Water Quality Analysis of the Lamprey River Watershed

Mark Kotowski ● University of New Hampshire ● Environmental Science: Hydrology ● mtp47@wildcats.unh.edu ● May 23, 2016

Why is Water Quality Important? Good water quality in rivers and streams provides for the protection of a balanced ecosystem of shellfish, fish, and wildlife and allows recreational activities in and on the water. Three important water quality parameters are dissolved oxygen (DO), pH, and nitrate (NO_3^-). DO enables respiration and plays a crucial role in sustaining a healthy aquatic ecosystem. A water body that has a low pH is acidic, which can lead to mussel shells dissolving or higher concentrations of toxic metals. NO_3^- is an essential nutrient for plants and animals. However, high concentrations of NO_3^- can cause algal blooms and dissolved oxygen depletion.

Analysis Spatial and temporal trends were examined at 18 sampling sites throughout the freshwater portion of the Lamprey River watershed from 1990 to 2013. Sites used for this analysis were sampled multiple times and were representative of the river network, not pipes or small tributaries. Annual average values at each site were calculated from 7/1 – 9/10 for DO, the entire year for pH, and 3/1 – 10/31 for NO_3^-.

Results Average summertime DO levels have remained stable over the past 23 years (Figure 1). Nearly all sites have average summertime DO concentrations above 5 mg/L, with the exception of one site located along New Boston Road in Candia that has a summertime average concentration of 4.4 mg/L. There was no clear spatial pattern of high and low DO within the watershed (Figure 2). Even though most sites have DO concentrations above 5 mg/L on average, sometimes DO concentrations fall below 5 mg/L, leading to the NHDES determination, based in part on these data, that many reaches are impaired for aquatic life. A decrease in pH was observed from 1990 to 2013, though it appears that levels may have stabilized from 2004 to 2013, suggesting that the region may be recovering from harmful acid rain impacts (Figure 1). From the headwaters to the river mouth, pH increases, meaning the water becomes less acidic (Figure 2). NO_3^- has remained stable over time. Spatially, it is variable with low to moderate concentrations spread throughout the watershed (Figure 2).

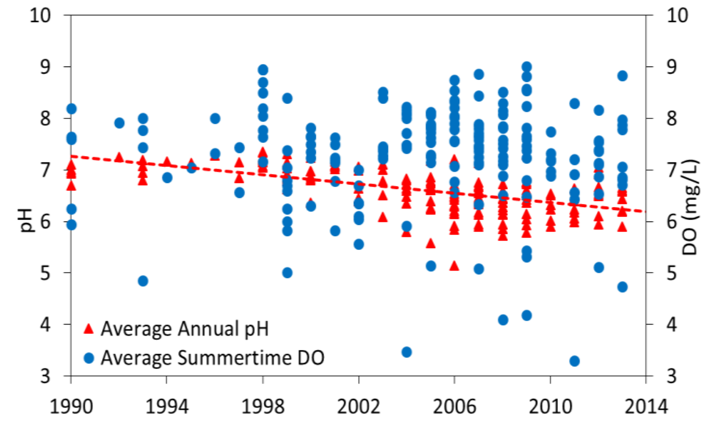

Figure 1. *Summertime average dissolved oxygen (DO) concentrations and annual average pH for each site over the entire record of data collection. The red dashed line shows a significant decreasing trend in pH.*

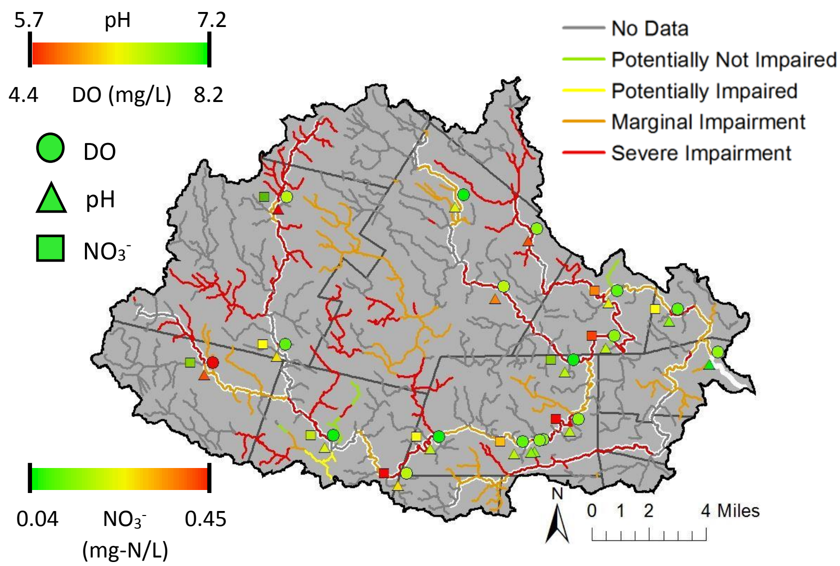

Figure 2. *The Lamprey River watershed with 7/1 – 9/10 average DO, annual average pH, and 3/1 – 10/31 NO_3^- values at each sampling location from 1990 to 2013. NHDES determined Impairments for DO are shown by the colored lines over the river network.*

Current Watershed Status and Future Steps

On average, DO and pH levels in the Lamprey River watershed are above the NHDES Class B standard and NO_3^- concentrations are far below levels that are detrimental to human health and below freshwater nuisance criteria. Therefore, these water quality parameters are usually at levels to sustain healthy aquatic conditions, but at times both DO and pH measurements fall below their respective standards, and NO_3^- concentrations are excessively high. Because of these periodic low DO and pH measurements, as well as high NO_3^- measurements, continuing to monitor and interpret new data in a timely fashion, as well as developing strategies to reduce pollutant loading, is crucial to protect water quality.

Acknowledgments Funding and guidance for this analysis were provided by the Wild and Scenic Subcommittee to the LRAC. Water quality data were provided by NHDES, the EPA, the NH Water Resources Research Center, NH Environmental Monitoring Database, EPA STORET, the Water Quality Portal, the NH Agricultural Experiment Station, the USGS, UNH Cooperative Extension, and the NH Sea Grant.

Water Quality Analysis of the Lamprey River Watershed

Mark Kotowski – University of New Hampshire

Mtp47@wildcats.unh.edu

May 23, 2016

Final report submitted to the Lamprey River Advisory Committee

Table of Contents

Introduction

Good water quality in rivers and streams provides for the protection and propagation of a balanced population of shellfish, fish, and wildlife, and allows recreational activities in and on the water. Water quality standards can help maintain the physical, chemical, and biological characteristics of water bodies that allow them to be used for drinking water, swimming, or recreation (NHDES CALM 2014). This analysis focuses on three water quality parameters: dissolved oxygen (DO), pH, and nitrate (NO_3^-). These parameters fluctuate due to naturally occurring processes, as well as from anthropogenic sources. Monitoring the levels of these parameters can help determine how safe the water is for human consumption, recreation, and the aquatic life which resides in and around the water.

The overall goal of this analysis is to explore spatial and temporal trends in DO, pH, and NO_3^- levels in the Lamprey River watershed. Water quality in Lamprey River is particularly important because it drains into the impaired Great Bay Estuary. Understanding historical trends in these parameters, among others, is important in assessing overall water quality, planning future monitoring, and mitigating potential causes of water quality impairment.

Dissolved Oxygen

Dissolved oxygen (DO) is gaseous oxygen which has dissolved in water and is measured as a concentration (mg/L). DO sustains aquatic life and is therefore an excellent indicator of stream health. According to the New Hampshire Department of Environmental Services (NHDES), the minimum DO concentration for Class B Rivers is 5 mg/L and the minimum for Class A Rivers is 6 mg/L calculated as a 75% minimum daily average, unless naturally occurring (NHDES CALM 2014).

The amount of DO present in water at equilibrium, called its solubility or saturation concentration is inversely related to the temperature of the water (Figure 1). In other words, the solubility of DO decreases as water temperature increases. In addition, biological processes that consume DO are also increased during summer months. As a result, DO concentrations are usually higher during the winter and lower during the summer, which poses extra stress for aquatic life.

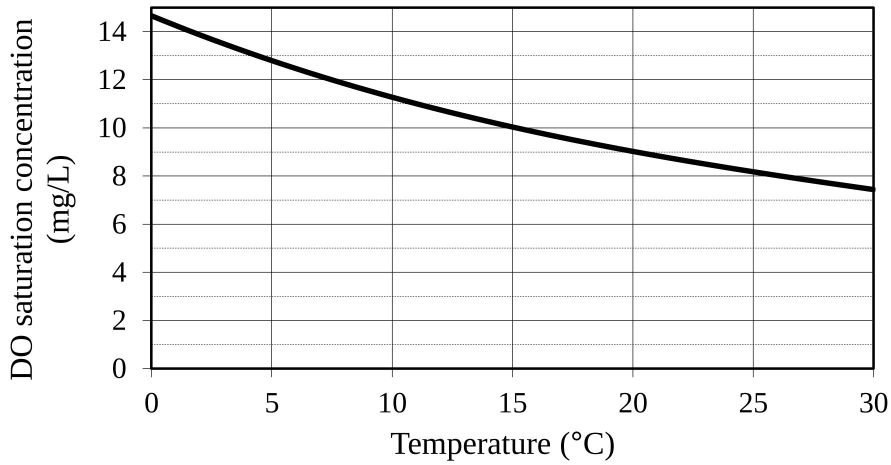

Figure 1. Inverse relationship between dissolved oxygen solubility and water temperature at standard atmospheric pressure.

Multiple processes affect DO concentration in rivers (Figure 2). Firstly, if water is under-saturated with oxygen (that is, if the DO concentration is less than the solubility of oxygen), the water will have a concentration deficit, which will cause the diffusion of oxygen from the atmosphere into the water body (Chapra 1997, p. 349). Reaeration from the atmosphere can occur more rapidly if the water body has more surface area relative to its volume or if the water is more turbulent. As a result, areas near or downstream of rapids, waterfalls, and other turbulent features usually have higher DO concentrations. On the other hand, if water is supersaturated with oxygen (that is, if the DO concentration is more than the solubility of oxygen), then oxygen will tend to diffuse from the water body into the atmosphere.

Secondly, oxygen is produced by photosynthesis during the day (Figure 2). Photosynthetic organisms including plants, algae, and plankton all consume carbon dioxide and expel oxygen beneath the water surface, directly increasing DO (Chapra 1997, p. 347). Conversely, aquatic life such as fish and macroinvertebrates consume DO during respiration (Chapra 1997, p. 349).

Finally, DO concentration is affected by transport within the river. Water with low DO levels can be advected out of a river reach and into downstream areas (Figure 2).

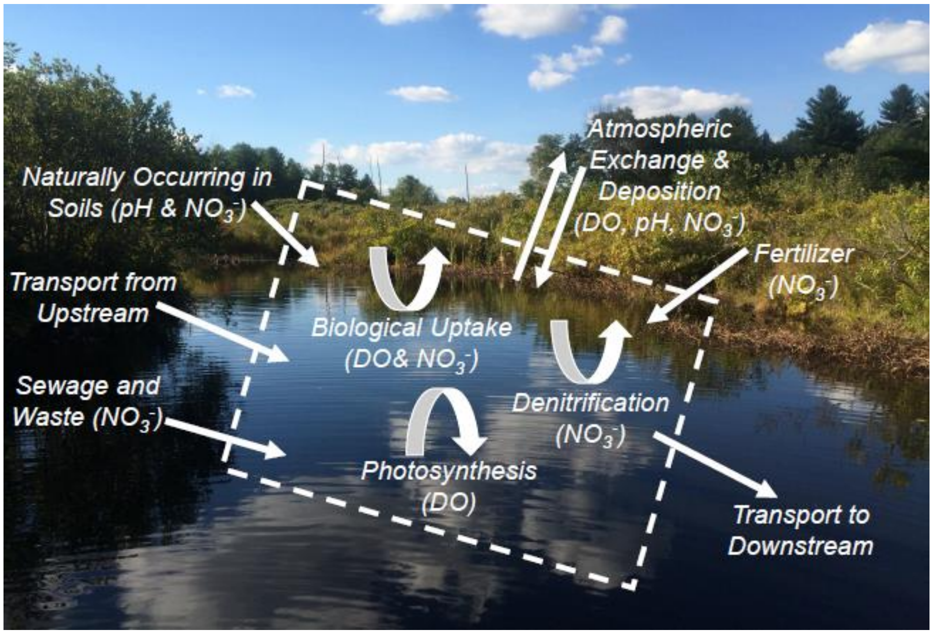

Figure 2. Box model showing sources and sinks of DO, pH, and NO_3^- in a control volume represented by the dashed lines.

pH

The pH of water is a measure of how acidic the water is. Specifically, pH is a measure of hydrogen ion activity, which is calculated by taking the negative logarithm of the hydrogen ion (H^+) concentration (moles/liter) of the sample. The unitless pH scale ranges from 0 – 14, with pH values less than 7 being acidic, values greater than 7 being basic, and values approximately equal to 7 being neutral. Due to the logarithmic nature of the pH scale, moving up or down one unit on the scale means there is a ten-fold change in the hydrogen ion concentration. For example, a water sample with a pH of 5 is ten times more acidic than a sample with a pH of 6, and one hundred times more acidic than a sample with a pH of 7.

