Quality Assurance Project Plan (v. 2.0)
Long Island Sound Hydrodynamic and Water Quality Modeling

August 22, 2022

Prepared for

New York City Department of Environmental Protection
Bureau of Environmental Planning and Analysis
59-17 Junction Blvd.
Flushing, NY 11373

Prepared by

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APPROVALS

David Lipsky — 9/30/2022

David Lipsky — Date
DEP Sr. Project Director

Abdulai Fofanah — 10/03/2022

Abdulai Fofanah — Date
DEP Project Director

Gregory Wilkerson — 9/30/2022

Gregory Wilkerson — Date
DEP Project Manager

Andrew J. Thuman
9/26/2022

Andrew Thuman
HDR Project Manager
Date

Thomas Dupuis
9/28/2022

Tom Dupuis
HDR Quality Manager
Date

It should be noted that the QAPP is considered preliminary until the QAPP is approved by EPA and concurred to by DEP.

In addition, the QAPP also covers the development of two embayment models, one along the LIS coast in Connecticut and one along the north shore of Long Island. Once the embayments and embayment models are chosen, the QAPP will be modified (if necessary) to include quality assurance procedures for these models and an updated QAPP version will be circulated.

The preliminary version of the QAPP was designated by a version number beginning with the number 0 (zero). Once approved by EPA and concurred to by DEP, the QAPP was assigned the version number 1.0. Revised preliminary versions of the QAPP will be prepared after significant updates to the project are made. Whenever a preliminary version of the QAPP is approved by EPA and concurred to by DEP, the QAPP version number will be incremented by one (e.g., 2.0, 3.0). Draft preliminary versions of the QAPP will be differentiated by incrementing the decimal in the version number.

U.S. EPA REGION 2 - QUALITY ASSURANCE PROJECT PLAN APPROVAL FORM

PROJECT INFORMATION

Quality Assurance Officer:	Omer Sohail
Project Officer:	Mark Tedesco
Title of Quality Assurance Project Plan:	Long Island Sound Modeling QAPP Revision
Assistance Agreement or Contract #:	LI96263917-3
QA File Number:	2022-67

REGIONAL QA MANAGER OR DELEGATED APPROVER

Approved ☑ Conditionally Approved* ☐

*** Conditional Approval may be provided when there are unresolved comments that do not impact the data collection or the quality of the data and where the project has a small window of opportunity to collect such data. Conditional Approval expires 30 days from the signature date. If updated quality documentation (QD) is not provided by the expiration date or another due date is not agreed upon by EPA, then the QD will be considered delinquent.**

Comments:

Signature EPA QA Officer OMER SOHAIL Digitally signed by OMER SOHAIL Date: 2022.08.19 11:03:05 -04'00'

Signature EPA PO or Project lead Tedesco, Mark Digitally signed by Tedesco, Mark Date: 2022.08.22 07:57:56 -04'00'

REVIEW SUMMARY:
A review was conducted on the above referenced Quality Assurance Project Plan. The subject QAPP was reviewed for conformance with the *EPA Requirements for Quality Assurance Project Plans* (EPA QA/R-5), EPA/240/B-01/003, March 2001; USEPA Region 2 Guidance for the Development of QAPPs for Environmental Monitoring Projects, April 2004 and other EPA QAPP guidance documents as appropriate.

This approval form documents EPA's decision of approval or conditional approval***** for the aforementioned QAPP. After the QAPP is approved by EPA via this approval form, obtain the required signatures from your organization on the QAPP Title/Signature page. Send the signed QAPP to the EPA Project Officer and others on the QAPP distribution list within the timeframe stipulated in the AA terms and conditions.

Document Revision History			
Date	**Section No.**	**Version No.**	**Comments about revision**
April 22, 2021	n.a.	1.0	Initial EPA and DEP approved version
July 21, 2022	1.1, 1.2	1.2	Hydrodynamic Modeling Lead Nicholas Kim (HDR) replaced with Dr. Damian Brady (University of Maine).
"	Throughout	1.2	The Consultant for this project prepared a memorandum in which several hydrodynamic and water quality models that could be used for this project were ranked. Subsequently, the memorandum was peer-reviewed by the MEG. Based on the memorandum, DEP chose the ROMS hydrodynamic model and RCA water quality model for this project. That these models were selected has been noted throughout the QAPP (v. 1.2).
"	1.5.2	1.2	After meeting with USGS staff, it was decided that depending on the amount of available data for a given river, either the LOADEST or WRTDS program will be used for river load estimation.
"	4.2	1.2	After receiving comments on QAPP (v. 1.0) from the MEG, the Consultant and DEP revised the project's model calibration and validation strategies. Under the revised calibration strategy, model calibration will be completed in two steps: preliminary calibration to data rich calendar years (CY) 2005-2006; and full calibration to CY2005-2014.
"	4.3	1.2	(See earlier comments about Sect. 4.2) Under the revised validation strategy, model validation will be completed with the split time period: CY2003-2004 and CY2015-2018.
"	1.4, 5.0	1.2	(See earlier comments about Sect. 4.2) In response to changes to the project's model calibration and validation strategies, the project schedule and list of key deliverables was modified.

Table of Contents

Attachments

Attachment 1 – Contact List

Attachment 2 – DHI Solutions Software Development Process

Attachment 3 – Water Quality Model Loading Memo (to be included at a later date)

Attachment 4 – Hydrodynamic Model Input Memo (to be included at a later date)

Tables

Figures

List of Acronyms and Abbreviations

AdH	Adaptive Hydraulics Model
A2EM	Advanced Aquatic Ecosystem Model
AESOP	Advanced Ecological Systems Modeling Program
BOD	Biochemical Oxygen Demand
BSi	Biogenic Silica
CE-QUAL-ICM	Corps of Engineers Integrated Compartment Water Quality Model
CH3D	Curvilinear Hydrodynamics in Three Dimensions
cm	Centimeters

List of Acronyms and Abbreviations

CSO	Combined Sewer Overflow
CT	Connecticut
CTDEEP	Connecticut Department of Energy and Environmental Protection
CTDEP	Connecticut Department of Environmental Protection
Delft3D	Delft Three-Dimensional Hydrodynamic Model
DELWAQ	Deltares Water Quality Model
DEP	New York City Department of Environmental Protection
DevOps	Development Operations
DHI	Danish Hydraulic Institute Water & Environment, Inc.
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
DQO	Data Quality Objective
DST	Decision Support Tool
ECOM	Estuarine, Coastal and Ocean Model
ECOMSED	Estuarine, Coastal and Ocean Model with Sediment Transport
EFDC	Environmental Fluid Dynamics Code
EHASP	Environmental Health and Safety Plan
EPA	United States Environmental Protection Agency
FVCOM	Finite Volume Community Ocean Model
GIS	Geographic Information System
GUI	Graphical User Interface
HDR	Henningson, Durham & Richardson Architecture & Engineering, PC
HSPF	Hydrological Simulation Program – Fortran
HWQM	Hydrodynamic and Water Quality Model
HWQMS	Hydrodynamic and Water Quality Model Support
IMF	Integrated Modeling framework
LI	Long Island
LINAP	Long Island Nitrogen Action Plan
LIS	Long Island Sound
LISS	Long Island Sound Study
LISICOS	Long Island Sound Integrated Coastal Observing System
LTCP	Long-Term Control Planning
MAG	Modeling Management Advisory Group
MEG	Model Evaluation Group

List of Acronyms and Abbreviations

MSSR	Model Selection and Setup Report
mg/L	Milligrams Per Liter
MS	Microsoft
NARR	North American Regional Reanalysis
NH4	Ammonium Nitrogen
NJ	New Jersey
NJHDG	New Jersey Harbor Dischargers Group
NLM	Nitrogen Load Models
NOAA	National Oceanic and Atmospheric Administration
NCDC	National Climatic Data Center
NO23	Nitrite Plus Nitrate Nitrogen
NY	New York
NYC	New York City
NYSDEC	New York State Department of Environmental Conservation
PAR	Photosynthetically Active Radiation
PCS-ICIS	Permit Compliance System-Integrated Compliance Information System
PDF	Portable Document Format
PMP	Project Management Plan
PO4	Orthophosphate
POC	Particulate Organic Carbon
PON	Particulate Organic Nitrogen
POP	Particulate Organic Phosphorus
psu	Practical Salinity Unit
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
QMP	Quality Management Plan
RCA	Row-Column AESOP
RMS	Root Mean Square
ROMS	Regional Ocean Modeling System
SaaS	Software as a Service
SAV	Submerged Aquatic Vegetation
SBU	Stony Brook University
SCDHS	Suffolk County Department of Health Services
SCHISM	Semi-implicit Cross-scale Hydroscience Integrated System Model
SFM	Sediment Nutrient Flux Model
SIA	Available Dissolved Silica

List of Acronyms and Abbreviations

SOD	Sediment Oxygen Demand
SPARROW	Spatially Referenced Regression on Watershed Attributes
SQL	Structured Query language
SWEM	System-Wide Eutrophication Model
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TON	Total Organic Nitrogen
TP	Total Phosphorus
ubRMSD	Unbiased Root-Mean-Squared Deviation
µg/L	Micrograms Per Liter
UConn	University of Connecticut
ugRCA	Unstructured Grid RCA
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WASP	Water Quality Analysis Simulation Program
WRRF	Wastewater Resource Recovery Facility

1 Project Management

1.1 Distribution List

The individuals who will receive a copy of the Quality Assurance Project Plan (QAPP) and any revisions are listed below.

Pinar Balci	DEP
David Lipsky	DEP
Abdulai Fofanah	DEP
Gregory Wilkerson	DEP
Mark Tedesco	EPA
Esther Nelson	EPA
Omer Sohail	EPA
Lampros Bourodimos	EPA
Jeff Barbaro	USGS
Andrew Thuman	HDR
Tom Dupuis	HDR
Robin Miller	HDR
Richard Isleib	HDR
Damian Brady	University of Maine
Cristhian Mancilla	HDR
Mary Anne Taylor	CDM Smith
Steve Blake	DHI Water & Environment, Inc.
Russ Dudley	Arcadis
Nicholas Canonico	Nova Consulting and Engineering, LLC

1.2 Project Organization

The Project Team will work together in a coordinated manner to assure the quality of the Long Island Sound Hydrodynamic and Water Quality Modeling Support (LIS HWQMS) project being completed for the New York City Department of Environmental Protection (DEP).

General Project Team responsibilities are summarized in Table 1 with more specific responsibilities identified in Section 1.4, "Project/Task Descriptions and Schedule." The organizational aspects of the program provide the framework for conducting the specified tasks. They can also facilitate project performance and adherence to quality control (QC) procedures and quality assurance (QA) requirements. Key project roles are filled by those persons responsible for ensuring the use of valid data and the person(s) responsible for approving and accepting final products and deliverables. The program organization includes relationships and lines of communication among all participants and data users, as shown in **Figure 1**. Attachment 1 contains a contact list for the LIS HWQMS project.

Table 1. Key Project Team Members and Responsibilities

Team Member	Organization	Role/Responsibilities
Pinar Balci	DEP	Asst. Commissioner in Charge.
David Lipsky	DEP	Sr. Project Director – Responsible for project oversight and EPA liaison.
Abdulai Fofanah	DEP	Project Director – Responsible for project oversight and DEP coordination.
Gregory Wilkerson	DEP	Project Manager – Responsible for DEP project coordination, implementation and main point of contact.
Mark Tedesco	EPA LIS Office Director	Stakeholder Coordinator – Responsible for coordinating EPA, DEP and stakeholder oversight and communication.
Omer Sohail	EPA Region 2	Quality Assurance Officer – Review and approve the QAPP
Robin Miller	HDR	Project Director – Responsible for project oversight and resource allocations.
Andrew Thuman	HDR	Project Manager – Responsible for project coordination, implementation, QAPP updates and distribution, and main point of contact.
Rich Isleib	HDR	Modeling Lead – Responsible for technical coordination between all Technical Leads.
Damian Brady	University of Maine	Hydrodynamic Modeling Technical Lead – Responsible for hydrodynamic model development.
Cristhian Mancilla	HDR	Water Quality Technical Lead – Responsible for water quality model development.
Tom Dupuis	HDR	Quality Manager – Responsible for QA/QC coordination and adherence to QA procedures. Oversees and coordinates modeling QA audits.
Thomas Gallagher	HDR	Technical Advisor – Providing internal Project Team technical reviews.
Mary Anne Taylor	CDM Smith	Watershed Load Development Technical Lead – Responsible for coastal watershed load development.
Steve Blake	DHI	GUI/DST Technical Lead – Responsible for GUI/DST development.
Russ Dudley	Arcadis	QAPP Development – Responsible for QAPP maintenance and support.
Chris Gobler	Stony Brook University	Technical Advisor – Providing internal Project Team technical reviews.
Andy Stoddard	Dynamic Solutions, LLC	MEG Lead – Providing independent technical reviews of project reports and coordinating MEG member reviews and presentations.
Carl Cerco	USACE ERDC (retired)	MEG Member – Providing independent technical reviews of project reports.
James O’Donnell	Coastal Ocean Analytics, LLC	MEG Member – Providing independent technical reviews of project reports.
John Warner	USGS	MEG Member – Providing independent technical reviews of project reports.

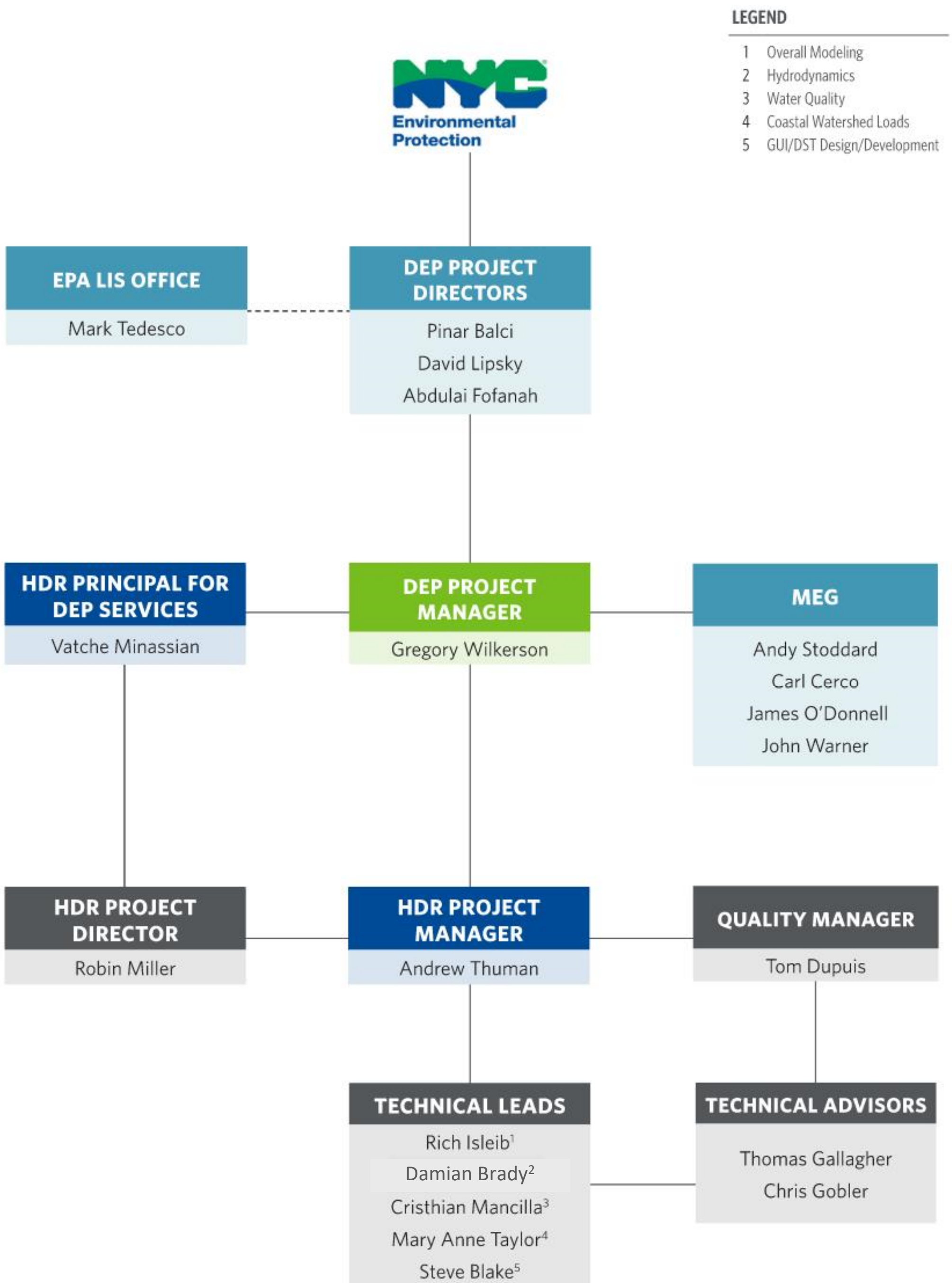


Figure 1. Project Organizational Chart

1.3 Project Definition/Background

Long Island Sound (LIS) is one of the largest estuaries in the US Environmental Protection Agency (EPA) National Estuary Program, with a watershed drainage area of about 16,000 square miles and includes: most of Connecticut; parts of Massachusetts, New Hampshire and Vermont; a small area of the Connecticut River in Canada; parts of New York City and Westchester County; and north shore areas of Long Island. LIS itself is longer (110 miles) than it is wide (21 miles), with an average depth of 65 feet and a surface area of 1,300 square miles. Unlike many other estuaries, LIS does not have a major tributary at its upstream end but is tidally connected on both ends by Block Island Sound on the east and by the East River on the west.

In addition, there are numerous embayments along the Connecticut shoreline (e.g., New Haven Harbor, Niantic Bay) and the north shore of Long Island (e.g., Huntington Bay, Port Jefferson Harbor). The major rivers entering LIS are primarily from Connecticut and include the: Norwalk River; Housatonic River and Naugatuck River; Quinnipiac River; Connecticut River; and Thames River. A unique aspect of LIS is the narrow (about 3.5 miles wide) and deep (depths greater than 300 feet) tidal entrance on the east end called "The Race" that exhibits very high tidal currents (upwards of 3-4 knots or 1.5-2.0 meters per second), which is an important feature of the circulation in eastern LIS. On the western end of LIS is the East River, which is another unique feature affecting circulation and nutrient loading due its proximity to NYC and major point sources. Of particular note is the direction of net water flux in the East River, which is comprised of completely mixed, unidirectional (western end) and vertically stratified, two-layered (eastern end) areas with an estimated net water flux direction from LIS to the NY/NJ Harbor (Blumberg & Pritchard, 1997).

1.3.1 LIS SWEM Review

The University of Connecticut performed a detailed independent evaluation of the prior System-Wide Eutrophication Model (SWEM) development (O'Donnell et al., 2010, 2014) that identified a number of modeling issues. During the application and calibration of SWEM, the vertical eddy coefficients calculated by the hydrodynamic model (ECOM) were reduced in the water quality model (RCA) to improve model-data comparisons of near-bottom DO levels in western LIS during the summer. It should be noted that this vertical mixing adjustment in the water quality model was presented to and approved by the SWEM Model Evaluation Group (MEG) at the time.

It was noted that recent work on mixing in the coastal ocean and comparison of ECOM results to these recent observations in LIS suggested that the original ECOM vertical mixing values were actually realistic and that the values imposed by the RCA vertical eddy coefficient reduction were much too small. In addition, recent observations in LIS indicated that both algal respiration and production were significantly underestimated in SWEM.

