Estimating the Amount of Phosphorus Released from Sediment into Utah Lake:

Technical Support Evaluation

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Preliminary Takeaway Points

- Recent studies of diatoms in lake sediment suggest that the amount of phosphorus in the main body of the lake has remained constant from pre-European settlement to the present.
- Although reducing phosphorus in treated water is always considered desirable, in Utah Lake the quantity of natural sources of this nutrient are now quite large in comparison.
- Natural phosphorus now exerts primary control on the amount of phosphorus in Utah Lake.
- Expensive additional upgrades to treatment facilities may not improve water quality in the lake.

Conclusions

Utah Lake has experience phosphorus cycling throughout its history from pre- to post-European settlement time. Phosphorus is naturally released from water entrapped in sediment by the natural process of diffusion, which is the largest source of this nutrient to the lake. Extreme reductions in phosphorus releases from WWTPs would appear to be desirable but may do little to change the amount of phosphorus in the water available to drive algal blooms. Rather, diffusion of large quantities of phosphorus from sediment water into lake water has "baked" a large and persistent source of this nutrient into the lake system. The best long-term management practice may be to work to clarify the water so that periphyton can use this nutrient on the lake bottom rather than allowing it to drive large algal blooms. Reestablishment of a healthy periphyton would be a desirable goal for the Utah Lake ecosystem in general.

Summary of Existing Research

Knowing how (and how much) phosphorus enters and leaves Utah Lake over time is critical to formulating policy as well as taking substantive steps to improve and maintain water quality. Phosphorus enters the lake externally from streams, groundwater, dust and waste water treatment plants (WTTPs). Also, phosphorus enters, or reenters the lake water *internally*. For example, water between the mud grains on the lake bottom (so-called pore water) contains higher levels of phosphorus than the lake water itself. Because of this difference in concentration, this phosphorus gradually moves into the lake water from the pore water by a process known as diffusion. Diffusion is spontaneous. And although it is slow, it occurs continuously across the entire lake. But how much phosphorus enters the lake water by diffusion? And is this amount significant compared to external sources, especially WTTPs? Some preliminary answers to this question are provided.

Recently, significant progress has been made in understanding how phosphorus moves internally within the lake water—pore water system from three studies. First, LeMonte et al. (2023) described how phosphorus sticks to and is released from sediment. Second, Williams et al. (2023) described the concentration of phosphorus, other metals, and organic matter over time in Utah Lake from before Europeans arrived up to 2019. Finally, Goel (2024) provided a detailed description of the movement of phosphorus between lake water, living organisms, minerals in sediment and organic debris. This study is new because it uses a method that captures and *averages* the detailed processes described in these other studies to give a new estimate of how much phosphorus is being released from sediment into the lake water by diffusion. Now it is possible to compare the size of this internal source of phosphorus to external sources. Armed with this information, policy makers can make better decisions regarding the management of resources to address water quality in Utah Lake.

Fick's Law & Freeze Core

In 1855, the German physiologist Adolph Fick proposed his laws of diffusion. For Utah Lake, his first law allows us to estimate how much phosphorus leaves the pore water and enters the lake water. These calculations are described in detail in Nelson and Smith (2024), and are based on data acquired from "freeze core." Freeze coring is a clever method to sample lake sediment by having it freeze as a slab onto the side of a large stainless-steel wedge. The frozen sediment is recovered nearly undisturbed. It can be cut up with a band saw and the water between the sediment grains can be recovered and analyzed for its phosphorus content. In summary, all of the needed information to apply Fick's first law is recovered and the amount of phosphorus that moves into lake water can be estimated. This paper reports the results from a first freeze core. Obtaining additional cores would improve our estimates of phosphorus diffusion.

