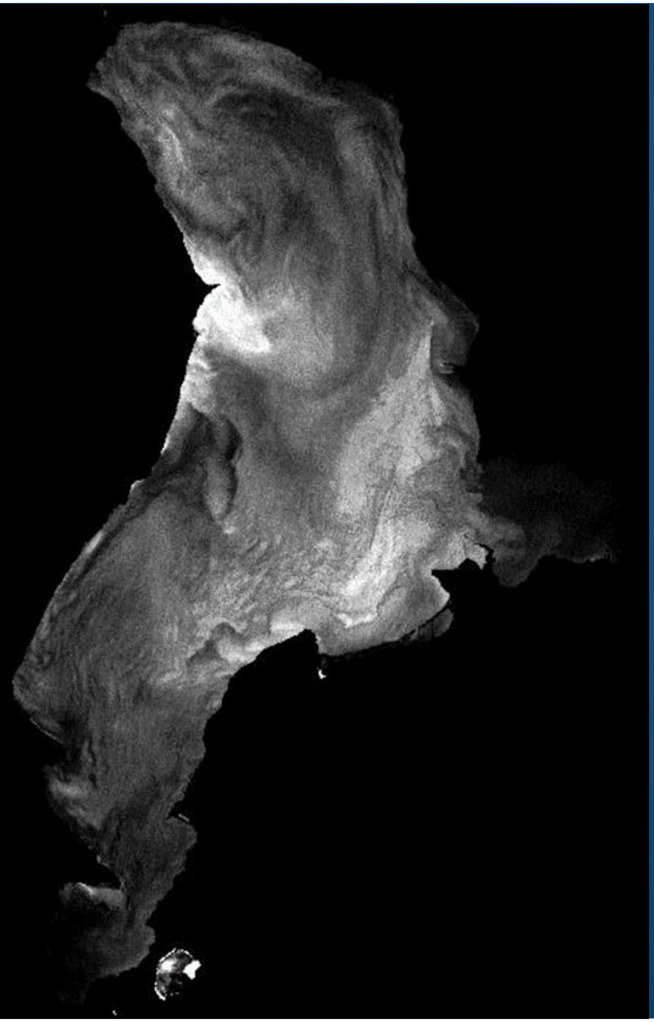
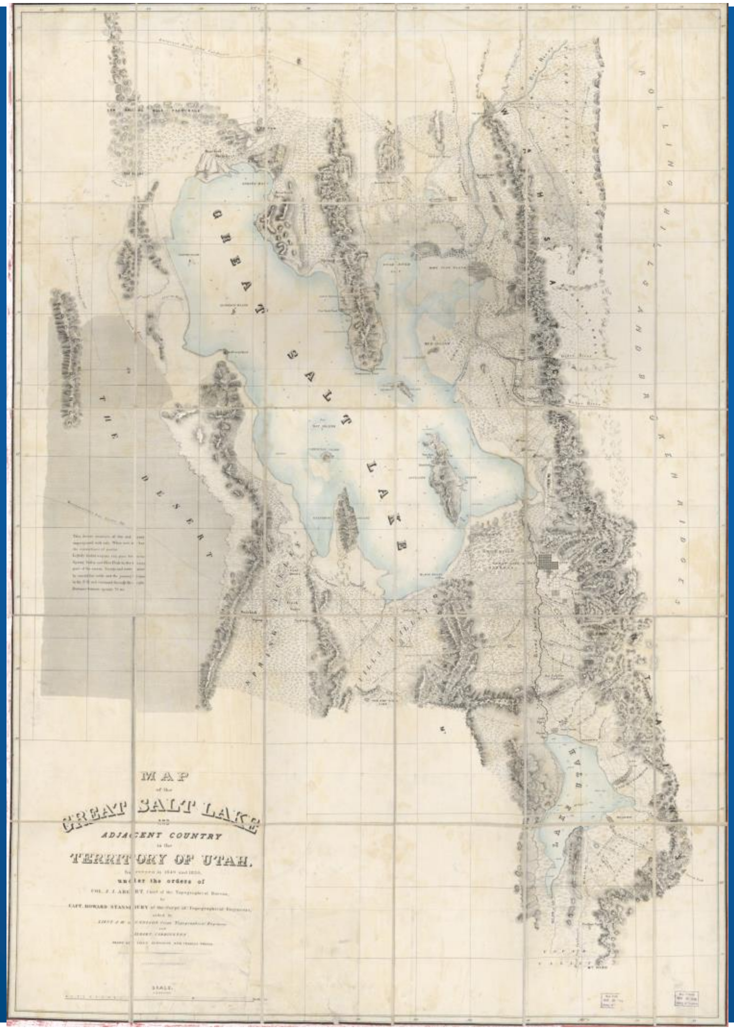
Atmospheric Nutrient Deposition to Utah Lake





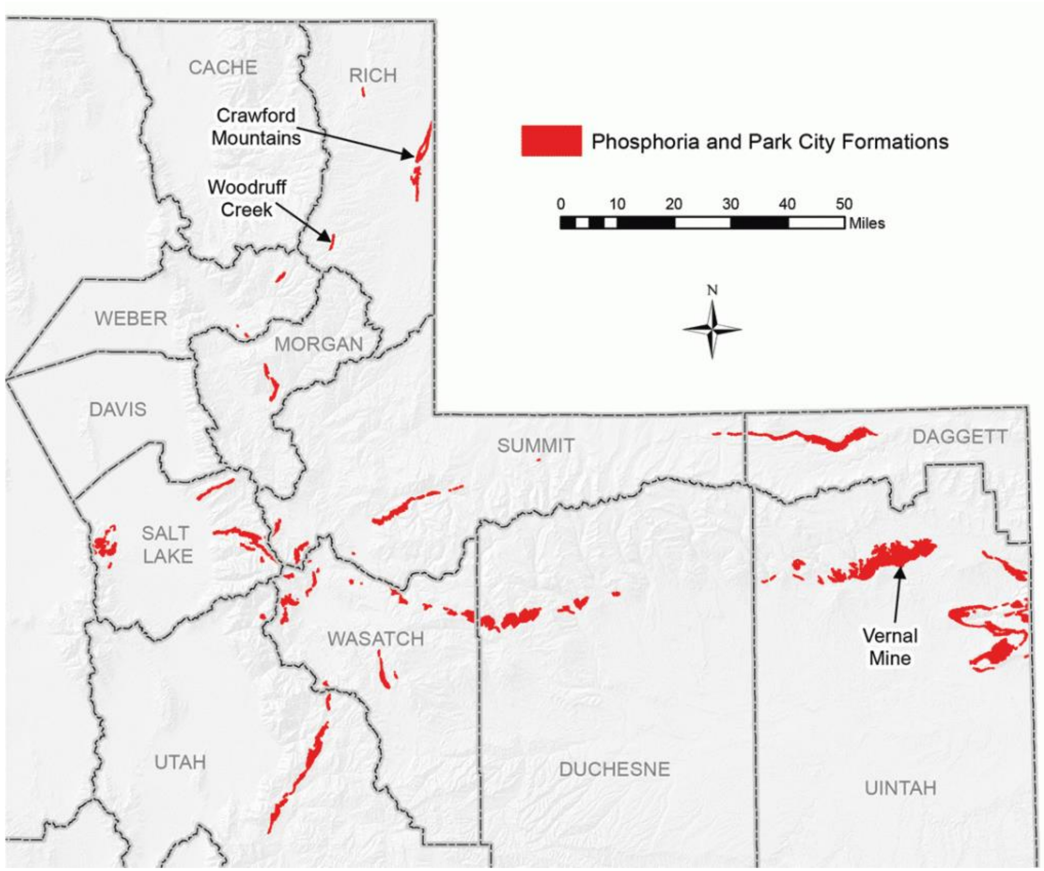
2022 Status and Summary

Gustavious Paul Williams, Ph.D.