Recommendations from these evaluations included: eliminating vertical mixing adjustment in RCA; use of recent estimates of algal respiration and production; refinement of the model grid to provide finer spatial resolution; and use of open-source models and data sharing standards.

1.3.2 Overview of LIS HWQMS Project

The LIS HWQMS project includes the development of updated and refined hydrodynamic and water quality models (HWQMs) of LIS. The Regional Ocean Modeling System (ROMS) has been chosen for the hydrodynamic model and Row Column AESOP (RCA) has been chosen for the water quality model. The updated HWQMs will provide a framework to integrate water management planning and assessments in the future to support Clean Water Act compliance required under the 2000 Dissolved Oxygen (DO) Total Maximum Daily Load (TMDL) (NYSDEC & CTDEP 2000) as well as future nutrient management activities and related evaluations. The models will need to accurately represent tidal transport/circulation and water quality, related to nitrogen and DO, over the entire inter-connected system (i.e., New York Bight, New York Harbor, offshore coastal waters) and other areas of the region (e.g., New Jersey tributaries, Newark Bay, Sandy Hook Bay) of the LIS study area.

Water quality in LIS and in NY/CT coastal embayments is a function of two main processes: physical controls due to tidal circulation, meteorology (wind mixing), and vertical density stratification (hydrodynamics); and biogeochemical controls driven by nutrient loading, algal nutrient cycling, sediment interactions and ecological processes (e.g., submerged aquatic vegetation (SAV) and shellfish). In LIS, the physical/hydrodynamic tidal processes that drive circulation in three dimensions are critical to reproducing water quality dynamics that affect nutrients, phytoplankton and DO levels in open waters, coastal embayments and the larger regional and coastal areas of NY, CT, and NJ. The important biogeochemical processes controlling DO levels in LIS include: oxygen production processes (phytoplankton growth and atmospheric reaeration); and oxygen consumption processes (phytoplankton respiration/death, biochemical oxygen demand (BOD) or carbon oxidation, sediment oxygen demand and ammonium nitrification). In addition, other coupled and important eutrophication processes include: algal nutrient uptake and recycling; particulate organic matter settling and subsequent decay (diagenesis) in the sediment; light attenuation in the water column due to suspended solids and potentially colored dissolved organic matter and its effect on algal growth; organic to inorganic mineralization and hydrolysis processes; zooplankton grazing; and potential ecological interactions with SAV and filtering shellfish. Ecological modeling is not included as part of this project, but the model and model inputs developed under this project can be used to support future ecological assessments and models.

ROMS will include the following features: time-variable and three-dimensional calculations; a curvilinear model grid with sufficient spatial resolution to represent shoreline features; vertical model grid segmentation to represent stratification processes; river, runoff, point source, and other relevant freshwater inflows; tidal and wind forcing; turbulent closure routines; density driven circulation; atmospheric coupling for surface mixing and heat exchange; and bottom roughness for bed induced mixing. ROMS must provide accurate tidal circulation information to RCA to appropriately reflect the transport of salt, heat, suspended solids, nutrients, and phytoplankton so ROMS-RCA can reproduce observed salinity, temperature, suspended solids, and water quality constituents, including dissolved oxygen concentrations, which are a key concern in LIS. Figure 2 presents the hydrodynamic model processes included in the LIS version of ROMS.

RCA will include the following features: time-variable and three-dimensional calculations using the same model grid as the ROMS hydrodynamic model; particulate and dissolved organic nitrogen, phosphorus and carbon including at a minimum labile and refractory fractions; inorganic nitrogen (ammonium and nitrite plus nitrate); dissolved inorganic phosphorus (orthophosphate); biogenic and available silica; multiple algal groups; dissolved oxygen; inorganic suspended solids; light attenuation; particulate organic matter settling; and a coupled sediment flux model (SFM). Figure 3 presents the eutrophication model kinetics to be included the LIS eutrophication model.

Brief descriptions of the SFM framework and processes that affect sediment nutrient fluxes and sediment oxygen demand (SOD) are presented below. A more detailed discussion of the SFM development is found in Sediment Flux Modeling (DiToro 2001). The general interactions occurring in the sediment are shown in the sediment model schematic presented in Figure 4. SFM is formulated with two compartments, an aerobic and anaerobic sediment layer, and uses the settling fluxes from the eutrophication model as inputs.

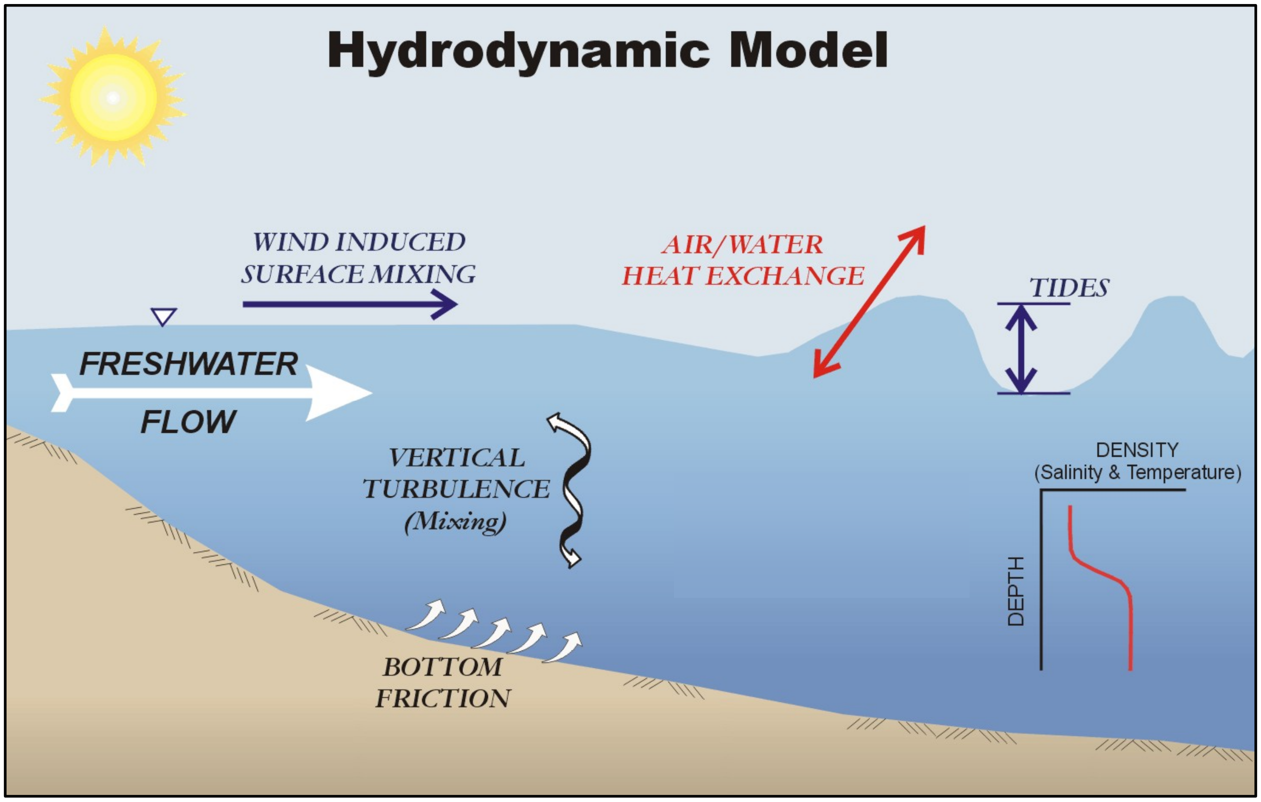


Figure 2. Hydrodynamic Model Key Processes

Particulate organic matter (POM), detrital or algal nitrogen, phosphorus, silica and carbon, settles through the water column and is deposited to the sediment. This settling of POM is the driving force behind the various decay mechanisms occurring in the sediment. The POM that settles into the sediment is classified into three reactivity classes referenced as G1, G2 and G3. The G1 component is the most reactive with a half-life of about 20 days. The G2 component has a half-life of about one year, and the G3 component is basically non-reactive.

Once POM settles to the sediment, it can either decompose through diagenesis to the various inorganic end products of nitrogen, phosphorus, carbon and silica or become buried in the sediments. The particulate organic nitrogen, phosphorus and silica that settle to the sediment eventually decompose following various temperature-dependent kinetic pathways into their associated inorganic forms: ammonium, nitrate, orthophosphate, and available silica. Depending upon overlying water DO concentrations and the water column/sediment dissolved concentration gradients, ammonium, nitrate, orthophosphate and available silica can either flux out of or into the sediments.

The temperature-dependent decomposition of particulate organic carbon in the sediment results in the formation of sulfide in marine systems and methane in freshwater systems or if the supply of sulfate from the overlying water is depleted. Depending upon the overlying water column DO concentration, the sulfide is either oxidized in the sediment (SOD) or fluxed into the water column at low dissolved oxygen levels as oxygen-demanding equivalents or aqueous SOD (O2EQ). In addition to the carbon component of the SOD, the nitrification of ammonium to nitrate consumes oxygen and, therefore, is also included in the calculation of the total SOD.

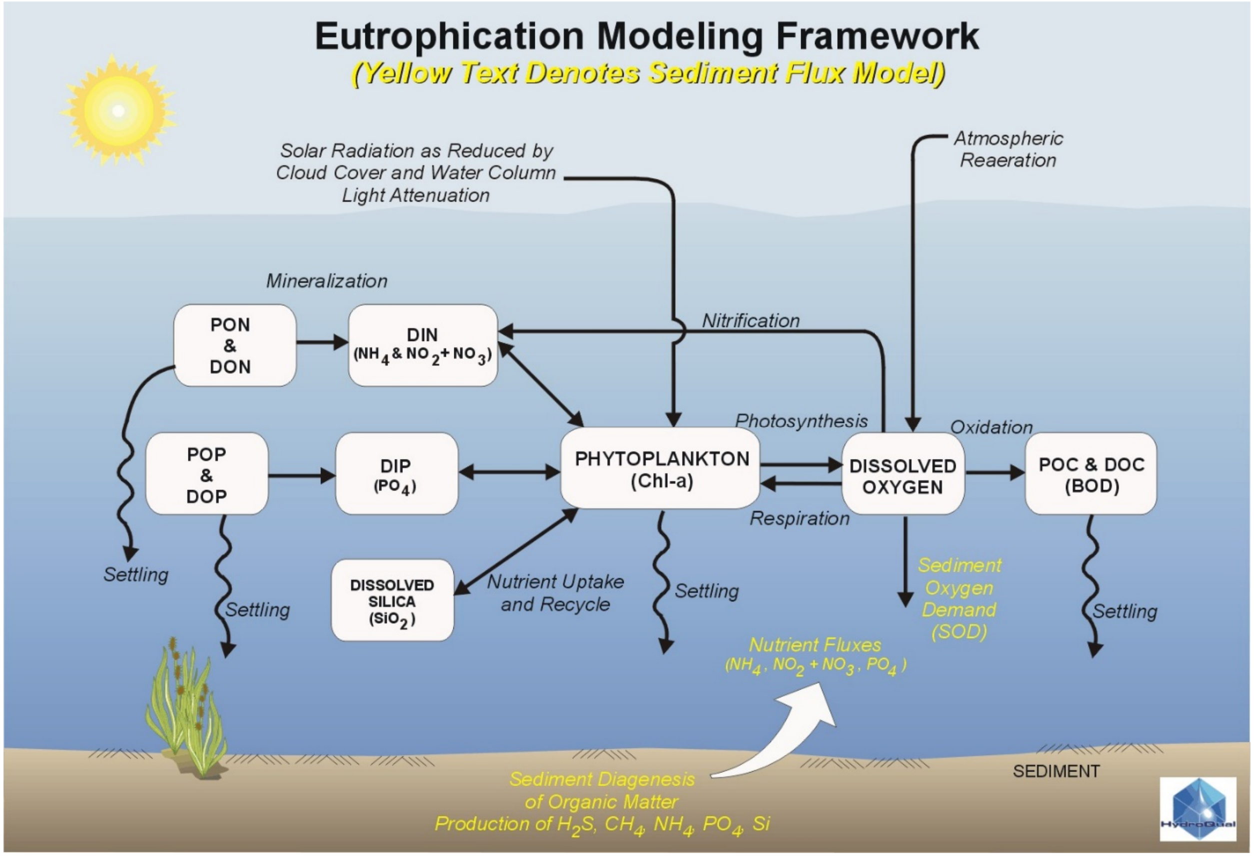


Figure 3. Eutrophication Model Kinetics

This simplified description of the sediment flux model should not detract from the importance of biogeochemical processes in the sediment bed in the context of an estuarine system like LIS. The nutrient fluxes into the water column can be a significant source of nutrients needed for algal growth and a significant source of deoxygenation potential via SOD. Also, the delivery and storage capacity of POM in the sediments during higher flow and cooler seasons (fall, winter, spring) plays a vital role in the cycling of nutrients back into the water column and exertion of SOD during the warmer spring and summer months. The use of the sediment flux model completes the mass balance between the sediment and the water column mechanistically, rather than having to estimate and assign nutrient fluxes as model inputs. In general, the inclusion of the sediment flux model in the modeling framework greatly improves the scientific credibility and the ability to predict water quality dynamics over long time periods on the order of a decade or more.

The project will refine the System-Wide Eutrophication Model (SWEM) model grid in LIS and coastal embayments to improve lateral mixing and vertical stratification in both the hydrodynamic and water quality models. Model grid refinements will include an increased number of lateral model segments in LIS (SWEM employed 3-9 lateral model segments) and model segmentation into LIS coastal embayments. The models will initially be tested using water year 1995 (WY95) conditions and then calibrated and validated with data from the 2003-2018 time period; and include post-audit testing of the models with data from 2019-2022. The WY95 time period was the original SWEM calibration period for LIS. In addition to the model updates, a Graphical User Interface/Decision Support Tool (GUI/DST) will be developed to allow DEP and stakeholders to view data, setup and run the models (pre-processing) and view model output (post-processing). The GUI/DST will also allow DEP and stakeholders the ability to evaluate nutrient management scenarios and view their effects on LIS water quality. Near the end of the project, technology transfer and

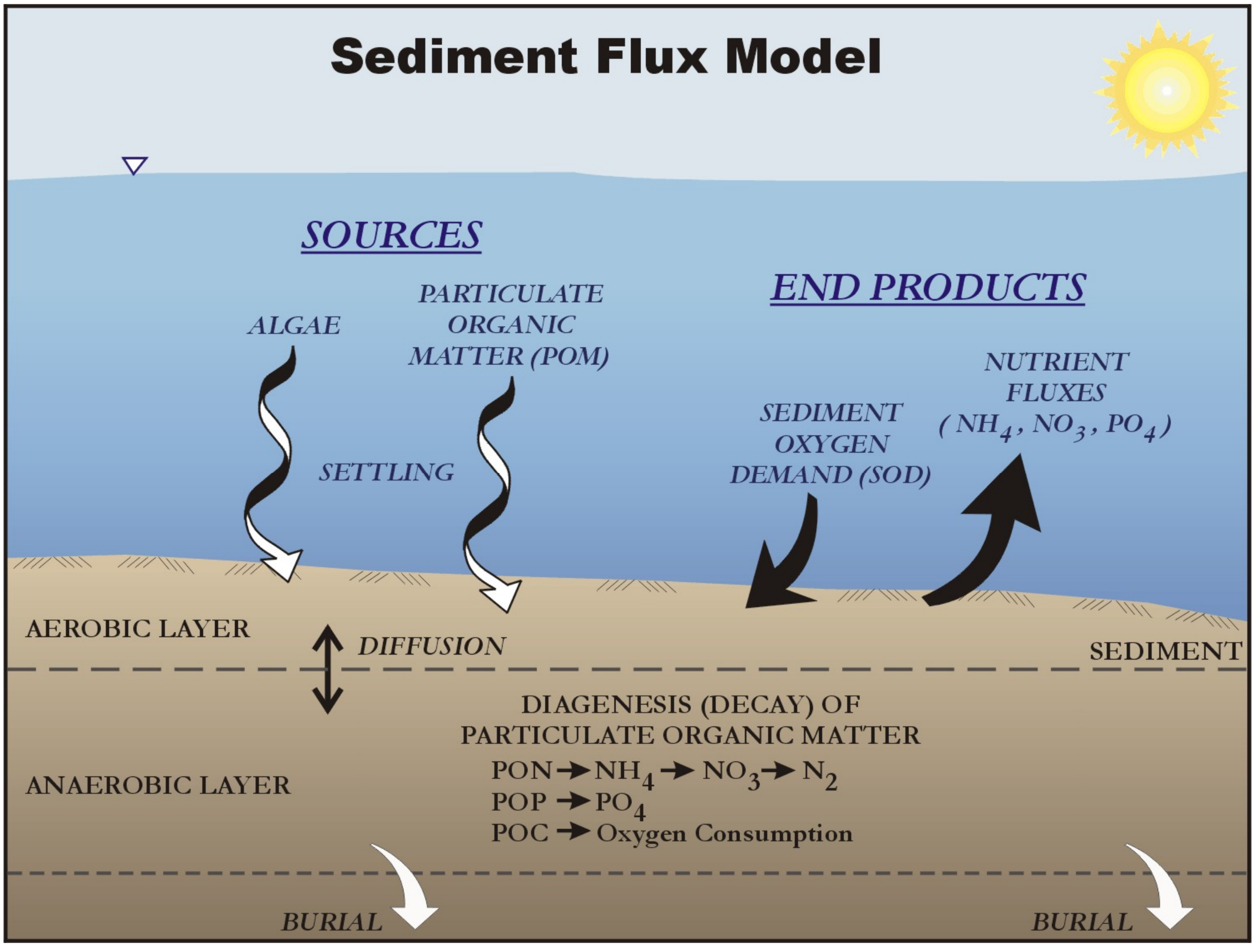


Figure 4. Sediment Flux Model Key Processes

training sessions will be conducted to transfer the models and GUI/DST to DEP. The six project objectives are presented below that outline both DEP and EPA goals of developing updated LIS HWQMs that are well documented and provide transparency for the LIS stakeholder community.

1. Objective #1 – Create and/or expand upon a three-dimensional hydrodynamic model with sufficient spatial resolution, including coastal embayments and tidal rivers, to represent complex bathymetry accurately and is capable of simulating significant physical characteristics and processes, including open water seasonal stratification, in LIS waters.
2. Objective #2 – Model eutrophication processes to accurately capture dissolved oxygen, phytoplankton, organic carbon, and nutrient distributions in the LIS and to provide accurate parameters to support future ecological assessments and models.
3. Objective #3 – Develop a robust model framework that is capable of linking multiple scale HWQMs, is updatable to use with new data, and can simulate future environmental conditions, such as climate change and sea level rise scenarios.
4. Objective #4 – Establish a model framework that facilitates evaluation of multiple planning and management scenarios on water quality (e.g., the impact of seal level rise, increased water temperatures due to climate change, or to estimate the benefits of reduced point or nonpoint source nitrogen loads).

5. Objective #5 – Incorporate open-source coding standards and interoperable data exchange standards to ensure broader access and ability to contribute to HWQMs testing and development.
6. Objective #6 – Create a GUI/DST to support centralized data management, provide tools for pre-processing and post-processing data to assist in data analysis, visualization, and assessment and management scenario evaluations, and to increase usability and transparency of modeling framework for the research community.

The project also includes the development of two embayment models (one in NY and one in CT), for yet to be chosen embayments, for roughly a one-year time period based on the availability of data needed to setup model inputs and complete model-data comparisons for model calibration.

