Identification of the Primary Sources of Bacteria Loading in Selected Tributaries of Onondaga Lake: Phase 3 Microbial Trackdown Study

Final Report

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Executive Summary

Onondaga Creek, Ley Creek, and Harbor Brook are moderately to severely impaired with fecal bacteria most parts of the year, affecting stream condition and biotic quality. However, the sources of these harmful contaminants, which could include faulty wastewater infrastructure, agricultural runoff, and wildlife, are poorly understood. This report summarizes collaborative efforts to identify those sources and provide recommendations intended to reduce bacterial inputs.

Phase 3 of the Microbial Trackdown Study began in 2014 for the purposes of (a) developing a comprehensive understanding of water quality conditions on spatial and temporal scales during dry weather conditions, (b) evaluating drivers of stream water quality conditions and biological integrity, (c) prioritizing identified impairments, and (d) providing recommendations for the improvement of stream water quality and biological integrity through meaningful and efficient restoration protocols. To achieve these goals, we conducted a tiered-approach for water sampling, biological sampling, and habitat assessments from 2014 to 2017.

Results from the study helped to elucidate spatial and temporal trends in bacteria and water quality, identify areas of concern, and make sewer conveyance system corrections, most notably:

A. Bacteria levels observed during Phase 3 were commonly above the NYSDEC Water Quality Standard for fecal coliforms (FC)[1]. During routine sampling events, 70%, 65%, and 57% of samples in Harbor Brook, Ley Creek, and Onondaga Creek, respectively, exceeded the NSDEC Water Quality Standard for fecal coliforms during dry weather.

B. In-stream bacteria levels varied significantly among the Harbor Brook, Onondaga Creek, and Ley Creek. Within-stream patterns in bacteria levels were evident and differed among the three systems:

    i. Bacteria levels in Harbor Brook were different between rural and urban locations; urban locations exhibiting significantly higher bacteria levels.
    ii. Sampling in Onondaga Creek did not identify distinct spatial (i.e., upstream to downstream) trends in bacteria concentration. Study results suggest bacteria from both rural and urban sources are negatively impacting water quality during dry weather conditions.

C. Decreases in bacteria levels were observed at multiple in-stream locations in Harbor Brook, Onondaga Creek, and Ley Creek during Phase 3 that have been attributed to point source corrections made during and after the completion of Phase 1 and Phase 2.

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[1] The NYS DEC criteria for acceptable fecal coliforms levels is defined as a geometric mean of at least five samples per month below 200 cfu/100 mL. Geometric means for Phase 3 were not calculated due to insufficient sampling frequency per month. Nevertheless, evaluating the fecal coliforms values observed in Phase 3 against the NYS Criteria for fecal coliforms provided a valuable measure of the magnitude of fecal coliforms inputs from point sources with persistent flow rates, as well as collectively among in-stream locations.

D. Poor water quality conditions aside from FC levels, including elevated turbidity, temperature, and specific conductivity levels, were evident at several routine locations in Harbor Brook, Onondaga Creek, and Ley Creek. Collectively, however, water quality measurements at most in-stream sampling locations were generally not considered detrimental to aquatic organisms or human health. Potential factors considered to be drivers of the observed trends in water quality that vary among the three systems are as follows:

   i. *Harbor Brook*
      - Urbanization
      - Road salts
   ii. *Onondaga Creek (including urban tributaries)*
      - Agriculture
      - Mudboil activity
      - Infiltration from brackish springs
      - Road salts
      - Animal wastes
      - Extensive channelization
      - Reduced or non-existent riparian zones
   iii. *Ley Creek*
      - High stream temperatures
      - Extensive channelization
      - Reduced or non-existent riparian zones

E. Even after significant basin-wide trackdown and remediation efforts, sources causing significant impairment remain unidentified.

F. Preliminary results during Phase 2 suggested animal waste may have been an important contributor to the relatively high bacteria levels observed at select in-stream locations, particularly for the urban tributaries to Onondaga Creek (i.e., Hopper Brook, Cold Brook, City Line Brook). As a result, microbial source-tracking (MST) was conducted to identify the specific source(s) of fecal contamination.

   i. Bacteroides analysis from samples collected suggest that water quality in Onondaga Creek is significantly impacted by human bacterial inputs upstream of the City's CSO system during dry weather. This finding suggests the potential for unidentified sources in the middle and/or upper subwatersheds, possibly septic.
   ii. The substantial increase in samples showing ruminant contributions to bacteria inputs within the Onondaga Creek watershed in 2017, compared to 2016, suggested a potentially negative impact on water quality and human health possibly related to agriculture practices in the upper watershed, and/or the growing urban deer population.

G. Results from fish and macroinvertebrate sampling showed that the type and extent of impairment differed among the three tributaries. Nearly all sites, however, showed some measure of impairment, with the severity of the impact(s) increasing downstream; an apparent effect of urbanization.

Results from this study effectively documented the effects of dry-weather inputs on bacteria levels and water quality in Harbor Brook, Onondaga Creek, and Ley Creek. Moreover, spatial and temporal trends in bacteria levels were identified that helped to: explain patterns in-stream water quality related to land use, detect relationships between measured parameters, identify the animal source of bacteria at select locations, measure the effects of remedial activities on bacteria levels, and assess long-term changes in bacteria levels since Phase 1 (2008). The collaborative and adaptive management-based approach used for this study supported the redirection of resources by decision-makers and Working Group members to focus on areas in the watershed that required further bacterial trackdown work.

Notes on this report: *This report is separated into two chapters because two concurrent (i.e., bacteria and biological) analyses with distinctly separate field activities were performed under Phase 3. Chapter 1 presents and discusses the results of water quality and bacteria monitoring. Chapter 2 presents and discusses the results of the biological sampling and examines how, and to what extent, biotic conditions may have been impacted by water quality conditions and bacterial contamination.*

Phase 3 Final Report Components

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1. Introduction

Bacterial contamination can significantly degrade water quality, pose health concerns, and ultimately damage the recreational and economic value of waterbodies. Urban creeks, particularly, are dynamic systems, and are continuously in flux from anthropogenic inputs and impacts. Spatial and temporal monitoring is necessary to identify sources of contamination and assess the potential threats of bacteria exposure to humans. Upgrades in treatment technologies, green infrastructure, and continued mitigation of Combined Sewer Overflows (CSOs) in recent decades have led to significant improvements in water quality in Onondaga Lake. Despite these improvements, studies have shown bacteria concentrations remained problematic in CSO-impacted tributaries under dry weather conditions and in the absence of wet weather-driven CSO events (OEI 2007); moreover, persistent sources of bacteria were degrading water quality during dry weather. The impetus for dry weather sampling was enhanced by the spatial signatures for bacteria that appeared to exist during periods of dry weather, offering a unique advantage for locating bacterial discharges.

1.1. Background

A study of pathogens in Onondaga Creek was conducted by the Onondaga Environmental Institute (OEI) in 2007 using USEPA Region 2 funding in support of the Onondaga Nation. OEI also performed an analysis of Onondaga County Department of Water Environment Protection (OCDWEP) fecal coliforms and rainfall data for the period 2000-2007 as part of the Onondaga Creek Revitalization Plan's (*State of the Creek*) Summary (OEI 2009). Results showed that fecal coliforms concentrations were above the NYS standard on an annual average basis of 16% (34 of 215) and 75% (162 of 215) of dry weather days at Dorwin Avenue and Kirkpatrick Street, respectively, indicating that wet weather Combined Sewer Overflow (CSO) discharge was not solely responsible for bacteria release to Onondaga Creek. In an August 21, 2007 letter to the Amended Consent Judgment (ACJ) parties, OEI identified dry weather releases were significant and multiple discharges at varying locations from an aging sewer conveyance system[1] were likely sources. Pursuant to the August 21, 2007 letter, OEI and OCDWEP submitted a proposal to the OLP on February 15, 2008. The scope-of-work proposed to identify urban and rural sources, measure seasonal and spatial variability, differentiate human and animal bacteria, and trace point source and non-point source releases such as those originating from pipes, agricultural runoff, septic systems, and sediment flux under both dry and wet weather conditions. After several iterations, the August 18, 2008 work plan was authorized by the New York State Department of Environmental Conservation (NYSDEC) via August 26, 2008 letter with some modifications including the stipulation that all sampling be conducted under dry weather conditions. On July 22, 2008, the OLP Projects Committee voted to recommend the sampling initiative, and on August 5, 2008, the OLP Executive Committee authorized via OLP Resolution 2008-2 that $85,000 of Environmental Benefit Project monies[2] be paid to OEI and OCDWEP to perform the Phase 1 Microbial Trackdown Study (MTS). NYSDEC was established as the lead

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[1] Associated problems include broken pipes, cross linkages and illicit connections, and unpermitted sources as over one-fourth and two-thirds of the Syracuse sewer system is greater than 100 and 80 years old, respectively; less than 10% is younger than 50 years old (Fig. A).

[2] Pursuant to a court order dated December 14, 2006, Onondaga County provided $145,000 for an Onondaga Lake Environmental Benefit Project (EBP) to be selected by the OLP.

agency overseeing the project. A microbial trackdown working group was subsequently established to provide technical guidance, comment on action items and deliverables, and provide project oversight. The following parties were represented:

- OEI
- Atlantic States Legal Foundation
- City of Syracuse Public Works
- Onondaga County Office of Environment
- OCDWEP
- NYSDEC Region 7
- NYS Department of Law
- USEPA Region 2
- US Army Corps of Engineers Buffalo District
- Onondaga Nation

Phase 1

OEI entered into a contract with Onondaga County on September 18, 2008. Field work began on September 19, 2008 and was suspended in mid-November 2008. An Interim Report was prepared by OEI, with the assistance of Onondaga County, and submitted for review to NYSDEC and other interested parties on January 21, 2009. After convening the Working Group, the project Work Plan was modified via a memorandum, dated March 5, 2009, which outlined work task modifications. Several tasks were deferred, pending additional funding and agency approvals. These modifications were approved by NYSDEC on March 23, 2009. As with the work carried out in the fall of 2008, several additional changes to the scope of work were made by the Working Group as the study progressed in the spring of 2009. Changes in scope were summarized in a handout at a Working Group planning meeting held on June 18, 2009 at the NYSDEC Region 7 office. On July 6, 2009, the OLP Executive Committee via Resolution 2009-3 voted to allocate the remaining $60,000 of the EBP money to supplement the Phase 1 Microbial Trackdown Study. OEI submitted a finalized Phase 1 Scope of Work to NYSDEC for review and approval on September 4, 2009. NYSDEC approved a conditional Scope of Work on September 21, 2009.

Further study of fecal indicator bacteria in Onondaga Creek conducted by OEI during Phase 1 of the Microbial Trackdown Study identified potential bacteria inputs into Onondaga Creek occurring during 2008 and 2009. The OEI and County monitoring data from Phase 1 supported several conclusions:

A. High concentrations of bacterial concentrations were frequently found in the urban reaches of both Onondaga Creek and Harbor Brook.

B. Fecal coliforms bacteria levels fluctuated in a pattern that could not be explained by precipitation-driven discharges of Combined Sewer Outfalls (CSOs) or storm water flow dynamics.

C. Bacteria concentrations and loadings in Onondaga Creek during dry weather generally increased moving downstream from Dorwin Ave. to Kirkpatrick St., and substantially higher concentrations are particularly evident in the downtown (downstream of W. Onondaga St.) section of Onondaga Creek.

D. Bacteria concentrations in Harbor Brook generally increased from upstream (Velasko Rd.) to downstream (Hiawatha Blvd.) during dry weather. Greater spatial resolution was unavailable.

E. Bacteria concentrations in rural sections of Onondaga Creek were generally high (> 5,000 cfu/100 mL) during rainstorms; they exceeded 100,000 cfu/100 mL at downstream, urban sites.

Several of the problematic point sources that discharged into Harbor Brook and Onondaga Creek were addressed (directly or indirectly) following the completion of Phase 1; however, further investigation and monitoring were still required to determine: (1) if corrective measures were successful, (2) whether uncorrected discharges remained problematic and to what extent, and (3) where (if any) new point sources appeared in the systems since the completion of Phase 1. Furthermore, relatively little was known about bacteria loadings in Ley Creek; the 3rd largest tributary to Onondaga Lake that is also impacted by bacterial concentrations.

Phase 2

A proposal for Phase 2 of the Microbial Trackdown Study was submitted to the Working Group in 2010 to evaluate systems dynamics since Phase 1. Work task modifications were made to the Phase 2 Work Plan through an iterative review process with the Working Group, and a final round of comments was received during the March 14, 2012 conference call. The final draft of the Phase 2 work plan was completed on April 4, 2012 and was approved by the NYSDEC on June 12, 2012. OEI entered into contract with NYSDEC September 17, 2012 (Contract No. C007422; project period April 1, 2012 - September 30, 2013). Field work began on June 25, 2012 and included routine, temporal, priority point source, point source identification, and tributary trackdown sampling events. Field work for the 2012 field season was completed on November 15th and a preliminary summary of data was presented to the Working Group in January 2013 that included the following findings:

1. Routine, in-stream bacteria levels generally increased downstream, with the most downstream locations having consistently moderate to high bacteria concentrations.
2. Temporal sampling showed fluctuations in bacteria levels consistent with peak hours of water demand (e.g., breakfast, lunch, and dinner).
3. Point source identification activities identified thirty-two (32) point sources in Ley Creek, four (4) new point sources in Onondaga Creek, and no new point sources in Harbor Brook
4. Priority point source sampling found four (4) point sources in Onondaga Creek and one (1) in Harbor Brook corrected from Phase 1 sampling. Several point sources in Onondaga Creek and Harbor Brook remained problematic and continued discharging high to severe levels of bacteria.

Based on those findings, and subsequent approval from the Working Group, minor modifications were made to the Phase 2 field methods for the 2013 field season that included the addition and removal of several point sources to the 'Priority Point Source' task. Phase 2 sampling resumed on June 3, 2013 and continued with the same sampling frequency as outlined in the original work plan. Based on Phase 1 and Phase 2 results (to-date), OEI compiled and presented a table of recommendations to the Working Group in August 2013 for continued sampling in the watershed used to most effectively and efficiently utilize the remaining Phase 2 funds for the identification and mitigation of problematic bacterial discharges. Following support from the Working Group, the remaining field activities proposed in the work plan were modified for the remaining 2013 field season. These sampling modifications included: (1) suspending field sampling at the end of October (as opposed to November), (2) reducing routine sampling frequency from three events to two per month, (3) withdrawing a second round of point source identification sampling in Ley Creek, and (4) allocating funds towards sewer and stormwater mapping for the development of a targeted strategy for trackdown sampling that would subsequently be initiated during the Phase 3 sampling program. Phase 2 sampling concluded on October 31, 2013.

At the end of Phase 2, over one dozen corrections had been made in the Onondaga Creek, Harbor Brook, and Ley Creek systems resulting from the Microbial Trackdown Studies. Sources of bacteria have included collapsed pipes, cross connections, and illicit discharges and connections:

- *Onondaga Creek*: Phase 1 sampling events led to the identification and emergency repair of two locations where sewer pipes had collapsed. Several illicit discharges and cross connections have also been identified and corrected in Onondaga Creek following Phase 1 and Phase 2 sampling efforts. Additional work in the Upper Onondaga Creek Watershed, in conjunction with the Microbial Trackdown Studies, has led to the identification and correction of several bacterial sources, including a septic system that had collapsed at an apartment complex near Kennedy Creek and a horse barn adjacent to an unnamed tributary to Onondaga Creek.
- *Harbor Brook*: Phase 1 sampling identified the failure of a nearby Laundromat's filtration system that was discharging high levels of bacteria directly into the creek; this discharge was subsequently corrected. The construction of the Harbor Brook Intercepting Sewer System (HBIS; completed 2013) following Phase 1 activities has contributed to the elimination of several dry-weather discharges caused by under-capacity Combined Sewer Overflows (CSOs). A cross connection was also identified and corrected in Harbor Brook in 2012 where a neighboring residence's sewer line was improperly connected to the storm drain system.
- *Ley Creek*: Over fifty (50) point sources were identified in Ley Creek during Phase 2 sampling, and only one (1) point source was identified to have severely high bacteria levels. Collaboration with Onondaga County and the Town of Dewitt allowed for the identification of the source and subsequent elimination of the discharge. The trackdown work in Ley Creek helped the County identify and correct an exposed pipe that crossed Ley Creek that had the potential to cause problems in the future.

Continued supporting work by Onondaga County and the City of Syracuse has included dye testing, TV scoping, verification that CSOs are not discharging during sampling, and legal action at point sources that remain problematic in Onondaga Creek and Harbor Brook. For example, one (1) point source in Onondaga Creek was identified as effluent from a building in the downtown area, and the owner was subsequently issued a Consent Order to repair the problem (the point source was remediated in 2015).

Each correction has led to improved water quality conditions. However, despite the localized corrections, results still showed areas of water quality degradation in Harbor Brook, Onondaga Creek, and Ley Creek. Therefore, a continued comprehensive assessment of the various water quality issues in these tributaries was implemented to accurately identify sources of impairment, to prioritize those concerns for restoration and remedial activities, and ultimately achieve water quality criteria for bacteria. As a result, a draft proposal for Phase 3 of the Microbial Trackdown Study was discussed with the Working Group during a January 21, 2014 conference call. The Working Group for the Phase 3 study consisted of:

- OEI
- USEPA Region 2
- NYSDEC Region 7
- NYS Dept. of Law
- OCDWEP
- Onondaga Co. Office of Environment
- City of Syracuse Public Works
- ASLF
- Onondaga Nation
- SUNY ESF

Phase 3

Funds for Phase 3 were provided from two sources: (1) County of Onondaga and (2) State of New York Department of Environmental Conservation. An initial Phase 3 scope of work was prepared in December 2013 for review by the Working Group in January 2014. Based on the sampling requests of each funder (e.g., Onondaga County requested upper Onondaga Creek sampling [Task 3.1] and NYDEC requested *Bacteroides* analyses [Task 6]), and differences in contracting timelines[3], it was decided by the Working Group to develop two different Scopes of Work (Appendix A). Both scopes were developed to be adaptive to sampling needs and the continual interpretation of laboratory analyses. The funds from Onondaga County largely supported field efforts completed in 2014 and 2015, while funds from NYSDEC largely supported field efforts completed in 2016 and 2017. The results of each Scope of Work were collectively analyzed and synthesized into one comprehensive report.

Phase 3 of the Microbial Trackdown Study began in June of 2014 to support: (1) the development of a comprehensive understanding of water quality issues on spatial and temporal scales, during dry weather conditions, (2) the evaluation of effects of those impacts on stream quality and biological integrity, (3) the prioritization of identified impairments, and (4) the provision of recommendations for improving stream quality through efficient restoration efforts. The primary objectives of the Phase 3 Microbial Trackdown Study were to: (1) monitor in-stream bacteria on a routine basis, (2) monitor priority point sources identified from previous Phase studies that discharge high levels of bacteria, (3) monitor newly identified point sources for bacteria discharges, (4) implement targeted trackdown strategies for problematic point source discharges, (4) monitor water quality and bacterial conditions in Upper Onondaga Creek, and (5) to evaluate habitat quality and associated fish and macroinvertebrate community structures.

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[3] Onondaga County Phase 3 contract was an amendment to the Phase 2 contract. That contract was awarded June 9, 2014, with an amendment occurring on December 18, 2014. The NYSDEC Phase 3 contract was awarded September 17, 2015.

2. Methods

Sampling was performed in Harbor Brook, Onondaga Creek, and Ley Creek (Fig. 1). Harbor Brook and Onondaga Creek are both tributaries that have been impacted by CSOs[4], and were the focus of the Phase 1 and Phase 2 MTS. Ley Creek has been routinely monitored as part of Onondaga County's Ambient Monitoring Program as a major tributary to Onondaga Lake impacted by multiple sources of municipal, industrial, and non-point source pollution. However, prior to Phase 2, little work had been done in the upper segments of Ley Creek to identify point sources and monitor spatial and temporal trends in water quality and bacteria concentrations.

Onondaga Creek has the second largest drainage area (298 km^2) in the Onondaga Lake drainage basin and contributes the greatest surface water inflow. The creek is approximately 26.7 mi (43 km) in length and descends more than 0.19 mi (0.30 km) from its headwaters (Coon and Reddy 2008). Land use is predominantly forest (50%) and agriculture (31%) (Rhea et al. 2006, Fig. 2). Harbor Brook (35 km^2) is roughly 7.52 mi (12.1 km) in length and drops more than 0.12 mi (0.19 km) from its headwaters, making it a high-gradient stream (Coon and Reddy 2008, Fig. M2). The upper watershed is a mix of forest and agriculture, but the watershed is predominantly urban (41%). Ley Creek (79 km^2) is a low-gradient, urban stream, descending less than 0.01 mi (0.02 km) over the course of its total length of 9.94 mi (16 km). The Ley Creek watershed is mostly (i.e., 69%) urbanized with heavily developed commercial and industrial property land use; only 31% of adjacent lands were classified as residential (Fig. 2).

All sampling was conducted under dry weather conditions between June and October 2014-2017. ***Dry weather was defined as a minimum of two days with de minimus precipitation in Syracuse. Sampling was initiated only when no more than 0.08 in (2 mm) of rain had fallen during the preceding 48-hour period; and sampling was only conducted when less than 0.04 in (1 mm) had fallen during any one-hour period during the sampling event as recorded at Metro, the MOST in Syracuse, Hancock International Airport, and/or select wunderground® weather stations in and around Syracuse and the Tully Valley***. Daily precipitation was recorded from wunderground.com.

Sampling crews consisted of a minimum of two people. Water quality parameters were measured and recorded in the field at each sampling location for all sampling events using a YSI 650 MDS hand held device equipped with either a 6600 multi-parameter water quality monitoring sonde or a 6820-V2 sonde. Measured water quality parameters included pH, dissolved oxygen, specific conductivity, temperature, and (depending on the sonde used) salinity and turbidity. Field and analytical methods, including equipment calibration and sample custody procedures, are described in detail in the Phase 3 QAPP (Appendix B).

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[4] Bacterial contamination from CSOs had been a major source of degradation in the Onondaga Lake Watershed for decades. After completion of the Intercepting Sewer System in 1922, 120 CSOs were collectively maintained on Harbor Brook, Onondaga Creek, and Ley Creek (Effler and Hennigan 1996, Rhea et al. 2006). Since 1998, the County has closed or abated 51 of its 72 pre-ACJ CSO locations, through a series of sewer separation and other projects. Today, 9 CSOs remain on Onondaga Creek, 11 remain on Harbor Brook, and 1 remains on Ley Creek (www.cso.savetherain.us).

2.1. Task 1 – QAPP, DAIP, and HaSP Updates

A Quality Assurance Program Plan (QAPP) was updated for Phase 3 sampling (Appendix B); originally adopted and modified from Onondaga County's AMP QAPP. The Data Analysis and Interpretation Plan (DAIP) and Health and Safety Plan (HaSP) from Phase 2 was also updated by OEI and Onondaga County for Phase 3 (Appendix C and Appendix D, respectively).

2.2. Task 2 – Field and Laboratory Mobilization

OEI and Onondaga County prepared and coordinated sampling and analyses for each type of field effort (refer to Tasks 3-7) that included:

- Identification and preparation of sampling methods (procure, test, and/or prepare, calibrate, and decontaminate sampling devices, equipment and supplies)
- Coordination of sampling teams (numbers of individuals, training, scheduling, transportation and sampling logistics, health and safety plans) and laboratories (sample preparation and delivery)
- Records management (field logs, chain of custody forms, data entry)
- Site reconnaissance (Conduct general survey of sampling site prior to sampling efforts in accordance with task-specific QA/QC and HaSP requirements. Identify, mark, photograph, and collect GPS coordinates of all sampling locations.)

2.3. Task 3 – Routine Sampling

Routine sampling involved regularly scheduled dry weather sampling during summer and fall months in 2014 and 2015 at predetermined locations for the identification of potential spatial effects along stream corridors (Fig. 3). Six sites in Ley Creek, seven sites in Harbor Brook, and 10 sites in Onondaga Creek were sampled from strategically selected and easily accessible locations (e.g., bridges, Table 1).

The predominant surrounding land use for each routine location, where existing land use data was not previously available in OEI databases (e.g., Ley Creek locations), was estimated using the web-based Geographic Information System (GIS), StreamStats (Ries III et al. 2008). Percent and use was determined for each basin using the Spatial Analyst ToolPak in ArcGIS10. These estimates were used to categorize locations as either "rural," which included agricultural land use, or "urban," which included low and high intensities (Table 1).

Each stream was sampled no more than two times per month under dry weather conditions. Grab samples were collected from the centerline of the stream using a Coli Sampler[5] just below the water surface for fecal coliformss. All sampling was performed in a downstream to upstream manner to prevent sampling the same slug of water. A total of 13 routine sampling

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[5] The Coli Sampler is a device developed by Onondaga County for sampling off bridges (refer to the QAPP, Appendix A).

events were conducted; six routine events were completed in 2014 and seven routine events were completed in 2015.

Table 1. Phase 3 routine sampling locations (Task 3) for the Onondaga Lake Watershed (2014-2015), classified by the predominant sub-basin land use.

Stream	Rural Sites[1]	Urban Sites[1]
Harbor Brook	Onondaga Rd Bellevue Ave *Grand Ave*	Velasko Rd Delaware St Fowler High School (HS) Hiawatha Blvd
Onondaga Creek	Tully Farms Road (south) *Bear Mtn. Rd*[2] NY Route 20 Gibson Road Hitchings Road – on West Branch Dorwin Ave	W. Seneca Turnpike W. Newell St South Ave (N) Walton St W. Kirkpatrick St
Ley Creek	Fly Road (North Branch)	Thompson Rd (North Branch) Exeter St (South Branch) Court St (South Branch) Lemoyne Ave (Mainstem) Park St (Mainstem)

[1] Sites denoted in italics were not sampled during Phase 1. All other sites were sampled in Phases 1 and 2.
[2] This location was mistakenly sampled during the 9/24/14 routine event instead of Tully Farms Rd (south). Results were separated from data analyses and interpreted accordingly.

2.4. Task 3.1 – Routine Upper Onondaga Creek Sampling

In 2012, a comprehensive survey of the upper Onondaga Creek watershed was performed, in which water quality and biological analyses were performed. The results of the study effectively documented the impacts caused by agricultural practices, mudboil activity, and saline discharges on water quality and biotic conditions. Notably, it documented the effects upstream sources of impairment can have on downstream conditions that potentially compounded or significantly impacted water quality conditions in the lower, urban Onondaga Creek watershed. One season of upper Onondaga Creek sampling was requested by the Working Group for inclusion in the Phase 3 MTS.

Routine water quality sampling was performed in upper Onondaga Creek no more than twice per month between June and October 2014. Sampling was performed irrespective of weather conditions (i.e., dry or wet weather), and included 21 locations (Table 2; Fig. 4). The inclusion of wet weather sampling during upper Onondaga Creek sampling was used to build upon the work performed in the Upper Onondaga Creek study; this elucidated the effects of rain events on in-stream bacteria and nutrient levels that may have been driven by surrounding land use practices (e.g., agriculture).

A total of nine events were completed in 2014. Samples were collected for fecal coliforms, ammonia (NH3), Total phosphorus (TP), Total Kjeldahl-Nitrogen (TKN), and Total Suspended Solids (TSS). *In situ* water quality was also measured. Nutrient sampling parameters in Upper Onondaga Creek were consistent with those measured during the 2012 Upper Onondaga Creek study to support the evaluation of temporal dynamics in nutrient concentrations in the context of potential land use impacts (e.g., agricultural practices, runoff, and sedimentation).

Table 2. Upper Onondaga Creek sampling locations (June-October 2014).

Stream	Sampling Location	Stream	Sampling Location
Onondaga Creek (mainstem)	Tully Farms Rd	West Branch	Red Mill Rd
	Woodmancy Rd		Hogsback Rd
	Solvay Rd		Hitchings Rd
	Tully Farms Rd. @ Fall Creek	Kennedy Creek	Winacre Dr
	Otisco Rd		Rte. 11
	Nichols Rd	Hemlock Creek	Webb Rd
	Bear Mountain Rd.		Quarry Rd
	Buffalo Hill Rd.		Rte. 11A
	Flood Control Dam (above)	Commissary Creek	Rte. 80
	Gibson Rd		
	Roswell Ave.	Williams Creek	Rte. 11A

2.5. Task 4 –Priority Point Source Sampling

Priority point source sampling was conducted to focus Phase 3 point source monitoring and evaluation on locations prioritized from Phase 1 and Phase 2 results that needed additional, long-term monitoring. Phase 1 Microbial Trackdown Study results identified a total of 55 point sources of dry-weather bacterial contamination (fecal coliforms) to Onondaga Creek. Of the 55 point sources, eight were identified as tributaries and the remaining 47 were identified as direct pipe point sources to the creek. Of the 47 dry-weather point sources, six of those discharges were identified as CSOs listed in the County's Metro WWTP SPDES permit; of which one was identified as a tributary. Phase 1 data indicated 11 of the 47 point sources had moderate to high potential to discharge fecal coliforms contamination in the creek during dry weather conditions. Phase 2 sampling supported the characterization of less obvious sources of potential contamination that remained unabated and required appropriate follow-up corrective action; point source sampling during Phase 2 involved a maximum of three samples per month collected during dry weather conditions at select point source discharges. In 2012, a total of 18 point sources were sampled and included 14 in Onondaga Creek and four in Harbor Brook. In 2013 under Phase 2, the number of priority point sources sampled in Onondaga Creek was reduced to 10, and included the addition of three point sources that were identified as discharging high levels of bacteria and the removal of seven point sources that were either found in to be 1) discharging high levels of bacteria and required further trackdown or 2) remedial work had been verified, and point source discharges were very low or dry in some instances.

The priority point source sampling task was extended for Phase 3. In 2014 and 2015, 14 priority point sources were sampled, including 10 in Onondaga Creek and four in Harbor Brook (Fig. 5). These point source sampling locations were found to be either: (1) discharging high levels of bacteria requiring further investigation, or (2) were those that had not been remediated following Phase 2 recommendations (Table 3).

Table 3. Phase 3 priority point source sampling locations (Task 4) for the Harbor Brook and Onondaga Creek (2014-2015) and sampling rationales.

Stream	Point Source[1]	Rationale
Onondaga Creek	OC-PS02 (Hopper Brook south)	No suspected source, bacteria levels were consistently low in Phase 2. Verify levels remain low.
	OC-PS93 (behind Van Duyn School)	Unknown, potential animal waste from catch basin; candidate for *Bacteroides* analysis
	OC-PS03 (W Glen Ave)	Unknown; Phase 2 trackdown work suggests a possible illicit connection from a neighboring house
	OC-PS04 (Ballantyne Rd)	Unknown; Phase 2 tributary trackdown work suggests an upstream source where City Line Brook gets diverted underground
	OC-PS09 (Hopper Brook)	Unknown
	OC-PS11 (Brighton Ave)	Unknown
	OC-PS71 (Centennial Dr)	Unknown, potential groundwater infiltration
	OC-PS20 (Byrne Dairy)	Source identified during Phase 2 from Byrne Dairy, verify corrective work
	OC-PS92 (Water St)	Unknown; sporadic discharge potentially related to construction activities. Verify if flowing in 2015
	OC-PS23 (EBSS)	Unknown
Harbor Brook	HB-PS100 (Velasko Rd)	Unknown
	HB-PS101BW (CSO 018)[2]	Outfall relocated and serves as Harbor Brook Wetland outfall; continue monitoring
	HB-PS103 (Depalma Ave)	Corrected/Verify
	HB-PS112 (Hiawatha Blvd)	Unknown

[1]Samples sites for each tributary are arranged upstream to downstream.
[2]HB-PS101B was eliminated as an outfall following the construction of the Harbor Brook Constructed Wetlands Facility. The new CSO 018 outfall was sampled during Phase 3 in place of PS101B.

Five priority point source events were completed in Harbor Brook and four events were completed in Onondaga Creek in 2014[6]. Similarly, seven priority point source events were completed in Harbor Brook and in Onondaga Creek in 2015. Each stream was sampled no more than two times per month under dry weather conditions. Grab samples were collected from the centerline of the stream/point source using a Coli Sampler, just below the water surface for fecal coliformss.

2.6. Task 5 – Onondaga Creek Tributary Trackdown

Tributary Trackdown involved dry weather sampling of all natural tributaries to Onondaga Creek to locate potential upstream sources of bacteria. The Phase 1 Microbial Trackdown Study identified freshwater entering Onondaga Creek via pipe or conduit at nine known locations within the City of Syracuse from seven tributaries. Of the nine point source locations, both Hopper Brook and Cold Brook have been segmented such that both tributaries have two discharge outfalls into Onondaga Creek. Hence, seven tributaries discharge into Onondaga Creek at nine separate point sources:

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[6] High stream flows in August 2014 prohibited sampling in Onondaga Creek.

- Dorwin Springs (OC-PS26)
- Cold Brook (OC-PS01)
- Kimber Brook (OC-PS00)
- Cold Brook shunt (OC-PS24)
- Hopper Brook North (OC-PS09)
- City Line Brook (OC-PS04)
- Hopper Brook South (OC-PS02)
- Furnace Brook (OC-PS51)
- Erie Blvd Storage System [EBSS] (OC-PS23)

One complete trackdown event was performed during Phase 3. On August 17, 2015, 21 sites among nine tributaries were visited; 18 locations were subsequently sampled (Table 4, Fig. 6). Samples were collected for fecal coliforms and water quality analyses. Grab samples were collected from the centerline of the stream/channel or directly from the outfall (i.e., if a pipe/culvert discharge) using a Coli Sampler at the surface. Additional sampling was performed in tributary locations in 2017 as part of Task 6 (see below).

Table 4. Phase 3 tributary trackdown sampling locations in lower Onondaga Creek (Task 5).

Stream	Location[1]
Dorwin Springs	PS-26: Dorwin Springs outfall, 500ft upstream Dorwin Ave
Cold Brook (diversion)	PS-24: 800ft downstream Dorwin Ave
Kimber Brook	PS-00B: Chaffee Ave
	PS-00: Kimber Brook outfall
Cold Brook	PS-01C: Byrne Pl
	PS-01B: St James Church
	PS-01: W Seneca Trpk
Hopper Brook (South)	PS-02B: Hopper Brook S Section, Detention Pond @ Seneca Pl
Spring Brook	PS-04D: Spring Brook, E. Glen Ave
	PS-04G: Cordova St
	PS-04F: E. Florence Ave
	PS-04E: Behind Valley Plaza
	PS-04C: Spring Brook, Valley Plaza
	PS-04B: City Line Brook, Slayton Ave
Hopper Brook (North)	PS-09I: Barnes Ave *(Not sampled due to lack of flow)*
	PS-09C: 148 Camp Ave *(Not sampled due to lack of flow)*
	PS-09E: 135 Valley View Dr
	PS-09D: 558 Valley Dr
	PS-09G: Upstream of Ford Ave
	PS-09H: Between Valley Dr and Ford Ave *(Did not sample)*
	PS-09B: Ford Ave

[1] Sites for each tributary are arranged upstream to downstream. Sites visited, but not sampled are also shown.

2.7. Task 6 – Point Source Trackdown

Numerous point sources were identified during the Phase 1 and Phase 2 Microbial Trackdown studies as discharging persistently high levels of bacteria into Harbor Brook and Onondaga Creek, and the source(s) of those discharges remained unknown. Point source trackdown is a targeted strategy for identifying the location of bacterial discharges during dry weather conditions. In 2015 and 2016, a collective four Working Group meetings and joint meetings with OCDWEP and City of Syracuse were held specifically to (1) identify the point sources of most concern, (2) review the respective sewer/watershed maps, and (3) select locations for trackdown sampling. In addition, a field trip was held with Working Group members to view point sources of concern and prioritize sampling efforts on June 29, 2016. Coordination between the City of Syracuse and OCDWEP helped to develop and implement a strategized sampling program at select manholes, as well as identify the need for performing dye testing and/or TV camera-scoping when necessary. During the first round of reconnaissance in 2014 (i.e., during Phase 2), County field personnel accompanied OEI staff in the field to help identify and pull manholes, as well as provide site safety (e.g., road cones, hazard lights, etc.). All sampling locations were documented (photographs and written description), and GPS coordinates were recorded.

A total of nine different point source trackdown events were completed between 2016 and 2017; four events in Harbor Brook and five in Onondaga Creek. Collectively, 10 sites were sampled in Harbor Brook (Fig. 7) and 14 sites were sampled in Onondaga Creek (Fig. 8). In Onondaga Creek, point source trackdown sampling was largely comprised of tributary sites (Table 5), specifically for Bacteroides analysis (see below). Similarly, two in-stream sites were sampled in Harbor Brook as part of point source trackdown (Table 5). Samples were collected using a Coli sampler. A total of 41 samples were analyzed for fecal coliforms. In addition, *Bacteroides* analysis was performed on a subset of samples (N=34) collected in Harbor Brook on 9/21/16, 7/10/17, and 8/16/17, and samples collected in Onondaga Creek on 8/24/16, 7/20/17, and 7/31/17.

Table 5. Point source trackdown sampling locations in Harbor Brook and Onondaga Creek (2016-2017).

Harbor Brook	Onondaga Creek
Velasko Rd. A: Velasko Rd in small drainage channel adjacent to creek	Dorwin Ave.
Velasko Rd.: Harbor Brook mainstem	PS-01C: Cold Brook, Byrne Pl
PS-100E: Pipe behind Burger King plaza; S. of Onondaga Blvd	PS-03A: Corner of W Glen Ave and Midler Ave
PS-100D: Open channel S. of Onondaga Blvd & W. of Velasko Rd; behind DD plaza	PS-03: W Glen Ave
PS-100C: Manhole at Velasko Rd & Onondaga Blvd, NW corner	PS-04D: Spring Brook, E. Glen Ave
	PS-04E: Behind Valley Plaza
PS-100B: Manhole at Velasko Rd & Onondaga Blvd E side	PS-04C: Spring Brook, Valley Plaza
PS-100A: Manhole between outfall and Onondaga Blvd	PS-04B: City Line Brook, Slayton Ave
PS-112C: Manhole at Hiawatha Blvd, NE of 690 on ramp	PS-09C: Hopper Brook N, Camp Ave
	PS-09E: Hopper Brook N, 135 Valley View Dr
PS-112B: Manhole N of Hiawatha Blvd; in car dealerships parking lot	PS-09D: Hopper Brook N, 558 Valley Dr
	PS-09H: Hopper Brook N, 500 block Valley Dr
PS-112A: Manhole N or Hiwatha Blvd; adjacent to creek in parking lot	PS-09G: Hopper Brook N, upstream of Ford Ave
	PS-09B: Hopper Brook N, Ford Ave

Several point sources in Harbor Brook and Onondaga Creek, as well as tributary locations, have been suspected to have bacterial contamination from animal sources, based on visual inspections of the surrounding and in-stream conditions. Distinguishing the source of the fecal coliforms is an invaluable component when developing effective remedial strategies. Species-specific bacteria identification was used as a method for determining the organismal source of the fecal coliforms, using viral markers. Specifically, *Bacteroides,* a genus of bacteria, was used to differentiate between human and animal sources of bacteria. This information was gathered to help elucidate bacterial sources for developing strategies for prioritizing and remediating bacterial sources. The point sources selected for *Bacteroides* analysis had unknown sources of moderate to severely high bacteria levels. The major categories detected from *Bacteroides* analysis include: human, bovine, and avian sources. *Bacteroides* analysis was performed by NYS Department of Health Wadsworth Laboratories (Albany, NY). The protocols for properly collecting and handling samples to be analyzed for *Bacteroides* is further discussed in Appendix E (prepared by NYSDEC on July 14, 2016).

Samples collected during Phase 3 were commonly analyzed for chlorine residual content, yet this analysis was considered too infrequent and utilized a detection limit too high (i.e., 0.10 mg/L) to provide robust and meaningful information for project analysis and reporting.

2.8. Task 7 – Biological Sampling

Please refer to Chapter 2.

2.9. Task 8 – Meeting & Correspondence

For the duration of the sampling period, OEI field technicians provided project updates to the Working Group via email updates (as requested), quarterly progress reports, and teleconferences (~quarterly between June 2014 and December 2017). Updates included information regarding sampling and analyses, as well as other activities performed by the project team. Ongoing findings were reported in the updates, when applicable. Routine meetings, and often in conjunction with field efforts, allowed the Working Group to continually review data as it became available, to discuss sites/areas of concern, identify areas where corrective action(s) appeared successful, and redirect sampling efforts and resources towards identifying bacterial sources. This adaptive management approach has been an invaluable component to the study design and has allowed the Working Group to devote its resources towards corrective actions to mitigate problematic bacterial sources.

Progress reports were provided to the Working Group to outline the task-specific activities performed to-date. A review of all available data and the associated tables, figures, and maps were presented (when applicable) to project members. Comments and suggestions made by the Working Group during these meetings allowed OEI to make edits to existing data and map templates, allowing for a more streamlined, automated process for generating robust project deliverables that supported management decisions.

A total of 11 quarterly progress reports have been sent to NYSDEC to-date (Appendix F). Since June 2014, a total of 11 Working Group meetings have been held (i.e., 2 in 2014 and 3 each in 2015, 2016, and 2017, Appendix G). An additional three meetings were held between

2014 and 2016 with Onondaga County and City of Syracuse engineers to review storm and sewer maps and to make determinations on sampling locations as part of the point source trackdown sampling efforts.

2.10. Task 9 – Database Construction & Maintenance

OEI compiled the Phase 3 Microbial Trackdown Study data into a newer, more user-friendly and comprehensive database, improving upon the design initiative set forth for database construction for the Phase 1 and Phase 2 studies. This new Phase 3 database served as the source for analyses that included the creation of related data tables and graphs performed under Phase 3. The comprehensive database includes:

- All laboratory results and field water quality parameters
- A unique sample site ID number for every sample location and task (i.e., routine, priority point source, point source trackdown, tributary trackdown, and Upper Onondaga Creek sampling programs)
- The inclusion of an 'event' (i.e., task) data column that improves data organization and analyses by task
- The inclusion of a downstream order data column that improves data organization for spatial analyses and data processing

All data underwent a series of Quality Assurance/Quality Control (QA/QC) procedures by Onondaga County and OEI prior to uploading to the Master Database; QA/QC procedures were conducted to ensure all data used for analyses and reporting were valid, accurate, and defensible. Any errors in data entry that could not be validated from field data sheets were considered invalid and removed from the database. Apparent errors with field equipment and inaccuracies in project data were noted on Chain-of-Custody forms and in the electronic database. Any changes that needed to be made to data entries, following review, were made in the master database and a unique identifier was given to mark changes made and/or data that failed to be adequately validated or verified. Several inaccuracies with the Phase 3 sonde water quality data were noted and subsequently removed or denoted in the master databases. QA/QC did not identify any errors with the Phase 3 laboratory data. A complete summary of the Phase 3 QA/QC data management and validation procedures are detailed in the QAPP (Appendix B).

2.11. Task 10 – Mapping

Under Phase 3, OEI created a series of maps for Harbor Brook, Onondaga Creek, and Ley Creek; modified from maps generated in Phase 2, which included information such as: known sewer pipe, storm drain, CSO number, and OEI site ID. Where information was available and ground truthing was possible, the maps display OEI point sources that coincide with storm drains and CSOs. OEI created a set of reference maps from base maps used to support field work, weekly updates, data interpretation, and the final report. The maps show sampling locations (i.e., both routine and point source) on a project-wide scale. If more than one map was necessary to cover the extent of the project area, each consecutive map thereafter shared the same scale, terminology, and legend. Maps were also linked to the Phase 3 comprehensive database and were used to create base maps for the spatial presentation of sample results.

Geospatial interpretation of analytical results was used to help identify potential sources of sewage leaks into Harbor Brook, Onondaga Creek, and Ley Creek, and strategize trackdown efforts. The maps were also used to help communicate with stakeholders the sewer system impacts on local waterways and the perceived benefits of Phase 1, 2, and 3 Microbial Trackdown work.

2.12. Task 11 – Data Analysis and Interpretation

Interpretative scales developed for all parameters analyzed during Phase 2 were used for Phase 3 data analysis (Table 6). These scales were applied to all tables and figures for comparative purposes; they were implemented to provide relative perspective of the parameter-specific levels or concentrations in the watershed, spatially (i.e., upstream-downstream gradients). Data tables (Tables 8-76) were compiled for each parameter, measured by task.

Statistical summaries (minimum, maximum, average, and counts) for values were estimated for each location and included with the data tables. References to interpretive scales in text include language within single quotation marks. For example, ‘high’ refers to a high interpretive scale.

Analytical methods for estimating bacteria concentrations are based on a membrane filter method (Appendix B). As a result, bacteria concentrations may not be precise and instead are represented as “less than (<)” or “greater than (>)” a threshold value. In those instances, the delineated value was used to calculate summary statistics and prepare graphs. For example, if a fecal coliforms concentration is represented as “< 6000 cfu/100 mL,” the value 6000 was used for calculating summary statistics and graphing. Highly variable fecal coliform concentration data is common (Sanders et al., 2013) and, for the purposes of data interpretation, were graphed using log scales. Due to the relatively low sample size of priority point source sampling and the nature of flow conditions for most point sources, the bucket-stopwatch method for calculating flow could not be effectively performed. Therefore, fecal coliform loading estimates were not performed with Phase 3 data; contrary to Phase 2.

Table 6. Interpretative scales used for determining level of impact, by parameter.

Parameter	Scale		Parameter	Scale	
Fecal coliform (FCOLI) (cfu/100 mL)	Severe	≥ 50,000	Dissolved oxygen (DO) (mg/L)	Extremely high	14-17
	Very high	10,000-50,000		Very high	12-14
	High	1000-10000		High	8-12
	Moderate	100-1000		Moderate	5-8
	Low	10-100		Low	3-5
	Very Low	≤ 10	pH	Highly alkaline	> 9
Ammonia (NH_3) (mg/L)	Severe	> 0.2		Alkaline	8-9
	High	0.1-0.2		Slightly alkaline	8
	Moderate	0.06-0.10		Neutral	7
	Low	0-0.6		Slightly acidic	6
Total Kjeldahl Nitrogen (TKN) (mg/L)	Hypereutrophic	≥ 1.5		Highly acidic	< 5
	Eutrophic	0.6-1.5	Salinity (SALI) (PPT)	Highly saline	10-35
	Mesotrophic	0.4-0.6		Moderately saline	3-10
	Oligotrophic	< 0.4		Slightly saline	1-3
Total Phosphorus (TP) (mg/L)	Hypereutrophic	≥ 0.1		Freshwater	0-1
	Eutrophic	0.025-0.1	Temperature (TEMP) (°C)	Hot	> 25
	Mesotrophic	0.015-0.025		Warm	20-25
	Oligotrophic	< 0.015		Mild	15-20
Total Suspended Solids (TSS) (mg/L)	Very cloudy	1250-3000		Cool	10-15
	Cloudy	420-1250		Cold	5-10
	Translucent	100-420		Frigid	0-5
	Transparent	40-100	Turbidity (TURB) (NTU)	Very high	> 1000
	Clear	< 40		High	150-1000
Specific Conductivity (COND) (µmHos/cm)	Saline	3000-15,000		Medium	50-150
	Moderately saline (brackish)	1600-3000		Low	10-50
	Slightly saline	800-1600		Very low	5-10
	Freshwater	400-800		Pristine	0-5
	Pristine	0-400			

2.11.1 Statistics

Where possible, the same statistical analyses performed during Phases 1 and 2 were repeated for Phase 3 for comparative purposes. Boxplots were generated for each measured parameter, by task and location, to supplement data tables and provide a visual representation of results. Colored interpretive scales are displayed as a legend within the top graph of two presented on each figure page. Boxplots summarize data into quartiles, with the upper and lower lines of the boxplot representing the 75th and first 25th percentiles, respectively. The interquartile range is the difference between the 75th and 25th percentiles. The middle line of the boxplot represents the second (50th) percentile, or median. The lines (i.e., or whiskers) extending from either end of the boxplot represent the 95th and 5th values and typically include maximum and minimum data points, respectively. A data value is identified as an outlier if it is at least 1.5 interquartile ranges below the first quartile (Q1, 25th percentile), or at least 1.5 interquartile ranges above the third quartile (Q3, 75th percentile). Outliers, if present, are points displayed as circles above and/or below the boxplot, and are the maximum and minimum values, respectively. The number of samples used for the creation of each box plot (i.e., $N = x$) was included in the graph title presented below each figure. For those instances where there were site specific differences in the number of samples used for the plot, the sample number was displayed above or within the plot itself. Line and scatter plots were created instead of boxplots for instances where one sample (i.e., $N = 1$) was collected for each sampling location (e.g., for tributary trackdown sampling graphical representations). Boxplots and line and scatter graphs were calculated using the statistical program Sigmaplot (Systat Software 2018).

Statistical probabilities (i.e., p-value) for the detection of significant differences was commonly (i.e., unless stated otherwise) set at $\alpha = 0.05$. Significant correlations were used to infer potential dependencies (i.e., cause and effect relationships) between observed parameter results. Spearman rank correlation analysis was performed for all parameters measured at each location, by task (e.g., routine, priority point source, etc.). The Holm-Bonferroni method was used to correct for family-wise error associated with numerous correlations (Holm 1979). Correlations were calculated using the statistical programs Sigmaplot (Systat Software 2018) and *Hmisc* in the program R 2.15.1 (Harrell 2012).

The coefficient of variation (i.e., CV, the relative variability or ratio of the standard deviation of the population to the mean) was used to interpret the variability of task-specific system parameter results. This method is used to normalize the apparent variability (i.e., based on standard deviation) of datasets with large standard deviations that also have large means (e.g., fecal coliforms). The associated variability results for small data populations, especially for point source trackdown results, should be interpreted with caution as these small sampling groups provide increased relative error for variability and a variety of other statistical analyses.

One sample t-tests were used to determine significant differences ($p < 0.05$) for water quality measures between system sites using site average data, and one sample signed rank tests were used for datasets with non-normal distributions. Non-normal datasets were identified using the Shapiro-Wilk normality test. Paired t-tests and analyses of variance (ANOVA) were performed for routine sampling locations to detect significant ($p < 0.05$) differences in water quality metrics by: (1) land use/geographic location (e.g., urban versus rural or mainstem versus branch), and (2) tributary. The Mann Whitney Rank Sum test was used for statistical comparisons for datasets where non-normal distributions existed. Where tests for equal variance failed, an ANOVA on ranks was conducted (i.e., Kruskal-Wallis One Way Analysis of Variance on Ranks). All statistical correlation tests were calculated in the statistical programs Sigmaplot (Systat Software 2018) and/or R 2.15.1 (Harrell 2012).

3. Results

3.1. Phase 3 Project Summary & Meteorological Conditions

Field sampling for Phase 3 began on June 11, 2014 and was concluded on August 16, 2017. Collectively, a total of 13 routine sampling events with a total of 24 sampling locations (i.e., Task 3) were completed in Harbor Brook, Onondaga Creek, and Ley Creek. 10 and eight priority point source sampling events (Task 5) were completed in Harbor Brook and Onondaga Creek, respectively. Nine point source trackdown sampling events (Task 6) were completed in Harbor Brook and Onondaga Creek, and one tributary trackdown sampling event (Task 7) was completed at 18 locations within Onondaga Creek.

The 2015 sampling year was the wettest of the four sampling years based on the sum of monthly rainfall data for the entire sampling season (i.e., June-October), with 24.5 inches of rainfall recorded at the Hancock International Airport weather station. The sums of monthly precipitation data for the 2014, 2016, and 2017 sampling seasons were 17.03, 19.82, and 18.09, respectively (Table 7). June 2015 was the wettest of all sampling months, with a total of 9.92 inches of rainfall recorded, while September 2017 was the driest of all sampling months, with only 1.38 inches of rainfall recorded (Fig. 9). The number of regularly scheduled sampling events (i.e., routine and priority point source sampling) that had to be cancelled due to rain was greater in 2014 than in 2015; four and one event(s) were cancelled in 2014 and 2015, respectively.

Table 7. Precipitation data (in inches) for Phase 3 sampling seasons, by year. The number of routine and priority point source events that had to be cancelled due to rain are denoted.

Year	*June*	*July*	*August*	*September*	*October*	***Mean***	***Total***	***No. Rain-driven event cancellations***
2014	2.74	5.18	3.13	1.6	4.38	**3.41**	**17.03**	**4**
2015	9.92	3.37	1.91	5.52	3.77	**4.90**	**24.5**	**1**
2016	1.95	2.65	4.05	3.76	7.41	**3.96**	**19.82**	**-**
2017	4.63	4.19	1.8	1.38	6.09	**3.62**	**18.09**	**-**

3.2. Routine Sampling (Task 3)

3.2.1. Harbor Brook

Routine bacteria sampling in Harbor Brook identified discharges at, and potentially upstream of, Velasko Rd. Bacteria levels have continued to be problematic in Harbor Brook since Phase 1 (2008-2009) and Phase 2 sampling (2012-2013). Differences in water quality between urban and rural sampling locations illustrate the broad effect of urbanization and anthropogenic influences on stream degradation in Harbor Brook. Impacts associated with increased runoff and development (commercial and residential), as well as the application of road salts, appear to be substantial contributors to water quality degradation and elevated bacteria concentrations.

3.2.1.1. Water Quality

Water quality parameters in Harbor Brook were significantly different among sample sites and their levels appeared to be driven by land use and the effects of anthropogenic impacts caused by urban runoff. While no significant differences were found for pH, both specific conductivity and salinity were found to be significantly different ($p < 0.05$, two sample t-test) among sample locations by land use categories (i.e. rural vs. urban). Measured pH in Harbor Brook ranged between neutral (6.5-7.5) and very alkaline (>9) levels (Fig. 10, Table 8). Consistent with Phase 2 observations, the highest average pH ($\bar{x}$=8.1) was observed at Onondaga Rd, the most upstream sampling location. Alkaline water quality conditions may be due to the geology of the area; exposed limestone bedrock is the predominant substrate type. Specific conductivity levels ranged between pristine (0-400 µmHos/cm) and saline (3000-15,000 µmHos/cm), with a noteworthy increase between rural and urban locations (Fig. 11, Table 9). The 43% increase in average concentrations between Grand Ave and Velasko Rd suggested a potential source between both locations (e.g., Western Lights Plaza) that was also apparent in the Phase 2 study (OEI 2015). Correspondingly, salinity levels displayed similar trends at routine sampling locations (Fig. 12) with average concentrations higher in more urban areas than at rural locations; which exhibited levels indicative of 'freshwater' conditions (Table 10). Average salinity concentrations (i.e., slightly saline) were highest at Delaware Street.

Dissolved oxygen (DO) concentrations were, on average, more spatially and temporally variable than other water quality metrics (Table 11). DO concentrations ranged between moderate and excessive levels (Fig. 13). Average DO was highest at Hiawatha Blvd and lowest at Fowler HS (Table 11). Average DO at all Harbor Brook routine sampling locations for the entire study was 10.4 mg/L, and the CV was 16.3%. There were no significant differences for average DO concentration by land use category (i.e., rural or urban, $p > 0.05$, two sample t-test). Measured stream temperatures ranged between cool (10-15º) and warm (20-25ºC) for all locations (Fig. 14). General trends in stream temperature data correspond with seasonal variation (Table 12). Turbidity levels for routine sampling locations ranged between pristine (0-5 NTU) and low (10-50 NTU). Consonant with Phase 2 observations observed average turbidity was lowest (1.64 NTU) at Grand Ave and highest (6.18 NTU) at Hiawatha Blvd (Table 13). Turbidity levels generally increased downstream of Grand Ave (Fig. 15), yet significant differences ($p < 0.05$, t-test) were not found for average turbidity concentrations by land use category. Hiawatha Blvd had the highest maximum turbidity level in Harbor Brook, observed during a routine sampling event on September 29, 2014 (22.1 NTU, Table 13). The high turbidity level observed during this event corresponded with above average measurements of conductivity and pH and a below average concentration of fecal coliforms. These combined findings are indicative of the potential influence of alkaline Solvay waste materials, which produce a milky-white discharge of suspended material high in ionic concentrations[7].

3.2.1.2. Fecal Indicator Bacteria

Measured fecal coliforms levels ranged between very low (0-10 cfu/100mL) to high (1000-10,000 cfu/100mL) at Harbor Brook routine sampling sites (Table 14). The minimum sampling value (9 cfu/100mL observed during two events at Bellevue Ave.) was an improvement from Phase 2 Fecal coliforms minimum levels, which fell within the moderate (100-1000 cfu/100mL) interpretive data range. The CV for fecal coliforms is high (i.e., 99.5%) between observed values for the sampling sites; highly variable data is common for this analyte (Sanders et al., 2013). The highest average fecal coliforms concentrations in Harbor Brook were observed at Hiawatha Blvd, while the lowest average fecal coliforms concentration was found at Bellevue Ave (Table 14). Bacteria levels were generally higher for most sampling locations in Harbor Brook during summer months (i.e., June-August, Table 14). Bacteria levels in Harbor Brook observed during Phase 3 routine sampling were often above the NYSDEC Water Quality

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[7] This is supported by investigative work performed by Onondaga County on September 15, 2017. Staff from WEP's Flow Control Division verified that white discharge was coming from a City storm outfall. It is believed that Solvay waste materials are infiltrating the storm pipe via breakages in the pipe.

Standard for fecal coliforms, with 70% of all samples exceeding the standard during dry weather; the highest of all three tributaries.

Average bacterial concentrations at the rural sampling locations (i.e., Onondaga Rd, Bellevue Ave, and Grand Ave) were significantly less ($p < 0.05$, t-test) than urban locations (Fig. 16, Table 1). Significant increases in site average bacteria levels downstream and between land use types suggest that these trends are due to dry weather bacterial inputs in urban locations. Phase 3 results tracked Phase 2, demonstrating substantive increases in bacteria levels between Grand Ave and Velasko Rd; this suggested ongoing bacterial source(s) just above Velasko Rd were impacting downstream fecal coliforms levels (Fig. 15). The average fecal coliforms concentration for Harbor Brook was 670 cfu/100mL; approximately three-fold higher than NYS DEC criteria levels (i.e., 200 cfu /100mL) for both years.

3.2.2. Onondaga Creek

Phase 3 routine sampling in Onondaga Creek documented the effects of several, often compounding, water quality and bacteria concerns that were also observed during Phase 2 and included: 1) the apparent effects of agriculture, mudboil activity, and infiltration from brackish springs impacted water quality at rural sampling locations and 2) bacteria concentrations increased downstream in the urban watershed, a likely effect of an increase in point source discharges and, likely, non-point sources from failing sewers.

3.2.2.1. Water Quality

All site average parameters measured during routine sampling were significantly different ($p < 0.05$, one sample t-test or Mann Whitney Rank Sum test) between sampling locations. The occurrence of significant differences for all water quality parameters between sampling locations observed for Onondaga Creek may be explained by a relatively large watershed (i.e., compared with Harbor Brook and Ley Creek) that undergoes substantial longitudinal differences in land use, landscape, and channel alteration. Nevertheless, unlike Phase 2 observations, no significant differences were found for water quality parameters and fecal coliforms concentrations between rural and urban spatial subgroups ($p > 0.05$, t-test).

Measured DO was consonant with Phase 2 observations and ranged between 'moderate' (5-8 mg/L) and 'excessive' (>14.6 mg/L, Fig. 18) for all sampling locations, and most DO data fell within the 'high' range; DO levels in Onondaga Creek were not considered problematic on average. The highest DO measurement was observed at South Ave and the lowest at Hitchings Rd and Rte. 20 (Table 15). The CV for DO was 17.6%. Stream temperature was somewhat more variable (i.e., CV = 20.1%). Average stream temperatures were 'mild' (15-20°C) for all sites; the lowest average temperature was observed at Bear Mountain Rd (Table 16). The decrease in stream temperature observed downstream of W. Newell St may be associated with increased shading through the urban corridor and cooler water inputs from adjacent tributaries. The highest average temperature was observed at Hitchings Rd (West Branch of Onondaga Creek) (Table 16). This conspicuous 'warm' water input from the West Branch of Onondaga Creek may be driven by a relative lack of shading along the stream corridor and/or comparatively sluggish conditions. Fluctuations in temperature at all sampling locations were consistent with seasonal temperature dynamics. Yet, consistently 'warm' observations and a single 'hot' observation at Hitchings Road are noteworthy (Fig. 19). These relatively high temperatures and associated low DO concentrations (i.e., in part, based on the inverse relationship between these two water quality metrics) may be due to the low gradient wetland areas that exist upstream of Hitchings Road.

Average pH ranged between 7.74 (‘slightly alkaline’) and 8.19 (‘alkaline,’ Table 17). Consonant with Phase 2 observations, pH at Tully Farms Rd was higher on average than at other routine sampling locations (Fig. 20) and was likely primarily driven by the geology of the upper watershed (e.g., limestone bedrock). The observed downstream decrease in pH during Phase 2 was also observed during Phase 3, and the lowest average pH was observed at W. Kirkpatrick St (Table 17); this apparent gradient from the upper, rural to the lower, urban subwatersheds (Fig. 20) was not statistically significant ($p < 0.05$, Mann Whitney rank sum test).

Trends in specific conductivity (Fig. 21), salinity (Fig. 22), and turbidity (Fig. 23) in Onondaga Creek from routine sampling indicated the noteworthy effects of the Tully Valley mudboils, as well as associated landslides, on stream water quality that tracked previous phases and other studies in the watershed (i.e., OEI, 2013). The CV for specific conductivity was 69.7%. Aligned with Phase 2 results, specific conductivity levels ranged from ‘pristine’ to ‘saline’ (Fig. 21). Average specific conductivity levels were lowest at the most upstream location, Tully Farms Rd, and highest at the most downstream location, W. Kirkpatrick St (Table 18). Moreover, average specific conductivity levels more than doubled between Walton St and W. Kirkpatrick St (Fig. 21). Previous research indicated this significant ($p < 0.05$, paired t-test) effect was likely manifested by the infiltration of natural saltwater springs discharging to the creek (OEI 2009, Kappel, 2014, OEI 2015). Site-specific salinity levels directly fluctuated with specific conductivity levels and displayed similar trends (Fig. 22); 98% of the differences in salinity could be explained by differences in specific conductivity (linear least squares regression). Salinity levels ranged between ‘freshwater’ and ‘slightly saline’ (Fig. 22, Table 19). Average salinity levels were highest at locations immediately downstream of the saline freshwater springs in the upper watershed (i.e., Rte. 20) and at the most downstream location, W. Kirkpatrick St (Table 19). The CV for salinity was 69.96%. Consonant with Phase 2 results, all salinity concentration observations at W. Kirkpatrick St fell within the ‘slightly saline’ interpretive scale (Fig. 19). The uniformity of both specific conductivity and salinity between study phases suggests the relatively unchanged location-specific salts impacts within the watershed.

Observed turbidity levels ranged between ‘pristine’ and ‘medium’ (Fig. 23). The highest and lowest site average turbidity levels were 44.62 NTU (Rte. 20) and 10.15 (W. Kirkpatrick St), respectively (Table 20). The CV for turbidity was 99.3%. Consonant with Phase 2 results, the highest average turbidity levels were at sampling locations immediately downstream of inputs from the Tully Valley (Fig. 23). A reduction in turbidity downstream of Gibson Road was also observed (Fig. 23). These data support other research (Kappel, 2014) that describes the impacts of the Tully valley mudboils’ sediment discharges on downstream water clarity. Based on apparent turbidity dynamics, suspended sediments appeared to settle somewhat downstream, following the immediate peak from mudboil discharges, and there is an apparent dilution effect from the convergence of the downstream West Branch of Onondaga Creek (Fig. 23).

3.2.2.2. Fecal Indicator Bacteria

Fecal coliforms concentrations for routine sampling in Onondaga Creek ranged between ‘very low’ and ‘high’ (Fig. 24), a noteworthy improvement from Phase 2 observations that had concentrations fall within the ‘very high’ interpretive scale range (OEI 2013). The lowest average fecal coliforms concentration (104 cfu/100mL) was observed at Hitchings Rd (Table 21). The highest site average fecal coliforms concentration was recorded at Rte 20 (941 cfu/100mL, Table 21). The CV for fecal coliforms was 151.1%. Despite the highly variable dataset, an increasing trend in fecal coliforms concentrations was observed downstream from Tully Farms Rd (Fig. 24); nevertheless, significant differences for average fecal coliforms concentrations between rural and urban watersheds were not observed ($p < 0.05$, Mann Whitney Rank Sum test). In alignment with Phase 2 results, bacteria levels tended to decrease during fall months (October and November). This may have been attributed to a decrease in land use activities (i.e., agricultural practices) within the watershed and/or the relative decrease in water temperatures that was not conducive to bacterial growth. Overall, average fecal coliform concentrations for all routine sites in Onondaga Creek were considered moderate (Fig. 25). Bacteria levels in Onondaga Creek observed during Phase 3 were commonly above the NYSDEC Water Quality Standard for fecal coliforms, with 57% of samples exceeding the standard during dry weather. Of the three tributaries, Onondaga Creek had more samples with fecal coliform concentrations below the NYSDEC Water Quality Standard than Ley Creek or Harbor Brook.

3.2.3. Ley Creek

Routine sampling documented spatial differences in site average water quality and bacteria concentrations in Ley Creek. Converse to Phase 2 results, observed average bacteria levels in Ley Creek were higher in the South Branch rather than North Branch sampling locations, and concentrations were greatest in the more urbanized mainstem. Consonant with Phase 2 sampling observations, the dilution of several site average water quality parameter concentrations downstream of the confluence of the two branches (i.e., the mainstem) was exhibited.

3.2.3.1. Water Quality

Site average water quality parameters were not significantly different ($p < 0.05$, Kruskal-Wallis One Way Analysis of Variance on Ranks) between stream segments (i.e., North Branch, South Branch, and the Mainstem), yet several differences were noteworthy. During routine sampling in Ley Creek, specific conductivity ranged between ‘slightly saline’ and ‘moderately saline’ levels (Fig. 26) and salinity levels ranged between ‘slightly saline’ and ‘freshwater’ (Fig. 27). The CV for all sampling locations for specific conductivity and salinity were 27.7% and 29.1%, respectively. Both parameters exhibited higher site-specific average concentrations in the South Branch than in the North Branch that were ‘averaged’ in part, in the mainstem downstream of the confluence of both branches (Tables 22 & 23). This difference between north and south branch measurements were inconsistent with Phase 2 results, which demonstrated lower average levels in the South Branch than in the North Branch (OEI 2015). Observed differences between Phase 2 and Phase 3 specific conductivity and salinity observations at Exeter St were particularly noteworthy. While average salinity and specific conductivity concentrations fell within the ‘pristine’ range at Exeter St (South Branch) during Phase 2, Phase 3 observations exhibited ‘slightly saline’ to ‘moderately saline’ conditions for both salinity and specific conductivity parameters. In fact, the highest site average salinity and specific conductivity concentrations were observed at Exeter St, while Thompson Rd (North Branch) exhibited the lowest (Tables 22 & 23).

DO concentrations during routine sampling ranged between 'moderate' and 'high' (Fig. 28), an apparent improvement from 'low' concentrations observed in Phase 2 that suggested DO levels may have been stressed in this system. Moreover, on several occasions in the mainstem, observed DO levels were "very high' (Table 24). Among the three branches, average site-specific DO concentrations at Thompson Rd (North Branch) were lowest while observations were highest at Court St. (South Branch). The CV for all site average DO concentrations was 19.9%. Levels of pH ranged between neutral and alkaline levels during sampling events (Fig. 29, Table 25). Average pH levels tracked Phase 2 observations and ranged between 7.5 and 8.0 (Table 25). Site average pH observations were highest at Court St (South Branch), which had the highest average pH level of any location, with seven out of 11 events having pH levels considered 'alkaline.' The CV for pH for routine sampling was 2.8%.

Consonant with Harbor Brook and Onondaga Creek, common seasonal dynamics in stream temperature were observed in Ley Creek (Table 26). Site average temperatures in Ley Creek during Phase 3 routine sampling did not differ significantly by stream reach ($p < 0.05$, Kruskal-Wallis One Way Analysis of Variance on Ranks). The CV for all average temperatures was 19.5%, with temperatures ranging between 'cold' and 'warm' (Fig. 30). The lowest average temperature was at Fly Rd (North Branch) and the highest at Lemoyne Ave (i.e., within the Mainstem, Table 26). Differences in average stream temperatures may have been, in part, driven by canopy cover, which was greater and less fragmented in the North Branch than along the South Branch and Mainstem. Turbidity levels were relatively low in Ley Creek, ranging between 'pristine' and 'low' (Fig. 31). The lowest site average turbidity level was observed at Court St (i.e., South Branch) and the highest at Park St (i.e., Mainstem, Table 27). The CV for turbidity was 77.5%; the relatively high (i.e., relative to other water quality parameters) variability for the turbidity metric is common (Dogliotti et al.). The almost two-fold difference in turbidity between the North and South Branches is noteworthy (Fig. 31). With the inclusion of the mainstem, however, significant differences among the stream segments were not found ($p < 0.05$, Kruskal-Wallis One Way Analysis of Variance on Ranks). When statistical analyses were conducted between the North and South branches only, differences in average turbidity were significant ($p < 0.05$, paired t-test).

3.2.3.2. Fecal Indicator Bacteria

Fecal coliforms concentrations ranged between 'low' and 'high' for Ley Creek sampling locations (Fig. 32), and were significantly different ($p < 0.05$, Kruskal-Wallis One Way Analysis of Variance on Ranks) among branches. Maximum bacterial concentrations ranged between 'moderate' and 'high' (Table 28); this was an improvement from Phase 2, which ranged between 'moderate' and 'very high.' During Phase 2, the highest site average fecal coliforms concentrations were observed at sampling locations in the North Branch (i.e., Fly Rd and Thompson Rd) and the lowest at locations in the South Branch (i.e., Exeter St and Court St). During Phase 3, site average fecal coliforms levels were higher in the South Branch than the North Branch and were highest in the mainstem (Fig. 33). The highest site average fecal coliforms concentration was observed at Park St. and the lowest at Thompson Rd. (Table 28).

The CV for all Ley Creek sites was 74.79%. In-stream fecal coliforms levels among branches (i.e., South, North, and Mainstem) were not significantly different ($P < 0.05$, Kruskal-Wallis One Way Analysis of Variance on Ranks). Average fecal coliforms concentrations for 2014 and 2015 were 402 cfu/100mL and 409 cfu/100mL, respectively, approximately one-fold higher than NYS DEC criteria (i.e., 200 cfu/100mL) for both years. Bacteria levels in Ley Creek observed during Phase 3 were commonly above the NYSDEC Water Quality Standard for fecal coliforms, with 65% of samples exceeding the standard during dry weather.

3.2.3.3. Relationships Between Parameters: Correlation Analysis

Correlation analysis for routine sampling data yielded several noteworthy, significant relationships ($p < 0.05$). The only parameters that exhibited a strong positive correlation were salinity and conductivity ($r = 0.98$; $p < 0.0001$), which supports the strong dependency expected between these metrics (Table 29). Weakly linear ($r = |0.40|$), yet significant ($p < 0.05$) relationships were observed for nearly all parameters, except for chlorine residual; chlorine residual was not significantly correlated with any of the other measured parameters (Table 29).

DO was significantly correlated with pH and temperature; DO was positively correlated with pH and negatively correlated with temperature (Table 29). In addition to salinity, specific conductivity exhibited significant relationships with both turbidity and fecal coliforms. Correlations showed a negative response in conductivity concentrations to turbidity, suggesting sites with increased turbidity levels tended to have lower specific conductivity. Specific conductivity was positively correlated ($p < 0.0001$) with fecal coliforms (Table 29). In addition to dissolved oxygen, pH was also significantly correlated with salinity ($p < 0.0001$), exhibiting a weak negative, linear relationship ($r < -0.40$). The significant, negative correlation between fecal coliforms and pH observed in Phase 2 was not observed in Phase 3.

Stream temperatures were significantly correlated with turbidity (Table 29). The weak positive relationship suggest increases in turbidity concentrations affects stream temperature. The established relationships between cool or excessively warm stream temperatures and bacterial die-off that was supported by significant dependencies observed in Phase 2 was not supported by observations in Phase 3; while, the positive relationship between the two metrics was evident, it was not significant in Phase 3 ($p > 0.05$).

Salinity was significantly correlated with turbidity concentrations ($p < 0.05$, Table 29). The observed weak negative relationship corresponds with the relationship observed between turbidity and specific conductivity, and further emphasizes the inherent dependency between conductivity and salinity (Table 29).

3.2.4. Upper Onondaga Creek Routine Sampling (Task 3.1)

3.2.4.1. Water Quality

Average water quality parameters measured during Upper Onondaga Creek sampling were significantly different ($p < 0.05$, one sample t-test and/or Mann Whitney Rank Sum test) among sampling locations. Similar with routine sampling in lower Onondaga Creek, DO ranged between ‘moderate’ (i.e., 5-8 mg/L) and ‘excessive’ (i.e., >14.6 mg/L, Fig. 34) for all sampling locations, and most DO observations were within the ‘high’ interpretive scale range. Overall, DO levels in Upper Onondaga Creek were not considered problematic. The highest average DO level was at Webb Rd. in Hemlock Creek, while the lowest was at Hitchings Rd. (Table 30). The CV for DO was 35.3%, substantially higher than the CV calculated from routine sampling results for lower Onondaga Creek (i.e., 17.6%); suggesting that the Upper Onondaga Creek watershed exhibited greater variability in DO than the lower, urban watershed. Stream temperatures in upper Onondaga Creek were less variable (i.e., CV = 16.7%) than in the lower watershed (i.e., routine sampling locations). Nevertheless, 35% of the differences in DO can be explained by differences in temperature (linear least squares regression); the magnitude of this dependency was slightly greater (i.e., 7%) than in the lower watershed. Fluctuations in temperature at all sampling locations were consistent with seasonal temperatures dynamics (Table 31). Average stream temperatures were mostly 'mild' (15-20°C) (Fig. 35), consonant with routine (Task 3) Onondaga Creek observations. The overall average temperature for all sites sampled in the upper watershed was 16.07°C, 1.17°C (i.e., 7%) lower than that reported for Onondaga Creek routine sampling locations. This difference may be due to enhanced canopy structure in the upper watershed relative to the lower, more urban watershed, and the fact that the upper watershed sampling sites are closer to the headwaters and groundwater inputs. The lowest average temperature (i.e., 14.05°C) was observed at route 11A in Williams Creek (Table 31). The highest average temperature (19.62°C) was observed at Red Mill Rd in Onondaga Creek's West Branch; most temperature observations at this location were between 'mild' and 'warm.'

Average pH in Upper Onondaga Creek ranged between 7.82 (i.e., 'slightly alkaline') and 8.3 (i.e., 'alkaline,' Table 32); both statistics were higher than reported for routine sampling for pH, indicating the upper creek is more alkaline. The observed general downstream decrease in pH (Fig. 36) was consistent with routine Onondaga Creek observations for Phase 3 and previous phases. This provided additional evidence of the impacts of the natural geologic condition (i.e., upstream limestone bedrock and the common downstream influence of organic acids) on water quality. The CV for pH in Upper Onondaga Creek was 2.6%, 7% greater than that metric of variability for pH during routine sampling.

The CV for specific conductivity measurements in Upper Onondaga Creek was 35.2%. Specific conductivity levels ranged from 'pristine' to 'moderately saline' (Fig. 37) and, unlike levels observed during routine sampling, never reached the upper 'saline' interpretive scale range. Conspicuous elevated specific conductivity levels between Otisco Rd (upstream) and Gibson Rd (downstream) were likely caused by mudboil saltwater spring discharges to the creek. Such observations have been made during previous studies and are the likely result of historic brine solution mining (OEI 2015). The lowest specific conductivity concentrations were observed at Tully Farms Rd. (south), consonant with observations from routine sampling. The highest specific conductivity levels were observed at Buffalo Hill Rd. (Table 33). Site-specific salinity levels directly fluctuated with specific conductivity levels and displayed similar trends (Fig. 38); 99% of the differences in specific conductivity could be explained by differences in salinity (linear least squares regression). Unlike observations during routine sampling, observed salinity levels were only within the 'freshwater' interpretive scale range (Table 34). The CV for salinity was 35.6%, substantially less than the CV calculated for salinity observations made during routine sampling (49%) that included urban downstream sampling locations. These data support the apparent influence of urban salts, likely road salts, which manifest elevated salinity levels in lower Onondaga Creek.

Turbidity levels in Upper Onondaga Creek ranged between ‘pristine’ and ‘high’ (Fig. 39). The lowest and highest site average turbidity levels were 2.12 at Woodmancy Rd. and 103.23 NTU at Tully Farms Rd., respectively (Table 35). The CV for turbidity was 117.7%, 16% greater than routine sampling turbidity data. This substantially greater variability in turbidity measurements observed in upper Onondaga Creek than for downstream, routine sampling locations was manifested by the inclusion of sampling sites within upper Onondaga Creek that varied between ‘pristine’ (i.e., at west branch sampling locations) and ‘very high’ turbidity levels; this is likely caused by the proximity of these sampling locations to the Tully Valley mudboils (Fig. 39). Consonant with routine sampling observations, the reduction in turbidity levels observed downstream of Otisco Rd. and Gibson Rd. indicate the dilution effects of adjoining tributaries, as well as the settling of suspended sediments downstream following the immediate peak from mudboil discharges. This assessment was further evaluated by the inclusion of Total Suspended Solids (TSS) sampling as part of the upper Onondaga Creek program. Site average total suspended solids concentrations ranged between 3 mg/L and 142 mg/L at Webb Rd. (i.e., Hemlock Creek) and Otisco Rd. (immediately downstream from the mudboils), respectively (Table 36). For nearly all sites, TSS values ranged between ‘clear’ and ‘transparent’ levels (Fig. 40).

3.2.4.2. Fecal coliforms and Nutrients

Site average fecal coliforms concentrations for upper Onondaga Creek ranged between 130 cfu/100mL (i.e. ‘moderate’) and 4394 cfu/100mL (i.e., ‘very high’) observed at Tully Farms Rd (south) and Solvay Rd, respectively (Table 37). The CV for fecal coliforms was 334.3%. The highly variable and non-normally distributed ($p < 0.05$, Shapiro Wilk normality test) site average dataset was significantly different ($p < 0.001$, one sample signed rank test) among sampling locations. Downstream trends within the Mainstem were not found. Yet, conspicuously lower bacteria concentrations were observed in associated tributaries than in the Mainstem (Fig. 41). Several sampling locations within the Mainstem exhibited relatively high fecal coliforms concentrations. An increasing trend in bacteria concentrations observed in Upper Onondaga Creek downstream of Tully Farms Rd was not identified; the inclusion of routine sampling data was necessary to identify this trend. Upper Onondaga Creek sampling locations where observed average bacteria concentrations were considered ‘high’ included: Solvay Rd., Otisco Rd., Nichols Rd., Buffalo Hill Rd., Flood Control Dam, Gibson Rd., and Webb Rd. (Fig. 42). Site average fecal coliforms concentrations observed at Solvay Rd. were nearly three-fold greater than the other six sites listed above.

All site average total phosphorus (TP), ammonia (NH_3-N), and total Kjeldahl nitrogen (TKN) concentrations were significantly different ($p < 0.001$, One-Sample Signed Rank Test) among sampling locations. The coefficients of variation for TP, NH_3-N, and TKN were 182.6%, 112.0%, and 62.0%, respectively. Site average concentrations for both TP (Fig. 43) and TKN (Fig. 44) for all locations were within the range of ‘oligotrophic’ and ‘eutrophic’ interpretive scales. Site average concentrations for NH_3-N for all locations ranged between ‘low’ and ‘high’ (Fig. 45). The highest site average TP concentration was observed at Otisco Rd. (Table 38). Relatively high TP concentrations at this sampling location may be attributed to upstream mudboil sediment discharges and the characteristics of TP adsorption to sediments (Tang et al. 2017). The highest site average concentrations for nitrogen series metrics (i.e., TKN and NH_3-N) were observed at Red Mill Rd. (West Branch, Table 39 & Table 40). Consonant with spatial trends observed for fecal coliforms observations, several of the sampling locations existing in the Mainstem exhibited relatively high nutrient concentrations; the Flood Control Dam and Gibson Rd. locations demonstrated relatively high concentrations of nutrients and bacteria. Of the fecal coliforms-nutrient dependencies examined spatially, the strongest relationship ($r = 0.31$) existed between fecal coliforms and NH_3-N, yet this relationship was not considered statistically significant ($p < 0.05$).

3.2.4.3. Relationships Between Parameters: Correlation Analysis

Correlation analysis demonstrated many strong ($r > |0.40|$) and significant relationships ($p < 0.05$) for parameters collected in the upper Onondaga Creek watershed (Table 41). Consonant with routine sampling, chlorine residual concentrations did not vary substantially among sites and events; therefore, significant relationships with the other measured parameters were not observed.

DO was found to be positively ($r = 0.48$) and significantly correlated ($p < 0.05$) with pH levels (Table 41). DO was also significantly correlated with TKN and TP ($p < 0.05$), though these relationships were weakly linear ($r < -0.40$). Consonant with routine sampling, specific conductivity was strongly positively correlated with salinity ($r = 0.98$; $p < 0.0001$). Unlike routine sampling, however, specific conductivity values in the upper Onondaga Creek watershed were correlated with turbidity ($r = 0.41$, $p < 0.05$); parameters exhibited a positive linear relationship (Table 41). Weak linear, but significant relationships ($p < 0.0001$) were also observed between specific conductivity and: fecal coliforms, TSS, TKN, and TP (Table 41). Not only was pH strongly linearly correlated with DO, it was also significantly correlated with specific conductivity, salinity, and NH_3-N (Table 41). In addition to DO, temperature was also significantly correlated with fecal coliforms, turbidity, TSS, NH_3-N, TKN, and TP. Forty percent of the differences in DO could be explained by fecal coliform ($r = 0.40$, Table 41). Nutrient concentrations (i.e., NH_3-N, total TKN, and TP) were also all significantly ($p < 0.0001$) and positively ($r > 0.40$) correlated with each, highlighting some dependencies, albeit weak, among these parameters (Table 41). In addition to temperature, fecal coliforms concentrations exhibited some positive, and significant relationships with turbidity, TSS, and TP ($r > 0.40$; $p < 0.0001$). A weak linear, but significant relationship was observed between fecal coliforms and salinity (Table 41).

Salinity was also moderately ($r > 0.40$) and significantly ($p < 0.05$) correlated with turbidity (Table 41). Significant correlations were also observed between salinity and TSS, TKN, and TP (Table 41). Turbidity was positively and significantly correlated TSS, TKN, and TP. Turbidity was also significantly correlated with NH_3-N, though this was a weak linear relationship (Table 40). Observed spatial trends for turbidity (Fig. 39) were congruous with those for TSS (Fig. 40). Turbidity is commonly used as a reliable surrogate metric for TSS (Hannouche et al., 2011) and the highly significant ($P < 0.001$) correlation between the measures ($r = 0.89$) provided strong support for its use here.

3.2.5. Priority Point Source Sampling (Task 4)

Priority point source sampling identified several point sources that were remedied following Phase 2 sampling, as well as several that remained problematic, or have since gotten worse. Regular sampling of these point sources helped to better understand temporal changes in bacterial inputs, as well as changes in water quality and flows, allowing for a better estimation of loadings and the potential effects on in-stream water quality.

3.2.5.1. Harbor Brook

3.2.5.1.1. Water Quality

Averages for all water quality parameters measured during priority point source sampling at Harbor Brook, except for DO, were significantly different ($p < 0.05$, one sample t-test) among sampling locations. Average DO concentrations at the three point source locations were within the 'high' or 'moderate' interpretive scale ranges (Table 40). The CV for DO was 125.0%, exhibiting 108.7% greater variability than for Harbor Brook routine sampling. DO concentrations (i.e., 4.6 mg/L and 4.9 mg/L) observed during two sampling events at the Harbor Brook constructed wetland outfall (PS-101BW) were within the 'low' interpretive scale range and the site average value (6.6 mg/L) was closer to the lower threshold for the 'moderate' interpretive scale range (Fig. 46, Table 42); PS-101BW continues to be a point source of concern for DO.

Priority point source temperature variability (i.e., CV = 15.8%) in Harbor Brook was only slightly greater (i.e., 3.1%) than during routine stream sampling, and the differences in DO could not be explained by differences in temperature ($p < 0.05$, linear least squares regression). Fluctuations in temperature at all sampling locations corresponded with seasonal temperature dynamics (Table 43). Stream temperatures fell within or between the 'cool' (10-15°C) and 'warm' (20-25°C) interpretive scales (Fig. 47). On average, priority point source discharge temperatures were 1.6°C warmer than for routine sampling locations. This may be attributed to low volumes and stagnating conditions, compared to in-stream, routine samples. The lowest average temperature (14.77°C) was observed at Depalma Ave. (i.e., PS-103), and the highest average temperature (19.00°C) was observed at the Harbor Brook constructed wetland outfall (i.e., PS-101BW, Table 44).

Discrete pH levels observed for Harbor Brook point sources ranged between 7.23 ('neutral') and 7.92 ('slightly alkaline,' Fig. 48). Most of the observed pH levels were considered 'slightly alkaline' (Table 44), which was consistent with observations made during routine sampling. Average differences in pH were significant ($p < 0.05$, one-sample t-test), yet extreme (i.e., highly acidic or highly alkaline) trends and longitudinal gradients (e.g., relationship between pH and downstream order for Harbor Brook) were not evident. Moreover, the CV for pH levels between priority point source sampling locations along Harbor Brook was 2.6%.

Specific conductivity concentrations ranged from 'slightly saline' to 'moderately saline' (Table 45) and were consonant with concentrations observed during routine sampling, exhibiting a slight increasing trend with downstream order (Fig. 49). Over 75% of observed specific conductivity levels for priority point sources were within the higher, 'moderately saline' interpretive scale range. The highest specific conductivity concentration (i.e., 2893 µmHos/cm) was observed at HB-PS101BW (Harbor Brook Constructed Wetland Outfall, Table 45). The CV for specific conductivity concentrations between priority point source sampling locations was 27.1%, and the differences between site average concentrations were significant ($p < 0.05$, one-sample t-test). Observed dependencies between specific conductivity and salinity levels were examined for point sources, and a strong positive significant correlation ($R = 1.00$, $p < 0.05$) was identified. Consistent with observations made during routine sampling, salinity ranged between 'freshwater' and 'slightly saline' levels (Fig. 50, Table 46). Average salinity levels were significantly different among sample locations ($p < 0.05$, one-sample t-test). Notwithstanding these statistical differences, most of the salinity observations at priority point sources were within the 'slightly saline' range (Fig. 50). The CV for salinity was 27.7%, 5.1% lower than the CV calculated for salinity observations made during routine sampling that included more sampling locations and urban downstream sampling locations.

The sonde used during priority point source sampling events was not equipped with a turbidity probe. Therefore, turbidity measurements were not taken.

3.2.5.1.2. Fecal coliforms

Site average fecal coliforms concentrations for Harbor Brook priority point sources ranged between 'moderate' (230 cfu/100 mL) and 'very high' (11,909 cfu/100mL) levels, with PS-103 (Depalma Ave) having the lowest average fecal coliforms level and PS-101BW (Harbor Brook constructed wetlands outfall) having the highest (Table 47, Fig. 51). The CV for fecal coliforms was 395.2%; fecal coliforms concentrations were highly variable, and the dataset was non-normally distributed ($p < 0.05$, Shapiro Wilk normality test). Furthermore, differences in concentration averages among sites were not significant ($p < 0.05$, one sample signed rank test) and may have been due to random sampling variability. HB-PS101BW is currently part of an ongoing investigation for bacteria based on the regulatory compliance requirements of Onondaga County for a NYSDEC SPDES permit necessary for constructed wetlands facility operations. Most fecal coliforms concentration observations made at HB-PS103 were low (Fig. 52), demonstrating important reductions in bacteria concentrations since the removal of a cross connection completed prior to Phase 2.

3.2.5.2. Onondaga Creek

3.2.5.2.1. Water Quality

All site average water quality parameters observed during priority point source sampling were significantly different ($p < 0.05$, one sample t-test and/or Mann Whitney Rank Sum test) between priority point source sampling locations. Dissolved oxygen observations ranged between 'low' (3-5 mg/L) and 'excessive '(>14.6 mg/L) for all sampling locations, and > 50% of observed DO values were within the 'high' interpretive scale range (Fig. 53, Table 48). On average, DO levels for Onondaga Creek priority point sources were not considered problematic. Nevertheless, DO concentrations were generally lower at priority point sources than at routine sampling locations. The highest average DO was observed at OCPS-03 at W. Glen Ave. and the lowest at OCPS-20, 100 ft upstream of West Adams St. (Table 48). Some relatively high DO observations existed, represented by wide ranging 95^{th} percentile ranges (i.e., long whiskers), for five monitored priority point sources (Fig. 53). One DO concentration observation at both OCPS-23 and OCPS-11 was within the 'low' interpretive scale. The CV for DO was 52.2%, 34.6 % higher than the CV calculated for routine sampling results for Onondaga Creek. Stream temperatures at Onondaga Creek priority point sources were less variable (i.e., CV = 16.8%) than at routine sampling locations, yet average temperature differences between sites were significant ($p < 0.05$, one sample t-test). The inverse relationship between temperature and DO was explored for priority point sources, and 60% (linear least square regression) of the differences in

DO could be explained by differences in temperature. The power of the statistical relationship is weak, in part, due to the low number (N=10) of sampling locations, and the dependency should be interpreted cautiously. Maximum temperatures were considered ‘warm’ at three sampling locations: OC-PS71 (300 ft downstream of South Ave.), OC-PS20 (100 ft upstream of West Adams St. near Byrne Dairy, CSO-037), and OC-PS92 (W. Water St., Fig. 54). Broadly, fluctuations in temperature at all sampling locations were consonant with seasonal temperature dynamics (Table 49). The overall average temperature for all priority point sources sampled in Onondaga Creek was 16.8°C (i.e., ‘mild’), 0.4°C (i.e., 2%) lower than that reported for routine sampling locations. The lowest average temperature (13.18°C) was observed at PS-11 near W Brighton Ave. (Table 49). The highest site average temperature (21.21°C) was observed at PS-71, 300ft downstream of South Ave. (Table 49). The narrow temperature range among Onondaga Creek routine (3.1°C) and Upper Onondaga Creek (5.6°C) locations, relative to the temperature range among priority point source sampling locations (8.0°C), highlights the longitudinal connectedness of in-stream sampling locations versus the disconnected, isolated point source sampling locations.

The CV for pH was 4.0% in Onondaga Creek priority point sources, and site average pH levels ranged between 7.2 (‘neutral’) and 8.1 (‘alkaline,’ Table 50). The lowest average pH value observed in priority point source samples (OC-PS20) was less than what was reported for routine sampling (W. Kirkpatrick St., $\tilde{x} = 7.8$). Furthermore, within-creek samples (for both routine and Upper Onondaga Creek sampling) were more alkaline on average (Table 25 and Table 32, respectively). General downstream decreases in pH levels were observed, exhibiting similar trends as for routine and Upper Onondaga Creek observations for Phase 3, as well as for previous phases (Fig. 55).

The CV for specific conductivity measurements observed in Onondaga Creek priority point sources was 47.8%. Specific conductivity levels ranged from ‘pristine’ to ‘moderately saline’ (Fig. 56, Table 51). Relatively low specific conductivity concentrations were observed at OC-PS71 (300 ft downstream of South Ave.), OC-PS20 (100 ft upstream of West Adams St., Byrne Dairy, CSO-037), and OC-PS92 (W. Water St.), compared with alternate sampled priority point sources. ‘High’ temperature observations were concurrent with the relatively low specific conductivity concentrations observed at these sources. These concurrent trends may be indicative of closed-source point source discharges, not impacted by road salt contamination or outside ambient air temperatures. The highest specific conductivity levels were observed at OC-PS04 (City Line Brook outfall, Table 51). Site-specific salinity levels broadly fluctuated with specific conductivity levels and displayed similar trends (Fig. 57); 77% of the differences in specific conductivity could be explained by differences in salinity (linear least squares regression). This lesser dependency for specific conductivity on salinity for priority point sources than for within stream sampling locations may be explained by a greater variability in the ionic composition and/or dissolution rates of impacting salts. Specific conductivity is a measure of ionic particles (www.fondriest.com). Salinity is the measure of dissolved salts in the water; many of which form ionic particles (i.e., have positive and negative charges) as they dissolve, thereby contributing to specific conductivity measurements and explaining the strong, positive relationship. The CV for salinity measurements for all sampling locations was 100.7%, greater than for sampling observations made for both routine and upper Onondaga Creek sampling. Aside from three apparent closed source priority point discharges, a conspicuous downstream increase in salinity (Fig. 57), as well as an increase in specific conductivity levels, may have been manifested by the use of urban salts; moreover, road salts are likely contributing to more saline conditions in Onondaga Creek.

The sonde used during priority point source sampling events was not equipped with a turbidity probe. Therefore, turbidity measurements were not taken.

3.2.5.2.2 Fecal coliforms

Site average fecal coliforms concentrations for Onondaga Creek priority point sources ranged between 108 cfu/100mL (low) at PS-71 (downstream South Ave) and 56,045 cfu/100mL (severe) at PS-92 W Water St (Table 53, Fig. 58). The CV for fecal coliforms was 278.2%. The highly variable and non-normally distributed ($p < 0.05$, Shapiro Wilk normality test) site average dataset was significantly different ($p = 0.002$, one sample signed rank test) among sampling locations. Sampling locations for priority point sources that were particularly notable and were identified to have ‘severe’ and ‘very high’ fecal coliforms concentrations included OC-PS03, OC-PS09 (Hopper Brook north outfall), OC-PS20 (100 ft. upstream West Adams St., Byrne Dairy, CSO-037), and OC-PS92 (W Water St.) (Fig. 59, Table 53). Of secondary concern (i.e., for the prioritization of future remediation efforts) was OC-PS04 (City Line Brook outfall); which flows at a consistent rate and observed fecal coliforms concentrations were considered ‘moderate’ and ‘high’ (Fig. 58). OC-PS11 (west Brighton Ave.) exhibited mostly ‘moderate’ levels of bacteria. OC-PS02 (Hopper Brook south outfall) and had the second lowest average fecal coliform concentration (132 cfu/100 mL) among priority point source locations, with most events having low fecal coliform concentrations (Table 53).

3.2.5.3. Relationships Between Parameters: Correlation Analysis

Correlation analysis of measured parameters collected during priority point source sampling identified several significant relationships. Dissolved oxygen was found to be significantly correlated ($p < 0.05$) with temperature. DO exhibited a weakly negative, linear relationship ($r < -0.40$, Table 54). Specific conductivity was negatively correlated with temperature and positively correlated with salinity ($r > |0.40|$); both relationships were significant ($p < 0.05$, Table 54). In addition to dissolved oxygen and specific conductivity, temperature was significantly correlated with salinity, exhibiting a strong negative relationship (Table 54). Neither fecal coliforms nor chlorine residual concentrations were found to be significantly correlated with any of the other measured parameters.

3.2.6. Tributary Trackdown Sampling (Task 5)

3.2.6.1. Onondaga Creek

Tributaries to Onondaga Creek were evaluated for water quality and fecal coliforms contamination as a continuation of the initiative from Phase 2. Data analysis and interpretation are based on single observations made at each tributary location; graphical representations are displayed as single points along a line graph, and all observed parameters values are presented on a single table. Significant differences for parameters between tributaries were not prepared because the power of the analyses was extremely low due to low sample sizes (N = 1).

3.2.6.1.1. Water Quality

DO ranged between ‘moderate’ (5-8 mg/L) and ‘excessive’ (>14.6 mg/L, Fig. 60) for all sampling locations, and most DO concentration observations were within the ‘high’ interpretive scale range (Table 55). On average, DO levels from the select tributary sources were not considered problematic. The highest DO concentration was observed at OCPS-24, ~800 ft. downstream of Dorwin Ave., while the lowest DO concentration was at OCPS-09E at 135 Valley View Dr. along the North section of Hopper Brook (Table 55). Stream temperatures at Onondaga Creek tributary trackdown sampling locations ranged between ‘cool’ and ‘warm;’ the highest temperature (24.3°C) was observed at PS-00B along Chaffee Ave. in Kimber Brook, and the lowest (12.2°C) was observed at PS-26 near Dorwin Spring outfall, 500ft upsteam of Dorwin Ave. (Fig. 61). The inverse relationship between temperature and DO was explored for tributary sources to Onondaga Creek, and 39% (linear least squares regression) of the differences in DO could be explained by differences in temperature. The power of the statistical relationship is weak due to the low number (N=18) of sampling locations and the singularity of the sampling event for each site (i.e., N = 1); therefore, dependencies should be interpreted very cautiously. Broadly, fluctuations in temperature at all sampling locations were consistent with seasonal temperatures dynamics during the time of sampling (Table 55). The overall average temperature for all tributary trackdown sites sampled in Onondaga Creek was 17.4°C (i.e., ‘mild’), consistent with average temperature data (17.2°C) reported for routine sampling locations.

Tributary trackdown pH levels ranged between 7.75 pH (‘slightly alkaline’) and 8.27 pH (‘alkaline,’ Fig. 62). The minimum site average value was consonant with what was reported for routine sampling (7.79 pH); nevertheless, within creek samples (i.e., for both routine and Upper Onondaga Creek sampling) were more alkaline on average. The general downstream decreases in pH levels observed for other tasks for Onondaga Creek was not observed here, yet the likely effect of increased alkalinity due to limestone bedrock within the watershed area was apparent (Table 55).

Specific conductivity levels ranged from ‘slightly saline’ to ‘moderately saline’ (Fig. 63). The highest specific conductivity levels were observed at OC-PS04C (Table 55), a sampling location close to a priority point source discharge (OC-PS04, City Line Brook Outfall) that also had reportedly high specific conductivity concentrations. An investigation of the common dependency between site specific salinity and specific conductivity levels showed 94% of the differences in specific conductivity could be explained by differences in salinity (linear least squares regression). Salinity levels ranged between pristine and freshwater concentrations (Table 59). Dorwin Springs and Kimber Brook had the lowest salinity concentrations among tributaries, while sites in City Line/Spring Brook and Hopper Brook had the highest concentrations (Fig. 64).

The sonde used during priority point source sampling events was not equipped with a turbidity probe. Therefore, turbidity measurements were not taken.

3.2.6.1.2. Fecal coliforms

Measured fecal coliforms concentrations for tributary trackdown sampling locations in Onondaga Creek ranged between 73 cfu/100 mL (‘low’) and 2900 cfu/100 mL (‘high’), observed at OCPS-00 (Kimber Brook outfall) and OCPS-01C (Byrne Place along Cold Brook), respectively (Table 55). More than 50% of sampled tributaries exhibited bacteria concentrations above the NYS criteria of 200 cfu/100 mL (Fig. 65). Of the tributaries sampled, relatively high concentration observations for fecal coliforms at both Hopper brook (PS-09) and Cold Brook (PS-01) indicated these two tributaries may be target priorities for further bacteria remediation (Fig. 66).

3.2.6.2. Relationships Between Parameters: Correlation Analysis

The correlation analysis among parameters was not robust nor representative due to the limited sample size. The only parameters significantly correlated ($p < 0.0001$) were salinity and conductivity; which exhibited a strong, positive relationship ($r = 0.92$, Table 56). Dissolved oxygen and temperature displayed a common, negative correlation that was not significant (Table 56). pH levels were negatively correlated with salinity and chlorine residual levels, yet these relationships were not statistically significant (Table 56).

3.2.7. Point Source Trackdown Sampling (Task 6)

Water quality and fecal coliforms sampling were conducted for identified point source discharges to investigate contaminant levels and evaluate their potential influence on Harbor Brook and Onondaga Creek stream ecosystems. A sampling program that included extensive point source trackdown sampling in the middle and upper Onondaga Creek sub watersheds was needed to identify the upstream sources of bacterial inputs and their contributions and effects on water quality in lower Onondaga Creek. Point source trackdown sampling included *Bacteroides* analysis at, and upstream, of point sources that were observed to discharge high concentrations of bacteria from unknown sources (location and host source). *Bacteroides* analyses indicated that the predominant sources of fecal coliforms were not solely from human sources and included agricultural and/or wildlife inputs.

3.2.7.1. Harbor Brook

3.2.7.1.1. Water Quality

All parameters measured during point source trackdown sampling at Harbor Brook, except for turbidity, were significantly different ($p < 0.05$, one sample t-test or one sample signed rank test) among sampling locations. DO observations ranged between ‘extremely low’ (<2 mg/L) and ‘high’ (8-12 mg/L, Fig 67). Average DO concentrations at five of the nine point source locations were within the ‘moderate’ interpretive scale ranges (Table 57). The CV for DO was 33.1%, exhibiting 16.8% greater variability than for routine sampling. Site average DO concentrations of 5.84 mg/L and 7.97 mg/L (i.e., ‘moderate’) were observed at PS-112A and Velasko Rd.A, respectively (Table 57). The average DO concentration at discharge PS-112C, along Hiawatha Blvd., was 2.35 mg/L (i.e., within the ‘very low’ interpretive scale range, Table 57), and one DO measurement at this location was ‘extremely low’ (1.2 mg/L); this point source discharge was identified as problematic for DO.

Priority point source temperature variability (i.e., CV = 19.9%) was 7.2% greater than for routine stream sampling, yet site average differences in temperatures could not explain differences in DO ($p < 0.05$, linear regression). Fluctuations in temperature at all sampling locations were consistent with seasonal temperatures dynamics (Table 58). The CV for temperature at Harbor Brook non-priority point sources was 20%. Temperatures for all sampling events were between the ‘cool’ (10-15°C) and ‘warm’ (10-25°C) interpretive scales (Fig. 68,

Table 58). On average, point source discharge temperatures were 2.5°C warmer than for routine sampling locations. The lowest average temperature (11.91°C) was observed at PS-100D in an open channel south of Onondaga Blvd., and the highest site average temperature (22.58°C) was observed at PS-112B, a manhole north of Hiawatha Blvd. (Table 58). All observed temperatures at both PS-112B and PS-112C were 'warm' throughout the duration of the study and were considered problematic point sources for temperature.

