Subject:	Utah Lake Water Quality Study Charge Questions Reporting
Sub-Topic:	Harmful Algal Blooms (HABs)
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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.

2.0 CHARGE QUESTIONS

2.3. What are the linkages between changes in nutrient regime and Harmful Algal Blooms (HABs)?

i. Where do HABs most frequently start/occur? Are there hotspots and do they tend to occur near major nutrient sources?

ii. Which nutrients are controlling primary production and HABs and when?

iii. If there are linkages between changes in nutrient regime and HABs, what role if any does lake elevation changes play?

iv. How do other factors affect HAB formation in Utah Lake (e.g., climate change; temperature; lake stratification; changes in zooplankton and benthic grazers and transparency)

v. What is the role of calcite “scavenging” in the phosphorus cycle?

vi. What is the relationship between light extinction and other factors (e.g., algae, TSS, turbidity)?

4.3. If the lake stays in a phytoplankton-dominated state, to what extent can the magnitude, frequency, and extent of harmful and nuisance algal blooms be reduced through nutrient reductions?

3.0 QUESTION EVALUATION

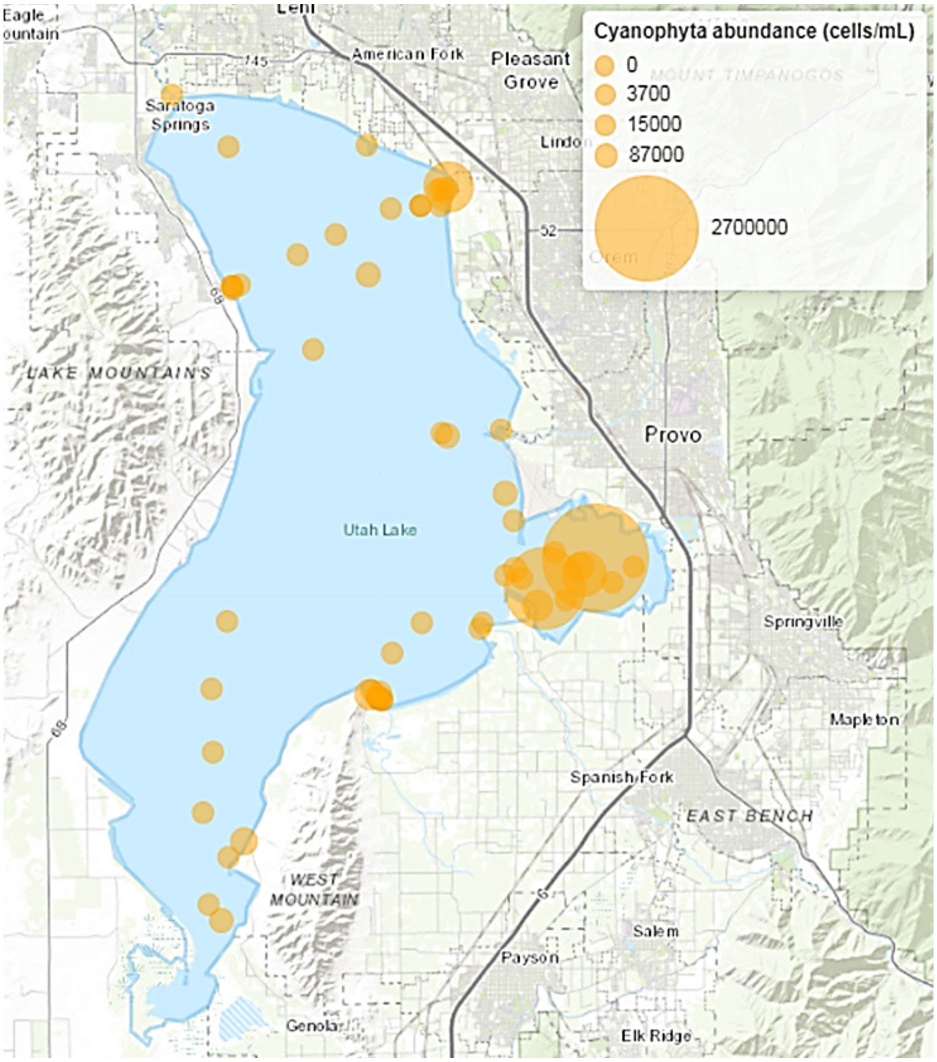
2.3. What are the linkages between changes in nutrient regime and Harmful Algal Blooms (HABs)?