March 16, 2022

Geologic Phosphorous Sources

- **Background on geology and phosphorus**
  - The UL watershed contains significant phosphate deposits that contribute to nutrients to the lake.
  - Utah has over 100 years of phosphate production
  - Potash is produced and is another phosphorous source.
  - Utah is a significant producer in the US
  - Rock deposits containing up to 30% percent P2O5
  - In UL watershed, the Park City Formation is prominent.
  - UL watersheds contain formations with high phosphorous
- **Two different studies in Deer Creek Reservoir**
  - Average sediment phosphorous from 1,107 – 2,572 mg-P/kg
  - 10-20% readily available to the water column.
- **Two different studies of UL sediments and soils**
  - UL sediments ranged from 280 – 1,710 mg-P/kg
  - Average value of about 900 mg-P/kg dry sediment
  - About 50% readily available to the water column.
  - Near-shore soils around UL contain about 900 mg-P/kg
    - Only about 10% readily available to the water column



Deer Creek Sediment Sampling During Dam Reconstruction

- **Collected ~90 sediment samples from delta**
- **P-Fractions**
  - Fr.W: water soluble
  - Fr.KCl: loosely sorbed
  - Fr.NaOH: Al- and Fe-bound
  - Fr.HCl: Ca-bound (apatite)
  - Fr.PFD: residual phosphorus,
    - probably mostly organic

Fraction	Avg P (mg kg^{-1})
W	4.7
KCl	4.5
W+ KCL	9.2
NaOH	174.1
HCl	926.3
PFD	1,460.0
Total	2,572.5

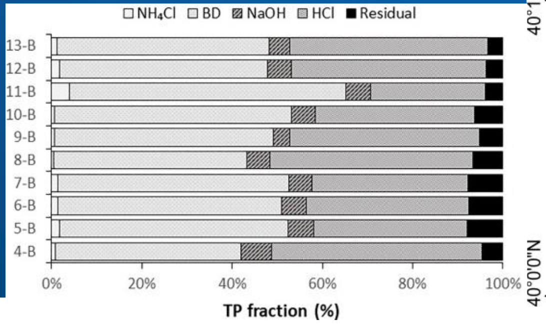
W. Casbeer, G. Williams, and M. Borup, "Phosphorus Distribution in Delta Sediments: A Unique Data Set from Deer Creek Reservoir," *Hydrology,* vol. 5, no. 4, p. 58, 2018.

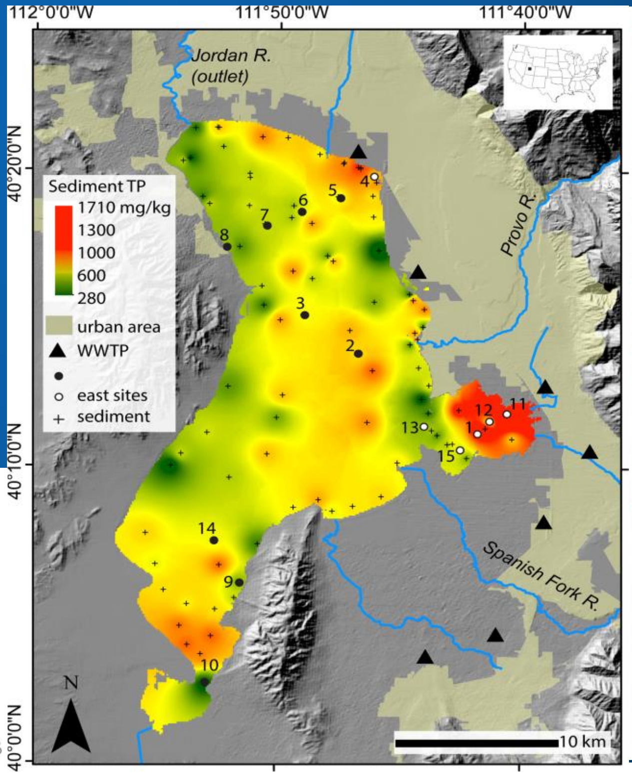
Two Sediment Studies – similar results

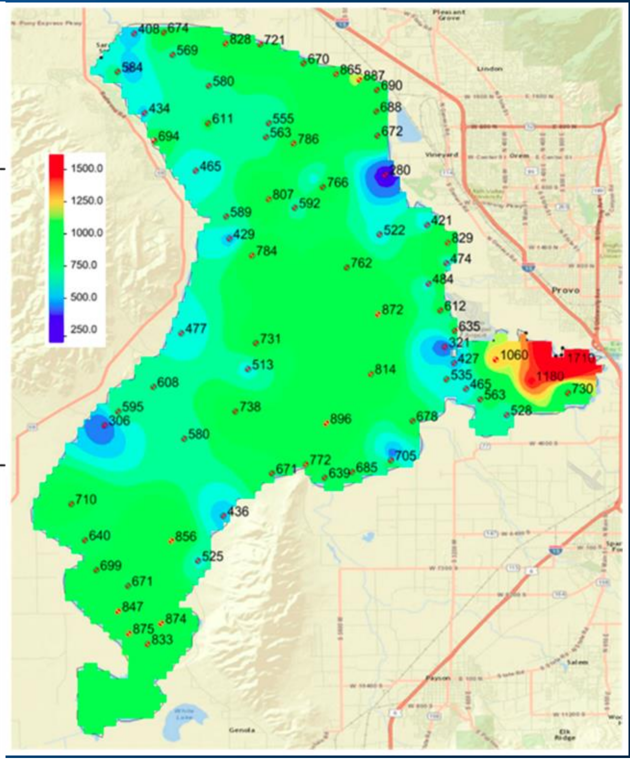
- **Two journal papers**
  - Randall 2019 (Carling) – 26 samples
    - ~50% available to water column
    - slightly different fractions than DC
  - Abu-Hmeidan 2018 (Williams) – 85 samples
- **Maps – Total-P**
  - Randall (left), Abu-Hmeidan (right)
    - Randall map includes data from both studies
    - Randall used Inverse distance – Abu-Hmeidan used Kriging
    - Very similar – different color scales
- **TP ranged from 280 – 1,710 mg/kg**
  - Low values in sandy areas
    - lowest 280 mg-P/kg located upper east side
      - Sandy with less fines than the other samples
  - Highest in shallow waters
    - Provo Bay and Goshen Bay
    - Highest in Provo Bay
    - No samples in Goshen Bay

M. C. Randall et al., "Sediment potentially controls in-lake phosphorus cycling and harmful cyanobacteria in shallow, eutrophic Utah Lake," PloS one, vol. 14, no. 2, p. e0212238, 2019.

