IPSWICH RIVER
WATERSHED ASSOCIATION
The Voice of the River

RiverWatch Water Quality Volunteer Monitoring Program

The Ipswich River Watershed Association (IRWA) is the voice of the Ipswich River. IRWA works to protect nature and make sure that there is enough clean water for people, fish and wildlife, today and for our children and theirs.

2019 Annual Results Report

143 County Road
P.O. Box 576
Ipswich, MA 01938
p. 978-412-8200
f. 978-412-9100
irwainfo@ipswichriver.org
www.ipswichriver.org

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Most of all, we would like to thank our dedicated volunteers that have monitored on sunny and rainy days, in cold and heat, and high and low river flows. Thank you for your considerable efforts and dedication to the Ipswich River!

Donnan Barnes
Brandon Boyd
Loring Bradlee and Janet Stone
Elizabeth Cameron
Russ Camp
Deborah Cassady
Michael & Susan DeAmario
Diane Dixon
Joan Flynn
Gayle Gleichauf
Peter Goodwin
Mary Hatton
Dan & Sally Heiter
Claire Hilsinger
Kim Honetschlager and Will Finch
Marguerite Hoover
Ingrid Johnson
Mary Ann Leekley
Marianna Mattin
Bill McDavitt
Sue McLaughlin
David Merrill
Deborah Nelson
Robert O'Donnell
Dave Paulin
Bruce Piper
Bill Reed
Rick Rogers
Carol Sandberg
Judy Schneider
Mary Smith
Chris Sobotowski
Rob Stevens
Martha Stevenson
Suzanne Sullivan
Frank Sullivan
David Tapley
Ellen Tiberi
Ben Wildrick
Dave Williams
Nancy & Michael Wolfe

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List of Abbreviations

Abbreviation	**Definition**
ACEC	Area of Critical Environmental Concern
DO	Dissolved oxygen
EEA	Executive Office of Energy and Environmental Affairs
USEPA	United States Environmental Protection Agency
ft	Foot
IRWA	Ipswich River Watershed Association
MassDCR	Massachusetts Department of Conservation and Recreation
MassDEP	Massachusetts Department of Environmental Protection
MassDER	Massachusetts Division of Ecological Restoration
MassDFW	Massachusetts Division of Fish and Wildlife
MBL	Marine Biological Laboratory
MDL	Method Detection Limit
mg	Milli-gram
mL	Milli-liter
N/A	Not Applicable
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
RL	Reporting Limit
RIFLS	River Instream Flow Stewards
s	Second
SC	Specific conductance
SOP	Standard Operating Procedure
TAC	Technical Advisory Committee
UNH	University of New Hampshire
USGS	United States Geological Survey
µS/cm	MicroSiemens/centimeter

Executive Summary

In 1997 the Ipswich River was listed as one of the 20 most threatened rivers in America. The level of threat to the Ipswich River was heightened in 2003 when it was ranked the third most endangered river in America by American Rivers, a national nonprofit, primarily due to low flow problems (American Rivers 1997 and 2003, IRWA 2003). Much of the upper half of the River dried up or was reduced to isolated stagnant pools in the summers of 1995, 1997, 1999, 2001, 2002, 2003, and 2005. In 1999, the River experienced record low-flows in May, June, July and August. In 2000, the United States Geological Survey (USGS) completed a model of river flow that linked withdrawals for regional water supply with low flows in the Ipswich River. Major fish kills were also documented in 1995, 1997, 1999, 2002, and 2005.

In order to assess the health of the Ipswich River and monitor ongoing threats, the Ipswich River Watershed Association has maintained the RiverWatch Volunteer Water Quality Monitoring Program since 1997. Volunteers collect data monthly from March-December on weather conditions, rain in the last 48 hours, water color, water odor, water temperature, dissolved oxygen (DO), velocity, depth, specific conductance (SC) and chloride. Streamflow is also monitored at three locations as part of the RIFLS program run by MassDER, in addition to the official USGS gages in South Middleton and Ipswich. In 2019, volunteers monitored a total of 35 sites monthly from March to December.

Streamflow gages maintained by the USGS have recorded regular episodes of extended extreme low flow events. "Extreme low flow" is defined based on the USGS summer "ecological protection flow" (Horsley and Witten 2002), that "provides adequate habitat for the protection of fisheries" (Ibid). In 2019, extreme low flows were observed for an average of 44 days at the USGS South Middleton and Ipswich gages primarily during the summer and early fall.

The Ipswich River and many of its tributaries continue to show impairment for DO and flow. In 2019, 29% of the collected samples did not meet the state standard for dissolved oxygen concentration of 5 mg/L. Under these conditions, DO levels decrease below what is suitable to aquatic life such as fish and aquatic macroinvertebrates. Dissolved oxygen is influenced by many factors including flow and temperature. Dissolved oxygen levels below 5 mg/L create a stressful environment for fish and other aquatic organisms. Levels below 3 mg/L can be fatal to organisms that cannot move to areas of higher concentration. Large fish kills can result from DO levels that fall below 1-2 mg/L, even if those levels are present for only a few hours. Certain fish species, like brook trout, are especially sensitive to low DO.

All temperature samples met Massachusetts State Water Quality Standards. This indicates that temperatures are in an acceptable range along the Ipswich River. This may be an indicator of the importance that cool groundwater plays in providing the river's baseflow in summer. Shading from trees along the river also benefits water temperature.

One of the primary impairments in the Ipswich River watershed are low flow alterations due to water withdrawals and impervious surfaces contributing to stormwater runoff. The Ipswich River experiences significant periods of extreme low flow during many years. Withdrawals for drinking and irrigation water are the primary cause of unnaturally low flows in the Ipswich River

(Armstrong 2001, Zarrielo and Ries 2000). Low flows can be expected to occur seasonally, but the lowest flows observed in the Ipswich River are about 1/10th of what is considered “natural” (Zariello and Ries, 2000). Due to low flow, the Ipswich River is classified as highly stressed by the MA Water Resources Commission (2001) and impaired under section 303(d) of the Clean Water Act.

Sites located in the headwaters region of watershed continue to show a higher degree of impairment than sites elsewhere. The headwaters region or upper watershed includes the towns of Wilmington and North Reading. This area continues to experience low dissolved oxygen levels, especially during the summer months, despite low flow conditions not being as severe as in years prior to 2006 when the town of Reading discontinued using wells adjacent to the Ipswich River.

Road salt is an emerging threat to water quality of the Ipswich River, as well as the broader region. Monitors measure specific conductance (SC) as an indicator of dissolved solids (or salts) such as chloride, sulfate, sodium and calcium. Significant changes in SC can be an indicator that a discharge or some other source of pollution has entered the water. Rivers that can support healthy fisheries should be in the range of 150 to 500 µS/cm. In 2019, SC levels greater than 500 µS/cm were recorded for 31% of samples, with many of these sites located in the upper watershed. Elevated readings are observed throughout the year and are most likely the result of road salt accumulating in wetlands and sediments through stormwater and surface runoff.

Bacterial pathogens are another threat that we are in the process of building capacity to begin monitoring. Bacterial pathogens, such as fecal coliform and *E. coli*, are one of the main sources of water pollution and can adversely impact recreational use of waterways as well as aquatic life. Possible sources of pathogen contamination include animal waste from pets or wildlife, failing septic systems, stormwater runoff and illicit sewer connections to storm lines. Information about bacterial pathogens is lacking across the watershed and our goal is to meet this need by providing routine, high quality data on bacteria levels to know whether or not water quality standards for recreation and for aquatic life are being met.

Ongoing monitoring to document trends and conditions across the watershed will continue to be an important goal of the Ipswich River Watershed Association and volunteers are critical to this mission. Among the many accomplishments of the organization is our commitment to community science programs including 23 years of monitoring the health the river on a monthly basis by more than 50 trained community-scientists. Our deepest thanks to the many volunteers that have monitored on sunny and rainy days, in cold and heat and high and low river flows. Thank you for your considerable efforts and dedication to the Ipswich River!

Section 1: Introduction

1.1 Ipswich River Watershed Association

The Ipswich River Watershed Association (IRWA) is a 501 (c) (3) nonprofit organization incorporated in 1977. We serve as the voice of the Ipswich River by working for the protection, conservation and sustainable management of the vital natural resources within the river's watershed. Our goals are for the Ipswich River to have enough clean water to support the river's essential functions, including healthy fisheries and natural habitats, sustainable drinking water, recreational opportunities and scenic values. Working with scientists and communities, we come up with solutions for the river's problems. Recognizing the growing importance of connecting people with the outdoors, we also help people enjoy and learn about the river via educational programs with a focus on underserved communities, creating beautiful public access landings along the river, and producing compelling videos and other outreach materials. Key programs include: Advocacy, Science & Monitoring, Restoration & Resiliency, Outreach & Education, and Community Services.

We serve 160,000 people who live in the watershed, as well as more than 350,000 people and businesses who get their water from the Ipswich River. We also serve the broader North Shore community, including 380,000 people in Essex County, through our Greenscapes North Shore Coalition and the Parker-Ipswich-Essex Rivers Restoration Partnership, both of which we co-founded. In particular, our Greenscapes Coalition works on behalf of 24 Essex County municipalities to improve environmental stewardship and creates environmental outreach and education materials for use by municipal partners, residents, schools, businesses, developers, and institutions.

The Ipswich River Watershed Association works on a number of ongoing programs dedicated to protecting and monitoring the River as well as educating the public about the River. Recent and current programs include:

- Monitoring, including the RiverWatch monthly baseline sampling program, an annual macroinvertebrate sampling program and an annual herring count are all conducted by volunteers.
- River restoration, focusing on assisting the region's communities in improving management and protection of water resources, as well as evaluating in-stream restoration opportunities such as dam removal, fish passage improvement and culvert replacement.
- Water conservation, focusing on the use of the Ipswich River for the region's water supply, the environmental costs of this use, and actions that residents and businesses can use water more efficiently indoors and out.
- Watershed education and outreach, including educational programs for municipal officials and the public.
- Supporting stream teams and other community based organizations in their efforts to lead local watershed protection efforts.
- Advocacy campaigns, to ensure that the interests of the River are represented at all levels of decision making. These projects include intervention in legal appeals as well as commentary on proposed projects.

The Ipswich River Watershed Association also administers the Parker, Ipswich, Essex Rivers Restoration Partnership (PIE-Rivers), a coalition of governmental and non-governmental organizations having the common interest of protecting the watersheds of Plum Island Sound and the Great Marsh Area of Critical Environmental Concern (ACEC). The PIE-Rivers Partnership includes The Parker River Clean Water Association (PRCWA), Chebacco Lake and Watershed Association (CLWA), the U.S. Fish & Wildlife Service, Mass. Department of Conservation and Recreation and Division of Ecological Restoration; town boards from Ipswich, Boxford and North Andover; Mass Audubon; Essex County Greenbelt Association, 8 Towns and the Great Marsh and Trout Unlimited, Nor'East Chapter. The Partnership has developed an Action Plan to restore these rivers to the healthiest condition realistically achievable, which includes short and long-term goals, objectives and priorities. Consistent, coordinated sampling and management of the three PIE-Rivers systems will address similar pollution issues and improve the quality of water entering the Plum Island Sound and Great Marsh ecosystem.

1.2 An Introduction to the Ipswich River

The Ipswich River watershed is 155 square miles and includes all or part of 21 communities in northeastern Massachusetts. The topography of this Atlantic coastal plain basin is characterized by low relief, with an average grade of 3.1 feet per mile. The length of the river is a meandering 40 miles. The surficial geology of the region consists primarily of glacial till with stratified sand and gravel deposits covering about 43 percent of the basin and alluvial deposits covering about 3 percent of the basin (Zariello and Ries, 2000). Extensive wetlands are present along the River and streams within the Ipswich River basin. These wetlands protect surrounding areas during flooding as well as positively affect the water quality of the River and streams in the basin.

This river system supplies water to more than 330,000 people and thousands of businesses, providing all or part of the water supply for 14 communities. The Ipswich River also sustains fish and natural communities, and provides a scenic natural corridor with outstanding opportunities for the residents and eco-tourists to enjoy the great outdoors.

Water quality issues have been identified in the Ipswich River and the Ipswich River watershed by both independent researchers and the State of Massachusetts. The 2016 Integrated List (MassDEP, 2019) lists all sections of the Ipswich River and many tributaries as impaired (Category 5: Waters Requiring a TMDL). These impairments include: repeated, exaggerated low flows, low DO, excessive nutrient, fecal coliform and/or E. coli as well as others. Low flows in summer have been linked to ground water withdrawals, particularly in the upper watershed (Zarriello and Ries 2000). Additionally, the diversion of wastewater to treatment plants outside the watershed also significantly reduces flow (Ibid). Many sub-basins in the watershed experience severe flow depletion seasonally due to groundwater withdrawals and significant annual flow depletion due to surface water withdrawals (Weiskel, *et al*. 2009).
A companion study by USGS and MassDFW found that the Ipswich River's fisheries have been degraded by low-flow problems and the River has experienced a decrease in biodiversity due to the loss of river dependent fish species (Armstrong et al., 2001). The study identified critical aquatic habitats and recommended minimum flows necessary to preserve those habitats. The Ipswich River Fisheries Restoration Task Group then developed recommendations to restore

healthy fisheries to the Ipswich River (2002). These recommendations include maintaining flow over riffle areas, maintaining water to the channel margins and maintain seasonal flow variations near natural levels (Ibid).