Aquatic life depends on certain habitable ranges of pH levels and is therefore sensitive to pH fluctuations (NHDES CALM 2014). If an organism is exposed to pH levels that are too high or low, it can become physiologically stressed (NHDES CALM 2014). In New Hampshire, normal pH levels range from 6.5 to 8 for both Class A and B Rivers, unless naturally occurring processes are responsible for driving levels outside of this range (NHDES CALM 2014). Furthermore, pH levels below 5.0 are considered to have a high impact on water quality (NHDES CALM 2014). A pH value from 5.0 to 5.9 is considered to have moderate to high impact, and a pH value from 6.0 to 8.0 is considered satisfactory (NHDES CALM 2014).

There are multiple physical and biogeochemical processes that can affect pH levels in streams. Geology and soil type are naturally occurring factors that can alter pH levels in surface waters (Langmuir 1997, p. 161). Chemical weathering, which is the breakdown of rocks and soils from the interaction with water resulting in mobilization of elements and ions, is one of the processes that can increase or decrease pH levels (Langmuir 1997, p. 162). Organic decay and respiration can also increase or decrease pH (Langmuir 1997, p. 162). Areas such as wetlands that contain high levels of organic matter can have low pH levels due to decomposition and respiration (Langmuir 1997, p. 158). Also, acid rain and atmospheric deposition can substantially decrease pH levels in streams (Langmuir 1997, p. 162).

$\boldsymbol{NO_3^-}$

Nitrate (NO_3^-) is an important nutrient and one of the most mobile forms of nitrogen, which is essential for life. Typically, nitrate concentrations are reported based on the mass of nitrogen (mg-N/L). The U.S. Environmental Protection Agency has set a maximum contaminant level for NO_3^- in drinking water at 10 mg-N/L in order to protect human health (EPA 2016). Dissolved inorganic nitrogen, of which NO_3^- is an important component, is important for the survival of many aquatic species, but can become problematic if it occurs in to high of concentrations. The overabundance of NO_3^- can lead to downstream eutrophication, which is especially worrisome in the Great Bay Estuary since it has shown characteristics such as low DO and excessive algal blooms (PREP 2013).

There are multiple natural and anthropogenic processes that affect NO_3^- in rivers and streams. NO_3^- is found in soils due to naturally occurring processes, where it is transported through groundwater (NHDES GBNNPS 2014). Also, NO_3^- can enter watersheds through both wet and dry atmospheric deposition. Although some atmospheric deposition occurs naturally, anthropogenic sources including fossil fuel emissions have rapidly increased the rate at which nitrogen compounds are deposited from the atmosphere (NHDES GBNNPS 2014). Other anthropogenic sources of NO_3^- include the application of fertilizer on agricultural land and lawns. Sewage can also contain high levels of NO_3^- (NHDES GBNNPS 2014). Sinks of NO_3^- include denitrification, in which it is transformed into nitrogen gas (N_2) and lost to the atmosphere. In addition, aquatic plants uptake NO_3^- directly, while higher trophic-level species will indirectly consume NO_3^- (NHDES GBNNPS 2014).

Site Description

The Lamprey River and its tributaries drain an area of 214 mi^2 in the coastal region of southeast New Hampshire (Lamprey River Advisory Committee 2013). The Lamprey main stem is 47 miles long. The land in the upper Lamprey River watershed includes wetlands, forests, and mostly non-urbanized surfaces including Pawtuckaway State Park (Lamprey River Advisory Committee 2013). Farther down in the watershed, reaches of the river run through more urbanized areas such as Raymond and Epping, making it more susceptible to detrimental human impacts (Lamprey River Advisory Committee 2013). The watershed is increasing in human population, with an expected 85 people/km^2 by 2020, an increase from 53 people/km^2 in 2000 (Lamprey River Advisory Committee 2013). Despite this continuing growth, the majority of the watershed has remained undeveloped, with 68% of the land forested as of 2010 (Lamprey River Advisory Committee 2013). The Lamprey River eventually drains into the Great Bay Estuary, where eutrophication has been observed in recent years (PREP 2013).

The Lamprey River and its five major tributaries (Little, North, North Branch, Pawtuckaway, and Piscassic Rivers) are designated into the New Hampshire Rivers Management and Protection Program. The lower main stem is also nationally designated as a National Wild and Scenic River. The Lamprey River is classified as a Class B River under the Rivers Management and Protection Program Act. Class B rivers sufficiently support uses of swimming, fishing, recreation, and for drinking water after treatment (NHDES CALM 2014).

NHDES Assessment

Through the Surface Water Quality Assessment Program, NHDES assesses each water body throughout the state every two years in order to determine potential impairments of numerous parameters, including DO and pH. For DO in Class B rivers, any location where at least 10% of DO samples are lower than 5.0 mg/L, or a single measurement is below 4.5 mg/L, is considered to not fully support the designated use of aquatic life (NHDES CALM 2014). DO samples used to determine whether DO levels are high enough must be obtained at particular times of the day and year; most samples should be obtained between 5:00 a.m. and 10:00 a.m. or between 2:00 p.m. and 7:00 p.m. and between June 1 and September 30 (NHDES CALM 2014).

NHDES has determined that the majority of the surface water network within the Lamprey River watershed does not have sufficient data to be assessed (NHDES 303d 2012). In the portions of the watershed that have sufficient data to be assessed, NHDES has determined that a large fraction exhibit impairments for aquatic life and thus appear on the 303(d) list of impaired waters (NHDES 303d 2012). Severe impairments exist throughout the watershed, both along headwater reaches as well as lower in the watershed in more urbanized areas.

Methods

Data

Dissolved oxygen, pH, and NO_3^- levels in the freshwater portions of the Lamprey River main stem and its major tributaries have been measured repeatedly from 1990 to present by the Lamprey River Watershed Association (through the Volunteer River Assessment Program), NH Water Resources Research Center (Lamprey River Hydrologic Observatory), Great Bay Coast Watch, and NHDES through the Ambient River Monitoring Program and the 2012

Pawtuckaway Release Sampling. Grab samples of river water were obtained by trained staff or volunteers and were subject to a quality assurance plan. DO concentrations and water temperature were measured in the field using standard methods APHA 4500-O-G or APHA 4500-O-C. All pH measurements were obtained using the standard method APHA 4500-H+B. DO and pH measurements obtained by the Lamprey River Hydrologic Observatory were mostly measured using field YSI 556 meters. Nitrate was measured using the standard methods USEPA 300, 300.1, and 353.2.

Water quality data for the Lamprey River and its tributaries were downloaded by Anne Lightbody from the New Hampshire Environmental Monitoring Database (NH EMD) between 3/3/2014 and 3/7/2014; downloaded by Patricia DeBeer from EPA STORET on 3/28/2014 and the Water Quality Portal on 3/14/2014; and provided by Melanie Titus, the NH EMD manager at DES, on 4/10/14. Patricia DeBeer combined and filtered all observations to only those in the Lamprey River watershed, and deleted duplicates. Patricia then excluded sites that had fewer than 38 DO observations, sites that were in salt water (tidal portions of the watershed), or sites that represented individual pipes and small tributaries. The resulting data set included 23 sampling sites on third to sixth order streams throughout the freshwater portion of the watershed, 18 of which were along the Lamprey main stem, 3 along the North River, 1 on the Little River, and 1 on the North Branch River. About 95% of the final data points were obtained from the NH EMD.

The latitude and longitude of each sampling location was provided separately by Melanie Titus on 4/3/2014 and 4/10/2014. The distance of each sampling location from the river mouth was determined by Anne Lightbody by combining the latitude and longitude of the sampling location with the New Hampshire Hydrography Dataset (NHHD) river network. Specifically, the distance of each sampling site from the river mouth was calculated in ArcMap 10.3 by integrating the river length from the salt-water mouth of the Lamprey to the sampling site. The Macallen Dam in Newmarket divides the freshwater from the saltwater portion of the Lamprey and is located approximately 3 km upstream from the river mouth (Table 1).

For both the DO and pH analysis, sampling sites that were located in close proximity to each other along the Lamprey main stem were combined and analyzed as a single site (Table 1). These sites are LMP-73 and 08-LMP (Packers Falls and Wiswall bridges in Durham), 09-LMP and LMP-67 (Lee Hook Road, Lee), 12-LMP and LMP-51 (Route 87, Epping), 13-LMP and 13F-LMP (Mill Street Bridge, Epping), and 21-LMP and LMP-27 (Langford Road, Raymond). Average parameter values for combined sites were calculated by averaging together each individual sites average over the entire record. T-tests were conducted for all data and also each sampling year for both DO and pH between each of the combined sites to check whether parameter values were significantly different. At four of the five combined sites (LMP-27 and 21-LMP, 13F-LMP and 13-LMP, LMP-67 and 09-LMP, and LMP-51 and 12-LMP), p-values for the overall data and for the majority of overlapping sampling years were greater than 0.05, meaning they were not significantly different from each other. The combined site of LMP-73 and 08-LMP, p-values for the overall data and the majority of overlapping sampling years were less than 0.05, meaning they were significantly different from each other. However, parameter values often overlap substantially (Figure D-2, Figure E-2). To better assess temporal trends near the USGS Packers Falls gage, these sites were combined for DO and pH analysis. Despite their close proximity, sites 12A-LMP and 12B-LMP were not combined because 12B-LMP is located upstream and 12A-LMP is located downstream of the Epping wastewater treatment facility. Discharge from this facility could, in theory, alter conditions downstream making it important to analyze these sites separately. The final data set for DO and pH included 18 sampling sites throughout the watershed, of which 13 were along the Lamprey main stem, 3 along the North River, 1 on the Little River, and 1 on the North Branch River (Figure 3). Of these, 11 included measurements from both before and after 2003, while 7 were monitored only after 2003.

For the NO_3^- analysis, sampling sites were not combined. The final data set for NO_3^- contained 16 of the original 23 sampling sites. Both total and dissolved nitrate data were combined to create a single dataset. Sites that had been combined in the DO and pH analysis continued to be analyzed together for the NO_3^- analysis.