The overall LIS project includes the following major tasks: mobilization; QC and QA; selection, calibration and validation of the HWQMs; set up and execution of a continuous long-term simulation of the HWQMs; build out and design of a GUI/DST; technology transfer and training; and involvement of a Model Evaluation Group (MEG). Further description of these tasks is presented in Section 1.4.

Figure 5 presents the LIS watershed and Figure 6 presents the LIS study area along with an example refined model grid.

A skilled modeling team has been assembled for this project, as outlined in Section 1.4, to develop LIS models that will fit the requirements and meet the objectives of this project. The technical/computer resources required for this project are available or can be acquired to meet increasing needs of the project. LIS has been well studied and significant data sources are available to create model inputs and conduct model calibration and validation as outlined in Section 2.1. The LIS HWQMs calibration and validation results will meet the model output quality criteria as presented in Section 1.7.2 in order to provide confidence that the modeling tool can be used to assess management alternatives.

This QAPP provides a general description of the modeling and associated analytical work that will be performed for the project, including following data quality objectives (DQOs) and quality control (QC) procedures to ensure that the final product satisfies DEP and EPA requirements. This QAPP also addresses the use of secondary data (data collected for another purpose or collected by an organization or organizations not under the scope of this QAPP) to support model development.

1.4 Project/Task Description and Schedule

In addition to project management services provided in each project task, additional descriptions of the Project Tasks are presented below. An overview of the project tasks is presented in a general workflow diagram in Figure 7 for the open waters LIS modeling. The embayment modeling (1 in CT and 1 in NY) will be calibrated with one year of data extracted from the 2003-2018 time period with finer model segmentation used than that used in the open waters LIS model. The embayment models will use offshore open boundary conditions information derived from data or extracted from the LIS open waters model. The detailed project schedule is presented in Figure 8.

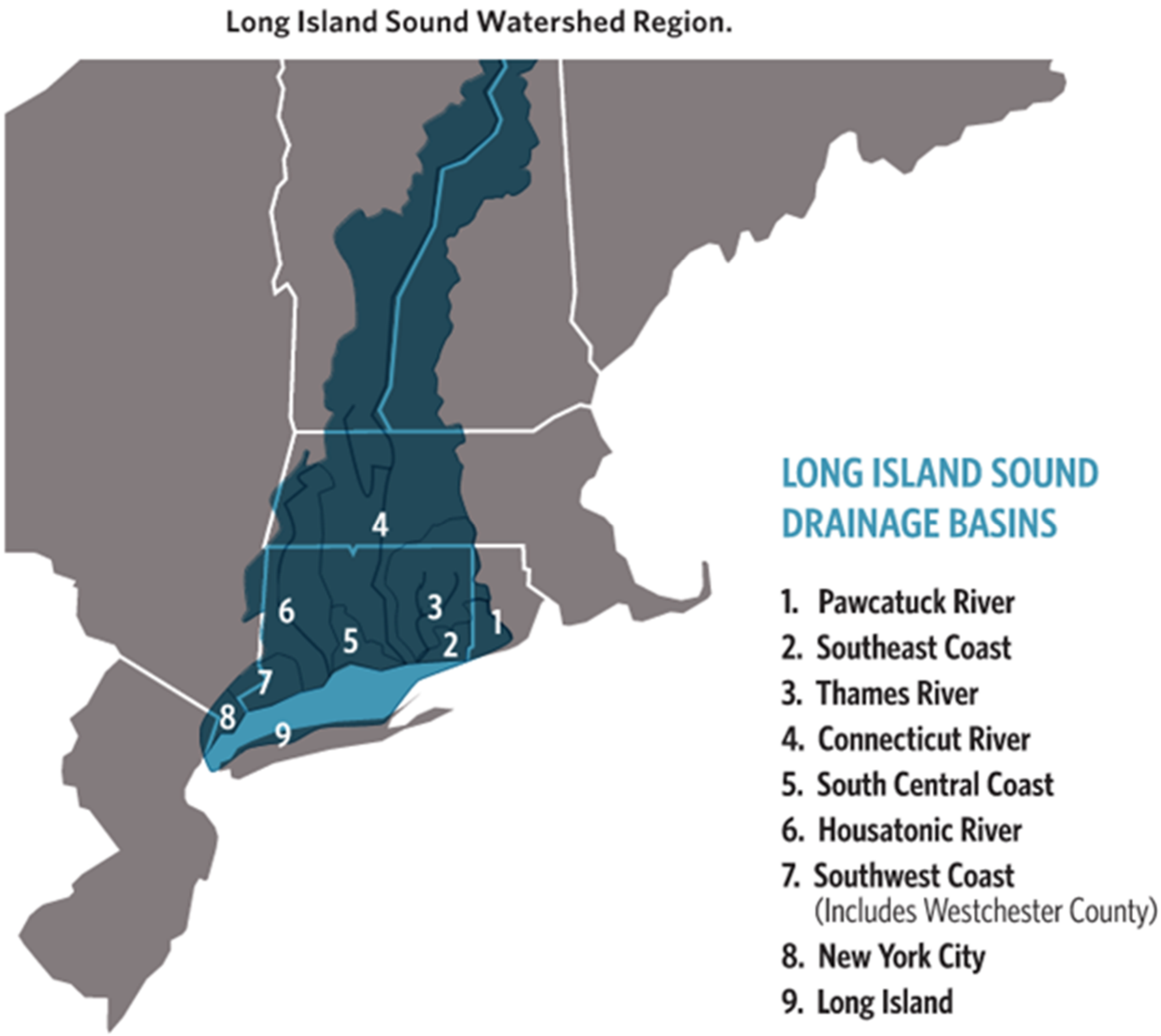


Figure 5. LIS Watershed

Figure 6. LIS Study Area and Example Refined Model Grid

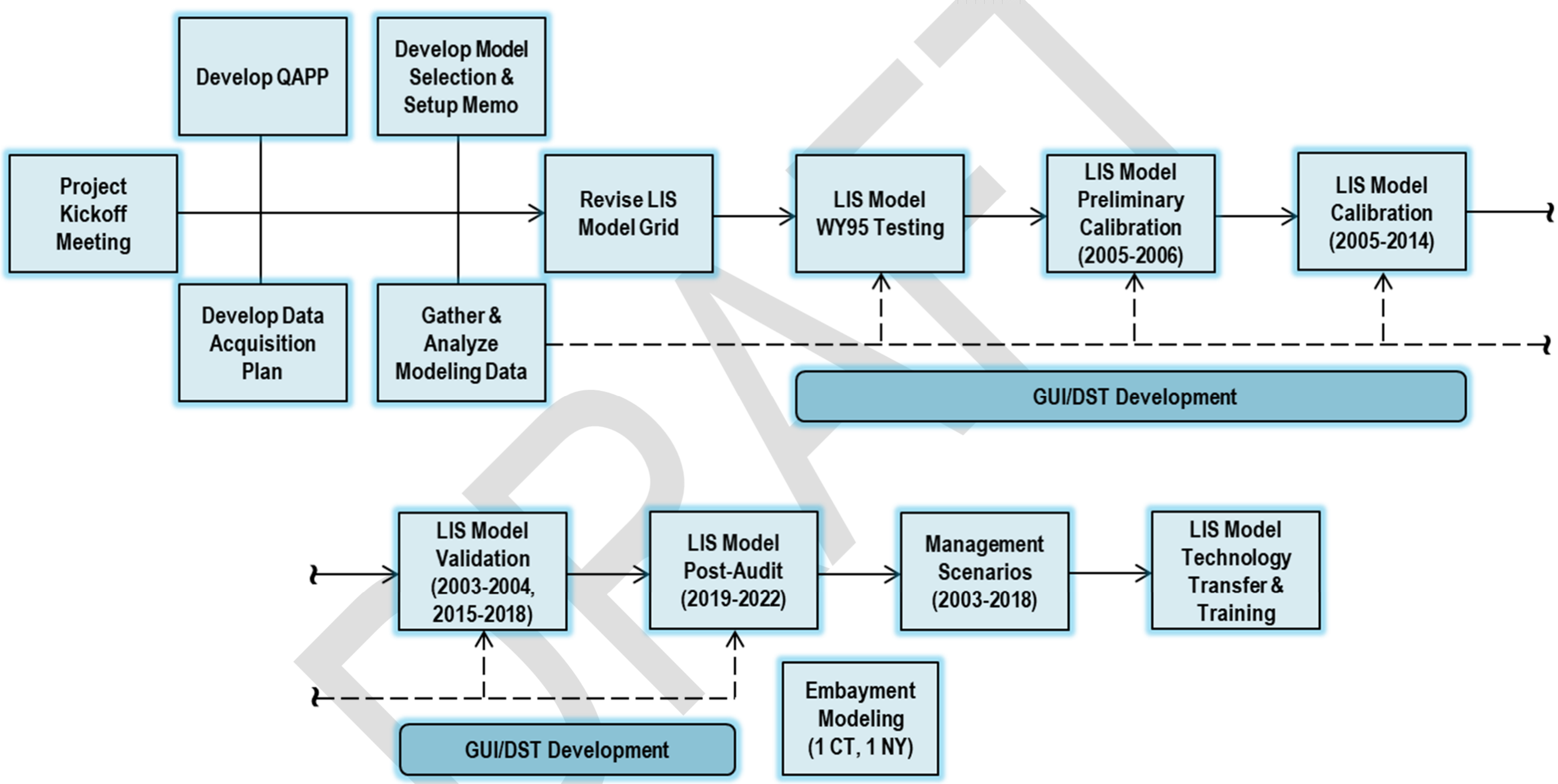
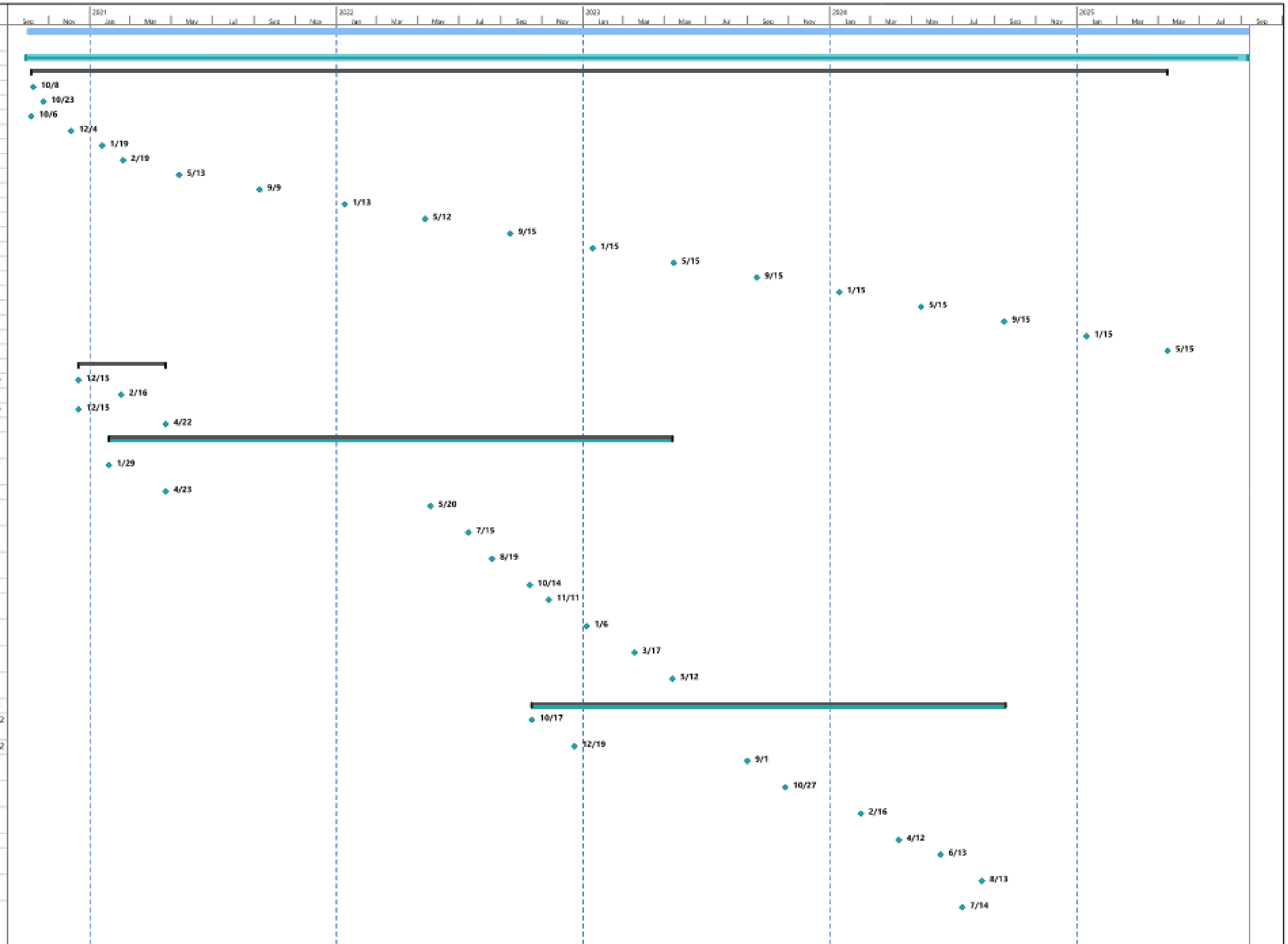


Figure 7. Project Tasks Workflow Diagram

Task Name	Start	Finish
Monthly Progress Reports & Progress Meetings (Tasks 1-7)	Wed 9/30/20	Fri 9/12/25
Project Management Services (Tasks 1-7)	Mon 9/28/20	Wed 9/10/25
TASK 1: Mobilization	**Tue 10/6/20**	**Thu 5/15/25**
1.2 Pre-Kickoff Meeting	Thu 10/8/20	Thu 10/8/20
1.2 Kickoff Meeting/Stakeholder Meeting	Fri 10/23/20	Fri 10/23/20
1.4 Submit Preliminary Draft PMP	Tue 10/6/20	Tue 10/6/20
1.4 Submit Draft PMP	Fri 12/4/20	Fri 12/4/20
1.4 Submit Final PMP	Tue 1/19/21	Tue 1/19/21
1.3 STAC Meeting	Fri 2/19/21	Fri 2/19/21
1.3 MAG Meeting	Thu 5/13/21	Thu 5/13/21
1.3 MAG Meeting	Thu 9/9/21	Thu 9/9/21
1.3 Stakeholder Meeting	Thu 1/13/22	Thu 1/13/22
1.3 Stakeholder Meeting	Thu 5/12/22	Thu 5/12/22
1.3 Stakeholder Meeting	Thu 9/15/22	Thu 9/15/22
1.3 Stakeholder Meeting	Sun 1/15/23	Sun 1/15/23
1.3 Stakeholder Meeting	Mon 5/15/23	Mon 5/15/23
1.3 Stakeholder Meeting	Fri 9/15/23	Fri 9/15/23
1.3 Stakeholder Meeting	Mon 1/15/24	Mon 1/15/24
1.3 Stakeholder Meeting	Wed 5/15/24	Wed 5/15/24
1.3 Stakeholder Meeting	Sun 9/15/24	Sun 9/15/24
1.3 Stakeholder Meeting	Wed 1/15/25	Wed 1/15/25
1.3 Stakeholder Meeting	Thu 5/15/25	Thu 5/15/25
TASK 2: Quality Control and Quality Assurance	**Tue 12/15/20**	**Thu 4/22/21**
2.2 Submit Draft Data Acquisition Plan	Tue 12/15/20	Tue 12/15/20
2.2 Submit Final Data Acquisition Plan	Tue 2/16/21	Tue 2/16/21
2.3 Submit Draft QAPP - MEG review	Tue 12/15/20	Tue 12/15/20
2.3 Submit Final QAPP	Thu 4/22/21	Thu 4/22/21
TASK 3: Selection Calibration and Validation of HWQMs	**Fri 1/29/21**	**Fri 5/12/23**
3.2 Submit Draft Model Selection & Setup Report - MEG review	Fri 1/29/21	Fri 1/29/21
3.2 Submit Final Model Selection & Setup Report	Fri 4/23/21	Fri 4/23/21
3.2 Submit Draft Hydrodynamic Model Testing Memo	Fri 5/20/22	Fri 5/20/22
3.2 Submit Final Hydrodynamic Model Testing Memo	Fri 7/15/22	Fri 7/15/22
3.2 Submit Draft Water Quality Model Testing Memo	Fri 8/19/22	Fri 8/19/22
3.2 Submit Final Water Quality Testing Memo	Fri 10/14/22	Fri 10/14/22
3.2 Submit Draft Hydrodynamic Model Preliminary Calibration Memo - MEG review	Fri 11/11/22	Fri 11/11/22
3.2 Submit Final Hydrodynamic Model Preliminary Calibration Memo	Fri 1/6/23	Fri 1/6/23
3.2 Submit Draft Water Quality Model Preliminary Calibration Memo - MEG Review	Fri 3/17/23	Fri 3/17/23
3.2 Submit Final Water Quality Model Preliminary Calibration Memo	Fri 5/12/23	Fri 5/12/23
TASK 4: Continuous Long-Term Model Simulations	Mon 10/17/22	**Mon 9/16/24**
4.2 Submit Draft Data Gaps Report - MEG review	Mon 10/17/22	Mon 10/17/22
4.2 Submit Final Data Gaps Report	Mon 12/19/22	Mon 12/19/22
4.2 Submit Draft Hydrodynamic/Water Quality Calibration Memo - MEG review	Fri 9/1/23	Fri 9/1/23
4.2 Submit Final Hydrodynamic/Water Quality Calibration Memo	Fri 10/27/23	Fri 10/27/23
4.2 Submit Draft Embayment Modeling Report - MEG review	Fri 2/16/24	Fri 2/16/24
4.2 Submit Final Embayment Modeling Report	Fri 4/12/24	Fri 4/12/24
4.2 Submit Draft Calibration, Validation & Assessment Modeling Report - MEG review	Thu 6/13/24	Thu 6/13/24
4.2 Submit Final Calibration, Validation & Assessment Modeling Report	Tue 8/13/24	Tue 8/13/24
4.2 Submit Draft Summary Response to Peer Review Comments on Summary Technical Report & Presentation (2003-2018) for Stakeholders	Sun 7/14/24	Sun 7/14/24