H. Abu-Hmeidan, G. Williams, and A. Miller, "Characterizing total phosphorus in current and geologic utah lake sediments: Implications for water quality management issues," Hydrology, vol. 5, no. 1, p. 8, 2018.

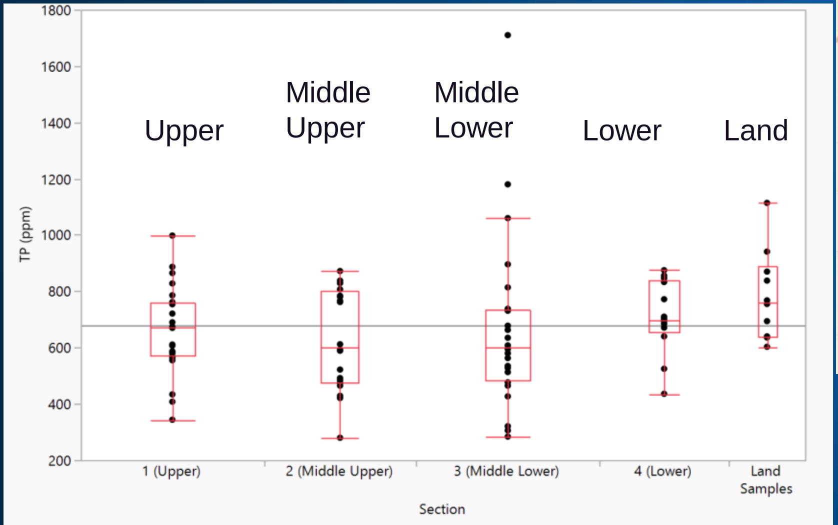


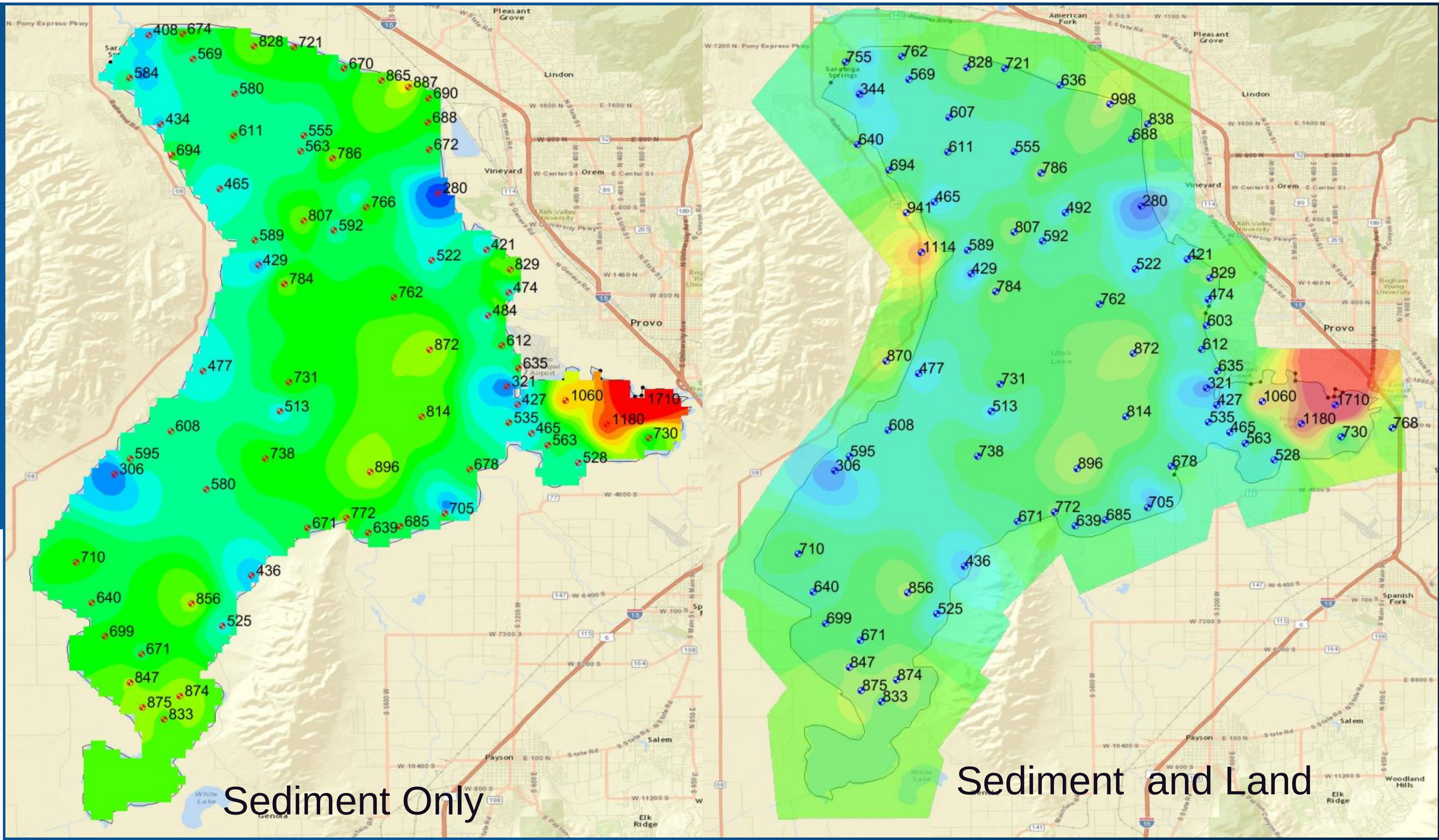




Sediment and Soils Study, 2015-2016

- **Samples**
  - 2015 (56 Samples)
  - 2016 (36 Samples)
  - Land Samples (10 Samples)
- **Average 666 mg/kg**
  - Problems with fractionation
  - Analyzed in 4 sections
- **Land and Sediment Similar**
  - Land samples highest





H. Abu-Hmeidan, G. Williams, and A. Miller, "Characterizing total phosphorus in current and geologic utah lake sediments: Implications for water quality management issues," *Hydrology*, vol. 5, no. 1, p. 8, 2018.

Atmospheric Deposition

- **Nearby soils can be mobilized and deposited in UL**
  - Recent studies have quantified AD for Utah Lake
    - Olsen: Master's thesis and journal article
    - Reidhead: Master's thesis
    - Barrus: Master's thesis and journal article
    - On-going, Telfer and Brown Master's students
  - Each study builds data set and addresses questions posed by earlier studies

J. Olsen, G. Williams, A. Miller, and L. Merritt, "Measuring and calculating current atmospheric phosphorous and nitrogen loadings to utah lake using field samples and geostatistical analysis," *Hydrology,* vol. 5, no. 3, p. 45, 2018.

