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Synthesis and Analysis of Historical Hypoxia Data in the Western Narrows of Long Island Sound

Final Report | April 2018

prepared for:

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TABLE OF CONTENTS

EXHIBITS

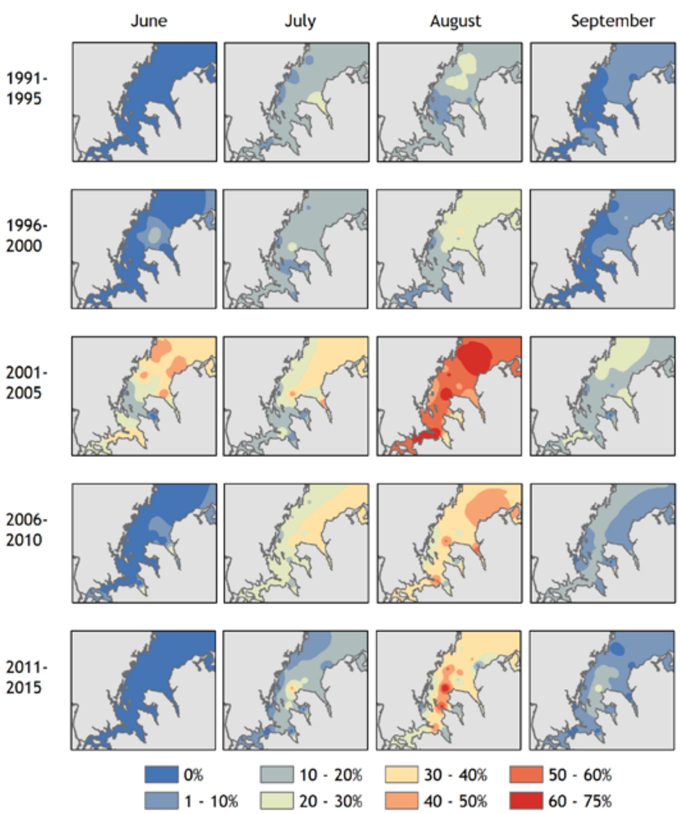
ACRONYMS

AIC	Akaike Information Criterion
APHA	American Public Health Association
BIC	Bayesian Information Criterion
BOD	Biochemical Oxygen Demand
CDM	Common Data Model
CO-OPS	Center for Operational Oceanographic Products and Services
CTDEEP	Connecticut Department of Energy and Environmental Protection
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
GHCND	Global Historical Climatology Network Daily
IEC	Interstate Environmental Commission
LCD	Local Climatological Data
LIS	Long Island Sound
LISS	Long Island Sound Study
MDL	Method Detection Limits
Mg/L	Milligrams per Liter
NDBC	National Data Buoy Center
NEIWPCC	New England Interstate Water Pollution Control Commission
NOAA	National Oceanic and Atmospheric Administration
PQL	Practical Quantitation Limit
QAPP	Quality Assurance Project Plans
RDBMS	Relational Database Management System
RL	Reporting Limits
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids

EXECUTIVE SUMMARY

This report describes the compilation of Interstate Environmental Commission's (IEC) 25 years of hypoxia-related water quality data from the Western Narrows of Long Island Sound (LIS) into a relational database management system (RDBMS) with a common data model (CDM) using Microsoft Access. The result was the compilation of approximately 25 thousand water quality sampling and meteorological records and the creation of a geodatabase. To facilitate future database efforts, numerous tools and tables were created that will allow for efficient updates and expansions. In addition, analyses were run on the data to describe and identify trends with hypoxia in the Western Narrows of LIS.

EXHIBIT ES-1 PERCENT OF SAMPLED DAYS HYPOXIC BY MONTH FOR LOWEST RECORDED DEPTHS



Queries of the RDBMS were performed to extract data for the purposes of identifying temporal and spatial trends in dissolved oxygen (D.O.) concentrations and hypoxic conditions. In general, the observed trends were consistent with the published literature and previous IEC reports. There was no overall annual trend across the 25 year dataset but hypoxic conditions tended to increase from 1991-2004 and then decrease from 2005-2015 (Exhibit ES-1). Over the 25 year period, hypoxic conditions generally began in July, peaked in August, and retreated in September (Exhibit ES-1). D.O. was lower more frequently at bottom depths, which indicates higher frequency of hypoxia relative to surface waters. Hypoxic conditions primarily decreased along a west to east axis. Generally, as nutrient concentrations increased, D.O. concentrations decreased. However, nutrient data were limited to select years. Additional data and increased data resolution may further elucidate these relationships and enable forecasting of hypoxic conditions.

In addition to incorporating data collected post-2015, analogous data from eastern LIS and additional environmental data may be incorporated into the database to further investigate hypoxic conditions. Future efforts may include analyses at a finer scale and/or focus on specific areas within the Western Narrows. Also, utilizing this compilation of data and existing hydrodynamic and D.O. models, a 3-D model could be developed to provide operational water quality forecasts and inform ecological management decisions.

CHAPTER 1 | INTRODUCTION

Established in 1936, the Interstate Environmental Commission (IEC) is a tri-state water and air pollution control agency for New York, New Jersey, and Connecticut. Since 1991, IEC has monitored hypoxia-related water quality parameters in the Western Narrows region of Long Island Sound (LIS or the "Western Narrows"). This multi-decade history of data collection, combined with relevant meteorological data, provides natural resource managers with a unique opportunity to better understand hypoxia in the Western Narrows. The primary focus of this effort was compiling IEC's historical hypoxia-related water quality data and related meteorological data into a relational database. The purpose of this report is to summarize these efforts, describe the relational database, and present opportunities for updating and expanding the scope of the database. In addition, analyses were run to summarize and describe trends within the compiled dataset.

HYPOXIA

Hypoxia is a condition where dissolved oxygen (D.O.) in the water column drops below levels sufficient to sustain life (Howarth et al. 2011). The Long Island Sound Study (LISS) defines hypoxia as conditions where D.O. drops below 3 milligrams per liter (mg/L), and it is generally accepted that hypoxia is defined as 2-3 mg/L D.O. (NEIWPCC and IEC 2015; Anderson and Taylor 2001; Howarth et al. 2011; Connecticut Department of Energy and Environmental Protection (CTDEEP) and IEC 2016; Rabalais et al. 2010). Connecticut and New York both have chronic and acute D.O. water quality standards of no less than 4.8 mg/L and 3.0 mg/L, respectively. The LISS and CTDEEP define severe hypoxia as conditions where D.O. is less than 2.0 mg/L and anoxia as D.O. below 1 mg/L (CTDEEP and IEC 2016). For the purposes of this report, we define hypoxia as D.O. below 3 mg/L, but also review data in these other categories: chronic (below 4.8 mg/L), severe hypoxia (below 2.0 mg/L), and anoxia (below 1.0 mg/L).

CAUSES OF HYPOXIA

Hypoxia is a complex condition resulting from multiple physical, biological, and chemical processes (Rabalais et al. 2010; Paerl et al. 1998; Zhou et al. 2014). Most commonly, increased nutrients from anthropogenic activities (e.g., wastewater treatment plants, storm water runoff) make their way into coastal water bodies and increase the ability for microbial species to bloom (Howarth et al. 2011). Increased nutrients stimulate phytoplankton blooms, which initially increase oxygen in the water column (predominantly in surface waters) during the day. At night microbes consume the phytoplankton, excess nutrients, and oxygen, depleting oxygen in the water column (Baird et al. 2004; Rabalais et al. 2010; Howarth et al. 2011). Physical characteristics of estuaries can also influence hypoxia. For example, density gradients caused by lower salinity water on the surface and solar warming of surface waters, stratifies the water column from the more saline, cooler, deeper waters, instigating hypoxic conditions (Baird et al. 2004). Longer water residence times can increase hypoxia due to accumulation of organic carbon and nutrients, subsequently promoting respiration (i.e., oxygen depletion; Rabalais et al. 2010). Increased freshwater flow can increase mixing and decrease water residence time, which can decrease hypoxia, but it can also increase nutrient loading and decrease surface salinities, further stratifying and exacerbating hypoxia (Rabalais et al. 2010). Wind speed and direction can affect hypoxic conditions by influencing water movement, in some cases enhancing mixing, which would increase D.O. and reduce stratification (Zhou et al. 2014; Rabalais et al. 2007).

IMPACTS OF HYPOXIA

Low D.O. in the water column creates an inhabitable living environment for aquatic organisms, especially benthic species that live at depths where hypoxia is more common (Baird et al. 2004; Rabalais et al. 2010; Diaz and Rosenberg 1995; Paerl et al. 1998). Hypoxia is linked to massive fish kills and benthic species mortality, as well as numerous sublethal effects to aquatic organisms in estuarine systems (e.g., increased predation, habitat reduction, impaired growth and development; Rabalais et al. 2010; Baird et al. 2004; Diaz and Rosenberg 1995; Dauer et al. 1992). Species sensitivity and tolerance for low D.O. concentrations is variable depending on the species, life stage, and exposure duration (Wannamaker and Rice 2000; Rabalais et al. 2010).

THE WESTERN NARROWS OF LONG ISLAND SOUND

LIS is an estuary of national significance and is atypical as an estuary due to the fact that it is open to the Atlantic Ocean at two ends (the East River to New York-New Jersey Harbor and the Race to Block Island Sound). LIS is influenced by multiple states and is connected to the New York City metropolitan statistical area (20 million people) via the East River. Additionally, LIS receives freshwater inputs via numerous southerly flowing New England rivers (e.g., the Connecticut River).

For the purposes of this report, the Western Narrows is defined as the region from the Bronx Kill at the mouth of the East River east to the Connecticut border on the northern side of LIS and to Matinecock Point on the southern side of LIS (Exhibit 1-1). The Western Narrows of LIS have experienced seasonal hypoxia since the 1970s (Anderson and Taylor 2001). Rivers that drain into the Western Narrows of LIS include Byram River, Hutchinson River, and Mamaroneck River. These rivers contribute freshwater to the Western Narrows, which can influence hypoxia via mixing, stratification, and transportation of nutrients. Tidal currents are minimal compared to the eastern end of LIS, which experiences greater tidal exchange near the inlet for the Atlantic Ocean. The tidal range in LIS is <0.5 meters to greater than 2 meters (Anisfeld et al. 1999; Fenster et al. 1990; Harrison and Bloom 1977), with greater tidal ranges in western LIS (UMCES 2013).

EXHIBIT 1-1 LOCATION OF THE WESTERN NARROWS

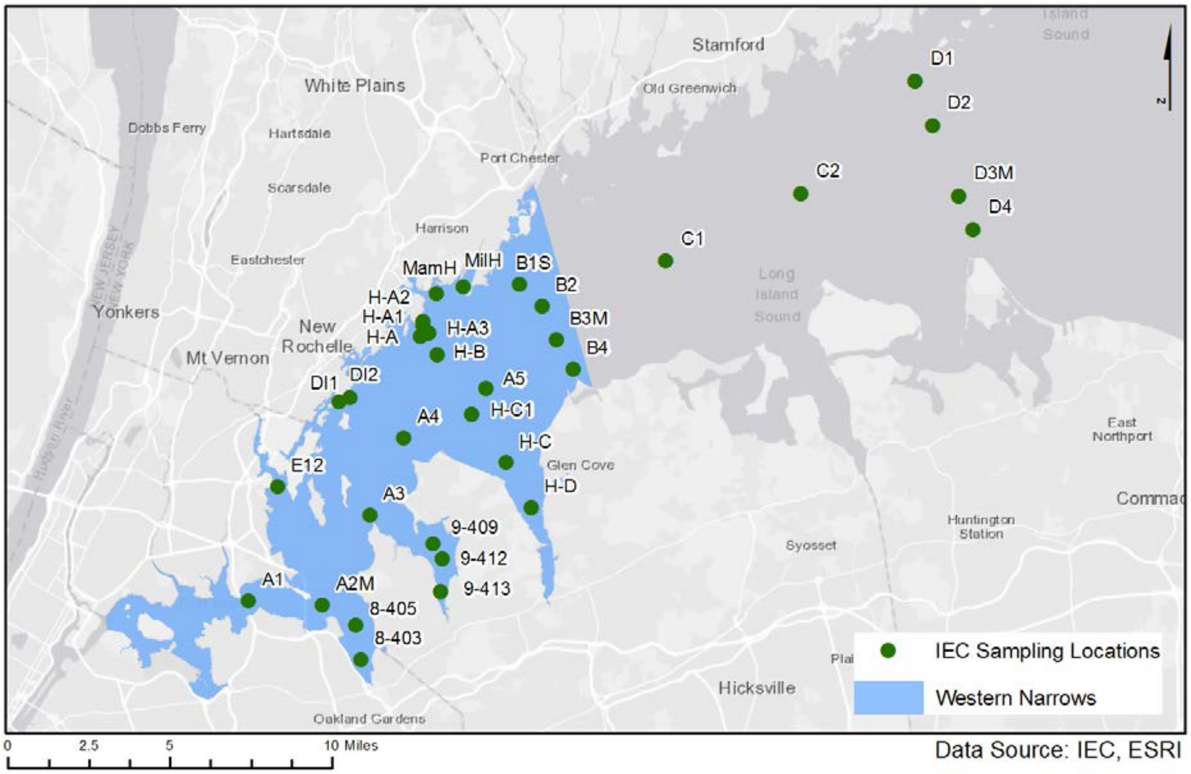
IEC'S LIS SAMPLING PROGRAM

Beginning in 1991 and continuing through the present, IEC has monitored D.O. levels and other key water quality parameters as part of its LIS monitoring program. IEC has conducted weekly summer water quality sampling in the Western Narrows. The remainder of this report focuses on the data available from the time period beginning in 1991 and continuing through 2015. The summer sampling program lasts 12 weeks from June through September. In total, 33 stations in and near the Western Narrows were sampled (Exhibit 1-2). However, some of the sampling stations have changed over time, so there are not continuous data across this 25 year range for each station. As this effort is in collaboration with CTDEEP, IEC's sampling stations included a select number of stations located within LIS but east of the Western Narrows. IEC produces an annual report that discusses that year's water quality data. These reports include depictions of the frequency, duration, and spatial extent of hypoxia for that season and over time (IEC 2011; IEC and NEIWPCC 2013, 2014, 2015; CTDEEP and IEC 2016).

SAMPLING DATA

IEC's data collection includes D.O., water temperature, salinity, chlorophyll a, cloud cover, tide range, sea state, Secchi disk depth, pH, biochemical oxygen demand (BOD), total suspended solids (TSS), and nutrients (year dependent; see Chapter Two for additional sampling collection dates and information). These data were collected in accordance with EPA-approved Quality Assurance Project Plans (QAPP; ISC 1991, 1992, 1993, 1994; IEC 2012; NEIWPCC 2013, 2014, 2015).

EXHIBIT 1-2. IEC LIS SAMPLING LOCATIONS FROM 1991-2015



PROJECT OVERVIEW

The overall objectives of this project are to compile and then utilize IEC's 25 years of D.O. and other related water quality data collection efforts to detect and assess spatial trends in hypoxic conditions, identify factors that may influence hypoxia, and, when data allow, assess the impact and effectiveness of management actions and programs. Below, we describe our methods to achieve these objectives. Initial efforts focused on understanding the water quality data, which included assessing the format in which data were collected and the quality of the data by using associated QAPPs, and identifying relevant meteorological or other potentially influential data. Next, we compiled all data into a comprehensive, standardized dataset using a relational database management system (RDBMS) in Microsoft Access, and into a spatial format in a geodatabase using ArcGIS.

Following the completion of the RDBMS, we investigated spatial and temporal trends related to severity, timing, extent, and duration of low D.O. events using ArcGIS and appropriate analytical software. Additionally, we investigated the relationship between D.O. and other available environmental data and meteorological data. Examples of other environmental data include water temperature, time of day the sample was taken, pH, salinity, Secchi disk depth, and chlorophyll a. Meteorological data include tides, ambient temperature, wind speed and direction, and precipitation. We present the results in a variety of forms throughout this report (e.g., graphs, tables, maps).

All work performed as part of this project followed the procedures and requirements outlined in the project specific QAPP (Industrial Economics 2017). The work entailed the use of existing data, commonly referred to as secondary data in the context of the QAPP. As such, no new samples were taken, and no new data were generated.

The remainder of this report is organized as follows:

- **Chapter Two – Data Identification and Review:** This chapter describes the types of data collected by IEC, the methods of collection, current format of data, assessment of data quality, and results of data review.
- **Chapter Three – Database Creation:** This chapter explains the structure, organization, and creation of the RDBMS and the GIS data products.
- **Chapter Four – Data Analysis Methods:** This chapter discusses the analytical methods including any data cleaning.
- **Chapter Five – Results:** This chapter discusses the results of the data analysis, any identified trends in hypoxia over time and any relationships between parameters.
- **Chapter Six – Discussion and Conclusions:** This chapter contextualizes the data analysis, discusses influential parameters on hypoxic conditions, and implications for hypoxia and low D.O.
- **Chapter Seven – Next Steps and Future Data Collection Efforts:** This chapter discusses future database options and potential analytical and modeling efforts.

CHAPTER 2 | DATA IDENTIFICATION AND REVIEW

Before data compilation and analysis efforts could begin, we identified and reviewed available data sources consistent with the QAPP developed for this project. As noted in Chapter One, this project did not involve the collection of any new data; it uses, evaluates, and collates existing data. The main data source is water quality data collected by IEC over 25 years. In addition, we identified, reviewed, and compiled select hypoxia-relevant meteorological data. This chapter provides an overview of the approaches used to identify and review the existing IEC data and relevant meteorological data, including any data reductions or transformations (e.g., for non-detects). In addition, this chapter provides a description of additional data sources we have identified that may influence D.O. and hypoxic conditions and for which we have built future database capacity.

EXISTING IEC DATA

Efforts related to the existing IEC data included identifying the full suite of available data in electronic and paper format, reviewing historical QAPPs developed by IEC to collect the data, and addressing the treatment of non-detects.

IEC DATA IDENTIFICATION

The main data source for this report is the water quality data from 1991-2015 which are stored in Excel format on IEC's server and on the original paper datasheets. Data from 33 sampling stations throughout the Western Narrows and further east were included in IEC's data (see Exhibit 1-2 in Chapter One). IEC transferred the Excel files to Industrial Economics using a cloud-based secure document portal and mailed the field datasheets via FedEx for scanning. Data that are included in the IEC water quality data encompass:

- D.O.
- Temperature
- Salinity
- Chlorophyll a
- Nutrients
- Cloud cover
- Tide range
- Sea state
- Secchi disk depth
- pH
- Sample depth
- Total Suspended Solids (TSS)
- Biochemical Oxygen Demand (BOD)

IEC DATA REVIEW

We reviewed the available data by year to determine the overall completeness of the various parameters (Exhibit 2-1). Though not shown below in Exhibit 2-1, nutrient data are available starting in 2014. The collection of Secchi disk depth data began in 2001, and pH data collection began in 2007. Where data values were left as blank cells in the IEC data Excel files, we filled in the table with “ND” for no data (e.g. early years of Secchi disk depth and pH data).

Temperature, salinity, pH, and D.O. measurements were taken weekly, with multiple measurements taken throughout the water column (i.e., at different depths). There were at least two samples (1 m below surface, 1 m above substrate) at each station, but stations with depths > 15 m were sampled an additional three times, equally spaced between the top and bottom samples. Chlorophyll a samples were collected every other week, and only one sample was taken at the surface of each station. At select stations, nutrients were analyzed starting in 2014 and BOD starting in 2015, (n=11). These parameters are sampled at the surface (1m below surface) every other week in the summer.

EXHIBIT 2-1. IEC 1991-2015 WATER QUALITY DATA AVAILABILITY.

YEAR	DATE	STATION	DEPTH	CLASS	D.O.	TEMP	SALINITY	CHLA	SECCHI DISK DEPTH	PH	TIME
2015	All data available	All data available	ND or blank for some data	Field not available	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data
2014	All data available	All data available	ND or blank for some data	Field not available	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data
2013	All data available	All data available	ND or blank for some data	Field not available	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data
2012	All data available	All data available	All data available	Field not available	All data available	All data available	All data available	ND or blank for some data	ND or blank for some data	All data available	All data available
2011	All data available	All data available	ND or blank for some data	Field not available	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data
2010	All data available	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	All data available	ND or blank for some data	All data available
2009	All data available	All data available	All data available	All data available	ND or blank for some data	All data available	ND or blank for some data	ND or blank for some data	All data available	All data available	All data available
2008	All data available	All data available	ND or blank for some data	All data available	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data
2007	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	All data available
2006	All data available	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	All data available	ND for all data	All data available
2005	All data available	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	ND or blank for some data	ND for all data	All data available
2004	All data available	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	All data available	ND for all data	All data available
2003	All data available	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	All data available	ND for all data	All data available
2002	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	ND or blank for some data	All data available	ND for all data	All data available
2001	All data available	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	ND or blank for some data	ND for all data	All data available
2000	All data available	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	ND for all data	ND for all data	All data available
1999	All data available	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	ND for all data	ND for all data	All data available
1998	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	ND or blank for some data	ND for all data	ND for all data	All data available
1997	All data available	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	ND for all data	ND for all data	All data available
1996	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	ND or blank for some data	ND for all data	ND for all data	All data available
1995	All data available	All data available	All data available	All data available	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND for all data	ND for all data	ND or blank for some data
1994	All data available	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	ND for all data	ND for all data	All data available
1993	All data available	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	ND for all data	ND for all data	All data available
1992	All data available	All data available	All data available	All data available	All data available	All data available	All data available	ND or blank for some data	ND for all data	ND for all data	All data available
1991	All data available	All data available	All data available	All data available	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND or blank for some data	ND for all data	ND for all data	All data available

All data available
ND for all data
ND or blank for some data
Field not available

Historical QAPP Review and Treatment of Non-Detects

For the 25 years of water quality data, we reviewed all existing IEC QAPPs for comparability of sampling methods, analysis type, equipment, storage and handling, and any specified detection limits. QAPPs were provided by IEC for sampling years 1991-1995 and 2012-2015. Available information in the QAPPs changed over time as the number of sampling stations increased and methodologies changed. For example, the number of sampling stations increased from approximately 15 in 1991 to 22 in 2015. The different sampling and analysis methods that changed over time mostly influence detection limits. We assessed data for each year and parameter individually to address detection limits and non-detects. For inclusion in the database, we compiled data regarding data quality in the QAPP information table.

Despite 'non-detects' being included in the Excel files and field sheets provided, actual detection limits were not consistently reported. For example, in earlier years (e.g., 1991-1995), there are no available detection limits provided with the data, or accompanying the actual methods. Since we did not have annual QAPPs for 1996-2011 and no detection limits were reported in QAPPs from 1991-1995, we reviewed raw data sheets and method sources (e.g., APHA Standard Methods, EPA methods documents) for additional details on equipment, sampling methods, and detection limits that would allow us to determine the methods used (e.g., APHA 1975, 1985, 1992, 1995, 1998).

QAPPs from 2012-2015 reported both method detection limits (MDL) as well as reporting limits (RL), with RLs commonly ranging from one to ten times the MDL. Depending on the parameter and year sampled, non-detects were treated differently. Some were reported as "0" while other data entries were reported with a "<" symbol followed by the value for RL or a practical quantitation limit (PQL). We compared all the data to their respective MDL, RL, and/or PQL. Where we identified non-detects, we substituted those values with one-half the RL or PQL (approximately equal to the MDL) in a separate table in the database. We discuss the identification, detection limits, and treatment of non-detects in detail in Attachment A.

COMPILATION AND PREPARATION OF HISTORICAL IEC DATA

Raw data provided by IEC were separated by year in different Excel tables. To combine the annual IEC datasets into one comprehensive database table, we created a common data model (CDM) that encompassed all of the data fields from each year and standardized the column names. Each original table was then imported into the table template to create a final table with all years of data. In addition, we scanned all of the paper datasheets sent by IEC into separate PDF documents for use in completing the data table quality control, and uploaded these documents to the online document library. For data not entered into the original IEC tables, we entered the data from the scanned field datasheets, and formatted the data into the standard table template before importing it into the final table. Transcription checks were performed on all new data entry. The structure of the database tables are discussed in Chapter Three.

As a quality control measure, we assessed the existing IEC entered values and completeness of each field to ensure the data values fell within a reasonable range (e.g. no below freezing water temperatures) and checked any potential outlying values against the original datasheet. In a few instances, we corrected water quality data for typos or omissions; these updates were reflected in a notes field in the table. Investigation and sampling run numbers in the original IEC tables were incomplete, so we entered the remaining numbers based on the information on the field datasheets. We added nutrient data to the final table for 2014 and 2015, and "ND" for those fields in remaining years. We removed any sampling data in the original Excel file without a time or depth from the final table (156 records) as it was determined that the data were not collected and were blank on the original datasheets. The end result is a table with 18,915 records of sampling data collected from 1991 to 2015.

METEOROLOGICAL DATA

In addition to water quality and nutrient parameters, environmental factors can have an effect on the occurrence of hypoxia. Thus, we conducted a literature search and sought input from IEC to determine the meteorological data variables that are most likely to influence hypoxia.

METEOROLOGICAL DATA IDENTIFICATION

The original Excel files from IEC contained field observation data relating to weather and field conditions such as cloud cover, sea state, tides, and precipitation. We completed a review of all potential meteorological data within the original data sheets (Exhibit 2-2) and determined that, due to gaps, we needed other sources of data to create a full record of meteorological data. We researched multiple online databases and downloaded daily data values for five datasets spanning the entire time frame from 1991-2015 including:

- Air Temperature
- Tidal Range
- Wind Speed
- Wind Direction
- Precipitation

Due to the presence of multiple weather stations within and near the Western Narrows with varying years of available data, we composed one comprehensive meteorological dataset for each data type (Exhibit 2-3) consistent with the QAPP developed for this project. The sources of each weather station are identified in Exhibit 2-3 and all were operated by the National Oceanic and Atmospheric Administration (NOAA). No other dependable and easily accessible data sources for the above information were identified.

METEOROLOGICAL DATA REVIEW

For years where multiple stations had available data (e.g. air temperature, wind speed, and wind direction from 1999 to 2015) we selected the nearest available value to the sampling station location as the representative daily value. Exhibit 2-4 shows the geographic location of the meteorological stations in the Western Narrows. For the database table, we also calculated the distance from the sampling station to the nearest weather station that provided the data values.

While the data collected for the meteorological dataset ultimately came from NOAA, the websites, formats, and time intervals for the data varied for, and sometimes within, each data type (Exhibit 2-5). Prior to inclusion in the database, we acquired data at a daily scale or performed calculations to obtain a mean or daily total. Data were stored in Excel format for compilation and quality control.

EXHIBIT 2-2. EXISTING METEOROLOGICAL DATA FROM IEC TABLES AND DATASHEETS.

YEAR	CLOUD COVER	SEA STATE	WEATHER	TIDE RANGE	TIDE TIME	RAIN 24 H	RAIN 48H
2015							
2014							
2013							
2012							
2011							
2010							
2009							
2008							
2007							
2006							
2005							
2004							
2003							
2002							
2001							
2000							
1999							
1998							
1997							
1996							
1995							
1994							
1993							
1992							
1991							

Data in Excel Files
Data in Field Datasheets
No Data Available

EXHIBIT 2-3. WEATHER STATION METEOROLOGICAL DATA AVAILABILITY BY YEAR.