In April 2006, the Towns of Reading and Wilmington began purchasing water from the out-of-basin, regional Massachusetts Water Resources Authority (MWRA). Reading completely phased out use of water from their Ipswich River basin headwater wells and switched to using only MWRA water while Wilmington supplemented their water supply with MWRA water but continues to pump water from Ipswich River basin headwater wells. MassDER, in consultation with MassDCR, analyzed streamflow data to evaluate any resulting improvements (increases) to streamflow in the Ipswich River during low flow periods. A comparison of flow data from 1997-2005 and 2006-2014 showed an improvement in low flows (MassDER, 2015). While not statistically significant, the difference was greater than reference gages with no water withdrawals.

Among the emerging threats to the Ipswich River are chlorides originating from deicing salts applied to roads. Chlorides can have a negative impact on aquatic life at relatively low concentrations in surface waters receiving stormwater runoff (Corsi, 2010). Specific conductance readings at most sites are similar for summer and winter reflecting the persistence of road salt in the environment.

Under the Massachusetts Surface Water Quality Standards (MassDEP 2013), most of the freshwater section of the Ipswich River is classified as a Class B water body and warm water fishery, except for public water supplies and certain tributaries (Table 1). The water quality goal for Class B waters is to be “fishable and swimmable” throughout the year. The tidal section of the river located downstream of the Ipswich Mills Dam in Ipswich is classified as a class SA water body. Class SA water bodies are tidal waters intended to be fishable, swimmable, and safe for shellfish harvesting. Table 2 details the water quality standards associated with these classifications.

Bacterial pathogens also have a significant, adverse impact on water quality in the Ipswich watershed and coastal region. Pollution from pathogens prevent surface waters from attaining EPA defined designated water use goals that include swimming and boating as well as shellfish harvesting. Almost 180 acres of highly productive shellfish beds in the Ipswich River estuary are frequently closed due to fecal coliform contamination. Contamination of the Ipswich River threatens other prime shellfishing areas as well, including productive growing areas in Plum Island Sound and at Crane Beach. Possible sources of pathogen contamination include animal waste from pets or wildlife, failing septic systems, stormwater runoff and illicit sewer connections to storm lines. The risk to human health is through primary and secondary contact recreation (swimming and boating) as well as consumption of contaminated shellfish. While there are many waterborne pathogens, *E. coli* is used as the standard indicator in freshwater systems (MassDEP, 2013). Bacteria monitoring will be the focus of future monitoring efforts in the coastal watersheds of Plum Island Sound. Funding was secured from MassDEP in 2019 to purchase a Colilert system from IDEXX to quantify bacteria levels in surface waters. A corresponding Quality Assurance Project Plan was also prepared with the Parker River Clean

Water Association and Chebacco Lake and Watershed Association to establish a regional bacteria monitoring program through the PIE-Rivers Partnership.

Water quality impairments are also caused by flow alterations from dams and road-stream crossings. There are 3 major dams on the mainstem of the river and approximately 70 throughout the watershed. Dams create pond-like impoundments, impair habitat and block fish passage. Streams are also segmented to some degree by the roughly 500 road-stream crossings in the Ipswich watershed (IRWA, 2018).

The RiverWatch water quality monitoring program is an effort to provide high quality data on the health of the Ipswich River in order to make informed decisions about water management practices and monitor ongoing restoration efforts.

BOUNDARY	MILE POINT	CLASS	OTHER RESTRICTIONS
Ipswich River			
Source to Salem Beverly Waterway Canal	41.1 - 16.4	B	Treated Water Supply, Warm Water, High Quality Water
Salem Beverly Waterway Canal to tidal portion	16.4 - 4.5	B	Warm Water, High Quality Water
Tidal portion and tributaries thereto	4.5 - 0.0	SA	Shellfishing (O)
Middleton Pond			
Source to outlet in Middleton and those tributaries thereto	-	A	Public Water Supply
Swan Pond			
Source to outlet in North Reading and those tributaries thereto	-	A	Public Water Supply
Mill Pond			
Source to outlet in Burlington and those tributaries thereto	-	A	Public Water Supply
Longham Reservoir			
Source to outlet in Wenham and those tributaries thereto	-	A	Public Water Supply
Wenham Lake			
Source to outlet in Wenham and those tributaries thereto	-	A	Public Water Supply
Putnamville Reservoir			
Source to outlet in Danvers and those tributaries thereto	-	A	Public Water Supply
Suntaug Lake			
Source to outlet in Lynn and Peabody and those tributaries thereto	-	A	Public Water Supply
Winona Pond			
Pond to outlet in Peabody and those tributaries thereto	-	A	Public Water Supply
Unnamed Reservoir (Emerson Brook Reservoir)			
Reservoir to outlet in Middleton and those tributaries thereto	-	A	Public Water Supply

Table 1. Massachusetts surface water classifications for the Ipswich River watershed.

	Class B Standards	Class SA Standards
AQUATIC LIFE		
Dissolved Oxygen	5.0 mg/L *	6.0 mg/L
Temperature	83° F Max ** (28.3° C) 68° F Max *** (20° C)	85 F (29.4° C) Max, 80 F Average
pH	6.5 - 8.3	6.5 - 8.5
PRIMARY CONTACT RECREATION		
E. coli	235 / 100 mL single sample 126 / 200 mL geo. mean	
Enterococci	61 / 100 mL single sample 33 / 100 mL geo. mean	104 / 100 mL single sample 35 / 100 mL geo. mean
SECONDARY CONTACT RECREATION		
E. coli	235 / 100 mL 126 / 100 mL geo. mean	
Enterococci	61 / 100 mL single sample 33 / 100 mL geo. mean	135 / 100 mL single sample 35 / 100 mL geo. mean
SHELLFISHERY		
Fecal Coliform	Not applicable	14 / 100 mL geo. mean 10% <= 28 / 100 mL
AESTHETICS		
Taste and Odor	None that are objectionable	None other than natural

* In 2008, the State eliminated standards pertaining to DO% saturation. Values in this report are based on the previous standard of a minimum of 60% DO saturation and presented for comparison with previous years.
** Warm water fishery.
*** Cold water fishery.

Table 2. Massachusetts Department of Environmental Protection water quality standards.

Monthly Water Quality Testing

The Ipswich River Watershed Association has conducted the RiverWatch water quality monitoring program since 1997. The program enlists a group of volunteers to collect water quality data on the Ipswich River and its tributaries. The purpose of the program is to establish and maintain monitoring of baseline data in order to identify and address impairments to water quality and quantity, as well as to promote awareness and stewardship of the river. The RiverWatch program expanded upon an earlier, informal water quality monitoring program that ran from 1988 – 1996. A USEPA-approved Quality Assurance Project Plan (QAPP) was finalized in 1999 and most recently updated and approved by MassDEP in 2016. The goal of the RiverWatch program is to provide high quality data regarding the health of the Ipswich River. This monitoring program has established a crucial baseline of water quality and biological data, which continues to enable work with researchers and government officials to better manage the watershed and improve the condition of the Ipswich River.

The specific goals of regularly monitoring the Ipswich River and its tributaries include:

- Defining the baseline water quality conditions of the Ipswich River and key tributaries.
- Defining the range of dissolved oxygen concentrations, temperature and specific conductance over the range of annual conditions in both mainstem and tributary locations.
- Determining the relative water level and flow at a variety of ungauged locations around the basin.
- To observe the River, habitat and wildlife, and report on observations.
- To identify pollution hotspots.
- To educate watershed residents about the river.
- To promote stewardship of the river.
- To inform ongoing restoration efforts.

Monitors collect data monthly on weather conditions, rain in the last 48 hours, water color, water odor, water temperature, dissolved oxygen, conductivity, velocity and depth. Streamflow data is recorded at two official gaging stations maintained by the USGS. Streamflow is also monitored at three additional sites through the RIFLS program with MassDER.

The purpose of this report is to summarize data collected in 2019 by volunteers for the RiverWatch program. Specific site data are available in the appendix.

2.1 Program Description and Monitoring Methods

As stated earlier, the Ipswich River Watershed Association has conducted informal monitoring from 1988-1996. The RiverWatch program took its current form in 1997 and has since been continuously monitoring the Ipswich River Watershed. In order to best use our resources to gain an accurate picture of the Ipswich River, 10 tributary sites and 22 sites along the mainstem of the River from Wilmington to Ipswich, have been identified for monitoring once a month from March through December (figure 1, table 3). Beginning in 2019, the program also includes one site in the Parker River watershed (Egypt River) and three sites in the Essex River watershed (Alewife Brook, Chebacco lake inlet and Walker Creek).

Volunteer monitors are responsible for monthly monitoring which takes place in the morning of the last Sunday of each month from March through December. All samples are collected between 8 am and 12:30 pm, except for the tidal locations, which are sampled within 1 hour of low tide closest to the 8 am to 12:30 pm time span. Sampling in the morning is extremely important because the lowest dissolved oxygen values are generally observed in the early morning. This is desirable, because low values have the most potential to affect the organisms living in the Ipswich River. As of the spring of 2006, sampling in January and February became optional. Historically, volunteers sampled during these months, but the River was often frozen and the data collected during these months was generally not used in management decisions.

Volunteers record information on weather, rain in the last 48 hours and river status (frozen or dry). Monitors then collect a grab sample using a bucket. While water is contained in the sampling bucket, observations of color, clarity and odor are made. Color is recorded as a range of pre-determined colors from Clear to Dark Tea. Clarity is recorded as the amount of turbidity in the water from a scale ranging from clear to highly turbid.

Water temperature and DO are both measured with the grab sample. Water Temperature is measured with H-B Enviro-Safe® Thermometers to the nearest 0.5 degrees Celsius.

Dissolved Oxygen is measured with a LaMotte Modified Winkler Method Test Kit. One drop of fluid from the direct reading titrator in the kit is approximately 0.2 mg/L. Thus, accuracy from the titrator is +/- 0.1 mg/L of dissolved oxygen.

For DO, a percent saturation value is also calculated. This is a percentage of the DO measured in the water relative to the maximum DO water could theoretically hold at the testing water temperature (and elevation).

Velocity is measured by dividing the average of three times that it takes an orange peel to travel a known distance (often the width of a bridge). If times are disparate, another three readings are taken. Velocity measurements are multiplied by a correction factor of 0.85.

Depth is measured at a consistent location on the bridge with a weight attached to a decimal measuring tape. Cross-sections are taken at monitoring sites located at selected bridges twice each year (April and September). Monitors measure depth across the channel at one or two foot increments. A cross-section profile is plotted and an approximate flow value can be calculated by adding the product of average velocity by each cross-sectional area.

Specific conductance is measured at selected sites as an indicator of human impact from sources such as stormwater runoff. Ions from sources such as road salts and leaking septic systems increase specific conductance which can negatively impact aquatic life. All nine tributary sites are monitored since these may be expected to vary more than along the mainstem of the river where five sites are monitored to detect variations. This is done using a handheld, digital meter that automatically adjusts readings to 25°C. The meter is first rinsed with deionized or distilled water. The meter is calibrated using 447 µSiemens/cm conductivity standard solution. The meter is rinsed again and placed in the sampling bucket to record the specific conductance value.

Data collected will be submitted to MassDEP for potential use attainment determinations under the Clean Water Act, reported to members, interested organizations, and conservation commissions through reports and presentations on the collected data. Atypical data will be reported to the appropriate agencies. Atypical data include dissolved oxygen data that vary significantly from adjacent sites over one or more months. Extended periods of no flow or extremely low dissolved oxygen (less than 2 mg/L) are also considered extremely important. When dissolved oxygen levels fall below 2 mg/L the health of fish and other aquatic organisms can be severely impacted.

For data to be reported to state agencies, a Quality Assurance Project Plan (QUAPP) is maintained with MassDEP and most recently updated for the period 2019-2021. The QUAPP requires all new and returning monitors to receive annual training, and an annual site audit of each volunteer. Prior to monitoring, new monitors receive a walk-through of the monitoring manual and hands-on training at a monitoring site. All new and returning monitors must attend an annual training that consists of an overview of the program and procedures followed by a collection and analysis of temperature, dissolved oxygen and conductivity samples for comparison with readings obtained by the Monitoring Project Coordinator. Records of data generated during this training as well as attendance records are retained.

As part of the Quality Assurance Project Plan, accuracy limits are set for each parameter (table 3). Water temperature, dissolved oxygen, specific conductance and chloride are evaluated for quality control purposes. Volunteers must attend an annual training and calibrate new chemicals for testing dissolved oxygen and the conductivity meter. Also, monitors undergo an annual site audit by the Program Coordinator where values for dissolved oxygen, temperature and specific conductance obtained by the program manager are compared to the values obtained by the monitor. Monitors also perform a duplicate test for dissolved oxygen once each year. Dissolved oxygen and temperature values must be within +/- 1 mg/L or 1°C. Specific conductance readings must be within 5% of the calibration standard. All conductivity meters are calibrated with a known standard of 450 µS/cm prior to each measurement at the training and during field testing. Any errors in procedure are recorded on the project audit sheet and problems discussed and resolved with the volunteers.

