Quality Assurance Project Plan For Utah Lake EFDC/WASP Model Development, Modification, Evaluation and Application

Utah Lake Water Quality Study

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March 2019

Distribution List

The people listed are responsible for distributing this QAPP to respective team members and stakeholders for the study.

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Table of Contents

Section **Page**

List of Tables

List of Figures

ACRONYMS AND ABBREVIATIONS

AWQMS	Ambient Water Quality Monitoring System
CBOD	Carbonaceous Biochemical Oxygen Demand
CUWCD	Central Utah Water Conservancy District
CWA	Clean Water Act
DO	Dissolved oxygen
EPA	United States Environmental Protection Agency
GIS	Geographic Information System software
HAB	Harmful algal bloom
NSE	Nash-Sutcliffe coefficient of model efficiency
PBIAS	Percent bias
POC	Particulate Organic Carbon/Detrital Carbon
POM	Particulate Organic Matter/Total Detritus
PON	Particulate Organic Nitrogen/Detrital Nitrogen
POP	Particulate Organic Phosphate/Detrital Phosphate
QA	Quality assurance
QC	Quality control
R^2	Coefficient of determination
RE	Relative error
RMSE	Root mean square error
RSD	Relative standard deviation
TMDL	Total Maximum Daily Load
UAC	Utah Administrative Code
UDWQ	Utah Division of Water Quality
ULSC	Utah Lake Steering Committee
ULSP	Utah Lake Science Panel
USBR	United States Bureau of Reclamation
UPDES	Utah Pollution Discharge Elimination System
USGS	United States Geological Survey
WASP	Water Quality Assessment Simulation Program
WWTP	Wastewater treatment plant

1 INTRODUCTION

This Quality Assurance Project Plan (QAPP) documents the systematic planning process following EPA guidance (2002). The QAPP includes the following key elements:

- Description of the project, goals, and objectives (Section 2).
- Project organization, responsible personnel, and schedule (Section 3).
- Data quality objectives for measured and modeled data (Section 4).
- Model framework to support the project goals and objectives (Sections 0).
- Data collection and acquisition to support model build and calibration (Section 6).
- Specification of quality assurance/quality control (QA/QC) activities to assess the performance criteria (Section 7 for EFDC; Section 8 for WASP).
- Model usability assessment (Section 9).
- Project reporting (Section 10).

2 PROJECT DESCRIPTION

2.1 Project Goals and Objectives

The project goal is to develop a hydrodynamic and sediment transport model of Utah Lake. The model will be coupled with a water quality model intended to simulate the impact of nutrients on nuisance and harmful algal bloom (HAB) formation.

The objective is to apply the coupled models to support development of numeric nutrient criteria for Utah Lake as a component of the Utah Lake Water Quality Study. The models may also be used in the future to support determination of nutrient load allocations to ensure that Utah Lake meets the adopted numeric criteria. In addition, the models may be used to simulate historic lake conditions in order to improve understanding of the drivers responsible for shifting stable states from clear to turbid.

2.2 Problem Definition

Utah Lake has experienced nuisance and harmful algal blooms during the past several summers that have resulted in beach and lake advisories and closures. The Utah Lake Water Quality Study was initiated in 2015 to determine the appropriate nutrient endpoints for the lake and to determine source reductions required to meet the endpoints.

Several key processes were identified that the hydrodynamic and sediment transport model is intended to simulate (UDWQ 2016).

1) Lake circulation due to inflows, outflows and wind and wave induced currents.
2) Sediment settling, deposition, and resuspension due to wind and wave action. Suspended sediment in the water column reduces water clarity and the amount of light available for photosynthesis and algal growth. Counterbalancing this affect, phosphorus adsorbed to sediment is potentially made bioavailable as a result of sediment resuspension, which could enhance algal growth.
3) Lake temperature affects kinetic rate coefficients, including algal growth rate. Ice cover in the winter also impacts lateral mixing and evaporation from the lake surface.

The model is anticipated to be utilized to inform several decisions related to the eutrophication of Utah Lake.

1) What is the achievable stable state for Utah Lake?
2) What are the appropriate numeric nutrient criteria for Utah Lake?
3) What are the source reductions/wasteload allocations to achieve the numeric nutrient endpoint?

3 PROJECT MANAGEMENT

3.1 Project Organization

Table 3.1 lists the project personnel and responsibilities.

Table 3.1: Project Personnel and Role

Name	Role	Affiliation
Erica Gaddis	Project Supervisor/Division Director	UDWQ
Jim Harris	Program Manager/QA Manager	UDWQ
Jodi Gardberg	Watershed Protection Section Manager/QA Manager	UDWQ
Scott Daly	Water Quality Study Project Manager	UDWQ
Nicholas von Stackelberg	Technical Lead/Water Quality Modeler	UDWQ
Juhn-Yuan Su	Water Quality Modeler	University of Utah
Mitch Hogsett	Chairperson, Utah Lake Science Panel	Forsgren Associates, Inc.
Michael Barber	Principal Investigator/Professor	University of Utah

3.2 Collaborative Modeling Approach

The Utah Lake model will be collaboratively developed between the University of Utah and UDWQ. The University of Utah's contribution will be funded under a grant from the EPA's Office of Research and Development. EPA issued a cooperative agreement (EPA 2016) that describes the roles and responsibilities of the University of Utah, EPA Region 8 and UDWQ.

3.3 Special Training Requirements and Certification

The project requires specialized training and expertise in computational fluid dynamics (CFD), sediment transport and water quality modeling. In addition, specialized skills in the use of the Environmental Fluid Dynamics Code (EFDC), Water Quality Assessment Simulation Program (WASP) and programming in FORTRAN is required. The Technical Lead at UDWQ will take the following courses to support the project:

- Computational Fluid Dynamics (University of Utah)
- Hydroinformatics (University of Utah)
- WASP Training Workshop (Denver, CO)

3.4 Project Oversight

The Utah Lake Science Panel (ULSP) will provide advisory oversight over the model development, calibration and application. In addition to periodic updates, the modeling team will provide updates to the ULSP at significant milestones and as requested on the modeling effort for feedback and direction.

