Delaware County Regional Water Quality Control Authority
CSO Long Term Control Plan Update

Water Quality Modeling and Monitoring Work Plan

Final

January 2017

(Revised July 2017)

GREELEY AND HANSEN

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Report Signature Cover Sheet

Signature of this cover signifies agreement with the content of the DELCORA Water Quality Modeling and Monitoring Work Plan.

I certify under penalty of law that the document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

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Director of Operation and Maintenance	______________________ *Signature*	__________ *Date*

REVISION CONTROL

REV. NO.	DATE ISSUED	PREPARED BY	DESCRIPTION OF CHANGES
0	1/11/2017	G&H/LimnoTech	Initial submittal to US EPA
1	July 2017	G&H/LimnoTech	• Updated Table of Contents • Page 1-8: Updated Figure 1-5 Project Team • Page 2-5: Updated Tables 2-1 and 2-2 • Page 2-7: Updated Table 2-3 • Page 3-6/3-7: Updated Appendix reference • Page 3-7: Changed DR-03 to DR-04 • Page 3-8: Updated Figure 3-2 • Page 3-9: Updated Table 3-1 • Page 3-10: Updated Table 3-2 • Page 3-11: Updated Table 3-3 • Page 3-13: Revised last paragraph for clarity • Page 3-14: Revised first, second and fifth paragraphs for clarity • Page 3-15: Revised second paragraph and Item 3 for clarity • Page 3-16: Revised items 1 & 4 • Page 3-17: Updated Sec. 3.5 appendix reference • Page 3-18: Updated Sec. 3.5.2 appendix reference • Page 3-21: Updated Sec. 3.5.4 appendix reference • Page 3-23: Updated Table 3-8 • Page 3-27: Updated Sec. 3.8.4 appendix reference

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Section 1 Introduction

1.1 Background of DELCORA's Facilities

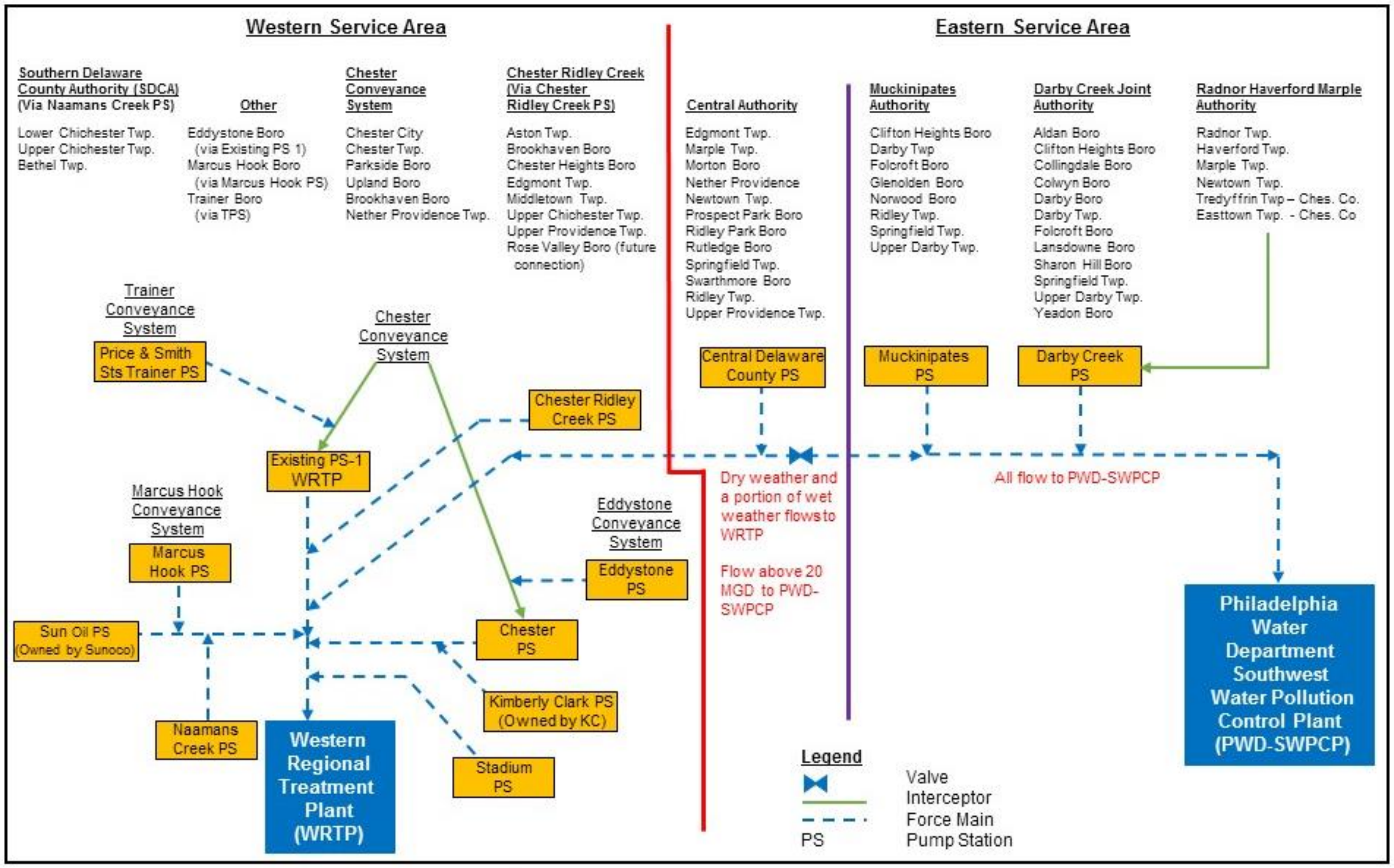
Delaware County Regional Water Quality Control Authority (DELCORA) is responsible for the collection, transmission, treatment and disposal of approximately 65 million gallons per day (MGD) of wastewater generated in southeastern Pennsylvania. DELCORA's facilities serve residential, commercial, institutional, and industrial customers in Delaware County. DELCORA owns and operates an extensive system of pump stations, force mains, and sewers that provide the core infrastructure for the transmission of wastewater to treatment facilities in Delaware County and the City of Philadelphia as shown diagrammatically in Figure 1-1. The total service area served by DELCORA, as shown on Figure 1-2, is approximately 82,977 acres which illustrates that DELCORA serves a significant and widespread portion of Delaware County.

The combined sewer area simulated in DELCORA's existing Hydrologic and Hydraulic model is located within the City of Chester and consists of a drainage area of approximately 1,510 acres. It comprises approximately half of Chester City's serviced area. To support the service area, DELCORA owns and operates over 129 miles of separate and combined sewers. Included in the 129 miles of sewers are: 11.7 miles of an interceptor system; 3,209 manholes; and twenty-five (25) combined sewer outfall regulators controlling storm overflows. The location of Chester City's service area is illustrated on Figure 1-2.

Historically, DELCORA has characterized its service areas as "Eastern" and "Western." The Western service area discharges to DELCORA's Western Regional Treatment Plant (WRTP). The Eastern service area discharges to the Philadelphia Water Department's Southwest Water Pollution Control Plant (PWDSWPCP). In 2002, DELCORA completed the installation of a force main that connects the Eastern Service Area's Central Delaware Pump Station (CDPS) to the Chester Force Main. This connection allows DELCORA to send flow from the CDPS to the WRTP. Flows above 20 MGD are directed to the PWDSWPCP. As such, dry weather flows and a portion of the wet weather flows (total flow less than 20 MGD) from the Central Delaware County Authority in the Eastern Service Area are discharged to the WRTP.

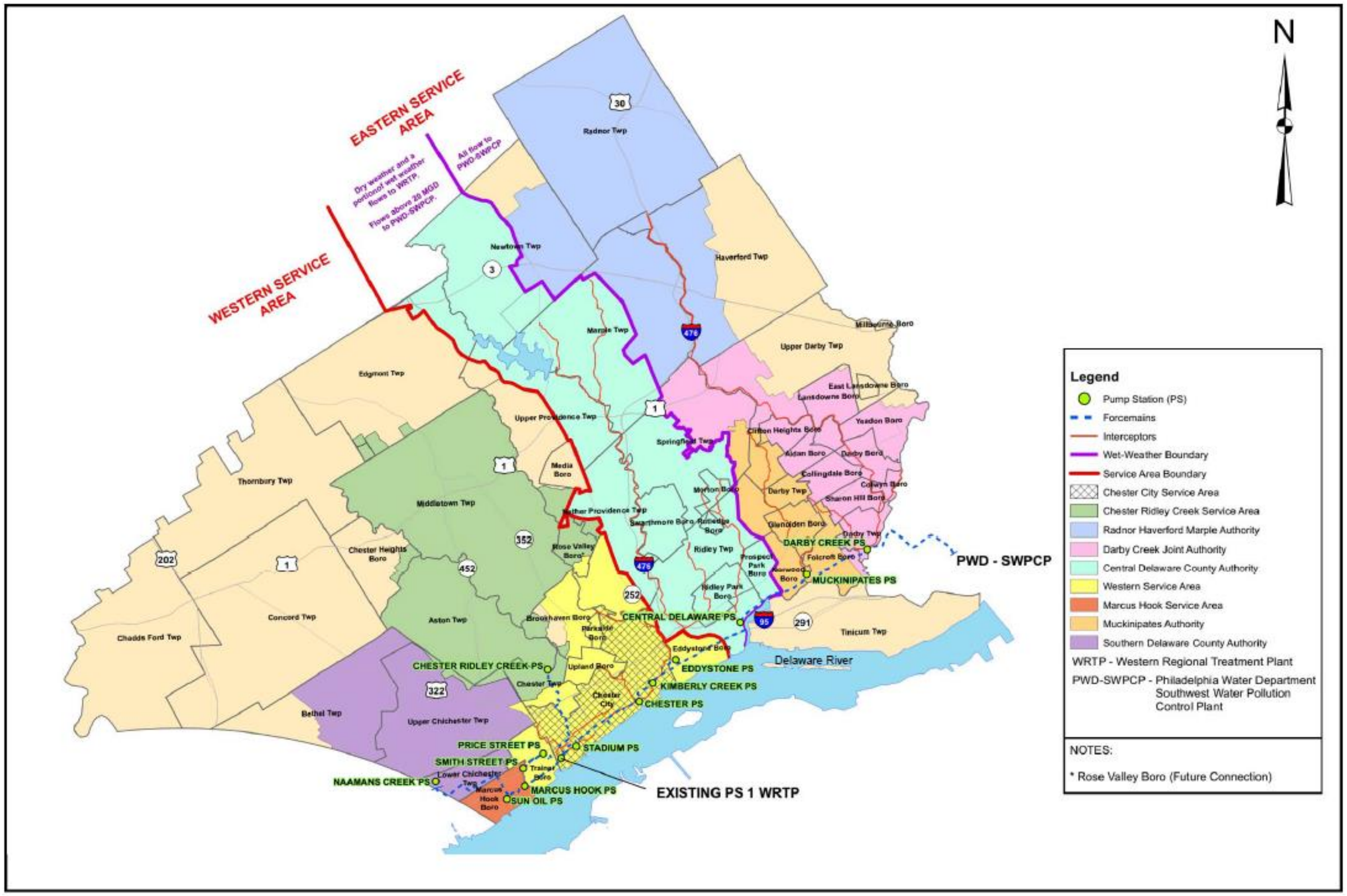
There are a total of 26 combined sewer overflow outfalls listed with 25 discharge points (Outfall #009 and #010 both discharge at Outfall #009) in DELCORA's existing National Pollutant Discharge Elimination System (NPDES) Permit. Under its NPDES Permit No. PA0027103, issued and administered by the Pennsylvania Department of Environmental Protection (PADEP), DELCORA is authorized to discharge from the Western Regional Treatment Plant (Outfall #001), four storm water outfalls at the WRTP (028-031) and from 26 combined sewer overflow outfalls (#002-#026, #032, #033) that ultimately discharge to the Delaware River, Chester Creek and/or Ridley Creek.

Figure 1-1: DELCORA's Conveyance System



CSO Long-Term Control Plan Delaware County Regional Water Quality Control Authority	GREELEY AND HANSEN WESTON SOLUTIONS	Figure 1-1 DELCORA'S CONVEYANCE SYSTEM

Figure 1-2: DELCORA's Service Area



CSO Long-Term Control Plan Delaware County Regional Water Quality Control Authority	GREELEY AND HANSEN	Figure 1-2 DELCORA'S SERVICE AREA

Part C – Other Requirements, Section V – Combined Sewer Overflows of the NPDES Permit details DELCORA's responsibilities with respect to the CSO system including reporting, continued implementation of and continued compliance with the Nine Minimum Controls (NMC), and implementation of the existing Long-Term Control Plan (LTCP) dated April 1999 and the July 2008 addendum to the LTCP until the updated LTCP is approved.

1.2 Consent Decree

On August 17, 2015, a Consent Decree was lodged in the United States District Court for the Eastern District of Pennsylvania that requires DELCORA to complete and submit a revised and updated LTCP to the United States Environmental Protection Agency (USEPA or EPA) and the Pennsylvania Department of Environmental Protection (PADEP or DEP) for review and approval. Consent Decree Paragraph V.A.15 (Water Quality Model Plan) requires that within ninety (90) days after EPA reviews and approves the Alternatives Evaluation Approach, DELCORA shall submit to EPA and PADEP a Water Quality Model Plan for review and approval. Details of the Consent Decree requirements for Water Quality Modeling and Monitoring Plan are respectively found in Section 2.1 and 3.1.1.

1.3 CSO and Receiving Water System Description

The combined portion of DELCORA's sewer system is located within the City of Chester (City), and it comprises approximately half of the City's serviced area. The combined wastewater/stormwater system in the City of Chester is complicated by the fact that parts of the system are owned, operated and maintained by two governmental entities, the City and DELCORA. DELCORA owns, operates and maintains the parts of the system that convey wastewater, such as the street sewers, collectors, interceptors, and CSO regulators and CSO outfalls. The City owns, operates and maintains the inlets, stormwater-only sewers that connect to the combined sewer system and any stormwater-only outfalls. The City is also responsible for the maintenance and cleaning of the streets, planning, zoning, and development controls. The Chester CSO system contains 26 permitted outfalls and they discharge to three receiving water bodies: the Delaware River, Chester Creek, and Ridley Creek. However, there are only 25 CSO discharge locations, as CSO #010 discharges to the Delaware River through CSO #009. Figure 1-3 depicts the locations of CSO regulators and outfalls that are DELCORA's responsibility. Figure 1-3 also provides a sewer system characterization and illustrate the breakdown of each outfall and how each drainage area has combined sewers and separate sewers. Figure 1-4 is a schematic of the Chester CSO system and shows the outfalls and the interceptors that are connected to each CSO.