J. M. Olsen, "Measuring and Calculating Current Atmospheric Phosphorous and Nitrogen Loadings on Utah Lake Using Field Samples, Laboratory Methods, and Statistical Analysis: Implication for Water Quality Issues," Masters, Civil and Environmental Engineering, Brigham Young University, Masters Thesis, 2018.

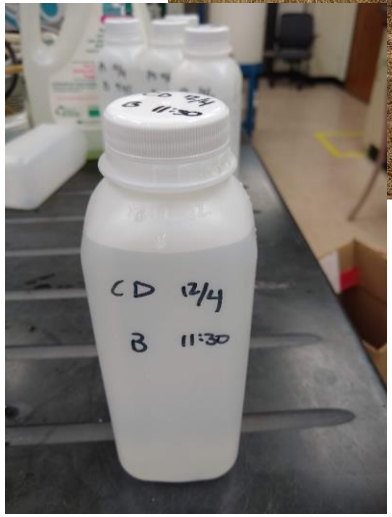
J. G. Reidhead, "Significance of the Rates of Atmospheric Deposition Around Utah Lake and Phosphorus-Fractionation of Local Soils," Masters, Civil and Environmental Engineering, Brigham Young University, Masters Thesis, 2019.

Barrus, S. M., G. P. Williams, A. W. Miller, M. B. Borup, L. B. Merritt, D. C. Richards, and T. G. Miller. 2021. Nutrient Atmospheric Deposition on Utah Lake: A Comparison of Sampling and Analytical Methods. *Hydrology* 2021, 8, 123.

Barrus, S. M. (2021). "Improvements of atmospheric deposition sampling procedures and further analysis of its impact on utah lake" Masters, Civil and Environmental Engineering, Brigham Young University, Masters Thesis, 2021

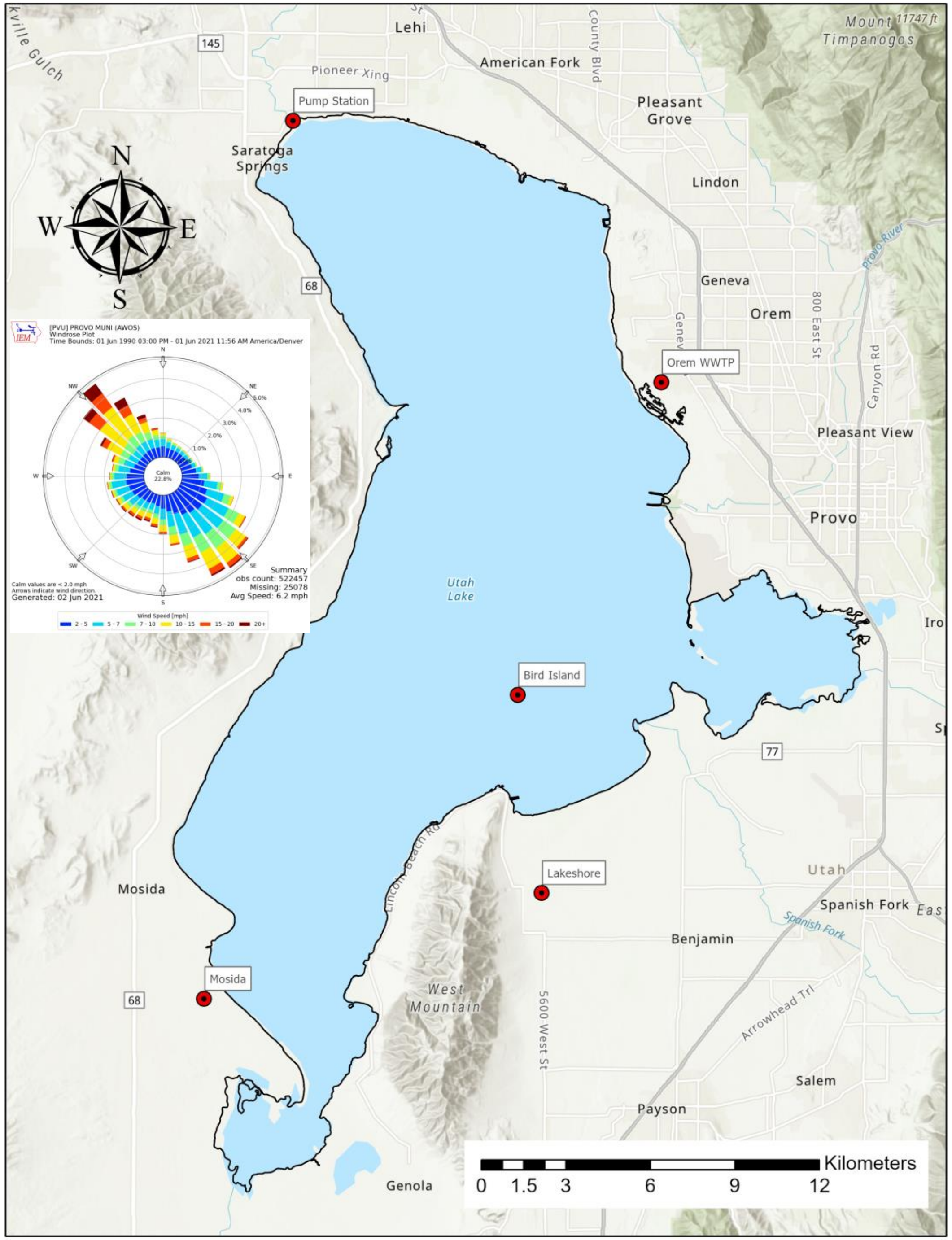
Sampling and Analysis Overview

- **Field sites have wet and dry buckets**
  - Automatically open and close based on precipitation
  - Generally followed the NADP methods
  - Collected weekly samples,
    - Wet-deposition sample and dry-deposition
    - Simulated the dry-deposition on lake surface with 3 liters of deionized water
- **Samples**
  - Analyzed by BYU Environmental Analytical Laboratory
  - Deposition rates :
    - Sample conc (mg/L) x Sample vol (L) = mass (mg)
      - Deionized water to bring samples up to analytical volume.
    - Unit area deposition rates (mg/m2/time)
      = mass (mg) / area (0.0615 m2)/ time (usually 1 week)



