TETRA TECH

MEMO

To:	Scott Daly
Cc:	
From:	Kateri Salk and Michael Paul
Date:	2021-01-11
Subject:	Summary of literature review and data compilation for Utah Lake C, N, P study

1.0 GOALS

The literature review gathered information from published peer reviewed literature and gray literature relevant to Utah Lake. Topics that Tetra Tech reviewed include:

- hydrologic and atmospheric inputs of elements to the lake, namely through tributaries, groundwater, drains, direct precipitation, and atmospheric deposition
- hydrologic and atmospheric outputs from the lake, namely through tributaries, groundwater, and evaporation
- water column transformations of elements
- sediment transformations of elements
- elemental fluxes between the water column and sediment
- elemental standing stocks in various pools in the water column and sediment

Topics that Tetra Tech will further investigate as modeling efforts move forward are:

- topics above that have not been measured in Utah Lake but have been measured in similar systems
- the controlling and modifying factors known to affect C, N, and P in the water column and sediments. These may include but are not limited to redox, temperature, biotic uptake, chemical and physical binding, stoichiometry, and water budget (e.g., changing depth of the lake);

2.0 LITERATURE REVIEW

2.1 SOURCES

Literature was compiled from several sources:

- Files received from client as part of the Utah Lake Nutrient Criteria Development Technical Support project
- Web of Science search
- Google Scholar search
- Direct contact with scientists conducting studies in Utah Lake

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2.2 SEARCH TERMS

For the literature searches in Web of Science and Google Scholar, the following search terms were used:

Search Term	Results	Engine
“Utah Lake” AND nitrogen	4	Web of Science
“Utah Lake” AND phosphorus	4	Web of Science
“Utah Lake” AND carbon	0	Web of Science
“Utah Lake” AND nutrient*	5	Web of Science
“Utah Lake” AND nitrogen	593	Google Scholar
“Utah Lake” AND phosphorus	423	Google Scholar
“Utah Lake” AND carbon	1030	Google Scholar
“Utah Lake” AND nutrient*	816	Google Scholar

In many cases, document(s) that appeared in a given search were repeated in other search(es). Further, many documents appearing in the Google Scholar searches were not relevant (e.g., mention carbon in the introduction but do not study carbon, study plant areas upland of Utah Lake, etc.). Documents were thus downloaded and included in the literature list if they were unique and relevant. In the case of Google Scholar searches, document evaluation was ceased after reaching a page that contained no relevant documents.

2.3 LITERATURE LIST

The final literature list contains 79 documents, comprising journal articles, reports, theses, and letters. Of these documents, 38 documents contain data on C, N, and/or P, 30 contain data on Utah Lake but not for C, N, or P, and 5 are relevant studies in other systems. 9 documents are detailed in the “Amospheric Deposition Notes” file and are relevant to the estimation of atmospheric N and P deposition in Utah Lake, 6 of which do not include data on rates but provide context for analyses and ongoing discussions. Additional documents will be added and incorporated to the data compilation report as they arise through discussion with the client and collaborators.

2.4 ADDITIONAL LITERATURE TO FILL GAPS IN UTAH LAKE DATA

- Filled in conceptual model with UL data, then highlighted missing stocks and processes
- Searched relevant textbooks and google Scholar/Web of Science for missing data

3.0 DATA COMPILATION

See Section 5: Appendix for a list of each document included in each portion of the data compilation. Data were extracted from the reviewed documents and compiled in the workbook “UtahLake_CNPDataCompilation.xlsx”, which accompanies this memo.

3.1 UTAH LAKE C, N, AND P STUDIES

Studies containing C, N, and/or P data in Utah Lake were characterized as follows:

- FileName
- Author(s)

- Publication Year
- Title
- ArticleType (Journal Article, Report, Thesis, etc.)
- Process or Pool (Phase and Element, e.g., water column N)
- Fraction (specific process or pool, e.g., TN)
- Rate or Amount Units
- Aggregation (e.g., mean, SD, maximum, etc.)
- Year
- Month
- Location
- Measured or Estimated?
- Approach (how were data measured or estimated?)
- Notes (any additional relevant information)
- Evidence amount, agreement, and confidence (see section 4: Data Uncertainty)

Note that many documents have multiple rows of data if they measured multiple elements, fractions, and/or aggregations.

