Utah Lake Water Quality Study—Analysis Plan

Final

March 6, 2019

PRESENTED TO

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Cover image: Aerial View of Provo Utah with River Valley and Utah Lake, by Aqua Mechanical. Source file available at https://www.flickr.com/photos/aquamech-utah/24776739750/in/photostream/

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ABBREVIATIONS

Abbreviation	Definition
ANCOVA	Analysis of Covariance
CCA	Canonical Correspondence Analysis
HAB	Harmful Algal Bloom
k_d	Light extinction coefficient
POTW	Publicly Owned Treatment Works
SP	Science Panel
UDWQ	Utah Department of Water Quality
ULWQS	Utah Lake Water Quality Study

1.0 BACKGROUND

The goal of the Utah Lake Water Quality Study is to evaluate the role of excess nutrients in the support of designated uses in Utah Lake, with a focus on development of in-lake water quality criteria that are protective of the lake's designated uses. A component of this work involved data characterization.

The data characterization task consists first of supporting additions to the existing compilation of Phase 1 data by compiling and incorporating information from Phase 2 and any other study data (including all information, reports, and data developed to date for ULWQS) as needed by UDWQ. In addition, the task includes conducting additional empirical (statistical) characterization and stressor-response modeling to complement that already performed with Phase 1 data and included in the Phase 1 report and Utah Lake Data Explorer; specifically targeting questions raised by the SP in reference to the charge questions that can be answered with existing data.

After data compilation (in process), a series of appropriate additional statistical analyses are being proposed in this analysis plan. These may include descriptive analyses, multivariate analysis of nutrient and biological response variables, and machine learning analyses to explore the data, as well as parametric and non-parametric regression and multilevel/hierarchical modeling to characterize stressor-response relationships of interest, including characterizing thresholds for and uncertainty in such relationships. Some success has been achieved for datasets like this using multilevel/hierarchical empirical modeling approaches to characterize stressor-response relationships for systems like Utah Lake where there may be subtle differences in response relationships based on location (e.g., Bay vs open water), but where there is an underlying functional response.

A first step in this work is to develop this analysis plan and work with the Science Panel to refine this plan ensuring it is consistent with SP objectives and their recommended analytical needs; specifically, to address important linkages identified in the conceptual model, address data gaps and uncertainties; and, most importantly, support their ability to answer the charge questions.

Based on feedback from the Panel, this analysis plan will be finalized and implemented. All model output will be made available through enhancement to the existing Data Explorer Shiny app.

2.0 PROPOSED ANALYSES AND APPROACHES

The following proposed analyses are based on the Phase 2 Purpose and Initial Charge to Science Panel from Steering Committee document (September, 6 2018), initial charge questions working content document (October 2, 2018 version), Attachment A ULWQS Science Panel Ideas for Studies, Experiments, and Literature Reviews (August 24, 2018), and feedback from the Science Panel during an analysis planning session on workshop 3 (February 8, 2019).

2.1 CARP EXCRETION

Question: What contribution do carp make to the total nutrient budget of the lake via excretion rates and bioturbation? How much nutrient cycling can be attributed to carp? (Charge question 2.1.i)

Objective: Estimate potential excretion rates of carp.

Approach: Using fish excretion data provided by R. King from two sources (Aquatic_animal_excretion_variable_descriptions.csv and Vanni_aquatic_animal_excretion_2017.csv) and estimates of lake fish densities, estimate fish nutrient excretion loads. Calculate standard measures of statistical uncertainty (means and standard deviations). Compare these to existing annual external load estimates as a percentage of load moving through fish.

2.2 ALGAL CELL COUNT AND PIGMENT RELATIONSHIPS

Question: What is the relationship between cell count, biovolume, and pigment concentration data? (Question raised in workshop 3)

Objective: Estimate relationships between cell count, biovolume, and pigment concentrations.

Approach: Using Phase I and II monitoring data which includes cell count, biovolume and chlorophyll a data, construct simple general linear models relating pigment concentrations to cell counts and biovolumes from paired samples. Calculate mean relationships and measures of uncertainty (confidence and prediction intervals).

2.3 SONDE DATA ANALYSIS

Question: Can sonde data be teased apart? (Question raised in workshop 3) (**Can the science panel please clarify the request here a little more as well**)

Objective: Extract sonde data and examine relationships among sonde variables.

Approach: Using Phase I and II continuous sonde data, examine relationships among sonde variables using standard correlation and regression analyses. Calculate mean relationships and measures of uncertainty (confidence and prediction intervals). Examine any differences in sonde location using, potentially, location as a random effect in regression models.

