Nutrients in Great Salt Lake Wetlands: Fluxes and the Role of Microbes

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Salt Lake County Watershed Symposium
The Great Salt Lake Wetlands

- 75% of Utah’s fresh water wetlands are located in the surrounding areas of the GSL (12,000 acres in FB)

- GSL Wetlands are “riparian”- very different vegetative species than adjacent areas and increased growth

- Farmington Bay Wetlands is a managed wetlands and sanctuary for over 200 avian species.

- Major migratory destination for birds.

- Jordan River inlet stream to Farmington Bay Wetlands
Why do we care about GSL Wetlands?

Ecological Benefits
• Performs several ecological functions such as supporting carbon and nutrient cycles
• Provides wildlife habitat
• Supports local food chain

Societal Benefits
• Important tourist place.
• Industrial benefits
• Flood control

Environmental Benefits
• Filters water before being reintroduced into groundwater
• Remediates nutrients in surface waters
• Sink of Carbon Dioxide and Methane
Dangers to Wetlands

• 30% of wetlands have disappeared from Utah since surveying began while the national average lies at around 50% lost.

• Pollutants from surface runoff contaminating wetlands

• Increased nutrients cause eutrophication

• For Farmington Bay, the Jordan River input water usually displays high nutrient concentrations

http://water.epa.gov/type/wetlands/outreach/upload/threats.pdf
Specific to GSL Wetlands

- How do the Farmington Bay Wetlands deal with nutrients?

- What will happen to this area as SLC expands?

- Is extra nutrient regulation needed?

To answer some of these questions, the Utah Division of Water Quality has worked towards developing methods to characterize wetlands and will apply these metrics to Farmington Bay Wetlands.
DWQ’s and UGS Efforts include

• Baseline measurements of nutrients, metals and other parameters.
• Establishing multi metric index (MMI) criteria for GSL wetlands
• Understanding whether GSL wetlands are fully supporting of their designated uses
• Coordinating with stakeholders and water practitioners to address different issues
Our Wetland Efforts
With support from USEPA’s Wetland Development Program

• Focused at a microscale
• Sediment water interactions- in and out fluxes
• Role of bacteria in contributing to nutrients cycling in GSL wetlands, i.e ammonia oxidation and nitrate/nitrite reduction
• Form of phosphorus- P speciation because not all P is bioavailable
Objectives

• Objective 1: Measure sediment nutrient flux at different sites of Farmington Bay.
• Objective 2: Determination of nitrification and denitrification rates of sediment at each site.
• Objective 3: Correlate sediment flux to bacterial communities present.
• Objective 4: Speciate P in terms of bioavailable, mineral bound, Al and Fe bound
Project Sites

<table>
<thead>
<tr>
<th>Farmington Bay Sites</th>
</tr>
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<tbody>
<tr>
<td>FBS</td>
</tr>
<tr>
<td>Dump Site</td>
</tr>
<tr>
<td>Turpin</td>
</tr>
<tr>
<td>South Area</td>
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<tr>
<td>Unit 1 NW</td>
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<tr>
<td>Unit 2</td>
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<td>Unit 1</td>
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</table>

<table>
<thead>
<tr>
<th>Other Wetland Sites</th>
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<tbody>
<tr>
<td>Bear River Unit 5C</td>
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<tr>
<td>Ambassador Pond #1</td>
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</tbody>
</table>

- Featured in this presentation
Early Summer and Late summer sampling

Part I: Nutrient flux- spiked and unspiked

Part II: Nitrification and denitrification rates in sediments

Part III: Sediment microbiology to compare rates

Part IV: Speciation of phosphorus in sediment
QA/QC Measures

• Field blanks were included.
• Instrument positive and negative controls
• New calibration curves
• All protocols and QA/QC plan approved by USEPA
• Research was conducted by trained personnel
• Input from UDWQ was sought during the project period.
Part 1: Nutrient flux- spiked and unspiked

The five sites with the most statistically observable fluxes were chosen for the rest of this presentation.
Sediment Flux Experimental

- Nutrient Flux Chambers – used for on-site analysis of nutrients changes throughout the day

- Monitored for four hours, followed by spiking with 0.5 mg/L NH₄-N, 0.5 NO₃-N, and 0.1 PO₄-P and monitoring for four more hours.