3.2 RELATED UTAH LAKE STUDIES

Studies focued on Utah Lake but not on C, N, or P were characterized as follows:

- FileName
- Author(s)
- Publication Year
- Title
- ArticleType (Journal Article, Report, Thesis, etc.)
- Details (relevant information on the information the document contains)

3.3 RELATED STUDIES IN OTHER SYSTEMS

- FileName
- Author(s)
- Publication Year
- Title
- ArticleType (Journal Article, Report, Thesis, etc.)
- Details (relevant information on the information the document contains)

3.4 ATMOSPHERIC DEPOSITION

Atmospheric deposition studies and evaluation documents are documented in the “Atmospheric Deposition Notes” document, which details the content of each document. These documents will be revisited when external atmospheric deposition estimates are needed for modeling tasks.

3.5 ADDITIONAL LITERATURE TO FILL GAPS IN UTAH LAKE DATA

Stock or Process	Amount or Rate	Additional notes	Source
Phytoplankton N content			
Phytoplankton P content			

Phytoplankton N uptake			
Phytoplankton P uptake			
Phytoplankton N excretion			
Phytoplankton P excretion			
Zooplankton N content			
Zooplankton P content			
Zooplankton N uptake			
Zooplankton P uptake			
Zooplankton N excretion			
Zooplankton P excretion			
Fish N content			
Fish P content			
Fish N uptake			
Fish P uptake			
Macrophyte N content			
Macrophyte P content			
Macrophyte N uptake			
Macrophyte P uptake			
Macrophyte N uptake			
Macrophyte P uptake			
Macrophyte N excretion			
Macrophyte P excretion			
Macroinvert. N content			
Macroinvert. P content			
Macroinvert. N uptake			
Macroinvert. P uptake			
Macroinvert. N excretion			
Macroinvert. P excretion			
DOP concentration			
PIP concentration			
PP settling rate			
PP resuspension rate			
Sediment TP speciation			

DON concentration			
PN concentration			
PN settling rate			
PN resuspension rate			
Porewater TDN concentration			
Denitrification rate			
N fixation rate			

4.0 DATA UNCERTAINTY

When proceeding with modeling efforts, the uncertainty associated with specific data values will be qualified using the procedures outlined in the Utah Lake Water Quality Study Uncertainty Guidance document. Aspects of uncertainty include:

- Evidence
- Agreement
- Confidence

Evidence comprises both quality and quantity. All studies evaluated for evidence in the Utah Lake C, N, and P Studies group of documents were data directly from Utah Lake, so evidence quality in terms of relevance is high for all of those documents. Additional aspects of quality include the methodology used to arrive at a specific value, with standard methods and direct measurements having higher quality than nonstandard or estimated methods. The quantity of evidence was determined as the number of studies that addressed that specific process or pool of nutrient (listed in the table as “Evidence amount (number of studies)”). Agreement was evaluated as follows:

High	< 10% difference in values
Medium-High	< 25% difference in values
Medium	< 50% difference in values
Medium-Low	>50% difference, <500% difference in values
Low	>500% difference in values

When there was only one study that addressed a given pool or process, evidence agreement could not be determined and was set as NA.