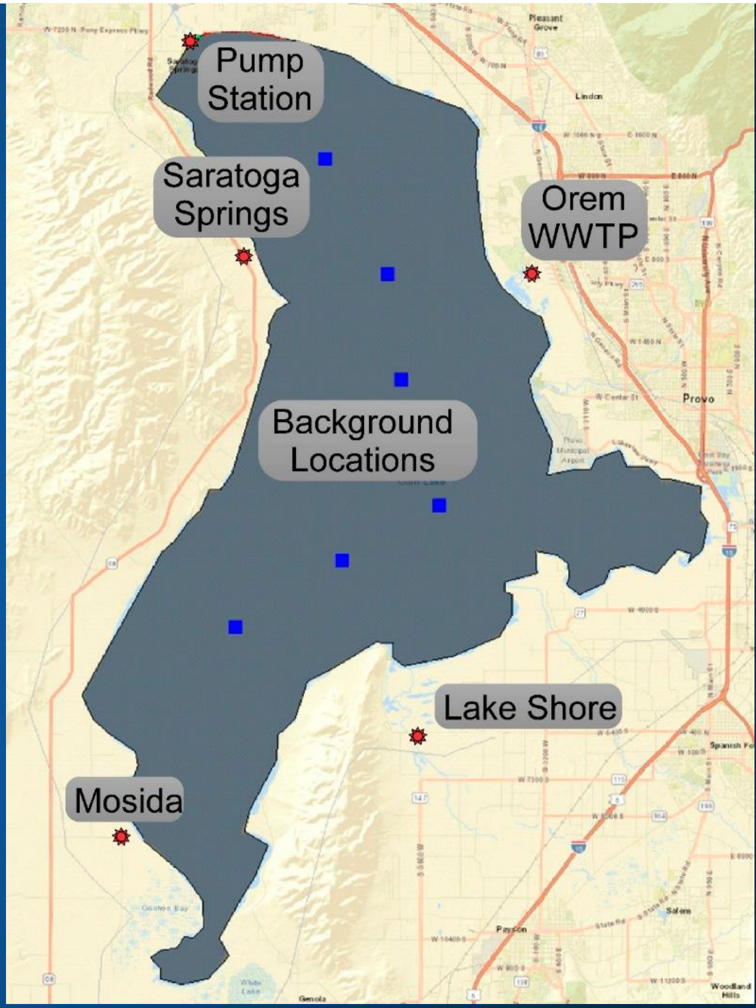
Sampling sites

- **Sites around Lake**
  - 4 sites – first two studies
  - 5 sites – last study and on-going
- **Site locations**
  - Away from high local dust sources (e.g., roads)
  - Near lake
  - Does not follow NADP guidelines
    - Want to measure dust deposited on Lake
    - Include both regional and local sources



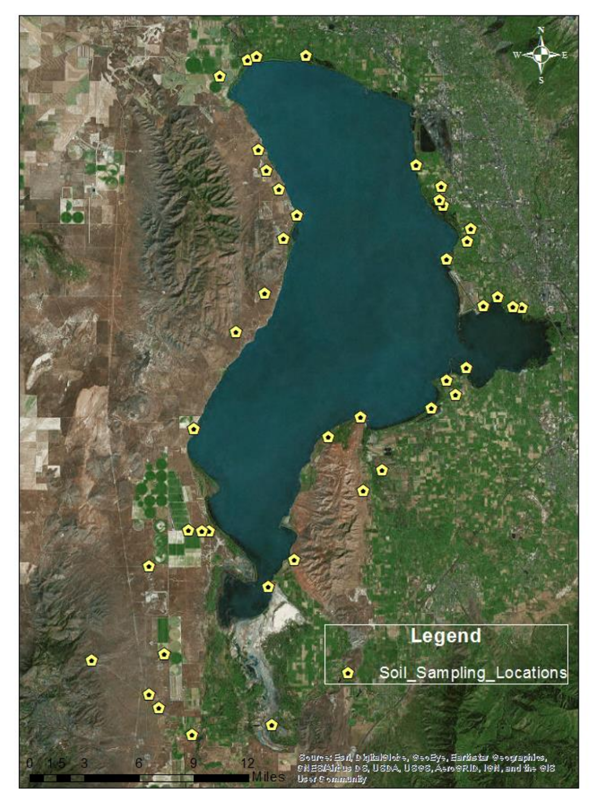
Olsen Study

- **Used 4 sample sites**
  - Created “dummy” sites in lake to simulate drop-out
  - assigned background deposition values for
    - TP 0.019 mg/m2/week (Mahowald, et al. 2008) and
    - DIN 0.112 mg/m2/week (NADP 2014)
    - Two orders of magnitude lower than shore measurements
  - Kriging,
    - variogram range of 1000m
    - 3,398 grid cells, 381x267m (101,722 m2)
    - Kriging estimates sample average if no point within range
      - Puts high weight on background dummy points
  - Computed two different load estimates
    - Only samples with no visible particles including dust/soil
    - All samples
      - Saratoga Springs site had many samples with insects
    - Provides two bounding values of deposition rates



Reidhead Study

- **Continued Olsen study**
  - Similar field methods and sites
  - Bucket tops at 1.2 m above ground
- **Sample Preparation**
  - All large particles removed prior to analysis
- **Different spatial estimate**
  - Used linear fall-off from each site
  - Not a standard method
  - Produces low estimate – samples do not influence very far into the lake
- **Collected soil samples**
  - 49 sites around the lake and surrounding area
  - TP ranged from 1,014 to 1,730 mg-P/kg
  - Similar to other sediment and soil results
  - Total digestion with ICP-OES



Critique About the Previous Research from the Utah Science Panel:

1) What can be done to prevent splash contamination of the samples during a rain event?
2) The existing (1-meter) tables result in inaccurate contaminated samples because they are too short.
3) The existing unscreened samplers result in inaccurate samples because of bug contamination.
4) What is the actual deposition rate as sources of AD progress towards the center of Utah Lake?

2019-2020 Study

- **Continue data collection**
- **Address Science Panel concerns**
  - Raised buckets to 2 m above the ground.
  - Placed 500-micron nylon mesh screens on dry side buckets
    - prevent insect or plant parts from entering the bucket
  - Moved solar panel at least 5 m from sample table to prevent any splash
  - Installed Miner’s moss®, a matting material thicker than artificial grass, on moving lid reduce potential splash and deflection of rain droplets from the lid to the wet bucket during a rain event.

Splash contamination

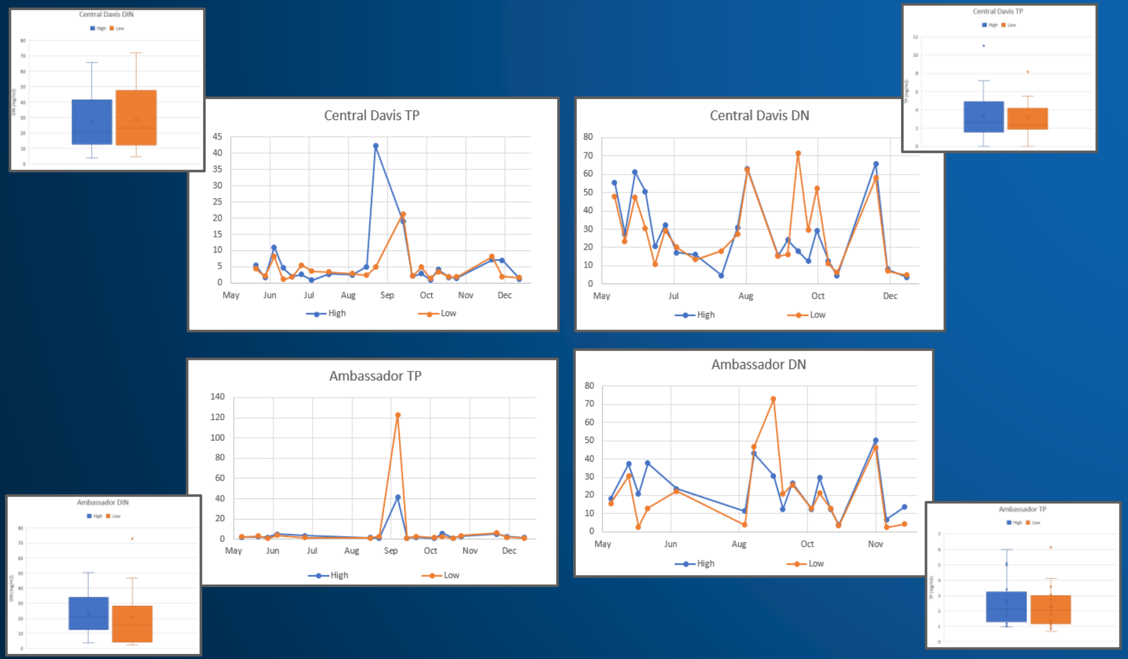
- **Solar panels**
  - Moved away from tables
- **Miners moss**
  - Added moss to lid to reduce splash
  - No side-by-side tables for comparison
    - Could not quantify impacts
  - Most of the deposition is dry deposition,
    - Would not be affected by these changes
  - Tested “simulated rainfall”, e.g., sprayed it with a hose,
    - did a good job of minimizing splashes