YEAR	AIR TEMPERATURE, WIND SPEED, WIND DIRECTION				TIDAL RANGE		PRECIPITATION	
	Kings Point[1]	Western Long Island Sound[1]	Execution Rocks[1]	La Guardia[2]	Kings Point[3]	Bridgeport[3]	Sea Cliff[4]	La Guardia[2]
2015								
2014								
2013								
2012								
2011								
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2009								
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1995								
1994								
1993								
1992								
1991								

Data sources:

1. NOAA National Data Buoy Center
2. NOAA Local Climatological Data
3. NOAA Center for Operational Oceanographic Products and Services
4. NOAA Global Historical Climatology Network Daily

EXHIBIT 2-4. IEC SAMPLING STATIONS AND METEOROLOGICAL DATA WEATHER STATIONS.

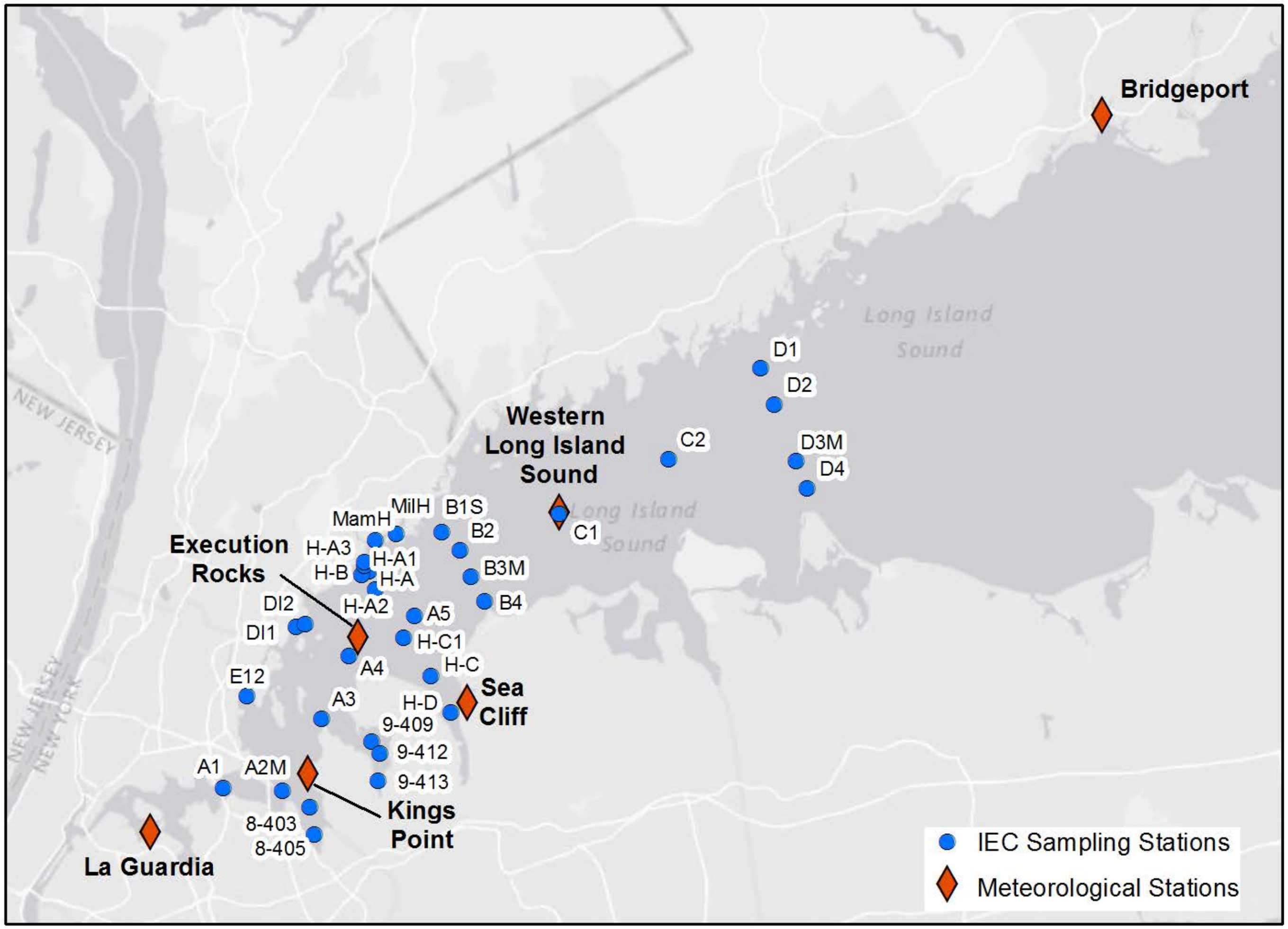


EXHIBIT 2-5. METEOROLOGICAL DATA SOURCES.

DATA SOURCE	WEBSITE	AVAILABLE DATA TYPES	WEATHER STATION AND DATE RANGE	TIME INTERVAL	DATA FORMAT
NOAA Local Climatological Data	https://www.ncdc.noaa.gov/cdo-web/datasets/LCD/stations/WBAN:14732/detail	Air temperature, precipitation, wind speed, wind direction	La Guardia: 1990-Present	Daily and Hourly	CSV
NOAA Global Historical Climatology Network Daily	https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USC00307587/detail	Precipitation	Sea Cliff: 1995-2005	Daily	CSV
NOAA National Data Buoy Center	http://www.ndbc.noaa.gov	Air temperature, wind speed, wind direction	Western Long Island Sound: 2004-2014 Execution Rocks: 2005-2015 Kings Point: 1999-2015	Hourly	TXT
NOAA Center for Operational Oceanographic Products and Services	https://tidesandcurrents.noaa.gov/stations.html?type=Water+Levels	Tide/water level	Kings Point: 1998-2015 Bridgeport: 1991-2015	Daily High/Low	CSV

COMPILATION AND PREPARATION OF METEOROLOGICAL DATA

Specifications on each meteorological data type and the process for compiling the data are detailed below.

Tide Range

The tide/water level data were accessed from NOAA's Center for Operational Oceanographic Products and Services (CO-OPS). The tidal range was calculated by finding the difference in meters between the day's highest and lowest tide for the Kings Point (40.81°N, 73.765°W) and Bridgeport, CT (41.18°N, 73.18°W), stations for 1998 to 2015 and 1991 to 2015, respectively. For the time period from 1998 to 2015, when two tide records were available, each sampling station was assigned the tidal range in meters from the nearest tide station. Bridgeport data were only used for stations D1 and D2 post-1997.While high and low tide time data are available for some years, many of the stations are far enough from weather station locations that the times would not be correct for each sampling station.

Precipitation

Precipitation data were accessed for La Guardia Airport (40.78°N, -73.88°W) from NOAA's Local Climatological Data (LCD) and for Sea Cliff (40.85°N, -73.65°W) from NOAA's Global Historical Climatology Network Daily (GHCND) database. While daily precipitation totals in inches were provided for most days in the La Guardia datasets, daily precipitation was calculated as the sum of hourly totals when a daily value was not available. In addition, the LCD dataset reported daily precipitation values from multiple sources. Where these varied, the values were averaged to obtain a single daily value in inches. The La Guardia dataset spans 1991 to 2015 while the Sea Cliff dataset spans 1995 to 2005. For the period in which two precipitation measurements are available, each sampling station was assigned the value from the nearest weather station.

Air Temperature

Air temperature data were available for four weather stations: La Guardia, Kings Point, Execution Rocks, and Western Long Island Sound. Temperature data for La Guardia were accessed from NOAA'S LCD dataset. As described above, the daily mean temperature value was calculated from a sum of hourly data when a daily value was not available. When multiple daily temperatures were reported, the average of the daily values was calculated. All temperature observations were converted to Celsius. The Kings Point (40.81°N, 73.77°W), Execution Rocks (40.88°N, 73.73°W), and Western Long Island Sound (40.96°N, 73.58°W) historical temperature observations were downloaded from NOAA's National Data Buoy Center (NDBC). Daily mean temperature was calculated as an average of the hourly observation for these three stations. Data for La Guardia, Kings Point, Execution Rocks, and Western Long Island Sound were available for 1991 to 2015, 2004 to 2016, 2006 to 2015, and 2005-2015, respectively. Each sampling station was assigned the closest temperature observation available for the sampling date.

Wind Speed

Wind speed data were also obtained from NOAA's LCD dataset for La Guardia and the NDBC for Kings Point, Execution Rocks, and Western Long Island Sound. When daily average values were not available for a sampling date, an average wind speed for the day was calculated as an average of hourly data. As described above, each sampling station was assigned the closest wind speed observation available for the sampling date.

Wind Direction

Wind direction data were accessed from the same data sources and for the same observation stations as the air temperature and wind speed data. When an average daily wind direction was not available, a vector average was calculated from hourly data using the method described by Grange (2014).

ADDITIONAL DATA SOURCES FOR POTENTIAL FUTURE ANALYSES

To assist IEC with inclusion and analysis of other potentially relevant local environmental data in the future, we reviewed publicly available information on data that may influence D.O. and hypoxic conditions. Water quality can be impacted directly by nearby land use, so our environmental data sources include a variety of land cover, facility, and nutrient loading data. These data can be mapped in GIS to establish the proximity of these sources to the IEC station locations, and regression analyses can assess the effects they have at certain distances. The data types we researched include:

- Impervious surfaces
- Wastewater treatment plants
- Agricultural lands
- Hydrography
- Nutrient loading data
- Combined sewer overflow (CSO)
- Restoration projects
- Conserved parks and lands

Some of the environmental data types above have multiple potential sources of data, so we have included all sources in one table for future research (Exhibit 2-6). Further, we downloaded some of the above data into GIS to show the proximity and quantity of these potential impacts on D.O. levels in the sound (Exhibit 2-7).

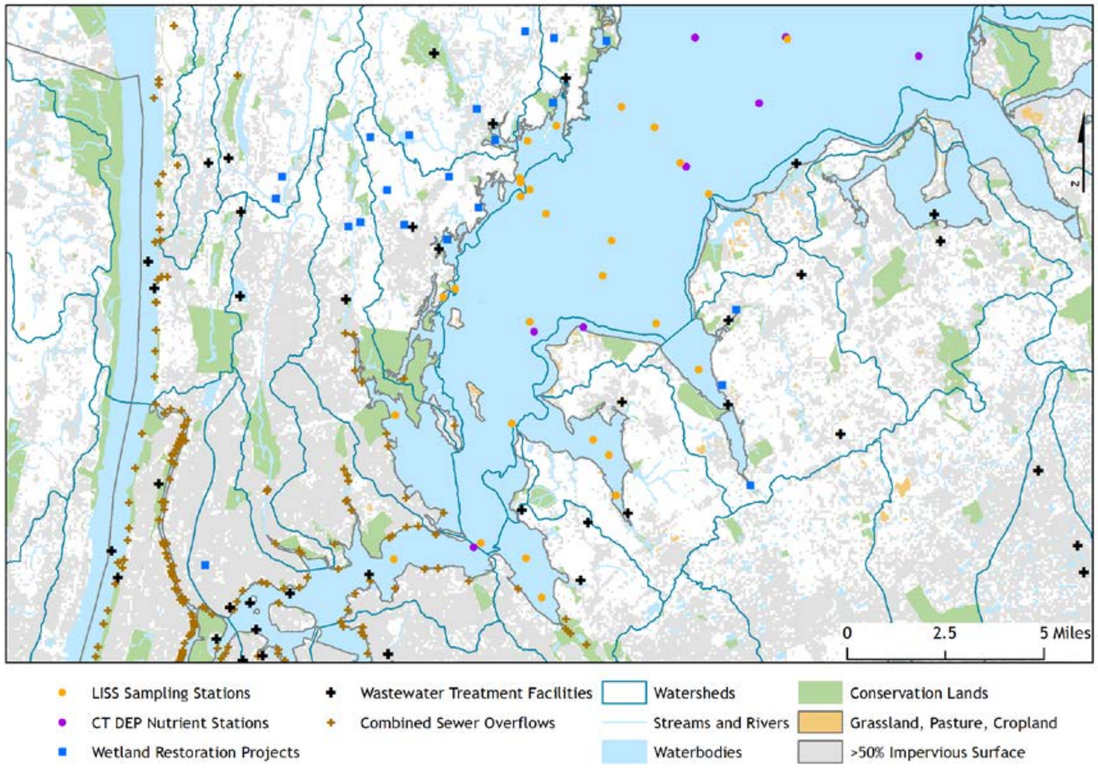
Exhibit 2-7 shows areas of greater than 50% impervious surface in gray, covering large areas of the land surrounding the Western Narrows, and numerous wastewater treatment and CSO facilities along the shoreline. Conservation lands and wetland restoration projects show areas that may mitigate runoff. CTDEEP sampling locations may also provide further information on nutrient loading and total suspended solids in the Western Narrows that can be used in regression analyses.

These example data were also added to the geodatabase in the Additional Data feature dataset (folder) for further review by IEC. To promote future expansion of the relational database and encourage exploration of other potential influences on hypoxic conditions, we created an additional data table in the database, which is detailed in Chapter Three.

EXHIBIT 2-6. ADDITIONAL ENVIRONMENTAL DATA SOURCES.

DATA CATEGORY	NAME AND WEBSITE LINK	SOURCE	DATA FORMAT	DESCRIPTION
Impervious surface	The National Map - 100-Meter Resolution Impervious Surface	USGS	Raster image	Impervious surface raster developed from the National Land Cover Dataset
Impervious surface	Global High Resolution Urban Data from Landsat	NASA	Shapefile	Estimates of fractional impervious cover
Impervious surface	UCONN 2012 Impervious Surface Download	UCONN	Raster image	Raster classified into buildings, roads, and other impervious surfaces
Impervious surface	UCONN Land Cover Maps	UCONN	By request only	Land cover maps for Long Island Sound area
Impervious surface	EnviroAtlas - New York	EPA	Raster image	Percent impervious surface within 1 km2 of a given point. Focused primarily on NYC.
Nutrient	UCONN Vaudrey Lab	UCONN	Excel, shapefile	Some data from studies of nitrogen loading available
Nutrient	UCONN LISICOS	UCONN	CSV	CT DEP nutrient data
Nutrient	National Water Quality Monitoring Council	National Water Quality Monitoring Council	CSV, Excel, KML	Nutrient data available from a variety of sources
Wastewater treatment	New York State Data, Waste Water Treatment Plants	NYS DEC	CSV	Locations of New York water treatment plants
Wastewater treatment	New York Stat Data, Municipal Wastewater	NYS DEC	CSV	Information on the treatment methods for municipal wastewater facilities
Wastewater treatment	New York State Data, Industrial Wastewater Treatment Plants	NYS DEC	CSV	Based on the wastewater treatment plants data set above.
Wastewater treatment	Combined Sewer Overflows (CSOs)	NYS DEC	CSV	SPDES permitted outfalls and locations
Restoration	Long Island Sound Riparian Buffer Management Projects	LISS	KML	Riparian buffer projects
Restoration	LISS Habitat Restoration and Protection Database	LISS		Habitat restoration projects
Restoration	Restoration Atlas	NOAA		NOAA's Habitat Restoration Projects
Agricultural	National Land Cover Database 2011	USGS	Raster image	Raster image of land cover categories for the contiguous US
Conservation	Protected Areas Database of the US	USGS	Geodatabase	Geodatabase of all protected lands in the US
Hydrography	National Hydrography Dataset	USGS	Geodatabase	Geodatabase of hydrography by state

EXHIBIT 2-7. MAP OF ADDITIONAL ENVIRONMENTAL DATA IN THE WESTERN NARROWS.



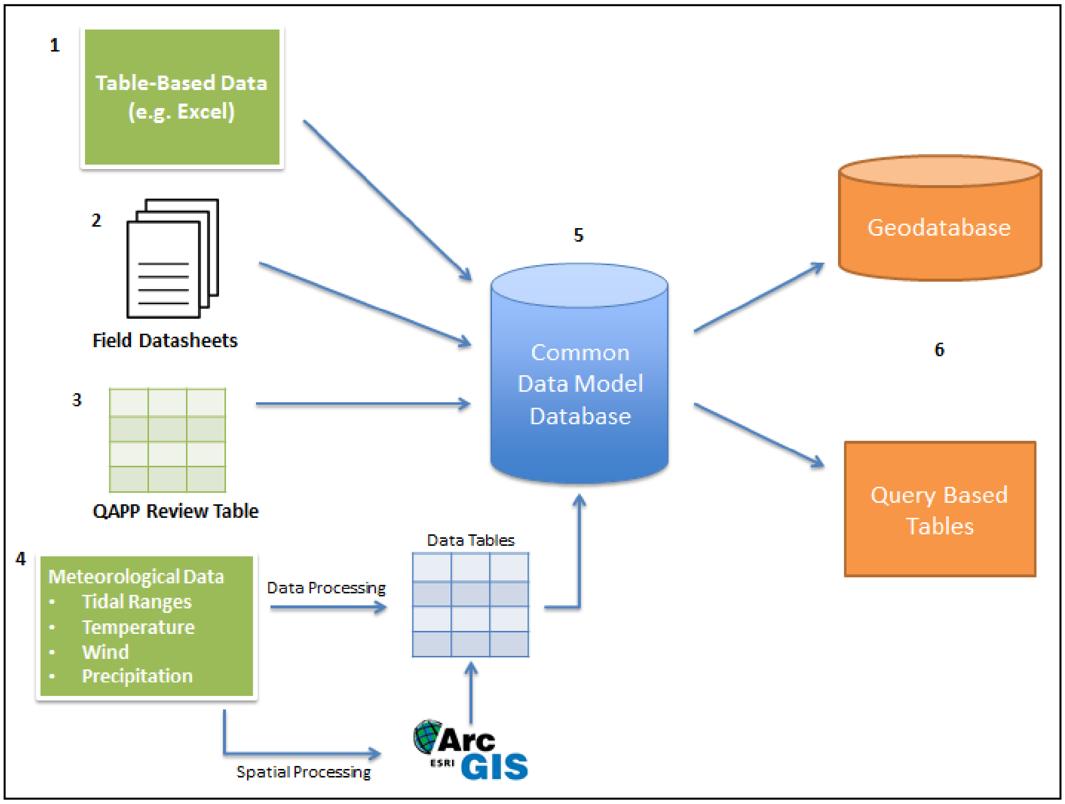
CHAPTER 3 | DATABASE CREATION

RDBMSs are ideal for organizing and relating data from multiple sources for the purposes of cross-data analysis, reporting, and the creation of data products. For this project we used a RDBMS to combine all datasets, since the IEC and meteorological data can be related by a combination of station location and date. We used a CDM to establish the structure of tables and the relationship between the various datasets. The CDM ensures column headers are clear, contain units where applicable, and are relatable across tables for ease of querying and reporting. This chapter discusses the database's design, the tables incorporated, and the geodatabase in more detail.

DATABASE DESIGN

The data tables we compiled for water quality, nutrient and weather observation data, historical QAPP information, and meteorological data were imported into a Microsoft Access relational database named "IEC 1991-2015 Water Quality Database" using our CDM (Exhibit 3-1, steps 1-5). The specifications for each database table model are described in detail in the following sections. In the database, QAPP information is related to the field data by year (annual data), and meteorological data are related to the field data by date (daily data). Queries were designed to output tables into Excel and Stata for regression analyses and GIS data into an ArcGIS geodatabase for spatial analyses (Exhibit 3-1, step 6).

EXHIBIT 3-1. FLOW CHART OF RELATIONAL DATABASE INPUTS AND PRODUCTS



1. Compile existing table based water quality data.
2. Enter data from field data sheets.
3. Enter information from QAPP review.
4. Compile historical meteorological data.
5. Synthesize all information in a RDBMS using a CDM structure.
6. Export data products as a geodatabase, and allow for query-based table outputs.

The RDBMS also allows for data entry of any data contained on field datasheets that may be collected in the future. Within the database, to facilitate interacting with data in the existing water quality and nutrients table, we have created a form that allows the user to locate and edit existing records or create new records in the system table. To ensure data entry accuracy, dropdown menus are used for fields that have specific entries and a calendar selector is used to enter dates. The form is discussed further in Chapter Seven.

DATA TABLES

The IEC 1991-2015 Water Quality Database has established relationships between four data tables which contain all compiled data and information:

1. IEC QAPP Information
2. IEC Water Quality and Nutrient Data
3. IEC Station Coordinates
4. IEC Meteorological Data

For each table, the following sections provide database specifications for table fields, including description of fields and any potential caveats.

WATER QUALITY AND NUTRIENT DATA TABLE

Within the Access database, the water quality and nutrients table is named “IEC Water Quality and Nutrient Data” and is made up of 44 fields containing information from Excel files and field datasheets provided by IEC, and additional data created as part of the CDM (e.g. Record ID). All blank values in the original Excel files from IEC were researched using the original field datasheets and converted to an “ND” (no data) value if applicable. Any edits made to IEC values were recorded in the “Edit Notes” field, and include corrections for typos and updates to field measurements. IEC table rows with no time or depth value (no information collected) were removed from the final dataset.

All years of data were compiled into one table of water quality data fields, and nutrients data were joined to the final table based on the sample, date, and upper depth value. Consistent with industry standards, we conducted extensive quality control to ensure all data were joined correctly. This included cross-checking data with the original data tables, ensuring the correct numbers of available data per sampling year were consistent with original data, and mapping data for visual inspections. There is an additional data table named “IEC Water Quality and Nutrient Data Half Detection Limit” which has all the same fields and definitions but where we have corrected non-detect values to equal half the detection limit for a particular analyte. We included a note in the Edit Notes for any non-detect changes. This table was used for analyses in this report. The final fields and descriptions are located within the table design view in the Access database and are detailed below (Exhibit 3-2).

EXHIBIT 3-2: WATER QUALITY AND NUTRIENT DATA TABLE FIELD INFORMATION.

TABLE FIELD NAME	DESCRIPTION
ID	Unique ID for table sorting
Record ID	Combination of station ID, date, time, and depth to create a unique record identifier
Date Station Link	Combination of date and station ID to link meteorological data to the water quality data
Date	Date data were collected in the field
Year	Year data were collected in the field, link to QAPP information table
Month	Month data were collected in the field
Time 24h	Eastern Standard Time in 24 hour format
Station ID	Identifier for the IEC sampling stations
Depth M	Depth of the collected data
Class	Classification of the depth of collected data (Surface, Bottom)
D.O. mg L	Measure of D.O. in mg/L
Temperature C	Measure of water temperature in degrees Celsius
Salinity PSU	Measure of salinity in parts per thousand
Chl A ug L	Measure of chlorophyll A in µg/L
Secchi Depth M	Depth of Secchi disk in meters
pH	Measure of pH using pH scale
BOD_5 mg L	Measure of biochemical oxygen demand in mg/L
TSS mg L	Measure of total suspended solids in mg/L
Ammonia-Ammonium mg L	Measure of ammonia/ammonium in mg/L
Nitrate Nitrite mg L	Measure of nitrate/nitrite in mg/L
Particulate N mg L	Measure of particulate nitrogen in mg/L
Orthophosphate mg L	Measure of orthophosphate in mg/L
Total Dissolved N mg L	Measure of total dissolved nitrogen in mg/L
Total Dissolved P mg L	Measure of total dissolved phosphate in mg/L
Particulate P mg L	Measure of particulate phosphate in mg/L
DOC mg L	Measure of dissolved organic carbon in mg/L
Particulate C mg L	Measure of particulate carbon in mg/L
Dissolved Silica mg L	Measure of dissolved silica in mg/L
Biogenic Silica mg L	Measure of biogenic silica in mg/L
Sampling Survey Run	Survey run number for a sampling day
Investigation	Investigation number for a sampling day recorded on datasheet
Station ID B	Station ID recorded on some field datasheets
IEC Study Area	Study area listed on some field datasheets
Edit Notes	Information on edits made to IEC data by Industrial Economics

Weather Observation Fields

We included the weather observation data in the Access database as additional fields in the water quality and nutrient data table to ensure all field collected data are available in the final database. Weather data were recorded to varying degrees on the original field datasheets and include notes on cloud cover, sea state, other field notes, and meteorological data like precipitation and tide times and ranges. We conducted extensive quality control to ensure all weather observation data were linked to the water quality records correctly. While the weather observations for some field data contain precipitation and tide range information, these data do not constitute a complete dataset and are included for reference but not analysis. For a complete set of precipitation and tide range, along with other environmental data, the meteorological data table should be used. The fields and descriptions for the weather observations data are located within the Access table design view and detailed below (Exhibit 3-3).

EXHIBIT 3-3: ADDITIONAL WEATHER OBSERVATION FIELDS IN THE WATER QUALITY AND NUTRIENT DATA TABLE.

TABLE FIELD NAME	DESCRIPTION
Cloud Cover	Percent cloud cover
Sea State	Description of sea state
Field Notes	Recorded field notes
Weather	Description of weather
Prev 24 H Rain	Rain amount in inches in the previous 24 hours
Prev 48 H Rain	Rain amount in inches in the previous 48 hours
HTide Time NR	Time of most recent high tide at New Rochelle
HTide Range FT NR	High tide range in feet at New Rochelle
HTide Time KP	Time of most recent high tide at Kings Point
HTide Range FT KP	High tide range in feet at Kings Point

STATION COORDINATES TABLE

The IEC data were collected at 33 different stations from 1991-2015, each with a unique location within LIS. Coordinates were sent to Industrial Economics in one Excel file for the stations that were visited for multiple years, and in a separate file for a set of stations that were only used in the 1990s (C1, C2, D1, D2, D3M, D4, MamH, MilH, HA, HA1, HA2). Stations D1 and D2 were converted to decimal degree coordinates from the original degrees-minutes-seconds coordinates from 1991. The “IEC Station Coordinates” table combines all stations into one table, and we mapped the coordinates in GIS to ensure all data were recorded correctly. The fields and descriptions are located within the Access table design view and detailed below (Exhibit 3-4).

EXHIBIT 3-4: STATION COORDINATES TABLE FIELD INFORMATION.

TABLE FIELD NAME	DESCRIPTION
Station ID	Identifier for the IEC sampling stations, link to the water quality and nutrients table
Latitude DD	Latitude in decimal degrees, WGS84 coordinate system
Longitude DD	Longitude in decimal degrees, WGS84 coordinate system

QAPP TABLE

Historical QAPP information was compiled into the "IEC QAPP Information" table in the database for ease of reviewing and reporting on the equipment types, field methods, analytical methods, and detection and reporting limits outlined in each available QAPP. As there is a QAPP document from 1995 but not for years 1996-2011, the information from the 1995 QAPP also applies to the years 1996-2011in the QAPP information table. For the purposes of linking these data to the water quality and nutrients table by year, each year from 1996-2011 has a record in the table with the information for the 1995 QAPP. For any information where the data are not applicable, the records include an "N/A" value. Data were cross-checked with the original QAPP information data to ensure the database table structure was organized correctly. The fields and descriptions are located within the Access table design view and detailed below (Exhibit 3-5).

EXHIBIT 3-5: QAPP INFORMATION TABLE FIELD INFORMATION.

TABLE FIELD NAME	DESCRIPTION
QAPP Name	QAPP document name
Revision/Release Date	Final date of QAPP document
Project Director	Project director
Project sponsor	Project sponsor
Year Covered by QAPP	Year covered by the QAPP document; link to water quality table
Analysis Name	Name of parameter detailed in QAPP
Equipment Type	Equipment used for analysis type
Field Method	Field method used for analysis type
Analytical Method	Analytical method used for parameter
Holding Time	Holding time for a sample collected for an analysis type
Method Detection Limit	Method detection limit for an analysis type
Reporting Limit	Reporting limit for an analysis type

METEOROLOGICAL DATA TABLE

Meteorological data for five parameters (precipitation, tide range, air temperature, wind speed, wind direction) were joined to sampling stations by date, proximity and availability. The resulting "IEC Meteorological Data" table includes one complete record for each station for each day the station was sampled. In addition to the meteorological data values, the table includes the weather station that provided the value and the distance from the sampling station to the weather station. The sources of the data are included in a separate "IEC Meteorological Generators" table. Every parameter in the data table has a value, so "no data" or "not applicable" values were not necessary to include. We performed a GIS check on the distances to the nearest stations to ensure the closest available meteorological data were used in the final table, and checked each of the data fields to ensure the data were within a normal range for each data type. The fields and descriptions are located within the Access table design view and detailed below (Exhibit 3-6).