Confidence was determined using Table 2 from the Uncertainty Guidance document:

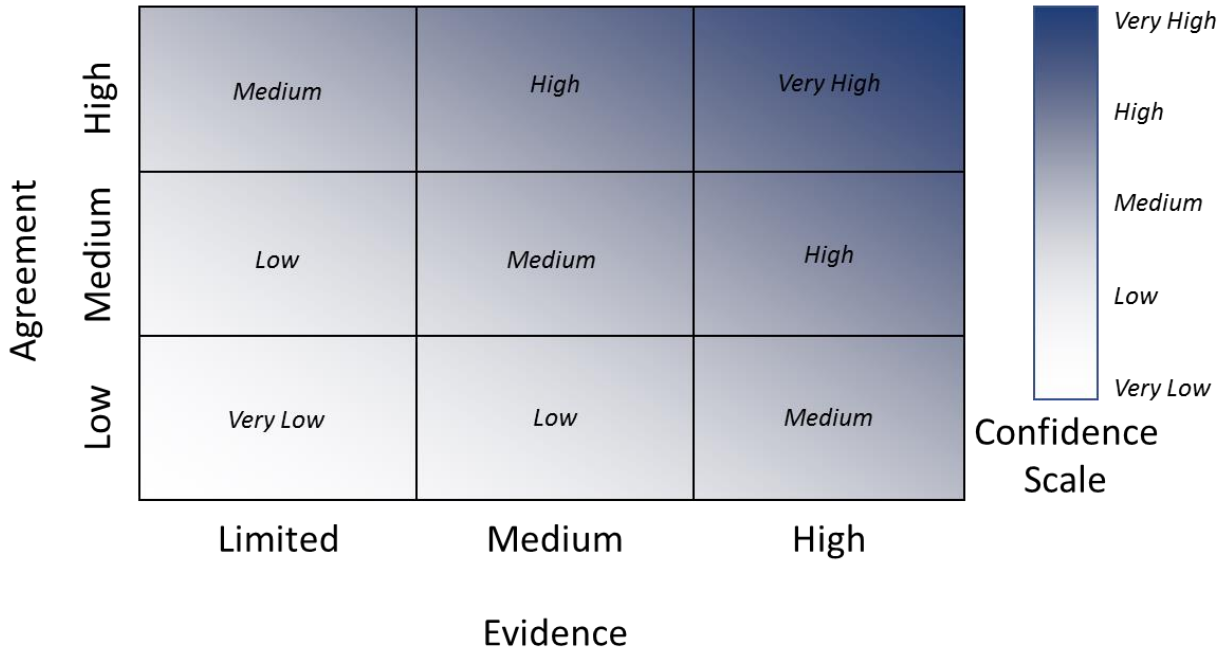

Figure 1. Example of a discrete rule matrix for deciding confidence.

When there was only one study that addressed a given pool or process, the methodology that was used to quantify that pool was evaluated to determine confidence (e.g., standard methods via APHA for measured data are of high quality, so confidence was assigned as high). Unusual circumstances impacting confidence are addressed in the "Comments" column. The most common comment provided to address confidence was that low agreement for water column nutrient concentrations arose due to variable concentrations across time and space, not necessarily inconsistency among studies.

5.0 APPENDIX: STUDIES INCLUDED IN LITERATURE REVIEW

5.1 UTAH LAKE C, N, AND P STUDIES

Total number of documents: 38

File Name	Title	Article Type
Abu Hmeidan 2017 thesis	Characterizing Current and Geologic Phosphorus in Utah Lake Sediment Using Field Samples, Laboratory Methods, and Statistical Analysis: Implications for Water Quality Issues	Thesis
Abu Hmeidan et al. 2018	Characterizing Total Phosphorus in Current and Geologic Utah Lake Sediments: Implications for Water Quality Management Issues	Journal Article
Allert et al. 2006	Using On-Site Bioassays to Determine Selenium Risk to Propagated Endangered Fishes	Journal Article
Bradshaw et al.	Chemical Response of Utah Lake to Nutrient Inflow	Journal

