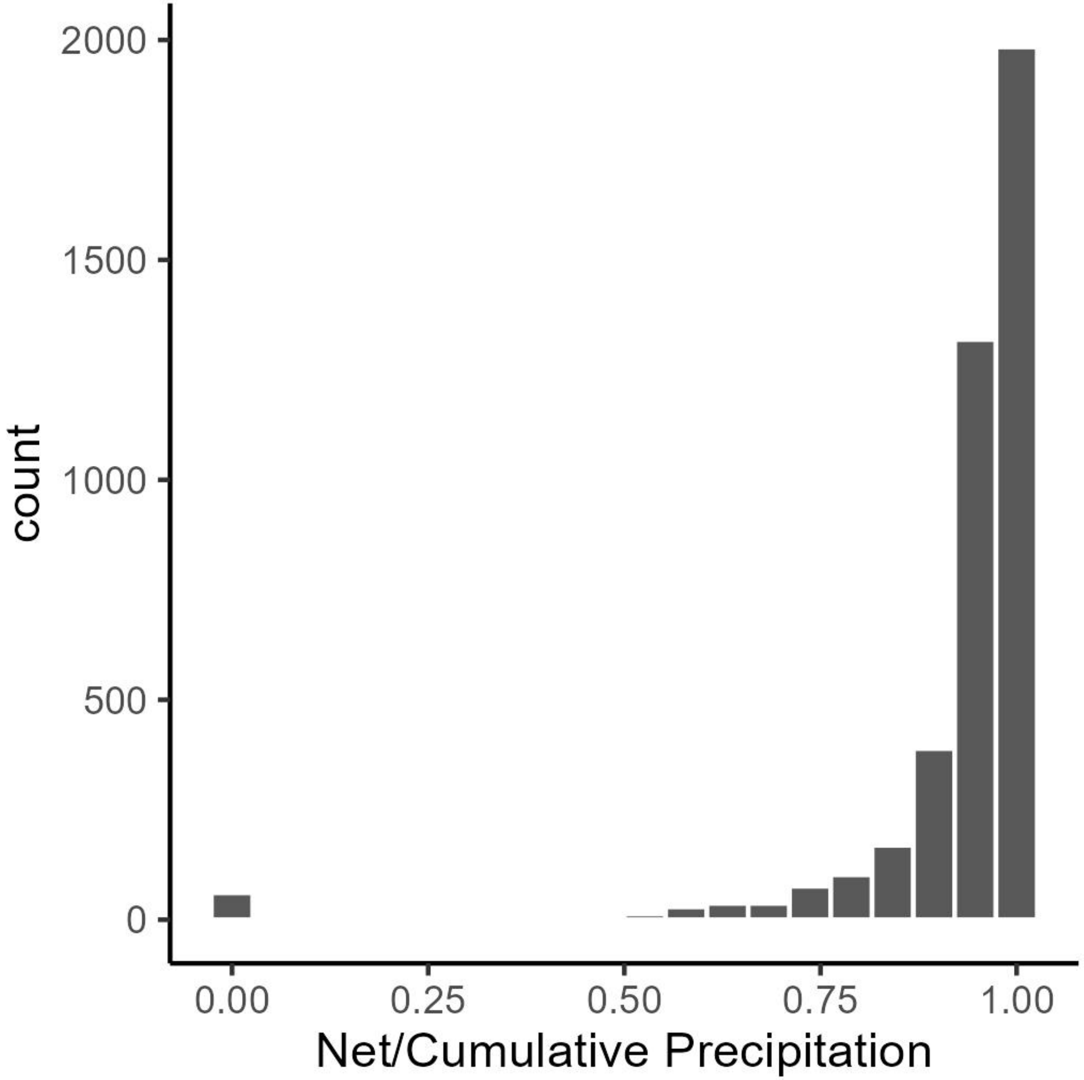
Wood Miller Evaporation Analysis

- **Evaporation rates:**
  - Mean = 6.3 mm/day
  - Median: 6.6 mm/day
  - 25th-75th percentiles: 4.57-7.87 mm/day
- **Evaporation would have proportionally less impact when sampler is full than when it is empty**
- **Note: represents May-October**



Wood Miller
Evaporation Analysis

- **Evaporation sometimes drew down the depth of water in the sampler**
- **Sampling events usually occurred close to rain events, so events with substantial evaporation impact were relatively rare**
- **Even some occurrence of net/cumulative <1 would have an impact on flux**
  - E.g., if precipitation volume was underestimated at 75% of its actual amount → flux would be overestimated by 33% due to concentration



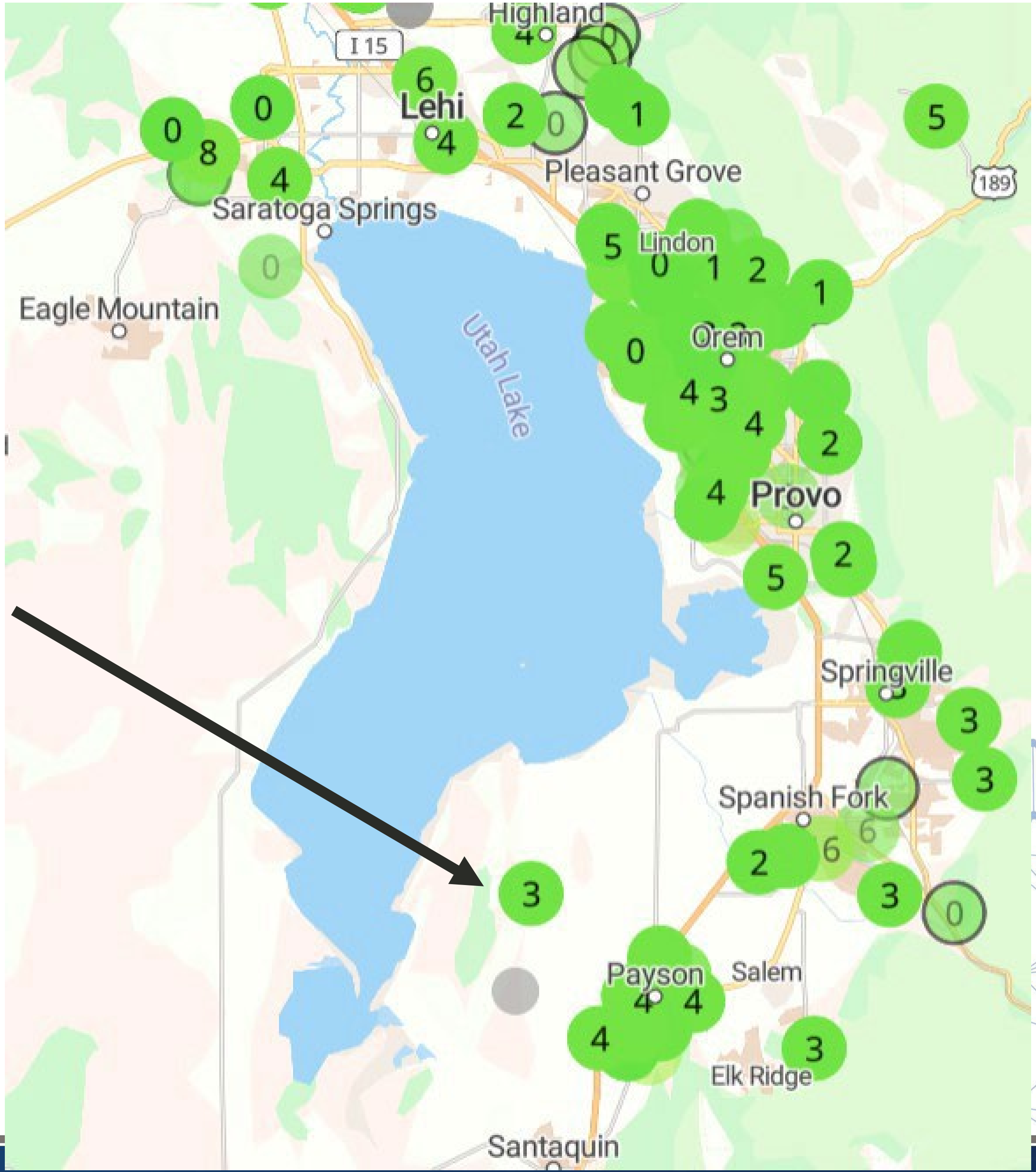
Next Steps for Wood Miller Analysis

- **Where would the SP like to go with these analyses? Options:**
  1. Consider evaporation as a source of uncertainty along with dry deposition blowing off, overflow, lack of sampler cleaning between samples, potential impact of snow, etc.
  2. Re-calculate fluxes based on quantification of evaporation impact

- **To help inform this point: How will Wood Miller's dataset be used in comparison to the Williams dataset?** Potential range of uses from "exclude W. Miller from consideration due to uncertainties" to "compare fluxes & loads directly as equal"

Purple Air

- Concern last time: EPA air quality station in Lindon captures urban conditions
- Explored data available from Purple Air to find more rural station
- West Mountain Ranch chosen as example
- Obtained PM2.5 and PM10 daily data

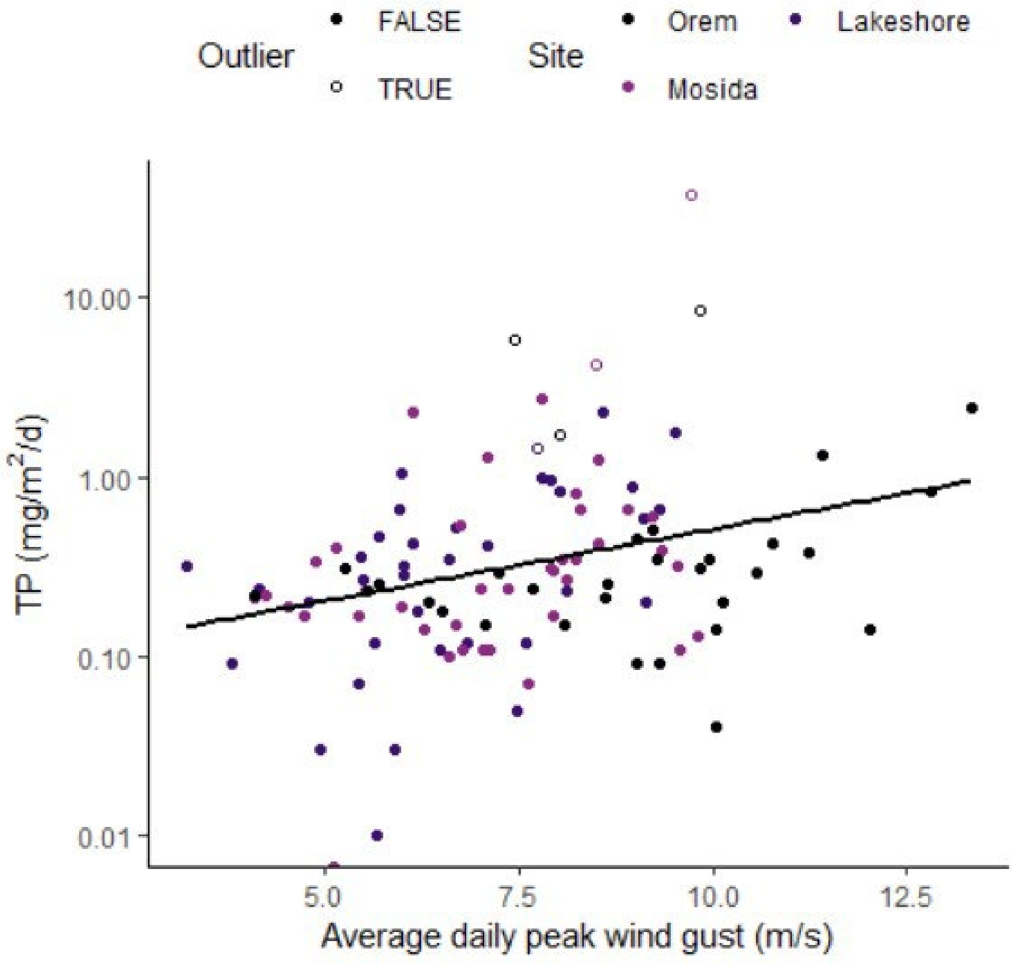


Exploring AD Flux in relation to weather

- **Variables**
  - Avg daily precipitation throughout sampling period
  - Average & max PM2.5 throughout sampling period
  - Average & max PM10 throughout sampling period
  - Average of daily average wind speed throughout sampling period
  - Max of daily average wind speed throughout sampling period
  - Average peak daily wind gust throughout sampling period
  - Max of peak daily wind gust throughout sampling period
  - Month (as factor)
- **Fed these into a stepwise selection linear model (AIC) → finds optimum set of variables that maximize explanatory power and minimize number of predictors**

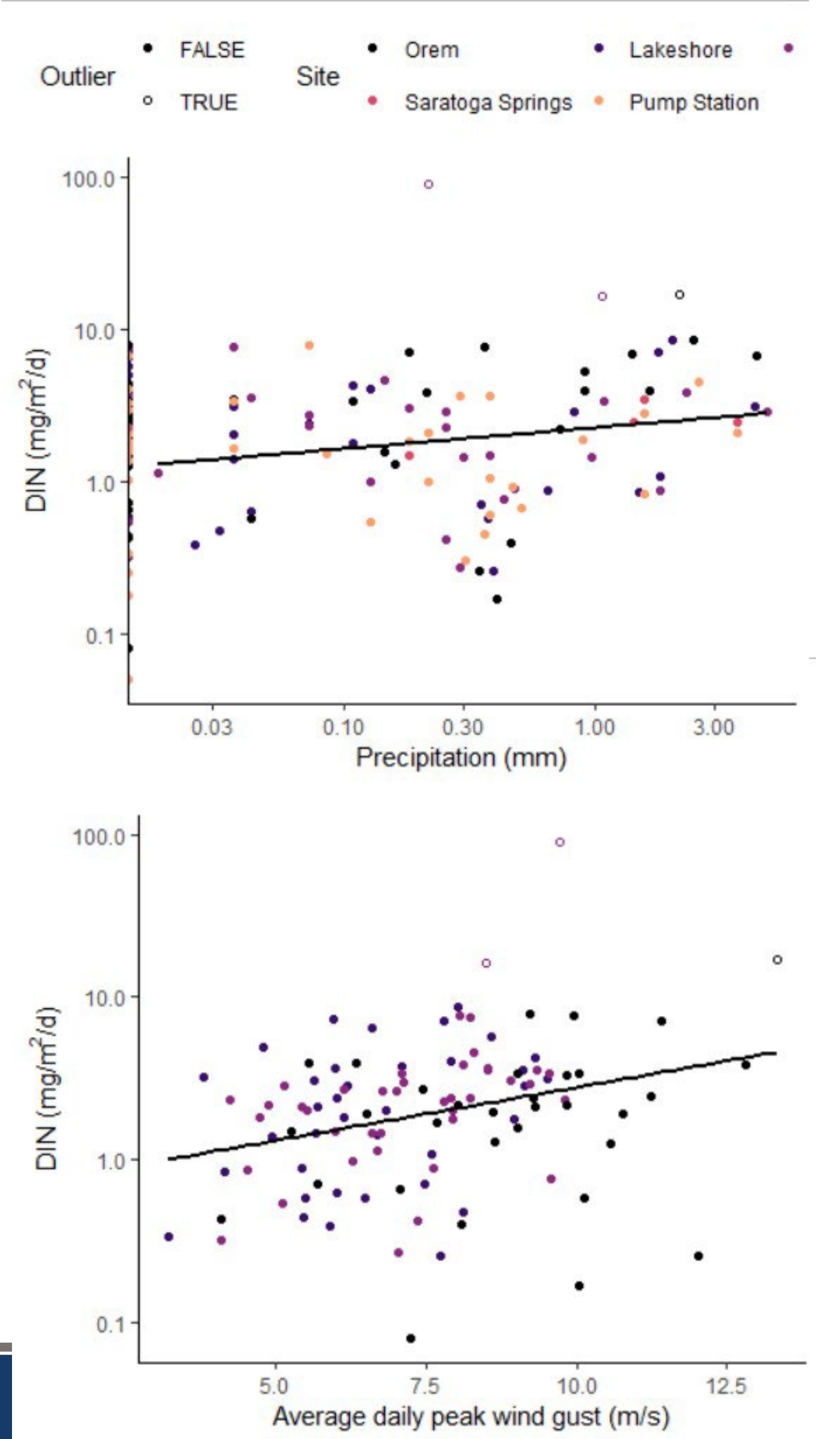
How does weather relate to TP flux?

- **Stepwise model selection**
  - Average peak daily wind gust
  - Max of peak daily wind gust
  - Note: Month was not a significant predictor
- **Model fit**
  - $R^2 = 0.12$, df = 106
  - Average wind gust coefficient = 0.176
  - Max wind gust coefficient = -0.045
- **Hypothesis: TP flux may be driven by processes not fully captured by daily summary statistics over ≥1 week of sampling**



How does weather relate to DIN flux?

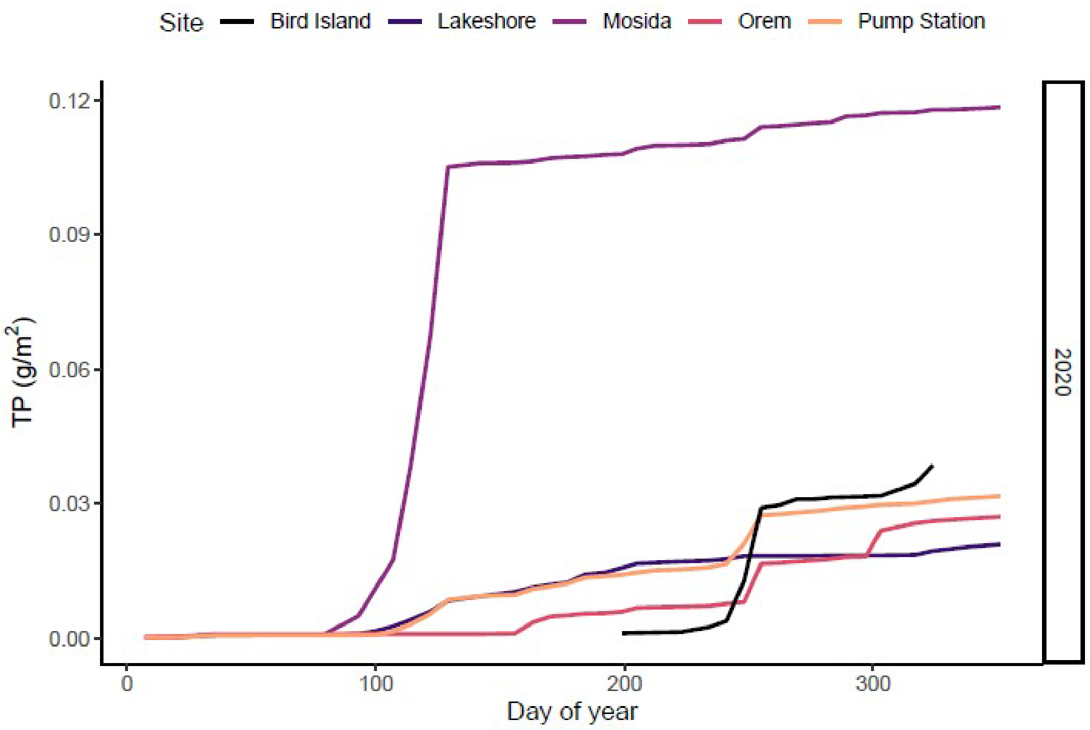
- **Stepwise model selection**
  - Avg daily precipitation
  - Mean PM2.5 & PM10
  - Average peak daily wind gust
  - Max of peak daily wind gust
- **Model fit**
  - $R^2 = 0.40$, df = 93
  - Average daily precipitation = 0.296 ($p < 0.001$)
  - Average PM10 = -0.604 ($p < 0.0001$)
  - Average PM2.5 = 0.657 ($p < 0.0001$)
  - Average wind gust coefficient = 0.188 ($p < 0.0001$)
  - Max wind gust coefficient = -0.088 ($p < 0.0001$)

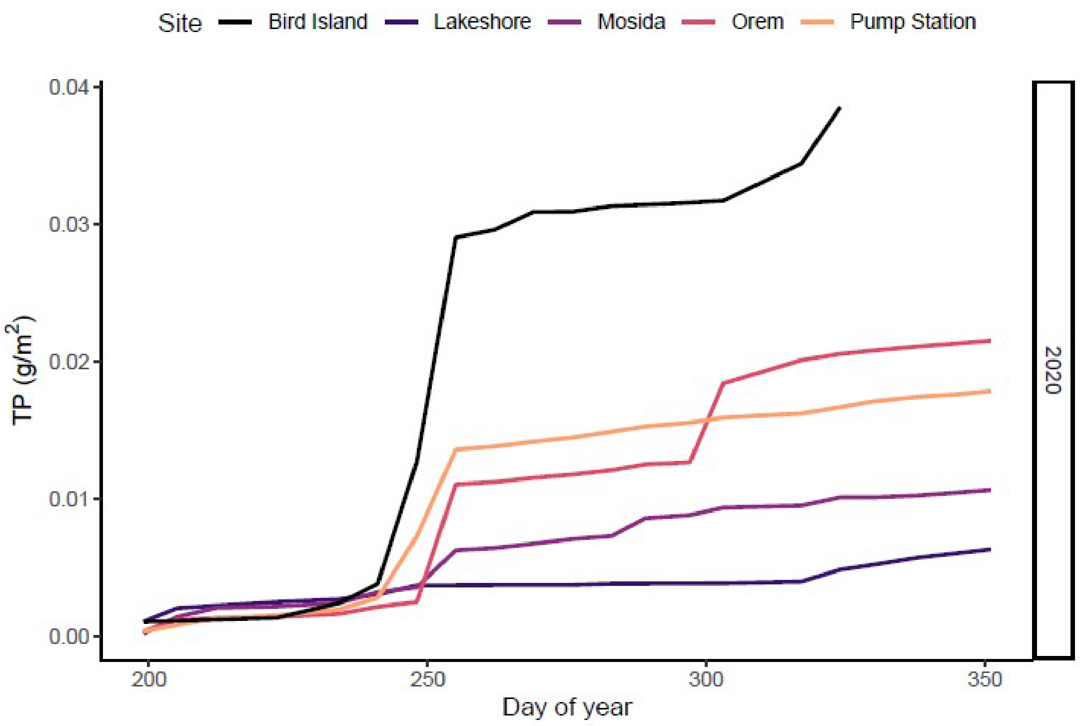


Next Steps for Event Analysis

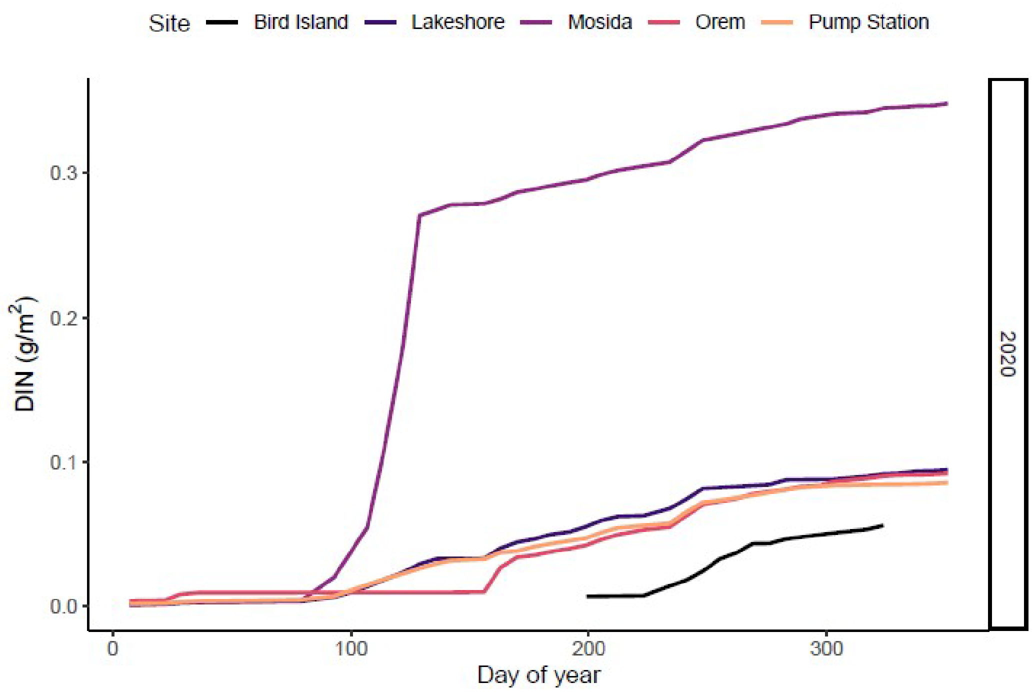
- **We have established that weather can partially explain variability in fluxes**
- **Still have some uncertainty that remains**
  - Temporal limitations of dataset
  - Potential local impacts
- **How would the SP like to proceed? Some ideas:**
  - Look into specific events to see if there is a pattern in weather, consistency between datasets
  - Interpolate missing sampling events that are between high flux events using weather relationship
  - Use weather information as context/discussion but proceed with calculating flux