Project: BEPA-LIS_HWQMS_Sch
Date: Fri 3/25/22

Figure 8. Detailed Project Task Breakdown and Schedule

Task Name	Start	Finish
4.2 Submit Final Summary Response to Peer Review Comments on Summary Technical Report & Presentation (2003-2018) for Stakeholders	Mon 9/16/24	Mon 9/16/24
TASK 5: Build Out & Design of GUI/DST	Fri 6/18/21	**Fri 5/30/25**
Workshop 1a	Fri 9/24/21	Fri 9/24/21
Workshop 1b	Mon 2/7/22	Thu 2/24/22
Workshop 2 (Presentation/Feedback Session)	Mon 3/21/22	Fri 4/22/22
5.2.1 Submit Draft UI/UX Design Report	Mon 2/28/22	Fri 5/27/22
Interview/Feedback Sessions 1 & 2	Mon 4/11/22	Fri 4/29/22
5.2.2 Build Out & Testing of GUI/DST	Mon 5/30/22	Tue 12/31/24
5.2.1 Submit Draft GUI/DST System Design Manual	Fri 7/22/22	Fri 7/22/22
Design Sprints	Mon 8/1/22	Fri 6/28/24
GUI/DST System Design Manual Update #1	Fri 11/18/22	Fri 11/18/22
GUI/DST System Design Manual Update #2	Fri 4/28/23	Fri 4/28/23
GUI/DST System Design Manual Update #3	Fri 8/25/23	Fri 8/25/23
GUI/DST System Design Manual Update #4	Fri 1/26/24	Fri 1/26/24
5.2.1 Submit Draft User's Manual for GUI/DST	Mon 7/15/24	Mon 7/15/24
5.2.1 Submit Final User's Manual for GUI/DST	Mon 9/16/24	Mon 9/16/24
5.3 Submit Draft Recommendation Memo for a Central Data Repository for Water Quality & Model Input Data	Wed 2/28/24	Wed 2/28/24
5.4 Submit Draft Recommendation Memo for In-house Hardware or Cloud Computing & Software Services	Wed 2/28/24	Wed 2/28/24
5.4 Submit Final Recommendation Memo for In-house Hardware or Cloud Computing & Software Services	Mon 4/29/24	Mon 4/29/24
5.3 Submit Final Recommendation Memo for a Central Data Repository for Water Quality & Model Input Data	Mon 4/29/24	Mon 4/29/24
5.5 Submit Draft Sharepoint Site	Fri 6/18/21	Fri 6/18/21
5.5 Submit Final Sharepoint Site	Fri 5/30/25	Fri 5/30/25
TASK 6: Technology Transfer & Training	**Mon 12/30/24**	**Fri 5/30/25**
6.2 Submit Draft Recommendation Memo - Licensing & Maintenance Costs & Additional Data Needs	Wed 1/29/25	Wed 1/29/25
6.2 Submit Final Recommendation Memo - Licensing & Maintenance Costs & Additional Data Needs	Mon 3/31/25	Mon 3/31/25
6.3 Training	Mon 12/30/24	Wed 2/26/25
6.4 Final Demonstration of Model/GUI/DST & Delivery of Project Documentation to DEP	Fri 5/2/25	Fri 5/30/25
TASK 7: Model Evaluation Group (MEG)	**Fri 11/13/20**	**Thu 8/14/25**
7.2 MEG Peer Reviews & Annual Modeling Workshops	Fri 11/13/20	Thu 8/14/25
Review Draft QAPP	Mon 8/2/21	Fri 9/24/21
Review Draft Model Selection & Setup Report	Tue 2/1/22	Sat 6/18/22
Review Draft Data Gaps Report	Mon 10/24/22	Mon 11/21/22
Review Draft Hydrodynamic Model Preliminary Calibration Memo	Mon 11/14/22	Mon 12/12/22
Hydrodynamic Model Preliminary Calibration MAG Workshop	Sun 1/15/23	Sun 1/15/23
Review Draft Water Quality Model Preliminary Calibration Memo	Mon 3/20/23	Mon 4/17/23
Water Quality Model Preliminary Calibration MAG Workshop	Fri 9/15/23	Fri 9/15/23
Review Draft Hydrodynamic/Water Quality Calibration Memo	Mon 9/4/23	Mon 10/2/23
Review Draft Embayment Modeling Report	Mon 2/19/24	Mon 3/18/24
Review Draft Calibration, Validation & Assessment Modeling Report	Mon 6/17/24	Mon 7/15/24
Hydrodynamic/Water Quality Calibration MAG Workshop	Sun 9/15/24	Sun 9/15/24

Project: BEPA-LIS_HWQMS_Sch
Date: Fri 3/25/22

Figure 8. (cont.)

Task 1 – Mobilization

HDR will provide coordination support between the LIS Program teams, multiple DEP bureaus, and the LIS HWQMS team. The Pre-Project Kickoff Meeting and Project Kickoff Meeting are both upfront opportunities to discuss communication protocols, roles and responsibilities, as well as key stakeholder contacts and expectations. The Pre-Project Kickoff Meeting was held on 10/8/2020 and discussed project management activities; deliverables; draft Project Management Plan (PMP), Quality Management Plan (QMP) and Environment Health and Safety Plan (EHASP); and draft Project Kickoff Meeting agenda and handouts. The Project Kickoff Meeting was held on 10/23/2020 at one of the LIS Modeling Management Advisory Group (MAG) meetings and included discussions on the following topics: project goals and expectations; Project Team roles and responsibilities; Project scope of work; major project task deliverables and schedule; formulation of the MEG; and an open discussion. The MAG consists primarily of State and Federal regulatory agency members (e.g., CTDEEP, NYSDEC, NJDEP, EPA, USACE) that will ultimately use results from the LIS HWQM management scenarios or use the LIS HWQM for further regulatory purposes.

This task also includes technical and administrative support for three MAG stakeholder meetings per year and one annual modeling workshop. HDR will not attend the three stakeholder meetings per year and will participate (as requested) in one annual model workshop. The MEG will participate in up to the three MAG stakeholder meetings per year and present at the annual model workshop.

Task 2 – Quality Control & Quality Assurance

HDR will create a Data Acquisition Plan and a QAPP following EPA QAPP guidance (EPA, 1999; EPA, 2002a; EPA, 2002b). Periodic updates will be made to these documents over the duration of the project.

The Data Acquisition Plan will outline what datasets are needed to develop model inputs (e.g., point and nonpoint source loads, offshore boundary conditions, atmospheric conditions) and those datasets to be used for model-data comparisons (model calibration and validation). In addition, the document will provide guidance for the QC checks to be completed on the secondary data (i.e., existing) obtained, metadata acquisition, a preliminary data gaps assessment and a schedule for the data acquisition and database storage.

The QAPP (this document) will identify the modeling and data quality objectives for the ROMS hydrodynamic and RCA water quality modeling, following EPA QAPP guidance documents. This document will identify the secondary data to be used and methods for data QC, the method for developing model loads and model inputs, and proposed model sensitivity analyses. The QAPP will also include a description of the GUI/DST to be developed for the models, the management scenario evaluation approach, and model and GUI/DST version control and archiving procedures. An important component of the QAPP will be the model calibration and validation statistical metrics (model skill) to determine how well the model performs and for determining the acceptability of the model calibration and validation.

Task 3 – Selection, Calibration & Validation of Hydrodynamic and Water Quality Models

Task 3 involves reviewing and ranking applicable HWQMs for application to LIS. A short list of candidate models was identified that are suitable for use in LIS and meet the project requirements. These models include the ECOMSED, FVCOM, EFDC (three versions), Regional Ocean Modeling System (ROMS), CH3D, Delft3D, AdH and SCHISM hydrodynamic models. Candidate water quality models include RCA, ugRCA, AQUATOX, A2EM, EFDC (three versions), WASP8, CE-QUAL-ICM and DELWAQ, all of which include full eutrophication kinetics and a sediment nutrient flux model (SFM). All of these models provide the necessary level of detail to accurately model tidal transport, vertical mixing/stratification processes, and water quality processes affecting DO.

HDR prepared a Model Selection and Setup Report (MSSR) that reviewed and ranked the hydrodynamic and water quality models noted above (HDR, 2021). The MSSR also included model Fact Sheets for the ten hydrodynamic models and ten water quality models reviewed. After the MSSR was reviewed and approved by the MEG, DEP selected the hydrodynamic model, ROMS, and water quality model, RCA, for application in LIS (DEP, 2021). The ROMS and RCA models were both ranked among the highest models reviewed in the MSSR.

After the QAPP is approved by EPA, HDR will begin development of the models (ROMS-RCA) using the historical October 1994 through September 1995 (WY95) dataset used for calibration of SWEM for model testing; and preliminary model calibration to data from 2005 through 2006. HDR has the WY95 dataset archived and available for use on this project. The following modeling steps will be completed:

- Refinement of the SWEM model grid to provide increased spatial resolution (e.g., increased lateral segmentation in western LIS) in the open water areas of LIS. In addition, the refined model grid will include model segmentation into embayments along the LIS coasts of NY and CT. The embayments included in the refined LIS model grid will be at a finer resolution than the open water areas of the refined LIS model grid but at a coarser resolution than the stand-alone embayment models to be developed. The embayment resolution in the open waters LIS model grid will be of sufficient spatial scale to represent the tidal mixing between the embayments and LIS open water areas. These grid refinements are meant to improve the model's ability to reproduce circulation and the variable vertical mixing in the open waters of LIS, particularly in western LIS.

- Development of model inputs (e.g., loads, boundary conditions, atmospheric inputs) for the LIS open waters model. Table 2 below presents the major model inputs to be developed for both the HWQMs.

- The LIS hydrodynamic and water quality models (ROMS-RCA) using the refined model grid will be tested against the WY95 data to evaluate the effect that the new finer model grid has on model-data comparisons. A limited number of hydrodynamic and water quality model sensitivities will be completed to test how certain input changes affect WY95 model-data comparisons and, thereby, help guide model calibration efforts. These input changes may include adjustments to ROMS mixing coefficients, bottom friction or atmospheric heat balance coefficients; and RCA algal productivity/respiration rates or other oxygen consumption processes. No model calibration efforts will be completed using the WY95 data.

- A preliminary LIS model calibration will be performed using data from the data rich time period of calendar year (CY) 2005-2006. The preliminary calibration will provide results for review and discussion with the MEG prior to the completion of the calibration effort under Task 4 below.

- During the preliminary model calibration process, the choice of model coefficients will be guided by site-specific field data, such as measurements of primary productivity and respiration (Welsh and Eller 1991, Goebel *et al.* 2006, Goebel and Kremer 2007) to guide the choice of algal growth rates. There are numerous water quality model coefficients that can be adjusted during the calibration process and for this project the key coefficients for adjustment are envisioned to include: algal growth and respiration rates, organic carbon oxidation rates, settling rates of algae and detrital organic matter as it relates to sediment oxygen demand (SOD), and nutrient fluxes calculated by the SFM. Recent updates and revisions to SFM coefficients based on Chesapeake Bay modeling will be reviewed as part of calibrating the LIS SFM (Brady, *et al.*, 2013, Testa, *et al.*, 2013). Any relevant and recent LIS sediment research and monitoring data retrieved as part of the data acquisition process will also be reviewed and used in setting SFM coefficients.

- In addition, the following LIS specific sediment studies (at a minimum) will be obtained and reviewed for use in the SFM modeling: Quantifying benthic-pelagic coupling in LIS (Wally Fulweiler, Boston University); Biogeochemical Nitrogen Loss vs. Recycling in Long Island Sound: Connecting Sediments to Overlying Water (Craig Tobias, UConn); Nitrogen loading and oxygen dynamics in LIS using stable isotope geochemistry (Mark Altabet, University of Massachusetts); Constraining Models of Metabolism and Ventilation of Bottom Water in Long Island Sound Using Oxygen Isotopes (Craig Tobias and James O'Donnell, UConn); Biogeochemical Nitrogen Loss vs. Recycling in Long Island Sound: Connecting Sediments to Overlying Water (Craig Tobias, UConn); Assessment of the Effects of Bottom Water Temperature and Chemical Conditions, Sediment Temperature, and Sedimentary Organic Matter (Type and Amount) on Release of Sulfide and Ammonia from Sediments in Long Island Sound: A laboratory study (Carmela Cuomo, University of New Haven); and The quantitative contribution of sedimentary nutrient fluxes to nitrogen loading and harmful algal blooms in Long Island estuaries (Christopher Gobler, SBU).

- Model skill assessment will be completed using the statistical metrics presented in Section 1.7.2 of this QAPP.

As part of this task, HDR will deliver the following model documents as major project deliverables:

1. Model Selection and Setup Report
2. Hydrodynamic Model Testing Memorandum (WY95)
3. Hydrodynamic Model Preliminary Calibration Memorandum (CY 2005-2006)
4. WY95 Testing and CY 2005-2006 Hydrodynamic Model Presentation and Workshop
5. Water Quality Model Testing Memorandum (WY95)
6. Water Quality Model Preliminary Calibration Memorandum (CY 2005-2006)
7. WY95 Testing and CY 2005-2006 Water Quality Model Presentation and Workshop

Table 2. LIS Model Inputs

Hydrodynamic Model	Water Quality Model
River flows and temperature	River loads
Offshore tidal boundary condition elevation, salinity and temperature	Offshore tidal boundary condition water quality concentrations
Meteorological conditions (e.g., wind speed, air temperature)	Solar radiation or cloud cover, fraction daylight
Point and nonpoint source (including groundwater) flows and temperature	Point and nonpoint source (including groundwater) and atmospheric water quality loads
Model coefficients (e.g., bottom roughness, horizontal mixing), n<10	Model coefficients (e.g., atmospheric reaeration, algal growth rate), n>30

Task 4 – Setup & Execution of a Continuous Long-Term Simulation of the Hydrodynamic & Water Quality Models from 2003-2018

HDR will further develop the LIS open waters HWQMs (ROMS-RCA) by applying them to a long-term simulation period from 2003-2018. This time period will provide further testing over a wide range of environmental conditions (e.g., river flows and loads, point and nonpoint source loads and meteorological conditions).

A model calibration time period (2005-2014) and two model validation time periods (2003-2004 and 2015-2018) will be used. The model calibration and validation time periods reflect conditions before and after East River Water Resource Recovery Facility (WRRF) nitrogen reductions. The refined model grid developed in Task 3 will be used for the long-term simulations. Similar model input development, model-data comparisons and model skill assessment steps will be completed as discussed in Task 2.

This long-term model simulation task may involve further refinement of model coefficients and parameters to best reproduce observed data. This further model refinement is not unusual when testing a model to new (longer-term) datasets and may be a function of the model being applied to a wider range of environmental conditions. The goal will be to develop the HWQMs with a consistent set of model coefficients that can reproduce the observed data from the entire 2003-2018 time period. HDR has acquired or will acquire the required data from sources listed in Section 2.1.

Model management scenarios will be completed using the 2003-2018 time period for three (3) conditions to be developed by DEP and the MAG.

Additionally, post-audit model testing with data from 2019-2022 will be conducted. The post-audit model testing will involve setting up model inputs using 2019-2022 data and comparing model output to observed data without adjustment to any model coefficients. This modeling step will be taken to determine how well the models are calibrated using data from after attainment of the 2014 Phase III TMDL nitrogen reduction targets.

Finally, the development of two stand-alone embayment models (one in NY and one in CT) for a roughly one-year time period will be completed based on availability of data needed to set up model inputs and complete model-data comparisons for model calibration. The model grid resolution for the two embayment models will be finer than that employed for embayments included in the open waters LIS model grid.

HDR will deliver the following documents as major model deliverables:

1. Hydrodynamic/Water Quality Calibration Memorandum (2005-2014)
2. Hydrodynamic/Water Quality Model Presentation and Workshop
3. Stand-alone Embayment Modeling Report
4. Calibration, Validation and Assessment Modeling Report
5. Data Gap Document

Task 5 – Build Out & Design of Graphical User Interface/Decision Support Tool (GUI/DST)

HDR subconsultant DHI Water & Environment, Inc. (DHI) will provide GUI/DST design and development using an Agile-like blueprinting development process (initial design stage) to determine the functional requirements of the GUI/DST with DEP. This process will involve project mapping; user’s needs definition;

conceptual GUI/DST sketch; system specifications; planning and prioritization of tasks; and development of a proof of concept.

After completing the initial design stage and upon receipt of feedback from DEP and stakeholders, a presentation (blueprint) that includes reports and technical notes covering the functional and non-functional requirements, high-level system flow charts, detailed flow charts for each system component, product descriptions, requirements for compliance with the target environment and the use of third-party software. It will also detail the next steps for prototype development and testing. At this stage, GUI/DST mock-ups will be created in order to allow the presentation of the concepts and features under consideration.

The GUI/DST will include, at a minimum, the following capabilities:

- Spatial input data editing via map selection of model segments provided in the GUI/DST through tabular editing of attribute tables;
- The GUI/DST will provide GIS-like viewing and mapping features with geo-referenced model data formats for GIS compatibility;
- Selected feature attribute field labeling will be provided in the GUI/DST with controls to manage on/off display; and navigation tools will be provided such as zoom to point and zoom to feature/selection;
- GUI/DST code version control will be managed using GitHub or alternate software external to the GUI/DST;
- Hydrodynamic and water quality monitoring data used for model input/output to be managed by the GUI/DST;
- GUI/DST components delivered as proprietary solutions and Software as a Service (SaaS) elements may be delivered as services or other web applications; and
- Project-specific software tools and utilities source codes and executable files will be provided.

The source codes and executable files will be delivered for any open-source component of the proposed solution. Proprietary and SaaS elements will be provided as services or other web applications and will include web resources, containers and the necessary supporting documentation for their use.

HDR will deliver the following documents as part of the GUI/DST design:

- GUI/DST Design Report
- GUI/DST Design Manual
- GUI/DST User’s Manual

HDR will also develop recommendations and cost estimates for a central data repository for model input and water quality data and for cloud computing and software services. In addition, HDR will design and manage an Integrated Modeling Framework (IMF) Wiki SharePoint site for communication of project status and schedule; final deliverables; HWQM calibration/validation status, code and documentation; GUI/DST development and documentation; and technical transfer and training materials.

Task 6 – Technology Transfer & Training

HDR will provide technology transfer and training for the LIS HWQMs (ROMS-RCA) and GUI/DST. This technology transfer and training will be provided in two formats as follows:

- Intermediate model and GUI/DST trainings (up to three) to provide early learning opportunities for the DEP modeling group (and interested stakeholders). The intermediate training is to allow potential users an opportunity to begin learning during the project as the models and GUI/DST are being developed. The intermediate training will be coordinated around monthly project meetings or annual stakeholder meetings via WebEx and will provide learning opportunities that break up the modeling process into easily digestible modules.

- A three-day technology transfer and training workshop will be held near the end of the project at DEP offices or via WebEx. The three-day workshop will be separated into the following schedule: Day 1 – overview of hydrodynamic and water quality model theory; Day 2 – hydrodynamic and water quality model setup (boundary conditions, loads, coefficients) and GUI/DST use for model pre- and post-processing; and Day 3 – GUI/DST use for evaluating multiple management planning scenarios.

The final demonstration of the LIS HWQMs (ROMS-RCA), including the GUI/DST to DEP, will include all data and modeling files, GUI/DST applications and documentation on a transfer drive for installation on DEP computers. This final technology transfer will occur at a one-day meeting at DEP's office or via WebEx by modeling and GUI/DST design leads.

A memorandum will be developed summarizing licensing and maintenance costs based on the selected modeling framework, GUI/DST, and Central Data Depository. If modeling calibration identifies data that are required to better constrain critical model coefficients, the memorandum will include data collection recommendations, which will be informed by guidance from the DEP, EPA, MEG, MAG and stakeholders.

Task 7 – Model Evaluation Group (MEG)

The MEG will consist of a four-person peer review panel, approved by DEP that will provide independent review of eight key deliverables to provide an additional QA step during the project. The eight deliverables the MEG will review are as follows:

- QAPP (this document),
- Model Selection and Setup Report,
- Hydrodynamic Model Preliminary Calibration Memorandum (CY 2005-2006),
- Water Quality Model Preliminary Calibration Memorandum (CY 2005-2006),
- Hydrodynamic/Water Quality Calibration Memorandum (CY 2005-2014),
- Stand-alone Embayment Modeling Report,
- Calibration, Validation, and Assessment Modeling Report, and
- Data Gap Report.