The modeling work completed for this project will partially serve as the basis for a dissertation in fulfillment of the requirements of a PhD at the University of Utah. The work will be completed under the advice and direction of a PhD committee chaired by Dr. Michael Barber. It is anticipated that the results will be published in a refereed and peer-reviewed journal.

3.5 Project Schedule

Table 3.2 lists the key project tasks and schedule.

Table 3.2: Project Schedule

Task	Timeframe
Model build	Fall 2018
Model calibration	Spring 2019
Data collection	Spring-Summer 2019
Model validation	Fall 2019
Model application	2020

3.6 Project Budget

The project is anticipated to be performed by salaried staff of the UDWQ and funded through existing and ongoing sources. Development and calibration of the WASP model will be performed by the University of Utah under a grant from EPA.

4 QUALITY OBJECTIVES

Quality objectives are statements of the precision, bias, and lower reporting limits necessary to meet project objectives. Precision and bias together express data accuracy. Other considerations of quality objectives include representativeness, completeness, and comparability.

4.1 Measurement Quality Objectives

Measurement quality objectives for data to be collected to support model build and calibration is documented in *Sampling and Analysis Plan: Data Collection to Support Utah Lake EFDC Model Build and Calibration* (UDWQ 2018).

4.2 Model Quality Objectives

The primary modeling quality objective is that the assumptions, limitations, goodness-of-fit, and uncertainty of the model are characterized. Natural resource managers, stakeholders, and policy makers can thereby evaluate the level of quality and uncertainty of model results against the magnitude of the potential decision or regulatory actions to determine which decisions the model results can support. Therefore, it is critical that this study provides a clear, accurate, and thorough job communicating each of these aspects of the model.

Further discussion of model performance metrics and evaluation criteria are provided in Section 7 and 8.

5 MODEL FRAMEWORK

This section describes the modeling framework selected to meet the study objectives.

5.1 Model Selection

A model selection process was previously completed to select the modeling approach best suited to meet the study objectives and selection criteria (UDWQ 2016). A three-dimensional hydrodynamic model coupled with a water quality model was selected to simulate the nutrient dynamics in Utah Lake. The Environmental Fluid Dynamics Code (EFDC) was selected to simulate hydrodynamics and sediment transport and the Water Quality Analysis Simulation Program (WASP) was selected to simulate nutrients and water quality in Utah Lake.

The open source, public domain EPA version of EFDC will be utilized for this project. Pre- and post-processing of the EFDC model will be accomplished utilizing Visual EFDC Version 2.0, which is distributed and maintained by Tetra Tech, Inc.

WASP Version 8.31 (December 2018 Version), maintained and distributed by EPA, will be utilized for this project.

5.2 Model Modifications

The EFDC program is considered capable of simulating the hydrodynamic processes, and the cohesive and non-cohesive sediment transport, in Utah Lake. However, bioturbation of sediment resulting from benthivorous carp activity was identified as a process not currently represented or simulated by the EFDC program that may be significant to the study objectives and therefore may need to be incorporated into the model or analysis.

Any modifications made to the EFDC source code will be made with the following provisions:

1. The model formulation shall be made based on sound science and peer-reviewed theory and application.
2. The source code shall be made available to interested stakeholders for review.

6 DATA COLLECTION AND ACQUISITION

6.1 Model Data Requirements

Table 6.1 lists the input data requirements for the model build and calibration for EFDC.

Table 6.1: Model Data Requirements and Sources for EFDC

Item	Source	Description
Physical Data		
Bathymetry – below water surface	ESRI ArcGIS	Bottom elevation of lake
Bathymetry – above water surface	2016 LiDAR Elevation Data	Bottom elevation of lake
Vegetative Resistance	Aerial imagery	Resistance to flow caused by submerged or emergent aquatic vegetation
Forcing Input Data		
Meteorological Data	Provo Airport Station	Parameters: air temperature, relative humidity, barometric pressure, precipitation, solar radiation, cloud cover, wind speed, wind direction
Jordan River Outflow	Utah Division of Water Rights	Daily and Monthly Flow Rate Records
Inflow Quantity	USGS, UDWQ	USGS flow gages for Provo River & Hobble Creek; UDWQ pressure transducers and WWTP discharge monthly reports for other significant inflows
Inflow Quality	UDWQ	Monthly sampling of temperature, turbidity, TSS, salinity
Groundwater	USGS	Groundwater reports for Utah Valley
Observed Calibration Data		
Water Surface Elevation	Central Utah Water Conservancy District	Stage gage maintained at Utah Lake Pump Station
Lake Quality	UDWQ	Monthly sampling at 10 sites and long term sonde deployments at 3 sites. Parameters: temperature, turbidity, TSS, salinity
Water Velocity	UDWQ	Measurement using ADCP and ADV
Wave Height	UDWQ	Measurement using ADCP
Ice Cover	Satellite Imagery	Period of ice cover and spatial extent

Table 6.2 lists the intended input data requirements for the model build and calibration for WASP.