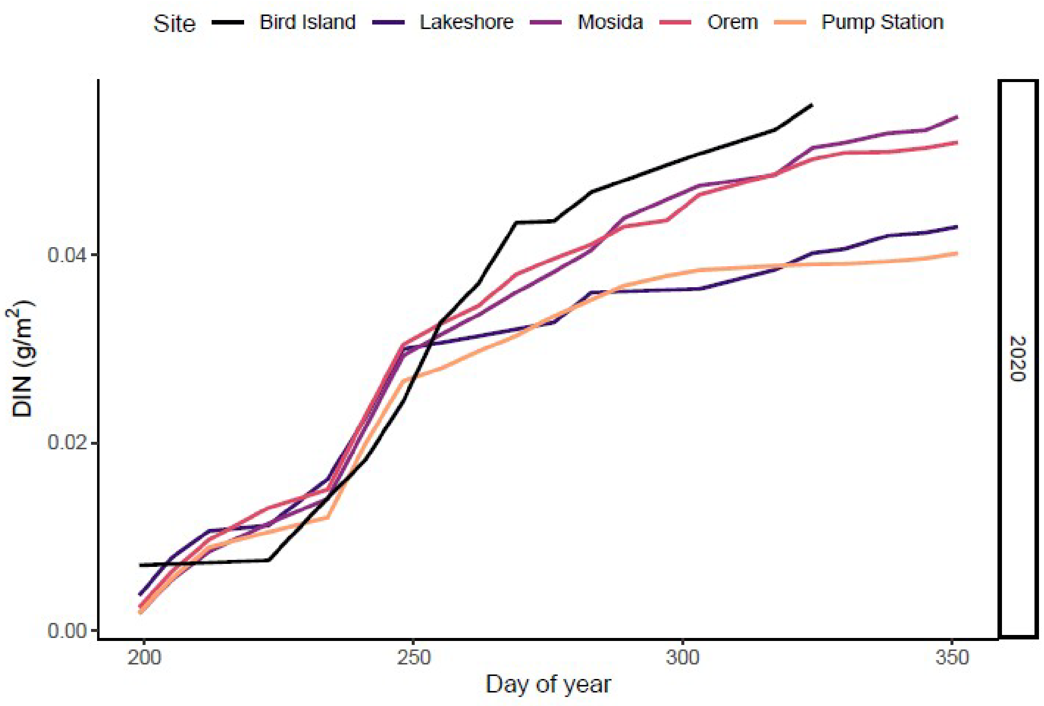
TP Cumulative Flux



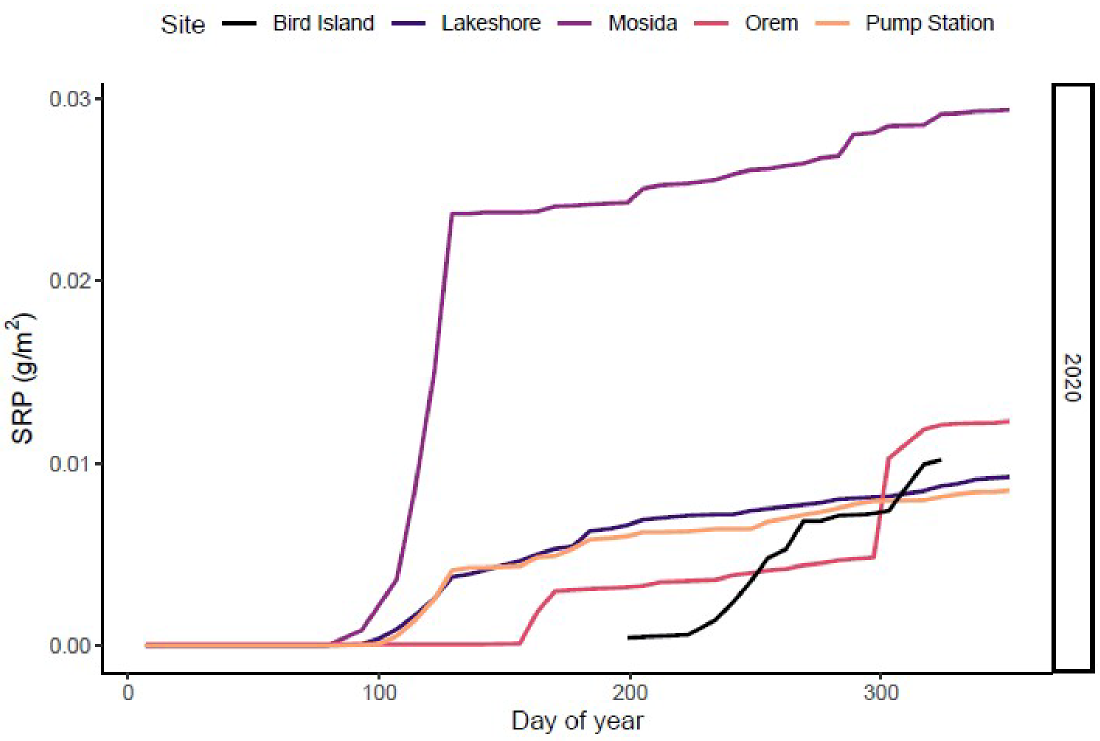


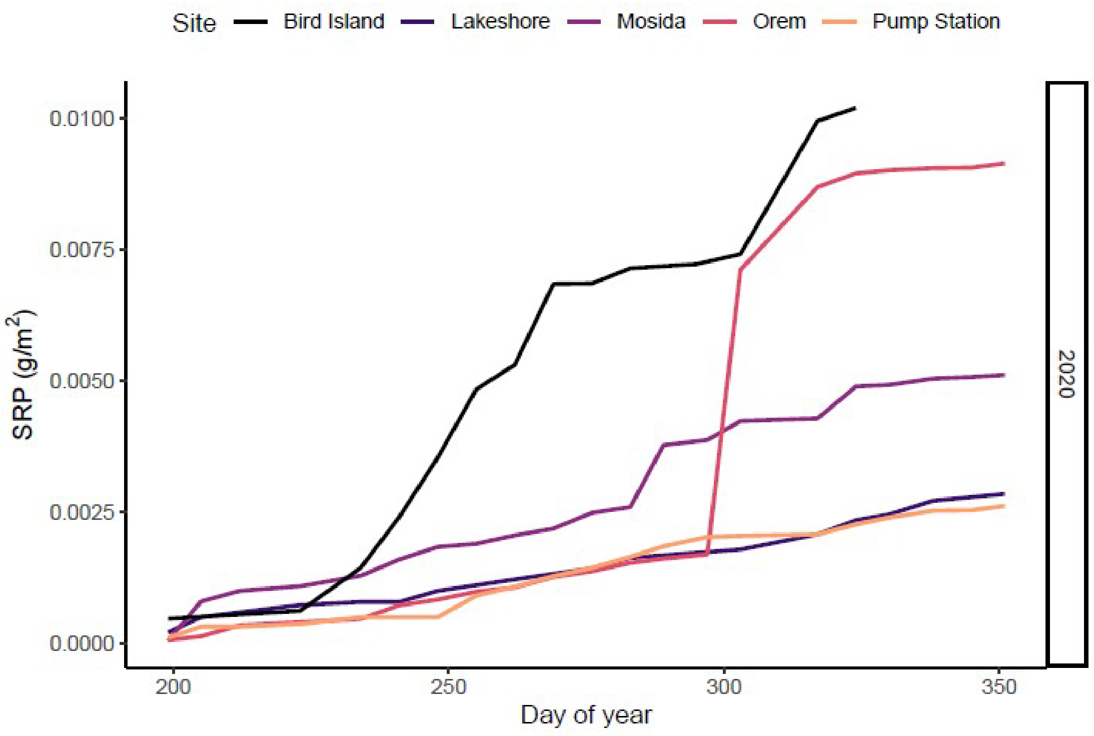
DIN Cumulative Flux





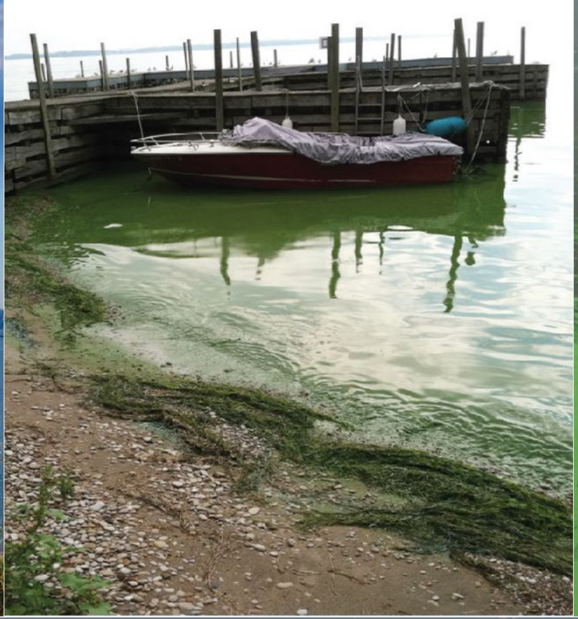
SRP Cumulative Flux

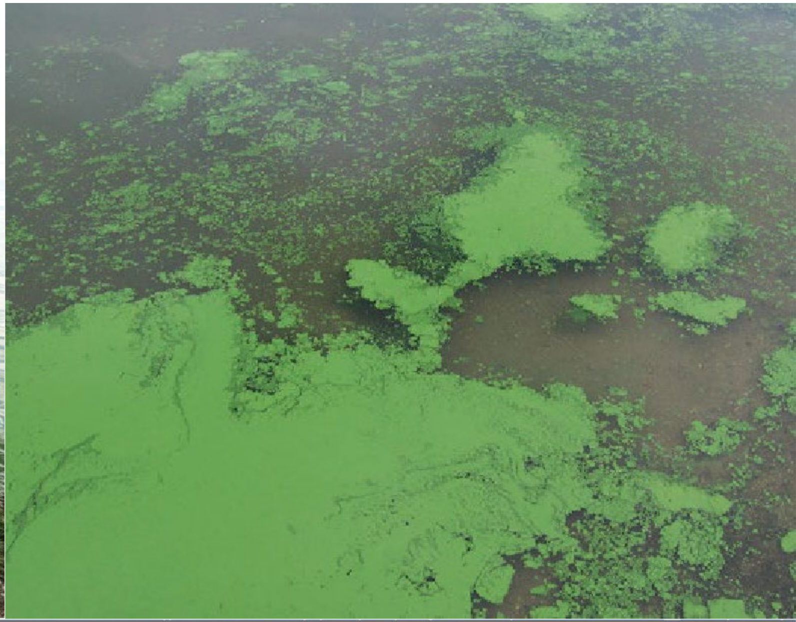




Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | November 17, 2022





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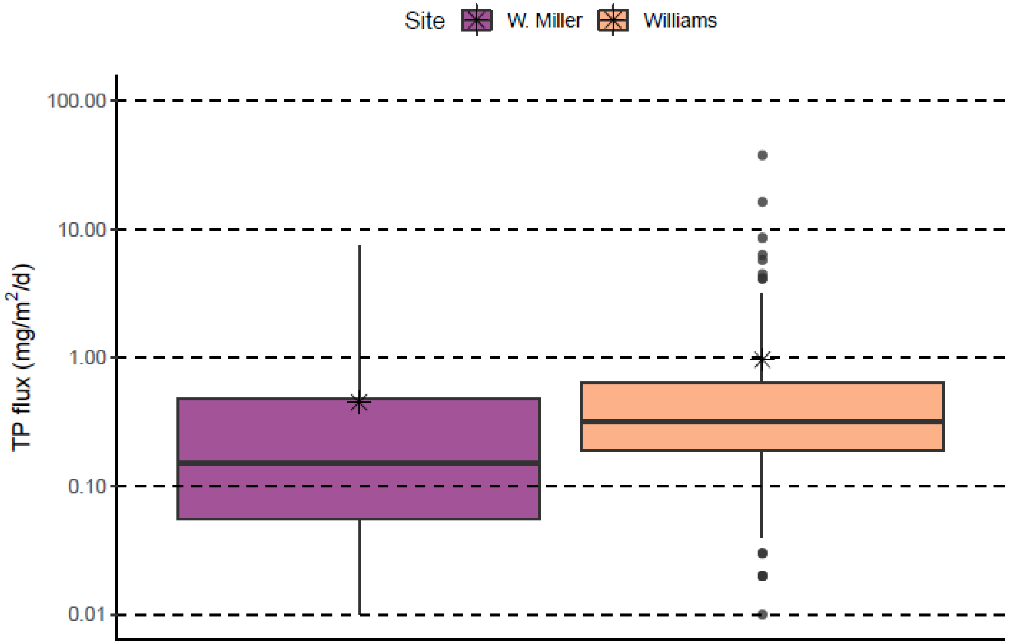
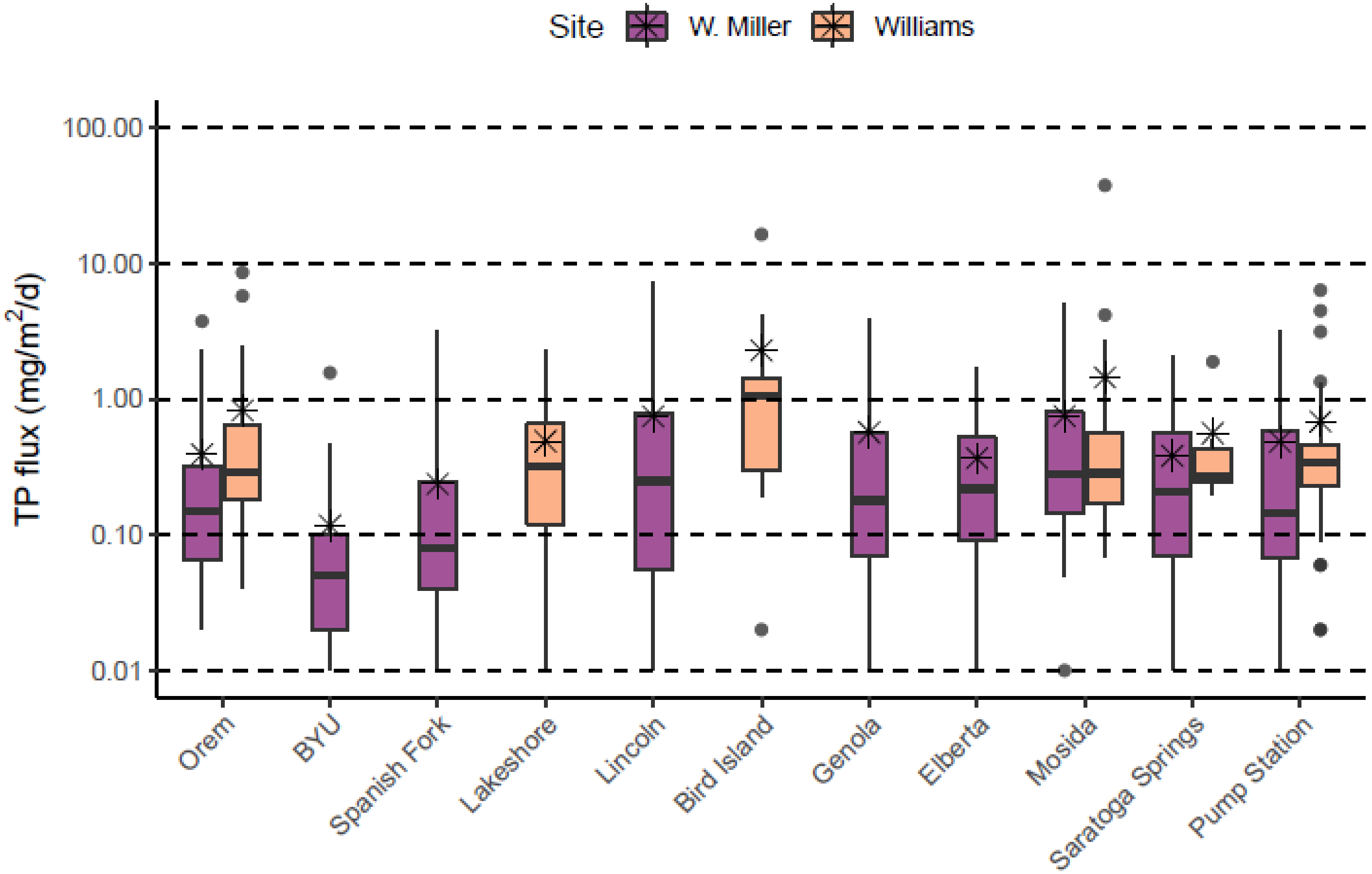
Action Items From Last Meeting

- ✓ Update boxplots
- ✓ Explore outliers

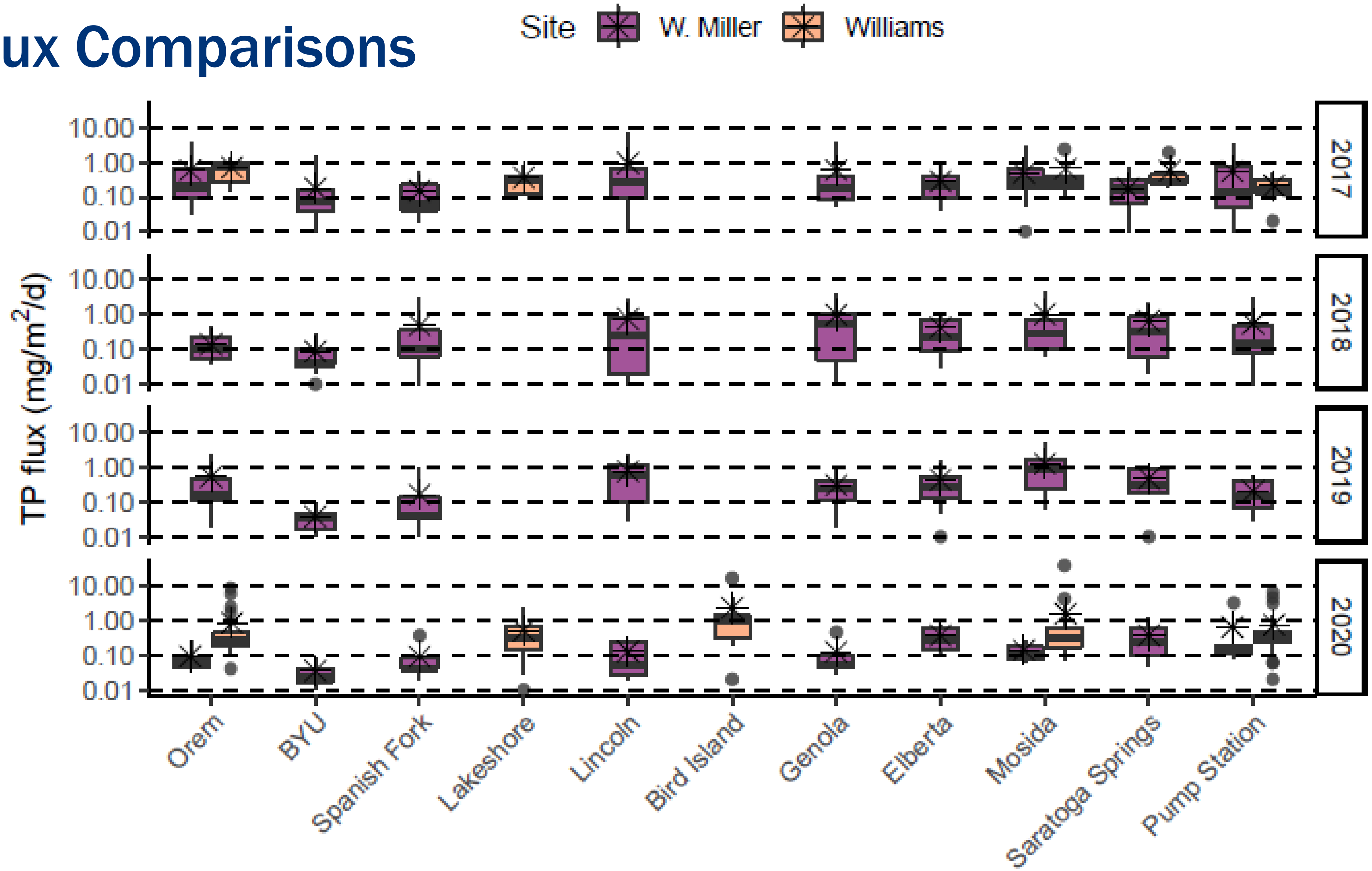
TP Flux Comparisons

- Box line: median
- Star: mean



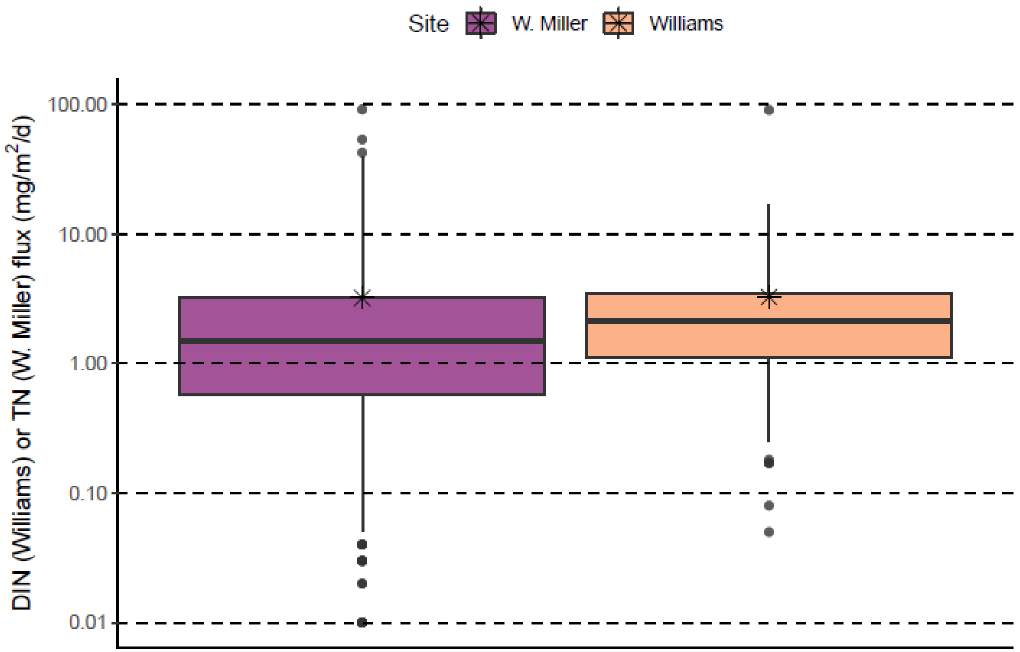


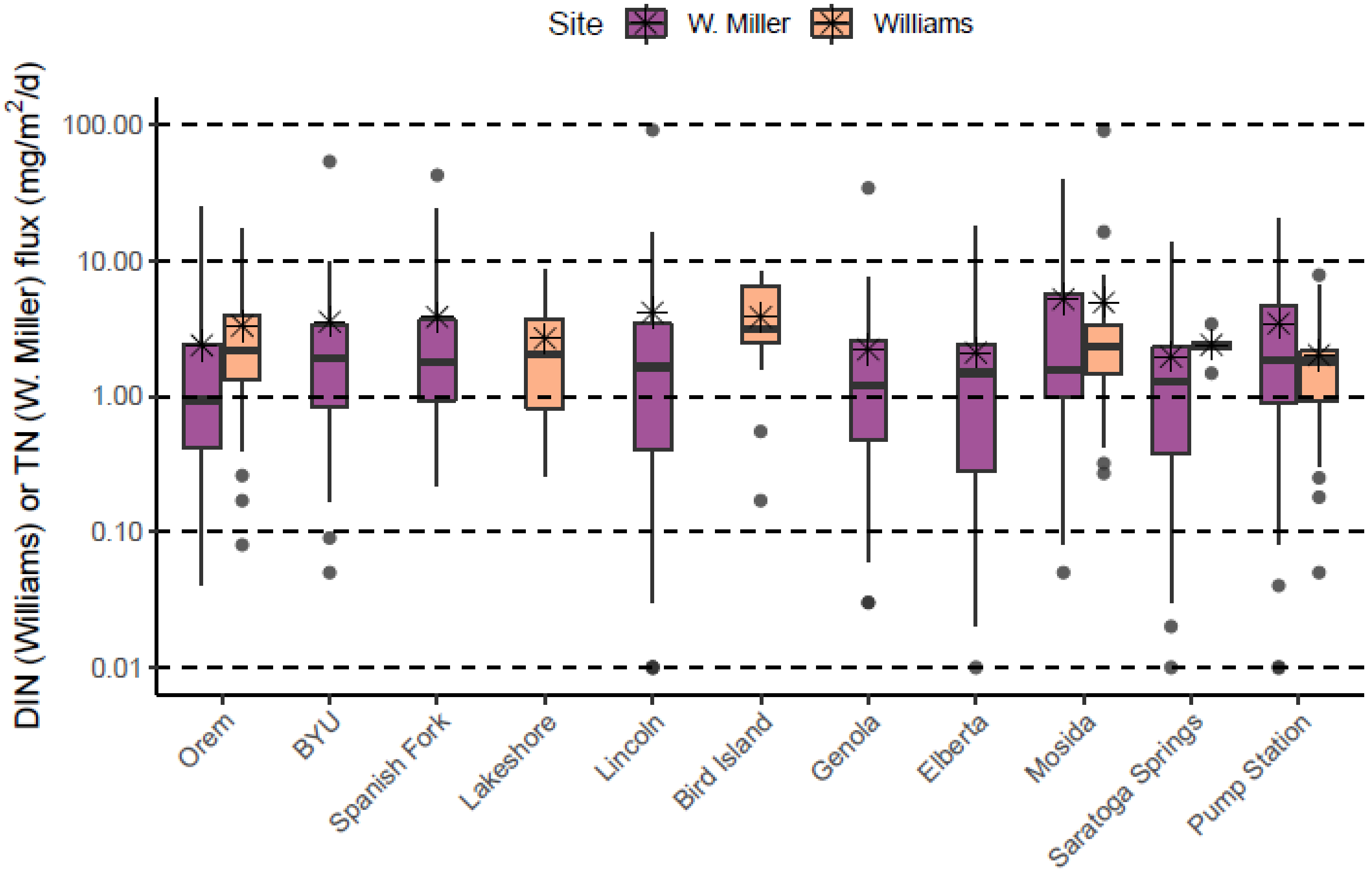
TP Flux Comparisons



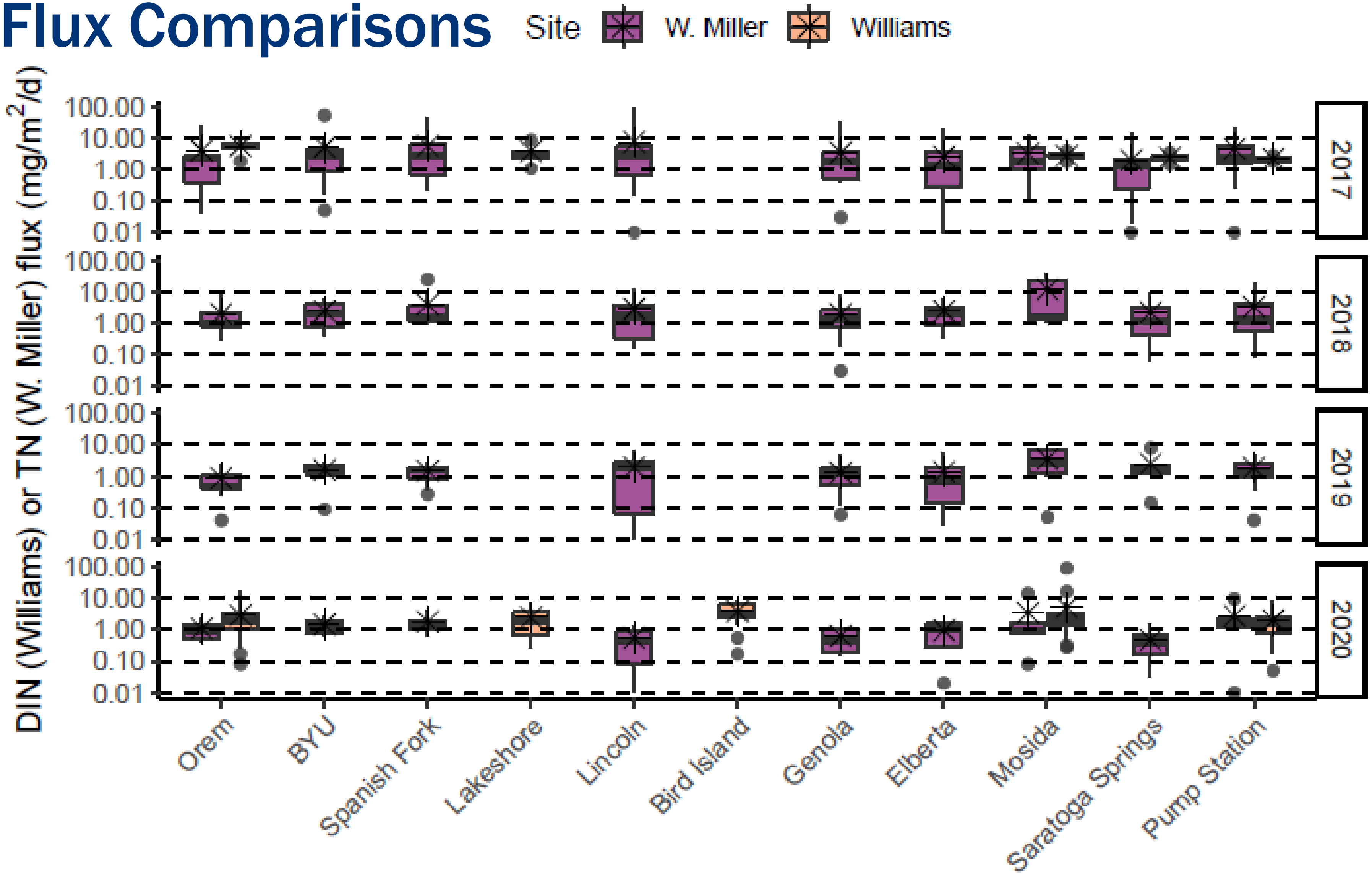
DIN and TN Flux Comparisons

- Box line: median
- Star: mean



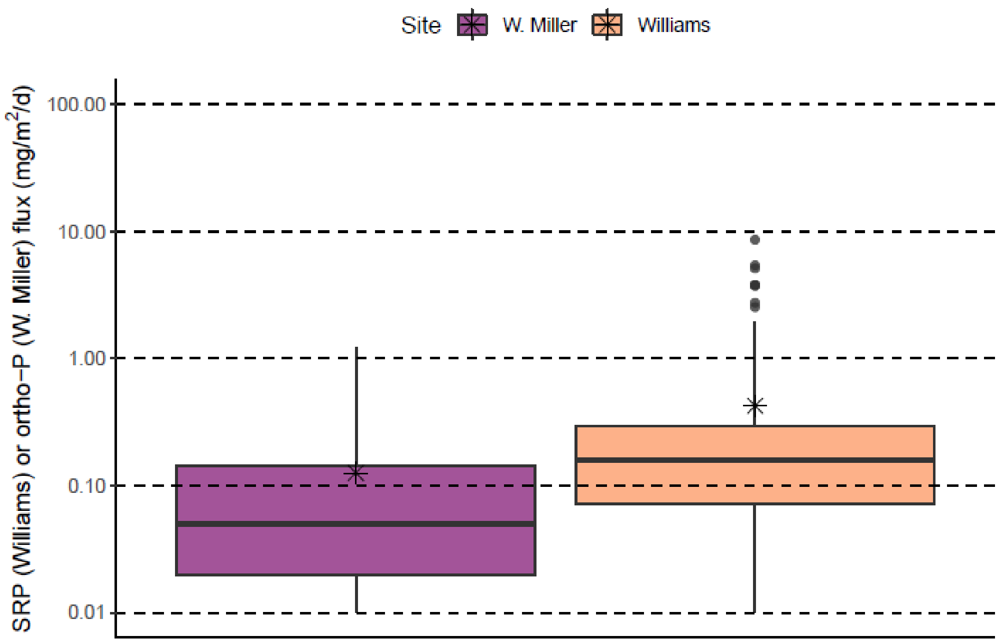


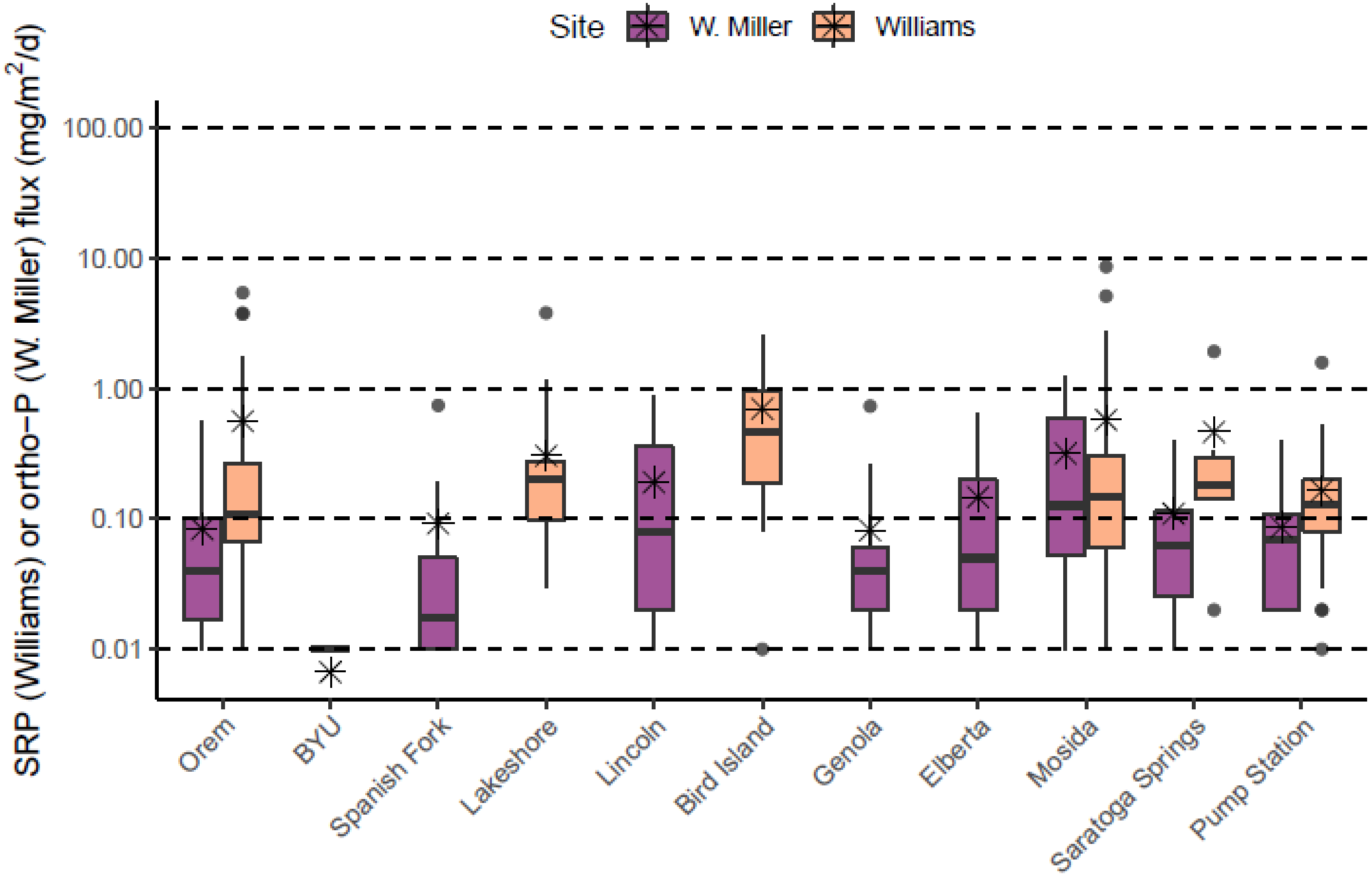
DIN and TN Flux Comparisons



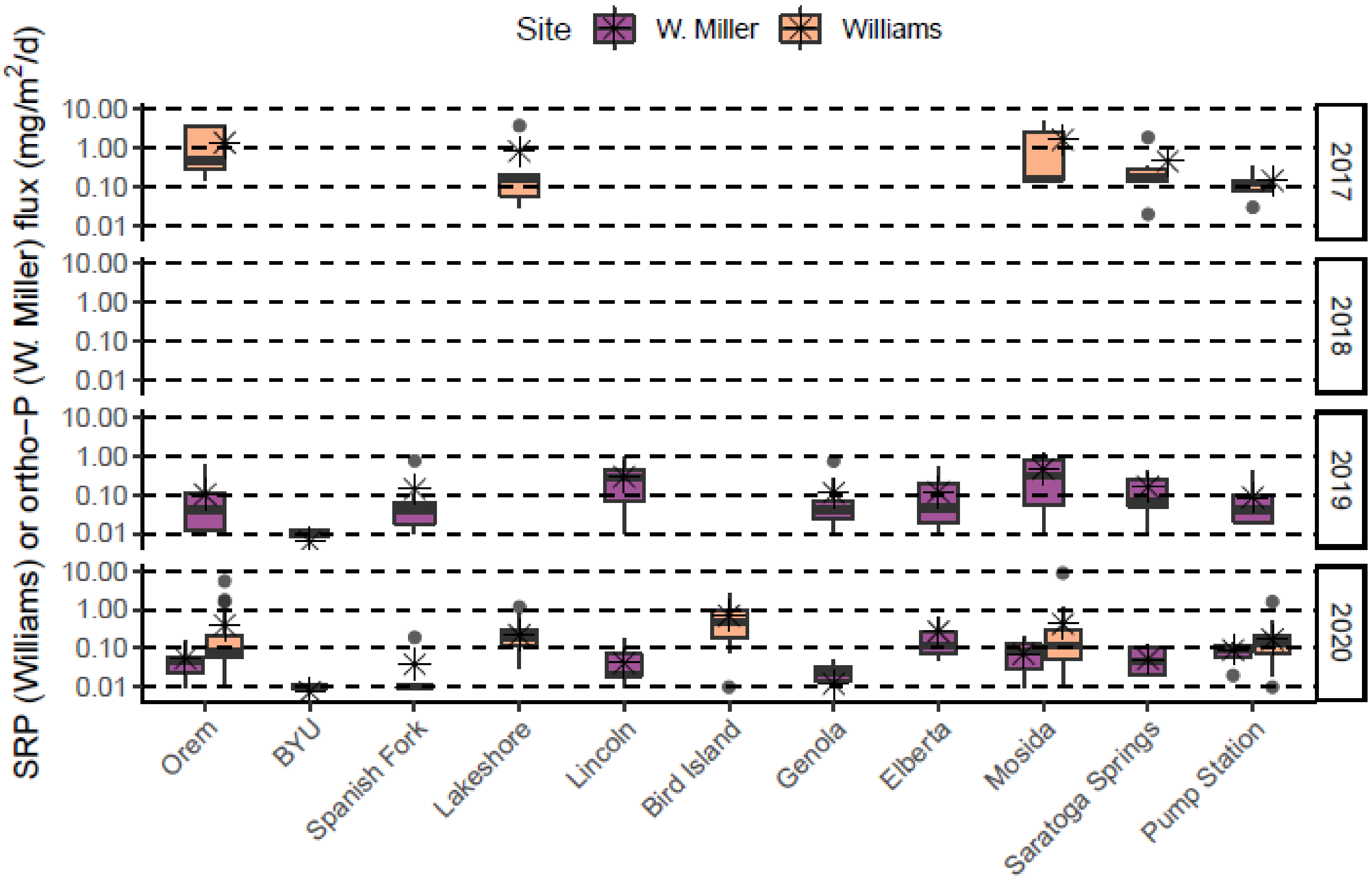
SRP and ortho-P Flux Comparisons

- Box line: median
- Star: mean





SRP and ortho-P Flux Comparisons

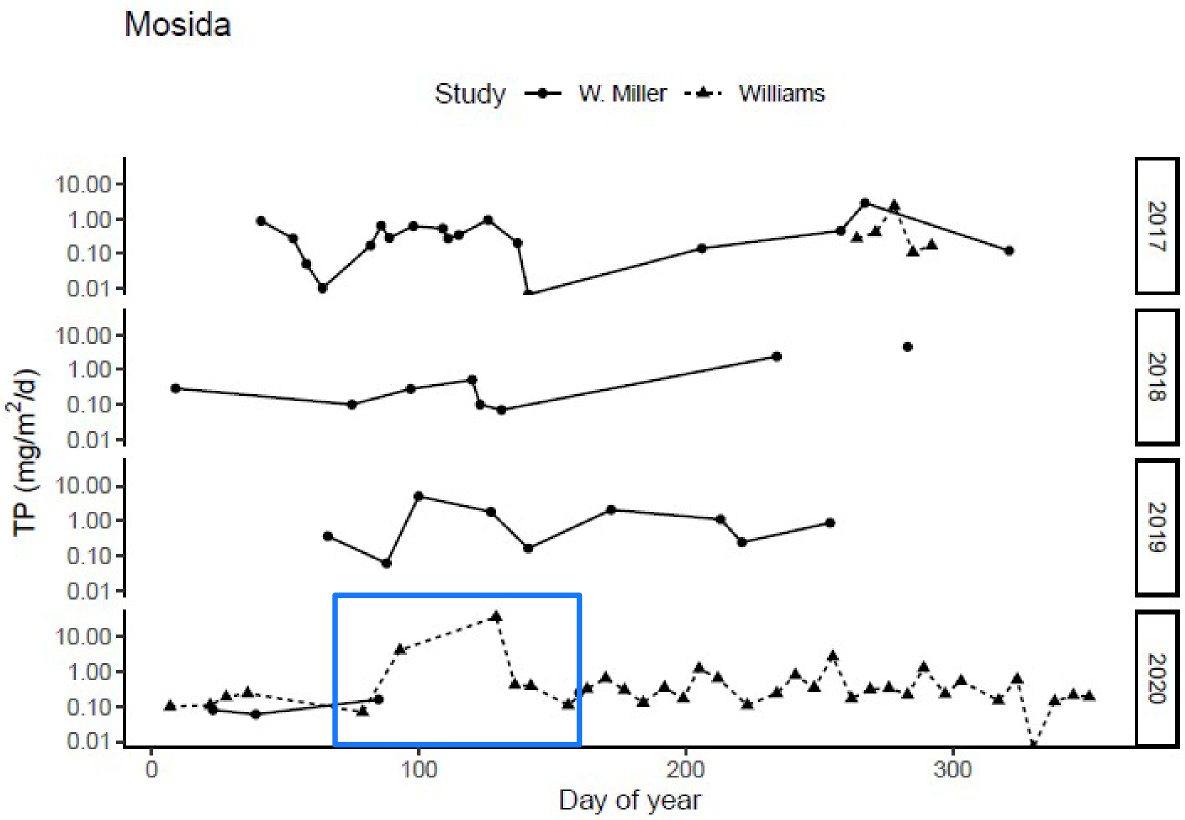


Possible explanations for Williams & W. Miller Differences

- **Generally, Williams > W. Miller for all constituents**
- **Hypotheses:**
  - W. Miller samples underestimate dry deposition
  - Some sites don't match up (BUT differences are still present in matching sites)
  - Time periods don't match up → Williams dataset captured time periods of higher flux
- **How to reconcile these datasets when estimating load?**

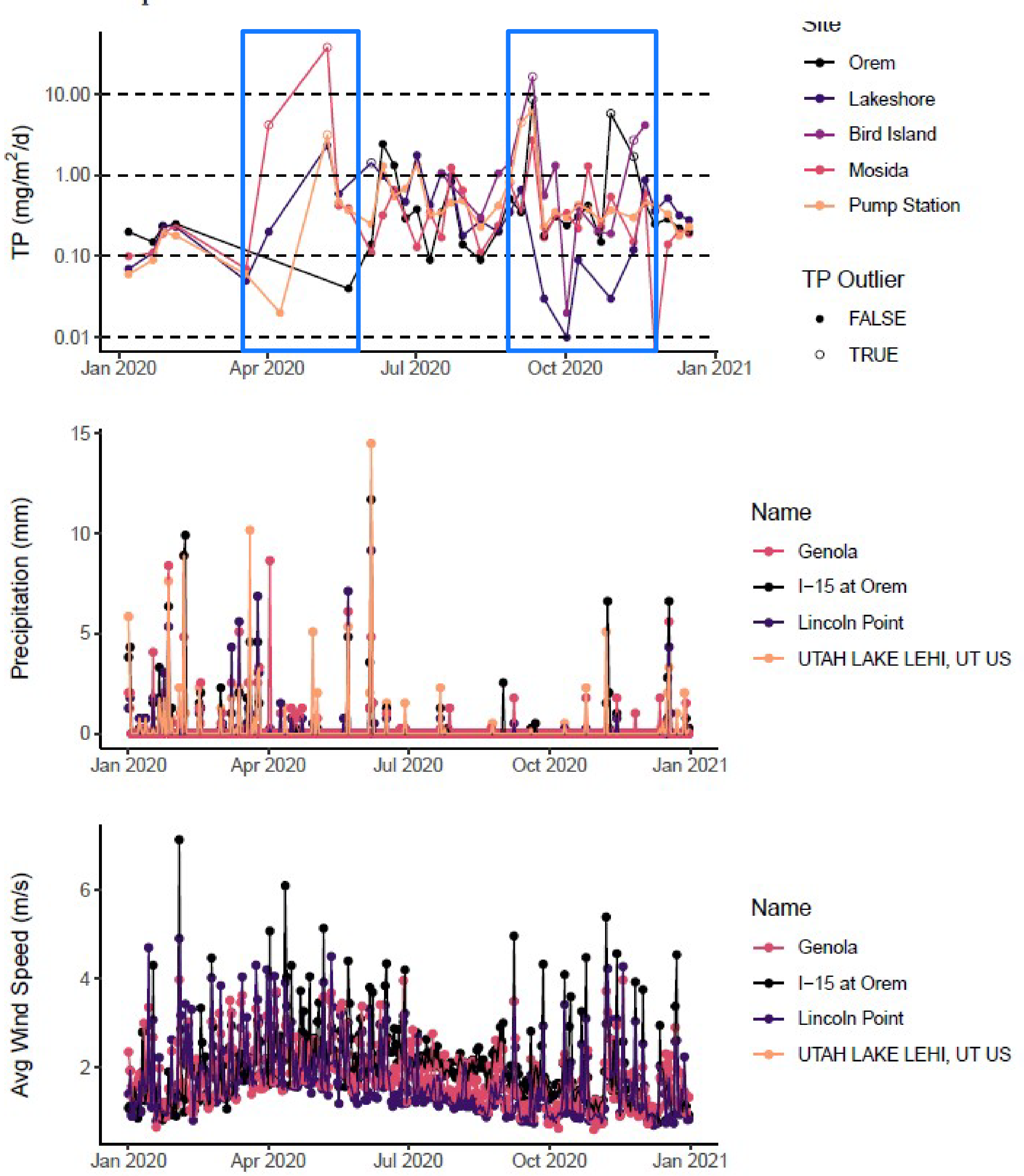
Event Analysis

- Recall, we noticed a possible issue with imputation at Mosida (imputing between two large events)
- Can we use W. Miller dataset to determine if fluxes were elevated over that period?
- Unfortunately, latest date in W. Miller dataset is June 8, 2020 → cannot evaluate the time period of interest