EXHIBIT 3-6: METEOROLOGICAL DATA TABLE FIELD INFORMATION.

TABLE FIELD NAME	DESCRIPTION
Date	Date of meteorological data values
Station ID	IEC Sampling Station ID
Date Station Link	Combination of date and station ID to link meteorological data to the water quality data
Precipitation in	Daily precipitation in inches
Precipitation Station	Weather station that provided the precipitation value
Precipitation Station Distance m	Distance from precipitation station to sampling station
Tide Range m	Daily range between highest high and lowest low tide in meters
Tide Station	Weather station that provided the tide range value
Tide Station Distance m	Distance from tide range station to sampling station
Air Temp C	Daily average air temperature in Celsius
Air Temp Station	Weather station that provided the air temperature value
Air Temp Station Distance m	Distance from air temperature station to sampling station
Wind Speed MPH	Daily average wind speed in miles per hour
Wind Speed Station	Weather station that provided the wind speed value
Wind Speed Station Distance m	Distance from wind speed station to sampling station
Wind Direction Degrees	Daily average wind direction in degrees
Wind Direction Station	Weather station that provided the wind direction value
Wind Direction Station Distance m	Distance from wind direction station to sampling station

ADDITIONAL ENVIRONMENTAL DATA TABLE

Our review of potential additional local environmental data revealed multiple public data sources for land use/land cover, nutrient loading, and wastewater discharge locations. As part of this review, we have created the "IEC Additional Environmental Data" structure (Exhibit 3-7) to enable the incorporation of any or all of potential spatial analyses from the additional data sources above. The table can be used to create one set of characteristics for each station, or could be expanded in the future to include years or dates of sampling for various dates of additional data to incorporate more detail (for example, to incorporate the 2001 and 2006 National Land Cover Database data as well as 2011 data). The data can be linked to the water quality and nutrient data using the Station ID field.

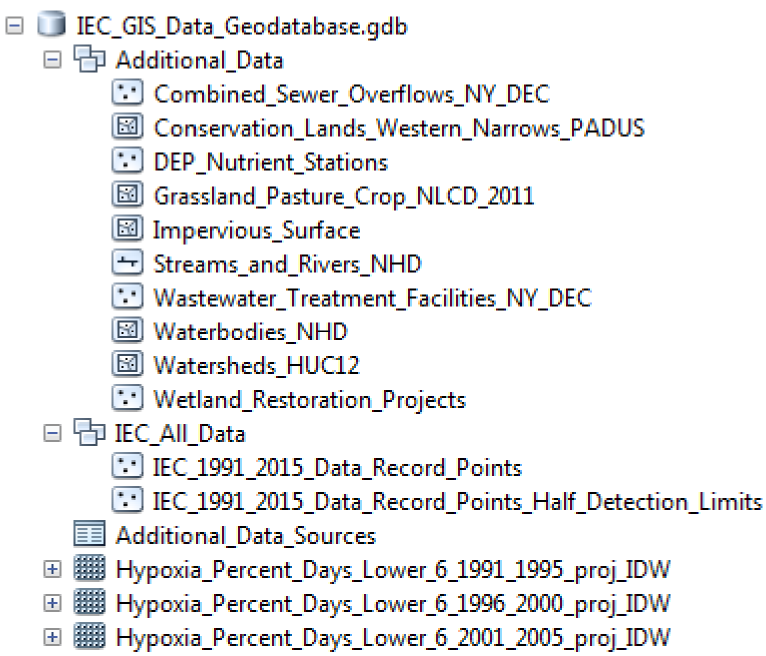
EXHIBIT 3-7. ADDITIONAL ENVIRONMENTAL DATA TABLE STRUCTURE.

TABLE FIELD NAME	DESCRIPTION
Station ID	Identifier for the IEC stations
Percent Impervious in Watershed	Average percent impervious surface within the nearest watershed
Distance to Nearest Treatment Plant	Distance in miles to the nearest wastewater treatment plant outfall
Distance to Nearest CSO	Distance in miles to the nearest combined sewer overflow (CSO) outfall
Percent Conserved in Watershed	Percent of conservation land within the nearest watershed
Percent Agriculture in Watershed	Percent of agricultural land within the nearest watershed
Distance to Nearest Restoration Project	Distance in miles to the nearest restoration project
Average Nearest Nitrogen Loading Value	Average value of the nearest nitrogen loading sample results
Nitrogen Analytical Methods	Methods for determining nitrogen levels
Nitrogen Detection Limit	Nitrogen detection limit for analysis
Average Total Suspended Sediment	Average value of the nearest total suspended sediment sample results
TSS Analytical Methods	Methods for determining the TSS levels
TSS Detection Limit	TSS detection limit for analysis
Average Nearest Phosphorus Loading Value	Average value of the nearest phosphorus loading sample results
Phosphorus Analytical Methods	Methods for determining phosphorus levels
Phosphorus Detection Limit	Phosphorus detection limit for analysis

GEODATABASE

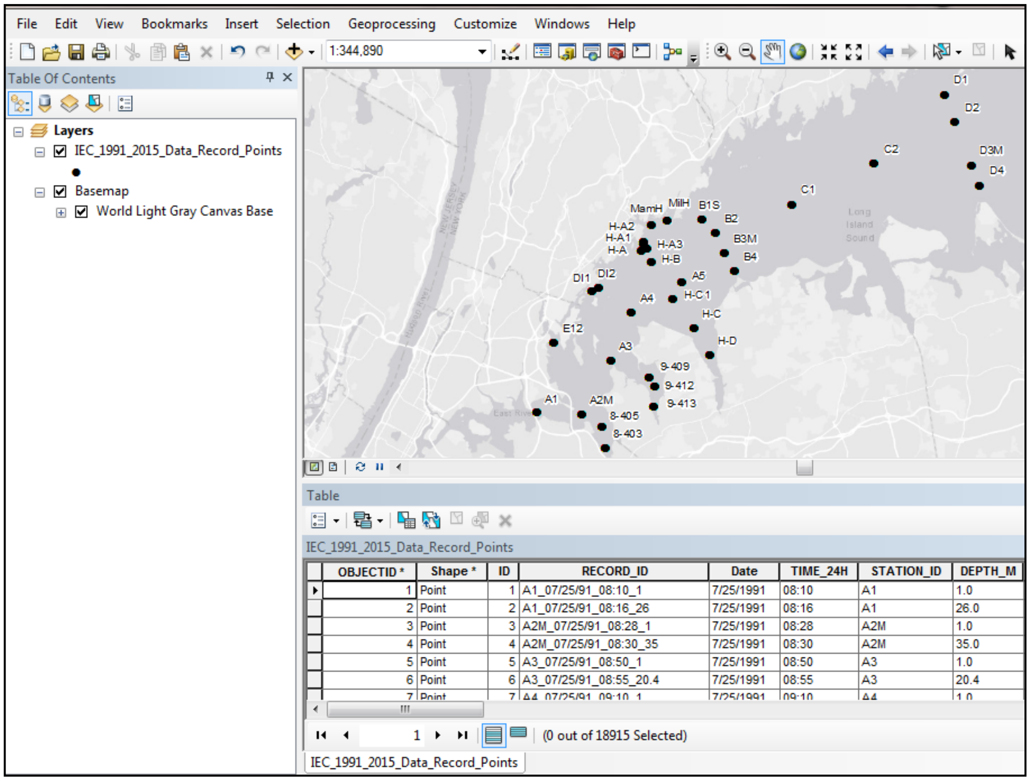
Geodatabases are primarily used to store and relate GIS shape and image files in the same way that Access databases are used to store tables. We have created a geodatabase file named “IEC GIS Data Geodatabase” to store a comprehensive point location file containing all relevant field and meteorological data to be used for mapping purposes, and to store the various spatial products from the spatial hypoxia analysis (Exhibit 3-8).

EXHIBIT 3-8: GEODATABASE STRUCTURE AND CONTENTS.



The “IEC 1991-2015 Data Record Points” point file is stored in a Feature Dataset (folder) named “IEC All Data” and contains all 18,915 records from the Access database. The file can be added to an ArcGIS map file and displayed with a basemap (Exhibit 3-9). We have included a nearly identical file “IEC 1991-2015 Data Record Points Half Detection Limits” which uses half detection limit values for non-detects (the dataset used in the analysis) instead of the values from the original lab data. All files in the geodatabase have associated metadata. The files can be easily filtered by any of the fields using the ArcGIS Definition Query functionality. Data in any field can also be displayed on the map using ArcGIS Symbology functionality. Points located at the same station are effectively “stacked” at the same location, so the best way to display the data is to set a filter for a date or range of dates. All data can be viewed by opening the attribute table for the GIS file.

EXHIBIT 3-9: IEC DATA GIS FILE IN ARCGIS WITH BASEMAP AND ATTRIBUTE TABLE.



To create new point files, points can be selected in GIS and exported as new files in the geodatabase, or users can create new Access database reports with "Latitude DD" and "Longitude DD" fields included to bring the table data into GIS as a new file. All spatial data products created during the analysis and next steps are also included as files in the geodatabase. Additional environmental data are contained in the "Additional Data" feature dataset along with a data sources table with more details on the sources of the additional spatial data (discussed in Chapter Two). GIS image file datasets created during the analysis are contained in the general geodatabase file and are named according to month and year group. These products and the spatial analysis process are discussed further in Chapter Five.

CHAPTER 4 | DATA ANALYSIS METHODS

We used the statistical analysis software JMP® Version 13 (SAS Institute Inc.) to analyze the compiled data. Initially we examined the distribution of the data for each parameter and applied box plots to identify potential outliers. While most all parameters contained data that were outside the 25th or 75th quartiles, we did not preliminarily exclude any data points as outliers because they were all within a scientifically realistic range. Based on a review of the resultant box plots, we determined most parameters were not normally distributed.

We ran a multivariate analysis to regress all parameters against each other to look for linearly correlated data or general relationships between parameters. Where there appeared to be relationships, we explored the data using linear and non-linear analyses. To further explore trends, we examined the data by station, depth, month, and year, or weighted them by potentially influential parameters. Variables were also analyzed and mapped spatially in GIS to confirm trends seen in the multivariate analysis.

Ultimately, our goal was to assess temporal and spatial trends in hypoxia in the Western Narrows of LIS using IEC and meteorological data and to identify potentially influential factors. To accomplish this goal, we used a variety of analytical methods, including those described below. The results of these analyses are presented in Chapter Five.

DATA ANALYSIS

For the purposes of analysis, we created additional data columns to bin data. In addition to binning data by month and year, we binned data by depth and D.O. condition (i.e., chronic criteria for life, hypoxia, severe hypoxia, and anoxia). Depth categories included surface water (less than 1 m), below surface (1 -5 m), and in five meter intervals (5-10 m, 10-15 m, 15-20 m) to 20 meters (> 20 m). D.O. condition categories included:

- Below 1 mg/L for anoxic conditions,
- Below 2 mg/L for severe hypoxia,
- Below 3 mg/L for hypoxic conditions, and
- Below 4.8 mg/L for the CT DEEP D.O. Chronic Exposure Criteria.

To assist in identifying relationships or trends, we weighted data by potentially influential factors (e.g., distance from sampling station to meteorological observations, depth, meteorological parameter, time of day). We identify in Chapter Five where we weighted data, how we weighted them, and if there was any influence or use in the final analysis.

MULTIVARIATE ANALYSIS

We ran a multivariate analysis to regress all water quality, nutrient, and meteorological parameters against each other, within and across categories, to look for linearly correlated data. While the premise of this analysis is to identify linearly related data, it plots the data allowing us to visually determine potential non-linear relationships between parameters. All data with potential relationships either linear or non-linear were carried through subsequent analyses.

LINEAR ANALYSES

Data that had apparent linear relationships existed between various nutrient parameters (e.g., total dissolved nitrogen and ammonia-ammonium, or particulate nitrogen and particulate carbon). Linearly related data were further analyzed using bivariate analysis.

NON-LINEAR ANALYSES

Visually observed potential non-linear relationships were plotted and curves were fit to the data. Goodness of fit curve was determined by relative Akaike Information Criterion (AIC) and Bayesian information criterion (BIC).

TIME SERIES AND ANALYSIS OF VARIANCE

To evaluate temporal trends, we plotted D.O. data over time and by month, station, and depth. We used box plots to visually represent the median and quantiles. Depending on the underlying distribution of the data, we applied Student's T tests or nonparametric comparisons using Kruskal-Wallis, Steel-Dwass, and/or Dunn's test to statistically assess temporal trends, spatial trends, or differences with D.O. and hypoxia. All tests for significant differences were conducted at a significance level of 0.05.

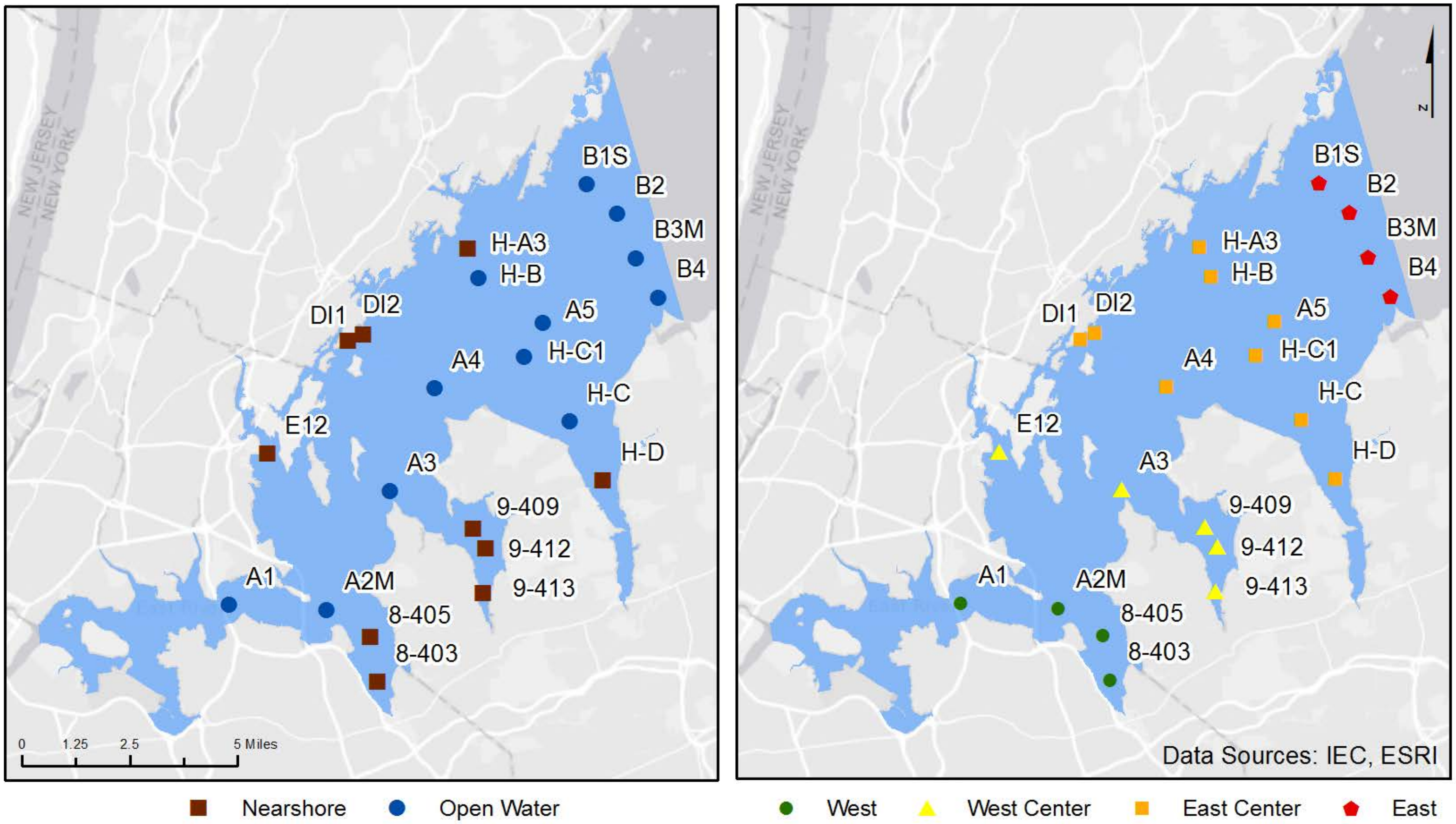
PERCENT OF HYPOXIC SAMPLES

To elucidate trends in frequency and severity of hypoxia, we used nominal D.O. category bins for each sampling station to determine the percent of samples each summer in each D.O. bin.

SPATIAL TREND DISPLAY

To spatially display trends in D.O. over time, we binned data by month and depth at five year intervals to show the percentage of days that were hypoxic (<3.0 D.O.) in the Western Narrows. We used inverse distance weighting to determine D.O. values between station locations and to generate maps showing potential hypoxic areas over time for upper (1 m) and lower (bottom) depths. Additional spatial analysis included displaying the frequency of hypoxia by location groupings and five year bins. The location groupings are Open Water and Nearshore, and West, West Central, East Central, and East (Exhibit 4-1).

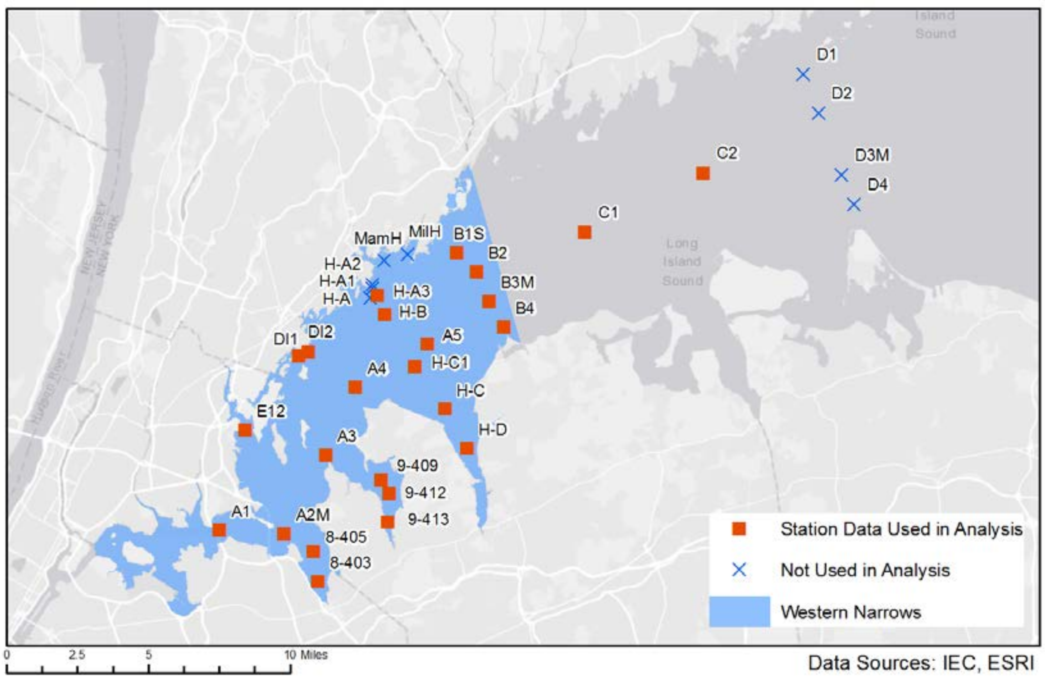
EXHIBIT 4-1. NEARSHORE AND OPEN WATER IEC SAMPLING STATIONS, AND WEST TO EAST IEC SAMPLING LOCATIONS.



DATA EXCLUSIONS

Data were sampled at 33 stations throughout the Western Narrows and further east, but nine of those sampling stations only had one year of data (1991; station names: D1, D2, D3M, D4, H-A, H-A1, H-A2, MamH, MilH). From all analyses, we excluded data from these nine sampling stations as they would likely complicate interpretation and not add much to a temporal and spatial analysis of D.O. and hypoxia. Only 22 stations have data spanning all 25 summers, with an additional two stations having six years of data (1991-1996 for stations C1 and C2); these are the stations that we used for the bulk of our analyses Exhibit 4-2). C1 and C2 were excluded from spatial analyses for consistency purposes, but included for statistical analyses. Any additional data exclusions were conducted after further examining the data and justifications (e.g., outliers) are detailed in Chapter Five.

EXHIBIT 4-2. IEC LIS SAMPLING LOCATIONS WITH EXCLUDED STATIONS.



CHAPTER 5 | RESULTS

We analyzed the compiled IEC and meteorological dataset to detect and assess spatial trends in hypoxic conditions and identify factors that may be influencing hypoxia in the Western Narrows. Initial analyses focus on identifying temporal trends of D.O. and resulting hypoxic conditions across sampling years, months, and depths. This is followed by an analysis of D.O. and resulting hypoxic conditions by depth and sampling station. Next, we investigated parameters that may influence D.O. and hypoxia (e.g., air temperature). In all cases, analyses progressed in complexity. For example, initial analyses investigated temporal trends for all data lumped by year and subsequent analyses investigated trends by month within a year. In Chapter Six, we qualitatively discuss the results presented below, and provide some context for the data with regards to LIS-wide management decisions that may impact D.O. and hypoxia (e.g., a TMDL).

DISSOLVED OXYGEN AND HYPOXIA TEMPORAL TRENDS

To identify temporal trends in D.O. and hypoxic conditions we investigated:

- D.O. by year and month
- Frequency of hypoxia by year and month
- Onset and end of hypoxia

The following paragraphs discuss the results of each analysis in more detail.

D.O. BY YEAR AND MONTH

On a high-level scale, to understand how D.O. concentrations have changed from year-to-year (for the months of June-September) we grouped all samples by year across month, sampling station, and depth. As shown in Exhibit 5-1, D.O. concentrations varied within a year from less than one mg/L to almost 20 mg/L. Across the full 25 year timeframe, there were no visible trends with summer D.O. Beginning in 1991 and continuing through 2004, there was a slight decreasing trend in D.O. and, from 2004 through 2015, there was a slight increasing trend. The lowest recorded D.O. observation was 0.03 mg/L from August 2005 (5.5 m depth, station H-C1) and the highest recorded value was 19.6 mg/L from July 2010 (1 m depth, station B3M).

Next, to understand variation within and between months, we grouped all samples by month across years, sampling station, and depth. As shown in Exhibit 5-2A, D.O. concentrations were significantly different across months (except July and September), with June exhibiting the highest D.O. concentrations (Kruskal-Wallis and subsequent Dunn's test: $p<0.001$). The average D.O. concentrations showed a decreasing trend from June (6.8 mg/L) to July (5.4 mg/L) to August (4.4 mg/L). However, in September, D.O. concentrations increased to levels consistent with those observed in July (5.2 mg/L). When examined within a year, average monthly D.O. concentrations showed a similar pattern (Exhibit 5-2B).

EXHIBIT 5-1. TIME SERIES OF ANNUAL SUMMER D.O. ACROSS ALL DEPTHS, STATIONS, AND MONTHS FROM 1991-2015

Black dots are data points, the blue line connects the average D.O. for each summer, and the horizontal red line displays D.O.= 3.0 mg/L.

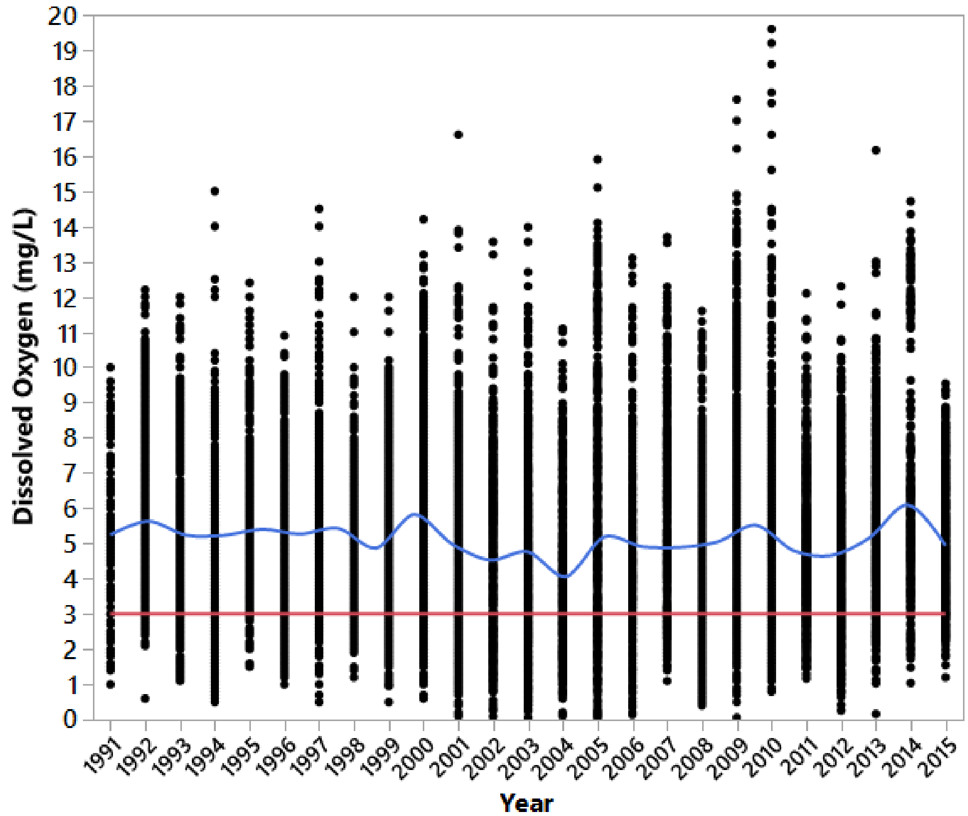


EXHIBIT 5-2A BOX PLOT OF MONTHLY D.O.VALUES ACROSS ALL DEPTHS, YEARS, AND STATIONS.

Black dots are data points, the horizontal grey line is the grand mean, and the horizontal red line displays D.O.= 3.0 mg/L. Box plots of different colors are significantly different (α = 0.05).