Average pH levels in Harbor Brook point sources ranged between 7.51 '(neutral') and 10.14 ('highly alkaline', Fig. 69, Table 59). Most observed pH levels were within the 'slightly alkaline' interpretive scale range, consistent with observations during routine sampling. Nevertheless, relatively high pH levels were observed at the three furthest downstream point sources, forming a slight longitudinal gradient (Fig. 69). Site average pH observations at PS-112C and PS-112A were 'highly alkaline,' and PS-112B was 'alkaline.' These relatively alkaline water quality observations may be indicative of the residual effects of ionic waste from Solvay Process, which were historically discharged in proximity that watershed location (Effler et al. 1996). Site average differences in pH were significant ($p < 0.05$), and the CV for pH levels between priority point source sampling locations in Harbor Brook was 14.9%.

Specific conductivity concentrations ranged from 'pristine' to 'saline' (Fig. 70). There were no conspicuous downstream trends in specific conductivity levels. The highest site average specific conductivity concentration (4461 µmHos/cm) was observed at PS-112A (Table 60). The lowest site average specific conductivity concentration (234.5 µmHos/cm) was observed at PS-112B, a manhole north of Hiawatha Blvd. The CV for specific conductivity concentrations for point source trackdown sampling locations was 88.6%, and differences between average concentrations were significant ($p < 0.05$, one-sample t-test). Specific conductivity levels at PS-112A were more than two-fold greater than all other point source trackdown sampling locations (Fig. 70) and may be considered problematic for water quality. Commonly observed dependencies between specific conductivity and salinity levels were examined for point source trackdown sampling locations, and a strong positive significant correlation ($r = 0.97$, $p < 0.05$) was identified. Consistent with observations made during routine sampling, most salinity levels observed during point source trackdown were within the 'freshwater' and 'slightly saline' interpretive scale ranges and site average salinity levels were significantly different ($p < 0.05$, one-sample t-test). 'Highly saline' salinity levels were observed at PS-112A (Fig. 71, Table 61), consonant with higher specific conductivity levels at that location. The CV for salinity was 99.5%, 66.7% higher than the CV calculated for salinity observations made during routine sampling.

Turbidity data is limited for point source trackdown efforts in Harbor Brook, due to the use of a sonde that lacked a turbidity sensor (i.e., on 7/11/16) and several probe malfunctions occurring on 7/10/17 and 8/16/17 (Table 62)[8]. Turbidity levels at sites within the PS-100 sewershed were very low and considered 'pristine.' PS-112C, the most upstream location, was the only point source in the PS-112 sewershed where a turbidity measurement was taken. Turbidity at this point source was 159 NTUs and was considered 'high.' At the time of

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[8] Due to the lack of turbidity data, a graph was not generated for this parameter for this task.

sampling, this manhole was completely full of water, nearly reaching street-level and contained a substantial amount of street litter.

3.2.7.1.2. Fecal coliforms

Site average fecal coliforms concentrations for Harbor Brook priority point sources ranged between 9 cfu/100 mL (‘very low’) and 2909 cfu/100 mL (‘high’) observed at PS-100D, at an open channel south of Onondaga Blvd., and PS-112C, at a manhole on Hiawatha Blvd., respectively (Table 63 Fig. 72). The CV for fecal coliforms at point source trackdown sampling locations was 101.1%, only 1.6% higher than calculated for priority point sources. Furthermore, differences in concentration averages among sites were significant ($p < 0.05$, one sample t-test). Of the ten point sources sampled, fecal coliforms concentration averages at three point source trackdown locations were below NYSDEC criteria (i.e., 200 cfu/100 mL, Fig. 73). Aside from relatively low fecal coliforms concentration observations at these point source trackdown sampling locations, concentrations observed at the remaining seven locations exceeded NYSDEC thresholds for standard criteria (Fig. 73). Bacterial discharge remediation and subsequent bacterial monitoring may be warranted for these locations.

3.2.7.2. Onondaga Creek

3.2.7.2.1. Water Quality

All site average water quality parameters observed during point source trackdown sampling were significantly different ($p < 0.05$, one sample t-test and/or Mann Whitney Rank Sum test) among sampling locations. DO ranged between ‘low’ (3-5 mg/L) and ‘high’ (>14.6 mg/L, Fig. 74) concentrations for all sampling locations, and > 50% of DO observations were within the ‘high’ interpretive scale range. On average, DO levels in point source trackdown sampling locations were not considered problematic. The highest average DO concentration was observed at PS-01C, at Byrne Place along Cold Brook, and the lowest at PS-09E, at Valley View Drive along Hopper Brook north (Table 64). Both DO concentration observations made at PS-09E were within the lower range of ‘moderate’ and one of two DO concentration readings made at PS-04E was within the ‘low’ interpretive scale range (Fig. 74), suggesting PS-09E and PS-04E may be problematic point sources for DO. The CV for DO was 19.5%, 1.9 % higher than the CV calculated for Onondaga Creek routine sampling locations. Stream temperatures at Onondaga Creek priority point sources (Fig. 74, Table 64) were less variable (i.e., CV = 13.2%) than at routine sampling locations. The inverse relationship between temperature and DO was explored for point source trackdown sampling locations, and the weak correlation ($r = 0.3$, linear least squares regression) between the two parameters was not significant; moreover, the power of the statistical relationship was very weak due to the low number ($N \leq 2$) of sample observations made at individual sampling locations. Generally, temperature observations ranged between ‘cool’ and ‘mild’ at sampling locations, except at PS-09D, which had one observation within the ‘warm’ range (Fig. 75, Table 65). Broadly, fluctuations in temperature at all sampling locations were consonant with seasonal temperatures dynamics (Table 65). The overall average temperature for all point source trackdown locations was 16.7°C (i.e., ‘mild’), 0.5°C (i.e., 4%) lower than that reported for routine sampling locations. The lowest average temperature, 12.5°C, was observed at PS-04D near East Glen Ave. along Spring Brook (Table 65). The highest site average temperature (19.4°C) was observed at PS-03A, a manhole at the end of west Glen Ave. Relative to routine and upper Onondaga Creek sampling tasks, temperature variation was greater among point sources (Δ7.51°C) than for Onondaga Creek routine (Δ3.12°C) and upper Onondaga Creek (Δ5.57°C).

The CV for pH was 4.2% in Onondaga Creek point source trackdown sampling locations, and site average pH levels ranged between 7.4 pH ('neutral') and 8.3 pH ('alkaline') at PS-09C and PS-09G, respectively (Table 66). The minimum site average value (PS-09C) was less than the minimum average that was reported for routine sampling (7.74 pH); furthermore, within-creek samples (i.e., for both routine and upper Onondaga Creek sampling) were more alkaline on average. Downstream trends in pH levels were not evident for point source trackdown sampling locations (Fig. 76).

The CV for specific conductivity measurements observed for Onondaga Creek point sources point source trackdown sampling locations was 34.4%. Specific conductivity levels ranged from 'slightly saline' to 'moderately saline' (Fig. 77). The highest specific conductivity levels (i.e., 2829 µmHos/cm^2) were observed at PS-09C, and the lowest (i.e., 243 µmHos/cm^2) were observed at Dorwin Ave (Table 67). In City Line/Spring Brook, a general increasing trend in specific conductivity concentrations was observed downstream (Fig. 77). For Hopper Brook, conductivity exhibited a downstream decrease in concentration (Fig. 77). Site specific salinity levels broadly fluctuated with specific conductivity levels and displayed similar trends; 99% of the differences in specific conductivity could be explained by differences in salinity ($r = 0.99$, linear least squares regression). The CV for salinity measurements for all sampling locations was 37.4%. Consistent with spatial trends observed for other sampling tasks within the Onondaga Creek watershed, the conspicuous downstream increase in salinity (Table 68, Fig. 78) and specific conductivity levels likely indicate the apparent influence of urban salts, likely road salts, that manifest elevated salinity levels in the lower watershed.

Turbidity measurements were limited for Onondaga Creek point source trackdown locations (Table 69)[9]. Turbidity values ranged between 'pristine' and 'medium.' Dorwin Ave. exhibited the highest observed turbidity, likely a result of impacts from the Tully Valley mudboils. For most sites (seven of nine), water quality did not appear to be impaired by turbidity; values ranged between 0 ('pristine') and 8.7 ('very low') NTUs (Table 69). The highest turbidity value was observed during the 8/24/16 sampling event at Spring Brook (i.e., behind Valley Plaza). While water clarity was high at this site, sediments were observed to be composed of fine material and were easily disturbed. The deployment of the sonde may have disturbed the stream bottom, and the reading may have been taken before sediments settled from out of the water column. Notwithstanding this possible sampling error, the contribution of fine sediments may be due to the proximity to the shopping plaza and related sediment runoff.

3.2.7.2.2. Fecal coliforms

Site average fecal coliforms concentrations for Onondaga Creek priority point sources ranged between 72 cfu/100 mL ('low') at PS-04D, at Spring Brook along East Glen Ave. and 66,150 cfu/100 mL ('severe') at PS-09E, at 135 Valley View Dr. along Hopper Brook north (Table 70). The CV for fecal coliforms was 273.6%. The highly variable and non-normally distributed ($p < 0.05$, Shapiro Wilk normality test) site average dataset was significantly different

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[9] Due to the lack of turbidity data, a graph was not generated for this parameter for this task.

($p < 0.001$, one sample signed rank test) among sampling locations. Three point source trackdown sampling locations, OC-PS03A, OC-PS09E, and OC-PS04E, were particularly notable and were identified to have 'very high' or 'severe' fecal coliforms concentrations (Fig. 79). Nearly all (93.3%) of observed site average fecal coliforms concentrations at Onondaga Creek point source trackdown sampling locations were above the NYS criteria threshold of 200 cfu/100 mL for bacteria (Fig. 80).

3.2.7.3. Bacteroides

Fecal coliforms and *Bacteroides* results from 2016 and 2017 suggest that water quality in Harbor Brook and Onondaga Creek was most prevalently impacted by human bacterial inputs. In 2016, human sources were the dominant bacterial source for all sampling locations in Harbor Brook (N=2; Table 71) and Onondaga Creek (N=10; Table 72), with no major animal groups detected in *Bacteroides* analyses. In 2017, both humans and ruminant animals were identified as the dominant contributors to fecal contamination in Harbor Brook (Table 73) and Onondaga Creek (Table 74).

In Harbor Brook in 2016, two routine locations at Velasko Rd. were sampled for *Bacteroides* analyses: 1) Velasko Rd. (A), a side channel that discharges to Harbor Brook immediately upstream of Velasko Rd., and 2) the Velasko Rd. routine location. *Bacteroides* only detected human sources of fecal contamination at both locations (Fig. 81). In 2017, both sites again tested positive for human bacterial sources, and Velasko Rd. also tested positive for ruminant animal contamination (Fig. 82). Fecal coliforms levels at these two locations were relatively constant, with levels considered 'moderate' for both sites, during both years (Table 71 and Table 73). In 2017, four of five sampling locations within the HB-PS100 sewer tested positive for human fecal contamination. Of those four, three sites (PS-100, PS-100A, and PS-100B) also tested positive for ruminant animal contamination (Fig. 82). *Bacteroides* did not detect any animal-based sources of fecal contamination at PS-100D, a location that also exhibited a 'very low' fecal coliforms concentration (9 cfu/100 mL). HB-PS100D is an open channel with continuous flow that travels east to west, parallel to Onondaga Blvd. It is possible that this point source is not connected to the PS-100 sewershed; further investigation may be warranted. Three point sources were sampled for *Bacteroides* within the HB-PS112 sewershed (Fig. 82). Fecal coliforms levels for these point sources ranged between 'very low' (<10 cfu/100 mL) and 'low' (18 cfu/100 mL); consistent with the bacterial level observations, *Bacteroides* analyses did not detect particular bacterial sources (Fig. 82).

Samples taken from Onondaga Creek at Dorwin Ave provided noteworthy *Bacteroides* findings. One sample was collected in 2016 and one in 2017, and both samples identified humans as the dominant source of fecal coliforms (Fig. 83 & Fig. 84, respectively). Dorwin Ave is located upstream of the City's CSO system indicating other potential dry-weather contributions of human-based bacterial contamination are impacting Onondaga Creek. In 2017, the Dorwin Ave sample also tested positive for ruminant animal contributions (Fig. 84).

In 2016, all samples tested positive for the presence of human bacterial sources (Fig. 83). In 2017, *Bacteroides* sampling in the tributaries to Onondaga Creek highlighted the spatial variability in not only the intensity of fecal contamination, but also the source of contamination. Tributary sampling included locations (N=11) in Cold Brook, Spring Brook, City Line Brook, and Hopper Brook, with fecal coliforms levels that ranged between 'low' and 'very high' (Table 74). The most upstream location in Hopper Brook (PS-09C) was only positive for human sources of bacteria. The second and third most upstream location (PS-09E, PS-09D), while having moderate fecal coliforms levels, did not test positive for any animal group (Fig. 84). Longitudinally (i.e., along the stream gradient, upstream to downstream) PS-09H is the first site where ruminant animal-based contamination was detected. For both PS-09H and PS-09G, the next downstream locations, ruminant animals were the sole group identified as bacterial contributors. At PS-09B, the most downstream location, both human and ruminant animals contributed to fecal contamination (Fig. 84).

Likewise, Spring & City Line Brooks (connected tributaries) exhibited trends in bacterial contamination indicative of localized, isolated impacts rather than longitudinal changes characteristic of compounding impacts observed in 2017. At the most upstream location, PS-04D fecal coliforms levels were considered 'low' (72 cfu/100 mL) and *Bacteroides* analysis tested weakly positive for human-sourced contamination (Fig. 84). Fecal coliforms levels were 'very high' at PS-04E (33,000 cfu/100 mL), the highest of any location sampled in 2017 (Table 74). Human and ruminant animals were identified as the major sources of fecal contamination (Fig. 84). Downstream of that location, however, bacterial levels dropped substantially to a 'low' concentration of 81 cfu/100 mL at PS-04C, and Bacteroides did not detect any major animal-group(s) as a contributor(s) (Fig. 84). At the most downstream location, PS-04B, fecal coliforms increased to a 'high' concentration of 3000 cfu/100 mL (Table 74), with both humans and ruminant animals were the major contributors (Fig. 84).

3.2.7.4. Relationships Between Parameters: Correlation Analysis

The comparatively low samples sizes for point source trackdown sampling resulted in a less robust correlation analysis than for other tasks. As such, the only two significant relationships detected. Specific conductivity and salinity, which like other tasks, exhibited a strong, positive relationship ($r = 0.97$, Table 75). A negatively linear relationship was also observed for conductivity and temperature ($r = -0.46$). The significant correlation ($p < 0.05$) suggests conductivity levels decrease with increasing temperatures (Table 75). Likewise, temperature exhibited a negative relationship with salinity, but was not significant (Table 75). Turbidity exhibited a linear relationship with pH ($r = 0.52$); however, this correlation was considered slightly significant ($p = 0.054$, Table 75).

4. Remedial Work & Potential Effects

Since the completion of Phase 1, 20[10] problematic locations have been identified that resulted in follow-up efforts by Onondaga County, City of Syracuse, and/or the Town of DeWitt, and a recorded 16 corrections have been collectively made in the Harbor Brook, Onondaga Creek, and Ley Creek watersheds and sewersheds (Table 76, Appendix H). Of the 16 corrections, four were completed during Phase 3 (Table 76). Sampling efforts since Phase 1 have led to the identification of collapsed pipes, illicit discharges, cross-connections, improper storage of agricultural wastes. Much of the work has been completed in Onondaga Creek, with a

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[10] At least five of the identified problematic locations were not identified as point sources under the MTS; nevertheless, remediation efforts contributed to the improvement of water quality. Several point sources were investigated more than once (e.g., OCPS-20, OCPS-21, OCPS-23, HBPS-100, HBPS-112).

total of 12 corrections being made. Based on the findings from Phase 1 and initial priority point source sampling (Task 5) in Phase 2, four point sources were able to be removed from priority point source sampling in Phase 3 due to successful corrective work: OC-PS22, OC-PS25, OC-PS69, and OC-PS76. Furthermore, Phase 3 priority point source sampling showed that corrective work performed during Phase 3 effectively eliminated bacterial discharges from OC-PS20, OC-PS21, and OC-PS23.

The effects of corrective work on in-stream bacteria levels appeared evident in Harbor Brook and Onondaga Creek, with several routine sampling locations showing declines in average fecal coliforms levels since Phase 2 that could be attributed to point source corrective work. In Harbor Brook, average in-stream fecal coliforms levels declined for all routine locations between Phase 2 and 3. Velasko Rd exhibited the most substantial decline in average fecal coliforms concentrations between Phases 2 and 3, with averages of 1905 cfu/100 mL and 987 cfu/100 mL, respectively (Fig. 85). The decline in levels between phases, however, was not statistically significant ($p > 0.05$). While bacteria levels declined between Phases 2 and 3, Phase 3 levels are still notably higher than those estimated for Phase 1, suggesting that persistent and pervasive sources of fecal coliforms continue to discharge to Harbor Brook. Of the Harbor Brook routine locations, Fowler High School was the only site to have average fecal coliforms concentrations significantly different among study phases ($p < 0.05$), with average fecal coliforms concentrations notably higher in Phases 2 and 3 than compared to Phase 1 (Fig. 85).

HB-PS100 (CSO-078) has been a persistent contributor of high fecal coliform loadings to Harbor Brook; discharging to the stream at Velasko Rd. During Phase 2, the average fecal coliform concentration at HB-PS100 was 2735 cfu/100 mL (‘high’) during priority point source sampling events. In Phase 3, average concentrations had declined to 576 cfu/100 mL. The declines in in-stream bacteria levels downstream of Velasko Rd between Phase 2 and Phase 3 appear to be, in part, due to reduced bacteria loadings from HB-PS100. In 2017, while performing repairs near the CSO-078 manhole, contractors for Onondaga County identified three sanitary sewer cross connections within the overflow line. Subsequent to this finding, the connections were separated for the CSO line and routed to the Onondaga Trunk Sewer. This work was competed on December 5, 2017 (Appendix I). Continued monitoring of HB-PS100 and Harbor Brook routine sampling locations will be critical to evaluating the success of the corrective work performed in CSO 078 and the potential effects on in-stream bacteria concentrations.

HB-PS101BW (CSO 018) was constructed as part of the Harbor Brook CSO 018 Constructed Wetland and serves as the sole outfall for CSO 018. The construction of the wetland effectively eliminated the former point source discharge for CSO 018, OEI code HB-PS101, and relocated it approximately 100 m east to receive flow from the constructed wetlands. During Phase 3 priority point source sampling (2014-2015), the outfall was observed to have continuous flow during dry-weather; in part due to flow from the wetlands. To ensure no flow from the constructed wetlands occurs during dry-weather and to increase overall residence time, and thus treatment of the CSO effluent, Onondaga County WEP installed a watertight stop-log within wetland Manhole-19. This stop-log is located immediately upstream (~ 1 m) of the outfall discharge point (HB-PS101BW) and installation was completed on November 12, 2017.

In Onondaga Creek, average fecal coliforms levels widely varied among sample sites, within sample sites, and among study phases (Fig. 86). Seven of the ten routine locations showed an increase in average fecal coliforms concentrations between Phases 2 and 3; the exceptions were Hitchings Rd., which showed a slight decrease in bacteria levels, and Walton St. and W Kirkpatrick St., which exhibited more substantial decreases. Overall, Hitchings Rd., located on the West Branch, displayed some of the lowest bacteria levels among routine locations. The narrow range in averages (48-155 cfu/100 mL) at this location suggest conditions in the West Branch subwatershed have remained constant and bacterial inputs are minor. Gibson Rd. was the only routine location in Onondaga Creek to show a significant difference in average bacteria levels among the three study phases, with levels increasing during each successive phase. The steady increases in average fecal coliforms levels at Rte. 20 and Gibson Rd. (rural, Mainstem sites) since Phase 1, suggest bacterial inputs into upper Onondaga Creek are increasing (refer also to §5.2). Further field investigations are warranted, especially those that enhance the evaluation of linkages between farming practices and bacterial perturbations within the watershed.

Despite increases in bacteria levels in the upper watershed, reductions observed at in-stream locations in the lower watershed are noteworthy. Both Walton St. and W Kirkpatrick St. showed substantial decreases in average fecal coliforms levels since the completion of Phase 2 (Fig. 86). The observed decreases at Walton St. since Phase 1, however, were not statistically significant ($p > 0.05$). Changes in fecal coliforms concentrations were significantly different among study phase at W Kirkpatrick St. ($p < 0.05$, Fig. 86). The decrease in bacteria concentrations at Walton St. may be attributed to corrective work performed at OC-PS21 (Walton St.). Similarly, the decline in bacteria at W Kirkpatrick St. may be attributed to corrective work performed and the Erie Blvd. Storage System (EBSS, OC-PS23). During Phase 2, average fecal coliforms concentrations for OC-PS21 and OC-PS23 were 'severe,' with average concentrations of 137,943 and 76,821 cfu/100 mL, respectively. During Phase 2, investigative work (i.e., dye-testing and scoping) performed by Onondaga County, WEP and City of Syracuse found a building adjacent to Onondaga Creek at Walton St. that was improperly connected to the storm drain system and discharging via OC-PS21 (i.e., under Walton St.). A consent order was issued to the property owner, who later sold the building. The new building owner, while performing renovations, subsequently repaired the cross-connection (Appendix H). This was confirmed in August 2014 when dye testing, performed by Onondaga County WEP, did not identify any connections to the storm sewer (Appendix I). During Phase 2 follow-up sampling, the point source was not observed flowing and was considered corrected. This appears to be substantiated by routine sampling, which occurred up to two years after the completion of the corrective work and did not elucidate any significant increases in bacteria levels that would be indicative a reoccurring discharge from OC-PS21.

Between 2013 and 2015, several remedial efforts were employed by Onondaga County to eliminate the discharge coming from the EBSS (OC-PS23). This included the identification of three sources of dry-weather bacterial discharges, two of which were blockages in the system and one of which was an illicit sanitary sewer connection to the storm sewer. Additional measures at the EBSS have included rehabilitation work inside the EBSS and operational changes to the gate system (Appendix I). As a result, EBSS was not observed flowing after September 10, 2014 and was considered corrected. While the average fecal coliforms level at

Kirkpatrick St. decreased from a level considered ‘high’ to one considered ‘moderate,’ these differences were not significant ($p > 0.05$). The consistently high flow rates combined with persistently high bacteria levels at OC-PS23 resulted in an average load rate of 1.6 billion cfu/12 hrs during Phase 2. The correction of this point source eliminated a major source of bacteria to Onondaga Creek and likely contributed to the reduction in average fecal coliform levels observed downstream at Kirkpatrick St.

During Phase 2, Point Source Identification sampling found 52 point sources discharging to Ley Creek. Of those, only one located in the South Branch was found to be discharging severely high bacteria levels. The source of the discharge came from a broken sewer pipe that was located directly in Ley Creek. During reconnaissance to repair the pipe, a second, failing pipe was also discovered. Both pipes were disconnected, filled with concrete, and reconnected to a new sewer line during Phase 2. Despite these corrections, average in-stream bacteria levels in the South Branch were slightly higher during Phase 3 routine events than in Phase 2 (Fig. 87), though increases were not significant ($p > 0.05$). Average fecal coliforms levels in the North Branch decreased substantially in Phase 3 and were significantly different for both locations at $\alpha = 0.1$, but not at $\alpha = 0.5$ (Fig. 87). Comparatively few point sources ($N = 13$) were identified in the North Branch during Phase 2 than other segments of Ley Creek. Of those, only three were located upstream of Thompson Rd, and only one of those was located above Fly Rd. At the time of sampling, bacteria levels for those point sources ranged between low and moderate levels and, therefore, did not appear to be the likely source of bacterial inputs to the North Branch during Phase 2. The North Branch watershed upstream of Thompson Rd is predominantly identified as forest and agriculture land use. It is hypothesized that reductions in bacteria levels in the North Branch since Phase 2 may be attributed to possible changes in agricultural practices. This, however, requires further investigation.

The substantive reduction in bacteria levels in the North Branch of Ley Creek appear to have positively influenced bacteria levels in the Mainstem, despite average increases in fecal coliforms concentrations in the South Branch. Reductions in bacteria levels in the North Branch between Phases 2 and 3 were not significantly different at $\alpha = 0.5$ but were significantly different at $\alpha = 0.1$ (Fig. 87). Both mainstem routine locations showed decreases in average fecal coliforms levels between Phase 2 and Phase 3 (Fig. 87); reductions, however, were not significantly different ($p > 0.05$). Routine monitoring, Onondaga County Ambient Monitoring Program, and Phase 2 trackdown activities showed downstream bacterial inputs at or near the Factory Ave sampling location. In 2015, Onondaga County WEP identified a series of lateral connections to the City storm system (Appendix I). Further trackdown investigations found that those pipes were illicit sanitary sewer connections from several houses along Harford Rd., south of the Factory Rd. routine sampling location. Corrections were subsequently made (following the conclusion of Phase 3 routine sampling), though it is uncertain what contribution those discharges may have had on in-stream bacteria levels prior to corrective work and what effect, if any, the corrective work has had on in-stream bacteria levels to-date. Nevertheless, such corrective work has demonstrated important reductions in bacteria levels observed within the Ley Creek watershed.

5. Discussion

The collective field efforts of the Phase 3 MTS provided a holistic understanding of the effects of dry weather discharges on spatial and temporal changes in bacteria concentrations and water quality in Harbor Brook, Onondaga Creek, and Ley Creek. This study helped to clarify the compounding effects of multiple dry-weather impacts and identify the most pervasive. Most notably: 1) routine sampling (Task 3) identified the effects of land use on in-stream water quality, 2) priority point source sampling (Task 4) identified persistently problematic point source discharges and corrected point sources from Phase 1 and Phase 2, 3) tributary trackdown sampling (Task 5) identified locations in select tributaries to Onondaga Creek with water quality impairments, 4) point source trackdown sampling (Task 6) helped to elucidate bacterial sources, and 5) Upper Onondaga Creek sampling (Task 3.1) identified trends in bacteria and other metrics of water quality in the upper watershed. Collectively, these efforts, as well as those provided for Phases 1 and Phase 2, have led to the successful identification and correction of 16 point sources. A more detailed discussion of task-specific results is presented within the sub-sections below.

Statistical correlation analyses between parameters were performed for each task with the target systems (i.e., Harbor Brook, Onondaga Creek, and Ley Creek) combined. It should be noted the unique and dynamic water quality conditions within Onondaga Creek were likely driving the abundance of statistically significant relationships identified for all three systems combined. Furthermore, significant findings from correlation analyses were not necessarily driven by cause-effect relationships between parameters, but instead by unique and independent spatial (i.e. downstream) trends in parameter dynamics. For example, increases in fecal coliforms and specific conductivity metrics in downstream order were not necessarily source-related or dependent on one another, but were more likely independent features occurring within the watershed. Such relationships appear to be an effect of the Urban Stream Syndrome (Walsh et al. 2005), where the compounding effects of urbanization have resulted in increasing concentrations downstream. These relationships also appear to be, in part, due to unique natural conditions. This is particularly true for Onondaga Creek, for example, which has increasing fecal coliform concentrations downstream, likely due to increase urbanization and is also impacted by natural salt springs near the lake inlet.

5.1. Routine Sampling

Routine sampling showed the effects of land use, seasonal variations, and site-specific impacts on in-stream bacteria levels and water quality. Bacteria levels were statistically significant ($p < 0.05$) between rural and urban locations in Harbor Brook, with urban sites generally having notably higher bacteria levels. The negative effects of urbanization on stream quality have been well documented (Klein 1979, Jones and Clark 1987, Limburg and Schmidt 1990, Wang et al. 2001, Allan 2004, Sawyer 2004), and increased bacterial levels is often one of the major effects (Porcella and Sorenson 1980, Paul and Meyer 2001, Simpson et al. 2002, Desai et al. 2010). Despite the separation of CSO's in the Syracuse sewershed, dry weather urban discharges are still having noteworthy impacts on bacteria levels in the tributaries to Onondaga Lake. Furthermore, bacterial inputs from agricultural sources are evident at upstream locations, particularly in Onondaga Creek. Average fecal coliforms levels were considered 'moderate' at locations in the Tully Valley, just downstream of several farms. Furthermore, both the Upper Onondaga Creek Study (OEI 2013) and the Phase 3 upper Onondaga Creek routine sampling (refer to §5.2) identified the impacts of agricultural practices during dry and wet weather. Bacteria levels also varied by season, with bacteria levels generally higher in the summer months (i.e., June-August) than during the fall months (i.e., September-November). Numerous studies have detected similar patterns (Eyles et al. 2003, Traister and Anisfeld 2006, Koiral et al. 2008).

Likewise, land use and stream alterations in the lower Ley Creek Watershed may be contributing to observed bacteria levels. Average fecal coliforms concentrations in the Mainstem of Ley Creek were consistently 'moderate,' and many observations were above NYS Criteria for fecal coliforms. Bacteria observations were 'high' during one sampling event at LeMoyne Ave. and during two events at Park St. Bacteria inputs to Onondaga Lake from Ley Creek are theorized to be a likely symptom of stream conditions and surrounding land use in the Mainstem. The Mainstem is highly channelized and has limited canopy cover, and the highest bacteria concentrations were generally found there, demonstrating a general downstream gradient increase in bacteria. This is supported by bacteria growth dependencies on temperature, relatively sluggish flows during dry-weather, and relatively warmer temperatures that occur in the Mainstem of Ley Creek. The optimal temperature for fecal coliforms ranges between 30 and 37°C (Todar, 2008). Higher temperatures in the Ley Creek Mainstem, approximately 1-3ºC warmer on average, appear to provide comparatively better conditions for bacterial growth (i.e., reproduction). Therefore, the warm, slow-moving conditions of the Ley Creek Mainstem likely supports enhanced bacterial growth, particularly just upstream of Onondaga Lake. In addition, conspicuous within-phase temporal differences may have been driven by seasonal precipitation dynamics that likely had a greater impact on the low-gradient, low-flow hydraulic conditions of Ley Creek than the other tributaries.

Land use also had noteworthy effects on water quality during Phase 3 routine sampling. In Harbor Brook, a significant increase in salinity and specific conductivity levels were observed between rural and urban locations. Apparent ionic inputs at and/or just upstream of Velasko Rd. were attributed to the impacts of urbanization and associated increased impervious surfaces, road salt runoff, and wastewater treatment (Pay and Meyer 2001, Walsh et al. 2005). Similarly, conductivity levels in Ley Creek were notably high, with average values ranging between 'slightly saline' and 'moderately saline.' The South Branch, in particular, exhibited the highest average conductivity levels for Ley Creek, 2-fold greater than those observed during Phase 2. These data suggest increased road salt usage in the South Branch watershed since the completion of Phase 2 may be degrading stream water quality.

Stream temperatures in Harbor Brook and lower Onondaga Creek were consonant with, if not lower, than upstream locations; furthermore, average temperatures were considered cool or mild. This is uncharacteristic of the "urban stream syndrome" (Walsh et al. 2005), whereby stream temperatures are typically elevated in urban streams due to a loss of riparian buffer. These Phase 3 temperature observations are consistent with what would be expected based on common within-stream thermodynamic regulation from volume dilution and shading (Johnson 2004) and may also be a result of stream channelization. Both lower Onondaga Creek and Harbor Brook are heavily channelized and situated, in some places, several feet below street-level. The shading provided by the channel walls may also keep temperatures low.

Natural conditions in the watershed also had noteworthy impacts on water quality, particularly turbidity, salinity, and specific conductivity. The Tully Valley mudboils contribute to increases in turbidity downstream (Bear Mountain Rd. and sites downstream) in Onondaga Creek. Average turbidity levels steadily decreased downstream of the mudboils, demonstrating effects of settling and dilution. The influence of salt springs and saline discharges from the mudboils on in-stream specific conductivity and salinity levels was evident at Bear Mountain Rd. and Rte. 20. The US Geological Survey (USGS) has documented steadily increasing specific conductivity and salinity levels in samples taken from mudboil depressurizing wells over the last 15 years (USGS 2014). Specific conductivity and salinity levels increased at W. Kirkpatrick St.; this was attributed to a salt spring discharging into the creek just downstream of Spencer St. (OEI 2009). Additionally, road salt application in urban areas was likely a contributing factor to increased specific conductivity levels. Specific conductivity has been identified as a primary parameter for assessing the impacts of urbanization on stream quality; urbanized/impacted streams typically having higher specific conductivity levels (Wenner et al. 2003). Despite these potentially problematic impacts, temperature and dissolved oxygen levels were not impaired in the sampled tributaries and were routinely at levels not considered stressful to aquatic life.

5.2. Upper Onondaga Creek

Bacteria and water quality metrics were investigated in Upper Onondaga Creek, following recommendations from Phase 2. Noteworthy high concentrations of bacteria were observed in the Mainstem, and within and downstream of the Tully Valley. Elevated levels of bacteria in upper Onondaga Creek may be attributed to non-point sources such as agricultural runoff from the greater watershed (Baxter-Potter and Gilliland 1988). Particularly, Solvay Rd., Otisco Rd., Nichols Rd., Buffalo Hill Rd., Flood Control Dam, Gibson Rd., and Webb Rd. may deserve further investigation that includes *Bacteroides* analyses for bacterial source identifications. Site average fecal coliforms concentrations observed at Solvay Rd. were nearly three-fold greater than the other six listed above and should be considered a priority for bacterial remediation and associated monitoring programs. During the 2012 upper Onondaga Creek Study (OEI 2013), severely high bacteria levels were observed at Solvay Rd. At that time, a horse barn with an uncontained manure pile was observed on a property immediately upstream (~50 m) of the sampling location. OEI contacted the property owner to notify them of this water quality impairment. Based on subsequent bacteria measurements at this location, it is unlikely that long-term action was taken by the property owner to remediate this non-point source discharge and follow-up sampling and site visits are needed to verify and remediate the source.

Aside from Solvay Rd., the hypothesized source for fecal coliforms contamination in the upper Onondaga Creek watershed is from agricultural sources. Commonly, temporal and spatial concentration fluctuations for bacteria from non-point sources are consonant with fluctuations in nutrient concentrations (i.e., bacteria are important for nutrient cycling, Rubin and Leff 2007). The strong, positive correlations observed in Phase 3 between fecal coliforms and nutrient concentrations support this hypothesis. The concurrent dynamics in bacteria and nutrients concentrations supports the use of nutrient concentration measurements as important indicators of water quality in the absence of bacteria concentrations measurements and can offer information and guidance for the determination of dependencies (Schaepe and Soenksen 2014).

Turbidity, total suspended solids, specific conductivity, and salinity observations tracked the substantive effects of sediment and brine discharges from the Tully Valley mudboils on Onondaga Creek. The significant correlation among these parameters indicates the common source and highlights the pervasive and persistent impacts they are having on water quality in Onondaga Creek. Spatial trends in these parameters also indicate these relatively isolated discharges have considerable effects on water quality far from their sites of origin.

5.3. Priority Point Source Sampling

Point source discharges can be major contributors to bacterial contamination in waterways; particularly in urban watersheds where municipal infrastructure is comparatively denser and more susceptible to failures that go unidentified. In an impaired, urban watershed in Texas, Petersen et al. (2005) found point source discharges were the predominant contributor to bacterial loads during dry weather. Similarly, Sercu et al. (2009) found storm drains to be the primary source of high bacteria concentrations in California streams during dry weather. The authors suspected the bacteria concentrations to be from exfiltrating sanitary sewers.

Fecal coliforms levels for priority point sources in Onondaga Creek and Harbor Brook varied dramatically both within and between sampling locations. Priority point source sampling helped to verify the successful correction of several point sources since the completion of Phase 1, including OC-PS20, OC-PS21, and OC-PS23 (Appendix H). Several point sources are currently also under investigation by Onondaga County and the City of Syracuse to identify the necessary correction; these sites include: OC-PS03, OC-PS61, and HB-PS100. Efforts have included contacting adjacent building owners (OC-PS 20, OC-PS21) and performing dye testing, TV camera scoping, and pipe cleaning in Onondaga Creek and Ley Creek.

During the MTS, regular sampling of point sources identified from Phase 1 and Phase 2 as problematic allowed for a more thorough understanding of the dynamics of bacteria contributions from select point sources in Harbor Brook and Onondaga Creek during Phase 3. Over half of the point sources selected for priority sampling (N = 9/14) in Harbor Brook and Onondaga Creek continually flowed during dry-weather, several of which discharged ‘very high’ levels of bacteria. One point source (i.e., OC-PS93) was never observed flowing during priority point source sampling. The remaining three intermittently-flowing point sources only flowed during 2014 events and were subsequently not observed flowing in 2015. While several of these point sources were corrected or were otherwise observed not flowing during Phase 3, the remaining nine priority point sources (i.e., three in Harbor Brook and six in Onondaga Creek) continue to discharge fecal coliforms at relatively constant rates and concentrations that collectively contribute to the degradation of water quality in their respective waterbodies.

5.4. Tributary Trackdown Sampling

Of the sampled tributaries to Onondaga Creek that discharge within the City of Syracuse, half appeared to be discharging high levels of bacteria. Problematic levels of bacteria (i.e., ‘high’) were observed in Cold Brook, Spring Brook/City Line Brook, and the north section of Hopper Brook. These results are spatially consistent with Phase 2 and suggest that persistent and pervasive inputs of bacteria continue to degrade water quality in these urban tributaries. Spatial trends for bacteria levels varied among the tributaries (i.e., upstream vs. downstream), further highlighting the dynamic and localized nature of contamination within these urban streams.

Identified bacterial problems at Cold Brook are a new and important discovery from Phase 3 sampling work and suggest that bacterial contamination has worsened since Phase 2. Point source trackdown sampling identified the bacterial contamination to be from humans and ruminant animals. Fecal coliforms levels in Spring Brook & City Line Brook showed a conspicuous significant downstream increase in fecal coliforms concentrations during the tributary trackdown event. Spring/City Line Brook transitions from a forested, primarily naturalized, residential headwater to a channelized, urban landscape in the downstream segment, before ultimately getting diverted underground. Consistent with Phase 2 results: 1) land use appears to be the primary driver of changes in water quality in this system, with urban development negatively affecting water quality; this is a likely symptom of the "urban stream syndrome," whereby point source discharges and stormwater runoff is greater in urban settings (Walsh et al. 2005) and 2) Hopper Brook (N) had elevated bacteria levels at nearly all the upstream sampling locations. Reconnaissance of those locations shows a narrow, shallow channel with sluggish flow and exposed canopy that meanders through residential properties for most of its length (Appendix J); this likely contributes to the high bacteria levels consistently observed in this system.

5.5. Point Source Trackdown Sampling

Temporal point source trackdown sampling during Phase 1 and Phase 2 showed conspicuous increases in bacteria levels during breakfast, lunch, and dinner; exfiltration from leaky sanitary sewers was thought to be the probable cause. Point source trackdown sampling during Phase 3 helped develop a comprehensive assessment of point source discharges on a spatial scale and helped prioritize sources for remediation. Results from this task helped to illustrate the dynamic nature of storm and sewer systems in heavily urbanized areas, where point source discharges can be the result of many factors including pipe failures, illicit discharges, runoff related to washing, construction, or sporadic, event-related (i.e., festivals) activities. In the City of Syracuse, where most of the infrastructure is over 100 years old and the occurrence of system failures is becoming more frequent (Gibas 2014, Weaver 2014), it can be assumed that the identification and monitoring of dry-weather point source discharges will be a necessary and ongoing process.

The inclusion of locations tributary to Onondaga Creek in this task also highlighted the dynamic nature of small, urban streams interconnected with the City's storm and sewer systems. Studies have shown in-stream bacteria levels to positively correlate with housing density (Young and Thackston 1999) and population density (Mallin et al. 2000, Holland et al. 2004). These factors ultimately lead to increased domestic animal density, which has been documented as an identifiable source of bacterial contamination in highly developed/urbanized areas (Young and Thackston 1999, Kelsey et al. 2004). Phase 2 sampling found OC-PS03 (a suspected diversion for City Line Brook), OC-PS04 (City Line & Cold Brooks), and OC-PS09 (Hopper Brook, North) to periodically discharge moderate to very high levels of fecal coliforms. Tributary trackdown and point source trackdown sampling confirmed that there were upstream contributions of bacteria entering these tributaries on a regular basis. Events showed locations with the highest fecal coliform concentrations were not the same throughout events for each respective tributary, suggesting that bacterial sources were coming from multiple sources and that those contributions were driven by localized conditions. Those results provided the impetus for a specialized form of bacteria analysis, *Bacteroides.*

The addition of *Bacteroides* analysis in Phase 3 helped elucidate the major contributors of fecal coliforms to the Onondaga Creek and Harbor Brook watersheds. Fecal coliforms and *Bacteroides* results from 2016 and 2017 suggest that water quality in Harbor Brook and Onondaga Creek are impacted from two animal sources, with human sources being predominant. In both 2016 and 2017, *Bacteroides* sampling at Dorwin Ave., upstream of the City's CSO system (i.e., Dorwin Ave.), showed that bacterial contamination from humans was a prominent source of fecal coliforms during dry weather. This rather surprising trend suggests that human sources of bacteria, presumably from failing septic systems, are negatively impacting water quality in the middle and upper reaches of Onondaga Creek. Further analyses are needed to substantiate this hypothesis. While animal contributions (from ruminant animals) were identifiable in *Bacteroides* analyses in 2017, collectively, human sources remained the most prominent source of fecal coliforms contamination, with 75% of samples testing positive between 2016 and 2017. These results validate the need for additional trackdown sampling and *Bacteroides* analyses, as well as for further collaborative, investigative work with the City of Syracuse and Onondaga County WEP to identify the physical source of the (human-based) bacterial inputs that support development of strategies for remediation.

Bacteroides sampling in the tributaries to Onondaga Creek also highlighted the spatial variability in not only the intensity of fecal contamination, but also the source of contamination; suggesting that impairments to water quality are not driven by longitudinal gradients, but rather localized, and potentially sporadic, inputs. In 2017 ruminant animals (e.g., deer, cows, etc.), were identified in 50% of the samples analyzed for *Bacteroides* (N=11). This compares with 0% in 2016 (N=12). The noticeable increase in ruminant contributions to bacteria inputs within the Onondaga Creek and Harbor Brook watersheds between 2016 and 2017 may be attributed to agricultural practices in the upper watershed as well as growing deer populations in urban neighborhoods; ruminant sourced bacteria may have a significant impact on water quality and human health. Guber et al. (2015) observed important microbial environmental pollution contributions from white tail deer that fluctuated with rainfall intensities and runoff.

6. Conclusions

The Phase 3 Microbial Trackdown Study helped elucidate the dynamic nature of stream systems and the compounding effects of multiple sources of point-source pollution on water quality and bacteria levels during dry weather. By comparison, bacteria levels observed during Phase 3 were commonly above NYS DEC criteria (i.e., 200cfu/100 mL)[11]. In-stream bacteria levels in Harbor Brook were significantly different between rural and urban locations, with urban locations exhibiting higher bacteria levels. New exploratory research examined the contributions

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[11] It should be reiterated that NYS Criteria is based on a geometric mean, of at least five observations per month, of 200 cfu/100 mL. While the Phase 3 analyses did not include a geometric mean calculation (N < 5 observations/ month), comparisons to the NYS Criteria for fecal coliformss, nevertheless, provides a useful measure of the magnitude of fecal coliforms inputs from point sources with persistent flow rates, as well as collectively among in-stream locations.

of non-point bacterial, nutrient, and sediment contaminants affecting the Onondaga Creek's upper watershed. Based on Upper Onondaga Creek sampling results increases in bacteria levels in the upper watershed are suspected to be caused by farming practices. Agriculturally-sourced bacteria in the upper watershed may have contributed to the lack of statistical significance in the differences in bacteria exhibited between rural and urban reaches of Onondaga Creek.

Priority point source sampling found several point sources in Onondaga Creek and Harbor Brook discharging 'severe' levels of bacteria. These sampling efforts identified point sources investigated during Phase 1 and/or Phase 2 that remained problematic or were remediated under Phase 2 and/or Phase 3. Routine and priority sampling of these persistent point sources for bacteria allowed Working Group members to further prioritize sampling efforts and develop strategies for investigating and remediating problematic discharges.

Two urban tributaries to Onondaga Creek, City Line Brook and Hopper Brook (N), had high levels of bacteria at several sampling locations during the 2017 tributary trackdown event. Furthermore, this most recent event elucidated problematic bacteria levels in an additional Onondaga Creek tributary, Cold Brook. Preliminary results suggest that site conditions (e.g., no canopy, low flows and stagnant waters) coupled with potential animal waste sources (i.e., from deer and/or domestic pets) may be important drivers of high bacteria levels observed for these urban tributaries; moreover, no point sources of bacterial discharges at these locations were evident. Decreases in bacteria at several downstream locations were attributed to point source corrections made during and after the completion of Phase 1 and Phase 2.

Despite several corrections made in Harbor Brook during and after Phases 1 and 2, substantive increases in bacteria levels occurred with downstream order. Sampling results for Harbor Brook suggest that perturbations at and just upstream of Velasko Rd. continue to be the source of the high bacteria levels observed downstream. Notwithstanding the commonly observed spatial gradient, bacteria levels were also problematic at Onondaga Rd., the most upstream location. Though this location typically dries up in the summer, contributions of bacteria to Harbor Brook at and upstream of this site could be significant during non-summer months and are likely sourced from agricultural inputs.

Decreased water quality, including elevated turbidity, temperature, and specific conductivity levels, was evident at several routine locations in Harbor Brook, Onondaga Creek, and Ley Creek, potentially driven by impacts of increased urban runoff, stream channelization, reduced riparian vegetative protection, sediment discharges from the Tully Valley mudboils, and the infiltration of natural salt springs. However, levels of these water quality metrics at most in-stream sampling locations were generally not considered detrimental to aquatic organisms or human health.

Results from this study effectively documented the effects of dry-weather inputs on bacteria levels and water quality in Harbor Brook, Onondaga Creek, and Ley Creek. In addition, spatial and temporal trends in bacteria levels were identified that helped: 1) explain patterns in-stream water quality related to land use, 2) detect relationships between measured parameters, 3) identify and prioritize point source trackdown work, 4) measure the effects of remedial activities on bacteria levels, and 5) assess long-term changes in bacteria levels since Phase 1. Through the combined efforts of the Phase 1, 2, and 3 Microbial Trackdown Studies, 16 point sources have been successfully corrected (7 during and after Phase 1, 5 during and after Phase 2, and 4 during Phase 3). Nevertheless, following the conclusion of Phase 3 sampling, there remained problematic point source discharges in Harbor Brook and Onondaga Creek that could have important long-term deleterious effects on water quality if left uncorrected. Results have also identified several in-stream locations where bacteria levels remain problematic since Phase 1; this suggested remedial efforts have failed and/or new problems have emerged in the system. This is particularly evident in Harbor Brook, where many in-stream routine sampling locations exhibited substantive fecal coliforms concentration increases since Phase 1.

7. Recommendations

Despite numerous corrections made in Harbor Brook, Onondaga Creek, and Ley Creek, this study shows that problematic dry-weather discharges remain; impacting overall in-stream water quality. To further understand the effects of dry-weather discharges on in-stream water quality, the following recommendations have been made for future studies:

a) *Continue in-stream, routine sampling during dry-weather* to better assess long-term seasonal and spatial changes in bacteria levels and the effects of continuous changes to the watershed, such as increased development, infrastructure failures and repairs, non-point source pollution (i.e., agriculture), and climate change, on water quality. Routine sampling has emphasized the importance of maintaining a long-term dataset that documents spatial and temporal changes in bacteria levels. This could have significant implications for establishing and maintaining water quality criteria (e.g., TMDL's).

b) *Develop and implement a strategized program for prioritizing and sampling point source discharges* that includes the ongoing identification of sources and the performance of repairs. By incorporating an adaptive-management approach that can be easily and cost-effectively implemented by organizations/agencies on a regular basis, project partners can prioritize where and how time and resources should be allocated. The Working Group is aptly serving this function. Priority point source and point source trackdown sampling demonstrated the dynamic nature of aging infrastructure, changes in development, and the unpredictable behavior of the frequency, duration, and location of point-source discharges in an urban setting. Routine, within-pipe bacterial trackdown studies (i.e., from the point of discharge moving up the pipe) would help identify locations where breaks exist. Furthermore, routine source testing using dye testing and/or television cameras at strategic manholes by a Syracuse City/Onondaga County bacteria trackdown taskforce may help with rapid identification of new sources. Inventories of point sources will help to understand those issues, as well as to help identify, prioritize, and correct problematic point source discharges on a case-by-case basis, ultimately helping to minimize remedial costs. In particular, the point sources that remain problematic and have unknown sources of fecal contamination include:

- HB-PS100 (Velasko Rd)
- HP-PS112 (Hiawatha Blvd)
- OC-PS01 (Cold Brook)
- OC-PS03 (Spring Brook)

- OC-PS04 (City Line Brook)
- OC-PS09 (Hopper Brook, N)
- OC-PS93 (Ballantyne Ave)
- OC-PS61 (W. Onondaga St)

c) *Continue and expand upon Bacteroides and upper Onondaga Creek sampling.* Fecal coliforms and *Bacteroides* results from 2017 suggest that water quality in Onondaga Creek is impacted by human and ruminant bacterial inputs upstream of the City's CSO system during dry weather. OEI intends to develop a proposal to conduct further trackdown sampling in the upper watershed to better investigate and identify water quality perturbations in upper Onondaga Creek.

d) *Develop a simple mathematical model for estimating point source contributions on in-stream bacteria levels*. Phase 2 loading estimates calculated from point sources have helped to conceptualize a preliminary understanding of bacterial contributions to in-stream bacteria levels. However, the development of a mathematical model could help better predict the contribution of individual point source discharges on ambient, in-stream concentrations. Additionally, such a tool could be used to estimate times-of-travel and the effects of point sources on downstream bacteria levels under dynamic conditions and predict bacterial exceedances within the context of regulatory compliance guidelines. In the long-term a well-developed and well-tested model could be implemented in place of field efforts, ultimately minimizing project costs.

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Table 8. pH levels for routine samples in Harbor Brook (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
Onondaga Rd.	NCF	NCF	NCF	NCF	NCF	NCF	8.34	7.86	NCF	NCF	NCF	NCF	NCF	7.86	8.1	8.34	2
Bellevue Ave.	7.6	7.75	7.64	7.81	7.77	7.41	7.78	8.15	7.87	8.01	7.95	7.74	7.85	7.41	7.795	8.15	13
Grand Ave.	7.79	7.87	7.81	7.86	7.95	7.66	7.95	8.29	7.95	8.07	7.98	7.88	7.93	7.66	7.922	8.29	13
Velasko Rd.	7.57	7.51	7.56	7.96	7.62	7.84	7.8	7.78	7.67	7.91	7.71	7.52	7.55	7.51	7.692	7.96	13
Delaware St.	7.67	7.64	7.7	7.86	7.84	7.53	7.78	7.81	7.8	7.76	7.89	7.73	7.71	7.53	7.748	7.89	13
Fowler H.S.	7.7	7.65	7.74	7.9	7.96	7.61	7.82	7.81	7.85	7.84	7.9	7.77	7.73	7.61	7.791	7.96	13
Hiawatha Blvd.	7.77	8.09	7.96	8.11	8.09	7.9	7.84	7.82	7.91	8.05	7.9	7.85	7.77	7.77	7.928	8.11	13

Notes:
1) NCF - not collected due to lack of flow

pH

🟥	**Highly Alkaline (pH >9)**
🟧	**Alkaline (pH 8-9)**
🟦	**Slightly Alkaline (pH 8)**
🟦	**Neutral (pH 7)**
🟦	**Slightly Acidic (pH 6)**
🟧	**Acidic (pH 5.5-6)**
🟥	**Highly Acidic (pH <5.5)**

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Table 9. Specific conductivity levels (µmHos/cm) for routine samples in Harbor Brook (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	N
Onondaga Rd.	NCF	NCF	NCF	NCF	NCF	NCF	754	1036	NCF	NCF	NCF	NCF	NCF	754	895	1036	2
Bellevue Ave.	958	838	914	843	15	821	1046	1428	1004	1027	942	837	860	15	887.2	1428	13
Grand Ave.	1552	1704	1529	2480	1681	1818	1767	720	1494	1569	1768	1656	1576	720	1640	2480	13
Velasko Rd.	2539	2547	2497	1311	2578	2473	2002	2394	2422	2342	2532	2478	2386	1311	2346	2578	13
Delaware St.	2450	2505	2392	2474	2518	2680	2015	2317	2370	2415	2485	2377	2377	2015	2413	2680	13
Fowler H.S.	2449	2500	2386	2469	2509	2673	2014	2314	2365	2416	2478	2368	2367	2014	2408	2673	13
Hiawatha Blvd.	2424	2443	2364	2439	2476	2481	2012	2293	2337	2321	2414	2322	2338	2012	2359	2481	13

Notes:
1) NCF - not collected due to lack of flow

Specific Conductivity (µmHos/cm)

🟥	Saline (3000 - 15,000)
🟧	Moderately Saline (Brackish) (1600 - 3000)
🟨	Slightly Saline (800 - 1600)
🟩	Freshwater (400 - 800)
🟦	Pristine (0 - 400)

Table 10. Salinity levels (ppt) for routine samples in Harbor Brook (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
Onondaga Rd.	NCF	NCF	NCF	NCF	NCF	NCF	0.37	0.52	NCF	NCF	NCF	NCF	NCF	0.37	0.445	0.52	2
Bellevue Ave.	0.48	0.41	0.45	0.42	0.01	TNP	0.52	0.72	0.5	0.51	0.47	0.41	0.43	0.01	0.444	0.72	12
Grand Ave.	0.79	0.87	0.77	1.29	0.86	0.93	0.9	0.35	0.76	0.8	0.9	0.84	0.8	0.35	0.835	1.29	13
Velasko Rd.	1.32	1.32	1.3	0.66	1.34	TNP	1.03	1.24	1.25	1.21	1.31	1.29	1.24	0.66	1.209	1.34	12
Delaware St.	1.27	1.3	1.24	1.28	1.31	1.4	1.03	1.2	1.23	1.25	1.29	1.23	1.23	1.03	1.251	1.4	13
Fowler H.S.	1.27	1.3	1.24	1.28	1.3	1.39	1.03	1.2	1.22	1.25	1.28	1.23	1.23	1.03	1.248	1.39	13
Hiawatha Blvd.	1.26	1.27	1.22	1.26	1.28	TNP	1.03	1.18	1.21	1.2	1.25	1.2	1.21	1.03	1.214	1.28	12

Salinity(ppt)

🟧	**Highly Saline (10 - 35)**
🟨	**Moderately Saline (3 - 10)**
🟩	**Slightly Saline (1 - 3)**
🟦	**Freshwater (0 - 1)**

Notes:
1) NCF - not collected due to lack of flow
2) TNP - test not performed; the sonde used at select locations on 10/13/14 was not equipped with a salinity readout

Table 11. Dissolved oxygen levels (mg/L) for routine samples in Harbor Brook (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
Onondaga Rd.	NCF	NCF	NCF	NCF	NCF	NCF	10.51	10.83	NCF	NCF	NCF	NCF	NCF	10.51	10.67	10.83	13
Bellevue Ave.	10.44	9.79	9.88	9.87	15.41	11.04	11.3	12.2	10.45	10.18	9.38	8.72	9.88	8.72	10.66	15.41	13
Grand Ave.	9.36	10.35	8.75	12.43	12.69	7.4	11.09	10.15	9.49	10.28	9.5	9.13	10.25	7.4	10.07	12.69	13
Velasko Rd.	9.58	9.15	9.34	13.2	13.79	11.8	12.06	10.88	9.34	5.15	9.05	9.03	9.6	5.15	10.15	13.79	13
Delaware St.	9.99	10.45	9.55	13.12	14.6	7.69	10.84	10.78	9.99	10.45	9.92	9.49	10.18	7.69	10.54	14.6	13
Fowler H.S.	9.86	9.63	9.27	12.43	13.62	7.79	10.74	9.69	9.72	5.97	9.48	9.26	9.69	5.97	9.781	13.62	13
Hiawatha Blvd.	10.15	10.58	9.71	13.7	14.3	11.2	10.41	11.13	9.63	10.91	9.79	9.13	9.62	9.13	10.79	14.3	13

Dissolved Oxygen (mg/L)

🟨	**Excessive (>14.6)**
🟩	**Very High (12 - 14.6)**
🟦	**High (8 - 12)**
🟩	**Moderate (5 - 8)**
🟨	**Low (3 - 5)**
🟧	**Very Low (2 - 3)**
🟥	**Extremely Low (0-2)**

Notes:

1) NCF - not collected due to lack of flow

Table 12. Temperature levels (°C) for routine samples in Harbor Brook (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	N
Onondaga Rd.	NCF	NCF	NCF	NCF	NCF	NCF	17.79	14.08	NCF	NCF	NCF	NCF	NCF	14.08	15.94	17.79	2
Bellevue Ave.	12.10	13.12	13.30	12.88	14.99	11.85	12.02	15.10	14.52	14.72	16.15	14.57	13.74	11.85	13.77	16.15	13
Grand Ave.	15.21	15.70	15.34	12.75	14.29	11.24	14.34	22.75	16.03	15.89	18.07	15.55	13.42	11.24	15.43	22.75	13
Velasko Rd.	15.07	15.20	15.04	13.50	14.65	11.70	14.08	15.66	15.61	16.69	16.64	14.26	13.17	11.70	14.71	16.69	13
Delaware St.	15.78	15.35	15.43	12.88	15.35	10.95	13.90	15.57	16.08	15.23	17.00	14.36	13.29	10.95	14.71	17.00	13
Fowler H.S.	15.57	15.03	14.85	12.50	14.73	10.74	13.53	15.17	15.88	15.63	16.72	14.27	13.31	10.74	14.46	16.72	13
Hiawatha Blvd.	16.05	15.92	15.36	13.60	14.68	11.10	13.39	15.59	16.21	17.75	17.65	15.34	13.78	11.10	15.11	17.75	13

Notes:

1) NCF - not collected due to lack of flow

Temperature

🟥	Hot (> 25°C) (>77°F)
🟧	Warm (20-25°C) (68-77°F)
🟨	Mild (15-20°C) (59-68°F)
🟦	Cool (10-15°C) (50-59°F)
🟦	Cold (5-10°C) (41-50°F)
⬛	Frigid (0-5°C)

Table 13. Turbidity levels (NTU) for routine samples in Harbor Brook (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	N
Onondaga Rd.	NCF	NCF	NCF	NCF	NCF	NCF	0.6	0.5	NCF	NCF	NCF	NCF	NCF	0.5	0.55	0.6	2
Bellevue Ave.	0.1	0.6	1.6	2	5.6	3.3	<0.1	<0.1	2.5	1.3	7.2	0.2	0.1	0.1	2.227	7.2	11
Grand Ave.	0.3	0.3	0.2	5.1	5	<0.1	2.4	<0.1	2.7	0.7	<0.1	1.1	0.1	0.1	1.79	5.1	10
Velasko Rd.	2.2	3	3.6	TNP	5.6	TNP	13	7.1	12.6	3.2	4.1	4.6	3.3	2.2	5.664	13	11
Delaware St.	8.4	4.6	3	0.6	5.5	2.1	11.4	6.4	4.8	2.6	1.4	2.1	1.6	0.6	4.192	11.4	13
Fowler H.S.	9.6	5.9	3.2	0.7	5	2.8	11.6	4	4.7	2.7	1.4	2.8	1.6	0.7	4.308	11.6	13
Hiawatha Blvd.	6.3	DNR	3.8	TNP	22.1	TNP	12.8	3.2	5.7	6.8	1.2	2	2.9	1.2	6.68	22.1	10

Turbidity (NTU)

🟥	Very High (> 1000)
🟥	High (150 - 1000)
🟧	Medium (50 - 150)
🟨	Low (10 - 50)
🟩	Very Low (5 - 10)
🟦	Pristine (0 - 5)

Notes:

1) NCF - not collected due to lack of flow
2) TNP - test not performed; the sonde used at select locations on 9/24/14 and 10/13/14 was not equipped with a turbidity sensor
3) DNR - did not record data

Table 14. Bacteria levels (count/100mL) for routine samples in Harbor Brook (2014-2015).

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	N
Onondaga Rd.	NCF	NCF	NCF	NCF	NCF	NCF	173	230	NCF	NCF	NCF	NCF	NCF	173	201.50	230	2
Bellevue Ave.	<100	82	73	100	9	18	164	9	18	27	27	100	36	9	58.70	164	13
Grand Ave.	91	182	118	580	45	370	290	250	173	240	1280	560	320	45	346.08	1280	13
Velasko Rd.	909	3000	1420	18	460	18	273	1640	1000	73	909	2200	3300	18	1170.77	3300	13
Delaware St.	1360	1820	1190	440	350	310	736	827	918	818	1010	782	500	310	850.85	1820	13
Fowler H.S.	2100	2200	1360	570	218	360	580	2000	818	570	864	827	450	218	993.62	2200	13
Hiawatha Blvd.	1090	3500	1730	480	380	320	1000	1640	545	809	818	1000	545	320	1065.92	3500	13

Fecal Coliform (cfu/100mL)

🟥	**Severe** **(> 50k)**
▨	**Very High** **(10k-50k)**
🟧	**High** **(1000-10,000)**
🟨	**Moderate** **(100-1000)**
🟩	**Low** **(10-100)**
🟦	**Very Low** **(0-10)**

Notes:

1) NCF - not collected due to lack of flow

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Table 15. Dissolved oxygen levels (mg/L) for routine samples in the Onondaga Creek watershed (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
Tully Farms Rd. (South)	9.86	10.32	10.79		10.36	8.81	DNC	9.64	10.79	10.15	9.78	8.21	10.9	8.21	9.965	10.9	13
Bear Mountain Rd.	DNC	DNC	DNC	9.62	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	9.62	9.62	9.62	13
Rte. 20	7.72	8.33	11.29	8.97	10.09	7.95	9.46	7.98	9.3	9	7.31	6.83	9.76	6.83	8.768	11.29	13
Hitchings Rd. (West Branch)	8.76	8.28	13.25	8.96	9.64	7.47	8.87	8.19	8.85	8.53	6.83	6.83	9.32	6.83	8.752	13.25	13
Gibson Rd.	7.66	8.75	11.08	9.25	9.62	7.69	8.76	8.08	9.24	9.58	7.48	6.97	9.35	6.97	8.732	11.08	13
Dorwin Ave.	9.14	9.81	12.72	10.4	11.5	12.6	9.37		9.88	7.42	9.04	7.71	9.39	7.42	9.915	12.72	13
W. Seneca Trpk.	9.29	10.26	13.43	10.47	12.05	7.79	9.54	8.14	9.14	10.9	9.11	7.66	9.75	7.66	9.81	13.43	13
W. Newell St.	DNR	9.19	13.31	10.64	14.59	7.54	9.7	7.89	9.67	10.29	8.54	7.3	10.85	7.3	9.959	14.59	13
South Ave. Downstream	9.03	9.15	12.51	10.77	14.93	8.03	9.7	7.83	9.06	9.95	8.25	7.29	9.78	7.29	9.714	14.93	13
Walton St.	9.04	8.71	11.06	9.79	11.93	10.7	9.39	7.84	8.5	9.42	7.95	7.06	9.86	7.06	9.327	11.93	13
W. Kirkpatrick St.	9.08	8.7	10.17	11.8	14.2	12.26	9.26	7.77	8.4	8.32	7.73	6.88	9.54	6.88	9.547	14.2	13

Dissolved Oxygen (mg/L)

🟨	**Excessive (>14.6)**
🟩	**Very High (12 - 14.6)**
🟦	**High (8 - 12)**
🟩	**Moderate (5 - 8)**
🟨	**Low (3 - 5)**
🟧	**Very Low (2 - 3)**
🟥	**Extremely Low (0-2)**

Notes:

1) DNC - did not collect

2) DNR - did not record; sonde improperly logged

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Table 16. Temperature levels (°C) for routine samples in the Onondaga Creek watershed (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	N
Tully Farms Rd. (South)	17.03	15.88	17.08	DNC	12.77	11.22	DNC	17.36	19.25	18.11	17.58	14.66	12.01	11.22	15.72	19.25	11
Bear Mountain Rd.	DNC	DNC	DNC	12.32	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	12.32	12.32	12.32	1
Rte. 20	20.51	19.25	18.60	12.52	14.45	9.47	15.87	21.61	19.76	18.44	21.83	16.82	12.90	9.47	17.08	21.83	13
Hitchings Rd. (West Branch)	25.32	20.31	20.40	13.72	16.13	10.05	19.31	22.65	21.83	20.46	22.94	18.63	14.00	10.05	18.90	25.32	13
Gibson Rd.	21.44	19.53	19.34	12.75	14.82	9.62	18.12	21.43	20.92	19.50	22.18	17.54	13.46	9.62	17.74	22.18	13
Dorwin Ave.	21.34	20.08	20.17	12.80	15.07	10.10	18.46	21.04	20.88	19.75	22.11	17.85	13.59	10.10	17.94	22.11	13
W. Seneca Trpk.	21.05	19.54	19.71	12.78	14.89	10.15	18.24	20.91	20.47	19.38	21.41	17.26	13.46	10.15	17.63	21.41	13
W. Newell St.	19.34	17.83	18.08	12.41	14.50	10.23	17.40	19.87	18.71	17.64	19.20	15.99	13.12	10.23	16.49	19.87	13
South Ave. Downstream	18.76	17.46	16.88	12.64	14.59	10.19	16.53	19.15	17.87	17.16	19.29	15.84	13.03	10.19	16.11	19.29	13
Walton St.	18.71	17.55	16.73	12.70	14.55	10.00	16.39	19.43	17.86	17.04	19.52	16.08	13.08	10.00	16.13	19.52	13
W. Kirkpatrick St.	18.66	17.53	16.74	12.96	14.72	11.49	16.31	19.57	17.84	17.03	19.49	16.26	13.20	11.49	16.29	19.57	13

Temperature	
🟥	Hot (> 25°C) (>77°F)
🟧	Warm (20-25°C) (68-77°F)
🟨	Mild (15-20°C) (59-68°F)
🟦	Cool (10-15°C) (50-59°F)
🟦	Cold (5-10°C) (41-50°F)
⬛	Frigid (0-5°C)

Notes:

1) DNC - did not collect; Bear Mtn Rd was mistakenly sampled on 9/24/14 in place of Tully Farms Rd

2) Power to the YSI sonde was lost before a reading could be taken at Tully Farms Rd on 7/6/15

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Table 17. pH levels for routine samples in the Onondaga Creek watershed (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
Tully Farms Rd. (South)	8.27	8.32	8.25	DNC	7.96	8.09	DNC	8.28	8.18	8.02	8.2	8.04	8.46	7.96	8.188	8.46	11
Bear Mountain Rd.	DNC	DNC	DNC	8.12	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	8.12	8.12	8.12	1
Rte. 20	8.07	8.12	8.03	8.09	8.01	7.88	8.1	8.13	8.16	7.94	7.99	7.71	8.14	7.71	8.028	8.16	13
Hitchings Rd. (West Branch)	7.58	8.04	7.99	7.99	8.02	7.86	8	8.1	8.07	7.84	7.91	7.72	8.09	7.58	7.939	8.1	13
Gibson Rd.	8	8.04	8.06	8.02	7.73	7.84	8.06	8.11	8.12	7.99	7.94	7.71	8.1	7.71	7.978	8.12	13
Dorwin Ave.	8.06	8.11	8.11	8.11	8.01	7.68	8.12	8.13	8.11	8.11	8.02	7.71	8.14	7.68	8.032	8.14	13
W. Seneca Trpk.	8.11	8.14	8.16	8.02	8.06	7.86	8.13	8.13	8.16	8.01	8.03	7.75	8.16	7.75	8.055	8.16	13
W. Newell St.	7.86	7.84	7.89	7.82	7.87	7.68	7.99	7.94	7.88	7.73	7.71	7.47	7.89	7.47	7.813	7.99	13
South Ave. Downstream	7.86	7.84	7.84	7.78	7.86	7.67	7.95	7.96	7.87	7.68	7.76	7.47	7.87	7.47	7.801	7.96	13
Walton St.	7.84	7.83	7.75	7.73	7.82	7.77	7.92	7.92	7.86	7.67	7.8	7.5	7.91	7.5	7.794	7.92	13
W. Kirkpatrick St.	7.71	7.76	7.7	7.91	7.9	7.86	7.9	7.88	7.75	7.62	7.68	7.27	7.74	7.27	7.745	7.91	13

Notes:

1) DNC - did not collect; Bear Mtn Rd was mistakenly sampled on 9/24/14 in place of Tully Farms Rd

2) Power to the YSI sonde was lost before a reading could be taken at Tully Farms Rd on 7/6/15

pH

🟥	**Highly Alkaline (pH >9)**
🟧	**Alkaline (pH 8-9)**
🟦	**Slightly Alkaline (pH 8)**
🟦	**Neutral (pH 7)**
🟦	**Slightly Acidic (pH 6)**
🟧	**Acidic (pH 5.5-6)**
🟥	**Highly Acidic (pH <5.5)**

Table 18. Specific conductivity levels (µmHos/cm) for routine samples in the Onondaga Creek watershed (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	N
Tully Farms Rd. (South)	504	513	507	DNC	527	556	DNC	507	1484	1688	493	493	534	493	709.6	1688	11
Bear Mountain Rd.	DNC	DNC	DNC	1347	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNR	DNR	1347	1347	1347	1
Rte. 20	1503	1912	1704	1450	1774	1979	951	1037	1618	1850	2557	2235	2068	951	1741	2557	13
Hitchings Rd. (West Branch)	688	711	667	660	650	801	705	6663	645	648	668	671	767	645	1150	6663	13
Gibson Rd.	1087	1295	1212	1096	1287	1439	828	828	1144	1254	1593	1361	1387	828	1216	1593	13
Dorwin Ave.	1062	1257	1157	1062	1241	1285	848	1049	1132	1218	1467	1223	1293	848	1176	1467	13
W. Seneca Trpk.	1096	1276	1174	1080	1255	1401	860	1057	1174	1287	1494	1239	1332	860	1210	1494	13
W. Newell St.	1238	1399	1277	1181	1352	1494	954	1148	1301	1397	1572	1353	1445	954	1316	1572	13
South Ave. Downstream	1323	1521	1374	1200	1361	1586	1026	1168	1389	1423	1571	1465	1579	1026	1384	1586	13
Walton St.	1348	1530	184	1241	1411	1552	1050	1165	1459	1492	1636	1539	1630	184	1326	1636	13
W. Kirkpatrick St.	3654	4310	3653	2959	3649	4228	2200	2649	4189	4333	5405	5234	4915	2200	3952	5405	13

Specific Conductivity (µmHos/cm)

🟥	**Saline (3000 - 15,000)**
🟧	**Moderately Saline (Brackish) (1600 - 3000)**
🟨	**Slightly Saline (800 - 1600)**
🟩	**Freshwater (400 - 800)**
🟦	**Pristine (0 - 400)**

Notes:

1) DNC - did not collect; Bear Mtn Rd was mistakenly sampled on 9/24/14 in place of Tully Farms Rd

2) Power to the YSI sonde was lost before a reading could be taken at Tully Farms Rd on 7/6/15

Table 19. Salinity levels (ppt) for routine samples in the Onondaga Creek watershed (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
Tully Farms Rd. (South)	0.24	0.25	0.25	DNC	0.26	0.27	DNC	0.25	0.75	0.86	0.24	0.24	0.26	0.24	0.352	0.86	11
Bear Mountain Rd.	DNC	DNC	DNC	0.68	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	0.68	0.68	0.68	1
Rte. 20	0.76	0.98	0.87	0.73	0.9	1.01	0.47	0.51	0.82	0.94	1.32	1.15	1.06	0.47	0.886	1.32	13
Hitchings Rd. (West Branch)	0.33	0.35	0.33	0.32	0.32	0.4	0.34	0.32	0.31	0.32	0.32	0.33	0.38	0.31	0.336	0.4	13
Gibson Rd.	0.54	0.65	0.61	0.55	0.65	0.73	0.41	0.41	0.57	0.63	0.8	0.68	0.7	0.41	0.61	0.8	13
Dorwin Ave.	0.53	0.63	0.58	0.53	0.62	TNP	0.42	0.52	0.56	0.61	0.74	0.61	0.65	0.42	0.583	0.74	12
W. Seneca Trpk.	0.54	0.64	0.59	0.54	0.63	0.71	0.42	0.52	0.59	0.64	0.75	0.62	0.67	0.42	0.605	0.75	13
W. Newell St.	0.62	0.7	0.64	0.59	0.68	0.76	0.47	0.57	0.65	0.7	0.8	0.68	0.73	0.47	0.661	0.8	13
South Ave. Downstream	0.66	0.77	0.69	0.6	0.69	0.8	0.51	0.58	0.7	0.72	0.79	0.74	0.8	0.51	0.696	0.8	13
Walton St.	0.68	0.77	0.09	0.62	0.71	TNP	0.52	0.58	0.74	0.75	0.83	0.78	0.83	0.09	0.658	0.83	12
W. Kirkpatrick St.	1.93	2.31	1.94	1.55	1.93	TNP	1.13	1.38	2.24	2.32	2.93	2.84	2.65	1.13	2.096	2.93	12

Salinity(ppt)

🟧	**Highly Saline (10 - 35)**
🟨	**Moderately Saline (3 - 10)**
🟩	**Slightly Saline (1 - 3)**
🟦	**Freshwater (0 - 1)**

Notes:

1) DNC - did not collect; Bear Mtn Rd was mistakenly sampled on 9/24/14 in place of Tully Farms Rd

2) Power to the YSI sonde was lost before a reading could be taken at Tully Farms Rd on 7/6/15

3) TNP - test not performed; the sonde used at select locations on 10/13/14 was not equipped with a salinity readout

Table 20. Turbidity levels (NTU) for routine samples in the Onondaga Creek watershed (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	N
Tully Farms Rd. (South)	5.1	2.6	2.7	DNC	6	1	DNC	8.2	51.6	50.7	1.1	1.1	1.2	1	11.94	51.6	13
Bear Mountain Rd.	DNC	DNC	DNC	27.9	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	27.9	27.9	27.9	1
Rte. 20	72.3	80.1	41.6	29.8	24	19.8	40.3	66.3	44	44.4	53.9	38.3	16	16	43.91	80.1	13
Hitchings Rd. (West Branch)	21.8	11.6	4.8	4.8	8	5.1	28.8	34.5	12.7	11	22.6	10.9	10.1	4.8	14.36	34.5	13
Gibson Rd.	74.2	63.3	29.3	18.8	26.5	10.5	41	110.4	25.6	20.2	35.5	33.9	17.5	10.5	38.98	110.4	13
Dorwin Ave.	27	11.2	9.1	TNP	23.8	TNP	27.1	51.2	10.7	7.2	16	23.5	15.7	7.2	20.23	51.2	13
W. Seneca Trpk.	24.1	7.5	5.1	17.6	20.1	8.5	25.7	55.2	8.4	6.3	14.7	19.9	17	5.1	17.7	55.2	13
W. Newell St.	20.9	7.2	5.1	15.7	12.2	5.5	36	62.9	5.7	7.6	7.9	9.5	7.8	5.1	15.69	62.9	13
South Ave. Downstream	20.7	7.6	2.9	11.1	9.7	4	20.6	82.6	5.5	3.2	6.6	7.4	6.5	2.9	14.49	82.6	13
Walton St.	21	7.2	53.8	TNP	8.5	TNP	29.7	93.6	5.3	4.1	7.6	8.2	6.5	4.1	22.32	93.6	13
W. Kirkpatrick St.	23.5	7.3	4.1	9	8.5	3.6	22	27.8	5.1	4.2	6.4	7.8	6.5	3.6	10.45	27.8	13

Turbidity (NTU)

🟥	Very High (> 1000)
▨	High (150 - 1000)
🟧	Medium (50 - 150)
🟨	Low (10 - 50)
🟩	Very Low (5 - 10)
🟦	Pristine (0 - 5)

Notes:

1) DNC - did not collect; Bear Mtn Rd was mistakenly sampled on 9/24/14 in place of Tully Farms Rd

2) TNP - test not performed; the sonde used at select locations on 9/24/14 and 10/13/14 was not equipped with a turbidity sensor

3) Power to the YSI sonde was lost before a reading could be taken at Tully Farms Rd on 7/6/15

Table 21. Bacteria levels (count/100mL) for routine samples in the Onondaga Creek watershed (2014-2015).

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	N
Tully Farms Rd. (South)	91	200	82	DNC	<10	<10	27	220	460	350	36	45	9	9	128.33	460	12
Bear Mountain Rd.	DNC	DNC	DNC	273	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	273	273.00	273	1
Rte. 20	727	570	390	590	136	109	4800	2000	454	273	300	260	290	109	940.82	4800	13
Hitchings Rd. (West Branch)	36	<100	109	73	82	173	<10	145	127	64	191	127	109	<10	103.83	191	13
Gibson Rd.	545	220	220	545	127	45	3400	2700	2000	<100	182	91	272	45	803.62	3400	13
Dorwin Ave.	364	470	230	845	440	36	18	2600	145	154	240	490	173	18	477.31	2600	13
W. Seneca Trpk.	182	400	145	754	350	164	182	2400	118	164	410	390	440	118	469.15	2400	13
W. Newell St.	3000	364	2800	590	310	136	127	1600	270	136	250	290	191	127	774.15	3000	13
South Ave. Downstream	1090	370	330	410	210	118	1820	3300	91	273	260	270	270	91	677.85	3300	13
Walton St.	545	470	454	454	100	64	3000	1730	91	560	290	330	109	64	630.54	3000	13
W. Kirkpatrick St.	454	649	454	182	210	126	2600	545	364	273	<100	182	<100	126	479.92	2600	13

Fecal Coliform (cfu/100mL)

🟥	Severe (> 50k)
▨	Very High (10k-50k)
🟧	High (1000-10,000)
🟨	Moderate (100-1000)
🟩	Low (10-100)
🟦	Very Low (0-10)

Notes:

1) DNC - did not collect; Bear Mtn Rd was mistakenly sampled on 9/24/14 in place of Tully Farms Rd

Table 22. Specific conductivity levels (µmHos/cm) for routine samples in Ley Creek (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	N
Exeter St.	2333	DNC	2445	2012	2484	2662	2349	2619	2543	2730	2751	2242	2360	2012	2461	2751	12
Court St.	2250	2435	2128	1918	2384	2540	2082	2563	2494	2675	2499	2148	2313	1918	2341	2675	13
Fly Rd.	1503	1625	1531	1600	1598	1797	878	1322	1665	1683	1467	1681	1538	878	1530	1797	13
Thompson Rd.	1184	1201	1160	1143	1162	1180	892	1146	1089	1070	1045	1086	1045	892	1108	1201	13
LeMoyne Ave.	1744	1899	1831	1656	1904	1807	1434	954	1931	2006	2003	1632	1761	954	1736	2006	13
Park St.	1951	2030	1987	1751	2003	2021	1535	1909	1953	2180	2142	1734	1929	1535	1933	2180	13

Specific Conductivity (µmHos/cm)

🟥	**Saline (3000 - 15,000)**
🟧	**Moderately Saline (Brackish) (1600 - 3000)**
🟨	**Slightly Saline (800 - 1600)**
🟩	**Freshwater (400 - 800)**
🟦	**Pristine (0 - 400)**

Notes:
1) DNC - did not collect

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Table 23. Salinity levels (ppt) for routine samples in Ley Creek (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
Exeter St.	1.2	DNC	1.26	1.03	1.29	1.39	1.21	1.36	1.32	1.42	1.43	1.15	1.22	1.03	1.273	1.43	12
Court St.	1.15	1.26	1.09	0.98	1.23	1.32	1.07	1.32	1.29	1.39	1.29	1.1	1.2	0.98	1.207	1.39	13
Fly Rd.	0.76	0.82	0.77	0.81	0.81	0.92	0.43	0.66	0.85	0.86	0.74	0.85	0.78	0.43	0.774	0.92	13
Thompson Rd.	0.59	0.6	0.58	0.57	0.58	0.59	0.44	0.57	0.54	0.53	0.52	0.54	0.52	0.44	0.552	0.6	13
LeMoyne Ave.	0.88	0.97	0.93	0.84	0.97	0.92	0.72	0.47	0.98	1.02	1.02	0.83	0.9	0.47	0.881	1.02	13
Park St.	0.99	1.04	1.02	0.89	1.03	TNP	0.78	0.97	1	1.12	1.09	0.88	0.99	0.78	0.983	1.12	12

Salinity(ppt)

🟧	**Highly Saline (10 - 35)**
🟨	**Moderately Saline (3 - 10)**
🟩	**Slightly Saline (1 - 3)**
🟦	**Freshwater (0 - 1)**

Notes:
1) DNC - did not collect
2) TNP - test not performed; the sonde used at select locations on 10/13/14 was not equipped with a salinity readout

Table 24. Dissolved oxygen levels (mg/L) for routine samples in Ley Creek (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
Exeter St.	7.66	DNC	8.77	7.70	8.99	7.45	9.13	8.57	7.60	7.13	6.04	6.74	9.53	6.04	7.94	9.53	12
Court St.	9.61	8.70	9.02	8.48	9.64	6.73	10.20	9.91	8.53	8.91	9.24	8.37	9.67	6.73	9.00	10.20	13
Fly Rd.	7.01	7.19	6.91	5.45	8.09	6.67	7.69	7.05	6.86	5.40	7.31	5.44	9.35	5.40	6.96	9.35	13
Thompson Rd.	5.65	5.73	6.37	7.14	8.55	7.12	7.45	6.43	6.40	6.73	5.94	6.23	7.32	5.65	6.70	8.55	13
LeMoyne Ave.	8.04	6.70	8.35	9.23	8.36	9.32	9.91	12.84	8.63	8.52	6.69	7.77	9.91	6.69	8.79	12.84	13
Park St.	6.31	7.82	12.65	9.99	8.36	12.30	6.38	7.64	6.70	9.67	6.51	7.03	8.68	6.31	8.46	12.65	13

Notes:
1) DNC - did not collect

Dissolved Oxygen (mg/L)

🟨	**Excessive (>14.6)**
🟩	**Very High (12 - 14.6)**
🟦	**High (8 - 12)**
🟩	**Moderate (5 - 8)**
🟨	**Low (3 - 5)**
🟧	**Very Low (2 - 3)**
🟥	**Extremely Low (0-2)**

Table 25. pH levels for routine samples in Ley Creek (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
Exeter St.	7.81	DNC	7.84	7.85	7.65	7.78	7.92	8	7.93	7.96	7.89	7.78	7.9	7.65	7.859	8	12
Court St.	8.08	7.87	8.04	8.03	7.78	7.9	8.08	8.11	8.07	8.04	7.98	7.94	7.93	7.78	7.988	8.11	13
Fly Rd.	7.57	7.6	7.31	7.43	7.14	7.34	7.75	7.73	7.51	7.65	7.8	7.57	7.49	7.14	7.53	7.8	13
Thompson Rd.	7.54	7.62	7.46	7.71	7.67	7.45	7.82	7.92	7.74	7.85	7.9	7.64	7.7	7.45	7.694	7.92	13
LeMoyne Ave.	7.71	7.62	7.81	7.93	7.76	7.68	7.95	8.14	7.91	7.88	7.79	7.78	7.83	7.62	7.83	8.14	13
Park St.	7.3	7.34	7.61	8.08	7.77	7.69	7.6	7.44	7.38	7.63	7.52	7.55	7.43	7.3	7.565	8.08	13

Notes:

1) DNC - did not collect

pH

🟥	**Highly Alkaline (pH >9)**
🟧	**Alkaline (pH 8-9)**
🟦	**Slightly Alkaline (pH 8)**
🟦	**Neutral (pH 7)**
🟦	**Slightly Acidic (pH 6)**
🟧	**Acidic (pH 5.5-6)**
🟥	**Highly Acidic (pH <5.5)**

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Table 26. Temperature levels (°C) for routine samples in Ley Creek (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	N
Exeter St.	21.86	DNC	19.92	14.96	16.13	12.08	19.21	21.83	20.81	19.69	22.89	19.00	14.76	12.08	18.60	22.89	12
Court St.	22.22	20.67	19.80	15.51	15.93	11.92	19.03	22.91	21.40	20.10	22.87	18.80	14.80	11.92	18.92	22.91	13
Fly Rd.	19.11	18.25	16.57	11.92	13.40	8.56	19.11	20.93	18.14	16.79	21.14	15.67	13.03	8.56	16.36	21.14	13
Thompson Rd.	20.60	19.33	19.11	14.19	15.14	11.39	18.70	21.42	19.06	18.32	20.77	17.28	14.28	11.39	17.66	21.42	13
LeMoyne Ave.	22.47	21.77	20.75	14.94	16.47	11.64	20.02	23.62	21.85	21.36	23.99	18.79	14.53	11.64	19.40	23.99	13
Park St.	22.21	21.56	20.36	14.80	16.75	10.70	19.06	22.80	21.77	21.14	23.55	19.01	14.80	10.70	19.12	23.55	13

Notes:
1) DNC - did not collect

Temperature

🟥	Hot (> 25°C) (>77°F)
🟧	Warm (20-25°C) (68-77°F)
🟨	Mild (15-20°C) (59-68°F)
🟦	Cool (10-15°C) (50-59°F)
🟦	Cold (5-10°C) (41-50°F)
⬛	Frigid (0-5°C)

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Table 27. Turbidity levels (NTU) for routine samples in Ley Creek (2014-2015)

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	N
Exeter St.	2.8	DNC	1.4	3.3	3.3	2.1	3.3	1	4.7	1.7	2.1	3	3.3	1	2.667	4.7	12
Court St.	2.7	2.9	1.8	3.7	2.6	2.2	1.9	2.2	5.4	2.4	1.5	3	2.8	1.5	2.7	5.4	13
Fly Rd.	3.9	3.6	2.6	2.8	3.6	6.2	3	4.1	7.8	6.2	4.7	4.1	6.5	2.6	4.546	7.8	13
Thompson Rd.	4.2	6.2	3.7	2.6	7.1	4.3	4.8	3.5	6.1	4.2	2.9	3.7	2.9	2.6	4.323	7.1	13
LeMoyne Ave.	3.2	2.4	2.4	3.1	3.5	5.4	5.2	1.2	5.5	2.2	1.5	5.5	3	1.2	3.392	5.5	13
Park St.	22.5	10.4	10.7	TNP	10.2	TNP	12.8	12.2	16	12.2	5.2	9.7	10	5.2	11.99	22.5	11

Notes:

1) DNC - did not collect

2) TNP - test not performed; the sonde used at select locations on 9/24/14 and 10/13/14 was not equipped with a turbidity sensor

Turbidity (NTU)

🟥	Very High (> 1000)
🟪	High (150 - 1000)
🟧	Medium (50 - 150)
🟨	Low (10 - 50)
🟩	Very Low (5 - 10)
🟦	Pristine (0 - 5)

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Table 28. Bacteria levels (count/100mL) for routine samples in Ley Creek (2014-2015).

Location	06/30/14	07/21/14	08/11/14	09/24/14	09/29/14	10/13/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	N
Exeter St.	454	DNC	91	364	136	36	91	273	364	273	545	91	182	36	241.67	545	12
Court St.	636	667	540	664	727	430	545	727	545	430	127	154	350	127	503.23	727	13
Fly Rd.	273	775	230	136	200	36	173	210	173	100	<10	54	380	36	211.54	775	13
Thompson Rd.	91	470	570	210	370	118	36	210	200	145	109	82	164	36	213.46	570	13
LeMoyne Ave.	545	560	590	360	136	310	191	290	460	909	1200	230	100	100	452.38	1200	13
Park St.	1270	81	736	18	800	450	773	1360	530	590	280	864	645	18	645.92	1360	13

Notes:

1) DNC - did not collect

Fecal Coliform (cfu/100mL)

🟥	Severe (> 50k)
🟪	Very High (10k-50k)
🟧	High (1000-10,000)
🟨	Moderate (100-1000)
🟩	Low (10-100)
🟦	Very Low (0-10)

Table 29. Spearman's rank correlation matrix of parameters measured during routine sampling (Task 3). Parameters significantly correlated ($p < 0.05$), using the Holm-Bonferroni correction method, are denoted in bold.

PARAMETER	DO	COND	PH	TEMP	FCOLI	SALI	TURB	CL2
DO	1.00							
COND	-0.02	1.00						
PH	**0.32**	-0.29	1.00					
TEMP	**-0.40**	-0.04	0.20	1.00				
FCOLI	0.05	**0.38**	-0.06	0.12	1.00			
SALI	-0.02	**0.98**	**-0.32**	-0.06	**0.40**	1.00		
TURB	-0.08	**-0.20**	0.16	**0.22**	0.13	**-0.22**	1.00	
CL2	-0.10	-0.07	0.07	0.00	0.13	-0.07	0.16	1.00

[1] Please refer to Table 6 for definitions of parameters codes.

Table 30. Dissolved oxygen levels (mg/L) for samples collected in the upper Onondaga Creek watershed (2014).

Location	06/11/14	06/19/14	07/09/14	07/24/14	08/14/14	09/04/14	09/15/14	09/18/14	10/02/14	10/08/14	Minimum	Average	Maximum	N
Woodmancy Rd.	9.7	9.89	17.51	9.39	9.18	9.58		10.43	10.57	9.12	9.12	10.6	17.51	9
Solvay Rd.	9.71	10.1	16.05	9.53	9.61	9.51		9.7	10.35	9.41	9.41	10.44	16.05	9
Tully Farms Rd. (South)	10.1	10.35	17.83	10.18	8.03	9.95		10.36	10.96	10.01	8.03	10.86	17.83	9
Otisco Rd.	9.48	9.91	17.35	9.22	9.65	9.83		10.29	10.46	8.66	8.66	10.54	17.35	9
Tully Farms Rd. @ Fall Creek	9.84	10.24	16.01	9.81	9.84	9.82		10.61	10.91	9.75	9.75	10.76	16.01	9
Nichols Rd.	9.4	9.77	17.67	9.16	9.3	9.66		9.63	10.75	9.07	9.07	10.49	17.67	9
Bear Mountain Rd.	9.35	9.65	17.89	8.99	9.4	9.39		9.9	10.18	8.94	8.94	10.41	17.89	9
Buffalo Hill Rd.	8.87	9.56	16.44	8.41	9.22	8.84		9.59	9.63	8.63	8.41	9.91	16.44	9
Red Mill Rd. (West Branch)	14.01	12.14	8.81	7.08	9.97	6.86	12.77		9.25	11.07	6.86	10.22	14.01	9
Hogsback Rd. (West Branch)	9.1	10.33	9.13	7.04	11.33	9.88	9.09		8.67	10.58	7.04	9.461	11.33	9
Hitchings Rd. (West Branch)	9.56	8.5	7.77	7.83	10.14	8.49	8.19		7.04	9.76	7.04	8.587	10.14	9
Flood Control Dam (above)	8.2	8.2	13.29	7.87	8.32	8.04		8.93	9.1	8.61	7.87	8.951	13.29	9
Gibson Rd.	8.31	8.56	14.35	7.78	8.07	8.04		8.92	9.08	8.97	7.78	9.12	14.35	9
Winacre Dr. (Kennedy Creek)	9.1	12.47	9.38	9.55	DNC	9.94	8.77		8	10.54	8	9.719	12.47	8
Rt 11 (Kennedy Creek)	8.95	12.08	9.26	9.56	11.31	9.67	8.67		7.45	10.41	7.45	9.707	12.08	9
Webb Rd. (Hemlock Creek)	9.92	46.92	9.35	10.17	11.41	9.94	9.79		8.93	10.41	8.93	14.09	46.92	9
Quarry Rd. (Hemlock Creek)	9.47	30.82	9.31	9.7	11.44	10.09	9.85		11.01	10.87	9.31	12.51	30.82	9
Swimming hole - upstream of Rte 11A	9.44	9.96	9.05	9.73	11.27	10.07	9.95		11.2	10.96	9.05	10.18	11.27	9
Rt 80 (Commissary Creek)	9.18	9.94	8.89	9.29	11.34	9.96	9.44		8.28	10.6	8.28	9.658	11.34	9
Rt 11A (Williams Creek)	10.13	10.8	9.96	9.75	11.61	10.33	9.88		11	10.52	9.75	10.44	11.61	9
Roswell Rd.	8.55	8.7	15.21	8.52	9.28	8.16		9.86	10.86	9.06	8.16	9.8	15.21	9

Notes:

1) Samples are arranged in downstream order

2) DNC - did not collect

Table 31. Temperature levels for samples collected in the upper Onondaga Creek watershed (2014).

Location	06/11/14	06/19/14	07/09/14	07/24/14	08/14/14	09/04/14	09/15/14	09/18/14	10/02/14	10/08/14	Minimum	Average	Maximum	N
Woodmancy Rd.	15.89	17.09	18.4	17.49	15.68	17.06		11.87	13.86	12.66	11.87	15.56	18.4	9
Solvay Rd.	15.55	16.81	17.81	16.89	15.7	17.41		12.04	14.08	12.82	12.04	15.46	17.81	9
Tully Farms Rd. (South)	14.84	15.84	16.57	15.67	17.35	16.73		11.48	13.37	12.54	11.48	14.93	17.35	9
Otisco Rd.	15.86	16.66	18.08	17.8	15.72	16.88		11.72	13.69	12.92	11.72	15.48	18.08	9
Tully Farms Rd. @ Fall Creek	16.47	17.48	18.03	17.1	15.09	17.3		10.94	13.49	12.28	10.94	15.35	18.03	9
Nichols Rd.	16.26	17.19	18.55	18.56	15.95	16.94		11.65	13.67	12.88	11.65	15.74	18.56	9
Bear Mountain Rd.	16.62	17.12	18.91	18.79	15.85	17		11.83	13.87	12.99	11.83	15.89	18.91	9
Buffalo Hill Rd.	17.65	18.01	19.81	19.77	16.81	17.97		12.41	14.52	13.19	12.41	16.68	19.81	9
Red Mill Rd. (West Branch)	21.46	22.4	23.57	23.19	18.5	20.54	14.49		17.71	14.73	14.49	19.62	23.57	9
Hogsback Rd. (West Branch)	16.7	18.43	17.79	17.11	15.51	16.85	11.33		13.28	12.35	11.33	15.48	18.43	9
Hitchings Rd. (West Branch)	19.57	20.19	20.83	20.69	17.39	19.37	13.49		16.02	13.91	13.49	17.94	20.83	9
Flood Control Dam (above)	18.24	19.08	20.33	20.32	17.35	18.92		12.64	15.03	13.51	12.64	17.27	20.33	9
Gibson Rd.	18.17	19.01	20.3	20.22	17.54	19.11		12.7	14.9	13.45	12.7	17.27	20.3	9
Winacre Dr. (Kennedy Creek)	15.94	15.7	17	15.98	DNC	15.6	11.5		12.78	12.12	11.5	14.58	17	8
Rt 11 (Kennedy Creek)	15.77	16.96	18.33	20.38	14.48	15.73	12.85		12.84	12.24	12.24	15.51	20.38	9
Webb Rd. (Hemlock Creek)	16.42	17.86	18.31	17.65	15.17	15.84	11.72		12.69	12.4	11.72	15.34	18.31	9
Quarry Rd. (Hemlock Creek)	17	18.83	18.67	18.11	15.46	17.16	12.28		13.34	12.65	12.28	15.94	18.83	9
Swimming hole - upstream of Rte 11A	17.27	17.49	17.47	17.92	15.66	17.32	11.24		13.08	12.74	11.24	15.58	17.92	9
Rt 80 (Commissary Creek)	16.73	16.99	18.13	17.84	16.28	17.82	11.86		17.35	13.43	11.86	16.27	18.13	9
Rt 11A (Williams Creek)	15.61	14.03	15.58	15.75	14.26	15.02	11.4		12.32	12.51	11.4	14.05	15.75	9
Roswell Rd.	18.01	18.79	20.03	20.08	17.67	19.21		12.78	16.16	13.21	12.78	17.33	20.08	9

Temperature

🟥	Hot (> 25°C) (>77°F)
🟧	Warm (20-25°C) (68-77°F)
🟨	Mild (15-20°C) (59-68°F)
🟦	Cool (10-15°C) (50-59°F)
🟦	Cold (5-10°C) (41-50°F)
⬛	Frigid (0-5°C)

Notes:

1) Samples are arranged in downstream order.

2) DNC - did not collect

Table 32. pH levels for samples collected in the upper Onondaga Creek watershed (2014).

Location	06/11/14	06/19/14	07/09/14	07/24/14	08/14/14	09/04/14	09/15/14	09/18/14	10/02/14	10/08/14	Minimum	Average	Maximum	N
Woodmancy Rd.	8.31	8.37	8.52	8.31	8.21	8.18		8.22	8.07	8.35	8.07	8.28	8.52	9
Solvay Rd.	8.23	8.39	8.5	8.29	8.28	8.22		8.29	8.18	8.32	8.18	8.30	8.5	9
Tully Farms Rd. (South)	8.28	8.4	8.55	8.39	7.49	8.21		8.29	8.09	8.4	7.49	8.23	8.55	9
Otisco Rd.	8.15	8.17	8.5	8.09	8.09	8.09		8.2	8.04	8.1	8.04	8.16	8.5	9
Tully Farms Rd. @ Fall Creek	8.28	8.46	8.36	8.21	8.33	8.18		8.28	8.24	8.41	8.18	8.31	8.46	9
Nichols Rd.	8.06	8.16	8.28	8.15	8.05	8.04		8.1	8.04	8.11	8.04	8.11	8.28	9
Bear Mountain Rd.	8.13	8.17	8.34	8.17	8.01	8		8.11	8.02	8.05	8	8.11	8.34	9
Buffalo Hill Rd.	8.08	8.18	8.38	8.12	8.01	7.97		8.13	7.98	8.01	7.97	8.10	8.38	9
Red Mill Rd. (West Branch)	7.78	8.01	7.88	7.61	7.89	7.73	7.66		7.76	8.1	7.61	7.82	8.1	9
Hogsback Rd. (West Branch)	7.95	8.29	8.29	7.52	8.22	8.17	7.85		7.99	8.22	7.52	8.06	8.29	9
Hitchings Rd. (West Branch)	8.02	8.13	8.12	7.95	7.95	7.84	7.73		7.74	7.99	7.73	7.94	8.13	9
Flood Control Dam (above)	8.01	8.04	8.21	8.02	7.86	7.82		7.99	7.85	7.96	7.82	7.97	8.21	9
Gibson Rd.	7.99	8.02	8.23	8.02	7.89	7.83		8.04	7.88	7.95	7.83	7.98	8.23	9
Winacre Dr. (Kennedy Creek)	8.03	8.22	8.21	8.05	DNC	8.02	7.84		7.85	8.14	7.84	8.05	8.22	8
Rt 11 (Kennedy Creek)	7.84	8.06	8.09	7.82	8	7.94	7.58		7.6	8.06	7.58	7.89	8.09	9
Webb Rd. (Hemlock Creek)	8.08	8.27	8.33	8.13	8.04	7.92	7.9		7.81	8.04	7.81	8.06	8.33	9
Quarry Rd. (Hemlock Creek)	8.19	8.44	8.47	8.3	8.23	8.22	8		8.14	8.49	8	8.28	8.49	9
Swimming hole - upstream of Rte 11A	8.19	8.37	8.35	8.3	8.2	8.2	7.98		8	8.51	7.98	8.23	8.51	9
Rt 80 (Commissary Creek)	7.95	8.28	8.3	8.14	8.25	8.12	7.86		7.7	8.29	7.7	8.10	8.3	9
Rt 11A (Williams Creek)	7.82	7.91	7.73	8.01	7.81	8.02	7.74		7.82	8.08	7.73	7.88	8.08	9
Roswell Rd.	7.9	8.04	8.24	7.91	7.9	7.73		8.03	8.05	7.93	7.73	7.97	8.24	9

pH

🟥 **Highly Alkaline (pH >9)**
🟧 **Alkaline (pH 8 9)**
🟦 **Slightly Alkaline (pH 8)**
🟦 **Neutral (pH 7)**
🟦 **Slightly Acidic (pH 6)**
🟧 **Acidic (pH 5.5-6)**
🟥 **Highly Acidic (pH <5.5)**

Notes:

1) Samples are arranged in downstream order.

2) DNC - did not collect

Table 33. Specific conductivity levels (uS/cm) for samples collected in the upper Onondaga Creek watershed (2014).