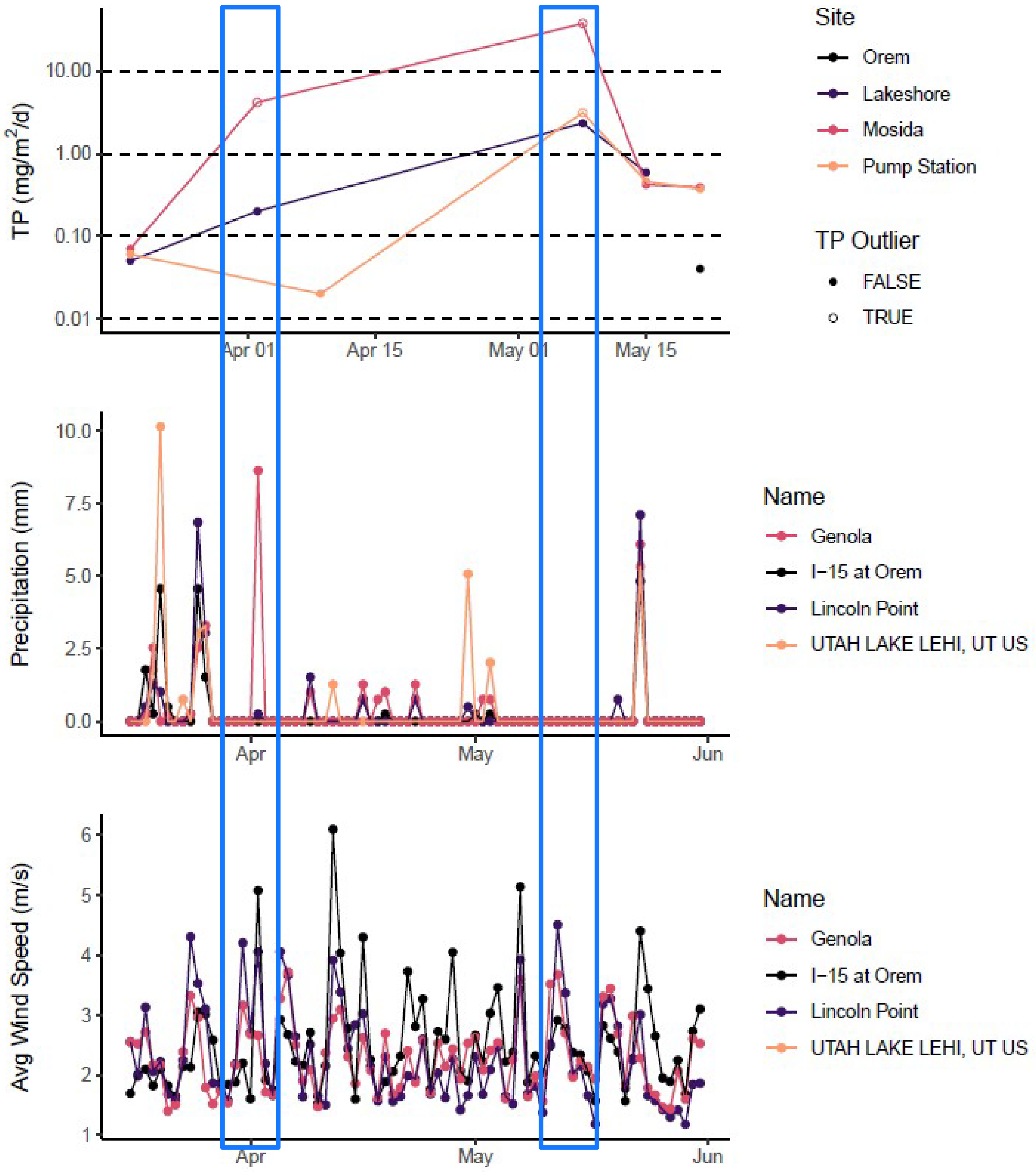
Event Analysis

- Evaluate weather patterns to see if precipitation and/or wind are linked to high flux events
- We have evidence that precipitation and wind in general have positive relationships with flux
- Plotted flux across sites, matched with weather stations (color coded)
- Zoomed in on two sampling periods of interest



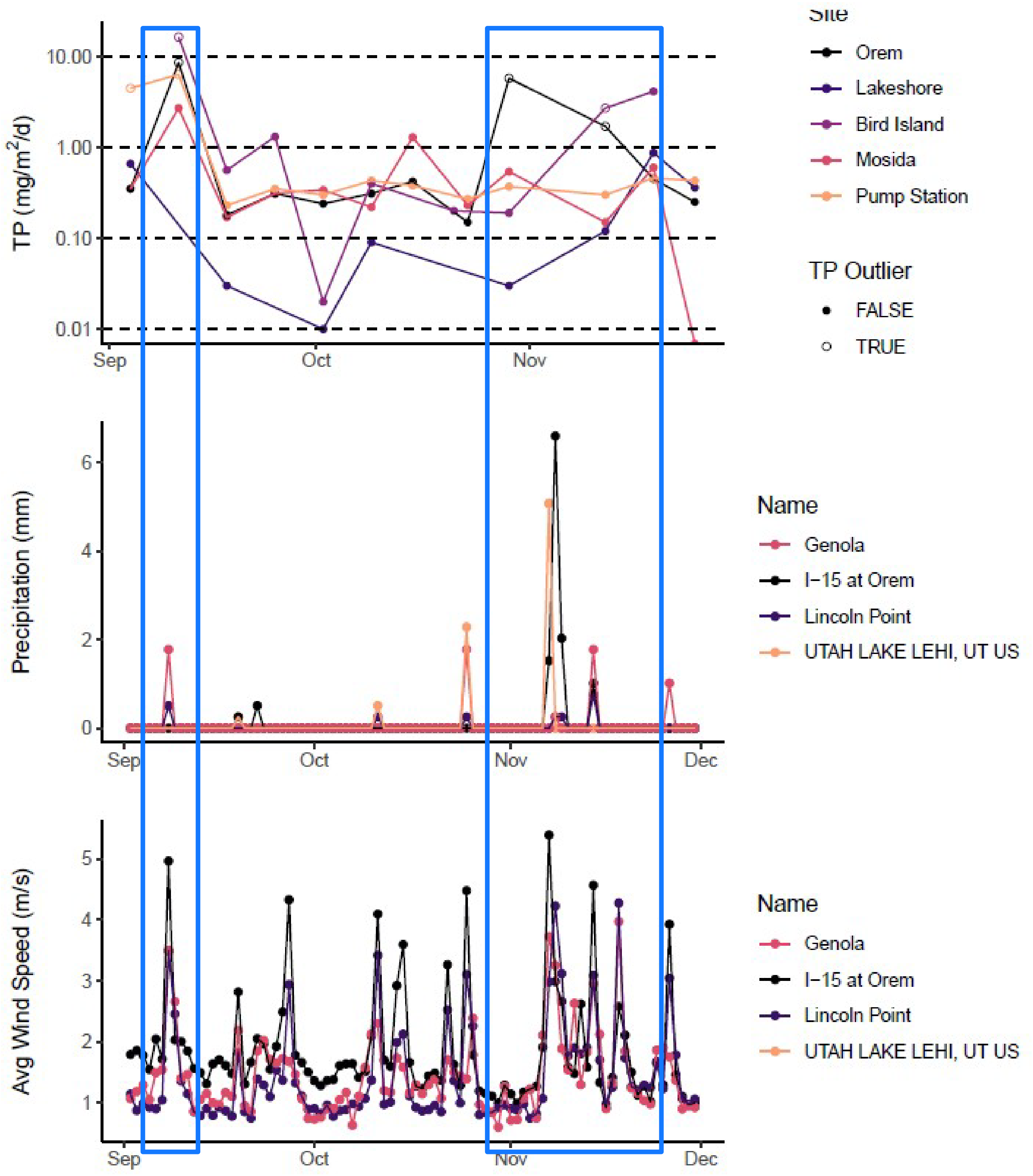
Event Analysis

- Two high events at Mosida:
  - Are these related to weather?
  - Do we have evidence that fluxes could be elevated between these events?
- **First high flux event associated with large precipitation event and preceded by a few days of elevated wind**
- **Second high flux event not associated with precipitation but preceded by elevated wind**
- **No major weather events in between → consider assigning a "background" flux or estimate from wind regression?**



Event Analysis

- **A few elevated events across stations in late 2020:**
  - September event elevated across sites
  - Oct-Nov events isolated across sites
- **September event consistent with elevated precipitation and wind**
- **High Orem event (late October) not associated with weather**
- **Some high wind and precipitation could help to explain November events**
- **Suggest retaining these**

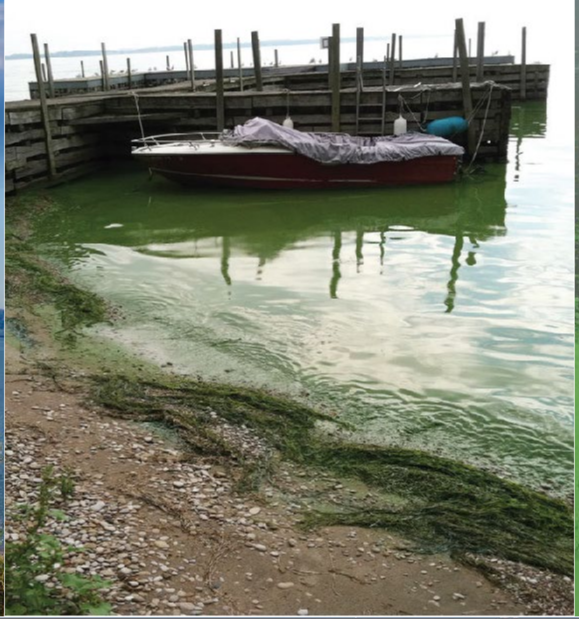


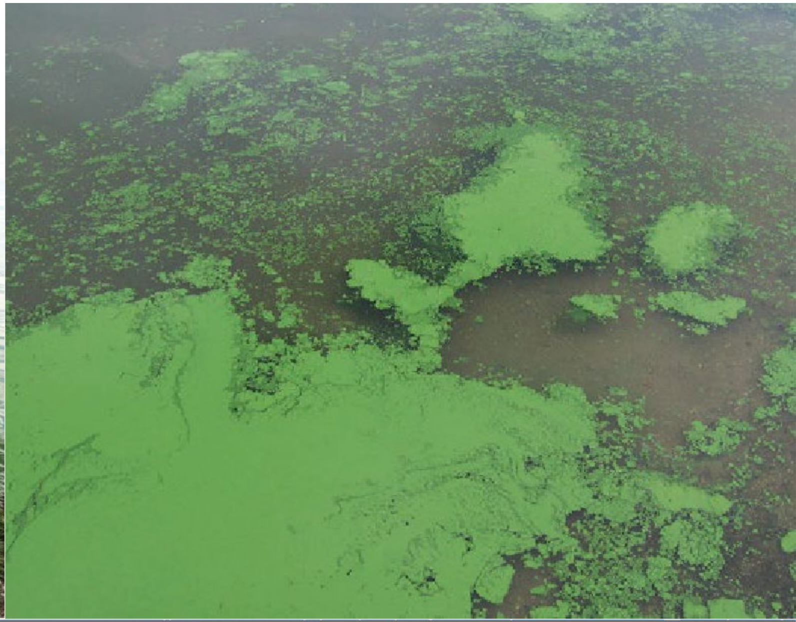
Event Analysis Takeaways

- **For most high flux events, these are preceded by high precipitation and/or wind**
- **Large precipitation and wind events are not always followed by high flux**
  - Context missing (e.g., direction and temporal pattern in wind)
  - Weather + high flux events could be coincidental
- **Mosida interpolation: may want to use method other than linear interpolation**
- **Other events: action needed?**

Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | December 1, 2022





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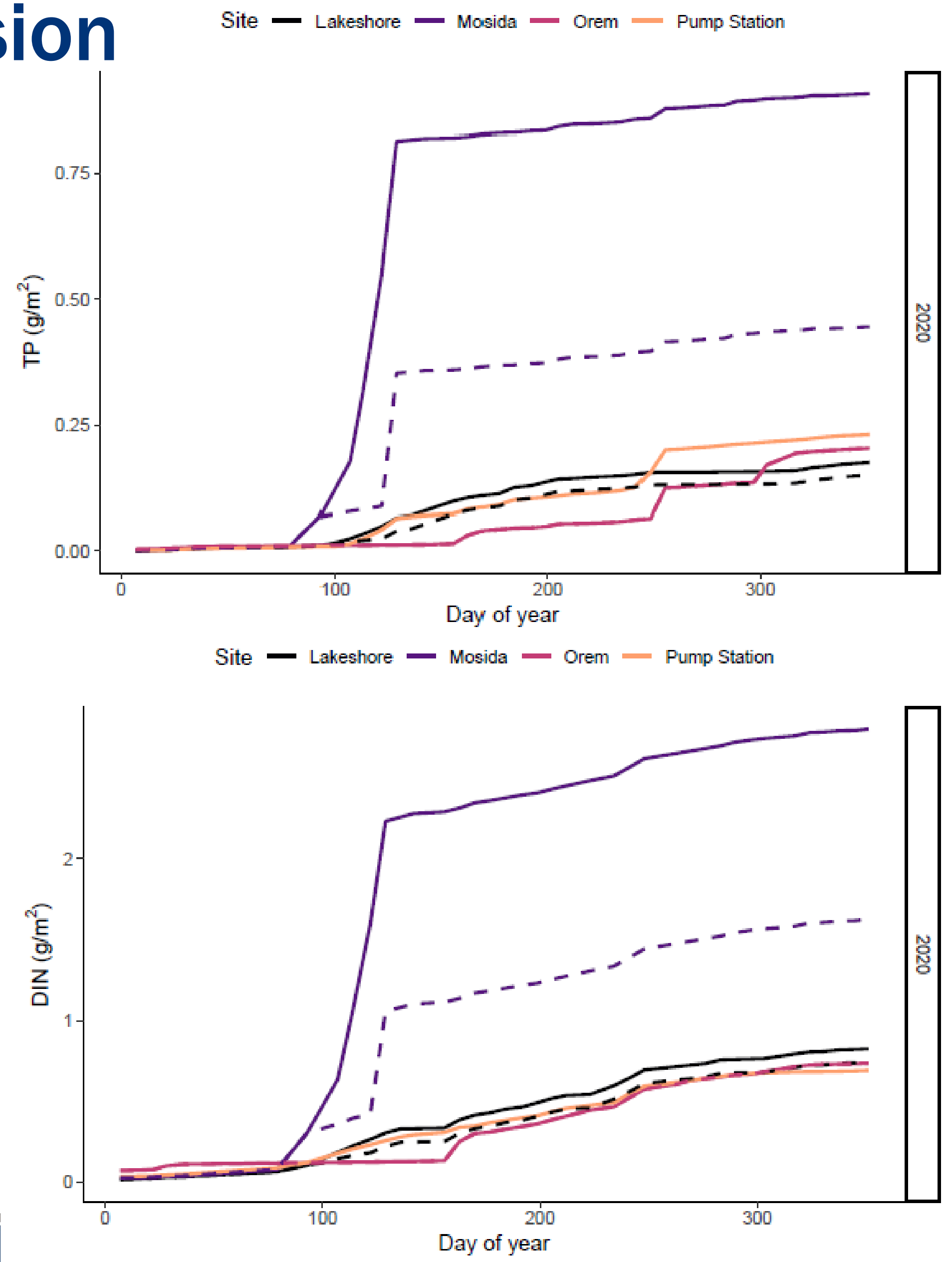
Action Items From Last Meeting

- ✓ Explore impact of linear interpolation vs. weather regression on fluxes
- ✓ Compare cumulative flux between studies
- ✓ SRP:TP ratios

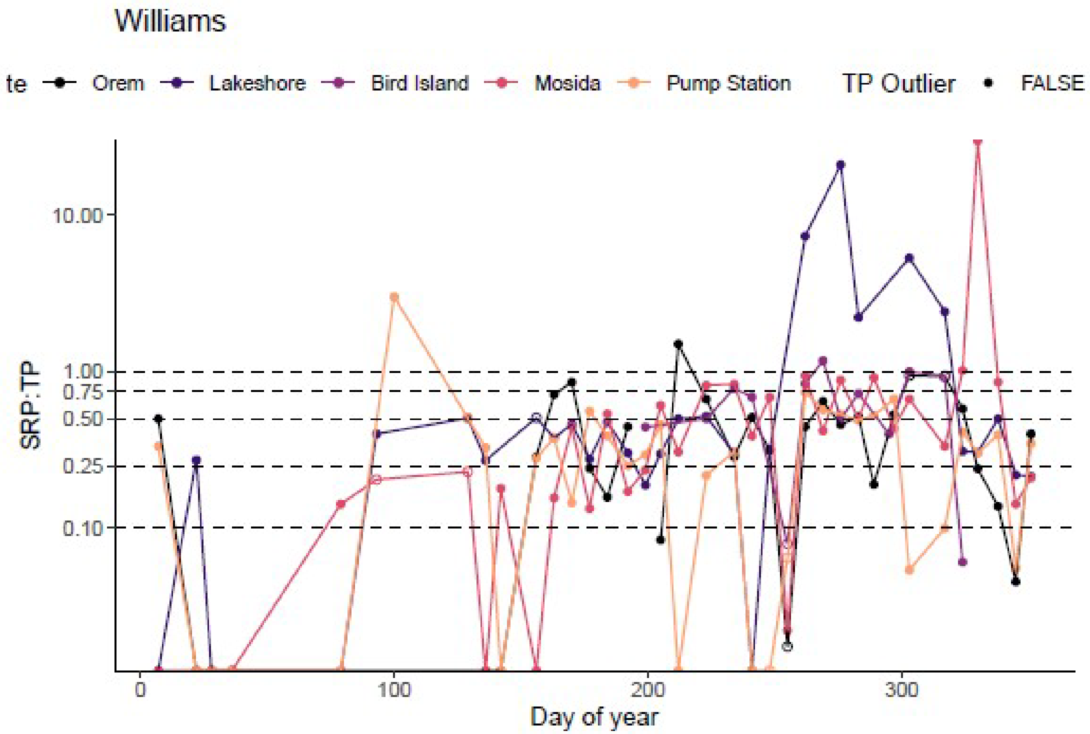
Linear interpolation vs. weather regression

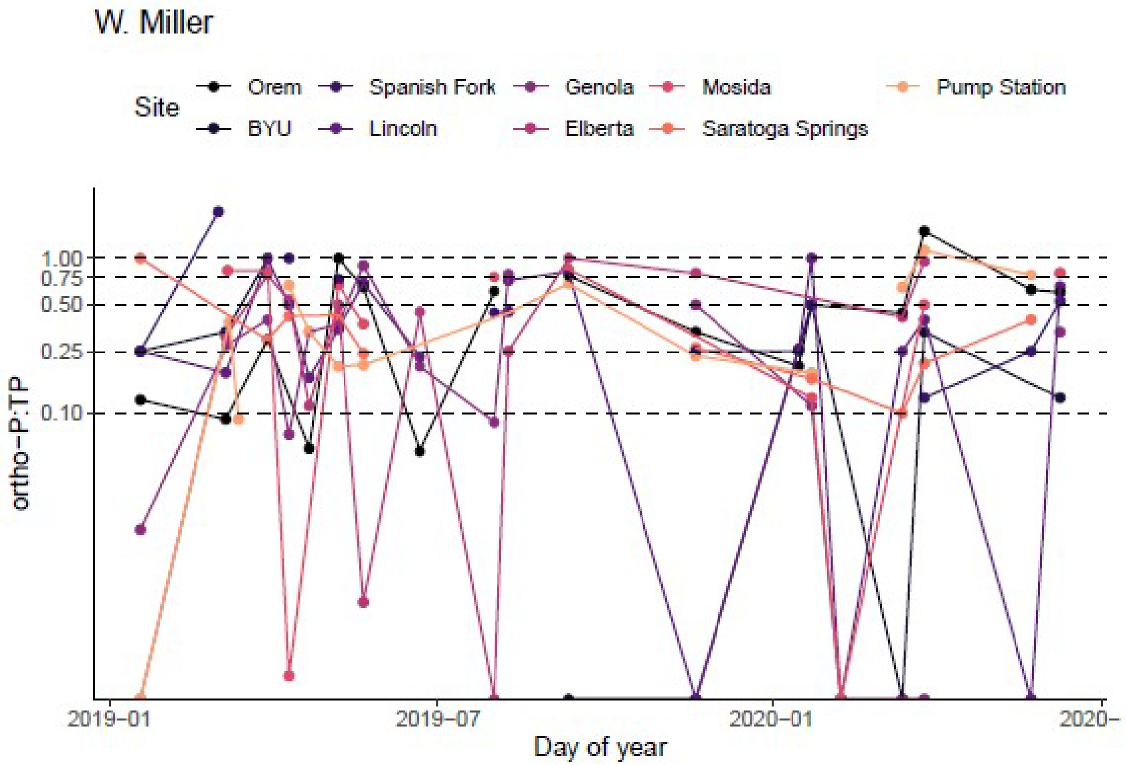
- **Best fit models:**
  - TP: avg peak wind, max peak wind
  - DIN: avg peak wind, max peak wind, daily precip, PM10, PM2.5
- **Filling in missing dates with weather regression (dotted line) results in lower flux than linear interpolation (solid line) for Lakeshore and Mosida**
- **Recommend using the weather regression**
  - Weather doesn't explain all variability in flux, but captures aspects of variability
  - Linear interpolation isn't effective to capture patterns for intermittent time series



SRP:TP Ratios

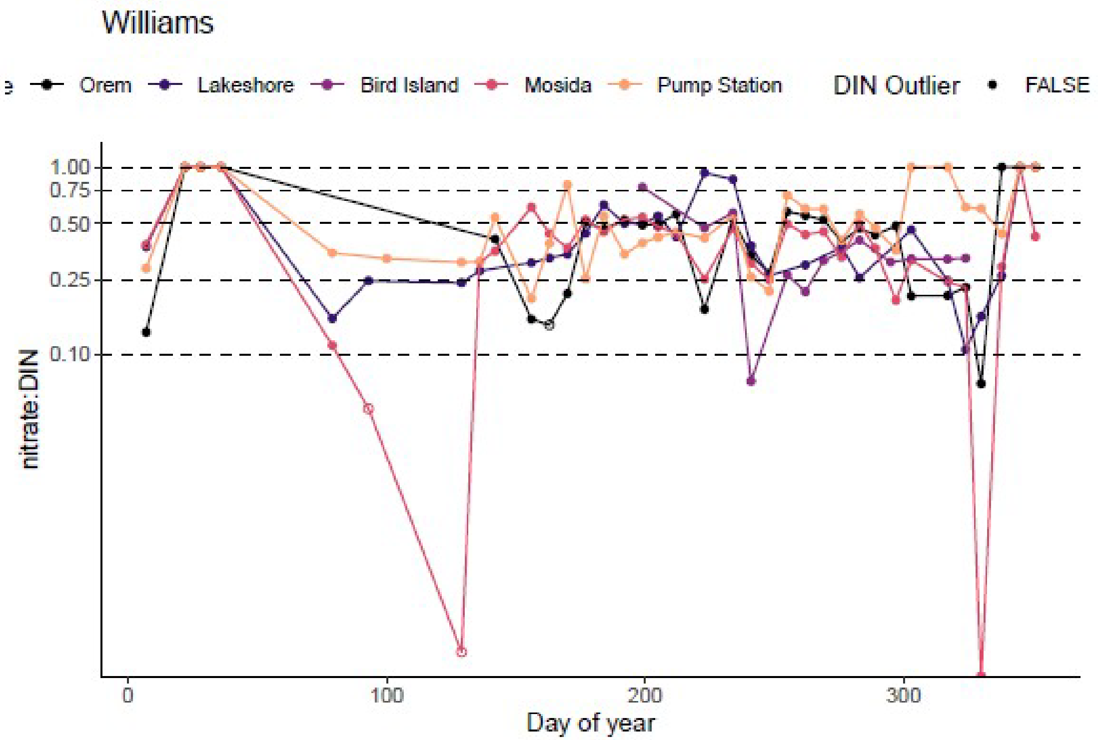
- Both studies have some impossible values >1
- TP outliers aren't associated with unusual SRP:TP ratios

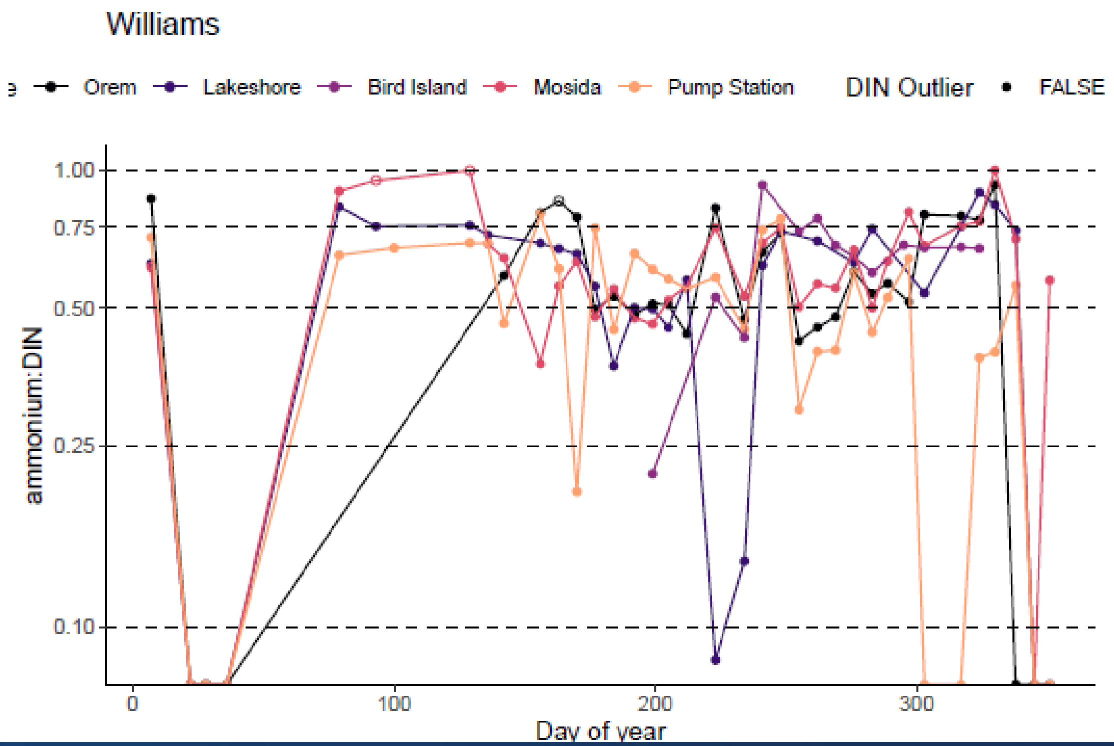




Nitrate:DIN and Ammonium:DIN ratios (Williams only)

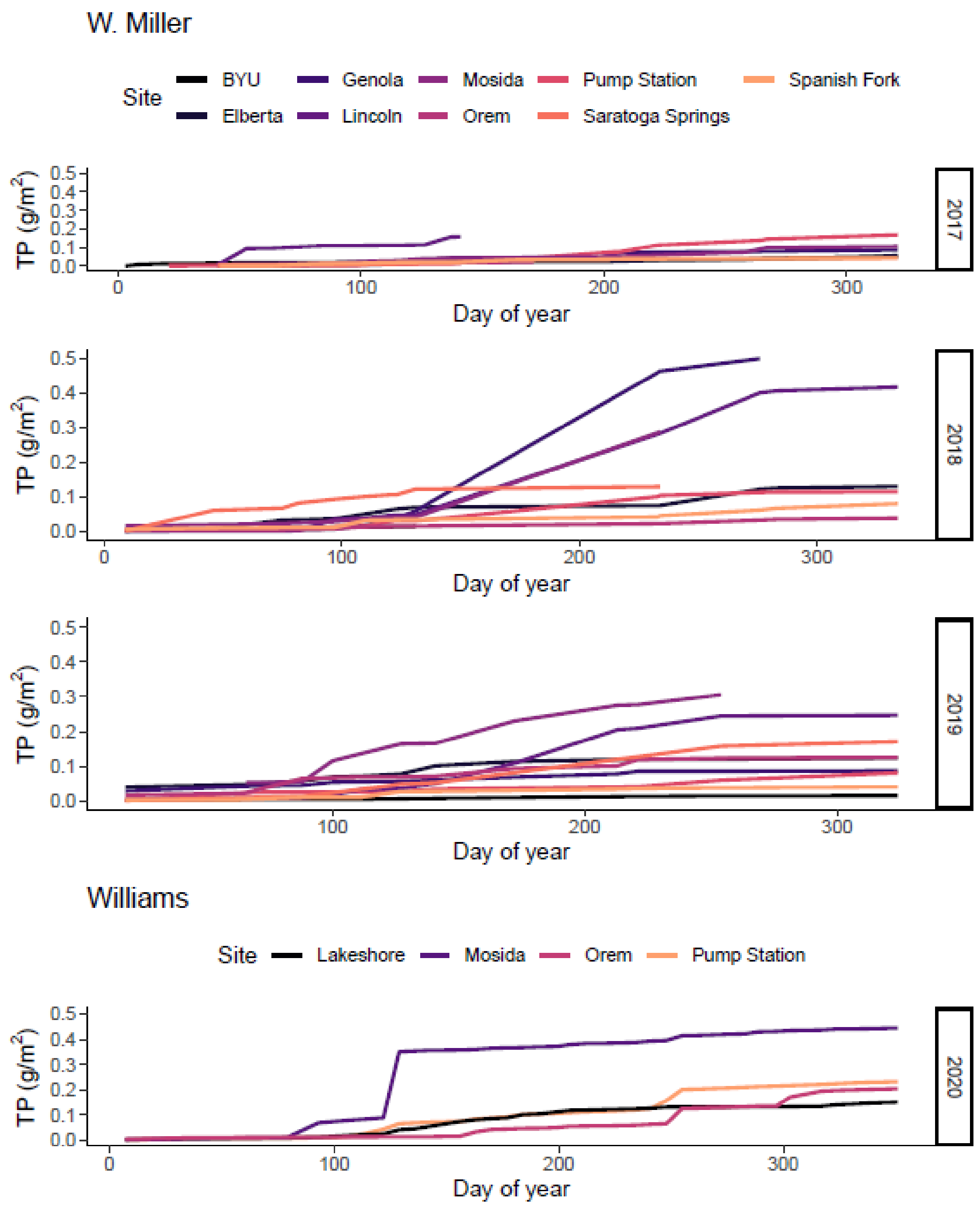
- Nitrate + Ammonium = DIN → values are never >1
- DIN outliers are associated with high proportion of ammonium





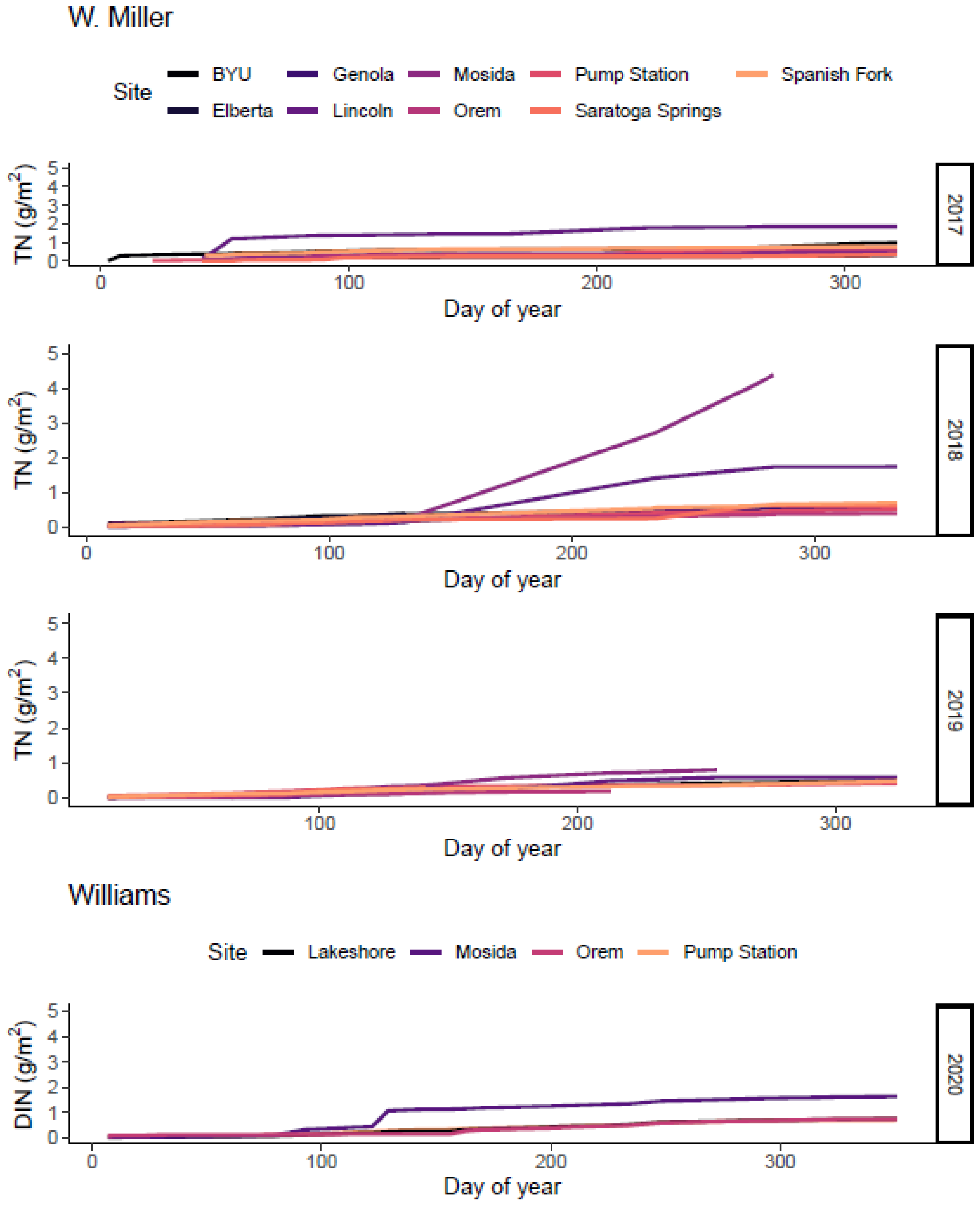
TP Cumulative Flux Comparisons

- Williams and W. Miller cumulative fluxes are in the same order of magnitude
- Often, Williams > W. Miller
- Mosida, Lincoln, Genola have higher annual fluxes than other sites