Table 6.2: Model Data Requirements and Sources for WASP

Item	Source	Description
Input Data		
Meteorological Data	Provo Municipal Airport	Parameters: Air Temperature, Dewpoint Temperature, Wind Speed, Wind Direction, Cloud Cover, Solar Radiation; Same Meteorological Data employed for the EFDC implemented for WASP, with dewpoint temperature calculated from air temperature and relative humidity
Inflow Quality	Utah Division of Water Quality; Ambient Water Quality Monitoring System (AWQMS) Database	Selected DWQ Sites with Selected WQ Constituents: **Nitrogen Species (Ammonia-Nitrogen, Inorganic Nitrogen (Nitrate and Nitrite), Dissolved Organic Nitrogen)**, **Phosphorus Species (Dissolved Inorganic Phosphate, Dissolved Organic Phosphate)**, **CBOD**, **DO**, **Phytoplankton Chlorophyll-a**, **Water Temperature**, **pH**, **Alkalinity**, **TSS**
Inflow Quantity and Quality: Timpanogos WWTP	Utah Division of Water Quality	Discharge Monthly Reports (DMRs) and/or Monthly Operating Reports (MORs) from the Timpanogos WWTP
Atmospheric Deposition Quality	Olsen (2018)	Atmospheric Deposition of selected WQ constituents over the entire Utah Lake, depending on data availability; Olsen (2018) describes the approaches attempted for approximating the atmospheric deposition of nitrogen and phosphate into Utah Lake.
Groundwater Quality	USGS	Groundwater quality sources for selected WQ constituents from Goshen Bay, Northern Valley, and Southern Valley, with sites provided under the weblink https://maps.waterdata.usgs.gov/mapper/
Model Parameters		
Phytoplankton Kinetics (Max Growth Rate, Respiration Rate, Death Rate from non-zooplankton predation, temperature-correction coefficients, phytoplankton respiration recycling fractions, phytoplankton death recycling fractions, phytoplankton fractions/grouping)	Dr. Ramesh Goel’s Research Lab	Results from periodic/monthly sampling conducted by Dr. Ramesh Goel’s Group over Utah Lake sites; up to 5 phytoplankton groups intended
Phytoplankton Stoichiometric Ratios per Group (Detritus-to-Carbon, Nitrogen-to-Carbon, Phosphorus-to-Carbon, Carbon-to-Chlorophyll-a)	Dr. Ramesh Goel’s Research Lab	Results from periodic/monthly sampling conducted by Dr. Ramesh Goel’s Group over Utah Lake sites; up to 5 phytoplankton groups intended
Detritus/Particulate Organic Matter (POM) Kinetics (Detritus Dissolution Rate, Detritus Settling Velocity, Detritus Dissolution Temperature-Correction Coefficient)	Dr. Ramesh Goel’s Research Lab	Results from periodic/monthly sampling conducted by Dr. Ramesh Goel’s Group
Sediment Diagenesis Inputs	Hogsett et al. (2019)	Initial POP sediment concentration based on Hogsett

Item	Source	Description
(Fractions into Sediment-Water Column Nutrient Exchange Classes, Initial Concentrations for POP/PON/POC, Sediment Diagenesis Segmentation	and Paraska et al. (2014)	et al. (2019) that provides phosphorus speciation results for sediment core samples over Utah Lake; sediment diagenesis nutrient parameters on fraction distributions toward Classes G1 (labile), G2 (refractory), and G3 (inert) possibly referenced from Paraska et al. (2014) that provides a review over three commonly-used sediment diagenesis routines in water quality models; nutrient fluxes (benthic ammonia-nitrogen flux, benthic inorganic phosphate flux, sediment oxygen demand) documented in Hogsett et al. (2019) that will be employed for enhancing WASP model calibration
Observed Calibration Data		
Nitrogen (Ammonia-Nitrogen, Inorganic Nitrogen (Nitrate and Nitrite), Organic Nitrogen, Total)	UDWQ AWQMS	Selected DWQ sites within Utah Lake from AWQMS within the model calibration period
Phosphorus (Dissolved Inorganic Phosphate, Organic Phosphate, Total)	UDWQ AWQMS	Selected DWQ sites within Utah Lake from AWQMS within the model calibration period
CBOD (Total)	UDWQ AWQMS	Selected DWQ sites within Utah Lake from AWQMS within the model calibration period; for Total CBOD concentration
DO (Concentration, Saturation)	UDWQ AWQMS	Selected DWQ sites within Utah Lake from AWQMS within the model calibration period
pH (pH, Alkalinity)	UDWQ AWQMS	Selected DWQ sites within Utah Lake from AWQMS within the model calibration period
Water Temperature	UDWQ AWQMS	Selected DWQ sites within Utah Lake from AWQMS within the model calibration period
Phytoplankton (Total)	UDWQ AWQMS	Selected DWQ sites within Utah Lake from AWQMS within the model calibration period; for Total Phytoplankton Chlorophyll-a concentration
Total Suspended Solids	UDWQ AWQMS	Selected DWQ sites within Utah Lake from AWQMS within the model calibration period
Total Dissolved Solids	UDWQ AWQMS	Selected DWQ sites within Utah Lake from AWQMS within the model calibration period

As displayed in Table 6.2, measured water quality data for selected sites monitored by the Utah Division of Water Quality from the Ambient Water Quality Monitoring System (AWQMS) database are employed for the WASP Model Calibration. Water Quality databases have been developed from selected sites for the water quality constituents described in Table 6.2 for this exercise. The following figure displays the locations and the corresponding DWQ IDs of the sites that are being implemented for the Utah Lake WASP Model Calibration.

