Subject:	Utah Lake Water Quality Study Charge Questions Reporting
Sub-Topic:	Sediments
Science Panelists:	Janice Brahney, Greg Carling, Mitch Hogsett, James Martin, Theron Miller
Tetra Tech Team:	Kateri Salk, Michael Paul
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1.0 Background and Approach

Subgroups of the Utah Lake Water Quality Study (ULWQS) Science Panel (SP) have compiled interim responses to the ULWQS Charge Questions according to topic areas. Charge questions are listed below, followed by a traceable account of the evidence evaluation, interim answer statement, and assessment of confidence in the answer. The evaluation of charge questions has proceeded according to the *Utah Lake Water Quality Study—Uncertainty Guidance* document:

- The first consideration in communicating the validity of any statement of finding (e.g., a response to a charge question) is to characterize the evidence (as to type, amount, and quality) as well as the agreement among evidence underlying the finding or conclusion.
- The type of evidence refers to its derivation (e.g., literature, mechanistic model output, field observations, experimental evidence, or expert judgment).
- The amount of evidence refers to the quantity of independent evidence types.
- The quality of evidence refers to the rigor with which the evidence was derived. In previous applications of this approach, the terms “limited”, “medium”, and “high” have been used to describe the evaluation of evidence. The SP can decide how to weigh or combine these three elements into an assessment of the evidence. For example, one large, comprehensive, high quality study of the lake itself may constitute more evidence than results from several observational studies of dissimilar lakes.
- Finally, agreement refers to how results or conclusions among the different lines of evidence differ or concur and the terms “low”, “medium”, and “high” are used to describe agreement. Once again, the SP can decide what constitutes these qualitative statements of agreement.
- The amount and agreement of evidence form axes that define a space that informs estimates of confidence.

An assessment of likelihood is offered as an additional step in the uncertainty guidance framework but is only done if sufficient uncertainty information is provided and can be quantified. Given this is an interim evaluation of charge questions, likelihood has not been assessed at this time.

Moving toward final assessment of the charge questions on the next iteration of this effort, an evaluation of the quality of evidence regarding the type of evidence (e.g., data, presentation memo, SP-reviewed report, thesis/dissertation, peer-reviewed manuscript) will be conducted.

2.0 Charge Questions

2.4. How do sediments affect nutrient cycling in Utah Lake?

i. What are current sediment equilibrium P concentrations (EPC) throughout the lake? What effect will reducing inputs have on water column concentrations? If so, what is the expected lag time for lake recovery after nutrient inputs have been reduced?

ii. What is the sediment oxygen demand of, and nutrient releases from, sediments in Utah Lake under current conditions?

iii. Does lake stratification [weather patterns] play a result in anoxia and phosphorus release into the water column? Can this be tied to HAB formation?

3.0 Question Evaluation

2.4. How do sediments affect nutrient cycling in Utah Lake?

Specifics of this question are addressed as part of sub-questions 2.4.i-2.4.iii below. Overall, there is a great deal of interaction between water column and sediments in Utah Lake. The sediments act as a net sink for nutrients but also release bioavailable forms of N and P. The assessments of confidence around these relationships are detailed as part of the response for each relevant sub-question.

2.4.i. What are current sediment equilibrium P concentrations (EPC) throughout the lake? What effect will reducing inputs have on water column concentrations? If so, what is the expected lag time for lake recovery after nutrient inputs have been reduced?

Evidence evaluation

Equilibrium P concentrations (EPC) means the concentration of P in the water column at which there is no net exchange between water column and sediment because the gradients that drive exchange one way or the other are equal (i.e., at equilibrium). EPC was estimated using the equilibrium water column concentrations in sediment core experiments after spiking with a range of P concentrations (Goel et al. 2020). The values for EPC in the water column were calculated as 0.27 mg/L for the Buoy site and 0.86 mg/L for Provo Bay. While these numbers provide a first estimate of EPC, it would be more correct to calculate EPC concentrations using controlled batch sorption experiments. Upcoming work as part of the P binding study (LeMonte et al. 2021) could provide better precision on EPC in Utah Lake.

As part of the sediment core experiments by Goel et al. (2020), decreased water column P concentrations (i.e., dilutions) caused increased P flux from sediments over the timeframe of hours to several days. This condition is commonly observed in other systems from the literature, due to the shift in gradient between the water column and sediment. The period of enhanced sediment loading levels off as a new equilibrium between sediment and water column is established; the time period to reach this new equilibrium is quite variable and can last days to decades depending on the system. Forthcoming studies will target finding out how EPC and sediment-water column interactions impact the response of internal sediment P loading to reduced watershed nutrient loads, including steady state mass balance modeling by SP member Michael Brett and scenario analysis as part of the EFDC/WASP and/or SedFlux model applications for Utah Lake, will evaluate the impacts of decreased P inputs on internal loading from sediment to water column and the lag time for reduced water column P concentrations to be realized.