The MEG will also present annually to the MAG on the technical modeling progress at modeling workshops. MEG peer review work products will be sent directly to DEP for review and compilation of comments before forwarding to HDR for response. The MEG will also participate in up to 15 stakeholder (MAG) meetings (three per year for the five-year project duration) and annual modeling workshops (a total of five). The MEG members have been selected as noted below:

- Andy Stoddard (Dynamic Solutions, LLC) – MEG Lead
- Carl Cerco (retired U.S. Army Corps of Engineers (USACE), consultant)
- James O'Donnell (UConn, consultant)
- John Warner (USGS Woods Hole Coastal and Marine Science Center)

1.5 Quality Objectives and Criteria for Model Inputs/Outputs

1.5.1 Objectives and Project Decisions

The QAPP has been completed to ensure that: (1) modeling input data are valid and defensible; (2) model setup and calibration/validation protocols are followed and documented; (3) model applications and output are reviewed and evaluated in a consistent manner; and (4) models are able to be used to assess the impact of nitrogen loading on phytoplankton (chlorophyll-a), water clarity and DO levels in LIS. Water clarity will be assessed using available light extinction data or Secchi depth, background water clarity and chlorophyll-a effects on total light extinction.

The models that are developed will be used to assess the impacts of nitrogen management on water quality in LIS. Modeling will focus on the LIS, but the model's ability to reproduce water quality in other areas of the LIS study area will also be assessed. The LIS HWQMs (ROMS-RCA) developed during this project will be publicly available/open source so that additional advancements can be made to the models for future modeling efforts. A GUI/DST will be constructed for the LIS HWQMs such that the model is accessible to multiple stakeholders with varying degrees of modeling experience.

1.5.2 Existing-Data Acceptance Criteria

Various types of data are needed to develop model inputs and for use in calibrating and validating the LIS HWQMs. These types of data include hydrographic (bathymetry, coastlines); tidal (elevations, currents); physical (salinity, temperature); meteorological (e.g., wind speed, air temperature); water quality (e.g., nutrients, chlorophyll-a, DO); and point and nonpoint source loads. The data needed to develop these model inputs and for use in calibrating and validating the LIS models will be obtained from secondary data sources.

No new data will be collected as part of this project. Only existing (secondary) data will be used for the development and calibration/validation of the LIS HWQMs.

The use of secondary data involves the gathering and/or use of existing environmental data for purposes other than those for which they were originally collected. These secondary data may be obtained from many sources, including literature, compilations from electronic databases and information systems, and mathematical models of environmental processes. As no new data will be collected as part of this project, the data quality of these secondary data sources will be reviewed prior to use in the modeling activities.

The main data sources to be used for the LIS modeling will have established guidelines and QA/QC procedures for their data collection activities. For example, the USGS has long-established guidelines for measuring river flows and water quality at their gaging stations and is closely supervised for QA by respective State agencies. Similarly, the NOAA National Climatic Data Center (NCDC) has long-established guidelines for measuring precipitation and other atmospheric data and has supervision for QA of their data.

Additional secondary data to be used in the LIS modeling with well-established routine nutrient monitoring programs and QA/QC procedures include the: DEP Harbor Survey Program; CTDEEP LIS Monitoring Program; NJHDG Monitoring Program; and IEC LIS Monitoring Program.

The following data quality objectives have been established for the LIS HWQMs:

- The primary input and calibration/validation data will be of a known and documented quality.
- Data will be collected from sources to provide sufficient temporal and spatial coverage of the open waters of LIS and the two selected embayments.
- The data will be comparable with respect to previous and future studies.
- Modeling data will be representative of the time, location and conditions of the period being modeled.
- The data used for primary input and calibration/validation will be sufficient to characterize the nitrogen loading to LIS, the interaction of nutrients and phytoplankton in LIS, and the impact of nutrients on phytoplankton (chlorophyll-a), water clarity and DO in LIS.

As part of obtaining the secondary data for use in developing the LIS models, all data source QA/QC procedures and/or QAPP documents will be obtained, reviewed and filed with the specific datasets for future reference. The QA/QC documents will be reviewed from the perspective of the intended use of the data for modeling based on the noted accuracy, precision, representativeness, completeness, and comparability of the data collected.

If a secondary data source does not have QA/QC documentation, the importance and usefulness of the dataset in model development will be documented and discussed with the project funding partners (DEP and EPA) as to whether the data can be used for model development. One option in this instance would be to use the data, note that QA/QC documentation was not available and not place as much significance on the data as opposed to use of fully QA/QC'd datasets. If a decision to use the data is reached, a disclaimer for the specific dataset will be noted in any documents referencing the data.

Data screening measures will be employed to ensure the validity of the data. These measures will include graphical (e.g., time-series) and statistical analysis (e.g., probability distributions) of the data in order to identify outliers and inconsistencies, checks on reporting units between the electronic data and QA/QC documents, constituent definitions (e.g., chlorophyll-a reported as total or corrected), calculated constituents (e.g., total nitrogen (TN) measured or calculated), and any missing data records (e.g., what values are assigned to missing data). Any anomalous values will be investigated and resolved. If the anomalous data result from data entry errors, they will be corrected. If the anomalous data do not result from data entry errors, they will be reported to the Model Technical Lead and Quality Manager for documentation and further investigation. If an explanation for the anomaly is not obtained, the anomalous data will be noted and removed from the project dataset; however, unedited datasets will first be archived to provide access to the original raw data.

With typical data collection efforts, the data are assessed in terms of precision, accuracy, completeness, representativeness, and comparability. In this QAPP, precision and accuracy are not included due to the fact that the data has already been collected and the data were collected and analyzed under existing Quality Assurance protocols.

Completeness is a measure of the amount of valid input data available to develop model inputs and the amount of data available to fully calibrate and validate a model. Deficiencies in the water elevation, meteorological inputs, freshwater flow, loading and water quality data are outside the control of the modeling effort. Data gaps will be addressed after the data sources are reviewed and will be identified in a Data Gaps Report.

Representativeness is a measure of how closely the model input and calibration/validation data reflect actual conditions. The primary model data sources have QA protocols in place prior to the use in the modeling effort. Data sources without QA protocols will undergo additional review to assess representativeness. The review will include comparisons to similar data from other sources.

Comparability expresses the confidence with which one data set can be compared to another. Comparability will be maintained by using consistent units, appropriate temporal scales, and consistent loading methodologies. For example, Secchi depths can be reported in feet and meters. Consistent units will be used when comparing modeling results to data. If inconsistencies are identified between data sets, analytical methods, sampling frequencies, and methodologies for the data sets will be investigated.

Additional information is provided below related to both the hydrodynamic and water quality model inputs and data needs. The Data Acquisition Plan developed for the project (stand-alone document) provides further detail on model data needs (input and calibration/validation), data sources, and data management.

It is assumed that the open waters LIS and embayment models will use the same modeling framework and, therefore, will require the same types of model inputs and calibration/validation data.

ROMS Hydrodynamic Model Inputs and Data Needs

The hydrodynamic model, ROMS, requires information to define the physical constraints of the model domain. This information includes coastline data as well as bathymetric data, so the model can be described in three dimensions. ROMS also requires data to define open (tidal) boundary conditions of the model domain including water elevation to define the tides, temperature and salinity data. Freshwater inputs also need to be defined. These freshwater inputs include rivers, WRRFs, stormwater (e.g., combined sewer overflow (CSO), stormwater and direct runoff) and groundwater depending on the importance of each source. The model also requires meteorological data to describe atmospheric influences on the calculated hydrodynamic circulation. These data include wind speed and direction, air temperature, atmospheric pressure, relative humidity, and solar irradiance. Other information includes water clarity, which influences the penetration of solar irradiance into the water column.

For most of these data, it is important to have a continuous record although the required time scale may differ by model input type. Tidal water elevation and meteorological inputs are generally required on an hourly basis. Other inputs such as river flows are adequate if daily information is available for model input. For some smaller WRRFs only monthly data may be available and is adequate for model input due to their smaller contribution to the overall water balance. Time-variable model inputs will be presented as time-series figures as a QC check that the inputs were created correctly. These model inputs include boundary conditions, freshwater flows, and meteorological inputs.

Calibration and validation data are used to help assess how well the model reproduces observed conditions, so these data help define water body conditions for the time periods being modeled. These data include tidal water elevation, temperature, salinity, and current speed and direction (where available). Continuous data (e.g., hourly) data are more useful for model calibration and validation, especially for water elevation and currents. Salinity and temperature grab sampling data are helpful for these constituents when continuous data are not available. It is preferable to have data that covers the spatial extent of the modeling domain and spatial coverage is more important when spatial variability is known to occur.

RCA Water Quality Model Inputs and Data Needs

The tidal water circulation in the model domain will be transferred from the ROMS hydrodynamic model to the RCA water quality model; and water quality calculations will be completed on the same model grid as that used for the hydrodynamic model. ROMS has been linked to RCA so that the two models can be run simultaneously. The RCA water quality model of eutrophication processes has more state-variables than the ROMS hydrodynamic model, which means that more constituents need to be defined at the model boundaries and for model loads. This translates to a larger data gathering effort. The RCA water quality model will include the following constituents:

- Particulate organic nitrogen (PON)
- Dissolved organic nitrogen (DON)
- Ammonium nitrogen (NH4)
- Nitrite plus nitrate nitrogen (NO23)
- Particulate organic phosphorus (POP)
- Dissolved organic phosphorus (DOP)
- Orthophosphate (PO4)
- Biogenic silica (BSi)
- Available dissolved silica (SIA)
- Particulate organic carbon (POC)
- Dissolved organic carbon (DOC)
- Inorganic suspended solids
- Multiple phytoplankton groups (as represented by chlorophyll-a)
    - At this time, it is anticipated that two algal groups will be used that represent winter/spring and summer algal groups.
- Dissolved oxygen (DO)

In addition, organic nitrogen, phosphorus and carbon will be divided by reactivity (i.e., reactive, labile, refractory) based on available information, prior studies and best professional judgment. Often the data are not available for all of the constituents and other measured data are used to define boundary conditions or loads. For example, total Kjeldahl nitrogen (TKN) and NH4 data can be used to calculate total organic nitrogen (TON) and then organic nitrogen can be split into PON and DON based on best professional judgment, literature values or as part of the calibration and validation process.

Boundary conditions inputs are generally based on grab sampling data (where available), a calibrated model with a larger domain that encompasses the LIS model domain or estimated in part from calibration and validation to observed data within the model domain. All boundary conditions that are developed from grab sample data or obtained from another model will be processed into time-series model inputs as required for the selected model and are usually linearly interpolated between observation dates.

External model loads (point and nonpoint source) will be based on WRRF discharge records, conveyance models (DEP InfoWorks models for CSO and stormwater discharges, other municipal modeling efforts), Nitrogen Load Models (NLM) and monitoring data (e.g., rivers and tributaries). Atmospheric loads will also be developed based on wet and dry atmospheric deposition data. These loads can be specified on a time frequency ranging from hourly (CSOs) to daily (WRRFs or rivers) to monthly (small WRRFs or tributaries). When external model loads are finalized and model calibration/validation complete, sensitivity analyses will be completed that may include evaluating external model loads, including those derived from external models. These sensitivity analyses may rank the importance of external model loads (i.e., magnitude) as part of selecting which model loads to include in sensitivity analyses.

The COVID-19 Pandemic may have an effect on wastewater contributions to WRRFs discharging to LIS, which may include reductions or changes to effluent flows and loads. Some of these wastewater flows may have even shifted to WRRFs that discharge outside of the LIS watershed. These potential WWRF load changes due to the pandemic will be represented in the modeling through the assignment of actual measured WRRF effluent flows and loads in the models. When a baseline loading condition is established for nutrient management evaluations, the post-COVID loading conditions will be taken into consideration.

Large river loads will be based on measured daily average river flow and available water quality data. Since river water quality data will most likely not be available on a daily basis, a load estimation program (e.g., USGS LOADEST and/or WRTDS) will be used to develop loads for large rivers (e.g., Connecticut River, Housatonic River, Raritan River). Use of these two USGS load estimation programs depends on the amount of data available for completing the load regressions with the more rigorous regression routines in WRTDS requiring more data. During river load development, the availability of data will be determined and will guide selection of whether LOADEST or WRTDS will be used to develop large river loads.

Smaller watershed areas that drain directly into embayments or LIS and are not included as part of the larger river watershed loads are considered coastal watersheds. Figure 9 presents an example of coastal watershed areas that will be used to develop the coastal watershed loads. Coastal watershed loads will be developed based on available NLMs for CT and the north shore Long Island (LI). These NLMs will be available from UConn (Dr. Jamie Vaudrey) or as developed by CDM Smith as part of LI nitrogen management planning efforts. It is anticipated that these coastal watershed loads will be set up on either an annual or seasonal basis and will include groundwater loads, where important. CTDEEP is funding the development of a Hydrological Simulation Program – Fortran (HSPF) model for Connecticut watersheds, the Connecticut Watershed Model (CTWM). It is possible that this model could be used for loading inputs to the LIS model, but it will depend on the completion date and availability of the CTWM output.

Time-variable inputs to the model will be presented as time-series figures as a QC check that the inputs were created correctly. These inputs include boundary conditions, time-variable functions, and loads.

It is expected that much of the calibration and validation data will consist of grab sampling data for routinely monitored parameters (e.g., TN and total phosphorus (TP), TKN, NH4, NO23, PO4, chlorophyll-a). This will require the various model constituents to be processed before comparison to the observed data (e.g., sum of PON, DON, NH4 and NO23 for TN). Chlorophyll-a will be used to assign concentrations for the various phytoplankton groups; and if algal species data are available these data can be used to specify how chlorophyll-a data can be split into different algal groups (e.g., winter/spring and summer groups). Generally, weekly or monthly data are available for model calibration and validation with certain locations having continuous DO data available.

If available, additional special study data may be used to help define model coefficients. These types of data may include algal productivity and/or respiration data to estimate algal growth and respiration rates;

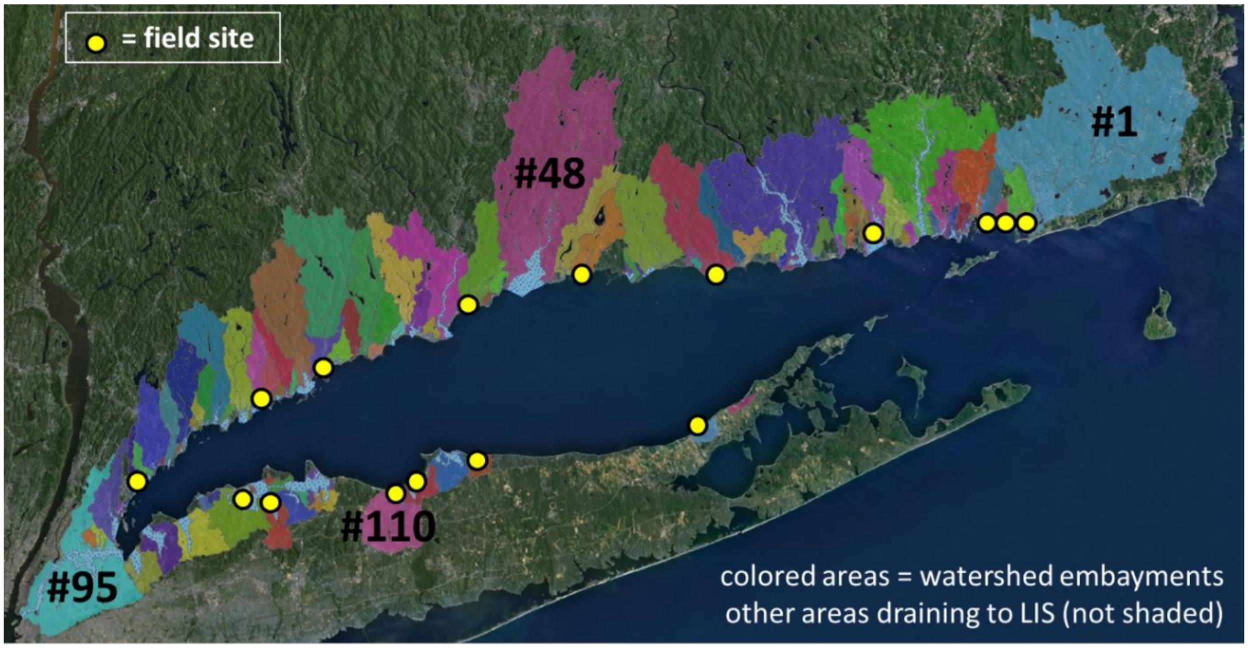


Figure 9. Example Coastal Watershed Areas
(Reproduced from Vaudrey, et al., 2016)

long-term BOD studies to estimate carbon oxidation; and Secchi depth or vertical profiles of photosynthetically active radiation (PAR) to estimate light extinction.

The RCA water quality model will also include a SFM for the calculation of SOD and sediment nutrient fluxes as a function of settled organic matter and subsequent sediment diagenesis. The types of sediment data needed to calibrate the SFM include: porewater and solid phase data; and SOD, ammonium, nitrate, and orthophosphate sediment flux data. Seasonal measurements of these types of data are ideal along with good spatial coverage in open water areas and in embayments. Recent sediment nutrient cycling research studies completed for the Long Island Sound Study (LISS) and other sediment studies in LIS and embayments will be reviewed to determine whether the data for the SFM is available. If available, the sediment data will be used for calibration of the SFM.

Model Performance Criteria

Model calibration and validation is often accomplished through a subjective trial-and-error adjustment of model coefficients (weight of evidence approach) because many interrelated factors can influence model output. The experience and judgment of the modeler is a major factor in calibrating and validating a model both accurately and efficiently. Although this method balances model comparison to data with the modeler's understanding of the physical, chemical and biological characteristics of the system it does not provide a quantitative measure of the "goodness of fit".

The model calibration "goodness of fit" measure may be either qualitative and/or quantitative. Qualitative measures of the calibration "goodness of fit" that will be used in the development of the LIS model include several types of analyses. The following graphical analyses will be performed as part of the model calibration and validation process.

- Time-series figures of model output and observed data at a given station
- Model output versus observed data cross-plot figures at a given station

- Graphical transect plots of model output and observed data for a given time period (e.g., monthly or seasonal)
- Model output contour and data disc plots (Fitzpatrick 2009)
- Comparison between model output and observed data as probability distributions at a given station (Helsel and Hirsch 2002)

Once an acceptable level of model calibration and validation is achieved using the qualitative measures, quantitative measures will be used that are sometimes referred to as skill assessment criteria. There is a large body of literature about coastal and estuarine modeling skill assessment (Blumberg et al., 1999; Fitzpatrick, 2009; Jolliff et al., 2009; Zhang et al., 2010; Ganju et al., 2016; and Ji, 2017). Typical measurements include relative error (RE), root mean square error (RMSE), correlation coefficient (r) and coefficient of determination (r^2). All statistical approaches have their limitations. Unfortunately, few references provide guidance as to the acceptable level of error for a satisfactory level of calibration.

Some of the quantitative skill assessment criteria to be considered include the following measures and will be finalized during MEG review and as the project progresses.

- Relative error (RE): $= 100 \times \frac{|\bar{M}-\bar{O}|}{\bar{O}}$
- Root mean square error (RMSE): $= \sqrt{\sum_{i=1}^{n}\left(\frac{(M_i-O_i)^2}{n}\right)}$
- Relative RMSE: $= \frac{RMSE}{Data\ Range}$
- Correlation coefficient (r): $= \frac{\sum(O_i-\bar{O}) \times (M_i-\bar{M})}{\sqrt{\sum(O_i-\bar{O})^2} \times \sqrt{\sum(M_i-\bar{M})^2}}$

Where: M_i – model point, O_i – observed data point, $\bar{M}$ – model average, $\bar{O}$ – observed data average.

Additionally, target diagrams (Jolliff *et al.*, 2009) plot model-data bias or normalized bias (y-axis) against the unbiased root-mean-square difference (ubRMSD) on the x-axis may be generated. These plots present graphically whether the model over-estimates or under-estimates the data (i.e., the bias) and whether the model standard deviation is larger or smaller than the standard deviation of the observations (i.e., the ubRMSD). The model bias and ubRMSD equations below are used for the target diagrams.