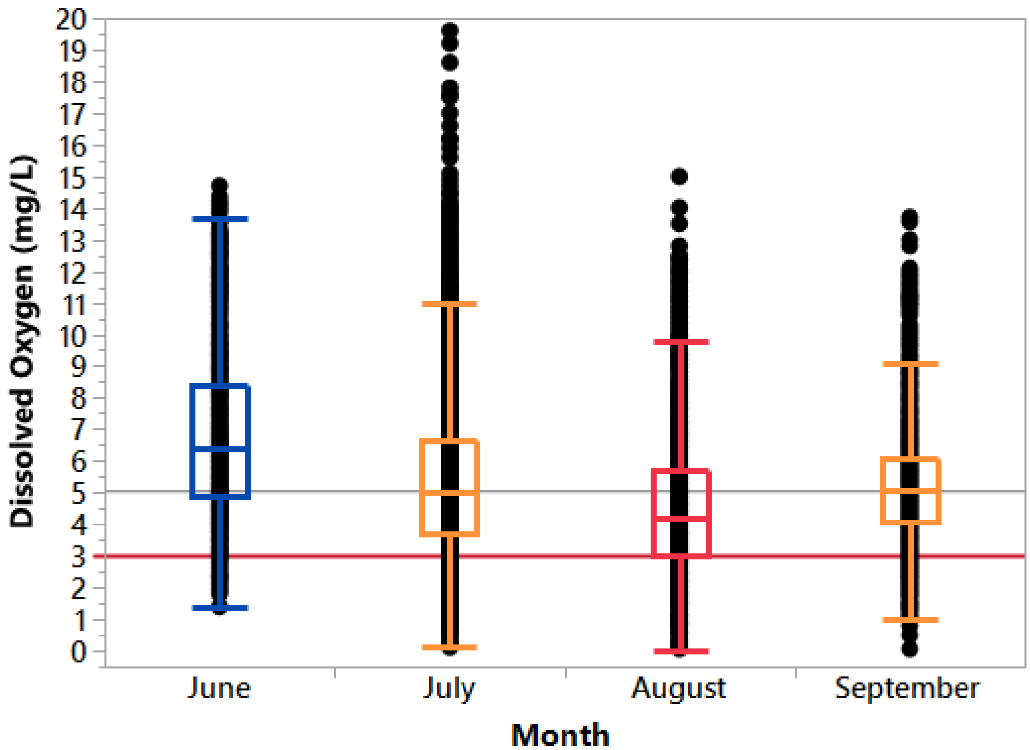


EXHIBIT 5-2B AVERAGE D.O. CONCENTRATIONS BY MONTH AND YEAR.

Months with different letters within a year indicate significant differences determined by Steel-Dwass method ($\alpha = 0.05$).

YEAR	MONTH			
	JUNE	JULY	AUGUST	SEPTEMBER
1991	N/A	4.4 (a)	5.3 (b)	5.9 (b)
1992	N/A	6.1 (A)	5.6 (B)	4.9 (C)
1993	7.9 (a)	6.1 (b)	4.4 (c)	4.8 (d)
1994	6.9 (a)	4.3 (B)	4.6 (B,C)	6.4 (A,D)
1995	7.5 (a)	5.8 (b)	5.8 (b,C)	5.3 (b,d)
1996	N/A	5.1 (a)	4.6 (b)	5.1 (A)
1997	8.5 (a)	6.0 (b)	4.9 (c)	4.5 (d)
1998	6.4 (a)	5.5 (b)	4.5 (c)	5.2 (b)
1999	5.4 (a)	5.4 (a)	4.3 (b)	5.5 (a)
2000	N/A	5.4 (a)	6.1 (b)	7.0 (c)
2001	N/A	5.6 (a)	4.0 (b)	4.2 (c)
2002	N/A	4.4 (a)	3.4 (b)	6.2 (c)
2003	5.6 (a)	5.1 (a,b)	4.0 (c)	5.7 (d)
2004	3.9 (a,b)	4.0 (a)	3.8 (b)	3.7 (a,b)
2005	5.7 (a)	6.8 (a,b)	3.9 (c)	5.6 (a,d)
2006	5.2 (a)	4.9 (b)	3.7 (c)	6.0 (d)
2007	7.0 (a)	5.6 (b)	4.6 (c)	5.5 (b,d)
2008	5.9 (a)	4.2 (b)	3.5 (c)	4.4 (b,d)
2009	8.2 (a)	7.1 (b)	4.6 (c)	6.5 (b,d)
2010	7.6 (a)	5.2 (b,c)	4.1 (c)	4.3 (b,d)
2011	6.9 (a)	5.3 (b)	4.2 (c)	4.6 (d)
2012	5.7 (a)	5.2 (a,b)	4.0 (c)	4.3 (d)
2013	6.4 (a)	5.9 (b)	4.8 (c)	4.7 (c,d)
2014	12.4 (a)	4.6 (b)	5.4 (c)	5.2 (c,d)
2015	7.0 (a)	5.2 (b)	4.6 (c)	4.2 (d)

FREQUENCY OF HYPOXIA BY YEAR AND MONTH

On a gross scale, to understand the occurrence of hypoxic conditions over time we grouped all samples by year across month, sampling station, and depth. As shown, in Exhibit 5-3A, the frequency of hypoxic conditions generally increased from 1991 to 2004, then generally decreased through 2015. Exhibit 5-3B demonstrates D.O. values below 3 mg/L and significant differences (Exhibit 5-3C) between years with respect to their mean hypoxic and lower conditions. Within a year, the onset of hypoxic conditions generally begins in July (Exhibit 5-4). That is, from July, hypoxic conditions continue and become more common through August and then taper in September.

EXHIBIT 5-3A FREQUENCY OF HYPOXIA: PERCENT OF ALL SAMPLES EACH YEAR ABOVE AND BELOW HYPOXIC CONDITIONS (3 MG/L).

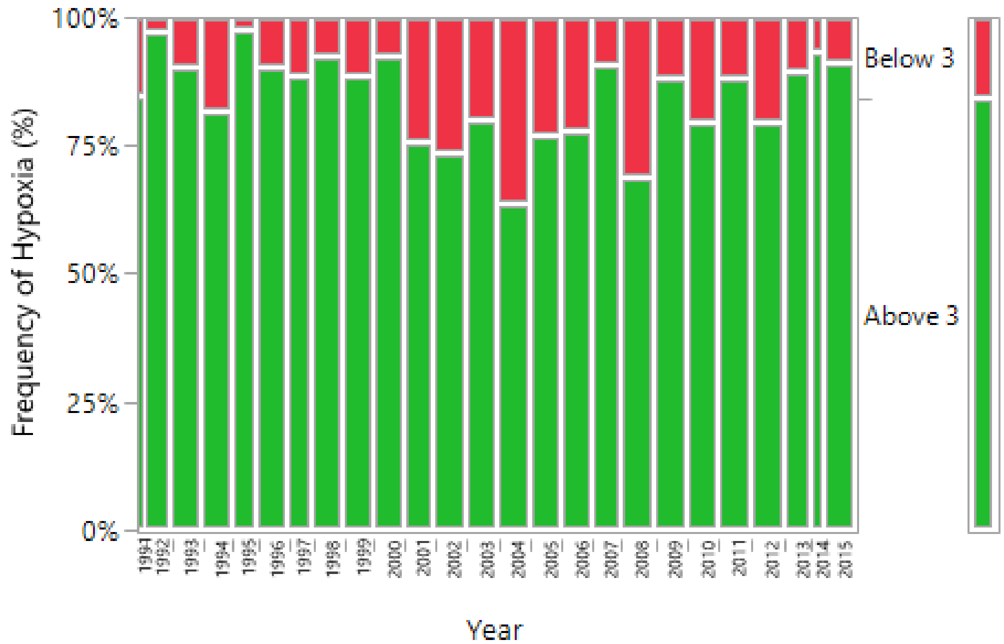


EXHIBIT 5-3B BOX PLOT OF ANNUAL DISSOLVED OXYGEN CONCENTRATIONS BELOW HYPOXIC CONDITIONS (3 MG/L) ACROSS ALL STATIONS.

Black dots are data points, the horizontal grey line is the grand mean..

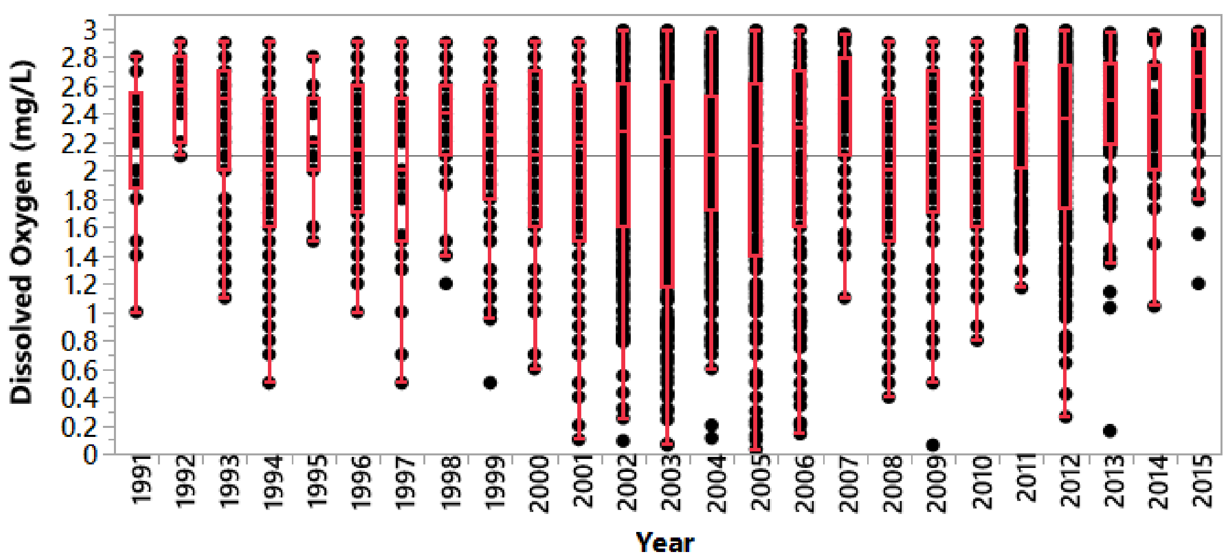


EXHIBIT 5-3C YEARS WITH SIGNIFICANTLY DIFFERENT HYPOXIC CONDITIONS ACROSS ALL STATIONS.

Only the years with significant differences are displayed in this table. All other comparisons between years were not significantly different. Year 1 is significantly higher than year 2 averages. Significant differences were determined by Wilcoxon each pair method (α = 0.05).

YEAR 1	YEAR 2	P-VALUE
1992	1991	0.0143
1992	1995	0.0128
1992	1998	0.0273
1992	2000	0.0125
1992	1996	0.0078
1992	2009	0.0317
1992	1999	0.006
992	1997	0.0007
1992	2003	0.0125
1992	2006	0.0135
1992	1994	0.0003
1992	2005	0.0041
1992	2001	0.0051
1992	2002	0.0105
1992	2010	0.001
1992	2008	0.0002
1992	2004	0.0012
1993	2000	0.0365
1993	1996	0.0295
1993	1999	0.0299
1993	2006	0.0329
1993	1997	0.0014
1993	2003	0.0078
1993	2002	0.0164
1993	1994	0.0002
1993	2001	0.0037
1993	2010	0.0007
1993	2005	0.0015
1993	2004	0.0012

YEAR 1	YEAR 2	P-VALUE
1993	2008	<.0001
1998	1994	0.0004
1998	1997	0.001
1998	1996	0.047
1998	2001	0.016
1998	2005	0.0072
1998	2010	0.0011
1998	2004	0.0042
1998	2008	<.0001
1999	2008	0.0099
2002	2008	0.0056
2004	2008	0.0191
2006	2008	0.0157
2007	2004	<.0001
2007	2005	0.0001
2007	2001	0.0003
2007	1994	<.0001
2007	2002	0.0024
2007	2003	0.0012
2007	2006	0.0049
2007	1997	0.0001
2007	1999	0.0057
2007	1996	0.0062
2007	2000	0.0088
2007	1991	0.0398
2007	2009	0.0295
2007	2010	<.0001
2007	2008	<.0001
2009	2008	0.007

YEAR 1	YEAR 2	P-VALUE
2009	1994	0.0463
2011	2008	<.0001
2011	2004	<.0001
2011	2010	<.0001
2011	2005	<.0001
2011	2001	0.0002
2011	1994	<.0001
2011	2002	0.0025
2011	2003	0.0011
2011	1997	0.0002
2011	2006	0.0041
2011	1999	0.0113
2011	1996	0.0087
2011	2000	0.0103
2011	2009	0.041
2012	2008	<.0001
2012	2004	0.0062
2012	2005	0.0055
2012	1994	0.0028
2012	2010	0.0087
2012	1997	0.0112
2012	2001	0.0223
2012	2003	0.0189
2013	2008	<.0001
2013	2004	<.0001
2013	2010	<.0001
2013	2005	<.0001
2013	2001	0.0001
2013	2002	0.0006

YEAR 1	YEAR 2	P-VALUE
2013	1994	<.0001
2013	2003	0.0005
2013	2006	0.0012
2013	1997	<.0001
2013	1999	0.0017
2013	1996	0.0023
2013	2000	0.003
2013	2012	0.0482
2013	2009	0.0099
2013	1991	0.0275
2014	2008	0.0042
2014	2004	0.0479
2014	2010	0.0205
2014	2005	0.0356
2014	2001	0.0487
2014	1994	0.0077
2014	1997	0.0149
2015	2008	<.0001
2015	2004	<.0001
2015	2002	<.0001
2015	2001	<.0001
2015	2010	<.0001
2015	2005	<.0001
2015	1994	<.0001
2015	2006	<.0001
2015	2003	<.0001
2015	2012	<.0001
2015	1997	<.0001
2015	1999	<.0001

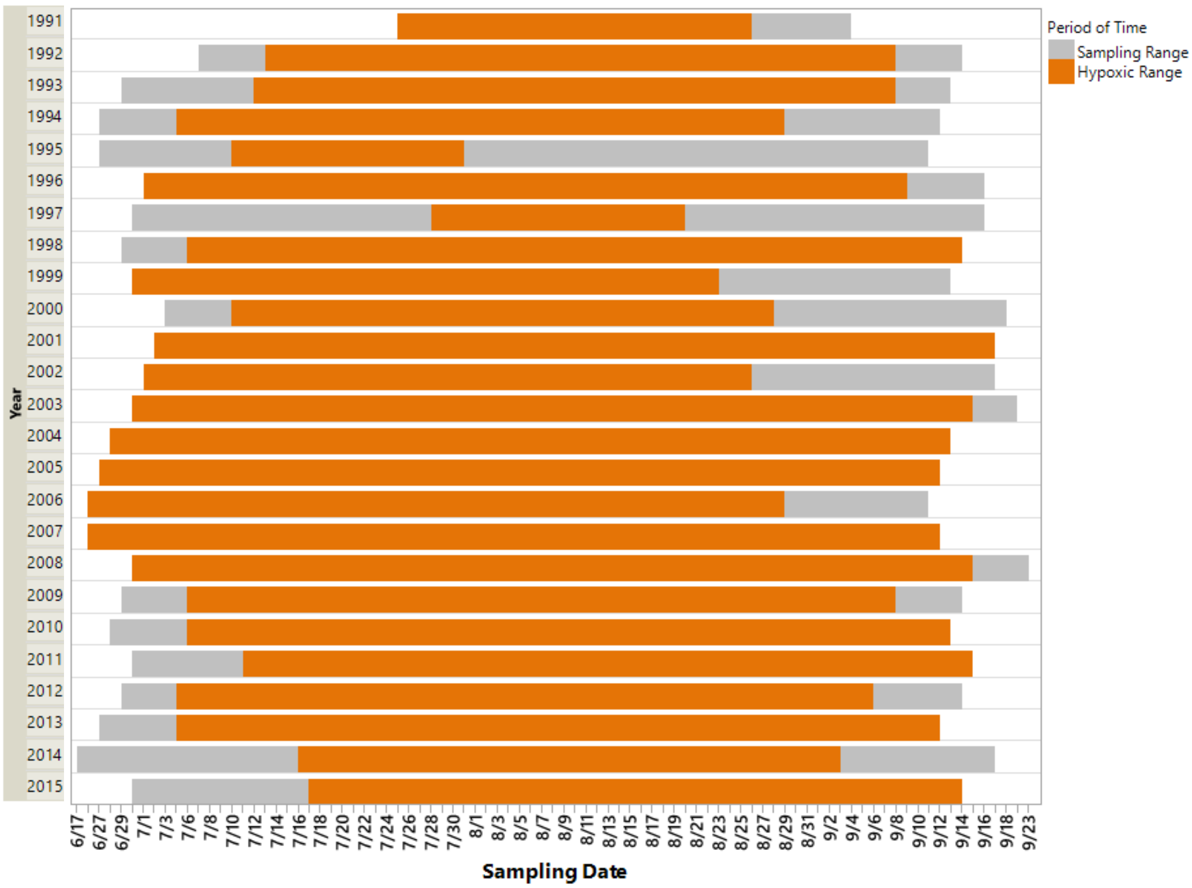
YEAR 1	YEAR 2	P-VALUE
2015	2009	<.0001
2015	1996	<.0001
2015	2000	<.0001
2015	1998	<.0001
2015	1991	<.0001
2015	1995	0.0005
2015	2011	0.0014
2015	1993	0.0004
2015	2007	0.0045
2015	2013	0.0196
2015	2014	0.0154

EXHIBIT 5-4 FREQUENCY AND DURATION OF HYPOXIA: PERCENT OF ALL SAMPLES BY YEAR AND MONTH ABOVE AND BELOW HYPOXIC CONDITIONS (3 MG/L).

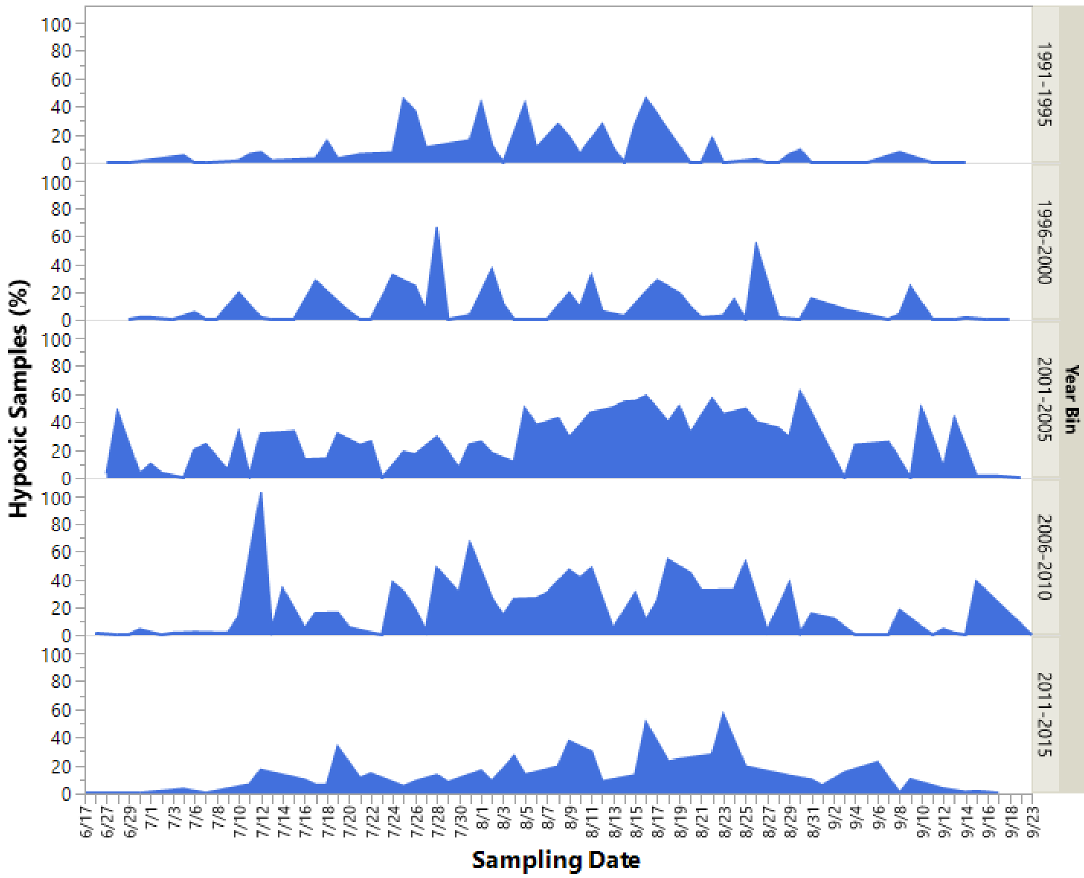
ONSET AND END OF HYPOXIA

To understand the onset of hypoxia each year we plotted the first date where at least one sample at any station or depth measured D.O. below 3 mg/L. The end of hypoxia was plotted as the last sampling day where at least one sample at any station measured D.O. below 3 mg/L (Exhibit 5-5A). Exhibit 5-5B demonstrates summer fluctuations, in five year bins, between the onset and end of hypoxia, where the magnitude of the frequency of hypoxia is evident.

EXHIBIT 5-5A ONSET AND END OF HYPOXIA EACH YEAR.



EXIBIT 5-5B ONSET AND END OF HYPOXIA IN FIVE YEAR BINS AND SUMMER FLUCTUATION.



DISSOLVED OXYGEN SPATIAL TRENDS

To identify depth and spatial trends in D.O. and hypoxic conditions we investigated:

- D.O. by depth. Samples were grouped into the following bins:
  - o Depth bin 1 is ≤1m depth;
  - o Depth bin 2 is >1m to 5 m;
  - o Depth bin 3 is >5m to 10m;
  - o Depth bin 4 is >10m to 15 m;
  - o Depth bin 5 if >15m to 20 m; and
  - o Depth bin 6 is >20 m
- Frequency of hypoxia by various locations:
  - o Station
  - o West, West Center, East Center, East
  - o Nearshore and Open Water

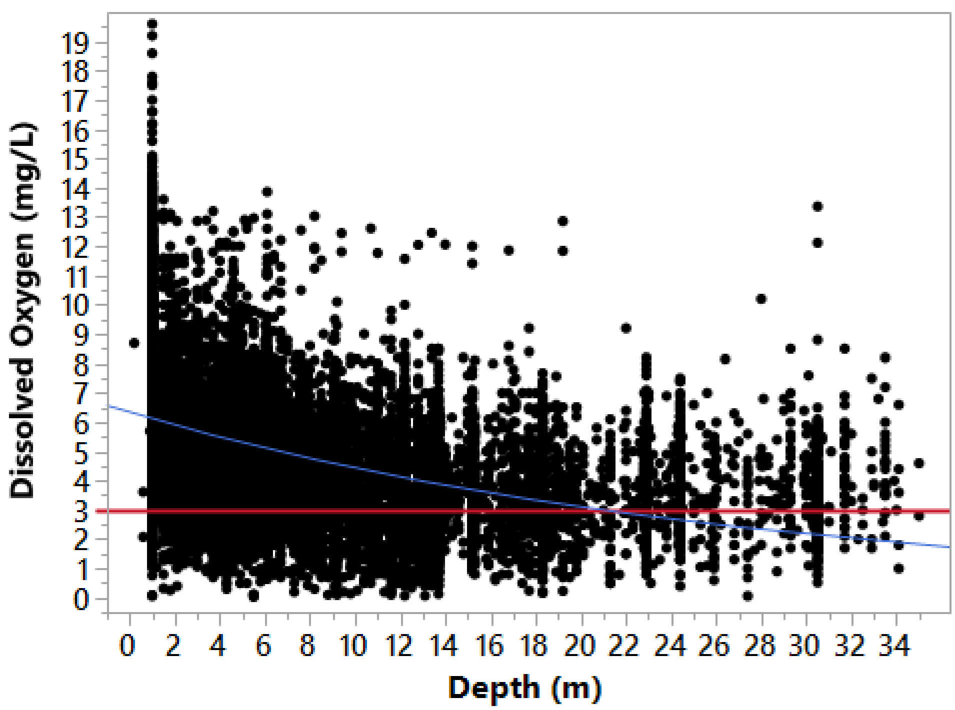
The following paragraphs discuss the results of each analysis in more detail.

D.O. AND HYPOXIC CONDITIONS BY DEPTH

When D.O. is plotted by collection depth, D.O. concentrations generally decrease with increasing depth (Exhibit 5-6). As shown in Exhibit 5-6, this trend is best modeled with an exponential curve.[1] Consistent with this observation, Exhibit 5-7 shows the variation of observed D.O. concentrations within a depth bin and compares D.O. concentrations across bins. The top 1 m depth has the highest average D.O. at 6.6 mg/L, followed by the 1-5 m depth bin with an average D.O. of 5.2 mg/L, followed by the 5-10 m depth bin with an average D.O. of 4.6 mg/L. The first four depth bins were all significantly different (Dunn's test; $p<0.001$). Finally, the three deepest depth bins showed the lowest D.O. and were similar when compared to each other; the differences were not significant ($\alpha=0.05$).

EXHIBIT 5-6 DISSOLVED OXYGEN CONCENTRATIONS BY DEPTH FOR ALL YEARS AND STATIONS.

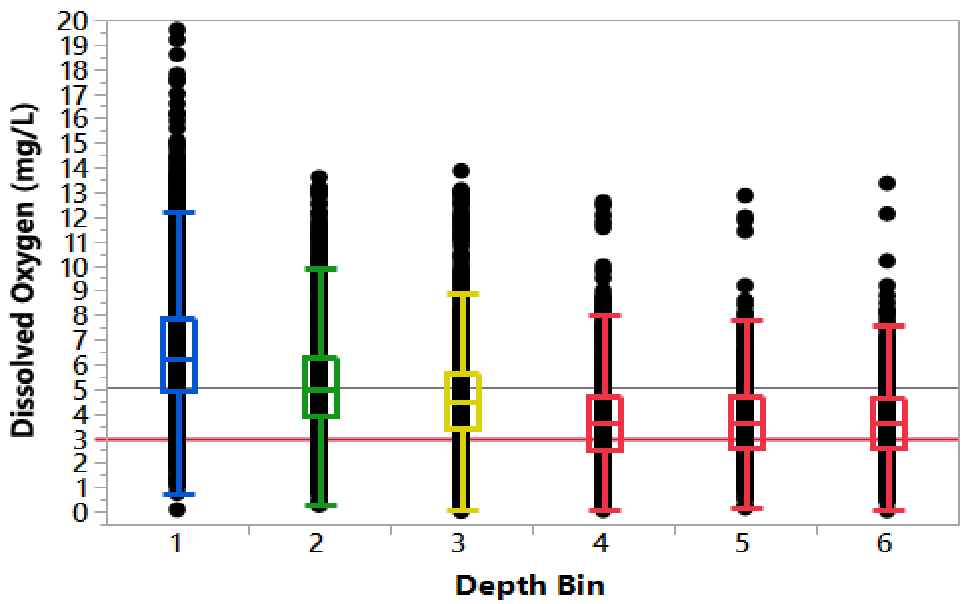
The blue line is an exponential line and the horizontal red line displays D.O.= 3.0 mg/L.



[1] For all analyses, model justification and AIC scores can be provided upon request.

EXHIBIT 5-7 DISSOLVED OXYGEN CONCENTRATIONS AND BOX PLOTS BY DEPTH BIN FOR ALL YEARS AND STATIONS.

Depth Bin 1 is ≤1 m; Depth Bin 2 is 1-5 m; Depth Bin 3 is 5-10 m; Depth Bin 4 is 10-15 m, Depth Bin 5 is 15-20 m; and Depth Bin 6 is >20 m. Black dots are data points, the horizontal grey line is the grand mean, and the horizontal red line displays D.O.= 3.0 mg/L. Box plots of different colors are significantly different.



FREQUENCY OF HYPOXIA BY LOCATION

To elucidate trends in the occurrence of hypoxic conditions across space, we grouped all samples by sampling station across years and depth. Next, we quantified the percent of samples below the chronic threshold criteria of 4.8 mg/L, those that demonstrate hypoxia (<3 mg/L), those below the severe hypoxia threshold (<2 mg/L), and those that represent anoxic conditions (<1 mg/L) at each station in the Western Narrows (Exhibit 5-8A and B). Station A4 demonstrated the highest frequency of hypoxia with ~26% of the samples below 3 mg/L and 11% of samples below 2 mg/L (for all depths sampled). Applying the 4.8 mg/L chronic threshold criteria (promulgated by Connecticut and New York) to the available data by station, we observe a decrease in the occurrence of hypoxic conditions moving west to east (Exhibit 5-8).

Then we grouped the stations by general location within the Western Narrows: West, West Central, East Central, and East. Then we grouped the samples into surface and bottom water samples, surface samples were defined as those with depths ≤10 m and bottom samples as those with depths ≥10 m. We quantified the percent of samples by surface or bottom waters that were above and below hypoxic conditions (<3 mg/L) for each general location (Exhibit 5-9).