File Name	Title	Article Type
1973		Article
Brahney 2019	Estimating total and bioavailable nutrient loading to Utah Lake from the atmosphere	Report
Brett 2019a Letter	Analysis of the Merritt and Miller 2016 "Nutrient Loadings to Utah Lake" report	Letter
Brett 2019b Letter	Response to LaVere Merritt June 12, 2019 memo	Letter
Brett 2019c Letter	Untitled	Letter
Collins 2019 Thesis	Bottom-Up Controls (Micronutrients and N and P Species) Better Predict Cyanobacterial Abundances in Harmful Algal Blooms than Top-Down Controls (Grazers)	Thesis
Gaeta and Landom 2016a	A whole-ecosystem response of a shallow lake to drought and an invasive carp removal, with an emphasis on endangered fish conservation	Report
Gaeta and Landom 2016b	Final environmental assessment for removal and control of nonnative carp in Utah Lake to support june sucker recovery	Report
Goel et al. 2020	Utah Lake Sediment–Water Nutrient Interactions	Report
Greaves and Hirst 1919	The Phosphorus, Potassium, and Nitrogen Content of the Waters of the Intermountain Region	Journal Article
Hines 2011 Thesis	Relative Importance of Environmental Variables for Spawning Cues and Tributary Use by an Adfluvial Lake Sucker	Thesis
Hogsett et al. 2019	The Role of Internal Nutrient Cycling in a Freshwater Shallow Alkaline Lake	Journal Article
Horns 2005	Utah Lake Comprehensive Management Plan Resource Document	Report
Kelso and Baker 2020	Organic Matter is a Mixture of Terrestrial, Autochothonous, and Wastewater Effluent in an Urban River	Journal Article
Li et al. 2019	High-throughput DNA sequencing reveals the dominance of pico- and other filamentous cyanobacteria in an urban freshwater Lake	Journal Article
Li et al. 2020	Microbial community successions and their dynamic functions during harmful cyanobacterial blooms in a freshwater lake	Journal Article
Merrell 2015 Thesis	Utah Lake Sediment Phosphorus Analysis	Thesis
Merritt 2017 Letter	Utah Lake: A Few Considerations	White Paper
Merritt and Miller 2016	Interim Report on Nutrient Loadings to Utah Lake	Report
Miller and Provenza 2007	Mechanisms of resistance of freshwater macrophytes to herbivory by invasive juvenile common carp	Journal Article
Miller 2020	Updated Interim Report on Nutrients in Precipitation on Utah Lake	Report
Miller and Richards	Executive Summary of recent Utah Lake Reports: (Richards and Miller	Report

File Name	Title	Article Type
2020 Summary Report	2019, Richards, 2019, Williams 2019, Miller 2019 and Merritt 2019)	
Narteh 2011	Mapping and Modeling Chlorophyll-a Concentrations in Utah Lake Using Landsat 7 ETM+ Imagery	Thesis
Olsen 2018 Thesis	Measuring and Calculating Current Atmospheric Phosphorous and Nitrogen Loadings on Utah Lake Using Field Samples, Laboratory Methods, and Statistical Analysis: Implication for Water Quality Issues	Thesis
Olsen et al. 2018	Measuring and Calculating Current Atmospheric Phosphorous and Nitrogen Loadings to Utah Lake Using Field Samples and Geostatistical Analysis	Journal Article
PSOMAS and SWCA 2007	Utah Lake TMDL: Pollutant Loading Assessment & Designated Beneficial Use Impariment Assessment	Report
Randall 2017 Thesis	Characterizing the Fate and Mobility of Phosphorus in Utah Lake Sediments	Thesis
Randall et al. 2019	Sediment potentially controls in-lake phosphorus cycling and harmful cyanobacteria in shallow, eutrophic Utah Lake	Journal Article
Reidhead 2019 Thesis	Significance of the Rates of Atmospheric Deposition Around Utah Lake and Phosphorus-Fractionation of Local Soils	Thesis
Shah et al. 2017	Nitrogen sources and transformations within the Jordan River, Utah and Microbial community response to energy and nutrient availability in the Jordan River, Utah	Report
Squires and Rushforth 1986	Winter phytoplankton communities of Utah Lake, Utah, USA	Journal Article
Sundrud 1971 Thesis	The biochemical response of Provo Bay to nutrient inflow	Thesis
Toole 1974 Thesis	The benthic communities of the eastern rocky shore areas of Goshen Bay, Utah Lake	Thesis
Wang et al. 2017	The Historical Records of Stable Isotopes ($\delta^{13}C$ and $\delta^{15}N$)and Trace Metals Along Utah Lake – Jordan River Transition Zone, Utah (USA)	Guidebook chapter
Whiting et al. 1978	ENVIRONMENTAL INTERACTION IN SUMMER ALGAL COMMUNITIES OF UTAH LAKE	Journal Article