Figure 1-3: Location of Regulators and Combined Sewer Outfalls with Drainage Areas

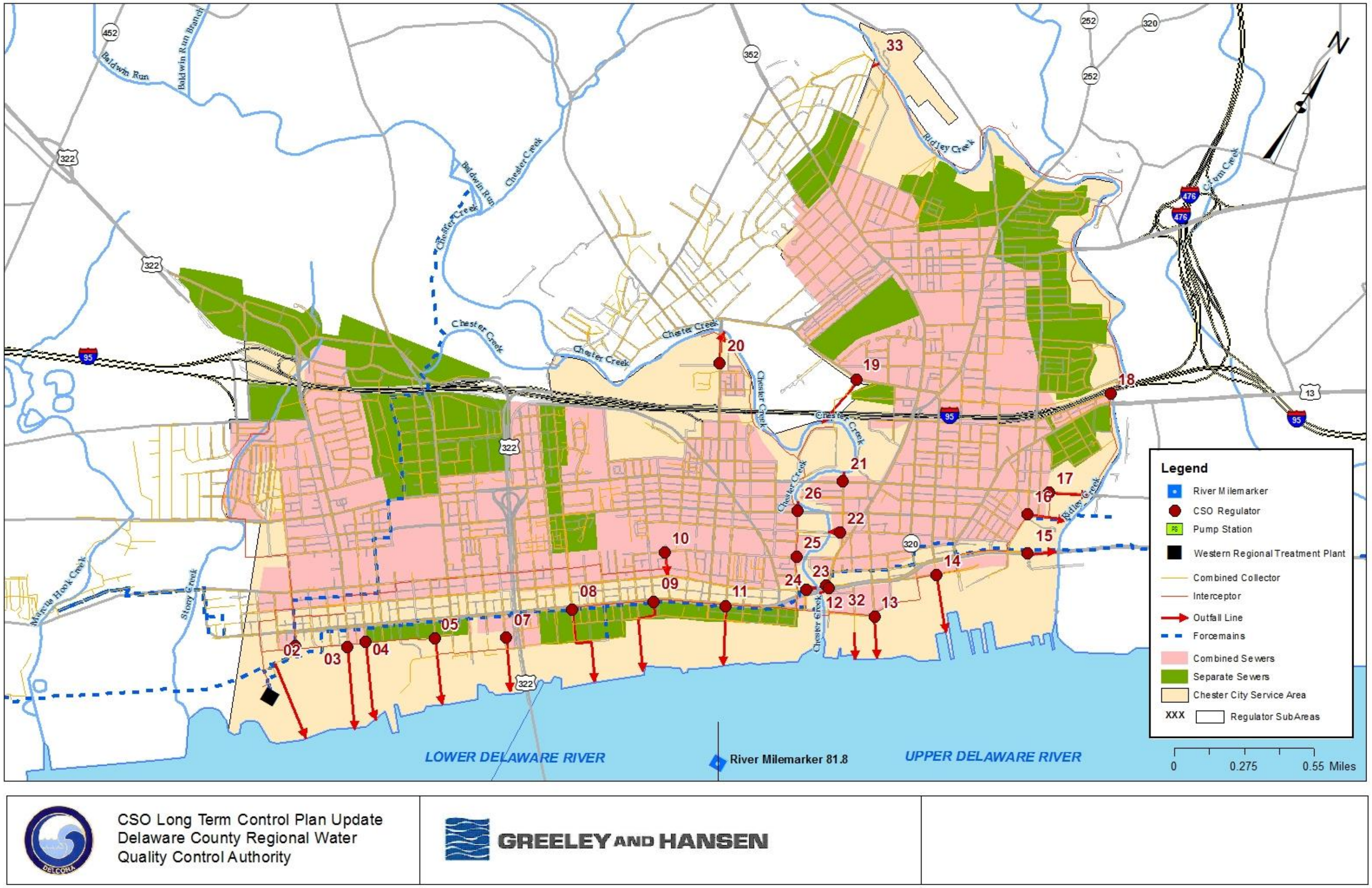
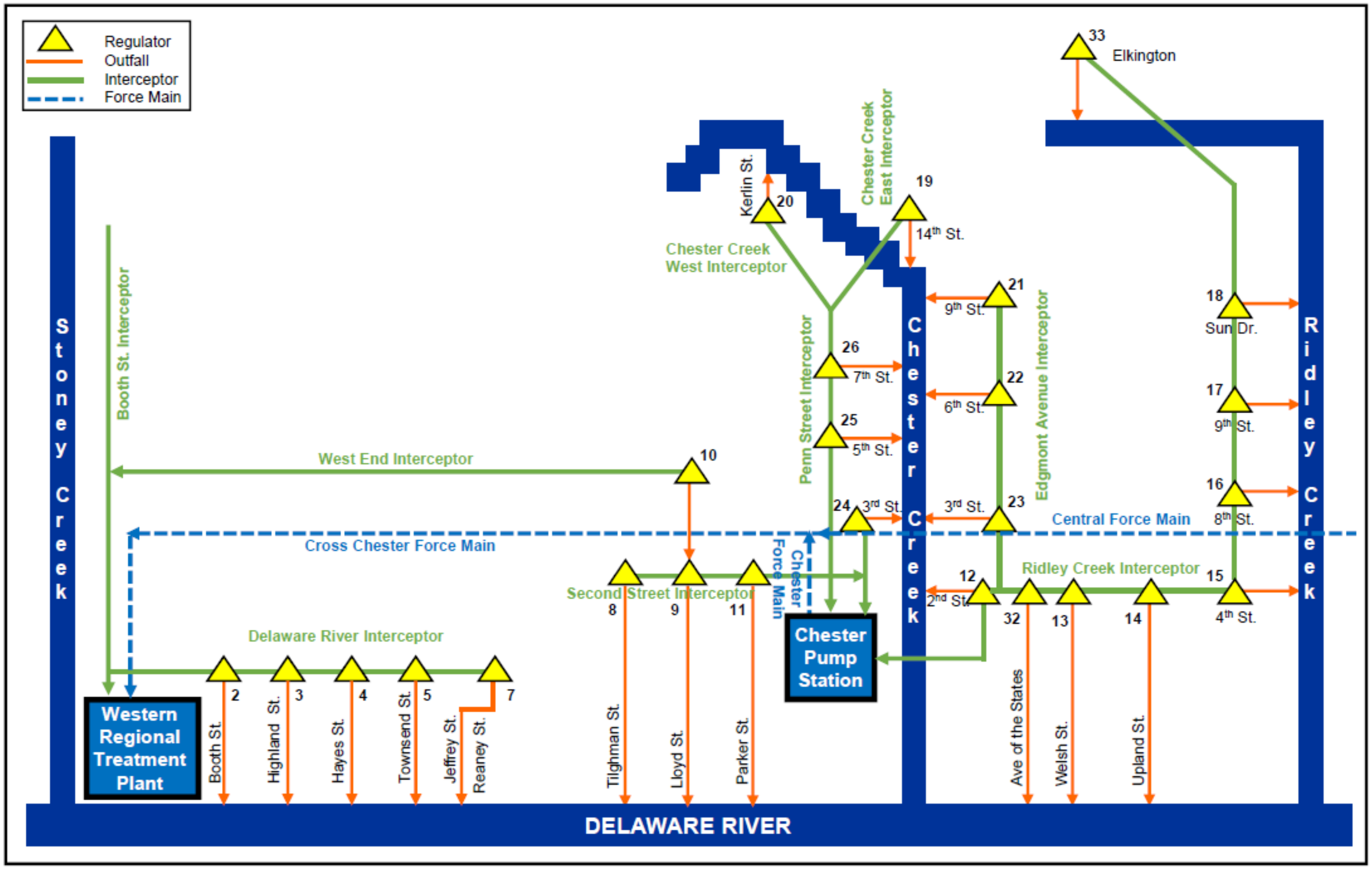


Figure 1-4: Schematic of Chester CSO System



CSO Long-Term Control Plan Delaware County Regional Water Quality Control Authority	GREELEY AND HANSEN	Figure 1-4 SCHEMATIC OF CHESTER CSO SYSTEM

1.4 Work Plan Purpose and Objectives

The purpose and objective of the Water Quality Monitoring and Modeling Work Plan is to provide a blueprint for the water quality modeling and monitoring work that will be consistent with EPA requirements as listed in DELCORA's Consent Decree.

1.5 Project Team Organization

The proposed project team organization, including key project personnel and their corresponding responsibilities, are shown in Figure 1-5.

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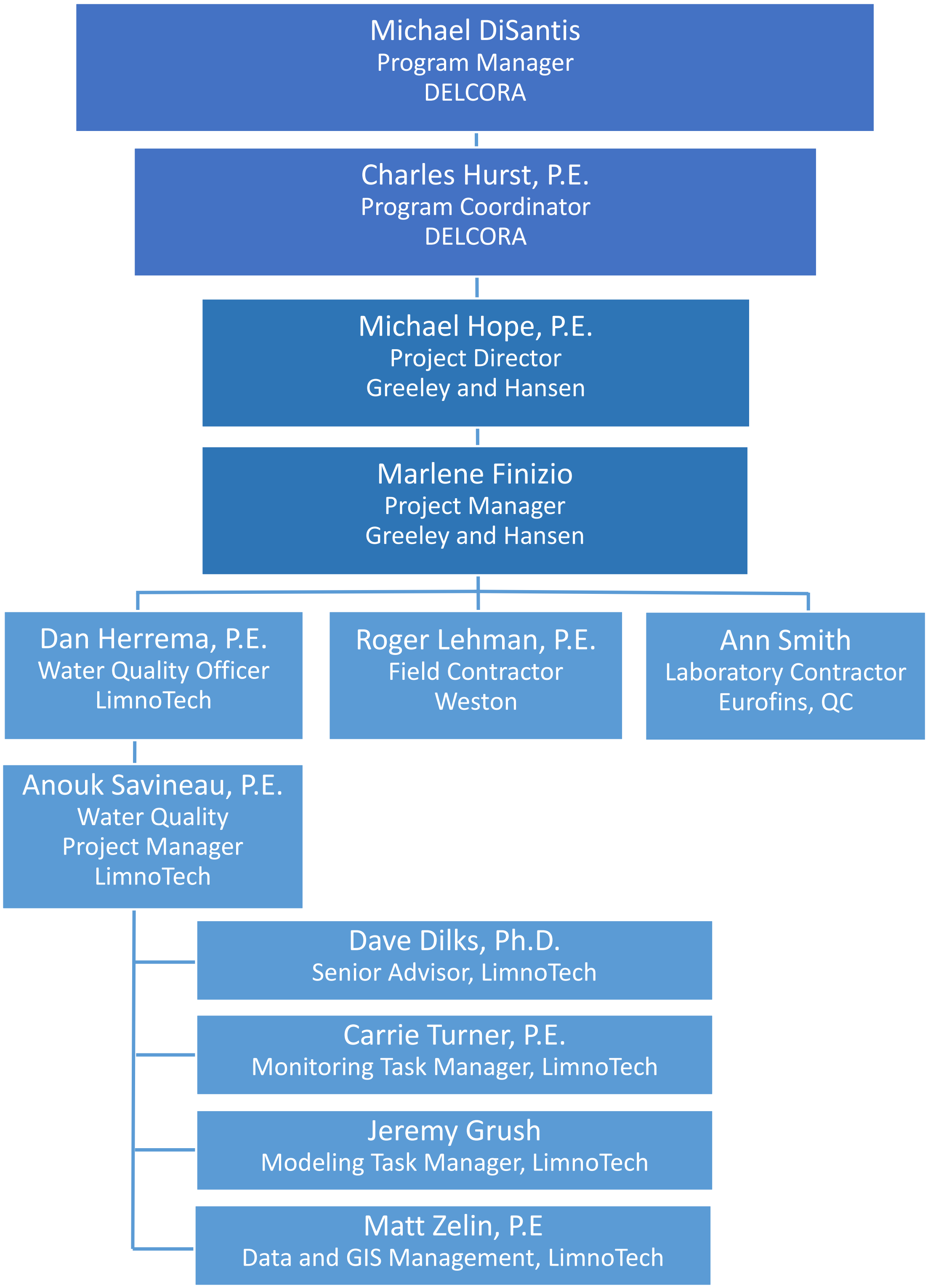
Figure 1-5: Project Team Organization



Section 2 Water Quality Model Plan

2.1 Regulatory Requirements

2.1.1 Consent Decree Requirements

The Consent Decree was lodged in the United States District Court for the Eastern District of Pennsylvania on August 17, 2015, and was approved by the Federal District Court on November 10, 2015. The Consent Decree requires DELCORA to complete and submit a revised and updated LTCP to the USEPA and the PADEP for review and approval. Consent Decree Paragraph V.A.15 (Water Quality Model Plan) requires that within ninety (90) days after EPA reviews and approves the Alternatives Evaluation Approach, DELCORA shall submit to EPA and PADEP a Water Quality Model Plan for review and approval. For each water body[1] in which the Demonstration Approach is to be used, the Water Quality Model Plan shall address:

i. Background, Scope and Purpose, Description of System;

ii. Water quality modeling software to be employed;

iii. Model configuration and development, including reaches to be modeled, and segmentation and boundary conditions;

iv. Calibration and validation (dry weather and wet weather, including events and data to be employed, detailed information regarding all additional data collection activities (if needed), quantitative and qualitative calibration criteria, and utilization of H&H Model outputs;

v. Use of the Water Quality Model to evaluate Typical Year instream conditions for each identified pollutant of concern;

vi. Schedule for model development and implementation, including integration into LTCP development consistent with other dates required pursuant to the Consent Decree.

The Consent Decree further specifies that within sixty (60) days after the approved Water Quality Model Plan is fully implemented according to the schedule included therein, DELCORA shall submit to EPA and PADEP a Water Quality Model Report for review and approval pursuant to Section VI (Review and Approval of Submittals) which shall specifically address each item set forth in Paragraph 15(a)(i)-(vi).