TN Cumulative Flux Comparisons

- Williams and W. Miller cumulative fluxes generally overlap with one another
- Mosida and Lincoln have higher fluxes than other sites



Flux Comparisons

- Williams fluxes > W. Miller fluxes
- Williams fluxes > Brahney and Carling fluxes
- W. Miller fluxes generally overlap with Brahney and Carling fluxes

Study	TP annual flux (mg/m²/yr)	DIN or TN annual flux (mg/m²/yr)
Williams Orem	203.5	735.5
Williams Lakeshore	150.0	740.8
Williams Mosida	444.5	1,624.5
Williams Pump Station	235.5	764.2
W. Miller Orem	37.8-101.9	223.1-571.6
W. Miller BYU	14.4-48.8	479.5-966.2
W. Miller Spanish Fork	40.1-80.2	467.0-768.7
W. Miller Lincoln	246.5-415.9	571.7-1852.2
W. Miller Genola	86.1-504.5	274.0-550.7
W. Miller Elberta	55.6-129.4	319.6-630.8
W. Miller Mosida	105.8-318.7	495.5-4385.3
W. Miller Saratoga Springs	41.0-170.7	365.0-628.3
W. Miller Pump Station	80.6-168.6	407.2-650.5
Brahney	93.6 (UT urban dust) 4.0 (regional dust) 5-15 (UT urban wet)	461 (CMAQ)
Carling	88.9-189.6 (UT urban dust)	

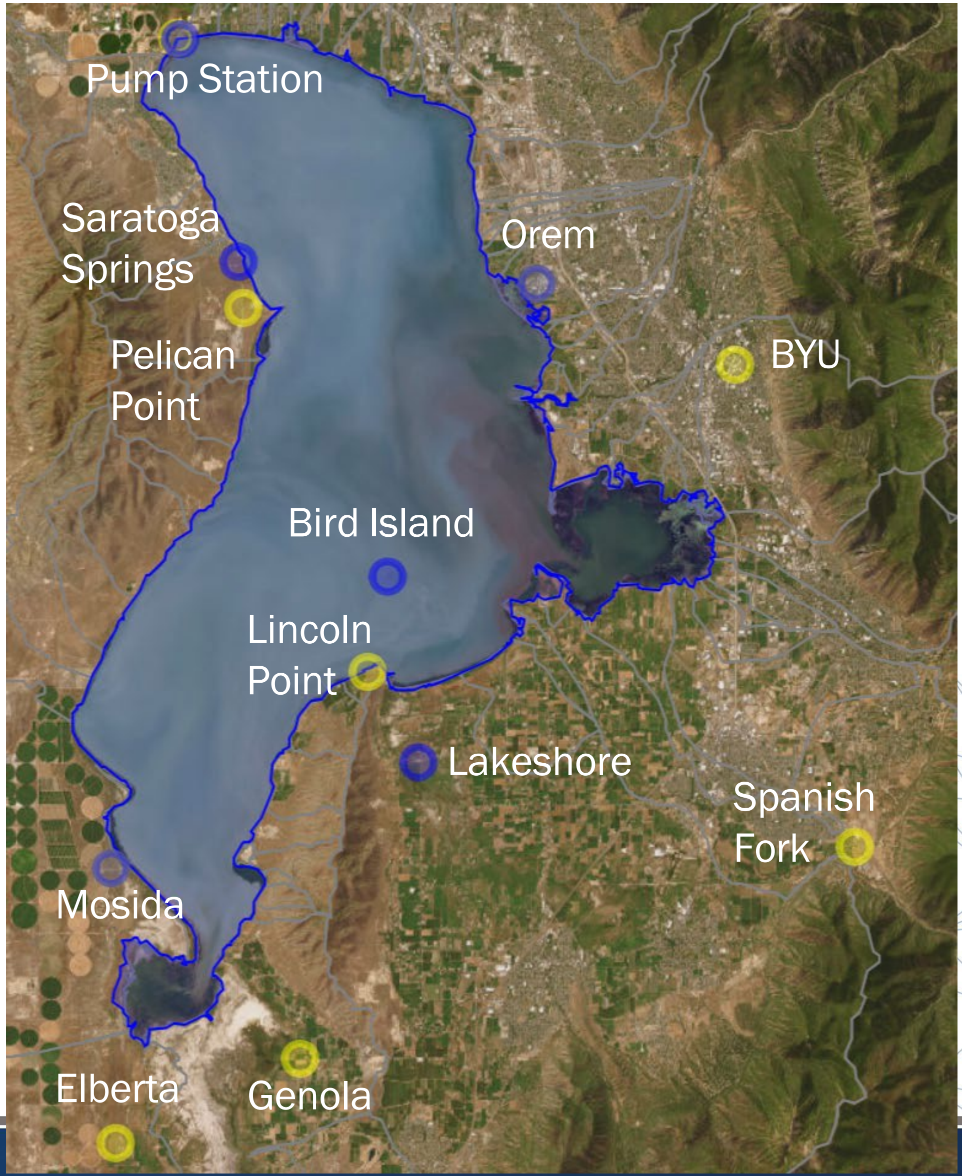
Looking Ahead: Calculating Lakewide Load

Converting Annual Fluxes at Sites to Lakewide Load

- **We have fluxes from several sites around the lake → extrapolate to flux over lake area**
- **Considerations**
  - Two studies with different methods → calculate separately
  - How to spatially aggregate across sampling locations
  - Address attenuation moving from lakeshore to lake center

Converting Annual Fluxes at Sites to Lakewide Load

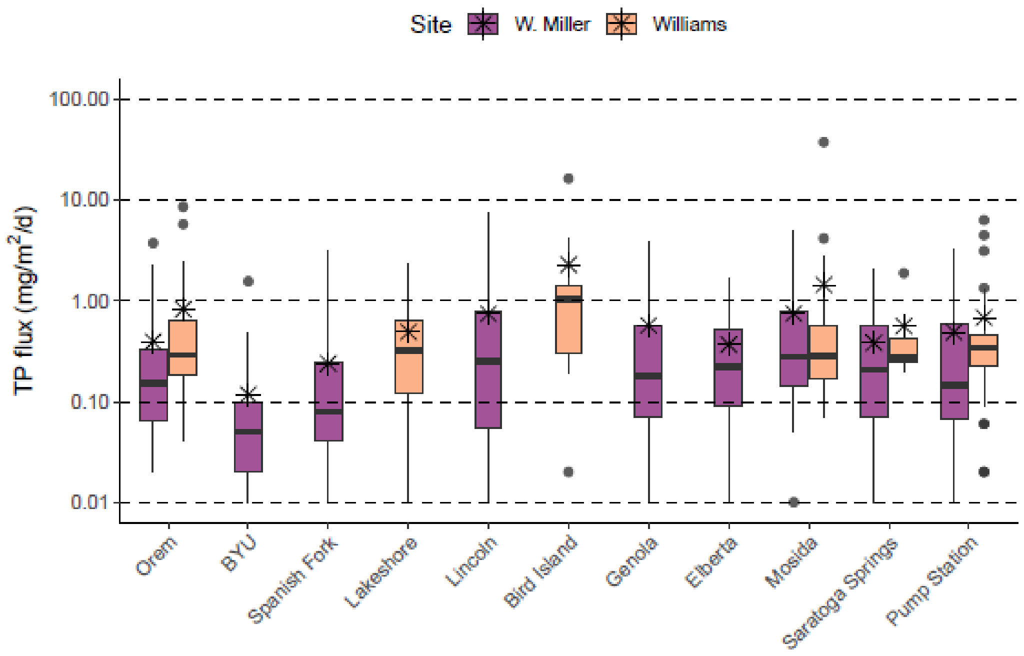
- **Mosida has evidence of localized source**
  - Playa dust from SW winds? Might expect to see elevated fluxes at Elberta and Genola as well
  - Agricultural sources? Elevated NH_4^+ and SRP
  - Potential impact: kriging or arithmetic averaging would result in Mosida flux applying to 25% of lake
- **Evaluating Bird Island for attenuation**
  - Bird Island site was sampled to quantify the potential for attenuation of fluxes → expectation that fluxes would be ≤ fluxes at shoreline sites
  - BUT fluxes at Bird Island were > other sites

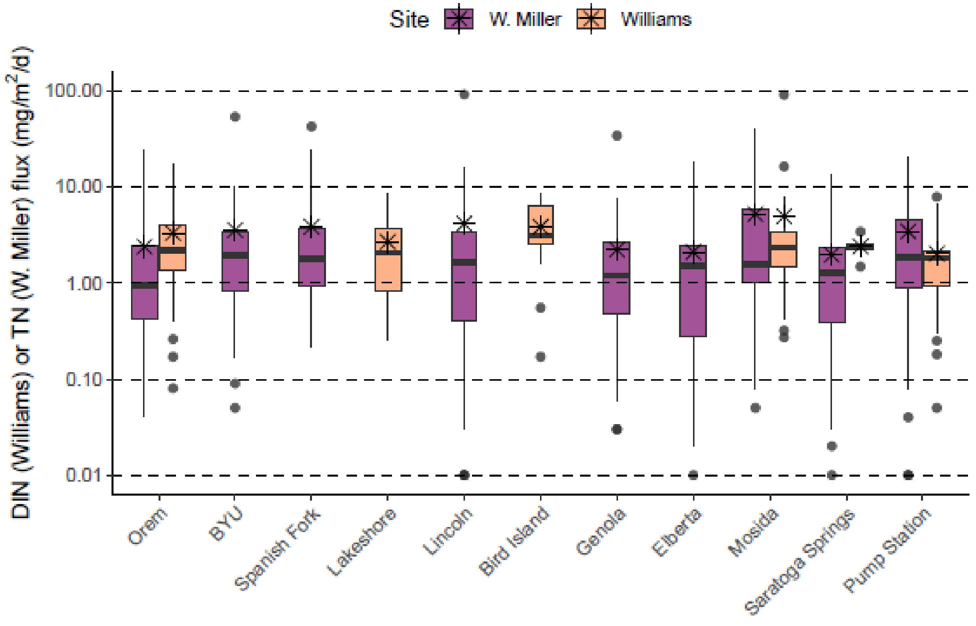


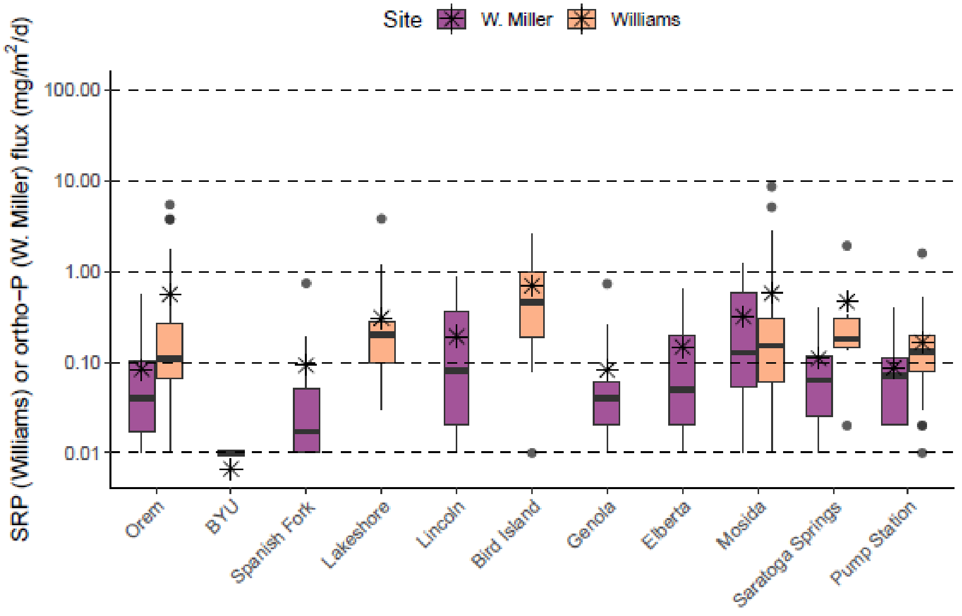
Bird Island

- **Fluxes for all constituents are higher at Bird Island than at other sites**

(note: organized by proximity)

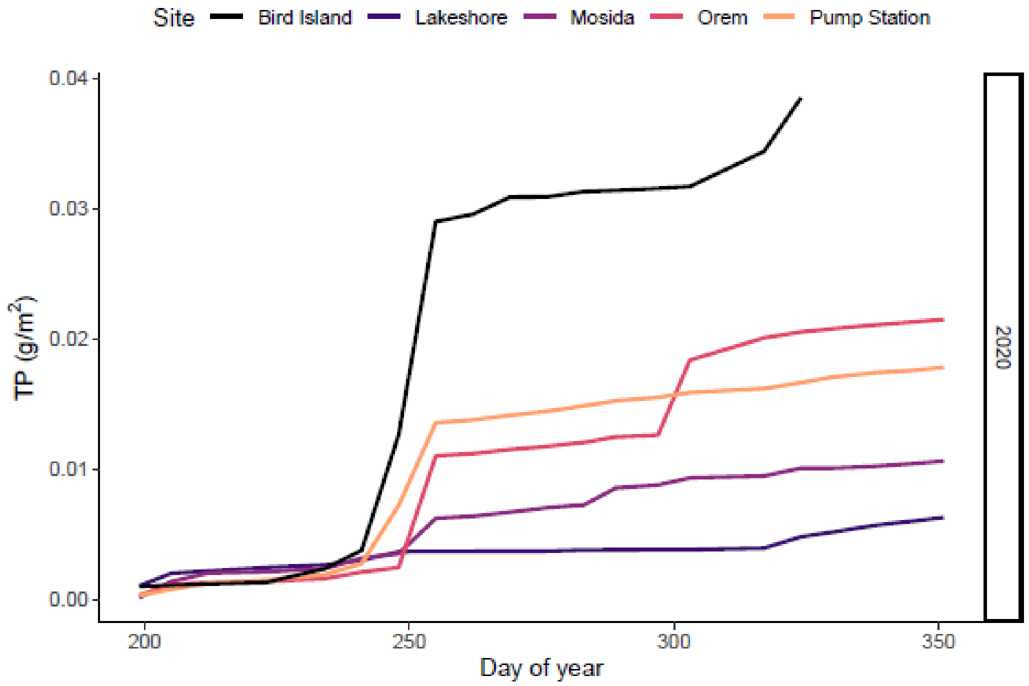


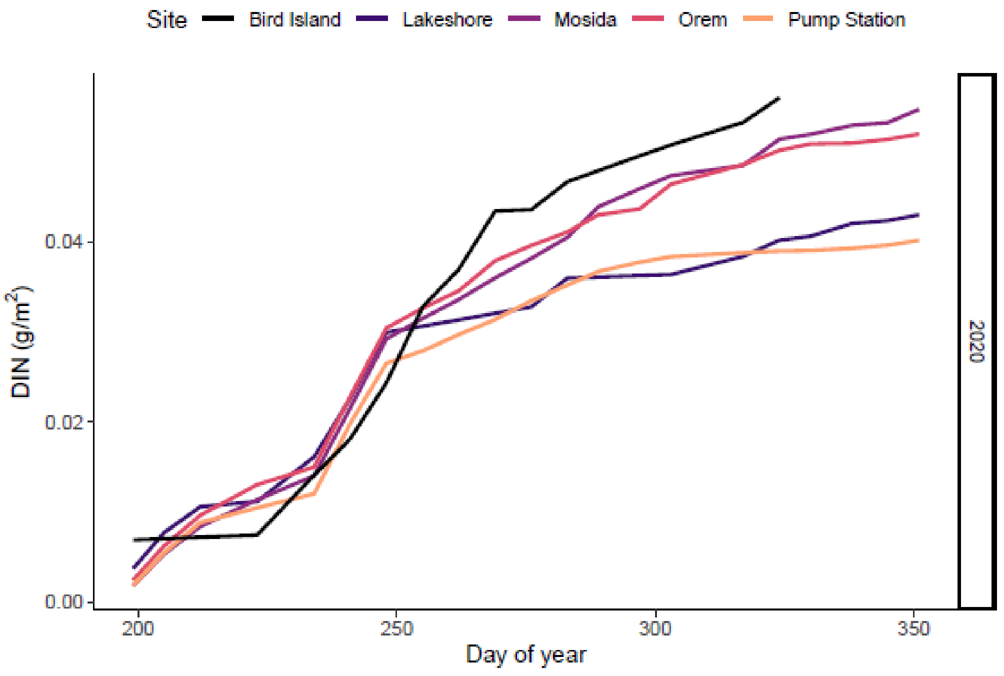


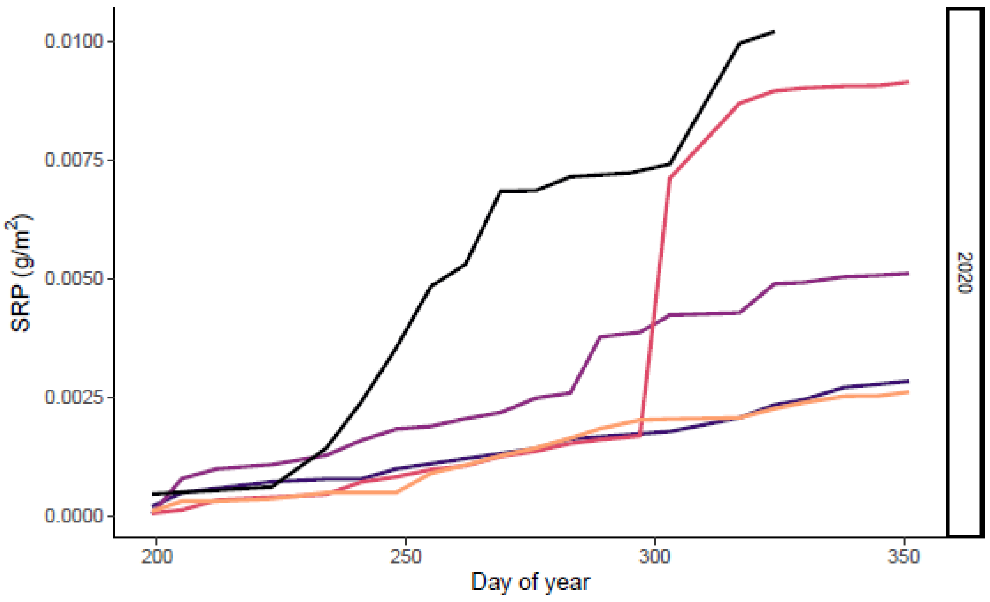


Bird Island

- Cumulative fluxes at Bird Island are higher than at other sites (Williams)

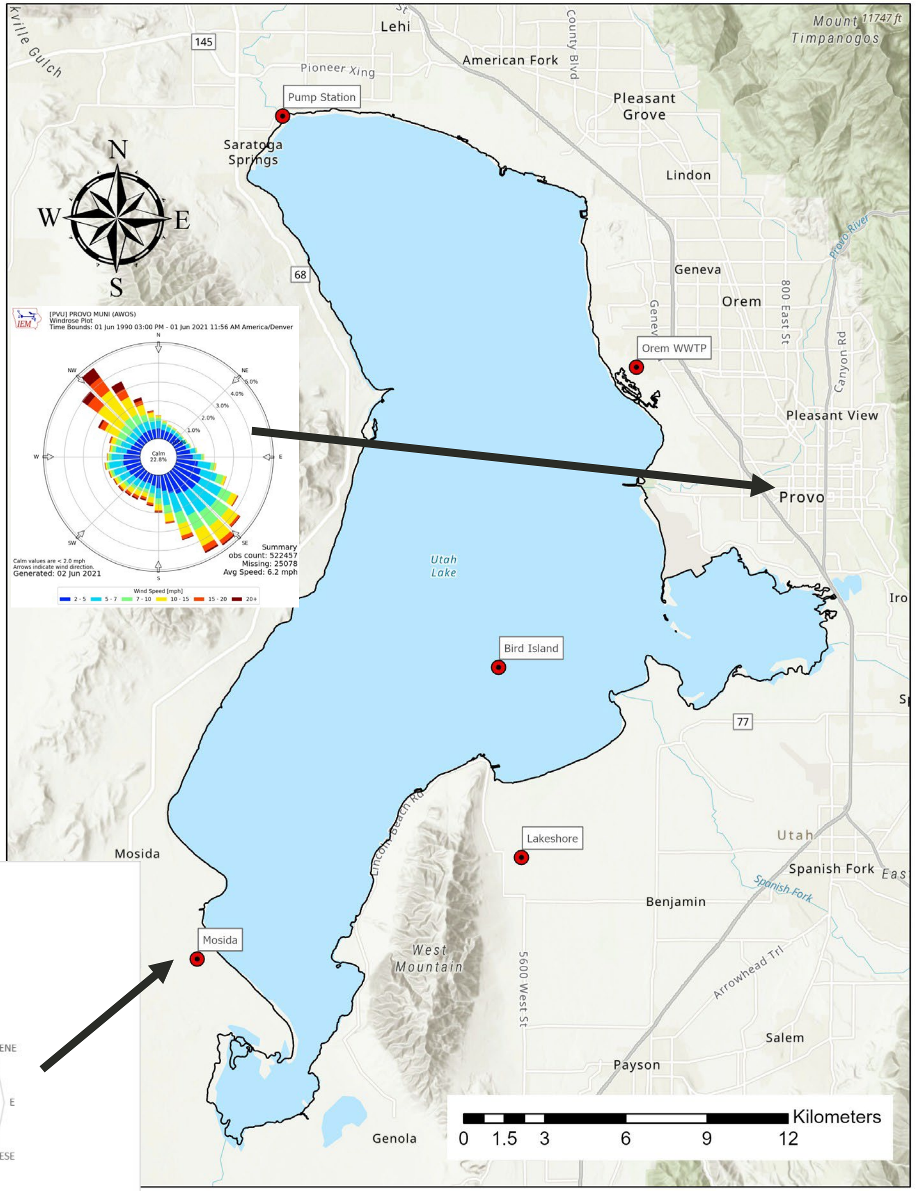


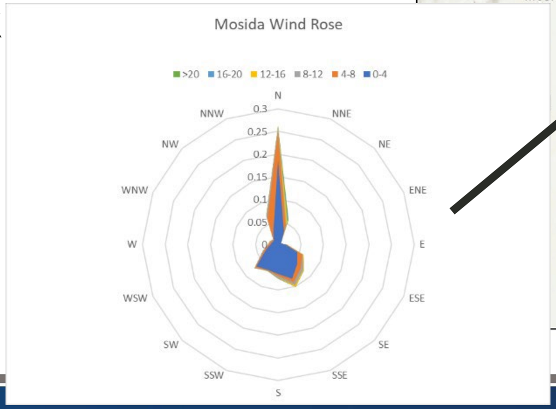




Hypothesis for high Bird Island fluxes

- In T. Miller report: “We expect that this is because of variable winds occurring across Utah Lake (i.e., downslope SE and east winds from the canyons during evening and early morning; SW winds during afternoon; and a combination during the passage of frontal boundaries – the combination of which could serve to concentrate dust and aerosols over the lake.”
- “The windrose… shows that Bird Island would be most influenced by shoreline rates from the northwest shore of Utah Lake and the area north of the Mosida sampling site. Neither of these areas have a shoreline sampler. The northwest shore area does not have much agriculture but is experiencing urban ex the cities of Lehi and Eagle Mountain. We are exploring the possibility of placing a sampler in this area for future collections.”





Review of Bird Island findings by David Gay (direct quotes)

- **I would expect criticism will come on these observations, such as**
  - Can you prove that there is no contamination going on in the lake that is not representative of the lake surface?
  - Condensation into the bucket because the sampler is colder than the water, for example?
  - Mist/droplets from waves being added to the sample?
  - Do the wet only samples also show this difference? Is the difference in the dry side?
  - Bird poop in the dry side? Are the birds using it as a resting place (although then you get into the argument of bird feces as a source)?
- **You might want to pull out very short term samples (2 or 3 day samples) that have not likely had a long time to collect contamination; i.e. to provide evidence that it is the atmosphere and not some other problem occurring. If you find the same with wet deposition side of the sampler and short term samples, this will give you more evidence that the observations are correct, and that the urban core and shifted wind on the east side of the lake are a major contributor.**
- **One way you might be able to show that this is a real signal goes something like this. The Lakeshore sampling site is not capturing the urban "plume" moving over the lake (plume is to the north). So put another shore line sampler north of Lakeshore where it would capture these high samples.**
- **I would again recommend beefing up the QA information for the Bird Island sampler. Prove to the reader that you have QA info that shows these samples are valid.**

Attenuation

- **Range:**
  - No attenuation: arithmetic averaging or kriging across sites (upper bound)
  - Attenuation: consider a range at which AD attenuates from shoreline
- **Considerations:**
  - Could run range of attenuation to submit to modelers for sensitivity analysis
  - Run attenuation on annual fluxes or on each date?
  - Attenuation distance:
    - Brahney used 200, 400, 600 m, beyond which was assigned background
    - Barrus assumed background at 5 interior points of the lake, then used kriging
    - Reidhead assumed linear fall-off to zero at center of lake

Decision Points

1. Should Bird Island data be used?
2. How should we compute attenuation?

Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | December 8, 2022

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Action Items from Last Meeting

✓ **Check into W. Miller data past June 2020**

- Found!
- FlatDataBase sheet has incomplete data through June 2020
- Sheet1 sheet has complete data through June 2022

Converting Annual Fluxes at Sites to Lakewide Load

- **We have fluxes from several sites around the lake → extrapolate to flux over lake area**
- **Considerations**
  - Two studies with different methods → calculate separately
  - How to spatially aggregate across sampling locations
  - Address attenuation moving from lakeshore to lake center

Attenuation

- **Range:**
  - No attenuation: arithmetic averaging or kriging across sites (upper bound)
  - Attenuation: consider a range at which AD attenuates from shoreline
- **Considerations:**
  - Could run range of attenuation to submit to modelers for sensitivity analysis
  - Run attenuation on annual fluxes or on each date?
  - Attenuation distance:
    - Brahney used 200, 400, 600 m with first-order decay, beyond which was assigned background
    - Olsen assumed background at 5 interior points of the lake, then used kriging
    - Reidhead assumed linear fall-off to zero at center of lake
    - Barrus assumed no attenuation and interpolated across sites including BI

Decision Points

1. **Should Bird Island data be used?**
   - If so, how?
   - If not, why not?
2. **How should we compute attenuation?**

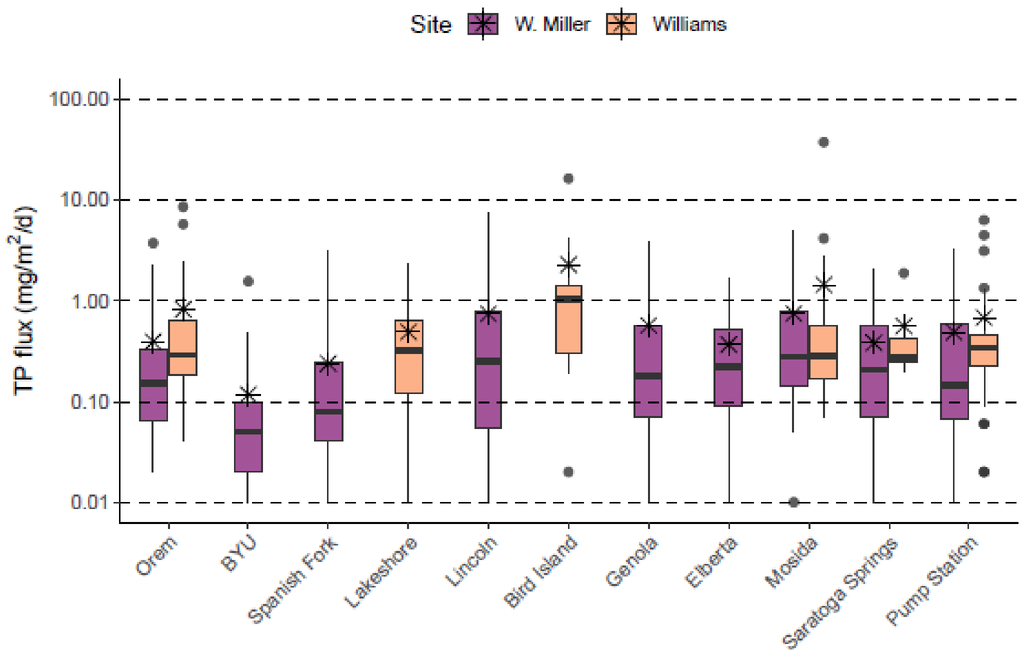
Bird Island Sampling Information

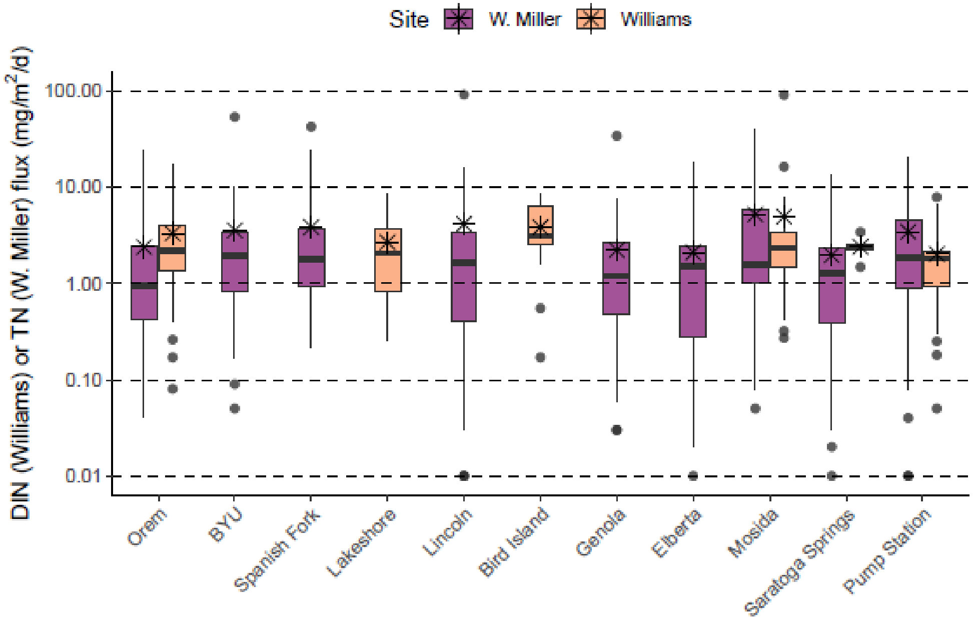
- **Sampled 7/17/20 to 11/19/20**
  - 7/17 and 8/10 samples have both wet and dry samples
  - 7/23 sample has only a dry sample, plus “wet bucket blown off”
  - Remaining 12 samples have only bulk samples
  - 9/4 sample marked with insect contamination → excluded per decision tree
- **Limited capacity to assess wet/dry fluxes**

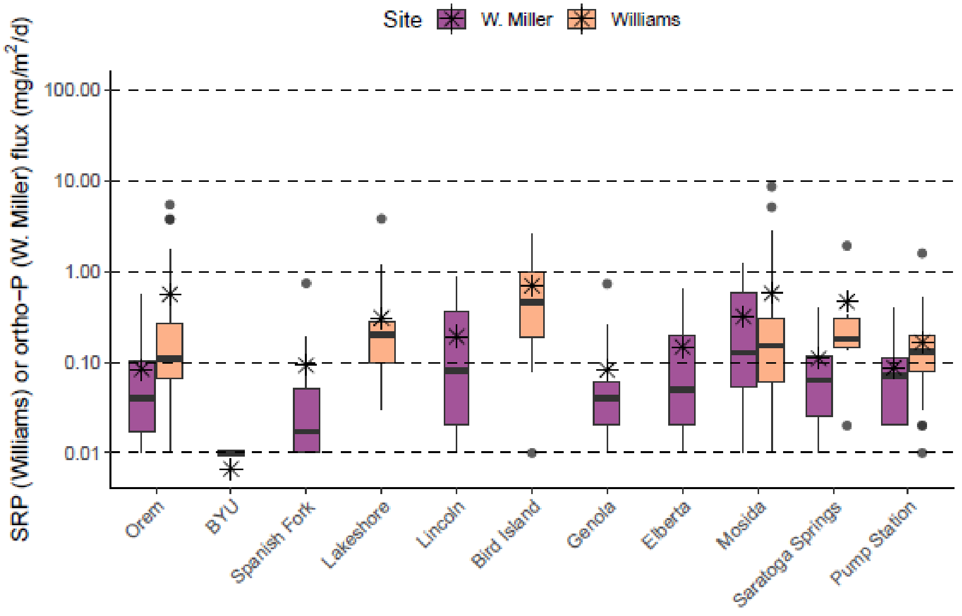
Bird Island

- **Fluxes for all constituents are higher at Bird Island than at other sites**

(note: organized by proximity)

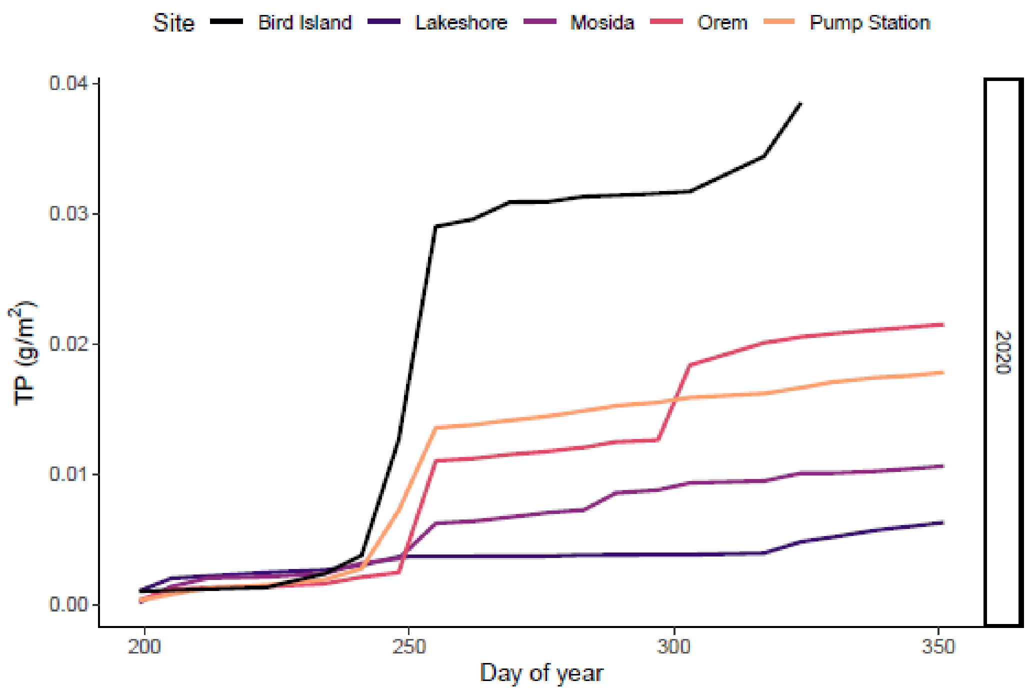


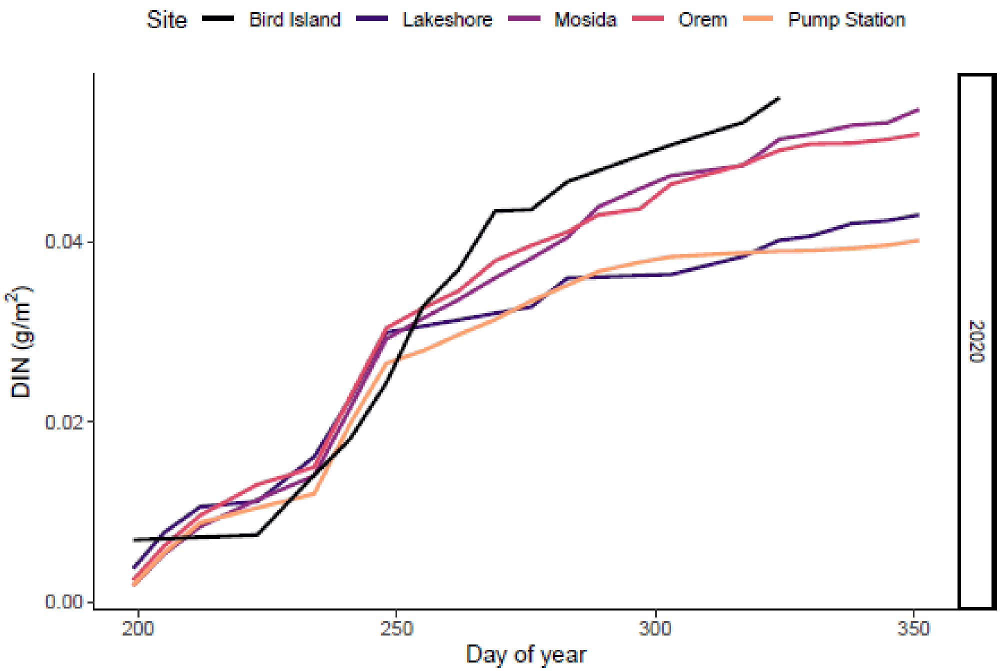


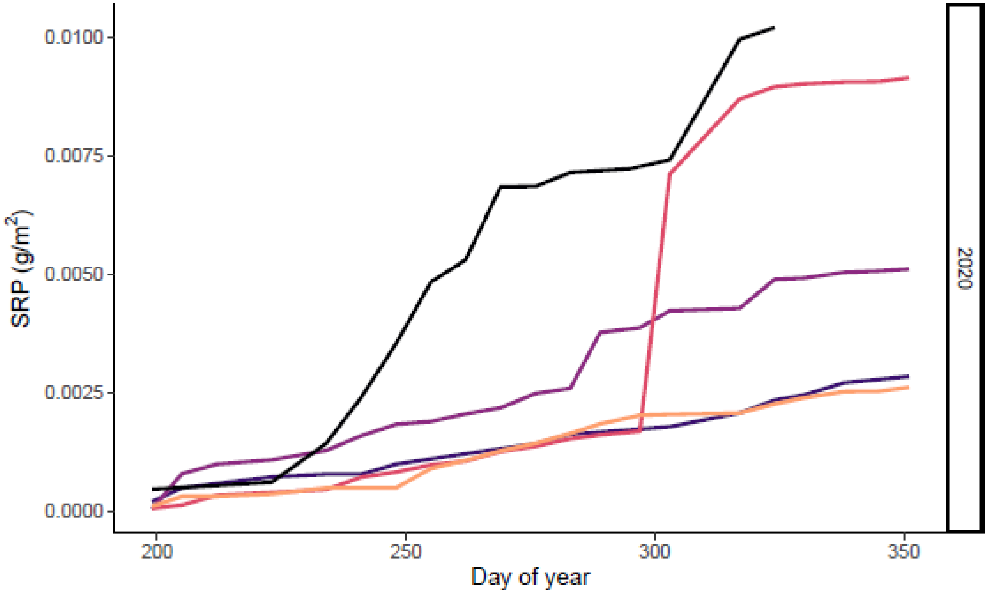


Bird Island

- Cumulative fluxes at Bird Island are higher than at other sites (Williams)







Why are fluxes at Bird Island higher than other sites?