Location	06/11/14	06/19/14	07/09/14	07/24/14	08/14/14	09/04/14	09/15/14	09/18/14	10/02/14	10/08/14	Minimum	Average	Maximum	N
Woodmancy Rd.	554	554	567	581	558	586		576	566	509	509	561.22	586	9
Solvay Rd.	508	484	484	487	509	555		521	537	499	484	509.33	555	9
Tully Farms Rd. (South)	507	514	505	507	382	576		519	526	492	382	503.11	576	9
Otisco Rd.	1204	1131	493	1458	1051	1067		1308	1103	1072	493	1098.56	1458	9
Tully Farms Rd. @ Fall Creek	473	501	1338	466	550	568		518	538	507	466	606.56	1338	9
Nichols Rd.	1009	935	1088	1193	888	913		1103	1074	888	888	1010.11	1193	9
Bear Mountain Rd.	1292	1158	1364	1599	1098	1154		1506	1449	1301	1098	1324.56	1599	9
Buffalo Hill Rd.	1308	1128	1484	1913	1061	1143		1534	1403	1585	1061	1395.44	1913	9
Red Mill Rd. (West Branch)	741	670	661	629	719	610	687		629	707	610	672.56	741	9
Hogsback Rd. (West Branch)	804	468	576	732	885	848	830		818	807	468	752.00	885	9
Hitchings Rd. (West Branch)	753	689	694	668	741	634	720		657	743	634	699.89	753	9
Flood Control Dam (above)	1057	925	1169	1483	884	876		1175	1058	1246	876	1097.00	1483	9
Gibson Rd.	1046	907	1164	1473	872	860		1157	1030	1211	860	1080.00	1473	9
Winacre Dr. (Kennedy Creek)	598	576	561	548	DNC	600	587		615	595	548	585.00	615	8
Rt 11 (Kennedy Creek)	635	624	609	633	626	615	665		660	627	609	632.67	665	9
Webb Rd. (Hemlock Creek)	876	821	787	790	822	786	841		876	866	786	829.44	876	9
Quarry Rd. (Hemlock Creek)	743	739	738	716	787	703	717		742	792	703	741.89	792	9
Swimming hole - upstream of Rte 11A	742	738	740	691	782	707	718		739	774	691	736.78	782	9
Rt 80 (Commissary Creek)	757	733	737	756	797	785	825		639	834	639	762.56	834	9
Rt 11A (Williams Creek)	848	837	791	762	876	853	821		810	770	762	818.67	876	9
Roswell Rd.	1037	874	1097	1269	851	836		1095	832	1143	832	1003.78	1269	9

Specific Conductivity (µmHos/cm)

🟥	**Saline (3000 - 15,000)**
🟧	**Moderately Saline (Brackish) (1600 - 3000)**
🟨	**Slightly Saline (800 - 1600)**
🟩	**Freshwater (400 - 800)**
🟦	**Pristine (0 - 400)**

Notes:

1) Samples are arranged in downstream order

2) DNC - did not collect

Table 34. Salinity levels (ppt) for samples collected in the upper Onondaga Creek watershed (2014).

Location	06/11/14	06/19/14	07/09/14	07/24/14	08/14/14	09/04/14	09/15/14	09/18/14	10/02/14	10/08/14	Minimum	Average	Maximum	N
Woodmancy Rd.	0.27	0.27	0.28	0.28	0.27	0.29		0.28	0.28	0.25	0.25	0.27	0.29	9
Solvay Rd.	0.25	0.23	0.23	0.24	0.25	0.27		0.25	0.26	0.24	0.23	0.25	0.27	9
Tully Farms Rd. (South)	0.25	0.25	0.25	0.25	0.18	0.28		0.25	0.26	0.24	0.18	0.25	0.28	9
Otisco Rd.	0.6	0.56	0.24	0.74	0.52	0.53		0.66	0.55	0.53	0.24	0.55	0.74	9
Tully Farms Rd. @ Fall Creek	0.23	0.24	0.67	0.23	0.27	0.28		0.25	0.26	0.25	0.23	0.30	0.67	9
Nichols Rd.	0.5	0.46	0.54	0.6	0.44	0.45		0.55	0.54	0.44	0.44	0.50	0.6	9
Bear Mountain Rd.	0.65	0.58	0.69	0.81	0.55	0.58		0.76	0.73	0.65	0.55	0.67	0.81	9
Buffalo Hill Rd.	0.66	0.56	0.75	0.98	0.53	0.57		0.78	0.71	0.8	0.53	0.70	0.98	9
Red Mill Rd. (West Branch)	0.36	0.33	0.32	0.3	0.35	0.3	0.34		0.31	0.35	0.3	0.33	0.36	9
Hogsback Rd. (West Branch)	0.4	0.23	0.28	0.36	0.44	0.42	0.41		0.4	0.4	0.23	0.37	0.44	9
Hitchings Rd. (West Branch)	0.37	0.34	0.34	0.33	0.36	0.31	0.35		0.32	0.37	0.31	0.34	0.37	9
Flood Control Dam (above)	0.53	0.46	0.58	0.75	0.44	0.43		0.59	0.53	0.63	0.43	0.55	0.75	9
Gibson Rd.	0.52	0.45	0.58	0.74	0.43	0.42		0.58	0.51	0.61	0.42	0.54	0.74	9
Winacre Dr. (Kennedy Creek)	0.29	0.28	0.27	0.27	DNC	0.29	0.29		0.3	0.29	0.27	0.29	0.3	8
Rt 11 (Kennedy Creek)	0.31	0.3	0.3	0.31	0.31	0.3	0.33		0.32	0.31	0.3	0.31	0.33	9
Webb Rd. (Hemlock Creek)	0.43	0.4	0.39	0.39	0.41	0.39	0.42		0.43	0.43	0.39	0.41	0.43	9
Quarry Rd. (Hemlock Creek)	0.37	0.36	0.36	0.35	0.39	0.34	0.35		0.37	0.39	0.34	0.36	0.39	9
Swimming hole - upstream of Rte 11A	0.36	0.36	0.36	0.34	0.39	0.35	0.35		0.36	0.38	0.34	0.36	0.39	9
Rt 80 (Commissary Creek)	0.37	0.36	0.36	0.37	0.39	0.39	0.41		0.31	0.41	0.31	0.37	0.41	9
Rt 11A (Williams Creek)	0.42	0.41	0.39	0.38	0.43	0.42	0.41		0.4	0.38	0.38	0.40	0.43	9
Roswell Rd.	0.52	0.43	0.55	0.63	0.42	0.41		0.55	0.41	0.57	0.41	0.50	0.63	9

Salinity(ppt)

🟧 **Highly Saline (10 - 35)**

🟨 **Moderately Saline (3 - 10)**

🟩 **Slightly Saline (1 - 3)**

🟦 **Freshwater (0 - 1)**

Notes:

1) Samples are arranged in downstream order.

2) DNC - did not collect

Table 35. Turbidity levels (NTU) for samples collected in the upper Onondaga Creek watershed (2014).

Location	06/11/14	06/19/14	07/09/14	07/24/14	08/14/14	09/04/14	09/15/14	09/18/14	10/02/14	10/08/14	Minimum	Average	Maximum	N
Woodmancy Rd.	5.1	4	1.1	0.7	2.4	3.3		0.2	1.2	1.1	0.2	2.122	5.1	9
Solvay Rd.	27.2	46.4	39.8	27.3	46	39.8		9.6	35.1	22.6	9.6	32.64	46.4	9
Tully Farms Rd. (South)	9.8	8.2	4.2	2	3.2	5.6		1.2	3.6	2	1.2	4.422	9.8	9
Otisco Rd.	68.5	85.6	53.3	163	73	96		70.1	92.6	73.8	53.3	86.21	163	9
Tully Farms Rd. @ Fall Creek	104.8	64.7	97.8	74.1	6	268.8		103.8	68	141.1	6	103.2	268.8	9
Nichols Rd.	50.6	64.1	79	119.6	74	111.3		54.3	57.7	90.4	50.6	77.89	119.6	9
Bear Mountain Rd.	37.8	65.3	68.8	137.5	70.1	92		43.7	48.5	73	37.8	70.74	137.5	9
Buffalo Hill Rd.	29.6	66.9	53	96.7	79.3	84.9		25.9	30.6	27.4	25.9	54.92	96.7	9
Red Mill Rd. (West Branch)	15.5	17.4	30.6	30.6	29.6	22.6	31.1		30.4	19.8	15.5	25.29	31.1	9
Hogsback Rd. (West Branch)	6.6	7.1	5.7	<0.1	9.1	13.6	2.4		2.9	6.9	2.4	6.788	13.6	9
Hitchings Rd. (West Branch)	<0.1	18.1	13.8	6.8	18.1	27.5	6.2		8.6	6.8	6.2	13.24	27.5	9
Flood Control Dam (above)	65	100.4	81.1	95.7	74.6	77.8		25.5	39.6	38.2	25.5	66.43	100.4	9
Gibson Rd.	60.7	88.3	69	74.6	77.5	82.9		25.1	36.5	35.7	25.1	61.14	88.3	9
Winacre Dr. (Kennedy Creek)	3.9	4.9	3.7	1.5	DNC	0.7	<0.1		7.7	1.6	0.7	3.429	7.7	8
Rt 11 (Kennedy Creek)	3.3	2.4	3.7	<0.1	3.9	0.7	<0.1		1.8	0.9	0.7	2.386	3.9	9
Webb Rd. (Hemlock Creek)	0.9	2.4	3.4	0.3	2.6	1	0.5		3	7.8	0.3	2.433	7.8	9
Quarry Rd. (Hemlock Creek)	12.4	7.8	10	2.2	21	72.3	2.7		2.5	27.7	2.2	17.62	72.3	9
Swimming hole - upstream of Rte 11A	8.5	11	9.4	1.2	15.9	6.2	1.7		2.5	31.2	1.2	9.733	31.2	9
Rt 80 (Commissary Creek)	4.4	0.6	2.9	<0.1	3.3	0.5	0.1		16.6	0.5	0.1	3.613	16.6	9
Rt 11A (Williams Creek)	4.7	0.9	3.8	<0.1	2.8	4.2	0.4		1.4	1.9	0.4	2.513	4.7	9
Roswell Rd.	26.6	63.3	33.2	14	64.4	151.5		16.2	23	18.6	14	45.64	151.5	9

Turbidity (NTU)

- 🟥 Very High (> 1000)
- ▨ High (150 - 1000)
- 🟧 Medium (50 - 150)
- 🟨 Low (10 - 50)
- 🟩 Very Low (5 - 10)
- 🟦 Pristine (0 - 5)

Notes:

1) Samples are arranged in downstream order.

2) DNC - did not collect

Table 36. Total suspended solid concentrations (mg/L) for samples collected in the upper Onondaga Creek watershed (2014).

Location	06/11/14	06/19/14	07/09/14	07/24/14	08/14/14	09/04/14	09/15/14	09/18/14	10/02/14	10/08/14	Minimum	Average	Maximum	N
Woodmancy Rd.	<5	14	<5	<5	<5	<5		5	<2	3	3	<7.33	14	9
Solvay Rd.	25	39	50	36	50	37		8	27	101	8	41.444	101	9
Tully Farms Rd. (South)	53	8	5	<5	8	24		<2	<2	<2	5	<19.60	53	9
Otisco Rd.	72	72	93	136	99	79		364	73	296	72	142.67	364	9
Tully Farms Rd. @ Fall Creek	80	93	42	52	<5	223		84	34	91	<5	<87.38	223	9
Nichols Rd.	39	45	58	96	51	79		36	28	50	28	53.556	96	9
Bear Mountain Rd.	24	57	43	94	62	66		24	19	33	19	46.889	94	9
Buffalo Hill Rd.	16	59	33	69	64	60		15	17	15	15	38.667	69	9
Red Mill Rd. (West Branch)	11	16	27	40	34	23	27		30	22	11	25.556	40	9
Hogsback Rd. (West Branch)	<5	6	<5	<5	7	6	<3		2	<3	2	<5.25	7	9
Hitchings Rd. (West Branch)	28	21	13	8	19	31	6		6	5	5	15.222	31	9
Flood Control Dam (above)	82	118	96	114	73	74		36	37	44	36	74.889	118	9
Gibson Rd.	70	92	72	78	79	86		27	30	34	27	63.111	92	9
Winacre Dr. (Kennedy Creek)	<5	<5	32	<5	7	<2	22		3	6	<2	<14.00	32	9
Rt 11 (Kennedy Creek)	<5	12	<5	10	<5	3	<3		<2	<3	<2	<8.33	12	9
Webb Rd. (Hemlock Creek)	<5	<5	<5	<5	<5	<5	<3		3	<5	<3	<3.00	3	9
Quarry Rd. (Hemlock Creek)	7	11	<5	<5	30	<5	<3		<2	13	<2	<15.25	30	9
Swimming hole - upstream of Rte 11A	5	9	<5	<5	5	<5	<3		<2	14	<2	<8.25	14	9
Rt 80 (Commissary Creek)	<5	<5	<5	<5	<5	<5	<3		17	<3	<3	<17.00	17	9
Rt 11A (Williams Creek)	<5	<5	<5	<5	<5	<5	<3		<2	<3	<2	<4.22	<5	9
Roswell Rd.	23	55	27	10	65	65		50	16	16	10	36.333	65	9

Total Suspended Solids (mg/L)

🟥	Very Cloudy [1250-3300)
🟧	Cloudy (420-1250]
🟨	Translucent [100-420]
🟩	Transparent (40-100]
🟦	Clear [0-40)

Notes:

1) Samples are arranged in downstream order.

Table 37. Fecal coliform concentrations (cfu/100 mL) for samples collected in the upper Onondaga Creek watershed (2014).

Location	06/11/14	06/19/14	07/09/14	07/24/14	08/14/14	09/04/14	09/15/14	09/18/14	10/02/14	10/08/14	Minimum	Average	Maximum	N
Woodmancy Rd.	91	454	<100	182	91	91		<100	91	109	91	158.43	454	9
Solvay Rd.	540	631	35000	721	450	182		180	1200	645	180	4394.33	35000	9
Tully Farms Rd. (South)	273	182	182	<100	91	91		<100	82	9	9	130.00	273	9
Otisco Rd.	182	1000	1270	1730	636	1270		91	2000	1270	91	1049.89	2000	9
Tully Farms Rd. @ Fall Creek	210	230	127	250	209	220		45	91	173	45	172.78	250	9
Nichols Rd.	360	700	1400	2500	1400	1100		191	600	973	191	1024.89	2500	9
Bear Mountain Rd.	273	1640	1090	4100	1270	1180		364	636	664	273	1246.33	4100	9
Buffalo Hill Rd.	273	1910	636	1730	2000	1450		91	1400	200	91	1076.67	2000	9
Red Mill Rd. (West Branch)	64	330	36	127	410	600	64		100	118	36	205.44	600	9
Hogsback Rd. (West Branch)	145	210	54	64	700	3800	45		18	91	18	569.67	3800	9
Hitchings Rd. (West Branch)	727	182	182	<100	727	1090	<100		136	210	136	464.86	1090	9
Flood Control Dam (above)	390	2800	450	845	3300	1600		127	3100	91	91	1411.44	3300	9
Gibson Rd.	454	1640	3910	818	1360	1730		<100	2800	91	91	1600.38	3910	9
Winacre Dr. (Kennedy Creek)	27	100	73	220	863	91	<10		9	109	9	186.50	863	9
Rt 11 (Kennedy Creek)	773	545	91	545	91	182	91		27	250	27	288.33	773	9
Webb Rd. (Hemlock Creek)	260	240	320	330	11200	127	27		91	227	27	1424.67	11200	9
Quarry Rd. (Hemlock Creek)	300	280	109	145	200	182	18		45	154	18	159.22	300	9
Swimming hole - upstream of Rte 11A	182	250	118	136	145	250	664		127	118	118	221.11	664	9
Rt 80 (Commissary Creek)	173	54	36	91	290	570	<10		100	100	36	176.75	570	9
Rt 11A (Williams Creek)	580	145	570	173	91	82	18		36	127	18	202.44	580	9
Roswell Rd.	145	1700	530	380	3200	1000		118	1200	200	118	941.44	3200	9

Fecal Coliform (cfu/100mL)

🟥	Severe (> 50k)
🟥	Very High (10k-50k)
🟧	High (1000-10,000)
🟨	Moderate (100-1000)
🟩	Low (10-100)
🟦	Very Low (0-10)

Notes:

1) Samples are arranged in downstream order.

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Table 38. Total phosphorus concentrations (mg/L) for samples collected in the upper Onondaga Creek watershed (2014).

Location	06/11/14	06/19/14	07/09/14	07/24/14	08/14/14	09/04/14	09/15/14	09/18/14	10/02/14	10/08/14	Minimum	Average	Maximum	N
Woodmancy Rd.	0.016	0.018	0.016	0.013	0.019	0.015		0.015	0.006	0.014	0.006	0.015	0.019	9
Solvay Rd.	0.046	0.056	0.057	0.045	0.057	0.027		0.052	0.092	0.072	0.027	0.056	0.092	9
Tully Farms Rd. (South)	0.021	0.022	0.012	0.016	0.022	0.013		0.007	0.007	0.006	0.006	0.014	0.022	9
Otisco Rd.	0.060	0.065	0.059	0.112	0.077	0.040		0.092	0.058	1.130	0.040	0.188	1.130	9
Tully Farms Rd. @ Fall Creek	0.057	0.075	0.038	0.044	0.018	0.166		0.055	0.035	0.081	0.018	0.063	0.166	9
Nichols Rd.	0.043	0.079	0.018	0.076	0.065	0.081		0.053	0.033	0.059	0.018	0.056	0.081	9
Bear Mountain Rd.	0.038	0.068	0.050	0.091	0.056	0.078		0.028	0.036	0.055	0.028	0.056	0.091	9
Buffalo Hill Rd.	0.037	0.079	0.044	0.081	0.065	0.071		0.024	0.029	0.028	0.024	0.051	0.081	9
Red Mill Rd. (West Branch)	0.049	0.056	0.080	0.023	0.067	0.087	0.081		0.060	0.048	0.023	0.061	0.087	9
Hogsback Rd. (West Branch)	0.063	0.078	0.063	0.061	0.083	0.116	0.053		0.061	0.041	0.041	0.069	0.116	9
Hitchings Rd. (West Branch)	0.049	0.056	0.048	0.045	0.060	0.083	0.026		0.026	0.027	0.026	0.047	0.083	9
Flood Control Dam (above)	0.083	0.121	0.082	0.086	0.094	0.028		0.051	0.061	0.052	0.028	0.073	0.121	9
Gibson Rd.	0.069	0.105	0.077	0.073	0.088	0.100		0.032	0.051	0.054	0.032	0.072	0.105	9
Winacre Dr. (Kennedy Creek)	0.007	0.016	0.021	0.008	0.028	0.009	0.044		0.006	0.012	0.006	0.017	0.044	9
Rt 11 (Kennedy Creek)	0.005	0.010	0.008	0.014	0.010	0.030	0.006		<0.003	0.007	0.005	0.011	0.030	8
Webb Rd. (Hemlock Creek)	0.010	0.029	0.015	0.012	0.014	0.009	0.005		0.007	0.024	0.005	0.014	0.029	9
Quarry Rd. (Hemlock Creek)	0.018	0.023	0.019	0.010	0.043	0.013	0.019		<0.003	0.020	0.010	0.021	0.043	8
Swimming hole - upstream of Rte 11A	0.013	0.022	0.015	0.007	0.020	0.013	0.007		<0.003	0.021	0.007	0.015	0.022	8
Rt 80 (Commissary Creek)	0.006	0.010	0.013	0.003	0.009	0.005	0.004		0.043	0.003	0.003	0.011	0.043	9
Rt 11A (Williams Creek)	0.011	0.007	0.008	0.008	0.014	0.009	0.006		0.004	0.009	0.004	0.008	0.014	9
Roswell Rd.	0.051	0.084	0.040	0.036	0.089	0.097		0.034	0.035	0.030	0.030	0.055	0.097	9

Total Phosphorus (mg/L)

- 🟥 Hypereutrophic (>0.1)
- 🟧 Eutrophic (0.025 - 0.1)
- 🟩 Mesotrophic (0.015 - 0.025)
- 🟦 Oligotrophic (<0.015)

Notes:

1) Samples are arranged in downstream order.

Table 39. Total Kjeldahl nitrogen concentrations (mg/L) for samples collected in the upper Onondaga Creek watershed (2014).

Location	06/11/14	06/19/14	07/09/14	07/24/14	08/14/14	09/04/14	09/15/14	09/18/14	10/02/14	10/08/14	Minimum	Average	Maximum	N
Woodmancy Rd.	0.391	0.342	0.416	0.440	0.323	0.390		0.252	0.296	0.323	0.252	0.353	0.440	9
Solvay Rd.	0.309	0.291	0.375	0.381	0.372	0.288		0.382	0.654	0.475	0.288	0.392	0.654	9
Tully Farms Rd. (South)	0.271	0.262	0.168	0.258	0.323	0.301		0.160	0.293	0.311	0.160	0.261	0.323	9
Otisco Rd.	0.355	0.552	0.353	0.464	0.473	0.484		0.299	0.423	3.120	0.299	0.725	3.120	9
Tully Farms Rd. @ Fall Creek	0.261	0.498	0.441	0.297	0.282	0.414		0.393	0.440	0.400	0.261	0.381	0.498	9
Nichols Rd.	0.451	0.548	0.456	0.541	0.408	0.418		0.412	0.379	0.382	0.379	0.444	0.548	9
Bear Mountain Rd.	0.333	0.469	0.496	0.537	0.503	0.504		0.390	0.442	0.417	0.333	0.455	0.537	9
Buffalo Hill Rd.	0.293	0.548	0.406	0.604	0.595	0.438		0.311	0.304	0.391	0.293	0.432	0.604	9
Red Mill Rd. (West Branch)	0.642	0.783	1.080	1.340	0.726	0.714	0.657		0.646	0.862	0.642	0.828	1.340	9
Hogsback Rd. (West Branch)	0.433	0.699	0.825	0.355	0.527	0.468	0.355		0.344	0.470	0.344	0.497	0.825	9
Hitchings Rd. (West Branch)	0.636	0.660	0.537	0.522	0.700	0.573	0.464		0.424	0.482	0.424	0.555	0.700	9
Flood Control Dam (above)	0.463	0.855	0.694	0.692	0.697	0.629		0.515	0.629	0.494	0.463	0.630	0.855	9
Gibson Rd.	0.461	0.801	0.598	0.595	0.605	0.565		0.502	0.516	0.598	0.461	0.582	0.801	9
Winacre Dr. (Kennedy Creek)	0.213	0.455	0.306	<0.150	0.374	0.186	0.382		0.265	0.299	<0.150	<0.310	0.455	9
Rt 11 (Kennedy Creek)	0.229	<0.150	0.348	<0.150	0.236	0.357	0.240		0.233	0.242	<0.150	<0.269	0.357	9
Webb Rd. (Hemlock Creek)	0.338	0.151	0.387	0.325	0.323	0.301	0.290		0.375	0.369	0.151	0.318	0.387	9
Quarry Rd. (Hemlock Creek)	0.233	0.176	0.382	0.417	0.436	0.158	0.233		0.240	0.273	0.158	0.283	0.436	9
Swimming hole - upstream of Rte 11A	0.266	0.277	0.319	0.221	0.265	<0.150	0.227		0.247	0.271	0.221	0.262	0.319	9
Rt 80 (Commissary Creek)	0.199	0.188	0.277	0.212	0.263	0.280	0.196		0.582	0.196	0.188	0.266	0.582	9
Rt 11A (Williams Creek)	0.193	0.156	0.207	0.175	0.419	0.221	0.179		0.333	0.325	0.156	0.245	0.419	9
Roswell Rd.	0.428	0.687	0.446	0.347	0.597	0.574		0.302	0.442	0.425	0.302	0.472	0.687	9

Total Kjeldahl Nitrogen (mg/L)

🟥	**Hypereutrophic (≥ 1.5 mg/L)**
🟧	**Eutrophic (0.6 - 1.5 mg/L)**
🟩	**Mesotrophic (0.4 - 0.6 mg/L)**
🟦	**Oligotrophic <0.4 mg/L**

Notes:

1) Samples are arranged in downstream order.

Table 40. Ammonia concentrations (mg/L) for samples collected in the upper Onondaga Creek watershed (2014).

Location	06/11/14	06/19/14	07/09/14	07/24/14	08/14/14	09/04/14	09/15/14	09/18/14	10/02/14	10/08/14	Minimum	Average	Maximum	N
Woodmancy Rd.	0.031	0.538	<0.030	0.032	0.040	0.047		<0.030	0.036	0.034	0.0312	0.108	0.538	9
Solvay Rd.	<0.030	0.073	<0.030	0.031	0.034	0.043		0.208	0.561	0.192	0.0314	0.163	0.561	9
Tully Farms Rd. (South)	<0.030	0.053	<0.030	<0.030	<0.030	0.057		<0.030	<0.030	<0.030	0.0525	0.055	0.0565	9
Otisco Rd.	0.050	0.085	0.043	0.055	0.035	0.063		0.049	0.052	0.079	0.0351	0.057	0.0851	9
Tully Farms Rd. @ Fall Creek	<0.030	0.062	<0.030	<0.030	0.036	0.034		<0.030	0.060	<0.030	0.0343	0.048	0.0621	9
Nichols Rd.	0.046	0.154	0.031	0.043	0.039	0.044		0.045	0.037	0.048	0.0306	0.054	0.154	9
Bear Mountain Rd.	0.047	0.047	<0.030	<0.030	0.040	0.039		<0.030	0.043	<0.030	0.0385	0.043	0.0473	9
Buffalo Hill Rd.	0.049	0.150	<0.030	0.033	0.047	0.040		0.036	0.038	<0.030	0.0333	0.056	0.15	9
Red Mill Rd. (West Branch)	0.134	0.152	0.277	0.515	0.113	0.088	0.103		0.142	0.168	0.0882	0.188	0.515	9
Hogsback Rd. (West Branch)	0.041	0.033	0.047	0.047	0.041	0.047	0.043		0.044	0.050	0.033	0.044	0.0498	9
Hitchings Rd. (West Branch)	0.086	0.132	0.070	0.073	0.085	0.053	0.046		0.070	0.066	0.0455	0.076	0.132	9
Flood Control Dam (above)	0.080	0.083	0.050	0.050	0.067	0.054		0.032	0.048	0.033	0.0318	0.055	0.083	9
Gibson Rd.	0.069	0.206	0.046	0.054	0.054	0.124		<0.030	0.052	0.056	0.0457	0.083	0.206	9
Winacre Dr. (Kennedy Creek)	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	0.034		<0.030	<0.030	0.0341	0.034	0.0341	9
Rt 11 (Kennedy Creek)	<0.030	<0.030	<0.030	<0.030	<0.030	0.030	<0.030		<0.030	0.035	0.0304	0.032	0.0345	9
Webb Rd. (Hemlock Creek)	0.039	0.099	<0.030	<0.030	<0.030	<0.030	0.045		<0.030	<0.030	0.039	0.061	0.0986	9
Quarry Rd. (Hemlock Creek)	<0.030	0.054	<0.030	<0.030	<0.030	<0.030	<0.030		<0.030	<0.030	0.0542	0.054	0.0542	9
Swimming hole - upstream of Rte 11A	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030		<0.030	<0.030	<0.030	<0.030	<0.030	9
Rt 80 (Commissary Creek)	<0.030	0.135	<0.030	<0.030	<0.030	<0.030	<0.030		0.165	<0.030	0.135	0.150	0.165	9
Rt 11A (Williams Creek)	<0.030	0.058	<0.030	<0.030	<0.030	<0.030	0.104		0.042	<0.030	0.0415	0.068	0.104	9
Roswell Rd.	0.065	0.064	<0.030	0.030	0.049	0.050		0.033	0.040	0.031	0.0304	0.045	0.0651	9

Ammonia (mg/L)

🟥	Severe (≥ 2 mg/L)
🟧	High (0.1 - 2 mg/L)
🟩	Moderate (0.06 - 0.4 mg/L)
🟦	Low (0 - 0.06 mg/L)

Notes:

1) Samples are arranged in downstream order.

Table 41. Spearman's rank correlation matrix of parameters measured during upper Onondaga Creek sampling (Task 3.1). Parameters significantly correlated ($p < 0.05$), using the Holm-Bonferroni correction method, are denoted in bold.

PARAMETER	**DO**	**COND**	**PH**	**TEMP**	**FCOLI**	**SALI**	**TURB**	**CL2**	**TSS**	**NH3**	**TKN**	**TP**
DO	1.00											
COND	-0.17	1.00										
PH	**0.48**	**-0.28**	1.00									
TEMP	-0.20	0.06	0.06	1.00								
FCOLI	-0.04	**0.37**	0.04	**0.40**	1.00							
SALI	-0.16	**0.98**	**-0.27**	0.07	**0.38**	1.00						
TURB	-0.16	**0.41**	0.07	**0.28**	**0.58**	**0.42**	1.00					
CL2	-0.17	-0.07	0.23	-0.13	0.27	-0.08	0.21	1.00				
TSS	-0.20	**0.33**	0.06	**0.36**	**0.61**	**0.34**	**0.88**	0.38	1.00			
NH3	-0.22	0.12	**-0.23**	**0.27**	0.22	0.14	**0.33**	0.35	**0.40**	1.00		
TKN	**-0.30**	**0.29**	-0.19	**0.39**	**0.39**	**0.31**	**0.59**	0.29	**0.61**	**0.57**	1.00	
TP	**-0.28**	**0.28**	-0.04	**0.35**	**0.53**	**0.30**	**0.77**	0.37	**0.81**	**0.55**	**0.77**	1.00

[1] Please refer to Table 6 for definitions of parameters codes.

Table 42. Dissolved oxygen levels (mg/L) for priority point source samples in the Harbor Brook watershed (2014-2015).

Location	07/23/14	08/06/14	08/28/14	09/10/14	09/25/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/08/15	Minimum	Average	Maximum	n
PS-100: Velasko Rd (CSO-078)	8.41	9.74	17.03	10.11	20.24	11.31	10.62	9.28	9.46	9.51	8.91	9.77	8.41	11.20	20.24	12
PS-101BW: Harbor Brook Wetland outfall (CSO 018)	7.66	4.57	5.16	5.19	6.53	4.91	10.78	5.59	7.06	8.13	7.58	6.32	4.57	6.62	10.78	12
PS-103: Depalma Ave	9.61	10.29	15.64	10.85	15.79	10.70	8.79	9.38	10.03	11.22	10.17	10.74	8.79	11.10	15.79	12
PS-112: Hiawatha Blvd	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU				0

Dissolved Oxygen (mg/L)

🟨	**Excessive (>14.6)**
🟩	**Very High (12 - 14.6)**
🟦	**High (8 - 12)**
🟩	**Moderate (5 - 8)**
🟨	**Low (3 - 5)**
🟧	**Very Low (2 - 3)**
🟥	**Extremely Low (0-2)**

Notes:

1) NCU - not collected; point source was underwater at the time of sampling

Table 43. Temperature levels (°C) for priority point source samples in the Harbor Brook watershed (2014-2015).

Location	07/23/14	08/06/14	08/28/14	09/10/14	09/25/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
PS-100: Velasko Rd (CSO-078)	16.47	14.67	15.52	16.33	14.17	14.07	15.89	15.42	15.04	19.96	14.17	14.4	14.07	15.51	19.96	12
PS-101BW: Harbor Brook Wetland outfall (CSO 018)	22.76	18.87	19.99	19.27	16.83	17.21	15.34	20.61	19.6	19.96	14.45	13.57	13.57	18.21	22.76	12
PS-103: Depalma Ave	13.54	13.51	15.14	13.85	13.6	13.8	19.53	15.09	15.5	14.13	13.41	12.62	12.62	14.48	19.53	12
PS-112: Hiawatha Blvd	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU				0

Notes:
1) NCU - not collected; point source was underwater at the time of sampling

Temperature

🟥	Hot (> 25°C) (>77°F)
🟧	Warm (20-25°C) (68-77°F)
🟨	Mild (15-20°C) (59-68°F)
🟦	Cool (10-15°C) (50-59°F)
🟦	Cold (5-10°C) (41-50°F)
⬛	Frigid (0-5°C)

Table 44. pH levels for priority point source samples in the Harbor Brook watershed (2014-2015).

Location	07/23/14	08/06/14	08/28/14	09/10/14	09/25/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
PS-100: Velasko Rd (CSO-078)	7.63	7.62	7.56	7.77	7.58	7.82	7.92	7.66	7.76	7.77	7.56	7.63	7.56	7.69	7.92	12
PS-101BW: Harbor Brook Wetland outfall (CSO 018)	7.59	7.28	7.23	7.23	7.38	7.3	7.81	7.27	7.35	7.81	7.71	7.45	7.23	7.451	7.81	12
PS-103: Depalma Ave	7.69	7.53	7.75	7.72	7.77	7.59	7.56	7.68	7.59	7.81	7.72	7.71	7.53	7.677	7.81	12
PS-112: Hiawatha Blvd	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU				0

Notes:
1) NCU - not collected; point source was underwater at the time of sampling

pH

🟥 **Highly Alkaline (pH >9)**
🟧 **Alkaline (pH 8-9)**
🟦 **Slightly Alkaline (pH 8)**
🟦 **Neutral (pH 7)**
🟦 **Slightly Acidic (pH 6)**
🟧 **Acidic (pH 5.5-6)**
🟥 **Highly Acidic (pH <5.5)**

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Table 45. Specific conductivity levels (µmHos/cm) for priority point source samples in the Harbor Brook watershed (2014-2015).

Location	07/23/14	08/06/14	08/28/14	09/10/14	09/25/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
PS-100: Velasko Rd (CSO-078)	2337	2353	1204	2252	2254	2010	2371	2346	2328	19	2454	2118	19	2004	2454	12
PS-101BW: Harbor Brook Wetland outfall (CSO 018)	1750	2018	1291	1735	2067	1762	2263	1190	2335	2893	2653	2567	1190	2044	2893	12
PS-103: Depalma Ave	2568	2486	2431	2588	2564	2028	2157	2199	2124	2549	2429	2467	2028	2383	2588	12
PS-112: Hiawatha Blvd	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU				0

Specific Conductivity (µmHos/cm)

🟥	Saline (3000 - 15,000)
🟧	Moderately Saline (Brackish) (1600 - 3000)
🟨	Slightly Saline (800 - 1600)
🟩	Freshwater (400 - 800)
🟦	Pristine (0 - 400)

Notes:

1) NCU - not collected; point source was underwater at the time of sampling

Table 46. Salinity levels (ppt) for priority point source samples in Harbor Brook (2014-2015)

Location	07/23/14	08/06/14	08/28/14	09/10/14	09/25/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
PS-100: Velasko Rd (CSO-078)	1.21	1.22	0.6	1.16	1.16	1.03	1.23	1.21	1.2	0.01	1.27	1.09	0.01	1.033	1.27	12
PS-101BW: Harbor Brook Wetland outfall (CSO 018)	0.89	1.03	0.65	0.88	1.06	0.9	1.17	0.59	1.2	1.51	1.38	1.33	0.59	1.049	1.51	12
PS-103: Depalma Ave	1.33	1.29	1.26	1.35	1.33	1.04	1.11	1.13	1.09	1.32	1.26	1.28	1.04	1.233	1.35	12
PS-112: Hiawatha Blvd	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU				0

Salinity(ppt)

- 🟧 **Highly Saline (10 - 35)**
- 🟨 **Moderately Saline (3 - 10)**
- 🟩 **Slightly Saline (1 - 3)**
- 🟦 **Freshwater (0 - 1)**

Notes:
1) NCU - not collected; point source was underwater at the time of sampling

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Table 47. Bacteria levels (count/100mL) for priority point source samples in Harbor Brook (2014-2015).

Location	07/23/14	08/06/14	08/28/14	09/10/14	09/25/14	07/06/15	07/20/15	08/03/15	08/10/15	09/09/15	09/17/15	10/07/15	Minimum	Average	Maximum	n
PS-100: Velasko Rd (CSO-078)	630	320	1500	273	540	909	454	273	560	227	827	400	227	576	1500	12
PS-101BW: Harbor Brook Wetland outfall (CSO 018)	590	8640	104000	182	2900	909	320	909	364	273	2200	364	182	10138	104000	12
PS-103: Depalma Ave	<10	<10	454	<100	91	<100	<10	<10	<10	145	64	9	9	84	454	10
PS-112: Hiawatha Blvd	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU	NCU				10

Notes:
1) NCU - not collected; point source was underwater at the time of sampling

Fecal Coliform (cfu/100mL)

🟥	Severe (> 50k)
▨	Very High (10k-50k)
🟧	High (1000-10,000)
🟨	Moderate (100-1000)
🟩	Low (10-100)
🟦	Very Low (0-10)

Table 48. Dissolved oxygen levels (mg/L) for priority point source samples in the Onondaga Creek watershed (2014-2015).

Location	07/23/14	08/28/14	09/10/14	09/25/14	07/13/15	07/22/15	08/24/15	08/31/15	09/16/15	10/08/15	10/12/15	Minimum	Average	Maximum	n
PS-02: Hopper Brook S outfall, W Seneca Trpk	8.01	12.16	10.44	12.41	9.45	9.01	11.58	10.09	9.24	10.05	5.41	5.41	9.80	12.41	11
PS-93: Outfall S of Van Duyn School ball field	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF				0
PS-03: W Glen Ave	9.79	14.17	9.91	21.35	10.38	9.68	15.11	9.98	10.08	10.44	7.28	7.28	11.65	21.35	11
PS-04: City Line Brook outfall, Ballantyne Rd	8.79	14.18	9.97	27.64	9.85	9.75	11.10	9.56	10.67	11.02	16.67	8.79	12.65	27.64	11
PS-09: Hopper Brook N outfall, Medora Pl	7.88	12.06	8.82	30.60	8.77	9.52	11.28	9.22	10.06	10.95	16.83	7.88	12.36	30.60	11
PS-11: W Brighton Ave	5.12	11.17	DNR	27.53	7.53	7.00	8.39	4.92	5.52	7.63	18.50	4.92	10.33	27.53	10
PS-71: 300ft downstream South Ave	6.02	10.85	6.83	26.41	6.11	6.16	9.36	7.54	NCF	NCF	14.94	6.02	9.91	26.41	9
PS-20: 100ft upstream W Adams St, Byrne Dairy (CSO-037)	5.44	NCF	5.92	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	5.44	5.68	5.92	2
PS-92: W Water St	6.24	12.25	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	6.24	9.25	12.25	2
PS-23: EBSS (CSO-080)	4.34	13.17	9.02	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	4.34	8.84	13.17	3

Notes:

1) NCF - not collected due to lack of flow
2) DNR - did not record data

Dissolved Oxygen (mg/L)

🟨	Excessive (>14.6)
🟩	Very High (12 - 14.6)
🟦	High (8 - 12)
🟩	Moderate (5 - 8)
🟨	Low (3 - 5)
🟧	Very Low (2 - 3)
🟥	Extremely Low (0-2)

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Table 49. Temperature levels (°C) for priority point source samples in the Onondaga Creek watershed (2014-2015).

Location	07/23/14	08/28/14	09/10/14	09/25/14	07/13/15	07/22/15	08/24/15	08/31/15	09/16/15	10/08/15	10/12/15	Minimum	Average	Maximum	n
PS-02: Hopper Brook S outfall, W Seneca Trpk	19.88	17.92	17.43	14.72	19.55	17.16	18.46	18.39	17.24	14.94	13.17	13.17	17.17	19.88	11
PS-93: Outfall S of Van Duyn School ball field	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF				0
PS-03: W Glen Ave	15.17	15.35	15.31	14.06	14.03	13.39	16.17	15	15.36	14.46	14.17	13.39	14.77	16.17	11
PS-04: City Line Brook outfall, Ballantyne Rd	17.12	14.77	15.24	13.21	14.63	15.58	15.82	16.23	15.88	13.47	12.82	12.82	14.98	17.12	11
PS-09: Hopper Brook N outfall, Medora Pl	18.28	15.65	15.84	13.66	16.72	15.04	15.68	16.66	15.3	13.64	13.34	13.34	15.44	18.28	11
PS-11: W Brighton Ave	12.84	13.32	DNR	12.88	13.08	13.19	13.51	13.43	13.68	12.84	12.82	12.82	13.16	13.68	10
PS-71: 300ft downstream South Ave	21.45	22.28	21.52	20.7	18.72	19.99	22.48	22.6	NCF	NCF	19.33	18.72	21.01	22.6	9
PS-20: 100ft upstream W Adams St, Byrne Dairy (CSO-037)	18.78	NCF	20.06	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	18.78	19.42	20.06	2
PS-92: W Water St	22.18	17.02	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	17.02	19.6	22.18	2
PS-23: EBSS (CSO-080)	17.59	17.2	17.65	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	17.2	17.48	17.65	3

Temperature

🟥	Hot (> 25°C) (>77°F)
🟧	Warm (20-25°C) (68-77°F)
🟨	Mild (15-20°C) (59-68°F)
🟦	Cool (10-15°C) (50-59°F)
🟦	Cold (5-10°C) (41-50°F)
⬛	Frigid (0-5°C)

Notes:

1) NCF - not collected due to lack of flow

2) DNR - did not record data

Table 50. pH levels for priority point source samples in the Onondaga Creek watershed (2014-2015).

Location	07/23/14	08/28/14	09/10/14	09/25/14	07/13/15	07/22/15	08/24/15	08/31/15	09/16/15	10/08/15	10/12/15	Minimum	Average	Maximum	n
PS-02: Hopper Brook S outfall, W Seneca Trpk	7.72	8.16	7.99	7.59	8.24	7.94	7.96	7.95	7.96	7.7	8.12	7.59	7.939	8.24	11
PS-93: Outfall S of Van Duyn School ball field	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF				0
PS-03: W Glen Ave	7.79	7.85	7.79	7.94	7.84	7.8	7.87	7.91	8.18	7.13	7.93	7.13	7.821	8.18	11
PS-04: City Line Brook outfall, Ballantyne Rd	7.83	8	7.87	7.95	7.96	7.96	7.97	7.99	8.12	8.08	8.02	7.83	7.977	8.12	11
PS-09: Hopper Brook N outfall, Medora Pl	7.86	7.98	7.89	7.96	8.04	8.01	7.94	7.89	8.1	8.04	8.03	7.86	7.976	8.1	11
PS-11: W Brighton Ave	7.32	7.13	DNR	7.33	7.26	7.35	7.46	7.04	7.37	7.46	7.21	7.04	7.293	7.46	10
PS-71: 300ft downstream South Ave	7.6	7.75	7.78	8.12	7.76	7.79	8.04	7.96	NCF	NCF	8.13	7.6	7.85	8.13	9
PS-20: 100ft upstream W Adams St, Byrne Dairy (CSO-037)	7.81	NCF	6.48	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	6.48	7.145	7.81	2
PS-92: W Water St	7.6	7.7	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	7.6	7.65	7.7	2
PS-23: EBSS (CSO-080)	7.44	7.79	7.9	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	7.44	7.71	7.9	3

Notes:
1) NCF - not collected due to lack of flow
2) DNR - did not record data

pH	
🟥	Highly Alkaline (pH >9)
🟧	Alkaline (pH 8-9)
🟦	Slightly Alkaline (pH 8)
🟦	Neutral (pH 7)
🟦	Slightly Acidic (pH 6)
🟧	Acidic (pH 5.5-6)
🟥	Highly Acidic (pH <5.5)

Table 51. Specific conductivity levels (µmHos/cm) for priority point source samples in the Onondaga Creek watershed (2014-2015).

Location	07/23/14	08/28/14	09/10/14	09/25/14	07/13/15	07/22/15	08/24/15	08/31/15	09/16/15	10/08/15	10/12/15	Minimum	Average	Maximum	n
PS-02: Hopper Brook S outfall, W Seneca Trpk	1559	1453	1610	1580	1065	1619	1702	1777	1197	1739	1629	1065	1539	1777	11
PS-93: Outfall S of Van Duyn School ball field	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF				0
PS-03: W Glen Ave	1897	1713	1896	1842	1948	1956	994	1793	1770	1810	1924	994	1777	1956	11
PS-04: City Line Brook outfall, Ballantyne Rd	2726	2689	2711	2676	2790	1637	2681	2759	2598	2579	2637	1637	2589	2790	11
PS-09: Hopper Brook N outfall, Medora Pl	1831	2031	2107	2744	1570	2496	2571	2115	2589	2730	2752	1570	2321	2752	11
PS-11: W Brighton Ave	2270	2262	DNR	2185	2547	1593	2136	2257	2123	2125	2089	1593	2172	2547	10
PS-71: 300ft downstream South Ave	494	516	488	477	611	287	447	464	NCF	NCF	604	287	473	611	9
PS-20: 100ft upstream W Adams St, Byrne Dairy (CSO-037)	95	NCF	355	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	95	225	355	2
PS-92: W Water St	409	408	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	408	408.5	409	2
PS-23: EBSS (CSO-080)	2247	2647	2614	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	2247	2503	2647	3

Specific Conductivity (µmHos/cm)

🟥	**Saline (3000 - 15,000)**
🟧	**Moderately Saline (Brackish) (1600 - 3000)**
🟨	**Slightly Saline (800 - 1600)**
🟩	**Freshwater (400 - 800)**
🟦	**Pristine (0 - 400)**

Notes:

1) NCF - not collected due to lack of flow
2) DNR - did not record data

Table 52. Salinity levels (ppt) for priority point source samples in the Onondaga Creek watershed (2014-2015).

Location	07/23/14	08/28/14	09/10/14	09/25/14	07/13/15	07/22/15	08/24/15	08/31/15	09/16/18	10/08/15	10/12/15	Minimum	Average	Maximum	n
PS-02: Hopper Brook S outfall, W Seneca Trpk	0.79	0.73	0.82	0.8	0.53	0.82	0.86	0.9	0.6	0.89	0.83	0.53	0.779	0.9	11
PS-93: Outfall S of Van Duyn School ball field	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF				0
PS-03: W Glen Ave	0.97	0.87	0.97	0.94	1	1	0.49	0.92	0.9	0.92	0.99	0.49	0.906	1	11
PS-04: City Line Brook outfall, Ballantyne Rd	1.42	1.4	1.41	1.39	1.46	0.83	1.4	1.44	1.35	1.34	1.37	0.83	1.346	1.46	11
PS-09: Hopper Brook N outfall, Medora Pl	0.93	1.04	1.08	1.43	0.8	1.3	1.34	1.09	1.35	1.42	1.44	0.8	1.202	1.44	11
PS-11: W Brighton Ave	1.17	1.17	DNR	1.13	1.32	0.81	1.1	1.17	1.09	1.09	1.07	0.81	1.112	1.32	10
PS-71: 300ft downstream South Ave	0.24	0.25	0.24	0.23	0.3	0.14	0.21	0.22	NCF	NCF	0.29	0.14	0.236	0.3	9
PS-20: 100ft upstream W Adams St, Byrne Dairy (CSO-037)	0.04	NCF	0.17	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	0.04	0.105	0.17	2
PS-92: W Water St	0.2	0.2	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	0.2	0.2	0.2	2
PS-23: EBSS (CSO-080)	1.16	7.5	1.36	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	1.16	3.34	7.5	3

Salinity(ppt)

🟧	**Highly Saline (10 - 35)**
🟨	**Moderately Saline (3 - 10)**
🟩	**Slightly Saline (1 - 3)**
🟦	**Freshwater (0 - 1)**

Notes:

1) NCF - not collected due to lack of flow

2) DNR - did not record data

Table 53. Bacteria levels (count/100mL) for priority point sources samples in the Onondaga Creek watershed (2014-2015).

Location	07/23/14	08/28/14	09/10/14	09/25/14	07/13/15	07/22/15	08/24/15	08/31/15	09/16/15	10/08/15	10/12/15	Minimum	Average	Maximum	n
PS-02: Hopper Brook S outfall, W Seneca Trpk	81	73	18	18	108	118	91	64	91	54	739	18	132	739	11
PS-93: Outfall S of Van Duyn School ball field	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF				0
PS-03: W Glen Ave	730	273	600	21000	3400	909	118000	5450	3640	<1000	1030	273	14185	118000	11
PS-04: City Line Brook outfall, Ballantyne Rd	2500	2100	570	2400	667	818	636	818	2700	636	8500	570	2031	8500	11
PS-09: Hopper Brook N outfall, Medora Pl	33000	7270	273	545	46000	1180	545	909	2700	6730	440	273	9054	46000	11
PS-11: W Brighton Ave	18	91	9	636	270	200	909	91	910	<1000	45	9	380	910	11
PS-71: 300ft downstream South Ave	10	<10	18	73	18	18	370	320	NCF	NCF	135	<10	108	370	9
PS-20: 100ft upstream W Adams St, Byrne Dairy (CSO-037)	17000	NCF	57000	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	17000	37000	57000	2
PS-92: W Water St	90	112000	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	90	56045	112000	2
PS-23: EBSS (CSO-080)	9730	8540	3300	NCF	NCF	NCF	NCF	NCF	NCF	NCF	NCF	3300	7190	9730	3

Notes:

1) NCF - not collected due to lack of flow

Fecal Coliform (cfu/100mL)

🟥	Severe (> 50k)
■	Very High (10k-50k)
🟧	High (1000-10,000)
🟨	Moderate (100-1000)
🟩	Low (10-100)
🟦	Very Low (0-10)

Table 54. Spearman's rank correlation matrix of parameters measured during priority point source sampling (Task 4). Parameters significantly correlated ($p < 0.05$), using the Holm-Bonferroni correction method, are denoted in bold.

	DO	**COND**	**PH**	**TEMP**	**FCOLI**	**SALI**	**CL2**
DO	1.00						
COND	0.24	1.00					
PH	0.39	0.07	1.00				
TEMP	**-0.34**	**-0.52**	0.10	1.00			
FCOLI	-0.05	0.13	0.19	-0.04	1.00		
SALI	0.24	**1.00**	0.06	**-0.52**	0.13	1.00	
CL2	0.16	-0.05	0.15	0.17	-0.12	-0.06	1.00

[1] Please refer to Table 6 for definitions of parameters codes.

Table 55. Water quality values for sites sampled during the 8/15/17 Tributary Trackdown event in the Onondaga Creek watershed.

Location	Dissolved oxygen	Temperature	Conductivity	Salinity	pH	Turbidity	Chlorine residual	Fecal coliform
PS-26: Dorwin Springs outfall, 500ft upstream Dorwin Ave	16.44	12.16	1312	0.66	8.01	TNP	<0.10	91
PS-24: 800ft downstream Dorwin Ave	16.84	12.53	1996	1.02	8.05	TNP	<0.10	600
PS-00B: Kimber Brook, Chaffee Ave	7.67	24.28	1245	0.67	DNR	TNP	<0.10	210
PS-00: Kimber Brook outfall	9.25	20.35	1222	0.67	7.81	TNP	<0.10	73
PS-01C: Cold Brook, Byrne Pl	9.63	16.02	1720	1.07	7.86	TNP	<0.10	2900
PS-01B: Cold Brook, St James Church	9.3	16.66	1728	1.06	7.9	TNP	<0.10	2100
PS-01: Cold Brook outfall, W Seneca Trpk	9.31	20.91	1550	0.85	7.98	TNP	<0.10	420
PS-02B: Hopper Brook S Section, Detention Pond @ Seneca Pl	13.46	21.74	2354	1.21	7.79	TNP	<0.10	91
PS-04D: Spring Brook, E. Glen Ave	9.3	16.66	1728	1.06	7.9	TNP	<0.10	100
PS-04G: Cordova St	10.21	13.78	2353	1.56	7.75	TNP	0.14	230
PS-04F: E. Florence Ave	10.22	14.33	2411	1.58	7.79	TNP	<0.10	854
PS-04E: Behind Valley Plaza	9.99	17.75	1447	0.85	7.84	TNP	<0.10	1260
PS-04C: Spring Brook, Valley Plaza	9.49	13.6	2475	1.58	7.81	TNP	<0.10	1600
PS-04B: City Line Brook, Slayton Ave	9.4	18.07	2438	1.47	7.92	TNP	<0.10	2100
PS-09E: Hopper Brook N, 135 Valley View Dr	6.69	19.99	2391	1.23	7.96	TNP	<0.10	2800
PS-09D: Hopper Brook N, 558 Valley Dr	15.26	17.53	1628	0.83	8.25	TNP	<0.10	1730
PS-09G: Hopper Brook N, upstream of Ford Ave	14.96	17.9	1614	0.82	8.23	TNP	<0.10	2600
PS-09B: Hopper Brook N, Ford Ave	14.55	18.86	1625	0.82	8.27	TNP	<0.10	2100

Notes:
1) TNP - test not performed; the YSI sonde used during this event was not equipped with a turbidity sensor

Dissolved Oxygen (mg/L)
- 🟨 Excessive (>14.6)
- 🟩 Very High (12 - 14.6)
- 🟦 High (8 - 12)
- 🟩 Moderate (5 - 8)
- 🟨 Low (3 - 5)
- 🟧 Very Low (2 - 3)
- 🟥 Extremely Low (0-2)

Temperature
- 🟥 Hot (> 25°C) (>77°F)
- 🟧 Warm (20-25°C) (68-77°F)
- 🟨 Mild (15-20°C) (59-68°F)
- 🟦 Cool (10-15°C) (50-59°F)
- 🟦 Cold (5-10°C) (41-50°F)
- ⬛ Frigid (0-5°C)

pH
- 🟥 Highly Alkaline (pH >9)
- 🟧 Alkaline (pH 8-9)
- 🟦 Slightly Alkaline (pH 8)
- 🟦 Neutral (pH 7)
- 🟦 Slightly Acidic (pH 6)
- 🟧 Acidic (pH 5.5-6)
- 🟥 Highly Acidic (pH <5.5)

Specific Conductivity (µmHos/cm)
- 🟥 Saline (3000 - 15,000)
- 🟧 Moderately Saline (Brackish) (1600 - 3000)
- 🟨 Slightly Saline (800 - 1600)
- 🟩 Freshwater (400 - 800)
- 🟦 Pristine (0 - 400)

Salinity (ppt)
- 🟧 Highly Saline (10 - 35)
- 🟨 Moderately Saline (3 - 10)
- 🟩 Slightly Saline (1 - 3)
- 🟦 Freshwater (0 - 1)

Fecal Coliform (cfu/100mL)
- 🟥 Severe (> 50k)
- 🟥 Very High (10k-50k)
- 🟧 High (1000-10,000)
- 🟨 Moderate (100-1000)
- 🟩 Low (10-100)
- 🟦 Very Low (0-10)

Turbidity (NTU)
- 🟥 Very High (> 1000)
- 🟥 High (150 - 1000)
- 🟧 Medium (50 - 150)
- 🟨 Low (10 - 50)
- 🟩 Very Low (5 - 10)
- 🟦 Pristine (0 - 5)

Table 56. Spearman's rank correlation matrix of parameters measured during tributary trackdown sampling (Task 5). Parameters significantly correlated ($p < 0.05$), using the Holm-Bonferroni correction method, are denoted in bold.

PARAMETER	DO	COND	PH	TEMP	FCOLI	SALI	CL2
DO	1.00						
COND	0.01	1.00					
PH	0.36	-0.36	1.00				
TEMP	-0.49	-0.31	0.07	1.00			
FCOLI	-0.01	0.32	0.37	-0.06	1.00		
SALI	-0.14	**0.92**	-0.62	-0.28	0.27	1.00	
CL2	0.07	0.16	-0.41	-0.26	-0.16	0.30	1.00

[1] Please refer to Table 6 for definitions of parameters codes.

Table 57. Dissolved oxygen levels (mg/L) for point source trackdown samples in Harbor Brook (2015-2017).

Location	09/09/15	07/11/16	09/21/17	07/10/17	08/16/17	Minimum	Average	Maximum	N
Velasko Rd. A: Velasko Rd in small drainage channel adjacent to creek			7.99	7.94		7.94	7.97	7.99	2
Velasko Rd.			9.00		PM				1
PS-100E: Pipe behind Burger King plaza; S. of Onondaga Blvd				PM					0
PS-100D: Open channel S. of Onondaga Blvd & W. of Velasko Rd; behind DD plaza				8.65		8.65	8.65	8.65	1
PS-100C: Manhole at Velasko Rd & Onondaga Blvd W side		NCF		NCF					
PS-100B: Manhole at Velasko Rd & Onondaga Blvd E side		8.52		8.13		8.13	8.33	8.52	2
PS-100A: Manhole between outfall and Onondaga Blvd		8.86		9.42		8.86	9.14	9.42	2
PS-100: Velasko Rd (CSO-078)		9.12		8.98		8.98	9.05	9.12	2
PS-112C: Manhole at Hiawatha Blvd, NE of 690 on ramp		3.50			1.20	1.20	2.35	3.50	2
PS-112B: Manhole N of Hiawatha Blvd; in car dealerships parking lot		10.80			PM	10.80	10.80	10.80	1
PS-112A: Manhole N or Hiwatha Blvd; adjacent to creek in parking lot		5.84			PM	5.84	5.84	5.84	1

Notes:
1) Sites are arranged in downstream order
2) NCF - not collected due to lack of flow
3) PM - probe malfunction
4) Blank cells indicate the site was not visited on that given date

Dissolved Oxygen (mg/L)

🟨	**Excessive (>14.6)**
🟩	**Very High (12 - 14.6)**
🟦	**High (8 - 12)**
🟩	**Moderate (5 - 8)**
🟨	**Low (3 - 5)**
🟧	**Very Low (2 - 3)**
🟥	**Extremely Low (0-2)**

Table 58. Temperature levels (°C) for point source trackdown samples in the Harbor Brook watershed (2015-2017).

Location	09/09/15	07/11/16	09/21/16	07/10/17	08/16/17	Minimum	Average	Maximum	N
Velasko Rd. A: Velasko Rd in small drainage channel adjacent to creek			21.27	19.06		19.06	20.17	21.27	2
Velasko Rd.			14.71		14.66	14.66	14.69	14.71	2
PS-100E: Pipe behind Burger King plaza; S. of Onondaga Blvd				14.42		14.42	14.42	14.42	1
PS-100D: Open channel S. of Onondaga Blvd & W. of Velasko Rd; behind DD plaza				11.91		11.91	11.91	11.91	1
PS-100C: Manhole at Velasko Rd & Onondaga Blvd W side		NCF		NCF					0
PS-100B: Manhole at Velasko Rd & Onondaga Blvd E side		15.17		14.58		14.58	14.88	15.17	2
PS-100A: Manhole between outfall and Onondaga Blvd		18.39		16.63		16.63	17.51	18.39	2
PS-100: Velasko Rd (CSO-078)		15.32		14.71		14.71	15.02	15.32	2
PS-103: Depalma Ave	14.13					14.13	14.13	14.13	1
PS-112C: Manhole at Hiawatha Blvd, NE of 690 on ramp		22.36			21.39	21.39	21.88	22.36	2
PS-112B: Manhole N of Hiawatha Blvd; in car dealerships parking lot		25.00			20.16	20.16	22.58	25.00	2
PS-112A: Manhole N or Hiwatha Blvd; adjacent to creek in parking lot		16.41			17.60	16.41	17.01	17.60	2

Temperature

🟥	Hot (> 25°C) (>77°F)
🟧	Warm (20-25°C) (68-77°F)
🟨	Mild (15-20°C) (59-68°F)
🟦	Cool (10-15°C) (50-59°F)
🟦	Cold (5-10°C) (41-50°F)
⬛	Frigid (0-5°C)

Notes:

1) Sites are arranged in downstream order

2) NCF - not collected due to lack of flow

3) Blank cells indicate the site was not visited on that given date

Table 59. pH levels for point source trackdown samples in Harbor Brook (2015-2017)

Location	07/11/16	09/21/16	07/10/17	08/16/17	Minimum	Average	Maximum	n
Velasko Rd. A: Velasko Rd in small drainage channel adjacent to creek		8.21	8.01		8.01	8.11	8.21	2
Velasko Rd.		7.98		8.17	7.98	8.075	8.17	2
PS-100E: Pipe behind Burger King plaza; S. of Onondaga Blvd			7.77		7.77	7.77	7.77	1
PS-100D: Open channel S. of Onondaga Blvd & W. of Velasko Rd; behind DD plaza			7.51		7.51	7.51	7.51	1
PS-100C: Manhole at Velasko Rd & Onondaga Blvd W side	NCF		NCF					0
PS-100B: Manhole at Velasko Rd & Onondaga Blvd E side	7.44		7.68		7.44	7.56	7.68	2
PS-100A: Manhole between outfall and Onondaga Blvd	7.52		7.83		7.52	7.675	7.83	2
PS-100: Velasko Rd (CSO-078)	7.46		7.63		7.46	7.545	7.63	2
PS-112C: Manhole at Hiawatha Blvd, NE of 690 on ramp	7.38			11.16	7.38	9.27	11.16	2
PS-112B: Manhole N of Hiawatha Blvd; in car dealerships parking lot	8.06			8.75	8.06	8.405	8.75	2
PS-112A: Manhole N or Hiwatha Blvd; adjacent to creek in parking lot	8.49			11.8	8.49	10.15	11.8	2

pH

🟥	**Highly Alkaline (pH >9)**
🟧	**Alkaline (pH 8-9)**
🟦	**Slightly Alkaline (pH 8)**
🟦	**Neutral (pH 7)**
🟦	**Slightly Acidic (pH 6)**
🟧	**Acidic (pH 5.5-6)**
🟥	**Highly Acidic (pH <5.5)**

Notes:

1) Sites are arranged in downstream order

2) NCF - not collected due to lack of flow

3) Blank cells indicate the site was not visited on that given date

Table 60. Specific conductivity levels (µmHos/cm) for point source trackdown samples in Harbor Brook (2016-2017).

Location	07/11/16	09/21/16	07/10/17	08/16/17	Minimum	Average	Maximum	n
Velasko Rd. A: Velasko Rd in small drainage channel adjacent to creek		598	648		598	623	648	2
Velasko Rd.		2131		2148	2131	2140	2148	2
PS-100E: Pipe behind Burger King plaza; S. of Onondaga Blvd			1465		1465	1465	1465	1
PS-100D: Open channel S. of Onondaga Blvd & W. of Velasko Rd; behind DD plaza			2356		2356	2356	2356	1
PS-100C: Manhole at Velasko Rd & Onondaga Blvd W Side	NCF		NCF					0
PS-100B: Manhole at Velasko Rd & Onondaga Blvd E side	1990		1465		1465	1728	1990	2
PS-100A: Manhole between outfall and Onondaga Blvd	1369		996		996	1183	1369	2
PS-100: Velasko Rd (CSO-078)	2105		1353		1353	1729	2105	2
PS-112C: Manhole at Hiawatha Blvd, NE of 690 on ramp	401			1431	401	916	1431	2
PS-112B: Manhole N of Hiawatha Blvd; in car dealerships parking lot	289			180	180	234.5	289	2
PS-112A: Manhole N or Hiwatha Blvd; adjacent to creek in parking lot	2093			6829	2093	4461	6829	2

Specific Conductivity (µmHos/cm)

🟥	Saline (3000 - 15,000)
🟧	Moderately Saline (Brackish) (1600 - 3000)
🟨	Slightly Saline (800 - 1600)
🟩	Freshwater (400 - 800)
🟦	Pristine (0 - 400)

Notes:
1) Sites are arranged in downstream order
2) NCF - not collected due to lack of flow
3) Blank cells indicate the site was not visited on that given date

Table 61. Salinity levels (ppt) for point source trackdown samples in Harbor Brook (2015-2017).

Location	09/09/15	07/11/16	09/21/16	07/10/17	08/16/17	Minimum	Average	Maximum	N
Velasko Rd. A: Velasko Rd in small drainage channel adjacent to creek			0.31	0.36		0.31	0.335	0.36	2
Velasko Rd.			1.38		1.39	1.38	1.385	1.39	2
PS-100E: Pipe behind Burger King plaza; S. of Onondaga Blvd				0.94		0.94	0.94	0.94	1
PS-100D: Open channel S. of Onondaga Blvd & W. of Velasko Rd; behind DD plaza				1.65		1.65	1.65	1.65	1
PS-100C: Manhole at Velasko Rd & Onondaga Blvd W side		NCF		NCF					0
PS-100B: Manhole at Velasko Rd & Onondaga Blvd E side		TNP		0.93		0.93	0.93	0.93	1
PS-100A: Manhole between outfall and Onondaga Blvd		TNP		0.59		0.59	0.59	0.59	1
PS-100: Velasko Rd (CSO-078)		TNP		0.86		0.86	0.86	0.86	1
PS-112C: Manhole at Hiawatha Blvd, NE of 690 on ramp		TNP			0.77	0.77	0.77	0.77	1
PS-112B: Manhole N of Hiawatha Blvd; in car dealerships parking lot		TNP			0.09	0.09	0.09	0.09	1
PS-112A: Manhole N or Hiwatha Blvd; adjacent to creek in parking lot		TNP			4.43	4.43	4.43	4.43	1

Salinity(ppt)

🟧	**Highly Saline (10 - 35)**
🟨	**Moderately Saline (3 - 10)**
🟩	**Slightly Saline (1 - 3)**
🟦	**Freshwater (0 - 1)**

Notes:

1) Sites are arranged in downstream order

2) NCF - not collected due to lack of flow

3) Blank cells indicate the site was not visited on that given date

Onondaga Environmental Institute

Table 62. Turbidity levels (NTU) for point source trackdown samples in the Harbor Brook watershed (2015-2017).

Location	09/09/15	07/11/16	09/21/16	07/10/17	08/16/17	Minimum	Average	Maximum	N
Velasko Rd. A: Velasko Rd in small drainage channel adjacent to creek			18.70	1.50		1.50	10.10	18.70	2
Velasko Rd.			5.00		PM	5.00	5.00	5.00	1
PS-100E: Pipe behind Burger King plaza; S. of Onondaga Blvd				PM					0
PS-100D: Open channel S. of Onondaga Blvd & W. of Velasko Rd; behind DD plaza				0.00		0.00	0.00	0.00	1
PS-100C: Manhole at Velasko Rd & Onondaga Blvd W side		NCF		NCF					0
PS-100B: Manhole at Velasko Rd & Onondaga Blvd E side		TNP		TNP					0
PS-100A: Manhole between outfall and Onondaga Blvd		TNP		0.00		0.00	0.00	0.00	1
PS-100: Velasko Rd (CSO-078)		TNP		0.20		0.20	0.20	0.20	1
PS-112C: Manhole at Hiawatha Blvd, NE of 690 on ramp		TNP			158.60	158.60	158.60	158.60	1
PS-112B: Manhole N of Hiawatha Blvd; in car dealerships parking lot		TNP			PM				0
PS-112A: Manhole N or Hiwatha Blvd; adjacent to creek in parking lot		TNP			PM				0

Turbidity (NTU)

🟥	Very High (> 1000)
🟥	High (150 - 1000)
🟧	Medium (50 - 150)
🟨	Low (10 - 50)
🟩	Very Low (5 - 10)
🟦	Pristine (0 - 5)

Notes:
1) Sites are arranged in downstream order
2) TNP - test not performed; YSI sonde used was not equipped with a turbidity sensor
3) PM - probe malfunction; data not accurately recorded
4) NCF - not collected due to lack of flow
5) Blank cells indicate the site was not visited on that given date

Table 63. Bacteria levels (count/100mL) for point source trackdown samples in Harbor Brook (2015-2017).

Location	07/11/16	09/21/16	07/10/17	08/16/17	Minimum	Average	Maximum	n
Velasko Rd. A: Velasko Rd in small drainage channel adjacent to creek		320	930		320	625	930	2
Velasko Rd.		910		960	910	935	960	2
PS-100E: Pipe behind Burger King plaza; S. of Onondaga Blvd			1300		1300	1300	1300	1
PS-100D: Open channel S. of Onondaga Blvd & W. of Velasko Rd; behind DD plaza			9		9	9	9	1
PS-100C: Manhole at Velasko Rd & Onondaga Blvd W side			NCF					
PS-100B: Manhole at Velasko Rd & Onondaga Blvd E side	3000		340		340	1670	3000	2
PS-100A: Manhole between outfall and Onondaga Blvd	3500		560		560	2030	3500	2
PS-100: Velasko Rd (CSO-078)	2900		2900		2900	2900	2900	2
PS-112C: Manhole at Hiawatha Blvd, NE of 690 on ramp	5800			18	18	2909	5800	2
PS-112B: Manhole N of Hiawatha Blvd; in car dealerships parking lot	<100			<10	0	55	0	0
PS-112A: Manhole N or Hiwatha Blvd; adjacent to creek in parking lot	<100			<10	0	55	0	0

Fecal Coliform (cfu/100mL)

🟥	Severe (> 50k)
▨	Very High (10k-50k)
🟧	High (1000-10,000)
🟨	Moderate (100-1000)
🟩	Low (10-100)
🟦	Very Low (0-10)

Notes:

1) Sites are arranged in downstream order

2) NCF - not collected due to lack of flow

3) Blank cells indicate the site was not visited on that given date

Table 64. Dissolved oxygen levels (mg/L) for point source trackdown samples in the Onondaga Creek watershed 2016-2017).

Location	07/13/16	08/24/16	09/21/17	07/19/17	07/31/17	Minimum	Average	Maximum	N
Dorwin Ave.		8.47		10.01		8.47	9.24	10.01	2
PS-01C: Cold Brook, Byrne Pl		9.38		10.90		9.38	10.14	10.90	2
PS-03A: Manhole, W. Glen Ave & Midler Ave	9.49					9.49	9.49	9.49	1
PS-03: W Glen Ave	9.90	9.53				9.53	9.72	9.90	2
PS-04D: Spring Brook, E. Glen Ave				9.87		9.87	9.87	9.87	1
PS-04E: Behind Valley Plaza		4.78		9.96		4.78	7.37	9.96	2
PS-04C: Spring Brook, Valley Plaza		9.77		9.36		9.36	9.57	9.77	2
PS-04B: City Line Brook, Slayton Ave		9.66		9.62		9.62	9.64	9.66	2
PS-09C: Hopper Brook N, Camp Ave					9.24	9.24	9.24	9.24	1
PS-09E: Hopper Brook N, 135 Valley View Dr			4.78		5.70	4.78	5.24	5.70	2
PS-09D: Hopper Brook N, 558 Valley Dr			9.50		PM	9.50	9.50	9.50	1
PS-09H: Hopper Brook N, 500 block Valley Dr					PM				0
PS-09G: Hopper Brook N, upstream of Ford Ave			9.09		PM	9.09	9.09	9.09	1
PS-09B: Hopper Brook N, Ford Ave; ~100 yd E of Valley Dr			8.17			8.17	8.17	8.17	1

Notes:
1) Sites are arranged in downstream order
2) PM - probe malfunction
3) Blank cells indicate the site was not visited on that given date

Dissolved Oxygen (mg/L)

🟨	**Excessive (>14.6)**
🟩	**Very High (12 - 14.6)**
🟦	**High (8 - 12)**
🟩	**Moderate (5 - 8)**
🟨	**Low (3 - 5)**
🟧	**Very Low (2 - 3)**
🟥	**Extremely Low (0-2)**

Table 65. Temperature levels (°C) for point source trackdown samples in the Onondaga Creek watershed (2016-2017).

Location	07/13/16	08/24/16	09/21/16	07/19/17	07/31/17	Minimum	Average	Maximum	N
Dorwin Ave.		18.52		18.39		18.39	18.46	18.52	2
PS-01C: Cold Brook, Byrne Pl		18.19		12.02		12.02	15.11	18.19	2
PS-03A: Manhole, W. Glen Ave & Midler Ave	19.42					19.42	19.42	19.42	1
PS-03: W Glen Ave	15.12	14.52				14.52	14.82	15.12	2
PS-04D: Spring Brook, E. Glen Ave				12.51		12.51	12.51	12.51	1
PS-04E: Behind Valley Plaza		17.19		13.97		13.97	15.58	17.19	2
PS-04C: Spring Brook, Valley Plaza		14.74		14.21		14.21	14.48	14.74	2
PS-04B: City Line Brook, Slayton Ave		16.40		15.17		15.17	15.79	16.40	2
PS-09C: Hopper Brook N, Camp Ave					18.62	18.62	18.62	18.62	1
PS-09E: Hopper Brook N, 135 Valley View Dr			17.19		18.48	17.19	17.84	18.48	2
PS-09D: Hopper Brook N, 558 Valley Dr			16.98		20.02	16.98	18.50	20.02	2
PS-09H: Hopper Brook N, 500 block Valley Dr					17.62	17.62	17.62	17.62	1
PS-09G: Hopper Brook N, upstream of Ford Ave			17.33		18.50	17.33	17.92	18.50	2
PS-09B: Hopper Brook N, Ford Ave; ~100 yd E of Valley Dr			17.88			17.88	17.88	17.88	1

Temperature

🟥	Hot (> 25°C) (>77°F)
🟧	Warm (20-25°C) (68-77°F)
🟨	Mild (15-20°C) (59-68°F)
🟦	Cool (10-15°C) (50-59°F)
🟦	Cold (5-10°C) (41-50°F)
⬛	Frigid (0-5°C)

Notes:

1) Sites are arranged in downstream order

2) Blank cells indicate the site was not visited on that given date

Table 66. pH levels for point source trackdown samples in the Onondaga Creek watershed (2016-2017).

Location	07/13/16	08/24/16	09/21/16	07/19/17	07/31/17	08/16/17	Minimum	Average	Maximum	n
Dorwin Ave.		8.27		7.89			7.89	8.08	8.27	2
PS-01C: Cold Brook, Byrne Pl		8.27		7.99			7.99	8.13	8.27	2
PS-03A: Manhole, W. Glen Ave & Midler Ave	7.78						7.78	7.78	7.78	1
PS-03: W Glen Ave	7.79	8.12					7.79	7.955	8.12	2
PS-04D: Spring Brook, E. Glen Ave				7.57			7.57	7.57	7.57	1
PS-04E: Behind Valley Plaza		8.4		7.72			7.72	8.06	8.4	2
PS-04C: Spring Brook, Valley Plaza		7.62		7.7			7.62	7.66	7.7	2
PS-04B: City Line Brook, Slayton Ave		7.28		7.88			7.28	7.58	7.88	2
PS-09C: Hopper Brook N, Camp Ave					7.36		7.36	7.36	7.36	1
PS-09E: Hopper Brook N, 135 Valley View Dr			8.4		7.58		7.58	7.99	8.4	2
PS-09D: Hopper Brook N, 558 Valley Dr			8.23		7.71		7.71	7.97	8.23	2
PS-09H: Hopper Brook N, 500 block Valley Dr					8.12		8.12	8.12	8.12	1
PS-09G: Hopper Brook N, upstream of Ford Ave			8.5		8.09		8.09	8.295	8.5	2
PS-09B: Hopper Brook N, Ford Ave; ~100 yd E of Valley Dr			7.92				7.92	7.92	7.92	1

	pH
🟥	Highly Alkaline (pH >9)
🟧	Alkaline (pH 8-9)
🟦	Slightly Alkaline (pH 8)
🟦	Neutral (pH 7)
🟦	Slightly Acidic (pH 6)
🟧	Acidic (pH 5.5-6)
🟥	Highly Acidic (pH <5.5)

Notes:

1) Sites are arranged in downstream order

2) Blank cells indicate the site was not visited on that given date

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Table 67. Specific conductivity levels (µmHos/cm) for point source trackdown samples in the Onondaga Creek watershed (2016-2017).

Location	07/13/16	08/24/16	09/21/16	07/19/17	07/31/17	Minimum	Average	Maximum	n
Dorwin Ave.		1069		816		816	942.5	1069	2
PS-01C: Cold Brook, Byrne Pl		1161		1220		1161	1191	1220	2
PS-03A: Manhole, W. Glen Ave & Midler Ave	1129					1129	1129	1129	1
PS-03: W Glen Ave	2115	1679				1679	1897	2115	2
PS-04D: Spring Brook, E. Glen Ave				1738		1738	1738	1738	1
PS-04E: Behind Valley Plaza		2658		2490		2490	2574	2658	2
PS-04C: Spring Brook, Valley Plaza		2246		2458		2246	2352	2458	2
PS-04B: City Line Brook, Slayton Ave		2545		2470		2470	2508	2545	2
PS-09C: Hopper Brook N, Camp Ave					2829	2829	2829	2829	1
PS-09E: Hopper Brook N, 135 Valley View Dr			2658		2718	2658	2688	2718	2
PS-09D: Hopper Brook N, 558 Valley Dr			1727		1621	1621	1674	1727	2
PS-09H: Hopper Brook N, 500 block Valley Dr					1490	1490	1490	1490	1
PS-09G: Hopper Brook N, upstream of Ford Ave			1719		1493	1493	1606	1719	2
PS-09B: Hopper Brook N, Ford Ave; ~100 yd E of Valley Dr			974			974	974	974	1

Specific Conductivity
(µmHos/cm)

🟥	**Saline** **(3000 - 15,000)**
🟧	**Moderately Saline** **(Brackish)** **(1600 - 3000)**
🟨	**Slightly Saline** **(800 - 1600)**
🟩	**Freshwater** **(400 - 800)**
🟦	**Pristine** **(0 - 400)**

Notes:

1) Sites are arranged in downstream order
2) Blank cells indicate the site was not visited on that given date

Table 68. Salinity levels (ppt) for point source trackdown samples in the Onondaga Creek watershed (2016-2017).

Location	07/13/16	08/24/16	09/21/16	07/19/17	07/31/17	Minimum	Average	Maximum	n
Dorwin Ave.		0.61		0.46		0.46	0.535	0.61	2
PS-01C: Cold Brook, Byrne Pl		0.67		0.82		0.67	0.745	0.82	2
PS-03A: Manhole, W. Glen Ave & Midler Ave	0.56					0.56	0.56	0.56	1
PS-03: W Glen Ave	1.09	1.08				1.08	1.085	1.09	2
PS-04D: Spring Brook, E. Glen Ave				1.18		1.18	1.18	1.18	1
PS-04E: Behind Valley Plaza		1.64		1.66		1.64	1.65	1.66	2
PS-04C: Spring Brook, Valley Plaza		1.46		1.63		1.46	1.545	1.63	2
PS-04B: City Line Brook, Slayton Ave		1.6		1.6		1.6	1.6	1.6	2
PS-09C: Hopper Brook N, Camp Ave					1.69	1.69	1.69	1.69	1
PS-09E: Hopper Brook N, 135 Valley View Dr			1.64		1.63	1.63	1.635	1.64	2
PS-09D: Hopper Brook N, 558 Valley Dr			1.05		0.91	0.91	0.98	1.05	2
PS-09H: Hopper Brook N, 500 block Valley Dr					0.88	0.88	0.88	0.88	1
PS-09G: Hopper Brook N, upstream of Ford Ave			1.03		0.87	0.87	0.95	1.03	2
PS-09B: Hopper Brook N, Ford Ave; ~100 yd E of Valley Dr			0.56			0.56	0.56	0.56	1

Salinity(ppt)

🟧	**Highly Saline (10 - 35)**
🟨	**Moderately Saline (3 - 10)**
🟩	**Slightly Saline (1 - 3)**
🟦	**Freshwater (0 - 1)**

Notes:
1) Sites are arranged in downstream order
2) Blank cells indicate the site was not visited on that given date

Table 69. Turbidity levels (NTU) for point source trackdown samples in the Onondaga Creek watershed (2016-2017).

Location	07/13/16	08/24/16	09/21/16	07/19/17	07/31/17	Minimum	Average	Maximum	N
Dorwin Ave.		18.7		52.4		18.7	35.55	52.4	2
PS-01C: Cold Brook, Byrne Pl		5		8.7		5	6.85	8.7	2
PS-03A: Manhole, W. Glen Ave & Midler Ave	TNP								
PS-03: W Glen Ave	TNP	0.7				0.7	0.7	0.7	1
PS-04D: Spring Brook, E. Glen Ave				0.8		0.8	0.8	0.8	1
PS-04E: Behind Valley Plaza		34.4				34.4	34.4	34.4	1
PS-04C: Spring Brook, Valley Plaza		0		5.4		0	2.7	5.4	2
PS-04B: City Line Brook, Slayton Ave		1.4				1.4	1.4	1.4	1
PS-09C: Hopper Brook N, Camp Ave					0	0	0	0	1
PS-09E: Hopper Brook N, 135 Valley View Dr			34.4		6.2	6.2	20.3	34.4	2
PS-09D: Hopper Brook N, 558 Valley Dr			5.3		PM	5.3	5.3	5.3	1
PS-09H: Hopper Brook N, 500 block Valley Dr					PM				0
PS-09G: Hopper Brook N, upstream of Ford Ave			1.7		PM	1.7	1.7	1.7	1
PS-09B: Hopper Brook N, Ford Ave; ~100 yd E of Valley Dr			6.1			6.1	6.1	6.1	1

Turbidity (NTU)

🟥	Very High (> 1000)
▨	High (150 - 1000)
🟧	Medium (50 - 150)
🟨	Low (10 - 50)
🟩	Very Low (5 - 10)
🟦	Pristine (0 - 5)

Notes:
1) Sites are arranged in downstream order
2) TNP - test not performed; YSI sonde used was not equipped with a turbidity sensor
3) PM - probe malfunction; data not accurately recorded
4) Blank cells indicate the site was not visited on that given date

Table 70. Bacteria levels (count/100mL) for point source trackdown samples in the Onondaga Creek watershed (2016-2017).

Location	07/13/16	08/24/16	09/21/16	07/19/17	07/31/17	Minimum	Average	Maximum	n
Dorwin Ave.		682		370		370	526	682	2
PS-01C: Cold Brook, Byrne Pl		604		260		260	432	604	2
PS-03A: Manhole at W. Glen Ave & Midler Ave	24000					24000	24000	24000	1
PS-03: W Glen Ave	14000	540				540	7270	14000	2
PS-04D: Spring Brook, E. Glen Ave				72		72	72	72	1
PS-04E: Behind Valley Plaza		1440		33000		1440	17220	33000	2
PS-04C: Spring Brook, Valley Plaza		811		81		81	446	811	2
PS-04B: City Line Brook, Slayton Ave		450	9000	3000		450	4150	9000	3
PS-09C: Hopper Brook N, Camp Ave					550	550	550	550	1
PS-09E: Hopper Brook N, 135 Valley View Dr			130000		2300	2300	66150	1E+05	2
PS-09D: Hopper Brook N, 558 Valley Dr			7360		1400	1400	4380	7360	2
PS-09H: Hopper Brook N, 500 block Valley Dr					910	910	910	910	1
PS-09G: Hopper Brook N, upstream of Ford Ave			2600		1100	1100	1850	2600	2
PS-09B: Hopper Brook N, Ford Ave; ~100 yd E of Valley Dr			9000		1200	1200	5100	9000	2

Fecal Coliform (cfu/100mL)

- 🟥 Severe (> 50k)
- 🟥 Very High (10k-50k)
- 🟧 High (1000-10,000)
- 🟨 Moderate (100-1000)
- 🟩 Low (10 100)
- 🟦 Very Low (0-10)

Notes:
1) Sites are arranged in downstream order
2) Blank cells indicate the site was not visited on that given date

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Table 71. Fecal coliform and *Bacteroides* results for Harbor Brook point source trackdown sampling locations in 2016. Sites are arranged in downstream order.

Site	Location	Sampling Date	Fecal coliform (cfu/ 100 mL)	*Bacteroides* Results[1]				
				Human	Dog	Ruminant	Goose	Gull
Velasko Rd(A)	Channel/ditch parallel to Velasko Rd. on the west side. Discharges to Harbor Brook at the Velasko Rd. bridge.	9/22/2016	320	+	-	-	-	-
Velasko Rd	Main channel upstream of the Velasko Rd. bridge	9/22/2016	910	+	-	-	-	-

[1] [+] = positive result; [-] = negative result.

Fecal Coliform (cfu/100mL)	
🟥	Severe (> 50k)
▨	Very High (10k-50k)
🟧	High (1000-10,000)
🟨	Moderate (100-1000)
🟩	Low (10-100)
🟦	Very Low (0-10)

Table 72. Fecal coliform and *Bacteroides* results for Onondaga Creek point source trackdown sampling locations in 2016. Sites are arranged in downstream order.

Tributary	**Site**	**Location**	**Sampling Date**	**Fecal coliform (CFU/ 100 mL)**	***Bacteroides* Results[1]**				
					Human	**Dog**	**Ruminant**	**Goose**	**Gull**
Cold Brook	OC-PS01-C	Byrne Pl	8/25/2016	604	+	-	-	-	-
Spring Brook diversion	OC-PS03	Outfall, b/w W. Seneca Tpke & Ballantyne Rd.	8/25/2016	540	+	-	-	-	-
City Line Brook	OC-PS04-B	Slayton Ave.	8/25/2016	450	+	-	-	-	-
City Line Brook	OC-PS04-C	Valley Plaza, near Churchill Ave.	8/25/2016	811	+	-	-	-	-
City Line Brook	OC-PS04-E	Behind Valley Plaza	8/25/2016	1440	+	-	-	-	-
Mainstem	Dorwin Ave	In-Stream below drop structure	8/25/2016	682	+	-	-	-	-
Hopper Brook	OC-PS09B	Ford Ave; ~100 yd E of Valley Dr.	9/22/2016	9000	+	-	-	-	-
Hopper Brook	OC-PS09D	Valley Drive crossing	9/22/2016	7360	+	-	-	-	-
Hopper Brook	OC-PS09E	Valley View Dr.	9/22/2016	130000	+	-	-	-	-
Hopper Brook	OC-PS09G	100 ' upstream of Ford Ave.	9/22/2016	2600	+	-	-	-	-

[1][+] = positive result; [-] = negative result.

Fecal Coliform (cfu/100mL)

🟥	Severe (> 50k)
🟥	Very High (10k-50k)
🟧	High (1000-10,000)
🟨	Moderate (100-1000)
🟩	Low (10-100)
🟦	Very Low (0-10)

Table 73. Fecal coliform and *Bacteroides* results for Harbor Brook point source trackdown sampling locations in 2017. Sites are arranged in downstream order.

Site	**Location**	**Sampling Date**	**Fecal coliform (CFU/ 100 mL)**	***Bacteroides* Results**[1]				
				Human	**Dog**	**Ruminant**	**Goose**	**Gull**
Velasko Rd(A)	Channel/ditch parallel to Velasko Rd. on the west side, adjacent to car wash.	7/11/2017	930	+	-	-	-	-
Velasko Rd	Main channel upstream of the Velasko Rd. bridge	8/17/2017	960	+	-	+	-	-
HBPS-100	Velasko Rd (CSO-078)	7/11/2017	2900	+	-	+	-	-
HBPS-100A	Manhole between outfall and Onondaga Blvd.	7/11/2017	560	+	-	+	-	-
HBPS-100B	Manhole at Velasko Rd & Onondaga Blvd. E side	7/11/2017	340	+	-	+	-	-
HBPS-100D	Open channel S. of Onondaga Blvd & W. of Velasko Rd.; behind DD plaza	7/11/2017	9	-	-	-	-	-
HBPS-100E	Pipe behind Burger King plaza; S. of Onon. Blvd.	7/11/2017	1300	+	-	-	-	-
HB-PS112A	Manhole N or Hiawatha Blvd.; adjacent to creek in parking lot	8/17/2017	<10	-	-	-	-	-
HB-PS112B	Manhole N of Hiawatha Blvd.; in car dealerships parking lot	8/17/2017	<10	-	-	-	-	-
HB-PS112C	Manhole at Hiawatha Blvd., NE of 690 on ramp	8/17/2017	18	-	-	-	-	-

[1][+] = positive result; [-] = negative result.

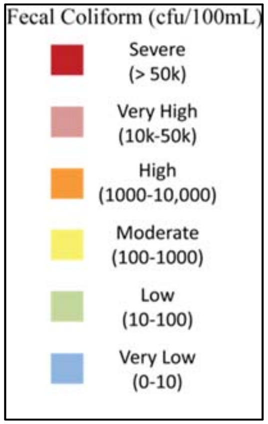


Table 74. Fecal coliform and *Bacteroides* results for Onondaga Creek point source trackdown sampling locations in 2017. Sites are arranged in downstream order.

Tributary	**Site**	**Location**	**Sampling Date**	**Fecal coliform (cfu/ 100 mL)**	***Bacteroides* Results**[1]				
					Human	**Dog**	**Ruminant**	**Goose**	**Gull**
Cold Brook	OC-PS01C	Byrne Pl	7/20/2017	260	+	-	+	-	-
City Line/Spring Brook	OC-PS04B	Slayton Ave	7/20/2017	3000	+	-	+	-	-
	OC-PS04C	Valley Plaza, near Churchill Ave	7/20/2017	81	-	-	-	-	-
	OC-PS04E	Behind Valley Plaza	7/20/2017	33000	+	-	+	-	-
	OC-PS04D	Spring Brook, E. Glen Ave	7/20/2017	72	/	-	-	-	-
Mainstem	Dorwin Ave	In-Stream below drop structure	7/20/2017	370	+	-	+	-	-
Hopper Brook	OC-PS09B	Ford Ave; ~100 yd E of Valley Dr	8/1/2017	1200	+	-	+	-	-
	OC-PS09D	Valley Drive crossing	8/1/2017	1400	-	-	-	-	-
	OC-PS09E	Valley View Dr	8/1/2017	2300	-	-	-	-	-
	OC-PS09C	Camp Ave	8/1/2017	550	+	-	-	-	-
	OC-PS09H	500 block Valley Dr	8/1/2017	910	-	-	+	-	-
	OC-PS09G	100 ' upstream of Ford Ave	8/1/2017	1100	-	-	+	-	-

[1] [+] = positive result; [-] = negative result; [/] = weakly positive result.

Fecal Coliform (cfu/100mL)

- 🟥 Severe (> 50k)
- ▨ Very High (10k-50k)
- 🟧 High (1000-10,000)
- 🟨 Moderate (100-1000)
- 🟩 Low (10-100)
- 🟦 Very Low (0-10)

Table 75. Spearman's rank correlation matrix of parameters measured during point source trackdown sampling (Task 6). Parameters significantly correlated ($p < 0.05$), using the Holm-Bonferroni correction method, are denoted in bold.

PARAMETER	DO	COND	PH	TEMP	FCOLI	SALI	TURB
DO	1.00						
COND	0.00	1.00					
PH	-0.18	-0.17	1.00				
TEMP	-0.38	**-0.46**	0.27	1.00			
FCOLI	-0.06	0.12	-0.17	0.04	1.00		
SALI	0.05	**0.98**	-0.29	-0.49	0.10	1.00	
TURB	-0.20	0.03	0.52	0.31	0.19	-0.06	1.00

[1] Please refer to Table 6 for definitions of parameters codes.

Table 76. Corrective work performed to-date. Corrections made during Phase 3 are denoted in blue.

Year Issue Identified	Study Phase	Stream	Specific Location	Problem	Remedy/Action	Date of Remedy	Documentation	Who Remedied?
2015	Phase 2	Harbor Brook	Velasko Rd (West side of road, drainage ditch between Velasko Rd and Western Lights Plaza; immediately upstream of HB-PS100)	The storm system along Western Lights Plaza was identifed by OCDWEP has receiving sanitary flows from an unknown source and discharged into a drainage ditch on the west side of Velasko Rd that subsequently discharged to Harbor Brook. Dye testing identified a cross-connection to the storm sewer coming from the Monroe Muffler.	A new lateral connection to the sanitary sewer was installed and the illicit connection was removed.	2015	Phase 3 Final Report (Appendix I)	OCWEP
2008	Phase 1	Harbor Brook	HB-PS100 (CSO 078 at Velasko Road)	High levels in fall of 2008 may have been linked to overflow from laundromat caused by blockage in 6 inch pipe; source of water may be former tributary originating in Town of Onondaga (Esposito pers. comm. 2009); lower bacteria levels in 2009 may be result of work subsequently performed by City and OCDWEP to eliminate blockage.	Cleaning of screens at Laundromat	2009	Phase 1 Report	City of Syracuse
2017	Phase 3	Harbor Brook	HB-PS100 (CSO 078 at Velasko Road)	Discussion with WEP Engineers in May 2018 stated 3 illicit cross-connections were identified in the CSO-078 sewershed and were subsequently corrected (Appendix I).	During contractor repairs related to a sinkhole near the CSO 078 manhole at the intersection of Velasko Rd and Bellevue Ave, CSO 078 was televised and three lateral cross connections were found. Laterals were disconnected from the CSO line and reconnected to the Onondaga Trunk Sewer. Follow-up sampling may be warranted to verify the effects of remedial activities.	12/5/2017	Phase 3 Final Report (Appendix I)	OCWEP
2008	Phase 1	Harbor Brook	HBPS-101B (CSO 018)	HB-PS101 was separated into two distinct outfalls: HB-PS101A and HB-PS101B. Only HB-101B had flow. High levels of fecal coliforms were found to be the result of the sewer system being overwhelmed by ground water, common during spring snow melt and wet weather conditions, causing dry-weather CSO discharges.	Information provided through this study was used, in part, by OCDWEP to justify rebuilding the HBIS and installing the Harbor Brook CSO 018 Wetland Treatment Facility to treat CSO discharges. In 2016, HBPS-101, HBPS-101A,and HBPS-101B were effectively eliminated by the creation of the CSO 018 Wetland Treatment Facility.	2016	Phase 1 Report	OCWEP
2009	Phase 1 - Phase 2	Harbor Brook	HBPS-103 (Depalma Ave)	Peresistenly high bacteria levels from an unknown source were observed during Phase 1.	Discharge & subsequent TV monitoring & dye testing confirmed cross-connection but no location (Phase 1); House was found to be tied into stormwater (Phase 2). Installed new lateral into sanitary sewer	9/25/2012 11/8/12 11/19/12	Phase 2 Report (Appendix F); documented work logs	Work performed by C&S Engineering.
2007	[Pre-BACT]	Kennedy Cr	Rte 11, Lafayette, NY	Willow Wood apt. complex failing septic system	New septic systems installed	2007	Phase 2 Report (Appendix F); 2/18/14 MJP email with Jul 2007 photos	Property Owner

Table 76. Corrective work performed to-date. Corrections made during Phase 3 are denoted in blue.

Year Issue Identified	Study Phase	Stream	Specific Location	Problem	Remedy/Action	Date of Remedy	Documentation	Who Remedied?
2009	Phase 1	Onondaga Cr	OCPS-25 (Longmeadow Due W. of Hilton Rd)	Raw sewage discharge.	Cross-connection, verified by TV work. Series of digs to repair broken pipe.	2/10/2010	Phase 1 Report	OCWEP (TV & Dye)/City (+Digs)
2009	Phase 1	Onondaga Cr	OCPS-69 (Newell St.Swirler)	Secondary CSO-067; sewer collapse of the Midland trunk sewer resulting in an overflow discharge at OC-PS69	Emergency pipe repair. OCWEP records state Midland trunk sewer collapse caused the only dry weather sewage release from OC-PS69 in 2009.	4/1/09	Phase 1 Report	OCWEP
2008	Phase 1	Onondaga Cr	Gifford St	Collapsed sewer pipe at Gifford St, caused discharge into CSO-035	Emergency repair of pipe began on 10/15/08	11/3/08	Phase 1 Report	Unknown
2009-2016	Phase 1 - Phase 3	Onondaga Cr	OCPS-20	Immediately upstream of CSO 037. Identified as discharge from Byrne Dairy	Storm drains in immediate prox of loading docks disconnected from storm system, tied to industrial pretreatment & sanitary sewer system - [only 1 had redirection as of 11/19/13, further dye testing needed to verify other connections]. **A new stormwater outfall to Onondaga Creek was completed at the Byrne Dairy Plant in June 2016.**	**6/29/2016**	Phase 2 Final Report: JS 5/23/13 email regarding 4000 gallon batch milk on 5/1/13; 11/20/13 JS email w/ 11/19/13 WEP Memo w/ diagram att. **Phase 3 Final Report (Appendix I): Email correspondence between Byrne Dairy, NYSDEC, and OnCo WEP**	**Byrne Dairy (Phase 2)** hired Greystone Evolutions for stormwater mgmt solutions **Byrne Dairy (Phase 3)**
2009-present	Phase 1	Onondaga Cr	OCPS-61 (CSO-036)	Unknown bacteria discharge, 6" plastic PVC pipe under W. Onondaga St. bridge. Also has high chlorine concentrations.	Pipe was televised in February 2009. Dye testing showed no cross-connection, but investigations are ongoing.	Further investigations are needed. Strategies for trackdown and remediation have not yet been developed.	Phase 1 Report: Daily Sewer Work Logs document February 2009 dye testing & June 2009 flush	
2008-present	Phase 1 - Phase 3	Onondaga Cr	OCPS-21 (Walton St.) CSO-029	Data suggest significant discharge may be occurring. [2012] Pipe was traced back to a building on Walton St.	As of 5/21/09, dye testing completed and showed no cross-connection; OCWEP planned to coordinate with City to TV pipe to i.d. origin. [2012] Onondaga County began the process of issuing a Consent Order to the building owner. **During the consent order process, the building was sold. The new property owner, evidently remedied the illicit discharge. OCWEP performed dye tests July 28-Aug. 8, 2014. No discharge was found. This was confirmed during Phase 3 sampling.**	**2014**	Brief Email b/w TRA & VE only. **Phase 3 Final Report (Appendix I); Email correspondence between WEP engineers.**	**Property Owner**
2008-2009	Phase 1	Onondaga Cr	OCPS-22 (Walled-off large outfall below Erie Blvd.)	Data suggest a significant discharge may be occurring	July 2014: SLJ Met with Kevin Walker of C&S Engineering. Mr. Walker stated that the discharge is likely due to back flow from EBSS during periods of high flow.		Phase 1 Final Report (Appendix D); Email communications	OCWEP, performed by C&S Engineering.

Table 76. Corrective work performed to-date. Corrections made during Phase 3 are denoted in blue.

Year Issue Identified	Study Phase	Stream	Specific Location	Problem	Remedy/Action	Date of Remedy	Documentation	Who Remedied?
2008-2014	Phase 1	Onondaga Cr	OCPS-23 (EBSS outfall CSO-080)	Discharge	[OnCo states samples are result of residual contamination from CSO wet weather storage until conveyance to MIS & Metro]. **OCWEP has performed multiple remedial efforts at EBSS, including operational changes, gate repair, dewatering pump system repair, and debris removal. A cross connection at Aldi & Peat Streets was that was discharging to the EBSS was also repaired.**	**Feb 2013: debris removal. Oct. 2013: cross connection repair, repair to dewatering pump system. Sept 2014: gate seal repair and operational changes**	**OnCo Save-the-Rain Compliance Program Monitoring Report; Email correspondece between OCWEP and NYSDEC.**	**OCWEP**
2012	Phase 2	Onondaga Cr	400 Leavenworth	Burns Bros, improper connection to storm system	Remove and abate interconnection to sewer system	11/1/12	Phase 2 Final Report (Appendix F)	Burns Bros, based on City request, based on County notification
2012	Phase 2	Ley Creek	151 Midler Park Dr (Boxwood Lane)	Broken sanitary sewer pipe adjacent to Ley Creek	Repair sewer	10/4/13	Phase 2 Final Report (Appendix F)	ToD (Lan-co via OBG)
2012	Phase 2	Ley Creek	Midler Park Dr (111 Boxwood Lane)	Direct sanitary sewer pipe discharge to creek	New lateral sanitary line installed and re-routed to sewer trunk. Broken pipe disconnected and filled with concrete.	May-13	Phase 2 Final Report (Appendix F)	ToD
2015	**Occurred during, but separate from, Phase 3**	**Ley Creek**	**Harford Rd**	**Illicit connections to the storm sewer. Investigative work by OCWEP and City of Syracuse collectively identified 8 cross connections to the storm system.**	**OCWEP contacted City of Syracuse on 12/9/15. In Sept. 2017, City of Syracuse started the Harford Rd Sanitary Sewer Lateral Replacement project. Eight lateral sanitary lines were disconnected from the storm sewer between Lemoyne Service Rd and Cadillac St and reconnected to the sanitary system.**	**2017**	**Phase 3 Final Report (Appendix I): OCWEP submitted a letter to City of Syracuse notifying the City of the problem.**	**City of Syracuse**
2017	**After Phase 3**	**Harbor Brook**	**CSO 078**	**Three lateral cross connections from sanitary lines were identified by Onondaga County contractors as discharging directly into the CSO line.**	**The CSO line was televised and the three connections were found. The sanitary lines were disconnected from the CSO and reconnected to the Onondaga Trunk Sewer**	**12/5/2017**	**Phase 3 Final Report (Appendix I); email exchange from Onondaga County WEP**	**OCWEP**

Notes:
OCWEP = Onondaga County Dept. of Water Environment Protection
ToD = Town of Dewitt
SLJ = Stephanie L. Johnson
TRA = Tyler R. Andre
VE = Vince Esposito
JS = Janaki Suryadevara

Onondaga Environmental Institute

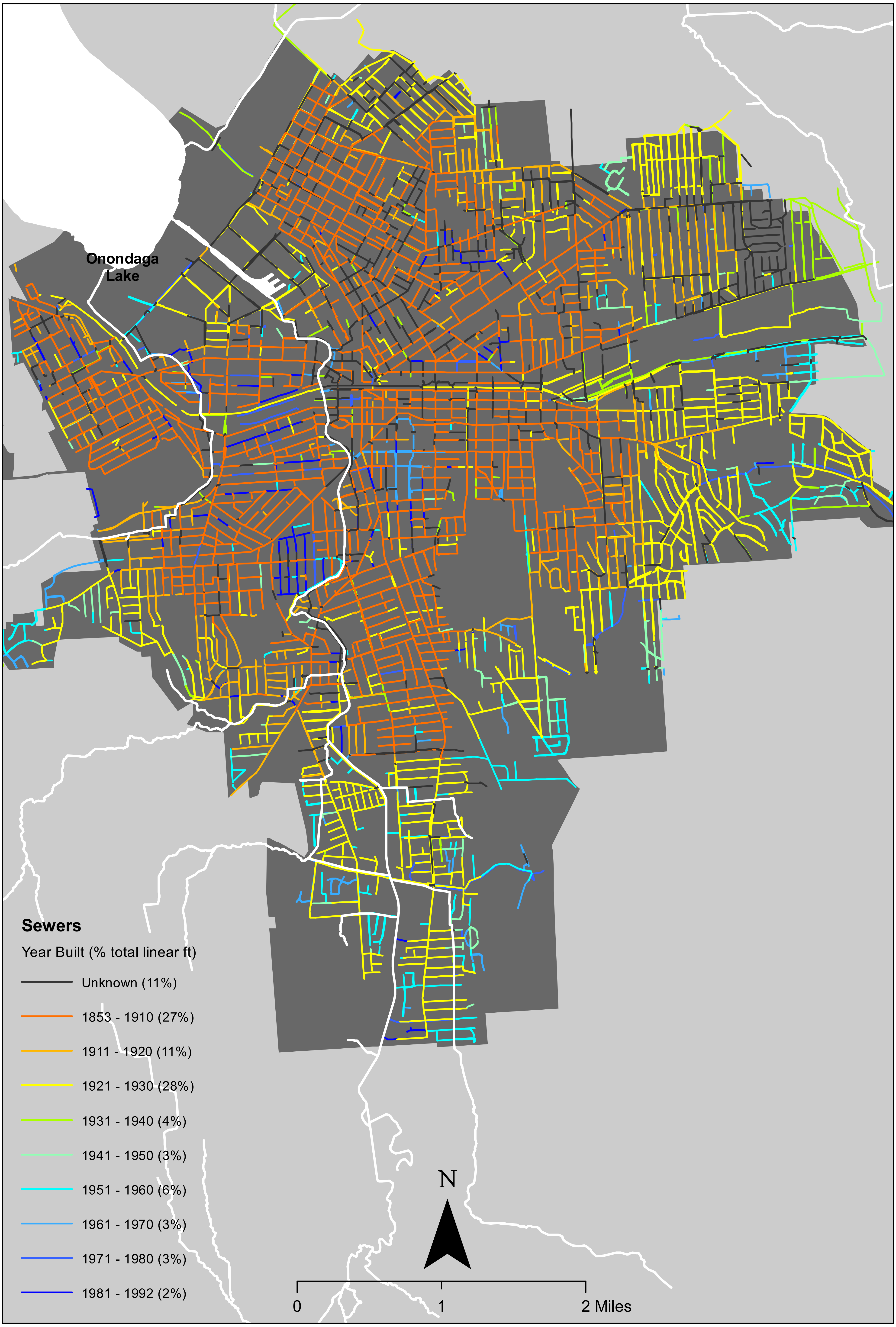


Figure A. Age of Syracuse sewer system.