[1] Water bodies include the Delaware River, Chester Creek and Ridley Creek.

2.2 Model Selection/Software

This section describes the objectives and criteria used to select the appropriate modeling approach and model software.

2.2.1 Objectives

The objective of the water quality modeling is to assess the impacts of the DELCORA combined sewer system overflows on the bacteria concentrations in the receiving waters, both under existing conditions and future LTCP alternatives conditions, and assess these impacts against applicable water quality standards. In order to achieve these objectives, a linked CSO, watershed, and receiving water model will be created. The CSO model, also called the “H&H” model, is currently being developed for the Long Term Control Plan, with calibration and validation to be completed in April 2017. The H&H model is designed to simulate CSO discharges from the DELCORA service area within the City of Chester. The watershed model is a new model that will be created to model the non-CSO areas that are within the DELCORA service area and the extent of the receiving water model. The receiving water quality model is also a new model that will be developed to simulate the bacteria concentrations in the receiving waters, including the Delaware River, Chester Creek and Ridley Creek. The receiving water quality model will account for bacteria load contributions from various sources such as upstream, CSO, and stormwater loads, as well as processes that account for bacteria transport and decay.

There are several objectives to consider when selecting appropriate modeling software for the watershed and receiving water model, including:

- Technical objectives: Can the model software adequately represent the physical, chemical, and temporal characteristics of the project site? Can it address the complexities of the project site without being overly complex or overly simplistic?
- Regulatory objectives: Can the model software produce results that can be used to evaluate water quality against applicable water quality standards? Does it have a proven track record with similar regulatory projects? Will it help fulfill regulatory requirements as described in the Consent Decree?
- User objectives: Does the end user have the necessary hardware and expertise to properly apply the model software to its fullest potential? Are there financial constraints to be considered with the model?

These objectives and how they were applied to select the watershed and receiving water models are further described in sections 2.2.3 and 2.2.4 respectively. The selection of the CSO H&H model was previously described in the H&H Model Update and Calibration Plan (DELCORA, 2015).

2.2.2 Review of Existing Studies

There have been numerous water quality modeling studies performed on the Delaware River and its associated tributaries. Some of these studies were used to inform the DELCORA work plan, and may be used in the future to further inform or develop the water quality modeling and monitoring efforts. A brief overview of these studies is provided below.

- The Philadelphia Water Department's "Tidal Waters Water Quality Model for Bacteria and Dissolved Oxygen Model" was completed in June 2015 (PWD, 2015) using EFDC as the model framework. The model was developed in response to requirements in the 2011 Consent Order and Agreement between the Pennsylvania Department of Environmental Protection (PDEP) and the Philadelphia Water Department (PWD). The objectives of the model were to represent bacteria and DO in the tidal receiving waters. The model's extent is from the head of tide at Trenton, New Jersey to near Delaware City, Delaware. Also included were 28 tributaries to the Delaware River including eight miles of the tidal portion of the Schuylkill River.
- The Delaware River Basin Commission's "DYNHYD5 Hydrodynamic Model (Version 2.0) and Chloride Water Quality Model for the Delaware Estuary" was completed in December 2003 (DRBC, 2003). The model was used for the development of the Stage 1 TMDLs for polychlorinated biphenyls (PCBs) for the Delaware River Estuary. The model's extent is from Trenton, NJ to the Mouth of the Delaware River. PCBs and chloride were the only water quality parameters modeled. Note that DRBC is currently evaluating the nutrient criteria strategy for the Delaware River and has an initiative to create a new eutrophication model to address dissolved oxygen issues in the river (DRBC, 2012). The new model would include an improved hydrodynamic model of the tidal Delaware River and a dissolved oxygen and nutrient water quality model.
- The University of Delaware's Center for Applied Coastal Research developed a "Hydrodynamic Model of Delaware Bay and the Adjacent Coastal Region" (UD 2011) using the Regional Ocean Modeling System (ROMS) framework. The latest model update was performed in 2011, with other similar studies performed since the 1990s. The purpose of this model is further characterize the hydrodynamics of the Delaware Bay and surrounding area. Salinity is the only water quality parameter modeled. The models domain extends into the offshore into the Atlantic Ocean and into the Delaware Bay.
- Hydraulic models have also been created for the purpose of FEMA's National Flood Insurance Program to analyze risk of flooding. These models were developed for FEMA by federal contractors. For Chester and Ridley Creek, the most recent modeling effort is likely from the 1970's. These models were only used to assess flood risk so no water quality parameters are modeled. The model extent for these two creeks extends from their confluence with Delaware River upstream into Delaware County.

Limited topographic and bathymetric surveys were performed for these models which will be useful in characterizing the bathymetry of Chester and Ridley Creek.

2.2.3 Watershed Model Selection

Many watershed model software packages are available and these models vary in their recognition by USEPA and their applicability to the Delaware River and its tributaries. The proposed watershed model framework for this project is EPA Storm Water Management Model (SWMM), which is supported by the USEPA and has been successfully applied by the project team at similar sites and for related purposes, including in East Rutherford, NJ, Washington, DC, and Richmond, VA. SWMM is a dynamic rainfall-runoff simulation model used for single event or continuous simulation of runoff quantity and quality from primarily urban areas (USEPA, 2015). A review of the Chester Creek and Ridley Creek watersheds using the USGS StreamStats[2] tool show that these two watersheds are 42% and 37% urban respectively. Additionally, the current H&H model for the DELCORA service area is also built using the SWMM software, so choosing SWMM for the watershed model provides consistency in the suite of models used by DELCORA.

A variety of enhanced SWMM platforms are available that integrate the EPA SWMM software with user friendly interfaces and GIS capabilities. For this project, PCSWMM, developed by CHI, will be used. Once the watershed model is built, the model files can be provided as PCSWMM or EPA SWMM files.

2.2.3.1 Attributes

The main attributes of the proposed watershed model are that it will be able to predict dry and wet weather flows and associated bacteria loads. The watershed model will provide necessary spatial resolution to account for different subcatchment physical characteristics such as slope, imperviousness, length and width, and soils. Additional, it will be able to predict variations in timing, peak flows, and flow volumes.

The inputs and outputs of the SWMM model are described in more detail in the following section.

2.2.3.2 Inputs and Outputs

Model inputs are site-specific estimates of environmental conditions or assumptions that influence modeled water quantity and quality. Model outputs are results of model calculations that describe conditions related to water quantity and quality. Table 2-1 describes the SWMM watershed model inputs and outputs that will be used for this project.

[2] http://water.usgs.gov/osw/streamstats/

Table 2-1: Watershed Model Inputs and Outputs

Process	Inputs	Outputs
Runoff Calculations	Area, width, imperviousness, slope, roughness, depression storage, soil infiltration, meteorology (precipitation, temperature)	Catchment runoff volume and flow rate, hydrograph of flow vs. time.
Water Quality Calculations	Event Mean Concentration for stormwater and CSO outfalls	Bacteria concentrations in dry and wet weather flows, pollutographs of pollutant concentration vs. time
Routing Calculations	Pipe and/or channel geometry, slope, roughness.	Dry and wet weather flow volumes and rates, hydrographs of flow vs. time

The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads according to their landuse, landcover, and soil characteristics (USEPA, 2014). Additional information on the main model inputs that will have to be defined for the runoff component of SWMM are shown in Table 2-2.

Table 2-2: SWMM Runoff Model Inputs

Inputs	Source of Information
Area	Delineated in GIS using topography and sewer network data
Width	Calculated in GIS based on the watershed delineation
Slope	Calculated in GIS using topography
Imperviousness	Calculated in GIS using NLCD data or estimated from landuse data
Roughness	Based on published values for impervious and pervious area
Depression Storage	Based on published values for different land covers
Soil Infiltration	Based on soil data and characteristics published by USGS (SSURGO). The Horton method is the preferred method to account for infiltration losses for this project.
Meteorology	Precipitation, temperature, evaporation data obtained from nearby weather stations

To calculate the bacteria loads associated with the watershed flows, bacteria event mean concentrations (EMCs) will be assigned to the flows. An EMC represents the average pollutant (bacteria) concentration present in runoff. The appropriate EMCs will be obtained through the sampling efforts as described in Section 3.

For the purpose of this project, the predicted runoff from the watershed model will be directly connected to the receiving water quality model. In other words, routing through the pipe/channel system will not be simulated unless the calibration of the receiving water model demonstrates a need for additional resolution in flow timing is needed. If explicit routing is needed, pipe and/or channel attributes such as slope, roughness, or cross-sectional geometry will be obtained from DELCORA or field studies. Routing would further be accomplished by applying the kinematic or dynamic wave routing method.

2.2.4 Receiving Water Quality Model Selection

Many water quality model frameworks are available and these models vary in their recognition by USEPA, adaptability for project-specifics needs, and their applicability to the Delaware River and its tributaries. The proposed water quality model framework for this project is EFDC (Environmental Fluid Dynamics Code), which is supported by the USEPA and has been successfully applied by the project team at similar sites and for related purposes. It may be beneficial to couple EFDC with another model to reduce simulation run times. EFDC could be used to compute hydrodynamics and those results could be linked to the RCA (Row-column AESOP) water quality model for water quality calculations. This potential approach would reduce model run times by allowing for a longer time step and for a smaller water quality model extent. RCA, like EFDC, is a highly regarded water quality model that has been applied at numerous sites.

EFDC is a state-of-the-art finite difference model that can be used to simulate hydrodynamic and water quality behavior in one, two, or three dimensions in riverine, lacustrine, and estuarine environments (TetraTech 2007a, 2007b). The model was developed by John Hamrick at the Virginia Institute of Marine Science in the 1980s and 1990s, and it is currently maintained under support from the USEPA. The model has been applied to hundreds of water bodies, including Chesapeake Bay and the Delaware River. Recently, LimnoTech has successfully applied EFDC to a number of estuarine sites including Newark Bay, East Rutherford, NJ, and San Diego Bay. The EFDC model is both public domain and open source, meaning that the model can be used free of charge, and the original source code can be modified to tailor the model to the specific needs of a particular application. As a result, EFDC provides a powerful and highly flexible framework for simulating hydrodynamic behavior and water quality dynamics for the Delaware River and Chester Creek and Ridley Creek.

The RCA model is a part of a family of generalized water quality models developed by HydroQual, Inc. and known as AESOP (Advanced Ecological Systems Operating Program) (HydroQual, 2004). The RCA model framework is capable of simulating water quality dynamics on a fine-scale, multi-dimensional computational grid based on linkage to an external hydrodynamic model application. RCA is specifically designed to interface with the EFDC model via a series of binary files generated by the latter model. The general transport fields predicted by EFDC (or another hydrodynamic model) are used by RCA to advect and disperse water quality constituents throughout the water column.

2.2.4.1 Attributes

To compute the movement (transport) and concentrations of pollutants, a water quality model must represent the primary physical and kinetic processes that influence transport and pollutant concentrations. It is anticipated that the following processes will be necessary to represent in this model application:

- Loading of local bacterial pathogens from the watershed, MS4s, CSOs, treatment plant(s), and other known sources to Chester Creek, Ridley Creek, and the Delaware River;
- Transport of pathogens from the riverine portions of creeks to the Delaware River estuary;
- Transport of pathogens via tidal currents and mixing within the Delaware River estuary; and,
- Net losses of pathogens during transport.

These attributes are described in more detail in the following section.

2.2.4.2 Inputs and Outputs

Model inputs are site-specific estimates of environmental conditions or assumptions that influence modeled water quality. Model outputs are results of model calculations that describe conditions related to water quality. Table 2-3 below describes model inputs and outputs relating to the primary physical and kinetic processes described in the previous section.

Table 2-3: EFDC Model Inputs and Outputs

Water Quality Model Process	Related Inputs	Related Outputs
Bacterial pathogen loadings	Pollutant concentrations for: • Delaware River boundaries • Chester Creek upstream watershed • Ridley Creek upstream watershed • CSOs • MS4 areas • WWTPs	• Pollution in-stream concentrations
Transport of pathogens within the riverine portions of creeks	Flow rates for: • Creeks • CSOs • MS4 areas • WWTPs Stream bathymetry	• Water depths and velocities in the creeks
Transport of pathogens via tidal currents and mixing within the Delaware River estuary	• Delaware River and major tributary flow rates, • Tidal water levels, and • Delaware River bathymetry	• Water depths and velocities in the Delaware River
Net losses of pathogens during transport	• First order bacteria decay rate • Water temperatures • Parameters influencing dependence of decay on water temperature	• Pollutant in-stream concentrations

2.2.5 Data Sources

Table 2-4 below describes data sources that are expected to help inform model inputs relating to the primary physical and kinetic processes described above.

Table 2-4: Data Sources Supporting Model Inputs

Water Quality Model Process	Related Inputs	Data Sources
Bacterial pathogen loadings	Pollutant concentrations for: • Creeks • CSOs • MS4 areas • WWTPs	• Bacterial pathogen concentration data (existing data and data proposed in Section 3 of this work plan to be collected) • WWTP DMR (discharge monitoring report data) • Literature-based event mean concentration data
Transport of pathogens within the riverine portions of local creeks	Flow rates for: • Creeks • CSOs • MS4 areas • WWTPs Stream bathymetry	• USGS flow data • Collection system model overflow rates • Watershed model flow rates • Bathymetric data
Transport of pathogens via tidal currents and mixing within the Delaware River estuary	• Delaware River and major tributary flow rates • Tidal water levels • Delaware River bathymetry	• USGS flow data • NOAA water level data • NOAA Delaware River bathymetric data
Net losses of pathogens during transport	• First order bacteria decay rate • Water temperatures • Parameters influencing dependence of decay on water temperature	• USGS and/or NOAA water temperature data • Bacterial pathogen concentration data (existing data and data proposed in Section 3 of this work plan to be collected)

2.3 Model Development and Configuration

2.3.1 Watershed Model

The watershed model will be developed and configured in order to calculate the runoff and bacteria loads generated by the Ridley Creek and Chester Creek watersheds, as well as by the separate stormwater areas within the DELCORA service area.