Specifics of this question are addressed as part of sub-questions 2.3.i through 2.3.vi below. Overall, there is a positive relationship between nutrients and HABs in Utah Lake, but this relationship is complicated by mediating factors including spatial and temporal variability, bioavailability of nutrient pools, non-algal turbidity, climate, and the balance of internal and external nutrient loading. The assessments of confidence around these relationships are detailed as part of the response for each relevant sub-question.

2.3.i. Where do HABs most frequently start/occur? Are there hotspots and do they tend to occur near major nutrient sources?

Evidence evaluation

There are hot spots of HAB abundance in Utah Lake. In some cases, HAB hot spots appear to be related to nutrients, but other physical and chemical factors may play a role as well (e.g., vertical and horizontal mixing, residence time, light). The abundance of HAB taxa, including cyanobacteria as well as individual genera (*Aphanizomenon*, *Oscillatoria*, *Phormidium*, *Dolichospermum*, and *Cylindrospermopsin*) have highest abundance in Provo Bay and in the northeast portion of the main basin (Tetra Tech 2021, Utah Lake Data Explorer). HABs in Provo Bay are in close proximity to sub-catchment outflows that contain publicly owned treatment works (i.e., Mill Race with Provo POTW, Spring Creek - Springville with Springville POTW, and Dry Creek - Spanish Fork with Spanish Fork POTW). HABs in the northeast portion of the main basin are located near Lindon Marina, which may have requisite chemical and physical conditions but is not necessarily associated with zones of high nutrient inputs. Future work, namely EFDC-WASP modeling for Utah Lake, will help to parse the causal relationship between nutrient loading and HABs.



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.

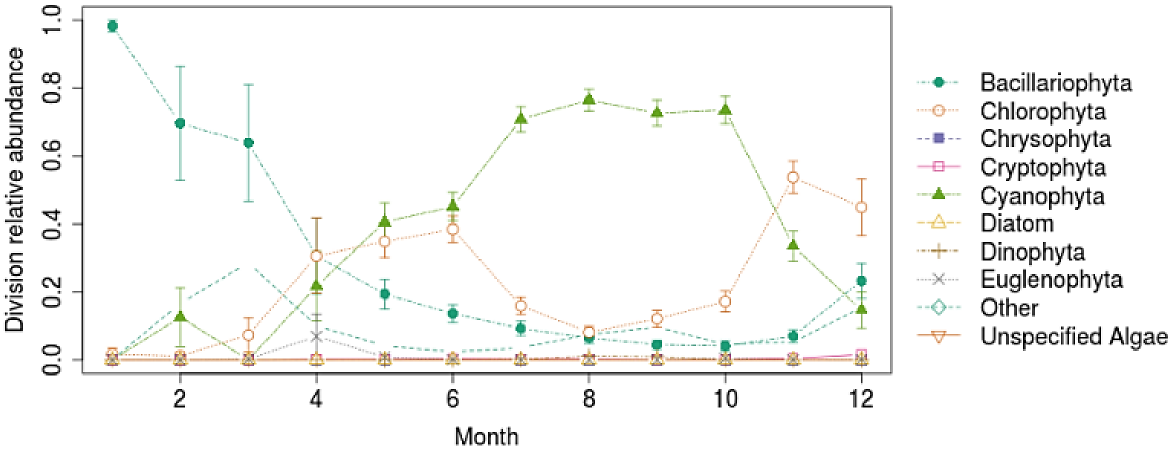
Interim Synthesis Statement

Given the available information, the SP has medium confidence that cyanobacteria grow across all parts of Utah Lake, but HAB hot spots occur in Provo Bay and in the northeast part of the main basin of Utah Lake. HABs in Provo Bay and the northeast occur near major nutrient sources from POTWs, but it is unclear if HABs in the northeast main basin occur due to a proximity to nutrient sources or due to mixing in Utah Lake which could stimulate HABs regardless of proximity to nutrient sources. The SP hypothesizes that HAB hotspots could also be due to wind-driven accumulation of surface HABs. Additional data from satellite imagery (NASA, CyAN) will bolster the monitoring dataset and increase the SP’s confidence in this statement.

2.3.ii. Which nutrients are controlling primary production and HABs and when?