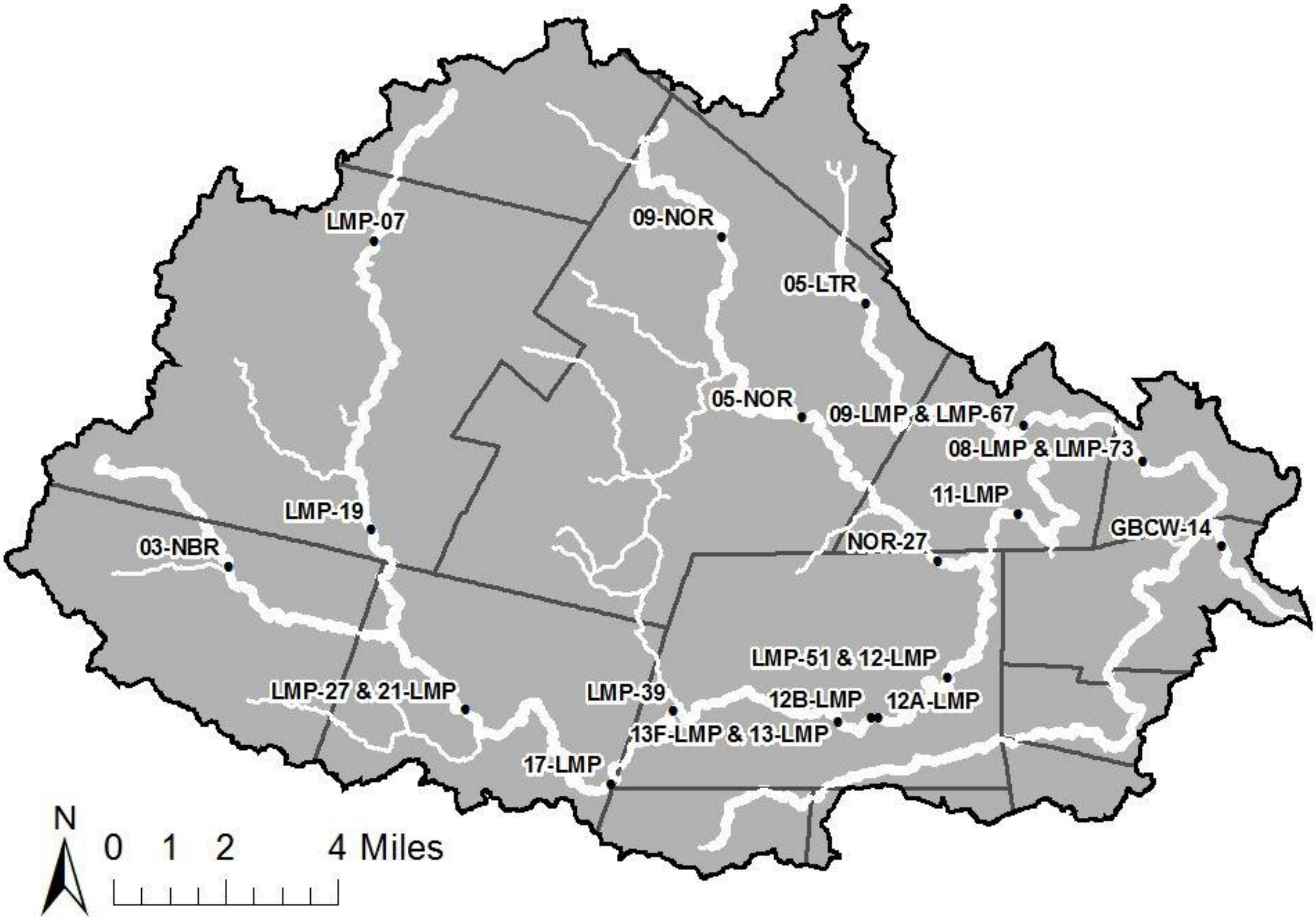

Figure 3. The Lamprey River watershed in southeast New Hampshire showing the main stem, major tributaries, and sampling site locations.

Station ID	Location	River Name	Miles from Lamprey Mouth	Km from Lamprey Mouth
LMP-07	BLAKES HILL ROAD, DEERFIELD	Lamprey mainstem	45.5	73.3
LMP-19	COTTON ROAD, DEERFIELD	Lamprey mainstem	38.7	62.2
LMP-27[5]	**LANGFORD ROAD, RAYMOND**	**Lamprey mainstem**	**33.5**	**53.8**
21-LMP[5]	**LANGFORD ROAD, RAYMOND**	**Lamprey mainstem**	**33.5**	**53.8**
17-LMP	PRESCOTT ROAD BRIDGE, RAYMOND	Lamprey mainstem	28.4	45.7
LMP-39	LAMPREY LANE, EPPING	Lamprey mainstem	25.7	41.4
13F-LMP[4]	MILL STREET BRIDGE, EPPING	Lamprey mainstem	21.8	35.1
13-LMP[4]	MILL STREET BRIDGE, EPPING	Lamprey mainstem	21.6	34.8
12B-LMP	U.S. OF EPPING WWTF, EPPING	Lamprey mainstem	21.0	33.8
12A-LMP	D.S. OF EPPING WWTF, EPPING	Lamprey mainstem	20.9	33.6
LMP-51[3]	ROUTE 87 BRIDGE, EPPING	Lamprey mainstem	18.4	29.6
12-LMP[3]	ROUTE 87 BRIDGE, EPPING	Lamprey mainstem	18.4	29.6
11-LMP	ROUTE 152 - WADLEIGH FALLS, LEE	Lamprey mainstem	13.3	21.4
LMP-67[2]	LEE HOOK ROAD, LEE	Lamprey mainstem	8.4	13.5
09-LMP[2]	LEE HOOK ROAD, LEE	Lamprey mainstem	8.4	13.5
08-LMP[1]	**WISWALL ROAD BRIDGE, DURHAM**	**Lamprey mainstem**	**5.4**	**8.8**
LMP-73[1]	**PACKERS FALLS ROAD, DURHAM**	**Lamprey mainstem**	**4.7**	**7.5**
GBCW-14	FOWLERS DOCK, NEWMARKET	Lamprey mainstem	2	3.2
09-NOR	FREEMAN HALL ROAD BRIDGE, NOTTINGHAM	North River	26.2	42.2
05-NOR	MCCRILLIS ROAD BRIDGE, EPPING	North River	20.4	32.9
NOR-27	ROUTE 125, EPPING	North River	15.8	25.4
05-LTR	SMOKE STREET BRIDGE, NOTTINGHAM	Little River	14.8	23.8
03-NBR	NEW BOSTON ROAD, CANDIA	North Branch	40.1	64.5

Table 1. Study sites within freshwater portion of the Lamprey River watershed. Sites are sorted first by river and secondly by distance from the mouth of the Lamprey. Combined sites are indicated by identical superscripts on their station ID.

Choice of Averaging Time Periods

A seasonal pattern in DO concentrations was observed in the Lamprey, with higher concentrations during the winter and lower concentrations during the summer (Figure 4-A). This analysis focused on summertime conditions, when DO levels are lowest and therefore most challenging for aquatic life. Three candidate time periods were compared (7/1 – 9/1; 7/1 – 9/10; and 6/20 – 9/15) at three different sites (LMP-07, GBCW-14, and LMP-73) on the main stem; these sites were selected because they were distributed throughout the watershed (Table 1) and each had numerous measurements (Table 2).

The time period chosen for further analysis was 7/1 – 9/10 for the following reasons. First, the average DO concentration calculated during this time period was relatively steady from year to year. The time period was long enough to incorporate multiple measurements and therefore reduce the impact of outliers. For example, for GBCW-14 (Figure 4-C), the summertime average calculated from 7/1 – 9/10 did not experience the brief increase in 1998 that the 7/1 – 9/1 summertime average experienced, likely because more measurements were used to calculate the 7/1 – 9/10 average. On average, 5 measurements were obtained at each site during the 7/1 – 9/10 time period each summer (Table 2).

In addition, this time period was short enough that it was not substantially increased by higher DO levels associated with spring and fall (Figure 4-A). For example, 12 of the 18 average DO concentrations at GBCW-14 were greater in the 6/20 – 9/15 time period than in the 7/1 – 9/10 period, suggesting that the shorter time period, which excluded spring and fall values, was more representative of summertime conditions (Figure 4-C).

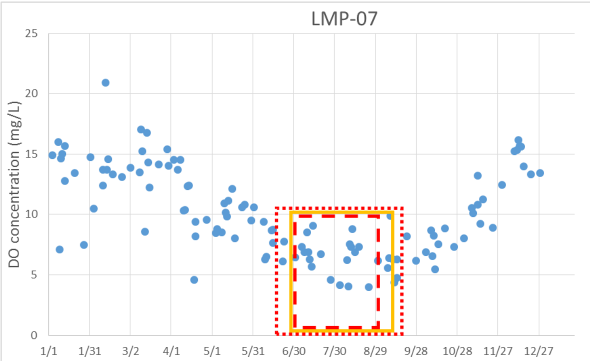

Figure 4-A. All DO concentration measurements from Blakes Hill Road in Deerfield (LMP-07), for all years, shown by day of the year. The outermost dashed box represents 6/20 – 9/15, the solid box represents 7/1 – 9/10, and the inner dashed box represents 7/1 – 9/1.

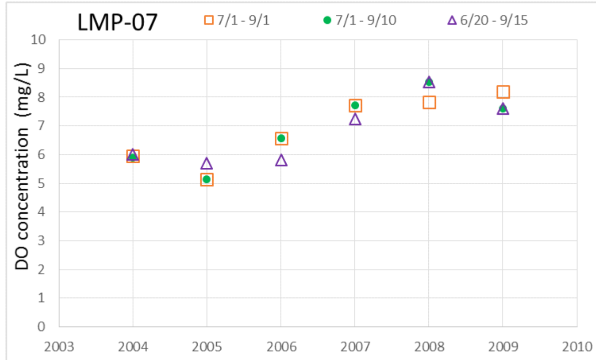

Figure 4-B. Comparison of summertime averages calculated for different time periods at Blakes Hill Road in Deerfield (LMP-07).

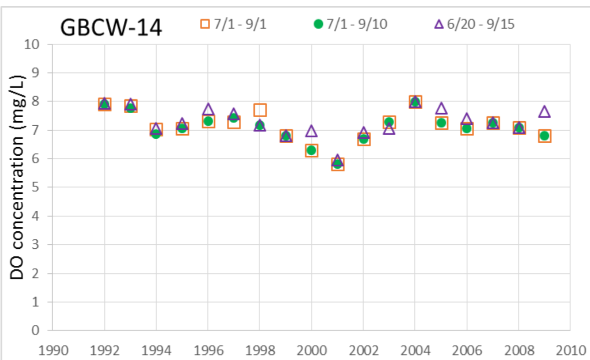

Figure 4-C. Comparison of summertime averages calculated for different time periods at Fowler's Dock in Newmarket (GBCW-14).

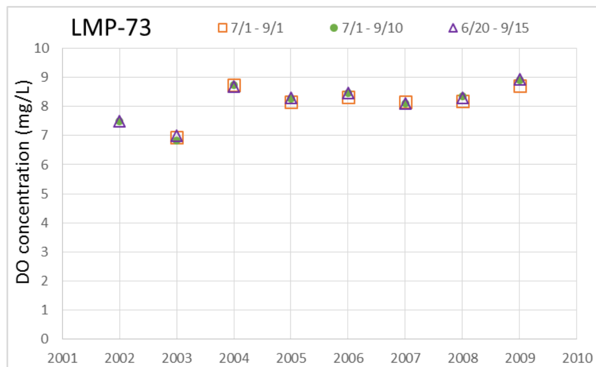

Figure 4-D. Comparison of summertime averages calculated for different time periods at Packers Falls Road in Durham (LMP-73).

No seasonal pattern was found for pH levels at the four sites with the greatest amount of data (LMP-73, NOR-27, GBCW-14, LMP-07) and therefore measurements from the entire year were used for further analysis (Figures 5A-D).

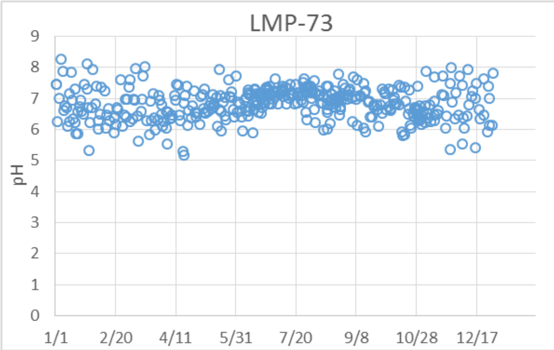

Figure 5-A. All pH data over the entire record at Packers Falls Road in Durham (LMP-73), shown by day of the year.

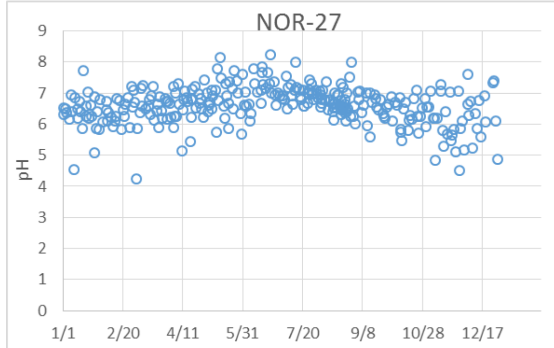

Figure 5-B. All pH data over the entire record at Route 125 in Epping (NOR-27), shown by day of the year.