Confidence

A single study to date has evaluated this question, with forthcoming studies expected to provide additional lines of evidence to answer this question. Given the low amount of information, albeit with high quality due to the use of established methods and direct applicability to Utah Lake, we conclude there is low confidence in answering this question at present.

Interim Synthesis Statement

Given the available information, the SP currently has low confidence in the ability to assess EPC in Utah Lake, the impacts of reduced P loading, and the expected lag time between reducing P inputs and lower water column P concentrations given the capacity for internal sediment loading. Upcoming work with the ULWQS is fully expected to increase confidence to assess this question. The SP hypothesizes that EPC is such that reducing P inputs may cause an increase in internal sediment P loading, but the widespread occurrence of calcite scavenging of P in Utah Lake may limit the occurrence of widespread and long-lasting enhanced sediment P loading. Forthcoming analyses will quantify the potential for sediment internal loading of P and determine how long these effects will last following a reduction in external P loading.

2.4.ii. What is the sediment oxygen demand of, and nutrient releases from, sediments in Utah Lake under current conditions?

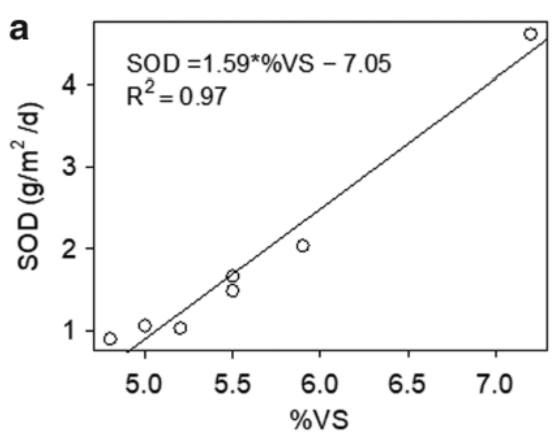
Evidence evaluation

Hogsett et al. (2019) conducted chamber deployments to evaluate sediment oxygen demand (SOD) in Utah Lake. SOD was measured as 1-2 g m^{-2} d^{-1} in the main basin, and ~4.5 g m^{-2} d^{-1} in Provo Bay. The water column removed significantly more oxygen as compared to the sediments, suggesting that most activity is occurring in the water column. SOD was correlated with % volatile solids, a surrogate for organic matter. Water column oxygen demand was not related to sediment %VS, suggesting the biota and reactions occurring in the water column are driving the ambient dissolved oxygen (DO) conditions in the water column.

TABLE 2. SEDIMENT AND WATER COLUMN AMBIENT DISSOLVED OXYGEN DEPLETION RATES

Site	*SOD, g/(m² · day)*	*WC*	*Ambient, g/(m³ · day)*	*%SOD*
1	−4.61	−6.66	−11.3	41
2	−1.42	−3.45	−4.9	29
3	−1.49	−2.28	−2.8	18
4	−2.04	−1.9	−2.9	35
5	−1.67	−3.4	−5.1	33
6	−1.03	−1.28	−1.7	27
7	−1.06	−4.17	−4.5	8
8	−0.9	−1.11	−1.4	21

SOD, sediment oxygen demand; WC, water column.

