# Utah Lake Water Quality Study—Numeric Nutrient Criteria Technical Framework

# FINAL REPORT

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Version 9.0

## 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 |
|---|---|
| DO | Dissolved oxygen |
| DWQ | Utah Division of Water Quality |
| EFDC | Environmental Fluid Dynamics Code |
| HAB | Harmful algal bloom |
| N | Nitrogen |
| NNC | Numeric nutrient criteria |
| P | Phosphorus |
| SC | Steering Committee |
| SP | Science Panel |
| S-R | Stressor-Response |
| TDS | Total Dissolved Solids |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| TMDL | Total Maximum Daily Load |
| TSD | Technical Support Document |
| ULC | Utah Lake Commission |
| ULWQS | Utah Lake Water Quality Study |
| WASP | Water Quality Simulation Program |

# 1.0 OVERVIEW AND BACKGROUND

Utah Lake is an important recreational resource for the State of Utah, supporting activities such as fishing, boating, water skiing, swimming, and wading. It also serves as wildlife habitat and a source of irrigation water. Utah classifies waters based on their beneficial uses and develops water-quality standards to protect those uses.

Utah Lake is currently protected for the following designated beneficial uses (Utah DWQ 2019a):

- Class 2A: Protected for frequent primary contact recreation where there is a high likelihood of ingestion of water or a high degree of bodily contact with the water.
- Class 3B: Protected for warm water species of game fish and other warm water aquatic life, including the necessary aquatic organisms in their food chain.
- Class 3D: Protected for waterfowl, shore birds and other water-oriented wildlife not included in Classes 3A, 3B, or 3C, including the necessary aquatic organisms in their food chain.
- Class 4: Protected for agricultural uses including irrigation of crops and stock watering.

Based on trophic state calculations, the lake is hypereutrophic, or very nutrient-rich, and has low transparency. In 2002, Utah Lake was listed on the 303(d) impaired waters list for exceedances of the state's water-quality indicator for **total phosphorus (TP)** (See R317-2, tables 2.14.1 and 2.14.2.). Agricultural uses were listed as impaired due to elevated **total dissolved solids** in 2006 (DWQ 2016). In recent years, Utah Lake has experienced extensive algal blooms, typically during late summer and fall, which degrades recreational uses and increases the potential for cyanobacteria toxin production, which further impacts beneficial uses and could create public health concerns. As a result, in its 2016 Integrated Report, the Utah Division of Water Quality (DWQ) identified Utah Lake as non-supporting for recreational use due to high levels of **blue-green algae (cyanobacteria), cyanotoxins, and chlorophyll *a***, which reflect the presence of harmful algal blooms (HABs) (DWQ 2016). Cyanotoxins may also threaten agricultural uses (Class 4) and downstream uses in the Jordan River (Class 1C). In addition to HABs, other potential concerns associated with elevated nutrient levels that have been observed in Utah Lake include low dissolved oxygen (DO) and elevated pH. The Provo Bay embayment of Utah Lake was listed as impaired for pH in the 2016 Integrated Report, which also contributed to a listing for ammonia toxicity (DWQ 2016).

HAB issues in Utah Lake have also been documented by recreational advisories. These advisories are determined according to threshold values for cyanobacterial cell counts and/or cyanobacterial toxins. From 2016 to 2019, part or all of the lake was assigned a "caution" or "warning" advisory for 11-18 weeks, and a "danger" advisory was issued for 0-14 weeks (out of a total of 13-25 monitored weeks). A "danger" advisory results in recreational closures.

In November 2015, Utah Division of Water Quality (DWQ) initiated the Utah Lake Water Quality Study (ULWQS) to address problems stemming from excessive concentrations of nutrients, which contribute to large seasonal algal blooms, elevated pH, and possible cyanotoxin production during harmful algal blooms. The goal of the ULWQS is to evaluate the effect of nutrient enrichment on Utah Lake's recreational, aquatic life, and agricultural designated uses and to develop site-specific numeric nutrient criteria (NNC) for nitrogen (N) and phosphorus (P) water quality criteria to protect these uses.

The ULWQS is guided by a Stakeholder Process, which established a 16-member interest-based Steering Committee (SC) and a 10-member disciplinary-based Science Panel (SP). The SC is chaired jointly by the Utah Lake Commission (ULC) and DWQ. It is charged with guiding water quality criteria development and recommending in-lake water quality criteria (including elements of magnitude, frequency, and duration) to the ULC and DWQ for adoption by the state Water Quality Board. The SC is supported by the SP, whose purpose is to oversee targeted scientific studies and modeling that support criteria development.

This document describes the approach that will be used to derive in-lake NNC recommendations for N and P in Utah Lake. Tetra Tech is supporting DWQ to coordinate all steps of the framework development process with the SP. The process is designed to be transparent and well-documented and is expected to take several years. DWQ will assure consistency of the process with any of its own regulatory requirements for site specific criteria setting. Figure 1 depicts the main components of the technical framework approach. The literature review summarized various criteria development options for the SP to consider and this information formed the basis of the approaches proposed in this framework. The literature review of scientific studies on Utah Lake also informed conceptual model development, which synthesize critical management goals, assessment endpoints and measures that will be the focus of criteria development. The data characterization effort synthesized what data are available to quantify linkages in the conceptual model and where data gaps exist. Data gaps analysis both informs and is informed by the data requirements outlined in the framework. Uncertainty analysis will inform how the level of understanding of model pathways critical for deriving criteria is to be considered in criteria setting. Finally, the plan for developing criteria will identify critical knowledge gaps that can be addressed through strategic research planning to improve derivation of scientifically defensible criteria. The following subsections provide more detailed information on each component.

This Framework is intended to be adaptive. It makes some assumptions about the availability of future data, performance of models, and agreement on the approach the SP and SC will use. As the data landscape changes and the SP adjusts its approach to that changing landscape and other factors, the approach used to derive numeric values may change. This document is considered a living document that may be adjusted to provide the flexibility for any adaptation.

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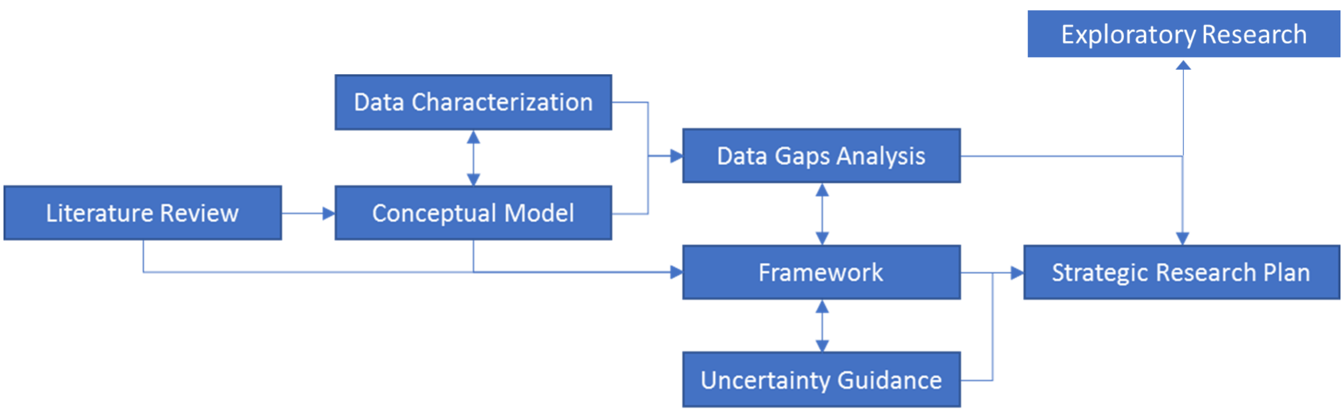



**Figure 1. Relationship among technical framework components**

## 1.1 LITERATURE REVIEW

The *Utah Lake Water Quality Study—Approaches for Developing Numeric Nutrient Criteria: A Literature Review* (Tetra Tech 2019a) evaluates applicable approaches for developing NNC for Utah Lake. Whereas much of the initial national guidance on nutrient criteria development was based on establishing a reference condition for water bodies (e.g., Nutrient Criteria Technical Guidance Manual, Lakes and Reservoirs [USEPA 2000]), more recently the focus has expanded to also include other recommended approaches such as empirical stressor-response modeling (e.g., Using Stressor-response Relationships to Derive Numeric Nutrient Criteria [USEPA 2010]) and the use of mechanistic models to link concentrations to desired endpoints such as DO concentrations or limited cyanobacteria presence (e.g., Carleton et al. 2009).

The primary approaches for developing NNC are: 1) reference-based; 2) stressor-response (S-R) relationships based on analyses of empirical (observational) data; and 3) scientific literature.

## Reference-Based Approach

For the **reference-based approach**, USEPA (2000) describes three approaches:

- Direct observation (data collection)
- Paleolimnological reconstruction of past conditions
- Model-based prediction or extrapolation of reference conditions

With **direct observation**, the reference condition of a lake is inferred from the distribution of data from a population of lakes in space or of lake data over time. This can take two forms: (1) higher quantiles of populations of sites or time periods that meet reference requirements and (2) lower quantiles of populations of lakes or time periods that do not meet reference requirements. It is assumed that these percentiles of either distribution can be used to estimate reference conditions which are further assumed to support beneficial uses. A lake's reference condition ideally describes the state of the lake in the absence of, or under minimal, anthropogenic influence. However, because it can be difficult to find undisturbed lakes, the reference condition typically describes the least impacted condition of a lake. Advantages of direct observation include ease of calculation, inherent incorporation of ecological interactions and complexity, quantifiable uncertainty, and implicit support for uses. Disadvantages include the relevance of regional populations to unique lakes and the lack of an explicit linkage to where harm to use begins, resulting in potentially overprotective or underprotective values.

The **paleolimnological reconstruction of past conditions** involves collecting lake sediment cores. Individual sediment layers are dated using radioisotopes or other techniques. Historic layers are being analyzed for the remains of various types of algae (like diatoms) that are responsive to changes in water quality (e.g., TP). The diatom community structure will change over time favoring different species at different nutrient concentrations (MPCA 2015). Past conditions, natural variability, timing of changes, and rates of change and recovery can be estimated from paleolimnological data. This type of information provides a point of reference that allows managers and researchers to put present environmental stresses into an overall perspective on the status of the resource and can inform criteria development because it may provide information to support discussions based on indicators of past ecosystem response and evolution. As a reference line of evidence, the approach may allow inference of past TP concentrations.

**Mechanistic water quality modeling to evaluate nutrient responses under reference conditions**. Mechanistic models will be performed to simulate the source, fate, transport, and effect of nutrients by modeling the processes driving hydrodynamic factors and water quality characteristics. These models are calibrated and validated with monitoring data and are used to explore the estimated effects of nutrient loading. To simulate reference conditions, the anthropogenic nutrient loads are set to minimal levels so that modeled responses based on natural background nutrient inputs can be evaluated. Other drivers (e.g., hydrology, macrophyte extent and density) can also be manipulated, allowing estimation of responses. This type of reference scenario may set a lower bound for what is necessary to ensure protection of beneficial uses. In addition, this information can be combined with paleolimnological evidence to assess how results of the mechanistic model run under natural background conditions compare to those associated with pre-settlement inputs. This might inform discussions of expected condition lake ecology under differing nutrient load circumstances. Disadvantages of mechanistic models include large data requirements, the limited incorporation of ecological interactions and their effects, and the effort required to develop, calibrate, and validate such models.