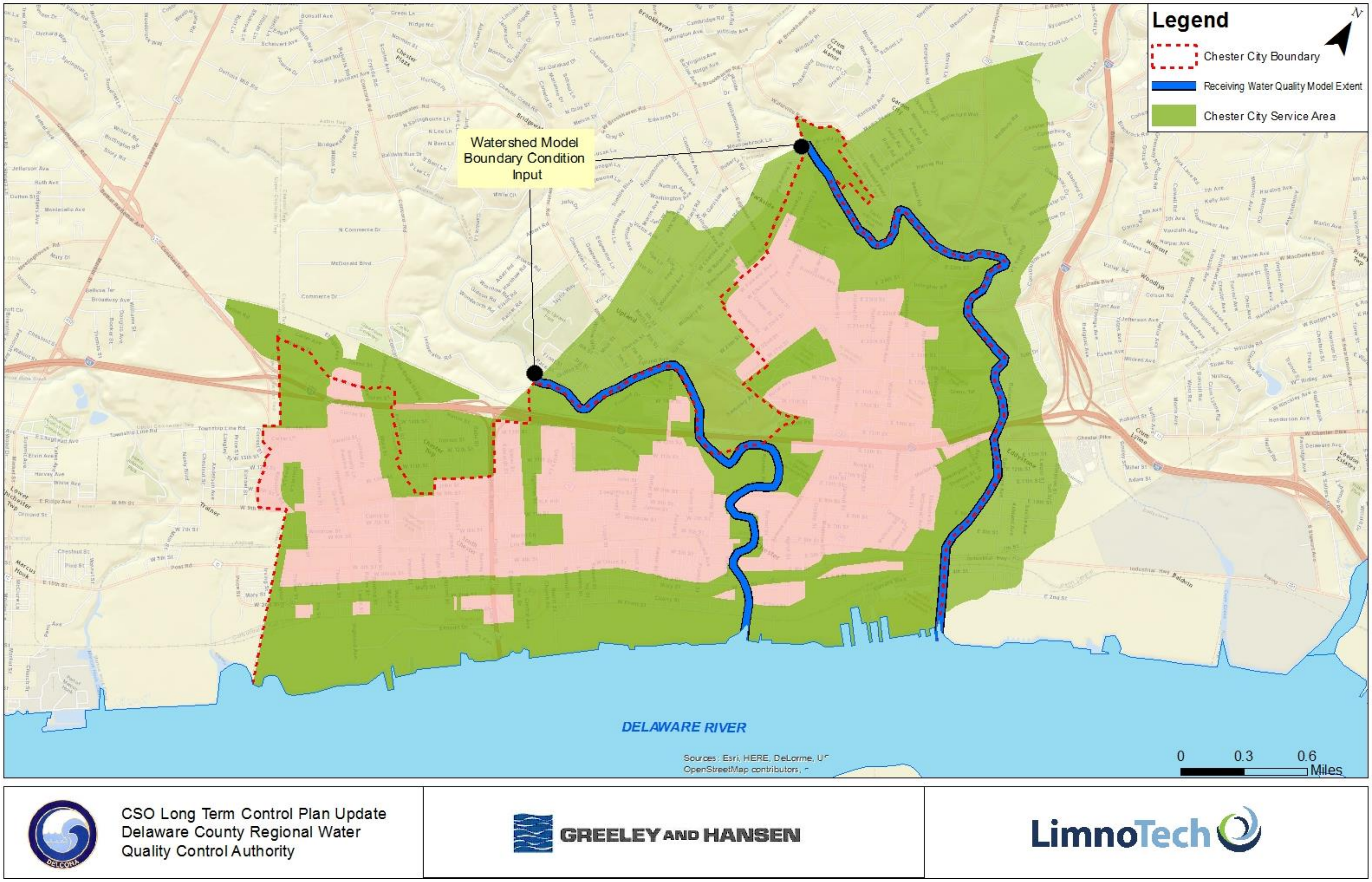
2.3.1.1 Extent

The flows and bacteria loads from the upstream portion of the Ridley Creek and Chester Creek watershed area will be represented through the use of boundary conditions. These boundary conditions will be determined through an analysis of USGS flow gage data and bacteria monitoring data. The portions of the Ridley Creek and Chester Creek watersheds that are within the DELCORA service area (and a small area upstream of the DELCORA service area) will be explicitly modeled using SWMM. Figure 2-1 below shows the extent of the proposed watershed model.

2.3.1.2 Segmentation

As described in the section above, the Ridley Creek and Chester Creek watersheds will be divided into upstream and downstream areas. The upstream area will be represented through the use of boundary conditions that describe the flow and load that are generated from the upstream area under different meteorological conditions. The downstream area will be divided into relatively small and homogenous catchments.

Figure 2-1: Proposed Extent of the Watershed Model



2.3.2 Receiving Water Quality Model

A few considerations guide the design of a receiving water quality model. First, models are designed to cover the locations of interest with respect to site-specific management questions. Second, the spatial extent of a model should be chosen to allow for accurate calculations of transport. This requires that the model's edges (boundaries) occur at locations where environmental conditions (e.g. flow rates) are well known and readily defined. For instance, it is often beneficial to locate a model boundary at the head of tide where tidal flows are zero, or at a monitoring location where tidal water levels are known. Third, an appropriate spatial resolution should be determined to balance the level of detail in the model against the run times of simulations. Finally, the model boundaries should be sufficiently distant from the source such that the pollutant mass assumptions from these boundaries would not significantly affect conditions simulated in the area of interest. The proposed model extent and spatial resolution are described in the following sections.

2.3.2.1 Extent and Reaches

On the Delaware River, we propose that the receiving water model extends from NOAA station 8551762 (Delaware City, DE) to the head of tide at Trenton near USGS station 01463500 (Delaware River at Trenton, NJ). Environmental conditions at these locations are well defined by data and the locations are sufficiently far from Delaware County that model results are not expected to be strongly influenced by water quality assumptions at the boundaries.

We propose that the receiving water model extends through the tidally influenced portion of the creeks and through all reaches adjacent to the DELCORA combined sewer system. This is because the receiving water model is better suited for representing tidal conditions at the mouth of the creeks than the watershed model, and representing CSOs exclusively in the receiving water model simplifies the modeling process. Tidal transport will likely influence the duration of time that pathogen sources influence the lower reaches of each creek. In some cases, it may be beneficial to extend the model farther in to the creeks (i.e. upstream of the tidally influenced reaches) to a sampling or monitoring location.

2.3.2.2 Segmentation

The segmentation of a model defines the degree of spatial detail in the model results and also determines how much time is required for a simulation to run. Determining an appropriate degree of spatial detail is related to both the detail necessary to address management questions and the degree of detail necessary to accurately model the processes of an environmental system. Occasionally, model segmentation must be iteratively refined during the model development process to reach a suitable degree of detail.

We propose that the receiving water quality model have roughly the following characteristics:

- Five to ten cells spanning the Delaware River cross section;
- One cell spanning the cross section of each creek;
- 2,000 to 4,000 total grid cells within the model extent;
- Typical Delaware River cell dimensions of roughly 150-300 feet (width) by 1,000 to 2,000 feet (length). Typical creek cell lengths of 200 to 400 feet; and,
- Five cells spanning the water depth.

The Delaware River is relatively deep (30-40 feet deep) near the location of maximum DELCORA impact, so a three-dimensional model is recommended for computing near-surface pathogen concentrations, which are occasionally elevated relative to those at greater depths due to discharge of CSOs near the water surface. A depth-averaged (two-dimensional) model would instantaneously mix pollutant concentrations over the water depth and understate near-surface concentrations.

2.3.2.3 Linkage with CSO (H&H) Model

The CSO H&H model will be linked to the receiving water quality model. The H&H model will be run for the calibration period as well as for each CSO alternative of interest, and CSO outfall results will be inserted into the EFDC model at the appropriate grid location in EFDC.

2.3.3 Linkage with Watershed Model

The watershed model will be linked to the receiving water quality model. The watershed model will be run for the appropriate meteorological period and results will be inserted into the EFDC model at the appropriate grid locations in EFDC.

2.3.4 Water Quality Parameters

The water quality parameters that will be evaluated in the water quality model are fecal coliform bacteria, *Enterococcus* bacteria, and *Escherichia coliform* (*E. coli*). These parameters are discussed in detail in the Identification of Sensitive Areas and Pollutants of Concern Report (DELCORA, 2016).

2.3.5 Boundary Conditions

Boundary conditions define environmental conditions at the edges of the model spatial domain and influence model calculations within the model domain. Boundary conditions will be used in both the watershed model and receiving water quality model.

Two types of boundary conditions are required in the watershed model: flow boundary conditions and water quality boundary conditions. As explained in Section 2.3.1, the flows and loads from the upstream portion of the Ridley Creek and Chester Creek watersheds will be represented through the use of boundary conditions. These boundary conditions will be determined through the analysis of USGS flow gage data and bacteria monitoring data. The flow and bacteria boundary conditions will vary according to meteorological and seasonal conditions.

Two types of boundary conditions are also required in the receiving water quality model: hydrodynamic boundary conditions and water quality boundary conditions. Hydrodynamic boundary conditions will include a water level boundary condition, which will define how water levels vary with the tides and other atmospheric conditions, and inflow boundary conditions, which will define flow rates into the model from freshwater sources such as from the Delaware River above Trenton, major tributaries, creeks of interest, MS4s, CSOs, and treatment plants. Water quality boundary conditions define the pollutant concentrations associated with all inflows to the model. Water quality boundary conditions will be defined based on the available sampling data for all pollutant sources of interest.

2.4 Model Calibration and Validation

Model calibration is described in USEPA guidance (USEPA, 1994) as the "process of adjusting model parameters within physically defensible ranges until the resulting predictions give the best possible fit to the observed data." Calibration will occur for the runoff and water quality components of the watershed model, as well for the hydrodynamic and water quality components of the receiving water quality model. Calibration will occur through the use of available monitoring data.

2.4.1 Calibration Objectives

The objectives for the hydrodynamic model calibration are to determine a set of model inputs (primarily bed roughness and turbulent mixing parameters) that produce model results consistent with the observed data. During the hydrodynamic model calibration, comparisons between modeled and observed water surface elevations and velocities will be made. The comparisons will allow for any adjustments to be made.

The objectives for the water quality model calibration are to interpret the water quality data to improve initial estimates of pollutant loads and potentially constrain assumptions related to bacterial decay. For instance, model tests would be run with different assumptions about pollutant concentrations in combined sewer overflows. Those tests would be evaluated for consistency with the receiving water sampling data to determine a range of pollutant concentration assumptions that are supportable. Likewise, model tests would be run with different assumptions about bacterial decay, and those tests would be evaluated to refine inputs related to decay.

2.4.2 Data for Calibration/Validation

Data available for the hydrodynamic model calibration include NOAA water level and velocity data, and USGS water level and flow data. Primary hydrodynamic model calibration stations include the following NOAA stations:

- Water level gages: #8540433 (Philadelphia, PA), #8546252 (Bridesburg, PA), #8539094 (Burlington, NJ), and #8548989 (Newbold, PA).
- Current velocity meter: Station dB0301 (Philadelphia, PA).

Model results will be compared to hourly water level and current velocity data at these locations.

Data available for the water quality calibration are pathogen grab sample data. Section 3 of this work plan summarizes the currently available water quality data by sample location. We propose to supplement these data with an additional sampling program described in Section 3 of this work plan.

2.4.3 Calibration Criteria

Hydraulic calibration will primarily focus on reproducing observed water levels and current velocities in the Delaware River. This approach provides a robust calibration by focusing on the hydraulic attributes that are the primary dependent variables of the hydrodynamic model. Calibration goodness will be determined by qualitative visual comparison of model and data time series, one-to-one plots, and cumulative frequency distributions (CFDs). Calibration will involve adjustment of the roughness height to values that best replicate water level and velocities at NOAA stations.

Bacteria models are often evaluated qualitatively with multiple tools such as time series plots, CFDs, and 1:1 plots. Because bacteria concentrations vary over many orders of magnitude and sources can be numerous, distributed, and highly variable with time, bacteria model results are not often held to quantitative calibration criteria. Instead, a rule of thumb is that modeled bacteria concentrations should mostly be consistent with observed bacteria concentrations within an order of magnitude. Agreement of model and data within a factor of two indicates a high degree of model performance.

2.4.4 Model Sensitivity

Model sensitivity tests complement and illustrate the model calibration. Model sensitivity tests are model simulations in which uncertain inputs are varied to assess their significance in determining, for instance, pollutant concentrations. These tests are useful for evaluating whether the model calibration is optimized within the limits of the available data, and for identifying uncertainty in significant model inputs. For instance, model sensitivity tests varying the assumed CSO pollutant concentrations would illustrate how a range of assumptions are more or less consistent with stream sampling data.

Model sensitivity tests will be conducted for the following inputs:

- Major pollutant loads (including at least CSO, MS4, and local watershed loads).
- Parameters influencing bacteria decay rates.

Results of model sensitivity tests will be summarized using plots such as CFDs, box plots, or time series plots.

2.5 Model Typical Year Application

An evaluation of the typical hydrologic period was conducted for DELCORA and is detailed in the report entitled "Typical Hydrologic Period Report" (DELCORA, 2016). The typical year that will be applied to evaluate CSO scenarios will also be used for the receiving water quality model. The recommended period for typical year application is 1994-1996.