Evidence evaluation

Utah Lake Data Explorer, sourced from the UDWQ monitoring program, indicates a seasonal progression of relative abundance of various phytoplankton taxa typical of eutrophic lakes, with relative abundance shifting from a dominance of diatoms (Bacillariophyta) in the early spring, green algae (Chlorophyta) in the late spring, cyanobacteria (Cyanophyta, which includes HAB taxa) in the summer and early fall, and green algae again in late fall. These successional patterns are suggestive of nutrient limitation and competition among taxa with different growth and nutrient uptake strategies. This observation is consistent with the hypothesis that lakes tend toward P limitation in the spring and early summer and co-limitation of N and P in the late summer and fall. A subset of cyanobacteria are able to fix N from the atmosphere, thus cyanobacteria may become dominant during periods of N limitation or co-limitation due to their N fixation capabilities.



The controlled experimental bioassay study by Aanderud et al. (2021) directly assessed the effects of N and P additions on phytoplankton, including cyanobacterial responses (i.e., phycocyanin and microcystin concentrations). The total phytoplankton pool was most commonly co-limited by N and P across sites and seasons, with more variable responses to nutrients in the early part of the growing season. Cyanobacteria displayed different nutrient limitation across sites, with Provo Bay exhibiting P limitation or co-limitation through spring and summer, and main basin sites exhibiting no limitation, P limitation, N limitation, and co-limitation. Cyanobacteria were not limited by N or P in late summer and fall. Microcystin production was not nutrient limited and displayed highest concentrations in the early and mid-summer in the bioassay experiments.

Variable and Location	spring	early summer	summer	late summer	fall
Cyanobacteria nutrient limitation					
East	No limitation	No limitation	P	No limitation	No limitation
West	N+P	No limitation	N	No limitation	No limitation
Provo Bay	P	N+P	P	No limitation	No limitation
Total phytoplankton nutrient limitation					
East	No limitation	N+P	N+P	N+P	N+P
West	P	No limitation	N+P	N+P	N+P
Provo Bay	N+P	N	N	N+P	N

N fixation was observed in both Provo Bay and the main basin and was four times higher in Provo Bay, potentially implying that N fixation has the capacity to alleviate N limitation in Provo Bay. Controlled experimental dilution bioassays also indicated a lowering of both N and P concentrations has the capacity to reduce primary production.

The ULWQS Analysis Report (Tetra Tech 2021) evaluated the relationship between phytoplankton metrics (phytoplankton and cyanobacteria cell count and biovolume) and nutrients as a part of a quantile regression and a hierarchical multiple regression. The quantile regression showed a positive relationship between phytoplankton and total P (TP) across all quantiles. A modest positive relationship was found between phytoplankton abundance and total N (TN) at the median quantile, but the relationship was not consistently positive across all quantiles. The hierarchical multiple regression showed a positive correlation of phytoplankton abundance with TP and a negative correlation with TN.

Upcoming work with empirical stressor-response modeling and the EFDC-WASP model will help to further evaluate the relationships between phytoplankton and nutrients, including scenarios for lower nutrient conditions and their potential impacts on bloom reduction in Utah Lake. Finally, supporting evidence from the literature may help to shed light on patterns of nutrient limitation in Utah Lake, including studies from comparable systems including Lakes Taihu, Okeechobee, and Erie.

Confidence

The evidence available to answer this question comprises evidence from the scientific literature, observational monitoring data, two statistical models, and bioassay experiments. The amount of evidence is therefore robust, and the sources of evidence agree that limitation of both N and P exists in Utah Lake, but the occurrence of N, P, and N+P colimitation is variable over time, space, and relevant taxa (total phytoplankton vs. cyanobacteria). We conclude there is high confidence in this statement.

Interim Synthesis Statement

Given the available information, the SP is highly confident that both N and P limit primary production in Utah Lake, and the degree of limitation of one or both nutrients varies across the growing season, location in the lake, and taxa of interest.

2.3.iii. If there are linkages between changes in nutrient regime and HABs, what role if any does lake elevation changes play?