Lastly we grouped the data by nearshore and open water. Nearshore stations include 8-403, 8-405, E12, 9-409, 9-412, 9-413, DI1, DI2, H-A3, and H-D. Open water stations include A1, A2M, A3, A4, HB, A5, HC-1, HC, B1S, B2, B3M, and B4. We quantified the percent of samples that were above and below hypoxic conditions (<3 mg/L) in five year bins (Exhibit 5-10 A and B).

EXHIBIT 5-8A FREQUENCY OF SAMPLES WITHIN EACH D.O. CATEGORY BY STATION.

Sampling stations generally move west to east along the X-Axis. The width of the columns correspond to the number of samples taken, with station A1 having the highest number of samples (n=1,358).

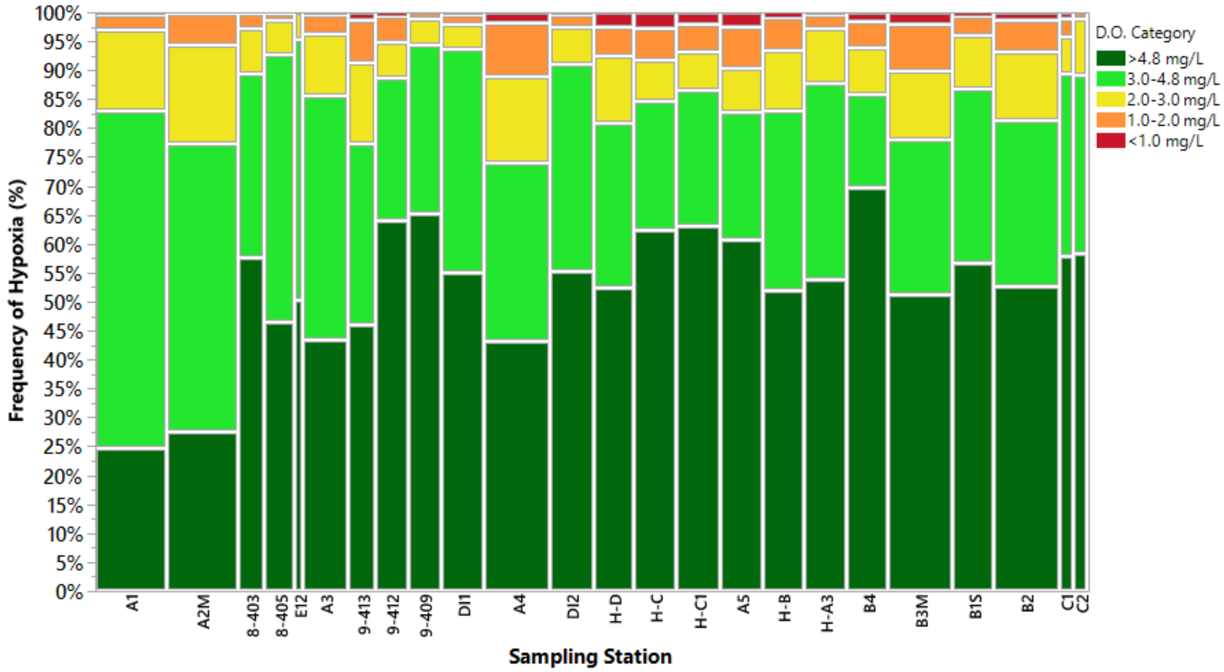


EXHIBIT 5-8B FREQUENCY OF HYPOXIA (D.O. <3.0 MG/L) BY STATION.

Sampling stations generally move west to east along the X-Axis. The width of the columns correspond to the number of samples taken, with station A1 having the highest number of samples (n=1,358).

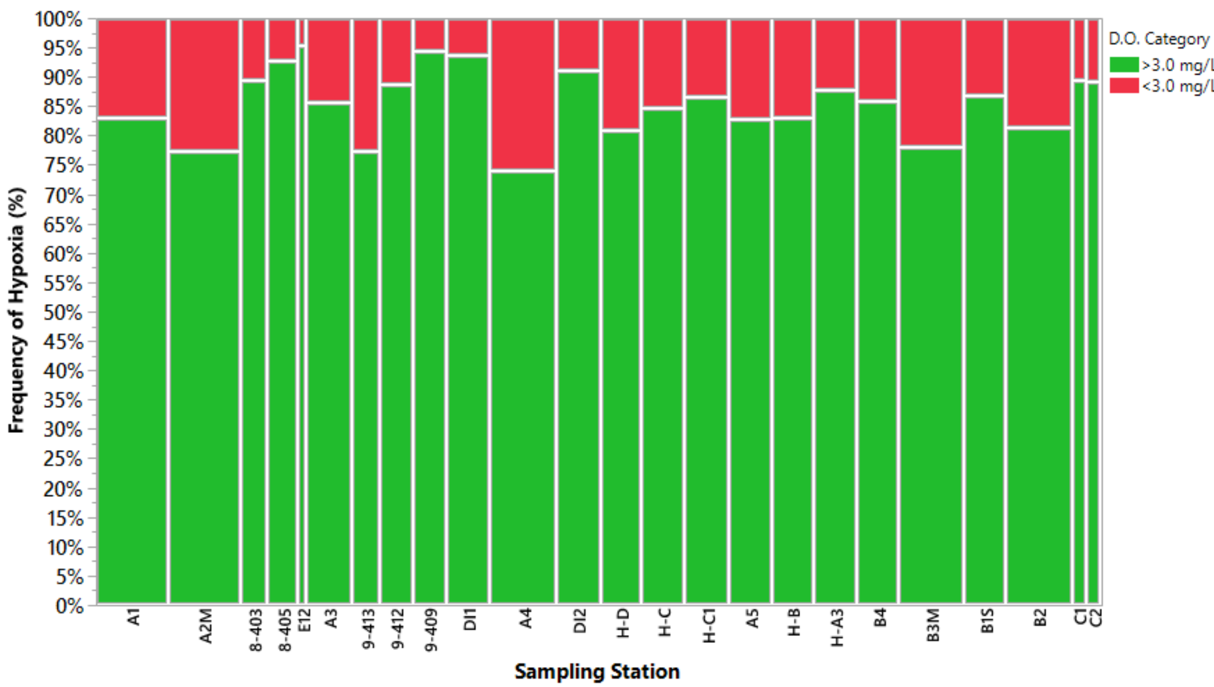


EXHIBIT 5-9 FREQUENCY OF HYPOXIA (D.O. <3.0 MG/L) BY GENERAL LOCATION.

The width of the columns correspond to the number of samples taken. Surface samples are defined as ≤10 m and bottom samples are ≥10m.

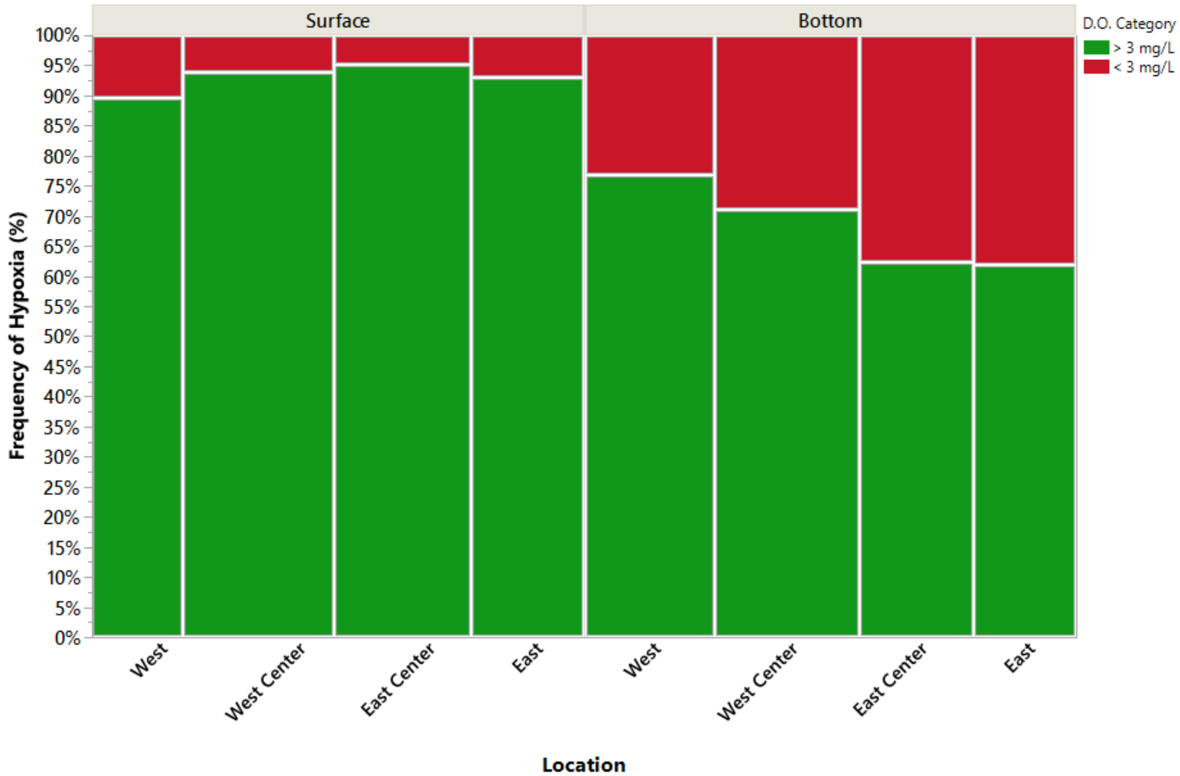


EXHIBIT 5-10A FREQUENCY OF HYPOXIA (D.O. <3.0 MG/L) BY NEARSHORE SAMPLING STATIONS.

The width of the columns correspond to the number of samples taken. Year bins are in five year intervals.

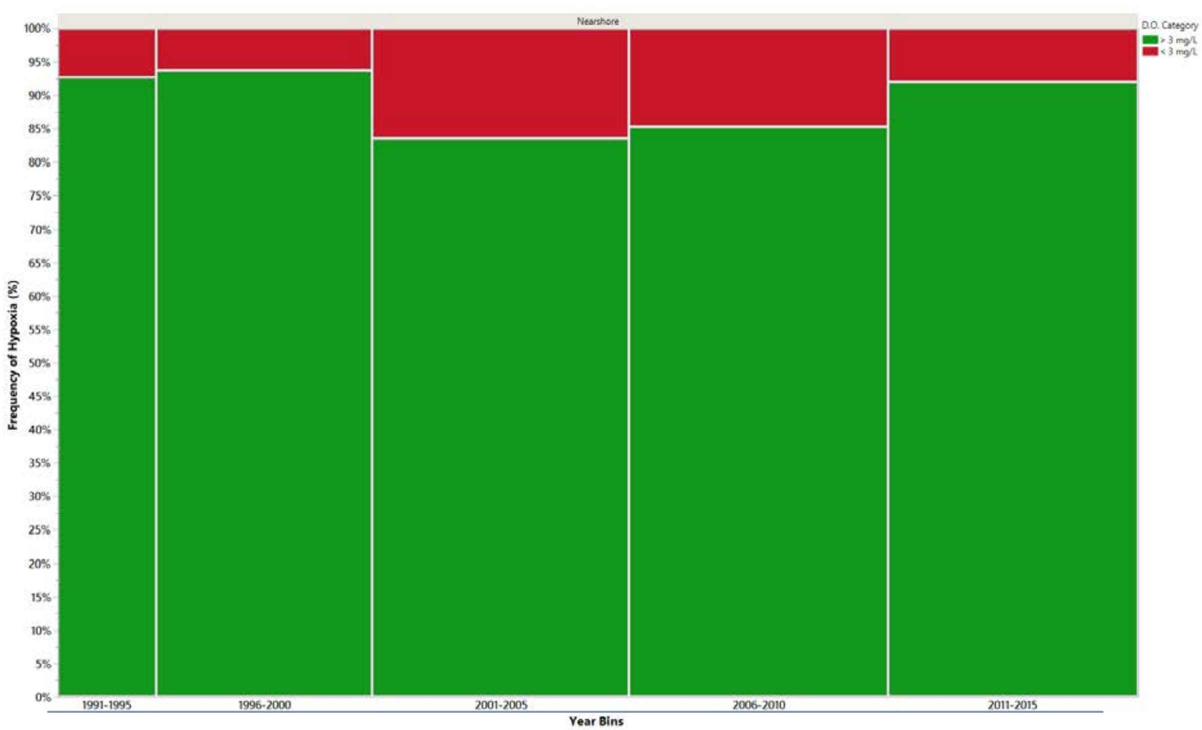
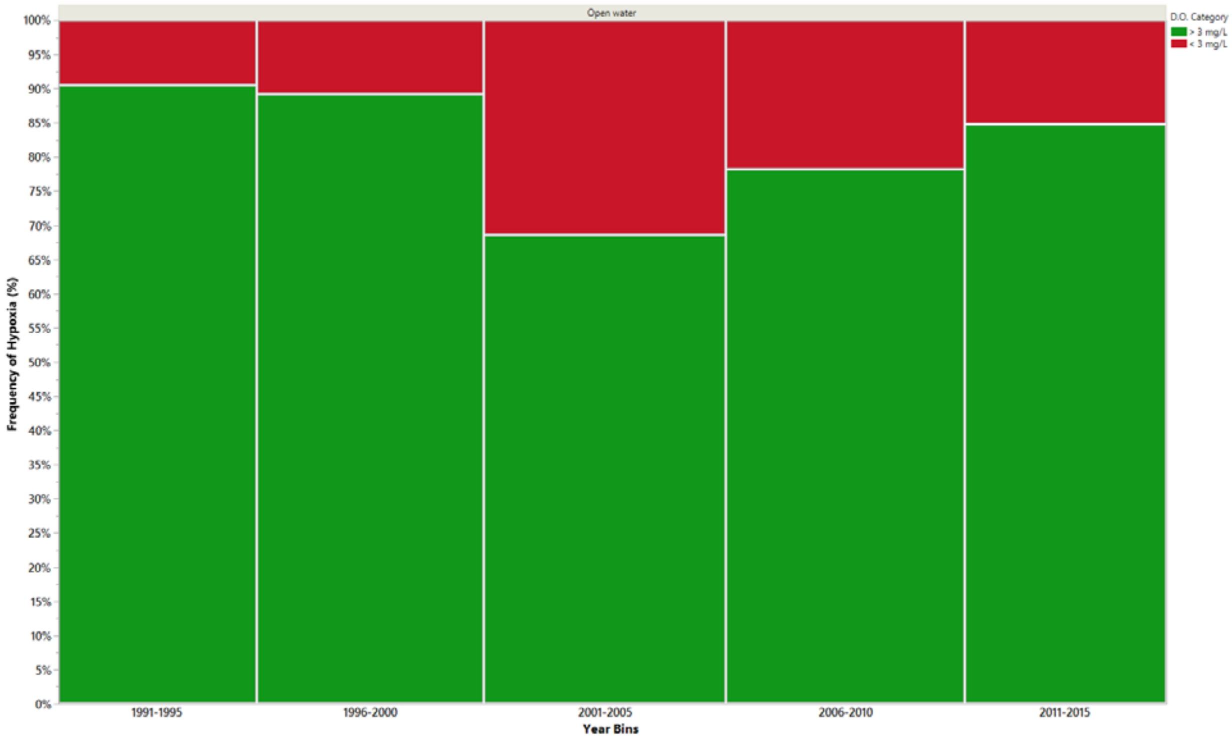


EXHIBIT 5-10B FREQUENCY OF HYPOXIA (D.O. <3.0 MG/L) BY OPEN WATER SAMPLING STATIONS.

The width of the columns correspond to the number of samples taken. Year bins are in five year intervals.



MAPPING PERCENT HYPOXIC DAYS OVER TIME

To show trends over time on a map-based spatial scale, we binned samples into five year increments and calculated the number of days sampled that had D.O. levels below 3.0 mg/L at each station (Exhibits 5-11 and 5-12). The number of days with hypoxic conditions were divided by the total number of sampled days at each station to generate a "percent of sampled days hypoxic" value. These data were further stratified by month and into two depth bins (uppermost sample in the water column and lowest sample in the water column). The percent values for each month/year group/depth category were then analyzed in GIS using the inverse distance weighting tool. This tool takes the locations that have values (i.e. the station locations) and interpolates data values for all areas in between the stations. This process generates a complete area surface of percent sampling days hypoxic for the Western Narrows. We generated two map matrices by month and year bin: (1) the lower depths (Exhibit 5-11) and (2) upper depths (Exhibit 5-12).

The two maps corroborate the previous exhibits, showing more hypoxic conditions in the lower depths, and the highest levels in the month of August. The year group of 2001-2005 shows the largest area with high percentages of days experiencing hypoxia, for both upper and lower depths. The resulting data products are stored in the final geodatabase with names indicating the month, depth, and year group of the data.

EXHIBIT 5-11: PERCENT OF SAMPLED DAYS HYPOXIC BY MONTH FOR LOWEST RECORDED DEPTHS

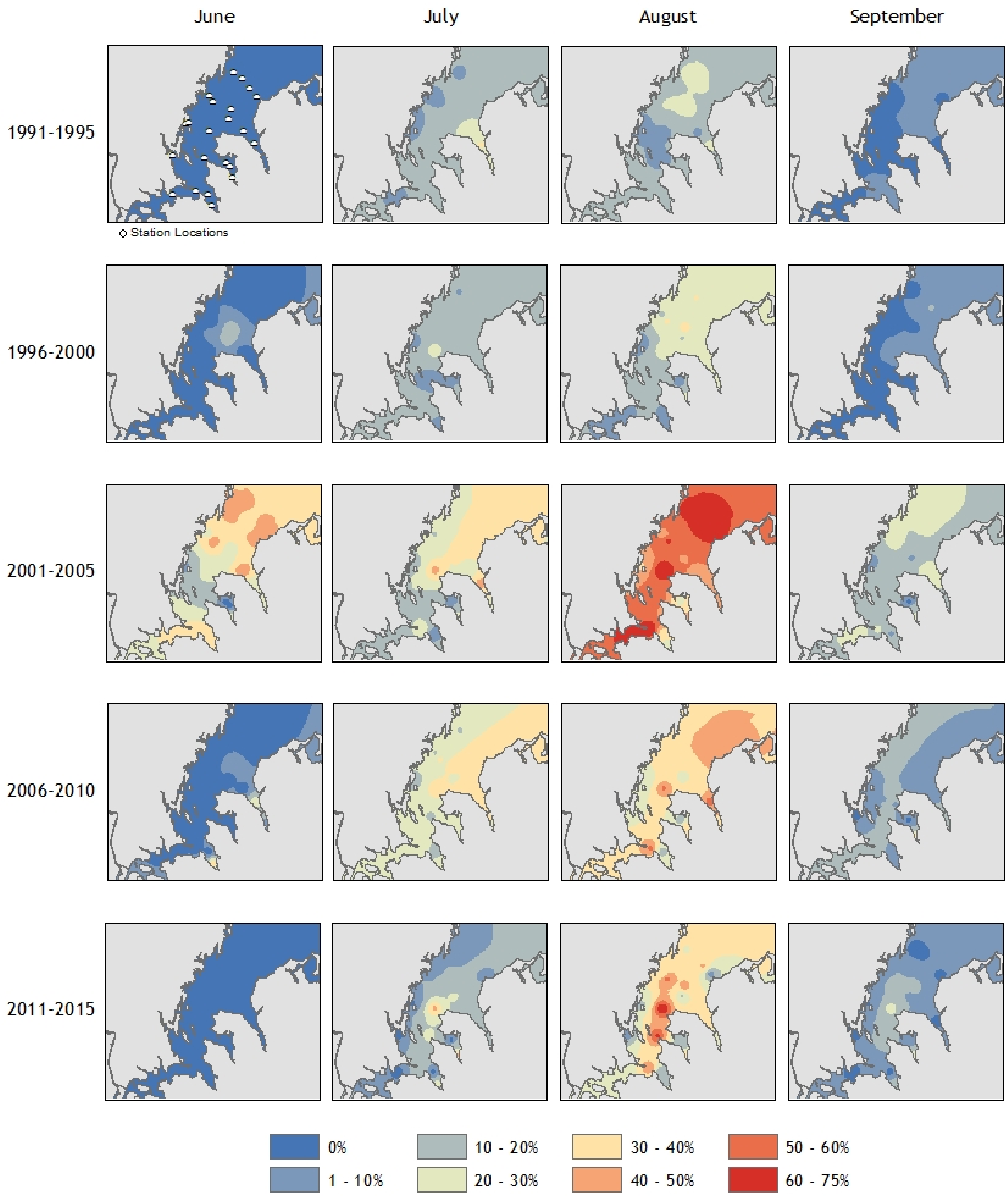
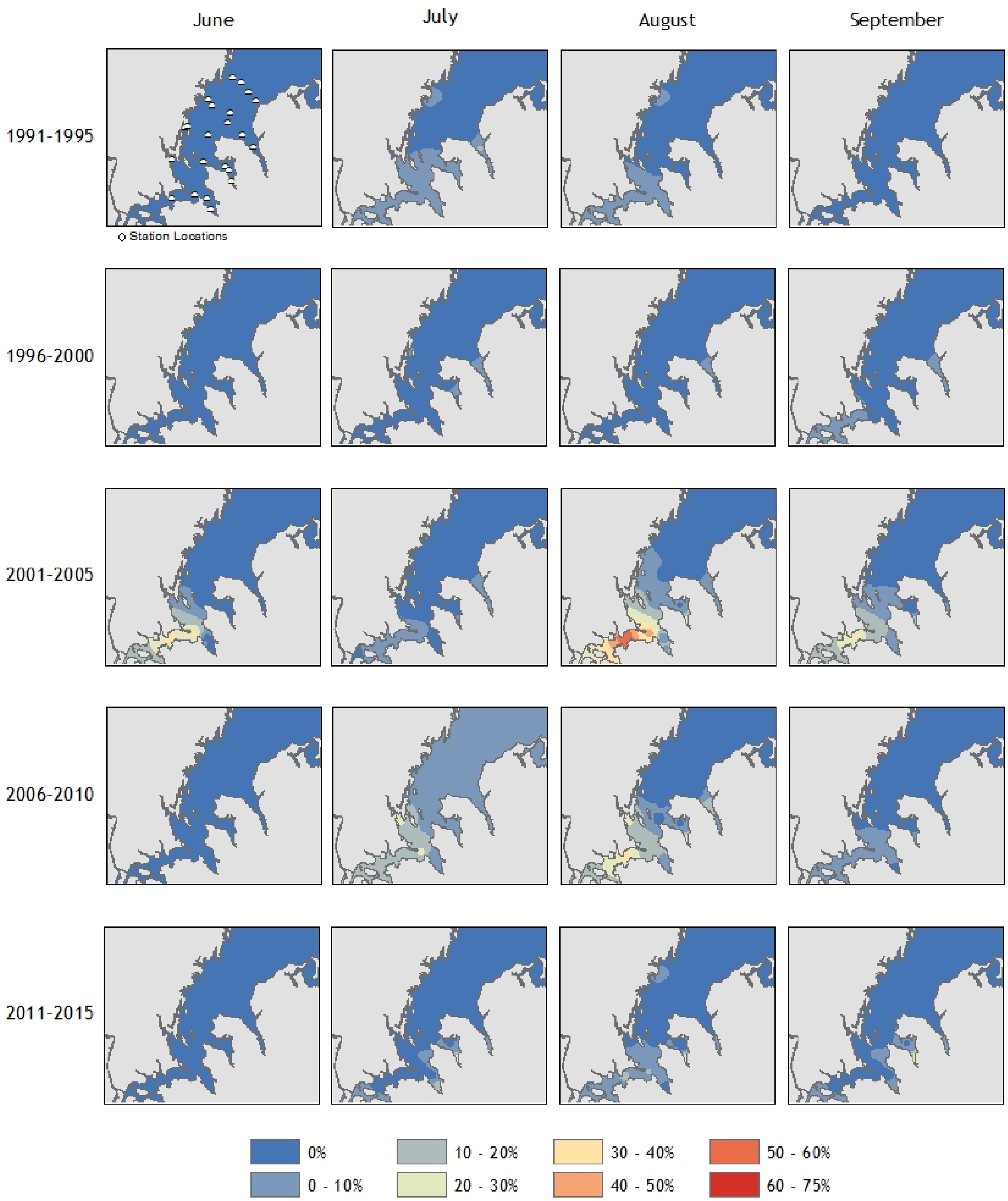


EXHIBIT 5-12: PERCENT OF SAMPLED DAYS HYPOXIC BY MONTH FOR UPPER (1 M) DEPTHS



INFLUENTIAL PARAMETERS ON DISSOLVED OXYGEN AND HYPOXIA

Many parameters may influence D.O. and hypoxic conditions. Based on a review of available information and availability of data, we investigated the following relationships:

- Meteorological parameters and D.O.
- Water quality parameters and D.O.
- Nutrients and D.O.

The following paragraphs discuss the results of these analyses in more detail.

METEOROLOGICAL PARAMETERS AND DISSOLVED OXYGEN

Analyses of D.O. and parameters for tide range, air temperature, precipitation, wind speed, and wind direction showed no discernable trends. Additionally, there were no consistent trends observed when weighting the data by distance to meteorological data source, or separating the analysis by depth, month, or station. For example, Exhibit 5-13 shows D.O. did not vary with tidal range. Further, Exhibit 5-14 presents the relationship between air temperature and D.O., which appears to show fewer hypoxic concentrations (<3 mg/L) below 19°C, but shows there is no discernable trend between the two parameters. We display the data for wind speed and D.O. in Exhibit 5-15, which demonstrates no relationship. However, while there is no discernable trend between D.O. and wind speed, there appear to be fewer instances of hypoxia when wind speed is greater than 13 mph. We display the data for wind direction and D.O., which demonstrates no relationship (Exhibit 5-16).

EXHIBIT 5-13 DISSOLVED OXYGEN CONCENTRATIONS BY TIDAL RANGE FOR ALL YEARS, DEPTHS, AND STATIONS.

Different colors correspond to different depth ranges (red being surface waters, then decreasing in approximately 5 m intervals to yellow, green, blue, purple, then black in the deepest waters). The horizontal red line displays D.O.= 3.0 mg/L.

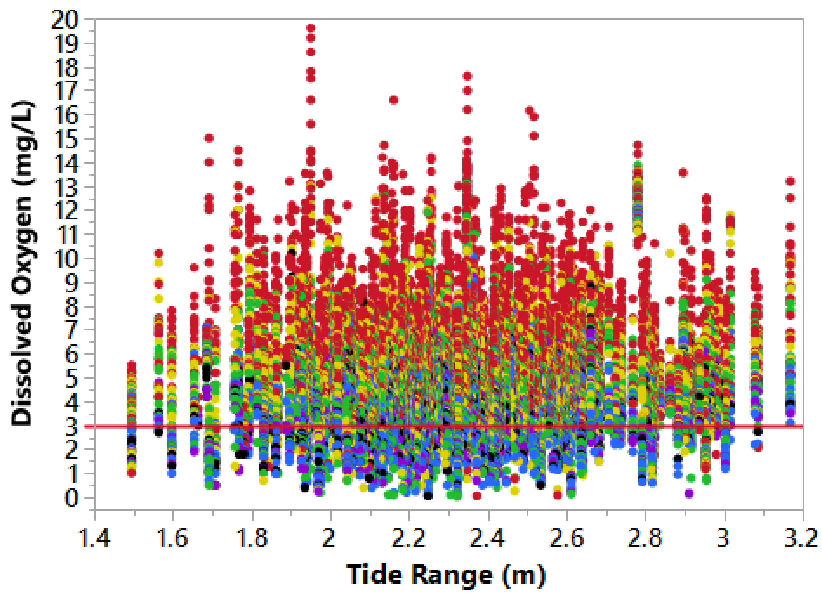


EXHIBIT 5-14 DISSOLVED OXYGEN CONCENTRATIONS BY AIR TEMPERATURE FOR ALL YEARS, DEPTHS, AND STATIONS.