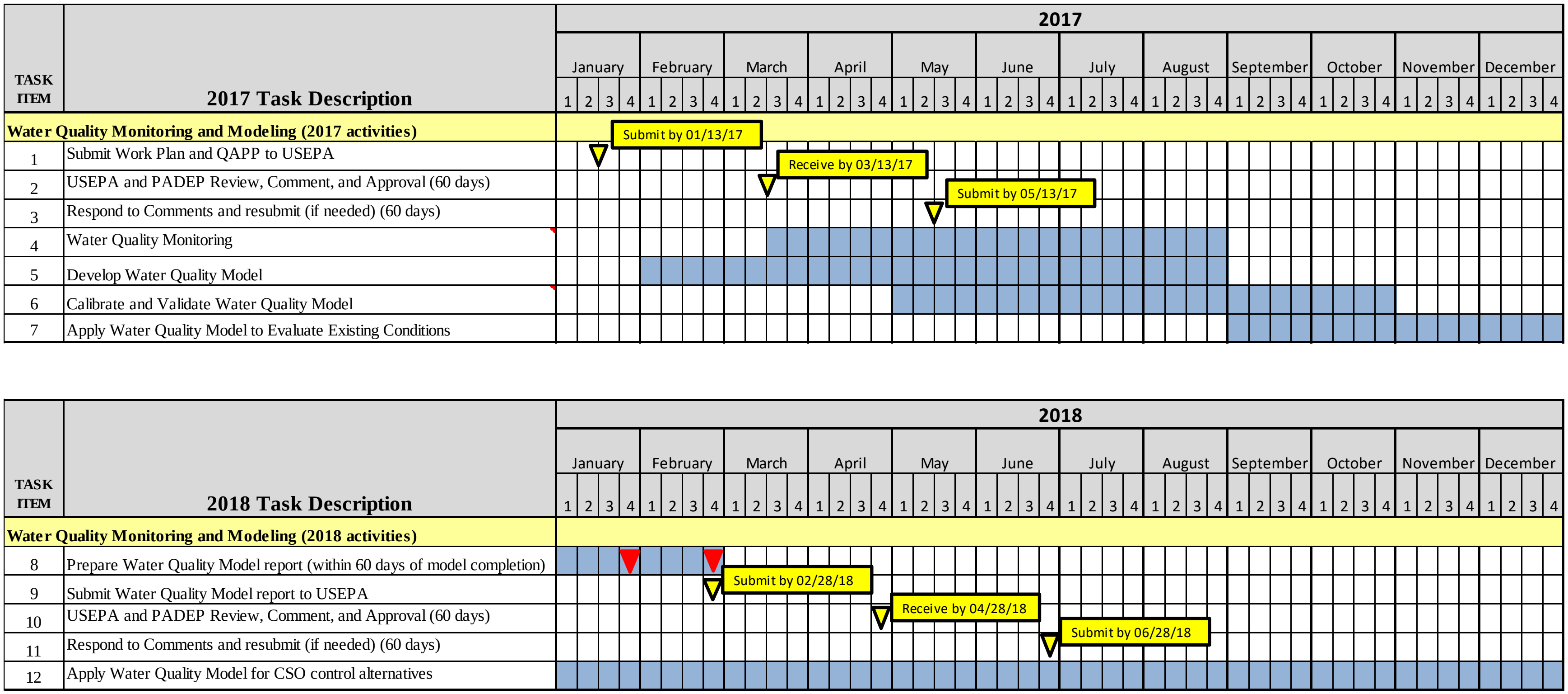
2.6 Model Development Schedule

The schedule for model development and application is shown in Figure 2-2 below. All tasks related to the water quality modeling development and application are included in the schedule. The schedule is integrated into the LTCP development consistent with other dates required to the Consent Decree.

2.7 Model Documentation

A report will be provided that summarizes the development, calibration, application, and results of the receiving water model. In accordance with the Consent Decree, this report will be submitted to EPA and PADEP within sixty (60) days after the approved Water Quality Model Plan is fully implemented according to the schedule included herein.

Figure 2-2: Schedule for Model Development and Application



NOTES:

- Consent Order Deadline
- Draft and Final Submittals

Section 3 Monitoring Work Plan

3.1 Regulatory Requirements

3.1.1 Consent Decree Requirements

On August 17, 2015, a Consent Decree was lodged in the United States District Court for the Eastern District of Pennsylvania that requires DELCORA to complete and submit a revised and updated LTCP to the United States Environmental Protection Agency (USEPA or EPA) and the Pennsylvania Department of Environmental Protection (PADEP or DEP) for review and approval. Consent Decree Paragraph V.A.10.e and V.A.10.f require that the development of the LTCP include

V.A.10.e. Develop and implementation of a Water Quality Model

V.A.10.f Characterization of the service area and the Receiving Waters as required by CSO Control Policy Paragraph II.C.1 and associated guidance.

Consent Decree Paragraph V.A.15 (Water Quality Model Plan) requires that within 90 days after review and approval of the Alternatives Evaluation Approach, DELCORA shall submit a report to the USEPA and PADEP that describes the use of the Water Quality Model to support the Demonstration Approach consistent with Section II.C.4 of the CSO Control Policy and the Paragraph V.13 of the Consent Decree (Alternatives Evaluation). Section V.A.15.a of the Consent Decree specifically states:

For each water body in which the Demonstration Approach is to be used, the Water Quality Model Plan shall address:

(i) Background, Scope and Purpose, Description of the System;

(ii) Water quality modeling software to be employed;

(iii) Model configuration and development, including reaches to be modeled, and segmentation and boundary conditions;

(iv) Calibration and validation (dry and wet weather), including events and data to be employed, detailed information regarding all additional data collection activities (if needed), quantitative and qualitative calibration criteria, and utilization of H&H Model outputs;

(v) Use of the Water Quality Model to evaluate Typical Year in-stream conditions for each identified pollutant of concern;

(vi) Schedule for model development and implementation, including integration into LTCP development consistent with other dates required pursuant to this Consent Decree.

3.3 Existing Water Quality Monitoring Overview

The Water Quality Monitoring Program (WQMP) is designed to collect data that will be used to assess water quality concerns identified in the Delaware River watershed and its tributaries, Chester Creek and Ridley Creek, in the vicinity of Chester, PA. Pollutants of concern (POCs) were identified in the Identification of Sensitive Areas and Pollutants of Concern Report (Greeley and Hansen, 2016). These POCs are fecal coliform, *E. coli*, and *Enterococcus* and are the primary focus of the WQMP. In completing the initial step of characterizing the watershed, historical data was compiled, reviewed and assessed to determine the need to augment existing data to address the watershed issues identified. This review indicated that one of the POCs, *E. coli*, has not been sampled in all the receiving waters and the data that have been collected for the remaining POCs are of insufficient frequency and spatial density to be useful in the modeling process.

3.3.1 Historic Sampling

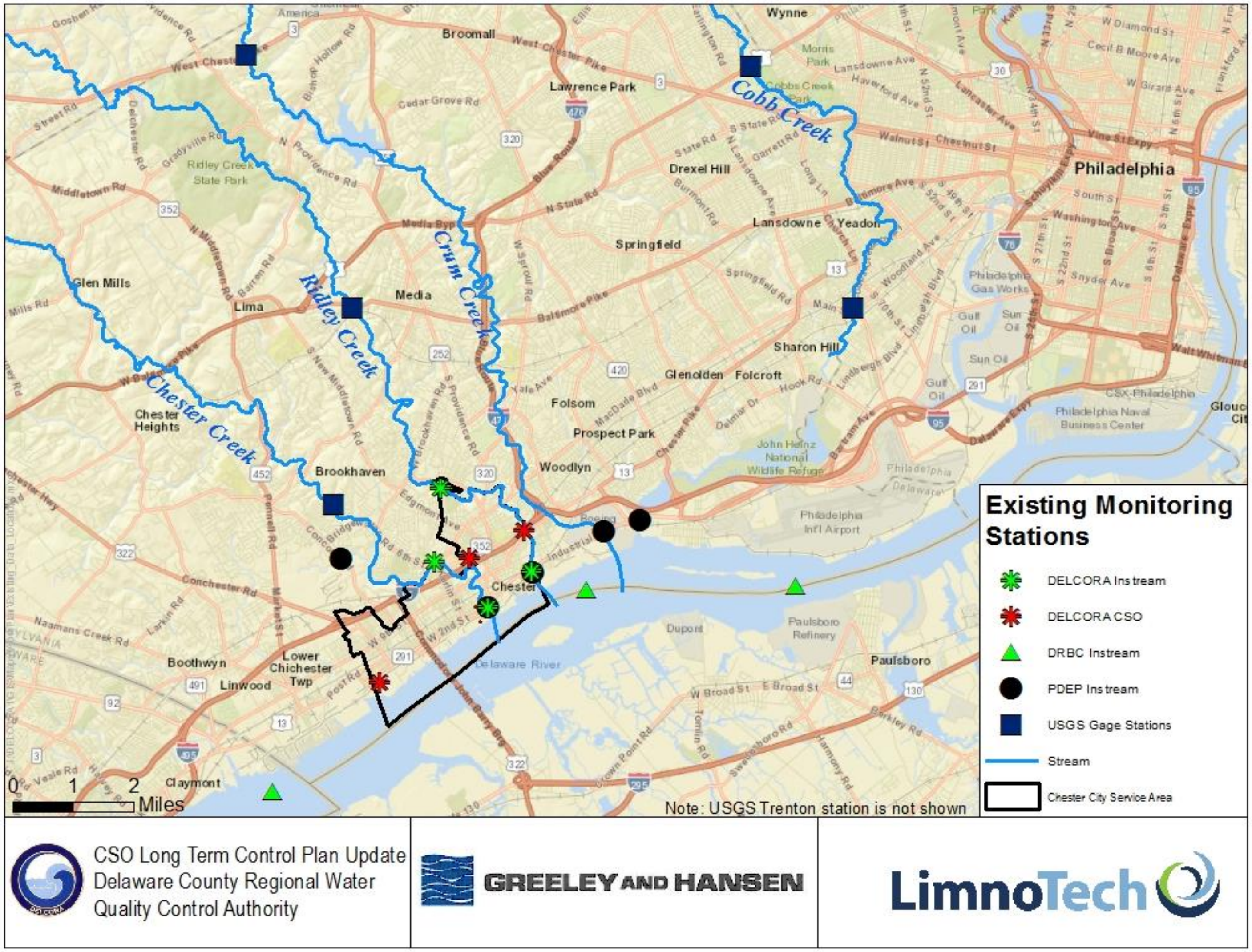
The Water Quality Model requires robust flow and water quality datasets to build confidence in its use as a tool for CSO planning. Data are needed in the modeled receiving waters for use in model calibration and validation as well as for the predominant wet weather sources, such as DELCORA's CSOs and the City of Chester's MS4 runoff to estimate pollutant loadings to the model. The existing water quality data were reviewed for their adequacy in meeting the data needs of the water quality model for the POCs (fecal coliform, *E. coli*, and *Enterococcus*). The review indicated that Chester Creek and Ridley Creek have limited POC data. Although the Delaware River has more extensive POC data, it lacks the temporal frequency needed to characterize wet weather impacts from DELCORA's CSOs. It would be difficult to constrain the Water Quality Model's representation of DELCORA's sources on the receiving waters without additional monitoring data designed specifically for calibrating and validating a robust water quality model. Existing flow data were also reviewed for adequacy; reports of mean daily stream discharge are available from several stream gages along the Delaware River and in tributaries near the DELCORA service area, ranging from as early as 1912 to the present. The existing flow and water quality data are described in this section.

Flow data for the Delaware River and tributaries in the DELCORA service area were obtained from the USGS National Water Information System. Reports of mean daily stream discharge were available from five stream gages in DELCORA service area measuring daily mean discharge: Crum Creek near Newtown Square, PA (1980-2016); Chester Creek near Chester, PA (1931-2016); Ridley Creek near Media, PA (1986-2016); Cobbs Creek at U.S. Highway No. 1 at Philadelphia, PA (1964-2016); and Cobbs Creek at Mt. Moriah Cemetery, Philadelphia, PA (2005-2016). Though not in service area, mean daily discharge data were also obtained from the gage at the Delaware River at Trenton, NJ (1912-2016) because it is expected that these data will be used to inform the upstream boundary for the hydraulic portion of the water quality model. The USGS Pennsylvania Water Science Center has conducted water quality sampling at various points in the state. However, none of their sampling locations are near to the DELCORA service area or local waterways.

Monthly effluent data from DELCORA's WWTP are available from the Pennsylvania Department of Environmental Protection's (PADEP) eDMR website (*www.dep.pa.gov/edmr*). Reported data include monthly geometric mean and instantaneous maximum values for fecal coliform from 2009 through 2016. PADEP also monitors water quality of tidal streams that empty into the Delaware River, through the Pennsylvania Water Quality Tributary Project funded by the Delaware River Basin Commission (DRBC). This program monitored for fecal coliform levels in Chester Creek, Ridley Creek, Darby Creek, Crum Creek, and others twice annually from 2007-2010. PADEP also operates the PA Surface Water Quality Monitoring Network, through which Baldwin Run (a tributary to Chester Creek) was sampled monthly for fecal coliform from 1998-1999.

The Delaware River Basin Commission operates its Boat Run program to monitor ambient, sampling for *E. coli*, *Enterococcus*, and fecal coliform at various sites along the Delaware River (Figure 3-1). Samples were collected from each station between one and three times each month from March through November every year since 1999. Through this program, data are available at three sites near DELCORA: Eddystone (2005-2016), Paulsboro (1999-2016), and Marcus Hook (1999-2016).

Figure 3-1: Historical Flow and Water Quality Sampling Locations Near DELCORA Service Area.



Since 2009, DELCORA has also done their own sampling at CSO outfall sites and in receiving waters. In 2010, a survey was conducted to measure fecal coliform levels in Ridley and Chester Creeks during wet and dry weather. There were two sample sites in each creek, and over the course of the study, six surveys were conducted. Four surveys occurred during dry weather, one during a wet event, and one during a wet event after a storm. During each survey, one sample was collected at each site. In 2009, DELCORA began sampling in the CSO system as required by their NPDES permit. Four outfalls and pump stations were sampled once annually for fecal coliform from 2009-2011, and three outfalls were sampled once annually for fecal coliform from 2012-2014. In 2015, four outfalls and pump stations were sampled for fecal coliform and *Enterococcus*, on three separate occasions. *E. coli* was not measured in any of these surveys.

The extent of existing water quality data and its adequacy to support the Water Quality Model development and calibration can be summarized as follows:

- Some CSO water quality data has been collected but mostly for fecal coliform. There are no CSO data for *E. coli*. Another limitation in the CSO data is that the CSO samples did not coincide with in-stream sampling, making it difficult to directly link CSO loads to in-stream impacts.
- No water quality sampling for the POCs has been done of the stormwater runoff in the separated areas of the DELCORA service area.
- Delaware River has the most data of the receiving waters and it has data for all three POCs. However, the data were collected at regular intervals, independent of weather condition, and typically only one sample per location per survey was collected. These periodic sampling events do not provide enough data to characterize DELCORA loads on the river.
- The tributaries (Chester Creek and Ridley Creek) have been sampled sporadically and rarely within the tidal zone adjacent to DELCORA's service area. Wet weather data collected by DELCORA, consisting of only one sample per event, are not sufficient to characterize the magnitude and duration of the POCs' pollutographs over a storm event. Data are most robust for fecal coliform. There is less data for *Enterococcus* and none for *E. coli*. In addition, no sampling has been conducted in these tributaries since 2010.