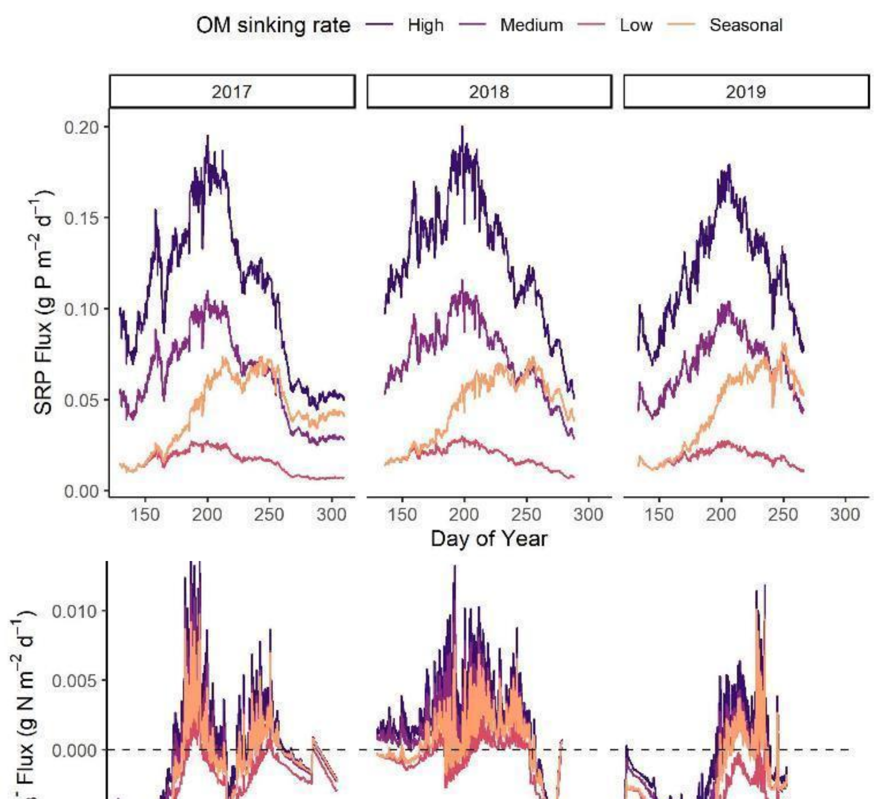


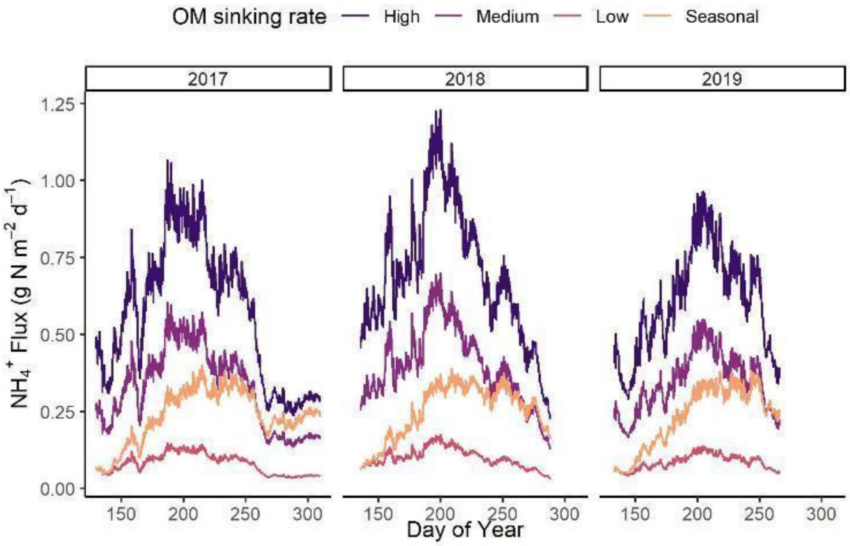
Goel et al. (2020) evaluated SOD as part of sediment core experiments. At the main basin site, SOD was calculated as 2.97 g m^{-2} d^{-1}. SOD was also modeled by the SedFlux model as part of the C, N, and P study (Tetra Tech 2021). SedFlux-modeled SOD rates were higher than measured SOD by an order of magnitude or more, suggesting that SedFlux may not be accounting for important factors driving SOD in Utah Lake, including the impacts of sediment resuspension and organic matter sinking rates. Future literature review of similar shallow, eutrophic systems will enable determination of whether observed SOD in Utah Lake is comparable to other systems.

Randall et al. (2019) found that areas with high P concentrations in sediment and pore water also had high concentrations in the water column. The east side of the lake (including Provo Bay) had the highest P concentrations in sediment, pore water, and the water column. This suggests that sediments store P and may act as a source of P to the water column. P concentrations were positively correlated with organic matter, CaO, and Fe_2O_3 abundances. The study showed that ~40% of P in sediments could potentially be released to the water column, but the study did not investigate release rates from sediments. Direct observations by Hogsett et al. (2019) and Goel et al. (2020) evaluated sediment nutrient fluxes through field and lab experiments. The sediments were found to be a source of ammonium, nitrate, and orthophosphate associated with decaying organic matter that has settled. The positive nitrate fluxes imply that the surface sediments are aerobic (Hogsett et al. 2019). It should be noted that the water column removed significantly more N and P than was released from the sediments.