## Stressor-Response Relationship Modeling

The second approach involves examining empirical **S-R relationship modeling. Empirical methods** relate stressors (e.g., N or P) to response endpoints such as changes in biological composition (ecosystem structure), biogeochemical processes (ecosystem functions), existing criteria (e.g., DO or pH), or assessment endpoints (e.g., chlorophyll *a*, cyanobacterial abundance, or toxin levels) which are linked to beneficial use and human health protection. To establish these relationships, stressor and response data are obtained from numerous sites, across lakes or within a lake, that encompass a range of nutrient levels. Next, statistical models are used to establish concentration thresholds for the nutrients most strongly associated with changes in assessment endpoint measures. NNC are then defined based on the nutrient concentration associated with less-than-adverse response conditions such as exceedance of a criterion or unacceptable changes in assessment endpoints. Advantages of empirical modeling include the inherent inclusion of ecological interactions, an explicit linkage to criteria and assessment endpoints, and quantifiable uncertainty. Disadvantages include the large data requirements and the relatively high uncertainty that can occur from covariate effects due to complex interactions.

As described above, **mechanistic models** simulate chemical, physical, and biological processes. They are calibrated using monitoring data and values from literature and other relevant sources. An advantage of the mechanistic model approach is that multiple future scenarios can be explored to help support the cause-effect relationships observed in empirical stressor-response relationships. Another advantage of mechanistic models is that they always generate an endpoint (in this context, an estimated protective concentration of N or P that could help inform NNC). Once the model is calibrated for a particular waterbody, the NNC can then be “backed out” of the models by asking what concentrations of N or P result in modeled protection of the designated beneficial use. As an example, a project in Weeks Bay (Alabama) examined three model scenarios: existing conditions (S1), no anthropogenic nutrient loads (S2), and 50 percent reduction of existing anthropogenic nutrient loads (S3). Results are shown in Table 1. Disadvantages of mechanistic models were described above.

**Table 1. Three scenarios for TN, TP and chlorophyll-a were run as part of the Weeks Bay mechanistic modeling exercise (source: Appendix B, Table 6 - GOMA 2013).**

| Parameter | Nutrient load alternative scenarios | | |
|---|---|---|---|
| | S1 (existing conditions) | S2 (no anthropogenic loads) | S3 (50% reduction in existing nutrient loads) |
| TN | 1.44 | 0.98 | 1.20 |
| TP | 0.070 | 0.053 | 0.062 |
| Chlorophyll-*a* | 34.70 | 30.90 | 33.00 |

## Scientific Literature

An additional line of evidence that can supplement the reference-base, S-R relationship, and mechanistic modeling approaches is examination of values from external, relevant **scientific literature**. Where available, studies from comparable lake ecosystems relevant to endpoints of interest can be gathered and used to reinforce the conceptual basis for the NNC and help demonstrate the protectiveness of any final values.

When Tetra Tech surveyed NNC development efforts in other places as part of its Literature Review (Tetra Tech 2019a), it found that many programs are now using **multiple lines of evidence**, where information from more than one of the approaches described above is integrated and used in combination to help inform the final criteria. A recent example is the derivation of the proposed NNC for Utah headwater streams (DWQ 2019b). Empirical S-R relationships, reference-based direct observation approaches (based on the distribution of observed TN and TP among reference streams), literature values and ecological confirmation of empirical thresholds were all considered during the derivation of the proposed thresholds (Ostermiller et al. 2019). Figure 2 shows the S-R statistical models that were reviewed for all possible combinations of each stressor (TN and TP) and all responses, overlaid with the proposed thresholds.

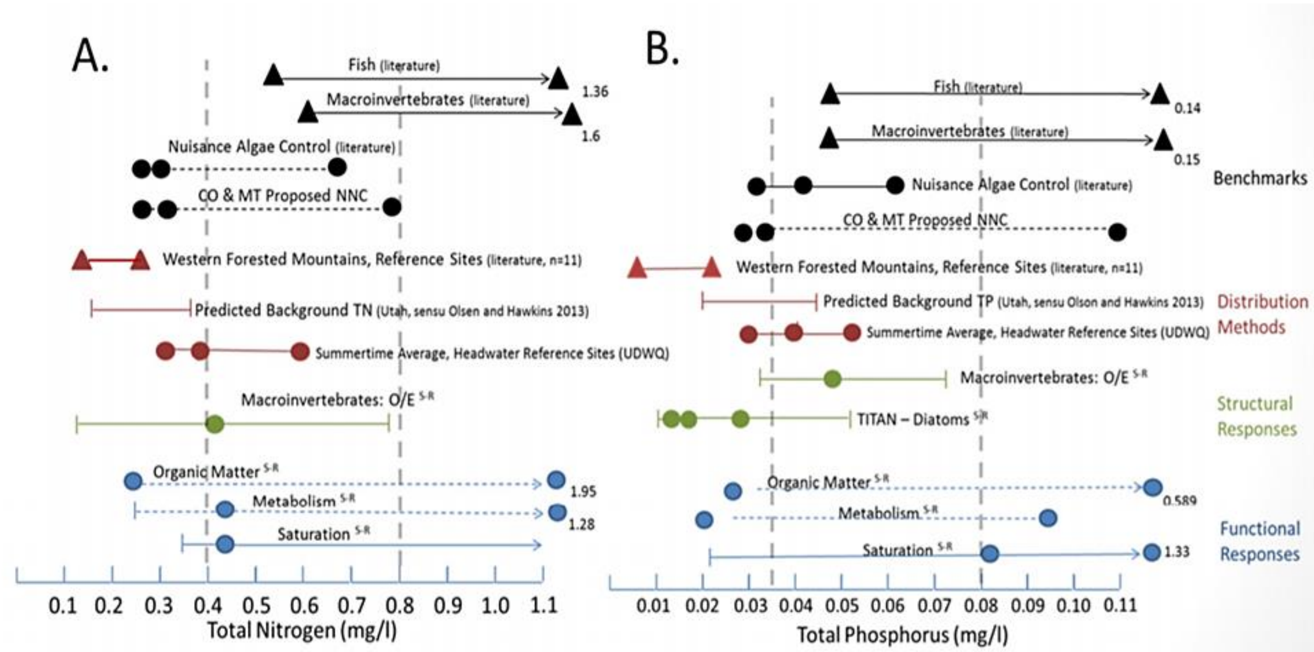



**Figure 2. Response thresholds for TN (Panel A) and TP (Panel B) along with Utah's proposed headwater stream NNC (dashed vertical lines) (source: Fig 7 from DWQ 2019b - headwater stream NNC).**

## 1.2 CONCEPTUAL MODEL

Conceptual model development is an integral part of NNC development and of all formal ecological risk-based assessment efforts. It is a key step in problem formulation, through which understanding of the system of interest is depicted including linkages among nutrient sources, nutrient loads and concentrations, intermediate effect pathways, responses including assessment endpoints, and finally, management goals that relate to protection of specific beneficial uses. Such models serve multiple purposes including but not limited to defining system understanding based on existing knowledge, illustrating important relationships for modeling, identifying gaps in knowledge that drive future studies, and communicating to stakeholders. For the purposes of this framework, the conceptual models reinforce the basis for linkages between nutrient pollution, assessment endpoints and designated uses for Utah Lake. These linkages establish the pathways of interest that are the focus of model analysis to establish endpoints and, for those with important data gaps, the focus of recommended strategic research to support further model analysis.

The *Utah Lake Water Quality Study—Conceptual Models* report (Tetra Tech 2019b) presents five conceptual models of nutrient effects in Utah Lake: a simplified nutrient model for public communication (

); a causal model for communicating the effects of nutrients on designated uses (Figure 4); nutrient cycling models for TP and TN to illustrate details of important drivers, cycling, and fate of N and P within the lake; and an ecosystem model which integrates the food web and nutrient cycling models. These models represent existing knowledge on the source, transport, cycling, and fate of nutrients in the lake and their effects on beneficial uses. As such, they are an important part of the conceptual basis behind the derivation of numeric criteria. They also help ensure that the key factors in the TN and TP pathways (from source to management goals) are considered during criteria development and help support continued discussion and communication of where gaps in knowledge exist, especially those important to deriving scientifically defensible criteria.