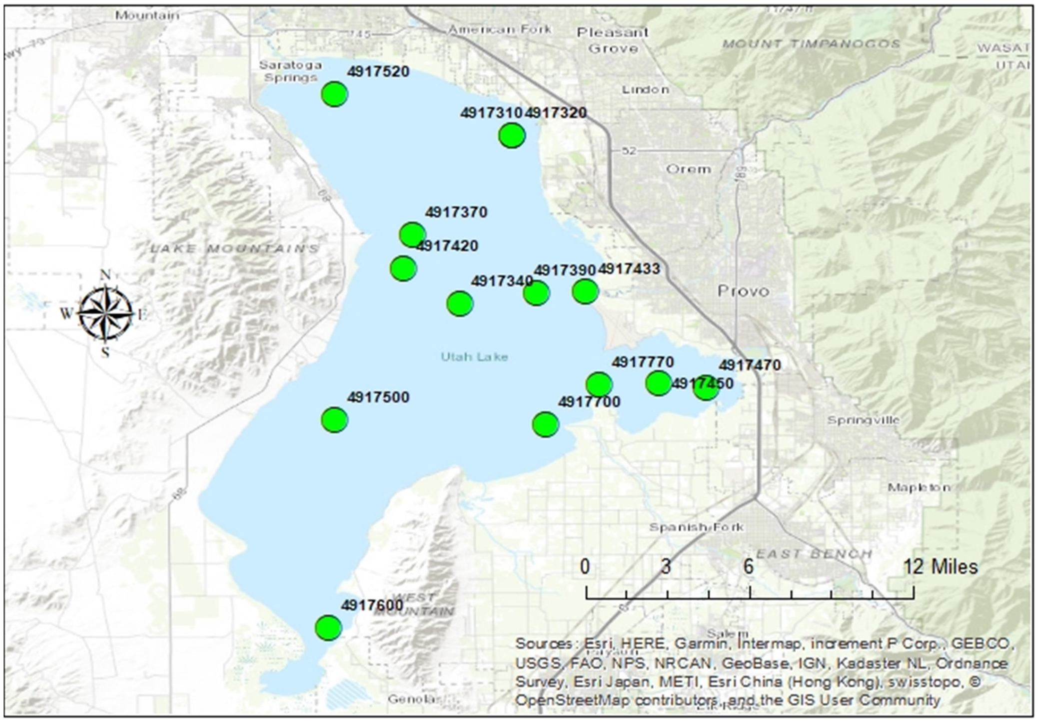


Figure 6.1: Utah Lake DWQ Sites from AWQMS for Utah Lake WASP Model Calibration

Meanwhile, due to significant non-detects observed upon the measured data, separate water quality databases have been developed for the WASP model calibration/validation. For this exercise, one water quality database is developed for neglecting non-detects, which this database tentatively is employed for the Utah Lake WASP model calibration incorporating statistical analyses. On the other hand, a separate water quality database is developed and substitutes non-detects with values that are 85% of the Lower Quantification Limit, which this database is tentatively employed for supplementing the model calibration/validation via graphical approaches/visual inspection analyses. At the same time, the AWQMS database is currently being reviewed and re-worked by the DWQ staff due to observed characteristics associated with the measured data, which will be provided for the Utah Lake WASP model validation/calibration once such issues have been resolved.

As indicated in Table 6.2, sediment diagenesis parameters will be implemented as model inputs for simulating sediment diagenesis in WASP. For this exercise, sediment diagenesis will be simulated for the Utah Lake WASP, yielding benthic nutrient fluxes (benthic ammonia-nitrogen flux, benthic inorganic phosphate flux, sediment oxygen demand) based on model inputs needed for such processes (initial POM concentrations, nutrient fraction distributions, etc.). Since WASP yields time-series data for different constituents and nutrient parameters from a successful simulation, the nutrient benthic fluxes documented in Hogsett et al. (2019) will be implemented as fluxes for the autumn time period for comparing simulated benthic fluxes by WASP against such measured results. At the same time, the experimental results documented in Hogsett et al. (2019) will be employed for populating the initial POP concentration needed for the sediment diagenesis routines in WASP. The following figure displays the sites that exhibit benthic nutrient fluxes and initial POP concentrations from experimental/sampling analyses conducted in Hogsett et al. (2019) for populating such sediment diagenesis inputs into the Utah Lake WASP.

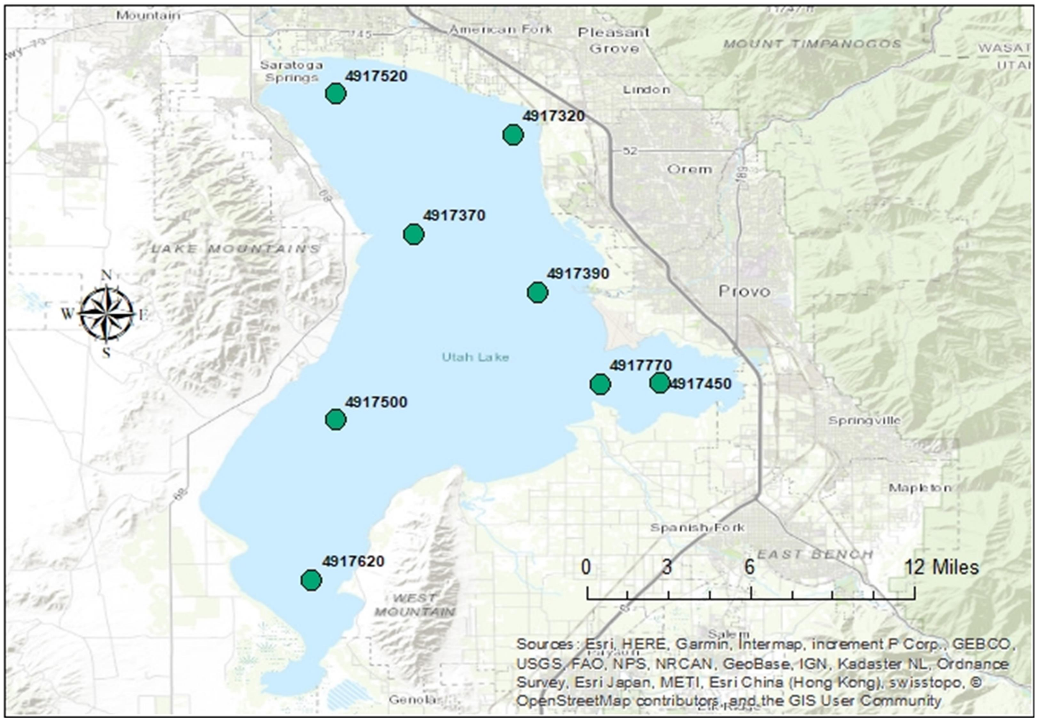


Figure 6.2: Sites Monitored in Hogsett et al. (2019) for Sediment Diagenesis Inputs into Utah Lake WASP

6.2 Data Collection

The data acquisition and collection requirements to support model development are detailed in separate documents.