Simple experiment
- Simulated heavy rainfall
  - Approximately 4 liters of dyed water on the dry side lid
  - Only a few tiny droplets (microliters) reached the wet sid
- Visually confirmed that Miners Moss
  - absorbed the energy of raindrop impact and
  - eliminated droplet splash or bounce

High vs Low Tables

Nutrient	Avg. Median Diff. (mg/m²)	% Lower than High Table	One-tail p-value
TP	1.52	7%	0.264
DIN	1.12	12%	0.116

- **2020**
  - Raised all tables to 2-meters
  - Two low tables were retained
    - Side-by-side with two tall tables at two locations
    - Used for comparison between the two designs.



High versus Low Tables

- **No statistically significant difference based on t-test**
  - P-value of 0.26 and 0.11 for TP and DIN, respectively
  - 1-tailed P-value and 95% CI (hypothesis is directional).
- **The distribution for both nutrients was skewed, so a natural Log transformation was performed on each pair prior to the test**
- **Low tables had slightly lower deposition rates than the high tables for side-by-side tables**

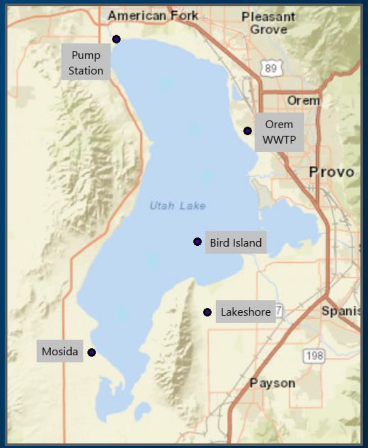
Screened vs Unscreened Analysis

- **Analyzed with a paired *t*-test with a 1-tailed P-value and 95% CI.**
- **Takeaways:**
  - Strong evidence that nonfiltered samples have a higher value than filtered samples for TP.
  - Moderately strong evidence for DIN.

Nutrient	Avg. Median Diff. (mg/m²)	Mult. Diff. between Unfiltered and filtered	One-tail p-value
TP	2.488	3x	0.0004
DIN	1.816	1.5x	0.0116

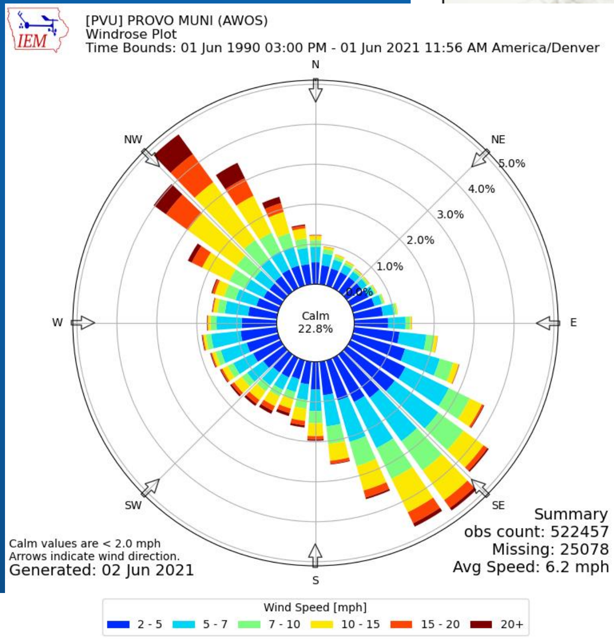
AD Fall-off – Bird Island Station

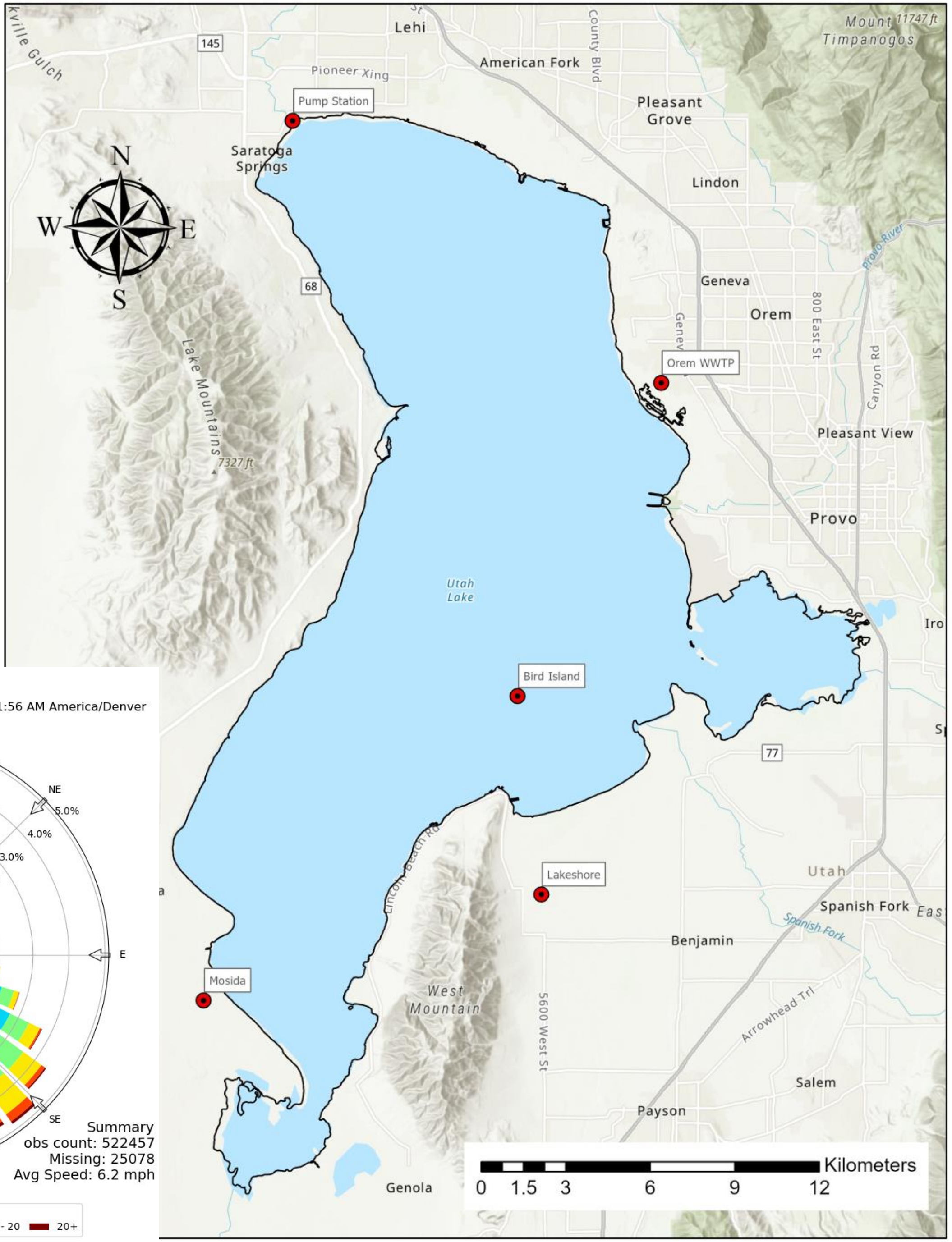
- **Added station in Lake**
  - Located at Bird Island
  - 5 m above lake surface