- Spiking occurred to help observe normally undetectable sediment flux and observe pulse effects.

- Duplicate Water and Sediment columns used to compare nutrient dynamics with exposure to sediment

<table>
<thead>
<tr>
<th>Site</th>
<th>1st Sampling Event</th>
<th>2nd Sampling Event</th>
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</thead>
<tbody>
<tr>
<td>FBS</td>
<td>4/24/2014</td>
<td>8/6/2014</td>
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<tr>
<td>Dump Site</td>
<td>5/13/2014</td>
<td>8/18/2014</td>
</tr>
<tr>
<td>Turpin</td>
<td>5/15/2014</td>
<td>8/20/2014</td>
</tr>
<tr>
<td>South Area</td>
<td>6/26/2014</td>
<td>9/19/2014</td>
</tr>
<tr>
<td>Unit 1 NW</td>
<td>5/22/2014</td>
<td>8/25/2014</td>
</tr>
<tr>
<td>Unit 2</td>
<td>5/23/2014</td>
<td>9/8/2014</td>
</tr>
<tr>
<td>Unit 1</td>
<td>5/27/2014</td>
<td>9/15/2014</td>
</tr>
<tr>
<td>Bear River Unit 5C</td>
<td>6/30/2014</td>
<td>9/17/2014</td>
</tr>
<tr>
<td>Ambassador Pond #1</td>
<td>6/5/2014</td>
<td>9/10/2014</td>
</tr>
</tbody>
</table>
• Most unspiked sites show sediments that are sources of ammonia-decomposition
• Spiking caused sediment to become sinks – potentially not all ammonia bioavailable
• Under un-spiked conditions, most of the sites either enabled positive or no flux (except Unit 2-May)
• Nitrate was always disappeared (i.e –ve flux) under both spiked and unspiked cases
• Based on serum bottle tests, it was perhaps due to denitrification in sediments
Spiking caused some sites to display sediment as phosphate sources.

Highest rate of negative phosphate flux corresponded to highest DO change at a site.
Nutrient Flux Conclusions

• Seasonal response for nutrient dynamics at the interface was observed. For example, unit 2 site showed ammonia sink in May under both conditions but enabled positive flux in August under both conditions.

• Decomposition > Nitrification – increase in sediment flux rates when spiked shows not all ammonia in sediment bioavailable.

• Sediment removed nitrate from water column at nearly every site-rate increased with adding nitrate.
  – Sediment source of nitrate = low rbCOD or other outside factors

• Sediment at each site a sink for phosphate, but phosphate spike made some sediments a source of phosphate
  – Phosphorus Speciation
Part II: Nitrification and denitrification rates in sediments
Serum Bottle Experiments

• Serum Bottle Tests – Used to prove the presence of nitrification (open) and denitrification (air tight) and determine maximum rate.
  • Known weight sediment made slurry with deionized water – duplicate and compared spiked versus non-spiked, mirroring nutrient flux study.
  • 12 hour run time
  • Normalized to VS for nitrification and denitrification.
  • N and C limitation for denitrification
Task 1: Nitrification Serum Bottle Tests

- Nitrification serum bottles ran in duplicate overnight. Bottles were unspiked and spiked to roughly 0.5 mg/L NH₄-N.

- In general, all sites showed nitrification potential.
- All sites showed nitrification rate increases after spiking with ammonium nitrogen.

![Average Nitrification Serum Bottle Results](chart)

- Sites: Turpin, South Area, Unit 2, FBS, Ambassador.
- Spiked Rates vs. Unspiked Rates.