The monitoring program presented in this work plan and QAPP builds on the sampling that has already been done while addressing the limitations identified in the existing data. This work plan includes a comprehensive monitoring assessment of all of the POCs to characterize loads and in-stream conditions. These data will be used to inform the Water Quality Model development, calibration and validation.

3.3.2 Ongoing Sampling

There is no routine on-going monitoring for the pollutants of concern in the tributary waterways adjacent to the DELCORA service area. The Delaware River Basin Commission samples the Delaware River near Chester approximately once a month between April and October. The analysis of these samples includes fecal coliform, *E. coli*, and *Enterococcus*, which are the pollutants of concern (POCs).

3.4 Sampling and Analysis Plan Overview

The WQMP is designed to collect data that will be used to develop and calibrate watershed and receiving water quality models which will be used to assess water quality concerns for the POCs identified in the Identification of Sensitive Areas and Pollutants of Concern Report (Greeley and Hansen, 2016). These POCs are fecal coliform, *E. coli*, and *Enterococcus*. Additional *in situ* parameters, such as salinity, temperature, and conductivity will also be collected to inform the development of the Water Quality Model.

Water quality monitoring will be undertaken at up to thirteen (13) in-stream locations (seven of which are Delaware River sampling locations), four (4) CSO locations in the DELCORA combined sewer system area, and two (2) stormwater locations in the City of Chester municipal separate storm sewer system, as shown in Figure 3-2. Water quality monitoring and sampling will be conducted as follows:

- Eleven (11) in-stream locations in the vicinity of the DELCORA CSO area will be sampled for water quality for (3) dry weather events; one of which will be targeted for collection during a tributary low-flow period (less than 25th percentile flow). The mid-stream and far-shore Delaware River locations will not be sampled during the dry weather surveys because it is expected that water quality in the river will be relatively uniform laterally due to the lack of active sources during dry weather. These dry weather events would preferably be distributed across the sampling season, which is assumed to be March through June of 2017. Grab samples and *in situ* measurements will be collected at each location during each event.
- All thirteen (13) in-stream locations will be sampled for water quality using grab samples and *in situ* monitoring for three (3) discrete wet weather events, according to the surface water quality monitoring program protocols described in this Monitoring Work Plan.
- Up to four (4) CSO and two (2) stormwater outfall locations will be sampled for water quality for the same three (3) discrete wet weather events according to the outfall monitoring program protocols described in this Monitoring Work Plan. Samples for all outfalls will be collected as grab samples.
- Field Standard Operating Procedures (SOPs) and the Sampling Analysis Plan (SAP) referenced in the following sections of the Water Quality Monitoring Work Plan are

provided in Appendix C of the Water Quality Modeling and Monitoring Quality Assurance Project Plan (QAPP).

The sampling events are planned to be distributed across the sampling season, which is assumed to be March through June 2017. Additionally, bathymetry surveys in the lower portion of the tributaries may be required to inform the development of the Water Quality Model, pending delivery of HEC models with transect information for these portions of the receiving waters.

3.4.1 Sampling Locations

Monitoring locations have been selected to characterize the watershed at a sub-watershed level, recognizing various political and hydrologic features, land uses and potential pollutant sources. Site selection and analytical parameters are designed to characterize stormwater outfalls, CSOs, tributaries upstream and within the Chester CSO discharge area, and the main stem of the Delaware River in the project area. The sampling locations are shown in Figure 3-2 and listed in Table 3-1, Table 3-2, and Table 3-3.

The tables include summaries of the rationales for each sampling location selected. The Chester Creek and Ridley Creek locations were selected to distinguish, to the extent possible, between upstream, stormwater and Chester CSO pollutant loads. The Delaware River sampling locations will provide a characterization of water quality entering the Chester CSO area from either tidal direction as well as water quality within the CSO discharge area. During wet weather, three samples will be collected across the transect corresponding to the DR-04 sampling location during each sampling round, when sampling across the river is feasible, to characterize lateral variability in the Delaware River during storm events. Delaware River conditions may be too hazardous for safe collection of one or more samples and/or sampling rounds (e.g. during periods of heavy barge traffic, small craft advisories, lightning, etc.). When these conditions occur, sampling will not be conducted in the river for safety reasons.

The CSO sampling locations were selected based on their outfall discharge location, relatively high frequency of overflow, their overflow volume, and their accessibility. The stormwater sampling locations were selected to characterize the water quality associated with the predominant land uses (residential and commercial/industrial) in the study area. Each stormwater sampling location is in an area that is representative of the land use elsewhere in the City’s stormwater area.

Note that it may be necessary to adjust the one or more sampling locations in response to hazards, construction or other factors that affect the safety of field sampling personnel. The CSO and stormwater sampling locations will be finalized prior to the initiation of the sampling program based on accessibility of sampling, safety of sampling personnel, equipment risk, and available resources.

Figure 3-2: Proposed Receiving Water (RW), Combined Sewer (CSO), and Stormwater (SW) Monitoring Locations

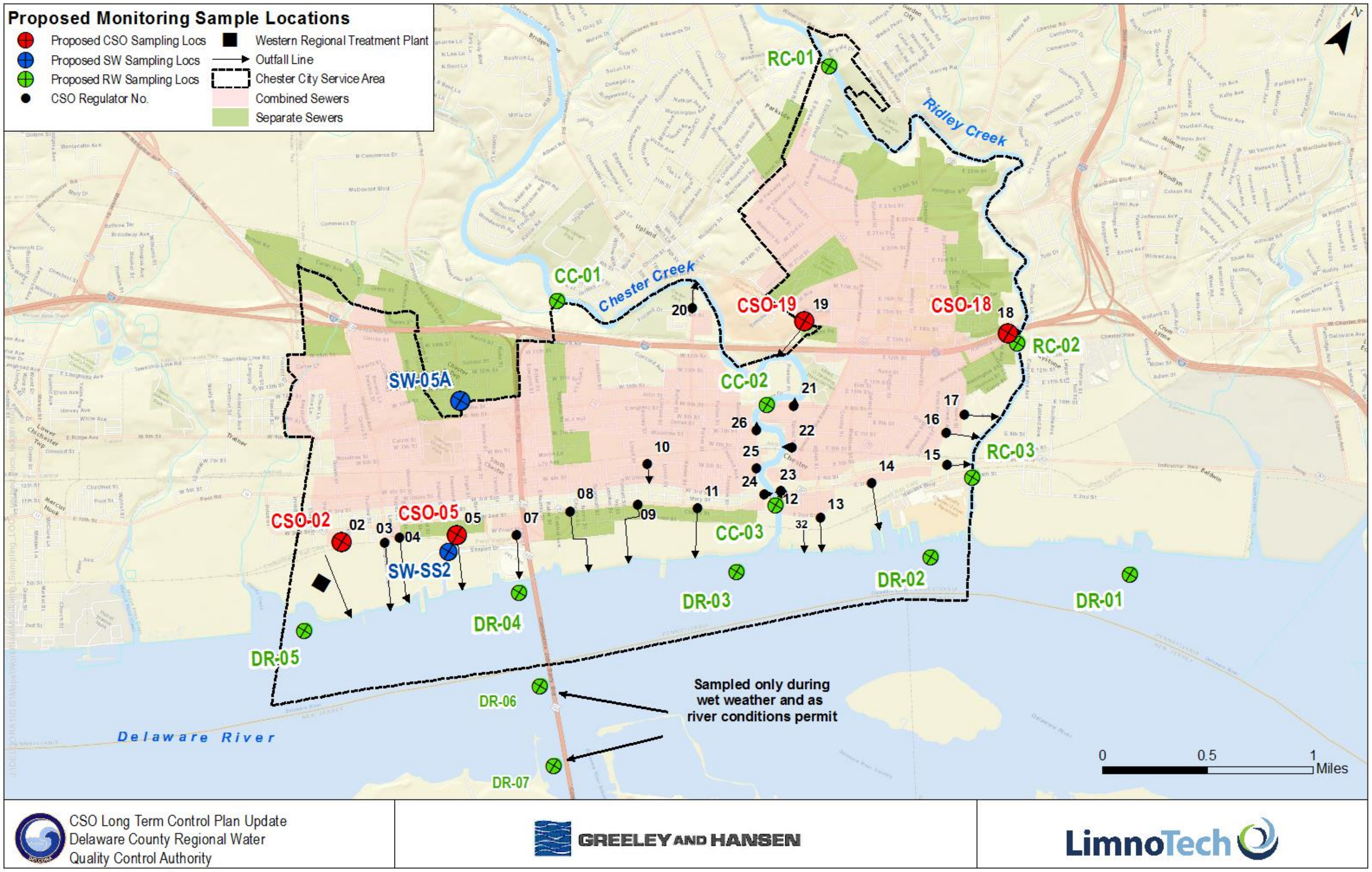


Table 3-1. Tributary Receiving Water Sampling Locations

Station ID	Latitude[1]	Longitude[1]	Receiving Water	Type	Description	Rationale
CC-01	39.850122	-75.386348	Chester Creek	Tributary	Chester Creek at Upland-Incinerator Rd.	Upstream of all City sources and upstream of tidal influence
CC-02	39.850709	-75.365530	Chester Creek	Tributary	Chester Creek at the 9th St Bridge; 54 W 9th St	Characterize impacts from non-CSO urban runoff sources
CC-03	39.845227	-75.360284	Chester Creek	Tributary	Chester Creek at E 2nd St., William Penn's Landing Park	Characterize impacts from all CSOs discharging to Chester Creek
RC-01	39.873264	-75.375183	Ridley Creek	Tributary	Ridley Creek at Chester Park Drive Bridge; 298 East Elkington Blvd	Upstream of all City sources and upstream of tidal influence
RC-02	39.863016	-75.348686	Ridley Creek	Tributary	Ridley Creek at Morton Ave. Bridge; 1300 Sun Drive	Characterize impacts from non-CSO urban runoff sources
RC-03	39.853435	-75.346350	Ridley Creek	Tributary	Ridley Creek at East 4th St. (Harrah's) Bridge	Characterize impacts from all CSOs discharging to Ridley Creek

Notes:
[1] **GPS Coordinates, WGS 1984**

Table 3-2. Main Stem Receiving Water Sampling Locations

Station ID	Latitude[1]	Longitude[1]	Receiving Water	Type	Description	Rationale
DR-01	39.85282	-75.3299	Delaware River	Main stem	Delaware River between Ridley Creek and Crum Creek	"Upstream" of DELCORA's CSO discharges[2]
DR-02	39.84715	-75.3462	Delaware River	Main stem	Delaware River between CSO-14 and Ridley Creek	Characterize Ridley Creek impacts on Delaware River, in the upper Delaware River (Secondary contact area)
DR-03	39.8398	-75.3606	Delaware River	Main stem	Delaware River between CSO-11 and Chester Creek	Characterize Chester Creek impacts on Delaware River, in the upper Delaware River (Secondary contact area)
DR-04	39.83132	-75.3766	Delaware River	Main stem	Delaware River at the boat launch off Highway 322	Priority area, in the lower Delaware River (Primary contact area)
DR-05	39.82182	-75.3917	Delaware River	Main stem	Delaware River between CSO-002 and Stony Creek	"Downstream" of DELCORA's CSO discharges[2], in the Atlantic sturgeon sensitive area
DR-06[3]	39.82636	-75.371	Delaware River	Main stem	Delaware River mid-stream along the transect of DR-04	Characterize lateral variability in the Delaware River during storm events
DR-07[3]	39.82203	-75.3665	Delaware River	Main stem	Delaware River far shore (left descending bank) along the transect of DR-04	Characterize lateral variability in the Delaware River during storm events

Notes:

[1] GPS Coordinates, WGS 1984

[2] "Upstream" and "downstream" subject to tidal conditions at time of sampling

[3] These locations will be sampled during the wet weather events only, when river conditions permit. POC concentrations are assumed to be laterally well-mixed during dry weather due to the absence of significant pollutant sources.

Table 3-3. CSO and Stormwater Sampling Locations

Station ID	Latitude[1]	Longitude[1]	Receiving Water	Type	Description	Rationale
CSO-19	39.857132	-75.366105	Chester Creek	CSO	14th and Crozer Hospital; 1 Medical Center Blvd	Discharges to Chester Creek, one of the largest volume CSOs in DELCORA system
CSO-05	39.832598	-75.383958	Delaware River	CSO	Front and Townsend; 101 Townsend St	Discharges to Delaware River, one of the largest volume CSOs in DELCORA system
CSO-02	39.828334	-75.392570	Delaware River	CSO	Front and Booth; 100 Booth St	Aggregates cumulative effect of CS conditions, one of the volume CSOs in DELCORA system
CSO-18	39.863501	-75.349203	Ridley Creek	CSO	Sun Drive and Hancock St.; 1310 Sun Dr	Discharges to Ridley Creek
SW-05A	39.838501	-75.387708	Chester Creek	SW	7th and Engle Street; by tennis courts	Characterize runoff quality from predominantly residential area representative of the residential portion of the study area
SW-SS2	39.832853	-75.384193	Delaware River	SW	Front and Townsend; 105 Townsend St	Characterize runoff quality from predominantly commercial/industrial area representative of the commercial/industrial portion of the study area

Notes:
[1] GPS Coordinates, WGS 1984

3.4.2 Analytical Parameters

All of the in-stream dry and wet weather samples will be analyzed for the parameters shown in Table 3-4. The outfall samples will be analyzed for only *E. coli*, *Enterococcus* and fecal coliform.

Table 3-4: Analytical and Field Parameters

Parameter	Description	Sampling Program	Type of Measurement
E. coli	Escherichia coli	Dry, Wet	Grab
Enterococcus	Enterococcus sp.	Dry, Wet	Grab
Fecal coliform	Fecal coliform	Dry, Wet	Grab
wTemp	Water temperature	Dry, Wet, Receiving Water Only	In-situ
Cond	Conductivity	Dry, Wet, Receiving Water Only	In-situ
Salinity	Salinity	Dry, Wet, Receiving Water Only	In-situ

3.4.3 Sampling Schedule

3.4.3.1 Dry Weather Sampling

Collection of water quality samples will be performed for three (3) dry weather events; with one dry weather sampling event planned to be collected during a low-flow period (less than 25th percentile flow) in Chester Creek and Ridley Creek (if possible). Two rounds of sampling will be conducted for each dry weather survey: one round to be completed during ebb (outgoing) tide and the second round to be completed during flood (incoming) tide.