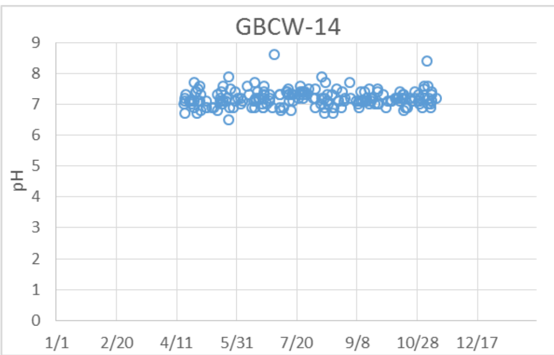

Figure 5-C. All pH data over the entire record at Fowler's Dock in Newmarket (GBCW-14), shown by day of the year.

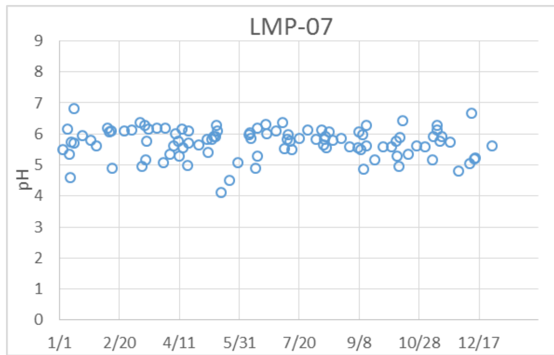

Figure 5-D. All pH data over the entire record at Blakes Hill Road in Deerfield (LMP-07), shown by day of the year.

Within the Lamprey River watershed, NO_3^- tends to be higher in the winter and lower in the summer (Figure 6), consistent with increased biological demand in summer. The critical time period for algal blooms in the Great Bay Estuary is 3/1 – 10/31 (NHDES Nutrient Criteria 2009), so this time period was chosen for analysis.

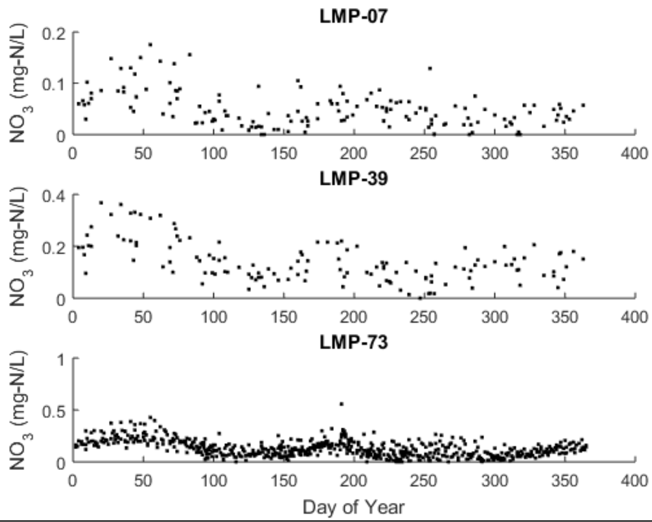

Figure 6. All NO_3^- measurements by day of the year at Blakes Hill Road in Deerfield (LMP-07), Lamprey Lane in Epping (LMP-39), and Packers Falls Road in Durham (LMP-73).

Analysis of Spatial and Temporal Trends

For each site, for each year, the summertime (7/1 – 9/10) average and minimum DO, annual average and minimum pH, and summertime (3/1 – 10/31) average NO_3^- values were calculated. An overall average value for each parameter was calculated by summing each individual year's average, and dividing by the total number of years of data. A best-fit straight line was fit to each of the time series of annual averages and the time series of annual minima for each site. A positive best-fit slope indicates that the concentration tended to increase over time; a negative slope indicates a decrease. To determine whether the observed change was significant, the magnitude of the Pearson correlation coefficient (r) for each best-fit line was compared to the correlation coefficient magnitude that would be produced for two uncorrelated random variables with a probability of 5% or less; this critical value depends on the number of years of data (Taylor 291). Calculations for DO and pH were performed in Microsoft Excel and calculations for NO_3^- were performed in Matlab.

For pH, some sites with significant decreasing trends had a few isolated years of data obtained many years before newer, more routine sampling occurred. For these sites, best-fit lines were fit to the annual average and minimum data with the isolated years excluded to ensure that significant trends were robust.

To examine spatial trends along the main stem in more detail, the summertime average at various sampling locations was compared to the position of dams and near-channel wetland area. Near-channel wetland area was calculated by determining the fraction of area within 100 meters of the stream center line that was included in the National Wetland Inventory. Wetland coverage was averaged over 500-meter long stream segments (Wilderotter et al. 2014).

To explore spatial and temporal trends among limited data, this analysis focused on comparing annual summertime averages. In addition, because of concern during sensitive parts of the year, summertime minimum values were also considered. NHDES assessments of aquatic use through the Surface Water Quality Assessment Program are based on a 10% exceedance threshold (NHDES CALM 2014), so are not directly comparable to this analysis.

Correlations of Individual Measurements with Discharge

In order to explore if stream discharge affected each parameter, each individual DO, pH, and NO_3^- measurement was compared to four discharge values calculated from the USGS stream gage at Packers Falls in Newmarket, NH. These values were the daily average discharge on the day of the parameter measurement, the average of the daily discharge on the seven days up to and including the measurement day, the median of the daily discharge on the seven days up to and including the measurement day, and the maximum of the daily discharge on the seven days up to and including the parameter measurement. Linear correlations were examined between each of these four discharge values and the parameter value in each of four seasons: winter (1/1- 3/31), spring (4/1 – 6/30), summer (7/1 – 9/30), and fall (10/1 – 12/31) for both raw and log-transformed data. To determine whether correlations were significant, the magnitude of the Pearson correlation coefficient (r) for each best-fit line was compared to the correlation coefficient magnitude that would be produced for two uncorrelated random variables with a probability of 5% or less (Taylor 1997, p. 291). Calculations were performed in Matlab.

Correlations of Site Averages with Watershed Land Cover

To determine the effects of land cover leading up to each sampling site, the nested subwatershed for each sampling site were delineated using ArcMap 10.3. Digital Elevation Model (DEM) quads 152, 153, 154, 166, 167, 168, and 169 from the Complex Systems Research Center at the University of New Hampshire were downloaded and mosaicked together in order to create one continuous digital elevation model of the entire watershed. The original DEMs had a 30 meter by 30 meter resolution. After mosaicking, the borders between some of the individual DEM quads were not populated with data resulting in an incorrect subwatershed delineation. To correct this problem, the Euclidean Allocation tool was used to assign a value to each cell that was missing data.

Once the nested subwatersheds were correctly delineated, the New Hampshire Land Cover Assessment 2001 layer (NH GRANIT) was clipped to each subwatershed to determine the fractional land cover of urban (residential/commercial/industrial, transportation, disturbed, other cleared), agriculture (row crops, hay/pasture, orchards), forested (beech/oak, paper birch/aspen, other hardwood, white/red pine, spruce/fir, hemlock, pitch pine, mixed forest, alpine, bedrock/veg), open water, and wetlands (forested wetland, open wetland, tidal wetland) in each. For each land cover, the percent of the area of the watershed was compared to the average parameter value for each respective watershed. To determine significant correlations, the magnitude of the Pearson correlation coefficient (r) for each best-fit line was compared to the correlation coefficient magnitude that would be produced for two uncorrelated random variables with a probability of 5% or less. The calculated r-value depended on the number of sites with average data points for each parameter (Taylor 1997, p. 291). All calculations were performed in Microsoft Excel.

Other land classification systems are possible. For example, the 2010 Impervious Land Cover layer had less impervious cover than the urban coverage in the layer that was used for this analysis. For example, the subwatershed of LMP-07 using the 2001 Land Cover Assessment layer had 4.1% urban cover, whereas using the 2010 Impervious Cover layer it only had 1.5% impervious cover. Again, for the subwatershed of LMP-39, the 2001 Land

Cover Assessment layer had 16.9% urban cover, whereas the 2010 Impervious Cover layer only had 6.7% impervious cover.

Field Deployment

To follow up on low DO concentration measurements at New Boston Road in Candia (03-NBR), continuously logging sensors (HOBO) were deployed to measure DO concentration and water temperature at 15-minute intervals at five different locations at, upstream, and downstream of New Boston Road for six weeks during August and September 2015. These five measurement locations were adjacent to the Deerfield Parcel, at New Boston Road, Deerfield Road, adjacent to the Candia town Cemetery, and Island Road. (Figure I-1). Each sensor was mounted on a cinder block and placed on the stream bed, measuring 5 to 10 centimeters above the stream bed.

Results

Dissolved Oxygen

Most of the sites that have been repeatedly monitored over the last 23 years have not demonstrated a significant increase or decrease in DO concentration over time. However, the North Branch River at New Boston Road in Candia (03-NBR) has a summertime average concentration of 4.4 mg/L. In addition, several other sites occasionally exhibit DO concentrations below the Class B standard of 5 mg/L. The NHDES standard states that DO concentrations may fall below 5 mg/L only 10% of the time in order to protect aquatic life, and many reaches do not meet that standard resulting in listing on the 303(d) impaired waters list (NHDES CALM).

No clear spatial pattern was observed in summertime DO concentrations in the Lamprey watershed (Figure A-1). The headwaters (3rd order streams) contained some locations with high DO levels and others with low levels. For example, the average DO concentration at New Boston Road in Candia (03-NBR) in the headwaters of the North Branch was 4.4 mg/L while the average DO concentration at Lee Hook Road in Lee (09-NOR) in the headwaters of the North River was 8.0 mg/L (Table A-1). Similarly, locations with both high and low DO concentrations were found in the lower main stem (5^{th} and 6^{th} order streams). The Epping wastewater treatment plant (located between sites 12A-LMP and 12B-LMP) did not appear to have a large effect on DO concentrations, which were not significantly different upstream and downstream of the plant ($p>0.05$). The location with the lowest DO concentration in the watershed was at New Boston Road in Candia (03-NBR), while the location with the highest DO concentration in the watershed was at Route 125 in Epping (NOR-27), which had an average summertime concentration of 8.2 mg/L (Table A-1).

Neither average nor minimum summer DO concentrations were strongly dependent on near-channel wetland area nor dam locations. For example, at LMP-27 and 21-LMP, the DO concentration was high (7.8 mg/L) and near-channel wetland area was low (22%) while at LMP-39, the DO concentration was also high (8.1 mg/L) but near-channel wetland area was high, at 100% (Figure A-2). Also, the DO concentration increased from Blakes Hill Road (LMP-07) moving downstream past Freese's Dam to Cotton Road (LMP-19), but the DO concentration decreased from Wiswall Road (08- LMP & LMP-73) moving downstream past the Wiswall Dam and Packers Falls to Fowler's Dock (GBCW-14).

In general, average summertime DO concentrations throughout the Lamprey River watershed have remained relatively stable over the past 23 years. There was no significant trend in the overall average DO concentration over the entire 23-year study period (Figure A-3). Of the 18 individual study sites, 10 showed increasing summertime DO concentrations from 1990 to 2014 while the other 8 sites showed decreasing summertime DO concentrations (Table A-1). A significant increase in summertime DO concentration was found at two sites (LMP-39 and LMP-07) and a significant decrease was found at one site (11-LMP). A significant increase in summertime minimum DO was found at one site (LMP-07). There were no significant decreases found in minimum summertime DO concentration.

Average summertime DO concentrations across all sites were not the same each year. For example, in 1998 the average DO concentration was 7.6 mg/L. The next year, in 1999, the average DO concentration was only 7.1 mg/L (Figure A-3). Annual variability may have resulted from annual changes in precipitation (although 1999 did not show abnormal precipitation), carbon loading, air temperature, or other factors.