1. *Utah Lake Water Quality Study: 2018 Sampling and Analysis Plan.* (UDWQ 2018a)
2. *Sampling and Analysis Plan for Data Collection to Support Utah Lake EFDC Model Build and Calibration: Utah Lake Water Quality Study* (UDWQ 2018b)
3. *Quality Assurance Project Plan for Prediction of Nonlinear Climate Variations Impacts on Eutrophication and Ecosystem Processes and Evaluation of Adaptation Measures in Urban and Urbanizing Watersheds* (Barber et al. 2016)

6.3 Data Acceptance Criteria

Data sources for this study are listed in Section 6.3. In the course of model development, additional data sources may be identified. It is typical in water quality modeling to use the best data available, assess the quality of that data, and then assess the effects of data quality on model quality.

Data obtained by UDWQ will be quality controlled and managed per standard operating procedures as described in the *Utah Lake Water Quality Study: 2018 Sampling and Analysis Plan*. (UDWQ 2018a).

For data from external sources, assessment of data for acceptance for use as model input and calibration will follow these steps:

1) The source of the data will be investigated for documented data quality procedures.
2) Any qualifications or other metadata provided with the data set will be documented and evaluated.
3) The data intended for use will be evaluated for outliers or unusual trends that may suggest data

quality problems. Based on the evaluation of the data, which would include investigation of unusual environmental or logistical conditions at the time of data collection, suspect data may be censored, qualified, or accepted.

4) An overall assessment of the variability and uncertainty of each data set will be conducted and documented in the project report.
5) As part of model quality assessment, the effect of data variability or uncertainty on model results will be evaluated, either qualitatively or through a quantitative analysis, such as a sensitivity or uncertainty analysis, and documented in the project report.

6.4 Data Management

Water quantity and quality data for input to the model, output results from the model and observed calibration data will be compiled in the Water Resources Database in the Binary Modeling Data File Version 2 (BMD2) format.

The final version of the model, including input, output, and executables will be maintained for archiving at the completion of the project. Electronic copies of the data, GIS, and other supporting documentation (including records documenting model development) will be saved and stored as appropriate for agency policies on records retention practices. Copies will be maintained in a task subdirectory, subject to regular system backups, and on disk for a maximum of 3 years after task termination, unless otherwise directed by agency management. The underlying data used for the model will be organized prior to the public comment phase of the project so that it can be easily shared upon request.

7 MODEL PERFORMANCE EVALUATION- EFDC

7.1 EFDC Model Parameterization

Table 7.1 lists the significant model parameters and estimation methods for EFDC. Parameters may be added or dropped depending on the results of the sensitivity analysis.

Table 7.1: Model Parameter Estimation Methods for EFDC

Parameter	Module	Estimation Method
Bottom roughness height (m)	Hydrodynamic	Calibration parameter
Smagnorinsky's coefficient (dimensionless)	Hydrodynamic	Calibration parameter
Vertical eddy viscosity (m^2/s)	Hydrodynamic	Calibration parameter
Vertical molecular diffusivity (m^2/s)	Hydrodynamic	Calibration parameter
Settling velocity (m/s)	Cohesive Sediment	Empirical coefficients that relate settling velocity to suspended sediment concentration
Deposition critical shear stress (N/m^2)	Cohesive Sediment	Related to measured sediment characteristics (i.e. D50)
Erosion critical shear stress (N/m^2)	Cohesive Sediment	Related to measured sediment characteristics (i.e. D50)
Surface erosion rate ($g/m^2/s$)	Cohesive Sediment	Calibration parameter
Sediment specific gravity (g/m^3)	Cohesive Sediment	Measured sediment characteristic

7.2 EFDC Calibration Approach

Model calibration is necessary because of the inherent uncertainty associated with simulating environmental conditions using simplified mathematical representations of complex systems. Mechanistic models are based on physical, chemical, and biological processes that use kinetics derived from previous research or applications to mathematically quantify these processes. Model calibration is the method of adjusting model parameters and kinetics to achieve an optimal match between the predicted output of the model to the observed conditions. Model calibration involves a qualitative graphical comparison and basic statistical methods that are used to compare model predictions and observations. To provide a credible basis for predicting and evaluating environmental scenarios and management options, the ability of the model to represent real-world conditions should be optimized and evaluated through a process of model calibration and, if appropriate, through validation (EPA 2009).

Following are the model state variables to be compared to observed:

1) Water surface elevation (m)
2) Water velocity (m/s)
3) Water velocity direction (deg)
4) Wave height (m)
5) Temperature (deg C)
6) Total suspended solids (mg/L)

A historical model will be built to simulate the conditions for Water Year 2006 through 2015; however, not all inputs are known during this time frame and some will need to be estimated. The historical model will be used to calibrate the parameters. The model will be calibrated to the following state variables: water surface elevation, temperature, salinity and total suspended solids. The model parameters will be adjusted manually during model calibration. It is not anticipated that an automated calibration optimization technique using a goodness-of-fit statistic will be employed for this project.

7.3 EFDC Validation Approach

Ideally, the performance of a calibrated model is validated by comparison to an independent data set. The model will be validated to observed measurements collected per the *Sampling and Analysis Plan for Data Collection to Support Utah Lake EFDC Model Build and Calibration: Utah Lake Water Quality Study* (UDWQ 2018b). Hydrodynamic and sediment data collection instrumentation is proposed to be sequentially deployed at up to six sites for approximately one month at each site. Each of the model state variables listed above will be validated. Due to the addition of several state variables from the calibration, it is anticipated that some model refinement will occur during the validation phase.

7.4 EFDC Performance Measures

A combination of graphical and statistical analyses will be conducted in order to measure performance of the model calibration and validation.

7.4.1 Graphical Performance Measures

The following graphical plots will be generated to compare the simulated results to the observed data.

1. <u>Time-series plot</u>: compare simulated results and observed data with time as a dependent variable.
2. <u>Scatter plot</u>: Plot of simulated results vs. observed data with least square regression to determine deviation form 1:1 line.

3. Flow/load duration curve: compare simulated and observed probabilities of exceedance.
4. Cumulative plot: compare cumulative simulated and observed data with time as dependent variable.

