Subject:	Utah Lake Water Quality Study Charge Questions Reporting
Sub-Topic:	Historical Condition
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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

1.1. What does the diatom community and macrophyte community in the paleo record tell us about the historical trophic state and nutrient regime of the lake?

i. Can diatom (benthic and planktonic) and/or macrophyte extent or presence be detected in sediment cores? And if so, what are they?

iii. How have environmental conditions changed over time?

1.2. What were the historic phosphorus, nitrogen, and silicon concentrations as depicted by sediment cores? (add calcium, iron, and potentially N and P isotopes)

1.4. What do photopigments and DNA in the paleo record tell us about the historical water quality, trophic state, and nutrient regime of the lake?

4.1. What would be the current nutrient regime of Utah Lake assuming no nutrient inputs from human sources? This question may require the identification of primary sources of nutrients.

3.0 Question Evaluation

1.1. What does the diatom community and macrophyte community in the paleo record tell us about the historical trophic state and nutrient regime of the lake?

Specifics of this question are addressed as part of sub-questions 1.1.i and 1.1.iii below. Overall, there is a higher degree of eutrophication and nutrient concentrations in Utah Lake at present compared to pre-industrial times, with associated shifts in the biological community that is preserved in the paleolimnological record. The assessments of confidence around these relationships are detailed as part of the response for each relevant sub-question.

1.1.i. Can diatom (benthic and planktonic) and/or macrophyte extent or presence be detected in sediment cores? And if so, what are they?

Evidence evaluation

Sediment cores collected across several locations in Utah Lake provide insight into the historical presence of benthic organisms. Physical plant remains have been found in cores from Goshen Bay and Provo Bay and gastropod remains in the former as well as the Bird Island core (King 2019, Brahney et al. 2021). Hardstem bulrush (emergent macrophyte) presence was indicated pre-1900 in Goshen Bay, but other sites were not tested. Sediment cores (~10 cm long) retrieved by hand from multiple nearshore areas around the lake in 2019 did not contain Characeae (submerged macrophyte) oospores (Brothers, unpublished data). Longer cores taken from sites further offshore may be more likely to contain the remains of this clear-water indicator species, but oospores were not found in cores collected by Brahney et al. .

Epiphytic diatom presence, based on the genus *Epithemia*, was indicated pre-1900 in cores from Goshen Bay and Bird Island (Brahney et al. 2021). Older studies use several benthic/epiphytic species to indicate benthic diatom presence and highlight *Diploneis smithii* as an indicator genus. Bolland (1974) found that from 26-176 cm and 180 to ~300 cm in a sediment core from the northern main basin, benthic/epiphytic species dominate the diatom community. Historical dominance of *D. smithii* was also indicated by Jakuval and Rushforth (1983), from 80 cm deeper in a sediment core collected north of Provo Bay. The ratio of planktonic to benthic diatoms increased through time in cores from Goshen Bay and Bird Island (Brahney et al. 2021)

Confidence

Paleolimnological information about diatom and macrophyte communities has been gathered from sediment cores in Utah Lake, indicating a high quality of evidence due to the direct measurement in the environment of interest and the use of established methods to evaluate the data. Macrophyte data were evaluated as part of three studies that assessed multiple cores, and diatom data were also evaluated as part of three studies that assessed multiple cores. Given the high quality of evidence and the high amount 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 diatoms and macrophytes can be detected in sediment cores. Historical presence of hardstem bulrush has been confirmed at Goshen Bay and Provo Bay sites, Gastropods feed on plant material and their presence in the historical sediments of Goshen Bay and Provo Bay suggest that plant material was readily available near these cores.Benthic and epiphytic diatoms dominated under pre-industrial conditions in Goshen Bay and Bird Island, with an increasing relative prevalence of planktonic diatoms approaching present day. The historical presence of epiphytic diatoms further indicates the presence of emergent and/or submerged macrophyte species, which provided submerged structures/surfaces upon which these diatoms attached.The historical presence of benthic diatoms (bottom sediment preferring) indicates the presence of clearer-water conditions, where ample light was reaching the sediment surface to permit growth.

1.1.iii. How have environmental conditions changed over time?

Evidence evaluation

Sediment cores provide insight into how aquatic community structure and associated environmental conditions have changed over time. Changes in zooplankton community over time were indicated, with an increase in cladoceran remains and a decrease in ostracods post-1890 (Brahney et al. 2021). Ongoing research will evaluate shifts in cladocera taxonomy and size as well as shifts in chironomid taxonomy. Diatom community structure provides an indication of the prevailing environmental conditions at the time of sedimentation, which have changed over time in Utah Lake. In a sediment core from Bolland (1975), a large, cool lake was indicated from 458-464 cm depth, oligo-mesotrophic conditions were indicated from 372 to 430 cm depth, shallow alkaline conditions were indicated from 26 to 176 cm depth, and shallow, alkaline, eutrophic conditions are indicated in modern sediments from 12 to 24 cm depth. Similarly, Brahney et al. (2021) found that pollution-tolerant species increase moving up-core (i.e., toward present) in all sediment cores collected.