![Chart](chart)
Denitrification Serum Bottle Tests

• Denitrification serum bottles ran in duplicate overnight. Three types of serum bottles run, to test for nitrogen and carbon dependency.
  – 0.5 mg/L NO$_3$-N and 25 mg C/L spiked
  – 0.5 mg/L NO$_3$-N spiked and no carbon
  – Unspiked- control
• Turpin showed highest denitrification rates by far.
• South Area and Unit 2 showed some carbon limitation
TOC Results

- Total organic carbon (TOC) for sediments and Non-Purgable Dissolved Organic Carbon (npDOC) were tested for each site using combustion and detection methods.

- Carbon content of water and sediments compared to denitrification results.

- Presence of TOC means the possibility of denitrification but how much is rbCOD

- % VS correlates very well with TOC- surrogate for organic carbon
Nitrification/Denitrification Rate Results

• Nitrification and denitrification rates increased with added nitrogen.
  – Outside factors interfere with sediment fluxes in field to reduce nitrification and denitrification rates.

• TOC supplying sufficient rbCOD for denitrification at most sites

• Not all VS responsible for metabolic processes
Part III: Sediment microbiology to compare rates
Why it is important

• At a fundamental scale, information on key microorganisms can guide us for false positive results.
• At an applied scale, the number of bacteria (instead of volatile solids) can be used to evaluate specific rates which in turn can be used for wetland modeling purposes because similar VS does not mean same numbers of bacteria.
• The information helps better understand the overall nitrogen cycle.
A little bit on functional genes involved

Nitrification- First step is $\text{NH}_4^+\text{-N}$ oxidation to $\text{NO}_2^-\text{-N}$

$$\text{NH}_4^+\text{-N} \rightarrow \text{NO}_2^-\text{-N}$$

amoA gene- Ammonium monooxygenase

Denitrification- First step is $\text{NO}_3^-\text{-N}$ reduction to $\text{NO}_2^-\text{-N}$

Denitrification- Second step is $\text{NO}_2^-\text{-N}$ reduction to $\text{NO}^-\text{-N}$

amoA and nir genes were targeted to quantify nitrifiers and denitrifiers respectively

Nir gene- Nitrite reductase

$$\text{NO}_2^-\text{-N} \rightarrow \text{NO}^-\text{-N}$$

Nir, Nor, Nos, Nar, Nrf, Nrf

NH$_4^+$
Quantitative PCR Results

- qPCR run for each site and normalized to % VS in each sediment

- All sites positive for nitrification and the data agrees with serum bottle data

- In general, amoA gene copy numbers increased from May to August
• All sites positive for nir (i.e. denitrification) gene nirS copy numbers increased from May to August.
• nirK is another subunit of nir (i.e. denitrification) gene
• Meanwhile, nirK amounts decreased from May to August with exception to FBS
Combine nitrification and denitrification rates with gene copy number

• Previous studies normalize nitrification and denitrification to VS, including non-bacterial biomass.

  – Inaccurate because only nitrifying bacteria involved in nitrification, for example- rest of VS does not contribute.

\[
g \frac{NH_4 - N}{amoA \text{ Copy} \times \text{day}} = \frac{(\frac{dC_{serum}}{dt} \times 24 \frac{\text{hours}}{\text{day}})}{m_{VS} \times \left(\frac{\# \text{ amoA Gene Copies}}{mg \text{ VS}}\right)}
\]

  – Same equations used for denitrification, except using nitrate and \textit{nirS/nirK}
• *amoA* normalized nitrification rates showed similar trend to sediment flux, unlike rates normalized to VS.
Denitrification Serum Bottle *nirS* and *nirK* Normalized

- Turpin was included with South Area, and Unit 2 as showing some carbon limitation
Why Normalize to Gene Copy?

- Amount VS ≠ Amount of Bacteria

**Genes Present vs Volatile Solids**

- mg VS values and gene copy # given for top 0-5 cm of sediment in sediment limnocorrals
  - Gene copies do not increase with mg VS
Conclusions from Molecular Analysis

• Sites tested positive for presence of nitrification and denitrification bacteria.