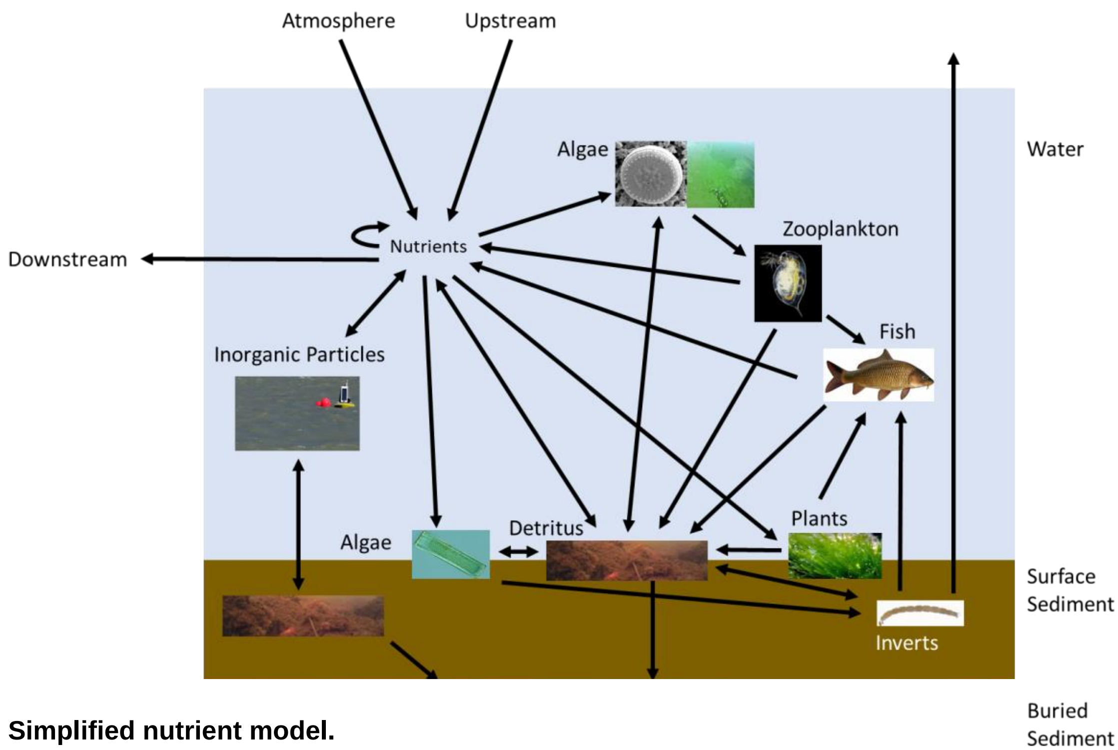



**Figure 3. Simplified nutrient model.**

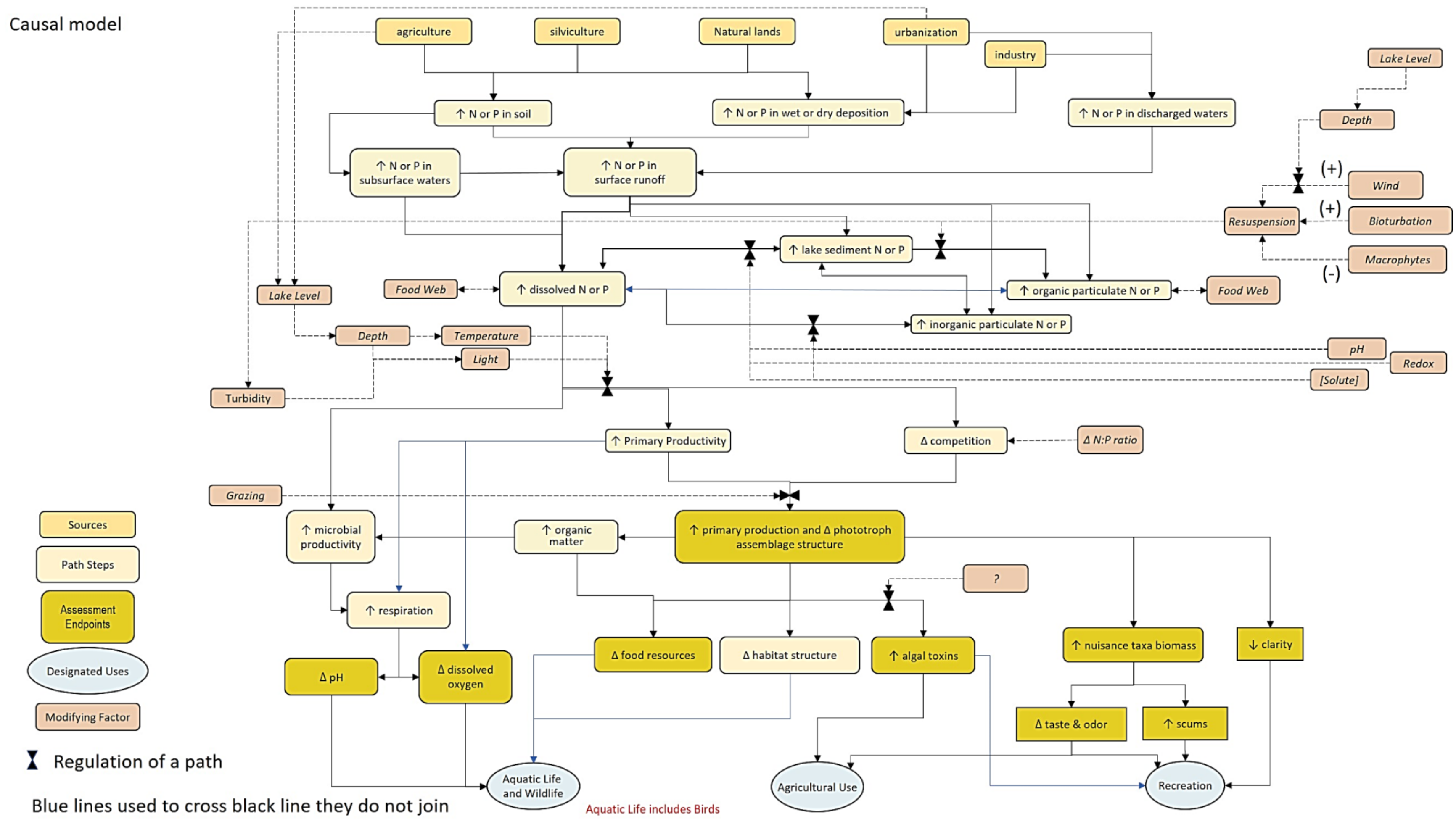



**Figure 4. Conceptual model of Utah Lake indicating linkages between nutrients, assessment endpoints, and designated uses.**

## 1.3 DATA CHARACTERIZATION AND DATA GAPS

Data characterization includes empirical (statistical) characterization and S-R modeling that allow for a better understanding of the linkages between nutrient pollution, assessment endpoints, and water management goals (which in turn help inform development of NNC). As part of its Phase 1 efforts on the Utah Lake Water Quality Study (ULWQS), Utah DWQ compiled all available water chemistry, flow data, zooplankton, phytoplankton, fish, and macroinvertebrate data for Utah Lake and its tributaries. Figure 5 shows representative locations of the DWQ Utah Lake water monitoring stations that are represented in the dataset. Results from this data gathering effort are summarized in the Phase 1 report (DWQ 2018). In addition, the data are publicly available through an interactive data-visualization tool called the Utah Lake Data Explorer (https://tetratech-wtr-wne.shinyapps.io/UtahLakeDataExplorer/).

In Phase 2, Tetra Tech is supporting additional SP data characterization efforts by performing additional statistical analyses and stressor-response modeling to complement the Phase 1 efforts and in direct response to the charge questions outlined by the SC. Analyses 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. These analyses, which are described in the *Utah Lake Water Quality Study—Analysis Plan* (Tetra Tech 2019c), are currently in progress (Tetra Tech 2020) and cover the following range of topics:

- Carp excretion
- Algal cell count and pigment relationships
- Sonde data analysis
- Phytoplankton and zooplankton analysis
- Cyanotoxins
- Environmental requirements of diatoms and macrophytes
- Wind and turbidity
- Turbidity and macrophytes
- Light extinction

Another ongoing component of the ULWQS and NNC development is a data gaps analysis and summary of additional monitoring needs. Identification of data gaps stems from the conceptual models (which establish the important pathways), data characterization and analysis (which identify the sufficiency of data to assess these important pathways) and discussions with the SP. The data gaps are being tracked and integrated into the Utah Lake NNC framework in two main ways: 1) they are combined with data on uncertainty to communicate confidence in the results of different evidentiary lines; and 2) they inform strategic research planning to fill data and knowledge gaps. Priority data needs have been identified by the SP and are currently being addressed through projects that will provide information on nutrient limitation (via bioassays), atmospheric deposition, nutrient budgets, paleolimnological data, and chemical phosphorus binding. These data will be used to help answer the SP's charge questions and inform NNC development.

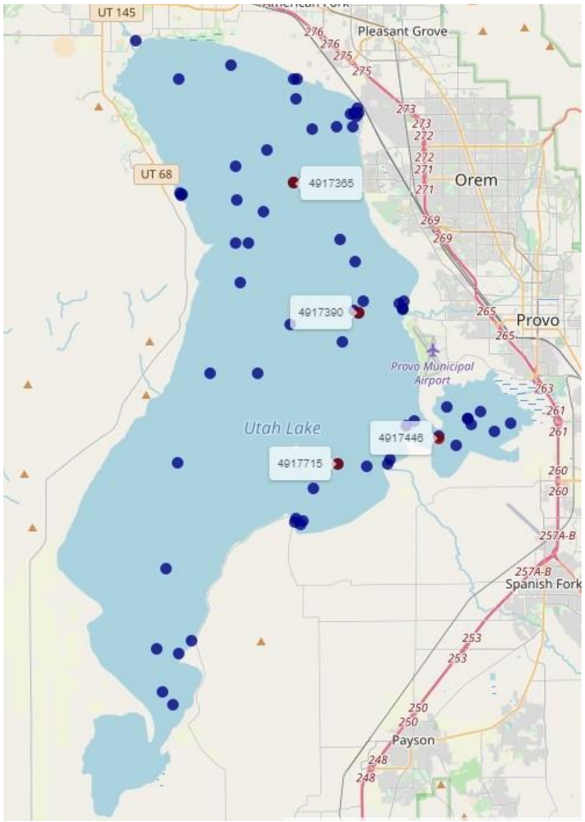



**Figure 5. Utah Lake water monitoring locations. High frequency sonde data are available for the stations marked with red points and numbered labels.**

## 1.4 UNCERTAINTY

Uncertainty is inherent to any scientific study, and it is important to quantify, contextualize, and communicate uncertainty to other scientists, decision-makers, and the public in consistent, transparent, traceable, and understandable ways. It is also an important part of the multiple lines of evidence process for evaluating relevant, strong, and reliable information. Considering multiple lines of evidence makes the decision process robust, but also presents a challenge for combining and communicating the different ways uncertainty is characterized and quantified in literature, mechanistic modeling, and statistical modeling output. The Steering Committee will ultimately decide how to interpret and potentially weigh each line of evidence.

For each line of evidence, uncertainty specifically associated with that line will be evaluated and communicated. The level at which beneficial uses are protected is associated with a prediction or credible interval, indicating a range of possible nutrient criteria subject to the state-specific application and risk management decision (USEPA 2021). The SP will then use their expert judgment to combine these various estimates of uncertainty into an overall characterization of the uncertainty associated with any conclusion, including the protectiveness of proposed numeric values. That evaluation will incorporate the amount of evidence, its quality, certainty, and level of agreement. The *Utah Lake Water Quality Study—Uncertainty Guidance* (Tetra Tech 2019d) provides guidance that will help the SP identify, characterize, and communicate uncertainty. The way in which uncertainty is evaluated will depend on the approach/line of evidence being used and includes both qualitative expressions of confidence as well as quantitative measures. An example of a quantitative measure that was used for a mechanistic model in Weeks Bay, AL is shown in Table 2 and Table 3. Performance targets were established a priori to assess how well the model simulations fit the observed data (Table 2), and then the performance of each parameter/station was 'graded' (very good, good or fair) (Table 3). Quantitative measures can also be generated for S-R approaches. For example, measures such as model fit, variance explained, and significance provide information on the strength of the relationship, which helps inform uncertainty (the stronger the relationship, the greater the level of certainty). Whatever type of measure is used, the amount of, and agreement among the evidence will be used to evaluate the confidence in scientific conclusions (Figure 6). The degree of consensus among experts will also influence estimation of confidence in any result.

**Table 2. Example of general calibration/validation targets and a performance summary table for a mechanistic model (in this example, EFDC/WASP7). The lower the percent difference between simulated and observed values, the greater the certainty in the results. Source: Appendix B, Table 6 in GOMA 2013 - Weeks Bays report.**

| State variable | % Difference between simulated and observed values | | |
|---|---|---|---|
| | Very good | Good | Fair |
| Salinity | < 15% | 15-25% | 25-40% |
| Water Temperature | < 7% | 8-12% | 13-18% |
| Water quality/D.O. | < 15% | 15-25% | 25-35% |
| Nutrients/Chl a | < 30% | 30-45% | 45-60% |

**Table 3. Quality of calibration and validation of Weeks Bay water quality model (source: Appendix B, Table 9 in GOMA 2013).**

| WASP variable | Station | Grade | WASP variable | Station | Grade |
|---|---|---|---|---|---|
| Chlorophyll *a* | MB | Very Good | DO | MB | Very Good |
| | WB | Very Good | | WB | Very Good |
| | MR | Very Good | | MR | Very Good |
| | FR | Very Good | | FR | Good |
| Mineral nitrogen | MB | Good | | WB1 | Very Good |
| | WB | Good | | WKBB1 | Very Good |
| | MR | Very Good | | WKBB2 | Very Good |
| | FR | Good | | WKBB4 | Very Good |
| | WB1 | Fair | | WKBB5 | Good |
| | WKBB1 | Fair | | WKBB6 | Very Good |
| | WKBB2 | Very Good | CBOD | WB1 | Good |
| | WKBB4 | Poor | | WKBB1 | Very Good |
| | WKBB5 | Very Good | | WKBB2 | Very Good |
| | WKBB6 | Fair | | WKBB4 | Good |
| Mineral TP | MB | Very Good | | WKBB5 | Very Good |
| | WB | Very Good | | WKBB6 | Good |
| | MR | Very Good | TSS | WB1 | Very Good |
| | FR | Very Good | | WKBB1 | Very Good |
| | WB1 | Very Good | | WKBB2 | Very Good |
| | WKBB1 | Very Good | | WKBB4 | Very Good |
| | WKBB2 | Very Good | | WKBB5 | Very Good |
| | WKBB4 | Very Good | | WKBB6 | Very Good |
| | WKBB5 | Very Good | | | |
| | WKBB6 | Very Good | | | |