In addition, there was variability present at individual sites from one measurement to the next. For example, in 2012 at Route 152 at Wadleigh Falls in Lee (11-LMP), DO measurements ranged from 5.88 mg/L to 9.42 mg/L (Figure A-5). Many factors affected individual measurements of DO concentration. First, there may have been sampling error, including calibration error, although a quality assurance plan was in place for all measurements in order to reduce error. Second, sampling protocols differed: samples may not all have been obtained at the same time of day, or from the same depth, or by the same analytical method. Third, there could have been temporally and spatially different sources of DO and dissolved organic carbon, including natural wetlands and human sources. Fourth, antecedent weather patterns could have created storm runoff, and seasonal changes in discharge may also have been important. As a result of this variability, site comparisons focused on annual summertime averages.

At the majority of sites, significant positive correlations were found between discharge and DO for the spring, summer, and fall (Appendix G). For example, at Blakes Hill Road in Deerfield (LMP-07), there were significant positive correlations between the 7-day-average discharge and DO concentrations for the summer and fall seasons ($R=0.60$, $N=29$; $R=0.44$, $N=25$; Figure A-6). With increasing discharge, DO concentrations tended to increase, which is consistent with increased reaeration due to the turbulence generated by higher stream flows and decreased biological demand. DO concentration was less correlated with discharge during winter, possibly due lower air temperatures and reduced biological processing, which increased DO regardless of streamflow conditions.

There were no significant correlations between average DO concentrations and land cover (Table H-1).

The field deployment confirmed diurnal fluctuations in DO concentrations at all measurement locations with levels increasing during the day and decreasing during the night. Nighttime levels at New Boston Road dropped below 1 mg/L during the hottest part of summer and early fall and daytime averages were typically below 2 mg/L. These observations were even lower than minimum data from the historical record (Figure D-18), possibly due to a slightly different measurement location or because of a particularly hot summer in 2015.

At the Deerfield Parcel upstream of New Boston Road, DO concentrations during the same period ranged from 2.5 to 6 mg/L, suggesting that decomposition in the large wetland in the reach between the Deerfield Parcel and New Boston Road is driving DO levels down. Other sinks are also possible.

DO levels rebounded very quickly moving downstream from New Boston Road. At Deerfield Road, which is the next road crossing downstream, DO levels had increased to 5 to 8 mg/L, which was comparable to Island Road, approximately 5 km downstream, and similar to summertime DO levels elsewhere in the Lamprey (Figure A-5). DO concentrations were slightly higher at the Cemetery Location than at Deerfield Road. Unfortunately, simultaneous measurements were not obtained at all three of the downstream sampling locations so specific longitudinal comparisons cannot be made.

pH

In general, pH levels in the Lamprey River watershed are above 6.0, which is satisfactory (NHDES CALM 2014). On occasion, at sites such as Blakes Hill Road in Deerfield (LMP-07), pH levels fall below the Class A and B standard of 5.0, suggesting detrimental impacts on water quality (Figure B-4).

Both average and minimum pH levels increased along the Lamprey main stem, moving from the headwaters to the river mouth (Figure B-2). Three of the four headwater site locations (3rd order streams) contained the lowest average pH levels for their respective stream (Figure B-1). For example, at Blakes Hill Road in Deerfield (LMP-07), which was the headwater site location of the Lamprey main stem, the average pH value was 5.72, which was also the lowest average pH value among all of the sites within the watershed (Table B-1). At New Boston Road in Candia (03- NBR), which was the headwater site location of the North Branch tributary, the average pH was 5.89 (second lowest among all sites, Table B-1). At the Smoke Street Bridge in Nottingham (05- LTR), which was the headwater site location of the Little River tributary, the average pH was 5.92 (third lowest among all sites, Table B-1). The exception was the Freeman Hall Road Bridge in Nottingham (09-NOR), the headwater site of the North River tributary, where the average pH was 6.47 (seventh lowest among all sites, Table B-1), which was not the lowest measured value in the North River. The greatest average pH was found nearest the mouth of the Lamprey mainstem at Fowler's Dock in Newmarket (GBCW-14) with a value of 7.19 (Table B-1).

Overall, fifteen sites showed decreasing trends in average pH over time, while only three showed increasing trends (Table B-1). None of the increasing trends were significant, while eight of the fifteen decreasing trends were significant at the 95% confidence level (Table B-1). When isolated years were excluded, only five of the fifteen decreasing trends were significant (Table B-1). In general, decreases in pH were observed lower in the watershed along the mainstem (Figure B-2). A significant decreasing trend was found in the annual average pH over the entire record when combining data from all sites ($R^2 = 0.34$ with 186 data points; Figure B-3). Seven new headwater sampling sites were added in 2004, which tended to have lower pH than sites that had been sampled prior to 2003. However, a significant decrease in pH was still observed from 1990-2013 when just considering the eleven sites that were sampled over the entire record (Figure B-3), suggesting that pH levels indeed decreased within the watershed. No significant trend was found between 2004 and 2013 in the eighteen sites sampled during that period, suggesting that pH levels may have recently stabilized.

The pH of rain in New Hampshire from 1990 to 2013 ranged from 4.17 to 4.87 and increased over time (NHDES Acid Rain Status and Trends 2015), while remaining lower than typical pH in surface water. In addition, recent observations of lakes in New England and the Adirondack region of New York have shown a small but significant increase in pH (decrease in acidity) starting in 1995, following the enactment of the Clean Air Act Amendments in 1990 (Waller et al. 2012). Specifically, hydrogen ion activity has been observed to decrease at a rate of 0.12 µeq/L/yr (Strock et al. 2014), similarly shown by an increase of 0.2 pH units/year since 1990 in Adirondack lakes (Waller et al. 2012). Such a small rate of increase would be difficult to detect given the amount of variability observed in pH throughout the Lamprey River watershed, though data are consistent with a reduction in rainfall acidity and resulting recovery in pH.

At all sites, significant negative correlations were found between discharge and pH for all seasons (Appendix G). For example, at Cotton Road in Deerfield (LMP-19), significant correlations were found between the daily average discharge and pH for winter, spring, summer, and fall (R =-0.64, N=24; R=-0.80, N=27; R=-0.38, N=27; R=-0.60, N=22; Figure B-5). Since precipitation in the northeast tends to be more acidic than river water, the input of rain water to the Lamprey likely decreases the pH during higher flow events.

Urban and agricultural land covers both showed positive correlations with average pH (R=0.58, N=18; R=0.66, N=18) while forested land cover showed a negative correlation with average pH (R=0.68, N=12; Table H-1). Urban and agricultural positive pH correlations could possibly be due to lime applications, which buffer pH in order to make soils less acidic. Using other land cover data sets may produce different results.

$\boldsymbol{NO_3^-}$

Individual summertime NO_3^- measurements ranged from 0.03 to 1.2 mg-N/L. Summertime average NO_3^- values ranged from 0.04 to 0.41 mg-N/L. All NO_3^- values are much lower than the 10 mg-N/L maximum contaminant level for human health concern (EPA 2016).

No clear spatial pattern was observed in average NO_3^- throughout the watershed (Figure C-1). Headwater locations tended to have lower NO_3^- values than farther down in the watershed, but no significant spatial correlation was observed along the Lamprey main stem (Figure C-2). For example, at the headwater site at Blakes Hill Road in Deerfield (LMP-07), the average NO_3^- concentration was 0.04 mg-N/L. At the Route 125 site in Epping (NOR-27), which is located much closer to the mouth of the Lamprey, the average NO_3^- concentration was similar, at 0.05 mg-N/L.

Across the entire watershed, summertime NO_3^- concentrations have remained stable over the last 23 years (Figure C-3). At two sites (LMP-07 and LMP-73), there were significantly increasing trends in the average NO_3^- (Table C-1).

At the majority of sites, significant negative correlations were found between discharge and NO_3^- during the winter and spring (Appendix G). For example, at Lee Hook Road in Lee (LMP-67), significant negative correlations were found between the daily average discharge and NO_3^- for the winter and spring (R=-0.55, N=31; R=-0.37, N=36; Figure C-6). With increasing discharge during winter and spring, NO_3^- concentrations tended to decrease, suggesting a dilution effect from the higher stream flows. Significant correlations were not present during the summer and fall, possibly due to a higher abundance of NO_3^- in the watershed and generally lower stream flows during these seasons.

There were no significant correlations between average NO_3^- concentrations and land cover (Table H-1).

Conclusions

This analysis focused on DO, pH, and NO_3^- concentrations at 18 sampling sites in the freshwater portion of the Lamprey River watershed from 1990 to 2013. On average, DO and pH levels meet or exceed the Class B standard and NO_3^- concentrations are below levels that are detrimental to human health or are excessive. However, temporal and spatial variability in all of these parameters sometimes lead to water quality concern

Since 2003, there is the possibility of a pH stabilization, possibly due to decreasing acid rain impacts. Also, the acidity of the water along the Lamprey main stem decreases from the headwaters to the river mouth. Lastly, DO and NO_3^- concentrations do not exhibit any significant temporal or spatial trends in the watershed. However, both DO and NO_3^- are of high importance due to their known role in aquatic health and eutrophication.

Because of periodic low DO and pH and high NO_3^- measurements, we recommend continued ongoing monitoring to protect fish, shellfish, and wildlife; and provide for uses such as recreational activities, public water supplies, agricultural, industry, and navigation. We further recommend that low DO and pH measurements that fall below the Class B standard be flagged at the time of measurement, in order to enable timely procedures to address the cause as quickly as possible.

Continued monitoring and analysis is important due to the expected growth in human population, as well as changing land cover in the watershed. With a more dense population, and presumably more impervious cover, water quality will inevitably be affected. It is the responsibility of state organizations, watershed groups, and individual citizens to help protect future water quality in the Lamprey River watershed.

Appendix A – DO Summary

Site	Best Fit Equation	R Value	Years of Data	Significance	Average DO (mg/L)
GBCW-14	y = -0.0214x + 49.956	0.21	18	No	7.1
08-LMP & LMP-73	y = -0.0552x + 118.1	0.41	16	No	7.8
LMP-67 & 09-LMP	y = 0.0139x - 20.229	0.12	9	No	7.6
11-LMP	y = -0.0397x + 86.939	0.52	12	Yes	7.3
LMP-51 & 12-LMP	y = -0.0025x + 12.119	0.01	8	No	7.1
12A-LMP	y = 0.0753x - 143.42	0.43	10	No	7.4
12B-LMP	y = 0.0379x - 68.476	0.12	7	No	7.4
13F-LMP & 13-LMP	y = 0.0222x - 36.876	0.15	10	No	7.7
LMP-39	y = 0.1795x - 352.13	0.85	6	Yes	8.1
17-LMP	y = -0.0081x + 23.128	0.09	9	No	6.8
LMP-27 & 21-LMP	y = 0.0087x - 9.6824	0.08	11	No	7.9
LMP-19	y = 0.1622x - 317.71	0.75	6	No	7.8
LMP-07	y = 0.5636x - 1124	0.84	6	Yes	6.9
NOR-27	y = 0.1218x - 236.13	0.43	6	No	8.2
05-NOR	y = -0.0869x + 181.39	0.34	9	No	6.8
09-NOR	y = 0.0567x - 105.87	0.28	9	No	8.0
05-LTR	y = -0.1441x + 296.87	0.40	8	No	7.4
03-NBR	y = -0.0105x + 25.415	0.09	8	No	4.4

Table A-1. Best-fit equations of annual average summer DO concentration regressed against sampling year, linear correlation coefficient (r) values, number of years with measurements, significance at the 95% level, and the average summertime DO concentration for each site. Sites are sorted by river and then distance from the mouth of the Lamprey.