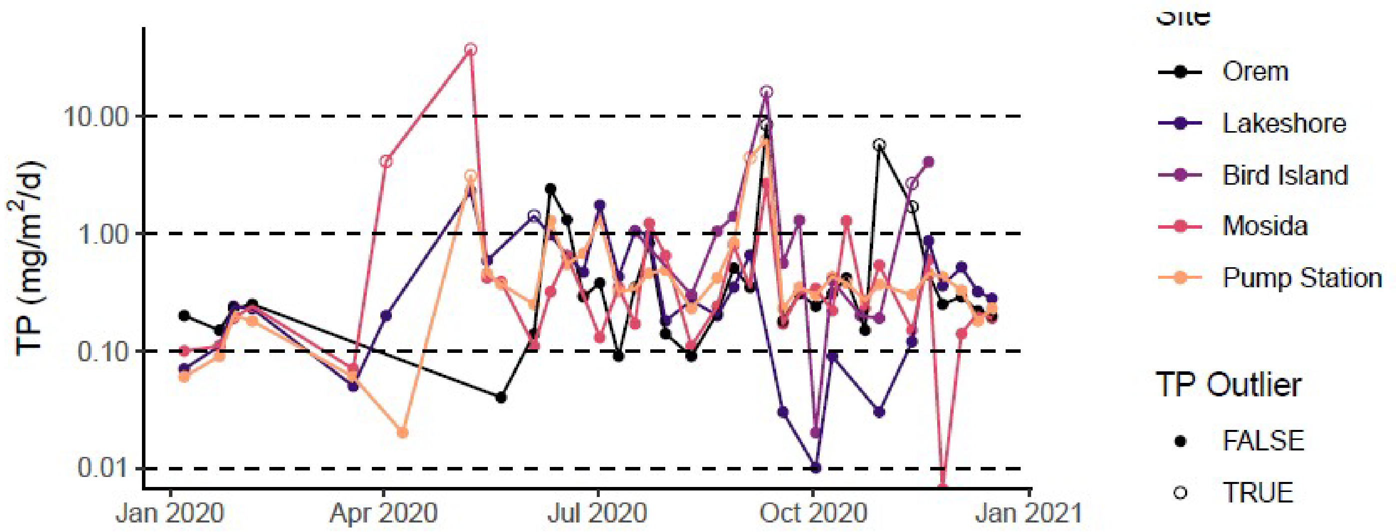
Hypotheses:

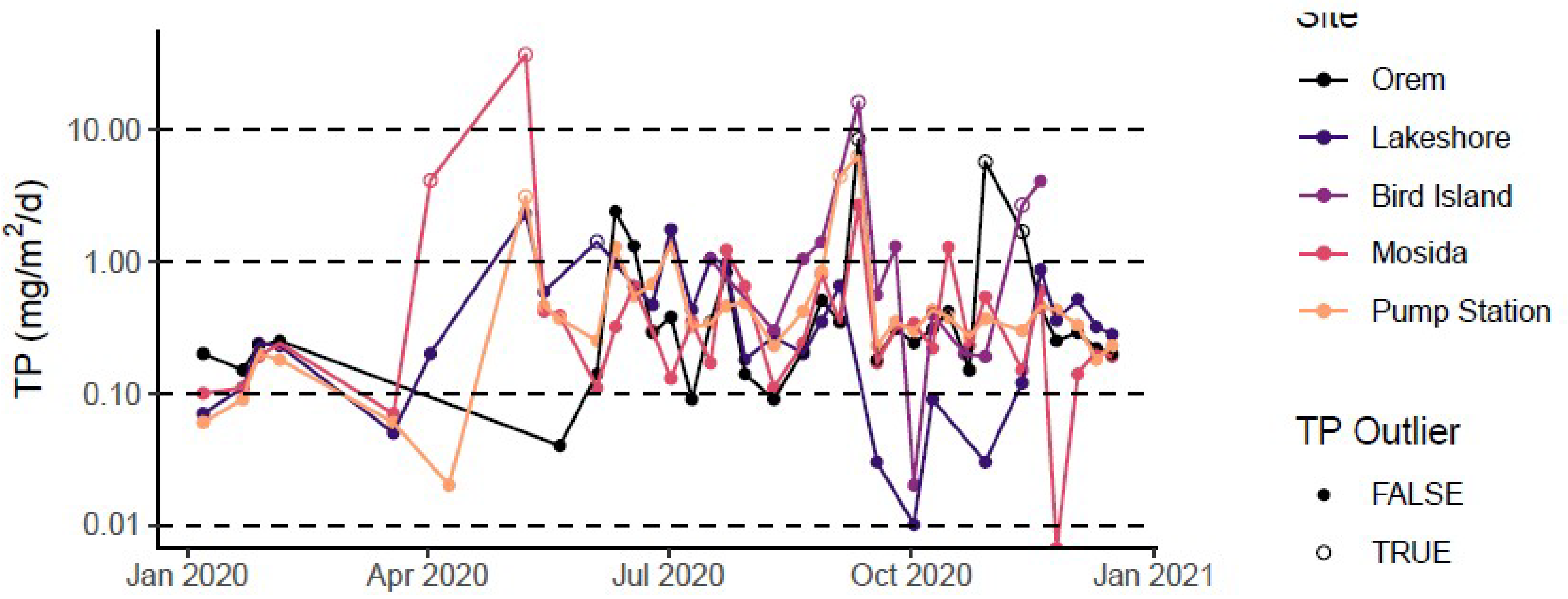
- **Source is coming from outside the lake**
  1. Site(s) on the shoreline have higher fluxes than the observed stations
  2. Wind concentrates flux over the lake
- **Source is coming from inside the lake**
  3. Contamination from bird droppings, volatilized material from the island
  4. Spray from lake water

Goal: evaluate support/non-support for each hypothesis with available information

Hypothesis 1: source from site(s) on the shoreline

- **If no attenuation occurs…**
  - Winds from NW should lead to BI signal similar to Pump Station
  - Winds from NE should lead to BI signal similar to Orem
  - Winds from SE should lead to BI signal similar to Lakeshore (closest sampler!)
  - Winds from SW should lead to BI signal similar to Mosida
- **Does this play out? We can look at time series to see if signals match up**



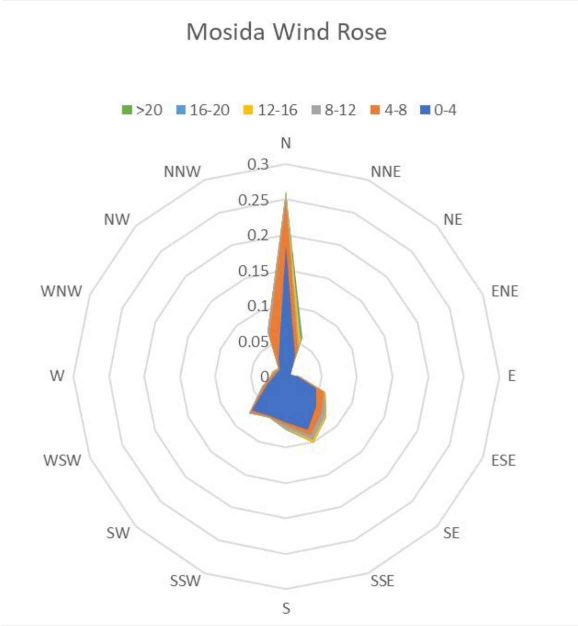


TP (mg/m²/d)
10.00
1.00
0.10
0.01
Jan 2020
Apr 2020
Jul 2020
Oct 2020
Jan 2021
Site
Orem
Lakeshore
Bird Island
Mosida
Pump Station
TP Outlier
FALSE
TRUE

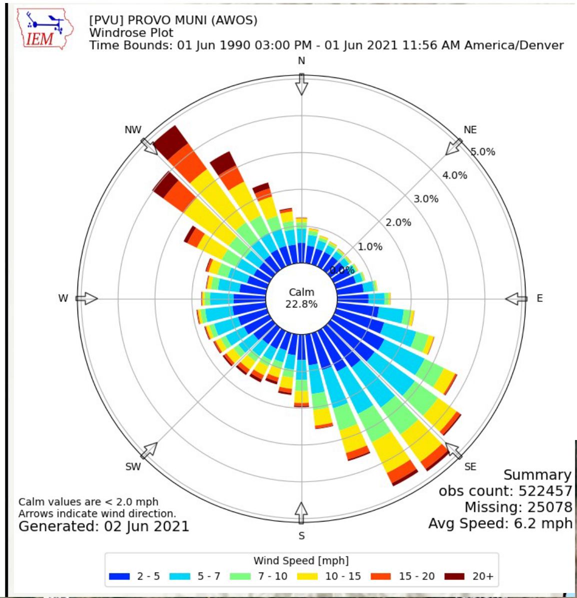
Hypothesis 1: source from site(s) on the shoreline

- **If there is a land-based source, the current shoreline samplers aren't catching it**
- **Hypothesis put forth in T. Miller report:**
  - "The windrose… shows that Bird Island would be most influenced by shoreline rates from the northwest shore of Utah Lake and the area north of the Mosida sampling site. Neither of these areas have a shoreline sampler. The northwest shore area does not have much agriculture but is experiencing urban expansion in the cities of Lehi and Eagle Mountain. We are exploring the possibility of placing a sampler in this area for future collections."

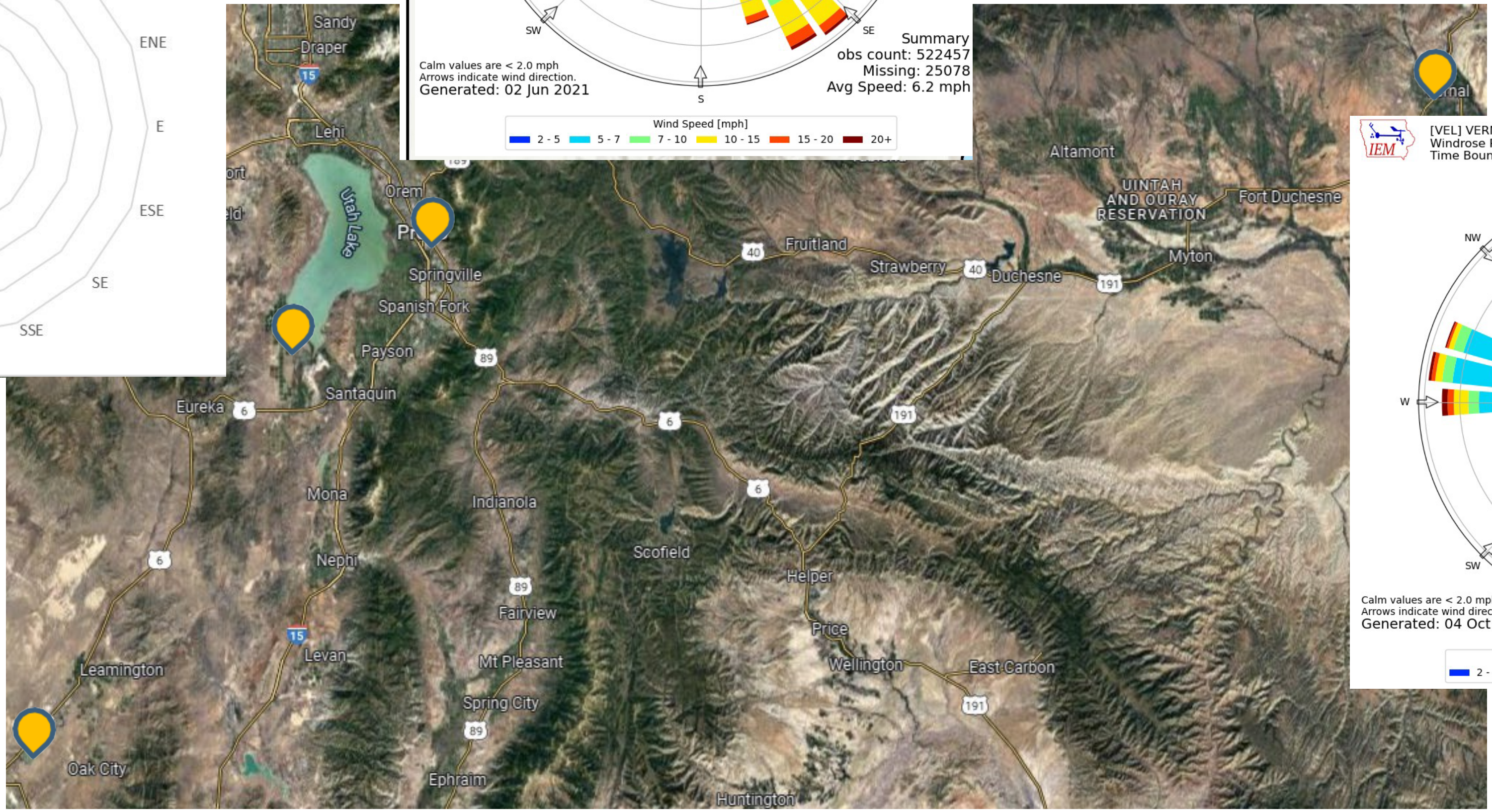
Wind Roses



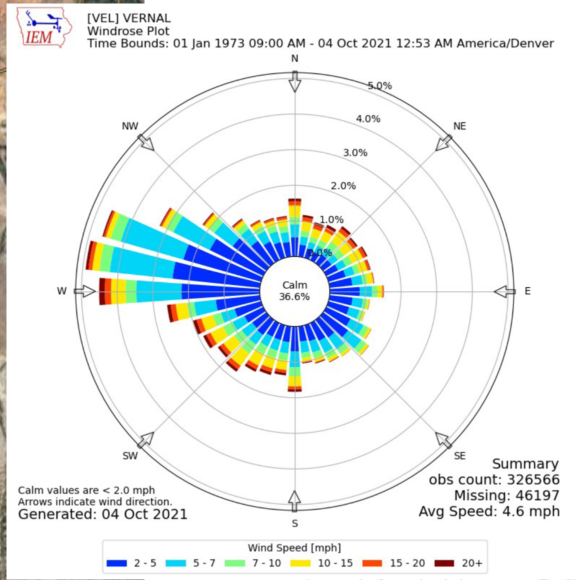
Mosida Wind Rose
>20 16-20 12-16 8-12 4-8 0-4
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
0.3
0.25
0.2
0.15
0.1
0.05
0



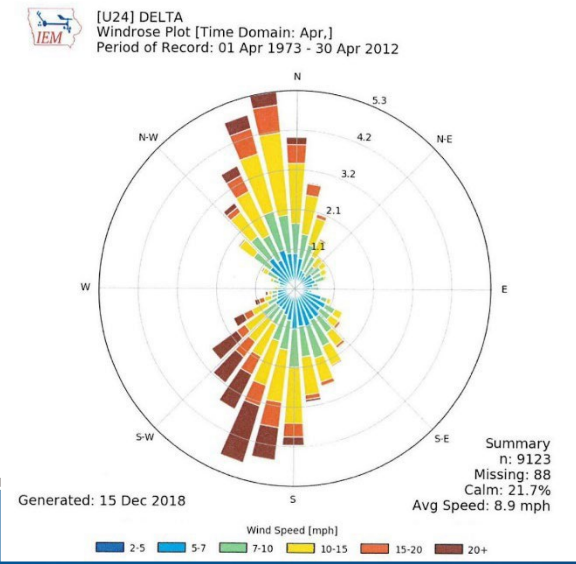
[PVU] PROVO MUNI (AWOS)
Windrose Plot
Time Bounds: 01 Jun 1990 03:00 PM - 01 Jun 2021 11:56 AM America/Denver
N
NE
E
SE
S
SW
W
NW
5.0%
4.0%
3.0%
2.0%
1.0%
Calm
22.8%
Calm values are < 2.0 mph
Arrows indicate wind direction.
Generated: 02 Jun 2021
Summary
obs count: 522457
Missing: 25078
Avg Speed: 6.2 mph
Wind Speed [mph]
2 - 5
5 - 7
7 - 10
10 - 15
15 - 20
20+



Sandy
Draper
Lehi
Orem
Utah Lake
Springville
Spanish Fork
Payson
Santaquin
Eureka
Mona
Nephi
Levan
Leamington
Oak City
Indianola
Fairview
Mt Pleasant
Spring City
Ephraim
Scofield
Helper
Price
Wellington
East Carbon
Huntington
Fruitland
Strawberry
Duchesne
Altamont
UINTAH AND OURAY RESERVATION
Myton
Fort Duchesne



[VEL] VERNAL
Windrose Plot
Time Bounds: 01 Jan 1973 09:00 AM - 04 Oct 2021 12:53 AM America/Denver
N
NE
E
SE
S
SW
W
NW
5.0%
4.0%
3.0%
2.0%
1.0%
Calm
36.6%
Calm values are < 2.0 mph
Arrows indicate wind direction.
Generated: 04 Oct 2021
Summary
obs count: 326566
Missing: 46197
Avg Speed: 4.6 mph
Wind Speed [mph]
2 - 5
5 - 7
7 - 10
10 - 15
15 - 20
20+



[U24] DELTA
Windrose Plot [Time Domain: Apr,]
Period of Record: 01 Apr 1973 - 30 Apr 2012
N
N-E
E
S-E
S
S-W
W
N-W
5.3
4.2
3.2
2.1
1.1
Summary
n: 9123
Missing: 88
Calm: 21.7%
Avg Speed: 8.9 mph
Generated: 15 Dec 2018
Wind Speed [mph]
2-5
5-7
7-10
10-15
15-20
20+

More Wind Roses

Hypothesis 1: source from site(s) on the shoreline

- **Wind direction alone cannot fully support hypothesis → must also have flux source measured**
- **To demonstrate support for this hypothesis, a sampler would need to be placed and fluxes measured**

- From David Gay: “One way you might be able to show that this is a real signal goes something like this. The Lakeshore sampling site is not capturing the urban “plume” moving over the lake (plume is to the north). So put another shore line sampler north of Lakeshore where it would capture these high samples.”

Hypothesis 2: Wind patterns concentrate flux over the lake

- **Hypothesized in T. Miller report:**
  - "We expect that this is because of variable winds occurring across Utah Lake (i.e., downslope SE and east winds from the canyons during evening and early morning; SW winds during afternoon; and a combination during the passage of frontal boundaries – the combination of which could serve to concentrate dust and aerosols over the lake."
- **Pattern shown in other systems is attenuation, not concentration** (VanCuren et al. 2012)

Hypotheses 3 & 4: Source from inside the lake

David Gay comments

- **“I would expect criticism will come on these observations, such as**
  - Can you prove that there is no contamination going on in the lake that is not representative of the lake surface?
  - Condensation into the bucket because the sampler is colder than the water, for example?
  - Mist/droplets from waves being added to the sample?
  - Do the wet only samples also show this difference? Is the difference in the dry side?
  - Bird poop in the dry side? Are the birds using it as a resting place (although then you get into the argument of bird feces as a source)?”
- **“I would again recommend beefing up the QA information for the Bird Island sampler. Prove to the reader that you have QA info that shows these samples are valid.”**

Hypothesis 3: Contamination from bird droppings, volatilized material from Bird Island

- **Potential sources:**
  - Bird droppings on dry side bucket
  - Volatilized material from the island
- **We don't have enough wet/dry samples to analyze this**
- **Bird droppings are not noted in the field sampling notes, but photos are not available to show absence of bird droppings**

Hypothesis 4: lake water

- **Potential sources:**
  - Mist/droplets from waves
  - Condensation into collection bucket
- **If this hypothesis was true, we would expect the AD samples to carry a chemical signature of lake water**

Addressing Hypotheses 3 & 4

- **David Gay comments**
  - "I would again recommend beefing up the QA information for the Bird Island sampler. Prove to the reader that you have QA info that shows these samples are valid."
  - "You might want to pull out very short term samples (2 or 3 day samples) that have not likely had a long time to collect contamination; i.e. to provide evidence that it is the atmosphere and not some other problem occurring. If you find the same with wet deposition side of the sampler and short term samples, this will give you more evidence that the observations are correct, and that the urban core and shifted wind on the east side of the lake are a major contributor."

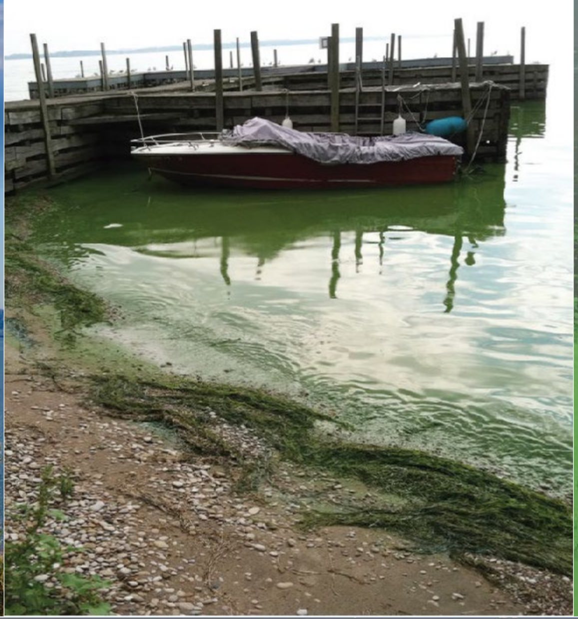
Decision Points

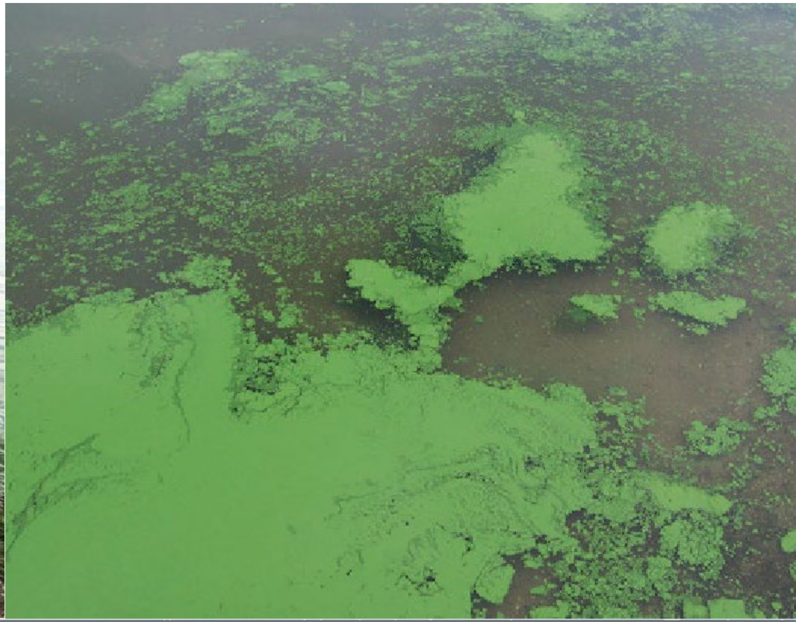
Goal: evaluate support/non-support for each hypothesis with available information

1. **Should Bird Island data be used?**
   - If so, how?
   - If not, why not?
2. **How should we compute attenuation?**

Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | December 22, 2022





Decision Points

1. **Should Bird Island data be used?**
   - If so, how?
   - If not, why not?
2. **How should we compute attenuation?**

Context from last meeting

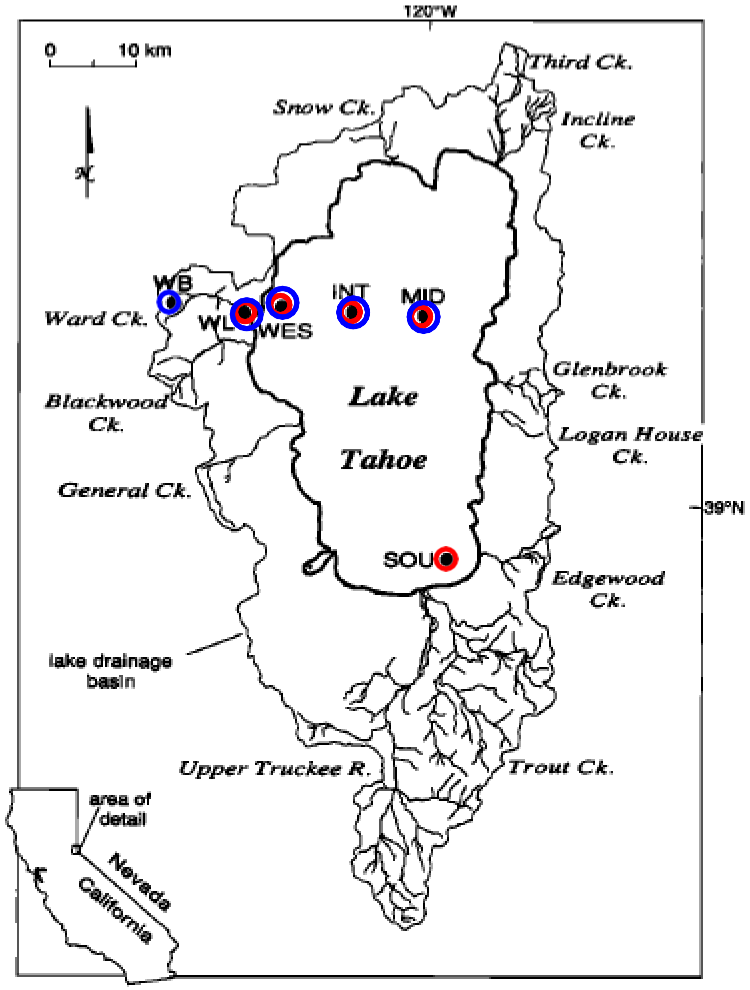
- **Presented Bird Island flux data**
- **Presented potential hypotheses for Bird Island fluxes**
  - Source is coming from outside the lake (represents AD source)
  1. Site(s) on the shoreline have higher fluxes than the observed stations
  2. Wind concentrates flux over the lake
  - Source is coming from inside the lake (represents a flux, but not necessarily AD)
  3. Contamination from bird droppings, volatilized material from the island
  4. Spray from lake water
  - No single hypothesis was ruled out or provided definitive support with available data
- **Discussed literature evidence**
  - Jassby, VanCuren (Lake Tahoe)
  - Potential other sources, e.g., Lake Taihu

Literature Review

- **Reviewed Lake Tahoe studies (see following slides)**
- **Searched for other studies that evaluated attenuation**
  - Lake Taihu study only had shoreline sampling sites
  - Searched for others, but could not find other studies that deployed mid-lake samplers

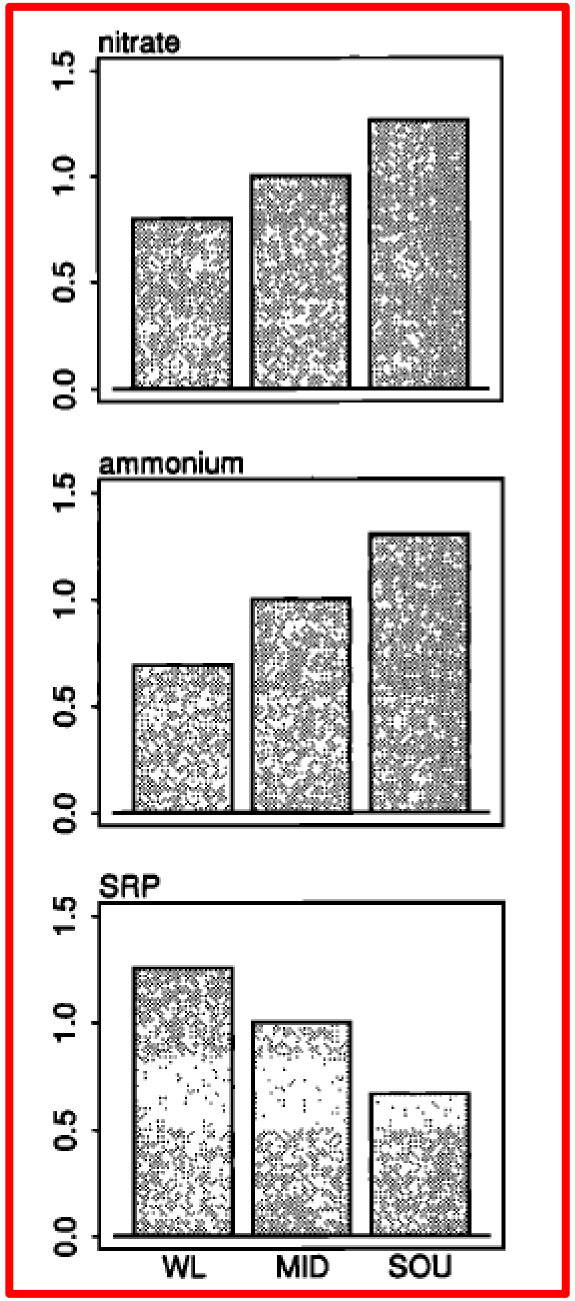
Jassby et al. 1994: Lake Tahoe

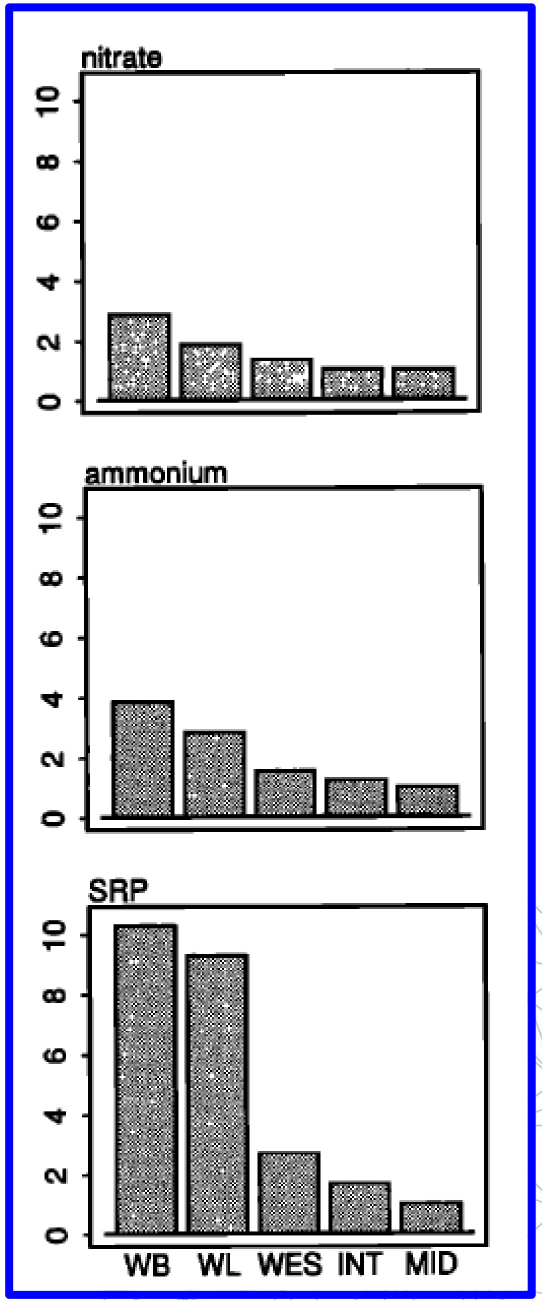
- **Buoy buckets: bulk buckets (mostly dry dep.)**
  - June-September
  - Mostly dry deposition
- **Snow tubes**
  - October-May
  - Precipitation collectors (90% of precip is snow)