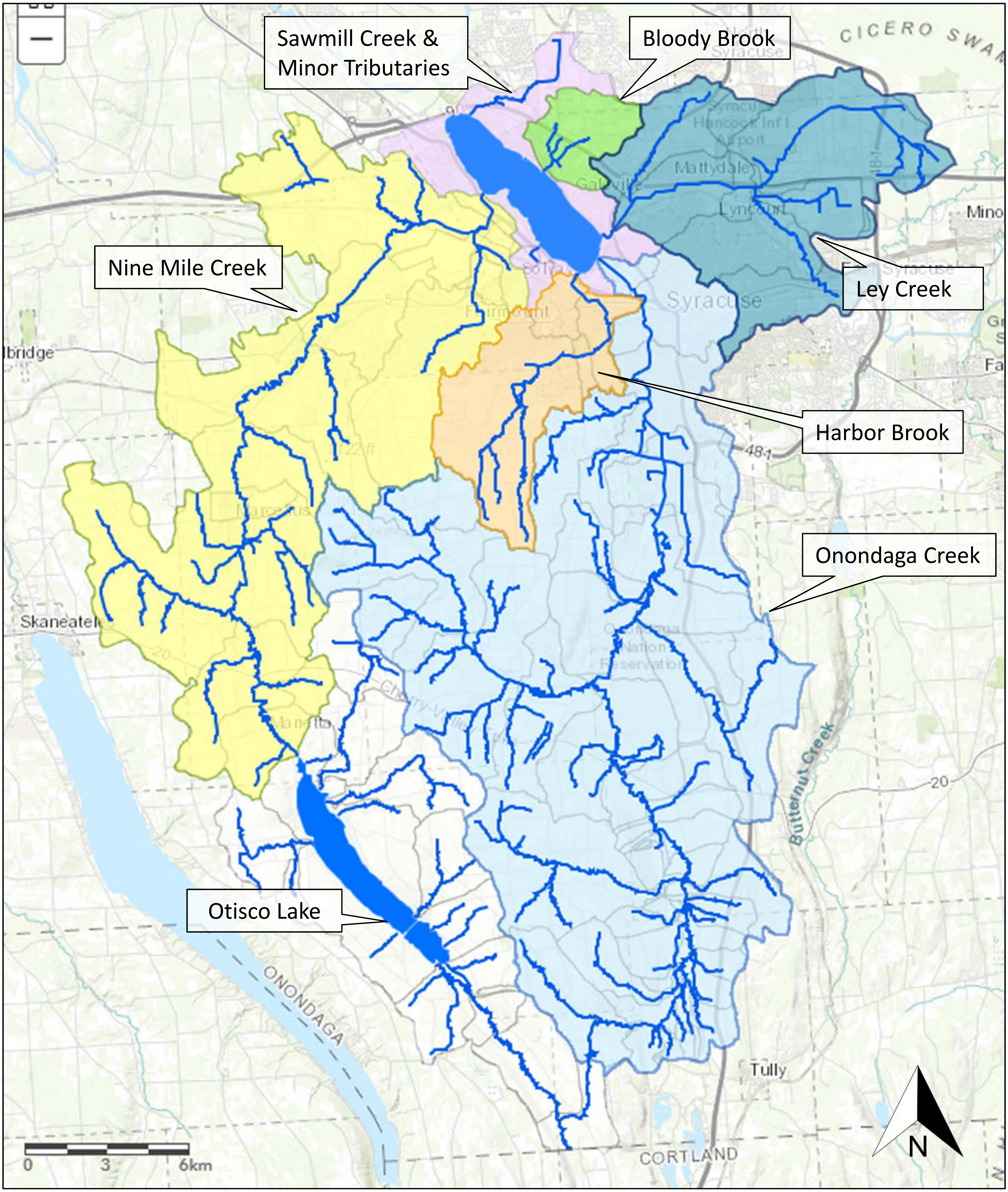


Figure 1. Onondaga Lake Watershed with delineated watersheds.

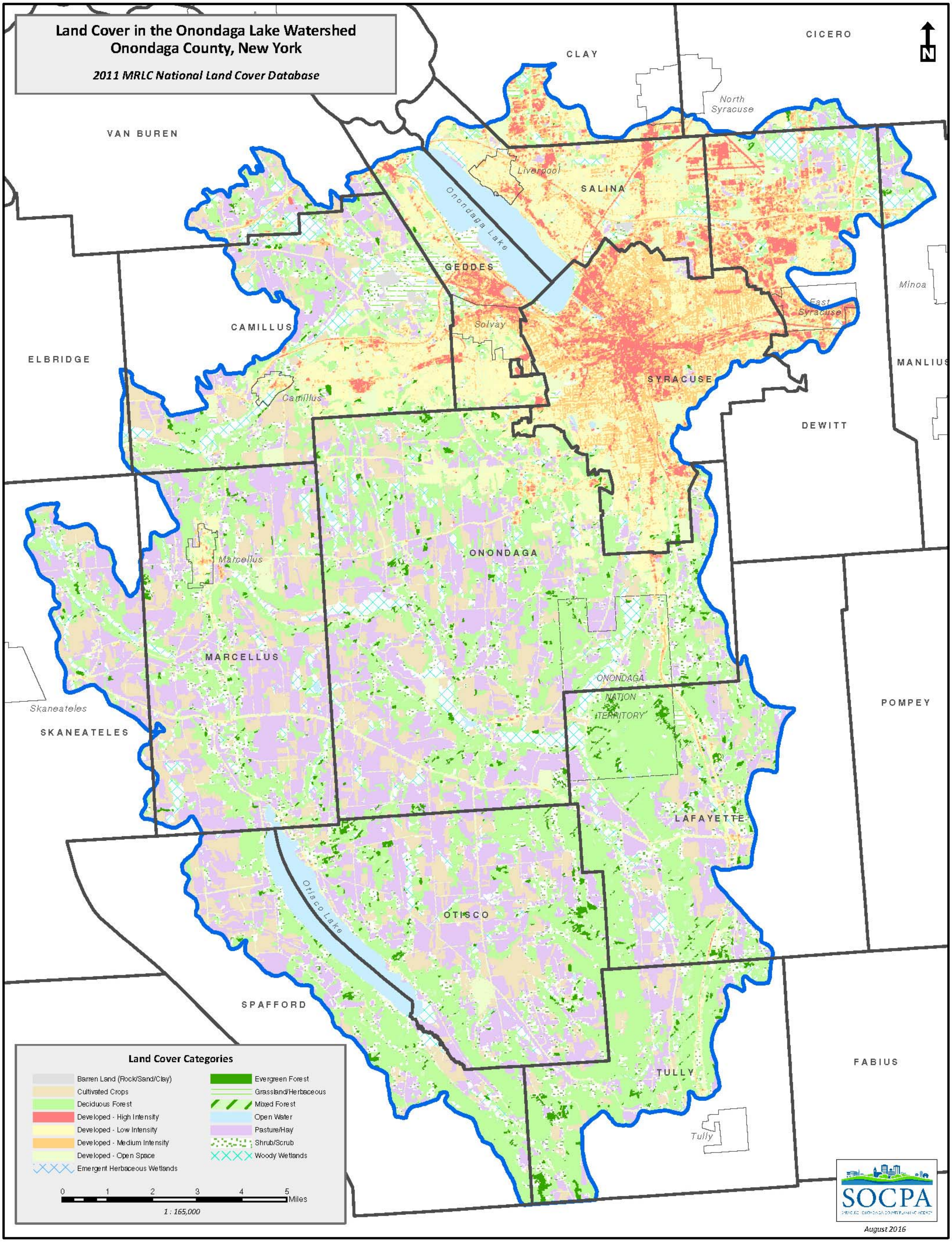


Figure 2. Onondaga Lake Watershed land use. Obtained from the 2015 Ambient Monitoring Program Annual Report (OCDWEP, 2017).

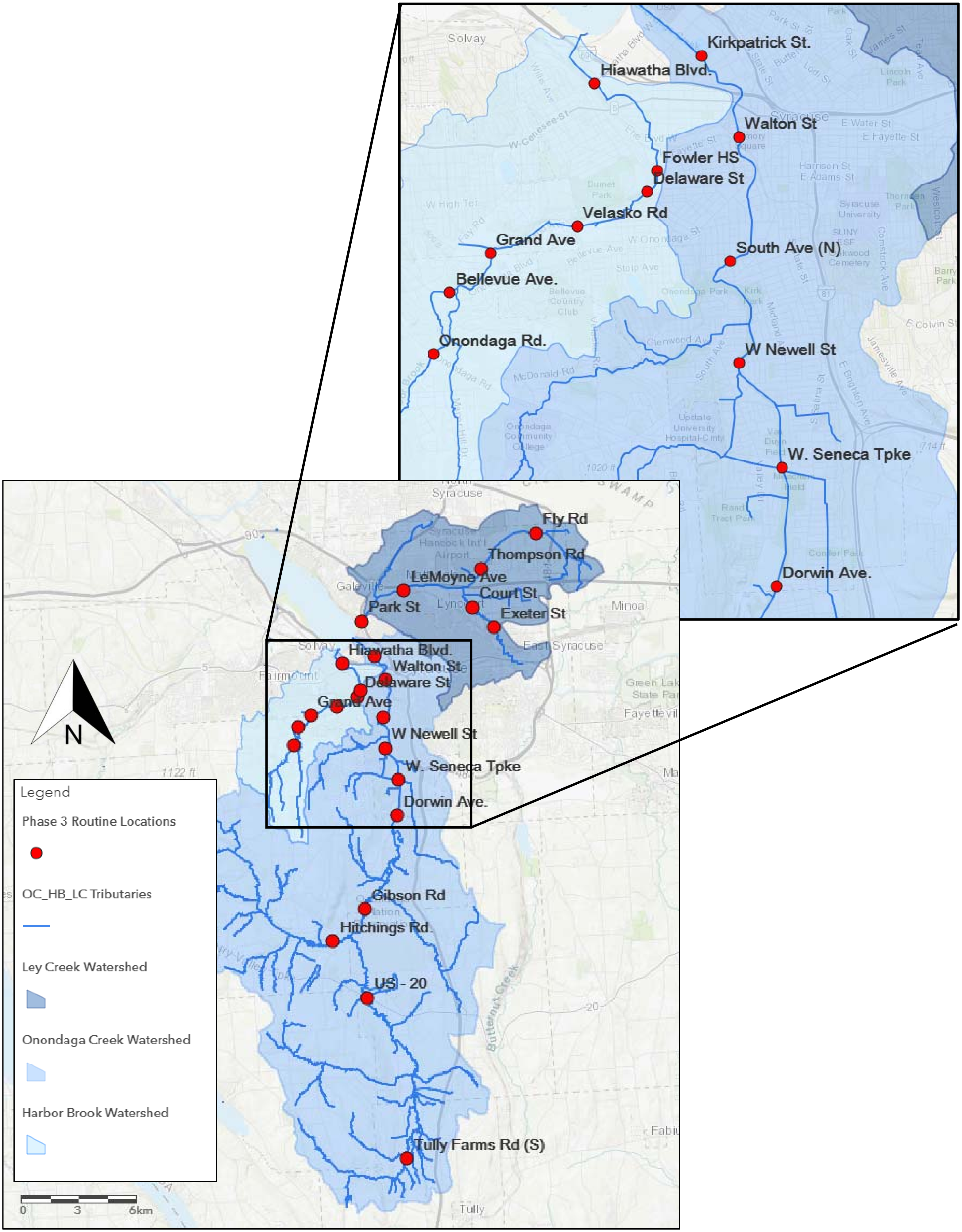


Figure 3. Phase 3 routine sampling locations (Task 3) (2014-2015).

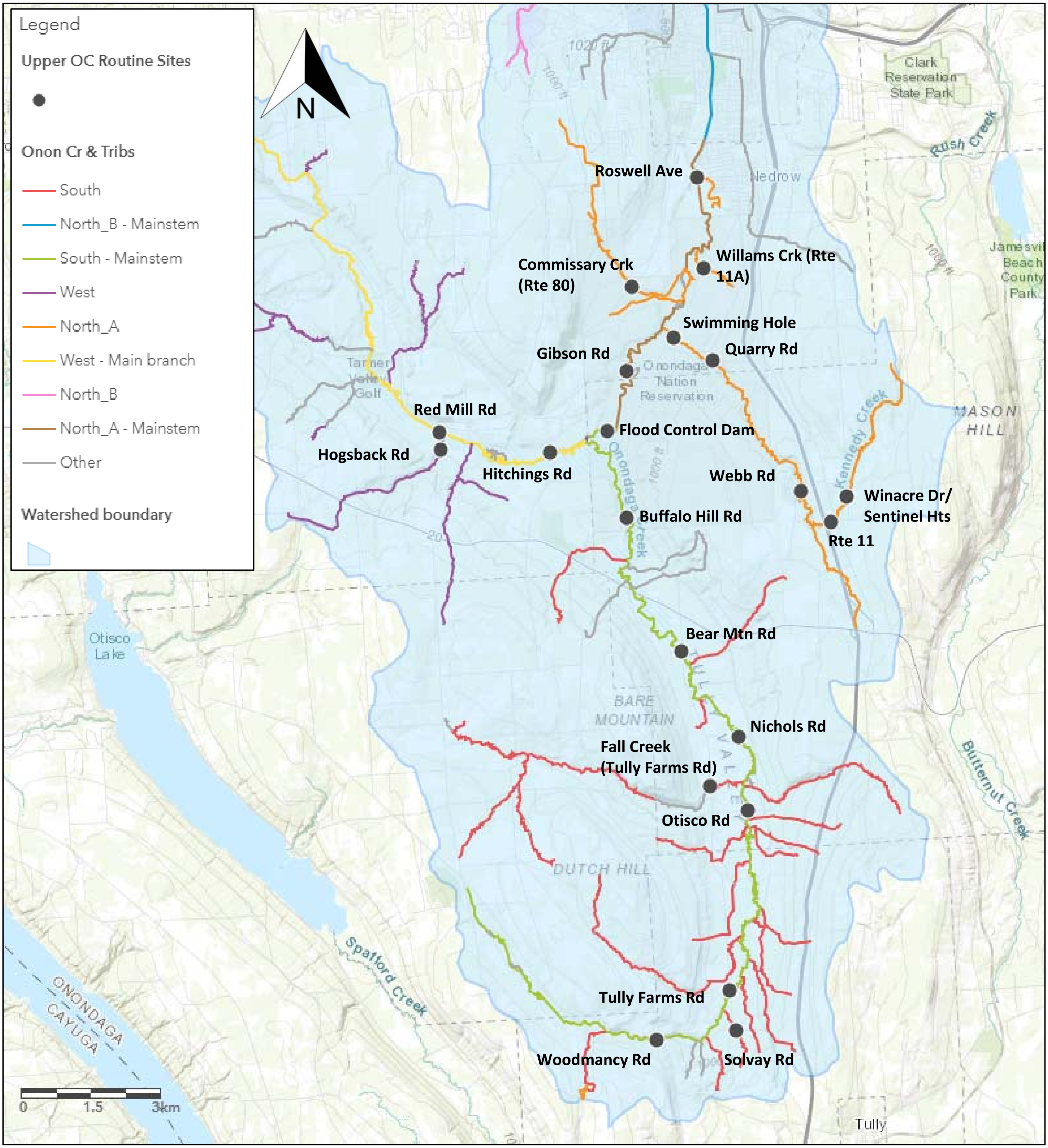


Figure 4. Phase 3 upper Onondaga Creek routine sampling locations (Task 3.1) (2014).

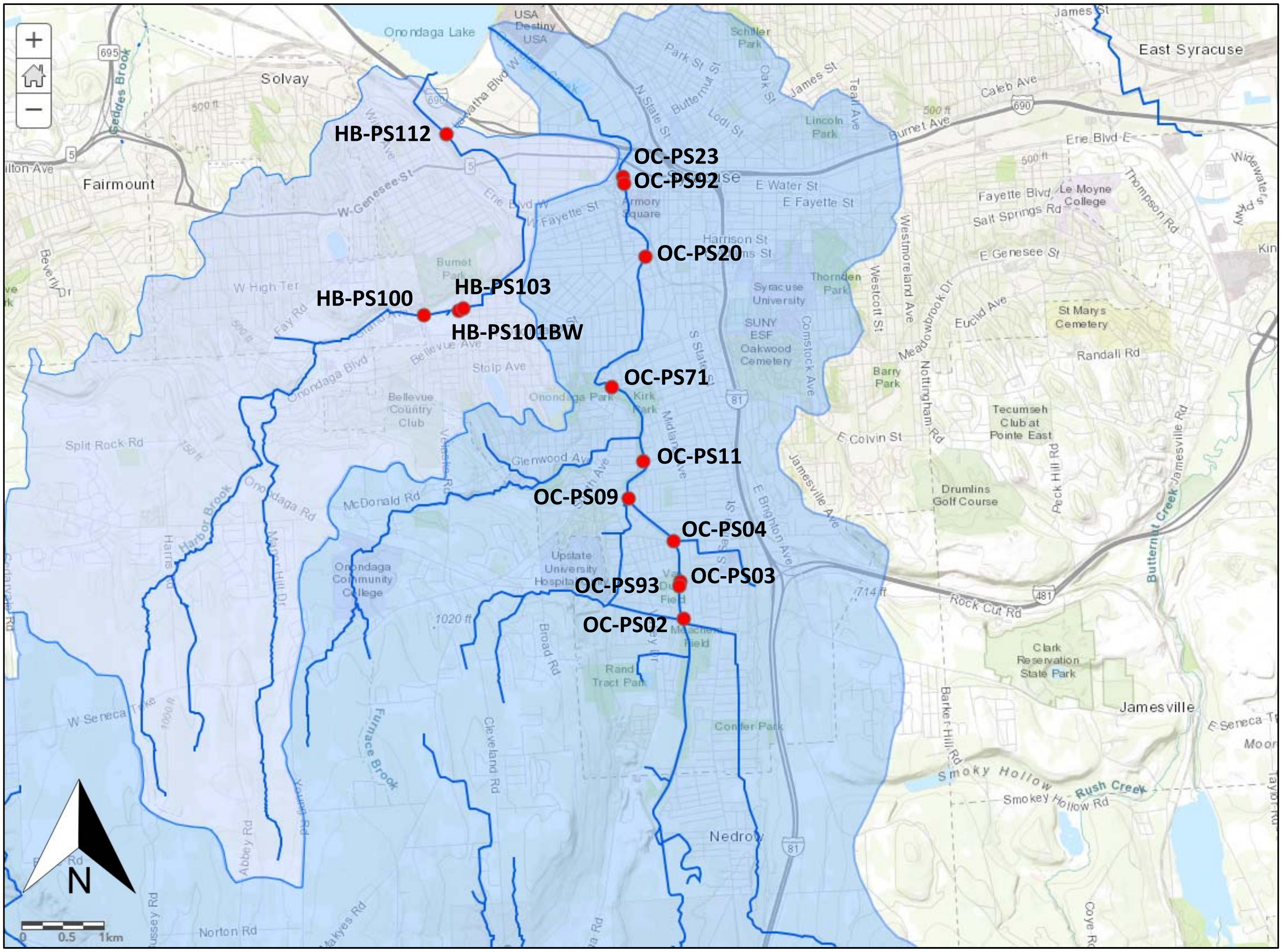


Figure 5. Phase 3 Priority Point Source sampling locations (Task 4) (2014-2015).

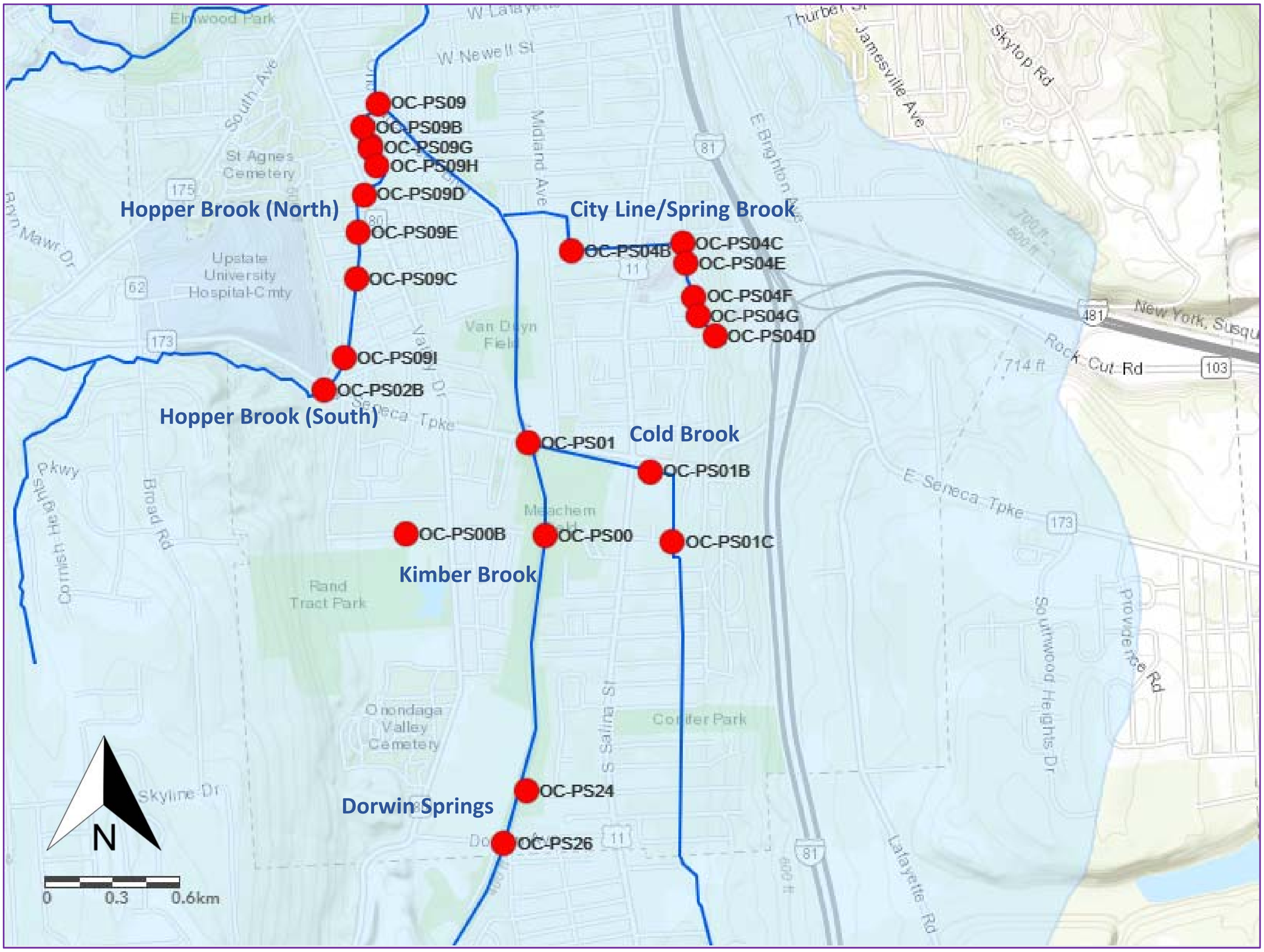


Figure 6. Phase 3 Tributary Trackdown sampling locations (Task 5) (2014-2015).

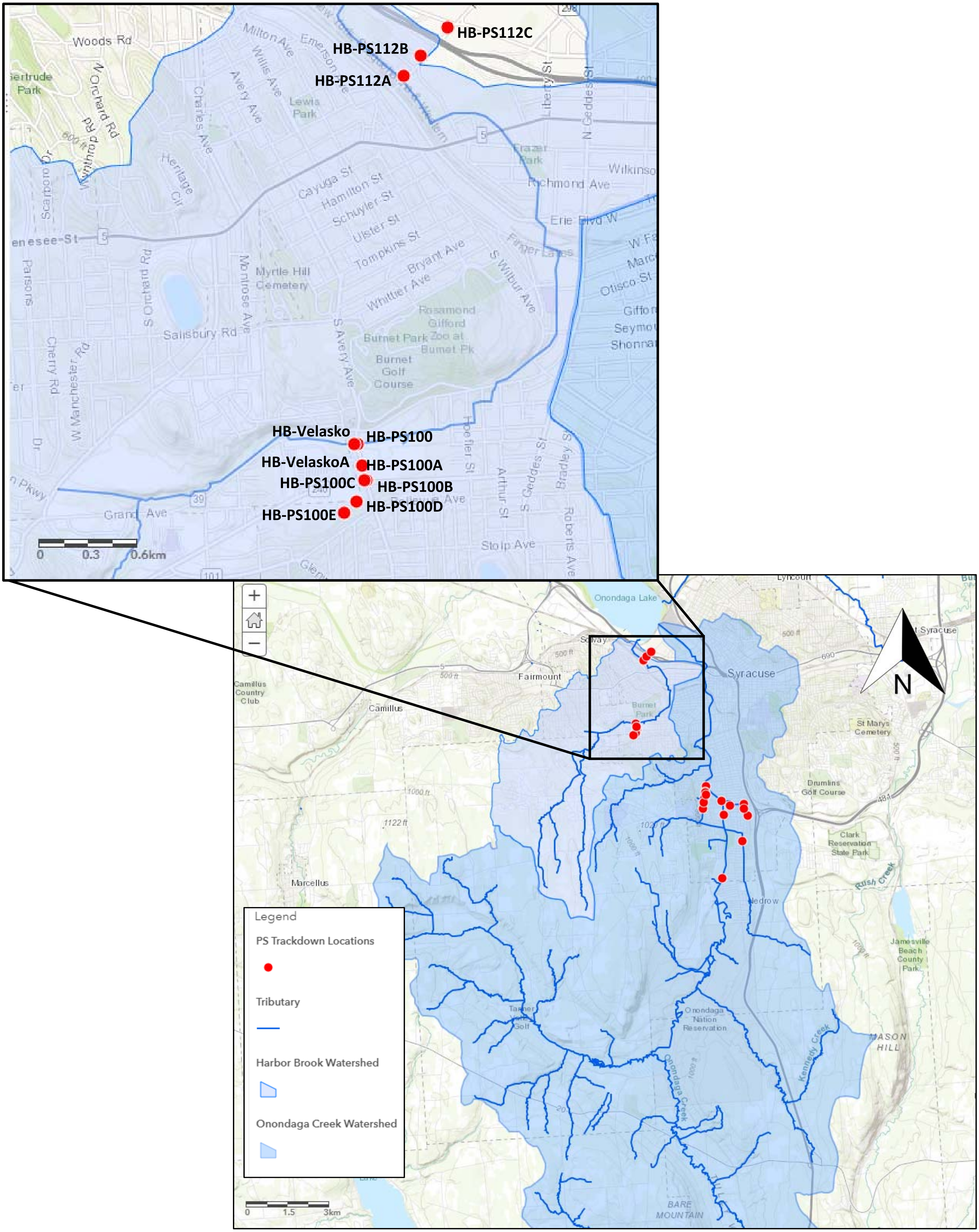


Figure 7. Phase 3 Point Source Trackdown sampling locations (Task 5) for Harbor Brook and Onondaga Creek (2014-2015). Harbor Brook locations are inset.

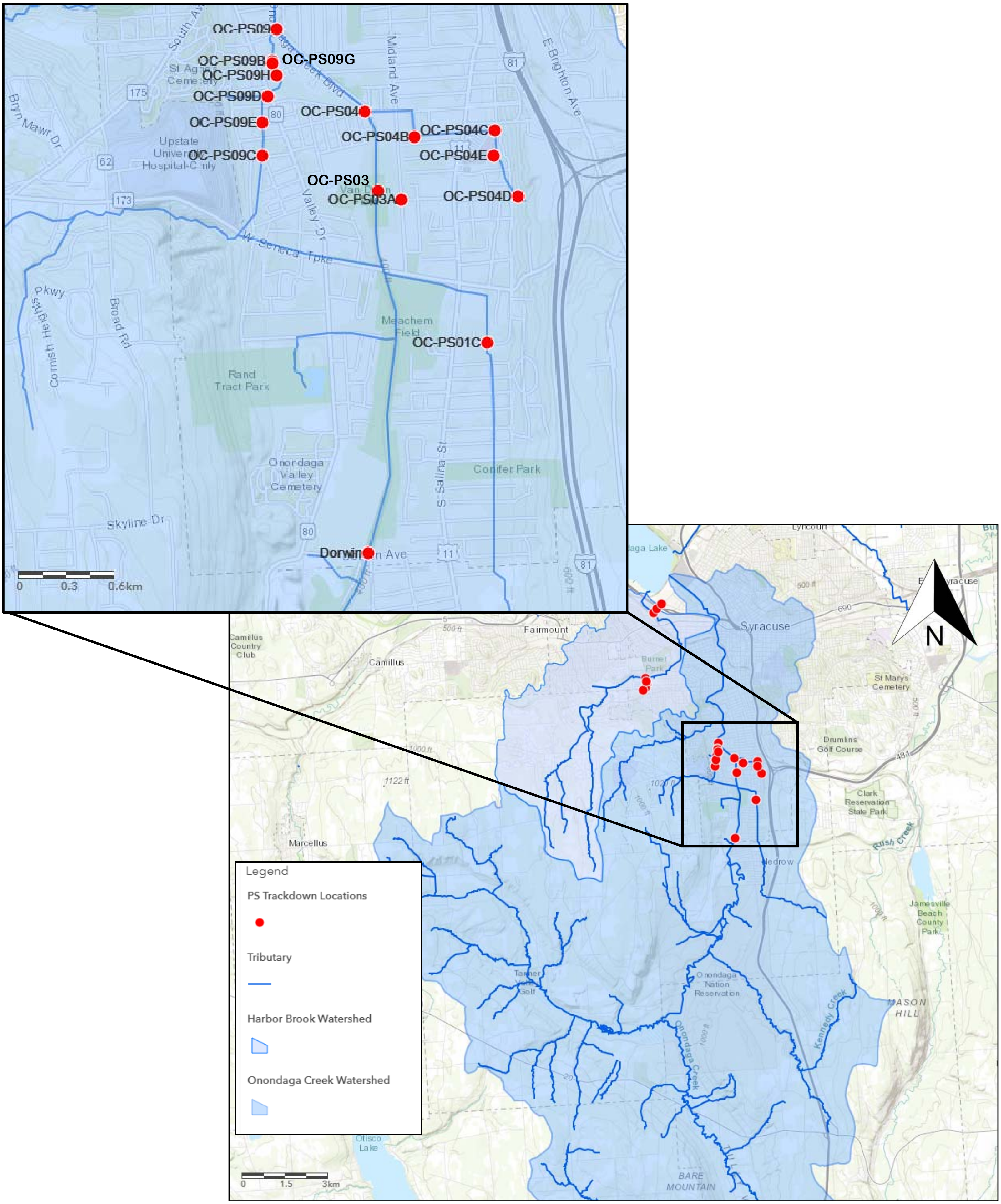


Figure 8. Phase 3 Point Source Trackdown sampling locations (Task 5) for Harbor Brook and Onondaga Creek (2014-2015). Onondaga Creek locations are inset.

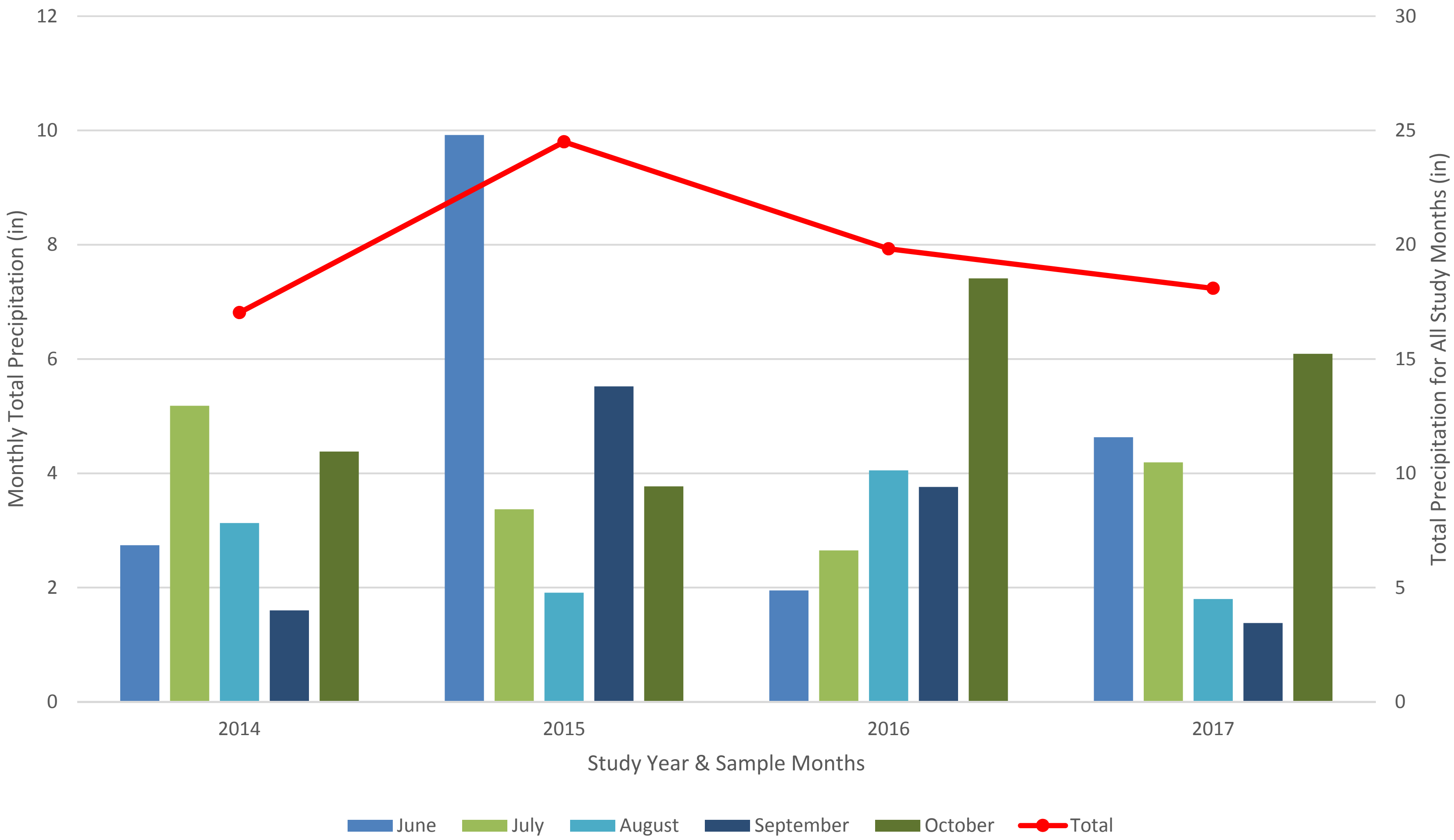


Figure 9. Total monthly and annual rainfall for the Phase 3 study period (2014-2017), during sampling months (June-October).

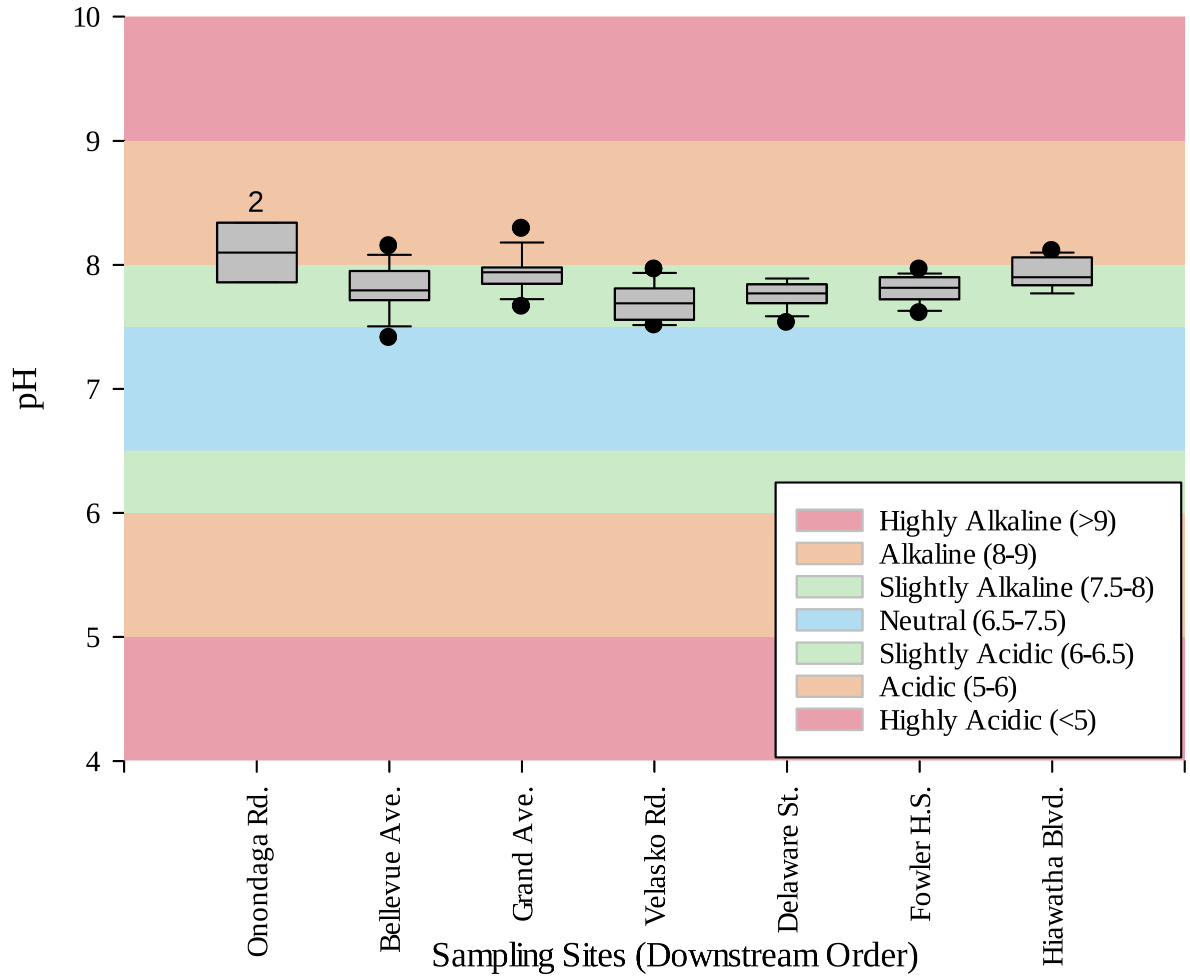


Figure 10. pH levels for Phase 3 Harbor Brook routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=14.

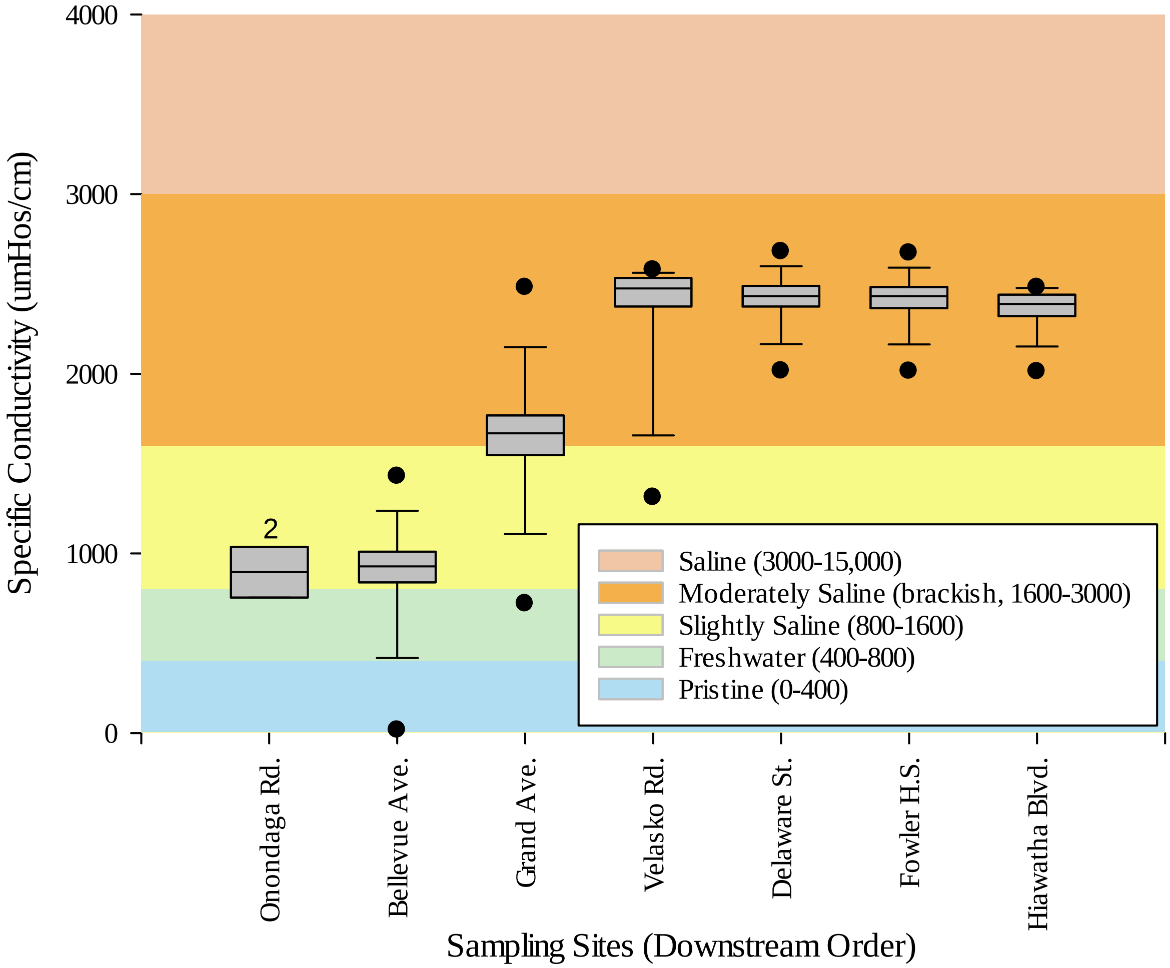


Figure 11. Specific conductivity levels for Phase 3 Harbor Brook routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=14.

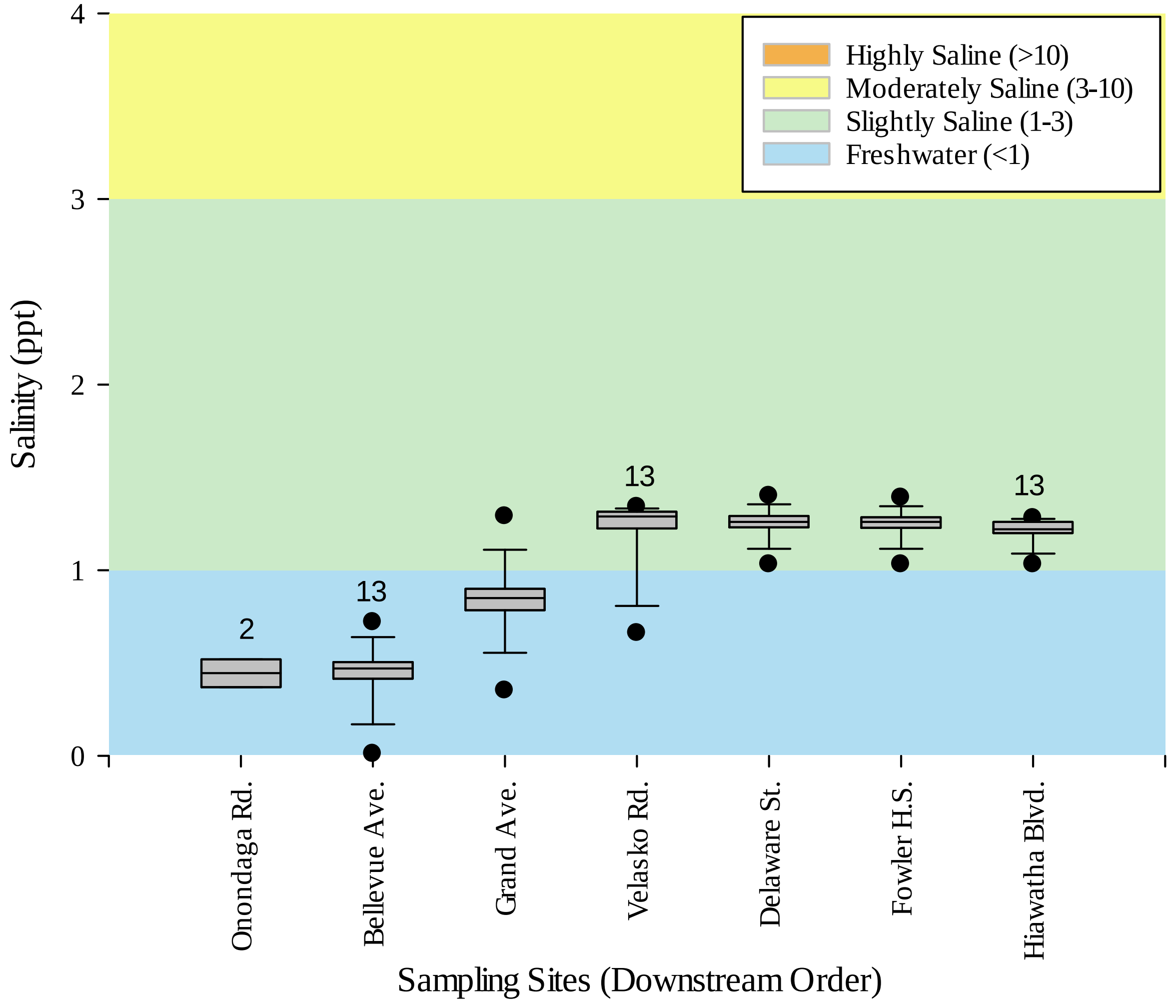


Figure 12. Salinity levels for Phase 3 Harbor Brook routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=14.

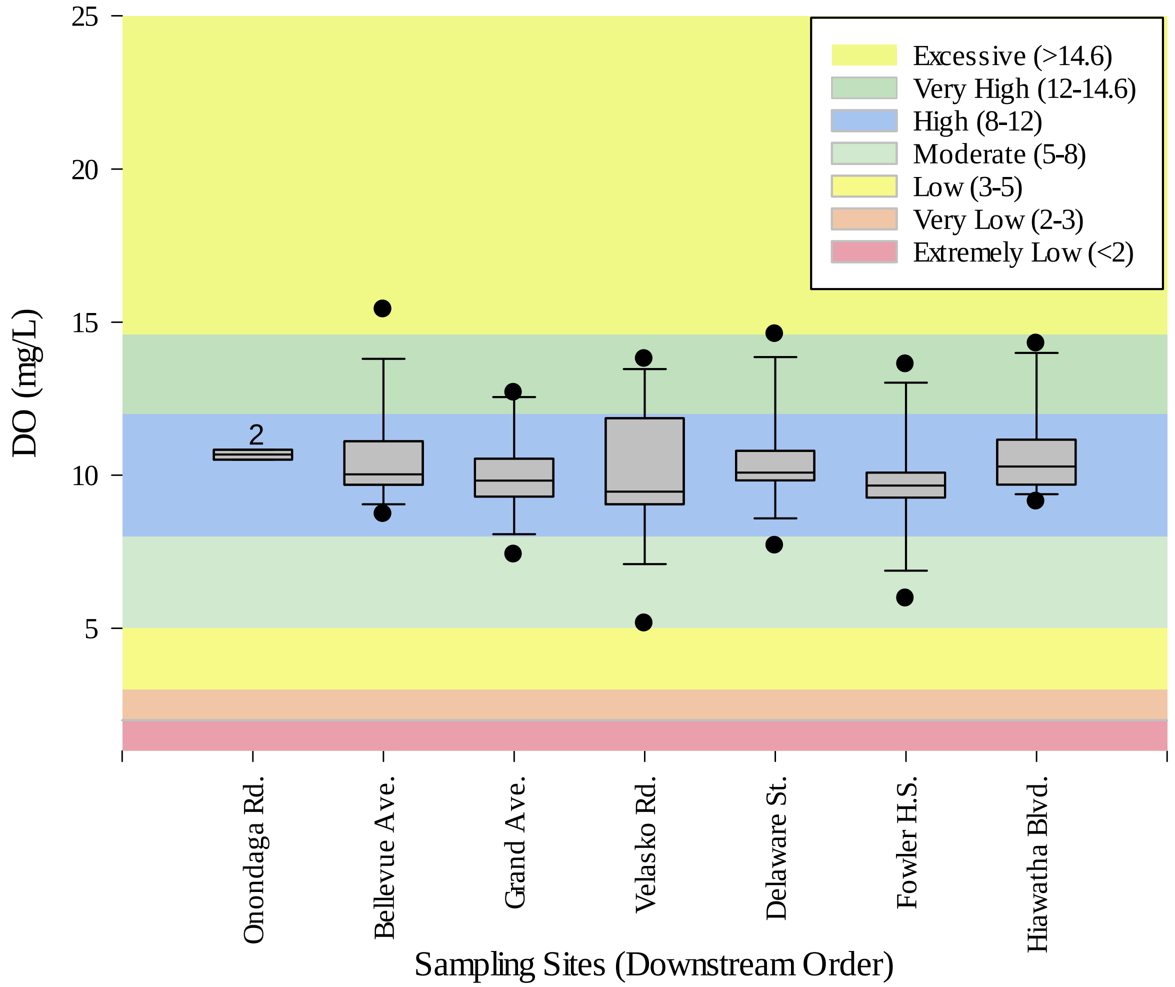


Figure 13. Dissolved oxygen levels for Phase 3 Harbor Brook routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=14.

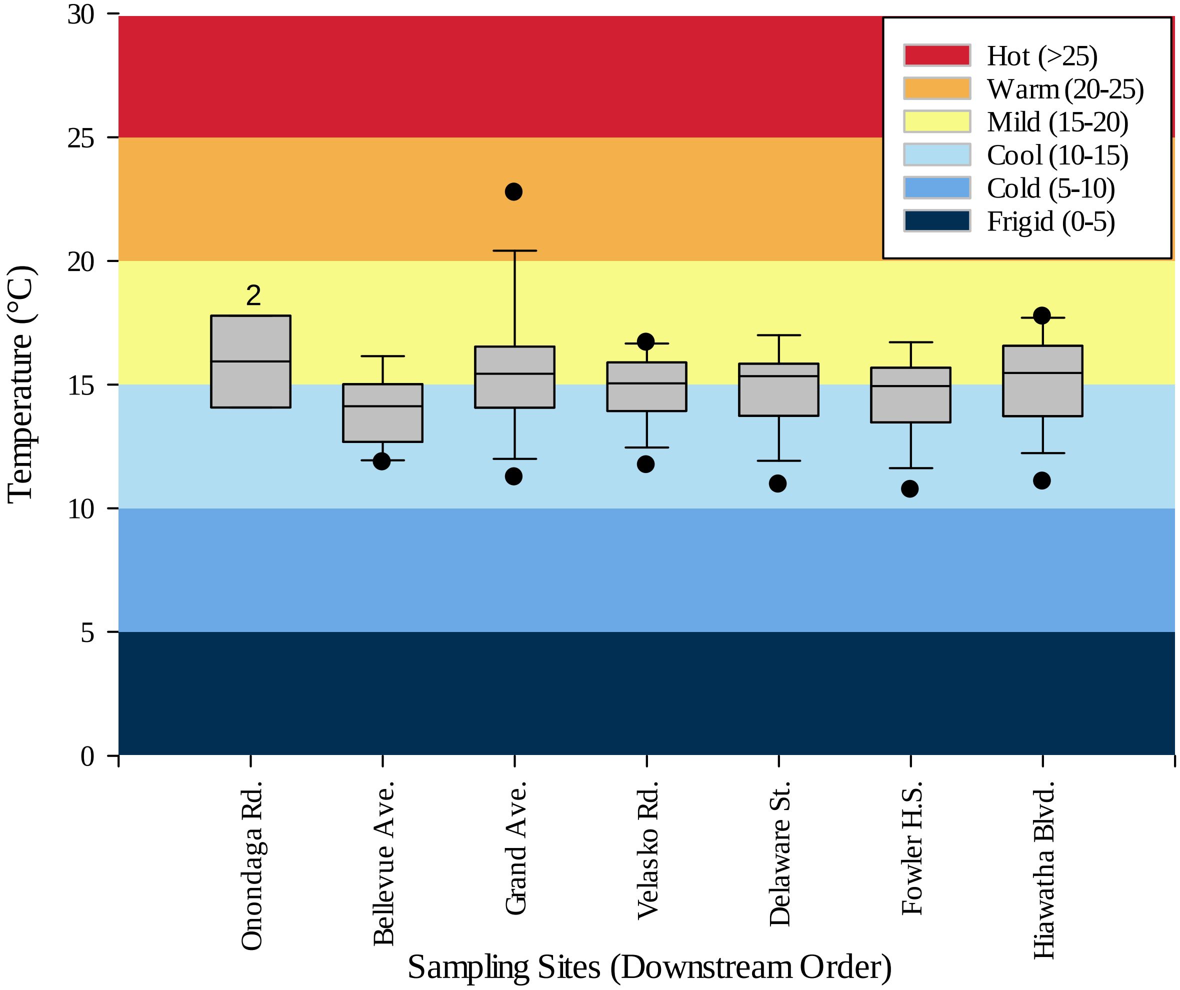


Figure 14. Temperature levels for Phase 3 Harbor Brook routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=14.

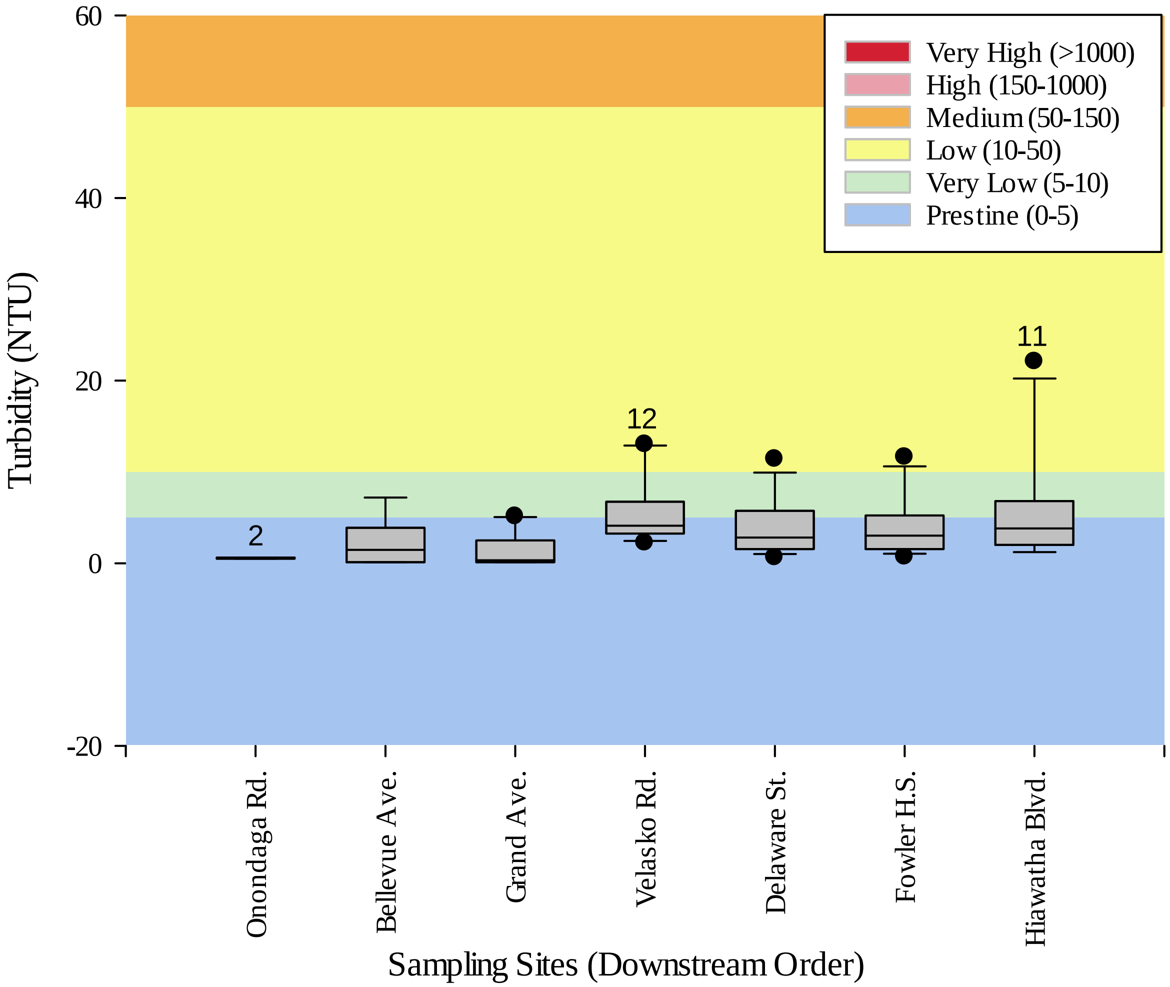


Figure 15. Turbidity levels for Phase 3 Harbor Brook routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=14.

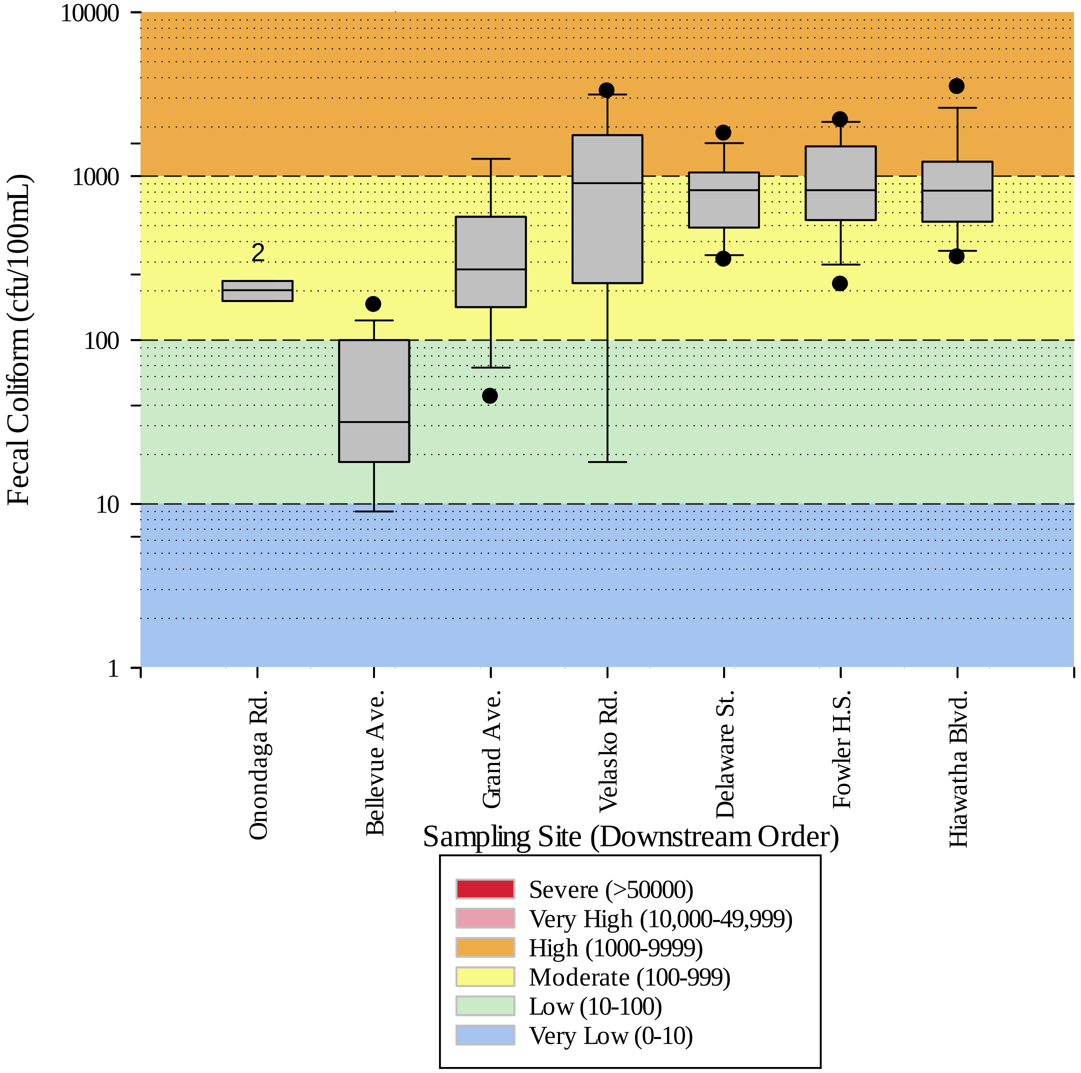


Figure 16. Fecal coliform levels for Phase 3 Harbor Brook routine sampling locations (2014-2015). Values are plotted on a logarithmic scale. Unless specified, the number of samples used to generate box plots is N=14.

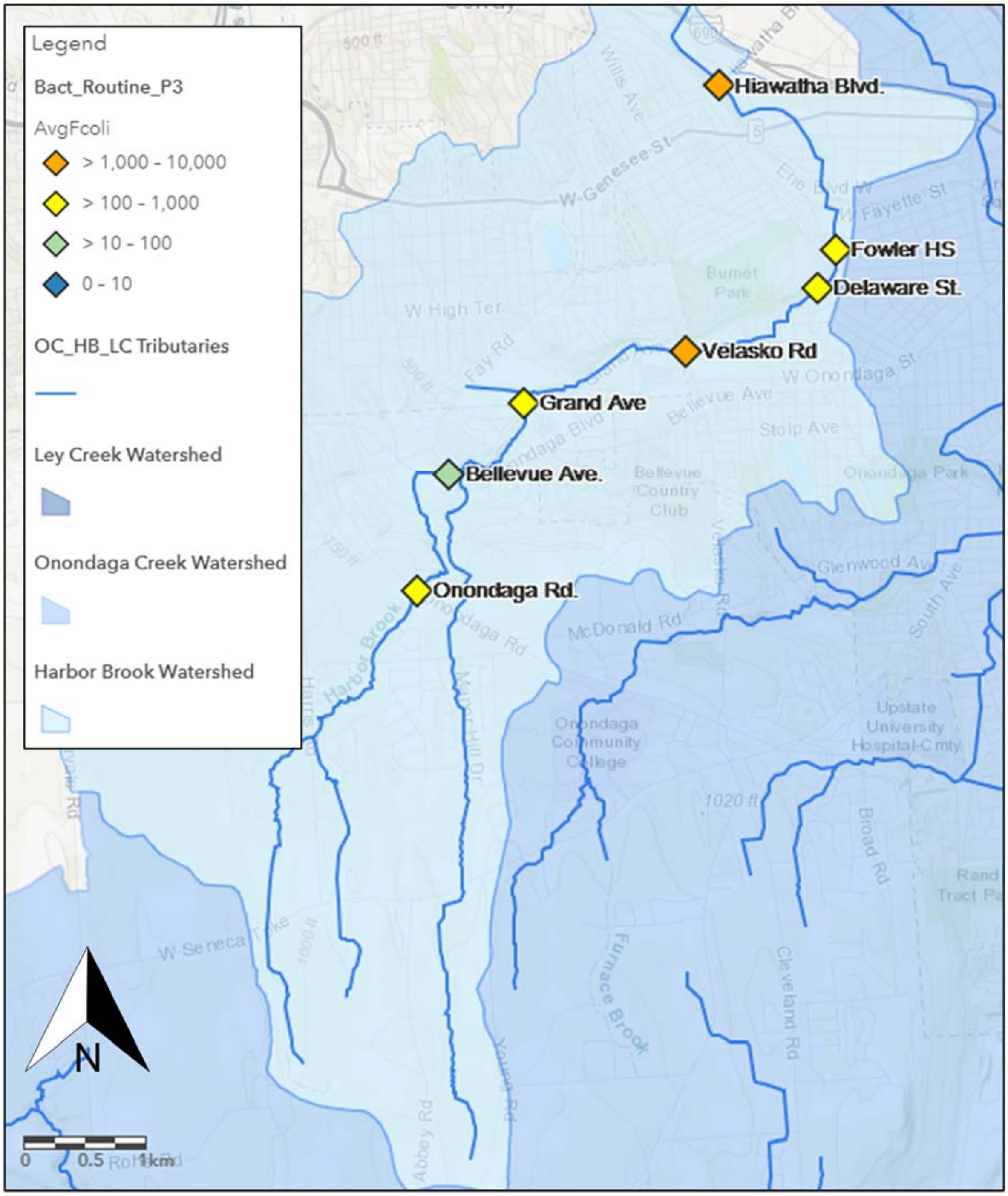


Figure 17. Average fecal coliform levels (cfu/100 mL) for Phase 3 Harbor Brook routine sampling sites (2014-2015).

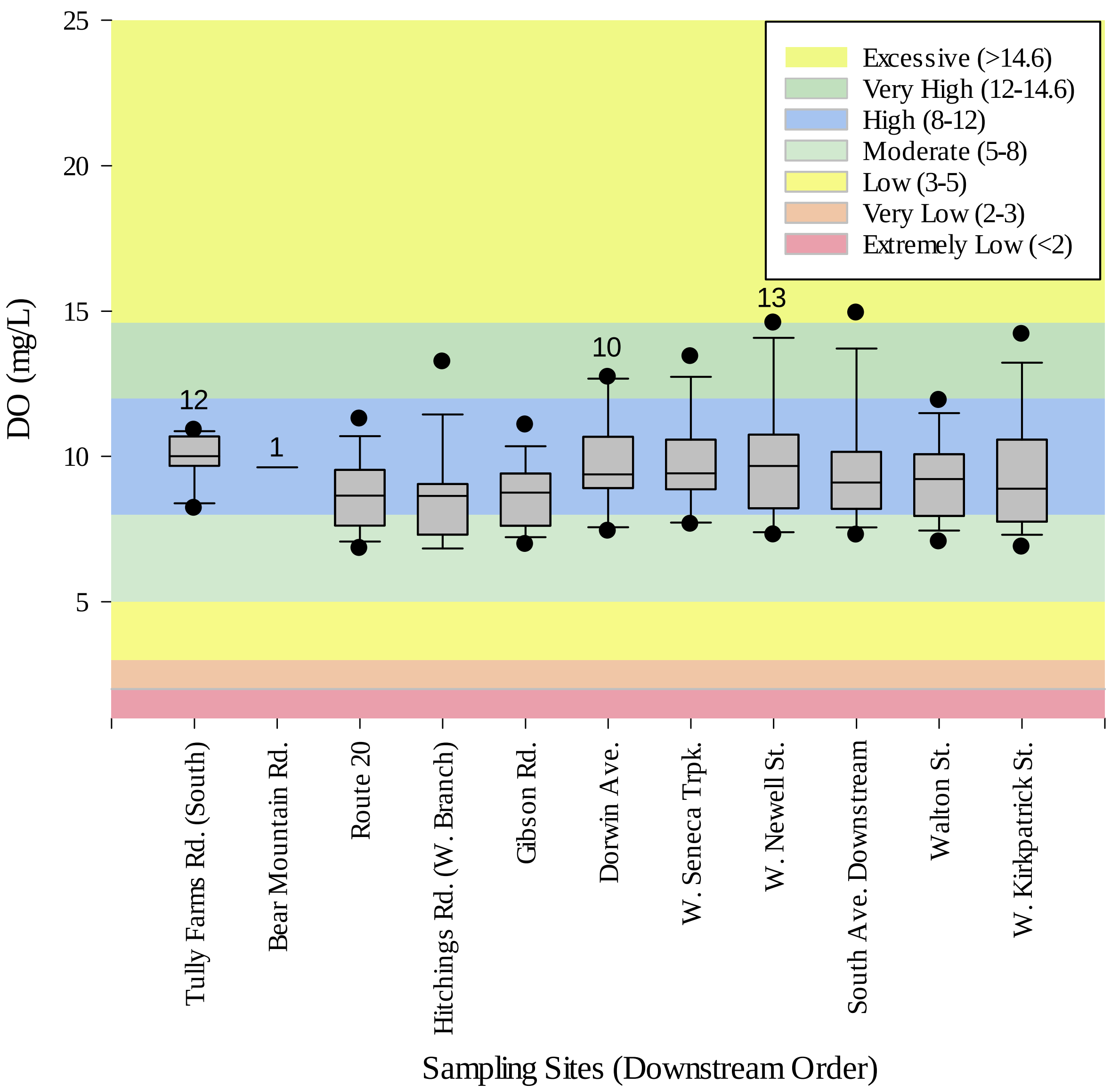


Figure 18. Dissolved oxygen levels for Phase 3 Onondaga Creek routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=14.

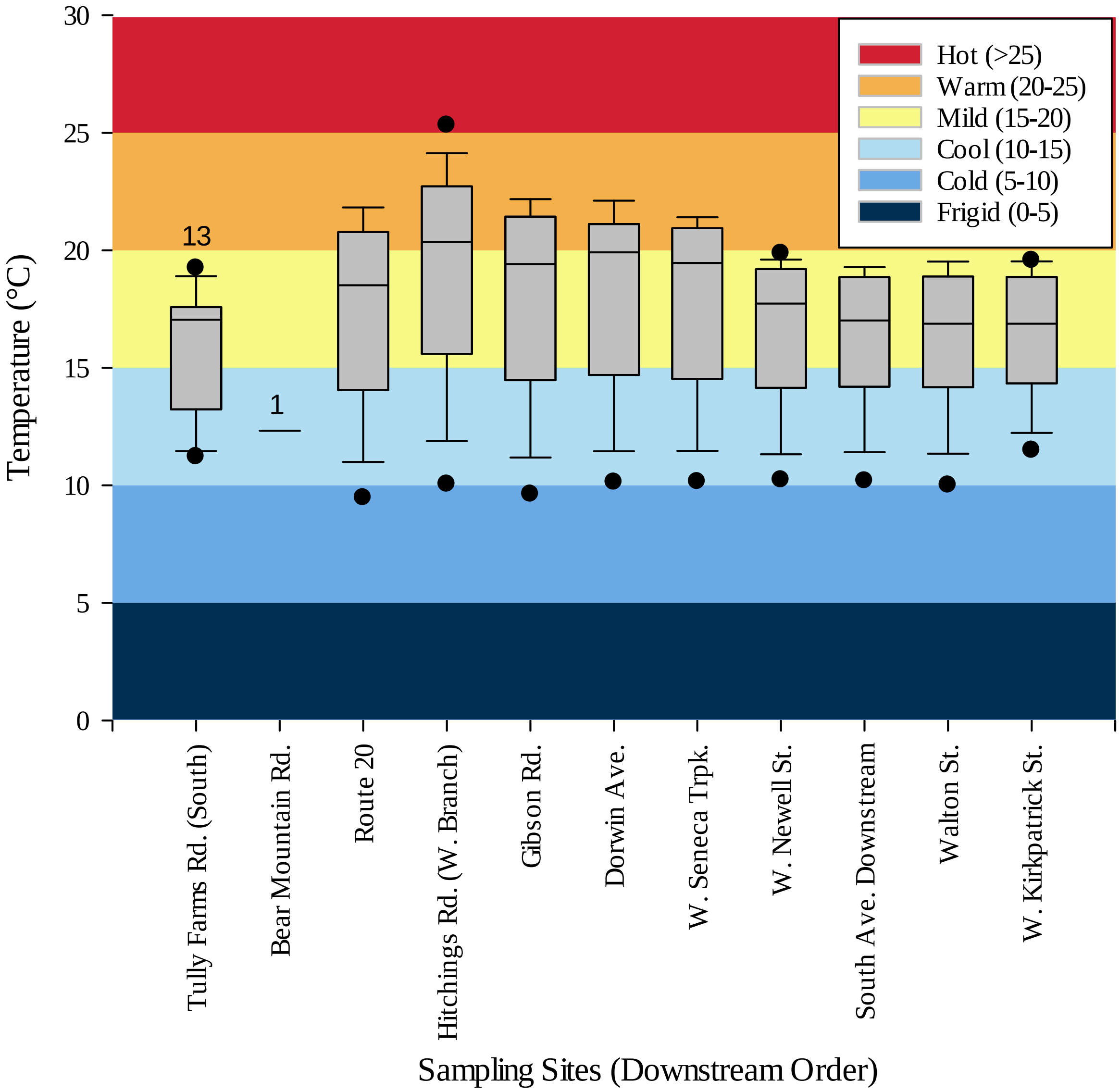


Figure 19. Temperature levels for Phase 3 Onondaga Creek routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=14.

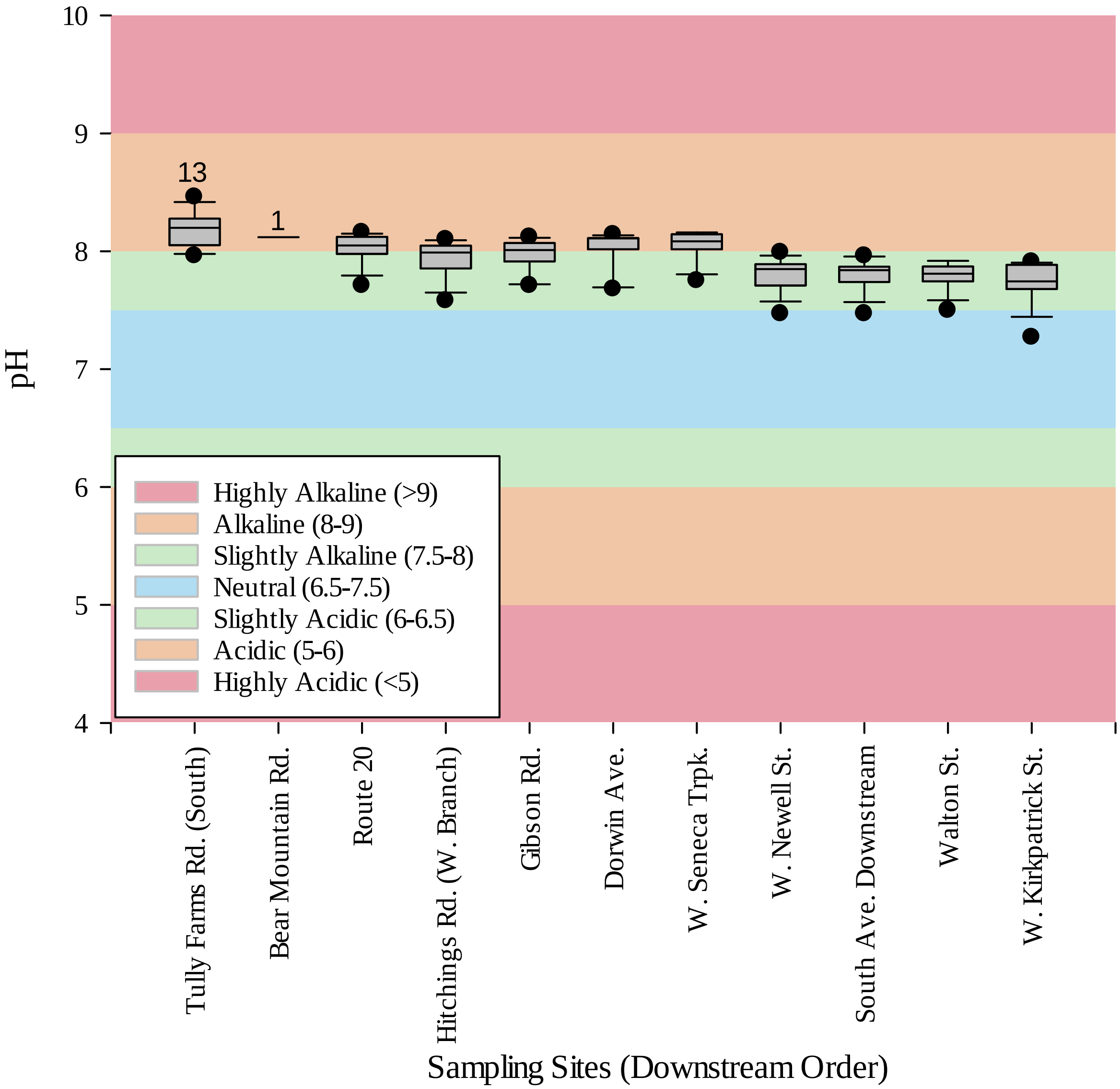


Figure 20. pH levels for Phase 3 Onondaga Creek routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=14.

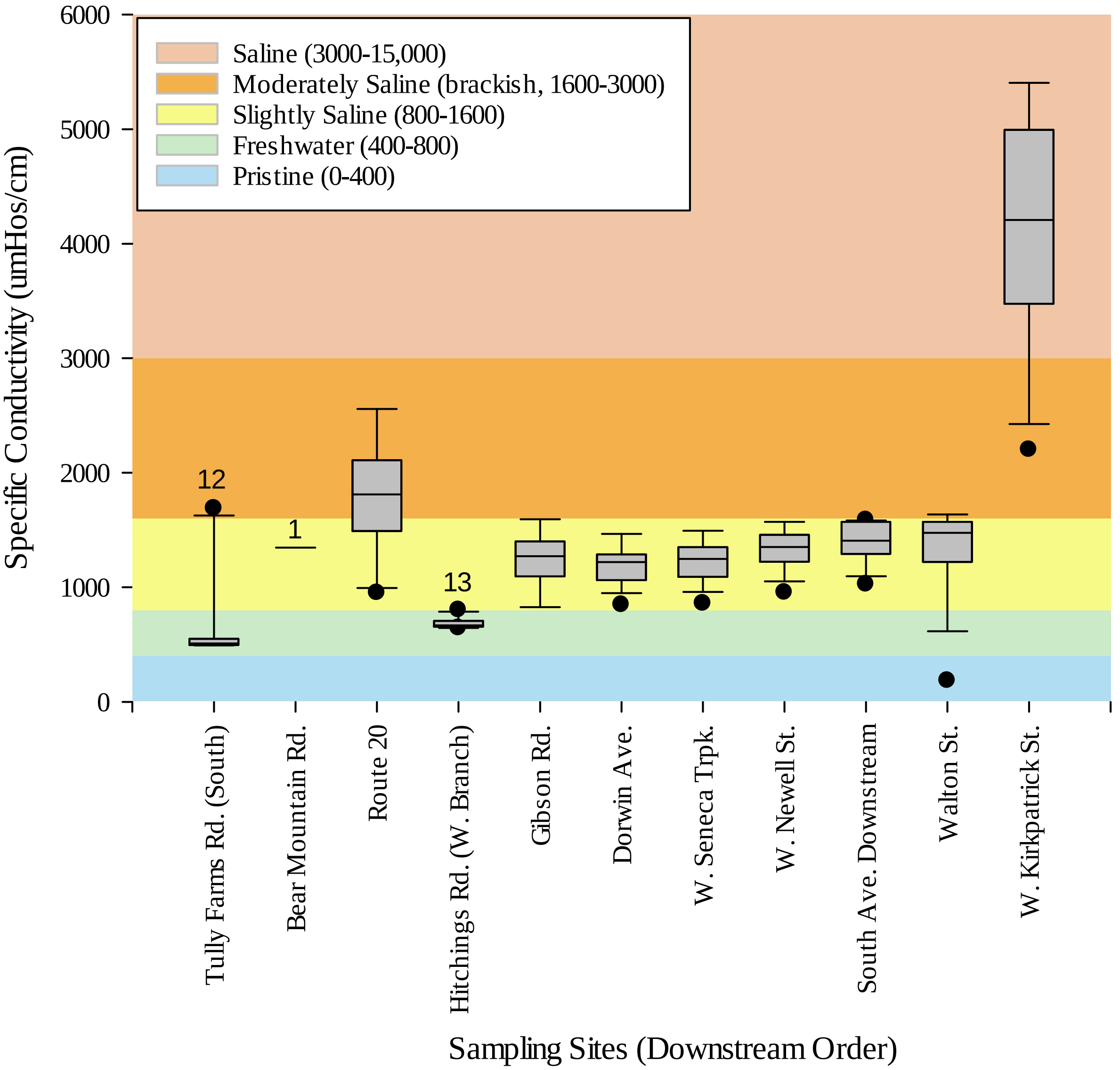


Figure 21. Specific conductivity levels for Phase 3 Onondaga Creek routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=14.

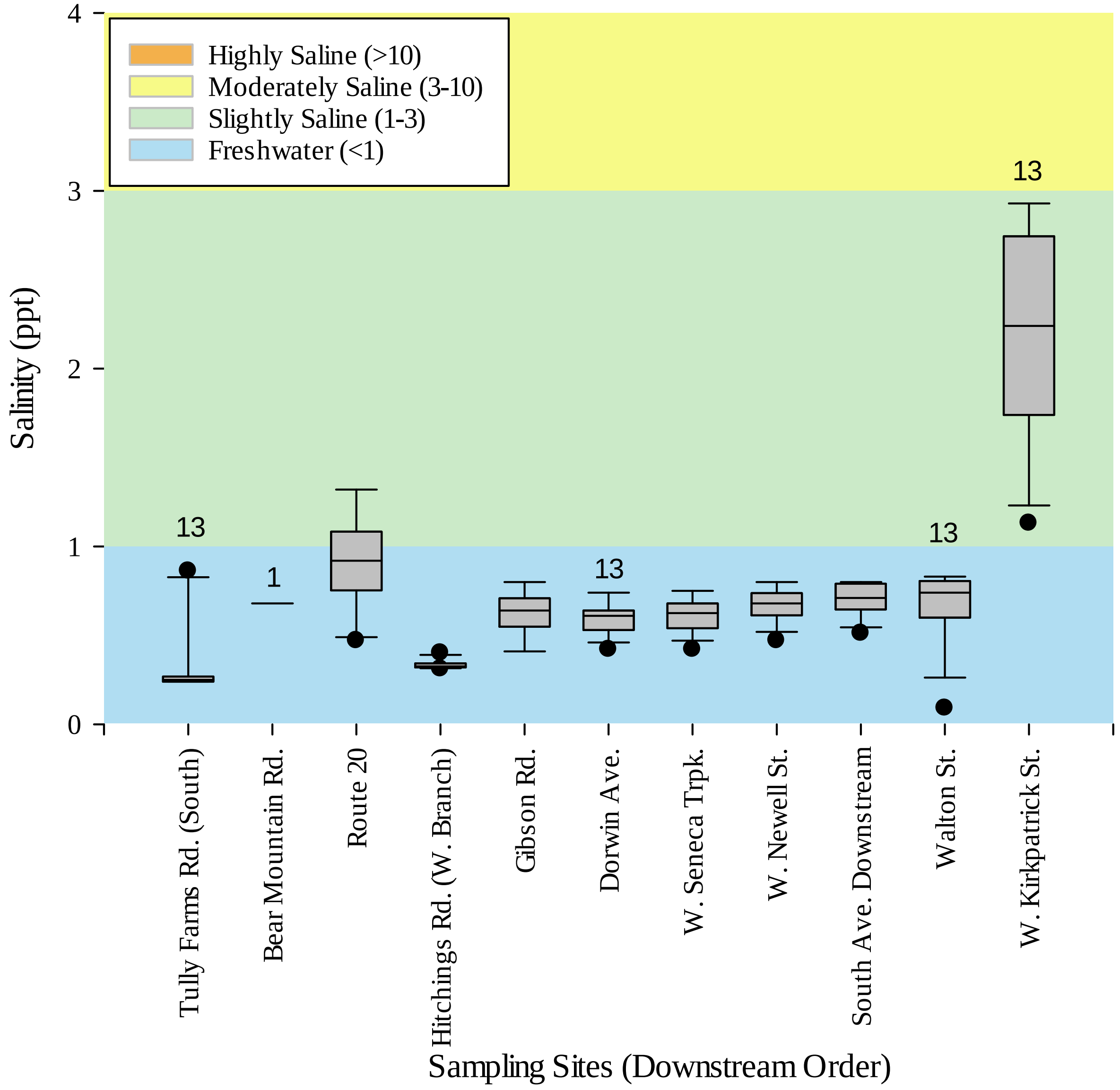


Figure 22. Salinity levels for Phase 3 Onondaga Creek routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=14.

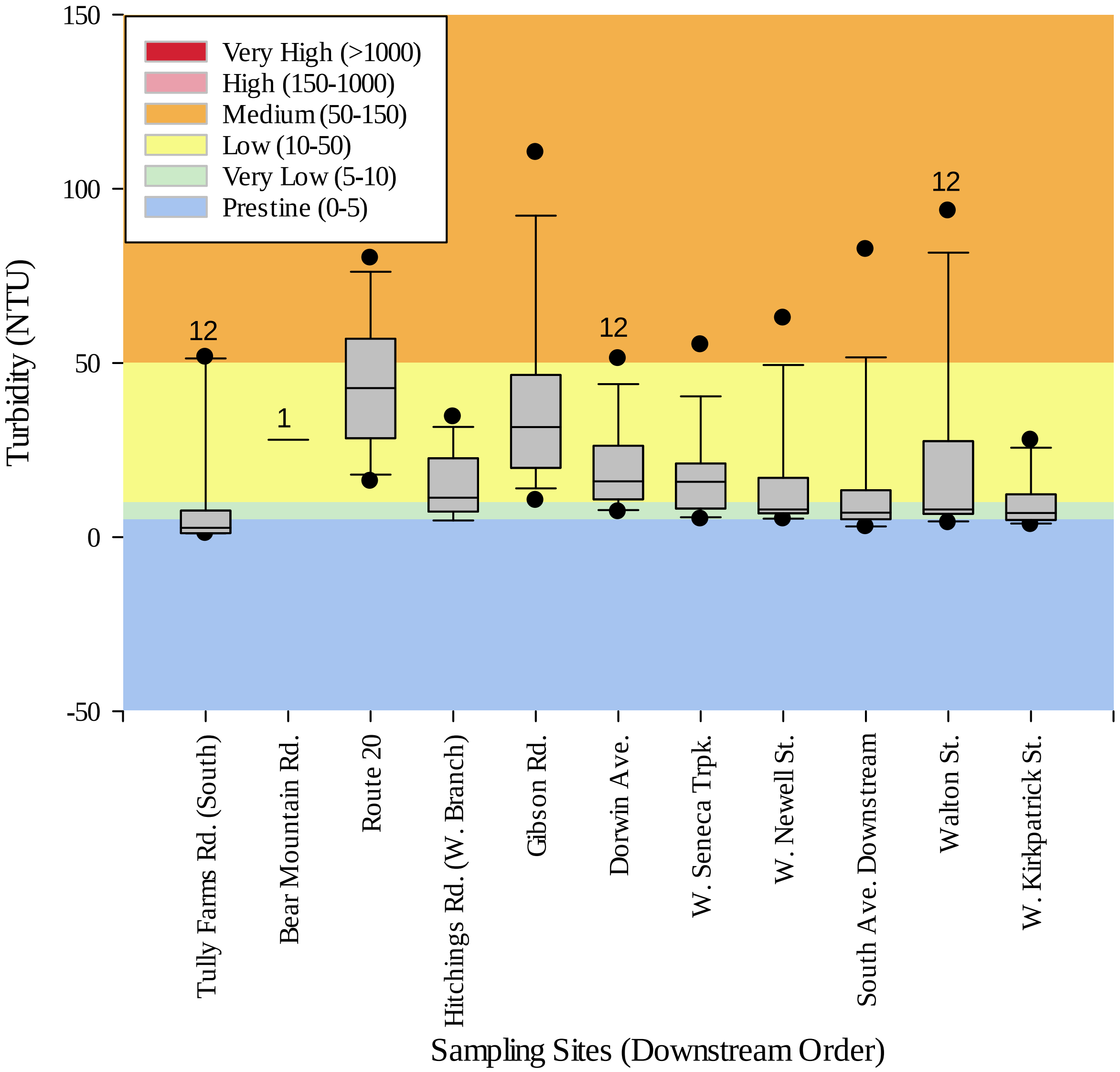


Figure 23. Turbidity levels for Phase 3 Onondaga Creek routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=14.

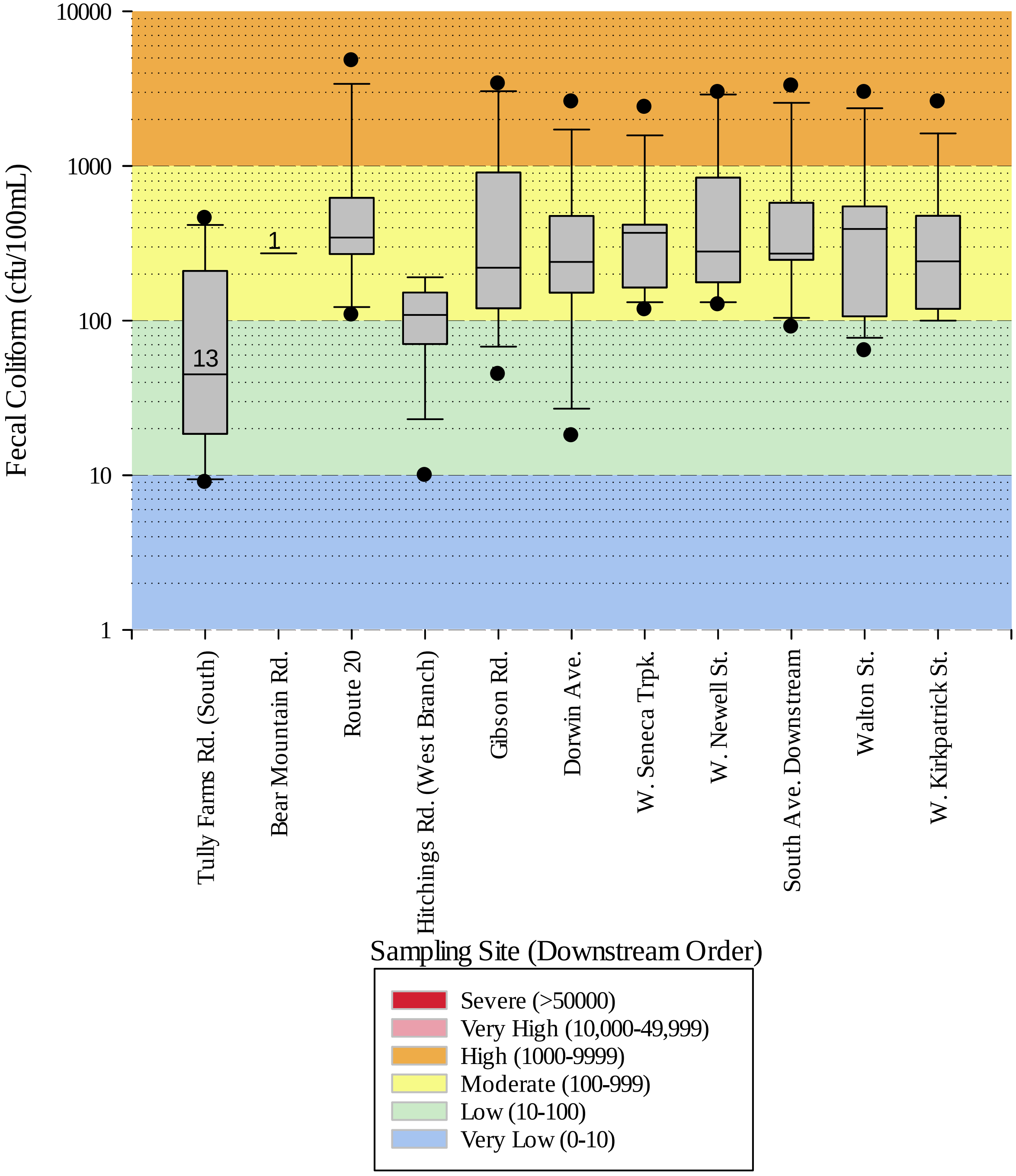


Figure 24. Fecal coliform levels for Phase 3 Onondaga Creek routine sampling locations (2014-2015). Values are plotted on a logarithmic scale. Unless specified, the number of samples used to generate box plots is N=14.

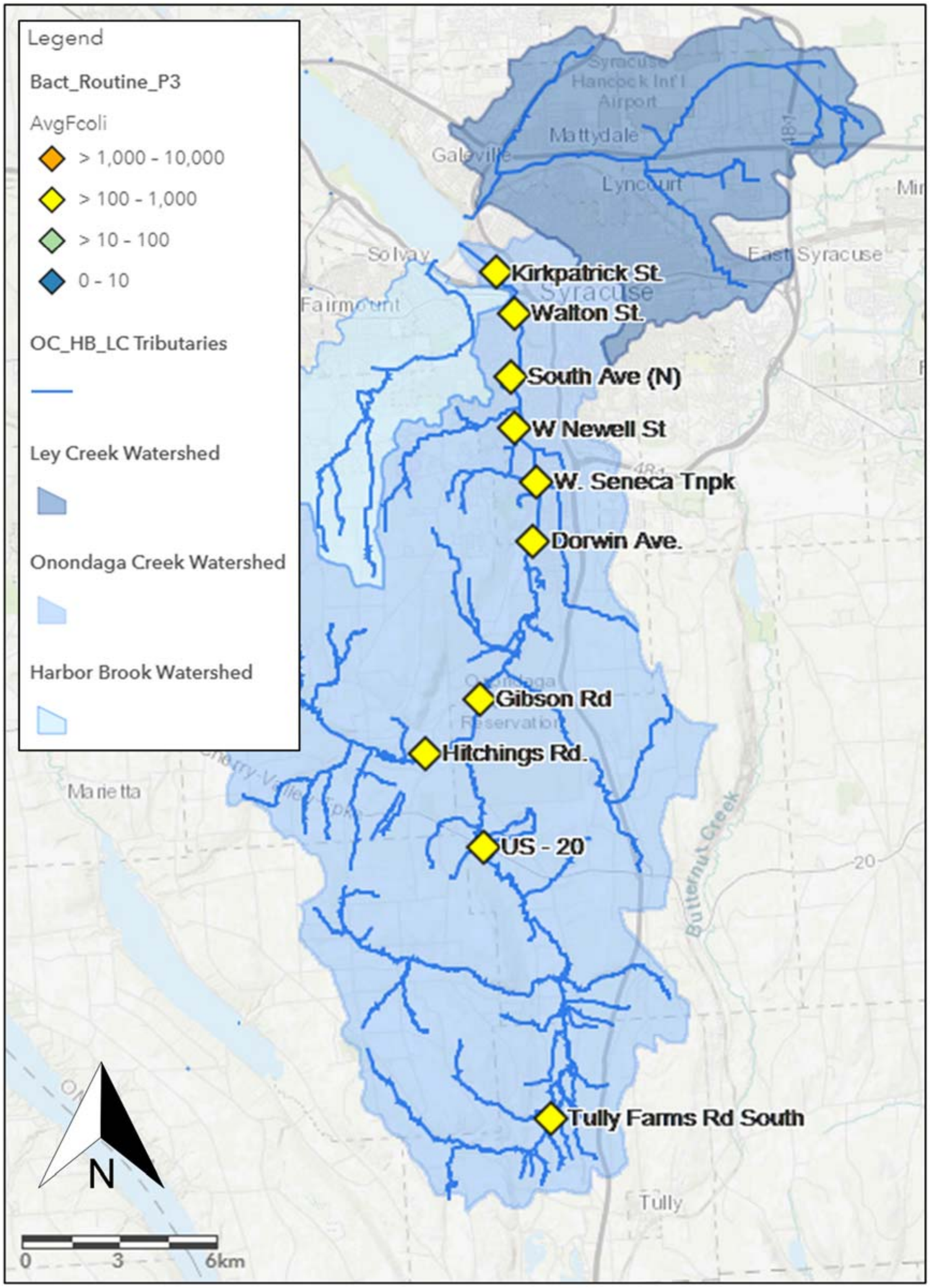


Figure 25. Average fecal coliform levels (cfu/100 mL) for Onondaga Creek routine sampling locations (2014-2015).

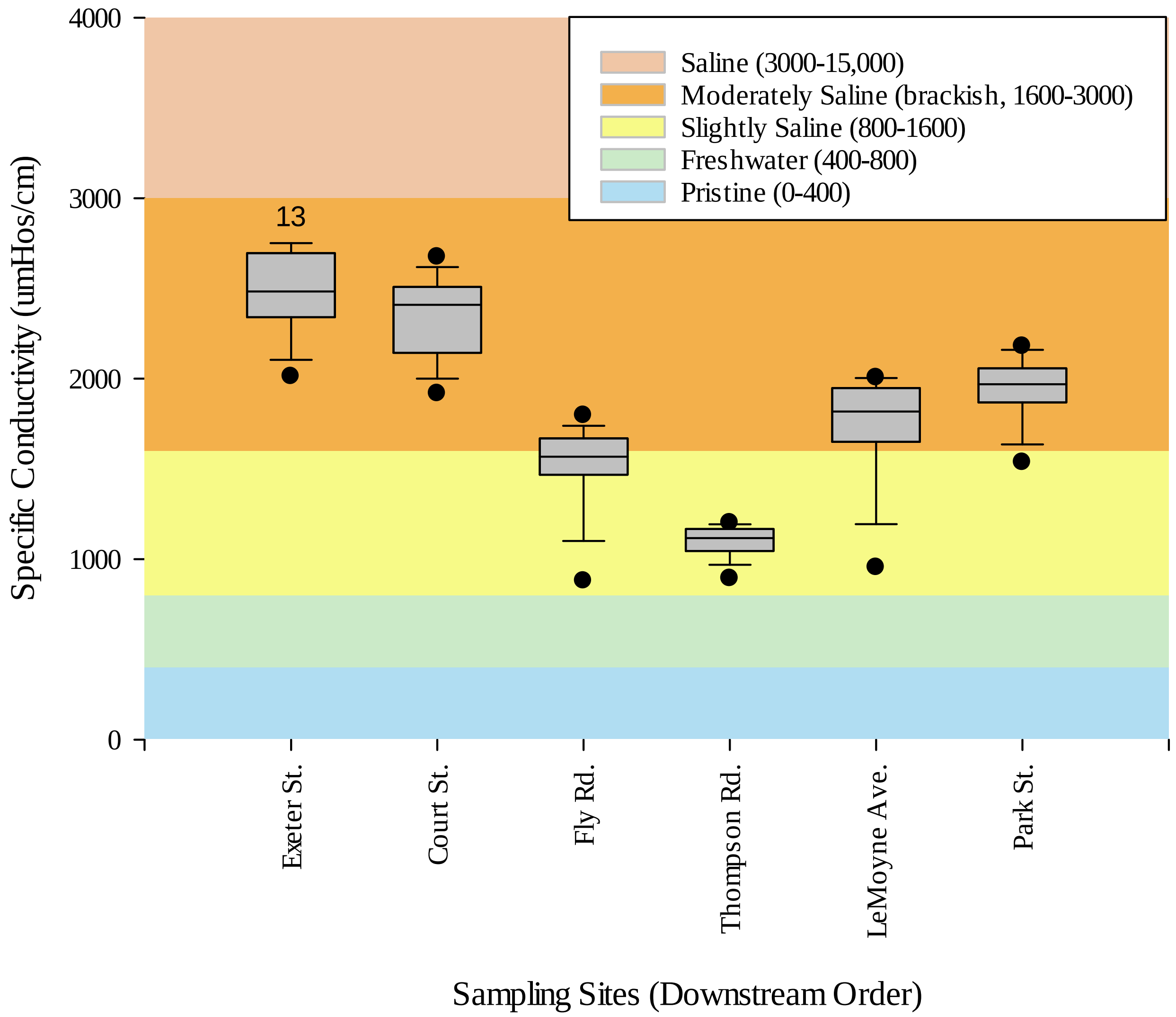


Figure 26. Specific conductivity levels for Phase 3 Ley Creek routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=13.