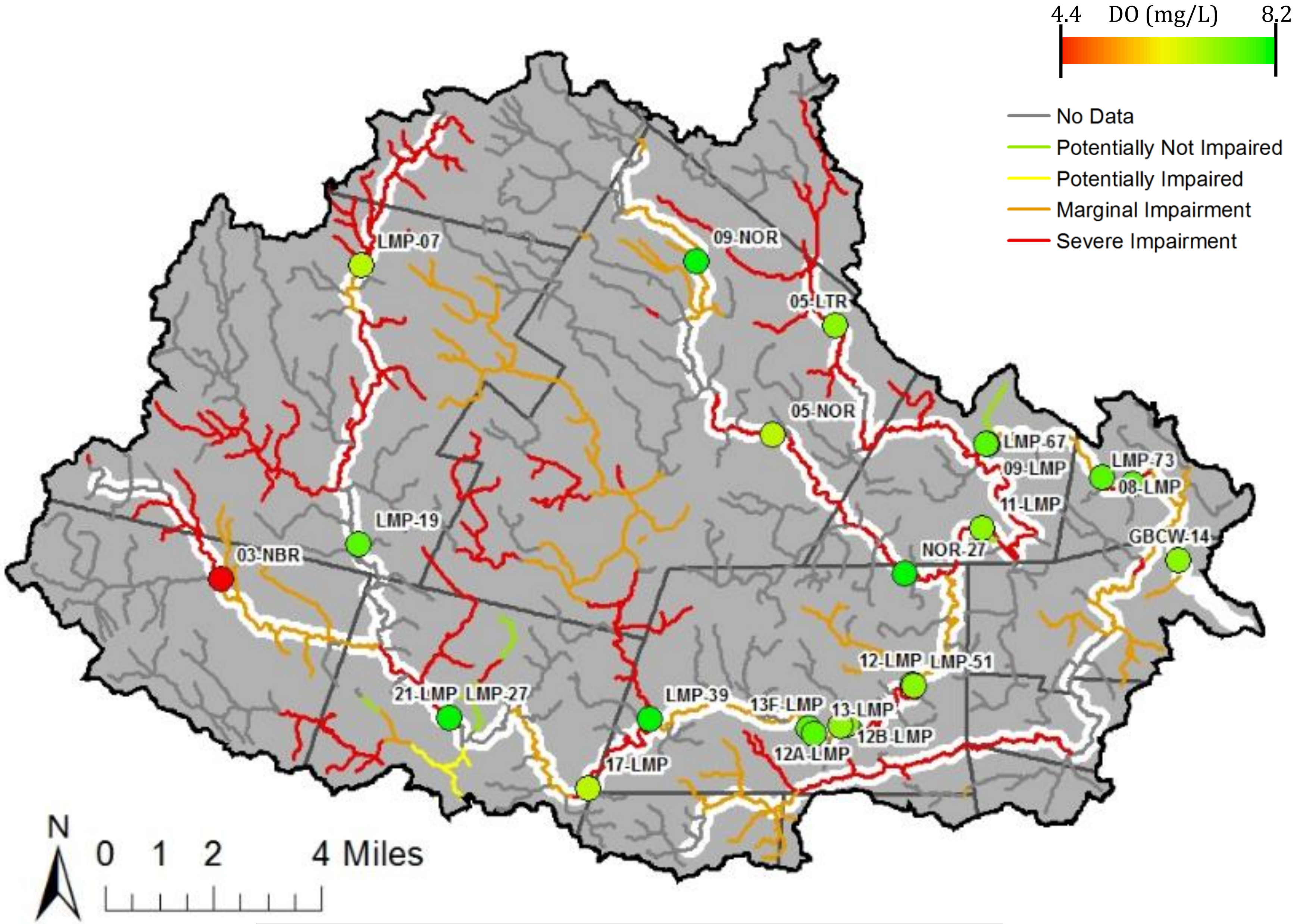

Figure A-1.Map of the Lamprey River watershed. Average summertime DO concentrations are shown for each site by the colored symbols. DO impairments are shown by the colored lines over the river network.

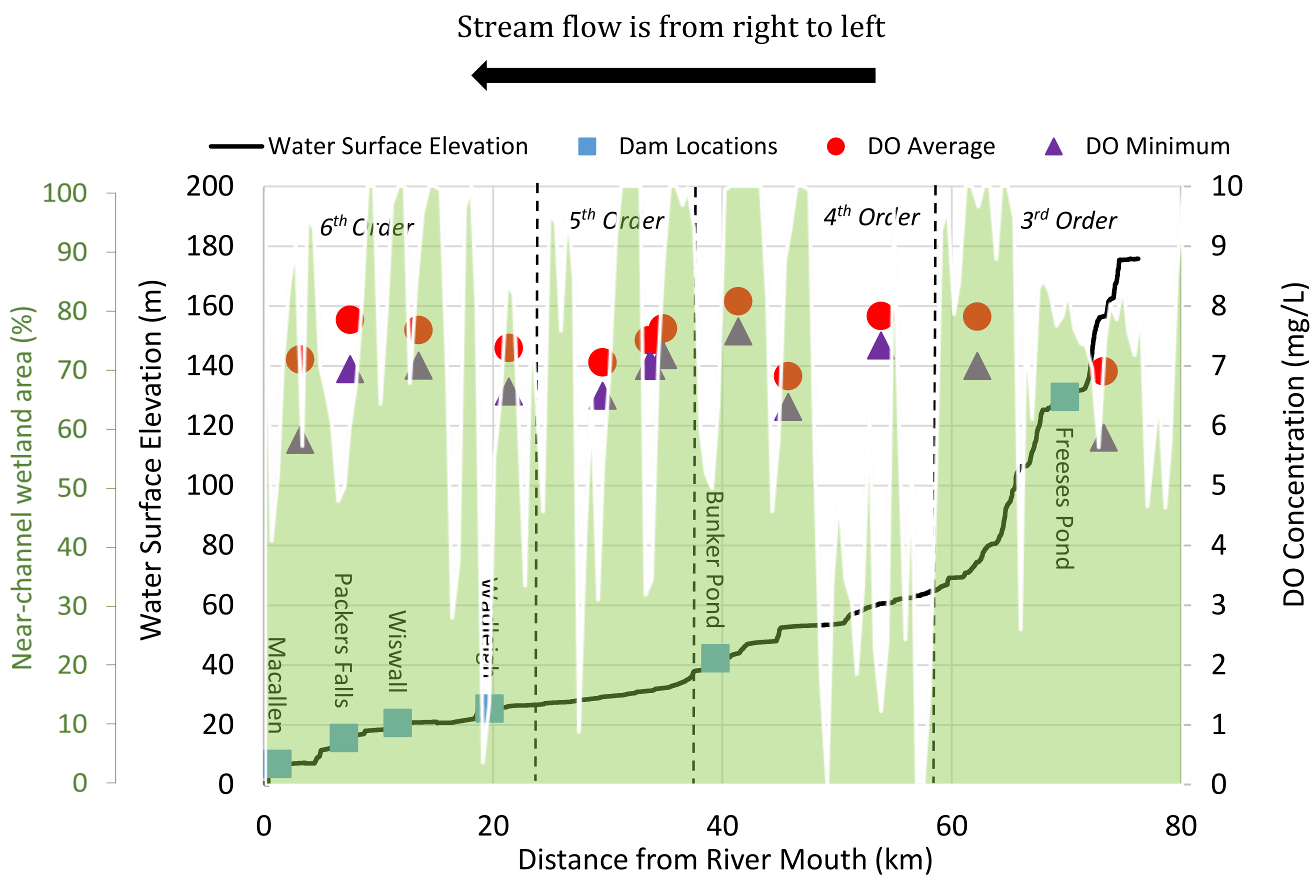

Figure A-2. Average and minimum summertime DO concentrations, dams, and near channel-wetland area along the Lamprey River main stem as a function of distance from the river mouth.

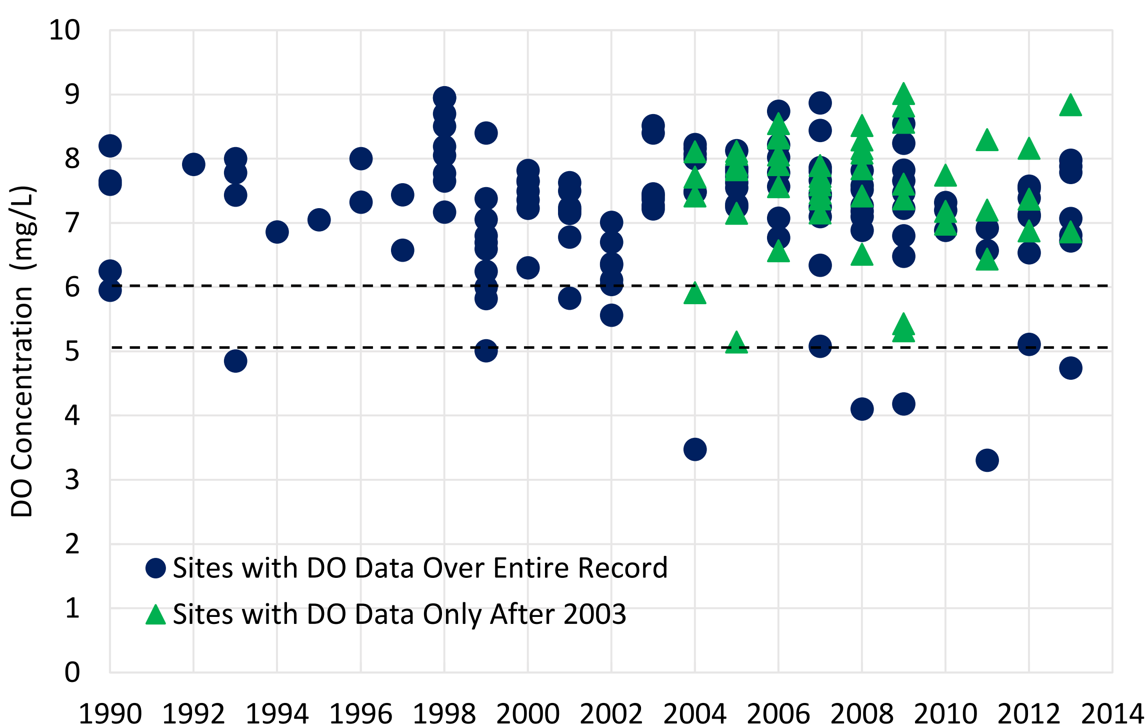

Figure A-3. Average summertime DO concentrations from 7/1 – 9/10 over the entire 23-year study period. Different symbols are shown for sites that have measurements both before and after 2003 and sites that only have measurements after 2003. The dashed horizontal lines represent 6 mg/L (Class A standard) and 5 mg/L (Class B standard).

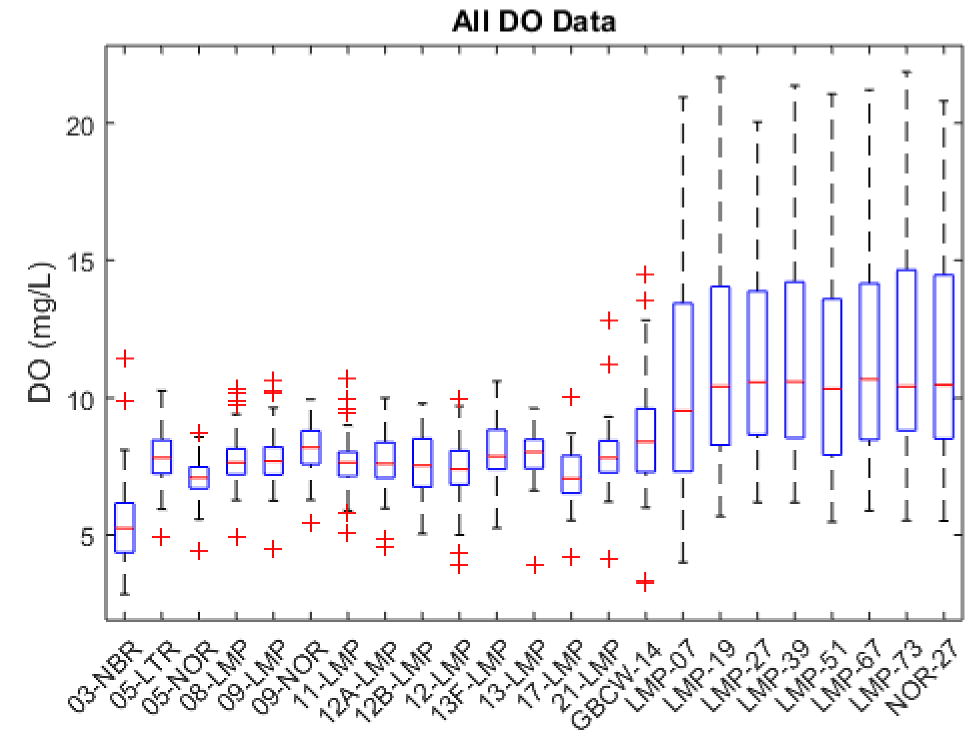

Figure A-4. Boxplot showing all DO data at each site, from the entire record. The top and bottom of each box represents the 25 and 75 percent quartiles, the red lines represent the median value, the whiskers represent the minimum and maximum values, and the red plus signs are outliers.