	Sediment nutrient fluxes, g/(m²·day)			
Site	*NH_4-N*	*NO_3-N*	*TIN*	*PO_4-P*
1	1.442	0	1.442	0.010
2	0.023	0.005	0.03	0.071
3	−0.033	0.021	−0.01	0
4	0.141	0	0.141	0.031
5	0.027	0.012	0.04	0
6	−0.001	0.004	0.00	0.010
7	0.093	−0.008	0.09	−0.004
8	0.027	0.08	0.11	0.001

Sediments were found to be active in terms of P release and uptake depending upon water column P concentrations (Goel et al. 2020). In lab experiments, sediment was a net dissolved P source under ambient or reduced P concentrations in the water column and a net dissolved P sink under elevated water column P concentrations. P release from sediments was highest when water column P concentrations were diluted 0.5x (maximum of 20.40±16.42 mg m^{-2} d^{-1}). P retention was highest at 4x water column P concentrations (maximum flux of -51.84±8.30 mg m^{-2} d^{-1} from the water column to sediments). SedFlux modeling suggested fluxes of bioavailable nutrients (soluble reactive P, ammonium, nitrate) were generally positive, i.e., from sediment to water column and were similar to the range of measured rates. Under scenarios of variable organic matter sinking rates, nutrient fluxes were highly variable (Tetra Tech 2021).





Confidence

SOD and nutrient fluxes have been (a) implied from observed concentrations in sediment, porewater, and water column, (b) measured directly as part of chamber and sediment core experiments, and (c) modeled by the mechanistic model SedFlux. There are four studies that have each addressed multiple sampling locations, replicate sediment cores, and model scenarios, indicating a high amount of evidence to answer this question. The quality of evidence is high due to its direct applicability to Utah Lake. The studies encompass multiple separate independent lines of evidence that employ different methods. With the exception of SedFlux-modeled SOD which has been deemed suspect due to model limitations, the lines of evidence have high agreement. Given the high amount, quality, and agreement of evidence to address this question, we conclude there is high confidence in this statement.

Interim Synthesis Statement

Given the available information, the SP has high confidence that sediments in Utah Lake consume oxygen, with higher rates in Provo Bay (4.5 g m^{-2} d^{-1}) than in the main basin (1-3 g m^{-2} d^{-1}). The sediments overall represent a net sink for total nutrients (~95% of incoming N and P loads), but bioavailable forms of N and P (soluble reactive P/orthophosphate, ammonium, nitrate) are released from the sediments depending on water column chemistry and organic matter content of sediments.

2.4.iii. Does lake stratification [weather patterns] play a result in anoxia and phosphorus release into the water column? Can this be tied to HAB formation?

Evidence evaluation

There is evidence of transient thermal stratification in Utah Lake (https://udwq.shinyapps.io/lakedashboard/), though the lake is polymictic and does not display consistent seasonal stratification in summer months. Utah Lake thus does not behave in the textbook nature of seasonal stratification and turnover that are associated with accumulation of nutrients and depletion of oxygen in the hypolimnion. Despite a lack of seasonal hypoxia or anoxia in the water column, it is possible that local zones of anoxia in the sediment may contribute to phosphorus because a fraction of P is bound to redox-sensitive Fe-oxyhydroxides. P release from sediments potentially contributes to HAB formation (Randall et al. 2019), particularly due to frequent wind-driven resuspension that bring surface sediments into contact with the water column.

Confidence

Data to evaluate this question were sourced from the Utah Division of Water Quality (UDWQ) monitoring program. While the amount of independent sources of evidence is limited to one (and thus no agreement can be assessed), the evidence comprises direct samples for Utah Lake that are accompanied by a documented quality assurance procedure. Given the limited amount of evidence but high quality of the evidence, we conclude there is medium confidence in this statement.

Interim Synthesis Statement

Given the available information, the SP has medium confidence that lake thermal stratification does not occur on a widespread seasonal scale, and the potential impacts on bottom water redox conditions and P release from the sediments are limited. Alternate processes, including anoxic microzones, diel fluctuations in water column DO, and sediment resuspension are mechanisms that are more likely at play in Utah Lake.

4.0 Evidence

Cited Studies and Analyses

Goel R, Carling G, Li H, Smithson S. 2020. Utah Lake sediment-water nutrient interactions. Final Report. Prepared for Utah Department of Environmental Quality.

Hogsett M, Li H, Goel R. 2019. The role of internal nutrient cycling in a freshwater shallow alkaline lake. Environmental Engineering Science 36(5): 551-563.

Randall MC, Carling GT, Dastrup DB, Miller T, Nelson ST, Rey KA, Hansen NC, Bickmore BR, Aanderud ZT. 2019. Sediment potentially controls in-lake phosphorus cycling and harmful cyanobacteria in shallow, eutrophic Utah Lake. PLoS ONE 14(2): e0212238.

Tetra Tech. 2021. Utah Lake Carbon, Nitrogen, and Phosphorus Budgets Study. Draft report submitted to Utah Division of Water Quality.

Forthcoming Studies and Analyses

Mechanistic lake (EFDC-WASP) and watershed modeling (Tetra Tech)

Paleolimnological study

P binding study

Littoral sediment study

TSSD Limnocorral Study