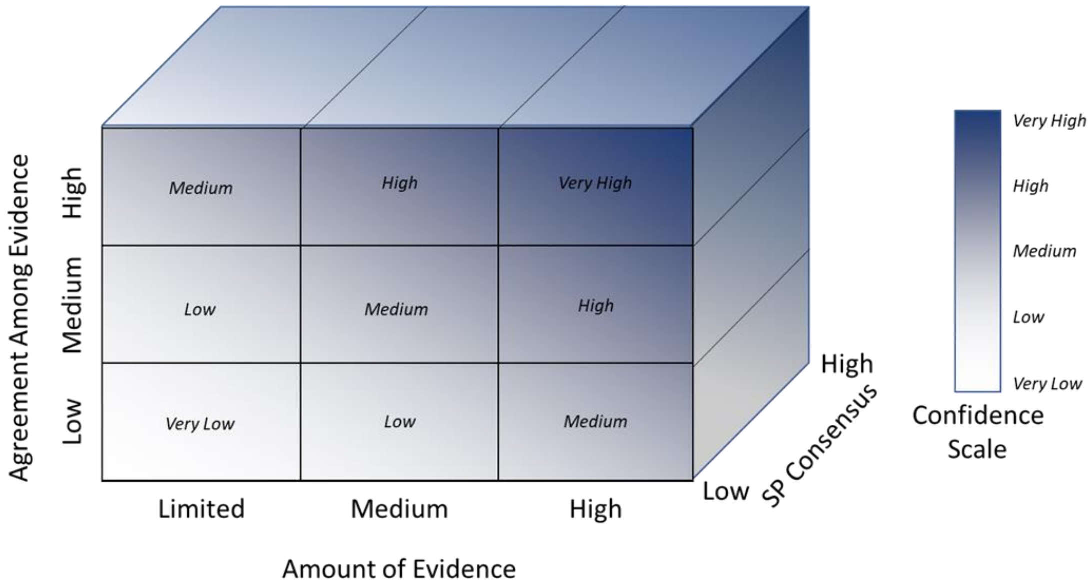



**Figure 6. Matrix for guiding evaluation of the confidence in scientific conclusions based on the amount and agreement among evidence.**

## 1.5 STRATEGIC RESEARCH PLAN

This framework document identifies the process by which the SP will recommend numeric values for TN, TP, and response indicators for consideration as NNC for Utah Lake, including ranges in credible intervals within acceptable uncertainty boundaries. In implementing this process, the SP is likely to identify knowledge gaps that constrain the confidence with which they can make recommendations on protective values. The strategic research plan will propose a series of studies and data analyses to fill knowledge gaps in the conceptual model and improve confidence in the conclusions the SP can reach.

# 2.0 APPROACH FOR UTAH LAKE NUMERIC CRITERIA DEVELOPMENT

This Section lays out the approach that the SP will use to develop NNC for TP and TN in Utah Lake. Multiple lines of evidence will be used and, described in greater detail in the ensuing sections. The proposed approach may be updated as more information from the data characterization and near-term data gap analyses becomes available.

## 2.1 RELEVANT DEFINITIONS

The *Utah Lake Management Goals, Assessment Endpoints, Measures, and Targets* document (ULWQS Steering Committee 2020) was developed by the SC and outlines the relationships between beneficial designated uses of Utah Lake and the conditions and variables that relate to these uses in the context of NNC development. The designated beneficial uses for the lake are Recreational Use, Aquatic Life and Wildlife Use, Agricultural Use, and Downstream Use (Figure 4, DWQ 2020). Each use is associated with multiple management goals, and each management goal is associated with one or more assessment endpoints, measures, and targets. Relevant definitions from the document are:

**Management goals** are statements about the desired condition for societal, economic, and ecological values of concern including recreation, aquatic life, and agricultural values (USEPA 1998). Management goals may come from the law, interpretations of the law (e.g., regulation), agency resource management mandates, desired outcomes voiced by community leaders and the public, and interests expressed by affected parties. Goals are often value-based and directional – using language such as improve, maintain, prevent, protect, reduce, restore, reestablish, etc. – rather than absolute. In this context, management goals are more specific than the broad designated use categories.

**Assessment endpoints** connect designated uses and their associated management goals to the ecological processes in the causal pathway (Figure 4). They represent explicit expressions of what is to be protected and should be neutral and specific. They are operationally defined by an ecological entity and any of its attributes (USEPA 1998). Ideal endpoints are relevant to specific management goals. For example, fish are valued ecological entities used in management goals; reproduction and age class structure are some of their important attributes. Together "fish reproduction and age class structure" form an assessment endpoint. Assessment endpoints may not always be distinguishable from measures and sometimes can be measured directly. This can lead to some confusion between assessment endpoints and measures.

**Measures (i.e., measure of effect and measure of exposure)** are attributes of an assessment endpoint, or its surrogate, that can be used to assess and quantify progress toward achieving a management goal (EPA 1998).

**Targets** are the numeric thresholds of measures that define support for the management goal, including existing criteria in Utah's Water Quality Standards regulations. Many are still to be developed (TBD) by, for example, the ULWQS or through a cost-benefit analysis.

## 2.2 ASSESSMENT ENDPOINTS, MEASURES, AND TARGETS

### Recreational Uses

Recreational uses in Utah Lake are affected by excess algal growth and toxins, whose concentrations represent a risk to the health of recreationalists through indirect and direct contact and incidental consumption and are important assessment endpoints. The USEPA has recommended ambient water quality criteria for cyanotoxins (e.g., 8 ug/L microcystin and 15 ug/L cylindrospermopsin, USEPA; https://www.epa.gov/wqc/recreational-water-quality-criteria-and-methods). Utah's 2022 303(d) Assessment Methods document (DWQ 2021) states "For this IR cycle, harmful algal bloom (HAB) assessments are currently on hold while DWQ develops and reviews implementation guidance and assessment methods based on recent EPA recommendations for water quality criteria for cyanotoxins… In future IR cycles, DWQ expects to continue assessing recreational uses for the occurrence of HABs." Toxin concentrations and linkages from them to chlorophyll *a* concentrations and cyanbacterial cell counts, will be evaluated as targets to protect recreational uses.

Recreational uses in Utah Lake are also affected by nutrients through the effect of eutrophication on primary production (algal biomass) and the subsequent effects on water clarity, unsightly scums, and taste and odor, all of which have corresponding assessment endpoint measures (Secchi depth, aesthetic score, and concentrations of taste and odor compounds, respectively). DWQ currently measures Secchi depth but does not have an aesthetic score or user perception-based chlorophyll *a* or cell count target that represents aesthetic scores (e.g., for scums) nor do they have a user perception-based odor score linked to odor producing chemicals that represents an odor target (e.g., 2-methylisoborneol, a chemical with a very low odor detection threshold). However, these assessment endpoints will be linked to measures of harmful algal bloom magnitude, frequency, and extent using empirical and mechanistic models (Table 4). A recreational survey is also proposed to identify thresholds relevant for recreational use (DWQ 2020).

Table 4 describes the management goals and associated assessment endpoints, measures, and targets associated with the primary contact recreation designated use. Additionally, the source for each target value is listed as well as the information gaps needed to develop target values currently listed as to be determined (TBD).

**Table 4. Management goals, assessment endpoints, measures, and targets associated with Utah Lake's primary contact recreation designated use.**

| Designated Use | Management Goal | Assessment Endpoint | Measures | Targets | Target source | Study/information gaps |
|---|---|---|---|---|---|---|
| 2A. Primary contact recreation use (human health, Recreation experience, Lake aesthetics) | Harmful algal blooms (HAB) will not create toxins that threaten public health. | Algal toxin concentrations | Microcystin concentration | 8 ug/L | EPA guidance<br>WQS, R317-2-14[1] | Frequency/duration to be incorporated from EPA guidance |
| | | | Cylindrospermopsin concentration | 15 ug/L | EPA guidance<br>WQS, R317-2-14[1] | Frequency/duration to be incorporated from EPA guidance |
| | | | Anatoxin concentration | 15 ug/L | Utah HAB guidance<br>WQS, R317-2-14[1] | |
| | HAB occurrence is limited in spatial extent and infrequent to support robust recreational industry and community. | Magnitude, frequency, and duration of algal blooms. | Annual number of lake closures due to HABs | • Microcystin: 2,000 ug/L<br>• Anatoxin: 90 ug/L<br>• Cylindrosprmopsin: 15 ug/L<br>• Cyanobacteria density: 10M cells/mL | Utah HAB guidance<br>WQS, R317-2-7.2[1] | |
| | | | Duration/frequency: Percent of recreation season with algal biomass exceeding health and nuisance thresholds at each monitoring site and target recreation | • Cyanobacteria density: TBD<br>• Toxigenic Cyanobacteria density: TBD<br>• Cyanobacteria relative abundance: TBD<br>• Toxigenic Cyanobacteria relative abundance: TBD<br>• Cyanobacteria biovolume: TBD | Recreation survey<br>USEPA 2021<br>R317-2-7.2[1] | Recreation survey to help determine nuisance thresholds for algal/ cyanobacteria density.<br><br>Need to agree on target sites for marinas and |

[1] *Rule R317-2. Standards of Quality for Waters of the State. https://adminrules.utah.gov/public/search/R317-2-7.%20%20/Current%20Rules*

| Designated Use | Management Goal | Assessment Endpoint | Measures | Targets | Target source | Study/information gaps |
|---|---|---|---|---|---|---|
| | | | site (e.g. marinas, beaches). | • Chlorophyll-a: TBD | | beaches for model output and monitoring. Refer to the Science Panel for recommendations. |
| | Improve submersible recreation (swimming, paddle boarding, water skiing, etc.) experience. | | Extent: Maximum % of lake surface exceeding algal biomass nuisance thresholds (reported separately for Provo Bay, Goshen Bay, and Open Water regions). | • Cyanobacteria density: TBD<br>• Toxigenic Cyanobacteria density: TBD<br>• Cyanobacteria relative abundance: TBD<br>• Toxigenic Cyanobacteria relative abundance: TBD<br>• Cyanobacteria biovolume: TBD<br>• Chlorophyll-a: TBD | Recreation survey<br>USEPA 2021<br>R317-2-7.2[1] | |
| | Swimming beaches and shoreline access locations are open all summer without nuisance algae or public health advisories. | | Magnitude: Maximum seasonal algal biomass (collected as integrated water column sample) at each monitoring site and target recreation site (e.g. marinas, beaches). | Cyanobacteria density: TBD<br>• Toxigenic Cyanobacteria density: TBD<br>• Cyanobacteria relative abundance: TBD<br>• Toxigenic Cyanobacteria relative abundance: TBD<br>• Cyanobacteria biovolume: TBD<br>• Chlorophyll-a: TBD | Recreation survey<br>USEPA 2021<br>R317-2-7.2[1] | |
| | Recreation water quality standards are supported | Support of 2A Recreational Use Standards | pH | 6.5 – 9 | WQS, R317-2-14[1] | |

| Designated Use | Management Goal | Assessment Endpoint | Measures | Targets | Target source | Study/information gaps |
|---|---|---|---|---|---|---|
| | | | Narrative water quality standards | See targets above. | WQS, R317-2-14[1] | Recreation survey to help determine nuisance thresholds for algal/ cyanobacteria density. |
| | Increase recreational opportunities and experiences. | Lake visitation and satisfaction statistics. | Annual visitation to Utah Lake. | Number of person-days per season or year: TBD | TBD | Recreation survey to help determine user experience issues related to water quality. |
| | Improve public perception of Utah Lake water quality. | | Measures from recreation survey to assess user experiences related to water quality. | User perception: TBD | TBD | |
| | Sport fish are safe for human consumption. | Fish tissue algal toxin concentrations<br>Mollusk tissue algal toxin concentration | Algal toxin concentrations: TBD. | TBD | TBD | Literature on protective values for fish consumption; or support for recreational values as protective of fish consumption exposure risks. |

## Aquatic Life Uses

Aquatic life in Utah Lake are directly affected by eutrophication through impacts on DO and pH caused by additions in organic matter loading that lead to increased respiration that result in decreased DO and increased pH. Additional habitat impacts include a decrease in water clarity that hinders visual predators. Aquatic life may also be indirectly affected by nutrient enrichment through the alteration in food resources, resulting from a shift to more nutrient tolerant and less palatable algal species. These shifts reduce the efficiency with which carbon is made available to the food web. Less palatable algae are not consumed as efficiently by zooplankton, which then disrupts energy supply to zooplanktivorous fish and their predators. Similar effects may occur with benthic algae and their consumers.