Water clarity and benthic primary production models indicate a historical clear-water state, a self-stabilizing submerged macrophyte community would likely require mean phytoplankton chlorophyll *a* concentrations < 18 µg/L and mean Secchi depths of ~ 1 m (considering 2018 water levels), compared to 2018 mean chlorophyll *a* concentrations of 40 µg/L and Secchi depths of 0.25 m (King 2019). Further analysis as part of the EFDC-WASP modeling will evaluate the relationship between pre-industrial nutrient concentrations and phytoplankton and water clarity, providing additional evidence for the modeling-centric portions of this question evaluation.

Confidence

Paleolimnological information about zooplankton and diatom communities has been gathered from sediment cores in Utah Lake, and commonly used indices to infer environmental conditions have been applied accordingly. Together, these indicate a high quality of evidence due to the direct measurement in the environment of interest and the use of established methods to evaluate the data. Multiple sediment cores were collected by Brahney et al. (2021) and compared against Bolland (1975). Given the high quality of evidence and the high amount of evidence to address this question, we conclude there is high confidence in this statement.

Water quality and benthic primary production models were applied as part of a direct study in Utah Lake. While the amount of evidence is low, the quality for that evidence is high. Therefore, we conclude there is medium confidence in this statement.

Interim Synthesis Statement

Given the available information, the SP has high confidence that environmental conditions have changed from oligo-mesotrophic conditions to eutrophic conditions with a prevalence of pollution-tolerant taxa from preindustrial times to present day. Anodonta mussel shells were collected from Bird Island and N cores and may be sensitive to turbidity as well as fish extirpation. The SP has medium confidence that the historical macrophyte-dominated state was negatively impacted by reductions in water clarity, but relationships evaluating the mechanistic link with nutrients will require further study as part of the EFDC-WASP application to Utah Lake.

1.2. What were the historic phosphorus, nitrogen, and silicon concentrations as depicted by sediment cores? (add calcium, iron, and potentially N and P isotopes)

Evidence evaluation

Sediment cores provide extensive information about historical concentrations and forms of elements. Phosphorus (P) concentrations increase over time from approximately 20 cm depth to present day (Brimhall 1972, Bolland 1974). Exchangeable P concentrations and Calcite-bound P representing ambient water column concentrations (the latter identified using three methods; chemical extraction, isolation and chemical extraction, and scanning electron microscopy) increased through time in sediment cores taken from Goshen Bay and Bird Island, whereas Fe- and Al-bound P were relatively stable through time (Brahney et al. 2021, Devey 2021). Isotope values of nitrogen (N) increase through time to values greater than terrestrial soil concentration (5-10 ‰) post-1900, indicating a greater prevalence of wastewater-derived N toward present day. Calcium concentrations increase slightly to ~2000, followed by a decrease in cores taken in Goshen Bay and Provo Bay (Brahney, unpublished). Iron concentrations are variable in cores taken in Goshen Bay and Bird Island, with a tendency toward higher values post-1900 in Bird Island (Brahney, unpublished). Long-term trends in iron concentrations increase at ~430 cm and again, but to a smaller extent, at ~100 cm (Brimhall 1972, Bolland 1974). Long-term changes in aluminum concentrations show a peak at ~120 cm (Brimhall 1972, Bolland 1974); however, the method used for dating in these studies is suspect, implying 2-3 cm of sediment deposition per year, a figure likely too high for Utah Lake. Additional sediment distributions of silicon, calcium, and iron throughout Utah Lake are described in table 5 of Sonerholm (1974).

Confidence

Paleolimnological information about historical elemental concentrations has been gathered from sediment cores in Utah Lake, indicating a high quality of evidence due to the direct measurement in the environment of interest and the use of established methods to evaluate the data. An exception to the high degree of quality in these data are the dating methods used in Brimhall (1972) and Bolland (1974), which are being improved upon in present-day studies of sediment cores. The sediment core information encompasses several studies that evaluated multiple sediment cores, thus representing a high amount of evidence with a high degree of 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 concentrations and forms of P, N, silicon, calcium, iron, and aluminum have changed from preindustrial times to present day, with indicators consistently pointing to a shift to more eutrophic conditions in Utah Lake.

Follow-up Items

The SP will refine the timeline of wastewater delivery and treatment to assist w/ interpretation of results as detailed from Scott Daly and Erica Gaddis (https://documents.deq.utah.gov/water-quality/locations/utah-lake/DWQ-2015-012774.pdf)

- Provo sewers were built in 1908, treatment plant was first built in 1956
- Orem sewers were first built in 1945 and treatment plant in 1959

1.4. What do phytopigments and DNA in the paleo record tell us about the historical water quality, trophic state, and nutrient regime of the lake?