Evidence evaluation

Phytoplankton metrics (cell count and biovolume of cyanobacteria) in Utah Lake are negatively correlated with lake elevation, as indicated by a hierarchical multiple linear regression (Tetra Tech 2021). However, lake elevation encompasses several possible drivers, including water clarity, hydraulic residence time, evaporation, sediment-water interactions, and external inflows of water and nutrients. Thus, lake level can impact HABs, but not necessarily as a direct driver. Upcoming work with the EFDC-WASP model will allow for scenario testing that incorporates changing lake level, which may help to parse the specific mechanistic drivers of lake level-associated impacts on HABs.

Confidence

The amount of evidence for this question is limited to a single analysis, the type of evidence is a direct stressor-response analysis for Utah Lake. The p-values for this analysis across various phytoplankton metrics were < 0.05 and the R^2 values ranged from 0.40 to 0.53, so the quality of this evidence is interpreted as medium. We conclude there is medium confidence in this statement.

Interim Synthesis Statement

Given the available information, the SP has a medium degree of confidence that lower lake elevations are associated with larger HABs. However, lake elevation appears to have a smaller impact than nutrients, and lake elevation encompasses several possible drivers which may co-occur in Utah Lake and should be parsed as part of future efforts.

2.3.iv. How do other factors affect HAB formation in Utah Lake (e.g., climate change; temperature; lake stratification; changes in zooplankton and benthic grazers and transparency)

Evidence evaluation

A hierarchical multiple regression indicated that all assessed phytoplankton parameters (phytoplankton and cyanobacteria cell count and biovolume) were negatively correlated with antecedent precipitation and evaporation, and cyanobacterial parameters were positively correlated with antecedent air temperature. In context, periods of higher phytoplankton abundance are likely to occur when TP and temperature are high and when precipitation and evaporation are low (Tetra Tech 2021). While transient stratification has been observed in Utah Lake (Tetra Tech 2021), frequent wind events prevent seasonal stratification and subsequent oxygen depletion and nutrient accumulation in the hypolimnion. Thus, Utah Lake does not behave like dimictic or monomictic lakes that experience redox-driven mobilization of hypolimnetic nutrients that may fuel blooms. Some information exists on zooplankton and macroinvertebrate communities in Utah Lake (Landom and Walsworth 2020), but the analyses to date have focused on their relationships with carp rather than the phytoplankton community. Future efforts may apply the EPA's chlorophyll-zooplankton model (https://nsteps.epa.gov/apps/chl-zooplankton/; EPA 2021) to assess the relationship between phytoplankton and zooplankton in Utah Lake; the coupling of zooplankton and phytoplankton biomass is expected to reduce at high phytoplankton biomass due to the inability of zooplankton to maintain grazing pressure on the phytoplankton community. Transparency is addressed in question 2.3.vi.

Confidence

The amount of evidence to answer this question varies by the specific constituent of interest, ranging from zero to several independent analyses. For the constituents which no evidence exists currently, forthcoming analyses will fill those gaps in knowledge. The p-values for the analysis of climate data across various phytoplankton metrics were < 0.05 and the R^2 values ranged from 0.30 to 0.47, so the quality of this evidence is interpreted as medium. We conclude there is medium confidence in the assessment of the impacts of climate change, temperature, and lake stratification on HAB formation, and low confidence for the other constituents due to a lack of analyses to date.

Interim Synthesis Statement

Given the available information, the SP has medium confidence that climate-related factors (precipitation, evaporation, air temperature) may have significant impacts on HAB formation in Utah Lake, with negative relationships between HABs and precipitation and evaporation, and positive relationships between HABs and temperature. The SP has medium confidence that lake stratification is unlikely to impact HABs in Utah Lake due to the transient nature of thermal stratification. The impact of zooplankton and benthic grazers on HABs in Utah Lake is unknown at this time.

2.3.v. What is the role of calcite "scavenging" in the phosphorus cycle?

Evidence evaluation

Previous work indicates that calcite precipitation may be a dominant pathway for P sedimentation in Utah Lake (LeMonte et al. 2021). Uncertainty remains as to whether calcite precipitation renders P non-bioavailable to phytoplankton, and how much sediment P returns to the water column for phytoplankton uptake. The forthcoming P binding study (LeMonte et al. 2021) will address these knowledge gaps and help to answer this question.

Confidence

Information is currently not available to determine a degree of confidence for this question. Forthcoming work will address knowledge gaps.