Indicator	Units	Reporting Limit (RL)	Accuracy	Overall Precision (RPD)	Range of results expected[1]	Sampling Equipment
Weather, rain in last 48 hours, water color and water odor	NA	NA	NA	NA	NA	NA
Dissolved Oxygen	mg/L	0.2	+/- 1.0 mg/L	<20% (between field duplicate samples or readings)	0.0 - 15.0	LaMotte modified Winkler Titration Method Dissolved Oxygen Kit
Water Temperature	°C	0.0	+/- 1.0 °C	< 10% (between field duplicate samples or readings)	0.0 - 30.0	Envirosafe® Armored Thermometer
Velocity	ft/s	0	+/- 0.5 ft/s	< 20% (between field duplicate samples	0 - 4	Stop watch, floatable
Depth (Center Stream)	ft	0.0	+/- 0.1 ft	< 20% between two different readers for same location	0.0 - 10.0	Measuring tape with 5 lb. weight attached
Specific Conductivity	μS/cm	20	+/- 5% of known standard	<20% (between field duplicate samples or readings	50-1,500	Oakton Big Display Conductivity ECTestr Low or Oakton ECO Testr EC Low
Chloride	mg/L	4	+/- 1.2 mg/L	<20% (between field duplicate samples or readings)	0-200	LaMotte modified APHA Argentometric Method Titration Kit

Notes:
[1]The range of sample values expected during the course of sampling activities

Table 3: Parameter method detection limits, reporting limits and data quality objectives.

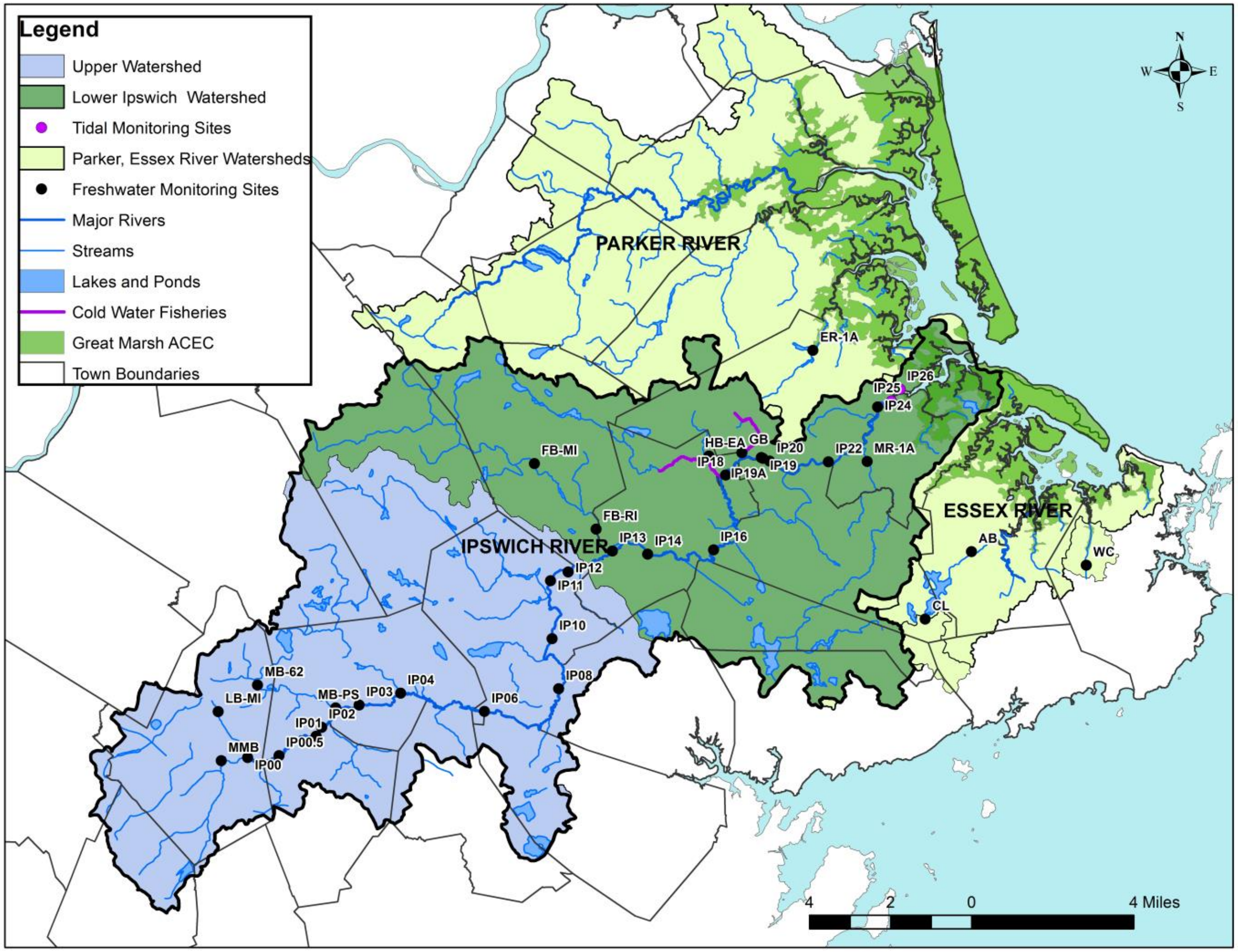

Figure 1. RiverWatch monitoring sites map.

Site ID	Watershed	Water Body	Station Description	Latitude	Longitude
LB-MI	Ipswich River	Lubbers Brook	Middlesex Ave., Wilmington	42.57028	-71.15797
MMB	Ipswich River	Maple Meadow Brook	Wildwood St., Wilmington	42.55276	-71.15662
IP00	Ipswich River	Ipswich River	Woburn St., Wilmington	42.55388	-71.14382
IP00.5	Ipswich River	Ipswich River	Reading Town Forest	42.55446	-71.12866
IP01	Ipswich River	Ipswich River	Mill St., Reading	42.56135	-71.11072
IP02	Ipswich River	Ipswich River	Main St., Reading/North Reading	42.56454	-71.10798
MB-62	Ipswich River	Ipswich River	Martins Brook, North Reading	42.57977	-71.13894
MB-PS	Ipswich River	Ipswich River	Park St., North Reading	42.57147	-71.10123
IP03	Ipswich River	Ipswich River	Central St., North Reading	42.57246	-71.08982
IP04	Ipswich River	Ipswich River	Washington St., North Reading	42.57659	-71.06977
IP06	Ipswich River	Ipswich River	Boston St., Middleton	42.56996	-71.02928
IP08	Ipswich River	Ipswich River	Log Bridge Rd., Middleton	42.57789	-70.99328
IP10	Ipswich River	Ipswich River	Maple St., Middleton	42.59577	-70.99637
IP11	Ipswich River	Ipswich River	Peabody St., Middleton	42.61649	-70.99693
IP12	Ipswich River	Ipswich River	Thunder Bridge, Middleton	42.61959	-70.98834
FB-MI	Ipswich River	Fish Brook	Middleton Rd., Boxford	42.65842	-71.00444
FB-RI	Ipswich River	Fish Brook	River Rd., Topsfield	42.6348	-70.97477
IP13	Ipswich River	Ipswich River	Rowley Bridge Rd., Topsfield	42.62696	-70.96694
IP14	Ipswich River	Ipswich River	Salem Rd., Topsfield	42.62576	-70.94984
IP16	Ipswich River	Ipswich River	Mass Audubon, IRWS Canoe Launch	42.62718	-70.91798
HB-EA	Ipswich River	Howlett Brook	East St., Topsfield	42.66071	-70.91992
IP18	Ipswich River	Ipswich River	Asbury Rd., Topsfield	42.65385	-70.91183
GB	Ipswich River	Gravelly Brook	Willowdale State Forest	42.66181	-70.90388
IP19A	Ipswich River	Ipswich River	100' Above Willowdale Dam, Ipswich	42.65999	-70.89451
IP19	Ipswich River	Ipswich River	Below Willowdale Dam, Ipswich	42.65975	-70.89379
IP20	Ipswich River	Ipswich River	Winthrop St., Ipswich	42.65874	-70.89051
IP22	Ipswich River	Ipswich River	Mill Rd., Ipswich	42.65829	-70.86208
MR-1A	Ipswich River	Miles River	Rt. 1A, Ipswich	42.65837	-70.84333
IP24	Ipswich River	Ipswich River	Ipswich Mills Dam, Ipswich	42.67777	-70.83806
IP25	Ipswich River	Ipswich River	Green St., Ipswich	42.67984	-70.83132
IP26	Ipswich River	Ipswich River	Town Landing, Ipswich	42.68401	-70.82708
ER-1A	Parker River	Egypt River	Rt. 1A, Ipswich	42.69818	-70.86919
AB	North Coastal	Alewife Brook	Apple St., Essex	42.62584	-70.79315
CL	North Coastal	Chebacco Lake Inlet	Chebacco Rd., Hamilton	42.60186	-70.81584
WC	North Coastal	Walker Creek	Forest Ln., Gloucester	42.62061	-70.7377

Table 4. RiverWatch monitoring site information.

Streamflow Monitoring

Having adequate amounts of flowing water is essential for the health of rivers and streams. The Ipswich River has a history of flow alterations from water withdrawals, particularly in the headwaters region of the watershed, so measuring streamflow is important to understanding low-flow impacts.

Two real-time streamflow gages are maintained by USGS on the Ipswich River in South Middleton and Ipswich that transmit real-time discharge data. These gages have recorded flow levels since the 1930's, as both a historical record of the river and vital source of real-time information needed to manage municipal water supplies. However, many sections of the river and streams in the watershed are not gaged.

Beginning in 2012, additional streamflow gages were added in partnership with MassDER to further document streamflow patterns. MassDER supports the River Instream Flow Stewards (RIFLS) program, which enables local groups to monitor streamflow as a way to investigate signs of flow alteration, with the goal of restoring more natural flow patterns. Three RIFLS monitoring gages were established where additional flow data would be beneficial: Martins Brook at Park St. in North Reading (MB-PS), the Ipswich River at Haverhill St. in North Reading (IP3.5). In November, 2014, a gage at Fish Brook, Mill Rd.m Boxford (FB-MR) was established. Volunteers read staff gages at these sites on a regular basis and enter data to the RIFLS website where it is converted to a streamflow value in cubic feet per second (cfs) from rating curves maintained by the RIFLS staff with MassDER. Water level data loggers were generously donated by the Nor'East Chapter of Trout Unlimited and installed at all the 3 RIFLS site locations and activated beginning in June 2014. Data loggers collect time series data on water pressure and temperature at 15 min. intervals that will allow for detailed analysis.

Analysis is conducted by downloading data from the RIFLS and USGS websites. Individual gage data are compared by converting mean daily streamflow values from cfs to cubic feet per second per square mile of drainage area for each gage (cfsm). Daily discharge values in cfsm can be compared relative to an ecological protection flow value determined by USGS for the entire watershed.

Section 3: Water Quality Results

3.1 Monthly RiverWatch Monitoring Results by Parameter

Temperature

In 2019, all samples met the Class B standard or Class SA standard for maximum water temperature. The Class B standard is a maximum of 28.5° Celsius (83°F); the Class SA standard is a maximum of 29.4° Celsius (85°F), and applies to the tidal sites of IP25 and IP26.

Temperature is an important measure of water quality, as temperatures higher than the natural observed range can reduce the amount of dissolved oxygen that the water can hold (more on dissolved oxygen in the next section). This can create a stressful environment for aquatic organisms. For example, some fish, like brook trout, cannot survive in warm water.

Annual Statistics

Table 5 is a summary of annual statistics for temperature. Temperature has exceeded the state standard only 5 times since 1997. This does not reflect the times the river has dried up and monitoring could not take place. Figure 2 is a comparison of average annual and maximum water temperature for 2019.

Year	# Samples (March-December)	Minimum (°C)	Maximum (°C)	Annual Average (°C) (March-December)	Summer Average (°C) (June-August)	# Samples Outside Class B, Class SA Standard	% Violations (% of samples not meeting standard)
1997	172	-4	31.0	11.6	20.9	2	1.2%
1998	227	1	26.0	14.5	21.2	0	0.0%
1999	257	0	28.0	13.7	22.9	0	0.0%
2000	247	0	25.0	13.1	20.5	0	0.0%
2001	236	-3	25.3	12.1	20.4	0	0.0%
2002	241	0	25.5	11.7	20.2	0	0.0%
2003	226	0	29.0	12.8	21.6	1	0.4%
2004	234	-2	25.0	12.2	20.2	0	0.0%
2005	237	-2.5	34.0	12.1	22.0	2	0.8%
2006	212	0	28.0	13.1	21.3	0	0.0%
2007	213	0	26.0	13.8	21.7	0	0.0%
2008	209	-1	29.0	13.1	21.2	1	0.5%
2009	202	0	24.0	14.2	19.2	0	0.0%
2010	217	0	27.5	14.7	22.5	0	0.0%
2011	224	0.5	26.0	12.8	20.6	0	0.0%
2012	266	0	30.0	14.2	22.2	1	0.4%
2013	234	1	26.0	14.7	21.8	0	0.0%
2014	274	0.5	26.0	13.3	21.7	0	0.0%
2015	244	0	26.0	13.7	21.0	0	0.0%
2016	260	0	28.0	13.8	22.7	0	0.0%
2017	279	0	25.2	14.5	20.6	0	0.0%
2018	290	0	27.0	13.1	21.4	0	0.0%
2019	305	0	26.0	13.1	13.8	0	0.0%
Entire Record	5506	-0.4	27.1	13.3	20.9	7.0	0.1%

Table 5: Annual temperature statistics.