DWQ has existing criteria for pH and DO which can be used as targets, and any exceedances can be linked to allowable nutrient levels. These include the following for the warm water aquatic life use:

pH: 6.5 – 9.0 (range)

Dissolved oxygen (DO), no less than:

- 5.5 mg/L as a 30-day average
- 6.0 mg/L for early life stages or 4.0 mg/L for all life stages as a 7-day average and
- 5.0 mg/L for early life stages or 3.0 mg/L for all life stages as a 1-day minimum.

These values will be explored for support in the lake as was done in the Psomas and SWCA (2007) report. Directed research by the Science Panel will analyze linkages between chlorophyll *a* and DO via S-R and mechanistic modeling to establish chlorophyll *a* targets that are protective of the DO criteria. Then, a translator between chlorophyll *a* and nutrient concentrations will establish the nutrient concentrations necessary to maintain the chlorophyll *a* target.

The aquatic life use narrative in Utah for warm water fishes reads: “Warm-water species of game fish, including the necessary aquatic organisms in their food chain”. This means that the invertebrates and plant communities necessary to fishes are to be protected. Therefore, it is reasonable to conclude that macrophytes, which provide physical habitat and food for invertebrate prey and fish larvae, are also to be protected, including sufficient light for macrophyte growth. With this in mind, chlorophyll *a* targets that provide sufficient light levels for macrophyte growth (Tetra Tech 2020, King et al. 2021) in conjunction with other nutrient-related targets will be another target for modeling to protect aquatic life.

Food resource impacts are more difficult to quantify, and identification of nutrient levels at which food web impacts occur would require complex and time-intensive studies. However, researchers have identified chlorophyll *a* concentrations associated with shifts in zooplankton:phytoplankton ratios (from the National Lakes Assessment) that reflect points at which inefficiencies in trophic transfer occur that affect food webs; these thresholds can be used to develop criteria (Yuan and Pollard 2018). Such chlorophyll *a* concentrations, dependent on the system-specific slope threshold and desired level of uncertainty, will be evaluated as assessment endpoints in Utah Lake.

Table 5 describes the management goals and associated assessment endpoints, measures, and targets associated with the aquatic life designated use. Additionally, the source for each target value is listed as well as the information gaps needed to develop target values currently listed as to be determined (TBD).

**Table 5. Management goals, assessment endpoints, measures, and targets associated with Utah Lake's aquatic life designated use.**

| Designated Use | Management Goal | Assessment Endpoint | Measures | Targets | Target source | Study/information gaps |
|---|---|---|---|---|---|---|
| 3B. Warm water fishery use | Warm water fishery is robust and healthy. | Water quality conditions | Minimum dissolved oxygen | 3.0 mg/L | WQS, R317-2-14[1] | |
| | | | • 7-Day average dissolved oxygen<br>• Supersaturation | • 7-Day Average: 4.0 mg/L<br>• Supersaturation: TBD | WQS, R317-2-14[1] | |
| | | | • 30-Day average dissolved oxygen<br>• Supersaturation | • 30-Day Average: 5.5 mg/L<br>• Supersaturation: TBD | WQS, R317-2-14[1] | |
| | | | pH | 6.5 – 9 | WQS, R317-2-14[1] | |
| | | | Ammonia | pH and Temperature dependent (mg/L) | WQS, R317-2-14[1] | |
| | | Food abundance and diversity | Zooplankton composition/diversity/abundance. | TBD | JSRIP and FWS<br><br>USEPA 2021 | Ongoing SP research/EPA NLA Analysis; add specific target for June sucker if available. |
| | | | Macroinvertebrate composition/diversity/abundance | TBD | JSRIP and FWS | Ongoing SP research/EPA NLA Analysis; add specific target for June sucker if available. |

| Designated Use | Management Goal | Assessment Endpoint | Measures | Targets | Target source | Study/information gaps |
|---|---|---|---|---|---|---|
| | | | Phytoplankton composition/ diversity and abundance | TBD | EPA NLA index[2] | |
| | | | Mollusk composition/ diversity/abundance | TBD | UDWR and FWS | |
| | HAB toxins do not cause fish mortality. | Algal toxin concentrations | Microcystin concentration | TBD | TBD | Need to research potential toxicity of cyanotoxins on fish. USFWS fish tissue cyanotoxin data available winter 2021. |
| | | | Cylindrospermopsin concentration | TBD | TBD | |
| | | | Anatoxin concentration | TBD | TBD | |
| | Warm water fishery can support reproductive populations of June Sucker. | Water quality conditions | Minimum dissolved oxygen in Provo Bay and Provo River delta from July – September. | 5.0 mg/L | WQS, R317-2-14[1] | Check fish spawning seasons and temperature/DO requirements (PSOMAS report). |
| | | | 7-Day dissolved oxygen in Provo Bay and Provo River delta from July – September. | 6.0 mg/L | WQS, R317-2-14[1] | |
| | Macrophyte habitat can support June | Macrophyte abundance and | Primary productivity (chl a/ algal | • Light compensation point: TBDClarity | JSRIP and FWS | Literature review for algal turbidity |

[2] *EPA National Lakes Assessment*

| Designated Use | Management Goal | Assessment Endpoint | Measures | Targets | Target source | Study/information gaps |
|---|---|---|---|---|---|---|
| | sucker recovery and early life stages of other ecologically or recreationally important fish species. | distribution in Provo Bay, Utah Lake Littoral Zones, and Provo River delta. | turbidity) supportive of macrophyte re-establishment in target areas. | ($K_d$, Secchi Depth): TBD<br>• Chlorophyll a: TBD<br>• Percent algal turbidity: TBD | | supportive of macrophyte re-establishment. |
| | Carp population does not inhibit June sucker recovery. | Carp density and water quality indicators related to carp activity. | Carp population density | TBD | JSRIP and FWS | Ongoing SP research/EPA NLA Analysis; add specific target for June sucker if available. |
| | | | Percent change in non-algal turbidity associated with carp bioturbation. | TBD | JSRIP and FWS | |
| | | | Percent change in macrophyte composition, density, and distribution. | TBD | JSRIP and FWS | |

| Designated Use | Management Goal | Assessment Endpoint | Measures | Targets | Target source | Study/information gaps |
|---|---|---|---|---|---|---|
| 3D. Waterfowl, shorebirds, and other water-oriented wildlife | Habitat conditions (e.g., shoreline vegetation; shallowly flooded and exposed vegetated and unvegetated mudflats; and open water) are supportive of waterfowl, | Nonnative plant abundance, diversity, and distribution. | Percent cover of Phragmites on Utah Lake shorelines. | TBD | TBD | |
| | | Macrophyte composition, abundance, diversity, and distribution. | Percent cover of emergent and submergent macrophytes in littoral waterfowl and shorebird habitat areas. | TBD | TBD | |

| Designated Use | Management Goal | Assessment Endpoint | Measures | Targets | Target source | Study/information gaps |
|---|---|---|---|---|---|---|
| | shorebirds, and other water-oriented wildlife. | | Primary productivity (chl a/ algal turbidity) supportive of macrophyte re-establishment in target areas. | Clarity ($K_d$, Secchi Depth): TBD | TBD | |
| | Macroinvertebrates provide a diverse and sufficient food source to birds that use the open water and shorelines of Utah Lake. | Invertebrate composition, abundance, diversity, and distribution. | Invertebrate index or density samples (and see 3B). | TBD | TBD | Audubon to provide measures if available from GSL habitat. Could rely on GSL health measures. |
| | HAB toxins do not threaten waterfowl and shorebirds and do not cause bird mortality. | Algal toxin concentrations. | Microcystin concentration | TBD | TBD | Need to research potential toxicity of cyanotoxins on birds. |
| | | | Cylindrospermopsin concentration | TBD | TBD | |
| | | | Anatoxin concentration | TBD | TBD | |
| | HAB spatial and temporal extent supportive of healthy waterfowl and shorebird habitat. | Harmful algal bloom magnitude and duration. | Maximum # days at each of littoral habitat exceeding TBD HAB threshold. | TBD | TBD | |
| | | | Maximum percent of littoral habitat area exceeding TBD HAB threshold. | TBD | TBD | |

[1] *Rule R317-2. Standards of Quality for Waters of the State.* *https://adminrules.utah.gov/public/search/R317-2-7.%20%20/Current%20Rules*

### Agricultural Uses

The primary concern for agricultural uses in Utah Lake is the production of cyanotoxins and their potential impacts on crop irrigation and stock watering. Information on the collection of these endpoints are given above for Recreational Uses. Specific values to protect crops and stock watering are not as well developed as for human health, so additional literature review or research will be conducted to identify appropriate values for stock and crop irrigation. Table 6 presents toxin assessment endpoints for agricultural uses as well as the information gaps needed to be filled to set an appropriate target.

**Table 6. Management goals, assessment endpoints, measures, and targets associated with Utah Lake's agricultural designated use.**

| Designated Use | Management Goal | Assessment Endpoint | Measures | Targets | Target source | Study/information gaps |
|---|---|---|---|---|---|---|
| 4. Agricultural Water Use | Water used to irrigate crops will not present health risk. | Algal toxin concentrations. | Microcystin, cylindrospermopsin, anatoxin concentrations | TBD | TBD | Evaluate any recent research on crop uptake studies. |
| | Water used to water livestock will not pose health risk to animals. | | Microcystin, cylindrospermopsin, anatoxin concentrations | TBD | TBD | Literature review on thresholds for stock watering. |

### Downstream Uses

EPA has issued drinking water health advisories for microcystin and cylindrospermopsin (https://www.epa.gov/cyanohabs/epa-drinking-water-health-advisories-cyanotoxins), but these advisories apply to finished water (i.e., their values depend on the ability for drinking water facilities to treat raw water). The EPA drinking water advisories therefore are not applicable to raw surface water in Utah Lake and the Jordan River

Applicable values would need to be determined later based on research or using recreational criteria and assuming treatment facilities can treat toxins as long as they are below recreational criteria.

Table 7 describes the management goals and associated assessment endpoints, measures, and targets associated with downstream designated uses. Most of these uses are presumed to be met if the Utah Lake designated uses from tables 4-6 are met. Note that while the Utah Primary Drinking Water Standard[3] of 10 mg/L nitrate applies to finished (treated) water, Utah Standards of Quality for Waters of the State[4] also apply a 10 mg/L nitrate standard to raw water for class 1C waters.