- Model bias: $= \bar{M} - \bar{O}$
- Normalized model bias: $= \frac{\bar{M}-\bar{O}}{\sigma_O}$
- ubRMSD: $= \sqrt{\frac{1}{n}\sum_{i=1}^{n}[(M_i - \bar{M}) - (O_i - \bar{O})]^2}$

Where σ_O is the standard deviation of the data (observations).

The quantity and quality of data will vary from station to station. Stations identified with good temporal coverage and within areas of interest, will be labelled primary stations for skill assessment. Stations with data gaps and less temporal coverage will be identified as secondary stations. Maps of primary and secondary stations will be generated after data are acquired and analyzed.

Skill assessment measures will be calculated with hydrodynamic model-data comparisons for water elevation, current velocity, salinity, and temperature at the primary and secondary stations with skill assessment criteria applied to the primary station calculations. Current velocity at discrete depths, where such data is available, will be qualitatively assessed using cross-plots of model and data to evaluate both direction and magnitude. If data are available during the model calibration and validation time periods or if past studies exist, the net residual flow in the East River will also be evaluated. The model will also be compared to previous modeling estimates of flux through the East River at Throgs Neck.

Since data availability may be different for open waters LIS areas and the two selected embayments, two sets of skill assessment criteria will be specified and further defined as the project progresses. This is to reflect that embayment station data may not be as robust as open waters LIS station data.

Table 3 provides the hydrodynamic model skill assessment criteria to be used for quantifying primary station model calibration and validation acceptability of the open waters LIS model. The model will be compared to both grab samples and continuous monitoring.

The primary surface water quality model output that will be used to complete skill assessment with the data will be DO, TN, dissolved inorganic nitrogen (DIN), TP, PO4 and chlorophyll-a. Table 4 provides the water quality model skill assessment criteria to be used for quantifying primary station model calibration and validation acceptability of the open waters LIS model. Arhonditsis and Brett (2004) reviewed over 150 modeling studies and assessed how well the models reproduced model constituents. The median of the relative error for several constituents in these studies were: DO – 12%, nitrate – 36%, ammonium – 48%, phosphate – 42% and phytoplankton biomass – 44%. The skill assessment criteria listed in Table 4 are noted as an upper bound value for relative error and RMSE (e.g., <10%, <1 mg/L) as these statistics can be a function of the magnitude of the parameter value.

The skill assessment criteria for the embayments will be further discussed with the MEG as the project progresses and Table 5 and

Table 6 will be completed at a later date as the quantity and quality of available embayment data is determined.

Table 3. LIS Hydrodynamic Model Skill Assessment Criteria

Parameter	Relative Error[a]	RMSE[a]	Correlation Coefficient[a]
Water Elevation	5-10%	< 20 cm	> 0.9
Current Speed	20-25%	< 20 cm/s	> 0.7
Salinity	10-15%	< 4.0 psu	> 0.7
Temperature	5-10%	< 2.0°C	> 0.9

Note:

[a] DEP tentatively agrees to these criteria; however, final agreement is reserved until the MEG has reviewed the QAPP on behalf of DEP.

Table 4. LIS Water Quality Model Skill Assessment Criteria

Parameter	Relative Error[a]	RMSE[a]	Correlation Coefficient[a]
DO	< 10%	< 1.0 mg/L	> 0.8
BOD5	TBD	TBD	TBD
TN	< 40%	< 0.2 mg/L	> 0.7
DIN	< 40%	< 0.1 mg/L	> 0.7
NH3	TBD	TBD	TBD
NO23	TBD	TBD	TBD
TP	< 40%	< 0.05 mg/L	> 0.7
PO4	< 40%	< 0.02 mg/L	> 0.7
Chlorophyll-a	< 40%	< 15 µg/L	> 0.7

Note:

[a] DEP tentatively agrees to these criteria; however, final agreement is reserved until the MEG has reviewed the QAPP on behalf of DEP.

TBD - To be determined

Table 5. Embayment Hydrodynamic Model Skill Assessment Criteria

Parameter	Relative Error	RMSE	Correlation Coefficient[a]
Water Elevation	TBD	TBD	TBD
Salinity	TBD	TBD	TBD
Temperature	TBD	TBD	TBD

Note:
TBD - To be determined

Table 6. Embayment Water Quality Model Skill Assessment Criteria

Parameter	Relative Error	RMSE	Correlation Coefficient[a]
DO	TBD	TBD	TBD
BOD5	TBD	TBD	TBD
TN	TBD	TBD	TBD
DIN	TBD	TBD	TBD

Parameter	Relative Error	RMSE	Correlation Coefficient[a]
NH4	TBD	TBD	TBD
NO23	TBD	TBD	TBD
TP	TBD	TBD	TBD
PO4	TBD	TBD	TBD
Chlorophyll-a	TBD	TBD	TBD

Note:
TBD – To be determined

Ultimately, the goal of model calibration and validation is “not to curve fit model to data, but to describe the behavior of the data with a modeling framework of the principal mechanisms relevant to the problem” (Thomann, 1982). This ultimate goal will require a “weight of evidence” approach that balances both qualitative and quantitative skill assessment results with the model calibration and validation guidance and acceptance provided by the independent peer review of the MEG.

Once the model is considered calibrated based on visual inspection and acceptable comparison to the skill assessment criteria, the model will be validated to the data from the validation period. Acceptance of the validation will also be based on visual inspection and skill assessment criteria. If the model does not meet the specified criteria during the validation period, then model inputs will be revisited in order to develop a consistent set of model coefficients so that the model comparison to both the calibration and validation periods are acceptable. Additional discussion of the calibration and validation process is described in Section 4.1.

Once the model is successfully calibrated and validated, sensitivity analyses will be performed as described in Section 4.1. The sensitivity analyses will also serve to assess the importance of the uncertainty in model inputs. Certain model inputs will have great uncertainty (e.g., coastal watershed loads, groundwater loads), but if the model is not sensitive to these inputs, then the inputs do not have a material impact on the model calibration and validation. Model coefficients have inherent uncertainty but are bound within scientifically accepted ranges and the model sensitivities will help ascertain the importance of the uncertainty to the model outcomes.

Model Limitations and Final Evaluation Criteria

It should be noted that all models are simplifications of environmental processes they intend to represent. Although there is no consensus on model performance criteria in the literature, a number of basic statements are generally accepted among professional modelers.

- Models are approximations of reality and cannot accurately represent natural systems.
- There is no single, accepted test that determines whether a model is calibrated and validated.
- Models cannot be expected to be more accurate than the sampling and statistical error of the model input and observed data.

- Exact duplication of observed data is not possible, nor is it a performance criterion for this project. The model calibration and validation process will measure the models' ability to simulate measured values.

- No single procedure or statistic is widely accepted as measuring or establishing acceptable modeling performance. Therefore, the combination of graphical comparisons, statistical tests, and professional judgment are proposed to provide sufficient evidence to base a decision of model acceptance.

This way of reviewing model a calibration is considered a "weight of evidence" approach. See Donigian & Imhoff (2009).

1.6 Special Training

No additional training is required in understanding the underlying ROMS hydrodynamic model physics and RCA water quality model kinetics. HDR personnel have been trained in the use of various HWQMs. HDR team members have developed a linkage between RCA and ROMS for use in a Chesapeake Bay application and these team members will provide assistance to the HDR staff in the use of ROMS-RCA.

1.7 Documents and Records

Modifications to the QAPP will be noted in any updated versions of the QAPP, which is to be maintained by the HDR Project Manager. Revision numbers will be in the format #.# as described on the approvals page. All revisions will be made with track changes in the original Word document beginning with Version 1.0. The revision date will also be noted, but not included in track changes. DEP and EPA will decide when changes are major or minor. All team members listed on the QAPP distribution list will be notified by e-mail when a new version of the QAPP has been approved. The updated QAPP will be made available on the LIS Wiki SharePoint site. The LIS Wiki SharePoint site will be accessible to all persons listed on the QAPP distribution list and as the project progresses will be generally accessible to LIS stakeholders.

Compiling LIS HWQM databases (e.g., MS Access, PostgresSQL) for data analyses, gaining understanding and to update the model will be included as part of the project. Key features of the LIS database will include:

- Spatial integrity of the acquired data checked and mapped using GIS software;

- Use of a common geodetic datum and projection type (e.g., North American Datum 1983);

- Filing structure and file naming labeled with unique identifiers, such as dates and person uploading, in order to maintain version control;

- Original, unedited datasets will be archived to have access to the original raw data;

- Version control for GIS and database files; and

- Use of a geospatial database management system to facilitate organization and analyses of large datasets and integrate the functionality of traditional database management systems with the geographic information stored in GIS data.

As the LIS HWQM databases are developed and updated during the project, working versions of the databases will be maintained on the LIS Wiki SharePoint site.

Notes on the LIS HWQM runs will be maintained in a model run log. Modifications made to model inputs or model code during the calibration and validation process will be documented in the run log. Notes will include the date, run name/number, run directory, location and name of the compiled code, changes made to the model code, changes made to the model inputs, reasons for the change in the model code or model inputs, outcomes of the model runs, and if the change will be kept in ongoing runs. A copy of the model run log will be kept on HDR's working model workstations.

Reports, technical memorandums, and technical presentations will be developed as noted in Section 1.4 to document project modeling and GUI/DST development tasks. Both hard copy and electronic (PDF) versions will be generated and distributed following the project Master Distribution List. Master copies of all reports will be maintained in electronic format by the HDR Project Manager. Written peer-review comments on eight major technical modeling reports (see Section 1.4) will be issued by the MEG, which will be followed by a Summary Response Report to those comments by HDR. Monthly Progress Reports will provide a continuous record of project activities and technical decisions.

Responsibility for the distribution and control of review and final versions of project documents will be by the HDR Project Manager. Before the HDR Project Manager releases any interim or final project documents, the documents will have undergone internal review initiated by the HDR Technical Leads and the HDR Quality Manager. A policy of maintaining an accurate chronology of project documents and records through the use of version numbers, release dates, interim and final designations will be implemented rather than a practice of deleting, altering, or replacing original records. Where appropriate, significant review comments will either be appended to the final versions of documents that incorporate the review comments or will be referenced in the final version and retained on a stand-alone basis as part of the project record.

During project execution, key working documents and project deliverables will be stored in HDR's ProjectWise management system, which is backed up every evening. Day-to-day modeling activities and data analyses are completed on HDR's Linux-based computer servers. These Linux servers and model/data files are backed up daily with CommVault to an external storage system with daily backups maintained for 60 days and end of month backups maintained for 1-year. After project completion, project files will be retained in accordance with HDR's records retention policy; in general, all financial and contractual documents, final deliverables and models, model output and model results are maintained for 3 years in active storage and after 3 years are moved to permanent storage on an external hard drive for 17 years (20 years in total).

DEP will decide on its own archiving process once the data and model inputs/outputs/documentation is delivered at the end of the project.

1.7.1 QA Project Plan Distribution

This QAPP will be implemented by HDR once EPA has approved the current working version. The QAPP is a "working document" and will be periodically updated and revised as technology, policy and protocol change. All QAPP updates will be distributed by the HDR Project Manager according to the distribution list in Section 1.3 with notification to EPA.

Upon approval, the QAPP will be stored on the LIS Wiki SharePoint site. All personnel responsible for implementation (HDR staff and subconsultants) will be required to review this QAPP within 30 days of approval. New personnel assigned to the project will be required to review this QAPP within 30 days of being assigned to the project.

2 Data Generation and Acquisition

2.1 Data Acquisition

All data used to develop model inputs will be obtained from outside (secondary) data sources and not collected specifically for the LIS HWQMS project. These sources are generally government agencies or universities that have QA programs in place. In some cases, these model inputs may be derived from another model (e.g., DEP InfoWorks for CSO loads). The associated modeling reports that discuss model calibration and “goodness of fit” will be obtained and filed in the project documentation. The Data Acquisition Plan (stand-alone document) developed for the project provides additional detail on the outside (secondary) data sources to be used in the project.

The following data types will be obtained with the anticipated data sources to be queried noted:

- Hydrographic: National Oceanic and Atmospheric Administration (NOAA), DEP, CTDEEP, University of Connecticut (UConn), LIS Integrated Coastal Observing System (LISICOS), and Stony Brook University (SBU).

- Bathymetry: NOAA, USACE, NYSDEC, CTDEEP, UConn, and LIS Resource Center (CTDEEP, UConn).

- Meteorological: NOAA, LISICOS, and NOAA North American Regional Reanalysis (NARR) atmospheric model.

- Water Quality: DEP Harbor Survey, CTDEEP, New Jersey Harbor Dischargers Group (NJHDG), USGS, Suffolk County Department of Health Services (SCDHS), EPA National Coastal Assessment, LISICOS, SBU, and on-going EPA efforts to establish nitrogen thresholds and allowable loads.

- Loads: DEP provided InfoWorks model output, DEP WRRF effluent data, NYSDEC, CTDEEP, NJDEP, NJHDG, IEC, EPA PCS-ICIS DMR database, USGS Northeastern SPARROW model, USGS CT groundwater model, UConn (Dr. Jamie Vaudrey) NLM, NYSDEC, SCDHS, CDM Smith north shore LI NLMs and groundwater modeling, NYSDEC LINAP efforts, and atmospheric loads.

Data screening measures will be employed to ensure the validity of the data. These include graphical and statistical (e.g., Chauvenet’s criterion) analyses of the data in order to identify outliers and inconsistencies or missing data. Any anomalous values will be investigated. If the anomalous data result from data entry errors, they will be corrected. If the anomalous data do not result from data entry errors, they will be reported to the Model Technical Lead and Quality Manager for documentation and further investigation. If an explanation for the anomaly is not obtained, the anomalous data will be noted and removed from the project data set; however, unedited datasets will first be archived to provide access to the original raw data.

In addition, the water quality model may use a number of time-variable functions: base light extinction coefficient, fraction of daylight and daily solar radiation. These functions are used as part of the light equations that influence phytoplankton growth. Fraction of daylight is calculated from a program that assumes the earth is a sphere and latitude is supplied as input. Daily solar radiation will be taken from the ROMS hydrodynamic model input, which will employ spatially variable meteorological inputs derived from the NOAA NARR atmospheric model. This atmospheric model provides time-series model inputs on a 30-kilometer spatial resolution for wind speed/direction, air temperature, atmospheric pressure, solar radiation and relative humidity for heat transfer calculations. It has been found for other modeling efforts that switching to spatially variable meteorological inputs in models with large spatial domains greatly improved model calibration to water temperature (horizontally and vertically).

2.2 Data Management and Hardware/Software Configuration

2.2.1 Data Management

Two types of data will be used for this project: data used for model input; and data used for model calibration and validation. A computer directory structure for each model will be set up to separate each data type and data source. The hydrodynamic model input directory structure will include directories for boundary elevations, boundary temperature and salinity, freshwater flow, and meteorological data. The water quality model input directory structure will include directories for boundary conditions, initial conditions, point source loads, nonpoint source loads, riverine loads, atmospheric loads, sediment inputs, and parameters and constants. A file from each data source will be kept in its original format, and additional files will be made to put these data into a file format compatible for model input. The final modeling report will identify the sources of all data used for model input.

Model output, while not data, will be treated as data for the purposes of this QAPP. Model output will not be saved and archived for all model calibration and validation runs. Only the final versions will be saved and archived. However, a log of the model input used for each model calibration and validation run will be kept, as well as notes on the changes made for each run, the outcomes of the change, and the rationale for changes for the next run. Thus, older calibration and validation runs can be reproduced using older model inputs, if necessary. Model output for each projection scenario will be kept in separate directories. A log of each management scenario projection and the inputs changed for each management scenario will also be maintained.

The project includes development of an inclusive LIS geospatial database and database management system with version control to document changes to database values. All data compiled and used for model inputs, assessment of model constants, calibration/validation, and skill assessment will be uploaded and maintained in the LIS database. Unedited datasets will be archived within the database to allow access to the original raw data. As the LIS HWQM databases are developed and updated during the project, working versions of the databases will be maintained on the LIS Wiki SharePoint site.

At the end of the project, the HWQM technical reports will include figures of the data that were used in the analysis and will discuss how the data addresses the needs of the modeling effort. These technical reports will also present the model inputs, model calibration and validation results, and model management scenario results.

2.2.2 Hardware/Software Configuration

There are two hardware component aspects to this project. Internally, HDR will perform model development on its own servers and user computers. Once the model has been developed to a point where end users can begin to work with the model through the GUI/DST it will be available on a cloud-based system. Internally at HDR, all user computers are leased for 36 months and covered under maintenance contracts for the duration of the lease term. Servers and networking equipment are leased for 60 months with maintenance contracts for the entire term. For cybersecurity, HDR adheres to NIST compliance guidelines and all end use computers are encrypted. All computers have antivirus and active threat protection from Microsoft. HDR has also implemented multi-factor authentication for all end users using Cisco Duo and/or DigiPasses as secondary authentication. Since HDR's equipment is under maintenance contracts, HDR does not maintain an inventory of spare parts.

Overall project software validation is the responsibility of the Quality Manager, and the modeling and GUI/DST Technical Leads. All of the candidate modeling codes are publicly available, and the most current code version will be obtained from reputable sources upon selection of the project models.

Project-specific code modifications will undergo rigorous checks by the programming staff before release and use in data or modeling analyses. The Model Technical Leads will review the modified software and associated output for correctness. At a minimum, model output associated with revised computer code will be compared against model output from the unrevised computer code to check for general consistency.

Code modifications will be documented directly in the code by date, identifying information for the person making the modification, and the purpose of the modification. Similar information will be included in a README file within the relevant modeling directory. In addition, the software development tool, git, will be used to track software development and modifications.

Previous code versions and input files will be maintained in separate read-only directories as version controls, so that models can be rolled back to earlier states, if desired. The HWQM Technical Leads will maintain modeling logs containing detailed metadata on modeling run versions, file names and file paths; input, output, and code file directories; changes to model constants, and other code modifications. Modeling logs will be reviewed by the general Modeling Lead and Quality Manager at least monthly.

Change management in the GUI/DST software design and development phases will be addressed through software versioning and documentation procedures. This will allow for routine changes necessary to evolve the software from design to delivery, while documenting any substantial variations for DEP and stakeholder consideration and approval. Development will utilize DHI's Development Operations (DevOps) framework for managing the development environment, code, and documentation. In this way, resources are directed at developing software that meets the defined requirements. DHI's general solutions software development process is contained in Attachment 2. During the GUI/DST development process, this software development process will be further refined.

HDR is currently working on city-wide HWQMs as part of DEP's Long-Term Control Planning (LTCP) efforts. The model grid being using for the city-wide modeling is of the same order of magnitude (i.e., number of model segments and vertical layers, spatial extent) as the envisioned new model grid for this LIS modeling effort. The city-wide models are run on high-end workstations, most of which use either the i9-9900x processor (10 cores, 3.3 GHz nominal mode, 4.3 GHz "turbo" mode) or the i9-7900x processor (8 cores, 3.6 GHz nominal mode, 5.0 GHz "turbo" mode). Each workstation has either 32 or 64 GB of high-speed RAM and approximately 6 TB of disk storage space. On these systems, a 1-year city-wide model simulation takes about: 20 hours for the hydrodynamic model using a 10-second time step; and 24 hours for the water quality model using a minimum 10-second variable, split time step. It is anticipated that similar model run times will be required for the LIS models using a new refined model grid. As the LIS HWQMs may ultimately be run in a cloud computing environment, similar cloud-based Virtual Machines (VMs) will need to be configured for the LIS modeling. Configuring the cloud-based VMs will be the subject of a project deliverable discussed next and is anticipated to be needed for the project during the second quarter of 2024.