2.4 PLANKTON SPATIAL ANALYSIS

Phytoplankton and zooplankton spatial analysis are requests found in both the charge question working content as well as Attachment A ULWQS Science Panel Ideas for Studies, Experiments, and Literature Reviews documents. Here they are split into a number of sub-analyses.

Phytoplankton and zooplankton temporal dynamics

Question: When do HABs most frequently start/occur? (Charge question 2.3.i) What are the temporal patterns in phytoplankton and zooplankton? What is the seasonal succession of phytoplankton and zooplankton? What is the typical pattern of phytoplankton and zooplankton, how do they wax and wane? (Attachment A ULWQS Science Panel Ideas for Studies, Experiments, and Literature Reviews question).

Objective: Estimate temporal patterns in plankton, including HAB, assemblages.

Approach: Explorer already has an analysis of gross temporal patterns of phytoplankton using Phase I data that will be updated with Phase II data and will have zooplankton data added, to the extent allowed by the data. To the extent allowed by the data, additional time series analyses will be conducted to test for specific patterns in plankton species/group composition using time as a predictor in multivariate models of phytoplankton assemblage structure. In addition, to the extent practicable with the data, use Cyan[1] (satellite imagery) database and calculate weekly cyanobacterial frequencies and using the available time series, evaluate the series for potential patterns using visual analysis or detrending algorithms. Calculate julian day estimates for maximum bloom frequencies (with uncertainty estimates) for each resolvable Cyan lake pixel.

[1] https://www.epa.gov/water-research/cyanobacteria-assessment-network-cyan

Phytoplankton and zooplankton spatial dynamics

Question: Are there hotspots and do they tend to occur near major nutrient sources? (Charge question 2.3.i) Do HABs generally begin near POTW outfalls? What is the typical pattern of phytoplankton and zooplankton, how do they wax and wane? (Attachment A ULWQS Science Panel Ideas for Studies, Experiments, and Literature Reviews question).

Objective: Estimate spatial patterns in plankton, including HAB, assemblages.

Approach: Explorer already has an analysis of gross spatial patterns of phytoplankton using Phase I data that will be updated with Phase II data and will have zooplankton data added, to the extent allowed by the data. To the extent allowed by the data, additional spatial analyses will be conducted to test for specific patterns in plankton species/group composition using location as a predictor in multivariate models of phytoplankton assemblage structure. Environmental variables will be overlaid on the spatial patterns in biota to examine congruence in environmental and biological structure. Distance to POTW will be calculated and included as a predictor in nested multivariate models of plankton structure and environmental predictors. Indicator species analysis may also be used to identify specific taxa driving any spatial patterns in plankton assemblage structure.

In addition, again using the Cyan database and weekly cyanobacterial frequency data for resolvable pixels, evaluate the time series for potential spatial patterns using visual analysis or testing for differences among pixels in Cyan index dynamics. Test for spatial differences using some frequency analysis, like chi-squared test for the number or pixels assuming random distribution.

Dynamics in plankton pattern related to nutrients

Question: Which nutrients are actually controlling primary production and HABs and when? (Charge question 2.3.ii) If there are linkages between changes in nutrient regime and HABs?? (Charge question 2.3.iii)

Objective: Test for a relationship between nutrient concentrations and HAB abundances.

Approach: Using the spatial analyses conducted in previous sub-analyses, test for relationships between nutrient concentration and HAB abundances. Using exploratory analyses like non-metric multidimensional scaling (NMS) and canonical correspondence analysis (CCA), first explore potential relationships between nutrient concentrations and HAB abundances. Test for statistical relationships between nutrient concentration and HAB abundances at specific locations, using adjustments for repeated measures as necessary. Location may be treated as a random effect in ANCOVA like models where nutrients are continuous predictors of HAB abundance. Uncertainty will be quantified and reported.

Dynamics in plankton pattern related to lake level

Question: If there are linkages between changes in nutrient regime and HABs, what role if any does lake elevation change play? (Charge question 2.3.iii)

Objective: Test for a relationship between lake level and HAB abundances.

Approach: Using the spatial analyses conducted in previous sub-analyses, test for relationships between lake level and HAB abundance. Using Phase I and II data, Cyan data (as allowed by availability), and lake level records, estimate the relationship between lake level and plankton (including HAB) abundance. This extends the plankton spatial analysis to add lake level as a predictor in multivariate models of plankton structure. We will also extend the ANCOVA like models of the previous sub-analysis of dynamics in plankton pattern related to nutrients to add lake level as a predictor and test for an effect on nutrient-plankton response relationships.

Dynamics in plankton pattern related to other factors

Question: 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)? (Charge question 2.3.iv)

Objective: Test for a relationship between temperature, stratification and HAB abundances.