Jassby et al. 1994: Lake Tahoe

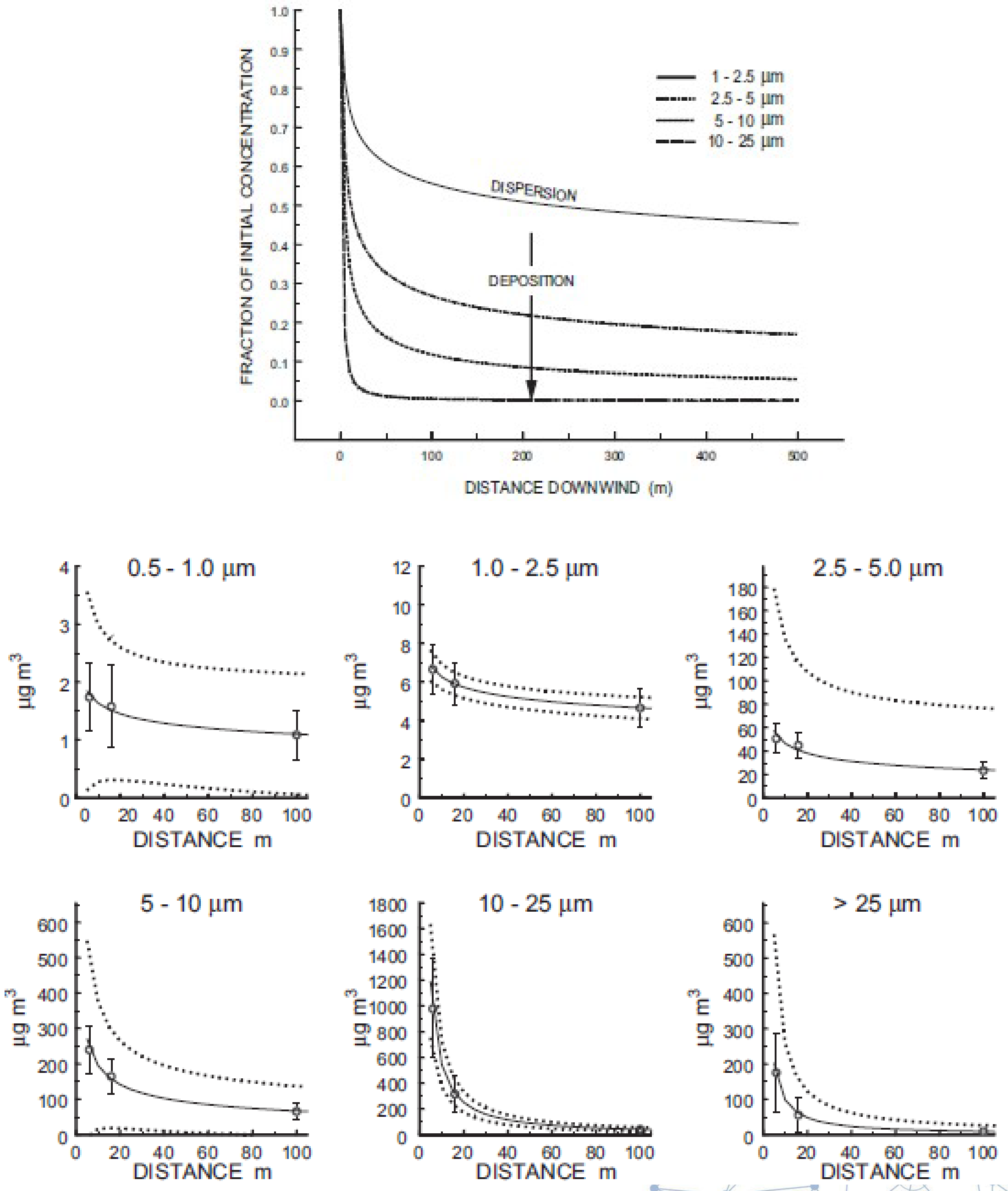
- Buoy buckets (bulk, mostly dry dep.)
  - NO_3^- and NH_4^+: WL > MID > SOU
  - SRP: WL > SOU, MID not different from either
  - "Suggests the possibility of canopy uptake of gaseous and aerosol N compounds…"
- Snow tubes (mostly wet snow dep.)
  - All constituents: loading decreases from W to E
  - Likely due to decrease in precip from W to E
- Findings from wet+dry sampler at WL
  - Dry dep makes up 28% of NO_3^- and 33% of NH_4^+
  - In combination, snow + buoy bucket data indicate "Ward Lake Level deposition probably overestimates lakewide DIN deposition by at most a factor of 3 and probably closer to a factor of 2"
  - SRP deposition at Ward lake is greater than mid lake by a factor of 9.3 in snow tubes and 1.3 in buoy buckets





VanCuren et al. 2012: Lake Tahoe (Atmospheric Environment #1)

- Observed aerosol size and concentrations in relation to local sources
- Found that road dust was a major source of aerosol deposition to the lake
- Aerosol load decreased with distance from source, with larger particles falling out nearer to the source



VanCuren et al. 2012: Lake Tahoe (Atmospheric Environment #2)

- **Observed aerosol size and concentration during monitoring cruises**
- **Aerosol concentrations sourced from regional sources were lower than those sourced from local sources**
- **Influence of local sources (e.g., urban areas) was highly localized, with fluxes dropping off moving farther away from shore**
- "The on-lake data reported here indicate that aerosols over the lake, and thus dry deposition to the lake, are dominated by the same processes that control onshore emissions, and that the impact is strongest in the near shore areas of the lake."

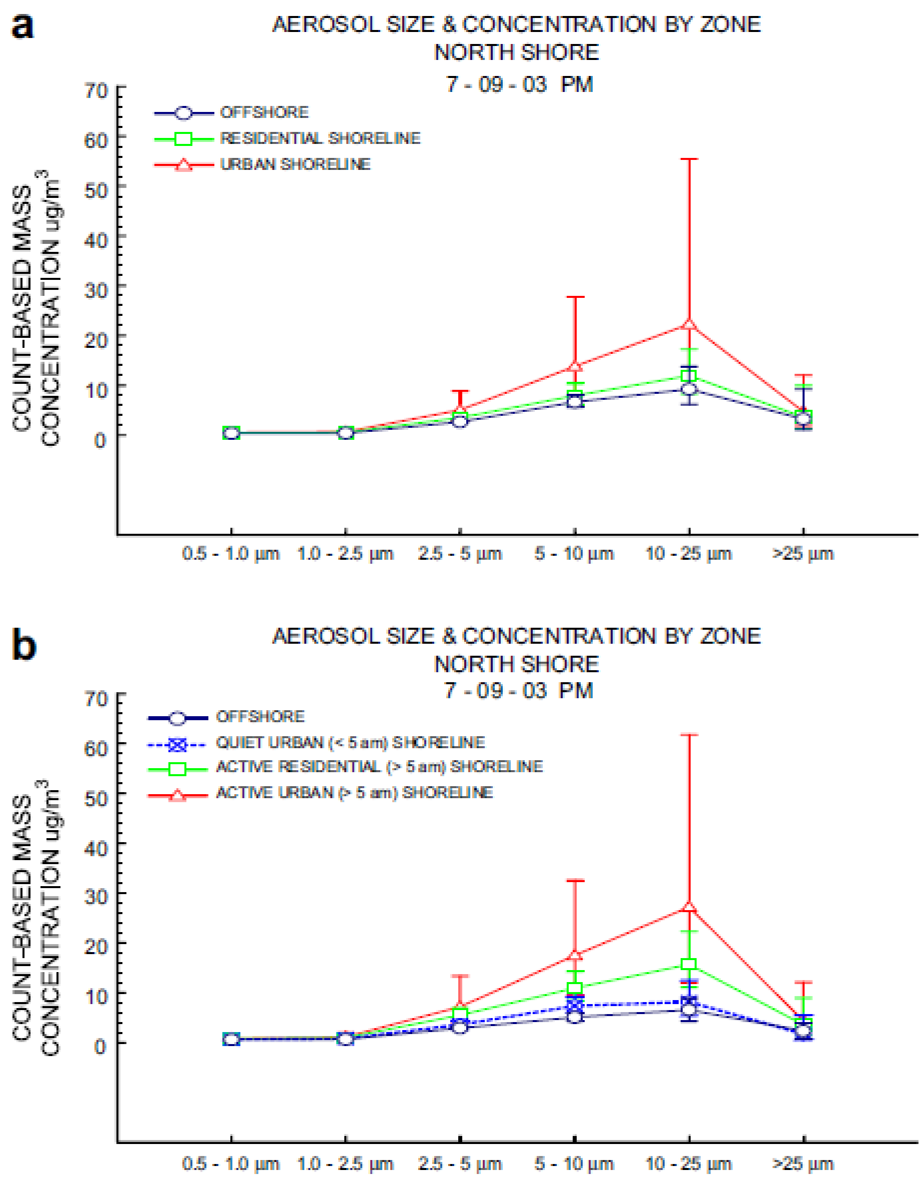


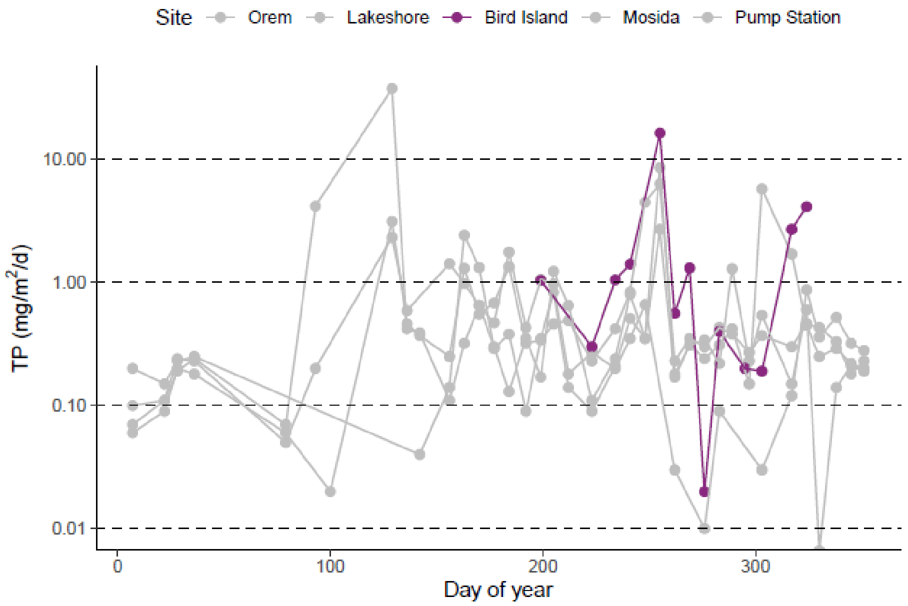
Fig. 4. Size-resolved aerosol mass concentrations for different areas during the north shore evening (a) and morning (b) cruises. Vertical bars are $\pm 1\sigma$ for the population of 1 min samples within each group.

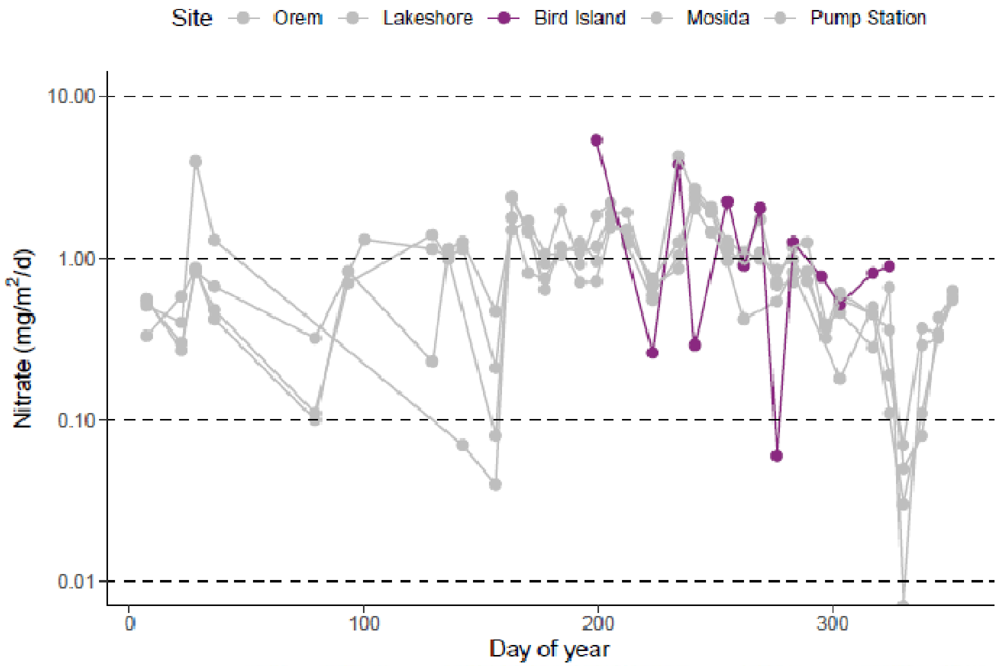
Takeaways from Lake Tahoe Papers

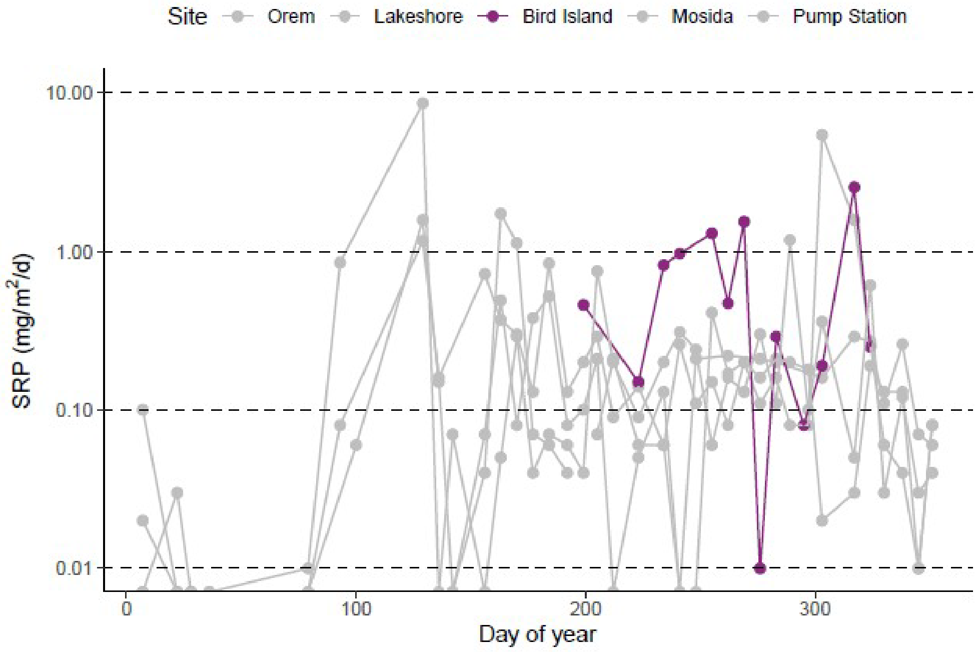
- **Attenuation patterns may differ between wet and dry deposition due to**
  - Seasonality
  - Precipitation patterns
  - Canopy uptake
- **AD from local sources dissipates moving farther away from source**
- **AD from regional sources likely remains steady, barring any weather patterns that impact transport**

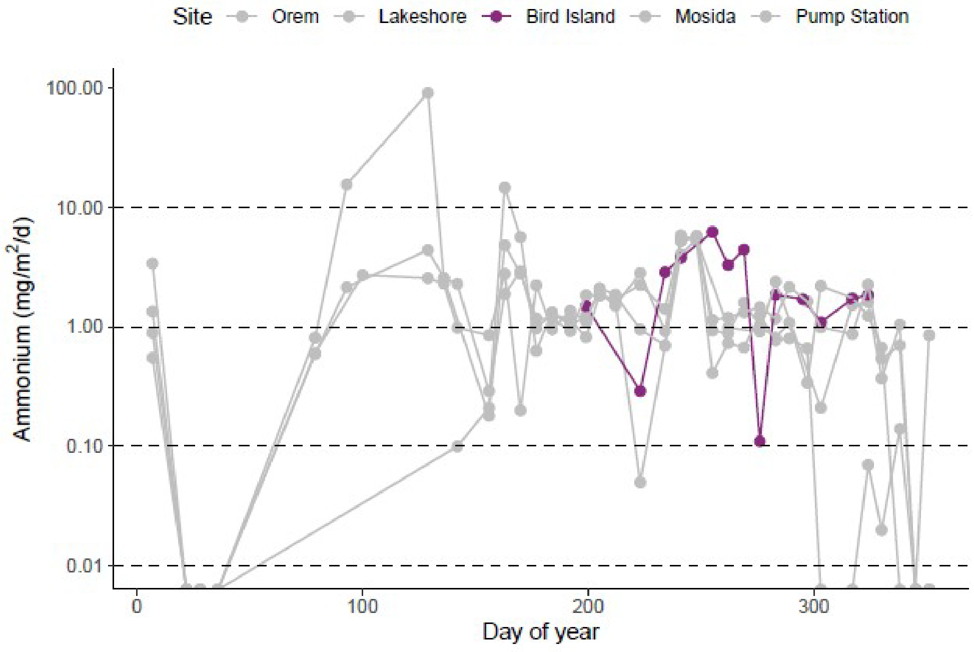
- **How does this relate to interpreting Utah Lake data?**
  - Parsing local vs. regional sources
  - Cannot evaluate wet vs. dry because both research teams provided only bulk

Bird Island Fluxes

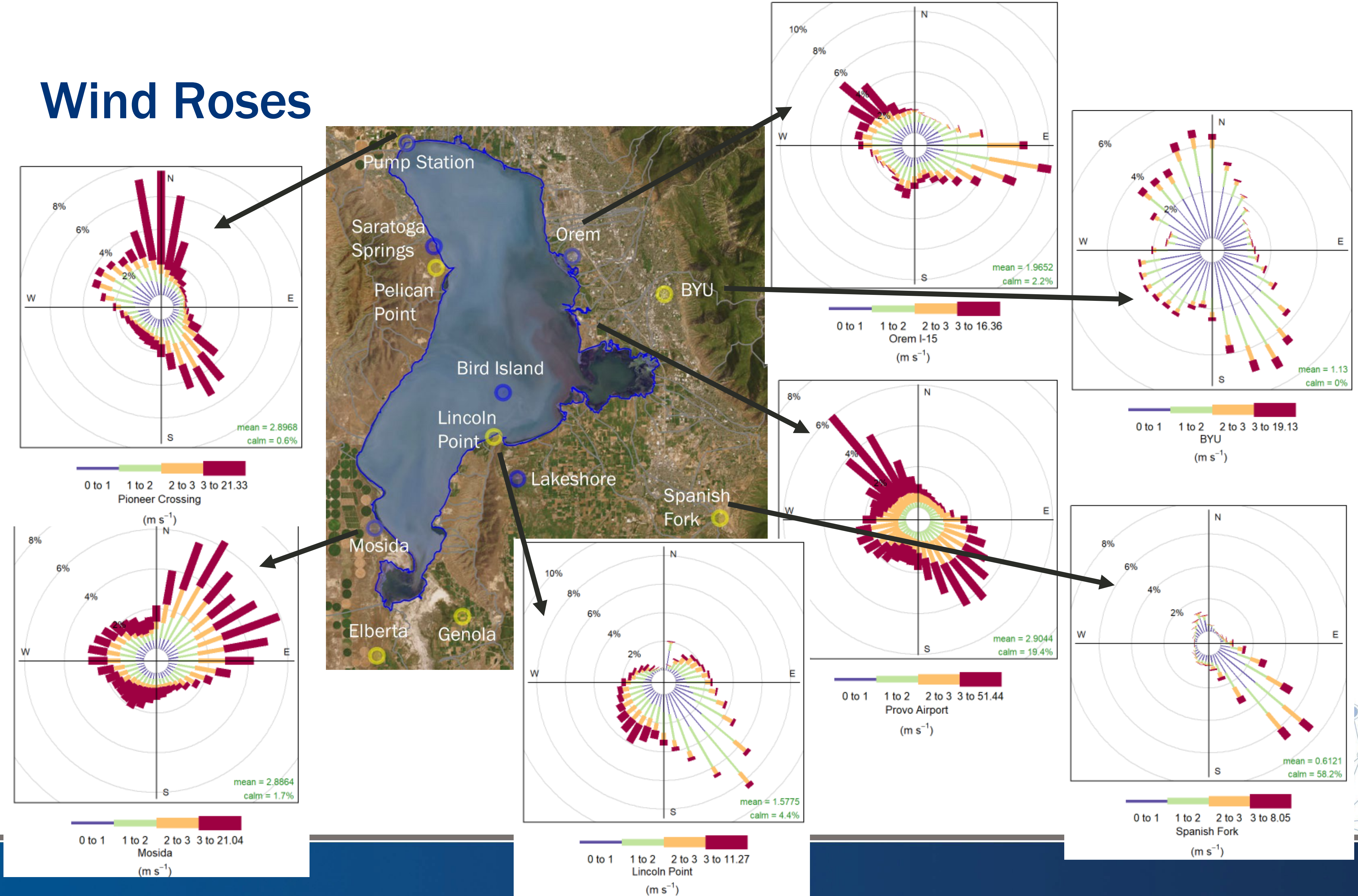








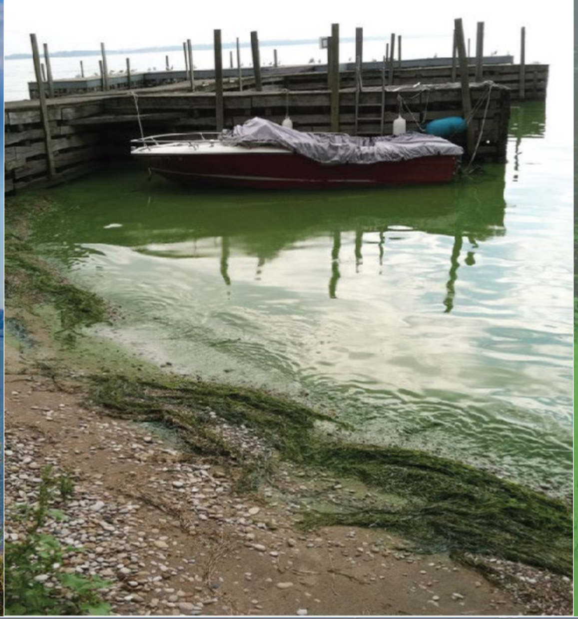
Wind Roses

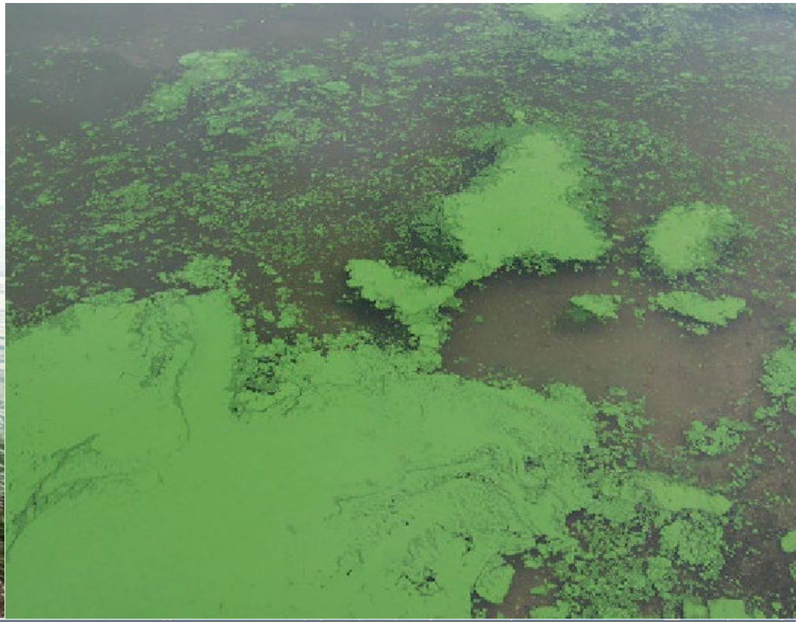


Pump Station
Saratoga Springs
Pelican Point
Orem
BYU
Bird Island
Lincoln Point
Lakeshore
Spanish Fork
Mosida
Elberta
Genola
mean = 2.8968
calm = 0.6%
0 to 1 1 to 2 2 to 3 3 to 21.33
Pioneer Crossing
mean = 2.8864
calm = 1.7%
0 to 1 1 to 2 2 to 3 3 to 21.04
Mosida
mean = 1.5775
calm = 4.4%
0 to 1 1 to 2 2 to 3 3 to 11.27
Lincoln Point
mean = 1.9652
calm = 2.2%
0 to 1 1 to 2 2 to 3 3 to 16.36
Orem I-15
mean = 1.13
calm = 0%
0 to 1 1 to 2 2 to 3 3 to 19.13
BYU
mean = 2.9044
calm = 19.4%
0 to 1 1 to 2 2 to 3 3 to 51.44
Provo Airport
mean = 0.6121
calm = 58.2%
0 to 1 1 to 2 2 to 3 3 to 8.05
Spanish Fork

Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | January 5, 2023





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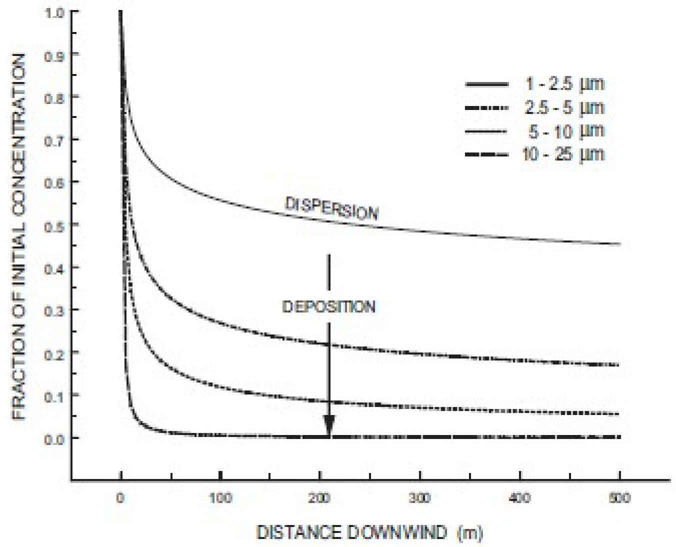
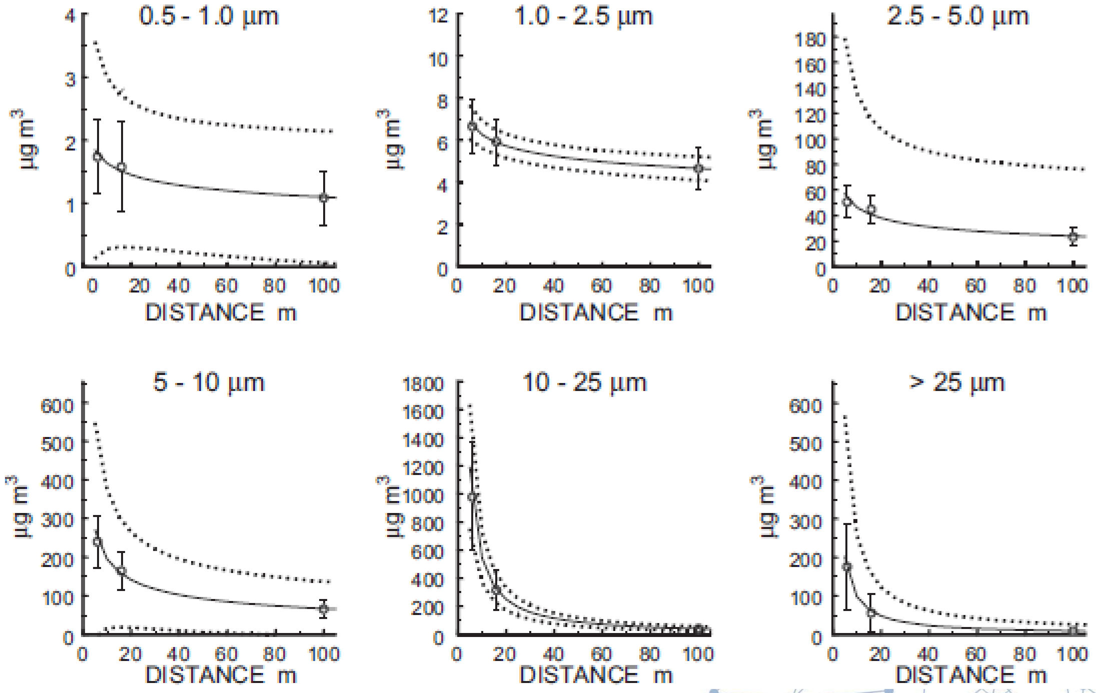
Action Items from Last Meeting

1. Explore particle size in relation to potential impact on dispersion vs. deposition
2. Prepare speciation data

VanCuren et al. 2012: Lake Tahoe (Atmospheric Environment #1)

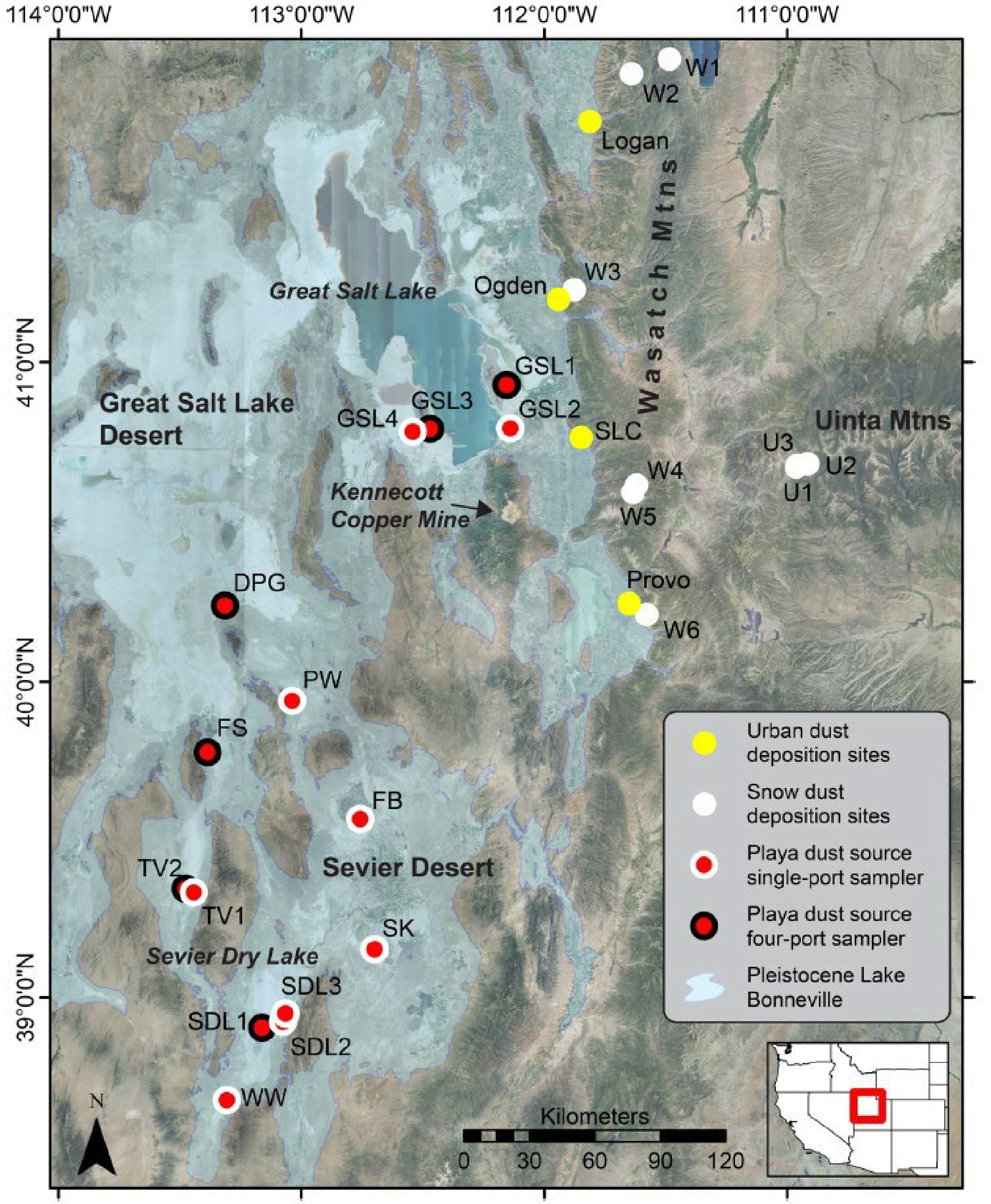
- Recall: one of the Lake Tahoe papers evaluated the extent of dispersion vs. deposition of various particle sizes
- Smaller particles are more prone to dispersion
- Larger particles are more prone to deposition (i.e., attenuation away from source)





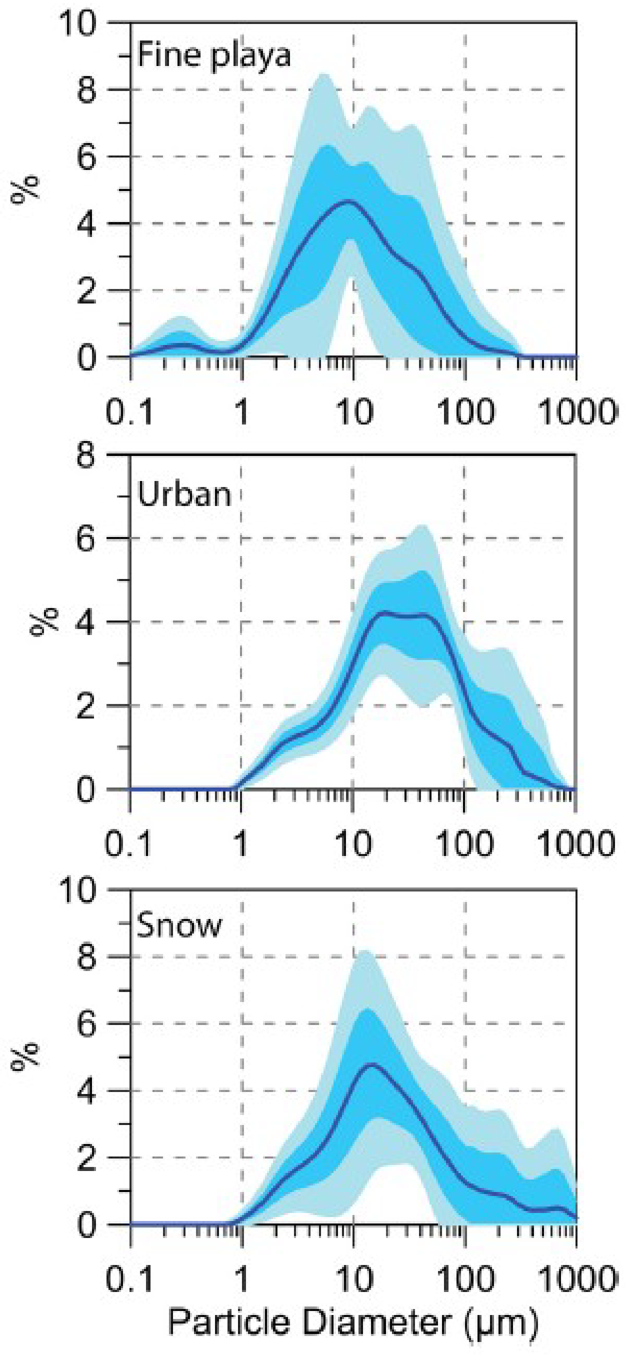
Goodman et al. 2019

- **Trace element chemistry of atmospheric deposition dust in the Wasatch Front**
  - Urban Dust sampler in Provo
  - Snow Dust sampler in Provo
  - Playa Dust samplers in Sevier Desert
- **Evaluated particle size in addition to concentration and trace elements**