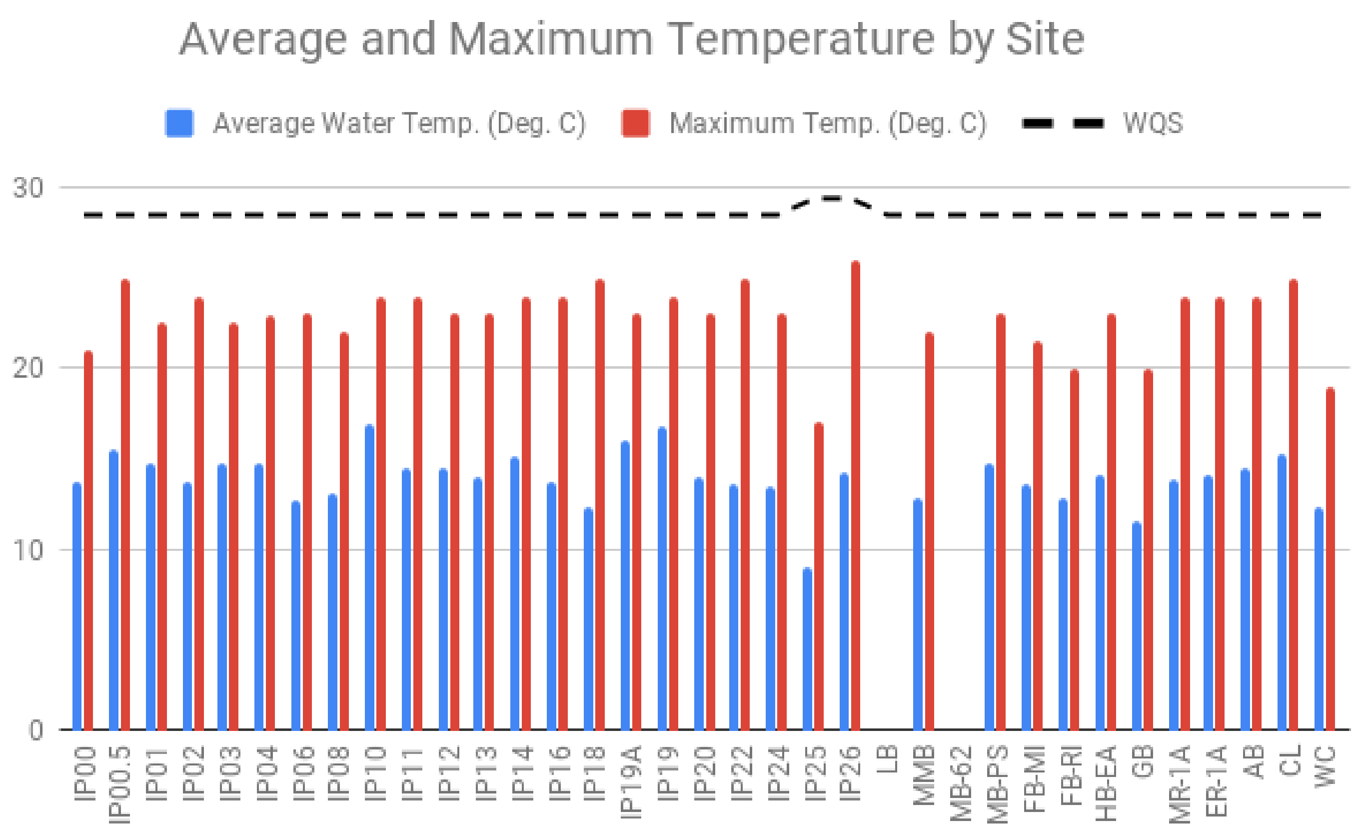

Figure 2: Maximum and average water temperatures, by site.

The dashed line indicates the maximum temperature for class B (28.5°C) and Class SA waters (29.4°C).

General Findings

Water temperature readings met state standards throughout 2019 across the watershed (i.e., temperatures remained below the state standard maximum temperature). It is important to note that recorded temperatures are conservative, as temperatures are not recorded when there is no water present in the river during extreme low flows. Also, monitoring is conducted in the morning, and may not represent the highest temperatures that occur in the course of that day or month.

Dissolved Oxygen

The amount of dissolved oxygen in water depends on numerous factors, including the temperature of the water and the gas exchange across the air-water interface. Dissolved oxygen can increase when water is at lower temperatures and in areas where there is turbulence in the water (e.g., riffles or rapids). Other primary factors affecting DO include oxygen production through photosynthesis and depletion through respiration and other oxygen-demanding processes. Dissolved oxygen changes on a diurnal basis as well as seasonally, and is affected by cloud cover and other weather conditions. The most critical time for organisms is in the early morning hours on hot summer days when water temperatures are high, flows are low and photosynthesis has ceased producing oxygen since sunset. The interactions of factors affecting DO in the natural environment are quite complex, and a full exploration of this topic warrants further investigation.

Sampling was conducted during morning hours because DO is typically lowest at or just after dawn, so morning sampling is likely to capture relatively low DO. Therefore the values observed generally represent a more stressed condition than if the values were mid-day or later.

For dissolved oxygen concentration, the Class B standard requires a minimum of 5.0 mg/L; the Class SA standard is a minimum of 6.0 mg/L DO, and applies to the tidal sites of IP25 and IP26. For dissolved oxygen percent of saturation, 60% is considered the minimum for good water quality in class B waters and 75% in class SA waters. The state of Massachusetts no longer uses the standard for percent of saturation; however, we continue to refer to this figure.

Table 6 (a and b) presents annual statistics for DO concentration and percent saturation for all sites monitored. The number of samples for percent saturation can differ from concentration if either a concentration or water temperature value is missing since it is calculated from both.

Annual Statistics

Year	# Samples (March-December)	Minimum (mg/L)	Maximum (mg/L)	Annual Average (mg/L) (March-December)	Summer Average (mg/L) (June-August)	# Samples Outside Class B, Class SA Standard	% Violations (% of samples not meeting standard). Average for entire record
1997	100	1.0	14.4	7.6	6.0	13	13%
1998	230	0.0	12.2	6.3	4.1	65	28%
1999	262	0.4	14.8	7.3	5.0	49	19%
2000	264	1.0	14.0	7.1	5.2	52	20%
2001	240	0.2	14.0	6.9	4.6	59	25%
2002	238	0.2	12.4	7.1	5.3	45	19%
2003	225	0.1	12.4	6.5	3.9	63	28%
2004	240	0.0	12.4	6.6	4.3	60	25%
2005	240	0.6	13.2	6.8	4.5	55	23%
2006	213	0.2	13.0	6.4	4.1	64	30%
2007	216	0.6	16.2	6.3	4.9	64	30%
2008	207	0.6	13.0	6.6	4.0	61	29%
2009	203	0.8	12.7	6.1	4.5	60	30%
2010	219	0.0	12.6	6.3	4.5	62	28%
2011	205	0.6	12.6	7.2	4.6	45	22%
2012	270	0.5	14.0	6.2	4.1	76	28%
2013	239	0.1	13.4	6.2	4.0	74	31%
2014	277	0.4	12.6	6.4	4.4	90	32%
2015	243	0.2	14.0	6.3	4.4	73	30%
2016	257	0.0	13.2	6.2	4.0	81	32%
2017	279	0.0	13.0	5.6	3.9	131	47%
2018	291	0.2	13.4	6.4	4.1	104	36%
2019	306	0.0	13.8	6.4	6.3	90	29%
Entire Record	5464	0.3	13.4	6.6	4.5	1536	27.5%

Table 6a. Annual statistics for dissolved oxygen concentration.

Year	# Samples (March-December)	Minimum	Maximum	Annual Average (March-December)	Summer Average (June-August)	# Samples Outside Class B, Class SA Standard	% Violations (% of samples not meeting standard)*
1997	89	7.8	122.6	66.0	67.6	27	30%
1998	224	0.0	101.2	59.2	45.7	103	46%
1999	249	4.4	101.7	67.7	58.1	78	31%
2000	239	11.7	112.9	64.1	56.7	92	38%
2001	214	2.2	105.5	61.1	51.8	95	44%
2002	231	2.1	119.7	63.8	58.6	90	39%
2003	217	0.7	99.2	58.9	43.7	99	46%
2004	229	0.0	97.4	59.1	47.4	102	45%
2005	227	6.7	115.9	59.9	50.9	104	46%
2006	209	2.4	117.9	58.2	45.4	105	50%
2007	207	6.2	123.6	59.0	54.6	102	49%
2008	197	6.5	104.0	58.7	45.1	90	46%
2009	199	9.1	112.5	58.1	48.3	98	49%
2010	216	0.0	94.6	59.0	51.8	99	46%
2011	203	6.9	115.5	64.9	51.3	79	39%
2012	262	5.7	98.5	57.7	46.1	143	55%
2013	234	1.2	110.0	58.5	45.7	113	48%
2014	274	0.0	100.4	57.9	49.9	139	51%
2015	240	0.0	105.5	57.4	49.6	111	46%
2016	252	0.0	106.9	55.9	45.4	136	54%
2017	277	0.0	114.4	52.1	42.6	170	61%
2018	290	2.3	107.8	57.4	46.2	154	53%
2019	296	0.0	110.4	57.6	55.5	144	49%
Entire Record	5275	3.3	108.6	59.7	50.4	2473	46%

Table 6b. Annual statistics for dissolved oxygen percent of saturation.

Note: In 2008, the State eliminated standards pertaining to DO% saturation. Numbers are presented for comparison with previous years and are based on the previous standard of 60% saturation for class B and 75% saturation for class SA waters.

In 2019, 29% of all samples taken by volunteers did not meet the combined state standards of 5 mg/L for class B and 6mg/L for class SA waters (100 of 290 samples). When calculating percent saturation of dissolved oxygen, 49% of these same samples fell below the combined standards of 60% saturation for class B and 75% saturation for class SA waters.

Low DO conditions have been widespread and frequent since monitoring began in 1997. for class B waters. Water has remained in the river year-round since the town of Reading converted to the MWRA water supply and discontinued use of groundwater wells in 2006, showing that reductions in water withdrawals and water restrictions by towns can have a beneficial effect on the Ipswich River.

Site Statistics

Low DO conditions have been widespread and frequent during the past 20 years of monitoring. In 2019:

- Summer averages (June, July, August) for 23 sites (out of 35) were less than 5.0 mg/L DO concentration. Eight sites had summer DO averages below 3.0 mg/L.
- Annual averages for 3 (out of 35) sites were less than 5.0 mg/L DO concentration.
- Twenty six sites out of 35 had a minimum DO concentration below 5.0 mg/L DO.
- 49% of the 296 samples for dissolved oxygen were below the standard for concentration (5 mg/L).

Figure 3 shows average and minimum dissolved oxygen concentration values for all sites in 2019.

The fact that DO levels were very low consistently over the past represents a significant impaired condition on the river, and indicates that many aquatic organisms are under high stress conditions. Many organisms may not likely survive during most summers.

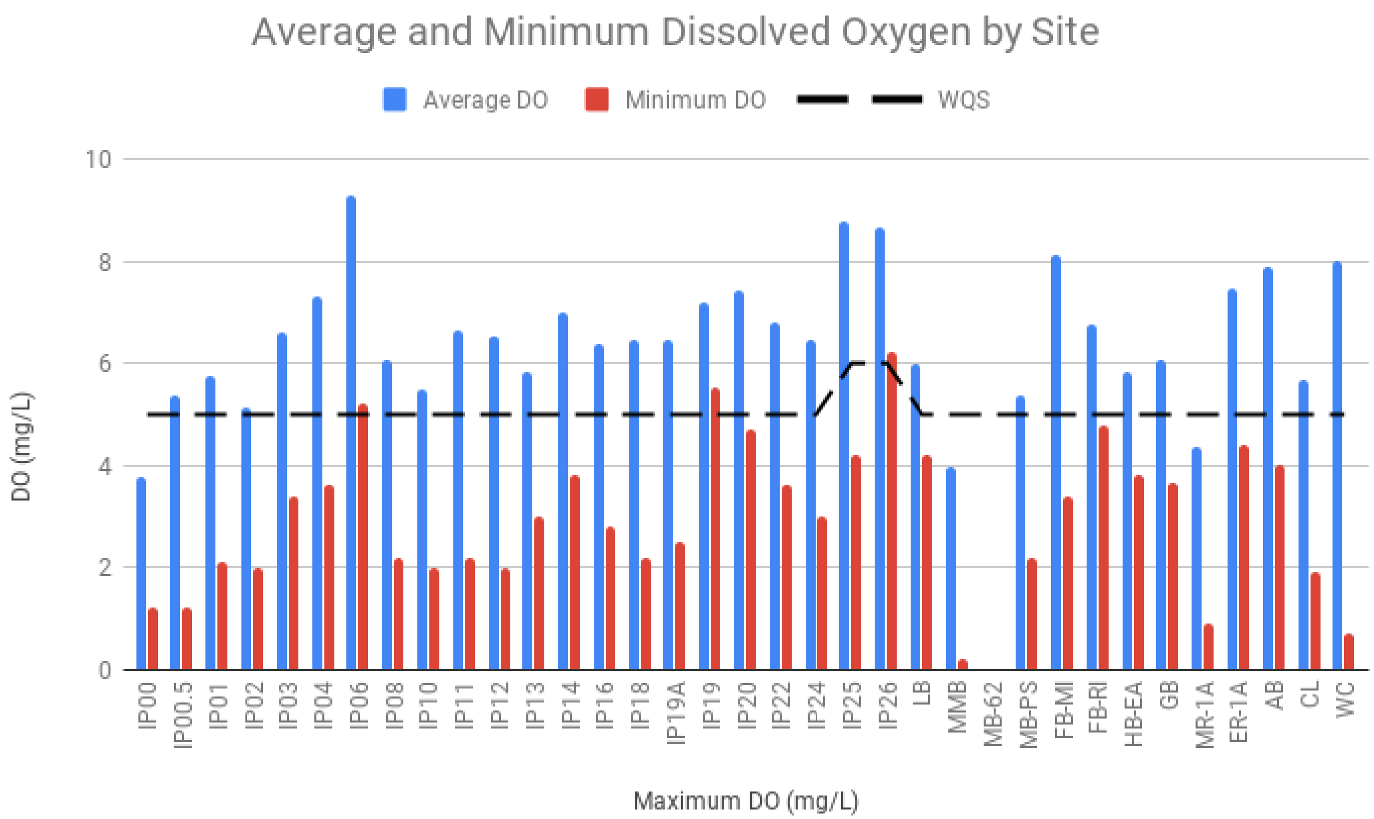

Figure 3. Average annual and minimum dissolved oxygen concentration for all sites.