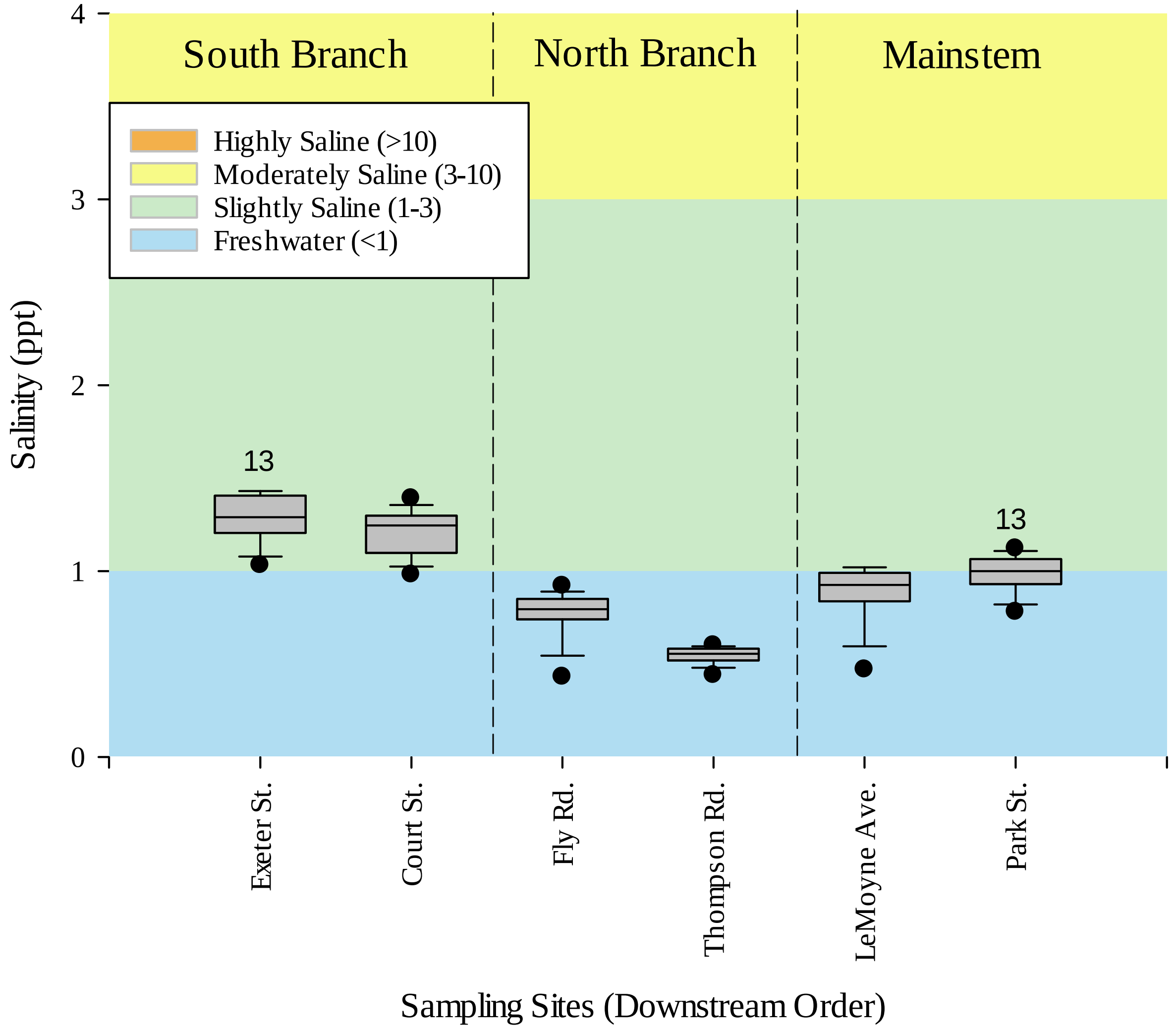


Figure 27. Salinity levels for Phase 3 Ley Creek routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=13.

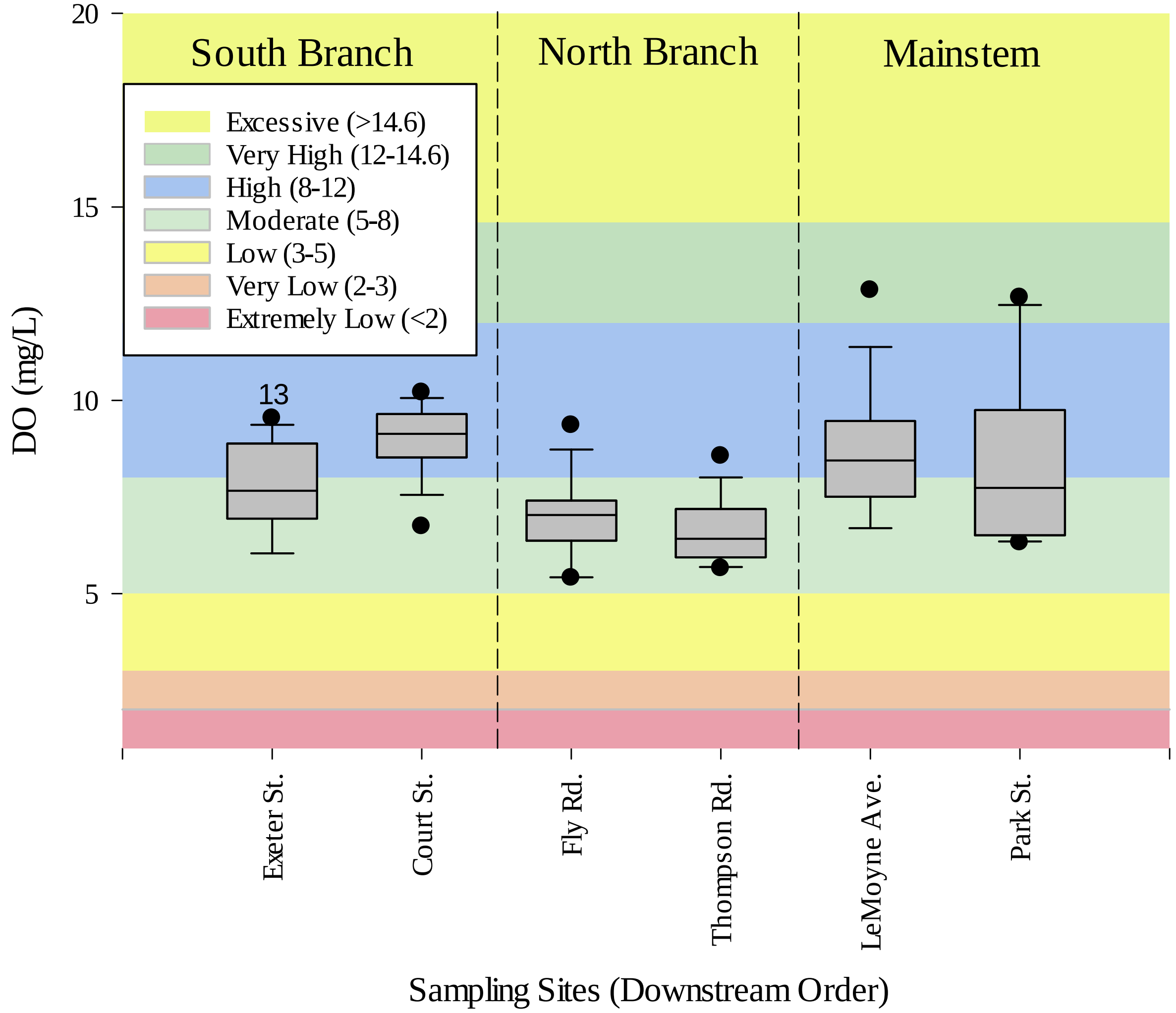


Figure 28. Dissolved oxygen levels for Phase 3 Ley Creek routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=13.

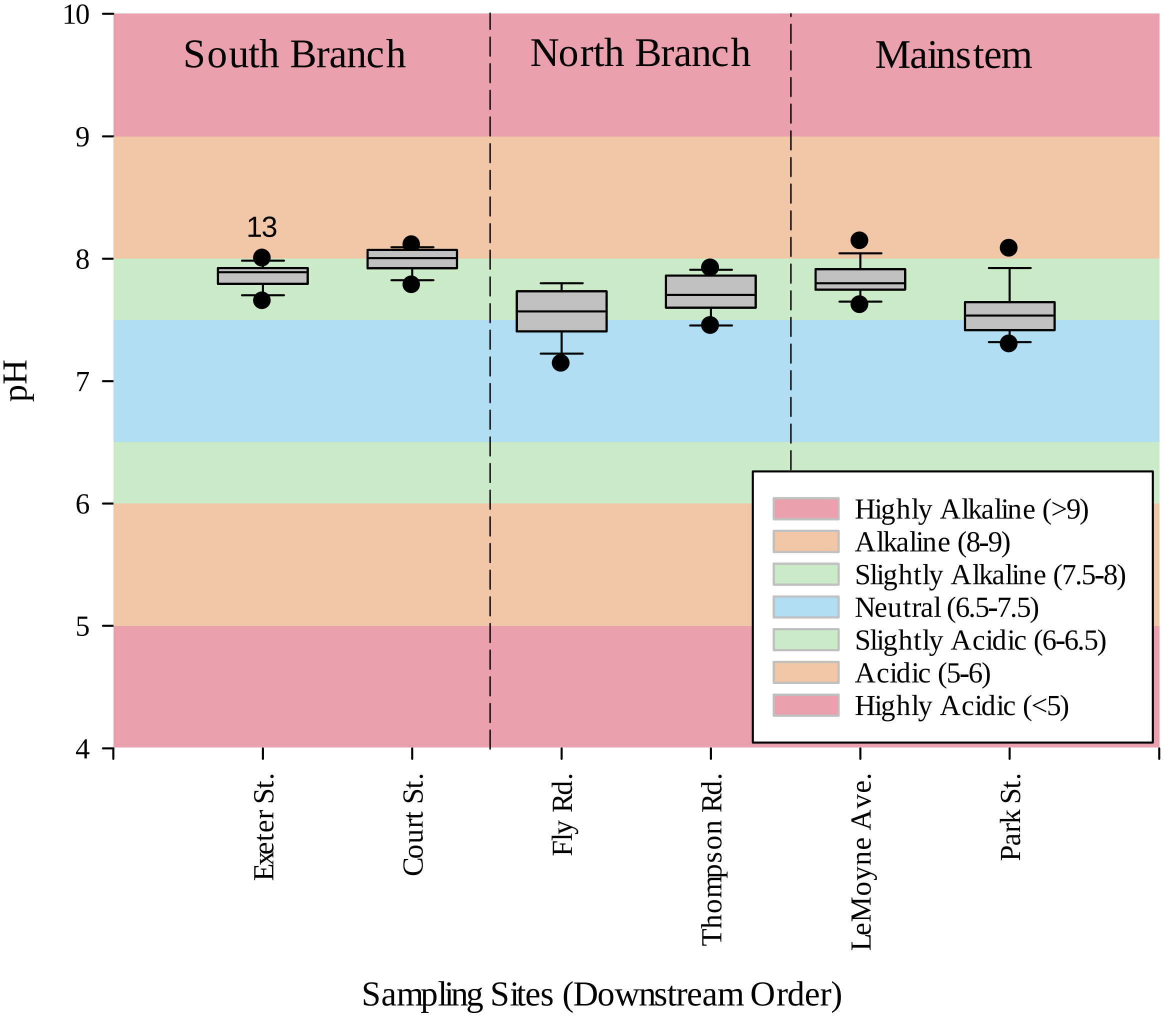


Figure 29. pH levels for Phase 3 Ley Creek routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=13.

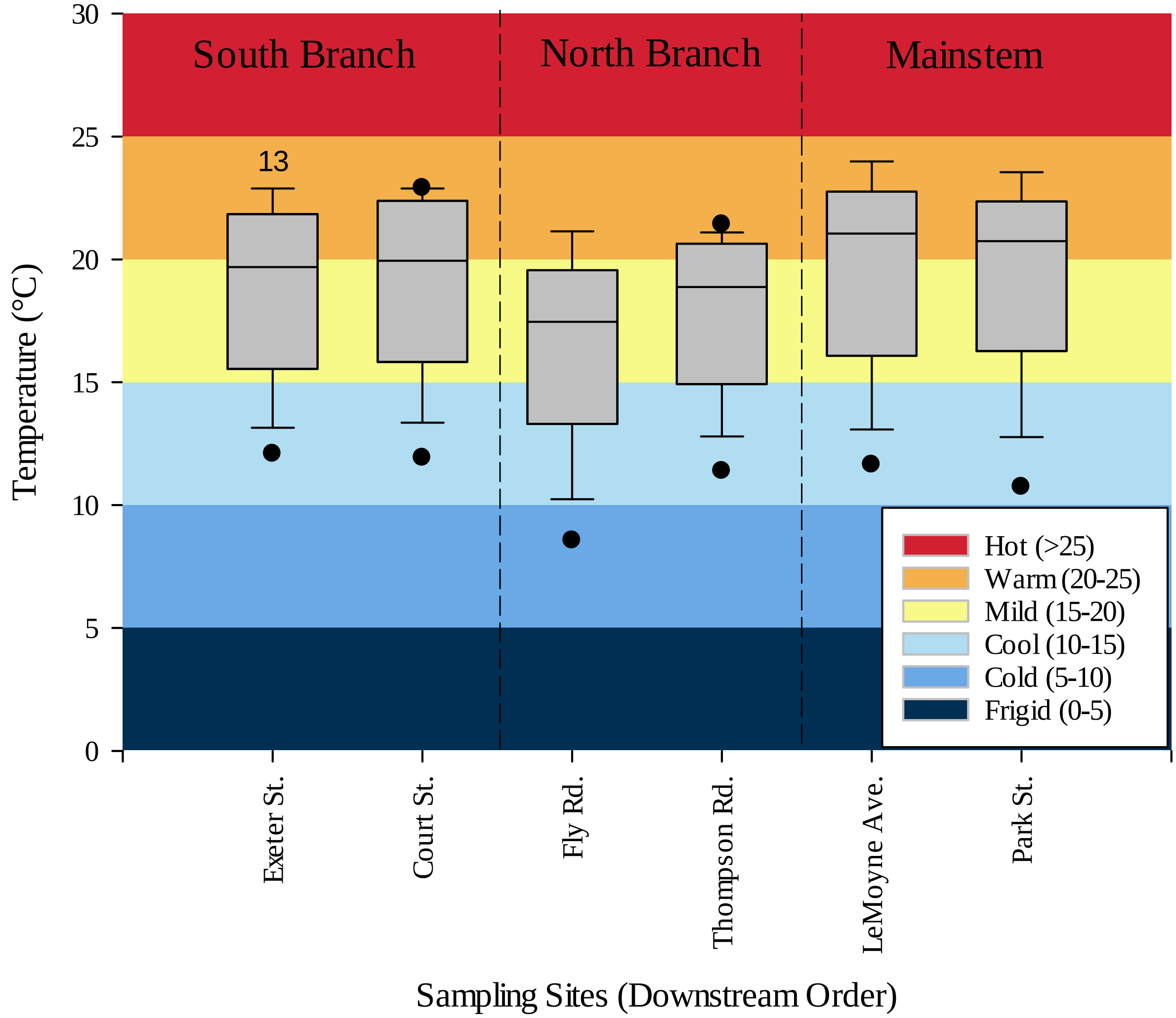


Figure 30. Temperature levels for Phase 3 Ley Creek routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=13.

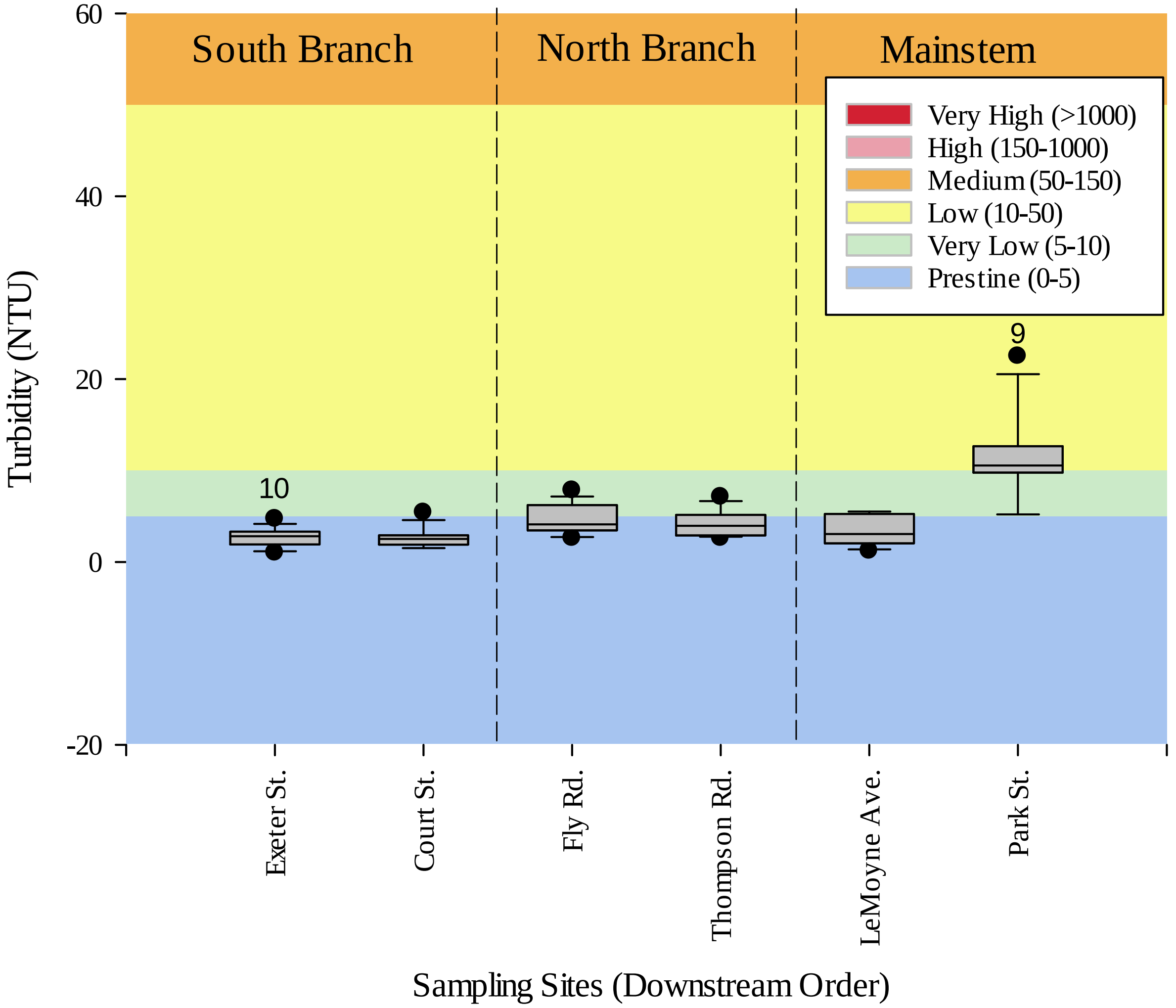


Figure 31. Turbidity levels for Phase 3 Ley Creek routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=13.

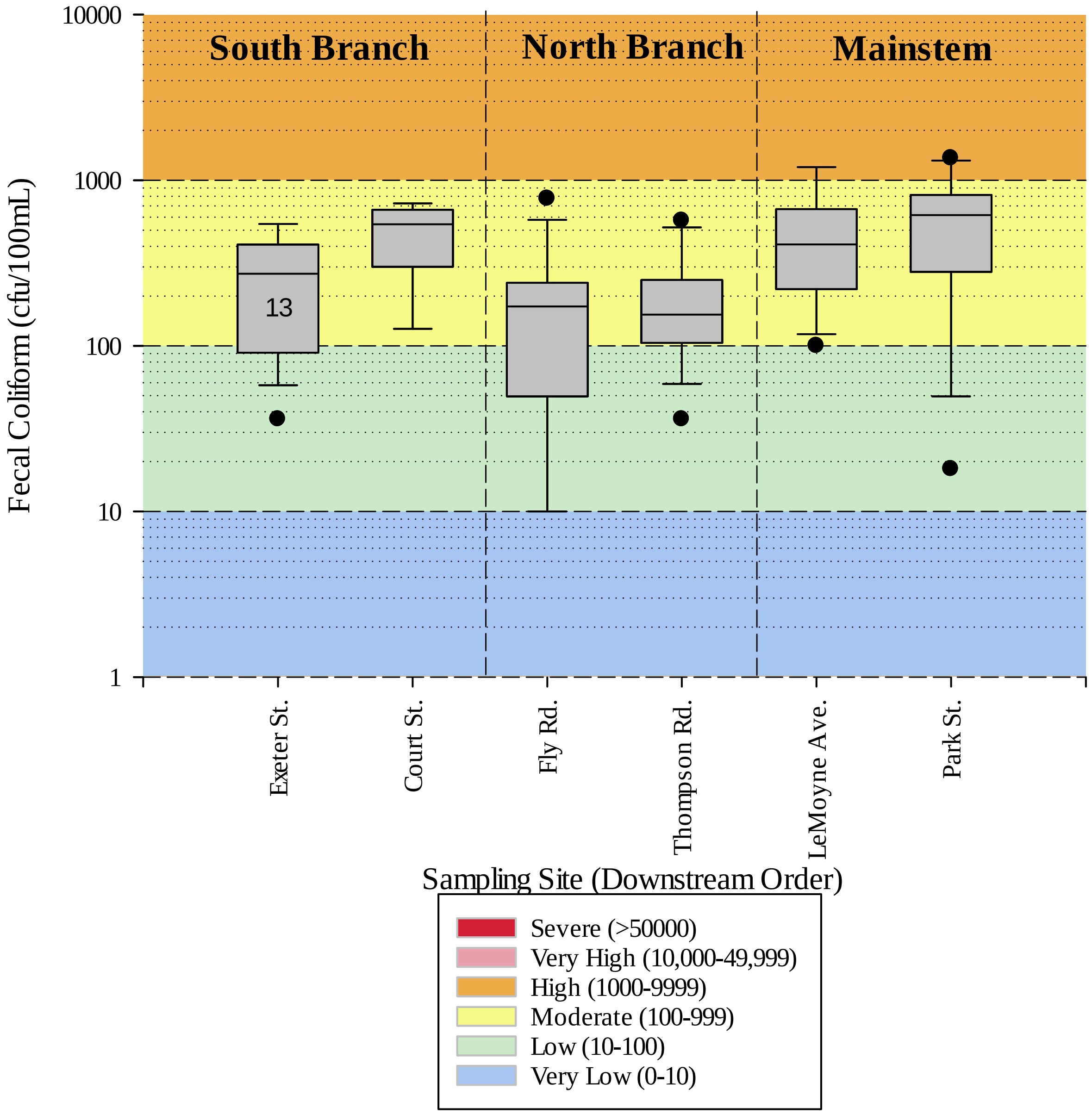


Figure 32. Fecal coliform levels for Phase 3 Ley Creek routine sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=13.

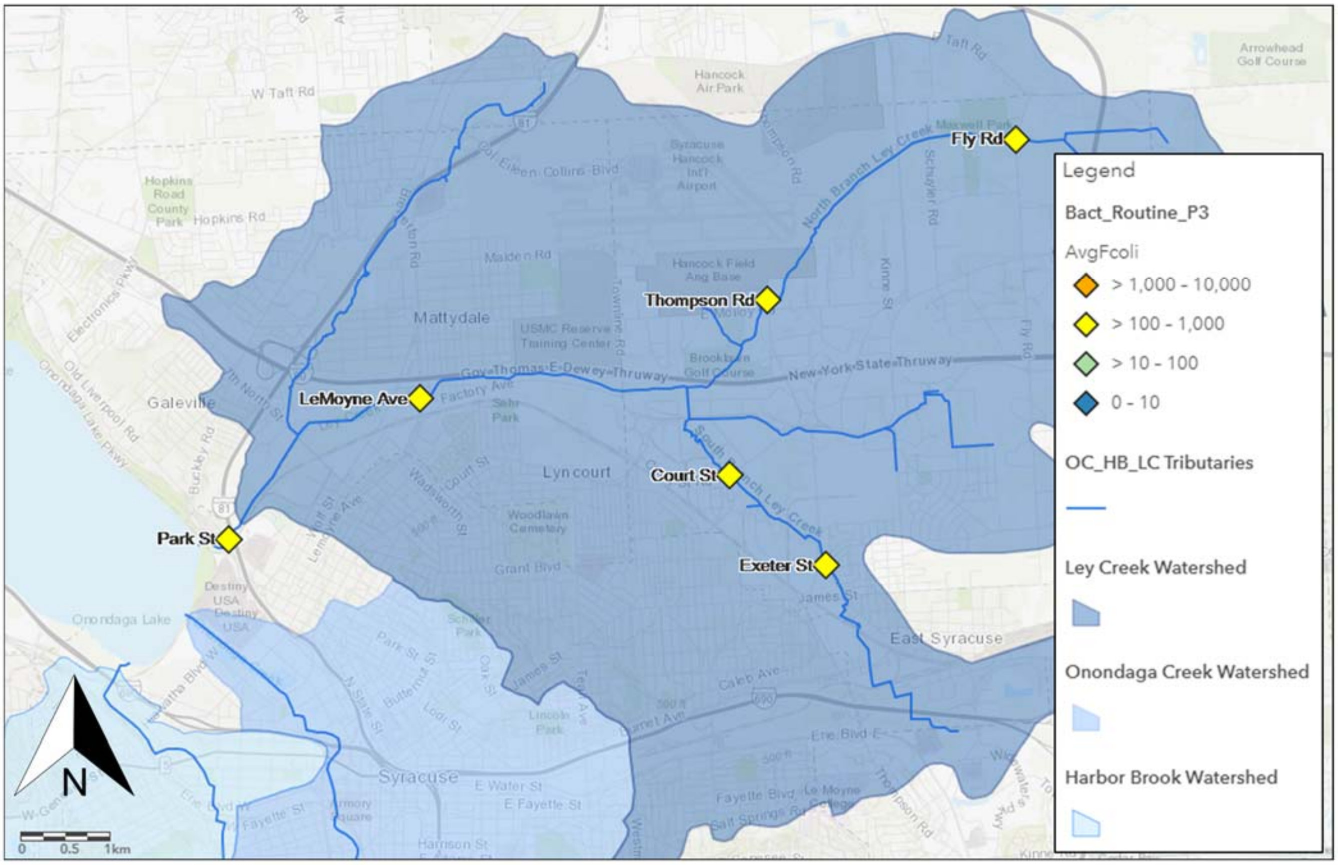


Figure 33. Average fecal coliform levels (cfu/100 mL) for Phase 3 Ley Creek routine sampling sites (2014-2015).

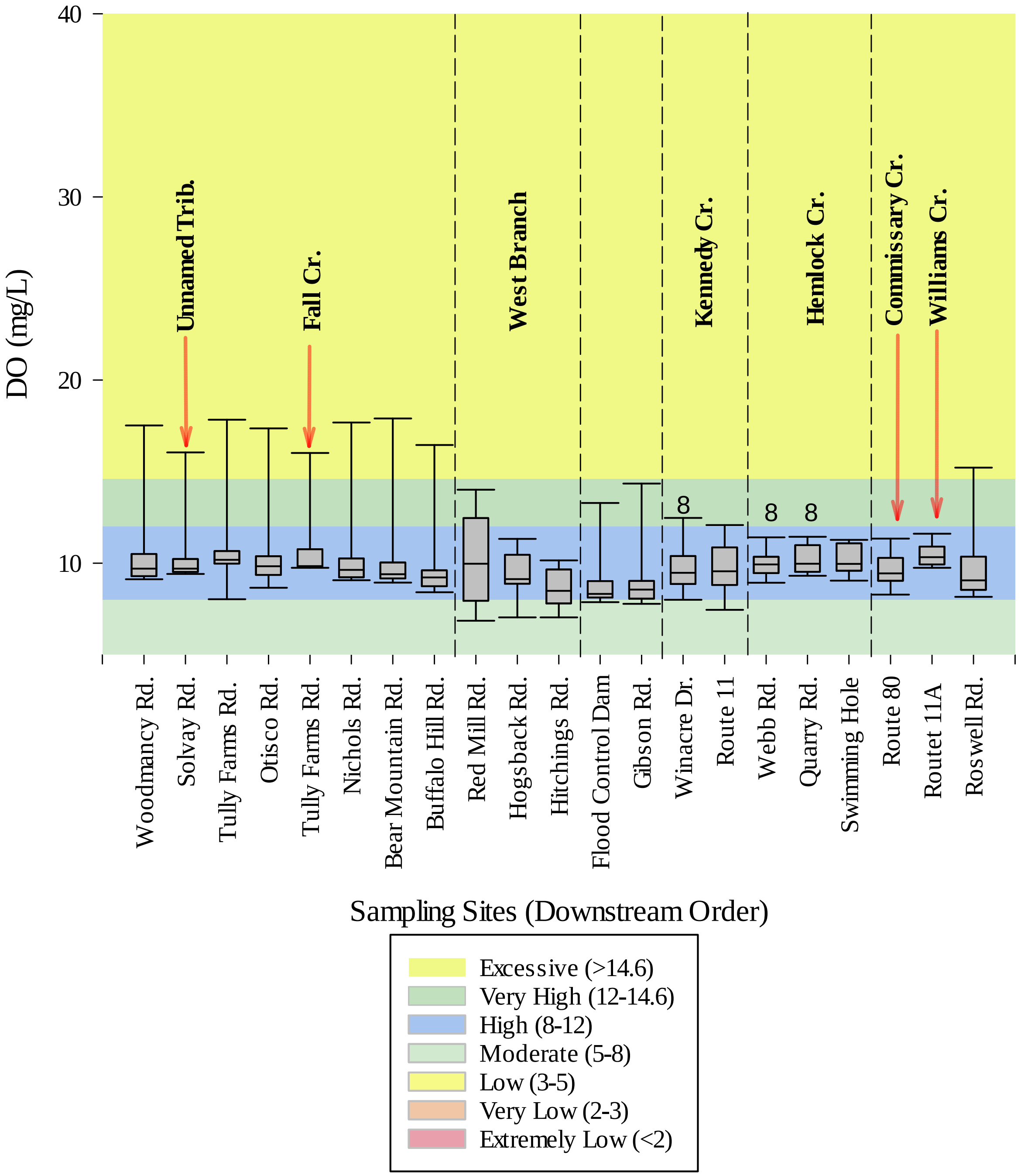


Figure 34. Dissolved oxygen levels for Phase 3 upper Onondaga Creek sampling locations (2014). Unless specified, the number of samples used to generate box plots is N=9.

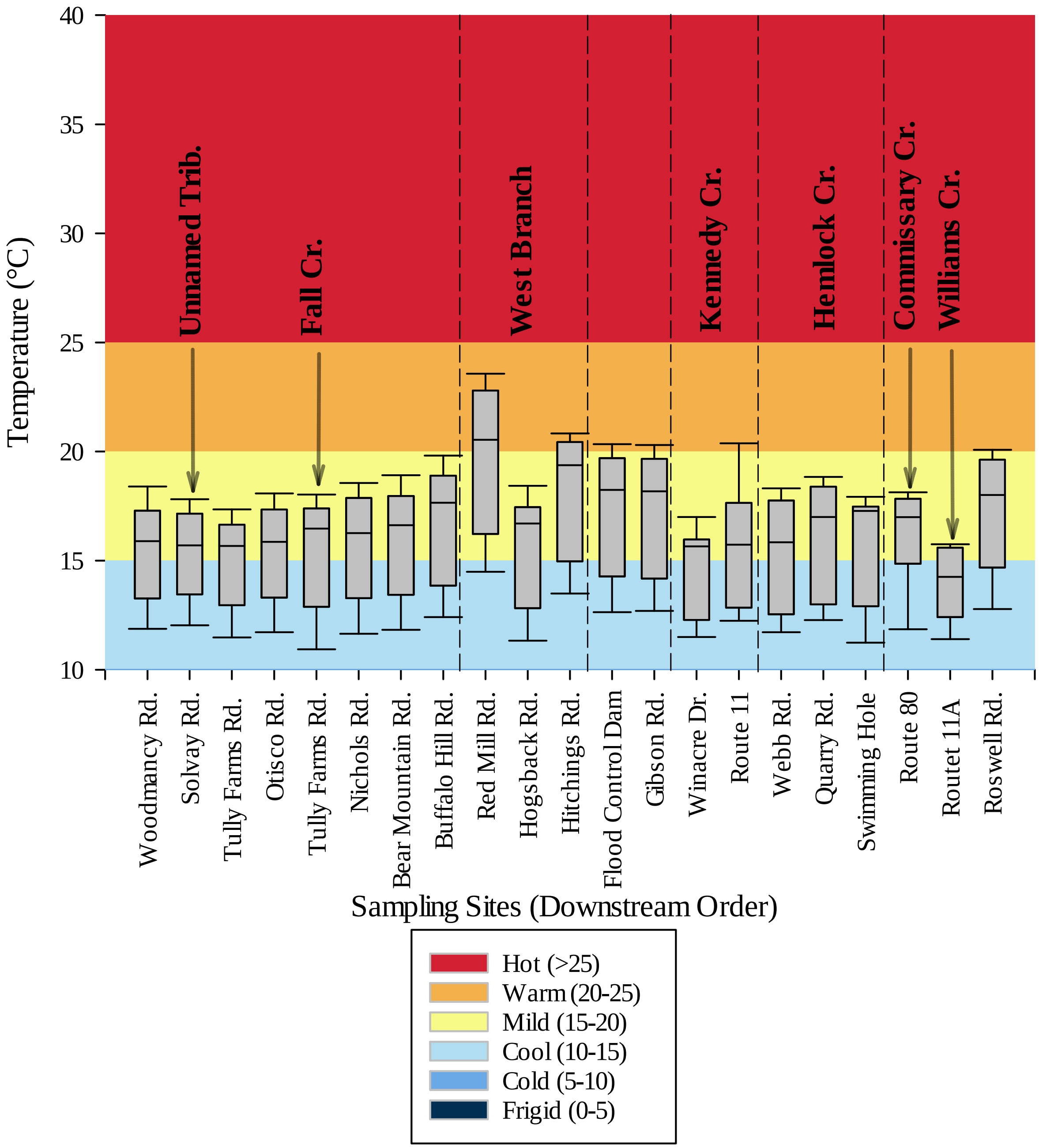
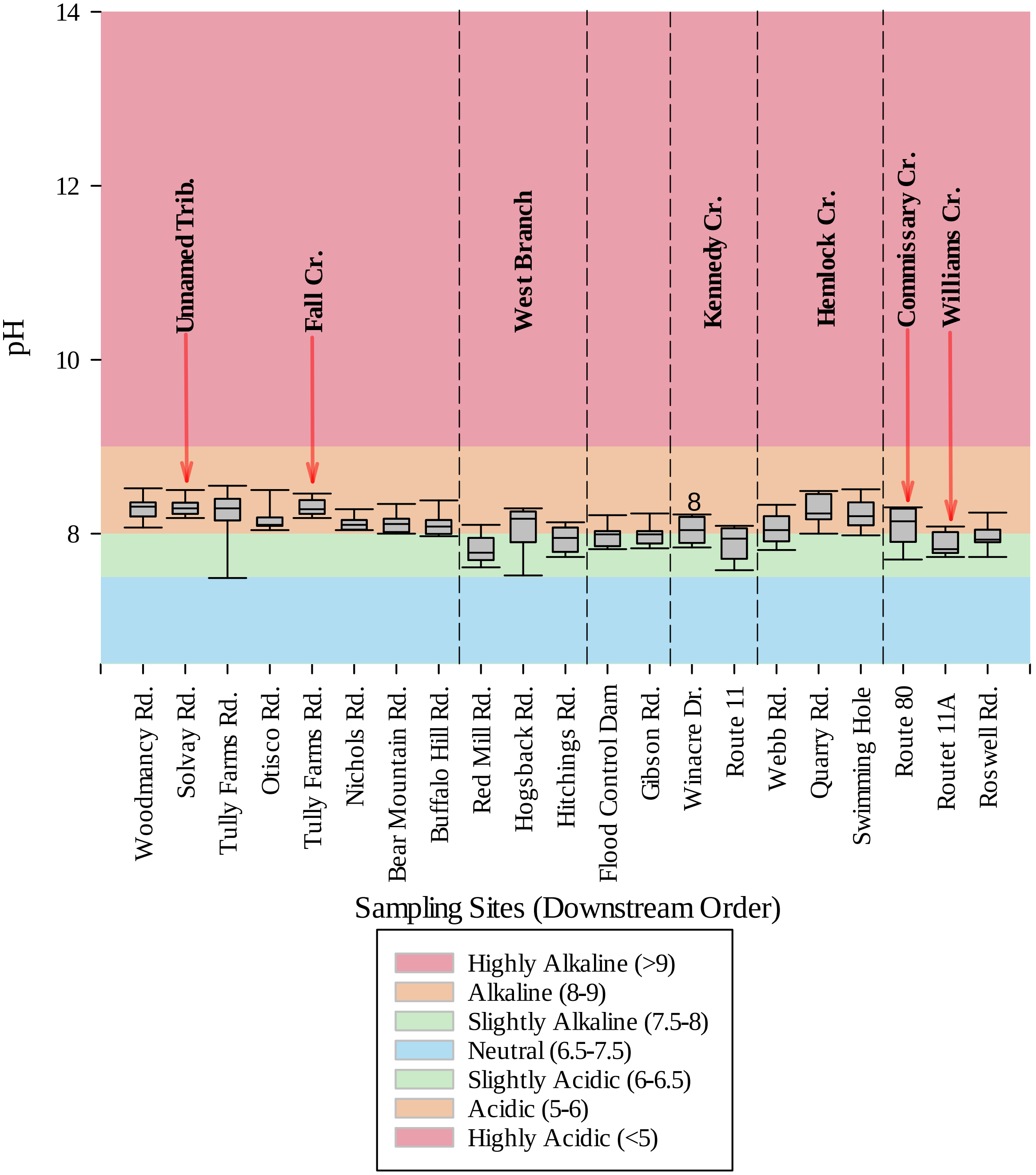


Figure 35. Temperature levels for Phase 3 upper Onondaga Creek sampling locations (2014). Unless specified, the number of samples used to generate box plots is N=9.



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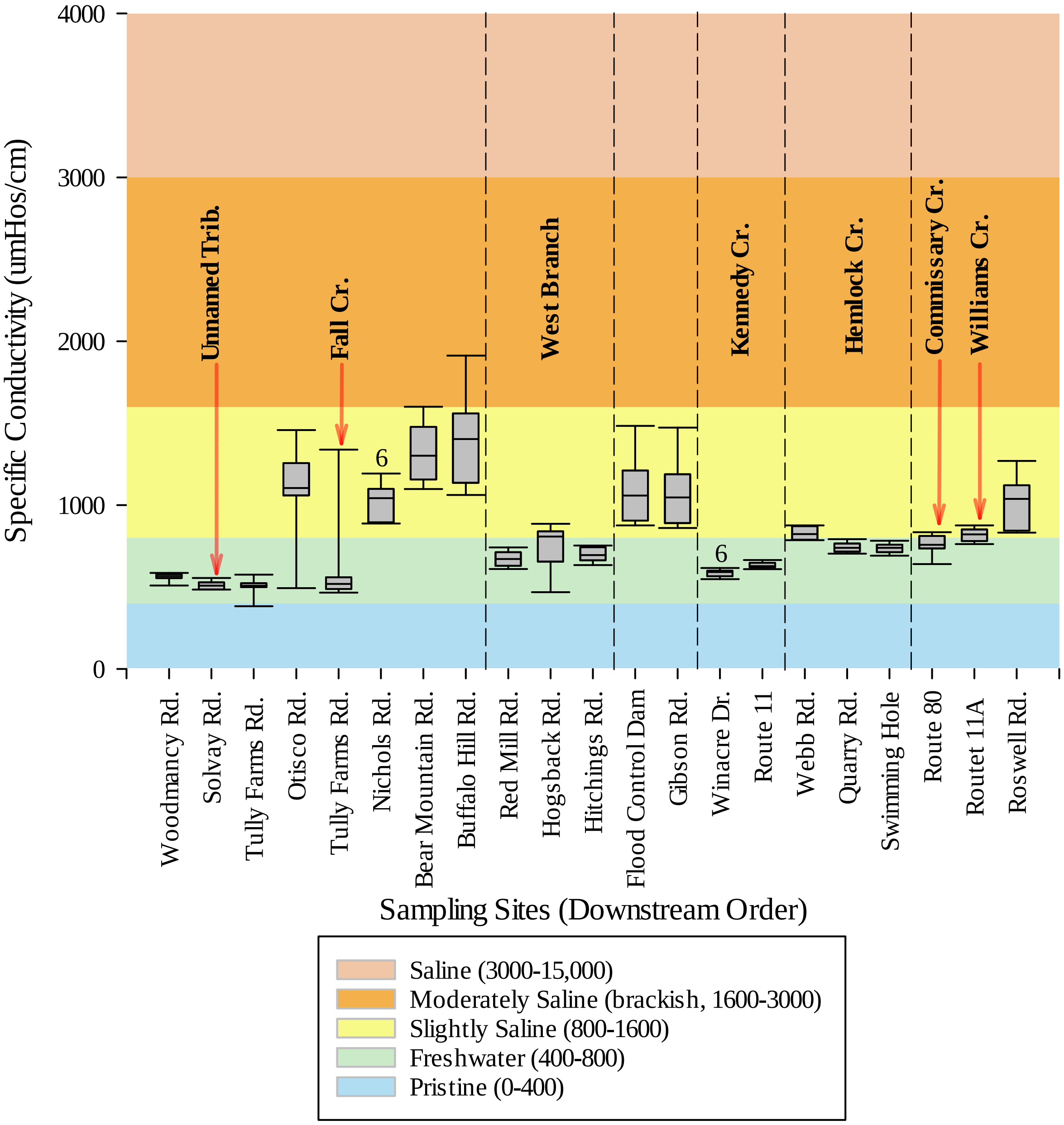
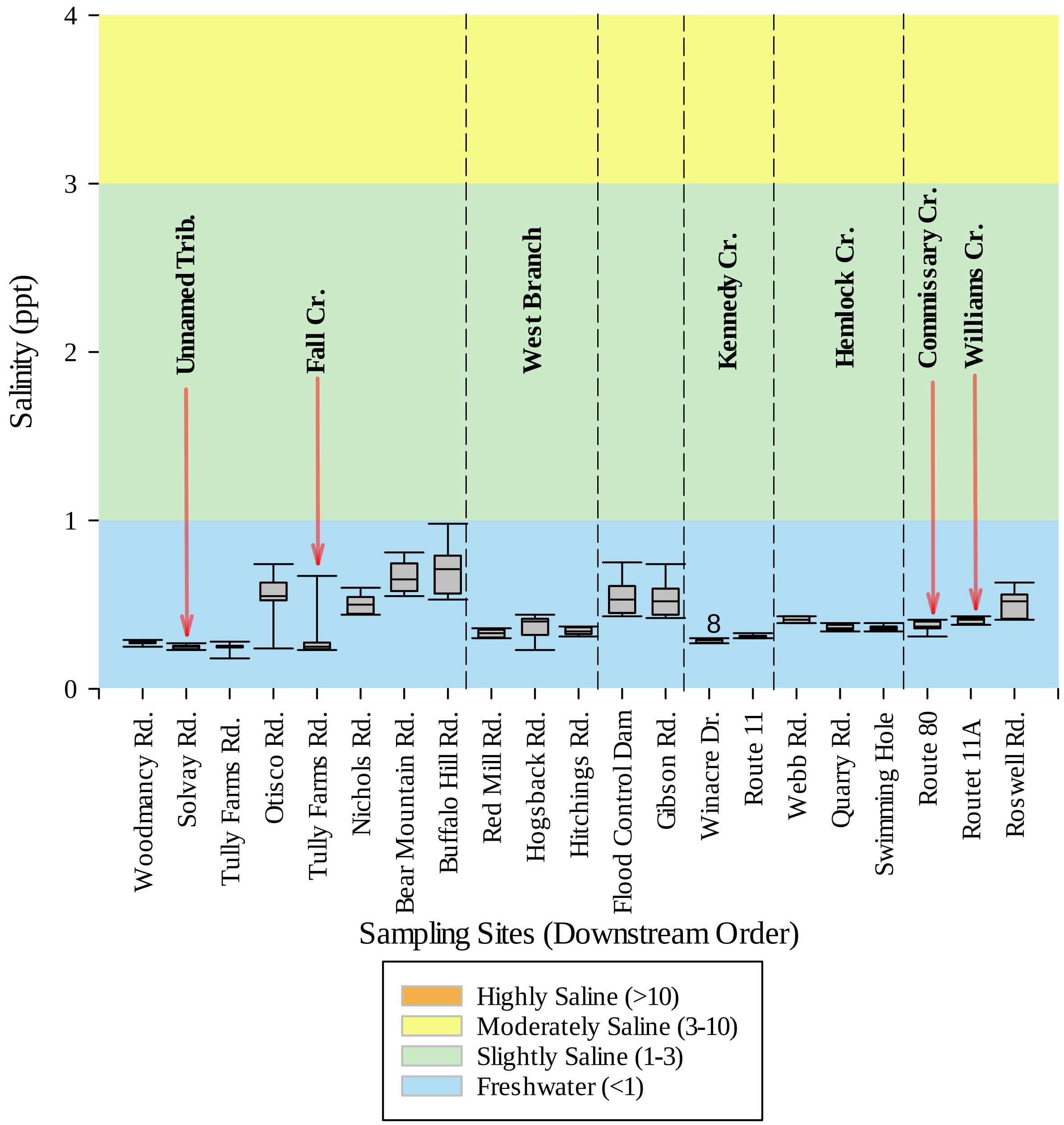


Figure 37. Specific conductivity levels for Phase 3 upper Onondaga Creek sampling locations (2014). Unless specified, the number of samples used to generate box plots is N=9.



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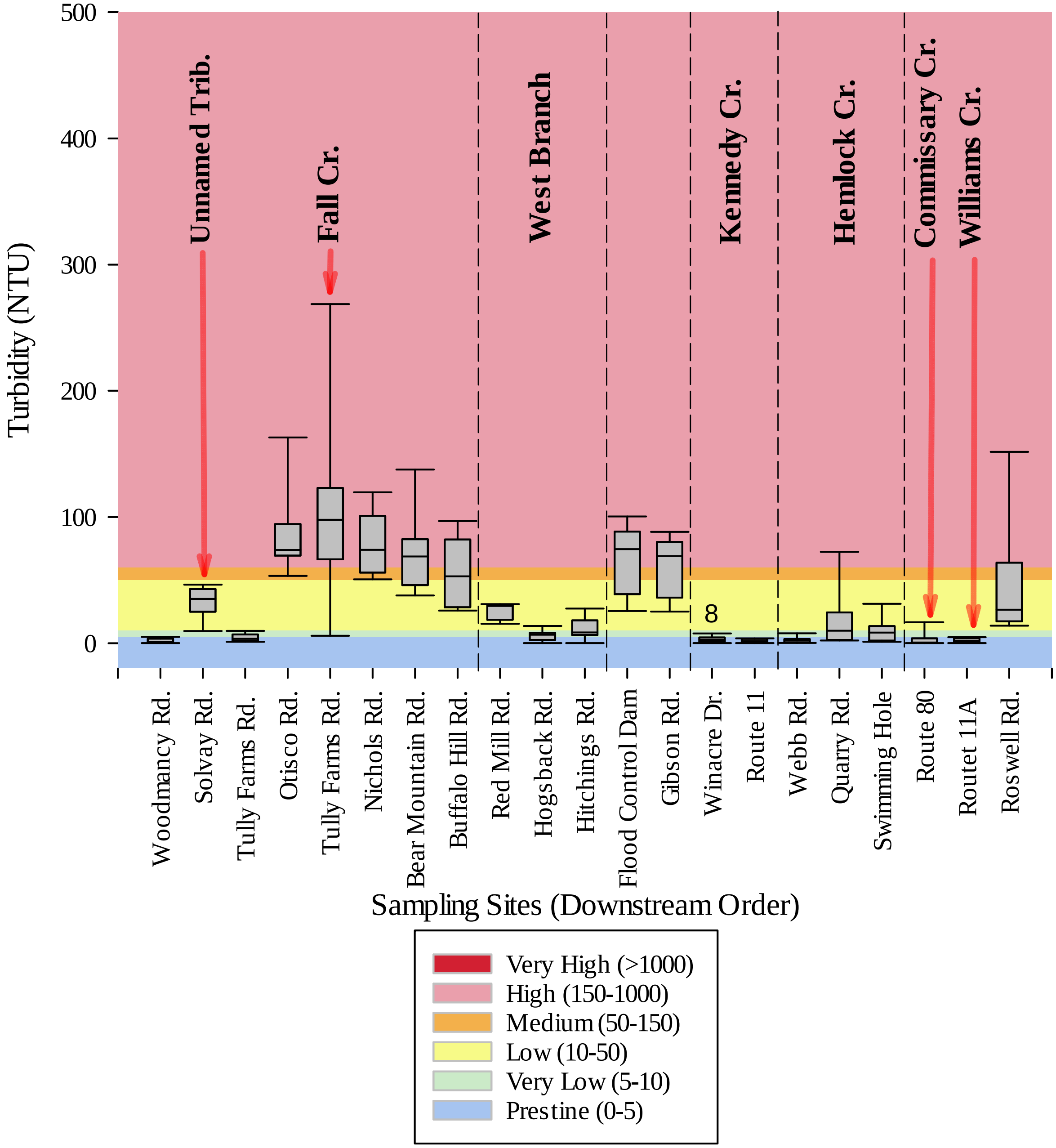

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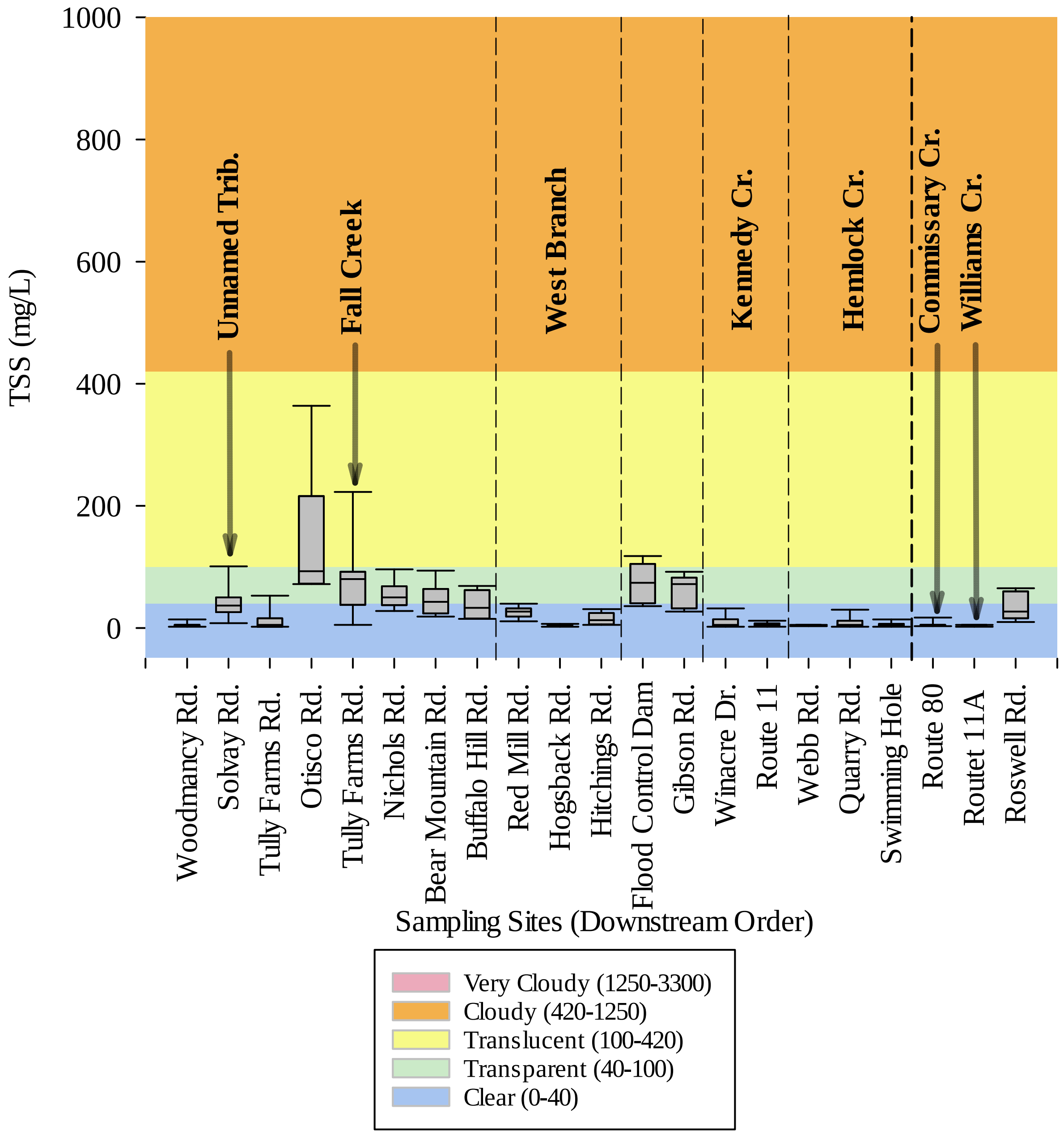

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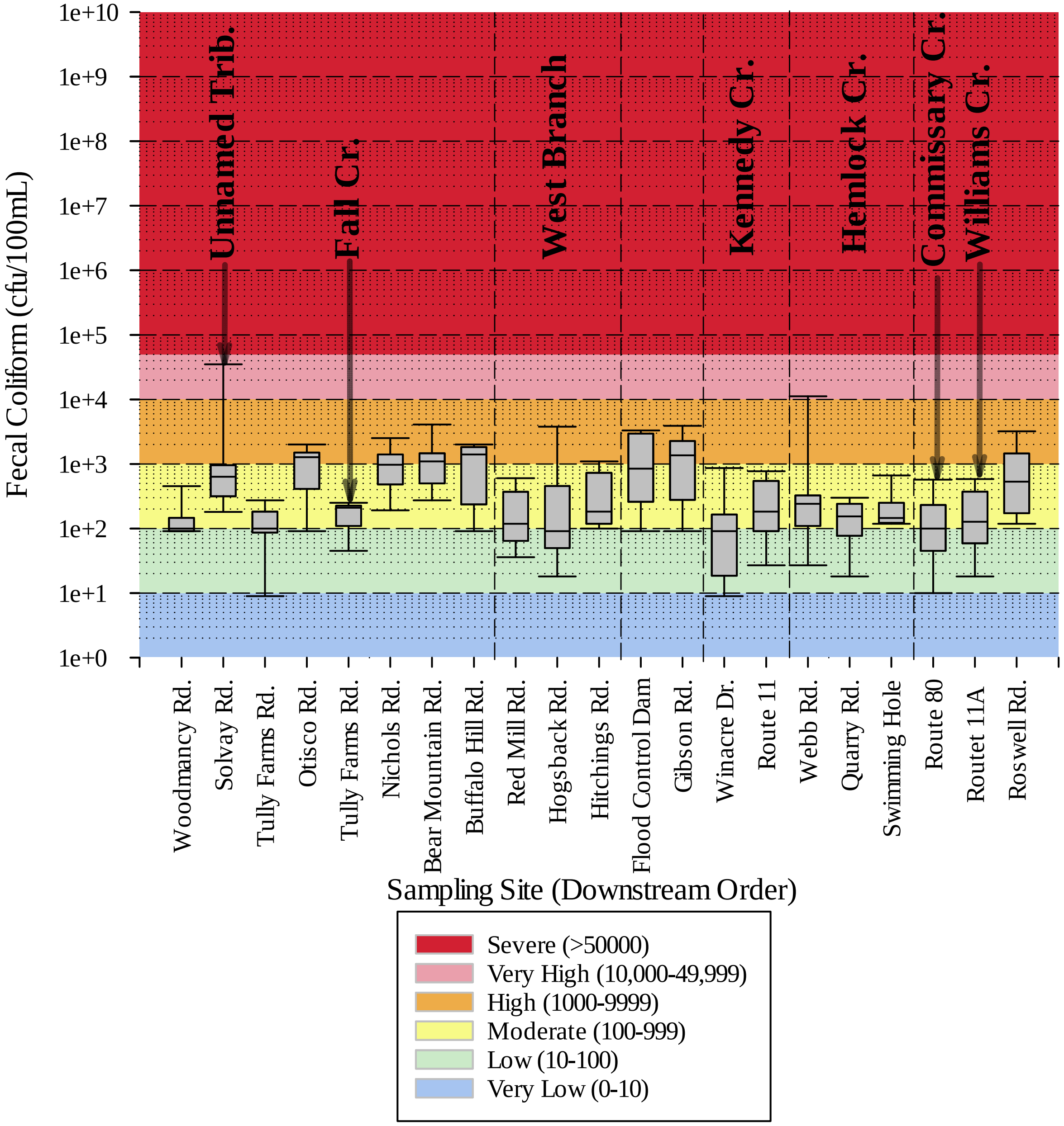

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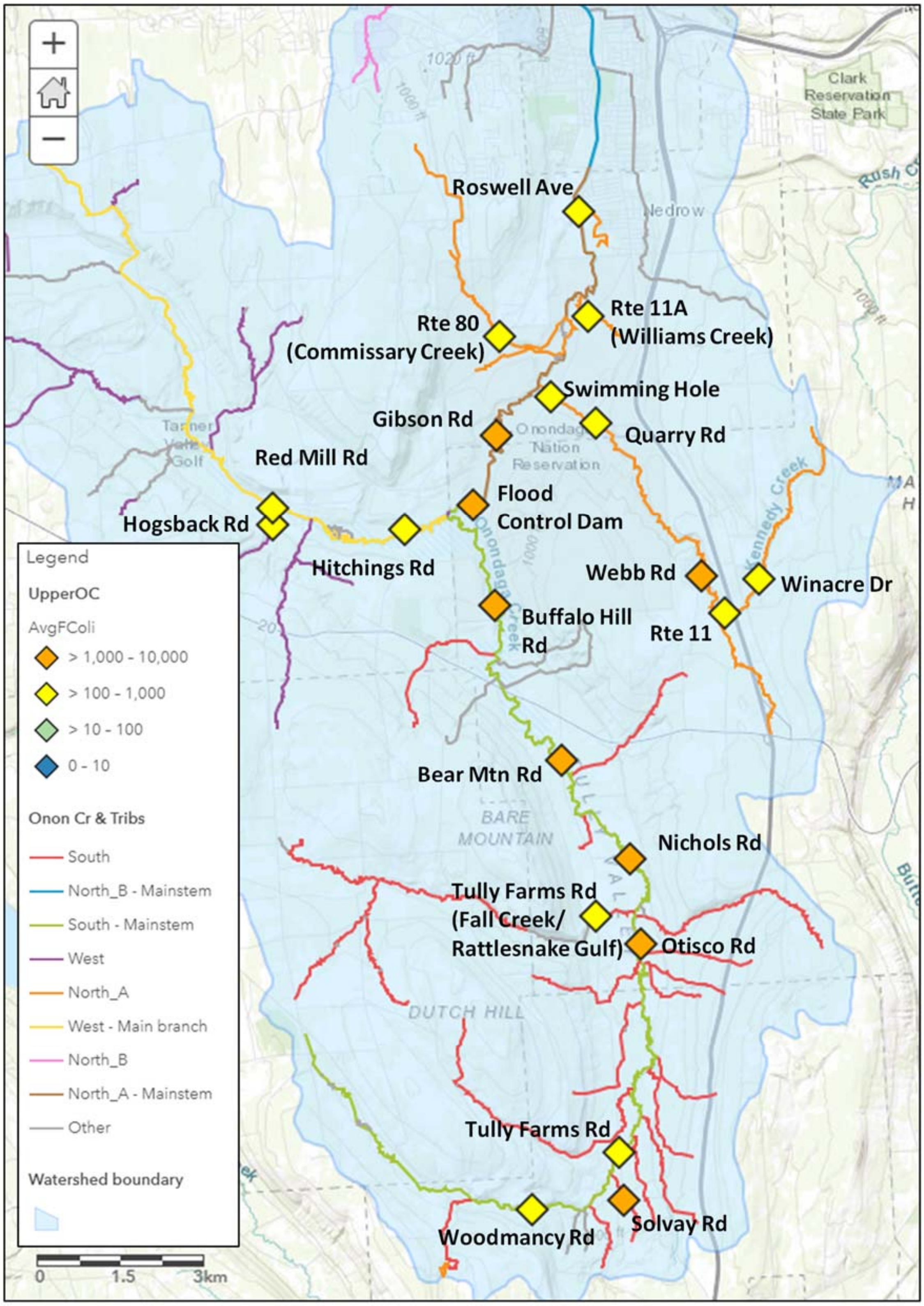

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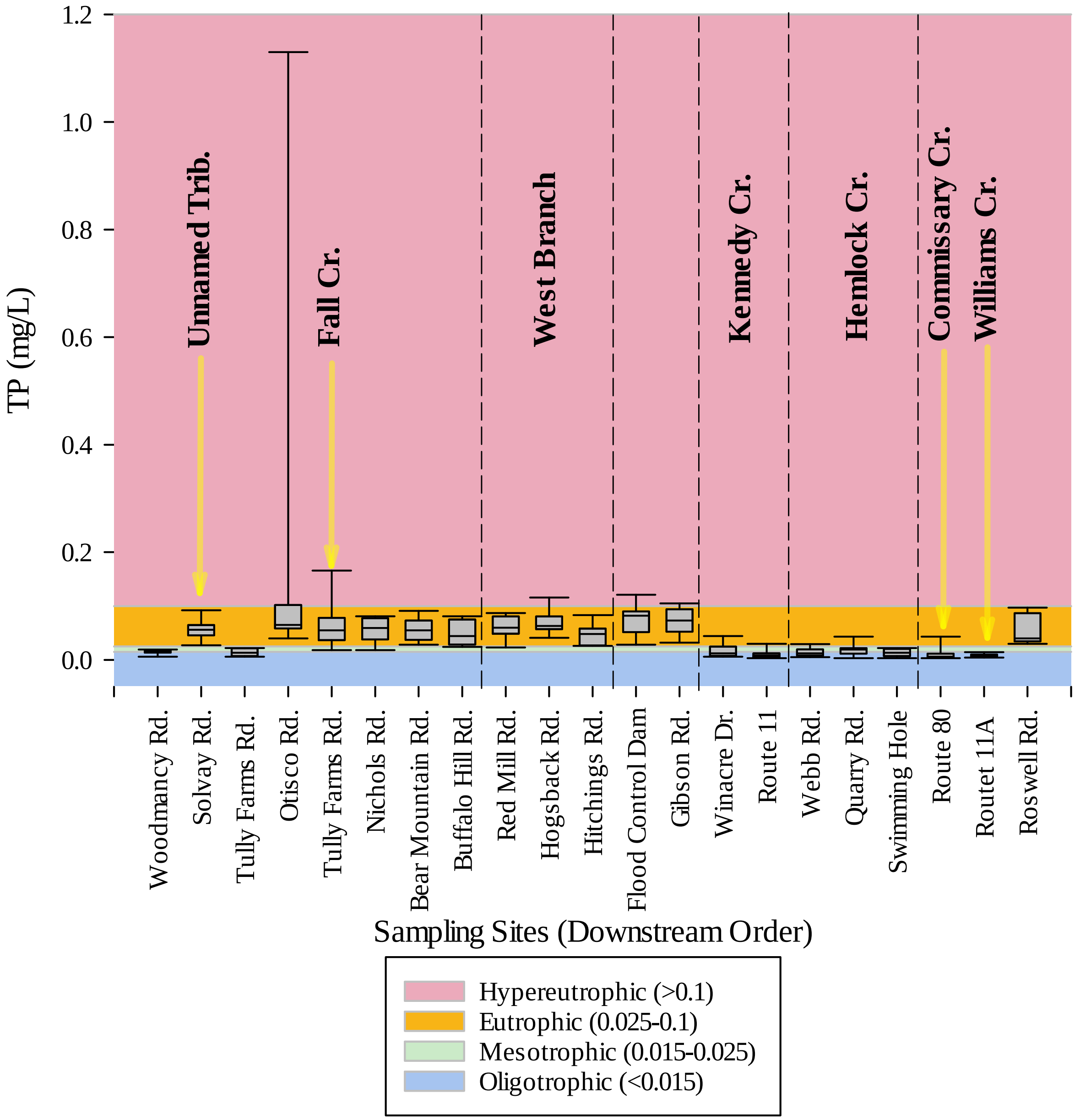
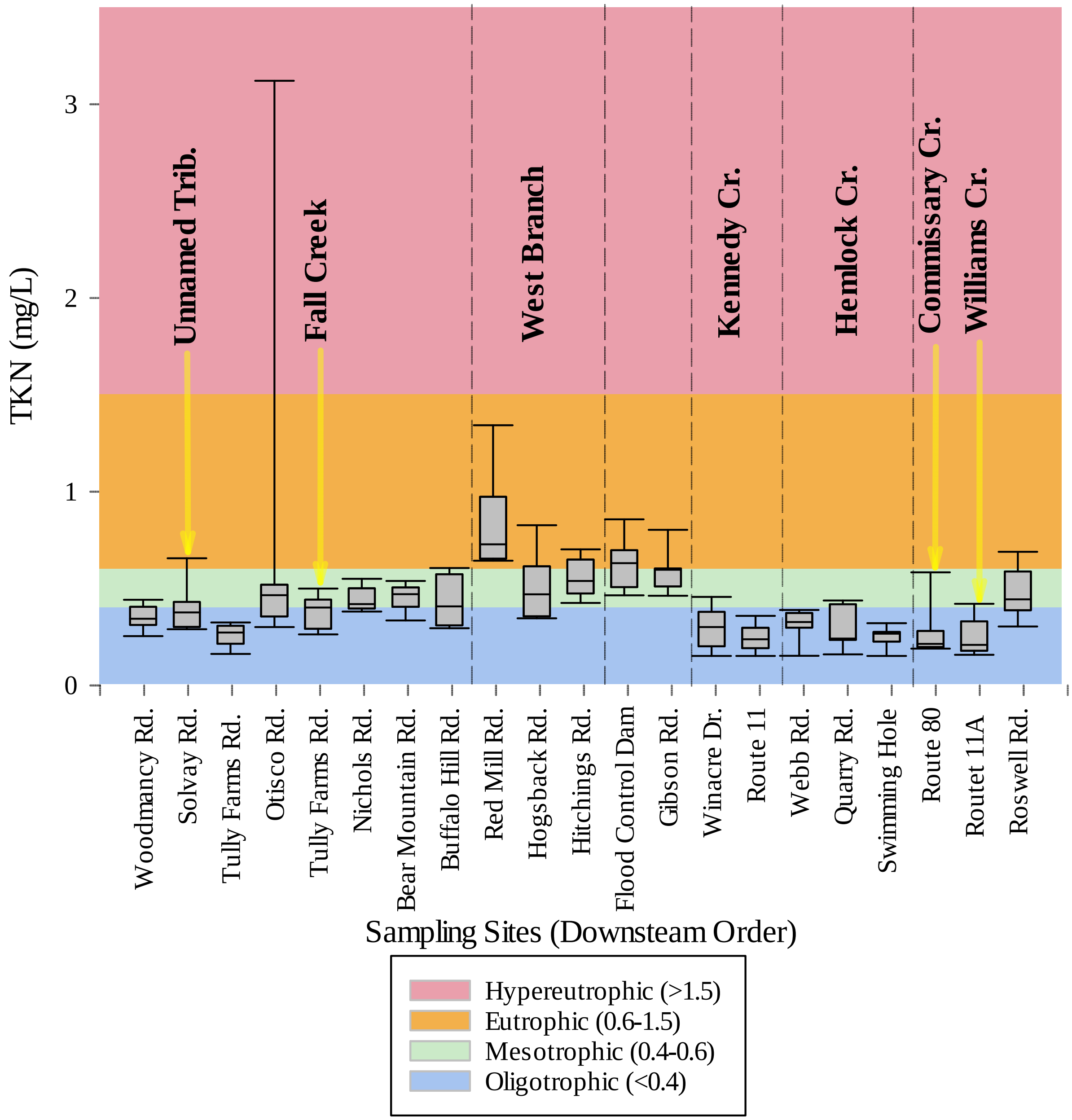


Figure 43. Total phosphorus levels for Phase 3 upper Onondaga Creek sampling locations (2014). Unless specified, the number of samples used to generate box plots is N=9.



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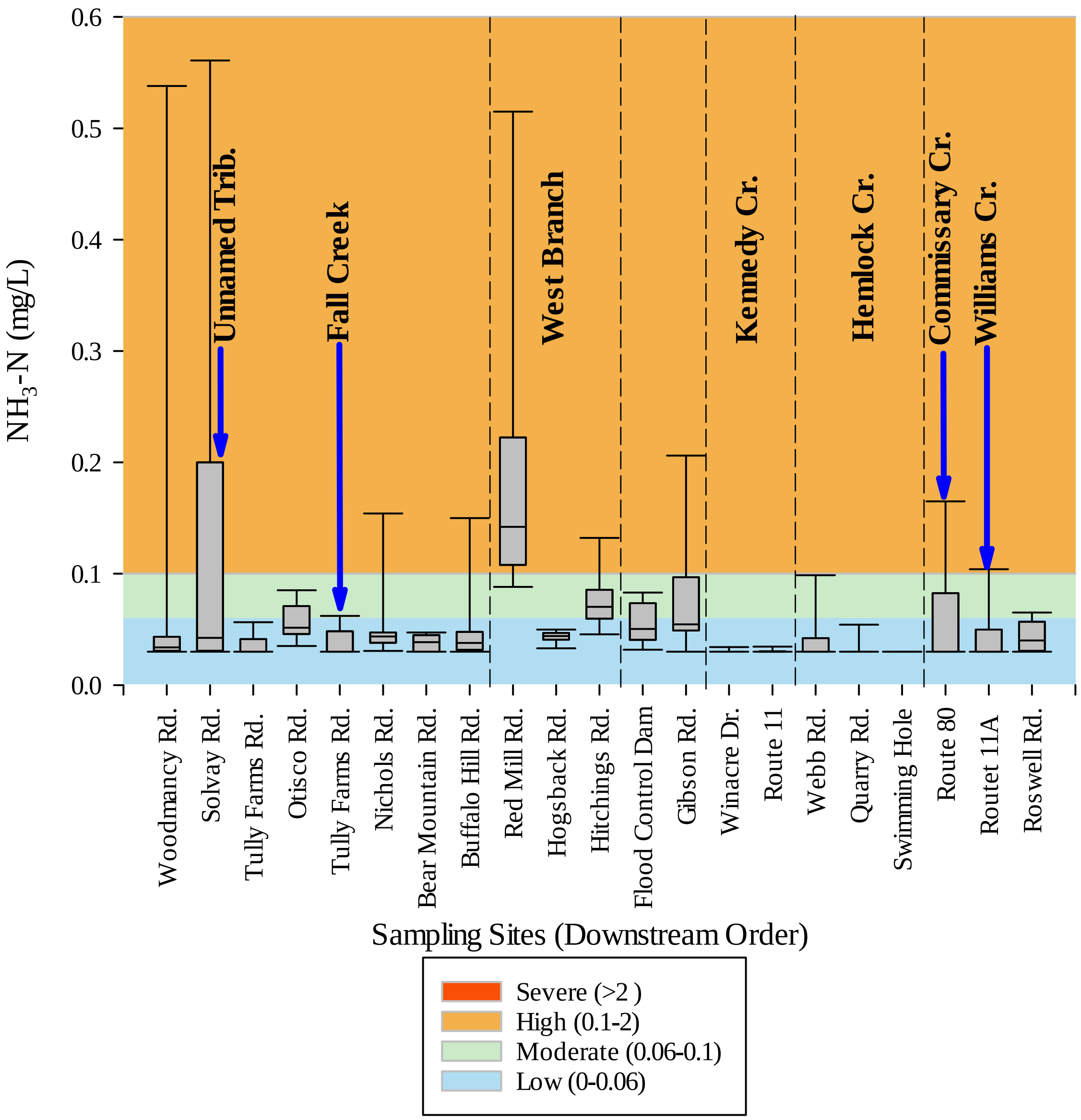


Figure 45. Ammonia levels for Phase 3 upper Onondaga Creek sampling locations (2014). Unless specified, the number of samples used to generate box plots is N=9.

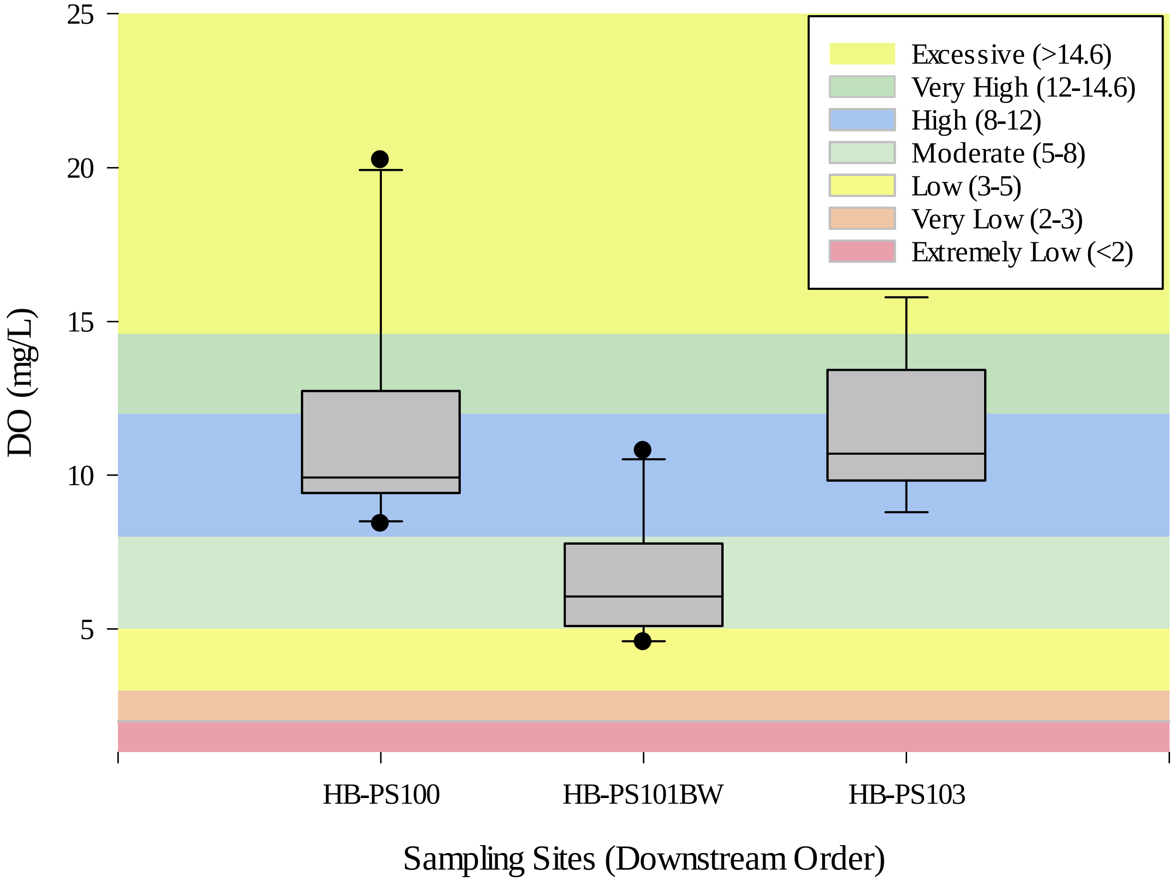


Figure 46. Dissolved oxygen levels for Phase 3 Harbor Brook priority point source sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=10.

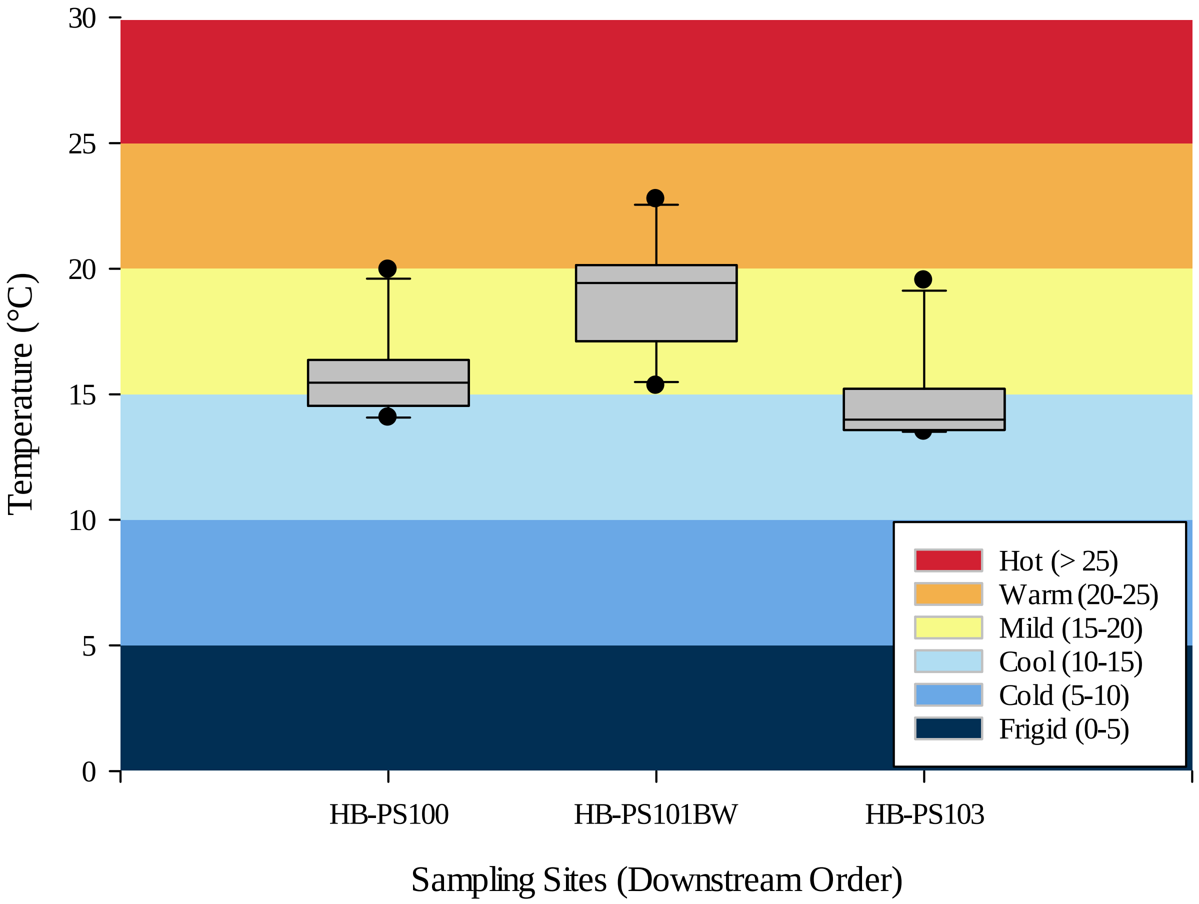


Figure 47. Temperature levels for Phase 3 Harbor Brook priority point source sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=10.

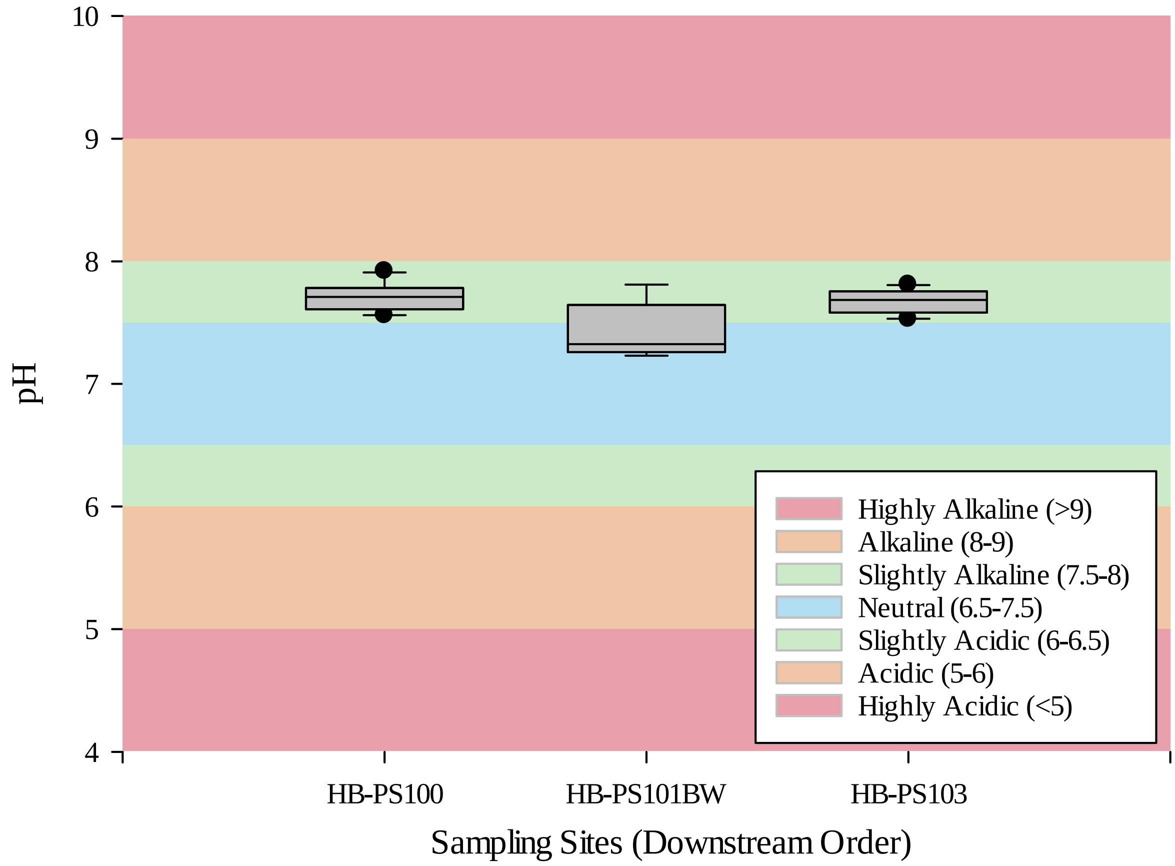


Figure 48. pH levels for Phase 3 Harbor Brook priority point source sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=10.

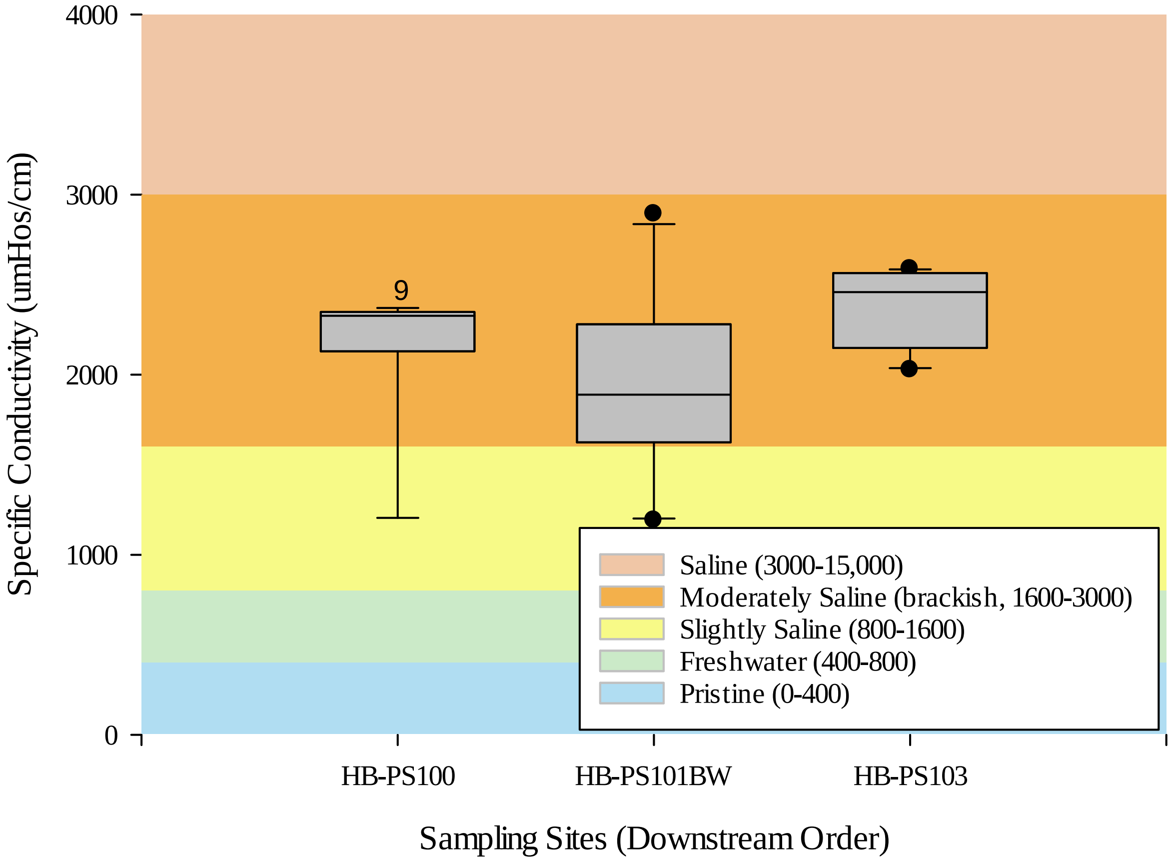
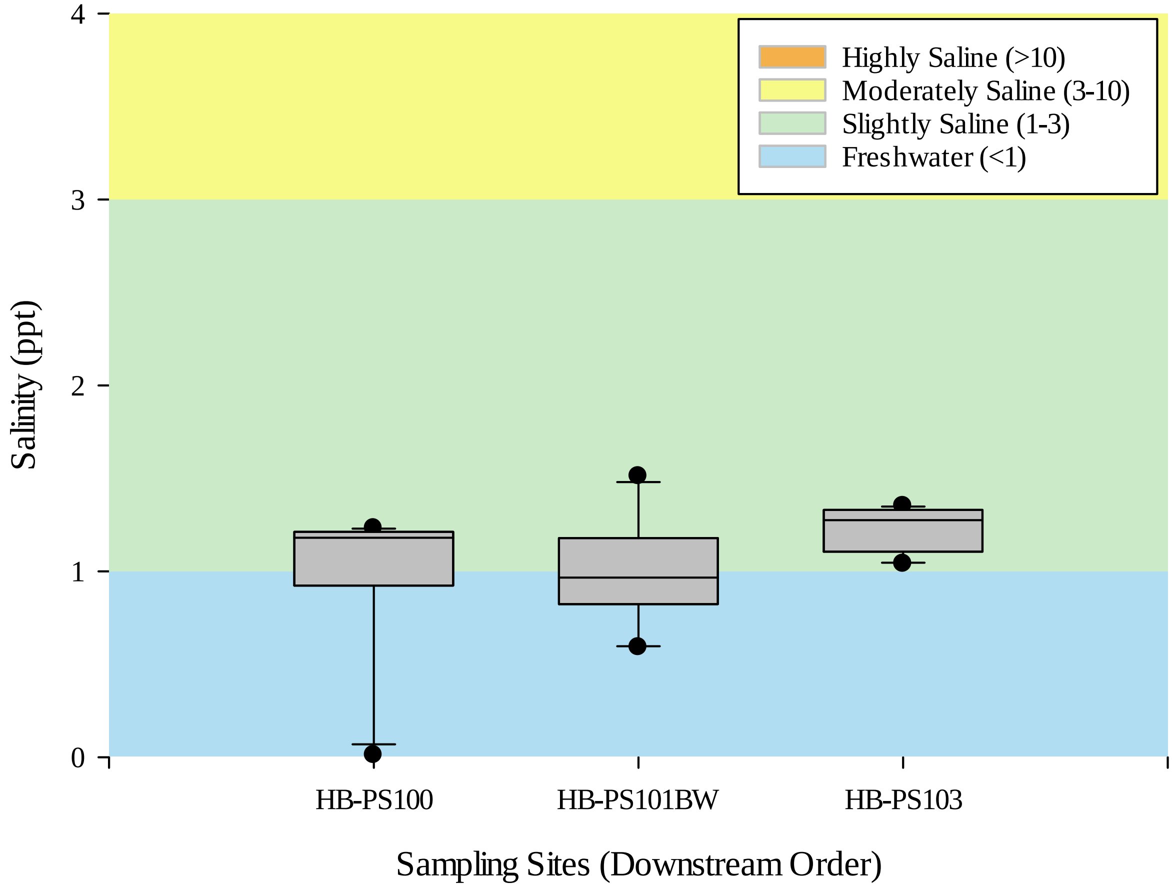


Figure 49. Specific conductivity levels for Phase 3 Harbor Brook priority point source sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=10.



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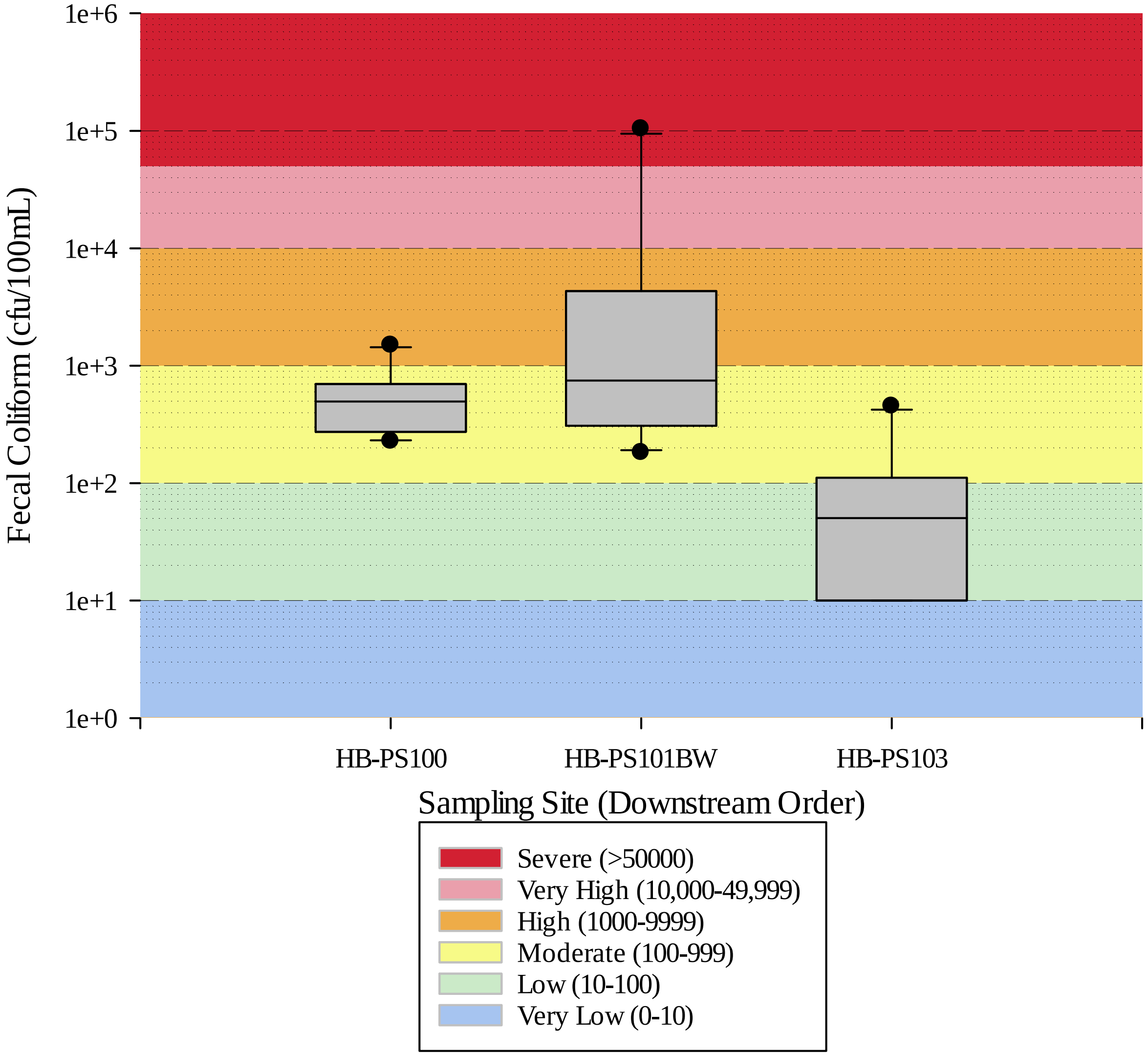
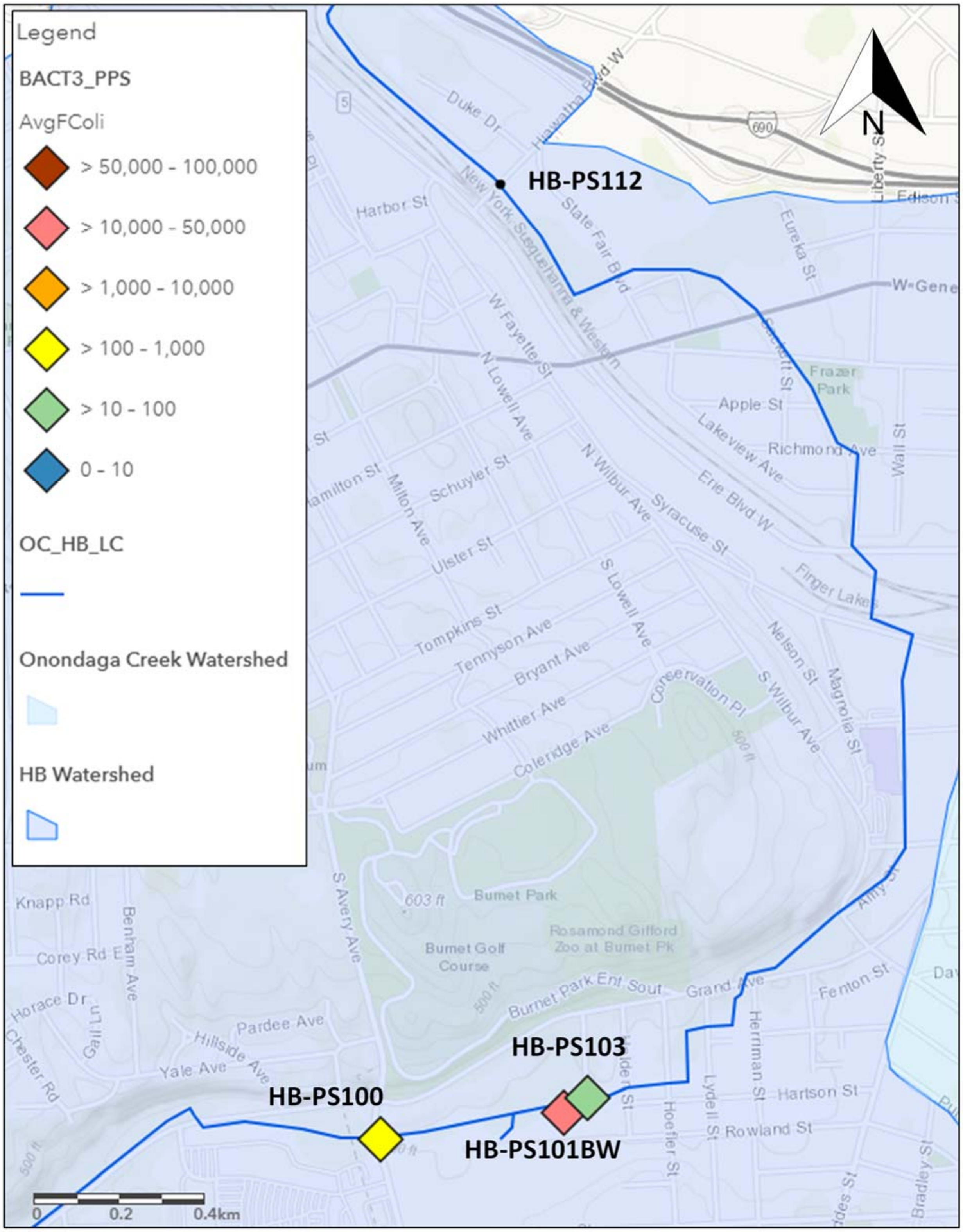


Figure 51. Fecal coliform levels for Phase 3 Harbor Brook priority point source sampling locations (2014-2015). Values are plotted on a logarithmic scale. Unless specified, the number of samples used to generate box plots is N=10.



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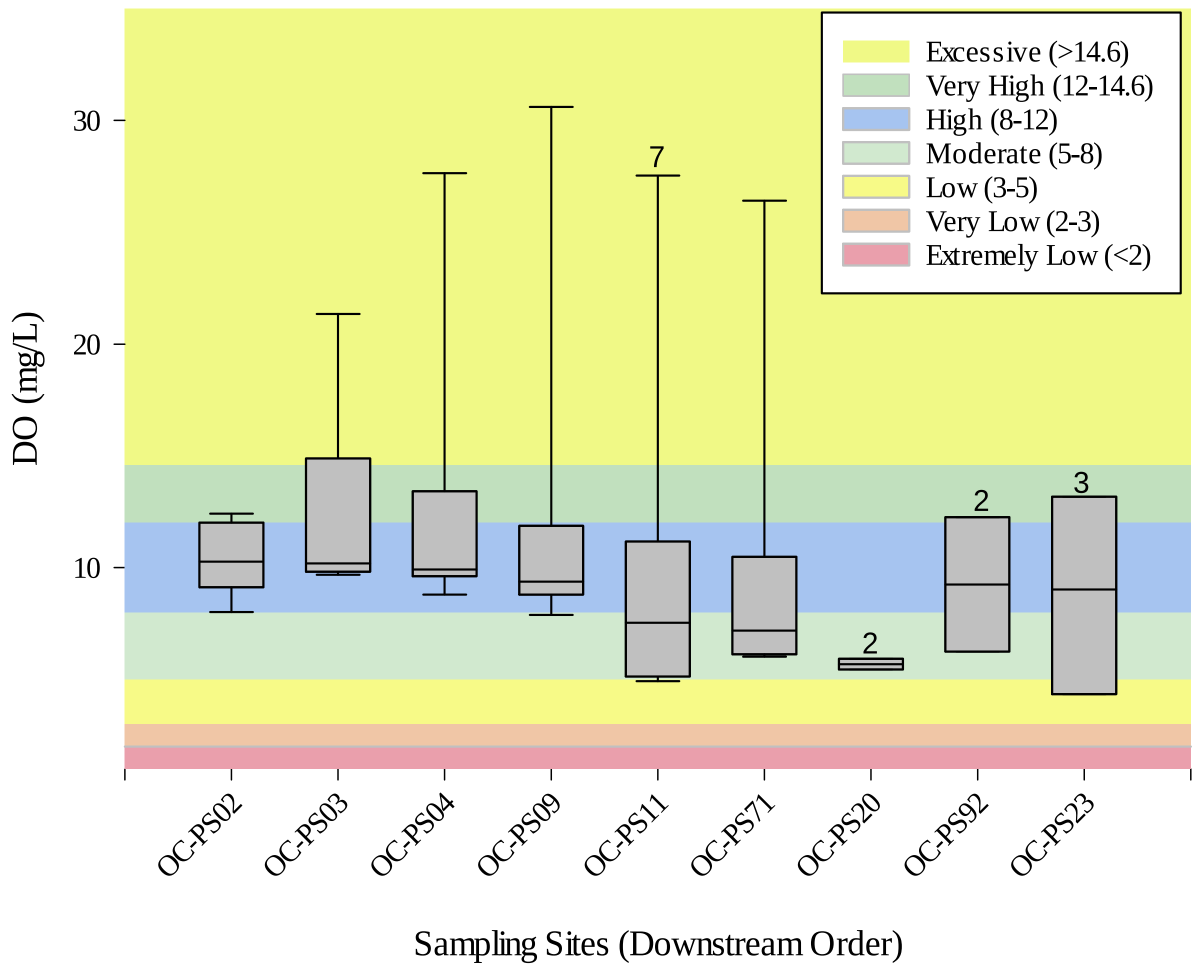


Figure 53. Dissolved oxygen levels for Phase 3 Onondaga Creek priority point source sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=8.

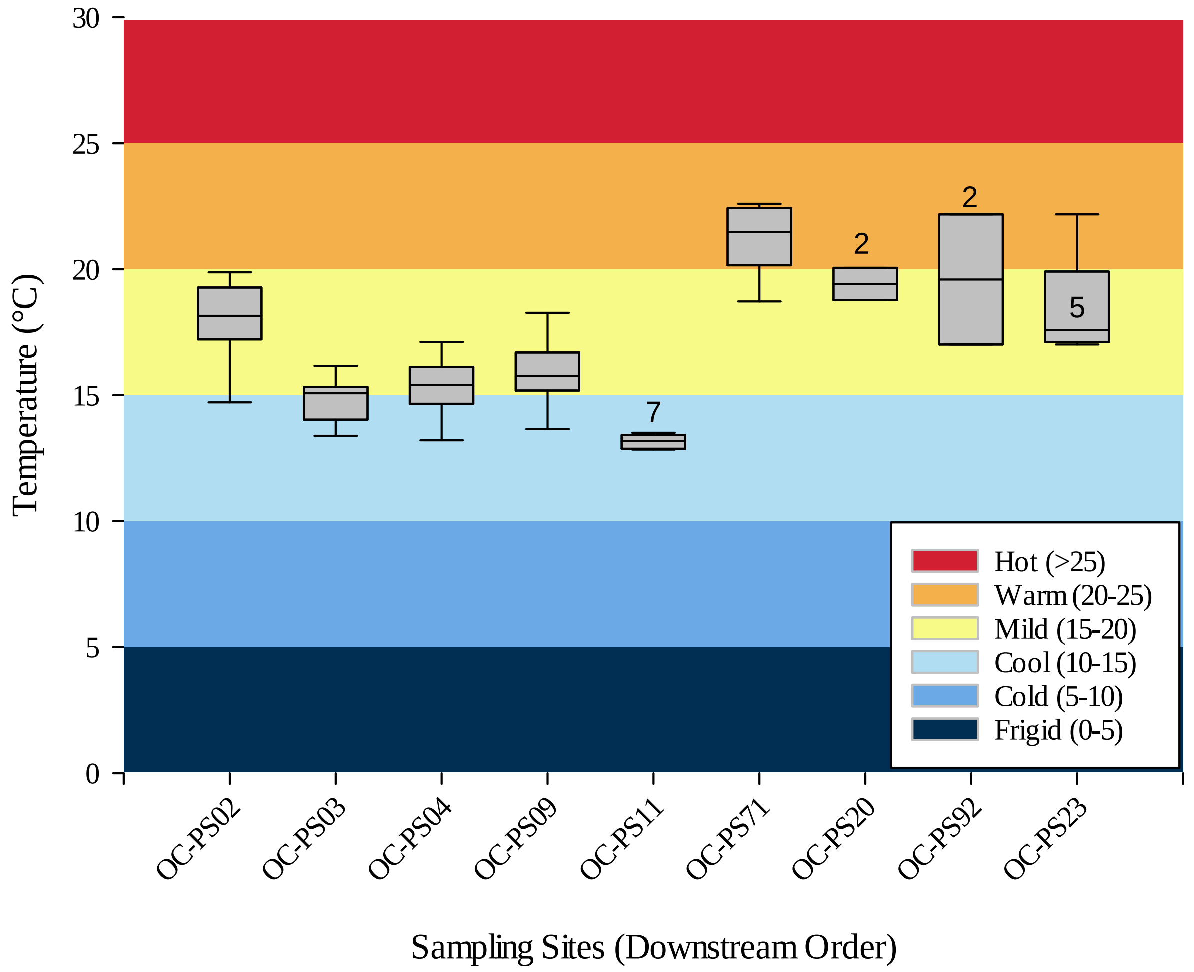


Figure 54. Temperature levels for Phase 3 Onondaga Creek priority point source sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=8.