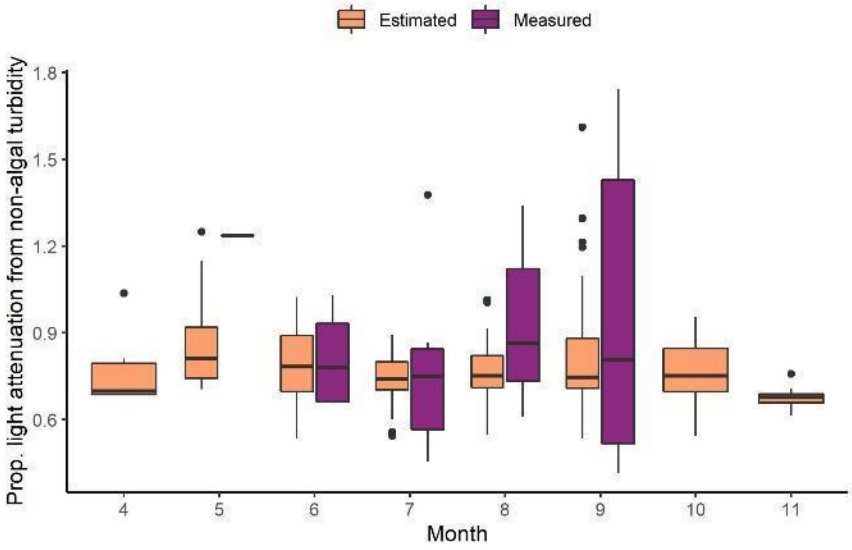
Interim Synthesis Statement

The interim assessment of the SP is that information is not limited to evaluate this question. Previous work suggests that calcite scavenging is a primary mechanism for P sedimentation in Utah Lake, but it is unclear whether this process renders the P permanently buried vs. available for phytoplankton uptake Forthcoming work will increase the confidence of the SP to answer this question.

2.3.vi. What is the relationship between light extinction and other factors (e.g., algae, TSS, turbidity)?

Evidence evaluation

Water clarity is influenced by several factors, including phytoplankton (algal turbidity), suspended sediment (non-algal turbidity), and dissolved organic matter. The ULWQS Analysis Report (Tetra Tech 2021) evaluated water clarity in Utah Lake across several analyses. Trophic state index as computed from Secchi depth were higher than those computed from chlorophyll, indicating non-algal turbidity contributes to reduction in clarity in Utah Lake. The ratio of observed vs. expected Secchi depth, the latter computed from chlorophyll concentrations, was 0.33 ± 0.23 (mean ± standard deviation). Light attenuation from non-algal turbidity made up 74 ± 8% (mean ± standard deviation) of total light attenuation. There was also a positive correlation between turbidity and total suspended solids (TSS). Light attenuation was positively correlated with turbidity, TSS, chlorophyll, and dissolved organic carbon, consistent with relationships observed in the literature in other systems (Brown 1984, Armengol et al. 2003, Zhang et al. 2007, Devlin et al. 2008). Non-algal turbidity may thus present challenges for phytoplankton as they relate to light availability, although some HAB taxa use buoyancy to alleviate light limitation and establish surface blooms.



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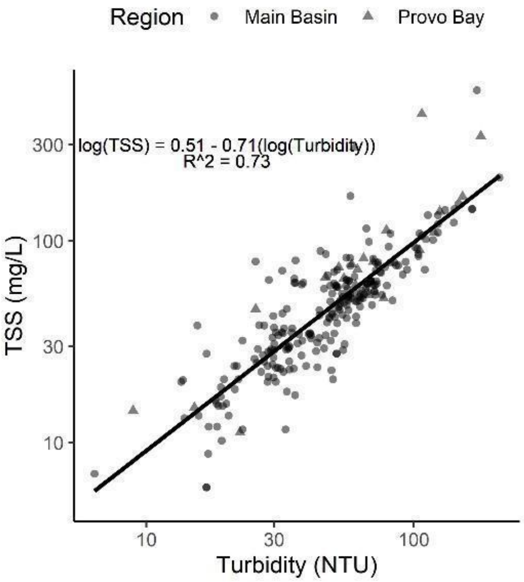

Confidence

The evidence available to answer this question comprises evidence from the scientific literature as well as five independent statistical analyses. The amount of evidence is therefore robust, and the sources of evidence agree that light extinction in Utah Lake is impacted by both non-algal turbidity and phytoplankton, in order of importance. The quality of evidence is also high, with data coming directly from Utah Lake and statistical tests finding a large proportion of variance explained. We conclude there is high confidence in this statement.