The dashed line indicates the minimum standard for class B (5.0 mg/L) and class SA waters (6.0 mg/L).

Dissolved oxygen, percent of saturation is defined as the amount of oxygen that can be absorbed by water at a given temperature. Colder water can absorb more oxygen than warmer water. The Commonwealth of Massachusetts discontinued use of a water quality standard for dissolved oxygen, percent of saturation in 2008, but the data are presented here for comparison with dissolved oxygen concentration (mg/L) measurements and for comparison with previous years. The previously used standard of 60% (class B) and 75% (class SA) saturation can be used to confirm water oxygen depletion, particularly in the upper watershed. Most sites in the upper watershed did not achieve 60% saturation over the course of the year and especially in summer months when water temperatures are highest. Site statistics for dissolved oxygen, percent saturation are presented in table 5b and figure 4.

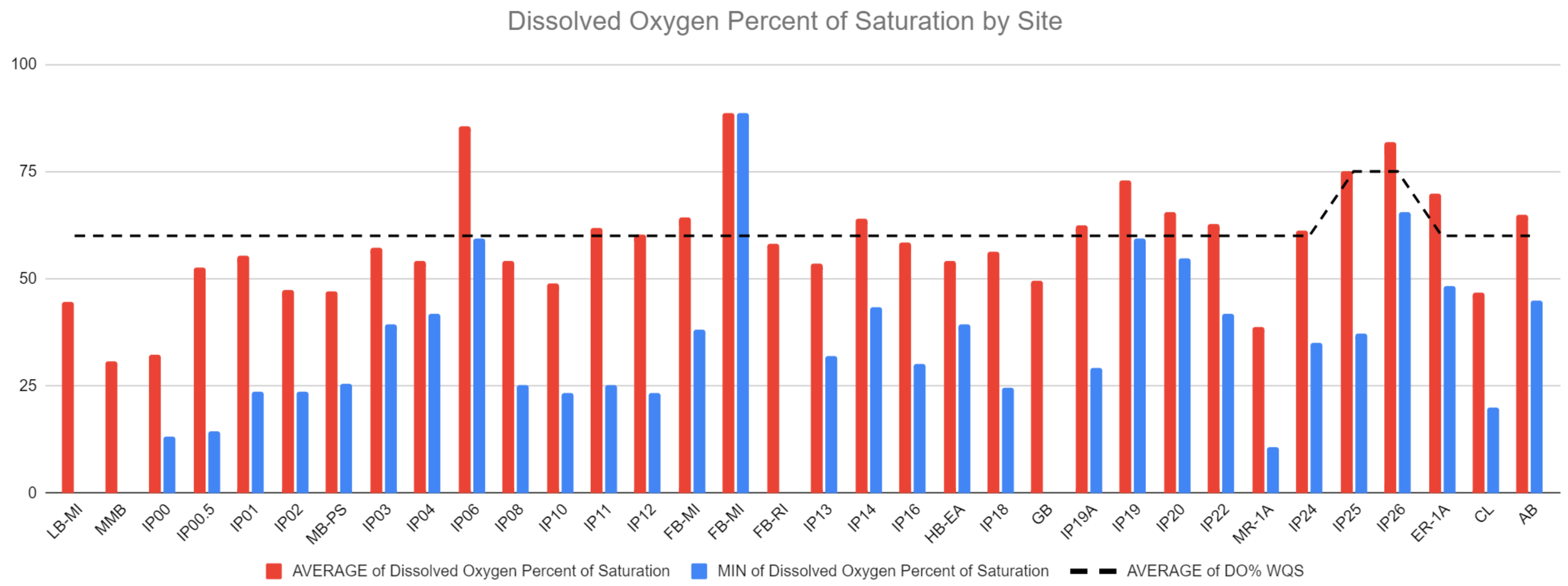

Figure 4: Average and minimum dissolved oxygen percent of saturation by site.

The dashed line represents the minimum standard for class B waters (60%) and class SA waters (75%). In 2008, the state discontinued use of the standard for dissolved oxygen percent saturation. Values are presented here for comparison with previous years.

General Findings

Dissolved oxygen (DO) is usually lowest at or shortly after dawn, and then increases during daylight hours. Sampling was conducted during morning hours, likely capturing lower DO than what occurs in the afternoon, and therefore the values observed represent the lower end of the daily DO fluctuation.

Frequent and prolonged low DO conditions represent a serious threat to aquatic organisms that are dependent on the river for survival. State standards represent a minimum condition that is protective of the health of aquatic organisms and the Ipswich River repeatedly and for extended periods of time does not meet those minimum standards. Fish kills were observed in 1995, 1997, 1999, 2002, and 2005.

Under natural conditions, DO varies considerably daily and seasonally, as well as in response to weather conditions and numerous other factors, so conclusively stating the causes of the extremely low DO documented on the Ipswich River is beyond the scope of this report. It might be expected that DO levels in the Ipswich River tend towards the lower end of that 5-10 mg/L healthy DO concentration range because of the relatively low gradient of the river and the presence of numerous wetlands and forest that contribute organic matter (like leaves) to the water. For example, sites IP08 and IP18 are both located downstream of wetlands. Both sites exhibit average summer DO levels lower than other surrounding sites (figures 6 and 7). However, the Ipswich River experiences DO levels that fall consistently lower than this natural range, and consistently lower than state standards for a healthy river.

A statistical investigation into the causes of low DO was conducted by IRWA in 2002, and indicated that variables most linked with DO levels are water temperature, river kilometer (how far upstream the site is), depth, and the previous 28-day rainfall amount (IRWA, 2002). While this study provides insight towards better understanding of variation in DO in the Ipswich River, there remain a number of unanswered questions warranting further study. For example: what is the role of these variables and their interactions on DO levels; what are the causes of the observed changes in these variables; what is the extent and health of wetlands adjacent to the river; and, how can management actions and behavioral changes alleviate low DO levels in the river?

Depth, Velocity and Streamflow

There must be enough flowing water in the river for fish and aquatic organisms to thrive. Low flows reduce the amount of habitat available and contribute to rising water temperatures and decreased oxygen levels. Depth, velocity and streamflow are measured Depth and velocity are measured as rough indicators of channel coverage and flow at individual sites. Because depth is measured from the middle of the channel at most sites, generally it is an optimistic indicator of depth across the channel, since drying will typically occur first at the channel margins. There are, however, occasions when flow is too high to accurately measure depth (or velocity), such as during flooding events. Conversely, velocity is a conservative indicator, since volunteers insert the floatable object only where there is noticeable current. Immeasurable velocities cannot be quantified. A summary of annual velocity and depth data is shown in table 7.

Water velocity is measured as an indicator of the amount of flow in the river. Monitors record the time it takes a floating object such as an orange peel to travel a known distance, usually the width of the bridge spanning the river or between two points along the bank. Only sites with a bridge or where it is convenient to do so will measure velocity. Water velocity is typically lowest in the headwaters of watershed where there is a low gradient to the river, tributaries and surrounding wetlands (figure 5). Site IP01 is located at a bridge where the channel width narrows, increasing water velocity during spring runoff events beyond what would be expected naturally. Water depth varies by site, time of year and data completeness, but is typically greatest during the October-March period (figure 6). The deepest location measured is at the bridge on Washington St. in North Reading.

Flow is an obvious and important measure of river health. Observations of a dry riverbed or very low flow associated with very small amounts of water in the river are indicative of a serious impairment. Unfortunately, numerous episodes of little or no flow have been documented for the Ipswich River.

Streamflow gages maintained by USGS have recorded regular episodes of extended extreme low flow events. “Extreme low flow” is defined by the USGS as discharge levels below a minimum summer “ecological protection flow” (Horsley and Witten 2002). This “ecological protection flow” is the minimum flow threshold that “provides adequate habitat for the protection of fisheries” (Ibid). The summer ecological protection threshold for the Ipswich River is 0.42 cubic feet per second per square mile (cfsm).

Percent of summer days (June-August) were compared for all flow monitoring gages, including the RIFLS gages. Daily average flows recorded by data loggers at the RIFLS gages allowed these sites to be included in the low flow analysis (figure 7).

Water Quality Parameter	Year	Number of Samples	Minimum	Maximim	Annual Average (March-December)	Summer Average (June-August)
Velocity (ft./sec)	1997	158	0.0	10.2	1.1	0.8
	1998	198	0.0	6.0	0.1	0.0
	1999	253	0.0	7.3	1.1	0.3
	2000	232	0.0	6.1	1.6	1.2
	2001	190	0.0	16.0	1.4	1.3
	2002	181	0.1	54.5	1.8	1.5
	2003	183	0.0	5.1	1.6	1.3
	2004	210	0.0	25.3	1.7	2.1
	2005	209	0.0	23.9	1.0	0.3
	2006	185	0.1	9.8	1.7	1.5
	2007	150	0.1	8.3	1.5	0.8
	2008	172	0.0	16.6	1.6	2.0
	2009	162	0.0	21.7	1.6	1.6
	2010	133	0.1	35.1	1.5	0.6
	2011	173	0.0	5.9	1.7	1.2
	2012	174	0.1	4.4	1.0	0.8
	2013	140	0.0	5.0	1.1	1.2
	2014	159	0.1	7.2	1.6	1.0
	2015	115	0.0	14.1	1.0	0.7
	2016	113	0.1	5.1	0.9	0.5
	2017	170	0.1	5.0	1.1	0.9
	2018	167	0.0	5.3	1.6	0.9
	2019	153	0.0	11.1	1.3	0.8
	Entire Record	3980	0.0	13.4	1.3	1.0
Depth (ft.)	1997	141	0.0	10	3.1	2.6
	1998	212	0.0	9	2.8	2.9
	1999	248	0.0	8	2.3	1.6
	2000	241	0.0	11	2.9	2.4
	2001	219	0.0	22	2.6	2.1
	2002	223	0.0	9	2.7	1.8
	2003	198	0.0	9	3.1	2.5
	2004	209	0.5	10	3.3	3.1
	2005	200	0.0	9	3.0	2.2
	2006	192	0.4	11	3.6	3.1
	2007	189	0.1	11	3.3	2.5
	2008	192	0.4	10	3.4	3.4
	2009	177	0.5	11	3.3	3.5
	2010	186	0.1	9	2.8	2.1
	2011	204	0.2	9	3.4	2.7
	2012	237	0.2	6	2.4	2.1
	2013	190	0.0	19	3.0	2.7
	2014	211	0.1	15	3.1	2.1
	2015	187	0.1	8	2.6	2.4
	2016	198	0.0	7	2.6	2.0
	2017	224	0.1	15	3.0	2.7
	2018	210	0.4	11	3.6	2.7
	2019	311	0.0	11	3.1	2.9
	Entire Record	4799	0.1	10.8	3.0	2.5

Table 7. Annual statistics for water velocity and depth data.

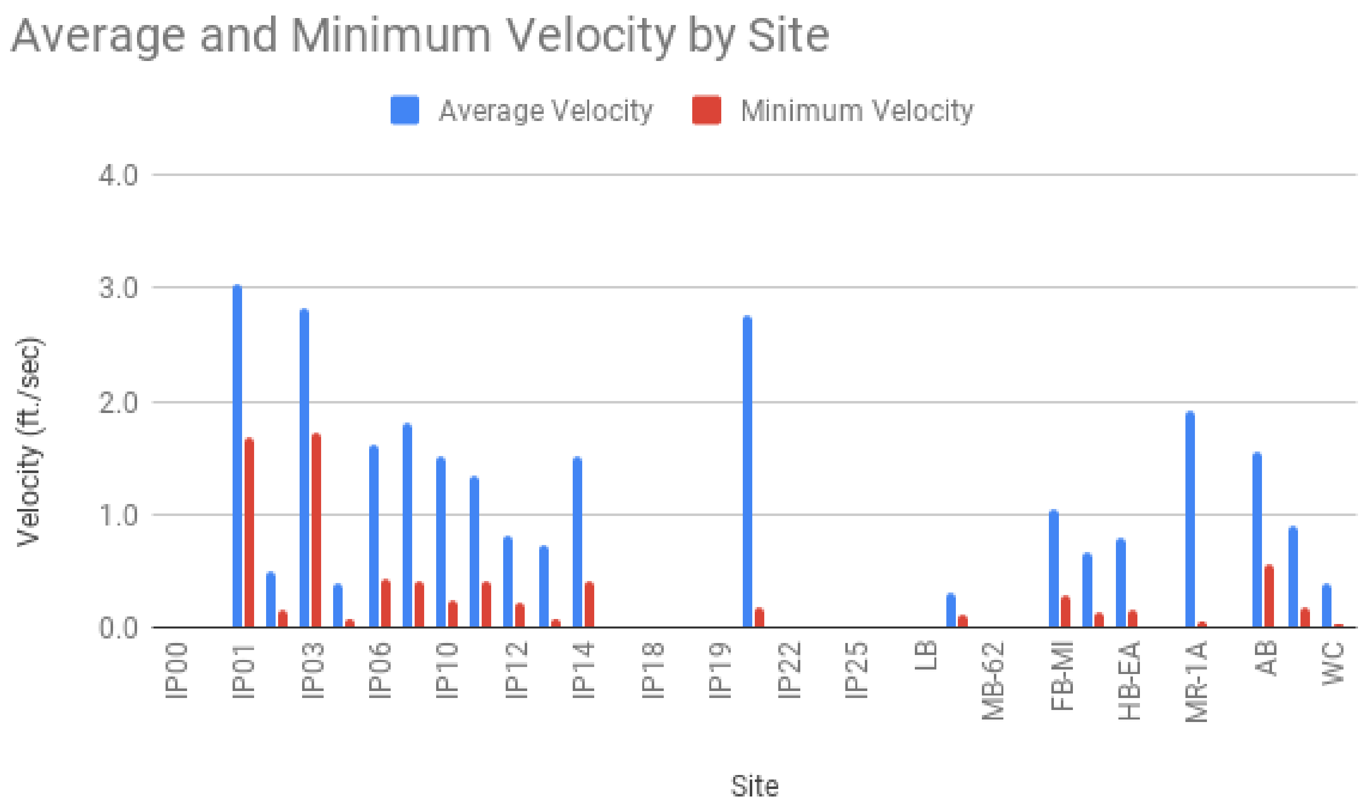

Figure 5: Average annual, summer and winter water velocity by site.