A Phosphorus Budget

The LeMonte et al. (2023) report provided some critical information, in particular the pH of pore water. The pH, or acidity of this water may be near neutral (pH=6.5 to 7), whereas the lake water is more alkaline (pH=8 to 9). However, LeMonte et al. (2023) acknowledge that their pH measurements may be too low. The pH of pore water is important because it determines how much phosphorus is "bioavailable," or is dissolved in a form readily used by algae and other plants. Nelson and Smith (2024) estimated that between 268 to 421 metric tonnes/year (mT/yr) of phosphorus in orthophosphate[1] could be released into Utah Lake water from pore water. Others have calculated large phosphorus

[1] Phosphorus is reported here as the fraction of this nutrient in orthophosphate, a dissolved form easily used by plants and algae.

fluxes from sediment. By another method, Hogsett et al. (2019) estimated even greater phosphorus releases from sediment, in excess of 1000 mT/yr. That experiment was conducted in the lake in the summer when phosphorus releases were higher than average due to warm temperatures. Dr. Hogsett's revised phosphorus releases, communicated orally, are similar to these when cooler average temperatures are considered.

Abu-Hmeidan et al. (2018) estimated external phosphorus sources as 100 mT/yr from streams and 171 mT/yr[2] from WTTPs. Brown et al. (2023) recently estimated 61 mT/yr from dust (atmospheric deposition). These fluxes are compared to diffusion from pore water into lake water in the pie diagrams in Figure 1.

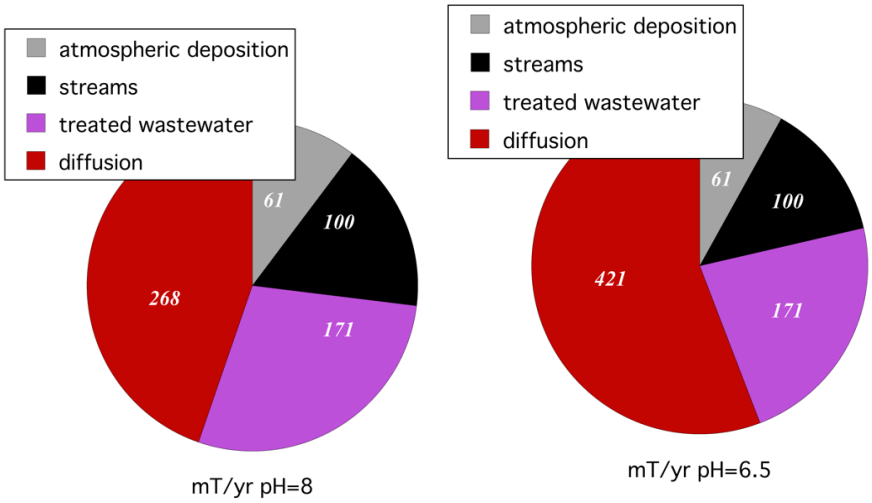

Figure 1. Pie diagrams showing the relative size of ortho phosphorus sources transporting this element into Utah Lake. Numbers of mT/yr phosphorus are shown within each slice.

WTTPs have reduced their phosphorus releases since the value reported by Abu-Hmeidan et al. (2018). Also, not all of the phosphorus released from WWTPs is bioavailable. In the next one to two years all WWTPs discharging to Utah Lake will be in compliance with a 1.0 mg/L State total phosphorus discharge standard. When these plants are in compliance, discharges will drop by about 50% to 60-65 mT/yr, half the value reported by Abu Hmeidan et al. (2018). Thus, the treated wastewater fraction of phosphorus slices of the pie diagrams (Fig. 1) will overrepresent the contribution of treatment plants compared to other sources.

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[2] Some studies like Abu-Hmeidan et al. (2018) cite "total phosphorus," of which approximately 50% is typically orthophosphate. In other studies, the form of phosphorus cited is ambiguous, making comparisons difficult, which comparisons made here. However, comparing orthophosphate from pore water to total phosphorus from other sources underestimates the importance of pore water.

Diffusion of phosphorus from pore water into the lake is, by far, the largest source of this nutrient in Utah Lake. This raises two questions: 1) Has this always been the case? and b) Can anything be done about it?

Has Utah Lake Always Been Phosphorus Rich?