Approach: Using the spatial analyses conducted in previous sub-analyses, test for relationships between temperature or stratification and HAB abundance. Using Phase I and II data, Cyan data (as allowed by availability), and temperature records (both average and vertical profile), estimate the relationship between temperature, lake water column stability (as measured by Schmidt stability and plankton (including HAB) abundance. This extends the plankton spatial analysis to add temperature and water column stratification as predictors in multivariate models of plankton structure. We will also extend the ANCOVA like models of the previous sub-analysis of dynamics in plankton pattern related to nutrients to add temperature and water column stability as predictors and test for effects on nutrient-plankton response relationships.

We understand that empirical data suggest Utah Lake rarely stratifies and given the average depths and area, physical models suggest it is unlikely that the lake consistent stratifies, however small summer temperature gradients in this lake can set up strong thermal stability and it is worth investigating how strong even small thermal gradients may be, how resistant they may be to mixing (i.e., what wind force would be needed to mix them), and what the relationship to some algal response measures may be.

Dynamics in plankton pattern related to climate

Question: If there are linkages between changes in nutrient regime and HABs, what role if any does precipitation play? (Attachment A ULWQS Science Panel Ideas for Studies, Experiments, and Literature Reviews question).

Objective: Test for a relationship between antecedent precipitation and HAB abundances.

Approach: Using the spatial analyses conducted in previous sub-analyses, test for relationships between antecedent precipitation and HAB abundance. Using Phase I and II data, Cyan data (as allowed by availability), and downloaded climate data, estimate the relationship between temporal differences in precipitation and plankton (including HAB) abundance. This extends the plankton spatial analysis to add antecedent precipitation as a predictor in multivariate models of plankton structure. We will also extend the ANCOVA like models of the previous sub-analysis of dynamics in plankton pattern related to nutrients to add antecedent precipitation as a predictor and test for an effect on nutrient-plankton response relationships. Different temporal ranges of antecedent conditions will be explored (day, week, month).

2.5 ENVIRONMENTAL REQUIREMENTS OF DIATOMS AND MACROPHYTES

Question: What are the environmental requirements for submerged macrophytes currently present at Utah Lake? Are certain species more resilient to drawdowns and nutrient related impacts? Can some species establish/adapt more quickly? (Charge question 2.2/2.2.i)

Objective: Identify the autecology of Utah Lake diatom and macrophyte species.

Approach: To the extent provided by available diatom and macrophyte autecological databases, summarize the environmental requirements of common diatom species and target macrophyte taxa; for the former, especially nutrient optima and for the latter, especially optima for nutrients, light and inundation.

2.6 WIND AND TURBIDITY

Question: What is the relationship between carp, wind, and macrophytes on non-algal turbidity and nutrient cycling in the lake? What impact could macrophyte reestablishment have? (Charge question 2.2.ii)

Objective: Identify wind condition necessary to entrain bottom sediments in Utah Lake.

Approach: Using physical limnological/hydrodynamic theory, calculate forces necessary to mix and entrain bottom sediments. Using mixing potential indices, like Wedderburn numbers, and calculations for bottom shear stress like the Darcy-Weisbach expression, calculate wind speeds necessary to entrain bottom sediments in Utah Lake. Using existing climate data on wind speeds and directions, calculate how frequently such wind speeds occur, where, and any pattern in their seasonality. Using existing turbidity data from synoptic and continuous samplers, develop empirical regression models relating wind speed or mixing force (e.g., Wedderburn number) to observed turbidities.

2.7 TURBIDITY AND MACROPHYTES

Question: What is the relationship between carp, wind, and macrophytes on non-algal turbidity and nutrient cycling in the lake? What impact could macrophyte reestablishment have? (Charge question 2.2.ii)

Objective: Identify the potential contribution of macrophytes to reducing turbidity.

Approach: Again, using the data from the previous sub-analyses and using physical limnological/hydrodynamic theory, calculate the effect of bottom roughness represented by macrophyte densities (using observed or literature data) and its effect on reducing bottom velocities using Manning's roughness or equivalent, and calculate the change in the effective windspeed then needed to entrain bottom sediments in the presence of macrophytes.

2.8 LIGHT EXTINCTION

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

Objective: Identify the potential contribution of turbidity/TSS and algal biomass to turbidity.

Approach: Using empirical models of light attenuation for lakes as well as empirical data from Utah Lake, we will attempt to identify the contributions of non-algal turbidity and chlorophyll to light attenuation. Decomposing attenuation into these effects will require calculating k_d from Secchi depth, from which there are fairly sound equations, that will be calibrated with any existing measured light attenuation and Secchi depth data for Utah Lake. Then, correlation and regression models of TSS, turbidity, and chlorophyll and k_d will be constructed and compared to published models.