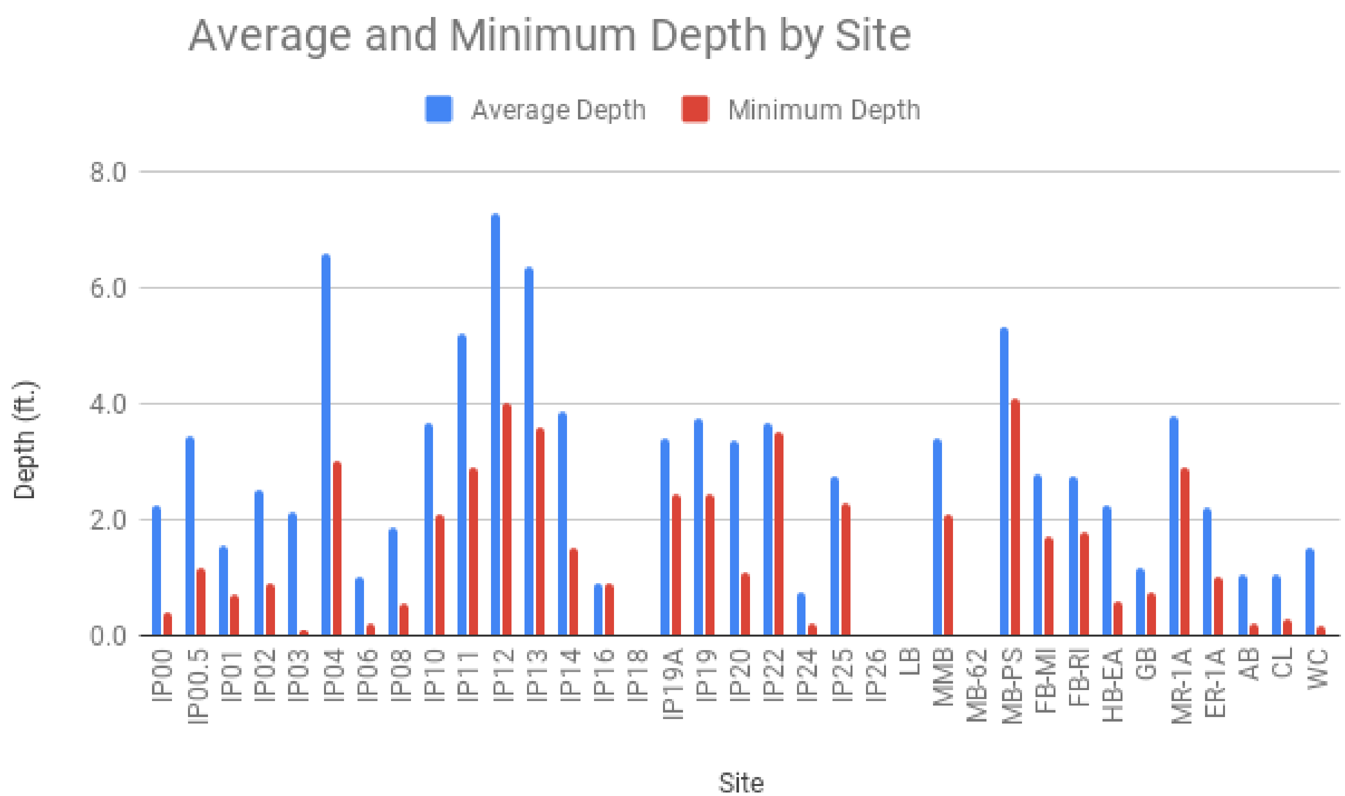

Figure 6: Average annual, spring and summer water depths by site.

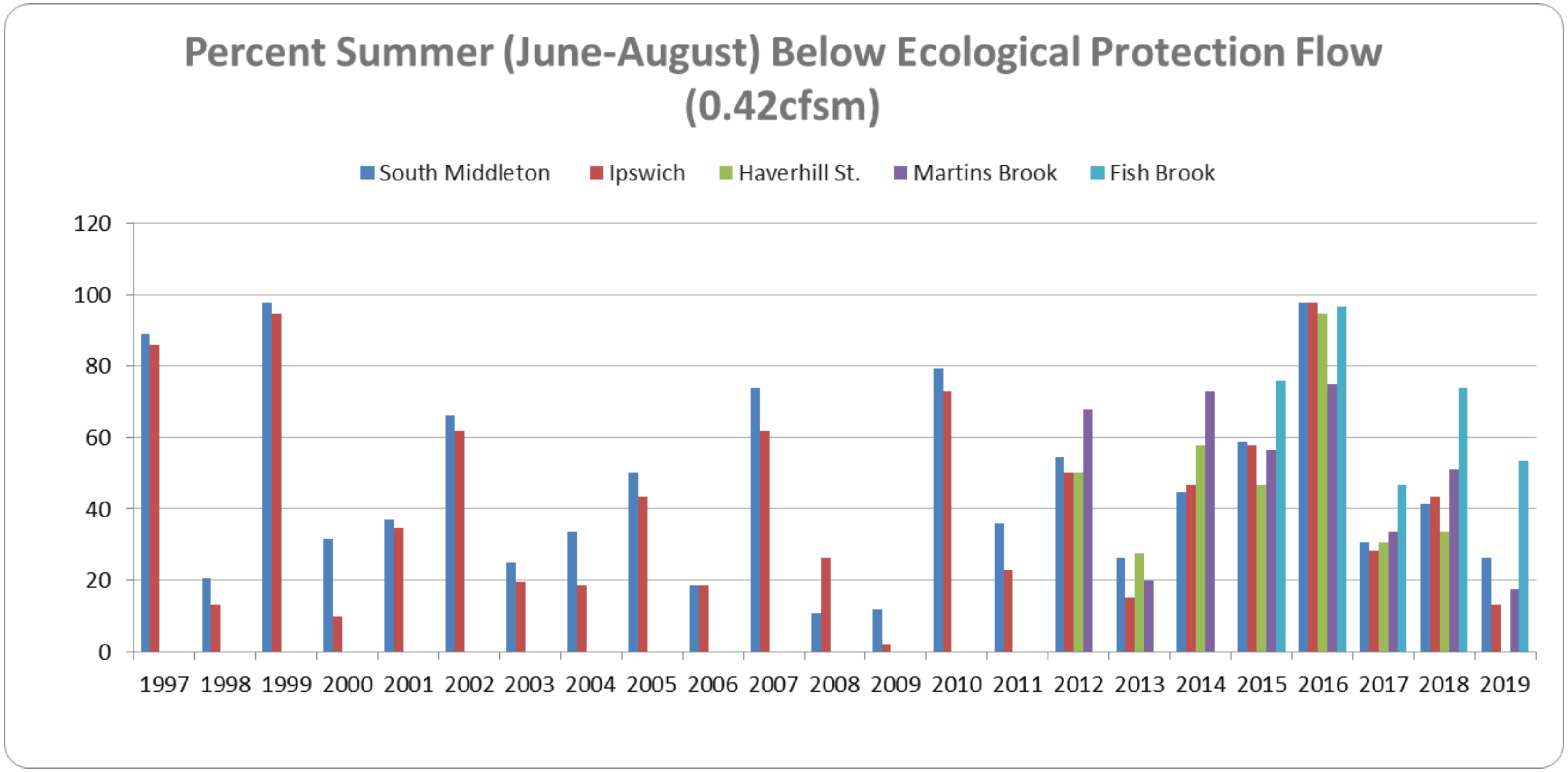

Figure 7. Percent average summer streamflow below ecological protection threshold (0.42 cfsm).

General Findings

Withdrawals for drinking water are the primary cause of unnaturally low flows in the Ipswich River (Armstrong 2001, Zarrielo and Ries 2000). While it might be expected that low flows occur seasonally, the low flows observed in the Ipswich River are about 10% of what might be considered “natural.” Due to low flows, the Ipswich River is classified as highly stressed by the MA Water Resources Commission (2001) and impaired under section 303(d) of the Clean Water Act.

Flow monitoring data indicate that fluctuations and differences in flows are more pronounced below the established threshold of 0.42 cfsm. Further analysis is needed to determine the exact role that groundwater withdrawals and land cover may have in causing the observed changes. Having access to continuous data at the RIFLS gages will also be important to determine the statistical significance of the observed trends. Water level loggers will continue to be used at the RIFLS sites on Martins Brook, Ipswich River at Haverhill St. and Fish Brook.

Specific Conductance

Specific conductance (conductivity at 25°C) measures the ability of water to pass an electrical current resulting from the presence of dissolved solids (or salts) such as chloride, sulfate, sodium and calcium, among others. Many factors can affect specific conductance including local geology, rainfall, low flows and salt water concentrations in tidal areas. Most streams have a fairly constant range under normal circumstances. Therefore, significant changes can be an indicator that a discharge or some other source of pollution has entered the water. According to the EPA, the specific conductance of rivers in the United States generally ranges from 50 to 1500 µS/cm (micro Siemens per centimeter). Rivers that can support healthy fisheries should be in the range of 150 to 500 µS/cm.

Conductivity was measured at 22 sites in 2019 (Table 8 and Figure 8). Tributary sites may be expected to vary more than sites on the mainstem of the Ipswich River, so all 10 tributary sites were selected for this parameter, with 12 out of 23 sites selected to be representative of conditions on the mainstem of the Ipswich River.

Year	# Samples (March-December)	Minimum (µS/cm)	Maximum (µS/cm)	Annual Average (March-December) (µS/cm)	Summer Average (June-August)	# Samples > 500µS/cm	% Samples Exceeding Water Quality Recommendations
2008	28	150	517	352	319	4	14.3%
2009							
2010							
2011	37	180	620	395	414	5	13.5%
2012	79	170	610	424	454	14	17.7%
2013	79	200	840	469	425	37	46.8%
2014	102	200	770	472	538	47	46.1%
2015	93	360	880	593	860	69	74.2%
2016	97	150	999	648	679	77	79.4%
2017	152	190	999	545	513	94	61.8%
2018	180	150	910	502	550	83	46.1%

Table 8: Annual statistics for specific conductance.

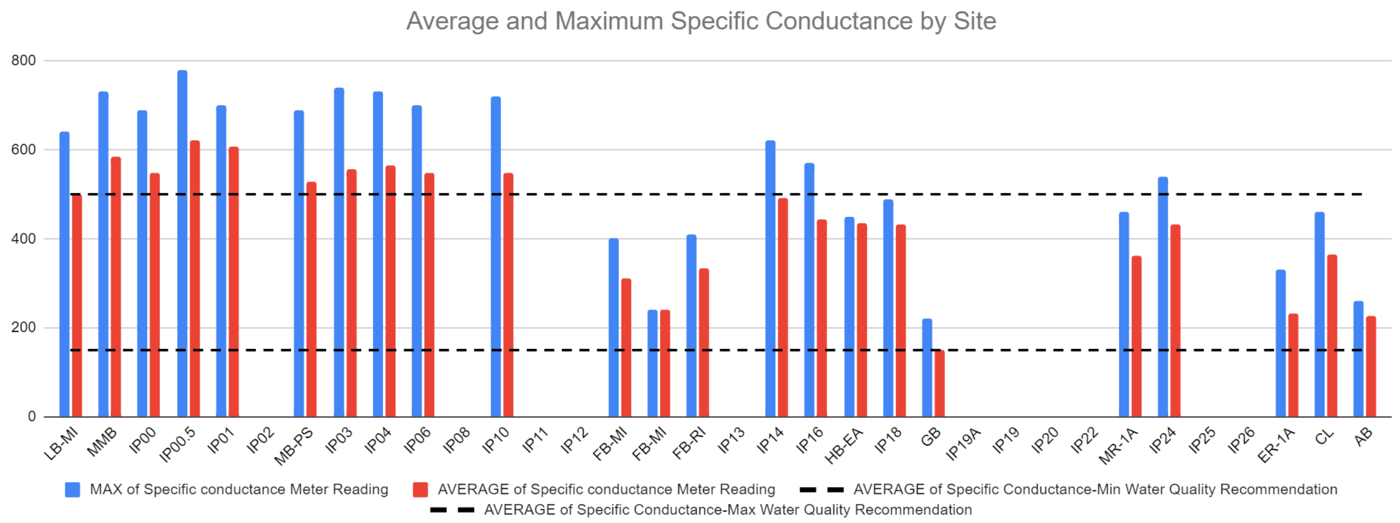

Figure 8. Average and maximum specific conductance by site.

The conductivity range considered suitable for healthy fisheries is < 500 µS/cm (micro Siemens per centimeter).