[3] R309-200-5; https://documents.deq.utah.gov/drinking-water/rules/DDW-2017-004214.pdf
[4] R317-2-14; https://adminrules.utah.gov/public/search/R317-2-7.%20%20/Current%20Rules

**Table 7. Management goals, assessment endpoints, measures, and targets associated with Utah Lake's downstream designated uses.**

| Designated Use | Management Goal | Assessment Endpoint | Measures | Targets | Target source | Study/information gaps |
|---|---|---|---|---|---|---|
| 1C. Jordan River Drinking water use | Water released into the Jordan River is of sufficient quality to be used as source water for drinking. | Algal toxin concentrations | Microcystin concentration | TBD | TBD | Literature review for cell count and toxin thresholds for source waters (e.g. Lake Erie). |
| | | | Cylindrospermopsin concentration | TBD | TBD | |
| | | Toxic nutrient concentrations | Nitrate concentration | 10 mg/L | WQS, R317-2-14[1] | |
| 2B. Recreational use | Assumed to be protective because UL 2A is more stringent. | NA | NA | NA | NA | |
| 3B. Warm water life | Protection of Jordan River aquatic life. | Organic matter load export to Jordan River (kg/yr) | Organic matter load (%) | 38% reduction | Phase 1 JR DO TMDL | |
| | | See applicable 3B assessment endpoints from above | See applicable 3B measures from above. | NA | NA | |
| 3D. Waterfowl and shorebirds | Protection of downstream waterfowl and shorebirds. | See applicable 3D assessment endpoints from above | See applicable 3D measures from above. | NA | NA | |
| 4. Agricultural Water Use | See Agricultural Use section in table above. | See applicable 4 assessment endpoints from above | See applicable 4 measures from above. | NA | NA | |

| Designated Use | Management Goal | Assessment Endpoint | Measures | Targets | Target source | Study/information gaps |
|---|---|---|---|---|---|---|
| Undefined Uses: Secondary Residential Water Use | Secondary use of Utah Lake water does not pose human health risk to residents. | Algal toxin concentrations | Microcystin concentration | Presumed to be protective if recreational thresholds are achieved within Utah Lake. | NA | |
| | | | Cylindrospermopsin concentration | Presumed to be protective if recreational thresholds are achieved within Utah Lake. | NA | |
| | | | Anatoxin concentration | Presumed to be protective if recreational thresholds are achieved within Utah Lake. | NA | |

[1] *Rule R317-2. Standards of Quality for Waters of the State. https://adminrules.utah.gov/public/search/R317-2-7.%20%20/Current%20Rules*

## 2.3 LINES OF EVIDENCE

As described in Section 1.1, there are several commonly used approaches to derive NNC. Here we refer to them as ‘lines of evidence’. They include the S-R relationship and reference-based approaches described above as well as using supporting scientific literature. Table 8 summarizes which lines of evidence the SP is planning to use for NNC development in Utah Lake.

**Table 8. Multiple lines of evidence will be used when deriving NNC for Utah Lake.**

| Type | Line of evidence | Planning to use | Notes |
|---|---|---|---|
| Reference-based | Paleolimnological reconstruction of past conditions | yes | Results of the paleo studies are intended to be used as a point of reference and to provide an overall perspective on the status of Utah Lake. Knowing the pre-settlement biological conditions, nutrient (phosphorus, nitrogen, silicon, calcium, iron, and potentially N and P isotopes) concentrations and how they have changed will help inform development of NNC. Analyses will address whether conditions changed radically over time, if the system has been stable over time, and the levels of historic nutrient conditions |
| | Model-based prediction or extrapolation of reference conditions | yes | ULWQS SC and SP will use the mechanistic model developed by University of Utah, and refined by the SP, to simulate a scenario in which there are minimal anthropogenic nutrient loads (the nutrient loads of all point sources are set to some minimal level). |
| Stressor-Response | Mechanistic model | yes | ULWQS SC and SP will use the mechanistic model developed by University of Utah, and refined by the SP, to model the effects of different anthropogenic nutrient loading scenarios on response conditions. Those results will be used as a line of evidence to identify loads and concentrations that support assessment endpoints and measures. |
| | Empirical | yes | Statistical models will be used to establish quantitative linkages between ambient nutrient concentrations and assessment endpoints and measures that reflect protection of designated uses. For example, TP and TN will be used as exposure variables and harmful algal density, cyanobacteria dominance, cyanotoxin concentration, and mean chlorophyll *a* as response variables (Figure 8). |
| Scientific Literature | | yes | Chlorophyll, phytoplankton composition, TP and TN values in Utah Lake will be compared to values from scientific studies of comparable or related lake ecosystems that support or inform the other lines of evidence. Scientific literature about similar aquatic systems in other states and countries may be used to support other response endpoints. |

## Reference Based

**Paleolimnological reconstruction of past conditions.** Paleolimnological data from Utah Lake will be used as a point of reference to help the SP better understand historical conditions, which is one of the original charge questions from the SC. Knowing the pre-settlement nutrient concentrations and how they have changed over time will also help inform setting NNC because it can inform both what reference conditions were, whether those conditions previously supported desired assessment endpoint conditions, if conditions have changed adversely and if so by how much. Existing research from paleolimnological coring in Utah Lake (Bolland 1974, Bushman 1980, Javakul et al. 1980, Janetski 1990 and Macharia 2012) was informative but incomplete and had some methodological limitations reducing confidence in the results. To address these limitations, the DWQ ULWQS has funded research approved by the SP to collect paleolimnological data that will help answer the following questions:

- What does the diatom community and macrophyte community in the paleolimnological record tell us about the historical trophic state and nutrient regime of the lake?
    - Can diatom (benthic and planktonic) and/or macrophyte extent or presence be detected in sediment cores? And if so, what are they?
    - What were the environmental requirements for diatoms and macrophyte species?
- How have environmental conditions changed over time?
    - What were the historic phosphorus, nitrogen, and silicon concentrations as depicted by sediment cores? (add calcium, iron, and potentially N and P isotopes)
- What do pollen, resting spores, photopigments, DNA, midge head capsules, mollusks, and exuviae from zooplankton in the paleo record tell us about the historical water quality, trophic state, and nutrient regime of the lake? (the group identified photopigments and DNA as near-term research topics)

With these new data, it may be possible to infer historical TP concentrations in Utah Lake, using an approach similar to the one used by Minnesota Pollution Control Agency for its Spring Lake Site-Specific Eutrophication Standard Justification (see Figure 7). It should be noted that there are limitations with these types of analyses, one being that the relationship between phosphorus and diatom abundances can be confounded with other variables such as alkalinity and lake depth. Also, the inference models may contain diatom taxa that are not significantly related to TP or TN (Juggins et al. 2013).

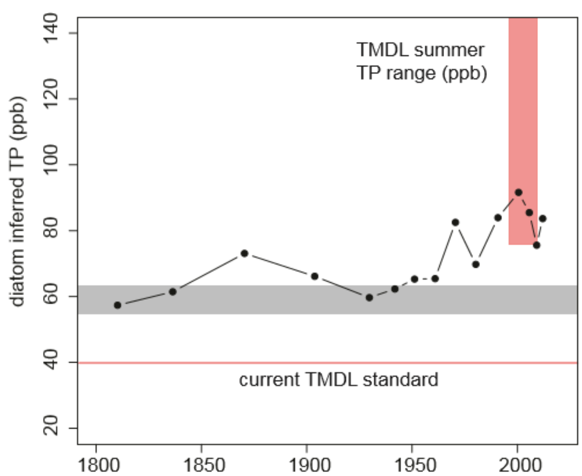



**Figure 7. The diatom-inferred TP reconstruction for Spring Lake, MN. The grey bar is the approximate historical background for Spring Lake prior to settlement. The red line is the current background or TMDL standard set for Spring Lake and the red shaded area represents the measured TP range over the last 10-15 years (Wenck 2011). Source: Figure 6 from MPCA 2015**

**Model based prediction.** Another reference-based approach is a component of the mechanistic modeling stressor-response line using the natural condition scenario. In this scenario, loads to the model will be set to minimal or no human contributions (as determined from anthropogenic watershed loading estimates) and model responses evaluated. Using the mechanistic model in this context will allow the SP to evaluate conditions under an assumption of no or low anthropogenic inputs. Additions to such a scenario may include the incorporation of macrophyte beds (depending on the outcome of paleolimnological studies) or lake elevation and/or bioturbation manipulations to investigate the effects of these variables on responses. Such scenarios would not only identify an additional reference concentration endpoint, but also inform deliberation of what achievable conditions might be in the lake.

## Stressor-Response

Stressor-response relationship modeling using mechanistic and empirical models is an important line of evidence. These efforts model the effects of varying nutrient levels in Utah Lake on assessment endpoints considered to be reflective of fully supporting designated and existing uses. Candidate variables for evaluation of stressor-response modeling are detailed in Table 9. The assessment endpoints outlined in Table 9 encompass the assessment endpoints outlined in Tables 4-7 that would be appropriate to implement in a stressor-response context. Feasibility to analyze a given stressor-response relationship is dependent on data availability, which is also outlined in Table 9. Further candidate variables may be identified during data analysis or emerge from additional effort. Under direction of the SC, DWQ will undertake user perception studies using established scientifically defensible survey methods that identify phytoplankton composition, Secchi depth, concentrations of odor chemicals or chlorophyll *a* concentrations associated with conditions deemed unacceptable (due to clarity, scums or odor levels) for contact recreation by the public. Such conditions could then be applied in the modeling to identify nutrient levels associated with meeting those target conditions.

**Table 9. Table of stressor-response relationship pairs for use in deriving endpoints. Targets for chlorophyll *a*, cyanobacterial abundance, and clarity are derived to protect assessment endpoints (gray cells) and then TN/TP criteria derived to meet the chlorophyll *a*, cyanobacterial abundance, and clarity targets (white cells). Cyanobacteria abundance encompasses cell count, biovolume, and proportional relative abundance**

| Use | Assessment Endpoint | Stressor | Response | Empirical S-R Data Available | Mechanistic Model Output |
|---|---|---|---|---|---|
| Recreation, Aquatic Life, Agriculture, Drinking Water | Algal toxins | Chlorophyll *a* | Microcystin concentration | Yes | No |
| Recreation, Aquatic Life, Agriculture, Drinking Water | Algal toxins | Cyanobacterial abundance | Microcystin concentration | Yes | No |
| Recreation | Algal blooms | Chlorophyll *a* | Cyanobacterial abundance | Yes | Yes |
| Recreation, Aquatic Life | pH | Chlorophyll *a* | pH | Yes | Yes |
| Recreation | Lake visitation | Chlorophyll *a* | Annual visitation | Yes | No |
| Recreation | Lake visitation | Cyanobacterial abundance | Annual visitation | Yes | No |
| Recreation | Lake visitation | $K_d$, Secchi depth | Annual visitation | Yes | No |
| Recreation | Public perception | Chlorophyll *a* | Public perception | Upcoming user perception survey | No |
| Recreation | Public perception | Cyanobacteria abundance | Public perception | Upcoming user perception survey | No |
| Recreation | Public perception | $K_d$, Secchi depth | Public perception | Upcoming user perception survey | No |
| Aquatic Life | DO | Chlorophyll *a* | DO | Yes | Yes |
| Aquatic Life | Food resources | Chlorophyll *a* | Zooplankton:Phytoplankton | National Model | No |
| Aquatic Life | Food resources | Chlorophyll *a* | Proportion cyanobacteria | Yes | Yes |
| Aquatic Life | Food resources | Chlorophyll *a* | Macroinvertebrate diversity/abundance | No | No |
| Aquatic Life | Food resources | Chlorophyll *a* | Mollusk diversity/abundance | No | No |
| Aquatic Life | Light | Chlorophyll *a* | $K_d$, Secchi depth | Yes | Yes |
| Criteria Setting | | TN | Chlorophyll *a* | Yes | Yes |
| Criteria Setting | | TP | Chlorophyll *a* | Yes | Yes |
| Criteria Setting | | TN | Cyanobacterial abundance | Yes | Yes |
| Criteria Setting | | TP | Cyanobacterial abundance | Yes | Yes |
| Criteria Setting | | TN | $K_d$, Secchi depth | Yes | Yes |
| Criteria Setting | | TP | $K_d$, Secchi depth | Yes | Yes |

**Mechanistic models.** The mechanistic model approach will play a critical role in NNC development for Utah Lake. The model that will be used was built and calibrated by a research team from the University of Utah under the direction of Dr. Michael Barber in the Civil and Environmental Engineering Department[5]. The model was developed to assess the impacts of climate change and urbanization on water quality in the Jordan River watershed and to inform total maximum daily load (TMDL) development in Utah Lake. The calibrated Utah Lake model has been delivered to DWQ for use in the ULWQS. The model consists of a three-dimensional hydrodynamic model coupled with a water-quality model. Hydrodynamics are modeled with the Environmental Fluid Dynamics Code (EFDC) and water quality with the Water Quality Simulation Program (WASP). Both models are supported by the EPA and have been widely applied for numeric nutrient-criteria development and TMDLs. The models will use TP and TN loading at various loading levels and ratios as causal variables. Response variables the mechanistic models will simulate include water column nutrient concentrations, measures of nutrient exposure for which the state has criteria (e.g., DO, pH) as well as measures of effect such as cyanobacterial densities and chlorophyll *a*. (DWQ 2016). Mechanistic models allow for exploration of multiple future scenarios to help support cause-effect relationships observed in empirical stressor-response relationships. These models can be used to generate N and P load targets that meet desired beneficial use conditions, and these can then be translated into concentrations for evaluation.