Different colors correspond to different depth ranges (red being surface waters, then decreasing in approximately 5 m intervals to yellow, green, blue, purple, then black in the deepest waters). The horizontal red line displays D.O.= 3.0 mg/L.

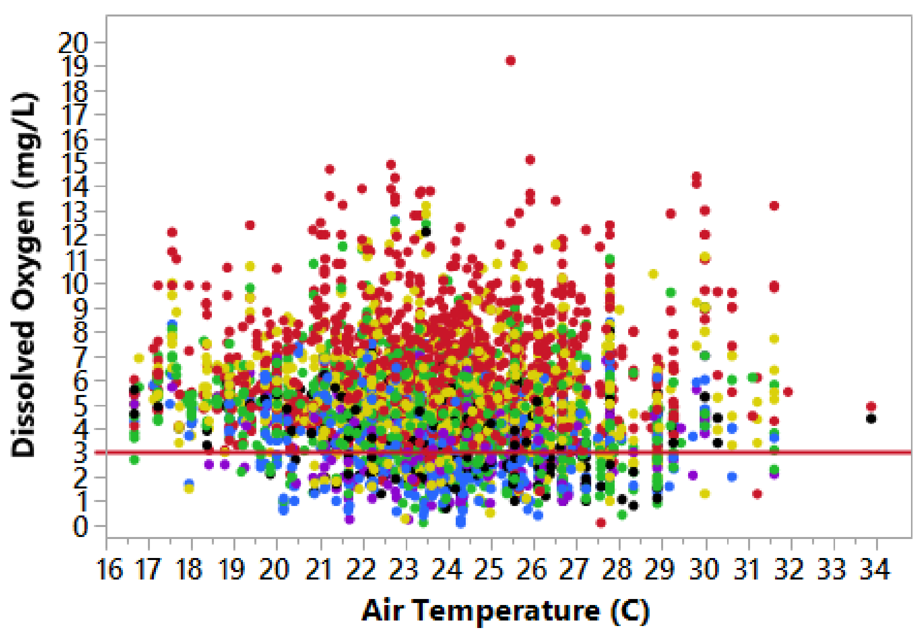


EXHIBIT 5-15 DISSOLVED OXYGEN CONCENTRATIONS BY WIND SPEED FOR ALL YEARS, DEPTHS, AND STATIONS.

Different colors correspond to different depth ranges (red being surface waters, then decreasing in approximately 5 m intervals to yellow, green, blue, purple, then black in the deepest waters). The horizontal red line displays D.O.= 3.0 mg/L.

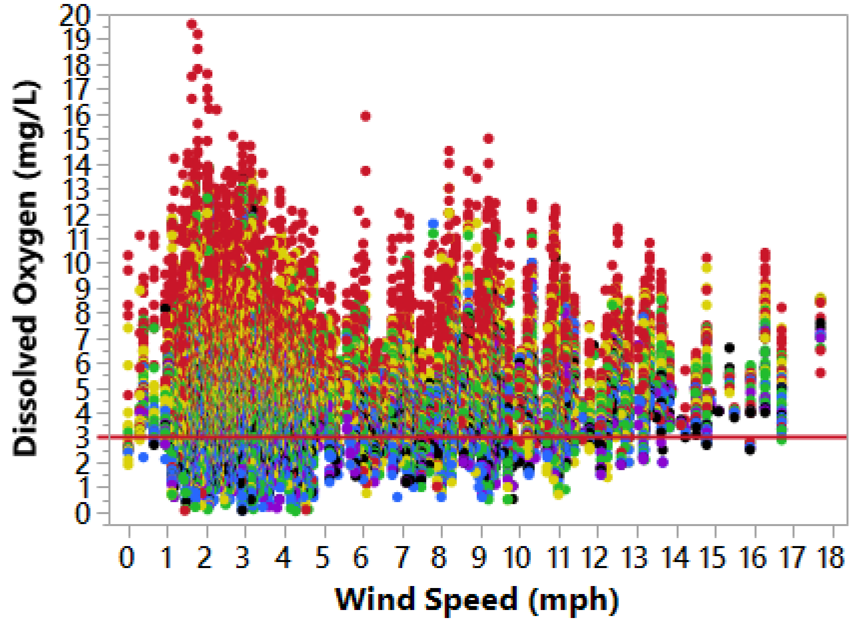
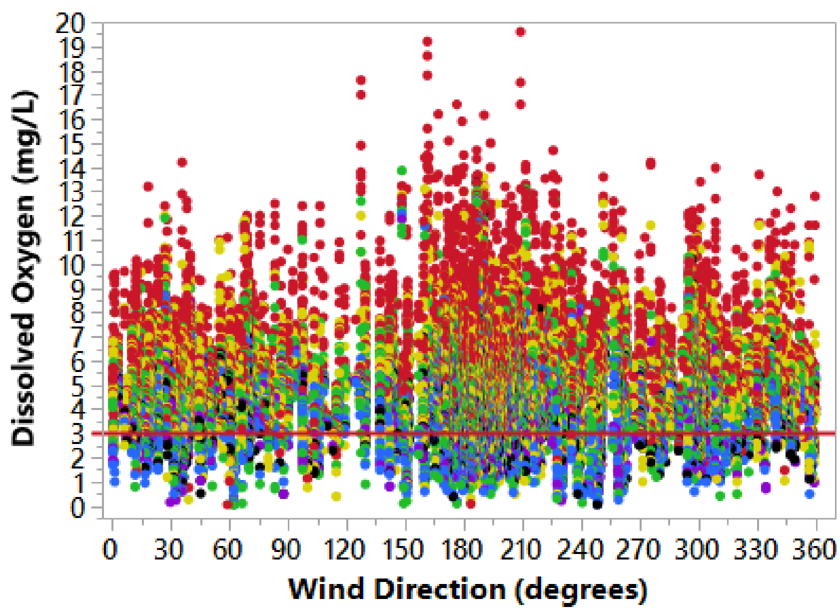


EXHIBIT 5-16 DISSOLVED OXYGEN CONCENTRATIONS BY WIND DIRECTION FOR ALL YEARS, DEPTHS, AND STATIONS.

Different colors correspond to different depth ranges (red being surface waters, then decreasing in approximately 5 m intervals to yellow, green, blue, purple, then black in the deepest waters). The horizontal red line displays D.O.= 3.0 mg/L.



WATER QUALITY PARAMETERS AND DISSOLVED OXYGEN

We conducted analyses of D.O. and the general water quality parameters including temperature, salinity, chlorophyll a, Secchi disk depth, pH, BOD, and TSS. Total suspended solids data were only available for 2014 and 2015 and BOD data were only available for 2015. As such, any relationship between these variables and D.O. should be reexamined after future data collection efforts. There were potential relationships between D.O. and water temperature and D.O. and chlorophyll a (Exhibits 5-17, 5-18).

D.O. and water temperature (Exhibit 5-17) visually display differences in depth, as such, we weighted the data by depth to explore any trends. However, there was no relationship between D.O. and water temperature across all years, depths, and stations (when weighted by depth). Analysis of D.O. and water temperature by depth bin demonstrated potential negative trends with D.O. decreasing with increasing water temperature, however, the variability is high.

Exhibit 5-18 displays D.O. concentrations and the relationship to chlorophyll a. While there may be a positive relationship between the two parameters, there is high variability.

There were no apparent relationships between D.O. and salinity, BOD, TSS, or Secchi disk depth (Exhibits 5-19 thru 5-22).

A relationship between D.O. and pH was observed across all depths, with D.O. increasing as pH increases (Exhibit 5-23). The best fit model for this trend is an exponential model. When examined by depth bins, this relationship is maintained to a depth of 15 m but breaks down at deeper depths (Exhibit 5-24).

EXHIBIT 5-17 DISSOLVED OXYGEN CONCENTRATIONS BY WATER TEMPERATURE (WEIGHTED BY DEPTH) FOR ALL YEARS, DEPTHS, AND STATIONS.

Different colors correspond to different depth ranges (red being surface waters, then decreasing in approximately 5 m intervals to yellow, green, blue, purple, then black in the deepest waters). The horizontal red line displays D.O.= 3.0 mg/L.

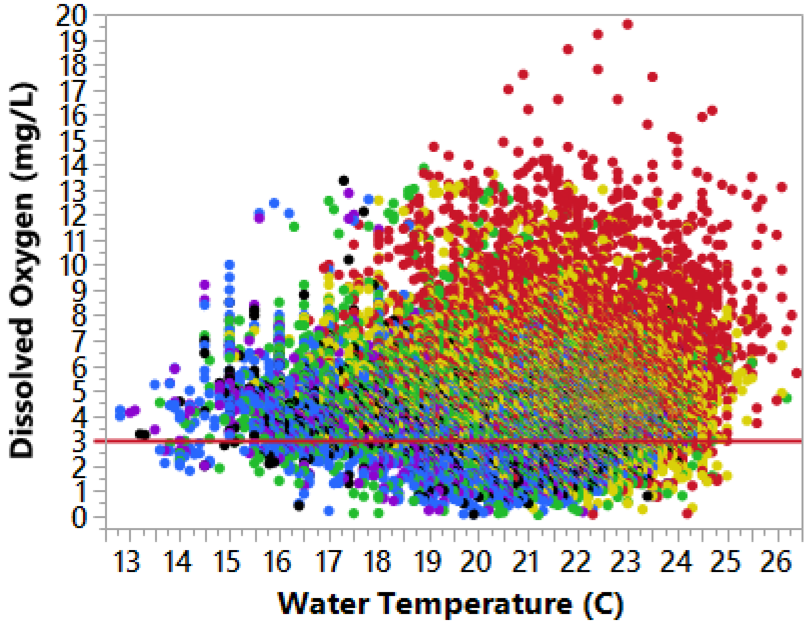


EXHIBIT 5-18 DISSOLVED OXYGEN CONCENTRATIONS BY CHLOROPHYLL A FOR ALL YEARS AND STATIONS.

The horizontal red line displays D.O.= 3.0 mg/L.

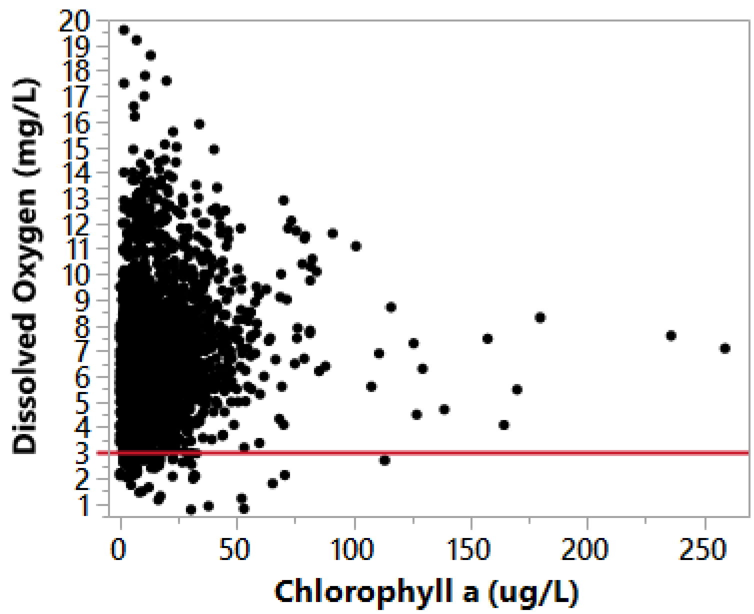


EXHIBIT 5-19 DISSOLVED OXYGEN CONCENTRATIONS BY SALINITY FOR ALL YEARS, DEPTHS, AND STATIONS.

Different colors correspond to different depth ranges (red being surface waters, then decreasing in approximately 5 m intervals to yellow, green, blue, purple, then black in the deepest waters). The horizontal red line displays D.O.= 3.0 mg/L.

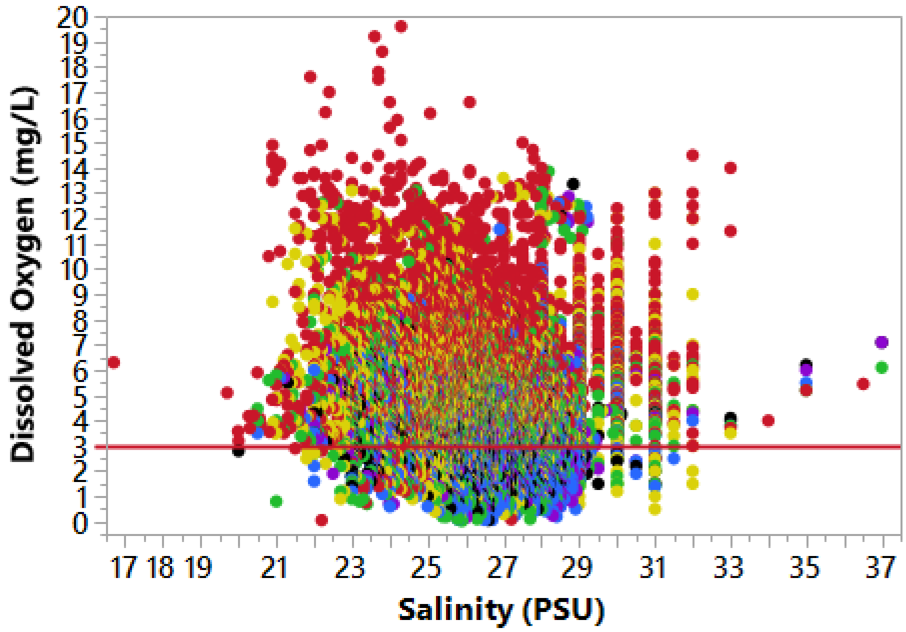


EXHIBIT 5-20 DISSOLVED OXYGEN CONCENTRATIONS BY SECCHI DISK DEPTH FOR ALL YEARS AND STATIONS.

The horizontal red line displays D.O.= 3.0 mg/L.

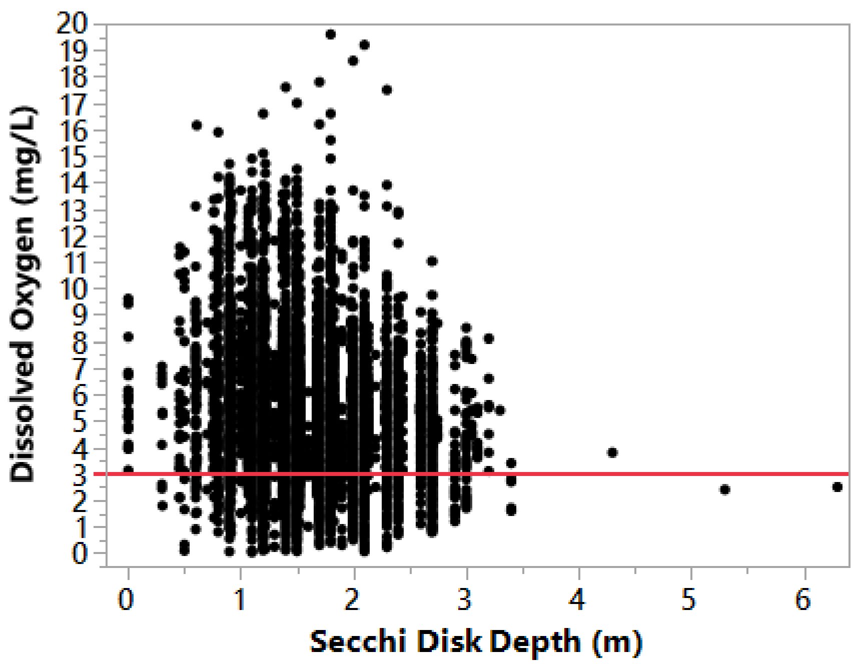


EXHIBIT 5-21 DISSOLVED OXYGEN CONCENTRATIONS BY BOD FOR ONE YEAR OF DATA ACROSS ALL STATIONS.

The horizontal red line displays D.O.= 3.0 mg/L.

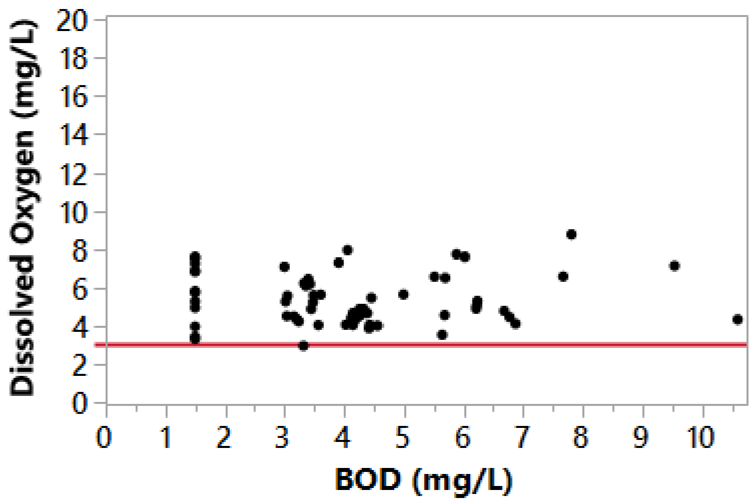


EXHIBIT 5-22 DISSOLVED OXYGEN CONCENTRATIONS BY TOTAL SUSPENDED SOLIDS ACROSS TWO YEARS OF DATA AND ALL STATIONS.

The horizontal red line displays D.O.= 3.0 mg/L.

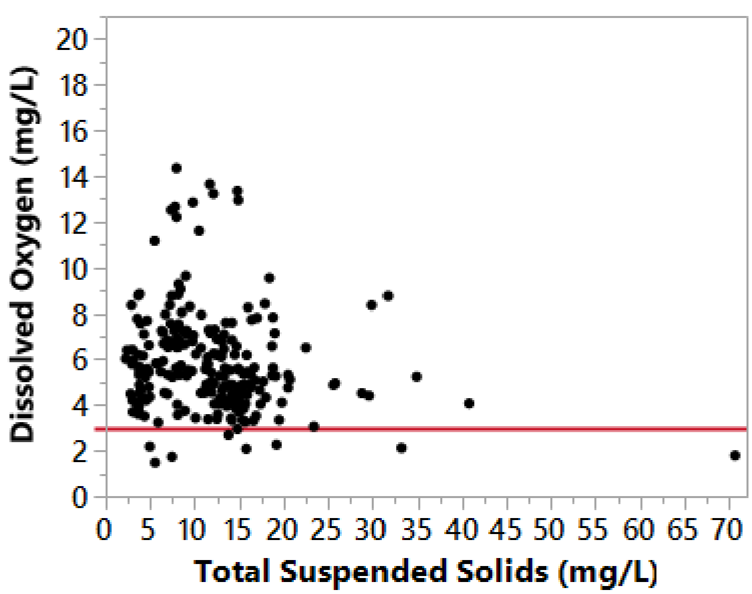


EXHIBIT 5-23 DISSOLVED OXYGEN CONCENTRATIONS BY PH FOR ALL YEARS, DEPTHS, AND STATIONS.

Different colors correspond to different depth ranges (red being surface waters, then decreasing in approximately 5 m intervals to yellow, green, blue, purple, then black in the deepest waters).The best fit model is an exponential model, fit here to all data, independent of depth. The vertical red line displays D.O.= 3.0 mg/L.

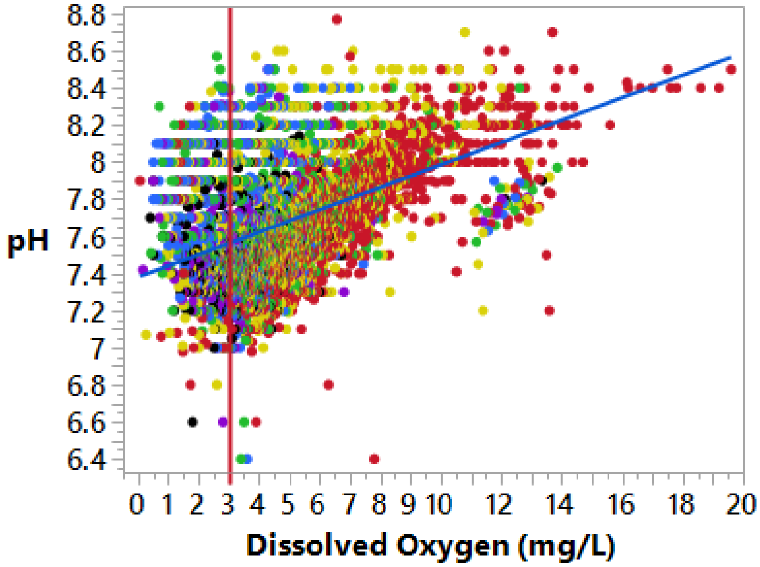
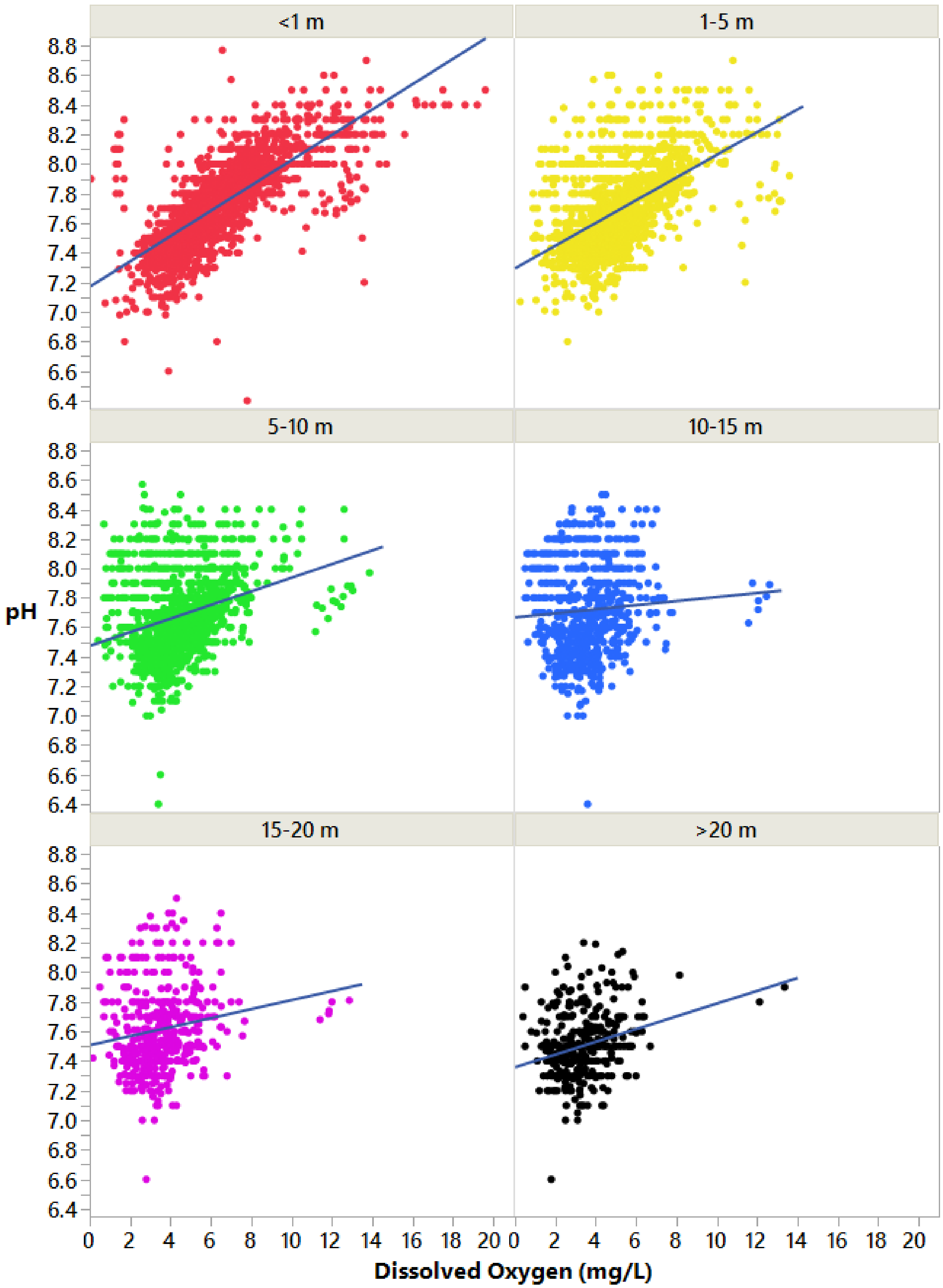


EXHIBIT 5-24 DISSOLVED OXYGEN CONCENTRATIONS BY PH IN EACH DEPTH BIN FOR ALL YEARS AND STATIONS.



NUTRIENTS AND DISSOLVED OXYGEN

We analyzed D.O. and its relationship with the nutrient parameters:

- Ammonia-ammonium
- Orthophosphate
- Particulate phosphorus
- Dissolved silica
- Nitrite-nitrate
- Total dissolved nitrogen
- Dissolved organic carbon
- Biogenic silica
- Particulate nitrogen
- Total dissolved phosphorus
- Particulate carbon

However, nutrient data were only available for two years (2014 and 2015) so any trends identified should be considered preliminary.

D.O. appeared to be related to the nutrients ammonia-ammonium, nitrate-nitrite, total dissolved nitrogen, orthophosphate, total dissolved phosphorus, and dissolved silica. These relationships had similar exponential relationships with decreasing D.O. as the nutrient increased. D.O. and its relationship with total dissolved nitrogen, orthophosphate, and dissolved silica are displayed in Exhibits 5-25, 5-26, and 5-27, respectively. While these relationships are based on two years of data, more data will enhance the usage of these models for forecasting the relationship with D.O. and hypoxic conditions.

Based on these relationships, it may be possible to forecast hypoxic events. Exhibit 5-25 shows the exponential model for total dissolved nitrogen and D.O. is D.O.=$8.95e^{(-1.06*TDN)}$. In Exhibit 5-26, the exponential model for orthophosphate and D.O. is D.O. = $10.36\ e^{(-6.15*orthophosphate)}$. In Exhibit 5-27, the exponential model for dissolved silica and D.O. is D.O. = $11.2\ e^{(-0.49*dissolved\ silica)}$.

We identified positive linear or nonlinear (exponential) relationships between chlorophyll a and (1) particulate nitrogen, (2) particulate phosphorus, (3) particulate carbon, and (4) total dissolved phosphorus. Such relationships demonstrate increasing chlorophyll a with increasing nutrient loading. Similarly, trends were identified for BOD. These relationships are presented in Exhibits 5-28 through 5-32.

EXHIBIT 5-25 DISSOLVED OXYGEN CONCENTRATION AND TOTAL DISSOLVED NITROGEN ACROSS ALL YEARS AND STATIONS[2].

The horizontal red line displays D.O.= 3.0 mg/L.