7.4.2 Statistical Performance Measures

The quality of model performance will be evaluated using statistical tests. Model performance statistics are used, not as absolute criteria for acceptance of the model, but as guidelines to supplement the visual inspection of model-data plots and to determine appropriate endpoints for calibration and corroboration of the model. This section lists a suite of tests that are used during model quality assessment. The exact statistical tests will be determined during model calibration and may include any of the following. In addition, if determined necessary and appropriate, additional tests of model fit may be applied.

Precision is a measure of the variability in the model results relative to measured values. The following statistics will be calculated to evaluate model precision:

1. Root mean square error (RMSE) is defined as the square root of the mean of the squared difference between observed and simulated values.

$$\mathrm{RSME} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2} \tag{1}$$

2. Relative error (RE) is the percent difference between predicted and observed.

$$\mathrm{RE} = \left|\frac{O_i - P_i}{O_i}\right| * 100 \tag{2}$$

3. Coefficient of determination (R^2) varies between 0 and 1 and indicates the proportion of the total variation in observations explained by the model.

$$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i - \overline{O})(P_i - \overline{P})}{\sum_{i=1}^{n}\sqrt{(O_i - \overline{O})^2}\sqrt{(P_i - \overline{P})^2}}\right]^2 \tag{3}$$

4. Nash-Sutcliffe coefficient of model efficiency (NSE) ranges from minus infinity to 1.0, with higher values indicating better agreement.

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \tag{4}$$

where,
O_i = observation
$\bar{O}$ = mean of observations
P_i = model predicition

$\bar{P}$ = mean of predictions
n = number of observed-predicted pairs

Bias is the systematic deviation or difference between the predicted and observed values. Bias in this context could result from uncertainty in modeling or from the choice of parameters used in calibration.

1. Percent bias (PBIAS) measures the average tendency of the predicted results to be larger or smaller than observed data.

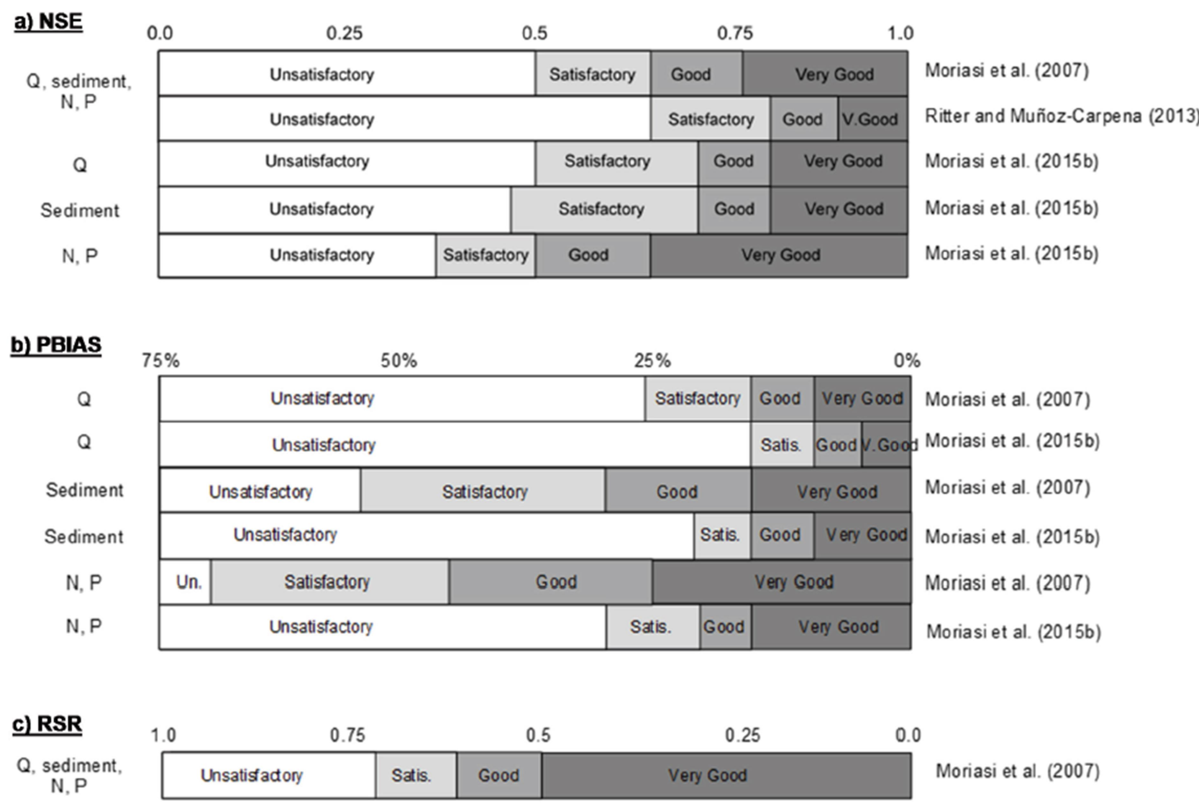
$$\mathrm{PBIAS} = \frac{\sum_{i=1}^{n}(O_i - P_i)}{\sum_{i=1}^{n} O_i} * 100 \qquad (5)$$

Model results will be assessed to determine how representative they are of the population of interest. Representativeness can be assessed by examining the ranges, distributions, trends, and other patterns in model results, and their congruence with known or likely characteristics of the modeled water body. The representativeness analysis for this project will consider factors such as model approach, input and calibration data collection methods, seasonality, time of day, flow conditions, and weather.

7.5 EFDC Performance Evaluation Criteria

Model performance will be evaluated using qualitative and quantitative measures in to order to assess the suitability of the model to support the stated project objectives. Absolute performance criteria for model acceptance or rejection are not recommended due to the lack of consensus of appropriate values in the literature, inherent error in input and observed data, and the approximate nature of model formulations. The performance measures will not be used to pass/fail or accept/reject the model, but rather provide the stakeholders and decision makers with a qualitative assessment of model suitability and help determine if additional data or model refinements are needed.