Prevailing Wind and Bird Island

- **Bird Island results were generally higher than shoreline stations**
- **Could be due to prevailing winds**
- **Provo Airport wind rose - 10 years of data**
  - – Wind is from NW or SE
  - – ~15% of time (by eyeball), higher than 10 mph
  - – Winds from Spanish Fork Canyon
  - – No sampling stations aligned with Bird Island
  - – May indicate local rather than regional
  - – Occasional high speed from S-SW
    - Sevier Lake
  - – Rare high speeds from W or NW





Lake Interior Deposition Rates

- **Bird Island data show that deposition rates do not significantly decrease away from the shore**
  - Most Bird Island measurements were higher than shoreline stations
  - There is some correlation with shoreline stations, but it is weak – determined using predictive modeling
- **Previous load estimates assumed significant decreases in deposition rates**
  - Assumed background levels – 2017-2018
  - Assumed linear decrease to zero (0), 2018-2019
- **Assumptions are not justified**
  - should interpolate the available data

TP data

Month	Bird Island	Lakeshore	Mosida	Pump Station	Orem	Avg of 4 shore sites
July	5.35	6.62	7.40	2.56	3.73	5.08
August	9.37	2.55	3.13	4.36	2.31	3.09
September	36.25	3.75	6.17	19.91	16.45	11.57
October	1.73	4.70	3.36	2.49	8.42	4.74
November	33.34	6.01	2.89	3.34	9.51	5.44

DIN data

Month	Bird Island	Lakeshore	Mosida	Pump Station	Orem	Avg of 4 shore sites
July	31.93	24.91	21.25	17.28	19.84	20.82
August	28.87	35.50	38.31	30.02	37.94	35.44
September	52.29	35.47	25.28	20.21	26.40	26.84
October	16.39	16.84	15.37	9.58	11.14	13.23
November	27.17	14.51	13.24	2.62	15.36	11.43

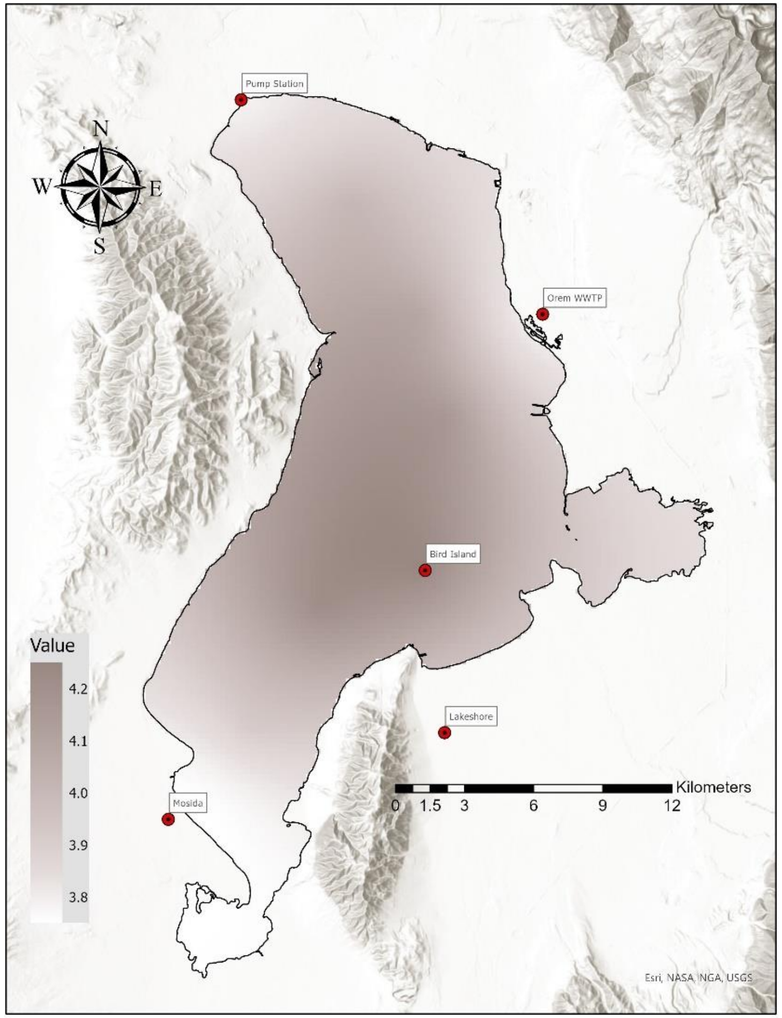
Total AD Load Computation

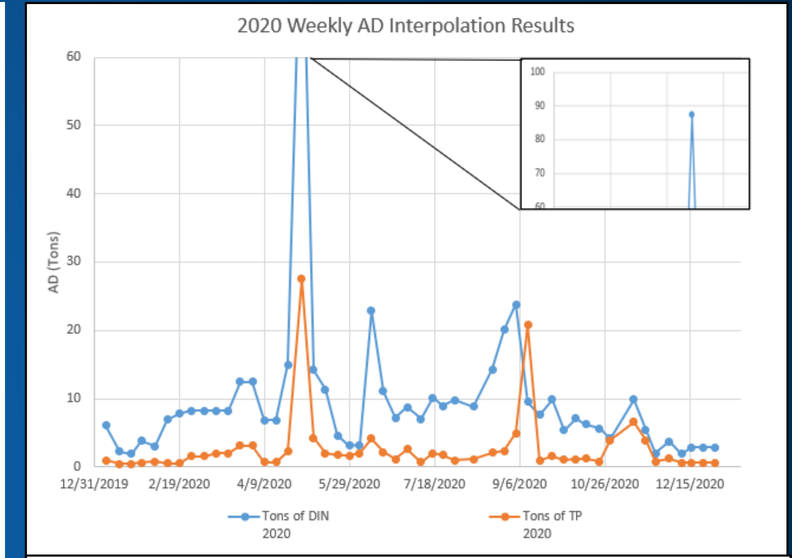
- **For 2017 – 2019**
  - Saratoga Springs site removed
  - Used ordinary kriging to estimate spatial deposition rate for each week over the entire lake
  - Multiplied rate by the Lake area and time period to obtain total load for the week
  - Integrated the weekly values over the year
  - For 2017 and 2018 we did not have complete data, so totals are for part of the year
  - The 2019 data had large spikes,
    - likely due to insects
- **For 2020**
  - We followed the same procedures but included Bird Island data
  - For the 7 months without Bird Island data, we estimated the Bird Island data using the shoreline stations.
- **Seasonal fluctuations in AD**
  - AD is higher in the early Spring (March/April) and then again sometime during the summer
  - Probably related to storms
  - Winter storms have either snow or frozen ground – dust may not be mobilized
  - Not enough data to quantity or verify these hypotheses