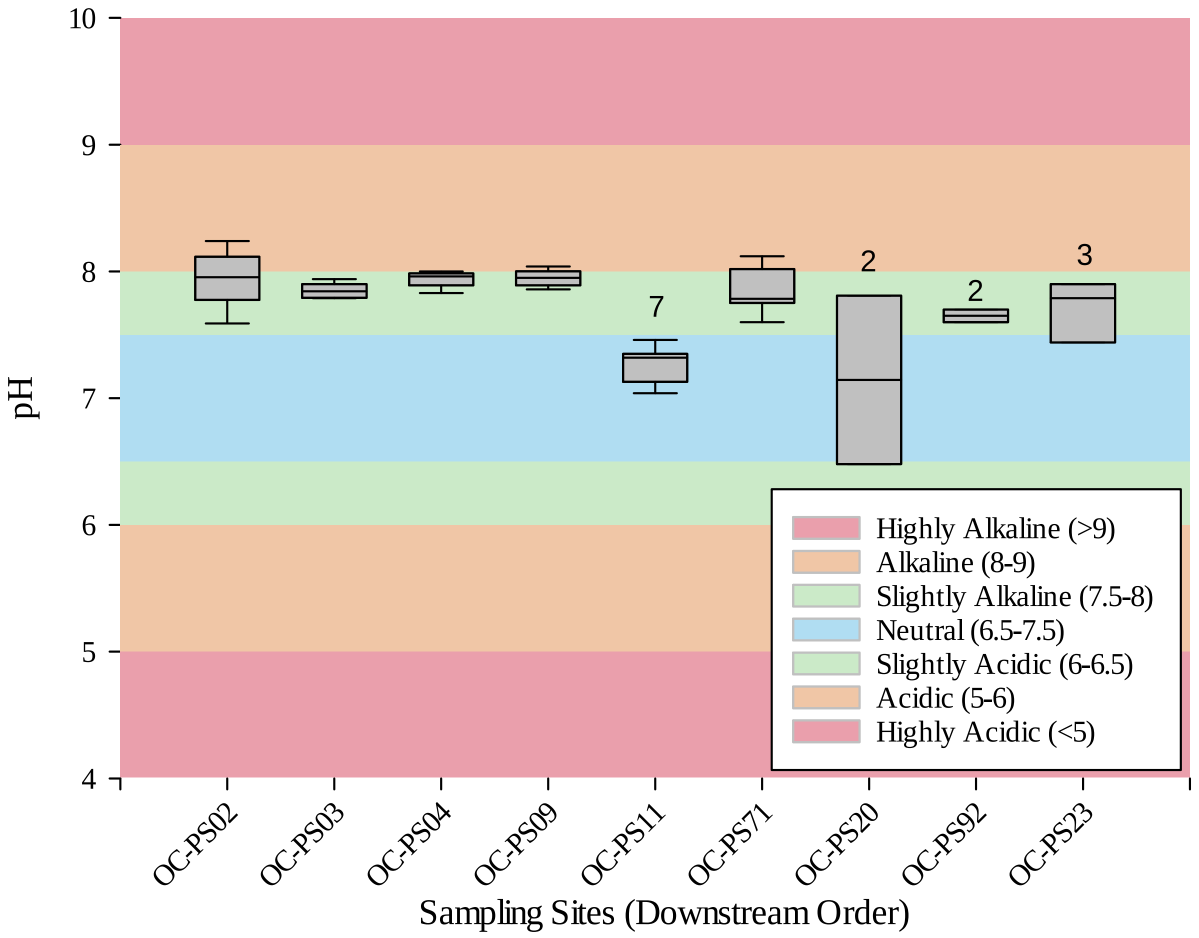


Figure 55. pH levels for Phase 3 Onondaga Creek priority point source sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=8.

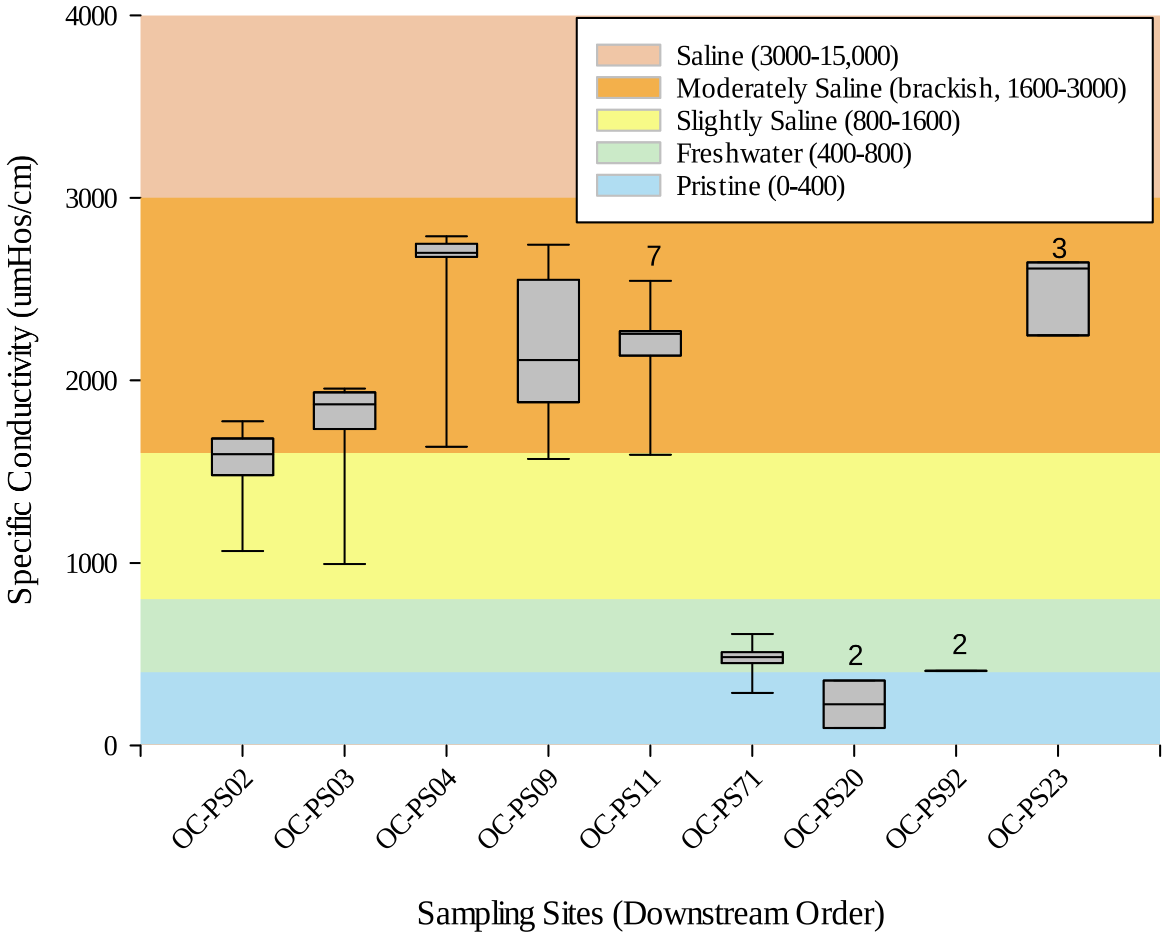


Figure 56. Specific conductivity levels for Phase 3 Onondaga Creek priority point source sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=8.

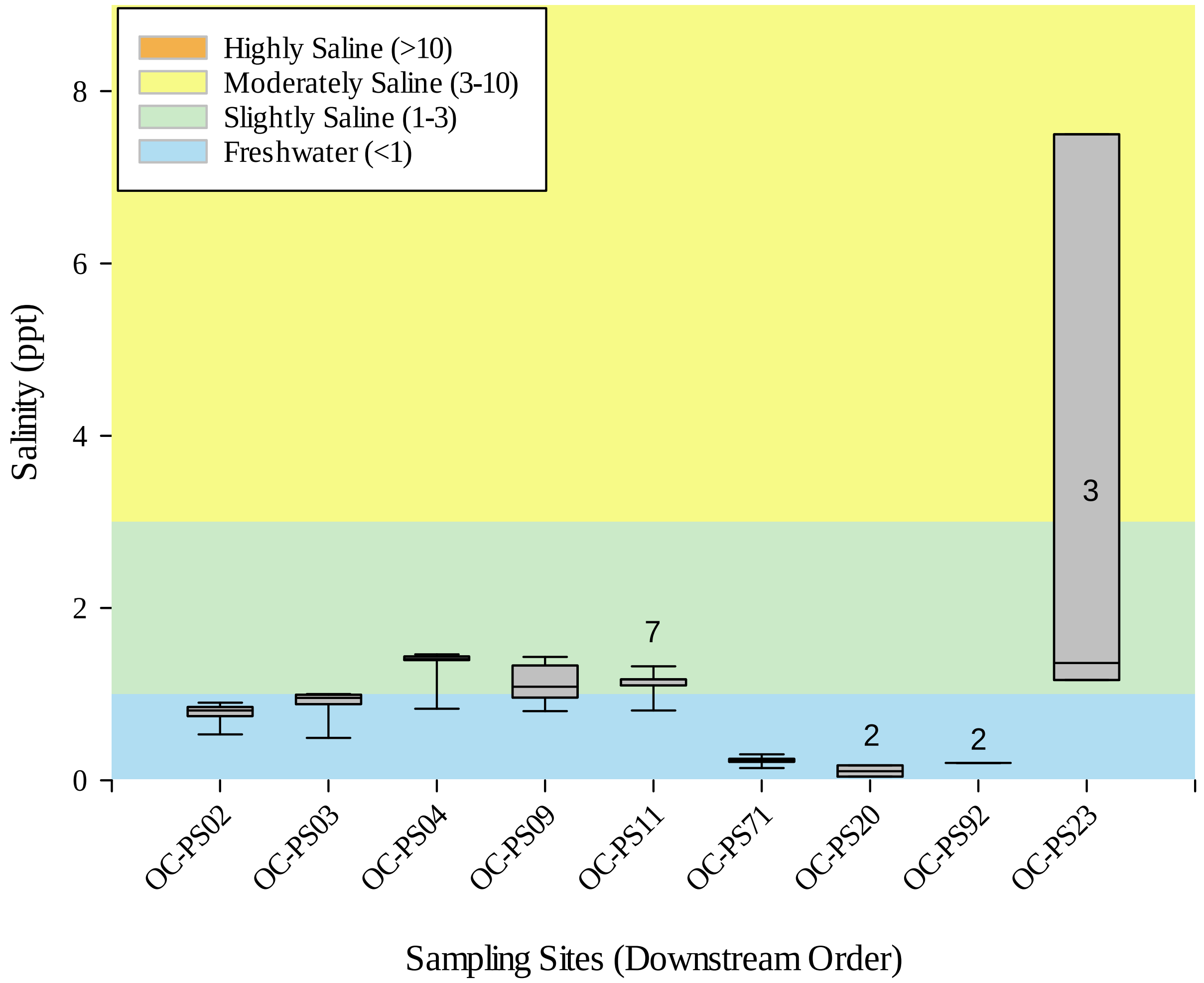


Figure 57. Salinity levels for Phase 3 Onondaga Creek priority point source sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=8.

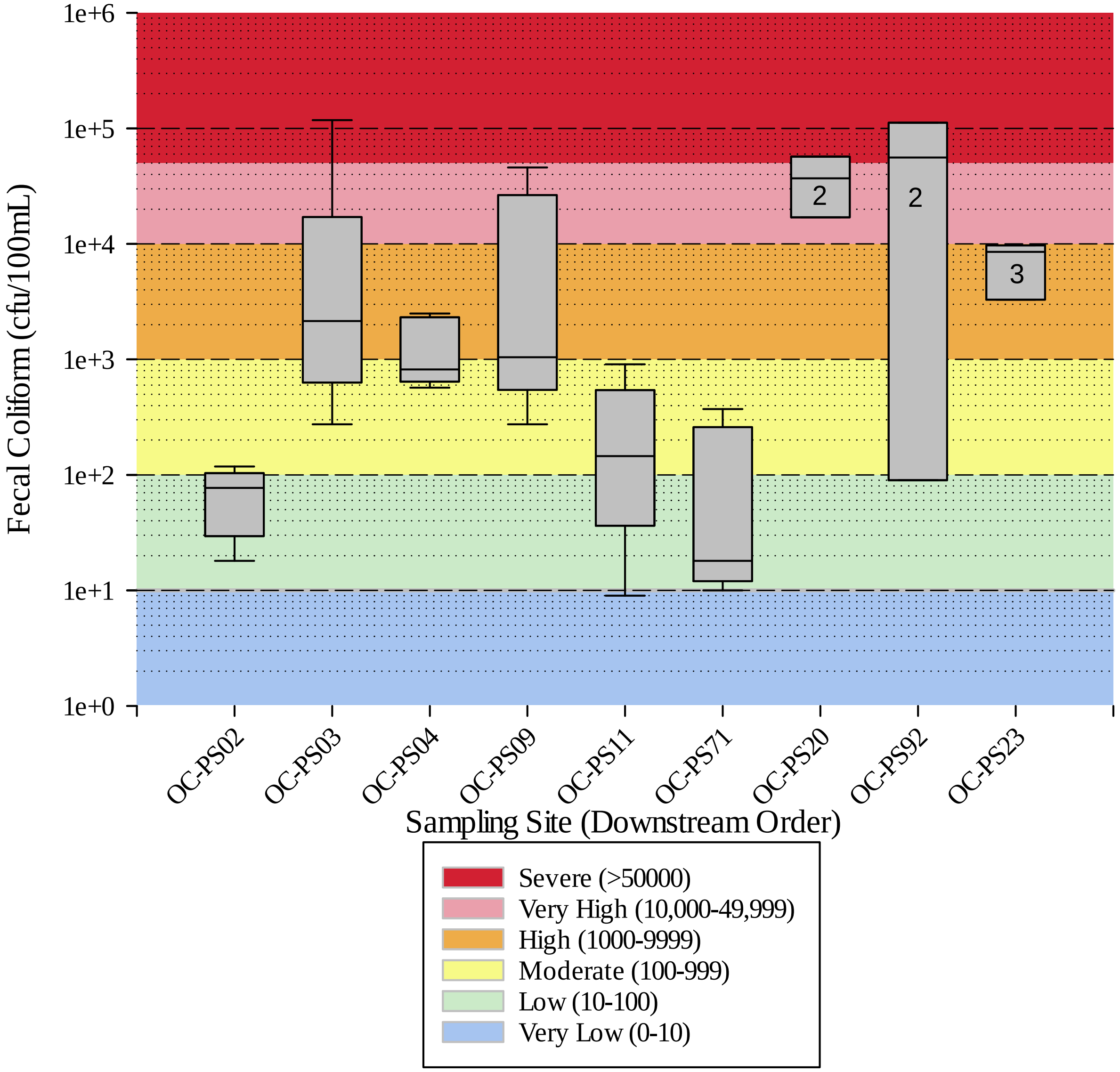


Figure 58. Fecal coliform levels for Phase 3 Onondaga Creek priority point source sampling locations (2014-2015). Unless specified, the number of samples used to generate box plots is N=8.

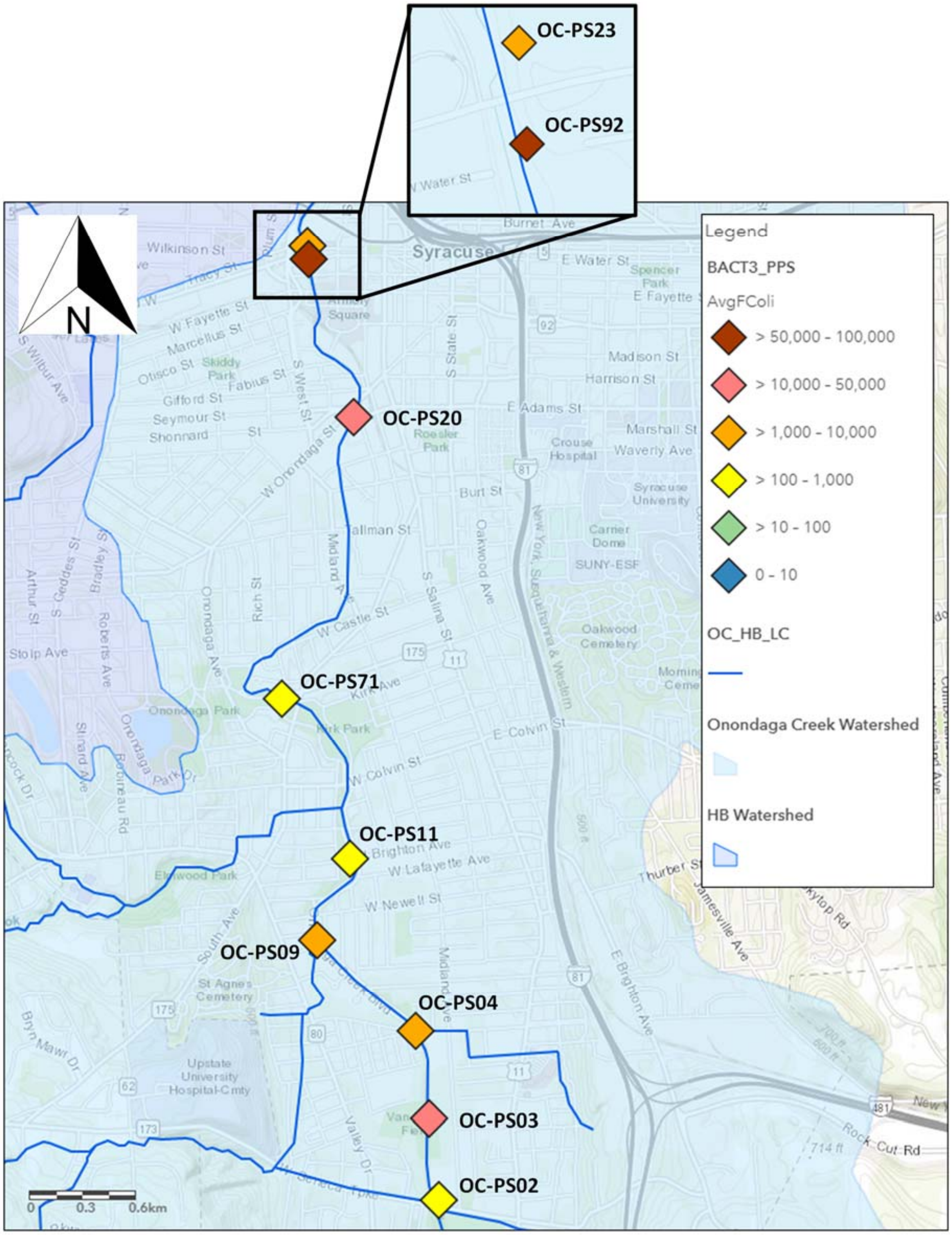


Figure 59. Average fecal coliform (cfu/100 mL) levels for Phase 3 Onondaga Creek priority point source locations (2014-2015).

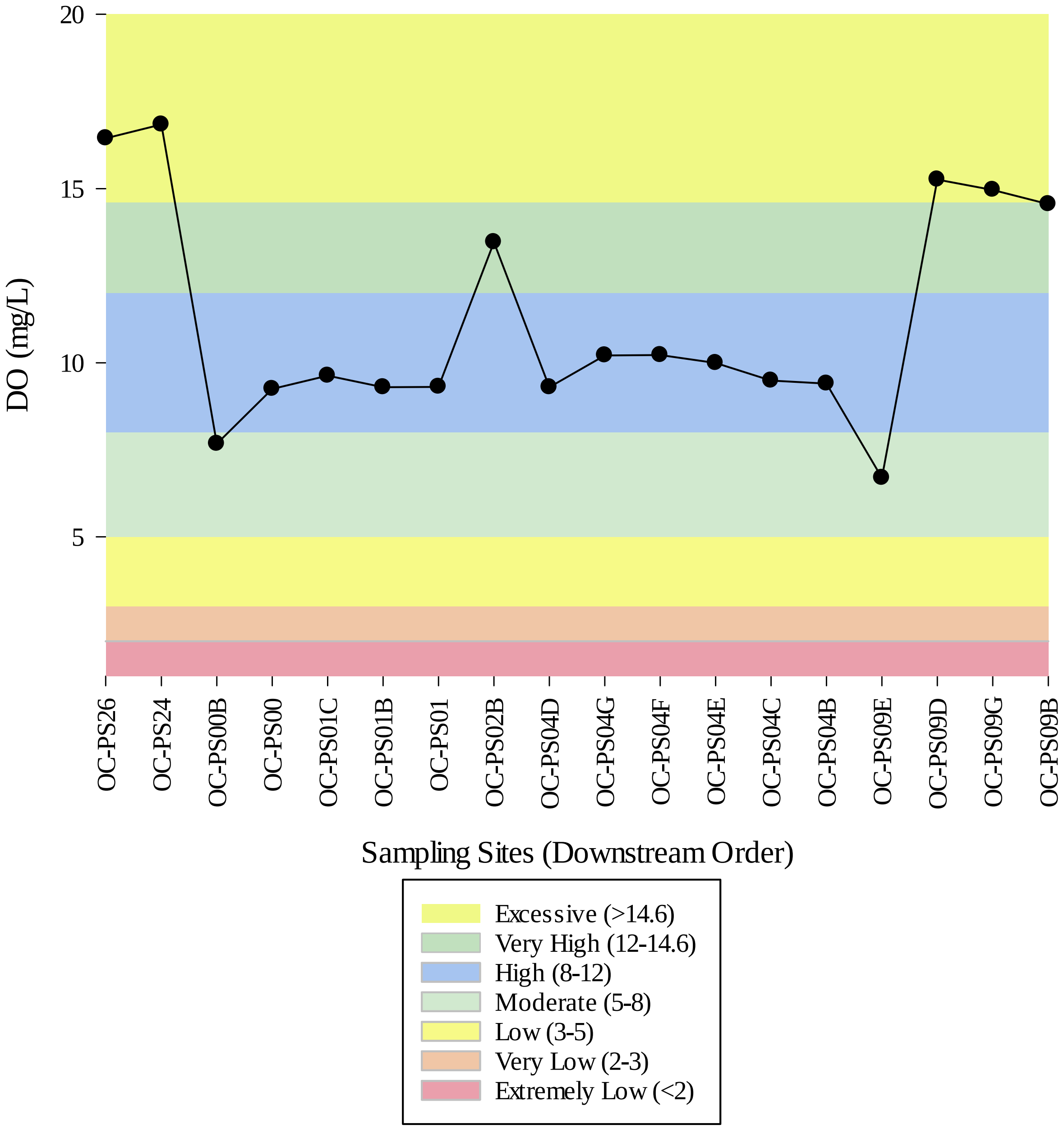


Figure 60. Dissolved oxygen levels for Phase 3 Onondaga Creek tributary trackdown sampling locations (8/17/15).

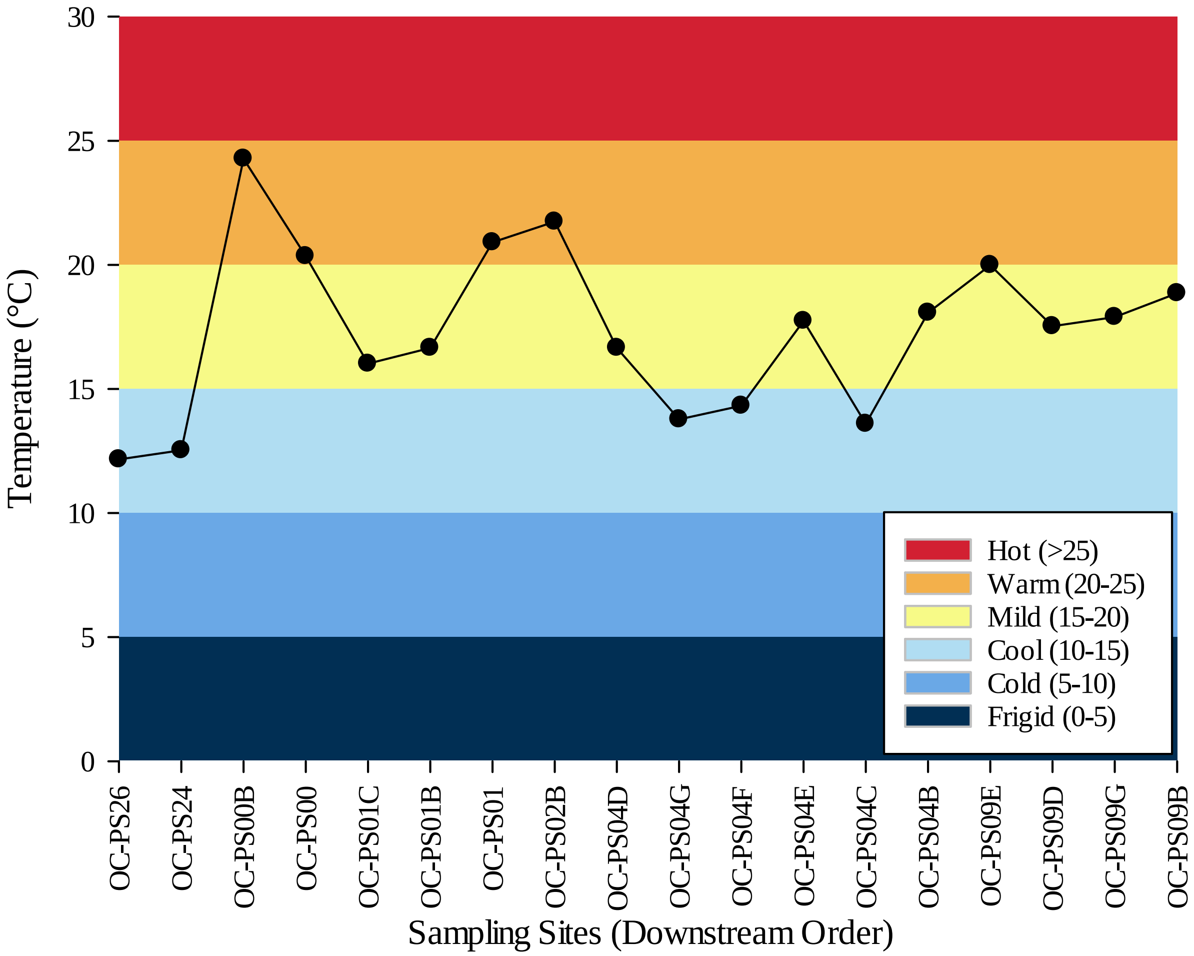


Figure 61. Temperature levels for Phase 3 Onondaga Creek tributary trackdown sampling locations (8/17/15).

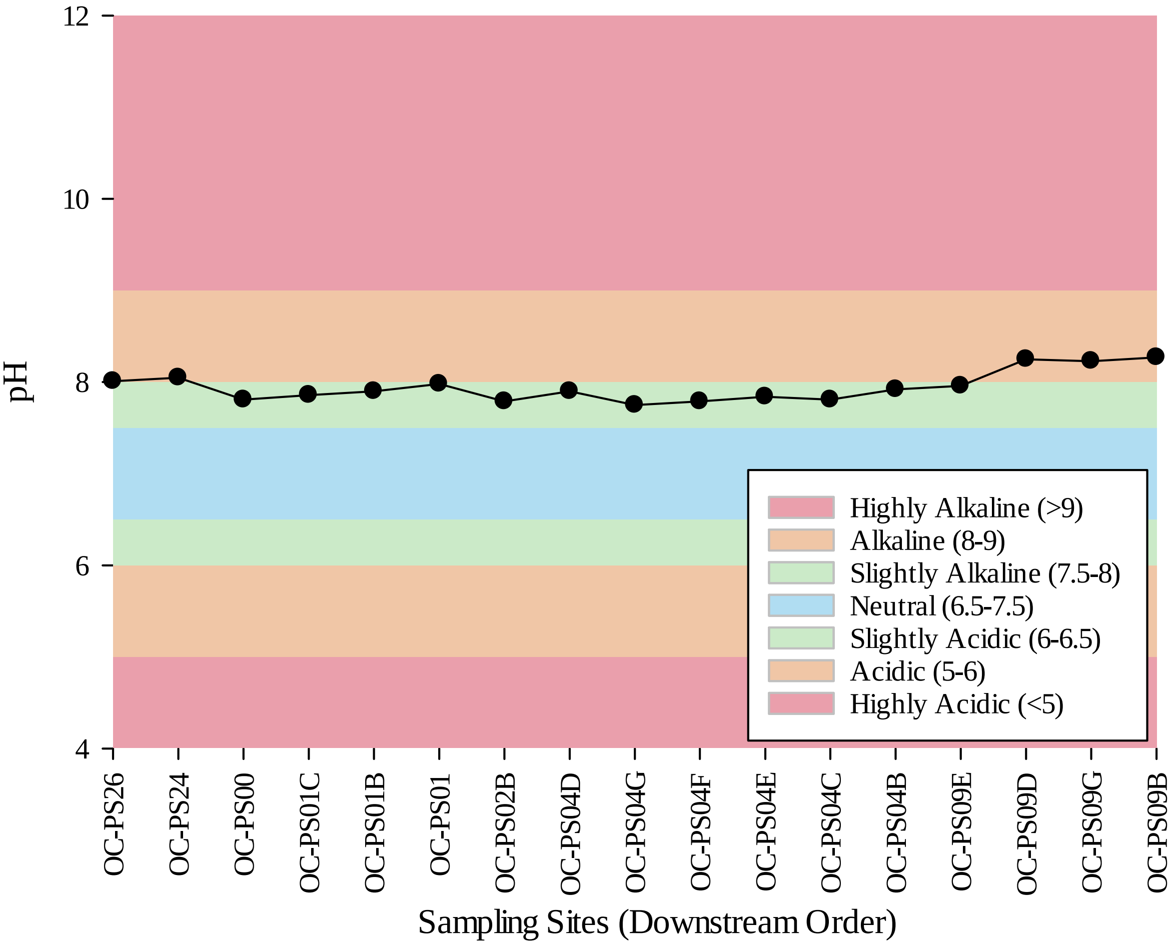


Figure 62. pH levels for Phase 3 Onondaga Creek tributary trackdown sampling locations (8/17/15).

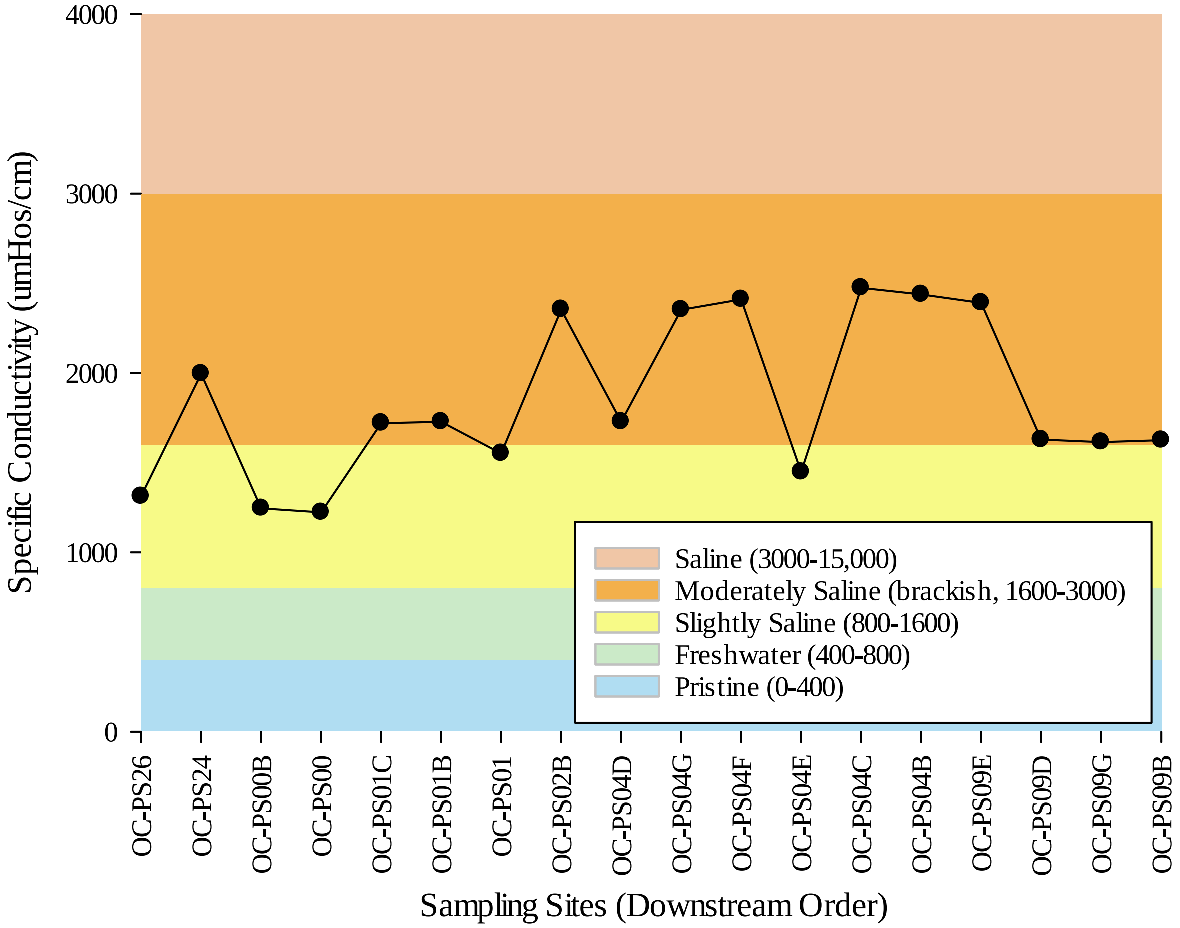


Figure 63 Onondaga Creek. Specific conductivity levels for Phase 3 Onondaga Creek tributary trackdown sampling locations (8/17/15).

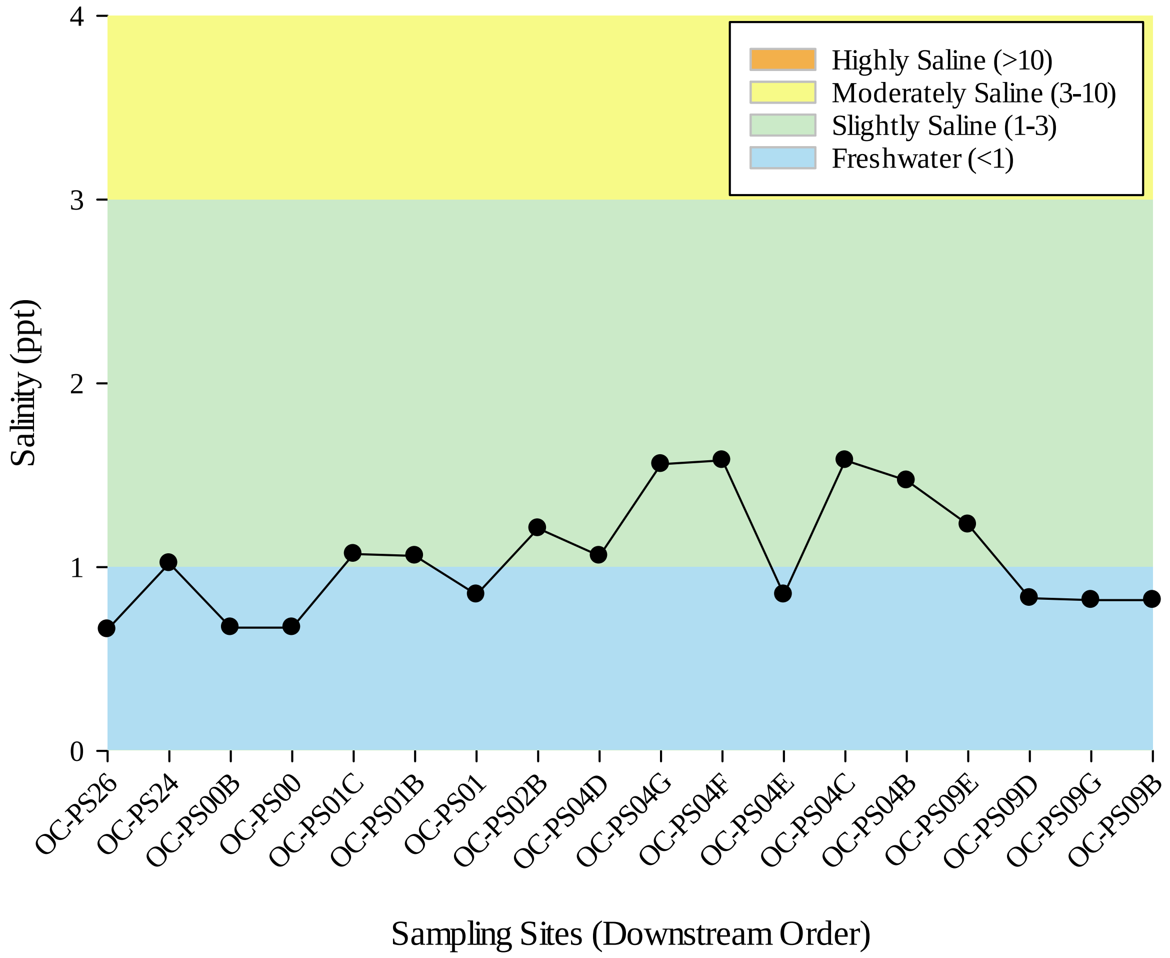


Figure 64. Salinity levels for Phase 3 Onondaga Creek tributary trackdown sampling locations (8/17/15).

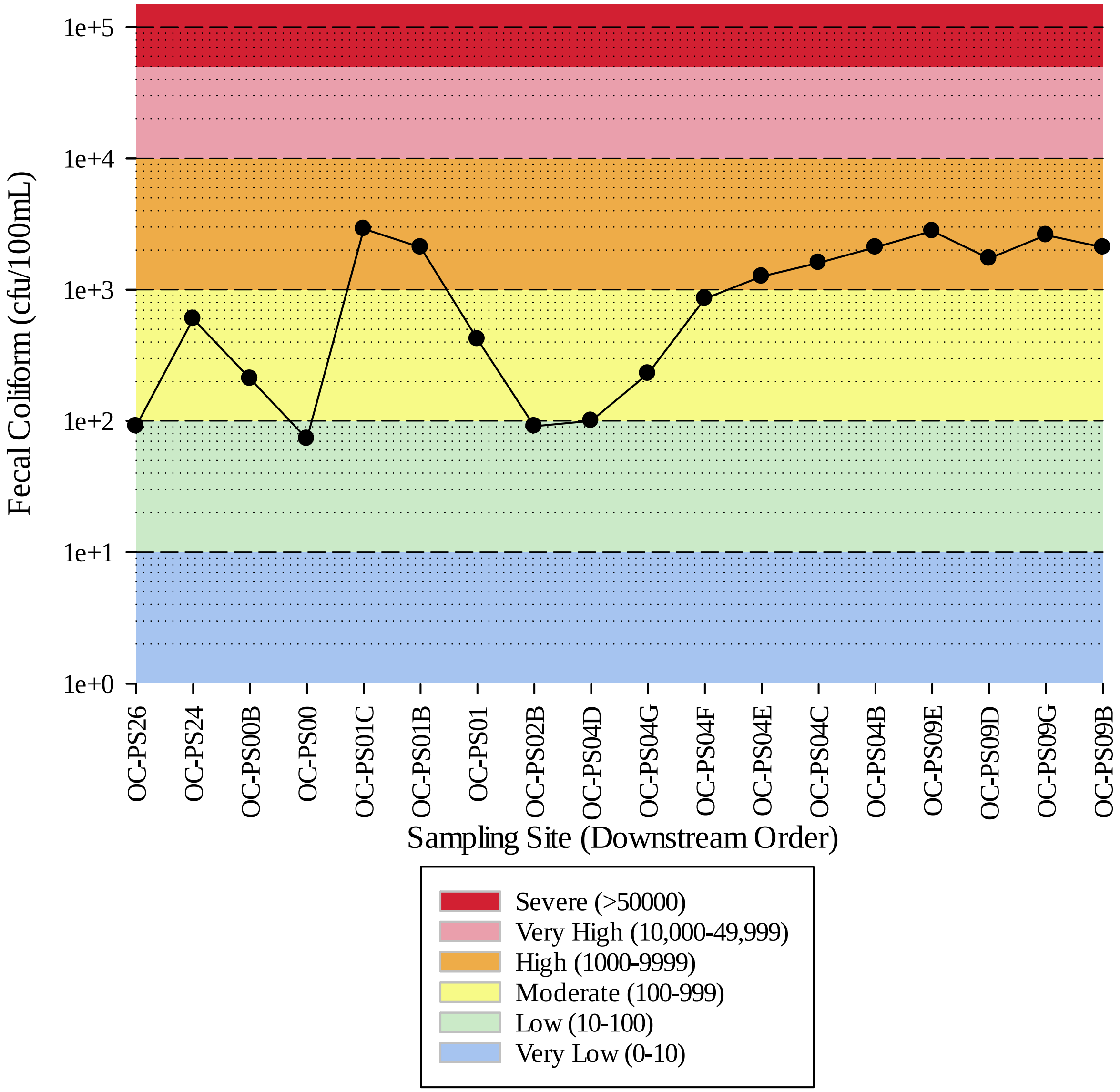


Figure 65. Fecal coliform levels for Phase 3 Onondaga Creek tributary trackdown sampling locations (8/17/15). Values are plotted on a logarithmic scale.

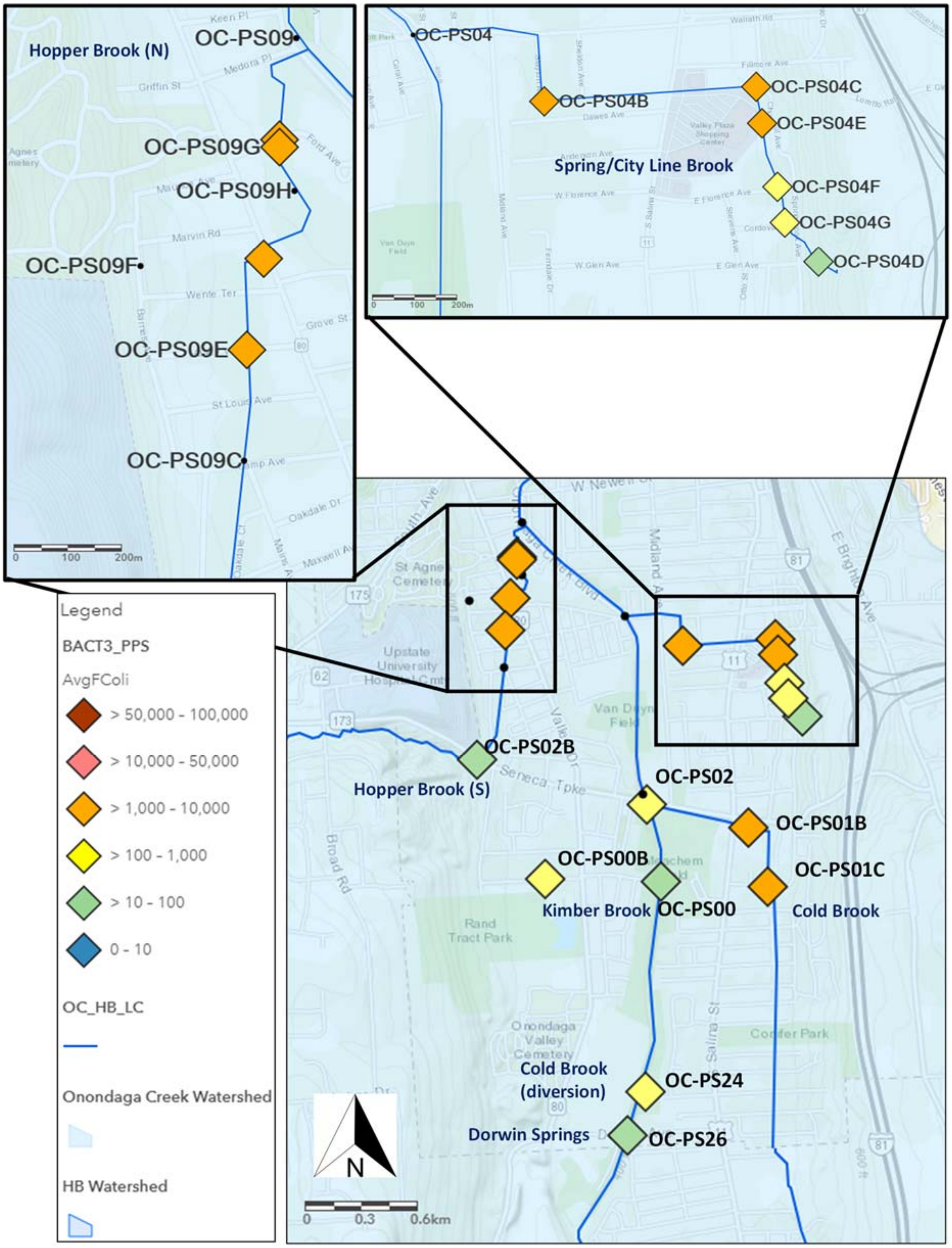


Figure 66. Fecal coliform (cfu/100 mL) levels for Phase 3 Onondaga Creek tributary trackdown sampling locations (8/17/15).

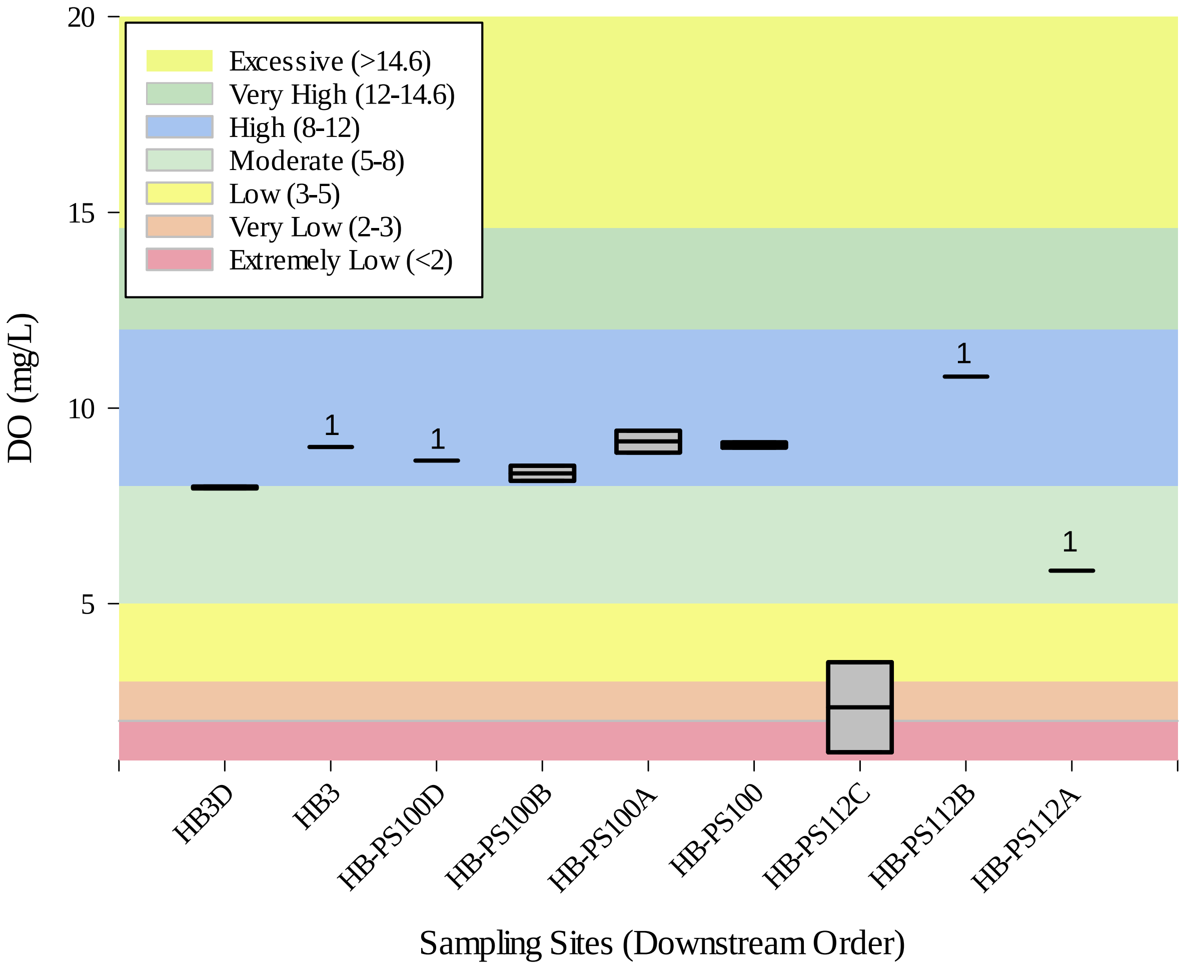


Figure 67. Dissolved oxygen levels for Phase 3 Harbor Brook point source trackdown sampling locations (2016-2017). Unless specified, the number of samples collected to generate box plots is N=2.

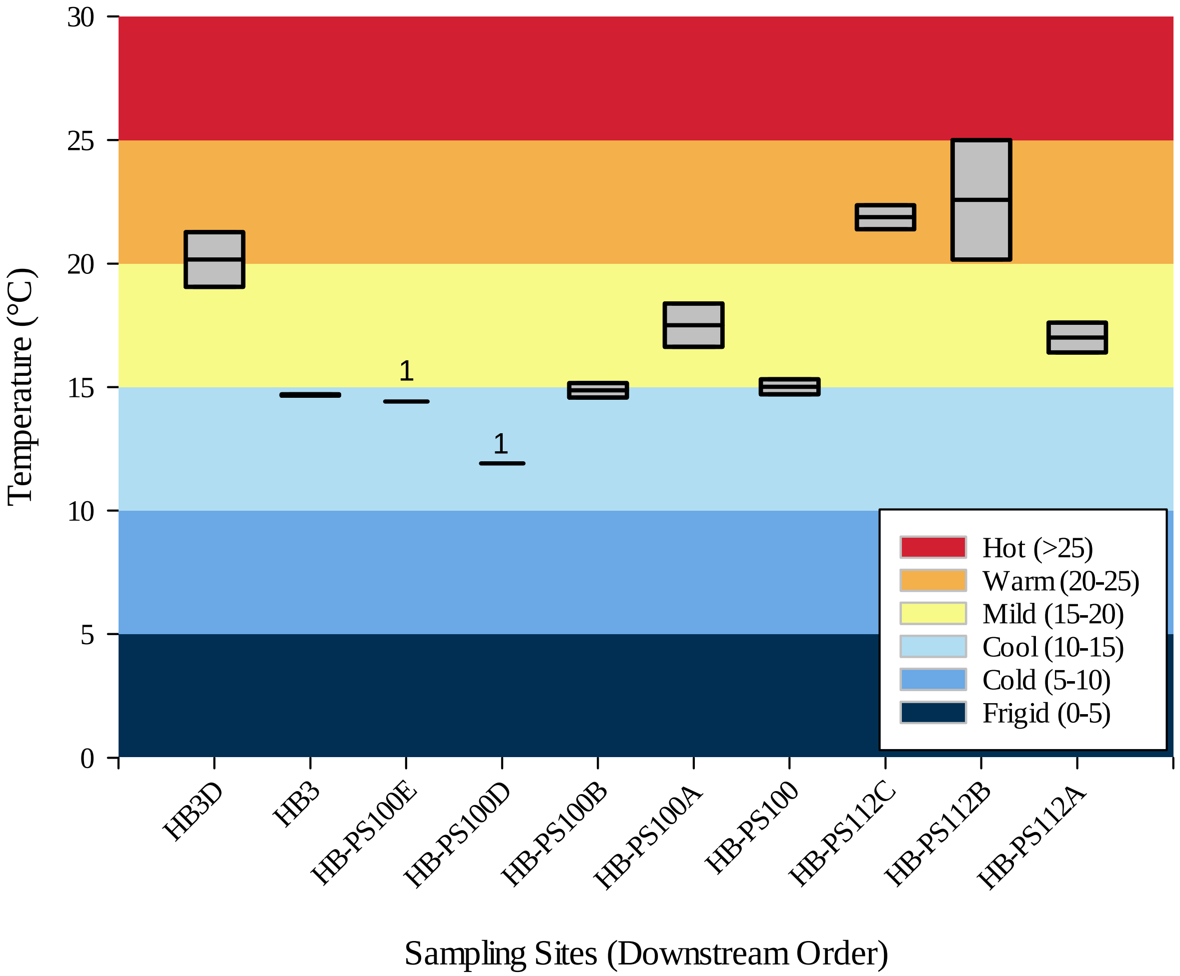


Figure 68. Temperature levels for Phase 3 Harbor Brook point source trackdown sampling locations (2016-2017). Unless specified, the number of samples collected to generate box plots is N=2.

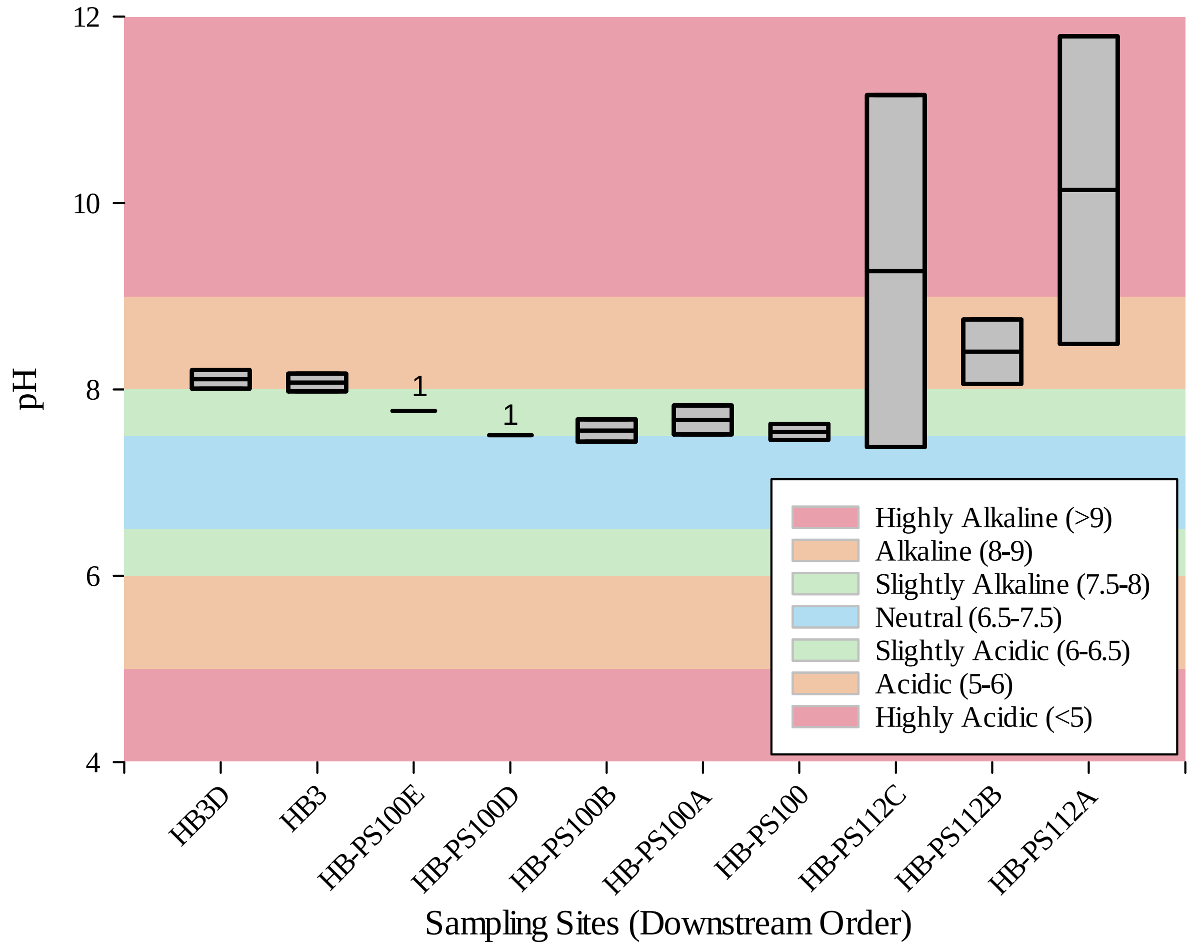


Figure 68. pH levels for Phase 3 Harbor Brook point source trackdown sampling locations (2016-2017). Unless specified, the number of samples collected to generate box plots is N=2.

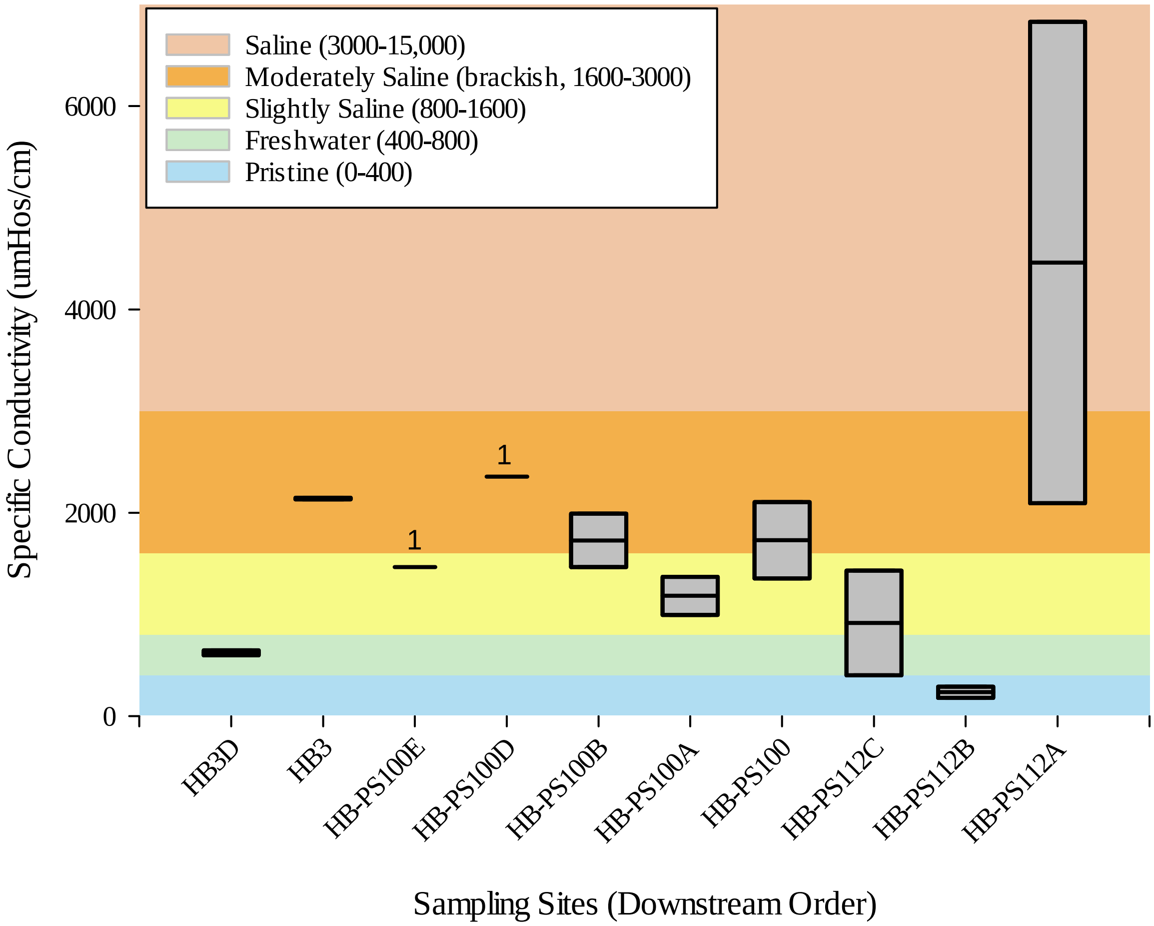


Figure 69. Specific conductivity levels for Phase 3 Harbor Brook point source trackdown sampling locations (2016-2017). Unless specified, the number of samples collected to generate box plots is N=2.

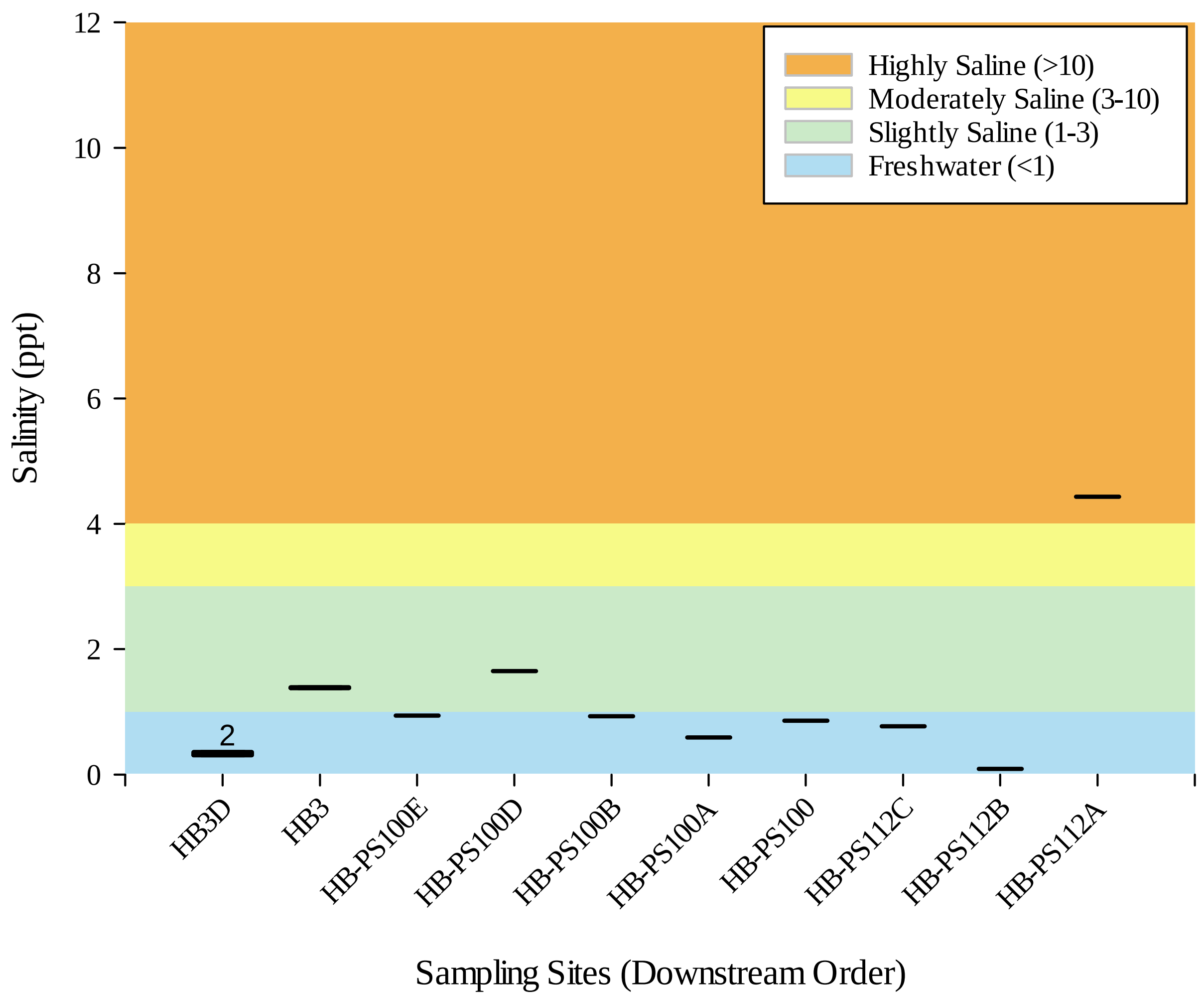


Figure 70. Salinity levels for Phase 3 Harbor Brook point source trackdown sampling locations (2016-2017). Unless specified, the number of samples collected to generate box plots is N=2.

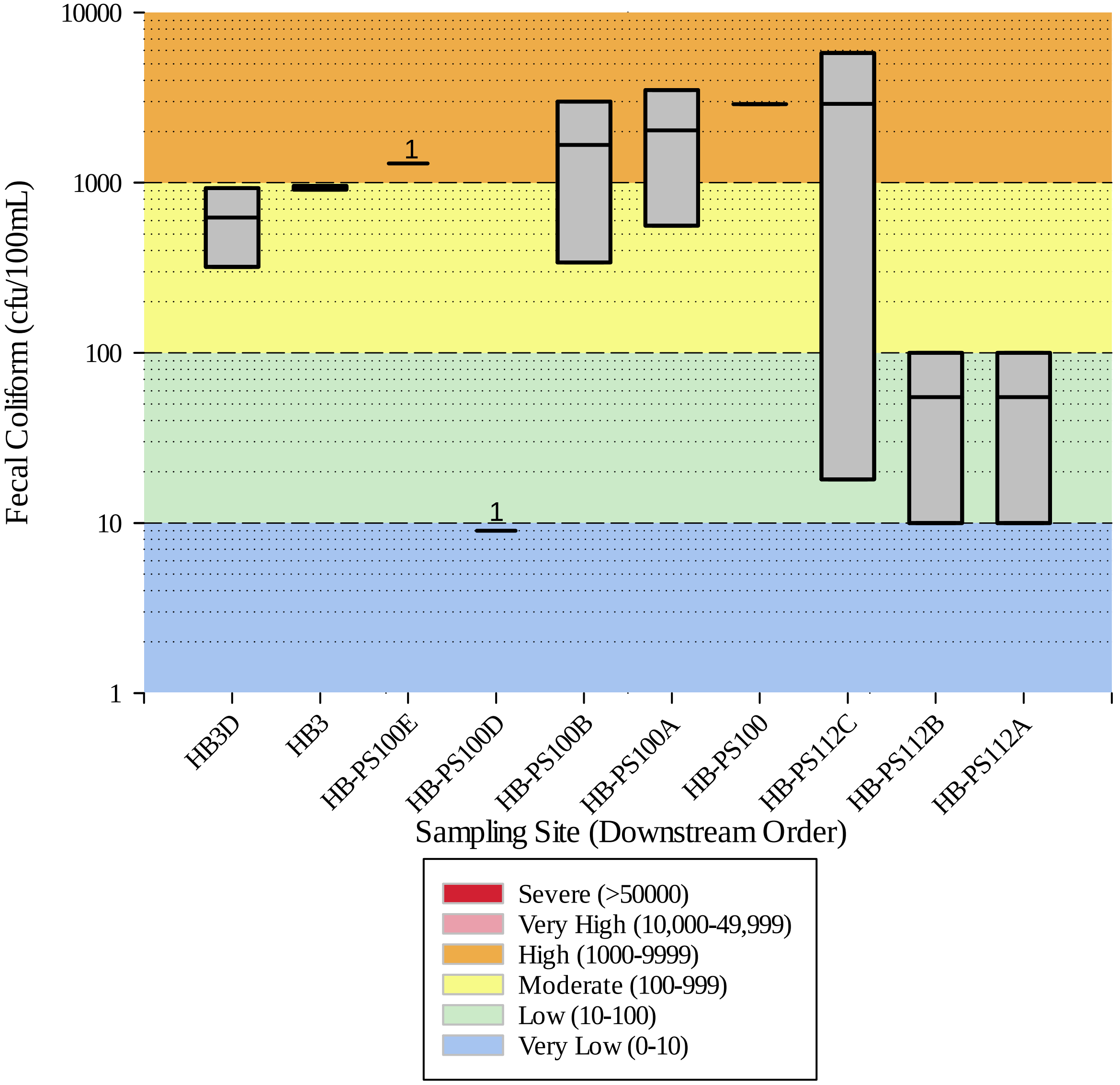


Figure 71. Dissolved oxygen levels for Phase 3 Harbor Brook point source trackdown sampling locations (2016-2017). Values are plotted on a logarithmic scale. Unless specified, the number of samples collected to generate box plots is N=2.

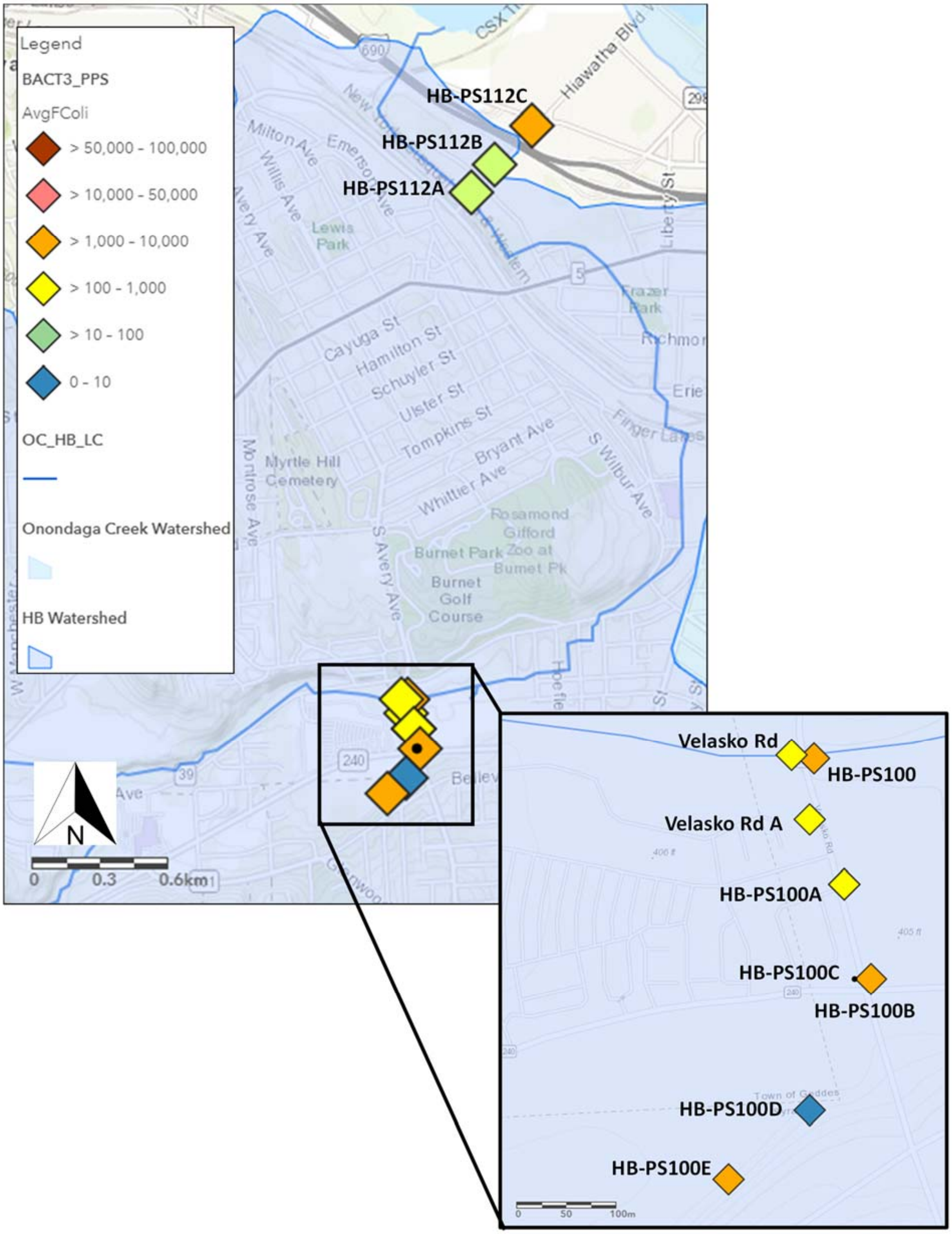


Figure 72. Average fecal coliform (cfu/100 mL) values for Phase 3 Harbor Brook point source trackdown sampling locations (2016-2017).

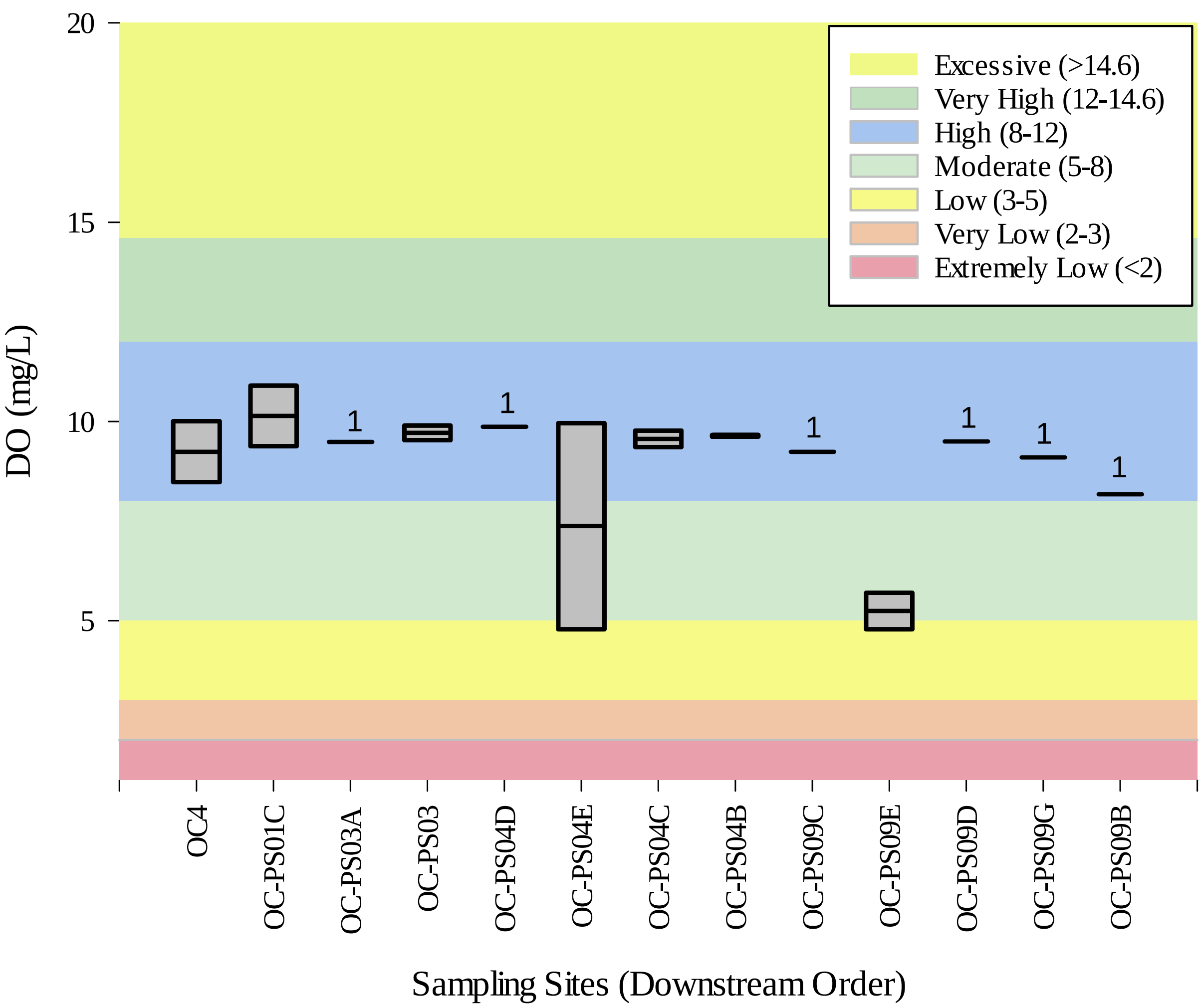


Figure 74. Dissolved oxygen levels for Phase 3 Onondaga Creek point source trackdown sampling locations (2016-2017). Unless specified, the number of samples collected to generate boxplots is N=2.

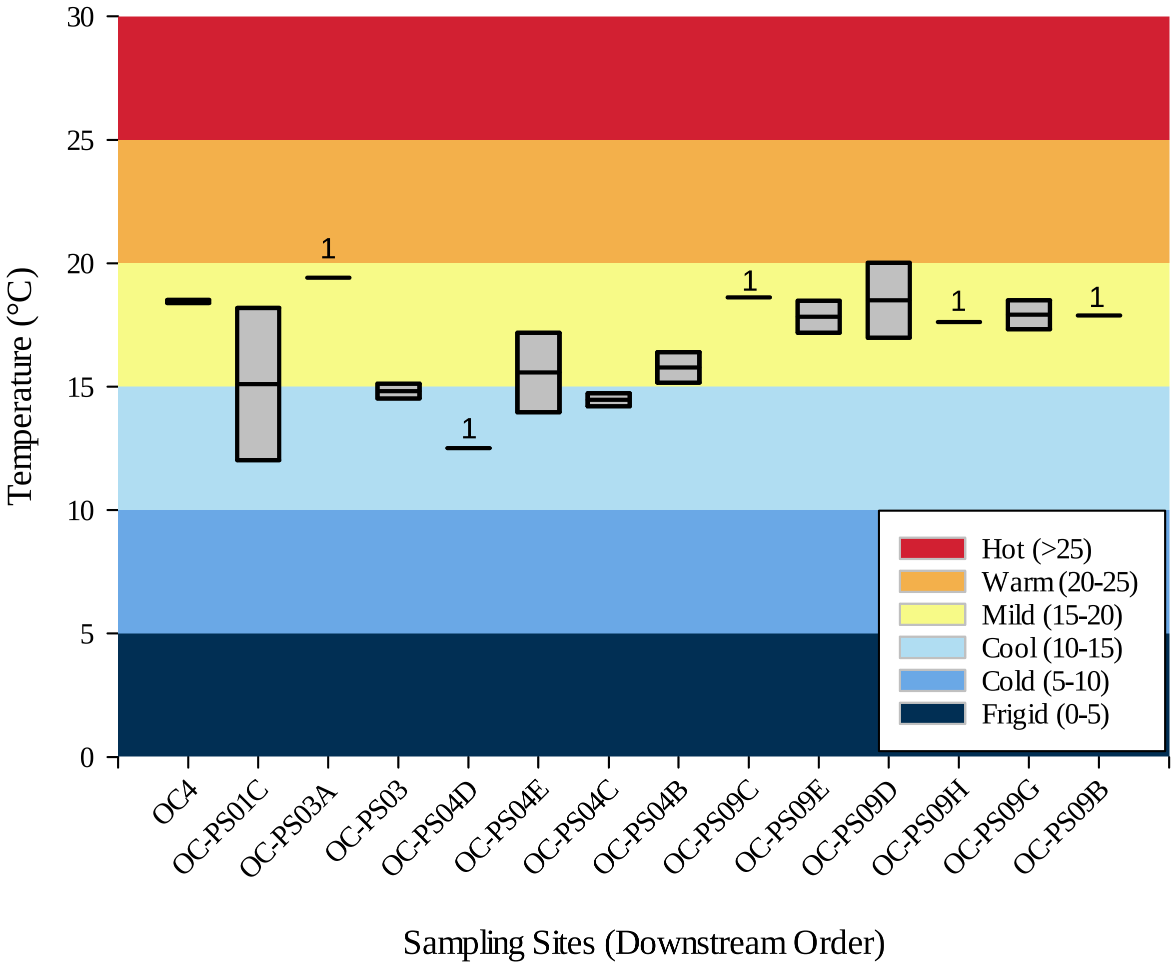


Figure 75. Temperature levels for Phase 3 Onondaga Creek point source trackdown sampling locations (2016-2017). Unless specified, the number of samples collected to generate boxplots is N=2.

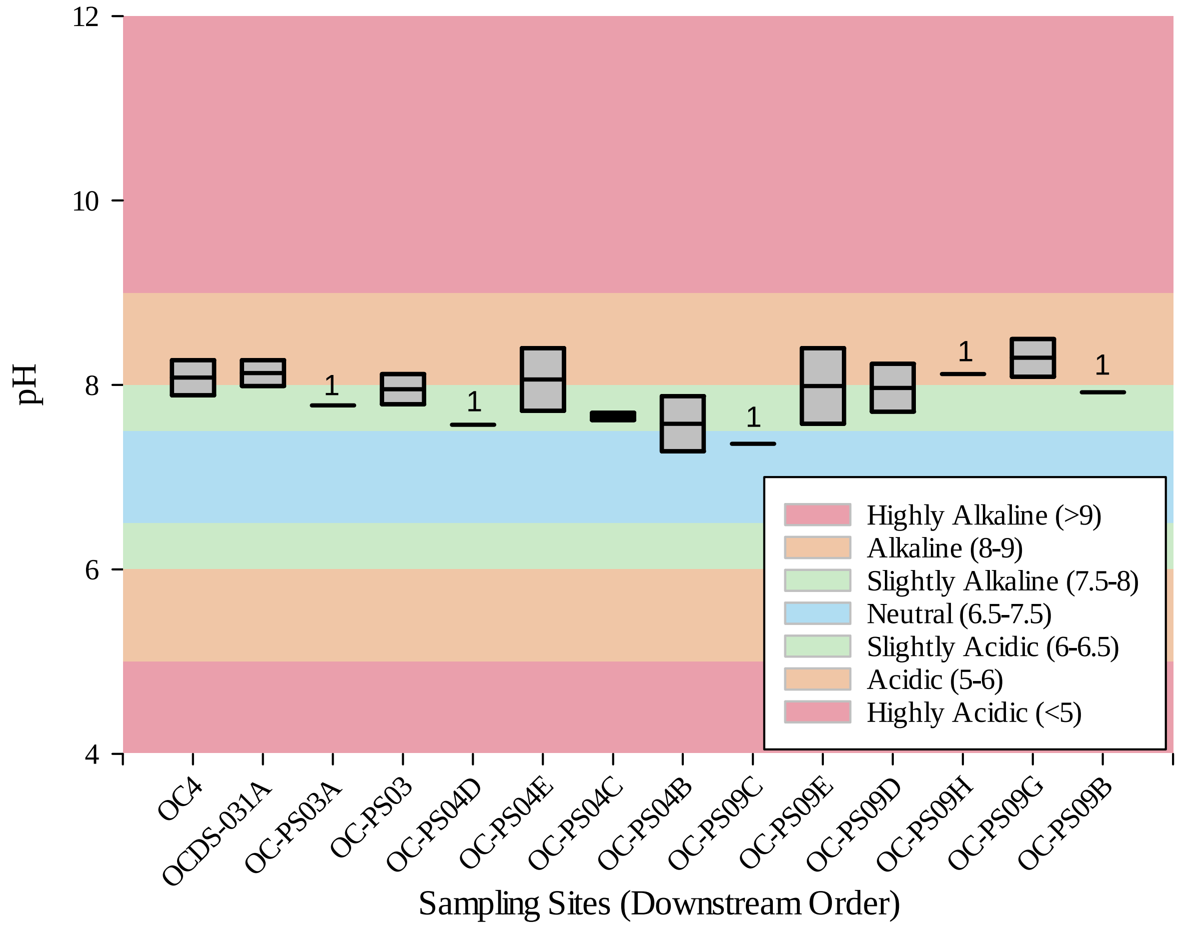


Figure 76. pH levels for Phase 3 Onondaga Creek point source trackdown sampling locations (2016-2017). Unless specified, the number of samples collected to generate boxplots is N=2.

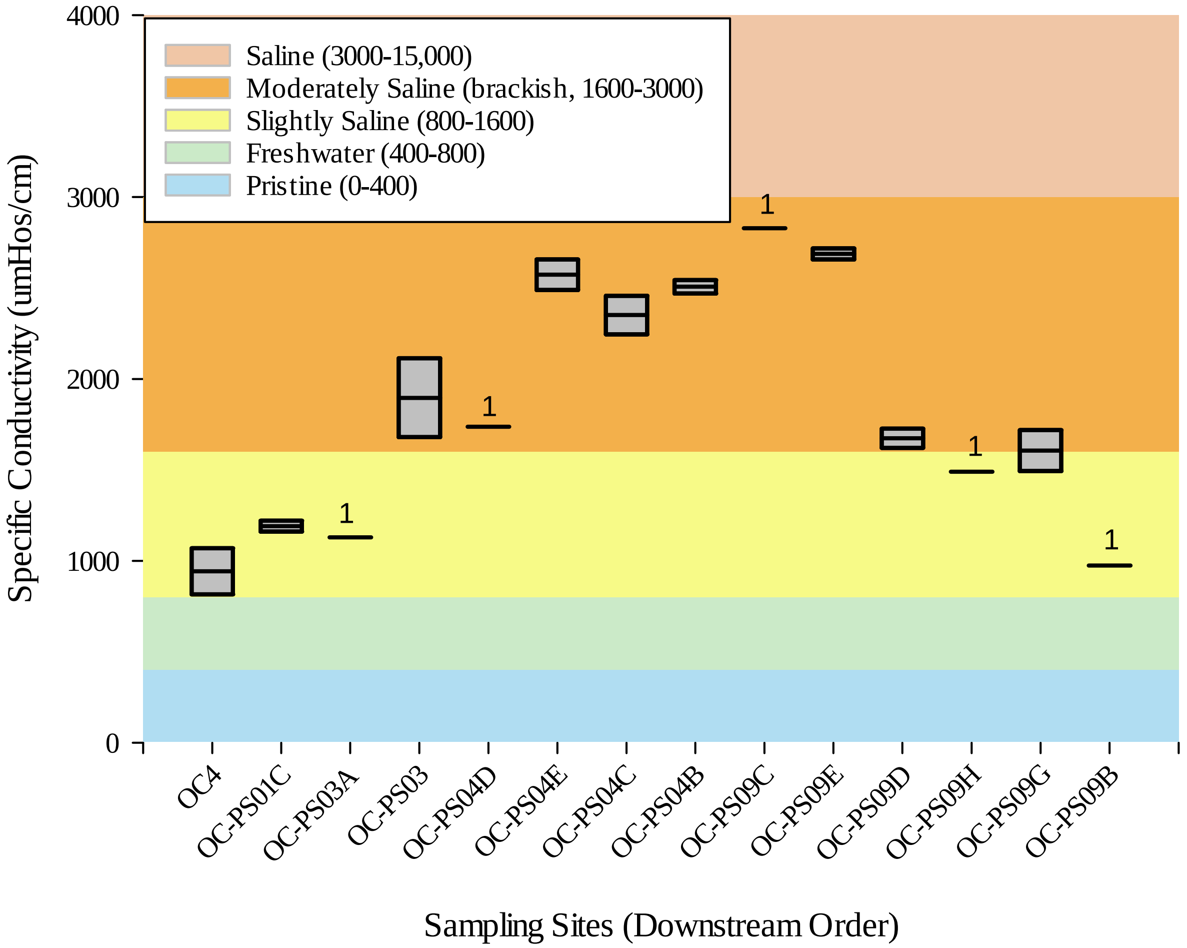


Figure 77. Specific conductivity levels for Phase 3 Onondaga Creek point source trackdown sampling locations (2016-2017). Unless specified, the number of samples collected to generate boxplots is N=2.

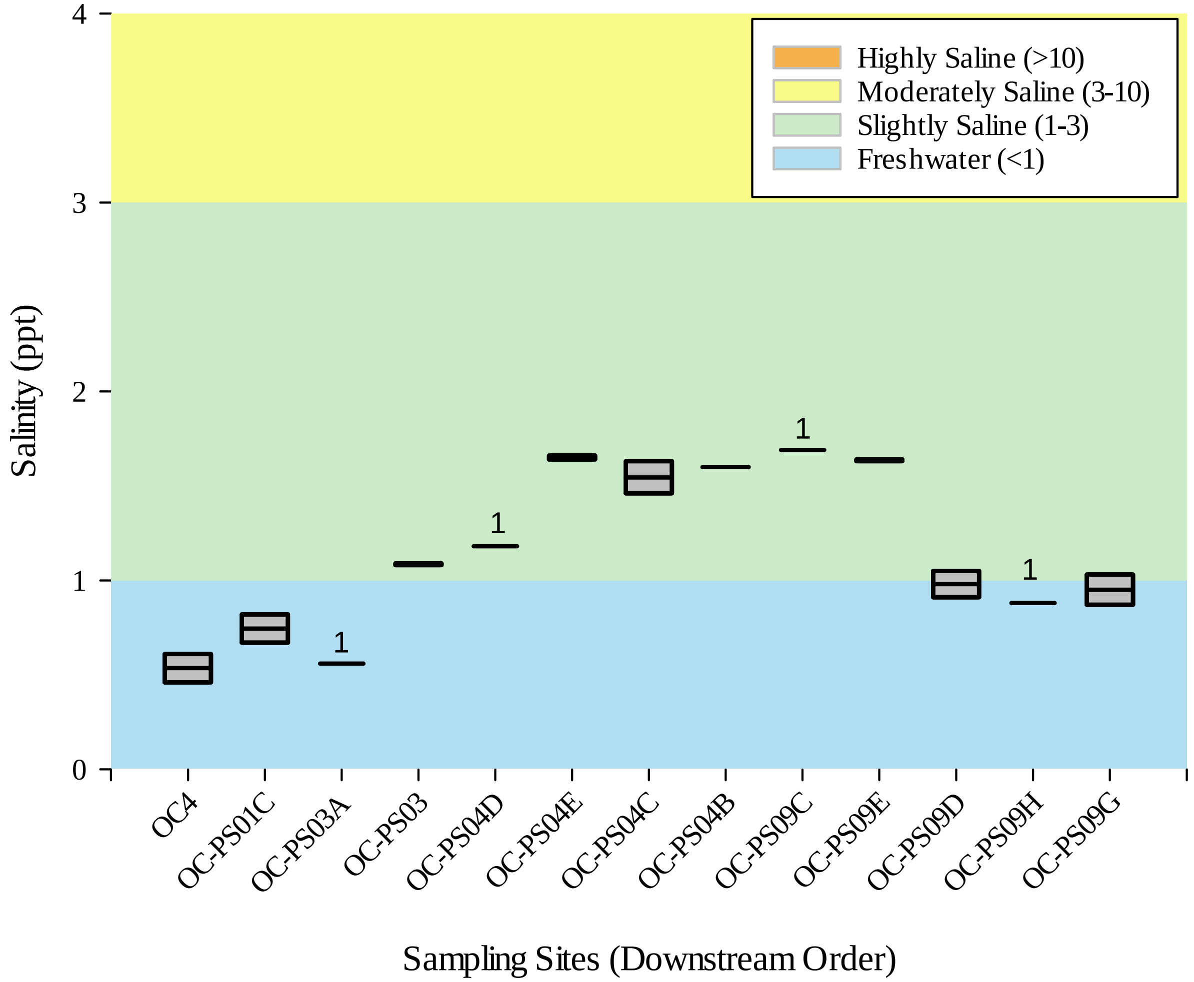
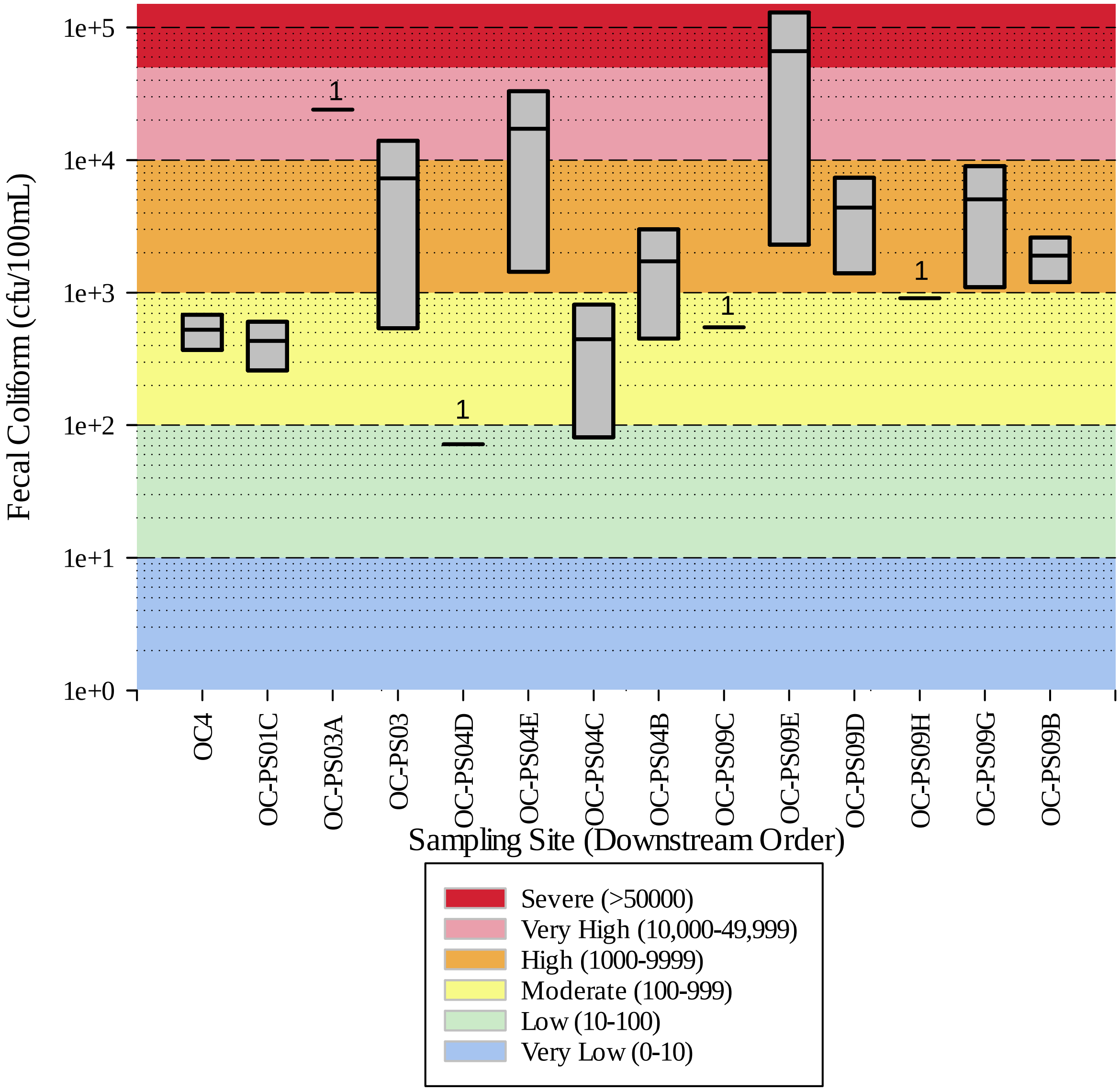


Figure 78. Salinity levels for Phase 3 Onondaga Creek point source trackdown sampling locations (2016-2017). Unless specified, the number of samples collected to generate boxplots is N=2.



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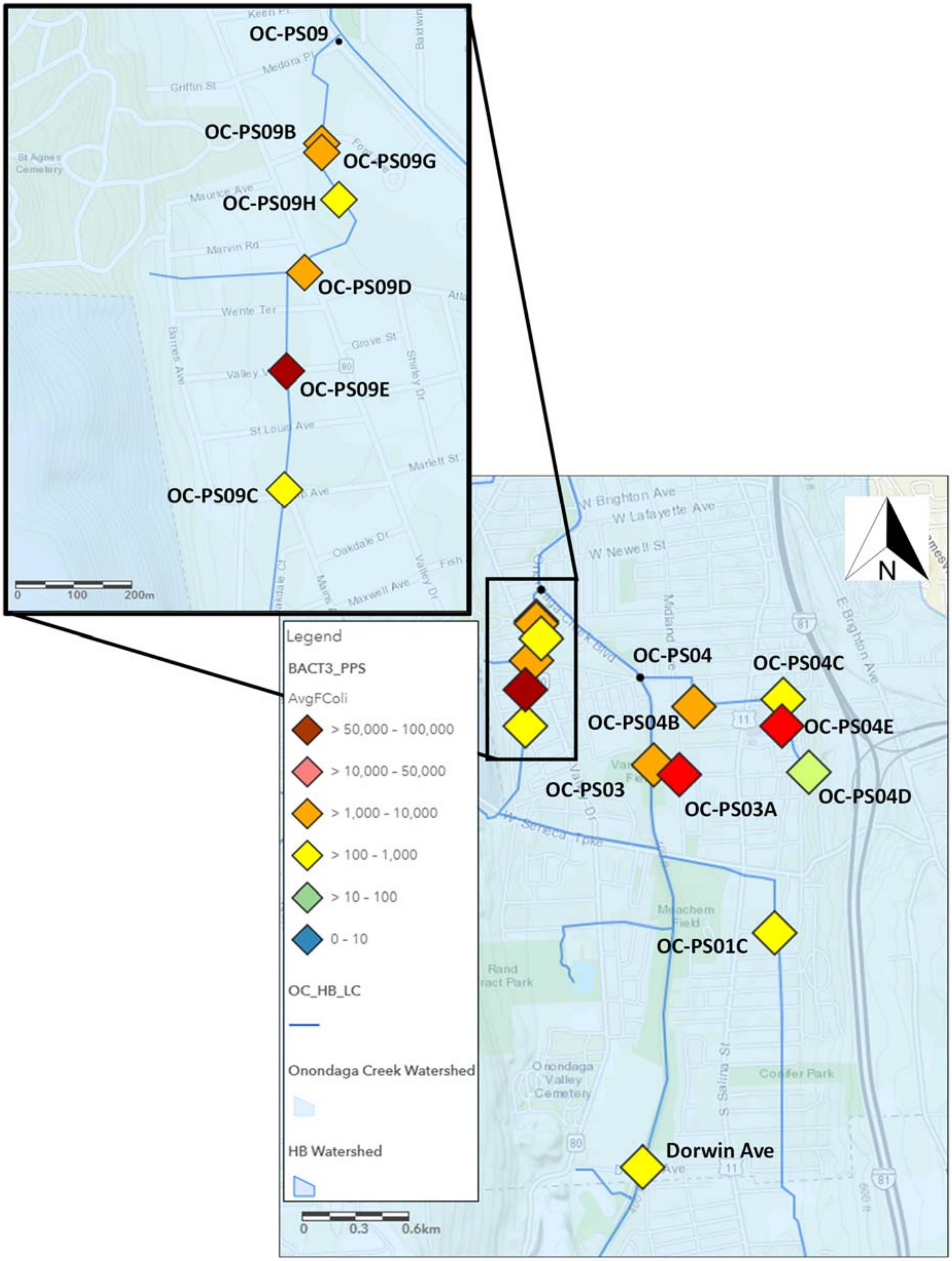


Figure 80. Average fecal coliform (cfu/100 mL) levels for Phase 3 Onondaga Creek point source trackdown sampling locations (2016-2017).

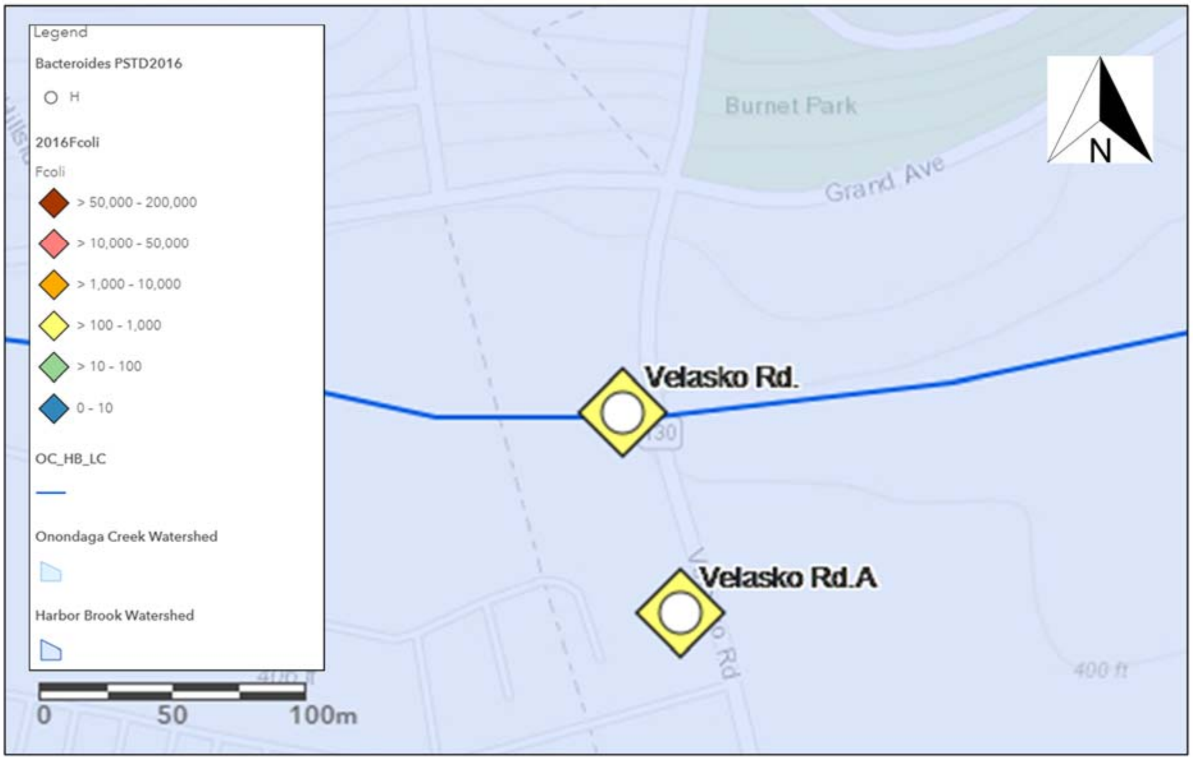


Figure 81. *Bacteroides* results for 2016 Harbor Brook point source trackdown sampling locations. Fecal coliform (cfu/100 mL) values are denoted by diamonds. Circles denote *Bacteroides* results: H = positive results for human sources.