One specific project deliverable will address hardware/software recommendations for the LIS HWQMs and is anticipated to be available during the first quarter of 2024. This deliverable will outline model and user-base requirements to further define the overall resources provisioning for the models and GUI/DST along with the necessary resources (cloud and hybrid solution elements and services). This deliverable will provide specific model execution timeframes for the selected HWQMs, and the necessary resource requirements, and will include the assumptions and expected program requirements and details of the preferred approach, along with performance expectations.

The hardware/software recommendations deliverable will also discuss the use of Fortran compilers for creating executable files of the ROMS and RCA model codes. The use of different Fortran compilers has been found to produce different model results when using the same model codes, but not specifically with RCA. These differences are typically small and not significant but can be great enough to produce significant differences. This Fortran compiler issue can become important when a different organization obtains the model code for an independent use and compiles the model code with a different Fortran compiler. The hardware/software recommendations deliverable will document what Fortran compiler and version were used for the LIS HWQMS project to avoid compiler induced model results differences. In addition, the deliverable will outline a model code benchmarking process so that LIS HWQMS model results from this project are reproduced by the user prior to further independent use. The specific model Fortran compilers and compiler flags used for model development will be noted with the documentation included when the model code is downloaded from GitHub, where these items will eventually be stored.

3 Assessment and Oversight

3.1 Assessment and Response Actions

The model output generated as part of the modeling process will be evaluated during the calibration and validation process. Visual model performance assessments will be made after each model run as outlined in Sections 4.1 and 4.2 by either the Hydrodynamic or Water Quality Modeling Lead and at least once a week by the Modeling Lead.

In addition, project performance will be evaluated by modeling audits to ensure that project goals are being met. Quarterly modeling audits will be performed by the Quality Manager and general Modeling Lead. Audits will focus primarily on model input and the model calibration and validation process in addition to overall management of the project. Audits will occur on a quarterly basis during periods when the models are actively being set up, calibrated, or validated. Audits will also occur before management scenarios are completed. The Quality Manager will note any deviations from the QAPP and suggest corrective actions. Corrective actions will be noted in the monthly progress reports.

In addition, and as noted in Section 1.4 (Task 7), the MEG will provide independent peer review of eight (8) major model deliverable documents. The MEG will consist of four (4) members and report directly to DEP. The MEG Team Leader will coordinate comments from the MEG members and deliver them to DEP. DEP will then provide the MEG comments, and potentially comments from DEP staff and other LIS stakeholders, to HDR for response. The eight (8) major model deliverable documents that the MEG will review include:

1. QAPP (this document),
2. Model Selection and Setup Report,
3. Hydrodynamic Model Preliminary Calibration Memorandum (CY 2005-2006),
4. Water Quality Model Preliminary Calibration Memorandum (CY 2005-2006),
5. Hydrodynamic/Water Quality Calibration Memorandum (CY 2005-2014),
6. Stand- alone Embayment Modeling Report,
7. Calibration, Validation and Assessment Modeling Report, and
8. Data Gaps Report.

Comments provided to HDR by DEP on the MEG review of deliverables (8 documents) will be appropriately documented and resolved.

During the calibration and validation modeling efforts, the team will conduct statistical analyses (skill assessment) to assess how well the model performs against the performance criteria listed in Section 1.7.2. It is anticipated that skill assessment will be completed for most all model runs and documented for future comparison to subsequent model runs. Model inputs and output will be screened by the Modeling Leads and the Quality Manager. Sensitivity analyses will be completed as outlined in Section 4.1.

The HDR Project Manager will maintain the overall responsibility for examining the work to ensure that the methodologies and processes are consistent with the procedures outlined in the QAPP. Identification of problems regarding technical performance will be the responsibility of all staff working on this project. The HDR Project Manager, HDR Task Technical Leads, and HDR Quality Manager will assess any problems that arise during model development, calibration and validation that might require a modification to the stated procedures and will decide on any changes. The HDR Task Technical Leads will document such changes, will append changes to the QAPP, and will include changes in the final report as needed. An amended QAPP will be distributed when needed to the project distribution list (see Section 1.3). Any corrective actions will also be documented in the monthly progress reports. Significant QA issues will be reported to DEP and EPA within one business day of finding the issue.

4 Model Application

4.1 Model Testing

The updated LIS hydrodynamic and water quality models (ROMS-RCA) will be tested against the WY95 data to evaluate the effect that the new finer model grid has on model-data comparisons. A limited number of hydrodynamic and water quality model sensitivities will be completed to test how certain input changes affect WY95 model-data comparisons and, thereby, help guide model calibration efforts. These input changes may include adjustments to ROMS mixing coefficients, bottom friction or atmospheric heat balance coefficients; and RCA algal productivity/respiration rates or other oxygen consumption processes. No model calibration efforts will be completed using the WY95 data.

4.2 Model Calibration

Model calibration is the process of adjusting model coefficients and parameters within acceptable limits until the resulting predictions provide favorable correlation with observed data. Commonly, calibration begins with the best estimates for model inputs based on field measurements and laboratory studies and subsequent data analyses. Results from initial simulations are then compared to observed data and used to guide changes to the values of the model input coefficients and parameters. Model calibration will be accomplished by comparison of model results with data independently derived from field observations.

As discussed in Section 1.4, the LIS HWQMs will be subjected to a preliminary calibration using data from the data rich time period from 2005-2006. Results from the preliminary calibrations will undergo MEG review (Task 3). The preliminary calibrations will be followed by full model calibrations for the time period of 2005-2014 (Task 4). This full model calibration time period will subject the LIS HWQMs to a wider range of environmental conditions.

For the 2005-2006 preliminary model calibration time period, the intent will be to develop a model calibration approach that can be reviewed, approved, and applied to the full model calibration time period. Model skill assessment using the criteria outlined in Section 1.7.2 (Model Output Criteria) will be completed to assess how well the model calibration compares with the data. The preliminary model calibrations will use the refined LIS model grid with increased horizontal spatial model segment resolution. In addition, the preliminary hydrodynamic model calibration may include adjustments to vertical and horizontal mixing coefficients and atmospheric heat exchange parameters and adjustments to various nutrient cycling and oxygen related coefficients in the water quality model. Once DEP is satisfied with the preliminary model calibration, the model calibration will commence for the full 2005-2014 period.

Day-to-day oversight of the model calibration will be conducted by the Hydrodynamic and Water Quality Modeling Technical Leads, with additional oversight by the Modeling Technical Lead. Modifications made to model inputs or model code during the calibration process will be documented in a calibration log. Model calibration will continue until the model skill assessment criteria are considered met. If the model skill assessment criteria cannot be met, the limitations of the model for use in projections will be described in a modeling report. Final model calibration inputs will be included in the model reports and archived for future reference.

ROMS Hydrodynamic Model

Model Inputs

Hydrodynamic model input sources are being identified as part of the Data Acquisition process. Some of the data that has been identified is as follows.

- NOAA does not have tide gages near the probable edge of the model offshore boundary locations, but existing gages on the NOAA website (CO-OPS Products - NOAA Tides & Currents) can be used to help define the model boundary water elevations. HDR will assess whether any existing publicly available models can also be used to assign water elevation at the model boundary conditions.

- In previous applications of models with similar model domains to the LIS model, data were not used to assign water elevations at the offshore boundaries. A process was developed that applied long-term circulation, tidal fluctuations, and sub-tidal meteorological forcing components. The process is described in the Passaic Valley Sewerage Commission (PVSC) modeling report (2020) in Appendix O at the site below. The approach used can vary based on the model framework selected, or the success, or lack thereof, of the original approach.

  https://www.nj.gov/dep/dwq/pdf/CSO_SIAR_AppendixO_PVSC_20201001.pdf

Model Calibration

The transport and mixing of loads introduced to coastal environments are controlled by the discharge characteristics of the loads and the circulation characteristics of the receiving water body. The complexity of the physical processes governing the transport of an introduced constituent requires the use of sophisticated hydrodynamic models. Hydrodynamic model calibration involves comparing model output to observed water elevation, salinity, temperature, and current velocity data at multiple monitoring stations in LIS and surrounding water bodies. Part of the assessment of model calibration is accomplished by comparing time-series of model output with time-series of measured/observed data and comparing modeled vertical profiles of salinity and temperature against measured/observed data to make sure that vertical density stratification is well reproduced in the hydrodynamic model. Reproducing the vertical density stratification in the hydrodynamic model is important for reproducing vertical DO stratification in the water quality model. In addition to comparing model output to observed water elevation, salinity and temperature data, available current speed data will be used to compare water circulation (current speed/direction) calculated with the hydrodynamic model. Properly reproducing water circulation (both horizontally and vertically) will be critical to achieving a good calibration for dissolved oxygen in the water quality model, given the correct assignment of oxygen-consuming and oxygen-producing mechanisms (e.g., algal production/respiration, carbon oxidation, SOD, atmospheric reaeration).

The model will be calibrated by modifying input, through trial and error, within acceptable ranges based on literature, similar modeling studies and best professional judgment to reproduce the observed data. In many cases the available data used for model input are imperfect or incomplete, so that modifications to the input must be made to reproduce the calibration data. Input modifications may include adjusting bottom friction, mixing coefficients, boundary conditions (if data are limited) or meteorological inputs (e.g., wind sheltering) to improve the model fit to measured data. During the calibration phase, model output will be plotted and compared against observed data and initially will involve qualitative comparisons of model versus data. These qualitative comparisons will consist of time-series and spatial plots, model contour/data disc plots and probability distributions for key hydrodynamic data. As the qualitative model calibration is judged to be acceptable, skill assessments will be performed to develop quantitative statistical metrics of the model calibration.

Table 3 in Section 1.5 provides guidance for the anticipated level of accuracy of the model to the available data. There are numerous monitoring stations within the LIS study area from the open waters of LIS to the East River and NYC area urban tributaries to the Hudson River, NY/NJ Harbor and the surrounding coastal waters. The main focus of model-data comparisons will be at identified “primary” monitoring stations with sufficient data in the open waters of LIS and western portions of the East River. A figure noting the primary monitoring stations will be included in the QAPP when they are identified as part of the Data Acquisition process. Model-data comparisons will also include surrounding stations because reproducing observed water quality at these other stations will be important to producing a successful model calibration in LIS. Where available, model-data vertical profiles for salinity, temperature and DO will also be used to assess how well the model reproduces vertical stratification and the location of the pycnocline or maximum density gradient. A figure identifying vertical profile stations will be added to the QAPP when these monitoring stations are selected as part of the Data Acquisition process.

A preliminary ROMS hydrodynamic model calibration memorandum for CY 2005-2006 will be developed for review by DEP, EPA and the MEG. The MEG will review the document and provide input to approve the model calibration or suggest improvements to the model calibration. Once the preliminary hydrodynamic model calibration for the CY 2005-2006 period is approved, the hydrodynamic model calibration will move to the longer 2005-2014 period.

Calibration Stop Criteria

Stop criteria can be useful to prohibit never-ending calibration efforts and allow for the introduction of more subjective criteria than the skill assessment criteria. In consultation with the HDR Project Manager and DEP, the Modeling Lead can invoke stop criteria to allow for the project to continue to move forward. The following stop criteria can be invoked in the following order:

- The calibration meets the subjective and objective skill assessment criteria described in Section1.5.2;
- The project schedule requires the project to move to the next phase;
- Budgetary constraints require the project to move to the next phase.

Before the stop criteria are invoked, HDR will prepare a memo to DEP documenting the need and discussing the potential impacts to the modeling. In addition, the stop criteria need will be discussed at monthly progress status meetings as needed. Any deficiencies in the model calibration due to invoking stop criteria will be documented in the Modeling Report.

Following the hydrodynamic model calibration, the project will move to completing the water quality model calibration.

RCA Water Quality Model

Model Inputs

Water quality models require numerous inputs, including temperature, salinity, transport and dispersion information (supplied by the hydrodynamic model), loading (point sources, riverine, stormwater, groundwater, atmospheric), boundary conditions, time-variable functions such as fraction of daylight and solar radiation, and constants and parameters. The sediment nutrient flux submodel (SFM) within RCA has its own set of constants. Model input sources are described in Section 2.1.

As RCA has parameters that may not be routinely monitored (e.g., particulate and DON and phosphorus), the available data will need to be processed to generate values needed for model inputs. Examples of a few data processing steps used in SWEM are outlined below.

- TON = TKN – NH4
- PON and DON estimated from other datasets, literature or best professional judgment (e.g., DON = 0.8 x TON, PON = 0.2 x TON)
- DON = Total dissolved nitrogen (TDN) – NH4 – NO23
- Total organic phosphorus (TOP) = TP – PO4
- POP and DOP estimated from other datasets, literature or best professional judgment (e.g., DOP = 0.8 x TOP, POP = 0.2 x TOP)
- DOP = Total dissolved phosphorus (TDP) – PO4

These data processing steps will be dependent on the available data from a specific data source and will be discussed and documented during the modeling process.

Model Calibration

The model will be calibrated and validated to existing water quality data in order to represent observed conditions. No new data will be collected as part of the water quality modeling. Model coefficients will initially be assigned based on the latest SWEM application to the WY95 data set. Various model coefficients will be adjusted as necessary to improve model-data comparisons at monitoring stations throughout the LIS study area. The water quality model calibration will focus on the constituents identified with skill assessment criteria: DO, TN, DIN, TP, PO4 and chlorophyll-a. Model versus data comparisons will be made for other available constituents including TKN, NH4, NO23, POC, BOD and Secchi depth.

During the model calibration process, the selection of model coefficients will be guided by literature information and site-specific field data. An example of site-specific field data that will be used include measurements of primary productivity and respiration (e.g., Welsh and Eller 1991, Goebel *et al.* 2006, Goebel and Kremer 2007) and will guide the assignment of algal growth and respiration rates. Other key model coefficients will be adjusted in a systematic way and checked to ensure that they are within acceptable literature ranges (e.g., Bowie *et al.* 1985, DiToro 2001) and based on best professional modeling experience. There are numerous water quality model coefficients that can be adjusted during the calibration process and for this project, the key coefficients for adjustment are envisioned to include: algal growth and respiration rates, organic carbon oxidation rates, and settling rates of algae and detrital organic matter as it relates to SFM calculated SOD and nutrient fluxes. While there are a number of adjustable coefficients in the SFM, our experience across a number of estuarine modeling studies has shown that it has not been necessary to vary many of the SFM coefficients, with the exception of phosphorus partition coefficients (DiToro 2001). Recent updates and revisions to SFM coefficients based on Chesapeake Bay modeling will also be reviewed as part of calibrating the LIS SFM (Brady, *et al.*, 2013, Testa, *et al.*, 2013).

The model will be calibrated by modifying input, through trial and error, within scientifically acceptable ranges in order to reproduce the observed data. During the calibration phase, model output will be plotted and compared against observed data and initially will involve qualitative comparisons of model versus data. These qualitative comparisons will consist of time-series and spatial plots, model contour/data disc plots and probability distributions for key water quality data. As the qualitative model calibration is judged to be acceptable, then quantitative skill assessments will be performed to develop quantitative statistical metrics of the model calibration. The model results will be compared to the data to determine if the calibration meets the criteria outlined in Table 4.

A preliminary water quality model calibration memorandum for CY 2005-2006 will be developed for review by DEP, EPA and the MEG. The MEG will review the document and provide input to approve the model calibration or suggest improvements to the model calibration. Once the preliminary water quality model calibration for the CY 2005-2006 period is approved, the water quality model calibration will move to the longer 2005-2014 period.

<u>Calibration Stop Criteria</u>

The same calibration stop criteria presented in the hydrodynamic model calibration section will apply to the water quality model calibration.

<u>Model Sensitivities</u>

After the model is calibrated, sensitivity analyses will be performed using the CY 2005-2006 modeling time period to assess the importance of specific model coefficients and inputs on the solution. The sensitivity to variations or uncertainty in input parameters is an important characteristic of a model. Sensitivity analyses are used to identify the most influential parameters in determining the reliability of model predictions. Sensitivity analyses quantitatively define the dependence of the model's performance on a specific parameter or set of parameters. This information is of importance to the user who must establish required accuracy and precision in model application as a function of data quantity and quality. The calibration process itself will provide guidance as to the sensitivity of the model to certain parameters and inputs. Model sensitivity may be expressed as the relative rate of change of selected output caused by a unit change in the input. If the change in the input causes a large change in the output, the model is then considered to be sensitive to that input parameter. Sensitivity analysis is typically performed by changing one input parameter at a time and evaluating the effects on the distribution of the dependent variable.

Model inputs subject to sensitivity analyses and/or modification during calibration may include:

- Kinetic coefficients and parameters (e.g., algal growth and respiration rates, carbon oxidation rates, particulate matter settling rates, atmospheric reaeration rates)

- External loads (e.g., point and nonpoint sources)
- Boundary conditions (e.g., specified concentrations)

Table 7 presents an example of how model sensitivity results may summarized for application in LIS. In this example, various important oxygen consumption and production rates are adjusted up/down with the resulting change in model calculated DO and chlorophyll-a noted at a specific location. In this manner, the importance of various model inputs (rates, loads) can be evaluated, and decisions rendered as to the importance on the model results, model uncertainty and potential effect on management scenarios.

Table 7. Example LIS Model Sensitivity Summary

Model Input	% Change from Calibration	Change in Min. DO (mg/L)	Change in Max. Chl-a (µg/L)
Carbon Oxidation Rate	-50% +50%	0.5 -0.5	0.0 0.0
Ammonium Nitrification Rate	-50% +50%	0.2 -0.2	0.5 0.2
Algal Growth Rate	-25% +25%	-0.5 0.5	-1.0 0.5
Algal Respiration Rate	-25% +25%	0.7 -0.7	0.5 -0.5
Atmospheric Reaeration	-50% +50%	-1.0 1.2	0.0 0.0

Only constants or inputs believed to be major contributors to the model solution will be assessed, with the previous SWEM model review and sensitivity analysis (UConn, 2010) being used as a guide. The selected parameters will be varied by some percentage (e.g., ±25%) and the effect on model output (e.g., DO, chlorophyll-a) will be evaluated. The range in coefficient variation will be limited by scientifically defensible literature ranges and if model coefficients are linked (e.g., algal growth and respiration), the model sensitivities may involve adjusting more than one coefficient at a time. These model sensitivities will provide insight into what coefficients have the largest effect on vertical stratification, DO and chlorophyll-a levels in LIS and can also be used to guide future monitoring studies to reduce uncertainty in model coefficients that produce the largest effect.

4.2.1 2005-2014 Model Calibration Approach

After the preliminary LIS model calibration is approved by DEP, EPA, and the MEG, or the calibration stop criteria are invoked, the calibration will move on to the longer 2005-2014 period as part of Task 4. The process followed for the hydrodynamic and water quality models for the preliminary CY 2005-2006 time period will be expanded to the full calibration period. The calibration will be subject to the same model output criteria presented in Section 1.7.2. Model sensitivities will not be conducted for the longer calibration period. The calibration process may require additional changes to model coefficients or the model structure from what was applied during the preliminary model calibration period in order to calibrate against the longer calibration period.

The results for the full model calibration will be included in a Hydrodynamic/Water Quality Calibration Memorandum for 2005-2014.