Key objectives for the mechanistic model include (von Stackelberg 2016):

- Provide a decision-support tool for Utah Lake, including the relationship of phosphorus and nitrogen to water-quality endpoints such as dissolved oxygen (DO), pH, ammonia, and nuisance and harmful algal blooms, as well as the export of total phosphorus (TP), total nitrogen (TN), and organic matter to the Jordan River.
- Improve understanding of the nutrient dynamics in Utah Lake and the formation of nuisance and harmful algal blooms (cyanobacteria).
- Predict the effects of various nutrient-loading scenarios on the formation of nuisance and harmful algal blooms.
- A secondary objective of the nutrient model is to identify input and calibration data gaps and support the planning of data collection efforts.

In addition, it should be noted that efforts will be made to model a range of conditions, including periods of normal, above normal, and below normal precipitation conditions and lake levels. Such information will be valuable in informing the duration and frequency components of any criterion. For example, the frequency with which a value could be exceeded as a result of natural variability or periodicity without a loss of beneficial use could be determined. This takes on added importance given future projections for more extreme weather events and changing thermal and hydrologic conditions (Wuebbles et al. 2017).

Specific outputs from the mechanistic modeling effort will include nutrient scenarios (loading and concentrations) that support beneficial use and management goals in the lake (e.g., DO, pH, cyanobacterial cell density, chlorophyll *a*) along with model diagnostic information that informs evaluation of uncertainty, and ultimately confidence, in those model results.

**Empirical analysis.** S-R relationships derived from analyses of Utah Lake empirical data will also play an important role in NNC development. Empirical methods relate stressors (e.g., N or P) to assessment endpoint measures such as changes in biological composition that reflect ecosystem structure (e.g., cyanobacterial densities or proportion) or biogeochemical measures of ecosystem functions such as DO or pH (Table 9). Potential stressor-response associations will be examined using traditional statistical methods such as regression

[5]There are other existing models for Utah Lake, including the Utah Lake Water Quality Salinity Model (LKSIM) computer model. LKSIM was developed by researchers in the Civil & Environmental Engineering Department at Brigham Young University (BYU) and was used in the 2007 TMDL. However, LKSIM has limitations that prevent it from being applied here.

analysis (linear and logistic) as well as more advanced (e.g., hierarchical and Bayesian) model formulations (USEPA 2010). EPA's Ambient Water Quality Criteria to Address Nutrient Pollution in Lakes and Reservoirs (USEPA 2021) will also be used, which includes of a set of empirical stressor-response models that can be run for any lake in the US to estimate nutrient concentrations associated with meeting adjustable target concentrations for measures of effect being considered in Utah Lake (e.g., toxin concentration). The S-R analyses will be used to establish nutrient-concentration thresholds that are most strongly associated with changes in assessment endpoints. Plots like the one shown in Figure 8 will be generated and used to help inform where to set the NNC thresholds in the context of uncertainty metrics. Prediction intervals around the line of best fit will inform ranges of protective values. Once the range of protective nutrient thresholds have been established, they can be related to protection of beneficial designated uses (USEPA 2021).

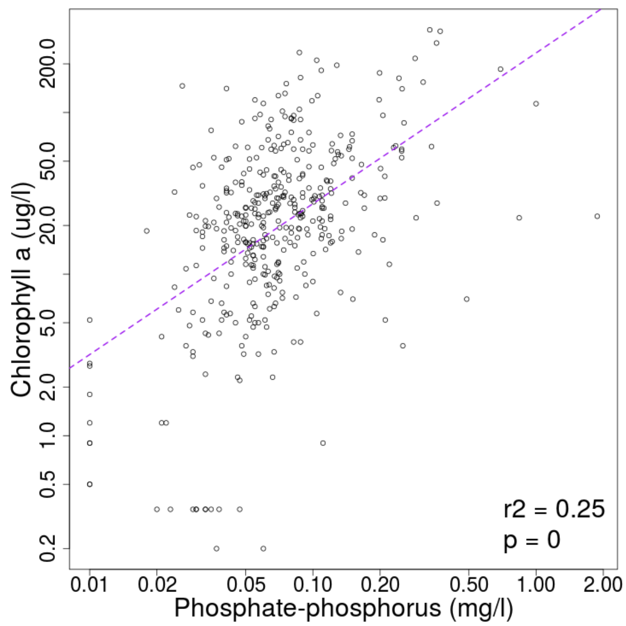



**Figure 8. Relationships between Chl a and TP ("phosphate-phosphorus") concentration in Weeks Bay (source: Figure 39 in GOMA 2013).**

In population-based stressor-response analyses used in nutrient criteria development (e.g., USEPA 2010) a sufficient gradient is usually guaranteed. Since this stressor-response analysis is being conducted using data from within one waterbody, that gradient is not guaranteed. Therefore, one limitation to the stressor-response analysis is the existing nutrient gradient across the lake. The range of responses will be limited by the range of nutrient exposures and it is anticipated that a sufficient gradient of nutrient stress, in space or time, will be identified and that the responses should be expected to be consistent to that gradient. If it is not, then the results are still valid, they would just need to be put into the context of a larger potential gradient informed by the paleo-studies, mechanistic model, reference-based results, literature and expertise. For example, the degree to which responses along a potentially abbreviated nutrient stress gradient in Utah Lake are representative of those expected across much broader nutrient gradients observed in other systems reinforces existing models and justifies the utility of the stressor-response gradient. Initial analyses indicate a gradient of stress and response exists in Utah Lake, but it is likely truncated compared to that which exists among the population of lakes statewide.

The Utah Lake S-R analyses that will inform NNC will use TP and TN as the causal variables. Measures of effect will be used as response variables and include chlorophyll *a*, cyanobacterial abundance, cyanotoxins, and water clarity. Targets for these measures of effect will be derived from S-R analysis based on the protection of beneficial uses and their associated assessment endpoints. For instance, DWQ regulations require protecting DO, pH, and ammonia levels to protect aquatic life, all of which can be altered by eutrophication resulting from nutrient enrichment. Stressor-response models can be explored that link DO and pH responses to critical chlorophyll *a* concentrations. Similarly, aquatic life use must protect the food web of the lake upon which fish depend and many of those taxa (zooplankton, phytoplankton, benthic invertebrates) may be harmed by excess algae or shifts in phytoplankton composition to less palatable forms that may impact trophic transfer and the lake food web. Specific S-R linkages are outlined in Table 9.

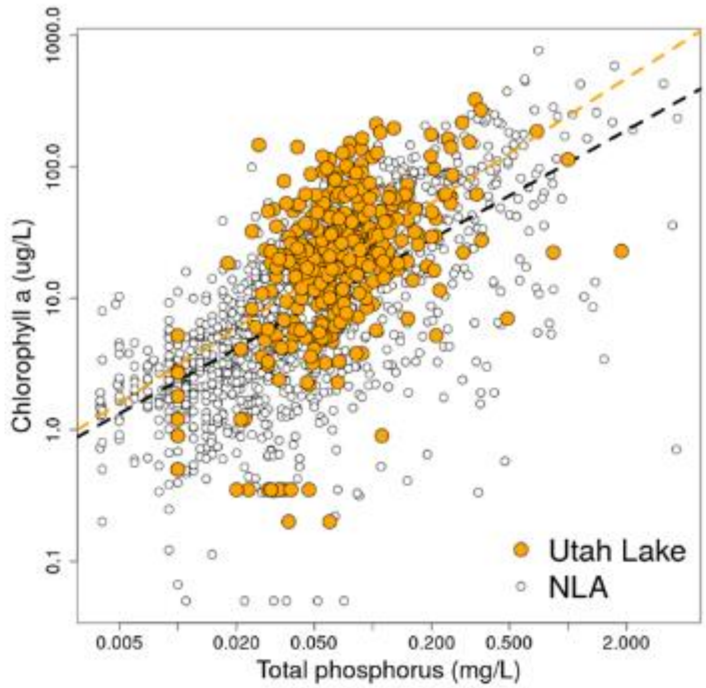
As part of the framework for deriving NNC, a user perception survey will be conducted as directed by the SC and implemented by DWQ. Once completed, endpoints from the survey will be used to model TN and TP. Advantages of user perception surveys include their scientific rigor and direct linkage to recreational beneficial uses. Disadvantages include the effort in time and resources to conduct such rigorous surveys. Utah has experience conducting these types of surveys (DWQ 2013, Nelson et al. 2015).

Once values of chlorophyll *a* or phytoplankton composition that protect the assessment endpoints are identified, stressor-response models that link TN/TP to these values can then be derived with uncertainty bounds and used to inform the selection of a range of protective criteria. Critical output for the stressor-response relationship modeling will, therefore, include TN and TP concentrations protective of the desired assessment response conditions as well as any additional response measures identified during analysis along with quantitative measures of uncertainty useful in evaluating confidence in any conclusions generated from the results.

## Scientific Literature

**Comparison with nutrient levels in other lakes.** The S-R relationships and reference approaches will be the primary lines of evidence that inform NNC development for Utah Lake. In addition, we will also evaluate how the NNC values proposed for Utah Lake using the lines of evidence above compare to values from other studies and research in the scientific and technical literature including EPA’s National Lake Assessment (see example in Figure 9) and EPA’s Ambient Water Quality Criteria to Address Nutrient Pollution in Lakes and Reservoirs (USEPA 2021). This additional line of evidence can help place the resulting values in context, provide additional support or recommend further inquiry based on potential conflicts with existing, established science.

**Figure 9. Comparison of TP and chlorophyll-*a* concentrations between Utah Lake (orange circles) vs. TP values from the 2012 EPA National Lakes Assessment (NLA). Source: Utah Lake Data Explorer). The Utah Lake data were collected from 1990-2016, and cover the entire lake, all months.**




## 2.4 COMBINING LINES OF EVIDENCE, RECOMMENDING AND COMMUNICATING FINAL VALUES

A multiple lines of evidence approach will be used including the S-R relationship and reference approaches. Here we propose to communicate results and response thresholds similar to the way they were communicated for the derivation of Utah's headwater stream NNC (see Figure 2). This presentation allows simultaneous consideration of all the data and information along with uncertainty, which creates a more holistic picture of the varied and often complex responses to eutrophication. It also identifies the ranges of nutrient levels deemed protective of designated uses across each line of evidence.

However, distillation of these multiple lines of evidence into a recommended value(s) that can be used for regulatory purposes can be challenging. A very simplistic approach is to use some statistic of the endpoints derived from different lines, such as the median or 25$^{th}$ percentile, and recommend that value. This has the advantage of being very transparent and replicable but has the disadvantage of not incorporating uncertainty and the complexity of information.