The answer to this question is yes and no. In one sense, the average phosphorus content of Utah Lake is surprisingly low given the available sources of this nutrient, both natural and man-made. This suggests that the lake is naturally efficient of trapping phosphorus in lake sediment. However, diffusion is also efficient in returning most of this phosphorus back into the lake water in a repeating cycle.

The main body of Utah Lake, excluding Provo Bay and perhaps Goshen Bay, has always had significant phosphorus in the water. In Figure 2, reproduced from Nelson and Smith (2024), the amount of dissolved phosphorus has remained fairly constant from before pioneer settlement about 1850 to the present. This reconstruction is based on the analysis of diatoms from freeze core. Diatoms are small single-cell algae that indicate water conditions at the time they were living and trapped in sediment.

The lake cannot be returned to a more pristine state than it was in the mid 19th century before European settlers arrived. If phosphorus could be entirely eliminated in WWTPs discharges, there may not be any real change in this nutrient in the water of the *main body* of the lake. Although this may not be true of Provo Bay, the diatoms suggest that the lake water has contained a fairly steady concentration of phosphorus, whether or not there have been treatment plants in operation.

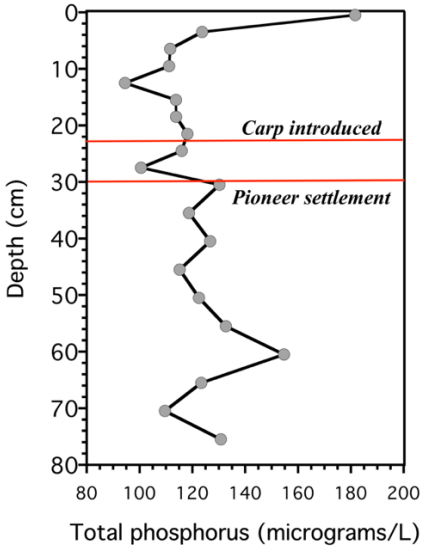

Figure 2. Reconstruction of Utah Lake water phosphorus content based on diatom communities that lived in the lake.

Can Anything Be Done About Phosphorus Diffusion?

The answer to this question is also yes and no. First, "no" is considered. As long as a significant contrast in phosphorus concentration exists between pore water and lake water, diffusion will release a lot of this nutrient to Utah Lake. There is probably very little that can be done about this. Diffusion will be the largest source of phosphorus, and its proportion will increase as WWTPs become more efficient at removing this nutrient. Other actions, dredging the lake, for example, would "reset" diffusion, resulting in large amounts of phosphorus entering lake water suddenly.

As for "yes," there may be some strategies to use natural processes to the lake's advantage. For example, increasing water clarity may help reestablish a healthy "periphyton," which is a layer of living matter such as algae or microbes that cling to the lake bottom. This periphyton has largely been destroyed due to human modification of the lake, including the introduction of carp, which feed on it. This destruction of the periphyton has also been been shown by diatom analysis (Nelson and Smith, 2024). It would be much better for the periphyton to rapidly use phosphorus diffusing from the sediment than it would be to allow it to drive harmful algal blooms. The best way to reestablish the periphyton is: a) to increase the clarity of the lake so that light can penetrate to the lake bottom, and b) reduce carp numbers, which continually disturb the bottom sediments by their foraging behavior, causing the water to become cloudy.

Where Does Phosphorus Go?

Phosphorus added to the lake water by the different sources in Figure 1 is removed by two processes. First, it exits the lake in water flowing into the Jordan River. However, this accounts for a small proportion of the phosphorus, on the order of 10%. The remainder of the phosphorus is returned to the sediment as organic matter (plant, algae and microorganism debris) or is trapped within minerals deposited on the lake bottom like calcite ($CaCO_3$, a very abundant mineral in the lake). Calcite and organic matter in the sediment on the lake bottom can, in turn, break down and release phosphorus to pore water. This release from sediment by diffusion and return to sediment in organic matter and calcite constitute a dynamic cycle of phosphorus in the lake. When these processes are in balance, they act to keep the concentration of phosphorus in the lake at a relatively constant level.

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