General Findings

Specific conductance readings are frequently elevated above 500 µS/cm. Studies have demonstrated a high influx of road salt to wetlands and wellfields in the Ipswich River watershed in areas adjacent to major highways following road applications in winter (Heath, et al., 2012). Elevated readings are observed in the headwaters region of the watershed where there are more impervious surfaces including major highways that are treated with road-salt. Tributary sites show more variability compared to sites on the mainstem of the Ipswich River most likely due to different land use patterns associated with tributary sub-watersheds. Levels decrease slightly among sites further downstream along the mainstem of the river. Some seasonal variability of conductivity is observed, but it is modest and there is no consistent pattern. Continuing to monitor specific conductance will be important to establish baseline trends and resolve underlying regional or seasonal differences.

Color and Odor

The Ipswich River is a tea-like color naturally. This color is due primarily to dissolved organic carbon (e.g., tannins from leaves and plants). There is a lot of dissolved organic carbon in the Ipswich River due to the wetlands that drain into the river throughout the watershed.

Each month monitors noted the color and odor of the river on their data sheets in order to track changes or events where color changed significantly. Color was measured on a scale of clear, very light tea, light tea), tea, and dark tea. If a particular odor was noticed, this was noted on the data sheet. Most colors noted were in the very light tea to light tea range. The river tended to be a light tea throughout the year.

Darker colors (tea to dark tea) were typically recorded in the summer months (July – August or September) and so may be associated with lower flow periods. However, in general it seems that there is no clear relationship between darker color and higher flow periods. Some sites were darker when it rained, some sites were variable, and some were lighter. It does seem, however, that darker colors are prevalent during summer months, and particularly associated with lower flows.

3.2 River Health Index

A River Health Index can evaluate long-term and recent data on water quality, water quantity, habitat, and human impacts in the Ipswich River watershed. The River Health Index is designed to compare measured conditions with optimal habitat conditions for native fish (based on published tolerances) at the sampling sites over the range of conditions during the year. Conditions accounted for include dissolved oxygen, water temperature and streamflow.

The river health index score is adapted from the work of OARS (Organization for the Assabet, Sudbury and Concord Rivers). Dissolved oxygen and temperature data are scored against published fish tolerances and Massachusetts surface water quality standards. Temperature data are evaluated against the warm water fishery standard except for Howlett Brook and Gravelly Brook which are designated as cold-water fisheries. See Appendix A for the scoring criteria and regression equation used to calculate individual scores.

The River Health Index focuses on habitat conditions for native fish. Subindices for dissolved oxygen and water temperature are calculated from measurements that are scored against published fish tolerances needed to support native fish. The subindex for streamflow is based on minimum streamflow recommendations needed to support suitable habitat conditions for fish in the Ipswich River as determined by USGS. Each parameter is scored on a scale from 1 (worst) to 100 (best) (table 8). These three index scores are combined into an overall “Stream Health” index by calculating the harmonic mean from the three subindices. Index scores are broken into five ranges and each range is given a grade and descriptor. Results for dissolved oxygen and temperature are combined by area of the watershed into two groups: upper and lower watershed, corresponding to the USGS South Middleton and Ipswich gages, respectively. Sites that are tidal are considered separate, as are the sites in the Essex watershed as well as the Egypt River (figure 9). Upper and lower sections consist of 14 and 15 sites, respectively. There are two tidal sites and three sites in the Essex watershed. Composite scores for dissolved oxygen and temperature subindices are averaged by month for each region. Average monthly streamflow data for the South Middleton and Ipswich gages are combined with each section corresponding to the upper Ipswich (South Middleton gage) and lower Ipswich (Ipswich gage). The tidal sites, Essex watershed sites and Egypt River site are scored based only on dissolved oxygen and temperature results.

The dissolved oxygen subindex is based on published fish tolerances (Oregon DEQ 1995), the Massachusetts Water Quality Standards (MassDEP, 2013), EPA recommended criteria (EPA, 1986) and EPA Ecoregion XIV subecoregion 59 data.

The temperature subindex is based on published fish tolerances (Oregon DEQ 1995, McCullough, 1999, McCullough et. al., 2001), the Massachusetts Water Quality Standards (MassDEP, 2013), and EPA recommended criteria (EPA 1986). Separate curves are drawn for cold-water and warmwater fisheries.

The streamflow subindices for the upper and lower Ipswich River were developed using data from three measures of streamflow—Tennant, R2Cross, and Wetted Perimeter—and calculations of theoretical natural-flow 7Q10 and August median flows using USGS’s StreamStats program.

A Tennant method analysis, which sets recommended flows based on analysis of long-term flow records, was conducted on the combined long-term records of two USGS streamgaging stations in the Ipswich watershed (Armstrong, *et. al*, 2001). During summer low-flow periods, minimum streamflows are defined as 40, 30, and 10 percent of the mean annual discharge (QMA); these streamflows create “good,” “fair,” and “poor” habitat conditions, respectively, according to Tennant (1976). R2Cross and Wetted Perimeter are standard-setting methods based on site-specific physical and hydraulic data.

Table 9 shows the calculated scores based on dissolved oxygen, temperature and streamflow used to calculate a score from data collected by volunteers through the monthly RiverWatch water quality monitoring program and USGS streamflow gages.

River Health Index Scale			
Index Category	**Index Score Ranges**	**Min**	**Max**
Excellent	**81-100**	**81**	**100**
Good	**61-80**	**61**	**80**
Fair	**41-60**	**41**	**60**
Poor	**21-40**	**21**	**40**
Very Poor	**0-20**	**0**	**20**

Table 9. Scoring criteria for the River Health Index

2019 River Health Index					
Month	**Upper Ipswich**	**Lower Ipswich**	**Tidal***	**Egypt River***	**Essex Watershed***
January	95	96			
February	99	100			94
March	91	93	97	100	100
April	92	92	95	91	93
May	80	84	83	80	77
June	42	54	50	41	36
July	39	52	15	33	25
August	47	59	50	48	55
September	31	39	65	57	61
October	62	65	79	88	81
November	97	99	100	100	92
December	99	99	99	99	99

Table 10. Health Index Scores in for sections by month.

Interpretation Range

80-100%: All water quality indicators meet desired levels. Quality of water in these locations tends to be very good, most often leading to preferred habitat conditions for aquatic life.

60- 80%: Most water quality indicators meet desired levels. Quality of water in these locations tends to be good, often leading to acceptable habitat conditions for aquatic life.

40–60%: There is a mix of good and poor levels of water quality indicators. Quality of water in these locations tends to be fair, leading to sufficient habitat conditions for aquatic life.

20–40%: Some or few water quality indicators meet desired levels. Quality of water in these locations tends to be poor, often leading to degraded habitat conditions for aquatic life.

0–20%: Very few or no water quality indicators meet desired levels. Quality of water in these locations tends to be very poor, most often leading to unacceptable habitat conditions for aquatic life.

Recommendations

Streamflow restoration will not only benefit water quantity and flow issues, but also habitat for native fish such as brook trout as well as anadromous fish like river herring. Repairing of fish ladders, dam removal and herring restocking will not only directly contribute also restore anadromous fish habitat to the entire upper watershed.

Compliance with water withdrawal permits and registrations should continue to be monitored.

Monitoring of aquatic life use conditions using macroinvertebrates as indicators should continue to be tracked through routine.

Monitoring of chlorides should be continued to better understand the impact of road salt on water quality.

Monitor bacteria levels to assess the status of the primary and secondary contact recreation uses. Bacteria sampling should also bracket potential nonpoint sources including agricultural and other potential land use sources.

Monitor target fish communities periodically to assess the impacts of restoration efforts.

Prevent the spread of non-native, invasive aquatic plants through monitoring, education and outreach.

Continue with stream cleanups, crossing signs and maintaining landings and navigation to encourage recreational opportunities on the river.

Ways You can Help

Water conservation on the part of individuals continues to be an important part of water management. While conserving water indoors is important, outdoor water use drives demand in the summer months, when the river most needs it.

Turn off your sprinklers. Grass only needs about 1" of water per week, which it will usually get from rainfall even during drier months. You can also switch to fescue grass, a native drought-tolerant variety that not only doesn't need watering, but comes in varieties that rarely ever need mowing.

Install a rain barrel to collect run-off from your roof to be used in outdoor watering during dry conditions.

Recharge groundwater by replacing lawn with shrubs, trees and native perennials. They create shade, habitat for wildlife and are low maintenance.

Use permeable pavers/pavement for walkways, driveways and parking areas. Leaving even a half inch between paving stones creates space for water to be absorbed into the ground.

Install a dry well or rain garden to let that water more quickly enter the ground.

3.3 Quality Assurance/Quality Control

Quality Assurance Project Plan (QAPP)

A formal Quality Assurance Project Plan (QAPP) for 2019-2021 was updated and approved in 2020 for the RiverWatch Program by the Department of Environmental Protection (DEP) and the Office of Coastal Zone Management (CZM). New sites were added in the Essex watershed and chloride testing is included.

Table 11 shows results for dissolved oxygen, temperature and specific conductivity calibration values at the annual training with 25 out of 35 sites in attendance. The dissolved oxygen meter with temperature was calibrated at air saturation and used to generate the calibration standard values for dissolved oxygen and temperature whereas the volunteers use Winkler Titration kits and field thermometers. Chemicals for dissolved oxygen kits are replaced annually and thermometers are replaced on an as-needed basis. Volunteers tested a sample of river water from a source bucket with one designated for dissolved oxygen and another for temperature and conductivity. The titration procedure was reviewed where there was an inconsistency. All readings for temperature, dissolved oxygen and conductivity readings were within data quality objectives.

Comparison of program manager site audit DO, temperature and conductivity readings are presented in tables 11 and 12. Field duplicates are performed by first calibrating the dissolved oxygen meter at air saturation and taking a reading from either the bucket grab sample or stream depending on where the volunteer fills the sample bottle for the Winkler Titration procedure. For 2019, 25 out of 31 monitors (three teams cover two sites) were audited for dissolved oxygen and temperature. For conductivity, 10 out of 20 sites reporting data were audited. This was due to a malfunctioning meter for part of the year that had to be replaced. Data quality objectives of field duplicates were met for 100% of audited sites for temperature, 79% of audited sites for dissolved oxygen and 80% of audited sites for specific conductance. Where exceedances were observed, problems were identified and recommendations made on procedures, in particular, making sure to eliminate air bubbles in the titrator syringe or to avoid air bubbles when filling the sample bottle.

Training 3/16/19															
	Temperature					Dissolved Oxygen					Conductivity				
Site	Monitor Calibration Temp. (°C)	Program Calibration Temp. (°C)	Difference Monitor, Calibration Temp. (°C)	Relative Percent Difference	Acceptable (Y/N)	Monitor Calibration DO (mg/L)	Program Calibration DO (mg/L)	Difference Monitor, Calibration DO (mg/L)	Relative Percent Difference	Acceptable (Y/N)	Monitor Calibration Conductivity (µS/cm)	Program Calibration Conductivity (µS/cm)	Difference Monitor, Auditor Conductivity (µS/cm)	Relative Percent Difference	Acceptable (Y/N)
IP00/MMB	10	10	0	0	Y	9.2	9	0.2	2.2	Y	620	640	20	3.2	Y
IP00.5	13	12	1	8	Y	9.2	9	0.2	2.2	Y	650	640	10	1.6	Y
IP01	13.5	12	1.5	11.8	Y	9.4	9	0.4	4.3	Y	690	640	50	7.5	Y
IP02	10	10	0	0	Y	9.4	9	0.4	4.3	Y					
IP03/MB-PS	11	10	1	9.5	Y	9.8	9	0.8	8.5	Y	640	640	0	0	Y
IP04	11	10	1	9.5	Y	9	9	0	0	Y	630	640	10	1.6	Y
IP06	11.5	12	0.5	4.3	Y	8.6	8.7	0.1	1.2	Y	380	380	0	0	Y
IP08															
IP10	11	10	1	9.5	Y	9.4	9	0.4	4.3	Y	640	640	0	0	Y
IP11	12	12	0	0	Y	10	9	1	10.5	Y					
IP12	10.5	10	0.5	4.9	Y	9	9	0	0	Y					
IP13	10	10	0	0	Y	9.2	9	0.2	2.2	Y					
IP14	11	10	1	9.5	Y	10	9	1	10.5	Y	630	640	10	1.6	Y
IP16	12	12	0	0	Y	10	9	1	10.5	Y	640	640	0	0	Y
IP18	11	10	1	9.5	Y	9.8	9	0.8	8.5	Y	650	640	10	1.6	Y
IP19/19A															
IP20	10	10	0	0	Y	9.3	9	0.3	3.3	Y					
IP22	11	11	0	0	Y	9.2	9	0.2	2.2	Y					
IP24															
IP25															
IP26	11	10	1	9.5	Y	9	9	0	0	Y					
LB-MI	11	10	1	9.5	Y	10	9	1	10.5	Y	640	640	0	0	Y
MB-62															
FB-MI	11	10	1	9.5	Y	9	9	0	0	Y	650	640	10	1.6	Y
FB-RI															
HB-EA	10	10	0	0	Y	8.5	9	0.5	5.7	Y	550	640	90	15.1	Y
GB															
MR-1A															
ER-1A	11	10	1	9.5	Y	8.2	9	0.8	9.3	Y	690	640	50	7.5	Y
AB	11	10	1	9.5	Y	9	9	0	0	Y					
CL															
WC	13	12	1	8	Y	9	9	0	0	Y	650	640	10	1.6	
Fill-In Monitor	13	12.6	0.4	3.1	Y	7	8	1	13.3	Y	320	310	10	3.2	

Table 11. Volunteer training calibration records.