5.2 RELATED STUDIES IN UTAH LAKE

Total number of documents: 30

File Name	Title	ArticleType
Andersen et al. 2006	Status of June Sucker in Utah Lake and Refuges	Journal Article
Barnes and Toole	Macroinvertebrate and Zooplankton Communities of Utah Lake: A	Journal Article

File Name	Title	ArticleType
1981	review of the Literature	
Baskin et al. 2002	Water-Quality Assessment of the Great Salt Lake Basins, Utah, Idaho, and Wyoming—Environmental Setting and Study Design	USGS Report
Brotherson 1987	Plant Community Zonation in Resopnse to Soil Gradients in a Saline Meadow Near Utah Lake, Utah County, Utah	Journal Article
Brotherson et al. 1986	Comparative Habitat and Community Relationships of Atriplex Confertifolia and Sarcobatus Vermiculatus in Central Utah	Journal Article
Brown and Baasandorj	Utah Winter Fine Particulate Study (UWFPS)	Proposal?
Callister 2008 Thesis	A Three-Dimensional, Time-Dependent Circulation Model of Utah Lake	Thesis
Cole 2014 Thesis	Ecomorphological and Genetic Investigations into Utah Lake, UT Sucker Complex with Comparisons to the Jackson Lake, WY Sucker Complex	Thesis
Gaeta et al. 2018	A preliminary common carp population model and standardized seining to evaluate of the common carp removal in Utah Lake, UT	Report
Gaeta et al. 2019	An age-structured common carp population model and standardized seining to support common carp removal in UtahLake, UT	Report
Grimes et al. 1980	Comparison of Epiphytic Diatom Assemblages on Living and Dead Stems of the Common Grass Phragmites Australis	Journal Article
Harding 1970	Preliminary Report on the Algal Species Presently Found in Utah Lake	Journal Article
King 2019 Thesis	The Response of Utah Lake's Plant and Algal Community Structure to Cultural Eutrophication	Thesis
Kulmatiski et al. 2010	Phragmites Australis Invaision into Utah Wetlands	Journal Article
Landom and Walsworth 2020	Biotic community response to Common Carp removal and lake level fluctuations in Utah Lake, UT	Report
Landom et al. 2019	Seasonal and annual changes in the near-shore Utah Lake macrophyte community	Report
Lytle and Smith 1995	Nutrient Cycling in Potamogeton Pectinatus of the Lower Provo River	Journal Article
Miller and Crowl 2006	Effects of common carp (Cyprinus carpio) on macrophytes and invertebrate communities in a shallow lake	Journal Article
Page et al. 2018	A novel cross-satellite based assessment of the spatio-temporal development of a cyanobacterial harmful algal bloom	Journal Article
Richards 2016 Letter	Utah Department of Water Quality 2016 Draft Integrative Report Comment Letter	Letter
Richards 2018	Relationships between Phytoplankton Richness and Diversity,	Report