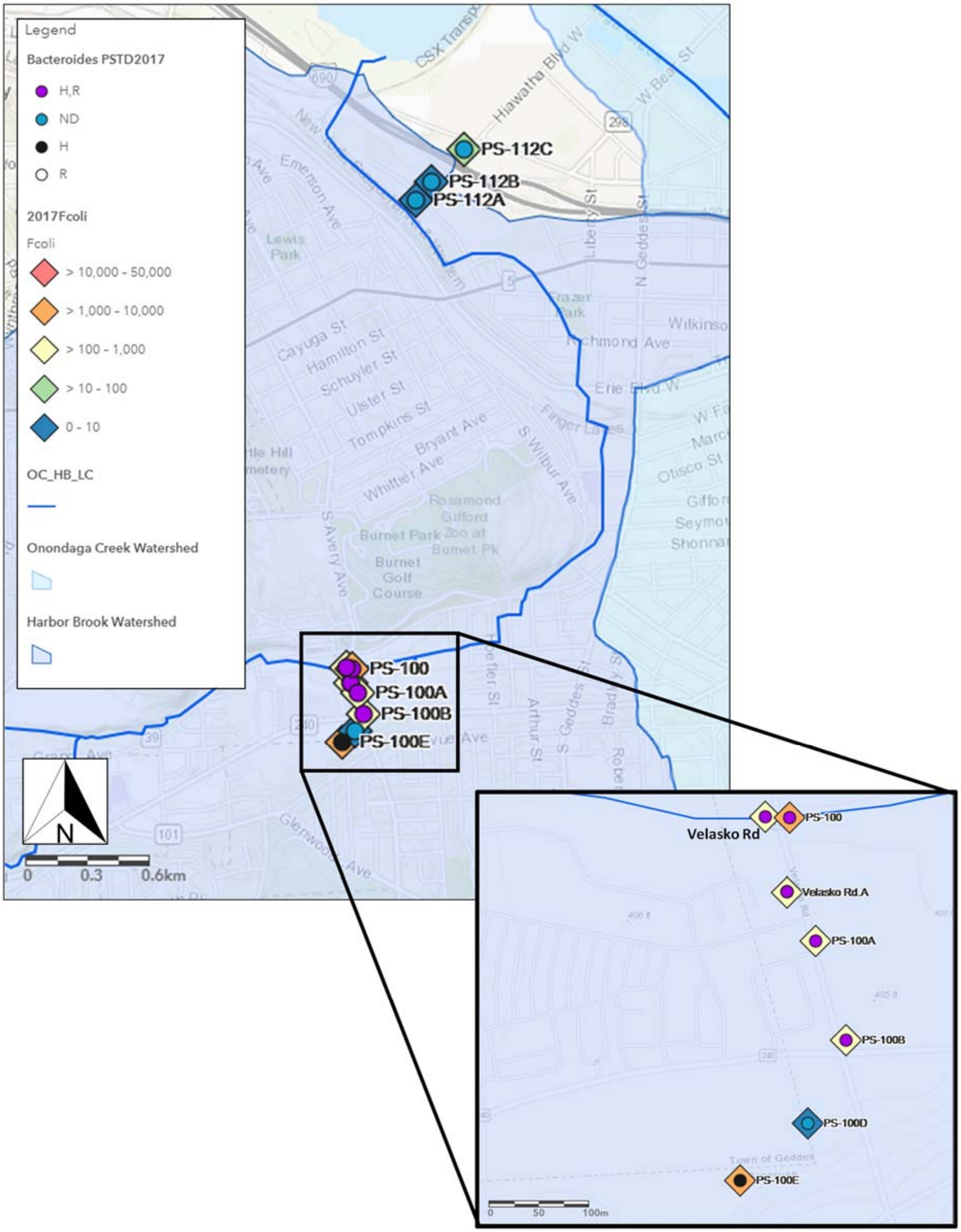
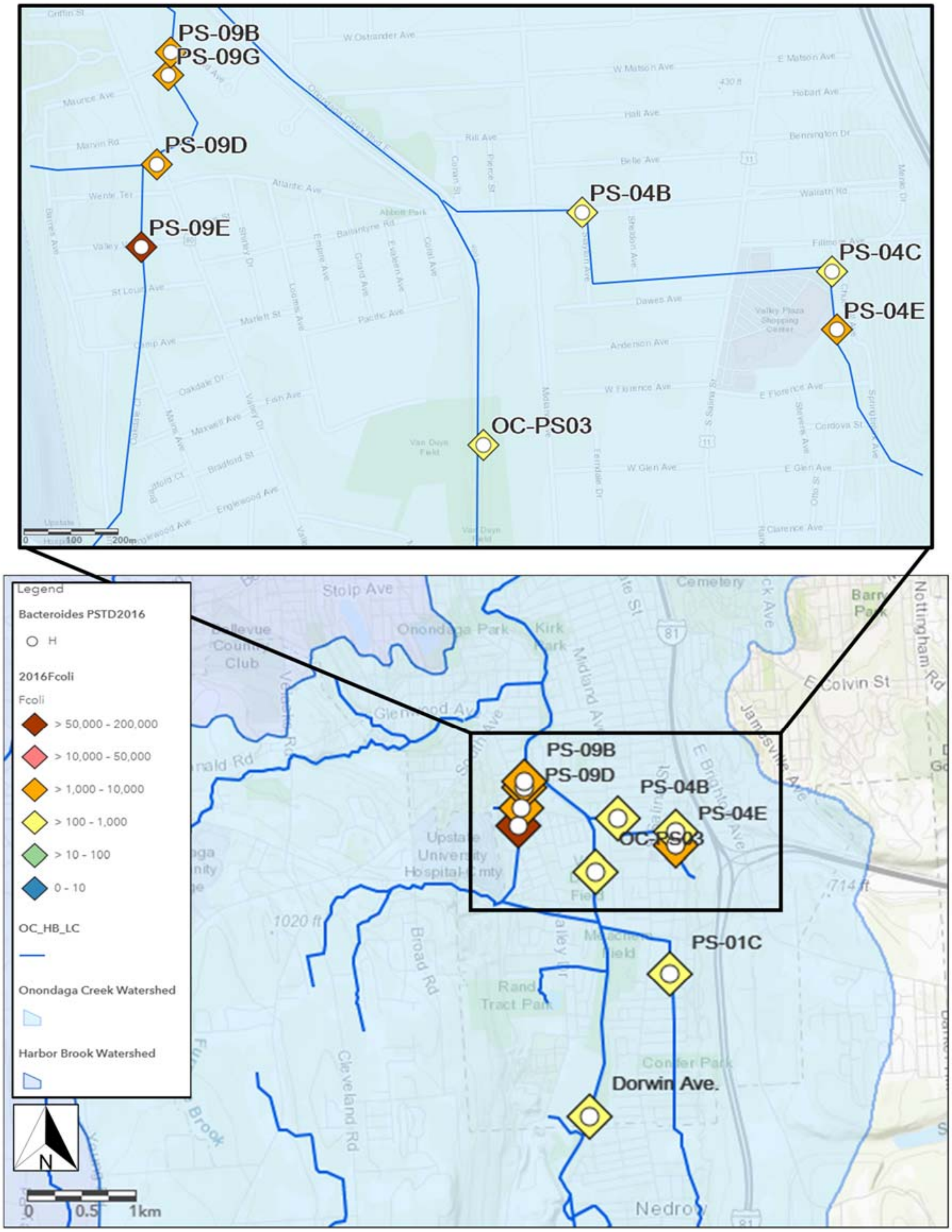


Figure 82. *Bacteroides* results for 2017 Harbor Brook point source trackdown sampling locations. Fecal coliform (cfu/100 mL) values are denoted by diamonds. Circles denote *Bacteroides* results for: H = positive for human sources; R = positive for ruminant sources; HR = positive for human and ruminant sources; ND = non-detect.



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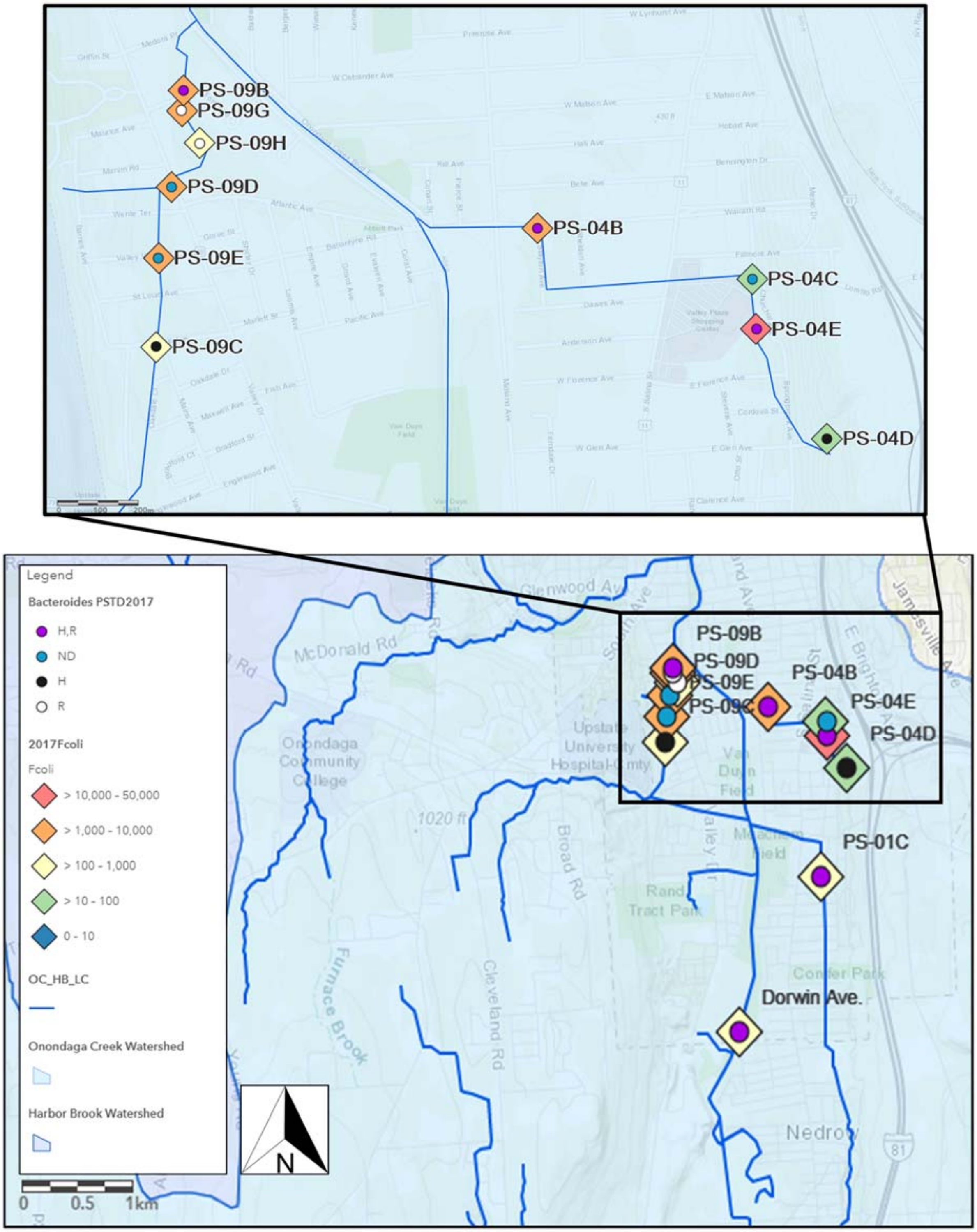

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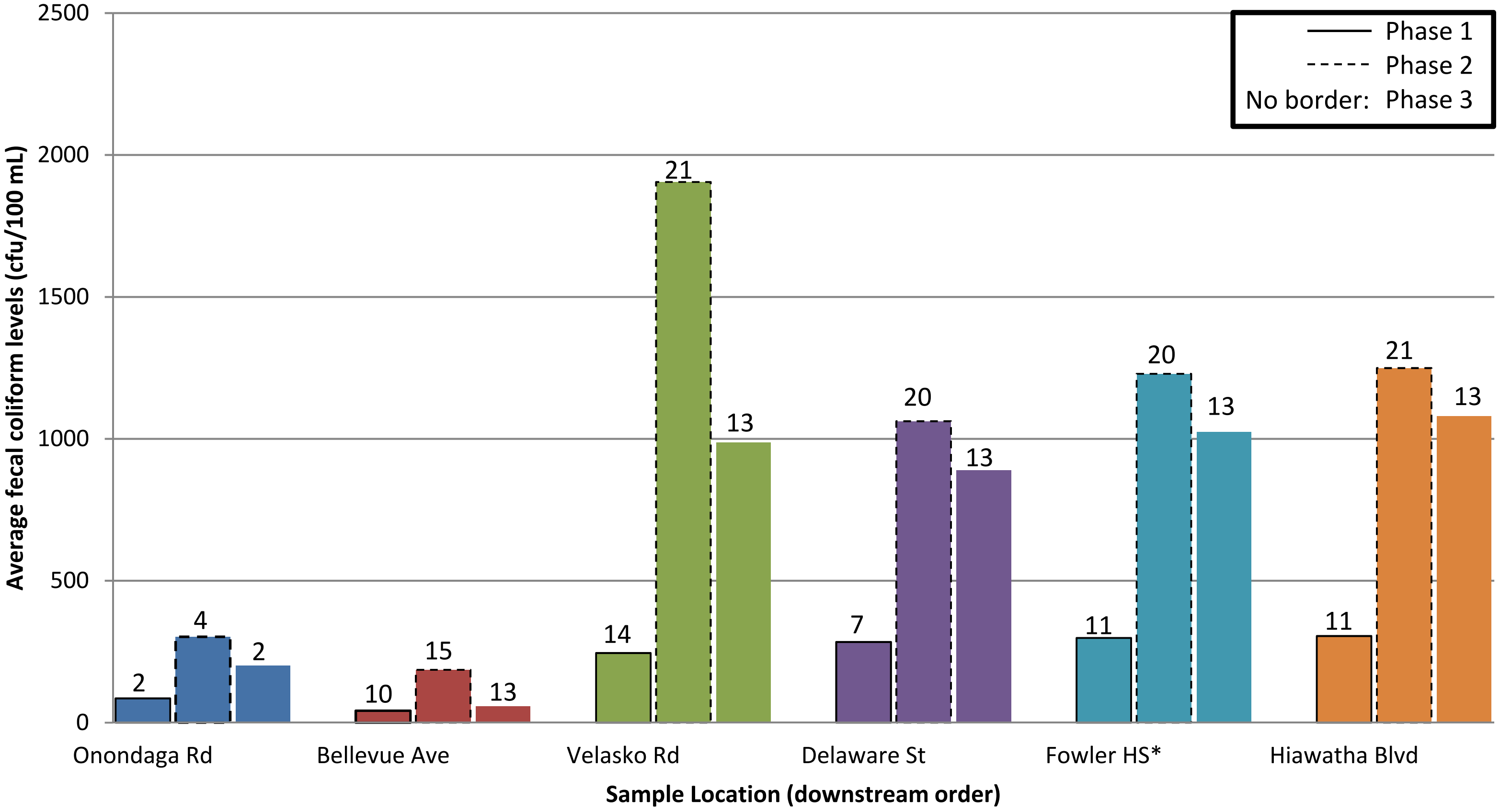

Figure 85. Temporal differences in average fecal coliform levels at routine sampling locations in Harbor Brook for Phases 1-3. Locations are arranged in downstream order. The number of sampling events per site per phase are shown above each bar. Locations where average fecal coliform concentrations are significantly different are denoted with an asterisk.

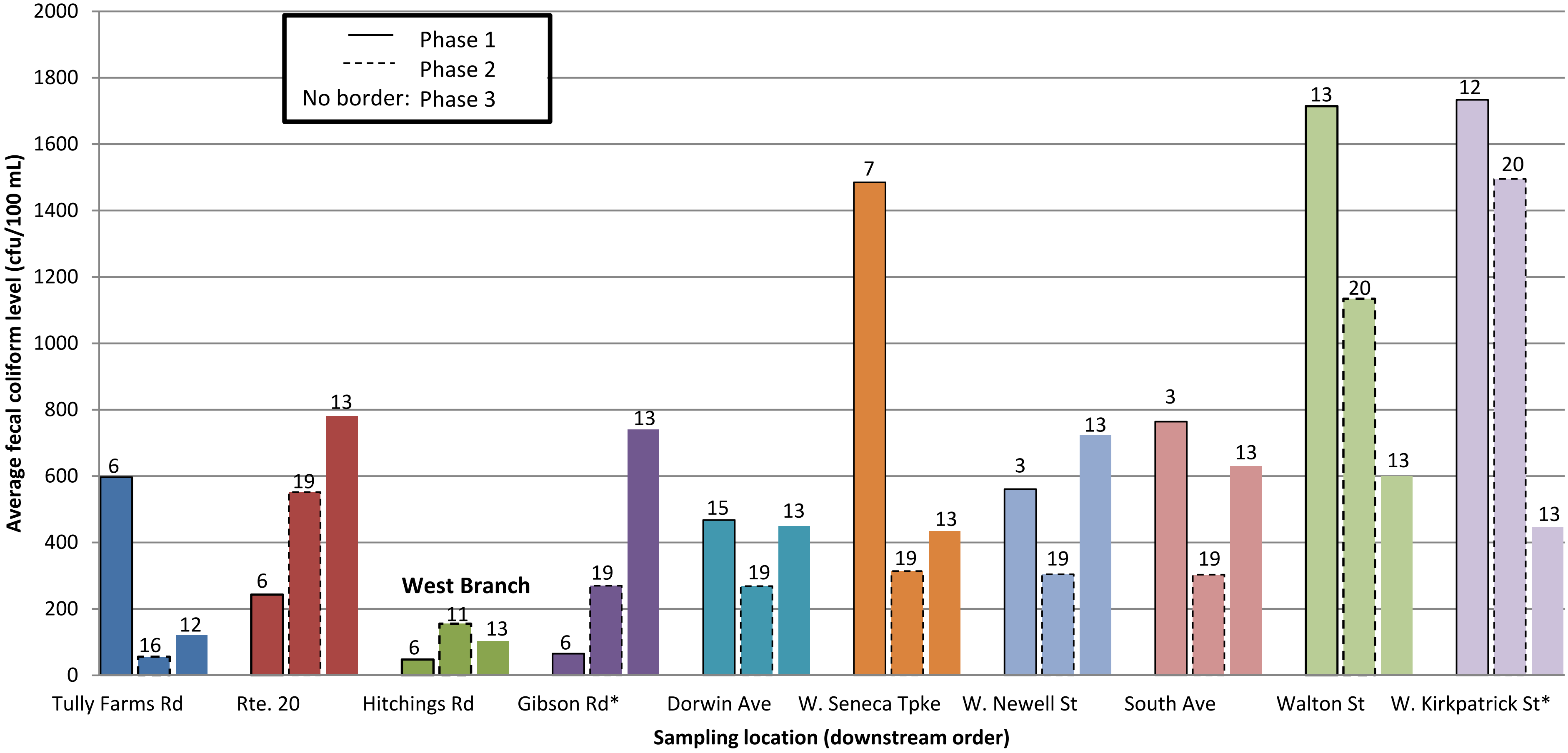

Figure 86. Temporal differences in average fecal coliform levels at routine sampling locations in Onondaga Creek for Phases 1-3. Locations are arranged in downstream order. The number of sampling events per site per phase are shown above each bar. Locations where average fecal coliform concentrations are significantly different are denoted with an asterisk.

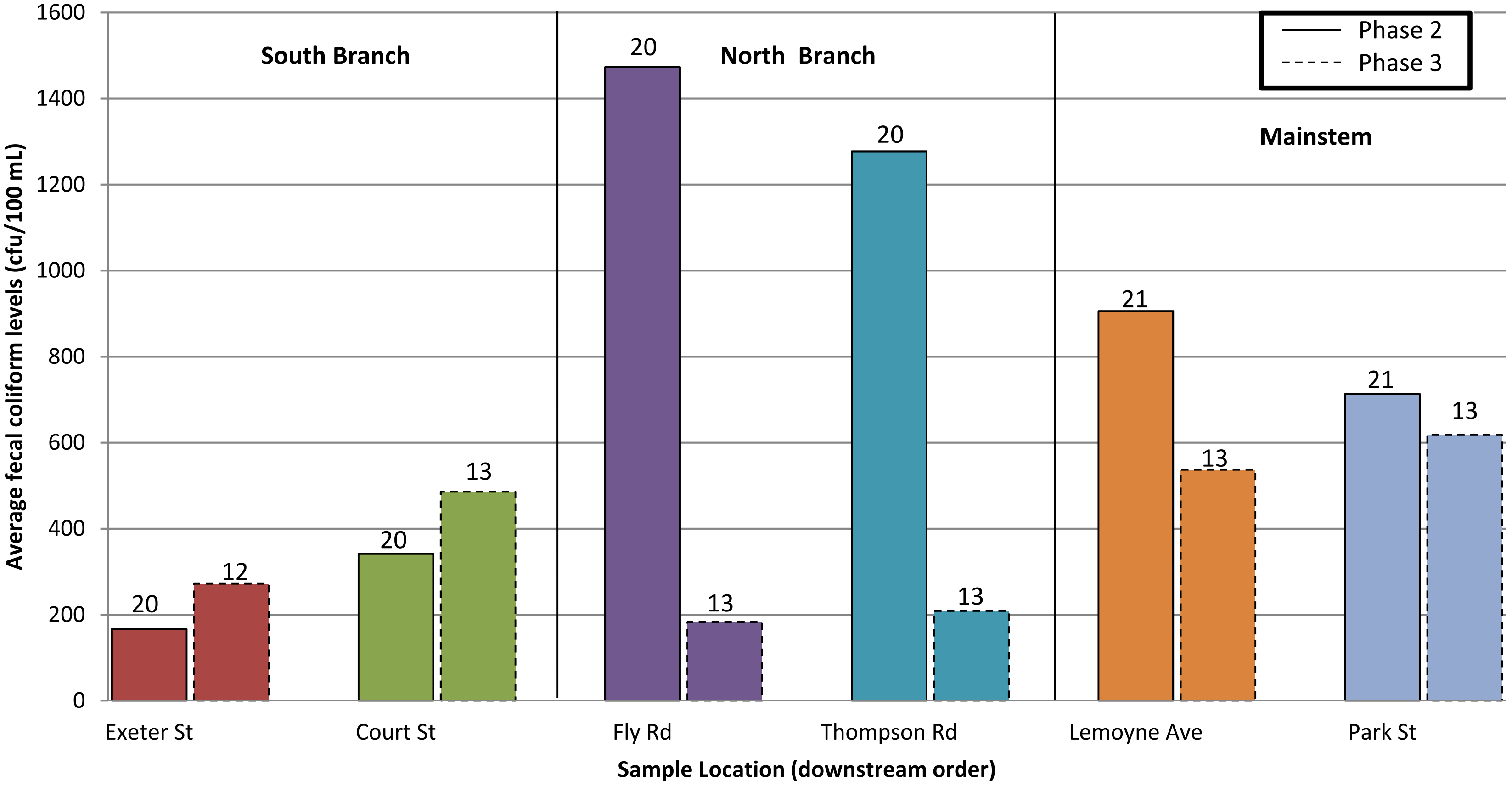

Figure 87. Temporal differences in average fecal coliform levels at routine sampling locations in Ley Creek for Phases 2 and 3. Locations are arranged in downstream order. The number of sampling events per site per phase are shown above each bar. Locations where average fecal coliform concentrations are significantly different are denoted with an asterisk.

Chapter 2

Biological Monitoring

(Task 7)

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1. Introduction

High bacterial concentrations and chemical contamination can significantly degrade water quality, pose health concerns, impact aquatic biota, and ultimately destroy the recreational and economic value of waterbodies. Studies conducted by the Onondaga Environmental Institute (OEI) and Onondaga County Department of Water Environment Protection (OCDWEP) in recent years have identified multiple sources of bacterial inputs to the Onondaga Lake watershed during both dry and wet-weather conditions. This suggests that sources other than precipitation-driven releases from Combined Sewer Overflows (CSOs) play a significant role in high bacteria loadings and concentrations in tributaries to Onondaga Lake. In 2007, OEI conducted a study which examined the biological communities (fish and benthic macroinvertebrates) and physical habitat of select sites in the Onondaga Lake Watershed (OEI 2008). The results of this study found that the level of impairment for physical habitat and biotic integrity increased downstream. More recently, OEI conducted a comprehensive ecological study in the upper Onondaga Creek watershed that attempted to understand the effects of multiple anthropogenic and natural stressors on stream condition (OEI 2014). The results of the study identified the impacts of agricultural practices on bacteria and nutrient loading on stream water quality and biological condition. Moreover, the results highlighted how these practices are exacerbated by heavy precipitation events. The effects of the Tully Valley mudboils were also found to be significantly impairing upper Onondaga Creek. The combined effects, of which, not only degrade upper Onondaga Creek, but impact and compound the issues identified in the lower watershed (e.g., dry-weather point source discharges).

Phases 1-3 of the Microbial Trackdown Study (MTS) have identified spatial and temporal changes in bacterial contributions to Harbor Brook, Onondaga Creek, and Ley Creek during dry weather. While at least 16 known corrections have been made during the MTS, there remains numerous dry-weather discharges that continue to impair water quality in all three tributaries. The long-term effect of those discharges on water quality as it relates directly to biotic condition has not been well studied in the Onondaga Lake watershed. Therefore, the inclusion of biological data in the MTS would help to better understand the spatial and temporal effects of these known impacts to water quality and ecological integrity in the Harbor Brook, Onondaga Creek, and Ley Creek watersheds; the results of which can then be used to assess and prioritize stream sections based on the level of impairment as determined from biotic analyses and metrics.

The usefulness of biotic data for assessing stream condition has been well documented and is often the primary component of governmental and organizational water quality monitoring programs (Barbour et al. 1999). As a result, it was decided by the MTS Working Group in 2014 to include biotic sampling as part of Phase 3 sampling efforts. The goal of this task is to make water quality assessments at routine sampling locations (Task 3) in Harbor Brook, Onondaga Creek, and Ley Creek. In order to make such assessments, the objectives of this task are to: (1) Describe the benthic macroinvertebrate and fish communities at routine sampling locations; (2) Apply biotic index methods designed for sampling macroinvertebrates and implemented by the New York State Department of Environmental Conservation Stream Biomonitoring Unit (NYSDEC SBU) to assess water quality and impairment; (3) Apply an Index of Biotic Integrity (IBI) for fish communities to assess water quality and impairment; (4) Apply a Visual Habitat Assessment (VHA) that is implemented by the USEPA and outlined in their Rapid

Bioassessment Protocols for each sampling site in the Onondaga Lake Watershed; and (5) Assess temporal changes to the macroinvertebrate and fish communities, habitat quality, and water quality.

2. Rationale

Many projects tasked to develop water quality monitoring programs or determine water quality impairments, conduct biological assessments. Biological communities reflect the overall ecological integrity of a water body and the aggregation of potential stressors affecting assemblage structure. Thus, aquatic organisms can provide valuable information about the integrated effects of multiple stressors and environmental variables by illustrating deviations from 'model' community types in pristine or undisturbed environments that would otherwise not be detected by chemical analyses (Reynoldson and Metcalfe-Smith, 1992). Incorporating biotic sampling into monitoring programs is also a cost-effective alternative to toxicity testing and chemical analyses of pollutants. Barbour et al. (1999) notes the importance of a properly executed and thorough biological monitoring program, stating that such a program can, "improve [water quality] reporting, increase the effectiveness of pollution prevention efforts, and document the progress of mitigation efforts". The use of Rapid Bioassessment Protocols (RBP) in stream monitoring have become a commonly used and highly effective method for monitoring spatial and temporal changes in aquatic biota, as well as changes in habitat and water quality.

Water quality has a direct relationship with the biota living within the water body. Thus, an invested interest in water quality is an invested interest in the health, diversity and abundance of biota. The implementation of a biological sampling program in conjunction with microbial trackdown efforts can help to better elucidate the potential long-term effects of bacterial pollution on biotic condition and how it may compound other types of pollution and/or degradation.

2.1. Fish

Fish sampling is a critical component of water quality sampling programs. Most of the water quality designations pertain to fish assemblages and fishing restrictions. In New York State assigned designations such as "swimming/fishing", "fishing", "trout", and "trout spawning" are used to describe water quality and stream health. Fish is a common biotic assemblage that is incorporated into biological assessments of streams because (Barbour et al., 1999):

- Fish are long-lived and mobile; therefore, they are good indicators of temporal changes in habitat condition.
- Fish assemblages typically include species that occupy different trophic levels. Trophic structure is reflective of overall stream quality.
- Fish are of recreational and commercial value to humans.
- Fish are relatively easy to collect and identify to species.

- Environmental requirements, life history, and distribution of fish are well known, and such data are usually easily obtainable.

2.2. Benthic Macroinvertebrates

Benthic invertebrates play a significant role in the structure and function of aquatic systems. An intermediate between algae, zooplankton and fish, benthic macroinvertebrates are key members of an aquatic community that can be used in understanding trophic relationships (e.g. ecosystem energy flows, bioaccumulation, biomagnification and ecological stoichiometry). As a vital food resource for many species of fish, the study of macroinvertebrates is a critical component in developing a comprehensive understanding of lake and river systems (Voshell, 2002).

Bioassessment using macroinvertebrates has been a well-documented and widely accepted method for assessing water quality and impairment (Barbour et al. 1999, Rosenberg and Resh, 1993; Bode et al. 2002; Voshell, 2002; Davis and Simon, 1995). The use of aquatic invertebrates in biomonitoring studies is a reliable and common approach for several reasons (including, but not limited to):

- They are abundant in most streams, in a wide range of habitats (Bode et al. 2002).

- They are relatively stationary animals, in comparison to fish. Therefore, aquatic invertebrates can provide valuable information about the water quality of a particular location within a stream or lake and the extent of potential perturbations (Merritt and Cummins, 1996).

- They are sensitive to various environmental and anthropogenic impacts, such as chemical pollution, agricultural runoff, changes in temperature and habitat modifications (Bode et al, 2002).

- They allow for rapid assessment of stream conditions based on the presence or absence of certain species, as the sensitivity to various impacts varies between species (Merritt and Cummins, 2008; Barbour et al. 1999; Bode et al. 2002).

- They are reasonably easy and inexpensive to collect (Bode et al. 2002; Voshell, 2002).

- They have comparatively long life cycles, making observations in temporal changes to population and abundance possible (Merritt and Cummins, 2008).

The following guidance documents were used to develop the methods for this study:

- Duffy BT. 2018. Standard operating procedure: Biological monitoring of surface waters in New York State. Albany (NY): NYSDEC Division of Water.

- Smith, AJ, Heitzman DL, and Duffy BT. 2009. Standard Operating Procedure: Biological Monitoring of Surface Waters in New York State. Albany (NY): NYSDEC Division of Water, 161 pp.

- Barbour MT, Gerritsen J, Snyder BD, and Stribling JB. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

- Bode RW, Novak MA, and Abele LE. 1990. Biological Impairment Criteria for Flowing Waters in New York State. Albany (NY): NYSDEC Stream Biomonitoring Unit, Division of Water.

3. Methods

Sampling was proposed to be performed at all routine sampling locations (N=23; Fig. 1). However, due to accessibility and safety issues, several routine sites were not sampled (Table 1).

Table 1. Phase 3 MTS Biological sampling locations (2015).

Stream	Location	Setting[1]	Fish	Macroinvertebrates
Harbor Brook	Onondaga Road	R	X	X
	Bellevue Avenue	R	X	X
	Grand Avenue	R	X	X
	Velasko Road	U	X	X
	Delaware Street	U	X	X
	Fowler High School	U	X	X
	Hiawatha Boulevard	U	X	X
Onondaga Creek	Tully Farms Road	R	X	X
	NY Route 20	R		
	Gibson Road	R	X	X
	Hitchings Road (West Branch)	R	X	X
	Dorwin Avenue	U	X	X
	W. Seneca Turnpike	U	X	X
	W. Newell Street	U		
	South Avenue (N)	U		
	Walton Street	U	X	X
	W. Kirkpatrick	U	X	X
Ley Creek	Fly Road	NB	X	X
	Thompson Road	NB	X	X
	Exeter Street	SB	X	X
	Court Street	SB	X	X
	Lemoyne Ave	MS	X	X
	Park Street	MS		X

[1] R = rural, U = urban, NB = North Branch, SB = South Branch, MS = Mainstem.

Specifically, three locations in Onondaga Creek and one site in Ley Creek could not be sampled for fish and/or macroinvertebrates due to unsafe conditions (e.g., high flows, no creek access, too deep). To eliminate the effects of seasonal changes to ambient conditions, all sampling was conducted within approximately 6 weeks, between June 4, 2015 and July 23, 2015.

3.1. Fish Sampling

A Smith Root Model 12 Backpack Electrofisher was used for most fish sampling[1]. Prior to unit operation, all technicians were trained in proper electrofishing methods. This includes how to operate the unit, appropriate power levels, how to change the battery, proper maintenance, and how to use the unit in the field for the most effective and safe sampling (i.e., how to move the anode and being aware of surrounding people and their location to the equipment).

Prior to sampling, the stream reach was delineated according to the representative habitat requirements (i.e., presence of reach, run, and riffle). Where natural barriers (e.g., waterfalls, log jams) were absent, a block seine was placed at the most upstream portion of the reach. Electrofishing began at a shallow riffle, or other physical barrier, and continued upstream to the block seine or natural barrier. The field crew consisted of three people, with one person operating the electrofisher unit and two members capturing fish with a scap net. The crew worked upstream, using a side-to-side sweeping motion between stream banks. All captured fish were placed in buckets for subsequent identification. Crew members wore polarized sunglasses to maximize capture efficiency.

All fish were measured using total length (recorded in millimeters), identified to species and recorded onto a field data sheet (Appendix B [Appendix A.1]). Anomalies (e.g., evidence of parasites, deformities, etc.) on individual fish were noted. If necessary, voucher specimens were retained to confirm proper identification. Fish not kept for collection purposes were released, unharmed at the point of capture following processing.

3.2. Macroinvertebrate Sampling

The kick sampling method is widely used for easily and rapidly collecting macroinvertebrates. The stream bottom was disturbed through a series of kicks. Dislodged organisms were collected downstream in an aquatic D-frame net (12” frame, 1,200 µm mesh opening). Sampling was conducted using the methodology developed and utilized by the Stream Biomonitoring Unit of the NYSDEC (Bode et al. 1990; Duffy et al. 2018). An aquatic net was placed approximately 0.5 m downstream of where the stream bottom was disturbed. Sampling was conducted for 5 minutes for a distance of 5 meters, moving in a diagonal transect to stream flow when possible. Where kick net sampling could not be performed due to deep or unsafe conditions, the jab sampling method was used (Duffy et al. 2018), whereby the stream

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[1] Seining had to be performed in Onondaga Creek at Gibson Rd and Kirkpatrick St in place of backpack electrofishing. At Gibson Rd, seining was performed due to high water levels and poor visibility. At Kirkpatrick St, seining was performed due to high salinity concentrations, which affect the performance and efficacy of the backpack shocker. A 10-m bag seine was utilized at these locations, whereby three people worked to drag the seine along approximately a 5-meter section of suitable stream habitat, working in an upstream manner.

banks were sampled using a kick net to disturb the habitat along the stream banks. Therefore, sampling only captures the nearshore macroinvertebrate community and not the benthic community in the stream channel. This type of sampling was only performed at Park St in Ley Creek.

Once sampling was complete, the content of the net was emptied into a pan. Large debris was removed from the sample, after all organisms have been removed from the debris. The remaining contents of the sample were sieved through a U.S. Standard No. 35 mesh sieve (0.5 mm) and transferred to a Whirl-pak® bag, where it was preserved in 95% ethanol. Labels with the date, location information (waterbody, county and township) and the collector(s) were placed both on the outside and inside of the bag to prevent the misplacement and switching of samples. The same information was also recorded on a separate datasheet that contained additional information about the stream conditions (Appendix B [Appendix A.2]).

Sorted and unsorted samples (if so requested) were sent to Watershed Assessment Associates (WAA) (Schenectady, NY), where Society of Freshwater Science-certified taxonomists identified organisms to the lowest taxonomic level achievable (i.e., species). Samples were shipped following WAA and OEI COC procedures (Appendix B [Appendix B.3]). Analyzed samples were returned to OEI and archived. Sample results were returned to OEI as an Electronic Data Delivery (EDD) and a summary report.

3.3. Visual Habitat Assessment

In-stream and surrounding habitat was evaluated using the Visual-based Habitat Assessment (VHA) method developed by the US Environmental Protection Agency (EPA) as part of the rapid bioassessment protocols used for wadeable streams (Barbour et al., 1999). Physical habitat was assessed and recorded on a standardized datasheet (Appendix B [Appendix A.3]). The VHA is a semi-quantitative method that allows for a comparison of habitat quality among sites. Two different data sheets were utilized for this study, depending on stream gradient (high gradient and low gradient) (Appendix B [Appendix A.4]). For example, low gradient streams contain more pools, whereas high gradient stream contain more riffles. These data sheets take into consideration these differences and alter the in-stream parameters accordingly. Barbour et al. (1999) recommends that at least one other biologist helps conduct the VHA at each site to reduce any bias that would be associated with only one person conducting the survey. Therefore, field technicians assisted the field team leader conduct the VHA.

General water chemistry and quality was measured and recorded in the field at each sampling location using a YSI 650 MDS hand held device equipped with a 6820 V2-2 water quality monitoring probe. Measured parameters included pH, dissolved oxygen, specific conductivity, temperature, and turbidity. Meteorological data was collected from publicly available sources located in the Tully Valley and City of Syracuse, such as the USGS, MOST, and METRO gauges. Like other Phase 3 tasks, all biotic sampling was performed during dry-weather conditions.

3.4. Data Analysis

All analyses performed for this task adhered to the procedures outlined in the Phase 3 Quality Assurance Program Plan (QAPP) (Appendix B) and the Data Analysis & Interpretation Plan (DAIP) (Appendix C). Where possible, comparisons between different assemblage-specific indices and VHA scores were performed in order to examine potential relationships and concordance between fish and macroinvertebrate communities in response to stream condition. Simple linear regressions (R^2) were performed and graphically displayed as scatter plots. To compare stream condition among the three streams, box plots were generated for fish, macroinvertebrate, and habitat metrics. Box plots include the entire spread of data for each respective stream, as denoted in (Fig. 2).

3.4.1. Fish Analytical Methods

Analyses included species lists, computation of metrics of fish community integrity, and descriptive statistics of all environmental variables for which data were collected. Calculated fish community metrics include:

- *Fish abundance*: total number of individuals collected/location

- *Shannon diversity (H')*: takes into account both species richness (number of species) and evenness (number of individuals in each species) and is calculated using the formula (Shannon and Weaver 1949):

  $$H' = -\left[\sum_{i=1}^{k}(p_i)\,(\ln p_i)\right] \qquad \textbf{[eq.1]}$$

  Where: p_i = percentage of species i in the sample
  k = species

- *Species richness*: total number of species per location

- *Index of Biotic Integrity (IBI)*: Twelve metrics, from three major categories comprise the IBI (Table 2). Scores range from 60 (excellent) to 12 (very poor). The IBI developed for the northern Mid-Atlantic drainage slopes (Daniels et al. 2002) will be used as reference for this study.

Table 2. Metrics used to calculate the fish Index of Biotic Integrity (IBI).

Category	Metric	Score 5	 3	 1
Resident fish richness and composition	Species richness	Maximum Species Richness Line[1]		
	Number of benthic-insectivorous species	Maximum Species Richness Line		
	Number of water column species	Maximum Species Richness Line		
	Number of terete minnow species	Maximum Species Richness Line		
	Percentage of dominant species	<40%	40-55%	>55%
	Percentage of white suckers (*Catostomus commersoni*)	<3%	3-15%	>15%
Trophic composition	Percentage of generalists	<20%	20-45%	>45%
	Percentage of insectivores	>50%	25-50%	<25%
	Percentage of top carnivores	>5%	1-5%	<1%
Fish abundance and condition	Fish density (fish/100 m^2)	Maximum Density Line		
	Percentage of species represented by 2 size classes	>40%	15-40%	<15%
	Percentage of individuals with diseases, tumors, fin damage, or other anomalies	0%	0-1%	>1%

[1] Adapted for the northern mid-Atlantic drainage basin (Daniels et al. 2002). The maximum species richness line (MSRL) is based on empirical data that suggest species richness increases with increasing stream size (Daniels et al. 2002). This method compensates for variation in species richness related to stream size. Species richness is compared with watershed area (km^2). Score criteria regions (i.e., 1, 3, and 5) are established for MSRL graphs and scores are computed based on where species richness falls on the graph, in relation to stream size. For example, low species richness (< 3) for a site with a watershed area > 100 km^2 receives a score of 1. This same method is applied for the Maximum Density Line.

3.4.2. Macroinvertebrate Analytical Methods

The results of the 100-organism subsample were used to perform the following calculations:

- *Taxon richness*: total number of taxa collected in a sample (e.g., genus)
- *Shannon diversity (H′)*: refer to Equation 1
- *Ephemeroptera-Plecoptera-Trichoptera (EPT) richness*: total number of taxa (e.g., species) of mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) found in a 100-organism subsample.
- *Hilsenhoff Biotic Index (HBI)*: measures organic (sewage) pollution effects on benthic invertebrate communities (Hilsenhoff 1987). Each species is assigned a tolerance value on a scale of 0 (intolerant) to 10 (tolerant). HBI values will be obtained from Smith et al. (2009) and scores can be calculated with the equation:

  $$\mathrm{HBI} = [\textstyle\sum_{i=1}^{k} S_i \text{ (tolerance value)}/\mathrm{N} \qquad \textbf{[eq. 2]}$$

  Where: S = number of individuals for each species *i*
  n = total number of individuals collected for each sample
  k = total number of species
- *Dominance-3 (DOM3)*: percent contribution of the three most dominant species (Bode et al. 2002)
- *"Non-Chironomidae and Oligochaeta" (NCO) richness*: total number of taxa found in all groups, except those in the groups Chironomidae and Oligochaeta.

- *Percent Model Affinity (PMA)*: measures the similarity of the sample collected to a model non-impacted community in New York State (Novak and Bode 1992). The percent similarity is calculated for each sample to a model kick sample community of 40% Ephemeroptera, 20% Chironomidae, 10% Trichoptera, 10% Coleoptera, 10% Other, 5% Plecoptera, and 5% Oligochaeta. The sample community percent contribution is compared to the model community and the lesser of the two values is used. The total sum of the lesser values for each taxonomic category is the PMA value.

- *Impact Source Determination (ISD)*: estimates the percent similarity of macroinvertebrate assemblages to model macroinvertebrate community types in an attempt to identify the type of impact (as opposed to severity) on macroinvertebrate assemblages (Riva-Murray et al. 2002). Six types of impacts are categorized in the ISD metric: (1) nutrients/pesticides, (2) municipal/industrial, (3) toxic, (4) sewage/effluent, (5) siltation, and (6) impoundment (Appendix D.1). The greatest percent similarity (≥50%) of the collected data to a particular model data indicates the likely source impact. If percent similarity was <50% for all source types, then data would suggest there was no impact, or that water conditions were good.

- *Biological Assessment Profile (BAP)*: multimetric index that integrates, and transforms select macroinvertebrate indices to a common scale for the assessment of water quality (Duffy et al. 2018). Values are standardized using formulas specific to each metric (Smith et al. 2009). Those values are summed and then divided by the number of metrics used. Values range between 0 (severely impacted) and 10 (non-impacted) and collectively represent the BAP. Two different models were used for BAP calculations: (1) kick net sampling from riffle habitat and (2) net jab sampling from slow, sandy streams (Smith et al. 2009)[2].

4. Results

4.1. Harbor Brook

4.1.1. Fish Community

Overall, the fish community in Harbor Brook was noticeably depauperate in both species richness and total abundance. Six different fish species were collected from routine sampling locations in Harbor Brook (Table 3). Harbor Brook at Fowler Ave was the only site sampled in Harbor Brook where no fish were collected; this severely channelized and partially tunneled stream section was devoid of fish at the time of sampling. Species richness was highest at Velasko Rd and Delaware Ave, where three species were collected (Fig. 3). In addition to having the highest species richness, Velasko Rd also had the greatest total abundance (N = 46)

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[2] It must be noted that the original NYSDEC Stream Biomonitoring Unit guidance document used to develop OEI's biological and sampling analysis program was the 2009 Standard Operating Procedure (SOP) (Smith et al. 2009). In 2014, NYSDEC issued an updated SOP that included a new metric for inclusion in the BAP, a Nutrient Biotic Index for phosphorus (NBI-P) (Smith et al. 2007). OEI is in the process of updating its database to include the NBI-P. Once that is complete, the BAP will be updated, and the report amended accordingly. For the purposes of this report, and to no detriment to data analysis and interpretation, the 2009 BAP calculation was completed.

(Fig. 3). Shannon diversity (H′) was greatest at Delaware St, with a value of 1.04. While only a total of four individual fish were captured, they included three species; thus, showing a high degree of evenness (Fig. 2). Correspondingly, percent-dominance, a metric used in the IBI calculation was lowest at this location, with the most abundant species representing 50% of the fish community (Table 3). Overall, diversity (H′) was low in Harbor Brook, with an average of 0.40. Brown trout (*Salmo trutta*) were found at three locations in Harbor Brook: Bellevue Ave, Grand Ave, and Velasko Rd. These sites are contiguous, and the presence of brown trout in this stream reach is suggestive of good stream condition. Similarly, blacknose dace (*Rhinichthys atratulus*) were found at all locations between Onondaga Rd and Velasko Rd (Table 3). In the northeast, blacknose dace are one of few fish species found with brook trout (*Salvelinus fontinalis*) in headwater streams (Werner 2004). The presence of blacknose dace at these locations may also be an indication of good stream condition. Two largemouth bass (*Micropterus salmoides*) were all that was collected in Harbor Brook at Hiawatha Blvd, the most downstream location (Fig. 3). This warmwater species is characteristically found in lakes (Werner 2004). The proximity of the Hiawatha Blvd location to the Onondaga Lake inlet likely explains their presence at this location.

Based on the Index of Biotic Integrity (IBI), fish community structure in Harbor Brook ranged between very poor and fair (Fig. 4). Most locations had IBI scores that ranged between 24 and 36, which were considered poor. Delaware St had the highest IBI score, with a rating of 38 (‘fair’). Between Onondaga Rd and Delaware St, there was a slight downstream increase in IBI scores, suggesting a longitudinal improvement in ecological condition. Values, however, still only ranged between poor and fair. From a trophic standpoint, many of the fish collected in Harbor Brook were generalists, comprising an average 38% of the total number of fish collected at each site. On average, top carnivores comprised 32% of the fish community per site; this is driven by the presence of brown trout (*Salmo trutta*). Insectivorous fish represented only about 15% of the fish community, suggesting a poor insect prey base in Harbor Brook (Table 4).

4.1.2. Macroinvertebrate Community

Based on the Biological Assessment Profile (BAP), stream condition in Harbor Brook ranged between slight to severe impairment (Table 5). According to the BAP, stream condition was least impaired at Grand Ave and the most impaired at Hiawatha Blvd. A noticeable downstream decrease in stream condition was observed for Harbor Brook (Fig.5a). As a function of several individual metrics, the BAP scores observed for Harbor Brook can be attributed to several key attributes of the macroinvertebrate community. Total species richness ranged between a low of six at Hiawatha Blvd, to a high of 20 at Grand Ave (Table 5). A downstream decrease in total richness was observed ($R^2 = 0.50$). Trends were similar for EPT and NCO richness, with both metrics highest at Grand Ave (Fig. 5f). EPT taxa comprised more 30% of the total species richness at Grand Ave, more than any other location in Harbor Brook; which contributed to the higher BAP score. Though diversity values (H′) in Harbor Brook declined along a longitudinal gradient ($R^2 = 0.48$; Fig. 5d), this relationship was slightly weaker than for total species richness; suggesting community evenness (i.e., the number of individuals per species) was more variable at stream locations. One notable example is the observed increase in diversity between Delaware St and Fowler HS (Fig. 5d). While species richness was similar for both sites (N = 12 and 10, respectively), community evenness was higher at Fowler

Ave. At Delaware St, 67% of the macroinvertebrate community was dominated by Hydrobiidae gastropods (i.e., snails). At Fowler HS, Hydrobiidae snails were the dominant taxa, however they comprised only 38% of total sample abundance. This is further supported by the dominance metric. The percent-contribution of the three most abundant taxa was higher at Delaware St (84%) than at Fowler HS (77%) (Table 5).

Percent Model Affinity (PMA), a measure of macroinvertebrate community similarity to a model, non-impacted stream, was comparatively low for all sites in Harbor Brook (15-42%) (Table 5). This suggests that macroinvertebrate community composition is moderately impaired throughout the Harbor Brook watershed. The overall decrease in PMA scores along the stream gradient ($R^2 = 0.50$) corresponds with an increase in Hilsenhoff Biotic Index (HBI) scores; a measure of organic pollution. HBI scores steadily increased downstream, highlighting the longitudinal and compounding effects of stream impairment. Of all the metrics calculated, HBI scores displayed the strongest linear trend ($R^2 = 0.76$) (Fig. 5c).

The results of the Impact Source Determination (ISD) model found macroinvertebrate communities in Harbor Brook to model communities impacted by impoundments (i.e., dams) (Table 6). Based on the ISD model, an impoundment result can be due to effects caused by lake or reservoir releases, upstream wetlands or ponds, sluggish conditions, or dammed stream segments (Bode et al. 1996). Lakes, ponds, or wetlands do not supply Harbor Brook. However, one significant flow-control structure at Depalma Ave (between Velasko Rd and Delaware St) could be contributing to the ‘impoundment’ scores observed downstream of Depalma Ave. Downstream of Velasko Rd, Harbor Brook turns into a low-gradient system that can contribute to sluggish conditions. Furthermore, except for Velasko Rd, all sampling occurred immediately upstream or downstream of bridges. The effects of bridge abutments could also be contributing to the ISD scores in Harbor Brook.

4.1.3. **Habitat Condition & Water Quality**

Physical in-stream and riparian habitat conditions in Harbor Brook declined downstream according to Visual Habitat Assessment (VHA) scores (Fig. 6). Out of a possible score of 200, Bellevue Rd had the highest VHA score, with a score of 160. While this site ran parallel to a major roadway (Onondaga Blvd) and impeded on the riparian zone, the narrow channel was well-shaded and in-stream habitat was in exceptional condition (Table 7). Onondaga Rd, the most upstream location, had a VHA score of 122. In-stream channel morphometry scored high at this site. However, the riparian zone was nearly devoid of a canopy due to adjacent land use practices (Table 7). Habitat condition at Grand Ave was comparable to conditions at Bellevue Rd, having a VHA score of 155 (Fig. 6). The reduced score at Grand Ave is attributed to increased sediment deposition and reduced pool habitat variability (Table 7). Between Velasko Rd and Delaware St, habitat scores declined substantially (Fig. 6). This is largely attributed to stream channelization. Beginning at Depalma Ave, Harbor Brook becomes a cement-lined channel with armored walls; degrading stream habitat and disconnecting the channel from its floodplain. Furthermore, residential and commercial development intensifies downstream of Velasko Rd, exacerbating habitat quality impairments. Between Delaware St and Hiawatha Blvd, a significant portion of Harbor Brook is tunneled underground, daylighting at State Fair Blvd, near the Harbor Brook CSO Storage Facility. Hiawatha Blvd, the most downstream site, had the lowest VHA score of 34. This site is channelized, incised, devoid of a riparian zone, and has significant sediment accumulation on the stream bottom.

For all sites, nearly all water quality parameters were within ranges that were suitable for aquatic life (Table 8). One notable exception was specific conductivity. As was also observed during Phase 3 routine sampling (Task 3), specific conductivity levels were elevated in the Harbor Brook watershed downstream of Grand Ave (Table 8). The moderately saline conditions could be negatively impacting aquatic health. Stream temperature, pH, and turbidity were highest at Onondaga Rd. This site is located near the headwaters of Harbor Brook and the stream bed is comprised solely of limestone bedrock. The higher turbidity level at this location may be attributed to dissolved minerals from the limestone. The low flow and exposed stream channel (i.e., lack of canopy) are most likely contributing to the higher stream temperature.

4.1.4. Relationships Between Metrics

Results of linear regression analysis among fish, macroinvertebrate, and habitat scores suggest that the major drivers for assemblage-specific (i.e., fish vs. macroinvertebrates) community structure differ. Similarly, the effects of physical habitat, based on VHA scores, differed for each assemblage. Based on measures of stream and biotic quality, VHA scores were not strongly correlated with IBI scores, suggesting that changes in fish community condition are not strongly influenced by physical habitat (Fig. 7a). Conversely, changes in macroinvertebrate community structure do appear to be driven by physical habitat. In Harbor Brook, the community metrics HBI, PMA, and BAP were strongly correlated with VHA scores (Fig. 7b-d) with R^2 coefficients of 0.88, 0.56, and 0.82, respectively. Both BAP and PMA scores increased in response to higher VHA scores, while HBI scores declined in response to higher VHA scores (Fig.7b-d). When comparing fish IBI scores to the aforementioned macroinvertebrate metrics only weak relationships existed among the metrics for Harbor Brook (Fig. 8a-c). This suggests fish and macroinvertebrate composition at stream locations respond differently to perturbations and habitat degradation. In other words, the locations where fish and macroinvertebrates communities are considered most impaired are not the same.

4.2. Onondaga Creek

4.2.1. Fish Community

Of the 10 routine sampling locations, only seven were accessible for fish sampling[3]. No fish were collected at Walton St, and this is attributed to fast-moving waters that significantly reduced visibility and thus, electrofishing efficiency. Eighteen species were collected in Onondaga Creek among the six remaining routine locations (Table. 9). Fish abundance and species richness were greatest at Dorwin Ave. Conversely, excluding Walton St, fish abundance and species richness were lowest at Kirkpatrick St, the most downstream location, with only two individual largemouth bass being collected (Fig. 9). Correspondingly, Shannon diversity (H′) was highest at Dorwin Ave and lowest at Kirpatrick St (again, excluding Walton St), with values of 1.81 and 0, respectively (Fig. 9). Average diversity in Onondaga Creek was 1.04. Two noticeable declines in species richness, abundance, and diversity occurred in Onondaga Creek.

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[3] Rte 20 could not be sampled due to unwadeable conditions. Both South Ave and Newell St could not be sampled due to inaccessibility to the creek.

One occurred between Tully Farms and Gibson Rd and the other occurred between Dorwin Ave and Walton St (Fig. 9). While Tully Farms Rd had a slightly lower diversity value than at Dorwin Ave, community evenness was greater at this site, as evidenced by the lower percent-dominance metric (Table 10). Dominance was approximately 25% at Tully Farms Rd, where it was more than 33% at Dorwin Ave. Brown trout, a sensitive coldwater species, were only found at Tully Farms Rd. Both Dorwin Ave and Tully Farms Rd were the only sites to have more than one species with individuals from multiple size classes (Table 10). The ability for a stream segment to support more than one size class (e.g., juveniles and adults) speaks to the health of the stream. At Tully Farms Rd, the fish community represented a range of species that dwell in different habitats, including bottom-dwellers (e.g., sculpin spp.), water column species (e.g., white sucker), high gradient-dwellers (e.g., blacknose dace), and low gradient-dwellers (e.g., longnose dace) (Table 9). At W. Seneca Tpke, the next downstream location from Dorwin Ave, the fish community was dominated by small, bottom-dwelling fish (Table 9). This is likely attributed to the channelized, homogenous, and fast-moving conditions at W. Seneca Tpke.

Among the three tributaries, Onondaga Creek had the greatest number of fish species unique to that watershed. Six species were found in Onondaga Creek that were not collected in Harbor Brook or Ley Creek (Table 9). This included common shiner (*Luxilus cornutus*), cutlips minnow (*Exoglossum maxillingua*), fantail darter (*Etheostoma flabellare*), northern hogsucker (*Hypentelium nigricans*), rockbass (*Ambloplites rupestris*), and slimy sculpin (*Cottus cognatus*). Like Harbor Brook, largemouth bass were found at the most downstream location in Onondaga Creek (Table 9) and was also the *only* species found at these sites. Kirkpatrick St is immediately upstream of the Syracuse Inner Harbor, which is more similar to lake physical conditions than Onondaga Creek (i.e., deep, sluggish conditions). The proximity of the Kirkpatrick St site to the Onondaga Lake inlet also likely explains their presence at this location.

Based on the IBI, fish community structure at routine locations in Onondaga Creek were considered predominantly fair/poor (Fig. 10). Tully Farms Rd and W Seneca Tpke had IBI scores of 36, which is on the line between poor and fair. Dorwin Ave had the highest IBI score with a value of 42 ('fair') (Fig. 10). Both Gibson Rd and Walton Ave had the lowest IBI ratings, being considered very poor. Trends in IBI scores, as would be expected, mirrored the trends observed for abundance, richness, and diversity; with two noticeable downstream declines being observed.

4.2.2. Macroinvertebrate Community

Stream quality in Onondaga Creek ranged from non-impacted to severely impacted, based on BAP scores (Table 11). Stream condition was highest at Tully Farms Rd and lowest at Gibson Rd. A longitudinal decline in BAP scores was not as strong ($R^2 = 0.40$) in Onondaga Creek as it was for Harbor Brook, suggesting impacts to stream condition in Harbor Brook are more localized. Despite Tully Farms Rd having the highest BAP score, it had comparatively lower total species richness and diversity, and higher dominance than other locations (Table 11). This site, however, had the highest proportion of EPT taxa of any site, with 60% of the total taxa identified (N = 12/20) belonging to the EPT group (Fig. 11f). Furthermore, 80% (N = 16/20) of the sample consisted for taxa belonging to non-Chironomidae and Oligochaeta families (Fig. 11f). Interestingly, macroinvertebrate diversity (H′) was relatively consistent throughout

Onondaga Creek, with all but one location ranging in diversity values between 2.15 and 2.91 (Fig. 11d). Walton St was the one exception to this, falling outside of that range to have a diversity value of 1.74. This was the lowest recorded diversity among the sampling sites. This can be attributed to a high dominance value (Table 11); the highest of any location (Fig. 11e). Nearly 80% of the macroinvertebrate community at Walton St was dominated by Amphipoda (crustacean), Coleoptera (larval aquatic beetle), and Trichoptera (caddisfly). Neither dominance nor diversity showed a strong linear relationship, with R^2 coefficients < 0.2 (Fig. 11d-e).

The percent-similarity of Onondaga Creek macroinvertebrate communities to that of a model, non-impacted community varied from a low of 39.65% at Kirkpatrick St to a high of 75% at Tully Farms Rd (Table 11). Despite an increase in PMA at W. Seneca Tpke, PMA scores generally declined downstream (Fig. 11b). The decline in PMA scores in Onondaga Creek corresponds with an increase in HBI scores (Fig. 11c). The most upstream location, Tully Farms Rd, had a macroinvertebrate community characteristic of one not impacted by organic pollution, while the most downstream location, Kirkpatrick St, had a macroinvertebrate community characteristic of one tolerant of organic pollution. It appears that while macroinvertebrate diversity changed relatively little in Onondaga Creek, there was a noticeable shift from pollution-intolerant invertebrates to pollution-tolerant ones.

Based on the ISD models, the types of impairment that best characterize macroinvertebrate community structure in Onondaga Creek varied among sampling locations (Table 12). Tully Farms Rd was considered non-impacted based on the BAP, and accordingly had an ISD assessment of ‘natural’ (Table 12). Both Hitchings Rd and W. Seneca Tpke had macroinvertebrate communities characteristic of ones impacted by siltation. Gibson Rd, Dorwin Ave, and Kirkpatrick St had macroinvertebrate communities characteristically found in impounded systems. Walton St was the only site to have an ISD assessment of ‘toxic’ (Table 12). Based on the ISD model, a site determined to be ‘toxic’ is one that is impacted by industrial, municipal, or urban runoff. ‘Toxic’ impacts can include discharges that are high in ammonia or chlorine (Bode et al. 1996).

4.2.3. Habitat Condition & Water Quality

Similar to Harbor Brook, VHA scores in Onondaga Creek identified a prominent decrease in stream condition from Tully Farms Rd downstream to Kirkpatrick St (Fig. 12). Tully Farms Rd had the highest VHA score, with a nearly perfect score of 195 (Table 13). Conditions at this site were considered natural, with no human disturbance. Minimal erosion and sediment deposition was observed that contributed to the comparatively lower VHA score. At Hitchings Rd and Gibson Rd, heavy sediment deposition and reduced bank stability contributed to the decline in habitat condition at these sites (Table 13). At Hitchings Rd, sluggish conditions and a loss of pool habitat variability also affected the VHA score (Table 13). Beginning at Dorwin Ave and continuing downstream, anthropogenic influences were the primary contributors to poor habitat condition. All three locations have similar VHA scores, ranging between 84 and 89 (Table 13). Upstream of Dorwin Ave, Onondaga Creek becomes channelized. At Dorwin Ave, a grade-control structure fragments stream habitat. Furthermore, as part of flood control maintenance and accessibility, the riparian zone is mowed to the streambanks, eliminating the riparian zone. Downstream of W. Seneca Tpke at Ballantyne Rd, in addition to channelization, the creek becomes lined with armored walls and a concrete bottom and is disconnected from the riparian zone/flood plain. Due to the armored banks at Walton St, bank stability scored higher than at W. Seneca Tpke, contributing to the slightly higher VHA score (86 vs. 84, respectively) (Table 13). At Kirkpatrick St, the most downstream location, stream conditions improved noticeably from Walton St, with a score of 108 (Fig. 12). The increase in habitat conditions between these sites is largely attributed to the prevalence of riparian vegetation upstream and downstream of Kirkpatrick St, a natural stream bottom, and the presence of pool habitat (Table 13).

Based on water quality interpretive scales, dissolved oxygen and pH were within ranges suitable for aquatic life for all sampling locations (Table 14). Both parameters varied little among sampling locations, ranging between dissolved oxygen levels of 8.18 and 9.66 mg/L and pH levels of 7.68 and 8.85. Dorwin Ave had the highest pH, with a level considered alkaline, while Kirkpatrick St, the most downstream location, had the lowest pH (Table 14). Stream temperatures varied between mild and warm levels and were within ranges characteristic for the time of year that sampling occurred (June-July). Specific conductivity varied from a low of 423 µS/cm at Tully Farms Rd to a high of 3,024 µS/cm at Kirkpatrick St; ranging between 'freshwater' and 'saline' conditions, respectively (Table 14). At Kirkpatrick St, saline inputs from saltwater springs are the prevalent cause of the high conductivity levels observed at this location (USGS 2000). Turbidity values ranged widely in Onondaga Creek between a low of 5.8 NTUs at Walton St, to a high of 90.3 NTUs at W. Seneca Tpke (Table 14). Because sampling did not occur on the same day for all sites, longitudinal trends in water quality cannot be adequately evaluated.

4.2.4. Relationships Between Metrics

Linear regression analysis suggests that the response of fish and macroinvertebrates to changes in physical habitat were more strongly correlated than what was observed in Harbor Brook. Similar to Harbor Brook, the effects of physical habitat on fish community composition was not evident according to linear regression analysis (Fig. 13a); suggesting that improvements in stream condition do not directly equate to improved fish communities in Onondaga Creek. The effects of habitat on macroinvertebrate community composition were stronger than for fish. The results of linear regression analysis between BAP and VHA scores was the weakest of the three macroinvertebrate metrics ($R^2 = 0.30$) (Fig. 13b). PMA was strongly correlated with VHA scores ($R^2 = 0.50$), with higher PMA scores generally associated with higher VHA scores (Fig. 13c). VHA and HBI scores were negatively correlated and the linear relationship, though the relationship was weak ($R^2 = 0.36$) (Fig. 13d). This suggests that assessments of stream quality based on macroinvertebrate data does not necessarily correspond to physical stream and riparian habitat conditions in Onondaga Creek. While overall relationships were weak ($R^2 < 0.22$), the correlation between the fish IBI and macroinvertebrate BAP and PMA scores suggest a slight positive relationship (Fig. 14a, c). This relationship indicates that sites in Onondaga Creek assessed as having a low-impacted fish community, similarly had a macroinvertebrate community indicative of good stream conditions. A linear relationship between fish IBI and macroinvertebrate HBI scores was not detected ($R^2 < 0.01$) (Fig. 14b).

4.3. Ley Creek

4.3.1. Fish Community

Fish community composition in Ley Creek displayed several interesting trends among the different segments. In the North Branch fish community abundance declined downstream, while in the South Branch, abundance increased (Fig. 15). Similarly, species richness declined upstream to downstream in the North Branch and increased in the South Branch. In the North Branch, species richness declined from seven species to five species (Table 15). In the South Branch, species richness doubled from two species to four species, upstream to downstream (Table 15). Longitudinally, species composition in the North Branch showed the loss of five species, the gain of three species, and two species that were found at both locations. In the South Branch, species composition showed the gain of two species (Table 15). The mainstem location at Factory Ave had the greatest abundance of fish among the sampling locations (Fig. 15). Species richness was greatest at Factory Ave and Fly Rd, with seven species collected at both sites (Table 15).

Increased abundance from Exeter Rd to Court St (South Branch) equated to an increase in diversity, with diversity values of 0.56 and 0.79, respectively. In the North Branch, despite a downstream decrease in abundance, diversity increased. At Fly Rd, diversity was 1.11, while at Thompson Rd, it was 1.52. The relatively even composition of individuals in each species and low dominance (33%) contributed to this high value; the highest of any of the sites in Ley Creek (Table 15). Diversity was lowest at Exeter St, driven primarily by the low species richness (N=2) (Fig. 15).

Central mudminnow (*Umbra limi*) were found at both locations in the North Branch. This species was not found anywhere else in the Ley Creek watershed, nor at any of the routine sites in Harbor Brook and Ley Creek (Table 15). Central mudminnows inhabit shallow, stagnant waters with soft stream bottoms (Werner 2004). These conditions are characteristic of the North Branch. Two minnow species, bluntnose (*Pimephales notatus*) and fathead minnows (*Pimephales promelas*), were also only found in the Ley Creek watershed (Table 15). The green sunfish (*Lepomis cyanellus*) was found at both Fly Rd and Factory Ave, and nowhere else among routine sampling locations (Table 15). One notable species found only in Ley Creek was the round goby (Neogobius melanostomus). This invasive species was first identified in Onondaga Lake in 2010. The presence of this invasive species at two locations in Ley Creek, Factory Ave and Thompson Rd in 2015, signify the aggressive geographic expansion of this invasive fish in the Onondaga Lake watershed.

Fish IBI scores among sampling locations in Ley Creek varied minimally, ranging between scores of 32 and 38; suggesting stream condition in Ley Creek is relatively homogenous. IBI scores in both the North and South Branches were considered poor (Fig. 16). Factory Ave had the highest IBI score, with a value of 38 and a rating of ‘fair’ (Fig. 16). Trophic composition of the fish community suggests that Ley Creek is absent of top carnivorous fishes (Table 16). Lower levels of the fish food web were well represented, with approximately 50% of the population comprised of generalists and the other 50% considered insectivores (Table 16).

4.3.2. Macroinvertebrate Community

Based on the results of metric scores, stream condition in Ley Creek was relatively homogenous. Contrary to Harbor Brook and Onondaga Creek, which showed downstream declines in BAP scores, BAP scores in Ley Creek displayed a linear increase in water quality ($R^2 = 0.63$) (Fig. 17a). Excluding Park St, which had a water quality rating of 'slight', all sites had BAP scores that were considered moderate, ranging between 2.61 and 3.91 (Table 17). Stream condition improved downstream for each respective stream segment (i.e., North Branch, South Branch, and mainstem). Of the locations, Fly Rd had the lowest BAP score, while Park St had the highest. Total species richness ranged between a low of 15 species at Fly Rd (North Branch) to a high of 26 at Park St (Table 17). Overall richness was higher in the mainstem than in the North or South Branches (Fig. 17f). One noticeable and highly influential trend (to metric calculations) was the near-absence of EPT taxa in Ley Creek. Park St and Fly Rd were devoid of EPT taxa, while Exeter Rd, Court St, and Factory Ave had one taxa present. EPT richness was greatest at Thompson Rd, which had two EPT taxa present (Table 17). NCO richness ranged between a low of 8 to a high of 12 (Table 17). NCO richness declined downstream in both the North and South Branches but increased in the mainstem (Fig. 17f). Diversity (H′) values were relatively consistent in Ley Creek, ranging between a low 2.07 at Thompson Rd and a high of 2.54 at Park St (Table 17). Similar to the BAP, diversity decreased downstream in the North Branch and increased in the South Branch and mainstem (Fig. 17d). The low diversity values appear to be driven by community evenness, as evidenced by percent-dominance. The dominance of the three most abundant taxa ranged between a low of 54% at Court St, to a high of 69% at Thompson Rd (Table 17). Overall, dominance varied little among the sites further describing Ley Creek as a relatively homogenous system (Fig. 17e).

HBI scores were high in Ley Creek, suggesting organic pollution is exerting a moderate effect on macroinvertebrate community composition. While the causes for the impacts may vary among sampling locations, they appear to be having a relatively similar effect. HBI scores varied between a low of 6.11 at Thompson Rd to a high of 7.85 at Park St (Table 17). HBI decreased downstream in the North Branch and increased slightly downstream in the South Branch. In the mainstem, HBI increased downstream, suggesting worsening stream conditions.

Similar to Harbor Brook, the percent similarity of macroinvertebrate communities in Ley Creek to that of a model, non-impacted community were generally low for the watershed, with values ranging between 33% and 49% (Table 17). Values for relatively constant in the North Branch, decreasing only slightly between Fly Rd and Thompson Rd (Fig. 17). In the South Branch, PMA scores displayed the most significant change among Ley Creek locations, with scores increasing from 34% at Exeter Rd to 49% at Court St; the highest score among all Ley Creek sites (Table 17). PMA scores decreased in the mainstem, from a value of 40% at Factory Ave, to a score of 35% at Park St.

Based on the results of the ISD metric, the types of impacts/conditions driving macroinvertebrate community structure fell into one of two categories for Ley Creek: impoundment or sewage/effluent. Fly Rd and Park St macroinvertebrate community structure best modeled a community impacted by sewage/effluent pollution (Table 18). The categorization of 'impoundment' was also observed in Harbor Brook and Onondaga Creek. Of all the sampling locations sampled (including Harbor Brook and Onondaga Creek), the sewage/effluent category was only identified in Ley Creek as a potential source of impairment. This category includes organic pollution associated with animal wastes (e.g., agricultural runoff) and human waste from septic and wastewater discharges (Bode et al. 1996). The rest of the sampling locations mirrored a macroinvertebrate community impacted by impounded conditions (Table 18).

4.3.3. Habitat Condition & Water Quality

In Ley Creek, trends in VHA scores differed between branches, with VHA scores decreasing downstream in the North Branch and increasing downstream in the South Branch (Fig. 18). The slight decline in VHA scores between Fly Rd (VHA = 148) and Thompson Rd (VHA = 141) (North Branch) is largely driven by a lack of riparian vegetation and increased sediment deposition at Thompson Rd (Table 19). Between Exeter Rd and Court St, habitat conditions improved from a score of 131 to 153 (Table 19). At Exeter Rd, in-stream habitat was significantly worse than Court St and it was the major driver for the noticeably different VHA scores. Habitat in the mainstem of Ley Creek was considerably worse than in the North and South Branches, with VHA scores of 92 and 91 at Factory Ave and Park St, respectively (Table 19). The entire mainstem is heavily channelized. Stream banks show evidence of considerable erosion and the adjacent riparian zone is heavily developed and lacking significant amounts of native vegetation. The invasive plant *Phragmites* dominates much of the streambanks and provides relatively little canopy cover. The nearly identical VHA scores between sites highlights the degraded homogenization of the mainstream stream habitat.

Dissolved oxygen levels ranged between moderate and high levels, with the lowest value (DO = 5.16 mg/L) reported at Fly Rd and the highest value (DO = 8.83 mg/L) reported at Court St (Table 20). The low dissolved oxygen values recorded at Fly Rd and Park St (DO=5.54 mg/L) are attributed to sluggish conditions (i.e., low flow). The comparatively lower average dissolved oxygen concentration in Ley Creek, compared to Harbor Brook and Onondaga Creek (c.f. Table 8 & Table 14), indicates this low gradient system may not be suitable for aquatic organisms that have a high oxygen demand (e.g., trout). Despite sampling on different days (6/5/15 and 6/12/15), stream temperatures varied relatively little among sampling locations, ranging between 16.07°C at Thompson Rd and 18.65°C at Park St and Fly Rd (Table 20); all of which fell within the 'mild' range. The higher temperatures at Park St and Fly Rd, similar to dissolved oxygen, can also be attributed to sluggish conditions and little canopy cover. Specific conductivity ranged between slightly and moderately saline levels (Table 20). Similar to Phase 3 routine sampling (Task 3), specific conductivity was noticeably higher in the South Branch than in other areas of the watershed. Both Exeter Rd and Court St had levels considered moderately saline (i.e., brackish). pH levels were constant throughout the watershed, with values ranging between 7.01 at Fly Rd and 7.66 Court St (Table 20). Turbidity ranged between pristine and low levels, with the lowest turbidity level recorded at Thompson Rd (turbidity = 3.5 NTUs) and the highest level recorded at Park St (turbidity = 18.5 NTUs) (Table 20). While turbidity levels were low overall, values were slightly higher in the mainstem than in the North or South Branches.

4.3.4. Relationships Between Metrics

The fish community in Ley Creek appeared to be affected, at least in small part, to physical habitat (Fig. 19a). While the linear relationship between IBI and VHA scores was weak ($R^2 = 0.35$), it was noticeably higher in Ley Creek than in Harbor Brook or Onondaga Creek. Conversely, habitat did not appear to have a strong influence on macroinvertebrate structure in Ley Creek. None of the major metrics (HBI, PMA, BAP) were strongly correlated with VHA scores (Fig. 19b-d). While the relationship was not notably strong, it is worth noting that a negative relationship between VHA and BAP scores was observed for Ley Creek ($R^2 = 0.39$) (Fig. 19b). This is contrary to the weakly positive relationships observed in Harbor Brook and Onondaga Creek (Fig. 7b & Fig. 13b); suggesting that declines in water quality (based on macroinvertebrate BAP scores) were correlated with increases in habitat condition. The concordant response of fish and macroinvertebrates to physical habitat appeared to differ; with the BAP, PMA, and HBI scores not exhibiting a strong linear relationship with IBI scores (Fig. 20). Of those correlations, the strongest relationship between biotic metrics was exhibited between the fish IBI and macroinvertebrate PMA, with a weak, positive linear correlation of $R^2 = 0.31$ (Fig. 20). Overall, correlations suggest that fish and macroinvertebrate communities responded differently to environmental conditions and impairments in Ley Creek.

4.4. Metric Comparisons Among Streams

4.4.1. Fish Metrics

Fish community structure appears to be stressed in Harbor Brook, Onondaga Creek, and Ley Creek. Based on IBI scores, average fish community structure at routine sampling locations were considered poor for all three streams (Fig. 21a). Average IBI scores ranged between a low of 30 in Harbor Brook and a high of 34.8 in Ley Creek. Fish community condition in Onondaga Creek was more variable than the other streams, as evidenced by the box plots (Fig. 21a). Stream condition, according to IBI scores, was relatively consistent throughout Ley Creek (Fig. 21a). According to the Shannon diversity Index (H'), fish diversity was lowest in Harbor Brook, with an average of 0.40 (Fig. 21b), corresponding with IBI scores. Average diversity was highest in Onondaga Creek ($\tilde{x} = 1.04$), however results among in-stream locations were relatively more variable than Harbor Brook and Ley Creek (Fig. 21b).

4.4.2. Macroinvertebrate Metrics

According to macroinvertebrate metric scores, stream quality varied considerably among the three streams, with overall water quality evidently higher in Onondaga Creek than in Harbor Brook or Ley Creek. Average total species richness was highest in Ley Creek, with a mean of 19.2 (Fig. 22a). Total species richness was slightly lower in Onondaga Creek than in Ley Creek, with an average of 18.9, and was considerably lower in Harbor Brook, with an average of 13 (Fig. 22a). Despite Ley Creek having the highest average total richness, average EPT richness was lowest among the three stream, with an average of 0.83 (Fig. 22a). Both average EPT and NCO richness were highest in Onondaga Creek, suggesting that the prevalence of pollution-sensitive taxa was greater in this stream (Fig. 22a). Average diversity was lowest in Harbor Brook and highest in Onondaga Creek (Fig. 22b). Diversity was considerably more variable in Harbor Brook than in Onondaga or Ley Creeks. In Ley Creek, diversity was relatively consistent, varying little among sampling locations (Fig. 22b). Correspondingly, percent dominance of the three most abundance taxa was lowest in Onondaga Creek, suggesting macroinvertebrate communities are more equitable than in Harbor Brook and Ley Creek (Fig. 22c). Average dominance was highest in Harbor Brook, but dominance was observably more variable than in Ley Creek (Fig. 22c). According to the HBI, the impacts of organic pollution were highest in Ley Creek, with an average HBI score of 7.12. While, the average HBI score was lowest in Onondaga Creek, this stream also had the highest observed HBI score (Kirkpatrick St) among the three streams (Fig. 22f). The average percent similarity of macroinvertebrate community structure to that of a model, non-impacted stream (PMA) was greatest in Onondaga Creek and lowest in Harbor Brook (Fig. 22e). Correspondingly, BAP scores followed a similar trend, with average stream impairment highest in Harbor Brook and lowest in Onondaga Creek. All three streams had average BAP scores indicative of moderately impaired water quality (Fig. 22d). BAP scores were much more variable in Onondaga Creek and it was the only stream to have at least one site (Tully Farms Rd) considered non-impacted (BAP > 7.5) (Fig. 22d).

4.4.3. Visual Habitat Scores

According to VHA scores, physical stream and riparian habitat was relatively similar among the three streams, with average scores ranging between a low of 112.6 and a high of 126 (Fig. 23). Despite the predominantly urban Ley Creek watershed, average habitat condition was highest in Ley Creek. Onondaga Creek had the lowest average habitat score but was the only stream to have a site with a near-perfect score (i.e., 200 out of 200), which occurred at Tully Farms Rd, and had a VHA score of 195. Harbor Brook had the lowest minimum VHA score among the three streams; this occurred at Hiawatha Blvd where a score of 69 was estimated.

5. Discussion

The results of these work elements collectively describe conditions in Harbor Brook, Onondaga Creek, and Ley Creek as being moderately impacted by pollution and habitat degradation. While the type and severity of certain impairments differed among the watersheds, the overall effects on stream health were similar and could largely be attributed to the impacts associated with increased urbanization. Both Harbor Brook and Onondaga Creek undergo a distinct rural-urban gradient from the headwaters to lake inlet (Table 1; refer also to Chapter 1, Fig. 2). The symptomatic effects of urbanization are having notable effects on macroinvertebrate community structure particularly in Harbor Brook and Onondaga Creek; as evidenced by substantial declines in several biotic metric assessments (i.e., BAP, PMA, HBI) along the stream gradients. Based on macroinvertebrate metrics scores, these declines in stream condition can be attributed to increases in organic pollution (HBI) and declines in natural, undisturbed habitat (PMA). Impact Source Determination (ISD), in combination with water quality measurements, suggest that increased turbidity and specific conductivity levels, as well as impacts associated with bacterial pollution are negatively impacting stream health in all three streams. These results align with the "urban stream syndrome" (Walsh et al. 2005), whereby streams affected by urbanization characteristically have similar "symptoms" that include increased pollution, alterations in hydrology, degradation of the physical habitat, and changes in energy sources.

Fish IBI scores did not identify longitudinal declines in fish community structure attributed to urbanization. Several abundance-based metrics that comprise the IBI are based on the watershed area of the sampling location (Daniels et al. 2002). Therefore, sites with larger watersheds, a function that increases downstream, are likely to have higher metric scores and lead to a higher IBI score. Furthermore, the River Continuum Concept (Vannote et al. 1980) identifies longitudinal changes in fish community structure associated with increased area, including an increase in planktivorous fishes tolerant of warm water, low-oxygen conditions. Therefore, the results of the IBI appear to be driven more so by the physical-hydrological changes in stream condition associated with increasing stream order (and therefore, watershed area) than anthropogenic influences. Despite this, however, IBI scores were generally low for all sites, with most of locations considered poor; suggesting that the fish communities for all three streams are impaired.

Linear regression analysis between the fish IBI and macroinvertebrate metrics (BAP, PMA, HBI) did not yield significant relationships, suggesting that the response of these assemblages to environmental perturbations differed. In other words, the environmental variables that negatively impact fish are not the same as those that negatively impact macroinvertebrate communities. Of the three streams, the response of fish and macroinvertebrates was comparatively more similar in Onondaga Creek, with weak positive relationships observed between fish IBI and macroinvertebrate BAP and PMA scores ($R^2 = 0.19$ and 0.22, respectively). The inclusion of more sampling sites would likely help to strengthen relationships, but results preliminarily suggest that fish and macroinvertebrate communities in Onondaga Creek weakly respond to impairments similarly.

Because fish and macroinvertebrates responded differently to environmental conditions, the sites that were considered most degraded differed according to the assemblage-specific metric and index scores. For example, in Harbor Brook, the site behind Fowler HS was determined to be the most severely impacted according to the Fish IBI, where no fish were found. Based on the macroinvertebrate BAP, however, this site was considered moderately impacted. Furthermore, according to the BAP, stream condition was most impacted in Harbor Brook at Hiawatha Blvd. In Onondaga Creek, Tully Farms Rd was considered non-impacted based on the macroinvertebrate BAP, but was considered in poor condition according to the fish IBI. For the few studies that have conducted similar comparative assessments of water quality, nearly all found that different taxonomic groups responded differently to the same suite of conditions and that ecological condition was better predicted from the use of multiple assemblage (Paller 2001, Griffith et al. 2005, Freund and Petty 2007, Flinders et al. 2008). Similar to published findings, the results of this study suggest that multiple assemblages should be utilized for assessing the effects of environmental factors and impairments on stream condition.

Impact Source Determination identified several impairments affecting macroinvertebrate community composition, and included the categories of: impoundment, sewage/effluent, nutrient/pesticides, siltation, and toxic. Only one location, Tully Farms Rd in Onondaga Creek, was considered non-impacted; this was also evidenced by the BAP score. The predominant impact type among the three streams belonged to the impoundment category. This impact source was the dominant category for 65% of routine sites. In Harbor Brook, all sites were determined to be impaired by impoundments. While Harbor Brook is not impounded by dams or reservoirs, the effects of urbanization do appear to be creating impounded-like conditions; presumably from the effects of road crossings. Road crossings have been shown to have deleterious impacts on habitat (Wissmar et al. 2003, McBride and Booth 2005). For Harbor Brook, all sampling occurred within 100 meters of a road crossing. It is theorized that sluggish conditions (i.e., low flow, increased sedimentation) created around bridge abutments contributed to the ISD assessments for Harbor Brook. In addition, the heavily channelized and armored channel downstream of Velasko Rd has created significant depositional zones in Harbor Brook. These heavily sedimented areas are likely creating stream conditions like those caused by impoundments.

In Ley Creek, half of sampling locations were identified as being impacted by impoundments, including one site in the North Branch (Thompson Rd) and both sites in the South Branch. Ley Creek is a low gradient stream that descends only 15 meters from the headwaters to the lake inlet (Coon and Reddy 2008). The naturally low flow, sluggish conditions for nearly all of the watershed has resulted in significant sedimentation that has created large areas of depositional habitat. The South Branch originates in the Town of DeWitt in a predominately commercialized landscape. As a result, the South Branch headwaters have been ditched and serve mainly as drainage channels for commercial lots and roadways; further exacerbating sediment deposition and likely contributing to the ‘impoundment’ designation under the ISD metric.

The North Branch of Ley Creek is situated in a predominantly agriculture landscape; contrary to the rest of the system, which is predominantly urban (Chapter 1, Fig. 2). Between Fly Rd and Thompson Rd, Ley Creek flows through a large area of forested wetlands, as well as through (and under) Syracuse Hancock Airport. This relatively undeveloped section of stream and wetland habitat has had observed beaver dams. The naturally sluggish conditions of the North Branch combined with the presence of beaver dams are likely the primary drivers for the ‘impoundment’ designation for Thompson Rd. Both Fly Rd and Factory Ave were determined to be impacted by sewage/effluent. At Fly Rd, the likely source of this designation is from adjacent agricultural practices. Upstream of Fly Rd, agriculture is the predominant land use. While average fecal coliform levels were considered moderate at this site during Phase 3 routine sampling ($\tilde{x}$= 228 cfu/100 mL), it was considered high during Phase 2 ($\tilde{x}$= 1473 cfu/100 mL); the highest of all Ley Creek routine locations during Phase 2 (OEI, 2014). Despite the decline in bacterial levels between Phases 2 and 3, the effects of agriculture on physical condition and water quality appear to still be impacting macroinvertebrate community structure. While it is unknown the specific type of agricultural practices and source(s), or the frequency or pervasiveness of the impact (e.g., crop rotation and fertilizer treatments) causing the ISD designation of ‘sewage/effluent’, it is likely to impact the macroinvertebrate community long beyond the cessation of certain practices. Fuchs and Statzner (1990) found macroinvertebrate recovery in an isolated section of stream in the Upper Rhine valley took more than five years. Furthermore, the natural conditions of the watershed could be a major contributor to the prevalence of fecal coliform concentrations in the North Branch over the long-term. The stream bottom of this low gradient systems is comprised mainly of fine sediments (i.e., clay) and detritus. These conditions presumably contribute to a stream bed lined with material high in organic content. Studies have shown that highly organic sediments can contribute to higher survival rates for indicator bacteria (Burton et al. 1987, Sherer et al. 1992, Howell et al. 1996). Moreover, these conditions in conjunction with warmer stream temperatures can cause increases in the rates of bacterial regrowth, which could indicate human/animal contamination in areas even where there are no known sources (Howell et al. 1996). In Ley Creek, temperatures can easily exceed 20°C during summer months. It is possible that while agricultural runoff may be a source of fecal contamination, the natural conditions of this area are exacerbating the extent (spatially and temporally) of bacteria levels in the North Branch.

Park St was the only location among all routine sampling locations to have an ISD of 'nutrients/pesticides'. This section of Ley Creek is downstream of an Onondaga Lake Superfund subsite (NYSDEC 2010). Despite remediation, legacy contamination may still be impacting stream health. In addition, this location is immediately downstream of CSO 074, an active Combined Sewer Overflow (CSO) on Ley Creek (savetherain.us). More recently, sewage pipe failures near Park St has contributed to significant bacterial pollution to Ley Creek and Onondaga Lake. The Ley Creek force main is currently being replaced, but it is feasible that the 50-yr old pipe was leaking sewage in much smaller volumes prior to the pipe burst in 2016 (Coin, 2017). Though the presences of leaks coming from the force main was not verified during Phase 3 sampling, it nevertheless highlights the continuous problem of aging infrastructure in the Onondaga Lake watershed and the yet-to-be identified failures that are occurring throughout the watershed.

In Onondaga Creek, ISD assessments varied throughout the watershed, highlighting the dynamic nature of this large watershed and suggesting that impairments to stream health are relatively diverse. Downstream of Tully Farms Rd, impairment categories for routine sites included: siltation, impoundment, and toxic. The siltation ISD for Hitchings Rd (West Branch), similar to Ley Creek, is likely a result of landscape conditions. While there is no impoundment on the West Branch, this section of stream is low-gradient and flows through forested wetland habitat. Stream flow is sluggish and sedimentation is high, contributing to the impoundment designation. At Gibson Rd and Dorwin Ave, sedimentation from the Tully Valley mudboils are likely the primary drivers for the ISD rating. At Dorwin Ave, sampling occurred immediately upstream of the 25-ft drop structure, which may also be contributing to the impoundment assessment. At the time of sampling (6/22/15), stream flow was relatively low. The very small lip of the drop structure (< 1 feet above stream bottom), aided by the confining channel walls and narrowing entrance to the bridge crossing, could have caused water to back up, creating impoundment-like conditions during low flow. At W. Seneca Tpke, the ISD model assessed macroinvertebrate community structure akin to those impacted by siltation. Stream habitat at this location was a mix of erosional and depositional habitat, resulting in a large gravel bar and areas of eroded/scoured stream banks. Bank stability at this site is extremely poor, as the stream is channelized, and the riparian zone is devoid of trees and shrubs due to continuous mowing throughout the growing season. Walton St was the only site among all routine sampling locations to have an ISD of toxic. The toxic category includes pollution from industrial, municipal, and urban sources. Walton St is in the Armory Square district of downtown Syracuse, where urban development is extremely high. This location is also downstream of several CSOs, including the Clinton St Storage Facility. Up until 2014, OC-PS21 was also discharging severely high bacteria levels at persistent rates, located underneath the Walton St bridge and immediately upstream of where the creek was accessed for biological sampling. Collectively, these inputs, some of which will continue to discharge during high rain events (i.e., CSOs, storm drains), are creating incredibly degraded conditions for aquatic macroinvertebrates; causing a reduction in overall stream health.

Physical habitat quality, according to VHA scores, was fairly similar for all three streams, with most scores ranging between 80 and 160 and averages ranging between 113 and 126. The similar range of habitat scores, combined with the significant linear decline of VHA score for all three streams, further highlights the negative impacts of urbanization on stream condition. The effects of physical stream condition on community structure were greater for macroinvertebrates than for fish. According to the fish IBI, linear correlations between VHA and IBI scores were not evident for Harbor Brook or Onondaga Creek ($R^2 = 0.06$, for each). In Ley Creek, the response of fish IBI scores to physical habitat was a weakly negative relationship ($R^2 = 0.35$), suggesting areas with high VHA scores had poor fish community structure and physical habitat is not a reliable indicator of fish condition. Nearly all major macroinvertebrate metrics (BAP, PMA, HBI) were positively correlated with VHA scores for all streams. For Harbor Brook and Onondaga Creek, these relationships were strong for nearly all of the metrics, suggesting that habitat condition is a major driver of macroinvertebrate community structure. One exception to this is the relationship between BAP and VHA scores in Onondaga Creek. This relationship was weak ($R^2 = 0.30$), suggesting community structure may be more driven by water quality; which is not incorporated into the VHA. The importance of water quality on macroinvertebrate community structure is evidenced by the ISD model, which indicates pollutants such as sewage pollution, turbidity (e.g., mudboils), and urban runoff are major factors affecting stream health in Onondaga Creek. The results of VHA regression analysis with biotic metrics are similar to other studies; whereby fish tend to respond to water quality and large-scale variables (e.g., land use) while macroinvertebrates tend to respond to small scale variables (Roth et al. 1996, Allan et al. 1997, Wang et al. 1997, Lammert and Allan, 1999, Sponseller et al. 2001, Fausch et al. 2002, Meador and Goldstein 2003, Townsend et al. 2003, Tran et al. 2010, Johnson and Ringler 2014).

6. Conclusions

The results of biological sampling suggest that stream condition in Harbor Brook, Onondaga Creek, and Ley Creek are moderately impaired for much of their respective watersheds, and that stream degradation tends to increase downstream. The impacts of urbanization on stream health are evident, and until comprehensive efforts (e.g., de-channelization, increased riparian buffers, etc.) are implemented on a large-scale, stream health is not likely to improve. Localized and persistent forms of impairment, such as the Tully Valley mudboils, urban runoff, CSO discharges, appear to be compounding and exacerbating ecological degradation. The effects of bacterial pollution are evident at locations in Onondaga Creek and Ley Creek. While Phase 3 microbial trackdown sampling has identified significant improvements and corrections to infrastructure, improvements to biotic condition are not likely in the near future, given that there were a number of other impairments identified in this study to be impacting stream health. Furthermore, the literature suggests that biotic recovery could take years. Therefore, it is highly recommended that biological monitoring in the Onondaga Lake watershed continues in order to effectively identify spatial and temporal trends in stream health and better inform management and restoration strategies. Such work could have tremendously important implications for the recovery and restoration of Onondaga Lake, and perhaps most notably, the Onondaga Lake fishery.

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Table 3. Fish community composition for Harbor Brook (2015).

Location[1]	Date	Blacknose dace	Brook stickleback	Brown trout	Dace Sp.	Largemouth bass	Tessellated darter	TOTAL
Onondaga Rd	6/4/2015	1						**1**
Bellevue Rd	6/4/2015	1		3				**4**
Grand Ave	6/4/2015	25		3				**28**
Velasko Rd	6/4/2015	25	2	19				**46**
Delaware St	6/4/2015		1		2		1	**4**
Fowler HS	6/4/2015							**0**
Hiawatha Blvd	6/4/2015					2		**2**
Total		**51**	**3**	**25**	**2**	**2**	**1**	**84**

[1] Sites are arranged in downstream order.

Table 4. Fish metric and IBI scores for Harbor Brook (2015).

Metric/Location[1] → ↓	Onondaga Rd	Bellevue Ave	Grand Ave	Velasko Rd	Delaware St	Fowler HS	Hiawatha Blvd	Minimum	Median	Maximum	Mean (N=7)
Abundance (N)	1	4	28	46	4	0	2	0	4	46	12.14
Total Species Richness	1	2	2	3	3	0	1	0	2	3	2
Shannon Diversity (H')	0.00	0.56	0.34	0.83	1.04	0.00	0.00	0.00	0.34	1.04	0.40
Native Richness	1	1	1	2	3	0	1	0	1	3	1
Exotic Richness	0	1	1	1	0	0	0	0	0	1	0
Benthic Insectivore Richness	0	0	0	0	2	0	0	0	0	2	0
Water Column Richness	0	0	0	1	1	0	0	0	0	1	0
Terete Minnow Richness	0	0	0	0	0	0	0	0	0	0	0
% Dominant Species	100.00	75.00	89.29	54.35	50.00	0.00	100.00	0.00	75.00	100.00	66.95
% White sucker	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
% Generalists	100.00	25.00	89.29	54.35	0.00	0.00	0.00	0.00	25.00	100.00	38.38
% Insectivores	0.00	0.00	0.00	4.35	100.00	0.00	0.00	0.00	0.00	100.00	14.91
% Top Carnivore	0.00	75.00	10.71	41.30	0.00	0.00	100.00	0.00	10.71	100.00	32.43
Species w/ > 1 size Class (N)	0	0	0	1	0	0	0	0	0	1	0
# Individuals w/ Anomalies	0	0	0	0	0	0	0	0	0	0	0
IBI Score	26	34	32	34	38	12	34	12	34	38	30
Rating	Poor	Poor	Poor	Poor	Fair	Very Poor	Poor	Very Poor	Poor	Fair	Poor

[1] Sites each arranged downstream order, left to right.

Table 5. Macroinvertebrate metric scores for Harbor Brook sampling locations (2015). Sites are arranged in downstream order.

Location[1] /Metric → ↓	Richness	EPT Richness	NCO Richness	Diversity	Dominance (%)	HBI	PMA (%)	BAP	BAP Rating
Onondaga Rd	13	1	5	1.98	67.00	5.67	39.00	3.49	Moderate
Bellevue Ave	16	4	7	1.71	79.00	5.71	36.00	4.31	Moderate
Grand Ave	20	6	11	2.26	59.00	4.96	42.00	5.44	Slight
Velasko Rd	15	1	5	2.11	63.00	6.29	40.00	3.49	Moderate
Delaware St	12	2	7	1.29	84.00	7.45	25.00	2.70	Moderate
Fowler HS	10	1	5	1.72	77.00	7.43	36.00	2.55	Moderate
Hiawatha Blvd	6	0	3	0.43	97.00	7.90	15.00	1.00	Severe
Minimum	6	0	3	0.43	59.00	4.96	15.00	1.00	
Median	13	1	5	1.72	77.00	6.29	36.00	3.49	
Maximum	20	6	11	2.26	97.00	7.90	42.00	5.44	
Mean (N=7)	13.14	2.14	6.14	1.64	75.14	6.49	33.29	3.29	

[1] Sites are arranged in downstream order.

Table 6. Impact Source Determination (ISD) for Harbor Brook (2015). Sites are arranged in downstream order.

Location[1] /Metric → ↓	Natural	Nutrients/ Pesticides	Municipal/ Industrial	Toxic	Sewage/ Effluent	Siltation	Impoundment	Maximum	ISD Category
Onondaga Rd	21.40	29.00	9.80	23.80	18.80	21.00	**32.60**	32.60	Impoundment
Bellevue Ave	18.03	18.65	29.20	26.28	20.00	29.93	**33.58**	33.58	Impoundment
Grand Ave	25.19	36.11	7.96	26.67	26.11	23.52	**38.70**	38.70	Impoundment
Velasko Rd	15.00	20.42	23.96	20.00	20.00	22.71	**38.33**	38.33	Impoundment
Delaware St	15.38	17.83	13.21	21.32	19.81	17.26	**33.21**	33.21	Impoundment
Fowler HS	9.80	11.96	21.57	24.71	24.71	16.96	**31.86**	31.86	Impoundment
Hiawatha Blvd	3.88	7.91	6.94	12.77	7.77	6.80	**17.77**	17.77	Impoundment

[1] Sites are arranged in downstream order.

Table 7. Visual Habitat Assessment (VHA) scores for Harbor Brook sampling locations (2015).

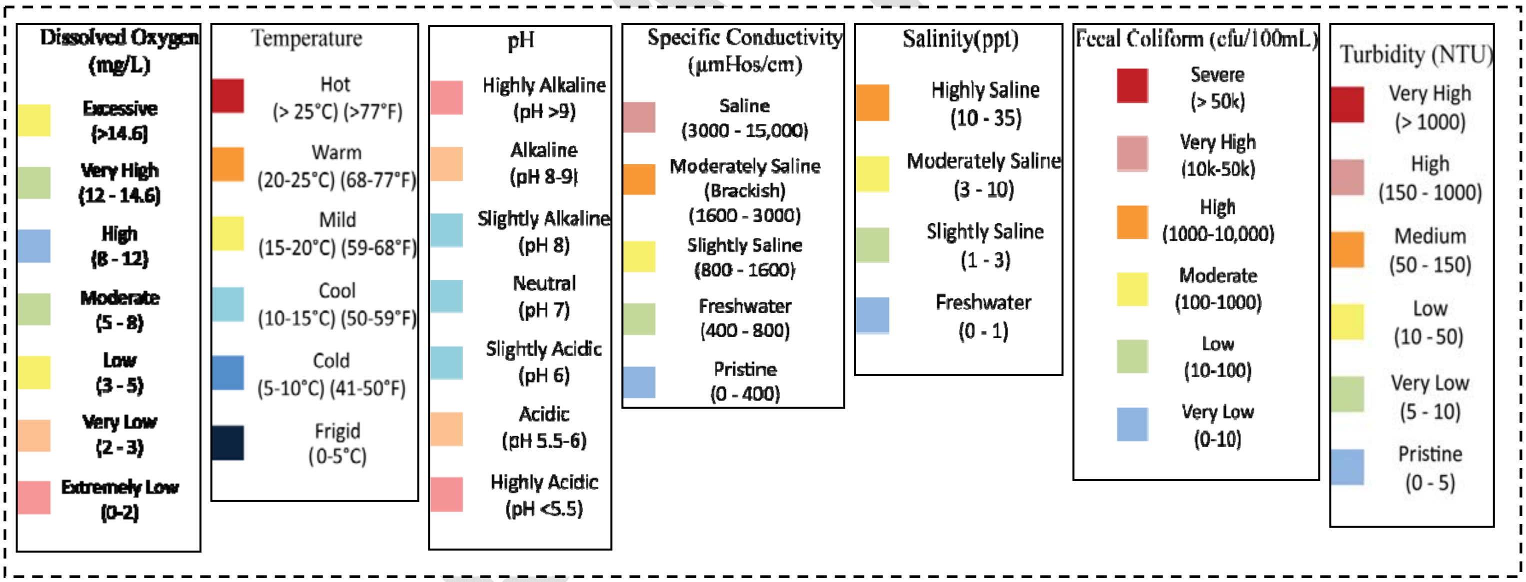
Site[1]	**Maximum Score Possible**	**Onondaga Rd**	**Bellevue Rd**	**Grand Ave**	**Velasko Rd**	**Delaware St**	**Fowler HS**	**Hiawatha Blvd**
Sampling Date		**6/4/2015**	**6/4/2015**	**6/4/2015**	**6/4/2015**	**6/4/2015**	**6/4/2015**	**6/4/2015**
Stream Gradient		**High**	**High**	**High**	**Low**	**Low**	**Low**	**Low**
Epifaunal Substrate/Available Cover	20	4	20	20	19	5	5	1
Pool Substrate Characterization/Embeddedness	20	17	18	15	15	0	15	6
Pool Variability/Velocity-Depth Regime	20	15	16	13	4	0	3	1
Sediment Deposition	20	19	20	13	16	20	20	0
Channel Flow Status	20	20	15	13	19	18	20	19
Channel Alteration	20	13	16	18	14	0	0	0
Channel Sinuosity/Frequency of Riffles	20	6	20	18	10	6	0	4
Bank Stability LB	10	7	8	5	7	10	8	8
Bank Stability RB	10	5	8	8	7	10	6	8
Vegetative Protection LB	10	8	7	8	6	0	1	6
Vegetative Protection RB	10	8	7	8	6	0	1	6
Riparian Vegetative Zone Width LB	10	0	2	8	5	5	0	9
Riparian Vegetative Zone Width RB	10	0	3	8	4	6	0	1
Total	**200**	**122**	**160**	**155**	**132**	**80**	**79**	**69**

[1] Sites are arranged in downstream order.