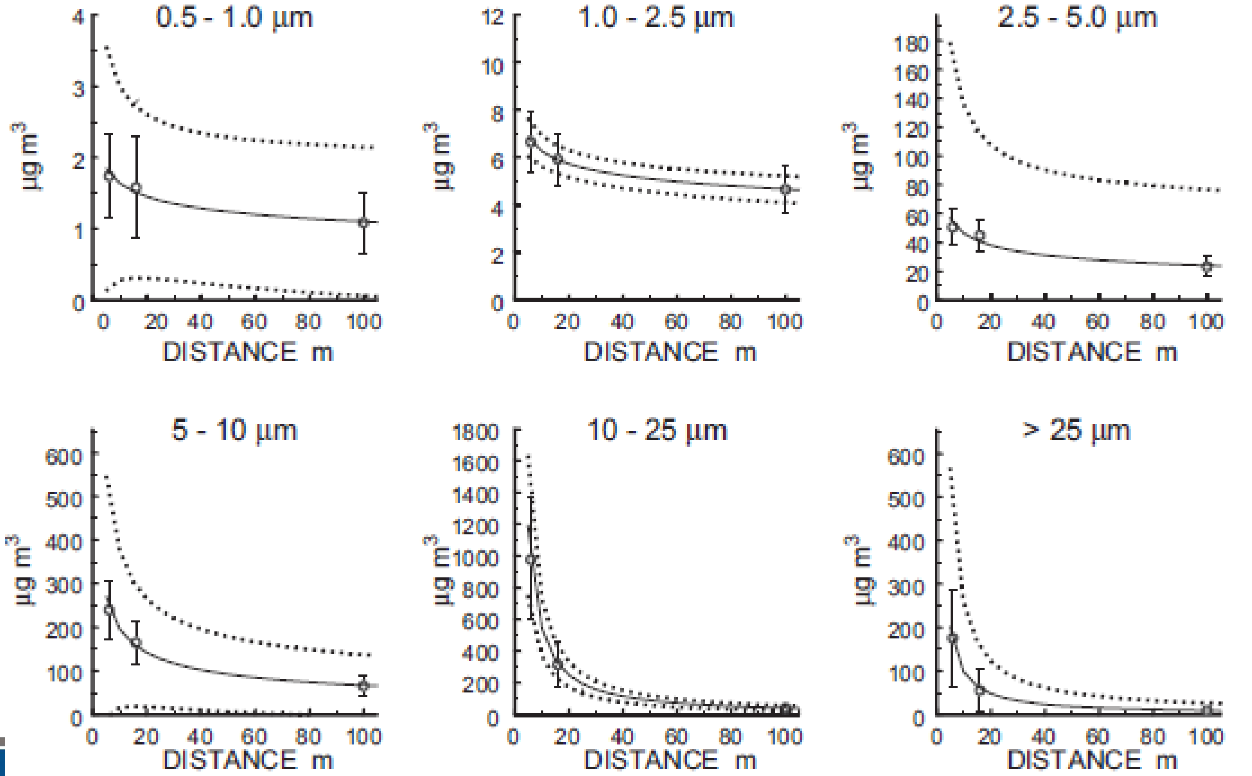
Goodman et al. 2019

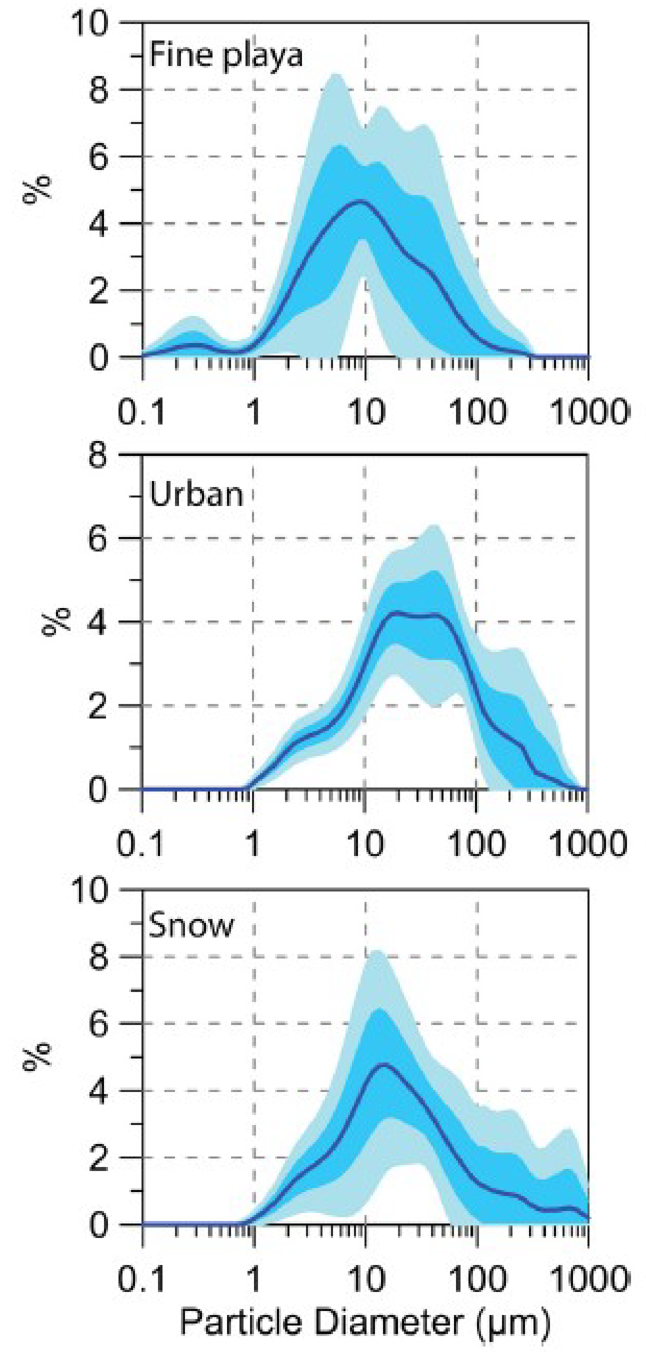
- **Grain sizes were similar between fine playa, snow, and urban dust**
- **Most common grain size:**
  - Playa: 10 µm
  - Urban: 20 µm
  - Snow: 20 µm



Comparing grain size to attenuation

Based on data observed from VanCuren et al., grain sizes of 10-20 µm should attenuate rapidly moving away from the source





Decision Point: Attenuation

- **Options (from highest to lowest load):**
  - Assume no attenuation
  - Assume attenuation at x distance (need to choose x), assign background flux beyond attenuation distance
  - Assume attenuation at x distance (need to choose x), assign zero flux beyond attenuation distance

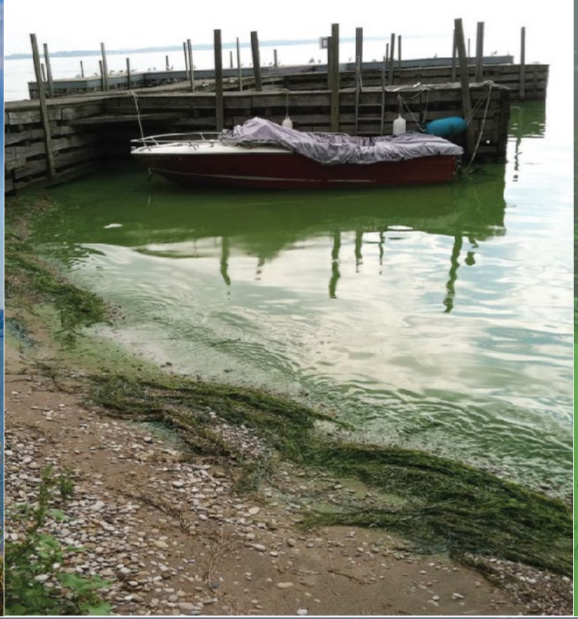
Speciation

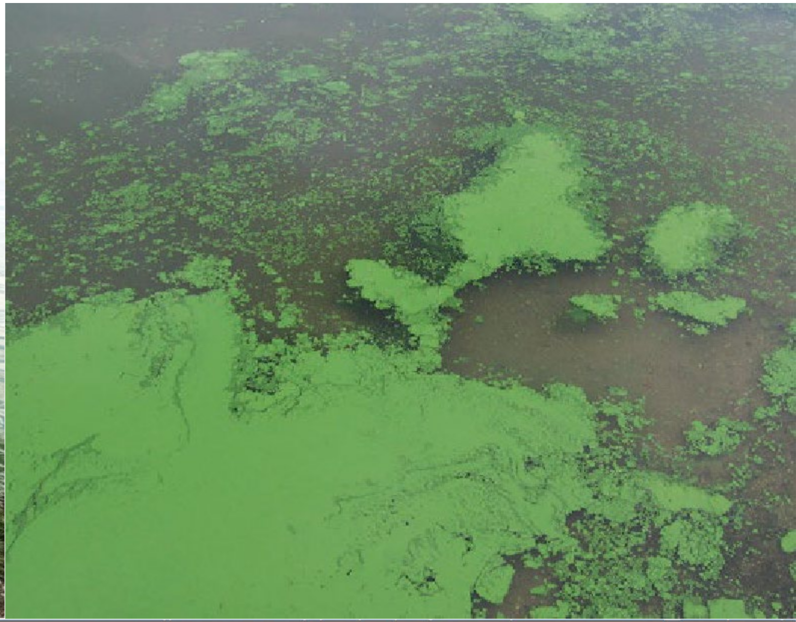
Study	Site	NO_3^-/DIN	NH_4^+/DIN	SRP/TP
Williams data 2020	Orem	0.35	0.65	0.46
Williams data 2020	Lakeshore	0.37	0.63	0.48
Williams data 2020	Mosida	0.10	0.90	0.24
Williams data 2020	Pump Station	0.39	0.61	0.27
Williams data 2020	Bird Island	0.38	0.62	0.32
Brahney 2019	Urban dust			0.75
Brahney 2019	Regional dust			0.34
Reidhead 2019	Utah Lake shoreline sites			0.37
W. Miller 2021	Utah Lake shoreline sites			0.32

- **SRP:TP ratios appear to be more consistent with regional dust than urban dust**
- **Mosida DIN ratios differ from other sites → support for evidence of localized source**

Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | January 10, 2023





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Action Items from Last Meeting

1. Evaluate potential regional “baseline” fluxes

Decision Point: Attenuation

- **Options (from highest to lowest load):**
  - Assume no attenuation
  - Assume attenuation at x distance (need to choose x), assign background flux beyond attenuation distance
  - Assume attenuation at x distance (need to choose x), assign zero flux beyond attenuation distance

Potential approach for calculating lakewide AD

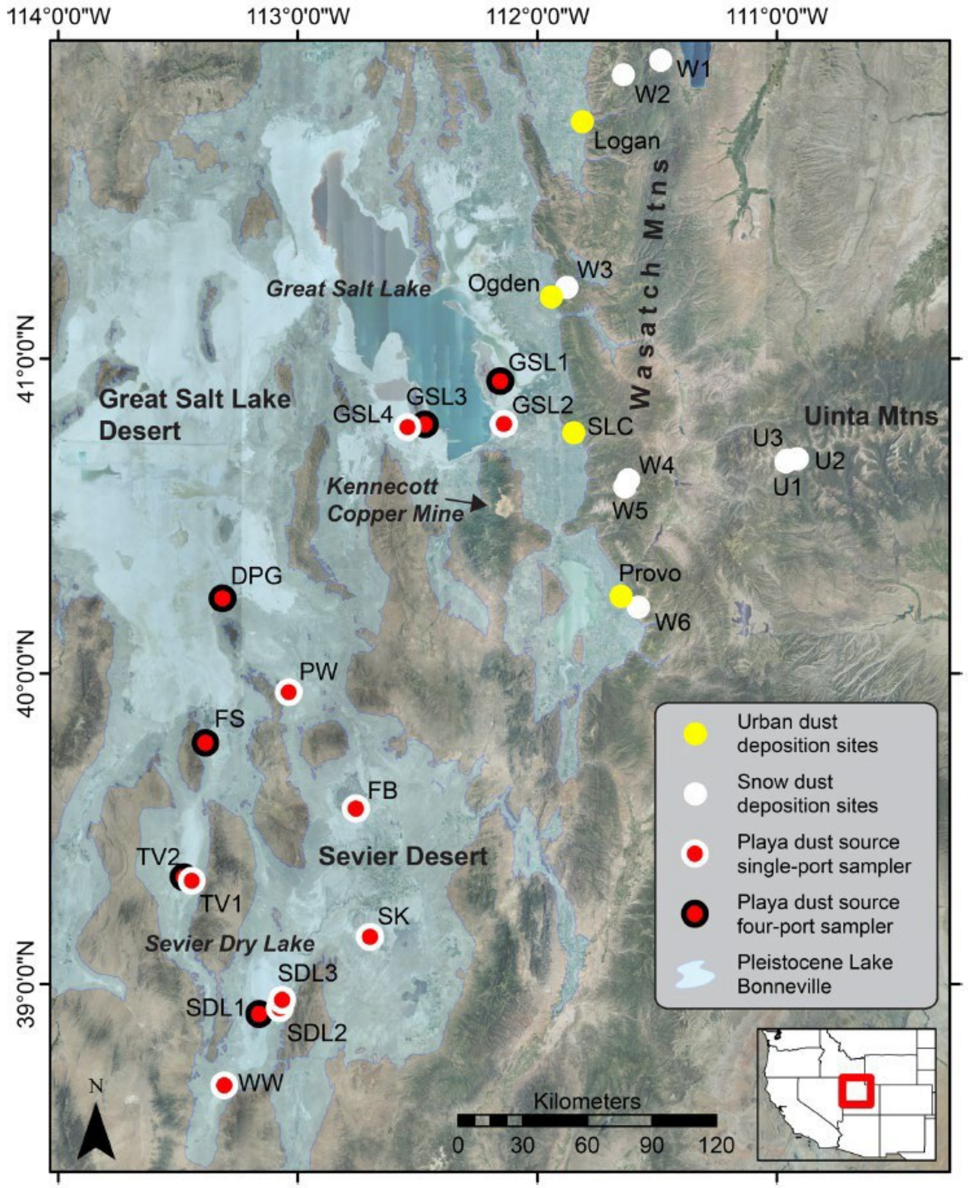
- **Shoreline samplers collect both local and regional fluxes**
- **Anticipate that local sources attenuate moving away from the source**
- **Assume regional sources are distributed fairly uniformly across the basin**
- **Steps:**
  1. Create raster layer of shoreline flux by interpolating between shoreline samplers (e.g., inverse distance weighted interpolation),
  2. Assign decay rate of shoreline flux moving toward mid-lake. The “floor” of the decayed shoreline flux is the regional flux. Base the decay rate on particle size distribution.
  3. Assign regional flux over the rest of the lake,

Estimating regional AD Flux

- **Samplers around the lake include both local and regional fluxes**
- **Local fluxes likely attenuate rapidly away from the source**
- **Intent: establish regional fluxes apart from local fluxes to apply to the lake**
- **Data sources:**
  - Carling 2022 and Goodman et al. 2019: bulk AD on marble collectors
  - Brahney 2019: review of AD information

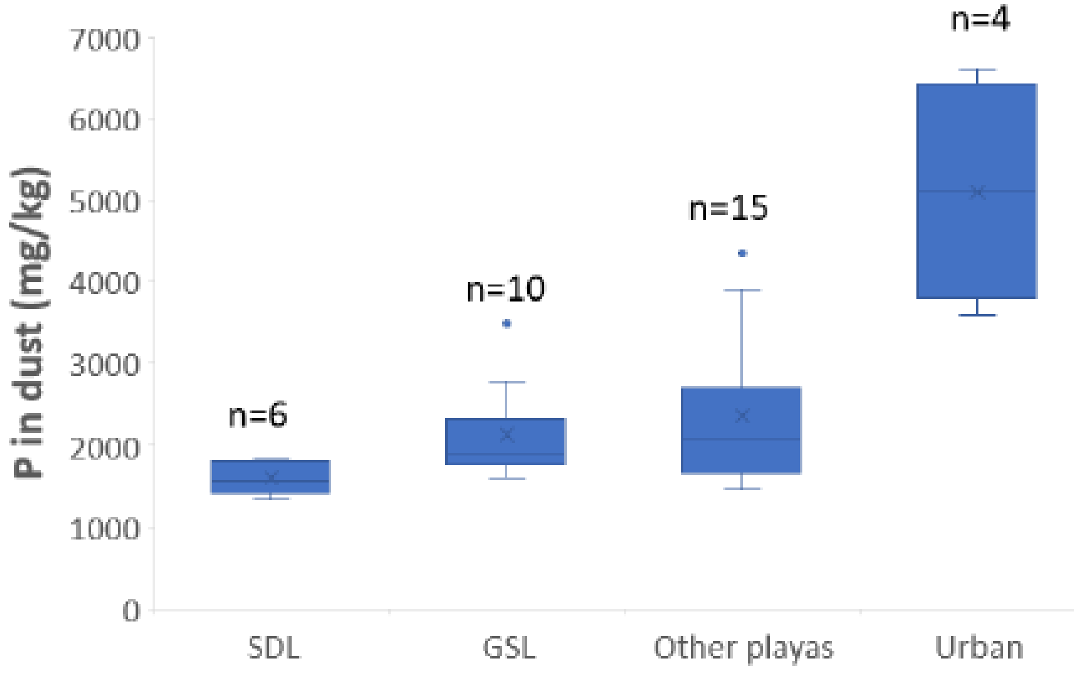
Carling 2022 and Goodman et al. 2019

- **Samplers deployed for 9 2-month periods**
  - Fall 2015
  - Spring 2016
  - June 2017-September 2018
- **Dust fluxes: 0.5-3.8 g/m²/month**
- **2017-2018 annual fluxes**
  - Provo: 28.7 g/m²/year
  - Salt Lake City: 34.9 g/m²/year
  - Ogden: 33.8 g/m²/year
  - Logan: 24.7 g/m²/year



Carling 2022 and Goodman et al. 2019

- **Annual flux: 24.7-34.9 g/m²/yr (urban)**
- **Based on trace element concentrations, 91% of urban dust was sourced from playa dust → 22.5-31.8 g/m²/yr (regional)**
- **Nutrient content:**
  - 1344-4340 mg/kg in playa dust (n = 31)
  - 3598-6608 mg/kg in urban dust (n = 4)
- **For regional fluxes, opt to use playa nutrient content rather than urban**
- **Potential range of TP flux: 30.2-138.0 mg P/m²/yr**



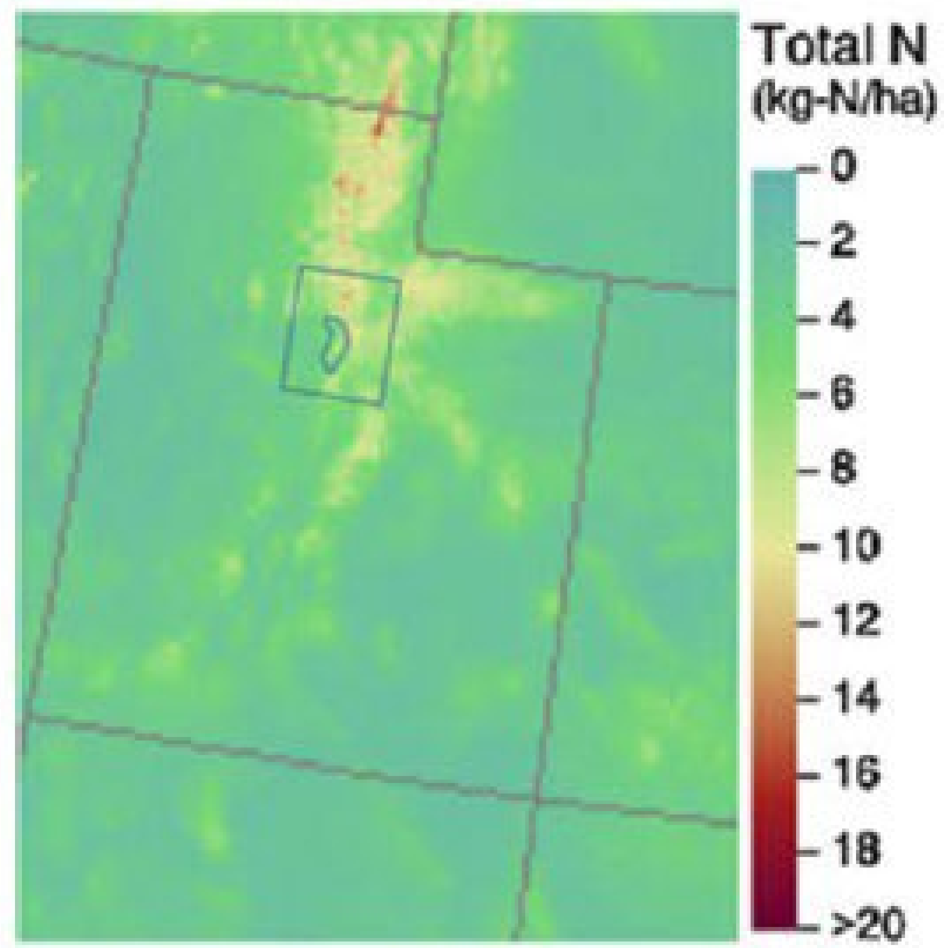
Brahney 2019: Regional TP

- **Range of regional deposition: 1.4-15.6 g/m²/yr**
  - Lower than Goodman
  - Sourced from mountain regions east of CO Plateau
- **P concentration in dust in Wasatch Front: 570-1150 mg/kg**
  - Similar to Goodman
- **Potential range of regional TP dust flux: 0.8-17.9 mg TP/m²/yr**
- **TP wet deposition: used NADP data from four sites in last five years: 2.0-4.1 mg P/m²/yr**

Deposition Region	Site	TP mg/g	Source
Utah/Uinta	DI 2011-2012	4.05	Munroe 2014
Utah/Uinta	DI 2012-2013	3.32	Munroe 2014
Utah/Uinta	D2 2011-2012	4.33	Munroe 2014
Utah/Uinta	D2 2012-2013	3.29	Munroe 2014
Utah/Uinta	D3 2011-2012	5.08	Munroe 2014
Utah/Uinta	D3 2012-2013	2.92	Munroe 2014
Utah/Uinta	D4 2011-2012	2.83	Munroe 2014
Average Uinta		*3.69*	
Utah/Wasatch Front	Lower Red Pine	0.92	Reynolds et al. 2014
Utah/Wasatch Front	Upper Red Pine	0.95	Reynolds et al. 2014
Utah/Wasatch Front	Upper Mill B	0.96	Reynolds et al. 2014
Utah/Wasatch Front	Lower Mill B	0.95	Reynolds et al. 2014
Utah/Wasatch Front	Blind Hollow	0.81	Reynolds et al. 2014
Utah/Wasatch Front	SOLA	0.79	Reynolds et al. 2014
Utah/Wasatch Front	Wasatch 209	1.03	Reynolds et al. 2014
Utah/Wasatch Front	Guardsman 1	0.57	Brahney & Skiles unpublished
Utah/Wasatch Front	D1 2017	0.89	Brahney & Skiles unpublished
Utah/Wasatch Front	Guardsman 2	0.99	Brahney & Skiles unpublished
Utah/Wasatch Front	DI 2017 2	1.15	Brahney & Skiles unpublished
Utah/Wasatch Front	Atwater	0.85	Brahney & Skiles unpublished
Average Wasatch Front		*0.90*	
Colorado	SASP	0.91	Lawrence et al 2010
Colorado	Rappit Ears	0.80	Zhang et al. 2018
Colorado	WillowCreek	0.65	Zhang et al. 2018
Colorado	Berthoud	0.60	Zhang et al. 2018
Colorado	Grizzly	0.66	Zhang et al. 2018
Colorado	Hoosier	0.56	Zhang et al. 2018
Colorado	Grand Mesa	0.68	Zhang et al. 2018
Colorado	McClure	0.63	Zhang et al. 2018
Colorado	Independence	0.57	Zhang et al. 2018
Colorado	ParkCone	0.56	Zhang et al. 2018
Colorado	SASP	0.60	Zhang et al. 2018
Colorado	SCP	0.68	Zhang et al. 2018
Colorado	Wolf Creek	0.63	Zhang et al. 2018
Average Colorado		*0.66*	
Average intermountain		*1.40*	

Brahney 2019: Regional N

- CMAQ model: includes data from CASTNET, NADP, AirMoN, and NADP NTN
- 2013-2017 estimate (last five years of available data)
- TN deposition (wet + dry): 400-750 mg/m²/yr

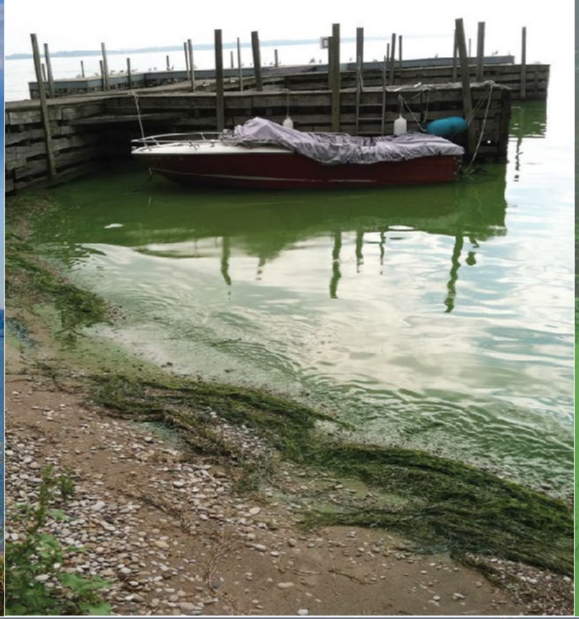
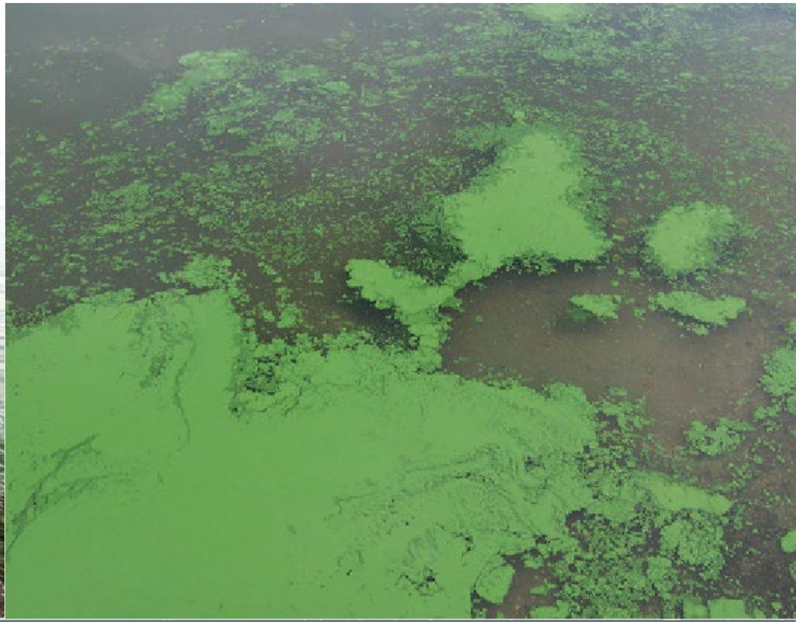


Comparing fluxes across studies

Study	Context	TP flux ($mg/m^2/yr$)	TN flux ($mg/m^2/yr$)
Williams samplers 2020	Shoreline samplers (local + regional bulk)	175.1-906.5	735.5-2801.0
Carling 2022 & Goodman et al. 2019	Regional bulk	30.2-138.0	
Brahney 2019	Regional dust (lower flux attributed to lower dust mass flux)	0.8-17.9	
Brahney 2019	Regional wet deposition	2.0-4.1	
Brahney 2019	Regional wet + dry deposition (CMAQ)		400-750

Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | January 19, 2023

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Action Items from Last Meeting

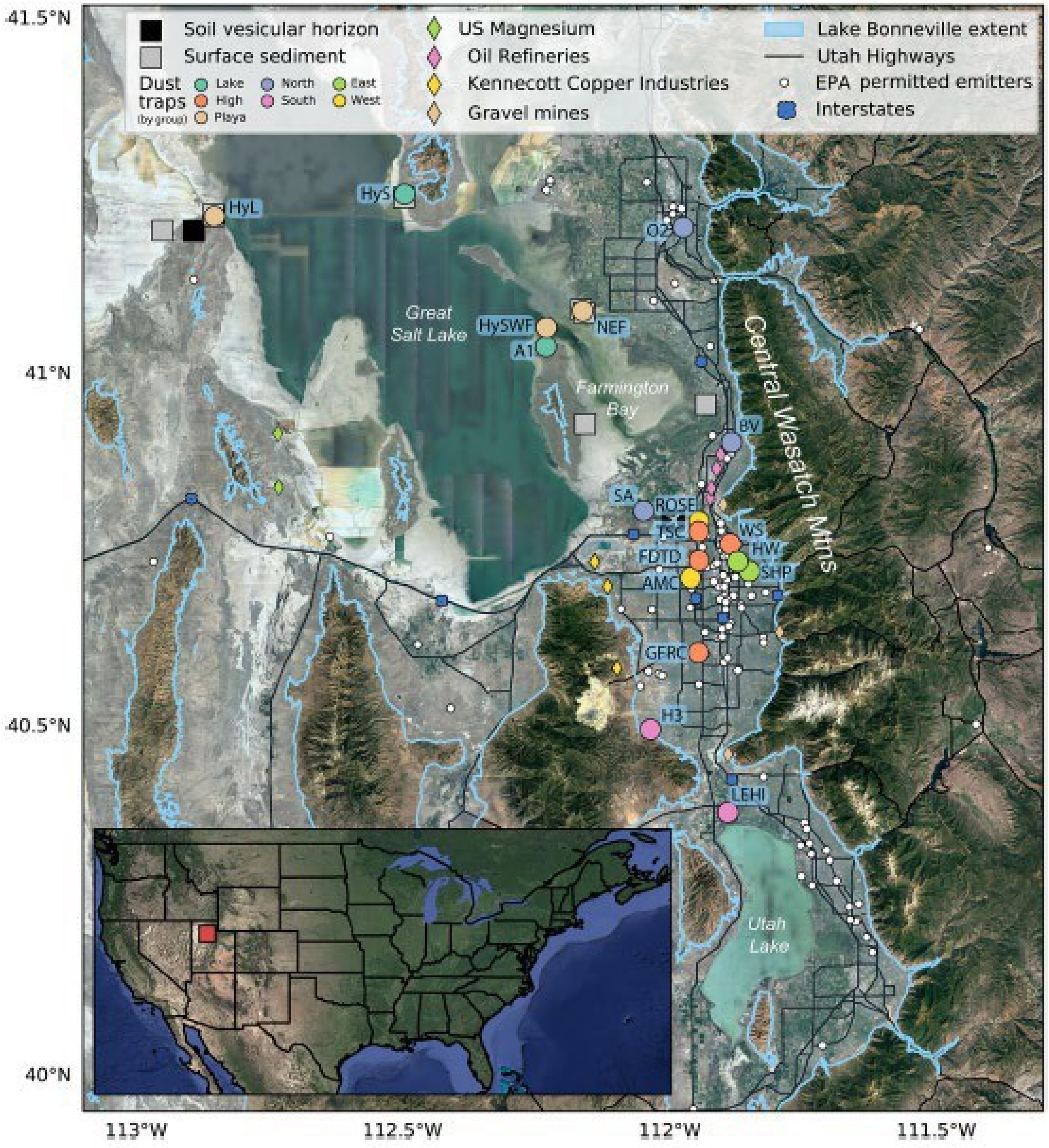
1. Further explore potential regional N and P fluxes
2. Evaluate attenuation evidence from other studies

Regional N and P fluxes

- **Shoreline samplers collect both local and regional AD**
  - If no attenuation occurred, shoreline samplers would all have similar fluxes. We see spikes that are spatially and temporally distinct → evidence of local AD that attenuates
  - Cannot parse out degree of local vs. regional flux from samplers alone
- **Recall: evaluated potential regional fluxes from different studies**
  - Carling 2022
  - Goodman et al. 2019
  - Brahney 2019

Regional N and P fluxes

- **Also looked into Putman et al. 2022, who had a dust sampler in Lehi**
  - Attributed local sources (larger particle sizes) to roads and fields → can parse local vs. regional
  - Can use this as an additional line of evidence to back up Goodman flux values
    - If in the same range, this increases our confidence
    - If not in the same range, can be used to inform the range of potential AD
  - Still tracking down info needed to calculate Lehi-specific fluxes



N:P Ratios in Williams data

- **Calculated N:P ratios in bulk deposition for the 2020 data**
- **By mass: average 3.6**
  - Orem: 3.6
  - Lakeshore: 4.7
  - Bird Island: 1.5 (excluded from average)
  - Mosida: 3.1
  - Pump Station: 2.98
- **Molar: average 8.0**
- **Per Mike Brett's suggestion, calculated potential TP regional flux by dividing CMAQ regional N flux by N:P ratio**
  - Assumes mechanisms for N and P deposition are similar – big assumption!
  - Provide another line of evidence to compare to Goodman/Carling regional TP flux

Comparing fluxes across studies

Study	Context	TP flux (mg/m²/yr)	TN flux (mg/m²/yr)
Williams samplers 2020	Shoreline samplers (local + regional bulk)	175.1-906.5	735.5-2801.0
Carling 2022 & Goodman et al. 2019	Regional bulk	30.2-138.0	
Brahney 2019	Regional dust (lower flux attributed to lower dust mass flux)	0.8-17.9	
Brahney 2019	Regional wet deposition	2.0-4.1	
Brahney 2019	Regional wet + dry deposition (CMAQ)		400-750
N:P ratios from Williams	P flux = Regional TN flux * N:P ratio	111-208	

VanCuren et al. 2012: Lake Tahoe (Atmospheric Environment #2)

- Observed aerosol size and concentration during monitoring cruises
- Aerosol concentrations sourced from regional sources were lower than those sourced from local sources
- Influence of local sources (e.g., urban areas) was highly localized, with fluxes dropping off moving farther away from shore