Figure 7.1 shows recommended qualitative evaluation criteria based on the statistical measures NSE and PBIAS (ASABE 2017). These evaluation criteria were developed for watershed flow and quality models, and not specifically for receiving water fate and transport models. These should be considered guidelines for establishing various levels of acceptability of model performance and are not intended to establish strict standards that can be applied in isolation to justify or reject model performance conclusions.



- For the Moriasi et al. (2007) ratings, ***all criteria*** must be met to achieve higher rating. Adjust strictness of criteria based on several factors including model intended use.
- The Ritter and Muñoz-Carpena (2013) ratings were designed to determine significance of model fit based on hypothesis test results. Utilize less restrictive significance level (e.g., α=0.10) for Exploratory uses; lower to α=0.05 or 0.01 with highly uncertain measured data or for Planning uses; lower to α=0.01 for Regulatory/Legal uses.
- For the Moriasi et al. (2015b) ratings, ***all criteria*** must be met to achieve higher rating. See Moriasi et al. (2015b) for applicable temporal scales for each statistical measure and output. Adjust strictness of criteria based on several factors including model intended use.
- Q - includes streamflow, surface runoff, base flow, and tile flow.

Figure 7.1: Performance rating guidelines for a) NSE, b) PBIAS, and c) RSR of flow components at any resolution and monthly water quality loads. Source ASABE 2017

Based on a review of water quality receiving models by Arhonditsis and Brett (2004), the 50th percentile of the coefficient of determination was 0.93 and of relative error was 7% for modeling temperature. Based on a review of performance of models applied to TMDLs by Sanderson and Pickett (2014), sediment models had Nash-Sutcliffe values that ranged from 0.36 to 0.98 for multiple locations.

7.6 EFDC Model Sensitivity and Uncertainty Analysis

Sensitivity and uncertainty analyses are useful for understanding the degree of confidence a user can place in the model results.

Sensitivity analysis involves testing the response of key model outputs to changes in key model inputs. The sensitivity of key model parameters will be evaluated by systematically perturbing individual parameters one-at-a-time by a specified relative amount (i.e. ± 20%) while keeping all other parameters fixed. This technique yields a local measure of sensitivity for each parameter relative to the base set of parameters.

This study will evaluate the level of model uncertainty and potential sources of that uncertainty. Uncertainty analysis refers to the examination of how lack of knowledge in model inputs, parameters, process representation, and solution techniques propagates through the model structure resulting in model error. Sources of model uncertainty are characterized in order to better understand how the model input data and parameters would potentially influence model output and prediction. Potential sources of model uncertainty include:

1) Estimated model parameter values
2) Observed model input data
3) Model structure and forcing functions
4) Numerical solution algorithms

An advanced method of sensitivity and uncertainty analysis is to a conduct a Monte Carlo experiment. Under Monte Carlo methods, the range and distribution of model inputs and parameters is specified. Then model inputs and parameters are randomly sampled for each individual model simulation and numerous simulations (>1,000) are run in order to obtain a probability distribution for the output of interest. The Monte Carlo experiment will estimate overall model uncertainty, as well as the sensitivity and uncertainty associated with individual model inputs and parameters.

Effective uncertainty communication requires a high level of interaction with the relevant decision makers to ensure that they have the necessary information about the nature and sources of uncertainty and their consequences. Performing uncertainty analysis for environmental regulatory activities requires extensive discussion between analysts and decision makers.

8 MODEL PERFORMANCE EVALUATION- WASP

8.1 WASP Model Parameterization

Based on the sensitivity analyses conducted upon the Jordan River WASP Steady-State (August 2009) Model, several model parameters for different water quality and environmental processes appear to exhibit significant effects upon particular constituents (e.g., ammonia-nitrogen concentration, phosphate concentration, etc.). Meanwhile, due to tentatively significant simulation times expected for the Utah Lake Model, only particular model input parameters will be implemented for such calibration/sensitivity analyses for WASP. Table 8.1 provides the input parameters and the estimation methods employed for the Utah Lake WASP Model.

Table 8.1: Tentative Calibration Parameters for Utah Lake WASP

Parameter	Module/Constituent	Estimation Method
Nitrification (1/day); Temperature-Correction Coefficient	Ammonia-Nitrogen, Inorganic Nitrogen (Nitrate and Nitrite)	Calibration Parameter/Jordan River WASP
Half-Saturation for Nitrification	Ammonia-Nitrogen, Inorganic Nitrogen (Nitrate and Nitrite), Dissolved Oxygen	Calibration Parameter/Jordan River WASP
Denitrification (1/day); Temperature-Correction Coefficient	Inorganic Nitrogen (Nitrate and Nitrite); Dissolved Oxygen	Calibration Parameter/Jordan River Qual2K/WASP
Half-Saturation for Denitrification	Inorganic Nitrogen (Nitrate and Nitrite); Dissolved Oxygen	Calibration Parameter/Jordan River WASP
Dissolved Organic Nitrogen (DON) Mineralization Rate (1/day); Temperature-Correction Coefficient for DON Mineralization	Dissolved Organic Nitrogen (DON)	Calibration Parameter/Jordan River WASP
Dissolved Organic Phosphate (DOP) Mineralization Rate (1/day); Temperature-Correction Coefficient for DOP Mineralization	Dissolved Organic Phosphate (DOP)	Calibration Parameter/Jordan River WASP
Reaeration Rate (1/day)	Dissolved Oxygen	Calculated based on **segment characteristics** by the **Covar (Internal) Method**; other available methods involve **O'Connor-Dobbins**, **Owens**, **Churchill**, and **Tsivoglou** Methods
Oxygen to Carbon Stoichiometric Ratio	Dissolved Oxygen	Calibration Parameter/Jordan River WASP
Phytoplankton Half-Saturation Constants (Optimal Light as Photosynthetically-Active Radiation (PAR), Mineralization Rate, Nitrogen Uptake, Phosphorus Update)	Phytoplankton, Nitrogen Species, Phosphorus Species	Calibration Parameter/Jordan River WASP; may be provided by Dr. Goel's Research Group
Light Constants (Background Light Extinction, Detritus/POM and Solids Light Extinction, Dissolved Organic Carbon (DOC) Light Extinction)	Macro/Benthic Algae, Dissolved Oxygen, CBOD	Calibration Parameter/Jordan River WASP; may be provided by Dr. Goel's Research Group and/or EFDC Utah Lake Model from UDWQ
Sediment Transport Inputs (Critical Shear Stress, Particle Diameter, etc.)	Total Suspended Solids	Inputs from EFDC for comparing performance against WASP
Sediment Diagenesis Inputs (Initial POC and PON concentrations)	Organic Nitrogen, Organic Carbon	Calibration Parameter/Jordan River WASP