Interim Synthesis Statement

Given the available information, the SP has high confidence that light extinction occurs rapidly with depth in Utah Lake, and the majority of light attenuation is due to non-algal turbidity, with a minor but substantial part of light attenuation occurring due to phytoplankton.

4.3. If the lake stays in a phytoplankton-dominated state, to what extent can the magnitude, frequency, and extent of harmful and nuisance algal blooms be reduced through nutrient reductions?

Evidence evaluation

Controlled experimental dilution bioassays by Aanderud et al. (2021) indicated that sufficiently low concentrations of dissolved N and P decrease phytoplankton growth in Utah Lake, but the relationship linking the magnitude of nutrient input reduction to a percent reduction in bloom biomass has not yet been assessed. Internal nutrient cycling will play a key additional role in determining the responses of phytoplankton to external nutrient loading reductions, with forthcoming work from Science Panelist Michael Brett. Upcoming work with empirical stressor-response models and mechanistic lake and watershed models that incorporate nutrient loading scenarios will help to answer this question.

Confidence

Information is currently not available to determine a degree of confidence for this question. Forthcoming work will address knowledge gaps.

Interim Synthesis Statement

The SP has high confidence and consensus that high nutrient concentrations lead to phytoplankton blooms in Utah Lake, and that lower nutrient concentrations lead to lower phytoplankton biomass. The hypothesis that reducing blooms will depend on reducing nutrients is supported by experimental work (dilution bioassays by Aanderud et al.), statistical analysis of monitoring data for Utah Lake (stressor-response models of nutrients vs. phytoplankton), and studies from the literature that demonstrate reductions in phytoplankton blooms with nutrient reductions. Forthcoming work of the ULWQS will quantify the impacts of nutrient reductions on the magnitude, frequency, and extent of blooms and will evaluate the combined effects of external and internal nutrient loading.

4.0 EVIDENCE

CITED STUDIES AND ANALYSES

Aanderud ZT, Abbott BW, Baker MA, Lawson GM, Jones EF, Bratsman SP, Buck R. 2021. Utah Lake bioassay final report – nutrient limitation of total phytoplankton, cyanobacteria, and cyanotoxins. Final Report submitted to Utah Division of Water Quality.

Armengol J, Caputo L, Comerma M, Feijoo C, Garcia JC, Marce R, Navarro E, and Ordonez J. 2003. Sau reservoir’s light climate: relationships between Secchi depth and light extinction coefficient. Limnetica 22(1-2): 195-210.

Brown R. 1984. Relationships between suspended solids, turbidity, light attenuation, and algal productivity. Lake and Reservoir Management 1(1): 198-205. doi: 10.1080/07438148409354510

Devlin MJ, Barry J, Mills DK, Gowen, RJ, Foden J, Sivyer D, and Tett P. 2008. Relationships between suspended particulate material, light attenuation and Secchi depth in UK marine waters.

Environmental Protection Agency (EPA). 2021. Ambient Water Quality Criteria to Address Nutrient Pollution in Lakes and Reservoirs. EPA-822-R-21-005.

Landom K and Walsworth TE. 2020. Biotic community response to Common Carp removal and lake level fluctuations in Utah Lake, UT. Draft report submitted to the June Sucker Recovery Implementation Program.

LeMonte JJ, Carling GT, Rey K, Nelson ST. 2021. Sampling analysis plan for Utah Lake Water Quality Study: Phosphorus Binding in Utah Lake. Submitted to Utah Division of Water Quality.

Tetra Tech. 2021. Utah Lake Water Quality Study Analysis Update. Draft Report submitted to Utah Division of Water Quality.

Section 2.4: Phytoplankton and zooplankton analysis

Section 2.7: Light extinction

Utah Lake Data Explorer (https://tetratech-wtr-wne.shinyapps.io/UtahLakeDataExplorer/)

Zhang Y, Zhang B, Ma R, Feng S, and Le C. 2007. Optically active substances and their contributions to the underwater light climate in Lake Taihu, a large shallow lake in China. Fundamental and Applied Limnology 170(1): 11-19. doi: 10.1127/1863-9135/2007/0170-0011

FORTHCOMING STUDIES AND ANALYSES

Empirical stressor-response analysis (as part of phase III of the ULWQS)

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

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