Site Audits																
	Temperature						Dissolved Oxygen					Conductivity				
Site	Date	Monitor Value	Audit Value	Difference	Relative Percent Difference	Acceptable (Y/N)	Monitor Value	Audit Value	Difference	Relative Percent Difference	Acceptable (Y/N)	Monitor Value	Audit Value	Difference	Relative Percent Difference	Acceptable (Y/N)
IP00/MMB	7/28/2019	21	22	1	4.7	Y	1.4	1.8	0.4	25	N	510	500	10	2	Y
IP00.5	12/15/2019	2	1.8	0.2	10.5	Y	7.9	7.8	0.1	1.3	Y	620	570	50	8.4	Y
IP01	6/30/2019	22.5	22.6	0.1	0.4	Y	2.2	2.4	0.2	8.7	Y					
IP02	7/28/2019	24	22	2	8.7	Y	2	2.3	0.3	14	Y					
IP03/MB-PS	7/29/2019	20	23	3	14	Y	5	3.3	1.7	41	N	660	490	170	29.6	N
IP04	6/30/2019	23	23	0	0	Y	3.9	4.2	0.3	7.4	Y	542	510	32	6.1	Y
IP06	6/30/2019	23	23	0	0	Y	7.4	7.3	0.1	1.4	Y	520	490	30	5.9	Y
IP08	6/30/2019	22	23	1	4.4	Y	3	3.9	0.9	26.1	N					
IP10	8/25/2019	22	22	0	0	Y	5.2	5.2	0	0	Y	670	680	10	1.5	Y
IP11	8/25/2019	20	22	2	9.5	Y	5.6	4.8	0.8	15.4	Y					
IP12	8/25/2019	23	23	0	0	Y	5.7	6.4	0.7	11.6	Y					
IP13	10/27/2019	11	11.4	0.4	3.6	Y	5.6	6.5	0.9	14.9	Y					
IP14	9/29/2019	17	17.5	0.5	2.9	Y	4.8	5	0.2	4.1	Y					
IP16	9/29/2019	19	19.5	0.5	2.6	Y	2.8	4	1.2	35.3	N					
IP18																
IP19/19A	4/28/2019	10	10	0	0	Y	7.5	8.4	0.9	11.3	Y					
IP20	9/27/2019	10.5	11.4	0.9	8.2	Y	7.5	8.6	1.1	13.7	Y					
IP22	10/27/2019	11.5	11.9	0.4	3.4	Y	8	8.7	0.7	8.4	Y					
IP24	4/28/2019	11	10.5	0.5	4.7	Y	4	6	2	40	N	340	310	30	9.2	Y
IP25	11/17/2019	1	1	0	0	Y	12.2	13	0.8	6.3	Y					
IP26	11/17/2019	1	1	0	0	Y	13.4	13	0.4	3	Y					
LB-MI																
MB-62																
FB-MI	8/25/2019	16	17	1	6.1	Y	5.9	8.3	2.4	33.8	N					
FB-RI	8/25/2019	18.5	18.5	0	0	Y	5.9	4.9	1	18.5	Y	330	330	0	0	Y
HB-EA	10/27/2019	13	11	2	16.7	Y	4.2	5.5	1.3	26.8	N	430	330	100	26.3	N
GB	10/27/2019	9	10	1	10.5	Y	7.4	8	0.6	7.8	Y					
MR-1A	4/28/2019	11	11.5	0.5	4.4	Y	7.2	8.2	1	13	Y	260	240	20	8	Y
ER-1A																
AB																
CL																
WC																
Fill-In Monitor	9/29/2019	18	19	1	5.4	Y	3.2	3.8	0.6	17.1	Y	560	540	20	3.6	Y

Table 12. Program Coordinator site audit records.

Table 9. Monitor field duplicate dissolved oxygen measurements.

Volunteer Qualifications

Volunteer quality assurance is maintained in the following ways:
Volunteers attend one training annually, led by the Monitoring Coordinator. The training includes a review of all procedures in the RiverWatch Monitoring Manual and a discussion of any changes. In addition, the previous year's data are presented, calibrations conducted, and QA/QC standards discussed.

Monitors are audited at their sampling site once per year.

Volunteers take duplicate samples at their site once per year, and equipment, data analysis and data control are held to QA/QC standards to the maximum extent possible.

Completeness

Table 10, below, summarizes the completeness of data collection through 2019. Completeness is calculated as the number of samples taken in a year divided by the maximum number of samples it was possible to collect during that year. Our goal is to collect at least 80% of the total number of samples possible, and that goal was met for every year except 2003 and 2010. However, there is excellent completeness for all other years of monitoring, indicating the strength of volunteer commitment. In 2009, the bridge at site IP18 was out for construction, so monitoring was not possible at that site for six months.

Year	Completeness	Year	Completeness
1997	86%	2009	78%
1998	90%	2010	73%
1999	92%	2011	85%
2000	89%	2012	87%
2001	83%	2013	82%
2002	89%	2014	87%
2003	76%	2015	86%
2004	81%	2016	88%
2005	88%	2017	91%
2006	91%	2018	92%
2007	82%	2019	87%
2008	83%		

Table 13: Percent of Samples Collected per year.

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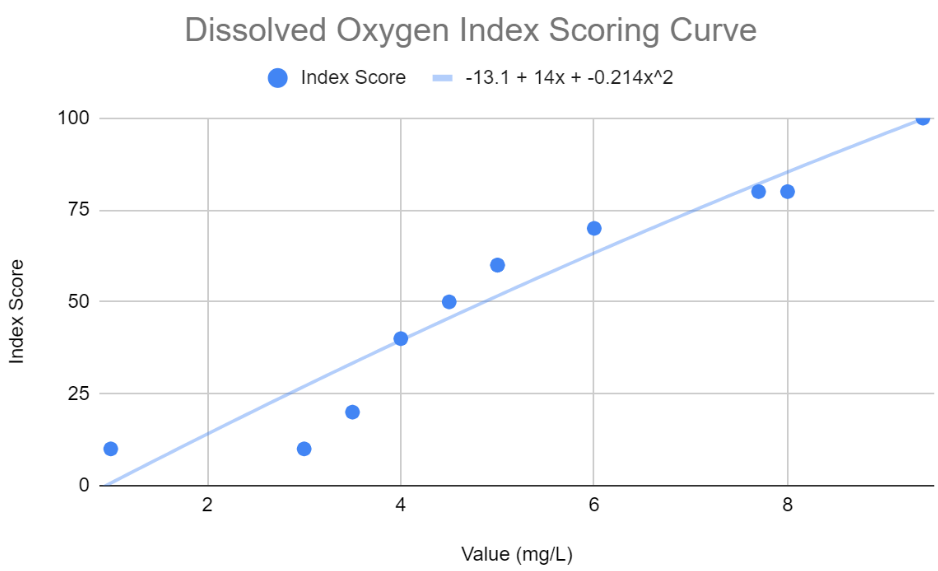
RiverWatch Data Appendices and Quality Assurance Project Plan (QAPP) available at: http://www.ipswichriver.org/our-work/library/research/

Appendix

Dissolved Oxygen Index Scoring Method

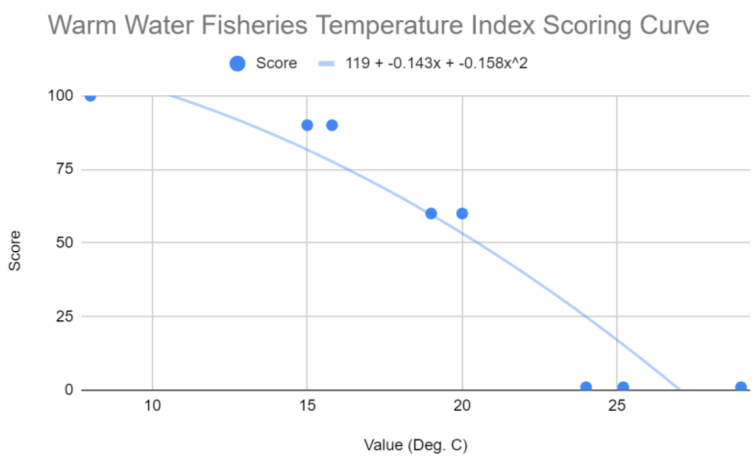
Dissolved oxygen scoring curve for warm-water fisheries with DO < 100% saturation	Value (mg/L)	Index Score
acute mortality for crappie (Oregon DEQ 1994)	1	10
acute mortality (EPA 1986), critical oxygen tension for largemouth bass (Oregon DEQ 1994)	3	10
Severe impairment (EPA 1986)	3.5	20
Moderate impairment (EPA 1986)	4	40
swimming performance reduced in largemouth bass (Oregon DEQ 1994)	4.5	50
Slight impairment (EPA 1986)	5	60
Massachusetts Water Quality Standards for warm-water fisheries	5	60
No impairment (EPA 1986), reduced growth rates in bass (Oregon DEQ 1994)	6	70
25th percentile calculated from Ecoregion XIV subregion 59 data (June - Sept)	7.7	80
onset of O2-dependent metabolism in brown bullhead (Oregon DEQ 1994)	8	80
75th percentile calculated from Ecoregion XIV subregion 59 data (June - Sept)	9.4	100



Temperature Index Scoring Method

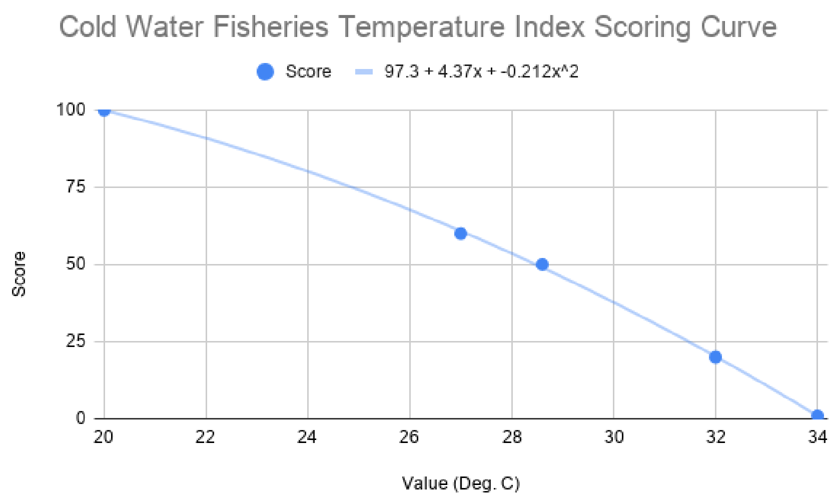
Warm Water Fisheries

Temperature scoring curve for warm-water resources	Value (Deg. C)	Score
Mass WQS cold (Mass WQS 1993)	20	100
maximum for growth in black crappie (EPA 1986)	27	60
Mass WQS for warm water fisheries (Mass WQS 1993)	28.6	50
maximum for growth of largemouth bass (EPA 1986)	32	20
maximum for survival of largemouth bass (EPA 1986)	34	1



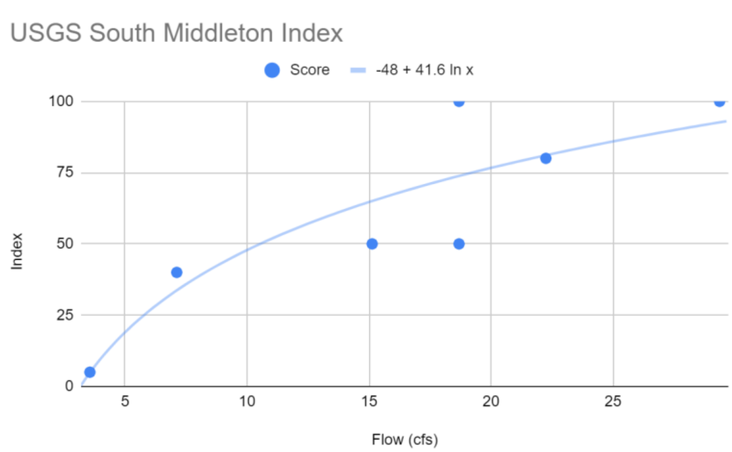
Cold Water Fisheries

Description & Citation	Value (Deg. C)	Score
excellent condition (Hallock 2001)	8	100
average optimum for growth of brook trout (McCullough 2001)	15	90
average optimum for growth of rainbow trout (McCullough 2001)	15.8	90
maximum for growth of brook trout (EPA 1986)	19	60
Mass WQS cold water fisheries	20	60
maximum for survival of rainbow and brook trout (EPA 1986)	24	1
maximum for survival of brown trout (McCullough 1999)	25.2	1
maximum for growth of blacknose dace & yellow perch (EPA 1986)	29	1



Flow Index Scoring Method

USGS South Middleton Gage			
Statistic	Flow (cfsm) from USGS study	Flow cfs (cfsm*drainage area)	Score
Tennant 40%	0.66	29.37	100
R2 Cross	0.42	18.69	100
Tennant 30%	0.5	22.25	80
Wetted perimeter	0.42	18.69	50
August median flow	0.34	15.13	50
Tennant 10%	0.16	7.12	40
7Q10	0.08	3.56	5



USGS Ipswich Gage			
Statistic	Flow (cfsm) from USGS study	Flow cfs (cfsm*drainage area)	Score
Tennant 40%	0.66	82.5	100
R2 Cross	0.42	52.5	100
Tennant 30%	0.5	62.5	80
Wetted perimeter	0.42	52.5	50
August median flow	0.34	42.5	50
Tennant 10%	0.16	20	40
7Q10	0.08	10	5