• Nitrification rates normalized to gene copy better predicted ammonia oxidation rates better than rates normalized to VS.

• Nitrification and Denitrification potential for individual bacteria quantified
  – Variation due to other microorganisms present such as ammonia oxidizing archaea

• VS is not a good representative of bacterial content of sediments.
Part IV: Speciation of phosphorus in sediment
Forms of Phosphorus in Sediment

- Loosely Bound P – Bioavailable
- Clay and Aluminum Bound P
- Calcium Bound P – Released in anoxic sediment- Low pH as well.
- Iron and Manganese Bound P (lumped into residual for this analysis)
- Residual P
<table>
<thead>
<tr>
<th>Site</th>
<th>Loosely Bound Phosphorus (mg P/kg dry sediment)</th>
<th>Clay and Aluminum Oxide Bound Phosphorus (mg P/kg dry sediment)</th>
<th>Calcium Bound Phosphorus (mg P/kg dry sediment)</th>
<th>Residual Phosphorus (mg P/kg dry sediment)</th>
<th>Total Phosphorus From Speciation (mg P/kg dry sediment)</th>
<th>Total Phosphorus (mg P/kg dry sediment)</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBS</td>
<td>79.6</td>
<td>157.4</td>
<td>747.9</td>
<td>93.2</td>
<td>1078.1</td>
<td>910.5</td>
<td>118%</td>
</tr>
<tr>
<td>Turpin</td>
<td>75.5</td>
<td>99.6</td>
<td>970.8</td>
<td>133.0</td>
<td>1278.9</td>
<td>1109.9</td>
<td>115%</td>
</tr>
<tr>
<td>Unit 2</td>
<td>193.7</td>
<td>226.5</td>
<td>930.9</td>
<td>141.2</td>
<td>1492.2</td>
<td>1323.8</td>
<td>113%</td>
</tr>
<tr>
<td>South Area</td>
<td>108.2</td>
<td>111.5</td>
<td>1011.2</td>
<td>96.3</td>
<td>1327.3</td>
<td>994.5</td>
<td>133%</td>
</tr>
<tr>
<td>AVG %</td>
<td>7%</td>
<td>10%</td>
<td>74%</td>
<td>9%</td>
<td>9%</td>
<td>9%</td>
<td></td>
</tr>
</tbody>
</table>

**Percentage Of Phosphorus**

- **Loosely Bound Phosphorus**
- **Clay and Aluminum Oxide Bound Phosphorus**
- **Calcium Bound Phosphorus**
- **Residual Phosphorus**
- **Total Phosphorus**
Conclusions from Speciation

• Majority of phosphorus attached to calcium in sediment.

• 7% of phosphorus bioavailable.

• Sites with Ca-bound Phosphorus released phosphate into water column – maximum sorption to sediment reached, possibly.
Overall Conclusion

• Sediments seem to be contributing nitrogen to the water column but not phosphorus.

• Nitrification and denitrification are contributing to fate of nitrogen, but no effect in the long run.

• Gene copy more important parameter to measure than VS.

• An average 74% of phosphorus in sediment is calcium-bound. 7% is loosely bound, 10% is bound to aluminum and clay, and 9% of phosphorus is residual.
Ongoing and planned research

• Study rhizosphere in Wetlands for nutrient dynamics, metal toxicity and iron chemistry.
• Develop bacteria based health indicators for wetlands.
• Pending funding, sample for sites previously sampled by UDWQ and conduct similar analysis.
• Re-estimate rates of nutrients disappearance using stable isotopes.
• Denitrification coupled to methane oxidation.
• For Jordan River, EcolImpact of nutrients and micropollutants.
• Sources of organic carbon in Jordan River.
• Sediment characterization for sediemnt transport.
• Contribution of methane oxidation to Low DO in Jordan River.
• Nitrogen cycling in Jordan River.
This presentation is not complete without thanking......

- USEPA for providing funding for the research
- UDWQ for constant support and help
- Dr. Theron Miller for partial funding the research
- All my labmates for helping me.
Any questions please