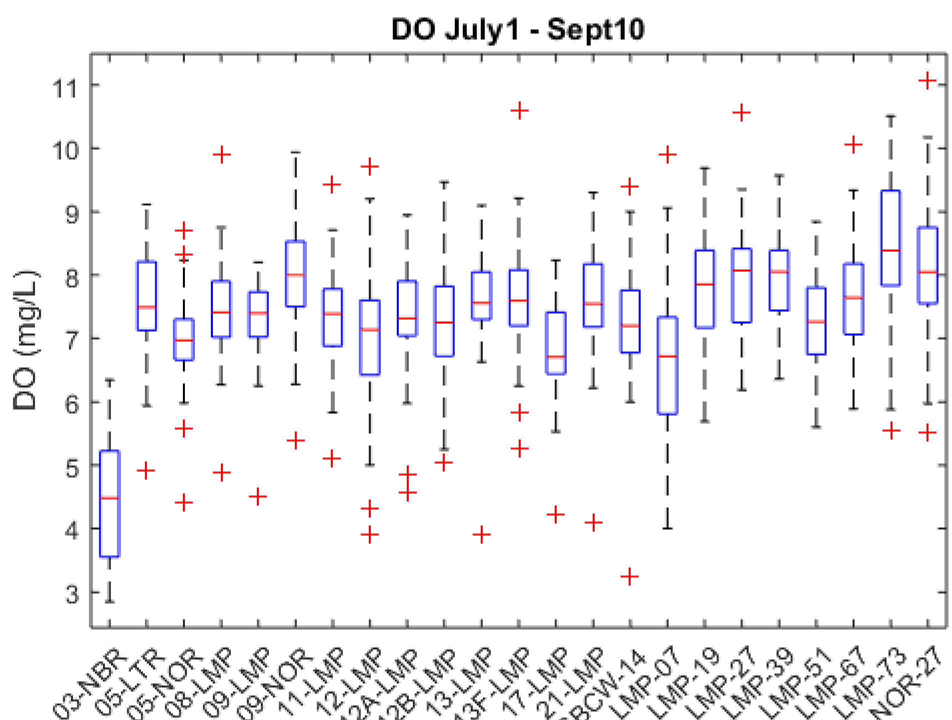

Figure A-5. Boxplot showing DO data from 7/1 – 9/10 at each site, from the entire record. The top and bottom of each box represents the 25 and 75 percent quartiles, the red line represents the median value, the whiskers represent the minimum and maximum values, and the red plus signs are outliers.

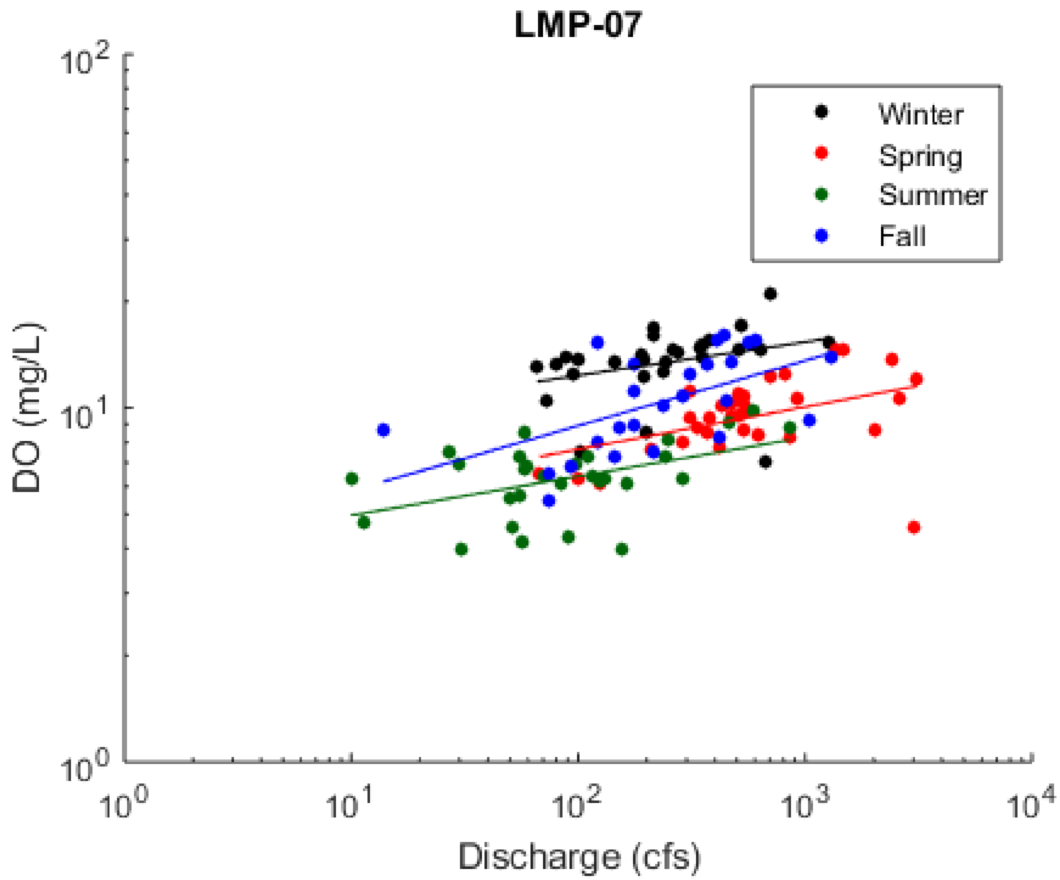

Figure A-6. Significant positive correlations at Blakes Hill Road in Deerfield (LMP-07) for spring and summer between DO measurements and the 7-day average discharge leading up to each of the DO measurements.

Appendix B – pH Summary

Site	Best-Fit Equation	R Value	Years of Data	Significance	Average pH
GBCW-14	y = -0.0019x + 10.943	0.10	17	No	7.19
08-LMP & LMP-73	y = -0.0238x + 54.429	0.62	13	Yes	6.80
w/o isolated years	y = -0.0461x + 99.136	0.67	12	Yes	6.80
LMP-67 & 09-LMP	y = -0.0207x + 48.227	0.55	14	Yes	6.50
w/o isolated years	y = -0.0188x + 44.41	0.42	13	No	6.50
11-LMP	y = -0.0304x + 67.59	0.72	13	Yes	6.66
LMP-51 & 12-LMP	y = -0.026x + 58.693	0.53	14	Yes	6.68
w/o isolated years	y = -0.027x + 61.799	0.53	13	Yes	6.68
12A-LMP	y = -0.0198x + 46.53	0.41	10	No	6.89
12B-LMP	y = -0.0524x + 111.82	0.55	7	No	6.86
13F-LMP & 13-LMP	y = -0.0234x + 53.519	0.49	15	Yes	6.66
w/o isolated years	y = -0.0264x + 59.577	0.43	14	No	6.66
LMP-39	y = -0.0091x + 24.95	0.20	6	No	6.61
17-LMP	y = -0.0597x + 126.25	0.82	11	Yes	6.42
LMP-27 & 21-LMP	y = -0.0338x + 74.326	0.67	14	Yes	6.50
w/o isolated years	y = -0.0031x + 12.469	0.05	10	No	6.50
LMP-19	y = 0.0467x - 87.329	0.63	6	No	6.33
LMP-07	y = 0.0803x - 155.5	0.47	6	No	5.72
NOR-27	y = 0.0273x - 48.227	0.30	6	No	6.61
05-NOR	y = -0.0171x + 40.527	0.26	9	No	6.09
09-NOR	y = -0.009x + 24.636	0.17	9	No	6.47
05-LTR	y = -0.0168x + 39.703	0.26	8	No	5.92
03-NBR	y = -0.046x + 98.135	0.79	9	Yes	5.89

Table B-1. Best-fit equations of annual average pH regressed against sampling year, linear correlation coefficient (r) values, number of years of measurements, significance at the 95% level, and average pH over the entire record. Sites are sorted first by river and secondly by the distance from the mouth of Lamprey main stem.

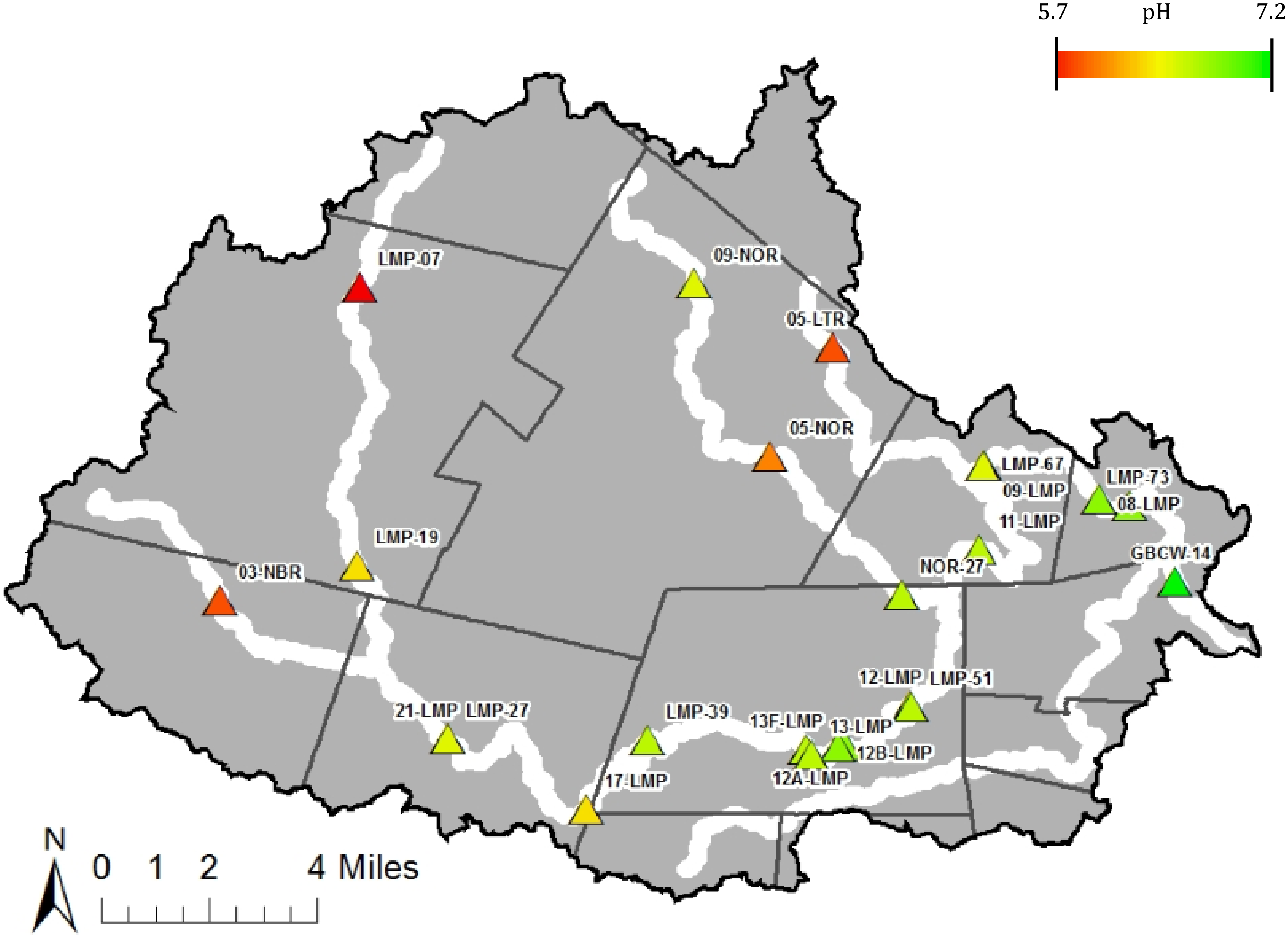

Figure B-1. Map of the Lamprey River watershed. Average pH over the entire record is shown for each site by the colored symbols.