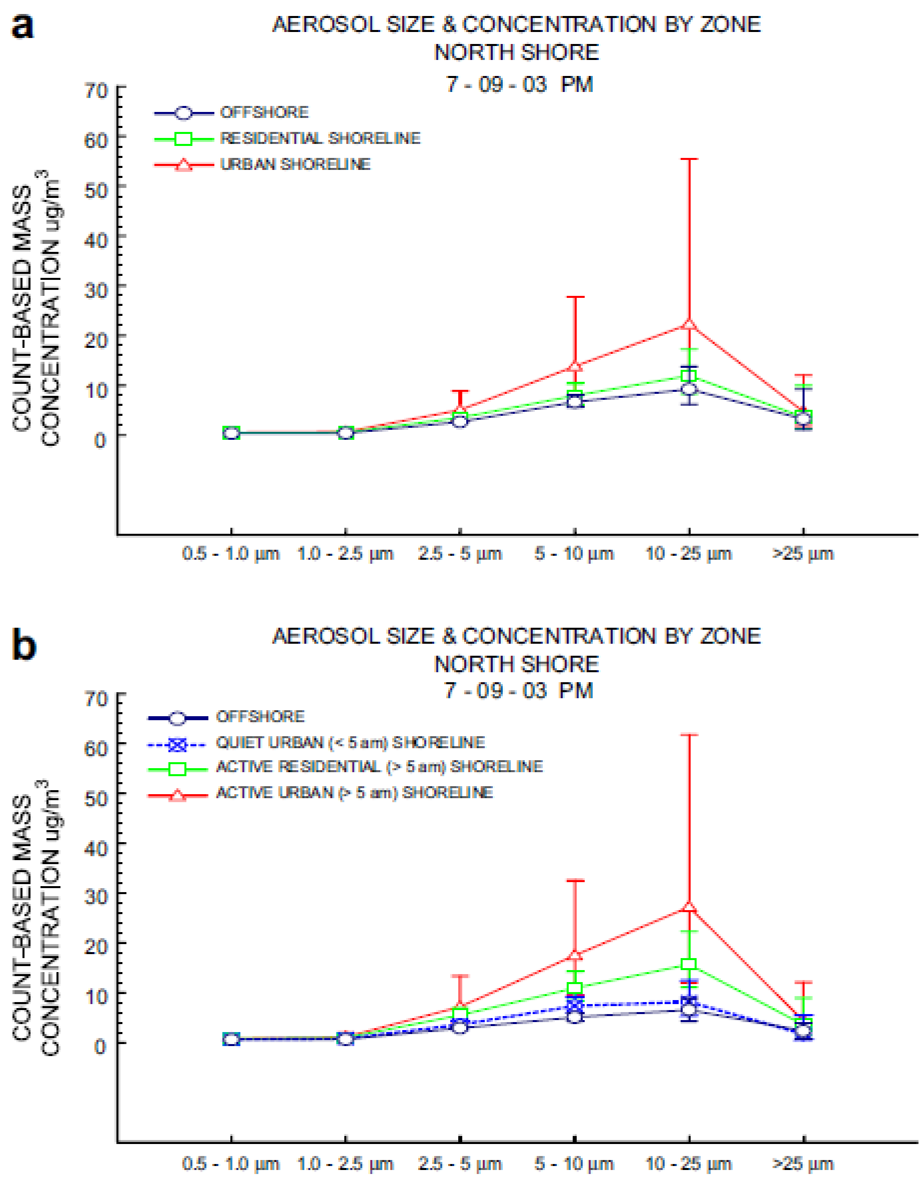
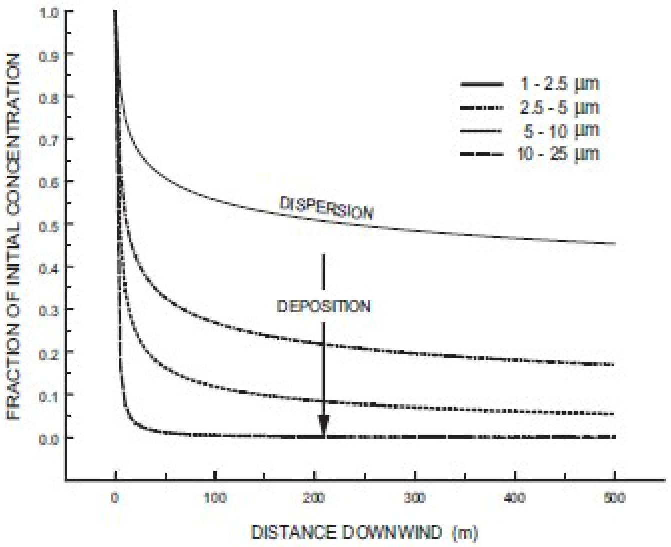
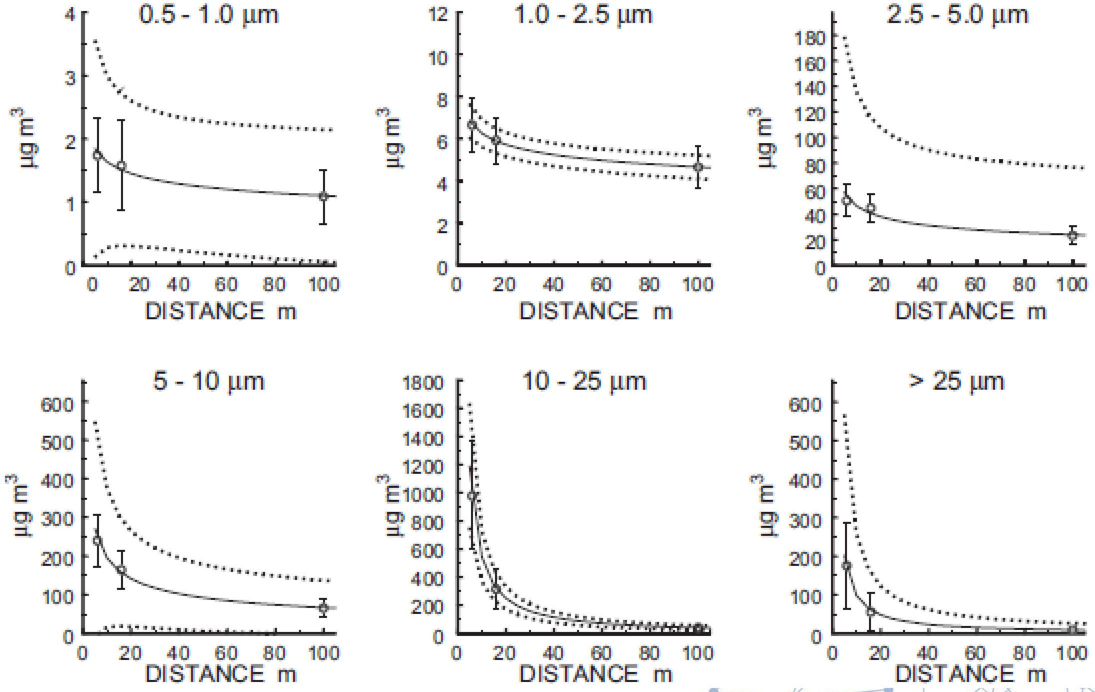


Fig. 4. Size-resolved aerosol mass concentrations for different areas during the north shore evening (a) and morning (b) cruises. Vertical bars are $\pm 1\sigma$ for the population of 1 min samples within each group.

VanCuren et al. 2012: Lake Tahoe (Atmospheric Environment #1)

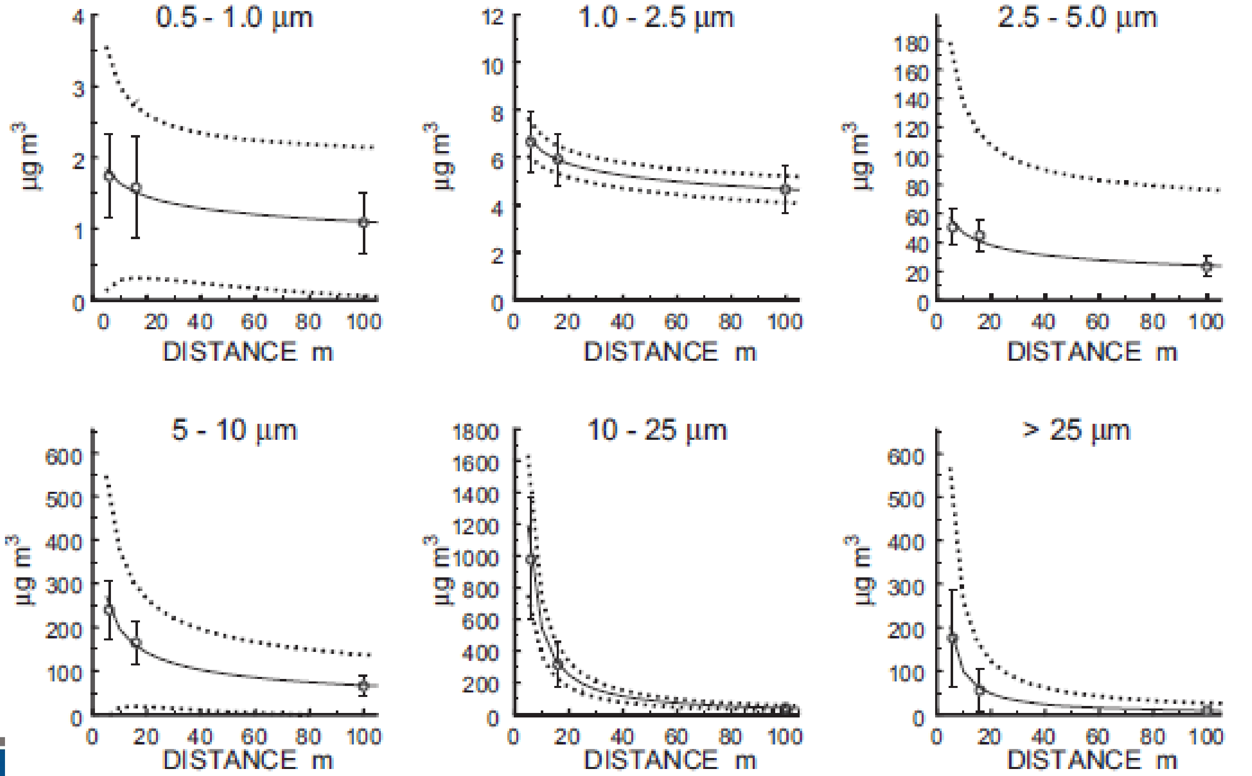
- Observed aerosol size and concentrations in relation to local sources
- Aerosol load decreased with distance from source, with larger particles falling out nearer to the source

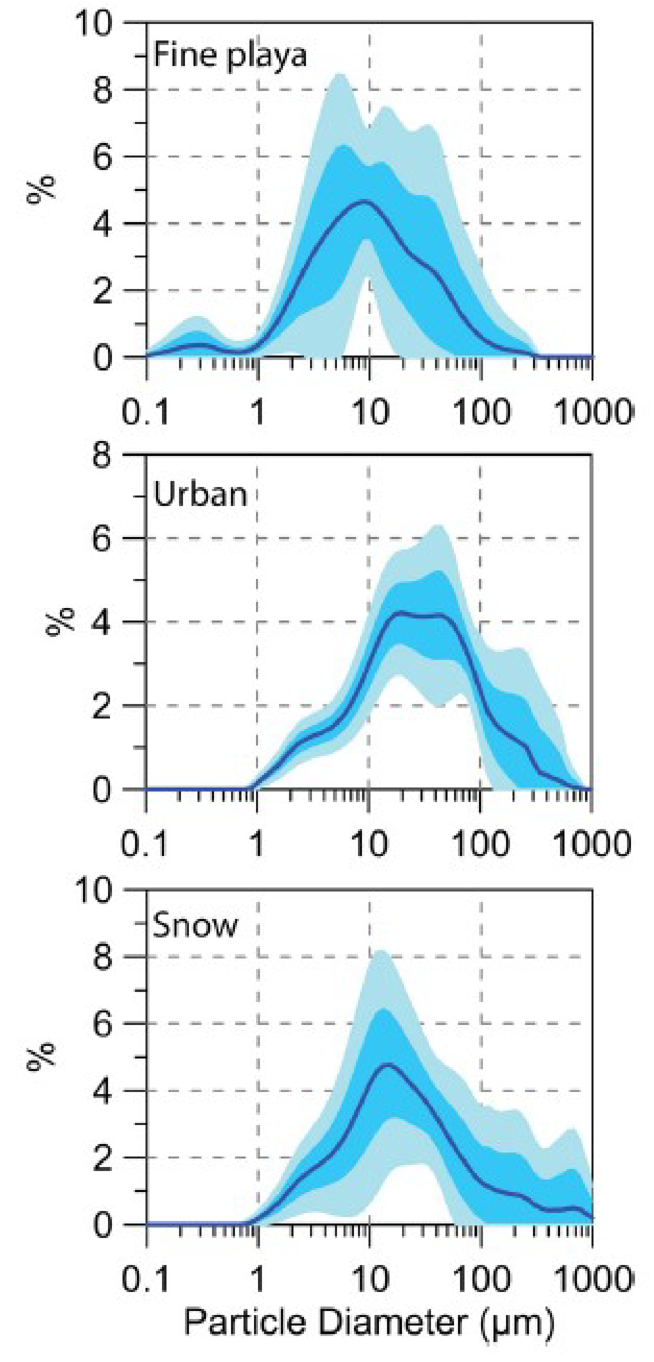




Comparing grain size to attenuation

Based on data observed from VanCuren et al., grain sizes of 10-20 µm should attenuate rapidly moving away from the source (~100 m)



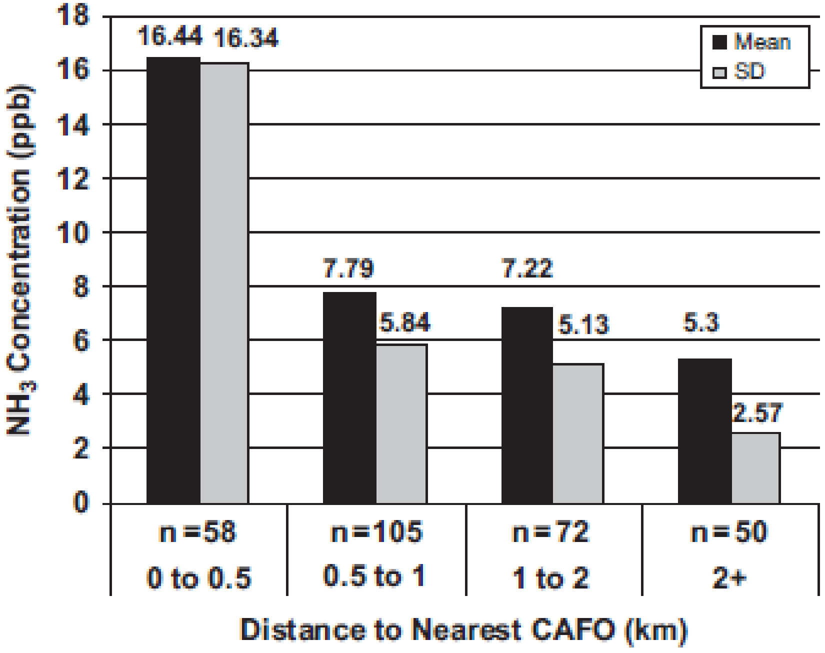


Anderson and Downing 2006: Ag systems in Iowa

- Tested correlation of deposition across six sites
- Wet deposition was driven by more regional processes → likely due to uniformity of land use (the same was not found in Florida)
- Dry deposition was driven by more local processes
- Study didn't tackle distance of attenuation

Wilson and Serre 2007: NH_3 deposition with distance from hog CAFOS in NC

- **NH_3 concentrations decreased with distance from CAFOS**
  - Steepest decrease from 0.0-0.5 km to 0.5-1.0 km
  - Regression coefficient: -6.20
  - Authors noted dominance of regional sources beyond distances of 2 km
  - Exposed sites 4-12x higher than background, less exposed sites 2x higher than background (1-3 ppb)
- **Additional variability in NH_3 deposition explained by**:
  - Hog density in nearest CAFO
  - Wind direction of max gust
  - Avg wind speed



Attenuation: Compiling Evidence

- **Goodman grain size + VanCuren attenuation rates by grain size**
  - Uses grain size information from areas around Utah Lake
  - Need to assume grain size and N & P flux are equivalent
  - Potential attenuation distance: 100 m

- **Wilson and Serre NC CAFO study**
  - Tackled local sources
  - Only analyzed ammonia, no other constituents
  - Potential attenuation distance: 2 km

Speciation

Study	Site	NO_3^-/DIN	NH_4^+/DIN	SRP/TP
Williams data 2020	Orem	0.35	0.65	0.46
Williams data 2020	Lakeshore	0.37	0.63	0.48
Williams data 2020	Mosida	0.10	0.90	0.24
Williams data 2020	Pump Station	0.39	0.61	0.27
Williams data 2020	Bird Island	0.38	0.62	0.32
Brahney 2019	Urban dust			0.75
Brahney 2019	Regional dust			0.34
Reidhead 2019	Utah Lake shoreline sites			0.37
W. Miller 2021	Utah Lake shoreline sites			0.32

- **SRP:TP ratios appear to be more consistent with regional dust than urban dust**
- **Mosida DIN ratios differ from other sites → support for evidence of localized source**

Potential Approaches for Speciation

1. Average proportions across sites for annual fluxes
2. Calculate flux for each constituent individually
3. Assume ~1/3 of TP is SRP, assume ~2/3 of DIN is NH_{4_+}

Utah Lake Atmospheric Deposition Updates

Science Panel Subgroup Meeting | January 26, 2023

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Action Items from Last Meeting

1. Follow up on Putman regional dust flux
2. Calculate AD load to Utah Lake
3. Compare AD load against constraining analyses
4. Compute speciation

Circling back on Putman et al. 2022

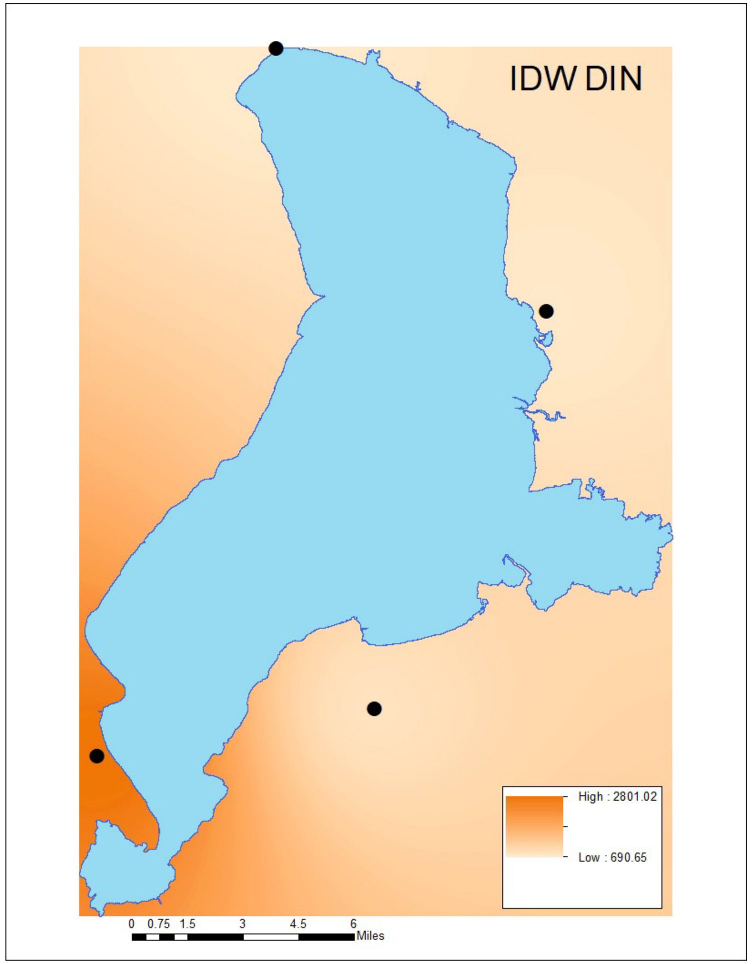
- **Acquired information from the authors to calculate fluxes at Lehi**
- **Putman regional fluxes at Lehi**
  - 14.6-36.6 g/m^2/y
  - Average 25.6 g/m^2/y
- **Compare to regional fluxes from Goodman et al. 2019**
  - 22.5-31.8 g/m^2/y
  - Average 27.8 g/m^2/y
- **Only a ~10% difference in average flux → good groundtruthing of Goodman!**
  - Similar sampler design
  - Different locations around Utah Lake
  - Different methods used to calculate proportion of regional (grain size vs. elements)

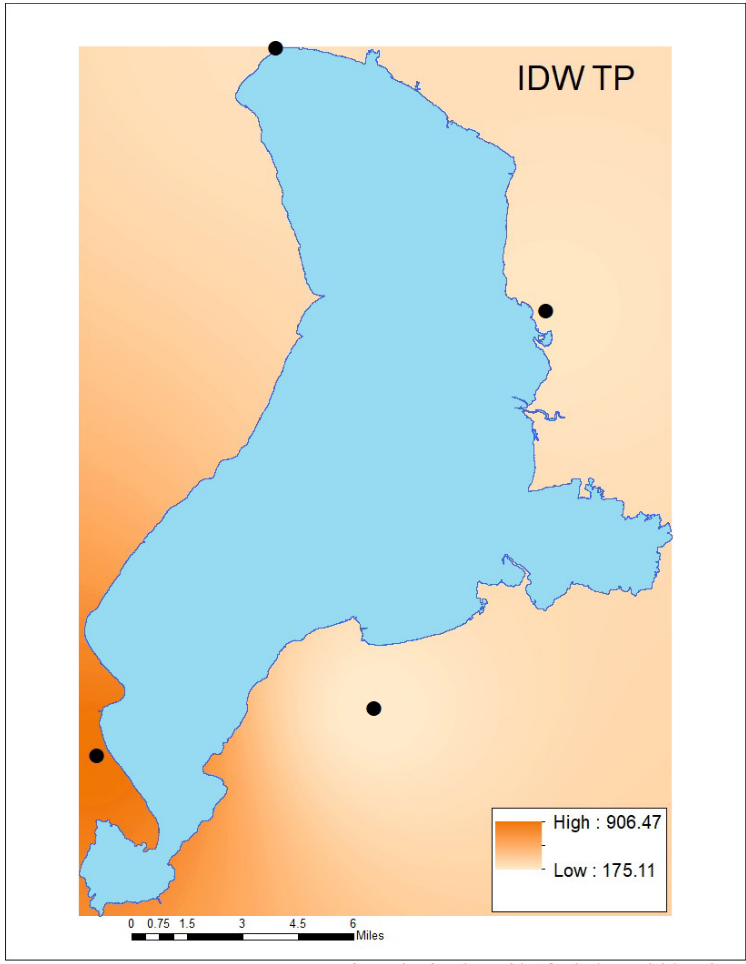
Calculating AD Load to Utah Lake

1. **Estimate shoreline fluxes around Utah Lake**
   - Use Williams sampler data for locations around the lake
   - Represents local + regional flux
   - Spatially interpolate between stations
2. **Assign decay rate of shoreline fluxes moving from shoreline to offshore**
   - Proportion of shoreline (local + regional) flux decreases moving offshore, proportion of regional flux increases
   - Low, medium, high scenarios
3. **Assign regional flux in areas beyond the shoreline decay distance**
   - DIN: CMAQ model (Brahney et al. 2019)
   - TP: Goodman et al. 2019 and Carling 2022, groundtruthed by Putman

Estimate shoreline fluxes around Utah Lake

- **Estimate conditions between sampling sites on the shoreline**
- **Used inverse distance weighted interpolation**
    - Assumes conditions are more alike in locations close to one another
    - Each measured point has a local influence that diminishes with distance (“weight” is greater the closer to the sampling point)
    - Plays out with Mosida location having an influence on the SW portion of the lake





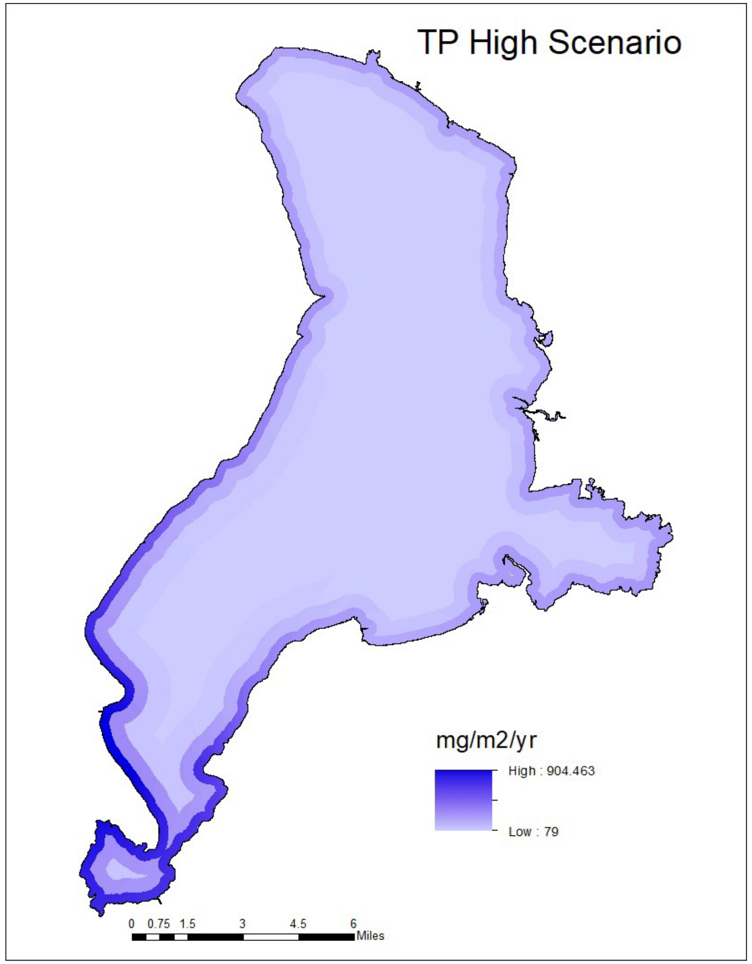
Assign decay rate of shoreline fluxes moving from shoreline to offshore

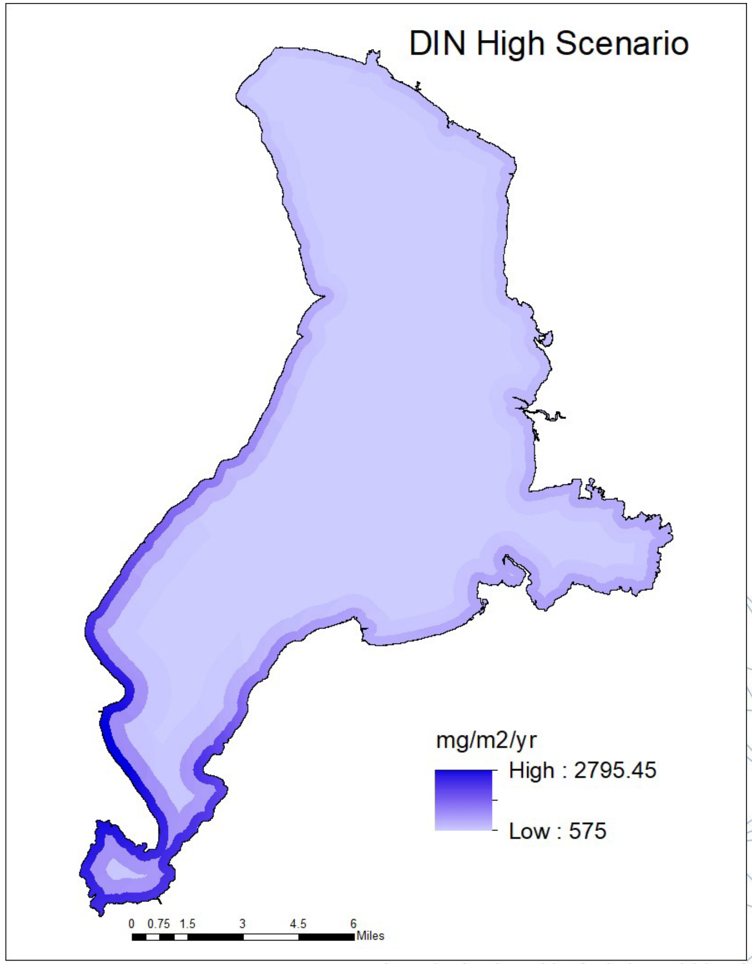
- **Decay rate ran for 3 scenarios:**
  - 100 m, based on decay rate of particles 10-25 μm in VanCuren et al. 2012
  - 200 m, based on decay rate of particles 10-25 μm in VanCuren et al. 2012, with distance doubled to account for uncertainty
  - 2000 m, based on decay distances from Wilson and Serre 2007

Shoreline proportion	Regional proportion	Low scenario	Medium scenario	High scenario
1.00	0.00	0 m	0 m	0 m
0.30	0.70	20 m	40 m	400 m
0.045	0.955	50 m	100 m	1000 m
0.026	0.974	100 m	200 m	2000 m

Assign regional flux in areas beyond the shoreline decay distance

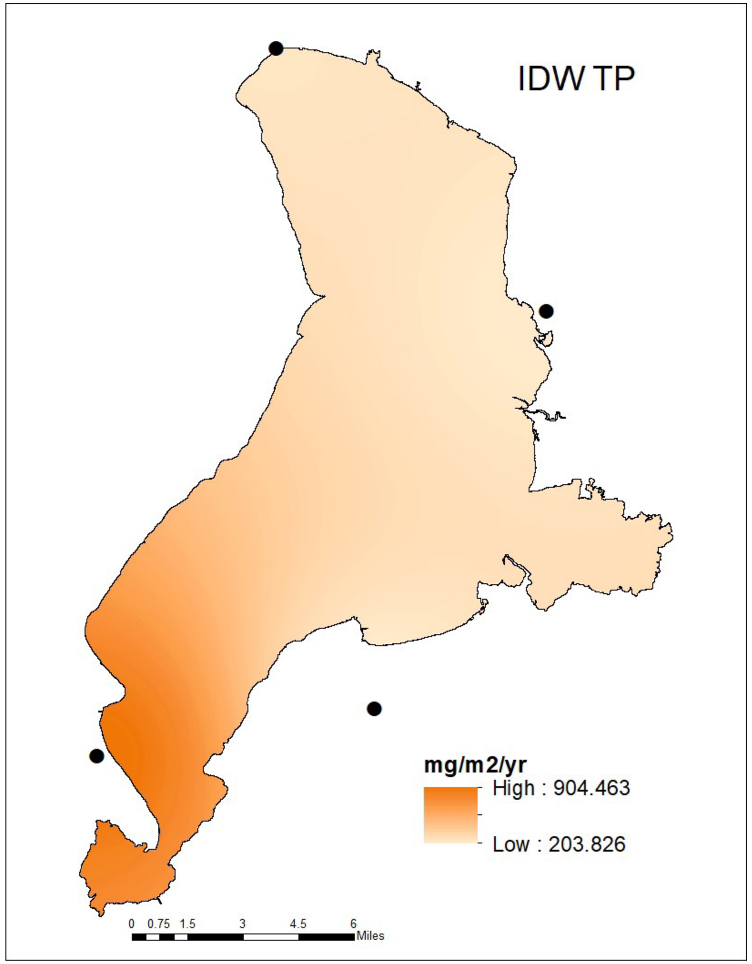
- **DIN**
  - 575 mg/m²/yr
  - Avg of CMAQ model range of 400-750 mg/m²/yr
  - Source: Brahney et al. 2019
- **TP**
  - 79.0 mg/m²/yr
  - Avg of 37.4-120.7 mg/m²/yr
  - Avg of dust deposition in 4 urban sites * fraction of urban attributed to regional * avg P content in regional dust
  - Source: Goodman et al. 2019 and Carling 2022

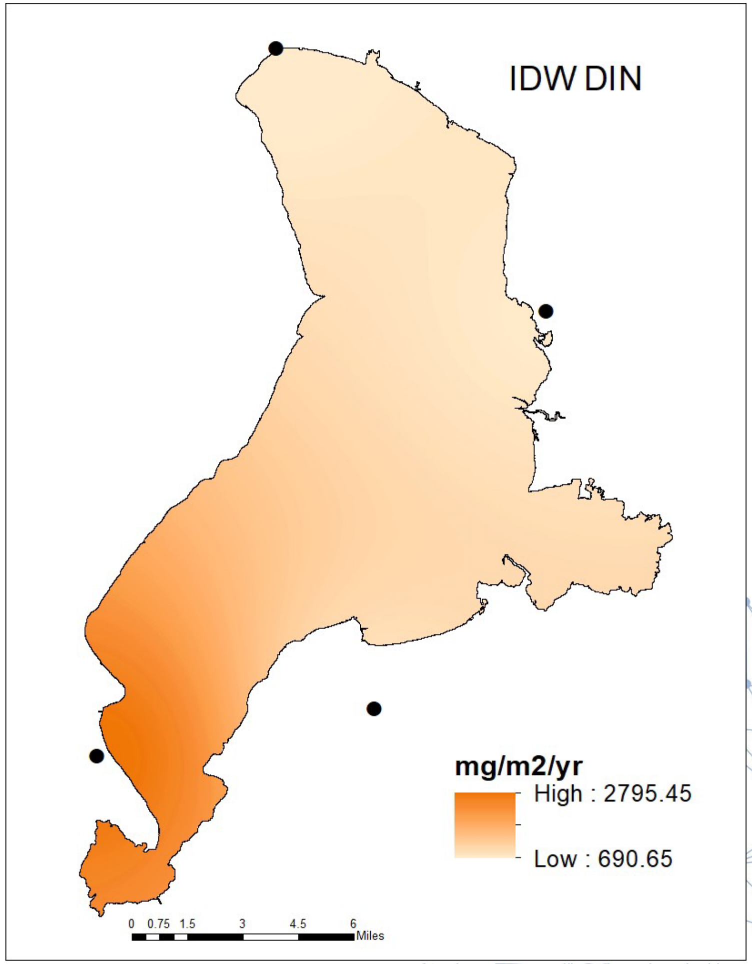




Upper Ceiling: What if no attenuation occurs?

- Use the same inverse distance weighted interpolation to interpolate across the lake





AD Load Estimates to Utah Lake

Scenario	DIN (metric tons/yr)	TP (metric tons/yr)
Attenuation @ 100 m	219.91	31.47
Attenuation @ 200 m	223.39	32.95
Attenuation @ 2000 m	276.59	55.60
No attenuation	449.12	132.61

Comparing Loads to Previous Studies & Constraining Analyses

Scenario	DIN (metric tons/yr)	TP (metric tons/yr)
Attenuation @ 100 m	220	31
Attenuation @ 200 m	223	33
Attenuation @ 2000 m	277	56
No attenuation	449	133
Carling 2022 (dust conversion)		57.5
Brahney et al. 2019	153-288	2-21
Brahney (mass balance)		33
Brett (mass balance)		60
Miller 2021 (assumed no attenuation)	257-409	50-104
Olsen et al. 2018 *(uncontaminated-contaminated)*	57-570	10-430
Reidhead et al. 2019 *(unscreened)*	637	193
Barrus et al. 2021 *(partially screened-unscreened)*	482-1052	133-262

Speciation

- NH_{4+}
  - Mean proportion of DIN across all sites: 69.75%
  - Compare against ~67%
- NO_3^-
  - Mean proportion of DIN across all sites: 30.25%
  - Compare against ~33%
- SRP
  - Mean proportion of TP across all sites: 37.5%
  - Compare against ~33%
  - Similar to regional dust estimate: 34% (Brahney et al. 2019)