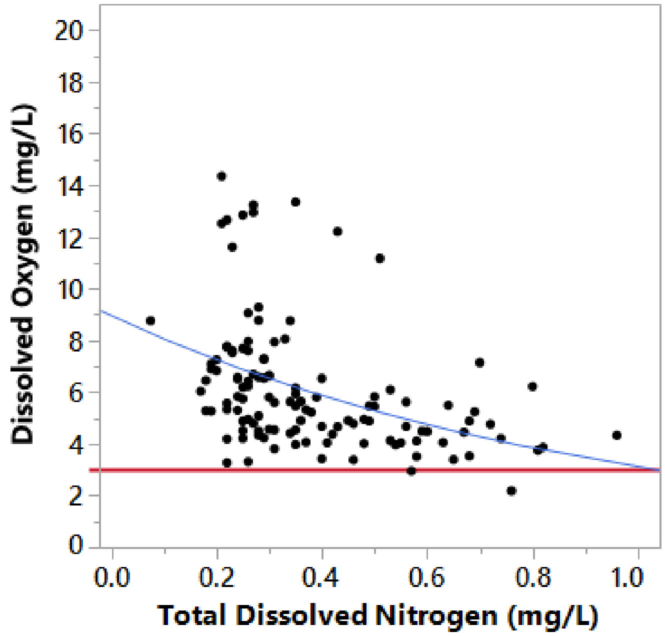
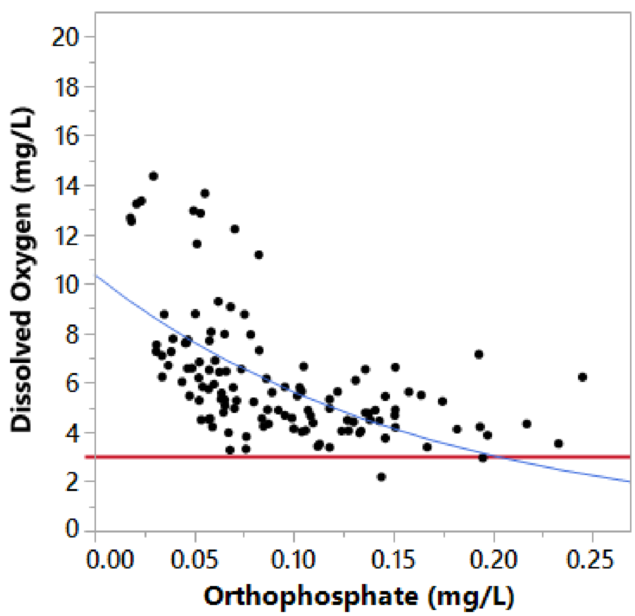


EXHIBIT 5-26 DISSOLVED OXYGEN CONCENTRATION AND ORTHOPHOSPHATE ACROSS ALL YEARS AND STATIONS.

No values were excluded from this plot. The horizontal red line displays D.O.= 3.0 mg/L.



[2] Note, in Exhibit 5-25, one value was excluded for total dissolved nitrogen analyses (ID 17716). This value was identified as an outlier based on the distribution of the total dissolved nitrogen data; additionally, both ammonia-ammonium and nitrite-nitrate are correlated with total dissolved nitrogen and in both linear plots this value appears to be an outlier as well.

EXHIBIT 5-27 DISSOLVED OXYGEN CONCENTRATION AND DISSOLVED SILICA ACROSS ALL YEARS AND STATIONS.

The horizontal red line displays D.O.= 3.0 mg/L. One value was excluded for dissolved silica (ID 17918). This value was identified as an outlier based on the distribution of the dissolved silica data.

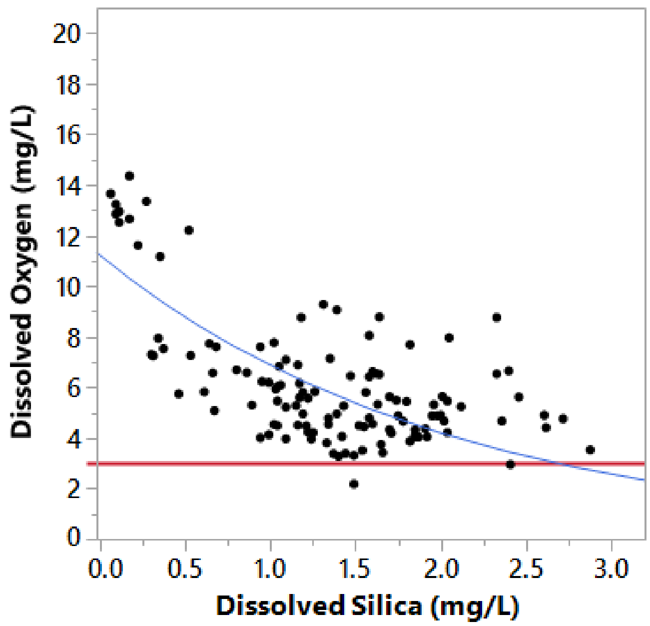


EXHIBIT 5-28 CHLOROPHYLL A AND PARTICULATE NITROGEN CONCENTRATIONS ACROSS ALL YEARS AND STATIONS.

No values were excluded from this plot.

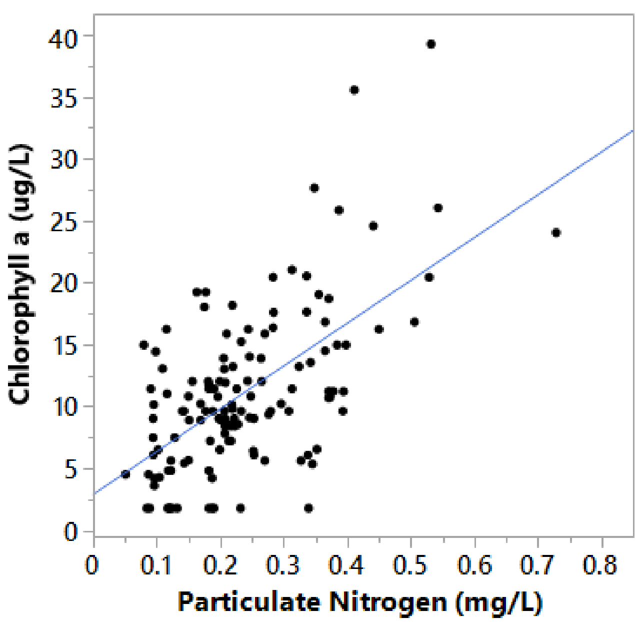


EXHIBIT 5-29 CHLOROPHYLL A AND PARTICULATE PHOSPHORUS CONCENTRATIONS ACROSS ALL YEARS AND STATIONS.

No values were excluded from this plot.

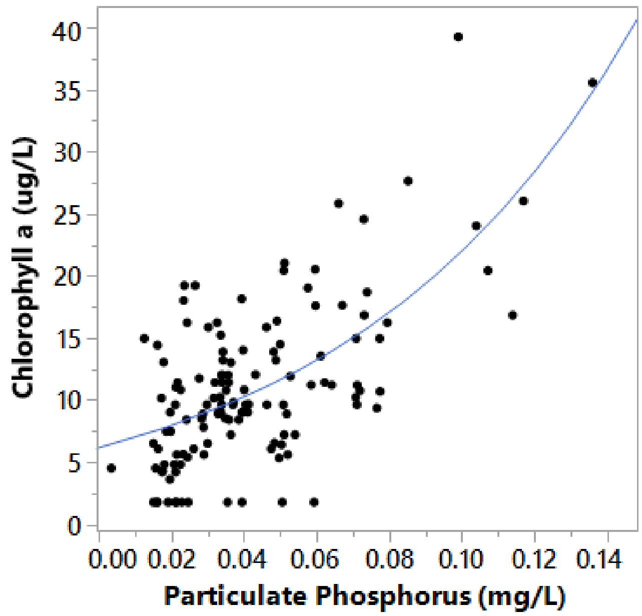


EXHIBIT 5-30 CHLOROPHYLL A AND PARTICULATE CARBON CONCENTRATIONS ACROSS ALL YEARS AND STATIONS.

No values were excluded from this plot.

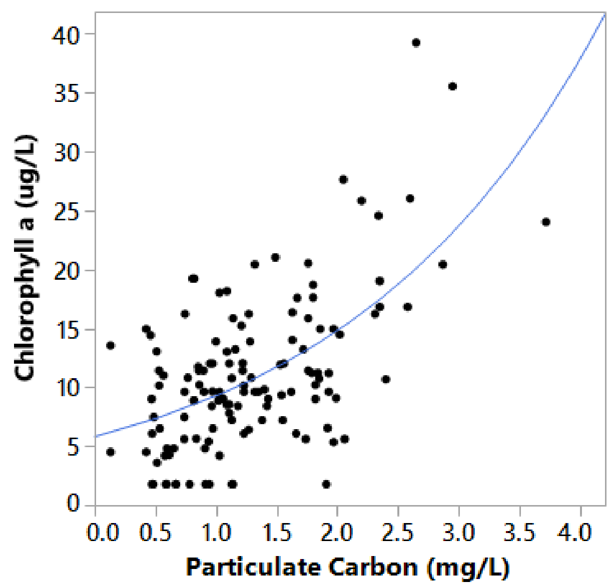


EXHIBIT 5-31 CHLOROPHYLL A AND TOTAL DISSOLVED PHOSPHORUS CONCENTRATIONS ACROSS ALL YEARS AND STATIONS.

One value was excluded for total dissolved phosphorus (ID 18754). This value was identified as an outlier based on the distribution of the total dissolved phosphorus (and because it was outside the linear relationship between total dissolved phosphorus and orthophosphate).

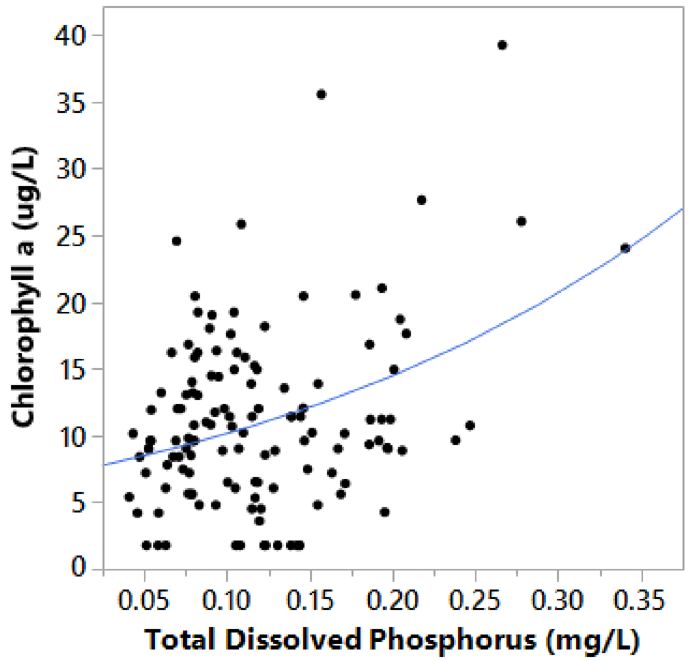
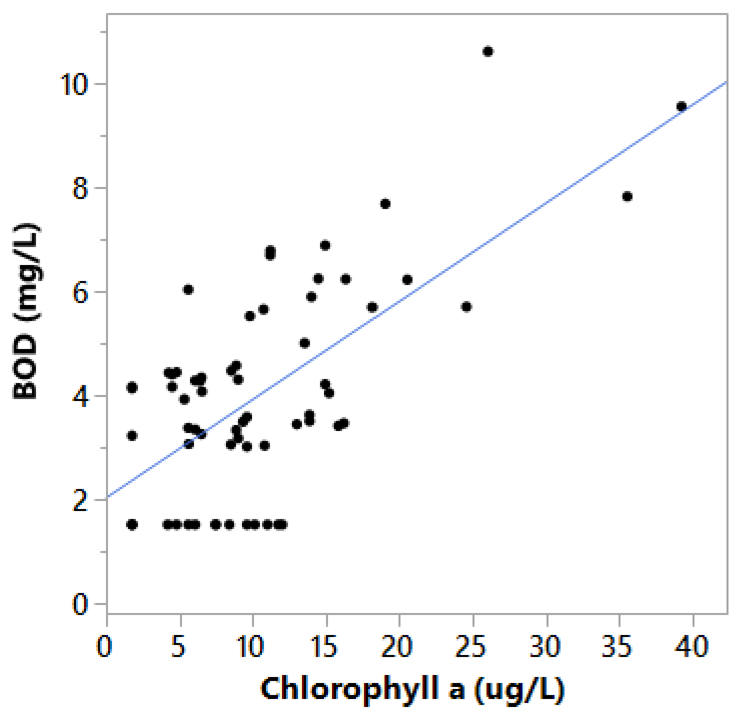


EXHIBIT 5-32 BIOCHEMICAL OXYGEN DEMAND AND CHLOROPHYLL A CONCENTRATIONS ACROSS ALL YEARS AND STATIONS.



STRATIFICATION (TEMPERATURE AND SALINITY)

While temperature and salinity may not predict hypoxic conditions, they can be influential since they stratify the water column. Exhibit 5-33 demonstrates the salinity differences by month, with lower average salinities in June and increasing salinity through September. Salinities were statistically different for each month (Steel-Dwass, p<0.001), except for September and August (p=0.20). Salinity generally increased with increasing depth, with most shallow salinities being significantly different from deeper depths (Exhibit 5-34). Generally, average salinity concentrations increased from west to east.

Exhibit 5-35 demonstrates the temperature differences by month, with lower average temperatures in June, then increasing to September. Temperatures were statistically different (Steel-Dwass; p<0.001) for each month except for September and August (p=0.1801). Temperatures generally decreased with increasing depth (Exhibit 5-36), with all temperatures significantly different across depth bins.

Exhibit 5-37 demonstrates decreasing trends in water temperature by depth for each month. This demonstrates the difference in water temperatures from surface to deeper waters decreases from June to September. There is a larger temperature differential in June between the surface and bottom waters than in August and September.

EXHIBIT 5-33 SALINITY CONCENTRATIONS BY MONTH ACROSS ALL DEPTHS, YEARS, AND STATIONS.

Box plots of different colors are significantly different.

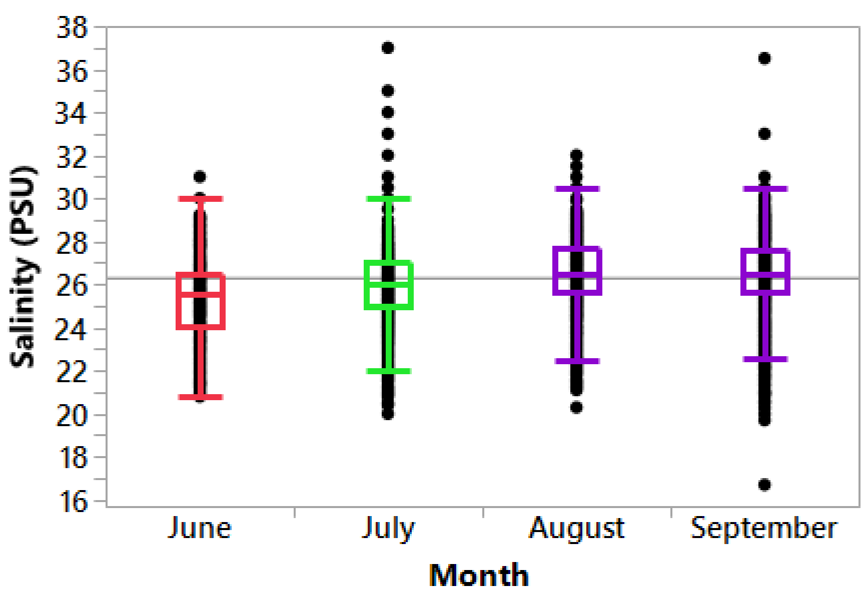


EXHIBIT 5-34 SALINITY CONCENTRATIONS BY DEPTH BIN ACROSS ALL MONTHS, YEARS, AND STATIONS

Table shows the comparison between each pair of Depth bins; significant differences were determined using Steel-Dwass with alpha set to 0.05. Depth Bin 1 is ≤1 m; Depth Bin 2 is 1-5 m; Depth Bin 3 is 5-10 m; Depth Bin 4 is 10-15 m, Depth Bin 5 is 15-20 m; and Depth Bin 6 is >20 m.

COMPARISON BETWEEN DEPTH BINS	P-VALUE
4 and 1	<0.001
4 and 2	<0.001
3 and 2	<0.001
5 and 1	<0.001
3 and 1	<0.001
5 and 2	<0.001
6 and 2	<0.001
6 and 1	0.0024
4 and 3	0.0024
5 and 3	0.0856
5 and 4	0.9993
6 and 3	0.9692
6 and 5	0.0724
2 and 1	0.3734
6 and 4	0.0070

EXHIBIT 5-35 WATER TEMPERATURE BY MONTH ACROSS ALL DEPTHS, YEARS, AND STATIONS.

Box plots of different colors are significantly different.

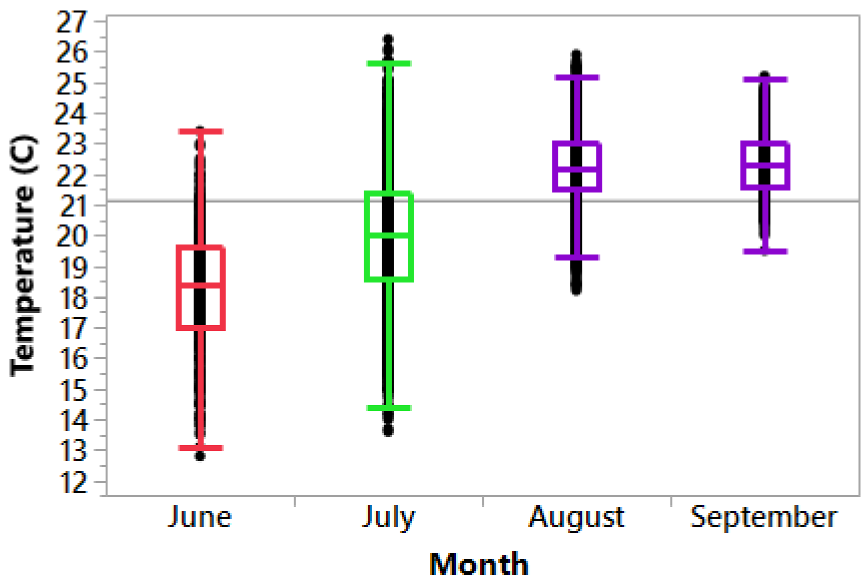
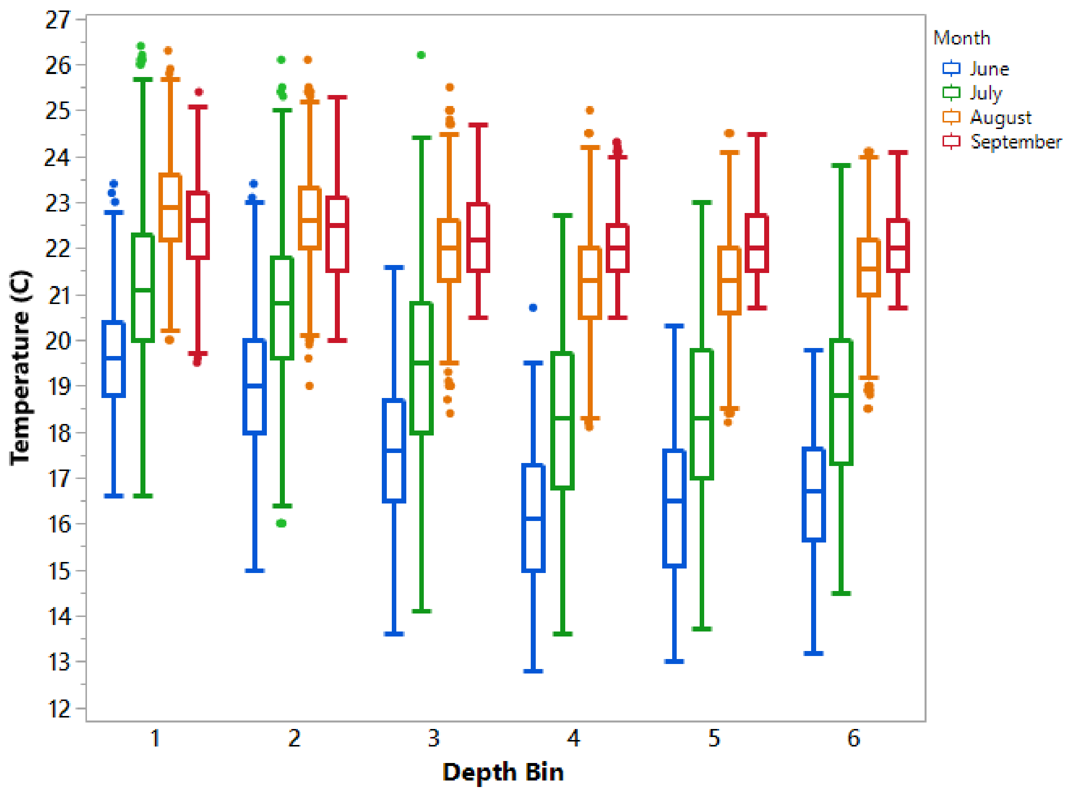


EXHIBIT 5-36 WATER TEMPERATURE BY DEPTH BIN ACROSS ALL MONTHS, YEARS, AND STATIONS.

Table shows the comparison between each pair of Depth bins; significant differences were determined using Steel-Dwass with alpha set to 0.05.

COMPARISON BETWEEN DEPTH BINS	P-VALUE
6 and 4	0.0019
6 and 5	0.0640
5 and 4	0.9792
6 and 3	<0.0001
5 and 3	<0.0001
2 and 1	<0.0001
4 and 3	<0.0001
6 and 2	<0.0001
3 and 2	<0.0001
5 and 2	<0.0001
4 and 2	<0.0001
6 and 1	<0.0001
3 and 1	<0.0001
5 and 1	<0.0001
4 and 1	<0.0001

EXHIBIT 5-37 WATER TEMPERATURE BY DEPTH BIN AND MONTH ACROSS ALL YEARS AND STATIONS.



CHAPTER 6 | DISCUSSION AND CONCLUSIONS

This chapter provides a summary of the analyses presented in Chapter Five and discusses their importance in detecting and assessing overall spatial trends in hypoxic conditions.

DISSOLVED OXYGEN TEMPORAL TRENDS

There are no evident temporal trends in hypoxia on an annual basis. However, a fluctuating but annual decreasing trend in D.O. is observed through 2004 at which point the trend reverses and increases. Many management actions and programs may impact hypoxia and could have contributed to this reversing trend. For example, this could be attributed to the Total Maximum Daily Load (TMDL) approved by the EPA in 2001 for New York and Connecticut (NYDEC and CTDEEP 2000). The TMDL limits the amount of nitrogen added to the system from various sources, which in turn may ultimately limit D.O. consumption by heterotrophic microorganisms.

The implementation of the TMDL has enforced nitrogen credit trading and bubble permits, as well as wastewater treatment plant upgrades, which reduces point source nitrogen loading to LIS. Nutrient loading has decreased in LIS since the implementation of the TMDL (CTDEEP and IEC 2016). The IEC data demonstrate that since the TMDL, the frequency of hypoxia in the Western Narrows of LIS increased through 2004, but subsequently declined since 2004.

There are trends in hypoxic conditions on a monthly basis. The IEC data demonstrate that hypoxia increases in frequency from June to August and then decreases in frequency through September. Such a trend could be due to a variety of different physical, chemical, and biological factors such as stratification of the water column, changing temperatures, or changes in phytoplankton activity and microbial processes (Howarth et al. 2011, Baird et al. 2004).

DISSOLVED OXYGEN SPATIAL TRENDS

IEC D.O. values generally decrease from surface waters to deeper waters. This can be explained by multiple factors such as mixing of surface waters by wind, increased photosynthesis (producing oxygen) in surface waters, tidal currents, and input of freshwater from rivers which is less dense than saline waters (Anderson and Taylor 2001; Howarth et al. 2011). Photosynthesizing microbes increase during the day, then sink to deeper waters at night where heterotrophic microorganisms consume the algae and D.O., creating low D.O. conditions at depth. Compared to the surface, there are fewer physical forces able to increase D.O. levels at depth, which instigate hypoxia’s spatial relationship with depth. This minimal mixing of surface water and water at depth can be caused by stratification from freshwater inputs, lower tidal velocity in the Western Narrows, higher turbidity (less light penetration), and lower wind speeds (Zhou et al. 2014).

INFLUENTIAL PARAMETERS ON DISSOLVED OXYGEN AND HYPOXIA

While depth and month have relationships with D.O. they are not necessarily influential factors. That is, they may be used to predict D.O. conditions, but are not responsible for low D.O. and hypoxia. Rather, it is the physical, biological, and chemical parameters that influence hypoxia.

METEOROLOGICAL PARAMETERS AND DISSOLVED OXYGEN

Analyses of D.O. and parameters for tide range, air temperature, precipitation, wind speed, and wind direction showed no discernable trends with D.O. Additionally, there were no consistent trends observed when weighting the data by distance to meteorological data source, or separating the analysis by depth, month, or station. Predominant wind direction, wind speed, and precipitation have been documented to influence hypoxia and low D.O. (Zhou et al. 2014; Howarth et al. 2011; Parker and O'Reilly 1991; Anderson and Taylor 2001; O'Donnell et al. 2008; Wilson et al. 2008), but were not evident in our data analysis. This could be due to a number of reasons related to data availability and groupings across time and space. Future analyses utilizing additional grouping strategies established *a priori* may elucidate such relationships.

WATER QUALITY PARAMETERS AND DISSOLVED OXYGEN

D.O. and pH are related because as D.O. is used by microorganisms during respiration, they emit carbon dioxide (CO_2) into the water column. In turn, CO_2 in the water column can decrease the pH of the water (Howarth et al. 2011). As such, pH is not a likely predicting variable for D.O., but rather D.O. may be a predictor variable of pH. D.O. increasing in the surface waters can be a direct result of photosynthesis, using CO_2 and producing oxygen, which would drive an increase in pH. Consistent with these observations, within the IEC dataset, D.O. demonstrated an exponential relationship with pH where one increases as the other increases.

The other relationships identified during multivariate analyses are BOD and chlorophyll a, Secchi disk depth and TSS, and BOD and Secchi disk depth. Observed chlorophyll a indicates an increase in phytoplankton, which increases food for respiring microorganisms that require more oxygen to decompose the photosynthetic algae, thus increasing BOD (Xu and Xu 2014; Anderson and Taylor 2001; Welch 1969). As such, chlorophyll a and BOD should both be coupled with some nutrient parameters, which does hold true with these data (see section below on additional relationships between water quality parameters).

Secchi disk depth and TSS are directly related because one is a measure of water clarity (Secchi disk depth) and the other is a measure of dissolved and particulate matter in the water column, which directly influences water clarity. BOD and Secchi disk depth are related where Secchi disk depth decreases as BOD increases, which can be explained by increased microorganisms requiring more oxygen as they multiply and the microbes increasing enmass can decrease water clarity.

NUTRIENTS AND DISSOLVED OXYGEN

There is a large body of literature that demonstrates the relationship between nutrients and low D.O. or hypoxia (Anderson and Taylor 2001; Zhou et al. 2014; Diaz and Rosenberg 1995). In this case, those relationships hold true for the two years of data analyzed. D.O. appeared to be related to (1) ammonia-ammonium, (2) nitrate-nitrite, (3) total dissolved nitrogen, (4) orthophosphate, (5) total dissolved phosphorus, and (6) dissolved silica, where D.O. decreased as nutrient concentrations increased.