Table 8. Water quality parameters for Harbor Brook biological sampling events.

Site	Date	Dissolved Oxygen (mg/L)	Temperature (°C)	Specific Conductivity (µS/cm)	pH	Turbidity (NTU)
Onondaga Rd	6/4/2015	10.03	18.91	776	8.09	7.1
Bellevue Ave	6/4/2015	10.38	10.01	737	7.44	0
Grand Ave	6/4/2015	10.27	13.45	1025	7.71	0
Velasko Rd	6/4/2015	10.72	16	2005	7.57	0.5
Delaware St	6/4/2015	10.86	15.2	1975	7.56	2.6
Fowler HS	6/4/2015	10.53	13.38	1888	7.59	2.7
Hiawatha Blvd	6/4/2015	10.18	12.39	DNR	7.59	2.5
	Minimum	**10.03**	**10.01**	**737.00**	**7.44**	**0.00**
	Median	**10.38**	**13.45**	**1456.50**	**7.59**	**2.50**
	Maximum	**10.86**	**18.91**	**2005.00**	**8.09**	**7.10**
	Mean	**10.42**	**14.19**	**1401.00**	**7.65**	**2.20**
	N	**7**	**7**	**6**	**7**	**7**

[1]DNR – data not recorded. Color-coding for interpretative scales are shown below. Sites are arranged in downstream order.



Dissolved Oxygen (mg/L)
- Excessive (>14.6)
- Very High (12 - 14.6)
- High (8 - 12)
- Moderate (5 - 8)
- Low (3 - 5)
- Very Low (2 - 3)
- Extremely Low (0-2)

Temperature
- Hot (> 25°C) (>77°F)
- Warm (20-25°C) (68-77°F)
- Mild (15-20°C) (59-68°F)
- Cool (10-15°C) (50-59°F)
- Cold (5-10°C) (41-50°F)
- Frigid (0-5°C)

pH
- Highly Alkaline (pH >9)
- Alkaline (pH 8-9)
- Slightly Alkaline (pH 8)
- Neutral (pH 7)
- Slightly Acidic (pH 6)
- Acidic (pH 5.5-6)
- Highly Acidic (pH <5.5)

Specific Conductivity (µmHos/cm)
- Saline (3000 - 15,000)
- Moderately Saline (Brackish) (1600 - 3000)
- Slightly Saline (800 - 1600)
- Freshwater (400 - 800)
- Pristine (0 - 400)

Salinity(ppt)
- Highly Saline (10 - 35)
- Moderately Saline (3 - 10)
- Slightly Saline (1 - 3)
- Freshwater (0 - 1)

Fecal Coliform (cfu/100mL)
- Severe (> 50k)
- Very High (10k-50k)
- High (1000-10,000)
- Moderate (100-1000)
- Low (10-100)
- Very Low (0-10)

Turbidity (NTU)
- Very High (> 1000)
- High (150 - 1000)
- Medium (50 - 150)
- Low (10 - 50)
- Very Low (5 - 10)
- Pristine (0 - 5)

Table 9. Fish community composition for Onondaga Creek (2015).

Location	Date	Banded killifish	Blacknose dace	Brown trout	Common carp	Common shiner	Creek chub	Cutlips minnow	Fantail darter	Largemouth bass	Longnose dace	Northern hogsucker	Pumpkinseed sunfish	Rockbass	Sculpin Sp.	Shiner Sp.	Slimy sculpin	Tessellated darter	White sucker	TOTAL
Tully Farms Rd	6/11/2015		13	14			3				14						15		2	**61**
Rte 20	6/11/2015	DID NOT SAMPLE																		
Hitchings Rd	6/19/2015						4						1	1		2			2	**10**
Gibson Rd	7/23/2015					1						3							1	**5**
Dorwin Ave	6/22/2015		4			1	7	14	7		21				1			1	7	**63**
Rte 173	6/22/2015	1			1				4		8							3	1	**18**
Newell St	6/22/2015	DID NOT SAMPLE																		
South Ave	6/22/2015	DID NOT SAMPLE																		
Walton St	7/23/2015																			**0**
Kirkpatrick St	7/23/2015									2										**2**
		1	**17**	**14**	**1**	**2**	**14**	**14**	**11**	**2**	**43**	**3**	**1**	**1**	**1**	**2**	**15**	**4**	**13**	**159**

[1] Sites are arranged in downstream order.

Table 10. Fish metric and IBI scores for Onondaga Creek (2015).

Metric/ Location[1] → ↓	Tully Farms Rd	Hitchings Rd	Gibson Rd	Dorwin Ave	Seneca Tpke	Walton Ave	Kirkpatrick St	Minimum	Median	Maximum	Mean (N=7)
Abundance (N)	61	10	5	63	18	0	2	0	10	63	22.71
Total Species Richness	6	5	3	9	5	0	1	0	5	9	4.14
Shannon Diversity (H')	1.61	1.47	0.95	1.81	1.48	0.00	0.00	0	1.4708	1.81	1.04
Native Richness	5	5	3	9	5	0	1	0	5	9	4.00
Exotic Richness	1	0	0	0	1	0	0	0	0	1	0.29
Benthic Insectivore Richness	2	0	0	5	3	0	0	0	0	5	1.43
Water Column Richness	0	0	0	0	1	0	0	0	0	1	0.14
Terete Minnow Richness	1	1	0	2	0	0	0	0	0	2	0.57
% Dominant Species	24.59	40.00	60.00	33.33	44.44	0.00	0.00	0	33.333	60	28.91
% White sucker	3.28	20.00	20.00	11.11	5.56	0.00	0.00	0	5.5556	20	8.56
% Generalists	29.51	90.00	100.00	30.16	11.11	0.00	0.00	0	29.508	100	37.25
% Insectivores	47.54	0.00	0.00	69.84	88.89	0.00	0.00	0	0	88.89	29.47
% Top Carnivore	22.95	10.00	0.00	0.00	0.00	0.00	100.00	0	0	100	18.99
Species w/ > 1 size Class (N)	2	1	0	2	0	0	0	0	0	2	0.71
# Individuals w/ Anomalies	1	0	0	0	0	0	0	0	0	1	0.14
IBI Score	36	32	24	42	36	12	32	12	32	42	30.57
Rating	Poor	Poor	Very Poor	Fair	Poor	Very Poor	Poor	Very Poor	Poor	Fair	Poor

[1] Sites each arranged downstream order, left to right.

Table 11. Macroinvertebrate metric scores for Onondaga Creek (2015).

Location[1] /Metric → ↓	Richness	EPT Richness	NCO Richness	Diversity	Dominance (%)	HBI	PMA	BAP	BAP Rating
Tully Farms Rd	20	12	16	2.34	56.00	3.61	75.00	7.76	Non
Hitchings Rd	28	6	18	2.91	38.00	5.58	61.00	6.65	Slight
Gibson Rd	9	1	6	2.15	45.45	5.82	49.09	2.26	Severe
Dorwin Ave	21	3	14	2.37	59.00	6.23	47.00	4.86	Moderate
W. Seneca Tpke	25	5	14	2.67	42.00	5.46	62.00	6.29	Slight
Walton St	12	4	9	1.74	79.00	5.86	40.00	4.13	Moderate
Kirkpatrick St	17	0	4	2.35	55.81	8.42	39.65	2.64	Moderate
Minimum	9	0	4	1.74	38.00	3.61	39.65	2.26	
Median	20	4	14	2.35	55.81	5.82	49.09	4.86	
Maximum	28	12	18	2.91	79.00	8.42	75.00	7.76	
Average (N=7)	18.86	4.43	11.57	2.36	53.61	5.85	53.39	4.94	

[1] Sites are arranged in downstream order.

Table 12. Impact Source Determination (ISD) for Onondaga Creek (2015).

Site/ Metric → ↓	Natural	Nutrients/ Pesticides	Municipal/ Industrial	Toxic	Sewage/ Effluent	Siltation	Impoundment	Maximum	ISD Category
Tully Farms Rd	**50.89**	37.77	29.85	32.97	20.89	27.92	24.80	50.89	Natural
Hitchings Rd	40.25	41.31	25.25	24.24	42.32	**46.36**	36.31	46.36	Siltation
Gibson Rd	23.18	27.27	9.09	28.18	27.27	28.18	**29.09**	29.09	Impoundment
Dorwin Ave	21.88	28.86	36.68	31.73	22.87	29.85	**40.69**	40.69	Impoundment
W. Seneca Tpke	28.70	36.74	34.35	39.78	32.39	**53.26**	39.13	53.26	Siltation
Walton Ave	33.91	47.97	56.63	**65.40**	55.64	50.79	49.80	65.40	Toxic
Kirkpatrick St	16.25	36.67	35.42	28.33	53.75	32.50	**81.25**	81.25	Impoundment

[1] Sites are arranged in downstream order.

Table 13. Visual Habitat Assessment (VHA) scores for Onondaga Creek (2015).

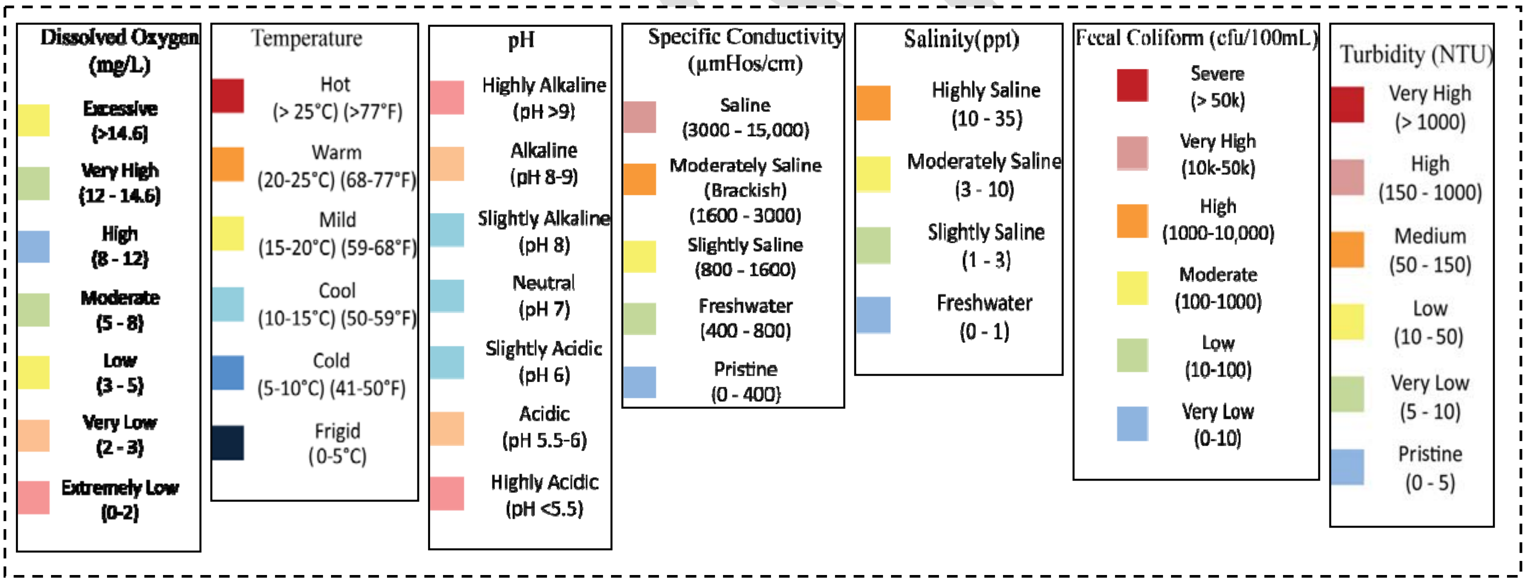
Site	**Tully Farms Rd**	**Hitchings Rd**	**Gibson Rd**	**Dorwin Ave**	**Rte 173**	**Walton St**	**Kirkpatrick St**
Sampling Date	**6/11/2015**	**6/19/2015**	**7/23/2015**	**6/22/2015**	**6/22/2015**	**7/23/2015**	**7/23/2015**
Stream Gradient	**High**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**
Epifaunal Substrate/Available Cover	20	8	10	8	8	16	16
Pool Substrate Characterization/Embeddedness	20	6	8	0	0	0	10
Pool Variability/Velocity-Depth Regime	20	0	13	0	0	0	6
Sediment Deposition	19	11	6	20	16	20	18
Channel Flow Status	19	20	19	20	20	20	19
Channel Alteration	19	18	14	5	5	0	0
Channel Sinuosity/Frequency of Riffles	20	7	4	0	3	0	5
Bank Stability LB	9	7	2	10	8	10	5
Bank Stability RB	9	6	2	10	8	10	5
Vegetative Protection LB	10	10	6	8	8	5	8
Vegetative Protection RB	10	8	6	8	8	5	8
Riparian Vegetative Zone Width LB	10	10	10	0	0	0	4
Riparian Vegetative Zone Width RB	10	5	10	0	0	0	4
Total	**195**	**116**	**110**	**89**	**84**	**86**	**108**

[1] Sites are arranged in downstream order.

Table 14. Water quality parameters for Onondaga Creek biological sampling events.

Site		Dissolved Oxygen (mg/L)	Temperature (°C)	Specific Conductivity (µS/cm)	pH	Turbidity (NTU)
Tully Farms Rd	6/11/2015	DNR	17.76	423	8.09	10.5
Hitchings Rd	6/19/2015	8.18	20.40	659	7.78	37.3
Gibson Rd	7/23/2015	8.8	17.62	883	7.86	24
Dorwin Ave	6/22/2015	9.4	18.70	738	8.85	76.5
Seneca Tpke	6/22/2015	9.01	20.17	705	7.88	90.3
Walton Ave	7/23/2015	9.56	15.99	1119	7.71	5.8
Kirkpatrick St	7/23/2015	9.66	16.38	3024	7.68	5.1
	Minimum	8.18	15.99	423	7.68	5.1
	Median	9.205	17.76	738	7.86	24
	Maximum	9.66	20.40	3024	8.85	90.3
	Mean	9.10	18.15	1078.71	7.98	35.64
	N	**6**	**7**	**7**	**7**	**7**

[1]DNR – data not recorded. Color-coding for interpretative scales are shown below. Sites are arranged in downstream order.



Dissolved Oxygen (mg/L)
🟨 Excessive (>14.6)
🟩 Very High (12 - 14.6)
🟦 High (8 - 12)
🟩 Moderate (5 - 8)
🟨 Low (3 - 5)
🟧 Very Low (2 - 3)
🟥 Extremely Low (0-2)

Temperature
🟥 Hot (> 25°C) (>77°F)
🟧 Warm (20-25°C) (68-77°F)
🟨 Mild (15-20°C) (59-68°F)
🟦 Cool (10-15°C) (50-59°F)
🟦 Cold (5-10°C) (41-50°F)
⬛ Frigid (0-5°C)

pH
🟥 Highly Alkaline (pH >9)
🟧 Alkaline (pH 8-9)
🟦 Slightly Alkaline (pH 8)
🟦 Neutral (pH 7)
🟦 Slightly Acidic (pH 6)
🟧 Acidic (pH 5.5-6)
🟥 Highly Acidic (pH <5.5)

Specific Conductivity (µmHos/cm)
🟥 Saline (3000 - 15,000)
🟧 Moderately Saline (Brackish) (1600 - 3000)
🟨 Slightly Saline (800 - 1600)
🟩 Freshwater (400 - 800)
🟦 Pristine (0 - 400)

Salinity(ppt)
🟧 Highly Saline (10 - 35)
🟨 Moderately Saline (3 - 10)
🟩 Slightly Saline (1 - 3)
🟦 Freshwater (0 - 1)

Fecal Coliform (cfu/100mL)
🟥 Severe (> 50k)
🟥 Very High (10k-50k)
🟧 High (1000-10,000)
🟨 Moderate (100-1000)
🟩 Low (10-100)
🟦 Very Low (0-10)

Turbidity (NTU)
🟥 Very High (> 1000)
🟥 High (150 - 1000)
🟧 Medium (50 - 150)
🟨 Low (10 - 50)
🟩 Very Low (5 - 10)
🟦 Pristine (0 - 5)

Table 15. Fish community composition for Ley Creek (2015).

Location[1]	Date	Banded killifish	Brook stickleback	Bluntnose minnow	Central mudminnow	Creek chub	Fathead minnow	Green sunfish	Longnose dace	Pumpkinseed sunfish	Round goby	Tessellated darter	White sucker	TOTAL
Fly Rd (NB)	6/12/2015		3		21	2	1	1				1	1	**30**
Thompson Rd (NB)	6/5/2015				2				4	1	2		3	**12**
Exeter Rd (SB)	6/5/2015					15			5					**20**
Court St (SB)	6/5/2015	1				8			30				2	**41**
Factory Rd (MS)	6/5/2015			3		1		1	38		2	3	1	**49**
Park St (MS)	6/5/2015	DID NOT SAMPLE												
		1	**3**	**3**	**23**	**26**	**1**	**2**	**77**	**1**	**4**	**4**	**7**	**152**

[1] Sites are arranged in downstream order. NB – North Branch; SB – South Branch; MS – Mainstem.

Table 16. Fish metric and IBI scores for Ley Creek (2015).

Metric/ Location[1] → ↓	Fly Rd (NB)	Thompson Rd (NB)	Exeter Rd (SB)	Court St (SB)	Factory Ave (MS)	Minimum	Median	Maximum	Mean (N=5)
Abundance (N)	30	12	20	41	49	12	30	49	30.4
Total Species Richness	7	5	2	4	7	2	5	7	5
Shannon Diversity (H')	1.11	1.52	0.56	0.79	0.91	0.56	0.91	1.52	0.98
Native Richness	7	4	2	4	6	2	4	7	5
Exotic Richness	0	1	0	0	1	0	0	1	0
Benthic Insectivore Richness	1	1	1	1	2	1	1	2	1
Water Column Richness	1	0	0	1	0	0	0	1	0
Terete Minnow Richness	2	0	1	1	2	0	1	2	1
% Dominant Species	70.00	33.33	75.00	73.17	77.55	33.33	73.17	77.55	65.81
% White sucker	3.33	25.00	0.00	4.88	2.04	0.00	3.33	25.00	7.05
% Generalists	86.67	50.00	75.00	24.39	12.24	12.24	50.00	86.67	49.66
% Insectivores	13.33	33.33	25.00	75.61	83.67	13.33	33.33	83.67	46.19
% Top Carnivore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Species w/ > 1 size Class (N)	0	1	1	0	0	0	0	1	0
# Individuals w/ Anomalies	0	0	0	0	1	0	0	1	0
IBI Score	32	32	36	36	38	32	36	38	34.8
Rating	Poor	Poor	Poor	Poor	Fair				

[1] Sites each arranged downstream order, left to right. NB – North Branch; SB – South Branch; MS – Mainstem.

Table 17. Macroinvertebrate metric scores for Ley Creek (2015).

Site[1]/Metric → ↓	Richness	EPT Richness	NCO Richness	Diversity	Dominance (%)	HBI	PMA	BAP	BAP Rating
Fly Rd (NB)	15	0	9	2.15	63.00	7.27	34.00	2.61	Moderate
Thompson Rd (NB)	18	2	8	2.07	69.00	6.11	33.00	3.91	Moderate
Exeter Rd (SB)	18	1	11	2.06	67.00	7.22	34.00	3.15	Moderate
Court St (SB)	18	1	9	2.33	54.00	7.33	49.00	3.75	Moderate
Factory Ave (MS)	20	1	8	2.14	67.00	6.92	40.00	3.70	Moderate
Park St (MS)	26	0	12	2.54	57.00	7.85	35.00	5.40	Slight
Minimum	15	0	8	2.06	54.00	6.11	33.00	2.61	Moderate
Median	18	1	9	2.14	65.00	7.25	34.50	3.72	Moderate
Maximum	26	2	12	2.54	69.00	7.85	49.00	5.40	Slight
Mean (N=6)	19.17	0.83	9.5	2.21	62.83	7.12	37.50	3.75	Moderate

[1] Sites each arranged downstream order. NB – North Branch; SB – South Branch; MS – Mainstem.

Table 18. Impact Source Determination (ISD) for Ley Creek (2015).

Site[1]/Metric → ↓	Natural	Nutrients/ Pesticides	Municipal/ Industrial	Toxic	Sewage/ Effluent	Siltation	Impound-ment	Maximum	ISD Category
Fly Rd (NB)	4.65	13.14	32.09	21.16	**40.23**	14.65	29.42	40.23	Sewage/Effluent
Thompson Rd (NB)	17.69	22.69	30.77	23.08	25.77	29.62	**32.31**	32.31	Impoundment
Exeter Rd (SB)	16.36	21.36	31.82	33.64	33.64	21.82	**34.55**	34.55	Impoundment
Court St (SB)	30.31	39.47	39.20	54.47	38.58	42.12	**55.09**	55.09	Impoundment
Factory Ave (MS)	19.06	26.41	32.97	33.28	**55.31**	31.88	32.66	55.31	Sewage/Effluent
Park St (MS)	11.78	**34.75**	21.19	28.64	33.05	26.10	33.56	34.75	Nutrients/Pesticides

[1] Sites each arranged downstream order. NB – North Branch; SB – South Branch; MS – Mainstem.

Table 19. Visual Habitat Assessment (VHA) scores for Ley Creek (2015). Sites are arranged in downstream order.

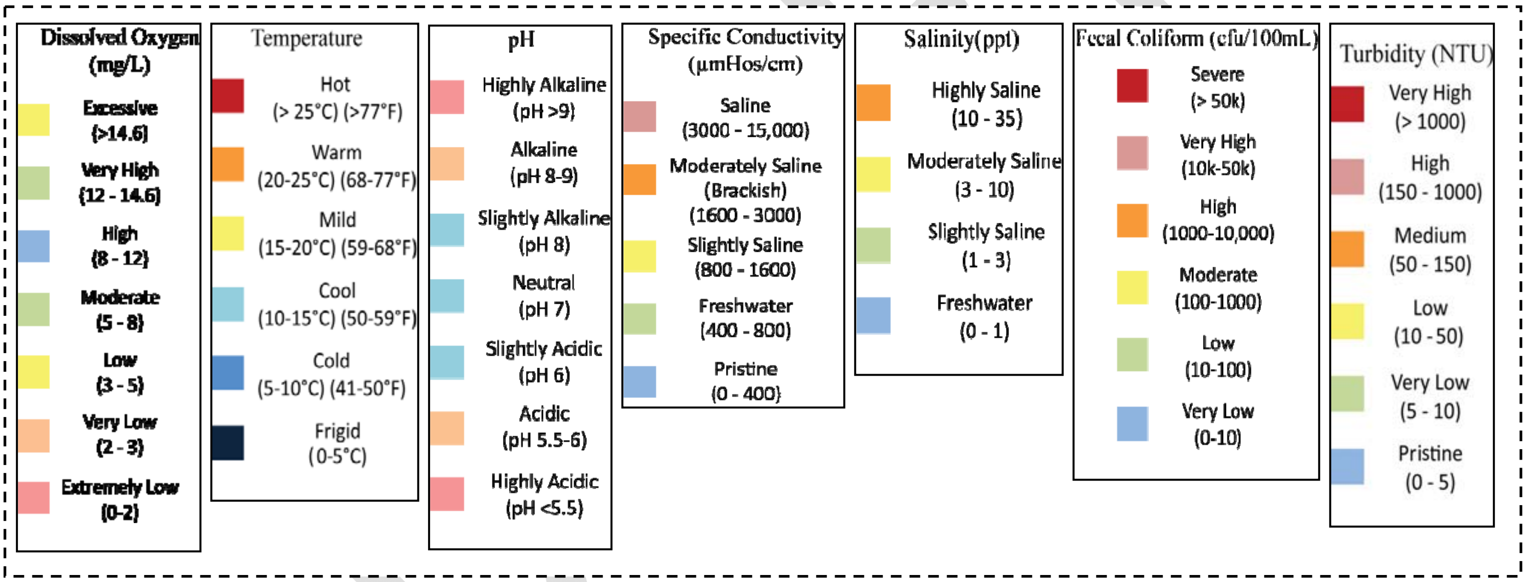
	Maximum Possible Score	North Branch		South Branch		Mainstem	
Site[1]		**Fly Rd**	**Thompson Rd**	**Exeter Rd**	**Court St**	**Factory Rd.**	**Park St**
Sampling Date		**6/12/2015**	**6/5/2015**	**6/5/2015**	**6/5/2015**	**6/5/2015**	**6/12/2015**
Stream Gradient		**Low**	**Low**	**Low**	**Low**	**Low**	**Low**
Epifaunal Substrate/Available Cover	20	14	13	6	15	8	0
Pool Substrate Characterization/Embeddedness	20	11	10	6	6	9	0
Pool Variability/Velocity-Depth Regime	20	10	15	9	14	5	0
Sediment Deposition	20	20	17	13	17	15	18
Channel Flow Status	20	20	19	17	15	15	20
Channel Alteration	20	15	19	17	15	5	7
Channel Sinuosity/Frequency of Riffles	20	6	16	16	19	1	2
Bank Stability LB	10	6	6	6	8	9	9
Bank Stability RB	10	6	6	6	8	6	9
Vegetative Protection LB	10	10	5	9	10	5	10
Vegetative Protection RB	10	10	5	9	10	8	10
Riparian Vegetative Zone Width LB	10	10	5	8	9	2	3
Riparian Vegetative Zone Width RB	10	10	5	9	7	4	3
Total	**200**	**148**	**141**	**131**	**153**	**92**	**91**

[1] Sites each arranged downstream order. NB – North Branch; SB – South Branch; MS – Mainstem.

Table 20. Water quality parameters for Ley Creek biological sampling events.

Site		Dissolved Oxygen (mg/L)	Temperature (°C)	Specific Conductivity (µS/cm)	pH	Turbidity (NTU)
Fly Rd	6/12/2015	5.16	18.65	1002	7.01	10.5
Thompson Rd	6/5/2015	6.29	16.07	1035	7.26	3.5
Exeter Rd	6/5/2015	6.52	17.61	2344	7.46	3.9
Court St	6/5/2015	8.83	17.89	2235	7.66	4.1
Factory Ave	6/5/2015	8.77	18.25	1560	7.56	12.3
Park St	6/12/2015	5.54	18.65	1257	7.21	18.5
	Minimum	**5.16**	**16.07**	**1002.00**	**7.01**	**3.50**
	Median	**6.41**	**18.07**	**1408.50**	**7.36**	**7.30**
	Maximum	**8.83**	**18.65**	**2344.00**	**7.66**	**18.50**
	Mean	**6.85**	**17.85**	**1572.17**	**7.36**	**8.80**
	N	**6**	**6**	**6**	**6**	**6**

[1] Color-coding for interpretative scales are shown below. Sites are arranged in downstream order.



Dissolved Oxygen (mg/L)
🟨 Excessive (>14.6)
🟩 Very High (12 - 14.6)
🟦 High (8 - 12)
🟩 Moderate (5 - 8)
🟨 Low (3 - 5)
🟧 Very Low (2 - 3)
🟥 Extremely Low (0-2)

Temperature
🟥 Hot (> 25°C) (>77°F)
🟧 Warm (20-25°C) (68-77°F)
🟨 Mild (15-20°C) (59-68°F)
🟦 Cool (10-15°C) (50-59°F)
🟦 Cold (5-10°C) (41-50°F)
⬛ Frigid (0-5°C)

pH
🟥 Highly Alkaline (pH >9)
🟧 Alkaline (pH 8-9)
🟦 Slightly Alkaline (pH 8)
🟦 Neutral (pH 7)
🟦 Slightly Acidic (pH 6)
🟧 Acidic (pH 5.5-6)
🟥 Highly Acidic (pH <5.5)

Specific Conductivity (µmHos/cm)
🟥 Saline (3000 - 15,000)
🟧 Moderately Saline (Brackish) (1600 - 3000)
🟨 Slightly Saline (800 - 1600)
🟩 Freshwater (400 - 800)
🟦 Pristine (0 - 400)

Salinity(ppt)
🟧 Highly Saline (10 - 35)
🟨 Moderately Saline (3 - 10)
🟩 Slightly Saline (1 - 3)
🟦 Freshwater (0 - 1)

Fecal Coliform (cfu/100mL)
🟥 Severe (> 50k)
🟥 Very High (10k-50k)
🟧 High (1000-10,000)
🟨 Moderate (100-1000)
🟩 Low (10-100)
🟦 Very Low (0-10)

Turbidity (NTU)
🟥 Very High (> 1000)
🟥 High (150 - 1000)
🟧 Medium (50 - 150)
🟨 Low (10 - 50)
🟩 Very Low (5 - 10)
🟦 Pristine (0 - 5)

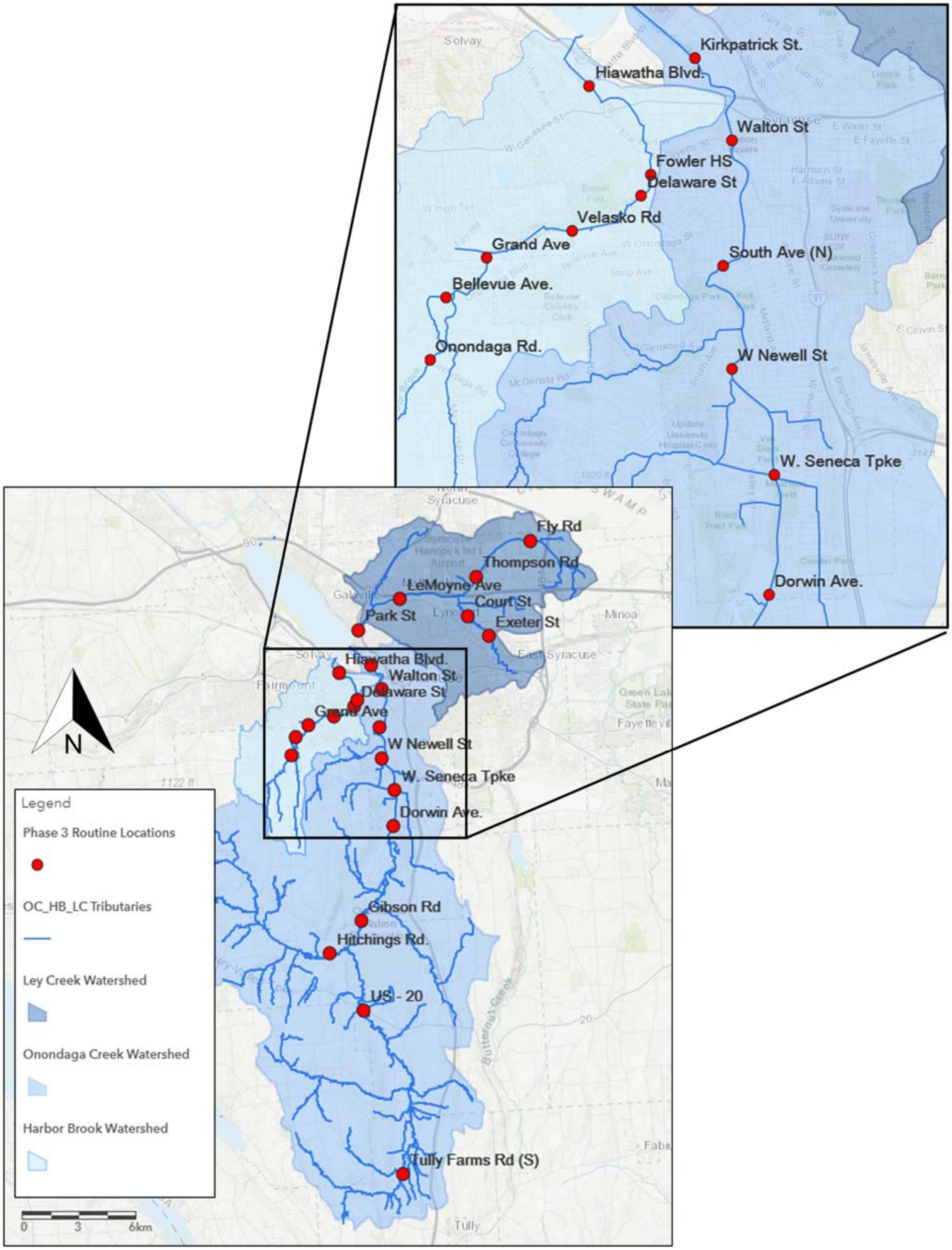


Figure 1. Phase 3 Routine sampling locations. Biological sampling occurred at sites in 2015.

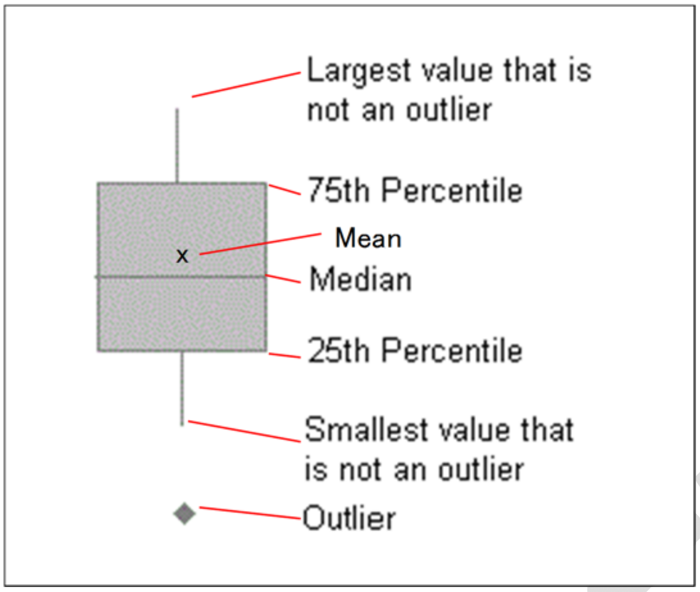


Figure 2. Non-parametric box plot with statistics depicted.

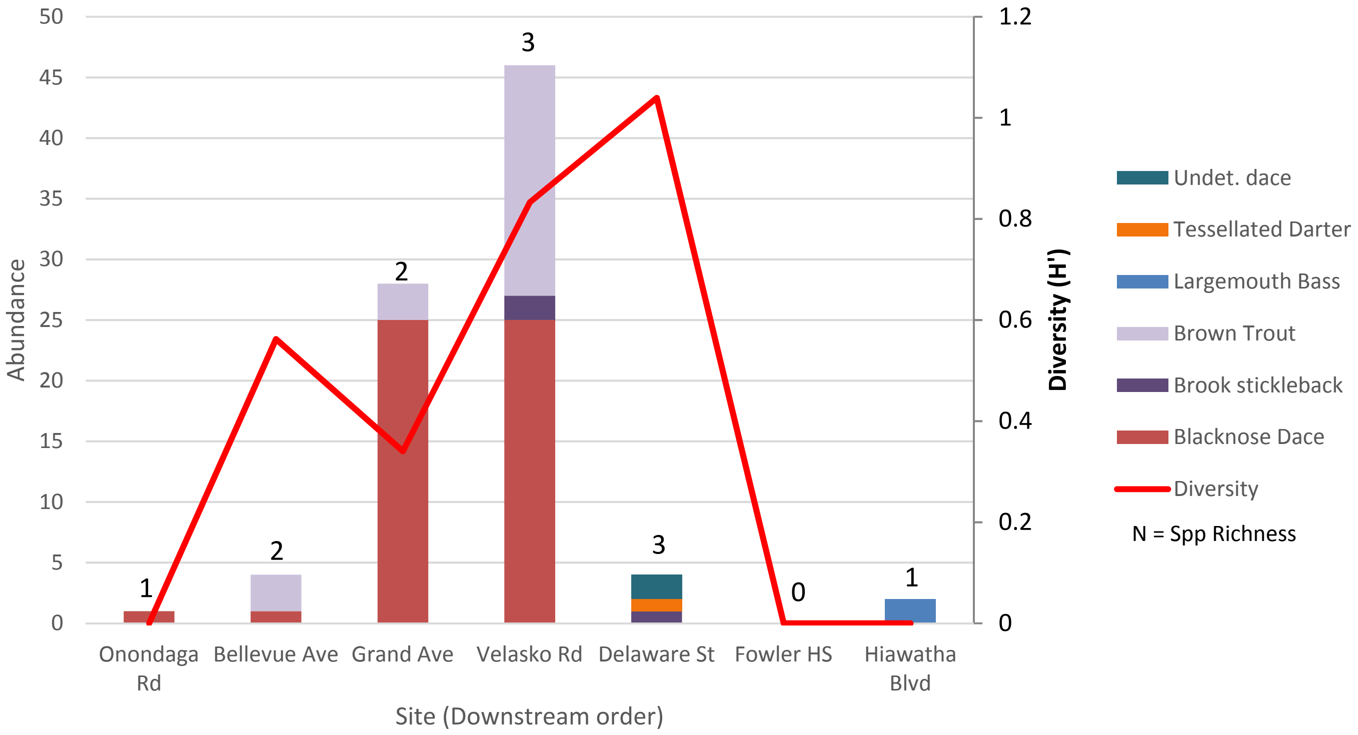


Figure 3. Fish community composition and diversity scores in Harbor Brook (2015). Species richness is shown above each bar.

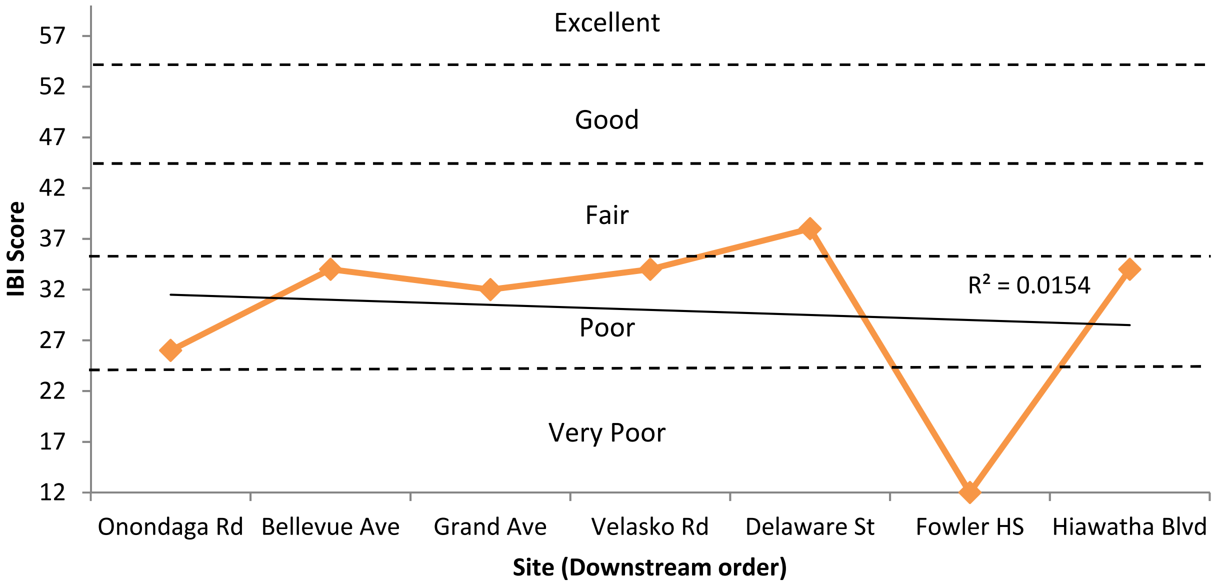


Figure 4. Fish IBI scores for Harbor Brook (2015).

Figure 5. Macroinvertebrate metrics for Harbor Brook. A linear regression trend line is displayed (R^2). Sites are arranged in downstream order.

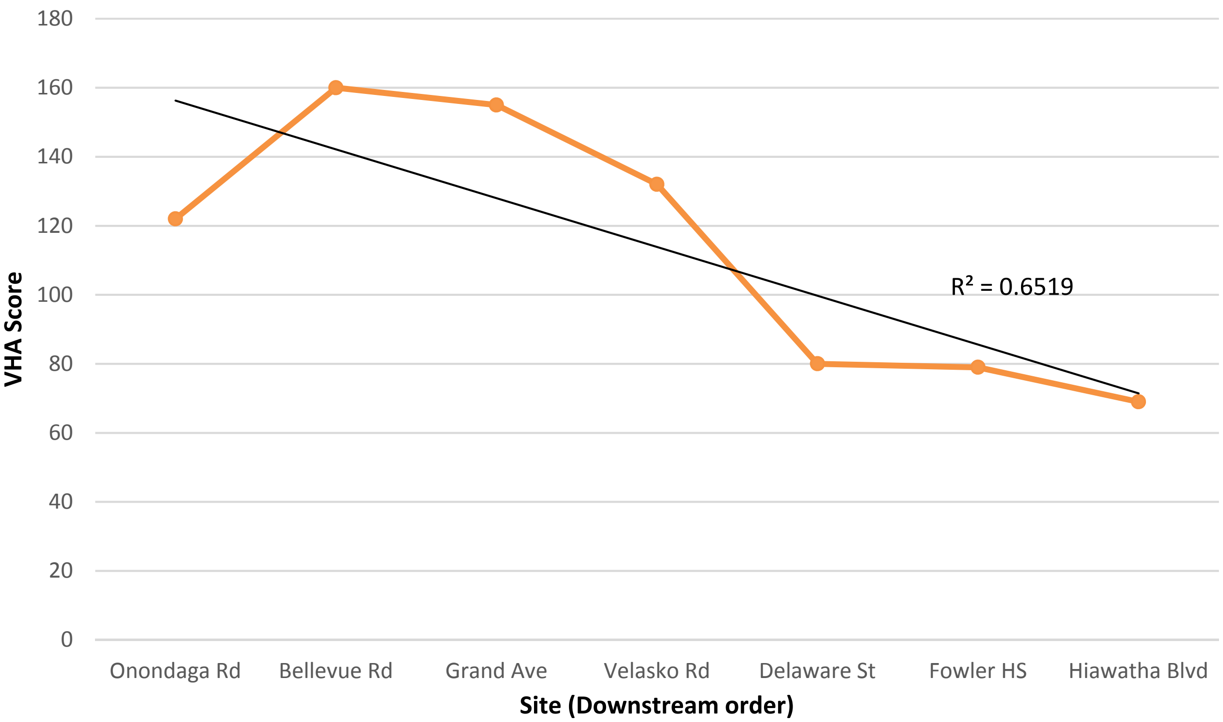


Figure 6. Visual Habitat Assessment (VHA) scores for Harbor Brook. A linear regression trend line is displayed (R^2).

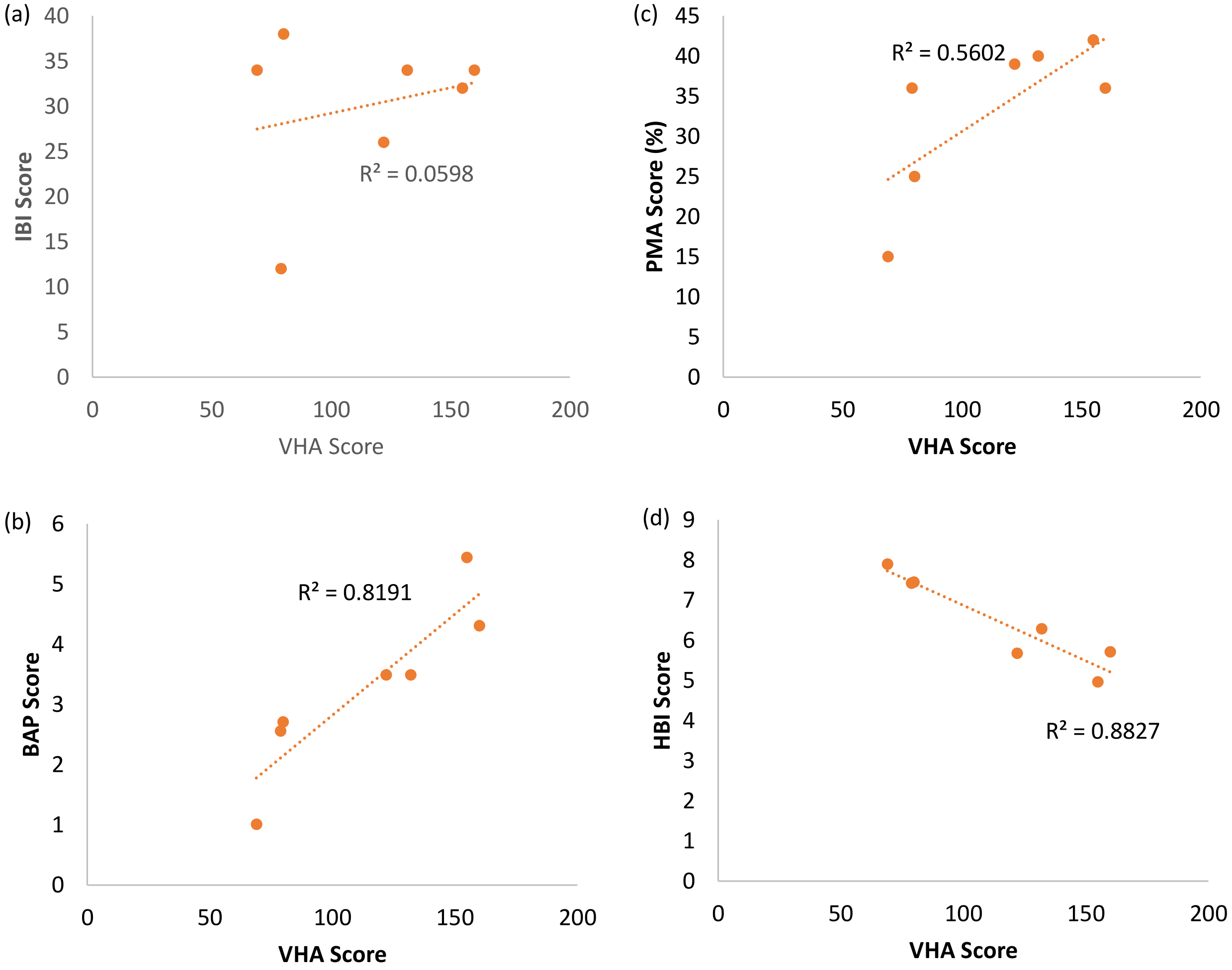


Figure 7. Correlation analysis of VHA scores to (a) fish and (b-d) macroinvertebrate metric scores for Harbor Brook sampling locations. A linear regression trend line is displayed (R^2) for each plot.

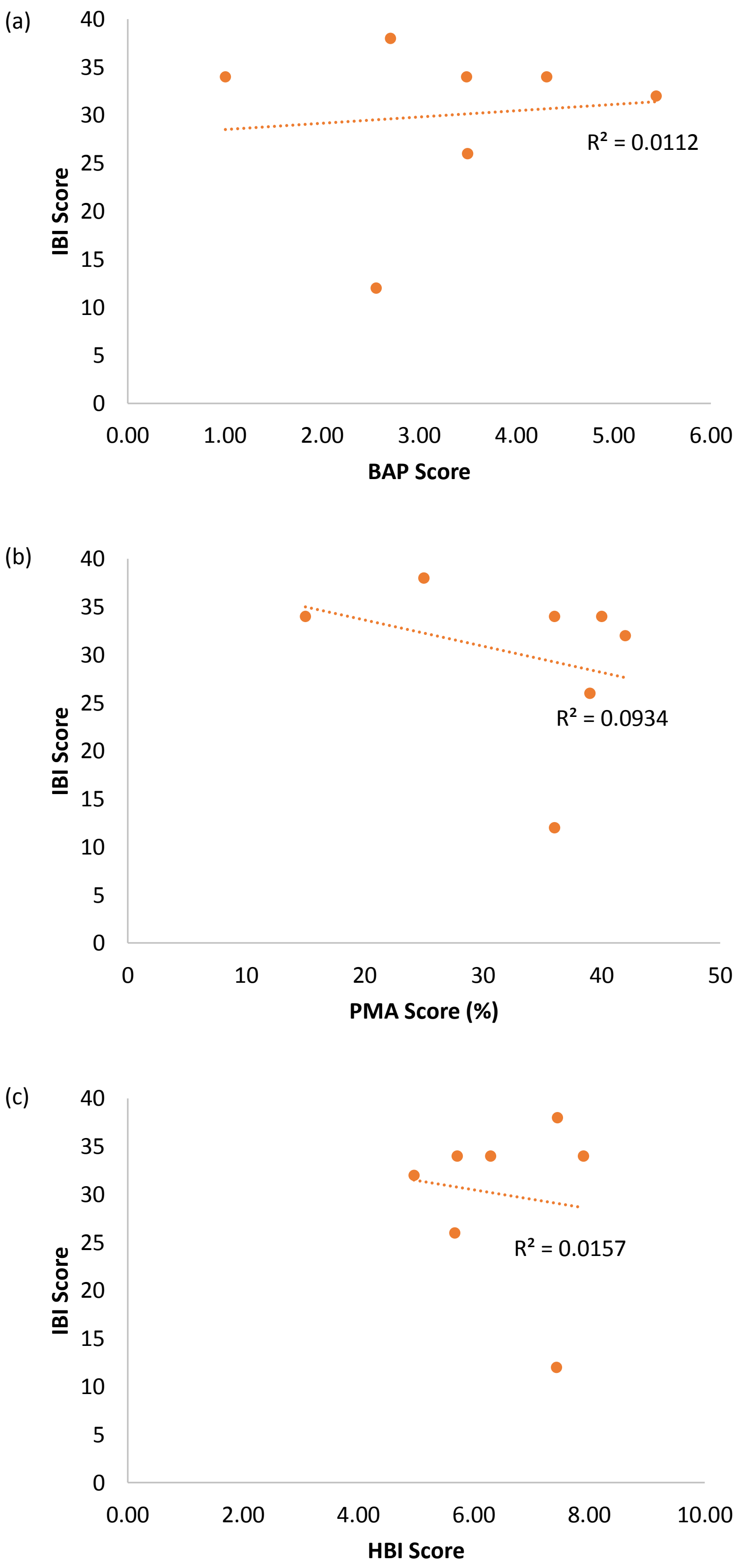


Figure 8. Correlation analysis of macroinvertebrate metric scores to fish IBI scores for Harbor Brook sampling locations. A linear regression trend line is displayed (R^2) for each plot.

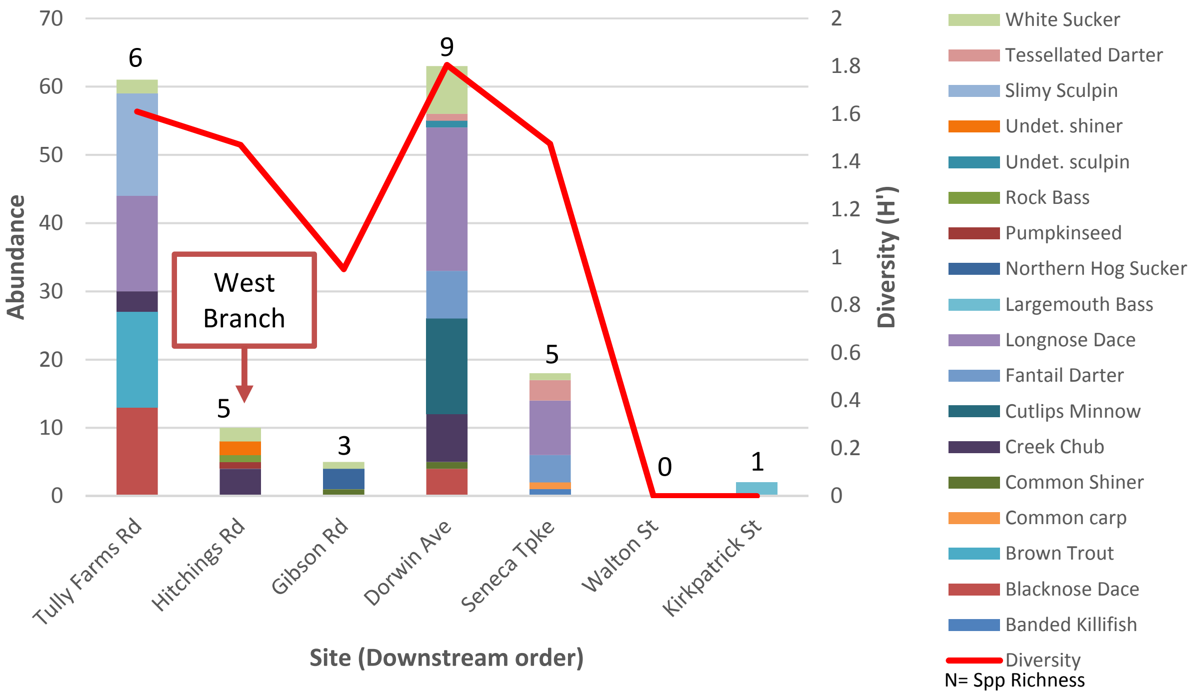


Figure 9. Fish community composition and diversity scores for locations in Onondaga Creek (2015). Sites that could not be sampled due to accessibility issues are not displayed. Species richness is shown above each bar.

Figure 10. Fish IBI scores for Onondaga Creek (2015). Sites that could not be sampled due to accessibility issues are not displayed.

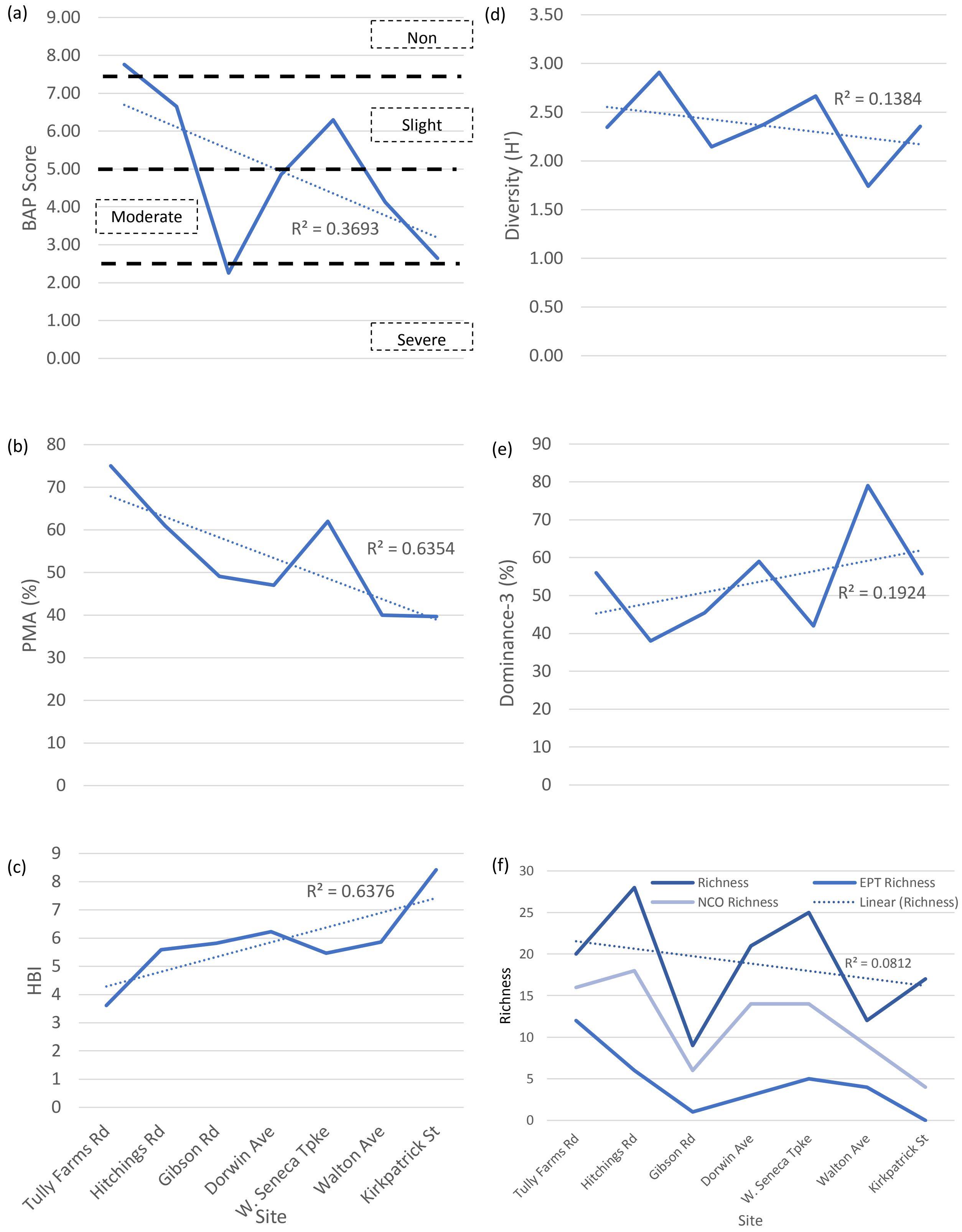

(a)
BAP Score
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Non
Slight
Moderate
Severe
R² = 0.3693
(b)
PMA (%)
80
70
60
50
40
30
20
10
0
R² = 0.6354
(c)
HBI
9
8
7
6
5
4
3
2
1
0
R² = 0.6376
Tully Farms Rd
Hitchings Rd
Gibson Rd
Dorwin Ave
W. Seneca Tpke
Walton Ave
Kirkpatrick St
Site
(d)
Diversity (H')
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
R² = 0.1384
(e)
Dominance-3 (%)
90
80
70
60
50
40
30
20
10
0
R² = 0.1924
(f)
Richness
30
25
20
15
10
5
0
Richness
EPT Richness
NCO Richness
Linear (Richness)
R² = 0.0812
Tully Farms Rd
Hitchings Rd
Gibson Rd
Dorwin Ave
W. Seneca Tpke
Walton Ave
Kirkpatrick St
Site

Figure 11. Macroinvertebrate metrics for Onondaga Creek. A linear regression trend line is displayed (R^2). Sites are arranged in downstream order. Note that Hitchings Rd is part of the West Branch, and is therefore, not contiguous with the other locations.

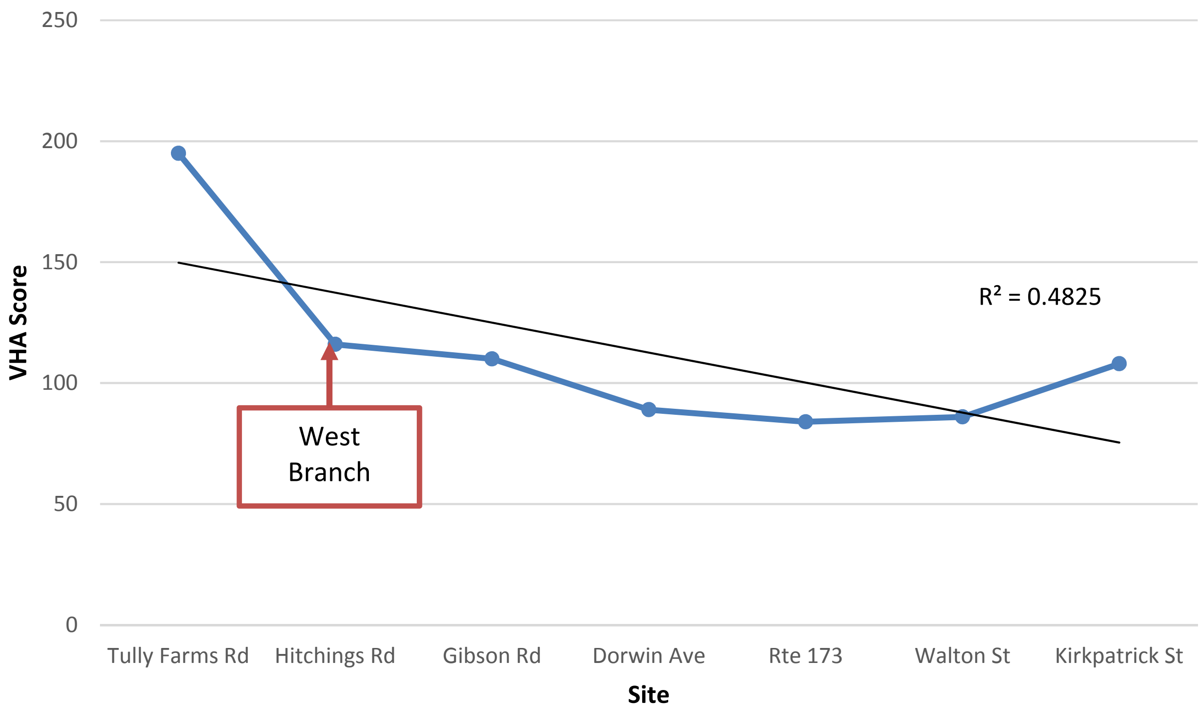


Figure 12. Visual Habitat Assessment (VHA) scores for Onondaga Creek sampling locations. A linear regression trend line is displayed (R^2).

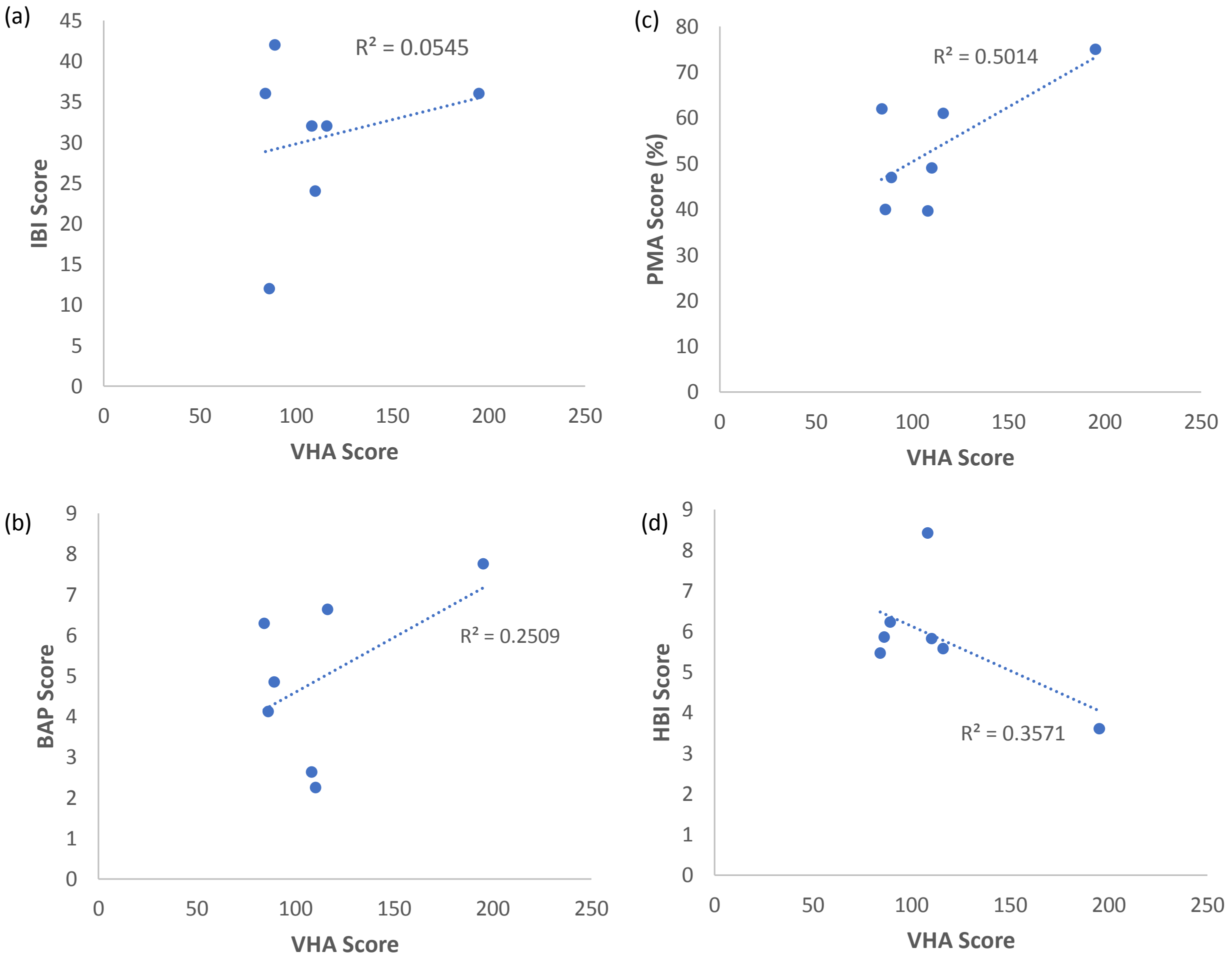


Figure 13. Correlation analysis of VHA scores to (a) fish and (b-d) macroinvertebrate metric scores for Onondaga Creek sampling locations. A linear regression trend line is displayed (R^2) for each plot.

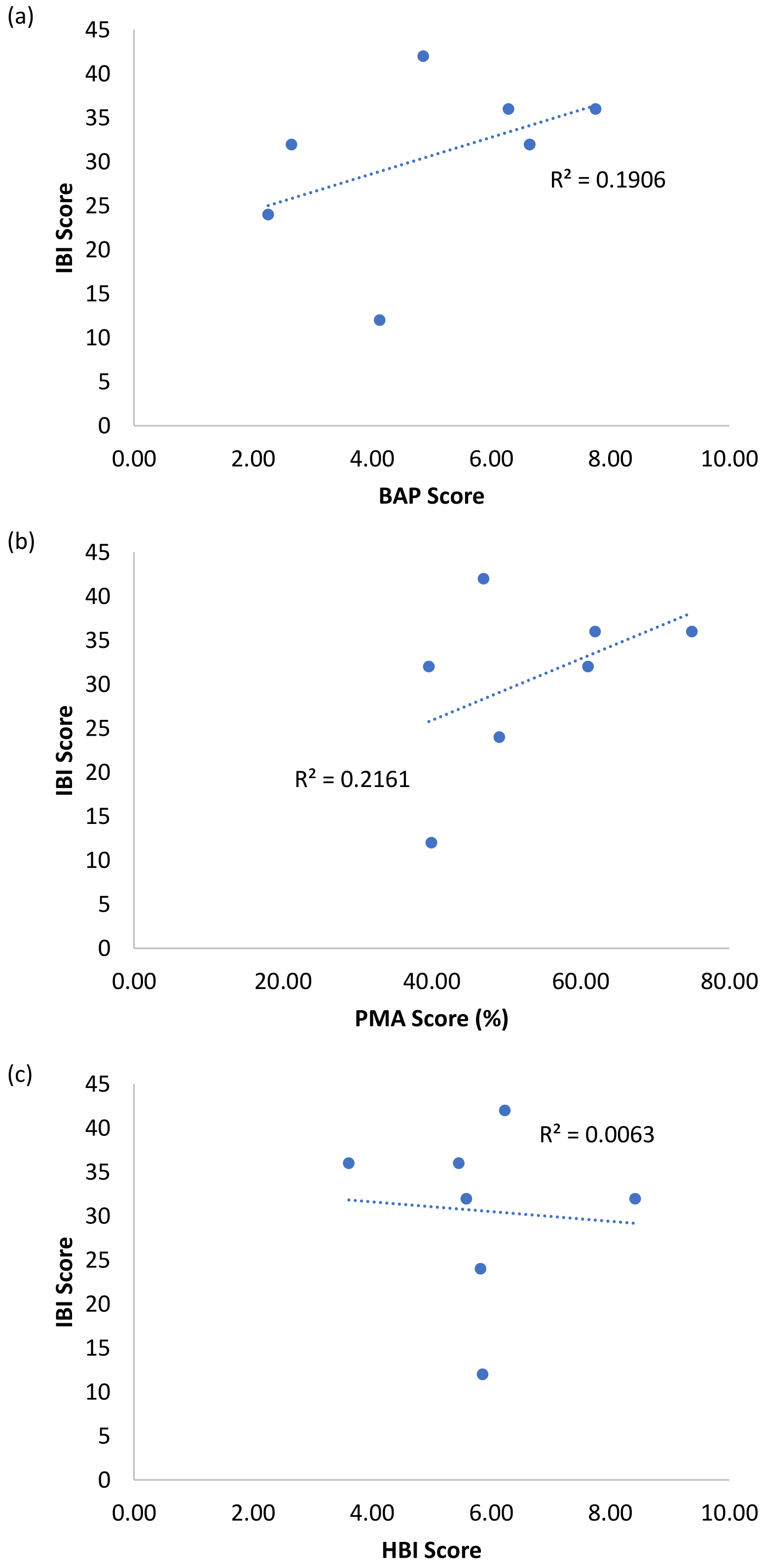


Figure 14. Correlation analysis of macroinvertebrate metric scores to fish IBI scores for Onondaga Creek. A linear regression trend line is displayed (R^2) for each plot.

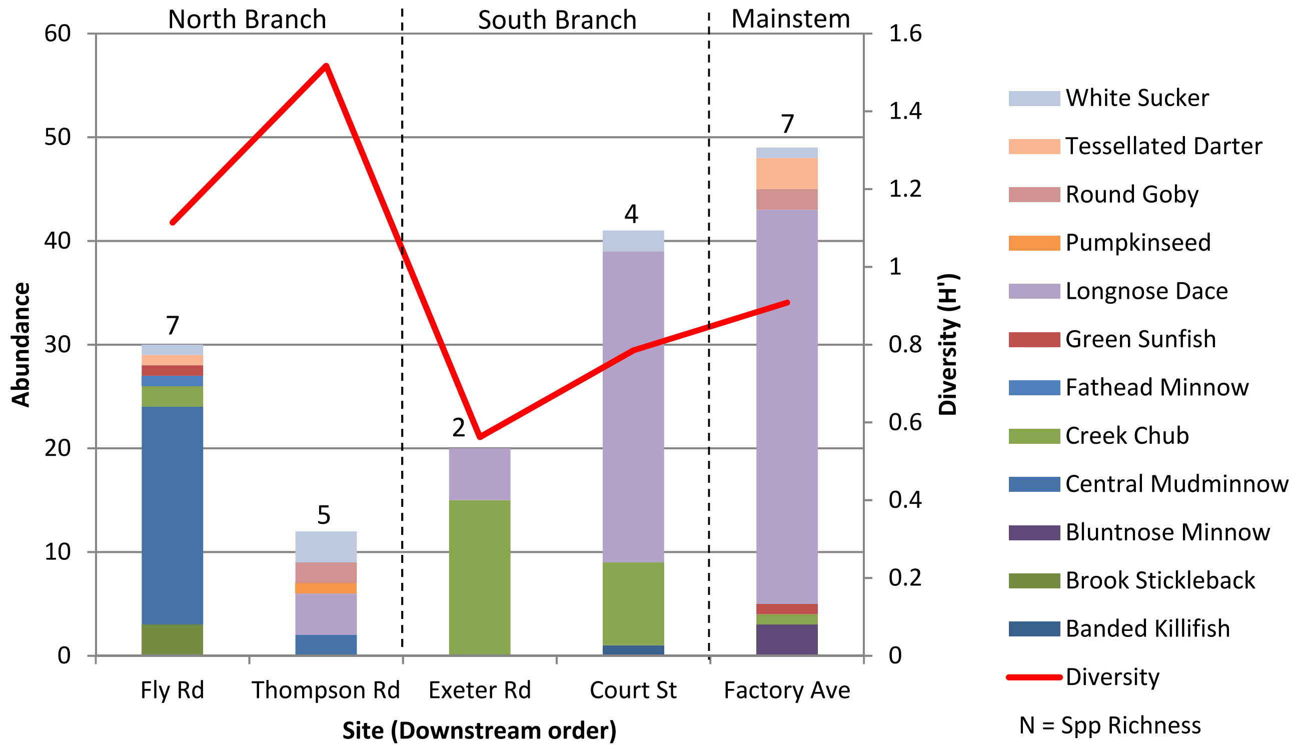


Figure 15. Fish community composition and diversity scores for locations in Ley Creek (2015). Sites that could not be sampled due to accessibility issues are not displayed. Species richness is shown above each bar.

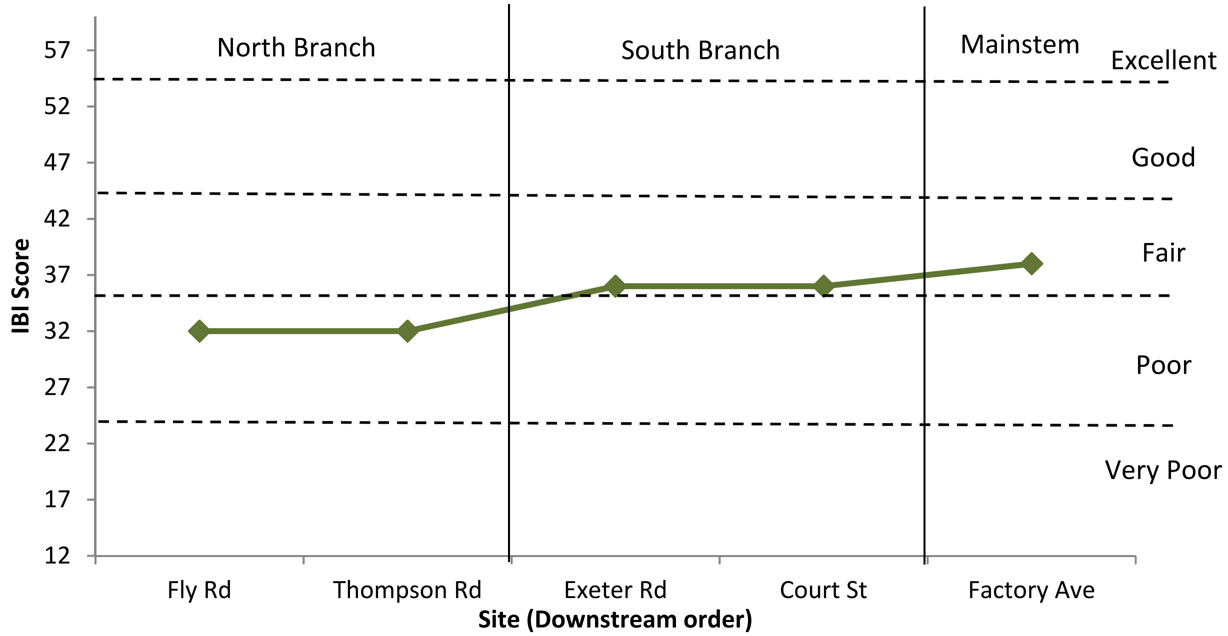


Figure 16. Fish IBI scores for Ley Creek (2015). Because sites are not contiguous, a linear regression analysis is not displayed. Sites that could not be sampled due to accessibility issues are not displayed.

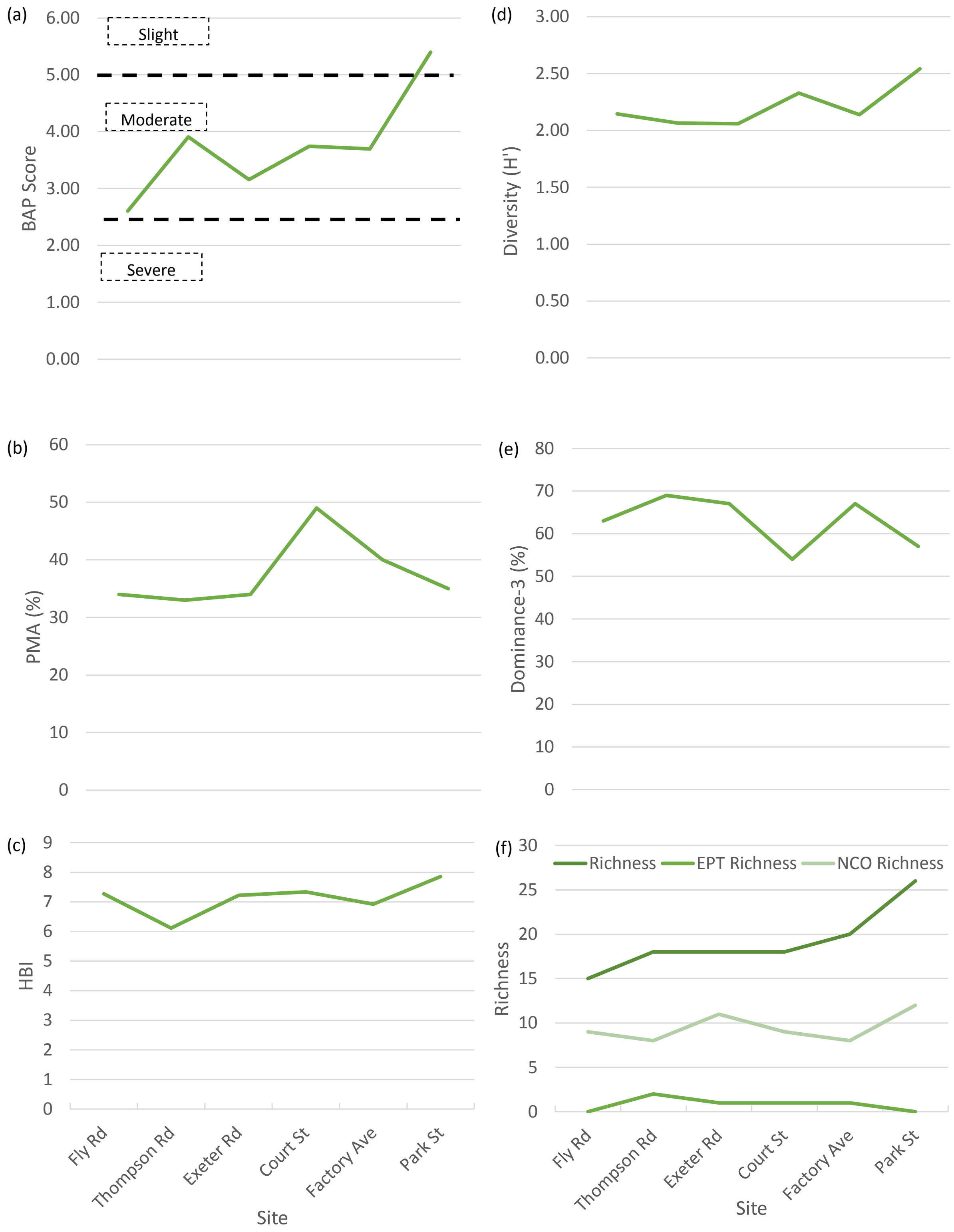


Figure 17. Macroinvertebrate metrics for Ley Creek. Because locations are not contiguous, a linear regression trend line is not displayed for plots. Sites are arranged in downstream order. Note: Fly &

Thompson Rds belong to the North Branch, Exeter Rd and Court St to the South Branch, and Factory Ave and Park St to the mainstem.

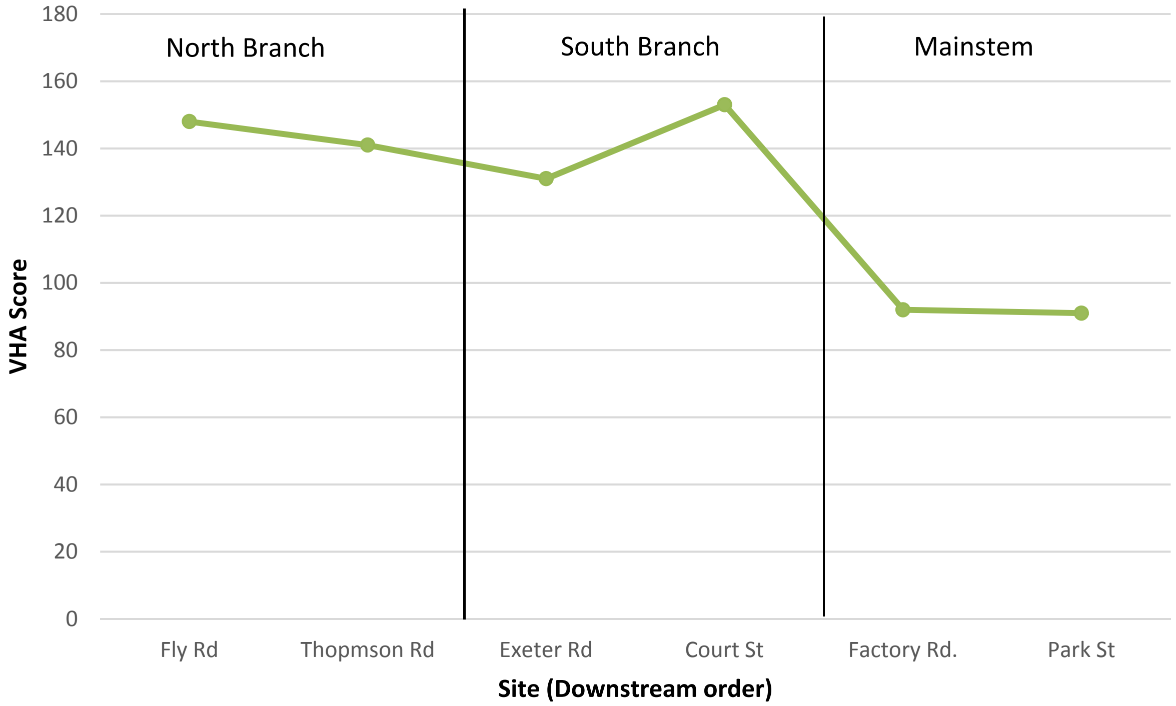


Figure 18. Visual Habitat Assessment (VHA) scores for Ley Creek sampling locations. Since locations are not contiguous, a linear regression trend line is not displayed. Sites are arranged in downstream order.

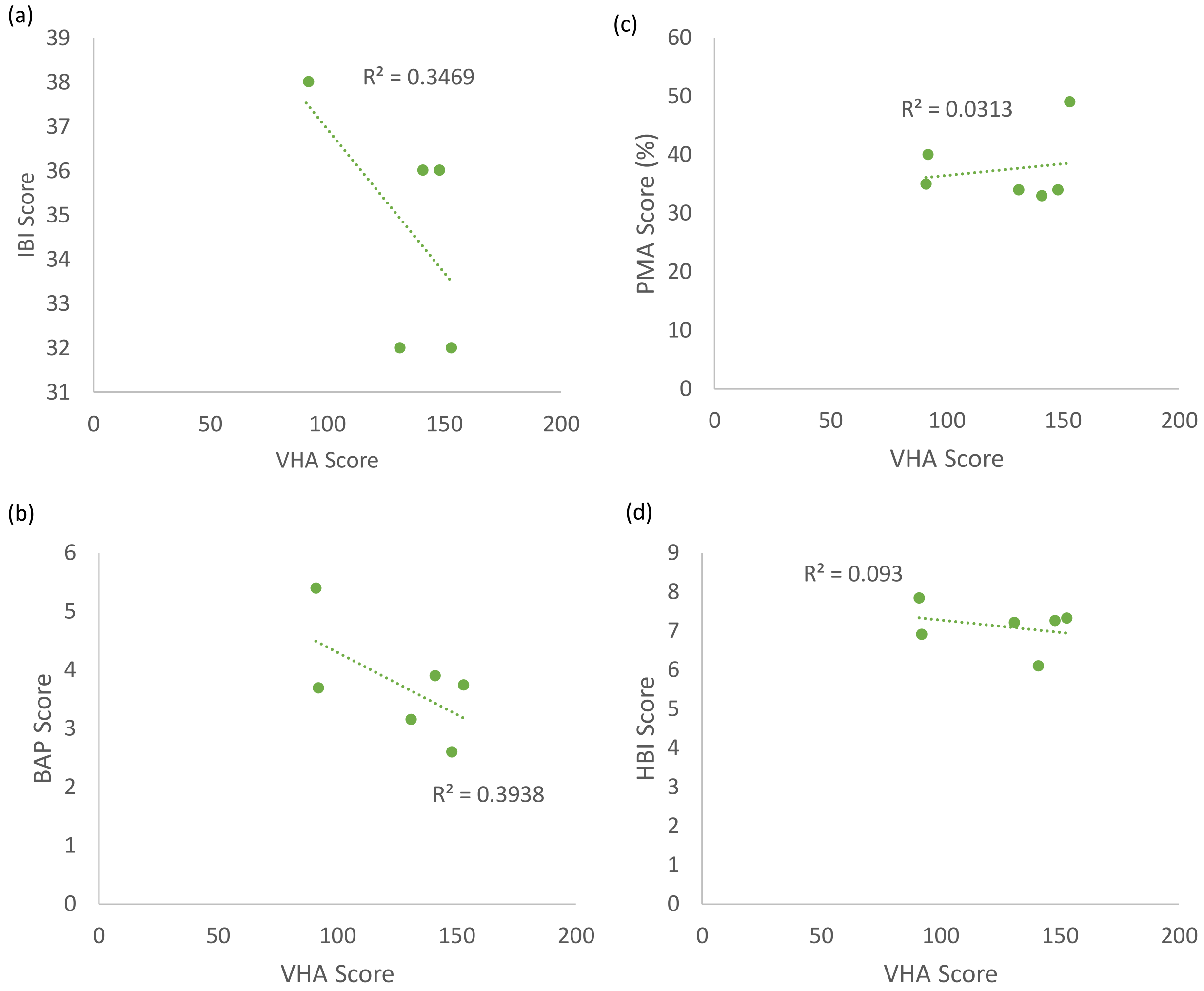


Figure 19. Correlation analysis of VHA scores to (a) fish and (b-d) macroinvertebrate metric scores for Ley Creek. A linear regression trend line is displayed (R^2) for each plot.

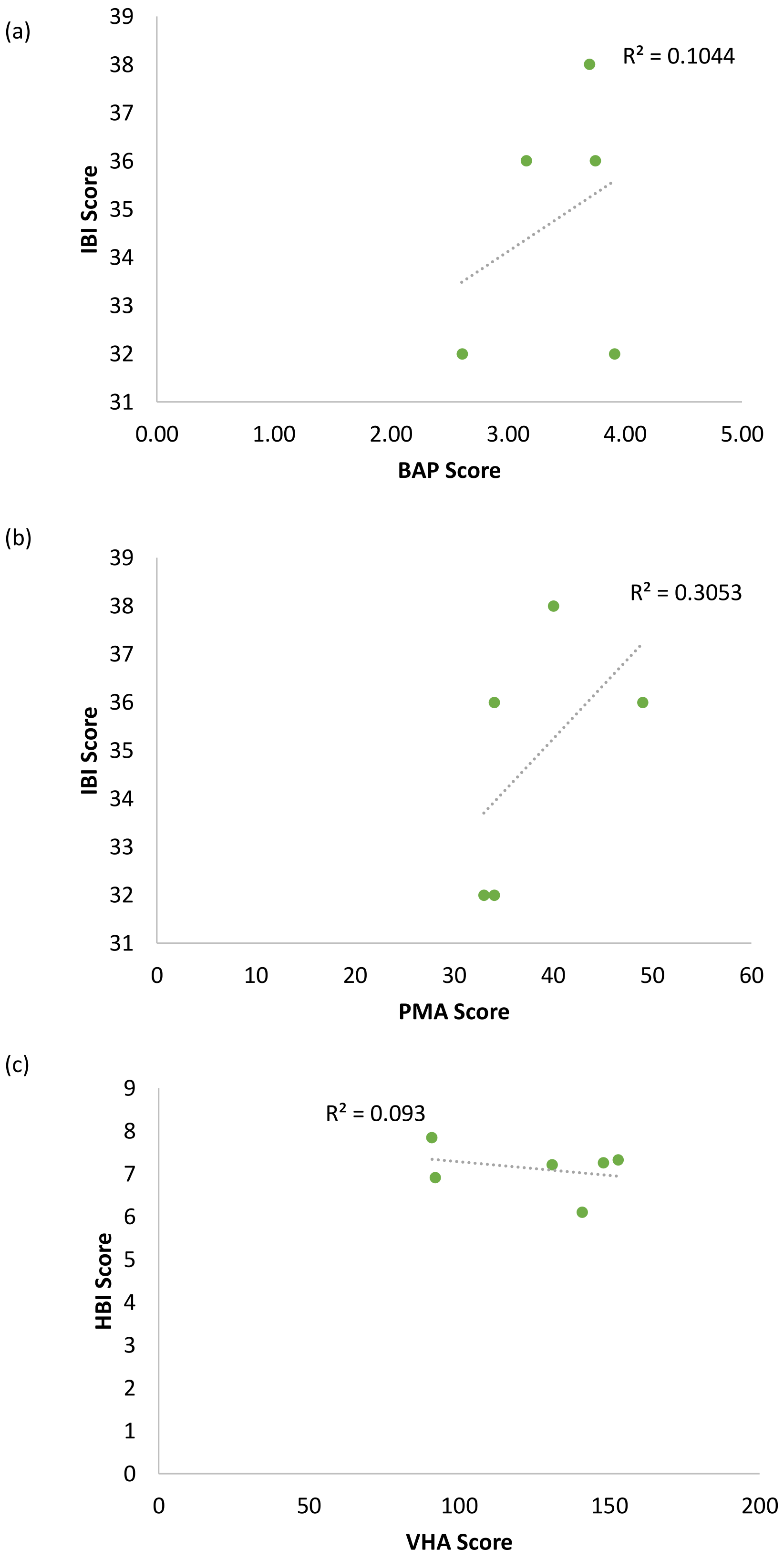

(a)
IBI Score
39
38
37
36
35
34
33
32
31
R² = 0.1044
0.00
1.00
2.00
3.00
4.00
5.00
BAP Score
(b)
IBI Score
39
38
37
36
35
34
33
32
31
R² = 0.3053
0
10
20
30
40
50
60
PMA Score
(c)
HBI Score
9
8
7
6
5
4
3
2
1
0
R² = 0.093
0
50
100
150
200
VHA Score

Figure 20. Correlation analysis of macroinvertebrate metric to fish IBI scores for Ley Creek. A linear regression trend line is displayed (R^2) for each plot.

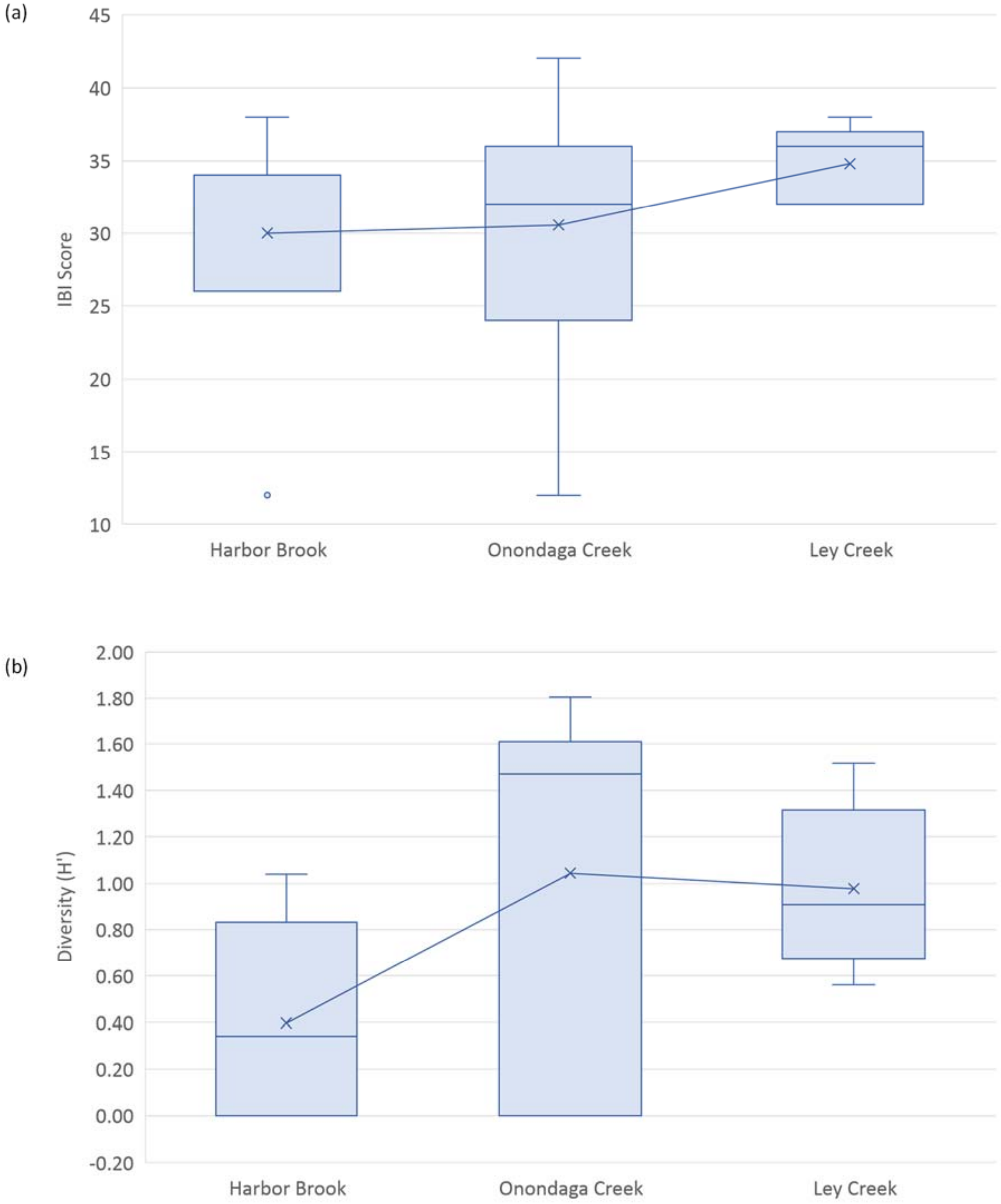


Figure 21. Box plot analysis of fish metrics among streams. (a) Index of Biotic Integrity (IBI), (b) Shannon Diversity index (H′). Refer to Fig. 2 to interpret box plots.

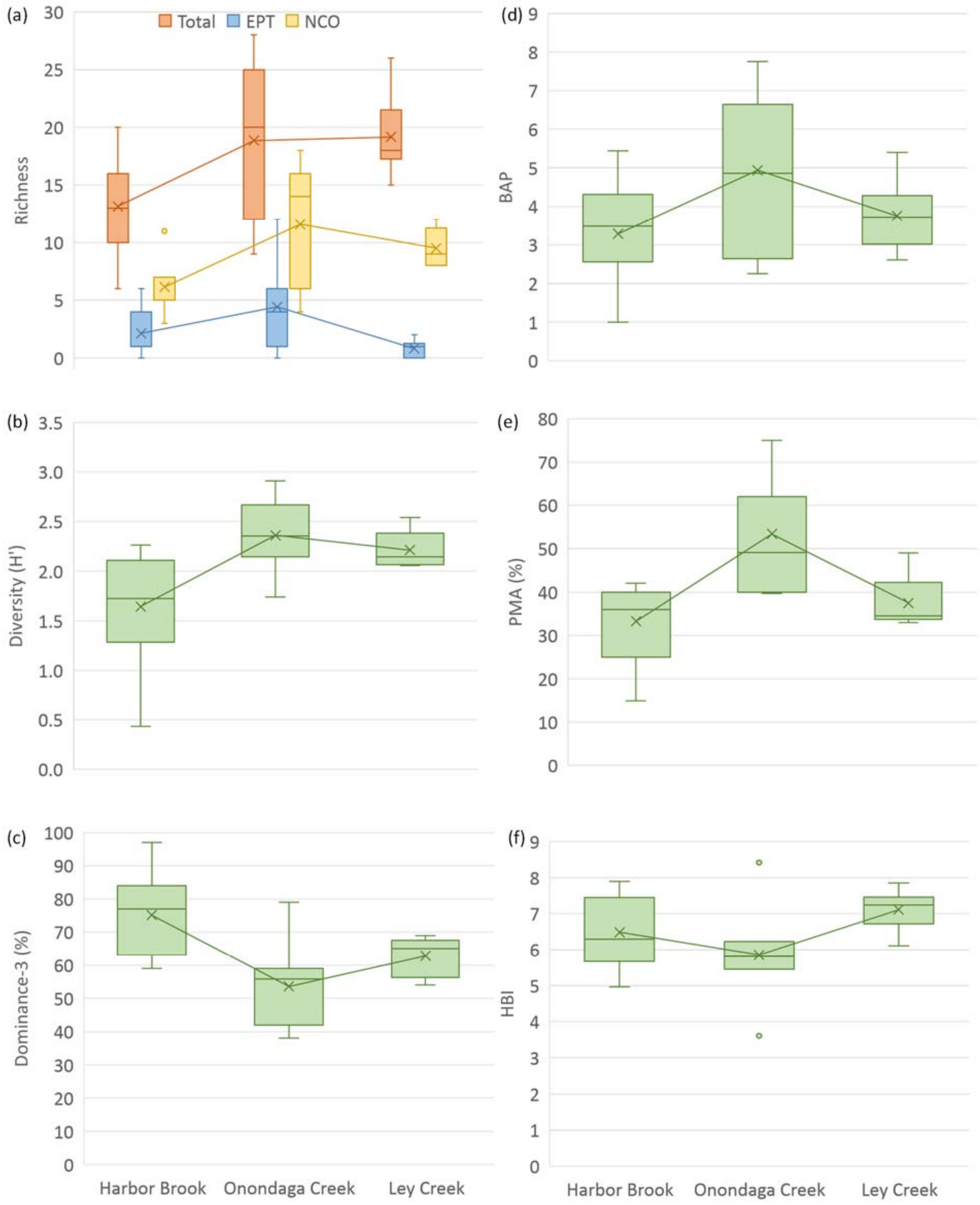


Figure 22. Box plot analysis of macroinvertebrate metrics among streams. (a) Total richness, Ephemeroptera-Trichoptera-Plecoptera (EPT richness, and Non-Chironomidae and Oligochaeta (NCO) richness; (b) Shannon diversity (H′); (c) % dominance of top three taxa (DOM-3); (d) Biological Assessment Profile (BAP); (e) % Model Affinity (PMA); (f) Hilsenhoff Biotic Index (HBI). Refer to Fig. 2 to interpret box plots.

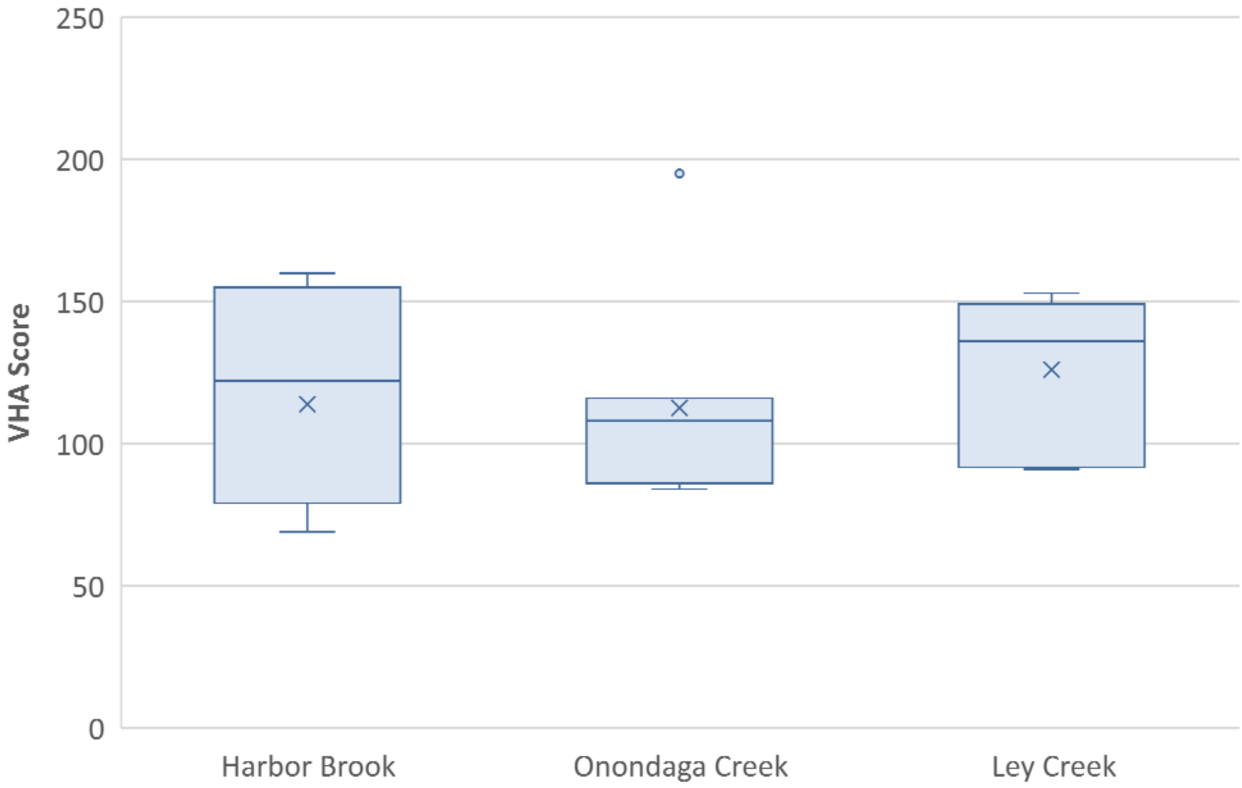


Figure 23. Box plot analysis of Visual Habitat Assessment (VHA) scores among streams. Refer to Fig. 2 to interpret box plots.