Evidence evaluation

Sediment cores provide information about phytopigments and DNA that serve as indicators for water quality conditions in Utah lake. Phytopigment information indicates a massive lake disturbance with an increase in diatom production around 1890 and greater chlorophyll a degradation rates post-1890 in Goshen Bay and Bird Island (King 2019, Brahney et al. 2021). The highest chlorophyll a concentrations were observed near the surface of sediment cores in Goshen Bay and Provo Bay, consistent with a transition from diatom production to cyanobacteria and green algae production in recent decades (King 2019, Brahney et al. 2021). Chlorophyll a concentrations and cyanobacterial pigments showed minor decreases in production around 1950 before increasing to highest concentrations toward present day (King 2019, Brahney et al. 2021). eDNA records show an increasing abundance of cyanobacteria post-1900 and representation of hardstem bulrush pre-1900 (King 2019, Brahney et al. 2021).

Confidence

Paleolimnological information about phytoplankton communities has been gathered from sediment cores in Utah Lake using common methods including chlorophyll extraction and eDNA analysis. Chlorophyll and eDNA represent two independent lines of evidence analyzed from sediment cores from three different locations in Utah Lake. The two methods are consistent in their interpretation of increasing cyanobacteria abundance from the pre-industrial period to present day, suggestive of a shift to more eutrophic conditions. Along with observed increased chlorophyll *a* concentrations and decreased diatom abundance, the lines of evidence have a high degree of agreement in the observed community shift that is indicative of higher nutrients and a more eutrophic state. Given the high quality of evidence, the medium amount of evidence, and the high degree of agreement among independent lines of evidence, we conclude there is high confidence in this statement.

Interim Synthesis Statement

Given the available information, the SP has high confidence that the independent lines of evidence from phytopigments and DNA show a shift from oligo-mesotrophic conditions to eutrophic conditions from pre-industrial time to present, indicative of an increase in nutrient abundance, in Utah Lake

4.1. What would be the current nutrient regime of Utah Lake assuming no nutrient inputs from human sources? This question may require the identification of primary sources of nutrients.

Evidence evaluation

There is currently little evidence demonstrating the predicted nutrient regime assuming no inputs from human sources. Evidence from Charge Question 1 (and associated sub-questions) indicates the lake had a less eutrophic nutrient regime in pre-industrial times compared to present, but it is unclear what changes have co-occurred alongside nutrient regime changes to impact the potential nutrient regime of present-day Utah Lake under minimal human input. Some evidence has been presented that a macrophyte-dominated clear water historical state was hypothesized to retain more nutrients than the current algal-dominated state, as indicated by the likely historical presence of clear water indicator species, *Chara aspera* (Miller and Crowl 2006, Hilt et al. 2017). Forthcoming work as part of the EFDC-WASP application for Utah Lake and mass balance modeling by SP member Michael Brett will incorporate a scenario under which human nutrient inputs are set to zero, thus directly addressing this question

Confidence

Given the lack of evidence to date, the SP has low confidence in the assessment of this question as of presently available information. However, the upcoming EFDC-WASP application and Brett mass balance analysis for Utah Lake and associated scenarios will increase the evidence amount and quality, thus increasing the SP's confidence in answering this question.

Interim Synthesis Statement

Given the available information, the SP hypothesizes the current nutrient regime of Utah Lake would be lower under a reduced human nutrient input scenario. However, direct evidence to answer this question has been limited to date and this statement thus has low confidence. Upcoming work with the ULWQS is expected to increase confidence to assess this question.

4.0 Evidence

Cited Studies and Analyses

Brahney, J et al. 2021. Paleolimnology of Utah Lake Update, presentation to the Utah Lake Science Panel

Brahney, J et al. 2021. What did Utah Lake look like 200 years ago? Utah Lake Symposium https://pws.byu.edu/utah-lake/what-did-utah-lake-look-like-200-years-ago-janice-brahney OR https://youtu.be/kaTpv6Od7QQ?list=TLGGaHoJqWGRonsxMjEwMjAyMQ

Brimhall. 1972. Recent history of Utah Lake as reflected in its sediments. A first report. Geology Studies Volume 19 part 2. Brigham Young University

Brotherson JD. 1981. Aquatic and semiaquatic vegetation of Utah Lake and its bays. Great Basin Naturalist Memoirs 5: article 5.

Bolland RF. 1974. Paleoecological interpretation of the diatom succession in the recent sediments of Utah Lake, Utah. University of Utah PhD Dissertation.

Javakul, Grimes, and Rushforth. 1983. Diatoms in sediment cores in Utah Lake, Utah. U.S.A. Hydrobiologia 98: 159-170.

King LR. 2019. The response of Utah Lake's plant and algal community structure to cultural eutrophication. Utah State University Master's Thesis.

Sonerholm. 1974. Normative mineral distributions in Utah Lake sediments: A statistical analysis. Geology Studies Volume 21, Part 3. Brigham Young University

Tate RS. 2019. Landsat collections reveal long-term algal bloom hot spots of Utah Lake. Brigham young University Master's Thesis. https://scholarsarchive.byu.edu/etd/8585

Williams, R. 2021 Determining the anthropogenic effects on eutrophication of Utah Lake since European settlement using multiple geochemical approaches. Brigham Young University Master's Thesis.

Forthcoming Studies and Analyses

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

Utah Lake nutrient mass balance and internal loading analysis (Michael Brett)

Paleolimnological SEM analysis results