File Name	Title	ArticleType
	Zooplankton Abundance, and cyanoHAB Dominance in Utah Lake, 2016	
Richards 2019a	Zooplankton Assemblages in Highly Regulated Utah Lake: 2015-2018	Report
Richards 2019a	Spatial and Temporal Variability in Zooplankton Assemblages in Utah Lake 2015 to 2019	Report
Richards 2019c	Factors Effecting the Ecological Health and Integrity of Utah Lake with a Focus on the Relationships between Water Column Regulators, Benthic Ecosystem Engineers, and CyanoHABs	Report
Richards and Miller 2017	Utah Lake Research 2016 Progress Report	Report
Richards and Miller 2019	A Provisional Multi-Metric Index of Biological Integrity (MIBI) to Assess Water Quality in Utah Lake centered on Regulatory Directives	Report
Squires et al. 1979	Displacement as a Factor Influencing Phytoplankton Distribution in Utah Lake, Utah	Journal Article
Stamp et al. 2008	Provo River Ecosystem Flow Recommendations Final Report	Report
Su and vonStackelberg 2020	Utah Lake Hydrodynamic (EFDC) and Water Quality (WASP) Model Report	Report
Toole 1974 Thesis	The benthic communities of the eastern rocky shore areas of Goshen Bay, Utah Lake	Thesis

5.3 RELATED STUDIES IN OTHER SYSTEMS

Total number of documents: 5

File Name	Title	Article Type
Collins 2019 Thesis	Bottom-Up Controls (Micronutrients and N and P Species) Better Predict Cyanobacterial Abundances in Harmful Algal Blooms than Top-Down Controls (Grazers)	Thesis
Penn et al. 2000	Seasonality in phosphorus release rates from the sediments of a hypereutrophic lake under a matrix of pH and redox conditions	Journal Article
Toner and Catling 2019	A carbonate-rich lake solution to the phosphate problem of the origin of life	Journal Article
USGS 2003	Water Quality at Fixed Sites in the Great Salt Lake Basins, Utah, Idaho, and Wyoming, Water Years 1999–2000	Report
USGS 2012	Assessment of Total Nitrogen and Total Phosphorus in Selected Surface Water of the National Park Service Northern Colorado Plateau Network, Colorado, Utah, and Wyoming, from 1972 through 2007	Report

5.4 ATMOSPHERIC DEPOSITION DOCUMENTS

Total number of documents: 9

Brahney 2019
Literature review and calculations of atmospheric deposition (wet vs. dry, entire mass, P, N) in Utah. See data compilation spreadsheet for data details and values.

Gay 2019 Letter
Recommendations for WFWQC atmospheric deposition study. These comprise methodological comments to bring the methods more in line with NADP methodology

Miller and Barrus 2020 SAP
Outline of methodology and sampling procedures for atmospheric samplers as part of the atmospheric deposition study for Utah Lake.

Olsen 2018 Thesis
Atmospheric deposition study of TP and DIN at gages near Utah Lake. Spatial interpolation of measurements to estimate loadings to Utah Lake. Contamination, mainly by insects, is discussed. Same data as Olsen et al. 2018.

Olsen et al. 2018
Atmospheric deposition study of TP and DIN at gages near Utah Lake. Spatial interpolation of measurements to estimate loadings to Utah Lake. Contamination, mainly by insects, is discussed. Same data as Olsen 2018 Thesis.

Science Panel Member Review of WFWQC with Miller Response V1.2 5-27-2020
Includes review comments of the atmospheric sampling SAP by Science Panel members and responses from Theron Miller

ULWQS - Atmospheric Deposition Study Comments_7-9-2019 (Draft, V2)
Review comments from members of the Science Panel on the WFWQC atmospheric deposition study

ULWQS SP AD Loading Recommendation - Approved – Final
Recommendation by the ULWQS Science Panel on the rates of atmospheric loading for various N and P species to use for atmospheric loading estimates and WASP model inputs. Recommendation to use Brahney 2019 as most thoroughly documented analysis thus far.

*SP Update and Request - Engaging with Sources of Information - FINAL_*
Section 2 of this letter focuses on “provide a comprehensive overview of the efforts undertaken to engage on the atmospheric deposition topic (as an example of how they have engaged with partners outside the contracted studies);”