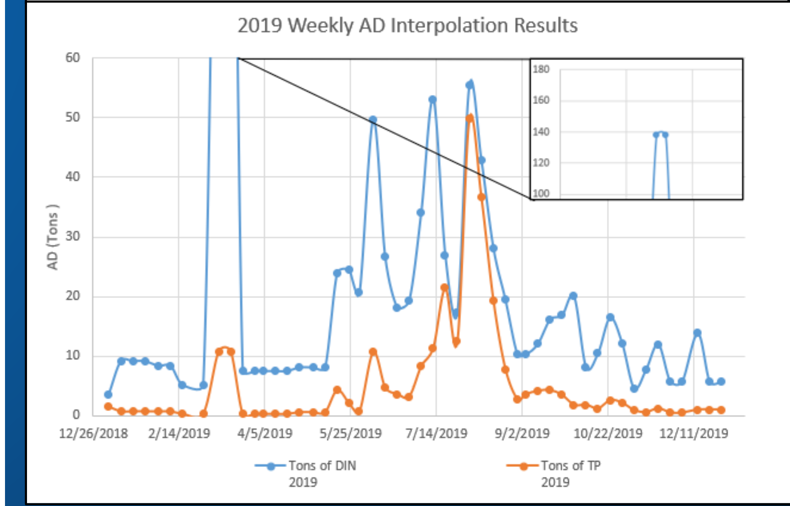
Year	TP (tons)	DIN (tons)
2017	350	460
2018	153	505
2019	392	1659
2020	133	482

2019 – 2020 Details and Example

- **Weekly deposition rates**
- **Example spatial interpolation**
  - August 23, 2020
  - Bird Island and Lake Shore similar
  - Other stations lower
  - Majority of lake at average





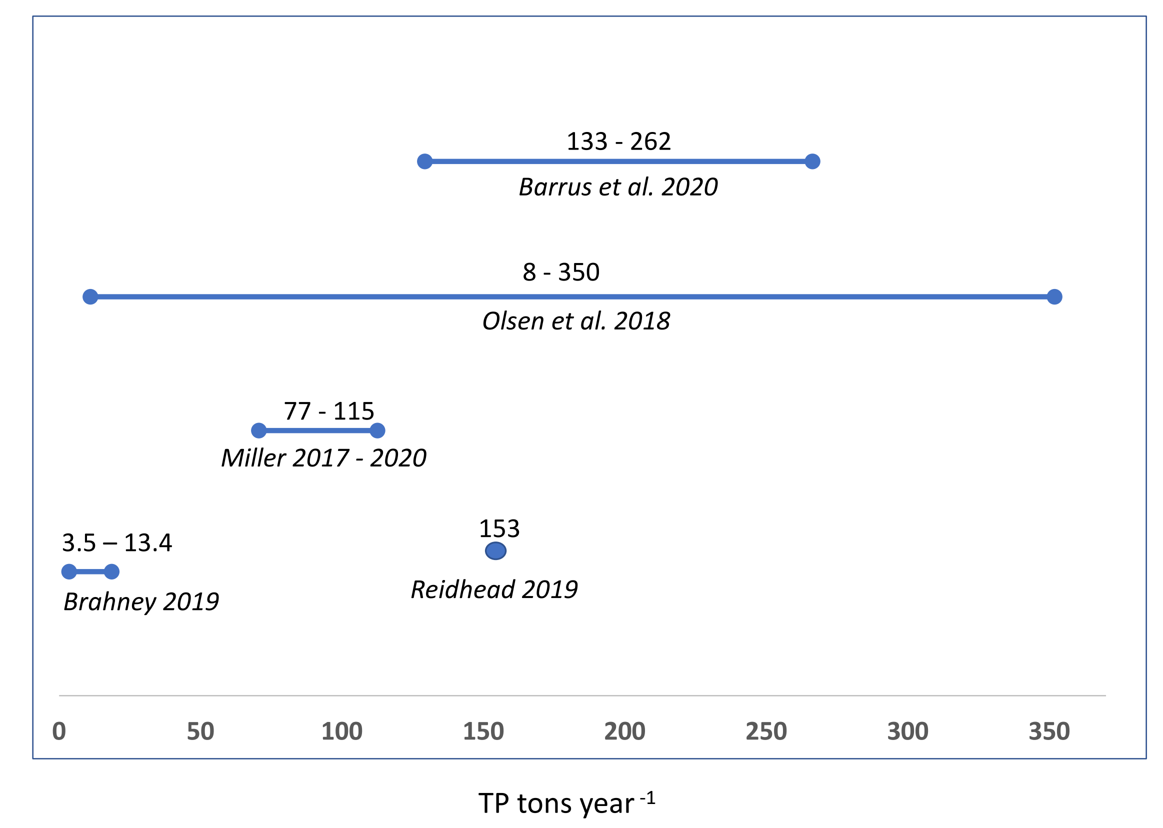


Estimated AD Loads

- **2019 – 2020 Data**
  - Most thorough
  - Best spatial interpolation
- **Olsen explored bounding cases**
  - Any sample with particle removed
  - All samples
  - Dummy points in center of the lake – background levels
- **Reidhead**
  - Removed debris before analysis
  - Very conservative fall-off
- **Barrus**
  - range based on with and w/o screens
- **Brahney**
  - Literature for regional and global transport
- **Miller – bulk samples**
  - Low is average values
  - High is precipitation weighted

Nutrient	2019	2020
TP[1]	262	133
DIN[1]	1,052	482

[1] All data are in tons/year.



Backup Slides

Data 2019 and 2020

- **Figures show that spikes occur**
  - Screens may significantly reduce spikes – not enough data for firm conclusion
  - Spikes in 2019 much higher – prior to placing screens on sample buckets
  - Spike in 2020 is prior to installation of screens which were installed in May.
- **Data show seasonal fluctuations in AD for Utah Lake**
  - AD is higher in the early Spring (March/April) and then again sometime during the summer
  - Probably related to storms
  - Winter storms have either snow or frozen ground – dust is not mobilized
  - Not enough data to quantity or verify these hypothesis.