This project will use a more robust approach which is to have the SP interpret these endpoints in the context of their uncertainty and provide an assessment of the probability of exceeding assessment endpoint measures such as dissolved oxygen, cyanobacterial density, chlorophyll *a* and toxin concentrations (thus impairing the use), with increasing nutrient concentrations based on the quantitative results from the lines of evidence. This results in a range of values which the SC will consider along with other factors in decision-making, including tolerance for exceedances, to select final recommended values. This may be an adaptive process during which communication between the SP and decision-makers, combined with emerging knowledge, is used to narrow the range or increase confidence in those TN and TP concentrations at which impacts are more certain. Specifically, the initial output from the SP will be presented in tables in which a range of TN and TP values are linked to assessment endpoints and effects on beneficial uses accompanied by information on likelihood and confidence from each line of evidence. This will allow the SC to make an informed recommendation based on desired endpoints, likelihood of exceedance, and confidence. In contrast to averaging all the numbers, this approach allows users to visualize all the values, what they protect and then weigh the pros and cons of values against uncertainty. The SC will select numeric criteria to protect all beneficial uses knowing that the most stringent criteria would be based on the most sensitive use.

In addition to magnitudes, the SP will provide duration and frequency components of any numeric nutrient criteria. The duration reflects the period over which the magnitude is averaged (e.g., seasonal mean, annual mean, daily mean) and there could be magnitudes with varying duration (a seasonal and annual mean). In typical nutrient criteria derivation, the duration is derived from the data used to conduct the analysis, but statistical and mechanistic analysis could also be used to identify relationships between durations different than those used to derive the values (e.g., Walker 1986). Frequency refers to how often the magnitude of a specified duration can be exceeded and not impair the use. For example, some criteria allow annual averages to be exceeded once every 3 years others to never be exceeded. The frequency component should be based on the resilience of the ecosystem to stress in excess of that presented by the magnitude For example, the SP may derive a range of magnitude values representing conditions which, if exceeded, would result in impacts that may be difficult to reverse or expensive to restore suggesting a magnitude with no allowable exceedance frequency. In contrast, the SP may derive a range of magnitude values that are an average condition with acceptable interannual variability from which the lake response condition would remain unchanged or should be able to recover within a reasonable timeframe if exceeded with no effect on uses (e.g., 1 in 3 years).

At this time, Table 10 and Table 11 are blank as to values, but include specific lines of evidence and specific endpoints as well as the two scenarios that may be considered. The intent of including them is to help the SP and SC visualize how the information will be presented and used to come up with a final recommended value. Note again that the SP may need to identify additional biological endpoints and assessment endpoints for each scenario.

The SP will produce a narrative for each line of evidence that describes the output captured in Table 10 and Table 11 and includes a traceable account of each value that clearly details how the value protects the assessment endpoint and associated management goal, the defensibility of the methods used, the resulting values of each line of evidence, the uncertainty around those values, and how they are being combined into a recommendation. These narratives will provide a level of detail that would allow the SP decision-making to be replicated by an independent party.

**Table 10. Example TP Table (FOR EXAMPLE ONLY)**

| | | Beneficial Uses Protected | | | Uncertainty | | Lines of Evidence | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Measures (and exceedance probability, where applicable) | TP (mg/L) | Recreation (2A and 2B) | Aquatic Life (3B and 3D) | Agriculture (4) | Likelihood (not likely, as likely as not, very likely) | Confidence (low, medium, high) | Mechanistic Modeling | Reference | S-R Modeling | Literature |
| Chlorophyll *a* < established target from user surveys or other analyses | | X | X | X | Very likely | Medium | X | X | X | X |
| Cyanobacterial Cell Density > X/ml | | X | X | | Very Likely | Medium | X | X | X | X |
| Microcystin > X ug/L | | X | | | As Likely As Not | Medium | | | X | X |
| Cylindrospermopsin > X ug/L | | X | | | As Likely As Not | Low | | | | X |
| Anatoxin-a > X ug/L | | X | | | As likely as Not | Low | | | | X |
| Annual visitation > X persons | | X | | | As Likely as Not | Medium | X | | X | |
| Secchi depth > X m | | | X | | As Likely as Not | Low | X | X | X | X |
| $K_d$ < X $m^{-1}$ | | | X | | As Likely as Not | Low | X | X | X | X |
| Sufficient Zooplankton Prey Densities | | | X | | As likely as Not | Low | | | X | |
| Cyanobacterial relative abundance < X% | | | X | | Very Likely | Medium | X | X | X | X |
| Dissolved Oxygen > state standard | | | X | | Very Likely | High | X | X | X | |
| pH within state standard | | | X | | Very Likely | Medium | X | X | X | |
| Ammonia < state standard | | | X | | Very Likely | High | X | X | X | |
| Toxin concentrations to protect irrigation or livestock watering | | | | X | As likely as Not | Low | | | | X |

**Table 11. Example TN Table (FOR EXAMPLE ONLY)**

| | | Beneficial Uses Protected | | | Uncertainty | | Lines of Evidence | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Measures of Effect/Measures of Exposure | TN (mg/L) | Recreation (2A and 2B) | Aquatic Life (3B and 3D) | Agriculture (4) | Likelihood (not likely, as likely as not, very likely) | Confidence (low, medium, high**)** | Mechanistic Modeling | Reference | S-R Modeling | Literature |
| Chlorophyll *a* < established target from user surveys or other analyses | | X | X | X | Very likely | Medium | X | X | X | X |
| Cyanobacterial Cell Density > X/ml | | X | X | | Very Likely | Medium | X | X | X | X |
| Microcystin > X ug/L | | X | | | As Likely As Not | Medium | | | X | X |
| Cylindrospermopsin > X ug/L | | X | | | As Likely As Not | Low | | | | X |
| Anatoxin-a > X ug/L | | X | | | As likely as Not | Low | | | | X |
| Annual visitation > X persons | | X | | | As Likely as Not | Medium | X | | X | |
| Secchi depth > X m | | | X | | As Likely as Not | Low | X | X | X | X |
| $K_d$ < X $m^{-1}$ | | | X | | As Likely as Not | Low | X | X | X | X |
| Sufficient Zooplankton Prey Densities | | | X | | As likely as Not | Low | | | X | |
| Cyanobacterial relative abundance < X% | | | X | | Very Likely | Medium | X | X | X | X |
| Dissolved Oxygen > state standard | | | X | | Very Likely | High | X | X | X | |
| pH within state standard | | | X | | Very Likely | Medium | X | X | X | |
| Ammonia < state standard | | | X | | Very Likely | High | X | X | X | |
| Toxin concentrations to protect irrigation or livestock watering | | | | X | As likely as Not | Low | | | | X |

# 3.0 PATHWAY TO CRITERIA

All the work described above is directed at deriving NNC recommendations that the SC will make to the Utah Lake Commission and Water Quality Board to protect designated uses in Utah Lake. This section highlights the pathway to criteria recommendation process and the central role of the SC in that process (Figure 10) and is adapted from the SC Charter document (DWQ 2017). Note that since adopting site specific criteria is ultimately a regulatory process, the DWQ Water Quality Standards (WQS) workgroup will be consulted on an ongoing basis along the pathway to assure that the derivation is consistent with regulatory requirements; moreover, the Director of DWQ is a co-chair of the SC and will provide additional guidance in assuring the process results in recommendations consistent with WQS adoption requirements.

The ULWQS SC has numerous responsibilities in the process including, but not limited to: directing, reviewing, and providing feedback on all SP activities including analyses for each of the lines of evidence, the Technical Support Document (TSD), and the SP criteria recommendations and ultimately providing the nutrient criteria recommendations to protect designated uses in Utah Lake.

Under SC direction, the SP is overseeing the development of all the research and data collection efforts for the ULWQS (e.g., research plans, data collection, modeling) that will generate the analyses for the major lines of evidence described above. The SC regularly reviews these activities and provides feedback to improve the SP oversight. Ultimately, a (TSD) will be developed detailing the data, analyses, and ranges of protective TP and TN concentrations generated from each of the lines of evidence along with uncertainty associated with those values. The SP will use this TSD as the basis of the recommendations they forward to the SC. Again, consistent with this Framework and the Uncertainty Guidance, these recommendations will likely consist of TP and TN ranges and statements about the certainty with which the SP believes values within the ranges are protective of designated uses.

The SC will then take the SP recommendations and construct recommended nutrient criteria to be forwarded to the Utah Lake Commission for review and endorsement as well as to the DWQ and the Water Quality Board. The SC recommendation will be based on a combination of two tracks that will proceed concurrently: (1) development of the TSD which outlines the ranges of TP and TN concentrations that protect the lake designated uses while characterizing the level of certainty around achieving management goals at the recommended nutrient concentrations, and (2) development of an implementation plan that will consider how the NNC will be implemented by considering the various contributors of nutrient to Utah Lake. The implementation plan will incorporate frequency and duration, any criteria decision frameworks, Utah Lake specific assessment methods, permitting considerations, the need for a holistic approach, and that, pursuant to legislation (Utah Statute 19-5-104.5), the economic costs and benefits, impacts on public health and the environment, and legislative review requirements are evaluated and communicated. Both tracks will be coordinated with the WQS workgroup to ensure that resultant criteria recommendations are consistent with state criteria adoption policy and regulatory requirements.

Once the SC recommendation is forwarded to DWQ, the formal criteria adoption process begins with established regulatory requirements that DWQ will be responsible for managing along with its Water Quality Standards workgroup. This will result in state adoption into Water Quality Standards of site-specific nutrient criteria for Utah Lake that will then be sent to US EPA for approval.

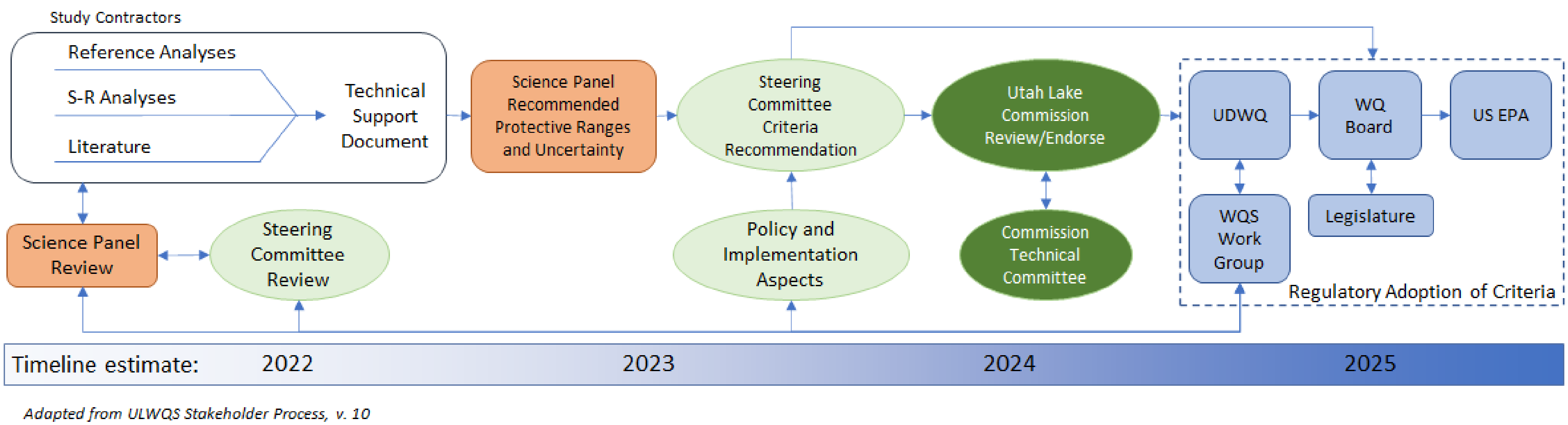



**Figure 10. Flow diagram of the pathway to criteria, adapted from the ULWQS Stakeholder Process, Version 10 document. This describes the relationship between the technical work to generate recommendations, the regulatory adoption of criteria and the central role of the Steering Committee along the pathway.**

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