8.2 WASP Calibration Parameters and Analyses

Due to significant model input parameters provided by Dr. Ramesh Goel's Research Group, limited parameters are selected for such model calibration/validation analyses upon the Utah Lake WASP Model. For this exercise, the Utah Lake WASP Model Calibration will be conducted based upon the adjustment and analyses of the parameters provided in Table 8.1. At the same time, due to the required hydrodynamic linkages for Utah Lake, the WASP Model Calibration, along with the model calibration period, significantly depends upon the performance of the EFDC model. For instance, uncalibrated hydrodynamic characteristics impose significant problems upon the water quality model calibration due to the flow mechanisms and water quality mass constituent calculations conducted by WASP.

Consequently, the model calibration/validation analyses in WASP will NOT begin until after the EFDC model calibration has been completed. At the same time, the model calibration period for the Utah Lake EFDC Model will be applied as the model calibration period for WASP.

The model calibration for the Utah Lake WASP will be conducted based upon the following state variables for comparing the simulated results against the measured data described in Table 6.2 (under "Observed Calibration Data").

1) Ammonia-Nitrogen (mg/L)
2) Inorganic Nitrogen (Nitrate and Nitrite) (mg/L)
3) Total Nitrogen (mg/L)
4) Total Phosphorus (mg/L)
5) CBOD (mg/L)
6) DO Concentration (mg/L)
7) pH
8) Alkalinity (mg/L as Calcium Carbonate)
9) Total Phytoplankton Chlorophyll-a (μg/L)
10) Total Suspended Solids (mg/L)

8.3 WASP Model Sensitivity Analyses

For the Utah Lake WASP, sensitivity analyses will be conducted by manually adjusting the model parameters indicated as **calibration parameters** provided in Table 8.1 by a particular amount/percentile **relative to** the value employed for the Jordan River WASP. For this exercise, each model parameter will be increased/decreased by a user-specified amount (e.g., increased/decreased by 50%, doubled in value, 10 times in value) toward assessing the calibration parameter's effects upon the model performance against the measured data, with all other model parameters remaining constant. The Water Resources Database (WRDB) Graph built with WASP will be applied for assessing the sensitivity of the calibration parameters described in Table 8.1.

8.4 WASP Model Calibration Approaches and Model Evaluation Performance Criteria

For this exercise, similar performance measures described under Section Error! Reference source not found. for EFDC are applied toward the calibration procedures and performance criteria for the WASP Utah Lake Model. On the other hand, such statistical analyses and visual inspections for model calibration depends on the measured data availability for each state variable (Section 8.2) in WASP. Therefore, the model calibration will apply the following options for each state variable for each site with measured data for WASP.

- **Graphical Measures** described in **Section 7.4.1** applied to DWQ AWQMS sites with **4 or fewer time-series measurements** for a **state variable** throughout entire model calibration period
- **Statistical Analyses/Quantitative Measures** described in **Section 7.4.2** applied to DWQ AWQMS sites with **5 or more time-series measurements** for a state variable throughout the entire model calibration period

Such graphical and statistical/quantitative measures are built into the Water Resources Database (WRDB) Graph, which will be employed for the Utah Lake WASP Model Calibration based upon the state variables described in Section 8.2.

9 MODEL USABILITY DETERMINATION AND RECONCILIATION

The model is anticipated to be one of several lines of evidence for determining appropriate numeric nutrient criteria for Utah Lake. Depending on confidence in the other lines of evidence, acceptable model uncertainty would be expected to be somewhat higher.

It is anticipated that the model will be the primary decision support tool for determining the necessary nutrient load allocations, which will likely require reductions from agricultural, stormwater, and treated wastewater sources. Considering the potentially significant economic costs associated with implementing these source reductions, acceptable model uncertainty would be expected to be somewhat lower for this task.

Based on the results of the model performance evaluation, the suitability of applying the model to numeric nutrient criteria development and/or nutrient load allocation will be determined. The Utah Lake Science Panel (ULSP) will make a recommendation to UDWQ and the Utah Lake Steering Committee (ULSC) regarding model suitability.

If the model is determined to be unsuitable as a decision support tool, the model development and calibration will be revisited to determine additional data collection, model modifications and model calibration required.

10 PROJECT REPORTS AND DOCUMENTATION

A project report will be prepared that will describe data collection, data analysis, model build including assumptions and limitations, model modifications, model calibration, model performance evaluation, and model sensitivity and uncertainty analysis. Model application will be documented is the report specific to the application, i.e. in the technical report for the numeric nutrient criteria development and/or the technical report for the load allocation determination.

The final model and documentation including pre- and post-processing files will be stored on the UDWQ computer network and will be made available to the public upon request.

10.1 Collaborative Modeling Approach

The EFDC and WASP models will be developed collaboratively by the University of Utah and UDWQ. Once calibration and the historical baseline model build are complete, the University of Utah will deliver the EFDC and WASP models to UDWQ for use. At that point, UDWQ may need to validate the models and make any necessary calibration refinements to meet the objectives of the ULWQS. The University of Utah will also apply the models to research questions posed in the EPA grant. Therefore, it is possible that two versions of the models may be utilized in the future to meet differing research and regulatory objectives.

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Note: The following references were consulted in developing the preceding QAPP template and companion checklist.

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