Microorganisms assimilate inorganic nutrients to facilitate growth (Collos and Berges 2003; Zehr and Ward 2002) and nitrogen is commonly the limiting nutrient in estuarine systems (Howarth et al. 2011). Thus, nutrients such as nitrogen and phosphorus will indirectly influence D.O. by increasing phytoplankton blooms and subsequent microbial respiration, or directly stimulating microbial respiration for those microbes which directly assimilate inorganic nitrogen and phosphorus. Further, ammonia-ammonium, nitrate-nitrate, and total dissolved nitrogen are related because inorganic nitrogen (ammonia-ammonium, nitrate-nitrite) is measured as a component of total dissolved nitrogen. For example, Anderson and Taylor (2001) noticed that D.O. concentrations were related to ammonium, as such, it makes sense that they have similar relationships with D.O. Similar to nitrogen, orthophosphate and total dissolved phosphate are related because orthophosphate can be a component of total dissolved phosphate. As such, it makes sense that these two parameters have similar relationships with D.O.

Silica is a nutrient necessary for growth, specifically with diatoms (Welch 1969; Gilbert et al. 2006). The relationship between D.O. and silica is similar as that for the aforementioned nutrients where D.O. decreases as dissolved silica increases. This relationship is logical where dissolved silica can increase phytoplankton growth, which stimulates heterotrophic microbial growth and the consumption of D.O.

Continued data collection on nutrients will confirm the relationships between D.O. and nutrients, or better define a relationship, to enable more accurate forecasting of nutrient concentrations that may influence hypoxia within the Western Narrows. We forecasted the nutrient concentrations that could influence hypoxic conditions with the two years of data at present. While these relationships provide insight on the conditions that contribute to hypoxia, they should be used holistically. For future data analysis efforts, we recommend analyzing nutrient loading data from each tributary river and their relationship to nutrients measured *in-situ*, then determine the concentrations that influence hypoxia. Some work has already been conducted on quantifying nutrient loading to LIS from CTDEEP, NYDEC, USEPA, USGS, and LISS (Mullaney 2016; NYDEC and CTDEEP 2000). Ascribing the nutrient concentrations observed *in-situ* to nutrient loadings and speciation from tributary rivers would then be beneficial for assessing past and future management decisions.

ADDITIONAL RELATIONSHIPS BETWEEN WATER QUALITY PARAMETERS

Both chlorophyll a and BOD increase with various dissolved and particulate nutrients such as particulate nitrogen, phosphorus, and carbon and total dissolved phosphorus. These relationships are likely explained by increased phytoplankton (indicator parameter: chlorophyll a) directly contributing to particulate matter. The relationships with BOD can be explained by enhanced growth of microbes in the water column requiring oxygen (increased BOD) to degrade the food sources (particulate and dissolved nutrients) stemming from primary producers; with more nutrients available there is increased BOD (Canuel and Zimmerman 1999).

STRATIFICATION

Temperature and salinity can create density gradients in the water column, resulting in colder, more saline water at depth, with less saline, warmer waters on the surface. This density gradient can stratify the water column and contribute to hypoxia because there is less turnover between surface water and water at depth (Anderson and Taylor 2001).

Freshwater inflow and rainfall contribute to the less saline surface waters observed in the Western Narrows. The lower salinities throughout the water column in June are likely attributed to spring melt and runoff, with dryer conditions through the summer. The larger temperature differentials in surface versus bottom waters can contribute to stratification of the water column, which can increase the hypoxic conditions observed at deeper depths due to a lack of mixing with D.O. rich surface waters.

Future data analysis efforts may include weekly averaged meteorological conditions (e.g., weekly average wind speed and direction, freshwater inflow, precipitation), since it has been observed that stratification can be mitigated with increased wind speeds and specific wind directions (Zhou et al. 2014).

CONCLUSIONS

Hypoxia is a condition of low D.O. with complicated relationships to various physical, chemical, and biological factors. To understand these relationships, it was crucial to first create a RDBMS and allow for water quality, nutrient, meteorological, and location data to be related, queried and reported in various formats. The flexibility of the IEC 1991-2015 Water Quality Database meant we could easily generate tables with key data fields for statistical analyses and import data into GIS for areal interpolation. The organization of the database also allowed us to store information about QAPP analysis methods and meteorological data sources for quick reference. The Water Quality database, and geodatabase for spatial data products, provided a comprehensive foundation from which to initiate and direct our analyses.

Based on our analysis of 25 years of IEC's data in the Western Narrows, nutrients, specifically inorganic forms of nitrogen, phosphorus, and silica, as well as stratification are the primary predictors of hypoxic conditions. While it is likely that meteorological parameters influence hypoxic conditions, the resolution of the data are not robust enough to forecast those relationships. These observations are in accordance with annual hypoxia reports (CTDEEP and IEC 2016), with nutrients being the factors that most often predict hypoxic conditions. However, depth and season, which are coupled with temperature and salinity, are important factors which can influence the duration, frequency, and extent of hypoxia (Zhou et al. 2014; O'Shea and Brosnan 2000). Excessive nutrient inputs in weakly stratified systems may contribute to hypoxia, with fewer nutrient inputs being required to influence hypoxia in more highly stratified waters (Howarth et al. 2011). LIS is considered a weakly stratified system, where high winds can influence stratification (Kemp et al. 2009).

CHAPTER 7 | NEXT STEPS AND FUTURE DATA COLLECTION EFFORTS

The compilation of IEC's water quality data, sampling metadata, and relevant meteorological data into an RDBMS has created a time series dataset allowing for related exploration of trends related to D.O. and hypoxia. As additional data are collected or identified, they may be added to the database via forms specifically created for this purpose (i.e., future database capacity). Further, analogous data collection efforts in CT may be incorporated into this database via a similar process. In addition, the analyses conducted and trends investigated in this report have provided a foundation for future more complex and rigorous statistical and modeling efforts. This chapter discusses future data collection and database efforts and discusses potential future analysis and modeling efforts.

FUTURE DATA COLLECTION AND DATABASE EFFORTS

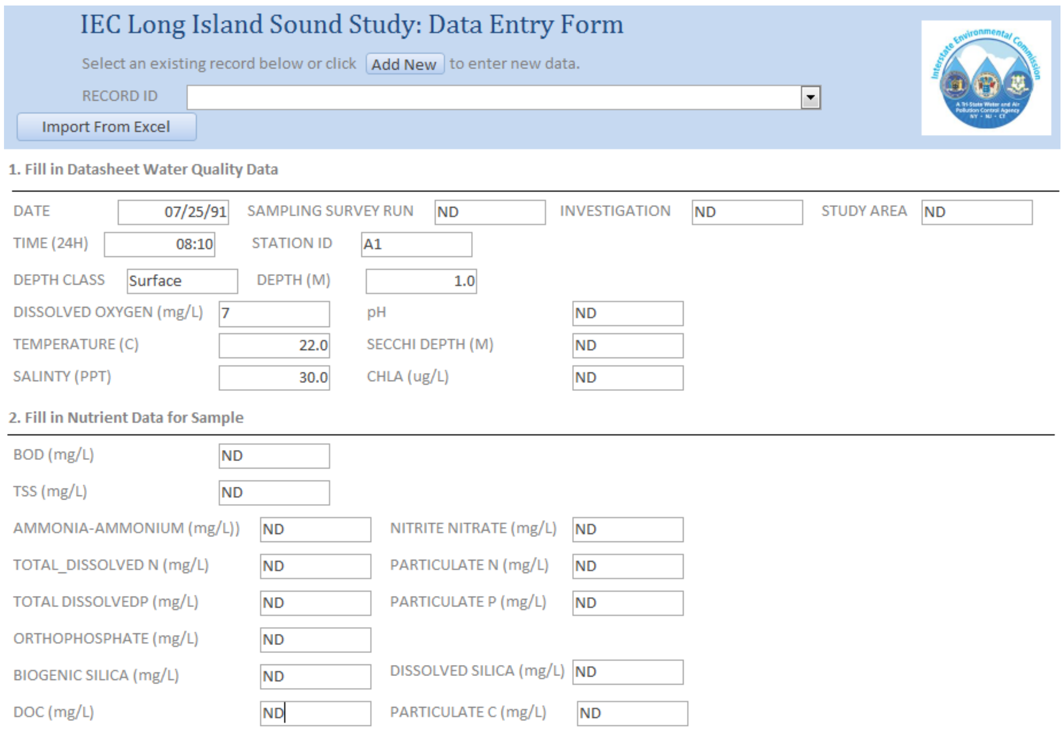
IEC collects annual water quality and nutrient data in the Western Narrows, and has transcribed data in Excel for the 2016 and 2017 sampling years that are not included in this version of the database, and CTDEEP conducts analogous sampling in eastern LIS waters. Also, nutrient data were only available for two years (2014 and 2015) and may be collected in future years. Anticipating this continuing work and other potential future additions of relevant data to the database, we have built tools and tables into the database to assist in future database efforts. We have also completed a review of potential other non-meteorological data sources that may affect hypoxic levels in the Western Narrows and have compiled a list of data sources that can be used to fill in the "IEC Additional Environmental Data" table created for this purpose.

DATA REVIEW AND ENTRY FORM

Database users are able to add entries to the water quality and nutrients table directly but, with over 30 fields, table data entry can be cumbersome and difficult to review. As such, to assist IEC with future data entry, we created a fillable form in the database which can be used to review the existing data, via a Record ID search bar, and type in data directly from field datasheets (Exhibit 7-1). The form uses dropdown menus, a calendar to select the date, and auto-generates the Record ID for each record from the information entered. These measures help to standardize the data and reduce disparities within the fields.

Recognizing that the 2016 and 2017 data have already been entered into an Excel file format, we have created an import tool to append existing data into the master "IEC Water Quality and Nutrient Data" table and for the "IEC Meteorological Data" table (Exhibit 7.2). Once an Excel file is formatted with the same fields and order as is currently in either data table, the user can click on the Import tool to automatically append all of the data into the database. These data can then be viewed through the data entry form.

EXHIBIT 7-1. WATER QUALITY, NUTRIENT AND WEATHER DATA FORM IN ACCESS DATABASE



IEC Long Island Sound Study: Data Entry Form

Select an existing record below or click Add New to enter new data.

RECORD ID

Import From Excel

1. Fill in Datasheet Water Quality Data

DATE 07/25/91 SAMPLING SURVEY RUN ND INVESTIGATION ND STUDY AREA ND

TIME (24H) 08:10 STATION ID A1

DEPTH CLASS Surface DEPTH (M) 1.0

DISSOLVED OXYGEN (mg/L) 7 pH ND

TEMPERATURE (C) 22.0 SECCHI DEPTH (M) ND

SALINTY (PPT) 30.0 CHLA (ug/L) ND

2. Fill in Nutrient Data for Sample

BOD (mg/L) ND

TSS (mg/L) ND

AMMONIA-AMMONIUM (mg/L)) ND NITRITE NITRATE (mg/L) ND

TOTAL_DISSOLVED N (mg/L) ND PARTICULATE N (mg/L) ND

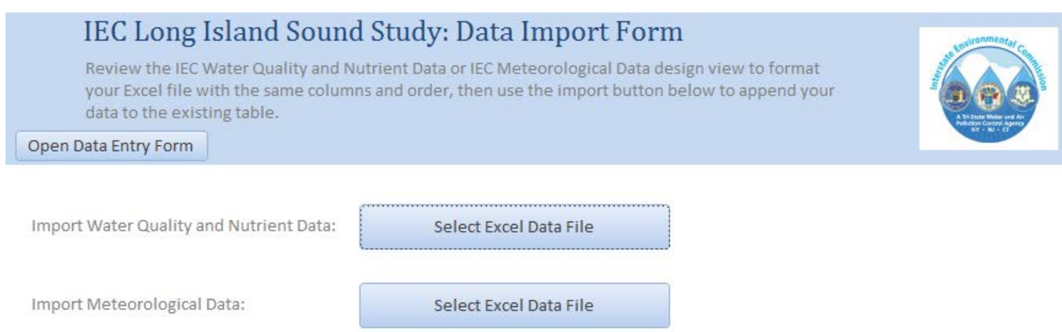
TOTAL DISSOLVEDP (mg/L) ND PARTICULATE P (mg/L) ND

ORTHOPHOSPHATE (mg/L) ND

BIOGENIC SILICA (mg/L) ND DISSOLVED SILICA (mg/L) ND

DOC (mg/L) ND PARTICULATE C (mg/L) ND

EXHIBIT 7-2. DATABASE DATA IMPORT TOOLS



IEC Long Island Sound Study: Data Import Form

Review the IEC Water Quality and Nutrient Data or IEC Meteorological Data design view to format your Excel file with the same columns and order, then use the import button below to append your data to the existing table.

Open Data Entry Form

Import Water Quality and Nutrient Data: Select Excel Data File

Import Meteorological Data: Select Excel Data File

FUTURE DATABASE CAPACITY

We recommend the following next steps for further database development for the IEC water quality data and related meteorological and environmental data parameters:

1. Use the Import tool to bring formatted 2016 and 2017 data into the water quality and nutrients master table.
2. Following the 2018 field data season, use the data entry form to enter water quality, nutrient, and weather data into the database.
3. Use the provided meteorological data sources to extract tide, precipitation, wind and air temperature data for the 2016 and 2017 data.
4. Use the environmental data sources and run spatial analyses to fill in the IEC Additional Environmental Data table for each station. Continue regression analyses for these new potential factors.

POTENTIAL FURTHER ANALYSES AND MODELING EFFORTS

A myriad of potential future analyses and modeling efforts exist that were beyond the scope of this effort. Such efforts may include analyses at a finer scale, focus on specific areas within the Western Narrows, or more robust statistical and modeling analyses. Meteorological data may be parsed and linked to samples at different scales, and additional environmental data including wastewater treatment plant and CSO outfall data. In addition, increased computing power and model development may provide considerable opportunities. For example, in the Chesapeake Bay, multiple government, non-profit, and academic efforts were undertaken to model water quality, including hypoxic conditions. As described in Irby et al. (2016), multiple models have been developed to predict hypoxic conditions in the Chesapeake Bay that incorporate a combination of hydrodynamics, biogeochemistry, food web complexity, riverine input, and other parameters. Utilizing the data compilation from this effort and data from CTDEEP, such a modeling approach may be employed for LIS to support forecasting efforts and management decisions.

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ATTACHMENT A | TREATMENT OF NON-DETECTS FOR DATA ANALYSIS

For each parameter that IEC sampled, we discuss how we identified the detection limits and any caveats to the data including the years sampled, sampling frequency, and relevant information from QAPPs. We also report the number of non-detects for each parameter, if identified, and how we treated those data.

SALINITY

Salinity was measured weekly at all stations and each depth from 1991-2015. No detection limits or ranges were available in QAPPs from 1991-1995 or when reviewing the published methods. As such, we defaulted to the detectable range from the 2012-2015 QAPPs, which is 0 to 70 PSU.

There was one value in 2002 that exceeded the detectable range and was reported as 236.6 PSU. This was a transcription error during data entry and, after reviewing the raw data sheets, was corrected to 26.6 PSU. There were no salinity values that needed treatment as non-detects.

TEMPERATURE

Water temperature was measured weekly at all stations and each depth from 1991-2015. No detection limits or ranges were available in QAPPs from 1991-1995 or when reviewing the published methods. As such, we defaulted to the detectable range from the 2012-2015 QAPPs, which is -5 to 65°C.

There were no temperature values outside the range of -5 to 65°C. As such, there were no temperature values that needed treatment as non-detects.

DISSOLVED OXYGEN

D.O. was measured weekly at all stations and each depth from 1991-2015. No detection limits or ranges were available in QAPPs from 1991-1995 or when reviewing the published methods. As such, we defaulted to the detectable range from the 2012-2015 QAPPs, which is 0 to 20 mg/L.

There was one value in 2005 that was reported as “0 mg/L.” This was a transcription error during data entry and, after reviewing the raw data sheets, was corrected to 0.03 mg/L. There were no values that needed treatment as non-detects.

PH

pH was measured weekly at all stations and each depth starting in 2007 and continuing through 2015. No QAPPs were available from 2007-2011. As such, we defaulted to the detectable range from the 2012-2015 QAPPs, which is 0 to 14 standard units.

There were no pH values outside the range of 0-14 standard units. As such, there were no pH values that needed treatment as non-detects.

CHLOROPHYLL A

Chlorophyll a was sampled from the surface (1m depth from surface) every other week at all stations. No detection limits or ranges were available in QAPPs, standard methods, or raw data sheets for chlorophyll a data from 1991-2000. The 2012-2015 QAPPs report detection limits for chlorophyll a, but differ from the laboratory provided method detection limits (MDL), reporting limits (RL), or practical quantitation limits (PQL). As such, the metadata included in the database report the detection limits provided in the QAPPs[3], but for the actual treatment of non-detects, we compared the data to the lab reported detection limits.

Depending on the method, MDLs from 2001 to 2015 range from 0.075-1.8 µg/L, with RLs or PQLs approximately double the MDL[4]. Data in more recent years treated non-detects for chlorophyll a by entering them into the database as "<" the value for RL or PQL. Based on this treatment of non-detects from the labs, we changed non-detects for chlorophyll a to:

- ½ the PQL in years where the PQL is known, or
- ½ the RL in years where the RL is known, or
- The average MDL from 2001 to 2015 in years where the PQL or RL are not known (because the MDL equals approximately ½ the PQL or RL). Exhibit A-1 displays a summary of how non-detects were previously treated in the data, then how we treated them for the database.

SECCHI DISK DEPTH

Secchi disk depth is a measure of water clarity. It was measured weekly at all stations (only one measurement per location) starting in 2001 and continuing through 2015. Secchi disk depth is the depth where you can no longer see the disk that you lowered into the water, as such, there is no detection limit for this parameter.

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[3] The MDL provided in QAPPs from 2012-2015 for chlorophyll a is 3.7 µg/L.

[4] Different limits of detection, such as MDL, PQL, and RL are variable depending on the lab conducting the analysis, even though there are usually general published MDLs for specific methods. It is standard practice for the lab to report detection limits with the data. However, in earlier years, there are no available detection limits provided with the data, or accompanying the actual methods.

TOTAL SUSPENDED SOLIDS (TSS)

TSS was only measured in 2014 and 2015 at 11 stations. Samples were taken from the surface (1m below surface). QAPPs listed the detectable range for TSS to be 0.1-20,000 mg/L.

There were no records in the TSS data that were outside the detectable range of 0.1-20,000 mg/L in 2014 and 2015. As such, no treatment of non-detects was necessary.

AMMONIA/AMMONIUM

Ammonia/ammonium was only measured in 2014 and 2015 at 11 stations. Samples were taken from the surface (1m below surface). QAPPs listed the RL for ammonia/ammonium as 0.01 mg/L.

Non-detect data for ammonia/ammonium were reported as the actual value reported by the lab despite it being below the detection limit. To identify non-detects, we compared these data to the RL for ammonia/ammonium in the QAPPs, which is 0.01 mg/L. There were 26 values of ammonia/ammonium in the data (16 from 2014, 10 from 2015) requiring treatment as non-detects. We substituted these values for 0.005 mg/L, which is equal to ½ the RL.

NITRITE/NITRATE

Nitrite/Nitrate was only measured in 2014 and 2015 at 11 stations. Samples were taken from the surface (1m below surface). QAPPs listed the RL for nitrite/nitrate as 0.0035 mg/L.

Non-detect data for nitrite/nitrate were reported as the actual value reported by the lab despite it being below the detection limit. To identify non-detects, we compared these data to the RL for nitrite/nitrate in the QAPPs, which is 0.0035 mg/L. There were 16 values of nitrite/nitrate in the data (13 from 2014, 3 from 2015) requiring treatment as non-detects. We substituted these values for 0.00175 mg/L, which is equal to ½ the RL.

PARTICULATE NITROGEN

Particulate nitrogen was only measured in 2014 and 2015 at 11 stations. Samples were taken from the surface (1m below surface). QAPPs listed the RL for particulate nitrogen as 0.033 mg/L.

There were no particulate nitrogen values below the RL of 0.033 mg/L. As such, there were no particulate nitrogen values that needed treatment as non-detects.

TOTAL DISSOLVED NITROGEN

Total dissolved nitrogen was only measured in 2014 and 2015 at 11 stations. Samples were taken from the surface (1m below surface). QAPPs listed the RL for total dissolved nitrogen as 0.15 mg/L.

Non-detect data for total dissolved nitrogen were reported as the actual value reported by the lab despite it being below the detection limit. To identify non-detects, we compared these data to the RL for total dissolved nitrogen in the QAPPs, which is 0.15 mg/L. There was 1 value of total dissolved nitrogen in the data (from 2014) requiring treatment as a non-detect. We substituted this value for 0.075 mg/L, which is equal to ½ the RL.

ORTHOPHOSPHATE

Orthophosphate was only measured in 2014 and 2015 at 11 stations. Samples were taken from the surface (1m below surface). QAPPs listed the RL for orthophosphate as 0.0025 mg/L.

There were no orthophosphate values below the RL of 0.0025 mg/L. As such, there were no orthophosphate values that needed treatment as non-detects.

PARTICULATE PHOSPHORUS

Particulate phosphorus was only measured in 2014 and 2015 at 11 stations. Samples were taken from the surface (1m below surface). QAPPs listed the RL for particulate phosphorus as 0.0070 mg/L.

Non-detect data for particulate phosphorus were reported as the actual value reported by the lab despite it being below the detection limit. To identify non-detects, we compared these data to the RL for particulate phosphorus in the QAPP, which is 0.0070 mg/L. There was 1 value of particulate phosphorus in the data (from 2015) requiring treatment as a non-detect. We substituted this value for 0.0035 mg/L, which is equal to ½ the RL.

TOTAL DISSOLVED PHOSPHORUS

Total dissolved phosphorus was only measured in 2014 and 2015 at 11 stations. Samples were taken from the surface (1m below surface). QAPPs listed the RL for total dissolved phosphorus as 0.0045 mg/L.

There were no total dissolved phosphorus values below the RL of 0.0045 mg/L. As such, there were no total dissolved phosphorus values that needed treatment as non-detects.

DISSOLVED ORGANIC CARBON

Dissolved organic carbon was only measured in 2014 and 2015 at 11 stations. Samples were taken from the surface (1m below surface). QAPPs listed the RL for dissolved organic carbon as 0.05 mg/L.

There were no dissolved organic carbon values below the RL of 0.05 mg/L. As such, there were no dissolved organic carbon values that needed treatment as non-detects.

PARTICULATE CARBON

Particulate carbon was only measured in 2014 and 2015 at 11 stations. Samples were taken from the surface (1m below surface). QAPPs listed the RL for particulate carbon as 0.263 mg/L.

Non-detect data for particulate carbon were reported as the actual value reported by the lab despite it being below the detection limit. To identify non-detects, we compared these data to the RL for particulate carbon in the QAPPs, which is 0.263 mg/L. There were 2 values of particulate carbon in the data (from 2015) requiring treatment as non-detects. We substituted these values for 0.1315 mg/L, which is equal to ½ the RL.

DISSOLVED SILICA

Dissolved silica was only measured in 2014 and 2015 at 11 stations. Samples were taken from the surface (1m below surface). QAPPs listed the RL for dissolved silica as 0.03 mg/L.

There were no dissolved silica values below the RL of 0.03 mg/L. As such, there were no dissolved silica values that needed treatment as non-detects.

BIOGENIC SILICA

Biogenic silica was only measured in 2014 and 2015 at 11 stations. Samples were taken from the surface (1m below surface). QAPPs listed the RL for biogenic silica as 0.03 mg/L.

Non-detect data for biogenic silica were reported as the actual value reported by the lab despite it being below the detection limit. To identify non-detects, we compared these data to the RL for biogenic silica in the QAPPs, which is 0.03 mg/L. There was 1 value of biogenic silica in the data (from 2015) requiring treatment as a non-detect. We substituted this value for 0.015 mg/L, which is equal to ½ the RL.

BIOCHEMICAL OXYGEN DEMAND (BOD)

BOD was only measured in 2015 at 11 stations. Samples were taken from the surface (1m below surface). QAPPs listed the RL for BOD at 3 mg/L.

BOD data were only available for 2015, the year this parameter was added to the sampling program. Non-detects were reported as "<3 mg/L" in the provided data. There were 16 non-detect values for BOD in 2015 requiring treatment as non-detects. For these records, we substituted the value of 1.5 mg/L, which is equal to ½ the RL.

EXHIBIT A-1. CHLOROPHYLL A TREATMENT

DATA YEAR	DETECTION LIMIT(S) REPORTED WITH DATA (µG/L)*			NUMBER OF ND**	PAST TREATMENT OF ND	CURRENT TREATMENT OF ND	SUBSTITUTED VALUE (µG/L)	JUSTIFICATION OF SUBSTITUTION METHOD
	MDL	RDL	PQL					
1991	N/A	N/A	N/A	3	ND listed as "0"	Average MDL from 2001-2009	0.1	No indication of detection limits for these years, however, analytical methods are the same as those for 2001-2009. As such, we used the average MDL from 2001-2009, because MDLs are approximately ½ the RL or PQL in subsequent years.
1992	N/A	N/A	N/A	12				
1993	N/A	N/A	N/A	5				
1994	N/A	N/A	N/A	10				
1995	N/A	N/A	N/A	7				
1996	N/A	N/A	N/A	1				
1997	N/A	N/A	N/A	None	N/A	N/A	N/A	N/A
1998	N/A	N/A	N/A	None	N/A	N/A	N/A	N/A
1999	N/A	N/A	N/A	None	N/A	N/A	N/A	N/A
2000	N/A	N/A	N/A	None	N/A	N/A	N/A	N/A
2001	0.1	N/A	N/A	None	N/A	N/A	N/A	N/A
2002	0.075	N/A	N/A	None	N/A	N/A	N/A	N/A
2003	0.075	N/A	N/A	None	N/A	N/A	N/A	N/A
2004	0.075	N/A	N/A	None	N/A	N/A	N/A	N/A
2005	0.075	N/A	N/A	None	N/A	N/A	N/A	N/A
2006	0.1	N/A	0.3	None	N/A	N/A	N/A	N/A
2007	0.1	N/A	0.3	None	N/A	N/A	N/A	N/A
2008	0.1	N/A	0.3	None	N/A	N/A	N/A	N/A
2009	0.1	N/A	0.3	None	N/A	N/A	N/A	N/A
2010	1.8	N/A	3.6	46	ND listed as <3.6	½(PQL)	1.8	Since non-detects were previously listed as less than the PQL value of 3.6 µg/L, we substituted one half of the PQL for non-detects.
2011	1.8	N/A	2.6	4	ND listed as <2.6, one actual value of 2	½(PQL)	1.3	Since three of the four non-detects were previously listed as less than the PQL value of 2.6 µg/L, we substituted one half of the PQL for non-detects. For consistency, the one value listed as 2 µg/L was also treated as a non-detect because it was below 2.6 µg/L.
2012	1.18	3.54	N/A	15	ND listed as <3.54	½(RL)	1.77	Since non-detects were previously listed as less

DATA YEAR	DETECTION LIMIT(S) REPORTED WITH DATA (µG/L)*			NUMBER OF ND**	PAST TREATMENT OF ND	CURRENT TREATMENT OF ND	SUBSTITUTED VALUE (µG/L)	JUSTIFICATION OF SUBSTITUTION METHOD
	MDL	RDL	PQL					
2013	1.18	3.54	N/A	4	ND listed as <3.54	½(RL)	1.77	than the RL value of 3.54 µg/L, we substituted one half of the RL for non-detects.
2014	1.18	3.54	N/A	9	ND listed as actual quantified value	½(RL)	1.77	Non-detects were previously listed as the actual quantified value. Since the analytical methods, detection limits, and reporting limits were the same as 2012, 2013, and 2015, we substituted one half of the RL for non-detects.
2015	1.18	3.54	N/A	17	ND listed as <3.54	½(RL)	1.77	Since non-detects were previously listed as less than the RL value of 3.54 µg/L, we substituted one half of the RL for non-detects.

*MDL= method detection limit; DL=detection limit; PQL=practical quantification limit.
**ND= non-detects.