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

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Avg P (mg kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>4.7</td>
</tr>
<tr>
<td>KCl</td>
<td>4.5</td>
</tr>
<tr>
<td>W+KCL</td>
<td>9.2</td>
</tr>
<tr>
<td>NaOH</td>
<td>174.1</td>
</tr>
<tr>
<td>HCl</td>
<td>926.3</td>
</tr>
<tr>
<td>PFD</td>
<td>1,460.0</td>
</tr>
<tr>
<td>Total</td>
<td>2,572.5</td>
</tr>
</tbody>
</table>

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


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

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


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/m^2/time)
      = mass (mg) / area (0.0615 m^2)/ 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
• 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
• **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 to 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

• 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.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Avg. Median Diff. (mg/m²)</th>
<th>% Lower than High Table</th>
<th>One-tail p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP</td>
<td>1.52</td>
<td>7%</td>
<td>0.264</td>
</tr>
<tr>
<td>DIN</td>
<td>1.12</td>
<td>12%</td>
<td>0.116</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Avg. Median Diff. (mg/m²)</th>
<th>Mult. Diff. between Unfiltered and filtered</th>
<th>One-tail p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP</td>
<td>2.488</td>
<td>3x</td>
<td>0.0004</td>
</tr>
<tr>
<td>DIN</td>
<td>1.816</td>
<td>1.5x</td>
<td>0.0116</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Month</th>
<th>Bird Island</th>
<th>Lakeshore</th>
<th>Mosida</th>
<th>Pump Station</th>
<th>Orem</th>
<th>Avg of 4 shore sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>July</td>
<td>31.93</td>
<td>24.91</td>
<td>21.25</td>
<td>17.28</td>
<td>19.84</td>
<td>20.82</td>
</tr>
<tr>
<td>August</td>
<td>28.87</td>
<td>35.50</td>
<td>38.31</td>
<td>30.02</td>
<td>37.94</td>
<td>35.44</td>
</tr>
<tr>
<td>September</td>
<td>52.29</td>
<td>35.47</td>
<td>25.28</td>
<td>20.21</td>
<td>26.40</td>
<td>26.84</td>
</tr>
<tr>
<td>November</td>
<td>27.17</td>
<td>14.51</td>
<td>13.24</td>
<td>2.62</td>
<td>15.36</td>
<td>11.43</td>
</tr>
</tbody>
</table>

TP data

<table>
<thead>
<tr>
<th>Month</th>
<th>Bird Island</th>
<th>Lakeshore</th>
<th>Mosida</th>
<th>Pump Station</th>
<th>Orem</th>
<th>Avg of 4 shore sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>July</td>
<td>5.35</td>
<td>6.62</td>
<td>7.40</td>
<td>2.56</td>
<td>3.73</td>
<td>5.09</td>
</tr>
<tr>
<td>August</td>
<td>9.37</td>
<td>2.55</td>
<td>3.13</td>
<td>4.36</td>
<td>2.31</td>
<td>3.09</td>
</tr>
<tr>
<td>September</td>
<td>36.25</td>
<td>3.75</td>
<td>6.17</td>
<td>19.91</td>
<td>16.45</td>
<td>11.57</td>
</tr>
<tr>
<td>October</td>
<td>1.73</td>
<td>4.70</td>
<td>3.36</td>
<td>2.49</td>
<td>8.42</td>
<td>4.74</td>
</tr>
<tr>
<td>November</td>
<td>33.34</td>
<td>6.01</td>
<td>2.89</td>
<td>3.34</td>
<td>9.51</td>
<td>5.44</td>
</tr>
</tbody>
</table>

DIN data
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

<table>
<thead>
<tr>
<th>Year</th>
<th>TP (tons)</th>
<th>DIN (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>350</td>
<td>460</td>
</tr>
<tr>
<td>2018</td>
<td>153</td>
<td>505</td>
</tr>
<tr>
<td>2019</td>
<td>392</td>
<td>1659</td>
</tr>
<tr>
<td>2020</td>
<td>133</td>
<td>482</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP(^1)</td>
<td>262</td>
<td>133</td>
</tr>
<tr>
<td>DIN(^1)</td>
<td>1,052</td>
<td>482</td>
</tr>
</tbody>
</table>

\(^1\) All data are in tons/year.
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 quantify or verify these hypothesis.