4.3 Model Validation

It is the intent of the hydrodynamic and water quality model calibration and validation to meet the model skill assessment criteria outlined in Table 3 through

Table 6. Through an iterative process, model inputs will be refined in order to adequately reproduce the available data for the calibration period, and the calibrated models will then be tested against data for the validation period. If the model skill assessment criteria cannot be met, it will likely be due to inadequacies in available input data (e.g., loading, boundary conditions, phytoplankton respiration rates, zooplankton grazing rates). Deficiencies in the model calibration and validation, if any, will be noted in the modeling reports. If deficiencies in the models are observed, then the limitations and uncertainties in the model outputs and their interpretations will be addressed in the modeling reports.

The LIS HWQMs will be validated with data from the 2003-2004 and 2015-2018 time periods. Although the model validation periods will represent a new dataset for model testing, further refinement of external model inputs may occur such that the LIS HWQMs reproduce the data that the models were calibrated against (i.e., 2005-2014). There will be no adjustments of model coefficients or rates during the model validation process. These time periods represent a wide range of environmental conditions (e.g., river flows, meteorological conditions, point and nonpoint source loads) for developing and testing the LIS HWQMs.

Similar steps will be completed as conducted for model calibration (see Section 4.1) and will include model input data evaluation (see Section 1.7) and model-data comparisons (qualitative and quantitative) for the 2003-2004 and 2015-2018 model validation time periods. Ultimately, a consistent set of model inputs (i.e., model coefficients and parameters) will be developed that allow the HWQMs to reproduce the observed data for the varying external inputs (e.g., river flows, loads, meteorological conditions) observed.

In addition to the model validation time periods, data from 2019-2022 (post-audit time period) will be used for further validation of the LIS HWQMs. The post-audit modeling will involve model setup of new external inputs for tidal boundary conditions, meteorological conditions, river/tributary inflows and loads, coastal watershed loads, and point sources (WRRFs, CSO, stormwater). The same model coefficients and parameters developed during the model calibration and validation (e.g., bottom roughness, algal growth and respiration rates) will be used and the model output compared to the observed data. Post-audit model results will be analyzed using the same qualitative and quantitative methods that will be used to assess validation model-data comparisons as part of model skill assessment. In addition, the post-audit model results will be compared to the calibration and validation skill assessment results.

The post-audit model results will provide an independent check on how well the LIS HWQMs reproduce observed data solely as a function of external model input changes. This will lend further support for the LIS HWQMs usage as a predictive tool when evaluating nutrient management strategies.

The results of the model validation will be included in a Calibration, Validation and Assessment Modeling Report that will be reviewed by DEP, EPA and the MEG.

4.4 Model Assessments

Model management scenarios will be completed using the 2003-2018 time period for three (3) conditions to be developed by DEP and the EPA. The scenarios will be completed after the models are calibrated and validated.

4.5 Reconciliation with User Requirements

HDR is committed to developing a representative modeling project and will ensure that: (1) complete documentation is maintained; (2) departures from the calibration and validation criteria are addressed; (3) calibration and validation methods are properly documented; and (4) the modeling data are properly used.

The goal of the modeling effort is to develop models that can reliably predict how nitrogen and other pollutant loadings impact dissolved oxygen levels in LIS and its embayments, with the expectation that the models can be used to assess nutrient management options and support future TMDL development (if pursued). The candidate HWQMs are complex three-dimensional, time-variable models that are well suited for assessing eutrophication issues and have been used previously for coastal estuaries. The models and modelers have the capability of achieving the model skill assessment criteria targets outlined in Section 1.7.

The model calibration and validation will demonstrate whether the models can reproduce water elevation, salinity, temperature, DO, TN, DIN, TP, PO4 and chlorophyll-a. The degree to which the models can reproduce the available data will determine the confidence in model projection results (i.e., nutrient management scenarios). If the models can reproduce the data within the tolerances outlined in Table 3 and Table 4, there should be high confidence in the model results. If the model calibrations fall outside of the skill assessment criteria, then the hydrodynamic and water quality modeling reports will discuss the weaknesses and uncertainty and will discuss how these factors might impact nutrient management projections and future TMDL development (if pursued). The modeling reports will also assess factors that could be causing the models to fall outside the skill assessment criteria and what actions might be taken to improve model skill.

As part of the reconciliation process, the modeling deliverables (e.g., modeling reports and technical memoranda) will be reviewed by the HDR Project Manager and Quality Manager to assess whether the quality requirements of the QAPP have been met. A comprehensive review of the final model files and documentation will be completed, and recommendations regarding the effectiveness of the models used in assessing the impact of nitrogen controls on water quality will be provided.

Model input and output will be available in NetCDF format so that it can be accessed by the wider modeling and scientific community.

Model Limitations and Final Evaluation Criteria

It should be noted that all models are simplifications of environmental processes they intend to represent. Although there is no consensus on model performance criteria in literature, a number of basic statements are generally accepted among professional modelers.

- Models are approximations of reality and cannot precisely represent natural systems.
- There is no single, accepted test that determines whether a model is calibrated and validated.

- Models cannot be expected to be more accurate than the sampling and statistical error of the input and observed data.
- Exact duplication of observed data is not possible, nor is it a performance criterion for this project. The model calibration and validation process will measure the models' ability to simulate measured values.
- No single procedure or statistic is widely accepted as measuring or establishing acceptable modeling performance. Therefore, the combination of graphical comparisons, statistical tests, and professional judgment are proposed to provide sufficient evidence to base a decision of model acceptance.

4.6 Reports to Management

Any issues that affect the cost, schedule, quality, or performance (e.g., model calibration and validation) of the project will be reported to the HDR Project Manager. Any significant issues will also be reported promptly to DEP, at a minimum as part of the monthly progress reports discussed below.

Thorough documentation of all modeling activities is necessary for the interpretation of project results. The HDR Project Manager will prepare monthly progress reports, task reports and other deliverables, which will be distributed to project participants. Data and assumptions used to develop the models will be documented in the various model technical reports (see Section 1.4). Key deliverables for this project are listed in Section 5; the project schedule (Figure 8) lists additional reports, written recommendations, technical memoranda, and other deliverables required for the project.

5 Key Deliverables

This project includes a number of key deliverables on the modeling and GUI/DST that include the following reports and memoranda:

- Data Acquisition Plan
- Model Selection and Setup Report
- Hydrodynamic Model WY1995 Testing Memorandum
- Water Quality Model WY1995 Testing Memorandum
- Hydrodynamic Model Preliminary Calibration Memorandum for CY 2005-2006
- Water Quality Model Preliminary Calibration Memorandum for CY 2005-2006
- Hydrodynamic/Water Quality Calibration Memorandum for 2005-2014
- Stand-alone Embayment Model Report
- Calibration, Validation, and Assessment Modeling Report (2003-2022)
- Data Gap Report
- GUI/DST Design Report and Manual

The HDR Project Manager will provide DEP with outlines of each report for approval before each report is prepared.

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ATTACHMENT 1

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ATTACHMENT 2

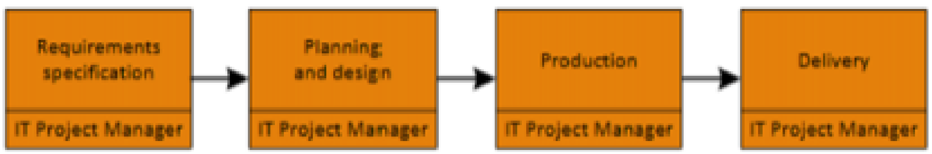
DHI Solutions Software Development Process

DHI Business Process Management and Quality Assurance

Consulting: Solutions Software Development

This process map outlines the Solutions software development process from requirements elicitation to released product. The principal steps or stages of the software development activity include the following, as illustrated below.

- Requirements
- Planning and Design
- Production
- Delivery

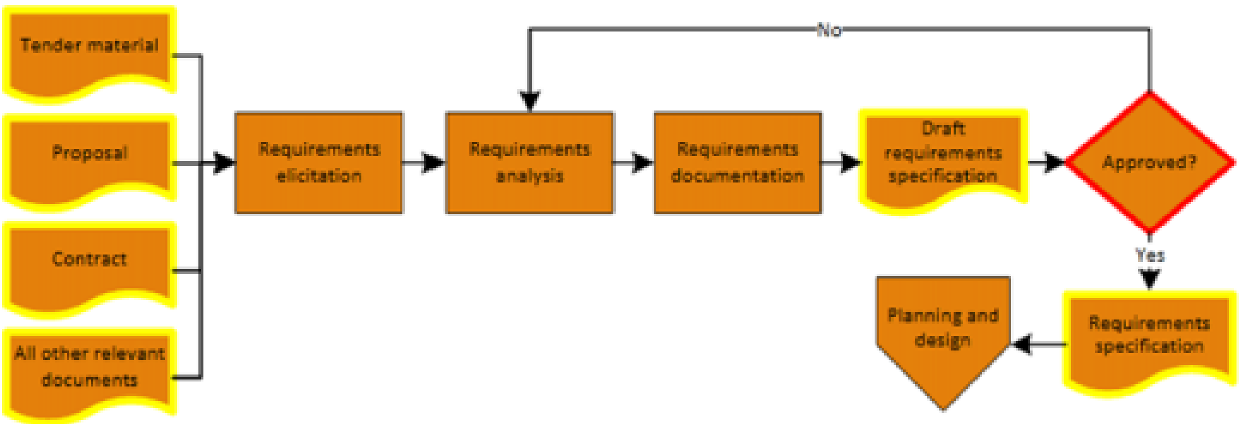


These items are described at a high level in the following sections.

Project implementation and management of the application lifecycle (including development operations) is administered according to the project needs and specifications. This often entails the use of specific project management approaches, in particular the methods of incorporating requirements, agile development methods, and means for integrating client and stakeholder input, reviews and acceptance. These considerations are included in the Project Implementation Plan.

1. Requirements Specification

The procedure for Requirements specification is illustrated in the figure below.



Key activities in the Requirements specification stage are provided below.

Requirements Elicitation

This activity may consist of the following tasks:

- Identify and understand the relevant information provided by the process inputs.
- Identify the relevant stakeholders, their interests and possible influences on the requirements and the final product.
- Identify the relevant elicitation techniques for each stakeholder.
- Perform the elicitation according to the preparations and with the relevant stakeholders.
- Document the results of the elicitation activities.
- A list of suggested questions that must be considered during elicitation is given here.

Elicitation techniques may typically involve one or more of the following techniques:

- Brainstorming
- Interviews
- Questionnaires
- Workshops (with customer, stakeholders, experts etc.)
- Software demonstrations

For smaller projects, or when requirements have already been explicitly specified, the elicitation phase may be short.

Requirements Analysis

This page describes how to make a requirements analysis.

The main purpose of the requirements analysis is to ensure that requirements are understood, of an acceptable quality (e.g. unambiguous, not assuming knowledge, not conflicting, precise, valid, clear and complete), agreed and reconciled. This activity consists of the following tasks:

- Define the structure of the requirements documentation, in agreement with the customer (e.g. a spreadsheet, document or an application life cycle management tool).
- Obtain agreement of the requirements among the relevant stakeholders.
- Identify any other issues that need to be further investigated.

Requirements Documentation

This page describes the activities related to requirements documentation.

- Document the requirements using the agreed requirements documentation style.
- Assign a unique identifier to each requirement according to the agreed identification convention.
- Assign a stakeholder to each requirement.
- Document any issue that needs to be further investigated.
- The requirement specification document must be filed in the working documents library on the SharePoint project site, and updated when required to reflect the current scope of the project.
- Publish the requirements in a suitable form so that they are accessible to relevant stakeholders in the organisation when they are ready for publication.
- Inform relevant stakeholders when the requirements are available.

In its simplest form, the list could be presented in a spreadsheet as illustrated below.

SRS

Req#	Title	Description	Stakeholder
TIM-01	Annual maximum tool	This tool extracts the annual maximum from the input time series. An output time series is produced for each input time series.	Project 1
TIM-02	...	...	...

2. Planning and Design

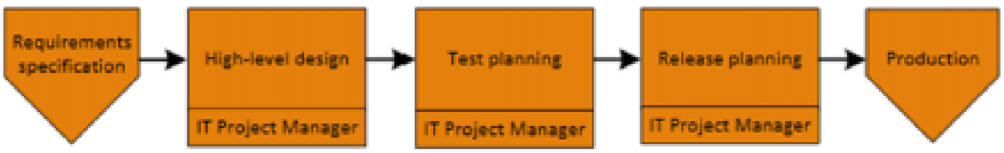
The Planning and design stage includes the following detailed steps.

- High-level design
- Test planning
- Release Planning

These steps are depicted in the following illustration.

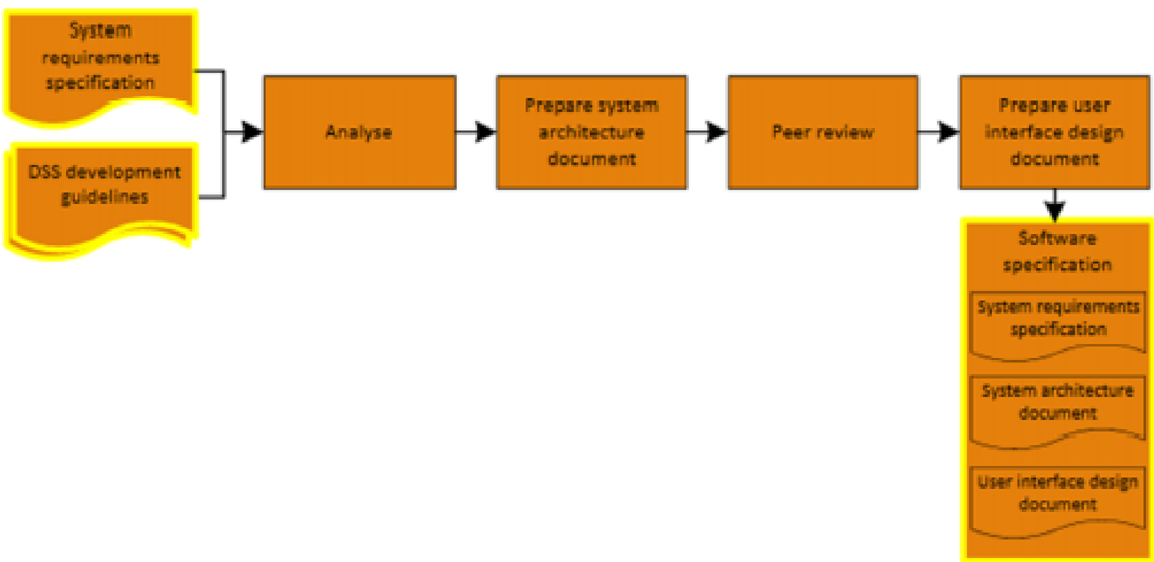
Planning and Design

This flowchart outlines the processes leading to a test and release plan, an activity for which the IT Project Manager has overall responsibility.



High-level Design

This flowchart outlines the process leading to the high-level system architecture and user interface design documents, an activity for which the IT Project Manager has overall responsibility.



The high-level design includes the need to evaluate the system requirements against the specific relevant domain knowledge and experience, as well as available technological assets. This analysis provides input to the development of the System Architecture document, which guides the continuing development.

The User Interface design document is developed within this stage, in coordination with the client and stakeholders. The process for this engagement is detailed in the Project

Implementation Plan. The results of the user interface design process are summarized in the project documentation.

The resulting Requirements specification, System Architecture and User Interface design documents form the Software specification for the project software development.
Peer Review is a required step, and may include internal and external reviews, security and integration components, and other features depending on the specific project needs.

Peer Review

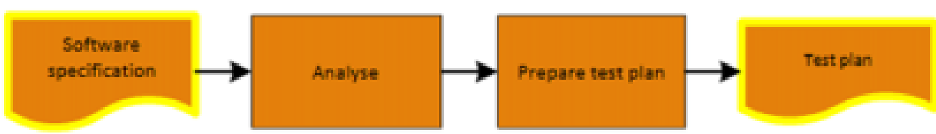
It is the responsibility of the IT Project Manager to ensure that the system architecture document undergoes peer review. The objective is to identify potential issues with a proposed architecture, prior to the construction phase, to determine its architectural feasibility and to evaluate its ability to meet its quality requirements.

The review comments must be filed in the working documents library on the SharePoint project site.

Test-driven development is a core component of the development of functional Solutions software. The specific procedures and approach for the development of the test plan are project specific and are described in the Project Implementation Plan.

Test Planning

This flowchart outlines the process leading to the test plan, an activity for which the IT Project Manager has overall responsibility.

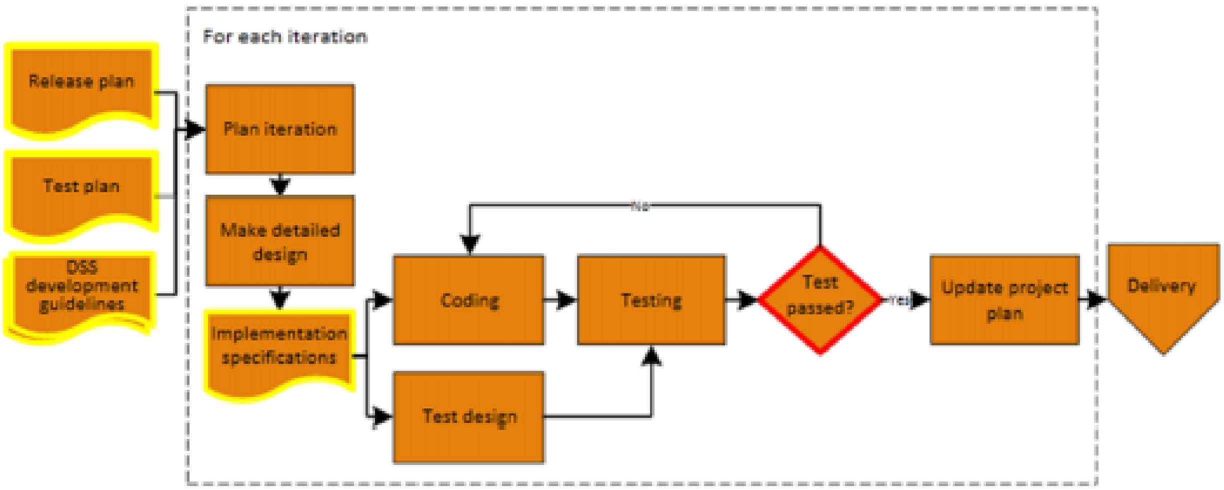


3. Production

Production of the specified software is developed in an iterative manner, and is dependent on the particular project management and delivery approach used for the project.

Production

This flowchart outlines the production procedures, an activity for which the IT Project Manager has overall responsibility.

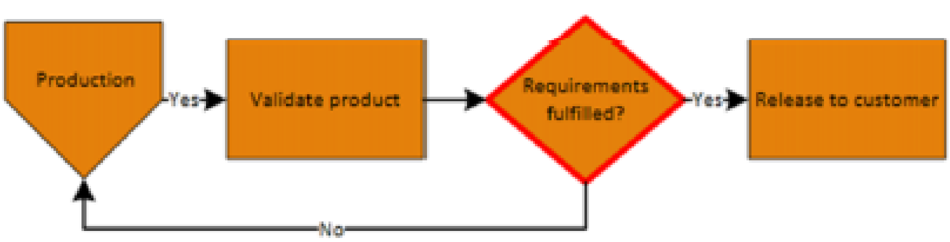


4. Delivery

Delivery of software is likewise iterative, in the case of agile development, and includes specific procedures relative to the delivery approach, which are detailed in the Project Implementation Plan. The procedure for software delivery is depicted in the figure below.

Delivery

This flowchart outlines the activities between production and delivery for which the IT Project Manager has overall responsibility.



The Delivery stage may also cover continuing product support, if that is part of the software lifecycle and project services. For ongoing projects with continued development, The Production and Delivery stages may both be employed, as required.