Dry weather event samples will be taken at up to eleven (11) locations:

- **Three (3) locations on Chester Creek** that will characterize water quality upstream of DELCORA's service area as well as in the portion of the creek adjacent to DELCORA's CSO discharges and the area adjacent to the City of Chester outside the combined sewer service area. Additionally, because DELCORA's CSO discharges are within the tidal extent of the Delaware Bay, the downstream sampling locations will also reflect these tidal influences on water quality.
- **Three (3) locations on Ridley Creek** that will characterize water quality upstream of DELCORA's service area as well as in the portion of the creek adjacent to DELCORA's CSO discharges and the area adjacent to the City of Chester outside the combined sewer service area. Additionally, because DELCORA's CSO discharges are within the tidal extent of the Delaware Bay, the downstream sampling locations will also reflect these tidal influences on water quality.
- **Five (5) locations on the Delaware River** that will characterize water quality in the vicinity of DELCORA's CSO discharges. Sampling locations have been selected to

separate to the extent possible the effect of DELCORA's CSOs on water quality from other sources contributing pollutants to the waterways. Sampling will be conducted near the shoreline adjacent to the City of Chester.

The locations of these stations are shown in Figure 3-2. Details for these stations are provided in Table 3-1, Table 3-2, and Table 3-3. The set of parameters for which the samples will be analyzed is provided in Table 3-4. In-situ measurements of physical parameters, such as salinity, temperature, and conductivity will be collected at each sampling location with a sonde. In the Delaware River, *in situ* measurements will be made at three depths at each sampling location during each round of sampling.

3.4.3.2 Wet Weather Sampling

Collection of water quality samples will be performed for three (3) wet weather events. The purpose of the wet weather sampling is to characterize the impact of CSO discharges and non-CSO source runoff on in-stream water quality. The wet weather events will span a range of precipitation, flow and seasonal conditions.

Wet weather event samples will be taken at all 13 in-stream locations as well as at up to six source locations in the intervals described below:

- **Six (6) In-Stream Tributary Sampling Locations:** Three (3) locations will be on Chester Creek and three (3) locations on Ridley Creek. The locations will be the same locations used for the dry weather surveys. Tributary locations will be sampled up to five times per event at the following approximate intervals: Hour 0.5-2.5, Hour 4.5-6.5, Hour 8.5-10.5, Hour 14.5-16.5, and Hour 22-24. Sampling intervals will be defined by the start of rainfall rather than CSO or SSO activation. A total of 30 samples will be collected during each wet weather sampling event from in-stream locations. One field blank and one field duplicate will be collected during each event to be used as field quality control (QC).
- **Up to Seven (7) In-Stream Delaware River Locations:** Up to seven locations will be on the Delaware River and will be sampled up to ten times per event at the following approximate intervals: Hour 0, Hour 2, Hour 4, Hour 6, Hour 9, Hour 12, Hour 15, Hour 18, Hour 21, and Hour 24. Sampling intervals will be defined by the start of rainfall rather than CSO or SSO activation. The frequency of sampling is intended to capture in-stream impacts in the vicinity of DELCORA's service area from both DELCORA's CSOs as well as upstream sources. Two additional locations on the Delaware River, one at mid-stream and one near the far shore, have been added to characterize lateral variability in water quality during storm event conditions, when sampling across the river is feasible. The sampling regimen is also designed to allow a semi-quantitative mass balance to be computed over a complete tidal cycle. A total of 70 samples may be collected during each wet weather sampling event. If river conditions are unsafe for sampling (e.g. small craft advisories, heavy barge traffic, etc.), sampling may be suspended for one or more locations and/or sampling rounds. One field blank and one field duplicate will be collected during each event to be used as field QC.

- **Up to Six (6) Outfall Locations:** Sampling will be conducted at up to two (2) stormwater outfalls and up to four (4) combined sewer overflow outfalls. It is assumed that each of the outfall locations will have up to eight sets of samples collected for each event at the following intervals: 1st flush, 30 minutes, and 60 minutes, 2 hours, 4 hours, 8 hours, 12 hours, 24 hours. If a location is not flowing, no sample will be collected. As many as 48 samples may be collected during each wet weather sampling event, depending on the number of monitored outfalls and if all monitored outfalls discharge for 24 hours. However, the actual number of samples is likely to be less than the amount indicated since it is unlikely that all of the monitored outfalls will discharge for the full 24 hour monitoring period. One field blank and one field duplicate will be collected during each event to be used as field QC.

The locations of these stations are shown in Figure 3-2. Details for these stations are provided in Table 3-1, Table 3-2, and Table 3-3. The set of parameters for which the samples will be analyzed are summarized in Table 3-4. *In-situ* measurements will not be collected at the outfall locations.

Sampling crews will conduct all wet weather event sampling using the protocols described in the Quality Assurance Project Plan. Samples will be delivered to the laboratory where the samples will be analyzed for the laboratory parameters identified in Table 3-4.

Determination to mobilize for a Wet Weather Event will be a collaborative effort between Greeley and Hansen, LimnoTech, the Weston Solutions, and Eurofins QC. The intent is to identify a 4 to 6 hour window in which a wet weather event may commence 24 hours in advance to assist in mobilization of the sampling crews.

3.4.3.3 Bathymetric Sampling

The project team has requested HEC models of the receiving waters from the U.S. Army Corps of Engineers. However, in the absence of these models, additional bathymetry data is needed for the tributaries to inform the development of the water quality model. If required, bathymetry surveys will be conducted in approximately the lower three miles of both Chester Creek and Ridley Creek, corresponding to the approximate extent of the water quality model domain. Because these reaches are in the tidal zone, they are unlikely to be wadeable so each transect will be characterized using a boat and a combination of sonar and ADCP profiler equipment. Transects will be spaced approximately every 0.25 miles or at significant morphometric features (e.g. dams, islands, etc.).

3.4.4 Sample Event Initiation Protocol

This section describes the protocols that will be used to initiate the dry and wet weather sampling events.

3.4.4.1 Dry Weather Sampling Protocol

Collection of dry weather water quality samples will be performed for three (3) events; one of which occurred during a low-flow period (less than 25th percentile flow). These events will be distributed across the sampling season, March through June of 2017. The criteria used to define a dry weather event are the following:

- No precipitation within the upstream watershed at least 48 hours before the event;
- No precipitation forecasted for a minimum of three days; and,
- For the low-flow survey, conditions when the in-stream flow at the USGS gage in Chester Creek (01477000) is less than the 25th percentile flow at this location will be targeted for sampling.

Decisions to initiate a dry weather event are given below:

1. Authorization for dry weather events will be determined by Greeley and Hansen, LimnoTech, the field sampling and laboratory contractor personnel as described in Section 3.4.1. LimnoTech will monitor predicted rainfall conditions to identify potential sampling event dates.
2. When the criteria described in the previous section are met (e.g. no rainfall the previous 48 hours), the Chester Creek and Ridley Creek flows are at a desirable level, and no rain is in the near forecast, the team members will be notified of an upcoming dry weather sampling event. The sampling teams will begin mobilizing equipment, bottles and personnel so that they can get into the field before conditions change.
3. The Field Manager will notify the laboratory contact that the sampling teams are planning on conducting a dry weather sampling event.
4. The Field Manager will notify LimnoTech if weather conditions change during the event.
5. Once the decision to conduct sampling has been determined, the Field Manager will confirm with the laboratory that sampling has begun.

3.4.4.2 Wet Weather Sampling Protocol

Three (3) wet weather events will be monitored over the study period. The wet weather events will span a range of precipitation, flow, and seasonal conditions. The goal is to sample storms of at least 0.5 inches of precipitation. The criteria used to define a wet weather event include:

- No precipitation within the upstream watershed 48 hours before the event;

- Forecasts for a 60% (or greater) chance of rain over the entire DELCORA project area; and,
- Approximately 0.50 inches of rainfall forecasted over a six-hour period.

Decisions to initiate and continue sampling for wet weather events are given below:

1. Authorization for wet weather events will be determined by Greeley and Hansen, LimnoTech, the field and laboratory contractor personnel as described in Section 3.4.2. LimnoTech will monitor predicted rainfall conditions to identify potential sampling event dates.
2. Sampling will begin approximately in March and conducted until approximately the end of June. If the water temperature is below 10°C when samples are collected, it is noted that the sample results are not reflective of conditions to assess the potential risk to human health.
3. When precipitation is forecasted meeting the criteria for a wet weather sampling event, the wet weather sampling teams will be put on alert. This alert will be considered "Go" status, unless otherwise notified. The sampling teams will begin mobilizing equipment, bottles and personnel so that they can get into the field as soon as possible after the precipitation begins.
4. The Water Quality Project Manager will notify the laboratory contact that the sampling teams are on alert.
5. The Field Manager's sampling teams will mobilize approximately 2-3 hours before the precipitation is forecasted to begin. Forecast tools include the National Weather Service website (forecast.weather.gov), Weather Underground website (www.wunderground.com), the Weather Channel website (www.twc.com), the Aviation forecast model (http://weather.rap.ucar.edu/model/index.php?model=gfs), local TV weather forecasts, and DELCORA's rain gage network data.
6. Sampling at the outfalls will begin during the first flush when water begins flowing out of the discharges. The field crews will be at the outfall locations waiting to collect the first flush water as soon as it happens.
7. The in-stream locations will be initiated at 0.5 hour after the start of rainfall for the first round of sampling. Subsequent in-stream sampling will be conducted at the intervals described in Section 3.4.3.2. The Field Manager will confirm with the laboratory Technical Director that sampling has begun.
8. Greeley and Hansen, LimnoTech and the Field Manager will continue to monitor the precipitation as the rain event progresses. If the storm conditions are significantly smaller than forecasted (either in rainfall depth or geographical extent), the sampling event will be aborted as soon as can be reasonably determined by Greeley and Hansen, LimnoTech and/or the Field Manager Local rain gages within the study area will be monitored for the event precipitation totals.

9. Samples collected during an aborted wet weather event will be discarded when directed by LimnoTech, after consultation with Greeley and Hansen. The laboratory will be notified as soon as possible by LimnoTech to stop the analysis on any samples they may have already received.

In-stream wet weather sampling will be conducted by 3 crews of two-person teams. Each crew will be responsible for sampling one of the receiving waters. For the outfall locations, a one or two person team will be deployed to each outfall to collect the samples in each round as individual grab samples. Due to the timing of sampling rounds, additional crews will be needed to relieve the sampling teams collecting the first few rounds of samples.

3.5 Field Sampling Methods and Procedures

This section provides a description of the field sampling collection methods, sampling equipment, and decontamination procedures that will be used during the monitoring program. The field sampling methods and procedures will be in accordance with the SOPs provided in Appendix C of the Water Quality Modeling and Monitoring QAPP.

3.5.1 Receiving Water and Source Sample Collection Methods

The physical, microbiological and chemical data that will be collected from the waterbodies are obtained either through direct (*in situ*) measurements or through analysis of a water sample. The microbiological and chemical data collected from the outfall discharges will be obtained through laboratory analysis of the water samples. The general collection procedures for receiving water and outfall sampling are as follows:

1. Clean all sampling equipment prior to sample collection according to the procedures in the SOP for Equipment Cleaning.
2. Don appropriate personal protective equipment (as required by the Field Safety Instructions).
3. Collect samples by dipping a container on a pole, into the water. The water is then poured into a bucket (until enough sample volume has been collected) and then poured from the bucket into the clean sample containers.
4. Care should be taken to avoid capturing bottom sediment or surface foam/scum during sample collection.
5. If field preservation is required, the appropriate preservative will be placed into the sample container prior to sample collection.
6. If field filtering is required, an appropriate sample aliquot will be filtered into the sample container.
7. Label all sample containers with the date, time, site location, sampling personnel, and other requested information.

8. Record sample collection information on the field logs and then store the samples in a cooler with ice as described in the SOP for the Shipping and Handling of Samples.
9. Handle, pack, and ship samples according to the procedures in the SOP for the Shipping and Handling of Samples, including the completion of a Chain-of-Custody (COC) form for each cooler shipped to the laboratory for analyses.

3.5.2 In situ Measurements (Receiving Water Only)

Instantaneous water quality measurements (such as salinity, temperature, and conductivity) using field instruments will be collected at the receiving water locations as specified in the following sections of this Water Quality Monitoring Work Plan. These measurements, along with calibration and maintenance, will be conducted following the SOPs for Water Quality Field Measurements in Appendix C of the Water Quality Modeling and Monitoring QAPP.

Field instruments will be calibrated before initiating monitoring activities for each event and a post-monitoring calibration check will be conducted at the end of the event. All calibration and maintenance activities will be documented on the Instrument Calibration Sheet (see Appendix C of the Water Quality Modeling and Monitoring QAPP). The field instrument calibration must be conducted in accordance with the SOP.

Salinity, temperature, and conductivity will be measured at all in-stream sampling locations using a YSI 6920 or similar instrument during both wet and dry sampling events, prior to sample collection. Measurements will be made mid-channel at mid-depth in the tributaries, whenever possible. In the Delaware River, measurements will be made at the surface, mid-depth and near the bottom, whenever possible. Measurements will be documented in the field logs. Documentation will include: date/time, location, type of measurement, personnel, equipment identification, and general site observations (e.g. weather, stream conditions).

3.5.3 Sampling Equipment

The sampling equipment required for the DELCORA monitoring program is included in Table 3-5.

Table 3-5: Sampling Equipment List

Sampling Activity	Required Equipment	
General Equipment (Required for all sampling activities)	Field log book with weather-proof paper and pen ("Rite-in-the-Rain") or field data sheets Pens and pencils Maps Sample bottles Sample bottle labels Chain-of-custody in zip lock bag Coolers with ice Stainless steel sample bucket and rope	Sample pole Sampling gloves Hand spray bottles with Liquinox solution Scrub brush Distilled water (10 gallons) Hip or chest waders Sun screen PPE as specified in FSI Monitoring Work Plan/QAPP Phone Emergency Contact List Field Safety Instruction
Wet Weather In-Stream Sampling	General Equipment Rain Gear Headlamps for night sampling & extra batteries Hydrolab/YSI multi-parameter sonde and instrument Instrument (sonde) calibration sheet Calibration materials and solutions Sonde instrument manual Sonde service kit Extra batteries for instruments (sondes) Laptop with appropriate power cable, data download cables, and software	
Wet Weather Outfall Sampling	General Equipment Rain Gear Headlamps for night sampling & extra batteries	
Dry Weather Sampling	General Equipment Hydrolab/YSI multi-parameter sonde and instrument Instrument (sonde) calibration sheet Calibration materials and solutions Sonde instrument manual Sonde service kit Extra batteries for instruments (sondes) Laptop with appropriate power cable, data and download cables, and software	

Table 3-6 presents a summary of the number of bottles and coolers needed for each day of each dry weather event. Table 3-7 presents a summary of the number of bottles and coolers needed for each crew for each wet weather sampling circuit. Three (3) bottles at each location are needed to collect the volume of sample required for the laboratory analyses (see footnote in Table 3-6 and Table 3-7). The laboratory will supply the bottles for each location and sample round to the Field Manager in advance of the event.

Table 3-6: Cooler and Bottle Requirements for Each Dry Weather Event

Sample Type	# of Two Person Teams	# of Locations	Locations per Team	Sampling Rounds	Number of Field QC Samples[1]	Number of Bottle Sets per Crew[2]	Number of Coolers per Crew
Chester Creek Tributary	1	3	3	2	1 FB 1 FDUP	8	2
Ridley Creek Tributary	1	3	3	2	1 FDUP	7	2
Delaware River	1	5	5	2	1 FB 1 FDUP	12	2

Notes:
[1] FB = field blank; FDUP = field duplicate
[2] The Bottle Set at each sampling location requires 3 **125 ml plastic sterile bottles (bacteria)**

Table 3-7: Cooler and Bottle Requirements for Each Wet Weather Event

Sample Type	# of Two Person Teams	# of Locations	Locations per Team	Sampling Rounds	Number of Field QC Samples[1]	Number of Bottle Sets per Crew[2]	Number of Coolers per Crew[3]
Chester Creek Tributary In-Stream	1	3	3	5	1 FB[4] 1 FDUP	17	3
Ridley Creek Tributary In-Stream	1	3	3	5	1 FB[4] 1 FDUP	17	3
Delaware River In-stream	1	7	7	10	1 FB[5] 2 FDUP	73	3
Outfall-Manual	6	6	1	8	1 FB 1 FDUP	8 (10 for crew doing field QC)	3

Notes:
[1] FB = field blank; FDUP = field duplicate.
[2] The Bottle Set at each sampling location requires 3 **125 ml plastic sterile bottles (bacteria)**
[3] The number of coolers is based on the frequency of sample delivery to the lab to maintain the 8-hour hold time for bacteria samples.
[4] It is assumed that each crew will also collect 1 field duplicate and prepare 1 field blank during one of the first three rounds of sampling (HR 0.5, HR 4.5, HR 8.5).
[5] It is assumed that the crew will collect 1 field duplicate in the first three rounds of sampling (HR 0, HR 2, HR 4), and will prepare 1 field blank and collect 1 field duplicate again in the remaining seven rounds of sampling (HR 6, HR 9, HR 12, HR 15, HR 18, HR 21, HR 24).

3.5.4 Equipment Decontamination

If sampling equipment, such as buckets, etc., are to be reused at more than one location in the field, they must be cleaned prior to collecting the next sample. Prior to leaving a site, the equipment must be rinsed at least three (3) times with distilled water. A brush may be used to remove deposits of material or sediment if necessary. At the next sampling site, the equipment must be rinsed at least three (3) times at each location with creek water prior to sampling.

Standard cleaning procedures for equipment decontamination are provided in SOP (included as Appendix C in the Water Quality Modeling and Monitoring QAPP).

3.6 Sample Handling, Storage and Shipment

Sample handling will be performed so as to collect, store, submit to the laboratory, and analyze representative samples using methods as specified in this section. Sample containers, volumes, preservatives and holding times are summarized in Table 3-8. Sample bottles (including those requiring preservative) will be provided by the laboratory in advance of each event. The laboratory will notify the Field Manager when sample bottles are ready for pickup. Sample bottles will be stored by the Field Manager until use.

3.6.1 Sample Handling

Sample packaging and shipping procedures are designed to ensure that the samples and the chain-of-custody forms will arrive at the laboratory intact and together.

1. All samples collected will be labeled in a clear and precise way for proper identification in the field and for tracking in the laboratory. The laboratory will pre-label each bottle with all information except for the date and time of sample collection using the method described below. The person collecting the sample will complete the label with date and time. No bottle sets will be distributed without the pre-labeling unless specifically agreed upon among Greeley and Hansen, LimnoTech, the field sampling and laboratory contractors prior to the sampling event.

   Use indelible waterproof marking pen and include:

   - *Sample identification code (ID)*– will include*:*
     - Site designation number - sampling round number, as follows:

__ __ - __ __ __ - __ - __

1 2 3 4 5 6 7

Where,

Characters 1-5: Sample Site ID (column 1 in Table Table 3-1, Table 3-2 and Table 3-3)

Character 6: Sampling round number

Character 7: B - Blank sample qualifier (if required)

- Duplicate samples will be labeled with a sample ID of:

  "DUP ___ ___ ___- ___ ___".

  1 2 3 4 5

  Where

  Characters 1-3: Duplicate ID number (numbers will be assigned to each sampling crew)

  Characters 4-6: Designation of RW for receiving water sample duplicate or OF for outfall sample duplicate

  A blank line will be placed in the location, date and time boxes of the sample label so the laboratory does not know where the sample was collected. The duplicate number in the duplicate sample ID will be assigned in the field and recorded in the field log book.

- Blank samples will be given a normal sample ID, with a B qualifier at the end of the ID.

  - *Sample type (water);*
  - *Analysis required;*
  - *Date sampled;*
  - *Time sampled;*
  - *Name or initials of person who collected the sample;*
  - *Mode of collection (composite or grab);*
  - *Preservation added, if applicable.*

2. Check the caps on the sample containers so that they are tightly sealed.
3. Cover the label with clear packing tape to secure the label onto the container and prevent the label from being illegible if wet.
4. Store samples in coolers with ice to maintain the samples at $\leq$6 degrees Celsius until they are received in the laboratory.
5. Complete the information needed on the field log book and the chain-of-custody, primarily sample date and time and any notes regarding deviations from the planned sampling protocol (e.g. limited volume precluded collecting the full volume required).

Table 3-8: Guidelines for Water Sample Container Preparation and Preservation

Parameter	Sample Container	Sample Volume	Storage Requirement	Preservative	Sample Holding Time	Analytical Method	Detection Limit
Fecal coliform	Plastic-Sterile	125 ml	Refrigerate to $\leq$6°C	Sodium Thiosulfate	8 Hours	SM 9222D	10 no./100 ml
E coli	Plastic-Sterile	125 ml	Refrigerate to $\leq$6°C	Sodium Thiosulfate	8 Hours	EPA 1603	10 no./100 ml
Enterococcus	Plastic-Sterile	125 ml	Refrigerate to $\leq$6°C	Sodium Thiosulfate	8 Hours	EPA 1600	10 no./100 ml

3.6.2 Sample Transport

Samples will be properly packaged for transport to the laboratory as summarized below.

1. Using packaging tape, secure the outside and inside of the drain plug at the bottom of the cooler that is used for sample transport;
2. Place the sealed container upright in the cooler;
3. Place additional cushioning material around the sides of each sample container as needed;
4. Place ice on top of sample containers. Do not pack ice so tightly that it may prevent the addition of sufficient cushioning material. Ensure that bottle caps will not be submerged in water if ice melts;
5. Fill the remaining space in the cooler with vermiculite or other cushioning material if the coolers are being shipped;
6. Place the chain-of-custody forms in a large Ziploc© type bag and tape the forms to the inside of the cooler lid; and,
7. Close the cooler lid and fasten with packaging tape. Wrap strapping or packaging tape around both ends of the cooler at least twice, if coolers are being shipped.

All shipments will be accompanied by the chain-of-custody form identifying the contents. It is preferred that a separate chain-of-custody form be completed for and placed in each shipping container/cooler. The original form will accompany the shipment and copies will be retained by the sampler for the project records.

During the dry weather and wet weather sampling events, representatives from the firm conducting the field sampling will be responsible for delivering the samples to the laboratory quickly enough so that hold times can be achieved for the bacteria parameters (8 hours from the time of sample collection). The Field Manager will manage the coordination of field crews and couriers during the sampling event.

3.7 Sample Documentation

3.7.1 Field Data Collection Forms

The field log book will serve as a daily record of events, observations and measurements during all field activities. All information pertinent to sampling activities will be recorded in the field logs and will include:

- Names of field crew and specifically the author of the field log;
- Date and time of the sample round beginning and ending;
- Location of sampling activity;
- Date and time of collection;
- Sample identification numbers; and,
- Field measurements.

Field observations and details related to analysis or integrity of samples (e.g., weather conditions, noticeable odors, colors, stream flow description, etc.)

The field log book may also include:

- Sampling method;
- Sampling equipment used;
- Number and volume of samples collected ;
- Type of sample;
- Summary of any meetings or discussions with the public, state agency, etc.; and,
- Levels of safety protection.

Field meters will be calibrated daily in accordance with the manufacturer’s recommendations. Standards, solutions used, concentrations and readings taken will be recorded daily in Instrument Calibration Sheet.

3.7.2 Sample Chain-of-Custody Forms

A chain-of-custody is a legally-binding record of the date and time periods that samples were in the possession (e.g. custody) of the parties indicated. Transfers between parties are documented by the custodial party signing over custody to the receiving party and the receiving party signing for receipt of the samples. Completed chain-of-custody forms will be required for all samples to be analyzed.

Chain-of-custody forms will be prepared in advance by the laboratory for each sampling location and round of sampling. Chain-of-custody forms will be initiated by the sampling crews in the field during the sampling events and must remain with the samples at all times. The samples and signed chain-of-custody form will remain in the possession of the sampling crew until samples are either delivered to the lab or placed in the custody of the personnel responsible for their delivery to the laboratory.

The chain-of-custody form will contain the sample's unique identification number, sample date and time, sample description, sample type and analyses required. Copies will be made prior to shipment for field documentation. The original chain-of-custody form will accompany the samples to the laboratory.

3.7.3 Data Submittal

Instrument Calibration Sheets and copies of the field log book will be turned over to the LimnoTech Water Quality Monitoring Program Task Manager following each monitoring event. Following review by the LimnoTech Water Quality Monitoring Program Task Manager, all field logs, photographs and chain-of-custody forms will be included in the project database.

3.8 Quality Control

The purpose of any quality assurance/quality control (QA/QC) program is to ensure that all sampling protocols and procedures are followed such that samples are representative of the water quality to which they are associated. The monitoring data that will be collected is intended to meet the quality assurance objectives described in the QAPP. Data quality will be measured in terms of accuracy and precision, completeness, representativeness, comparability, and the required detection limits for the analytical methods. Each of these data quality indicators is defined in the QAPP. QC samples will be collected in the field to support the assessment of data quality. The QA/QC program includes the following elements:

- Training of all field staff;
- Field quality control procedures;
- QA/QC samples; and,
- Equipment calibration.

3.8.1 Training

All field staff will receive training covering the QAPP and this Water Quality Monitoring Work Plan. The training will include proper procedures for sample collection, handling and submission and general field procedures. Specific emphasis will be placed on QA/QC issues as well as on health and safety. The training will also cover the operation, maintenance, and calibration of field equipment including multi-parameter sondes and all other on-site equipment used throughout the field program. SOPs for all program elements will be distributed to staff and will be available at all times.

3.8.2 Field Quality Control

The quality of data generated in a laboratory depends primarily on the integrity of the samples that arrive at the laboratory. Consequently, necessary precautions must be taken to protect samples from contamination and deterioration. Procedures detailed in SOPs for Collection of Discrete Water Samples and SOPs for Water Quality Field Measurements will be followed to ensure field quality control.

3.8.3 QA/QC Samples

This section describes the type and frequency of QC samples for the monitoring program.

3.8.3.1 Field Blanks

Field accuracy will be assessed through the use of field or equipment blanks. In order for the accuracy assessment to be relevant, all appropriate protocols concerning sample collection, handling, preservation, and hold times must be maintained. Equipment that is used to collect samples for analysis may become cross-contaminated through the normal course of monitoring. If not properly cleaned and rinsed, samples may be contaminated during sampling from previous locations.

Field blanks will consist of a distilled water rinse of sampling equipment collected into separate sample containers and submitted to the laboratory to assess the quality of the data resulting from the monitoring program. Field blanks should be collected after the sampling equipment has been cleaned in accordance with appropriate specified cleaning procedures. The laboratory will provide the sampling crews with the water to be used to prepare the field blanks.

Field blanks will be collected at a frequency of one blank during each sampling event per sampling crew.

3.8.3.2 Field Duplicates

Precision is a measure of the agreement between two or more measurements. Duplicate or replicate samples will be taken for a portion of the samples to assess field precision. A field duplicate is defined as a sample produced when a single sample is split into two or more aliquots immediately after the sample is collected. Each aliquot is placed into a separate container and analyzed separately.

Field duplicates will be collected at a frequency at least one field duplicate per sampling crew.

3.8.4 Calibration of Field Equipment

Instantaneous water quality measurements (such as salinity, temperature, and conductivity) using field instruments will be collected as specified in the preceding sections of this Water Quality Monitoring Work Plan. Salinity, temperature, and conductivity will be measured at the specified sampling locations using an YSI 6920 or similar instrument, prior to sample collection. All field instruments will be calibrated at the beginning of the day of sampling and checked again at the end of each day, as required by the QAPP. Field instrument calibration and sample measurement data will be recorded on the Instrument Calibration Sheet and in the field log book, respectively.

The field instrument calibration must be conducted in accordance with the SOP included in Appendix C of the Water Quality Modeling and Monitoring QAPP.

3.9 Program Safety

The most critical component of a sampling program is crew safety. Safety is of paramount importance as stream sampling can be extremely dangerous. The conditions are often wet and dark adding to the dangers. The element of danger is accentuated if personnel are unfamiliar with their surroundings and/or procedures. Consequently, staff must be properly trained in both safety and monitoring procedures, following a well thought out program.

Field Safety Instructions (FSI) have been developed by LimnoTech for the Water Quality Monitoring Program. The FSI include safety precaution information and emergency procedures. The LimnoTech FSI is the governing health and safety document for the sampling program.

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