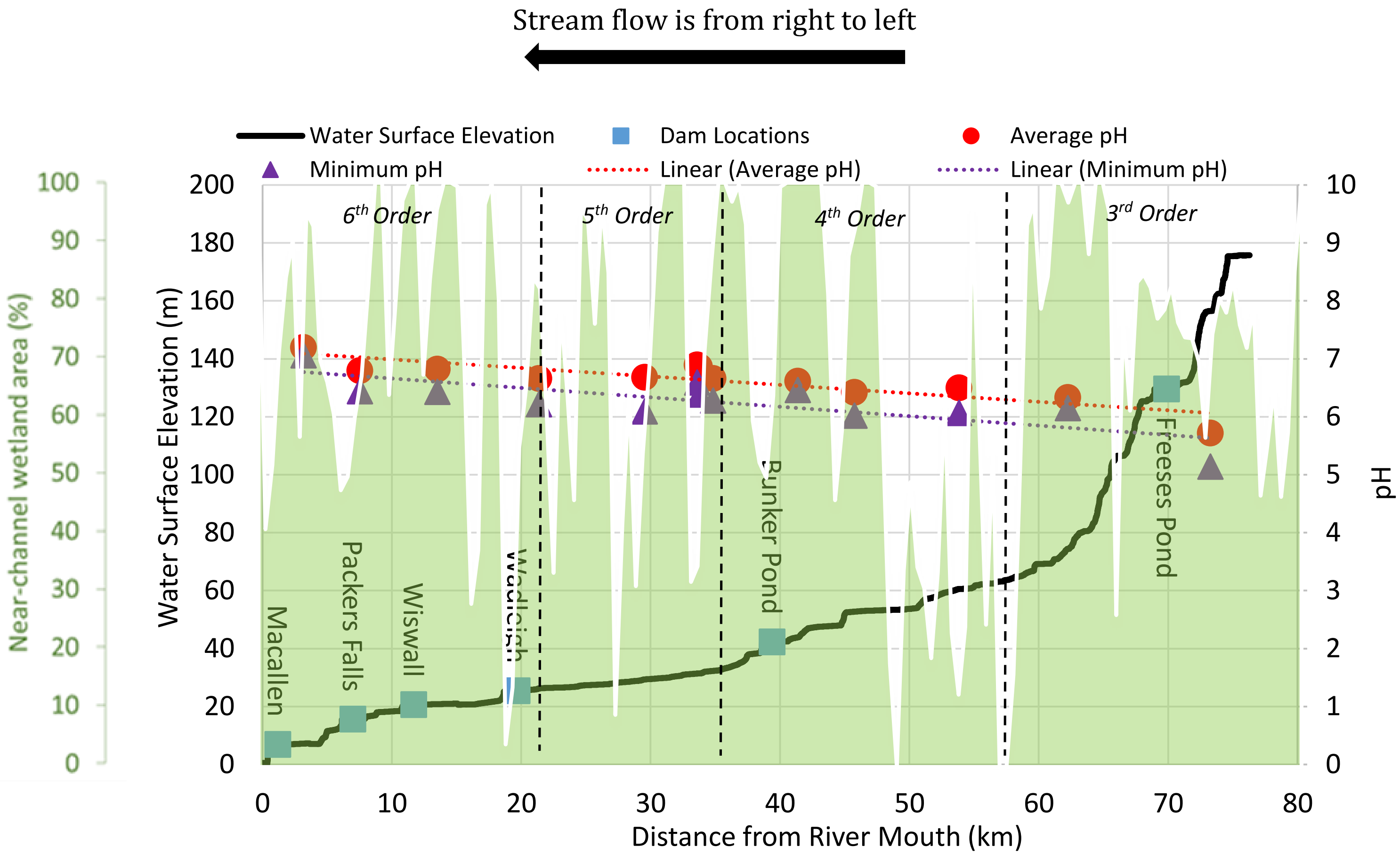

Figure B-2. Average and minimum pH, dams, and near channel-wetland area along the Lamprey River main stem as a function of distance from the river mouth. A significant increase from the headwaters to the mouth of the Lamprey was found for both the average (R^2 = 0.75) and minimum (R^2 = 0.60) pH.

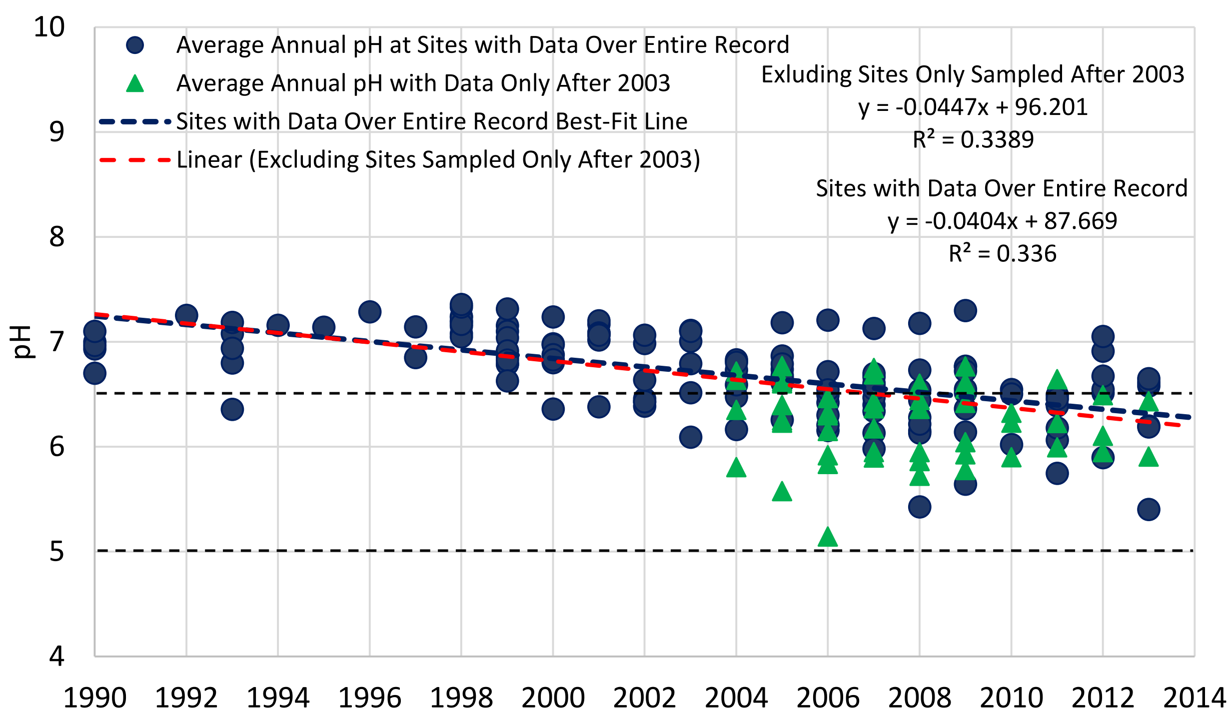

Figure B-3. Average annual pH over the entire 23-year study period. The blue circles represent sites that have measurements both before and after 2003 while the green triangles show sites that only have measurements after 2003. The dashed horizontal lines represent the NHDES pH standard of 5 (below which is high impact on water quality) and 6.5 (above which is considered normal).

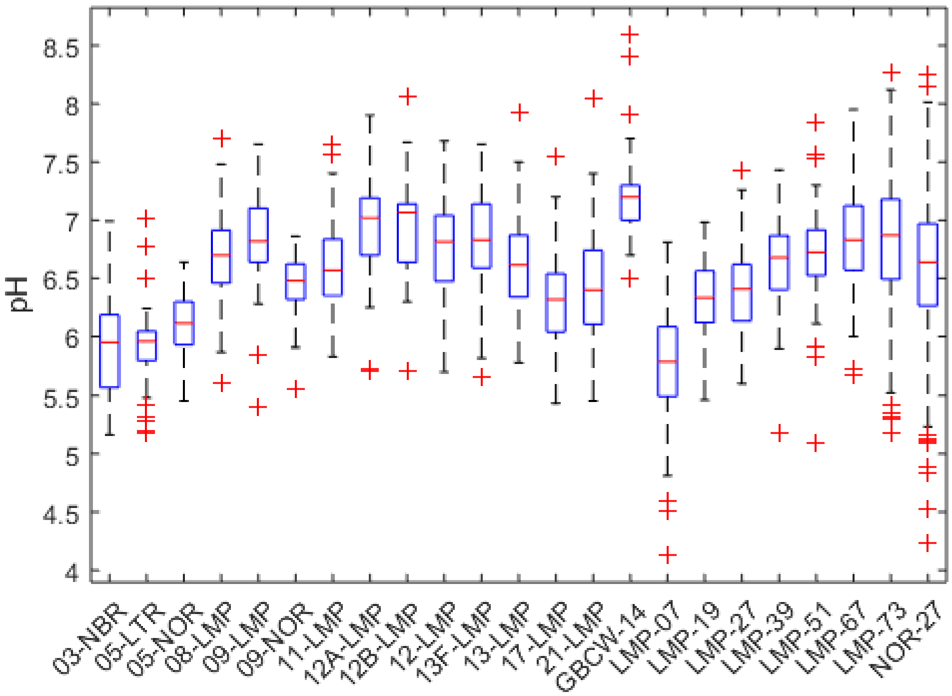

Figure B-4. Boxplot showing all pH data at each site, from the entire record. The top and bottom of each box represents the 25 and 75 percent quartiles, the red lines represent the median value, the whiskers represent the minimum and maximum values, and the red plus signs are outliers.

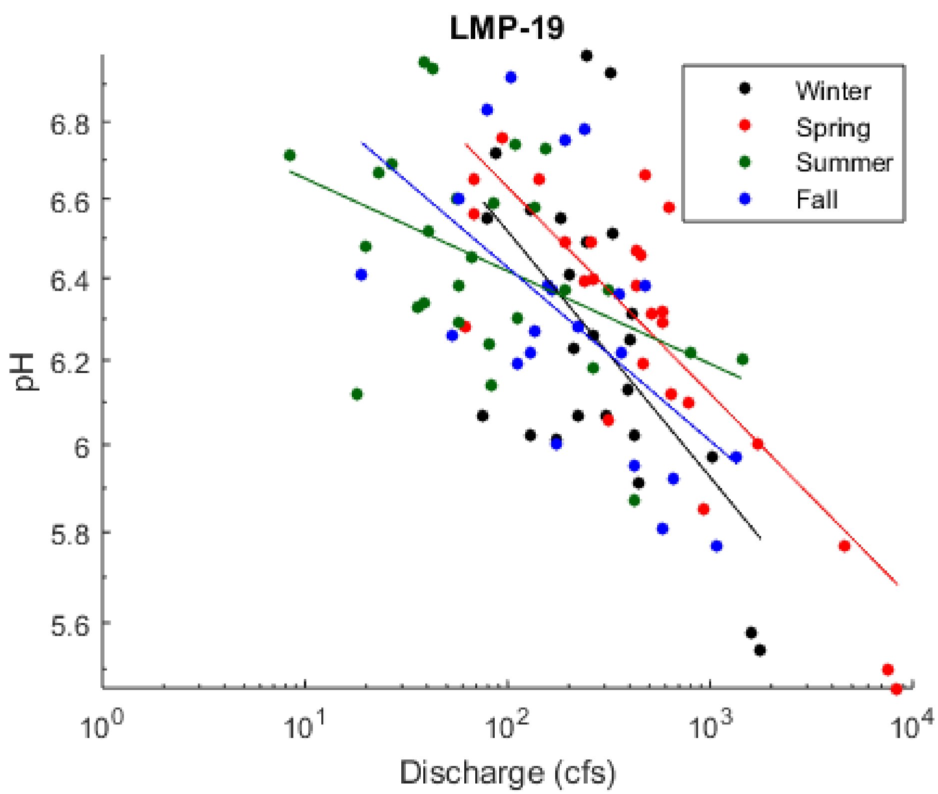

Figure B-5. Significant negative correlations at Cotton Road in Deerfield (LMP-19) for all seasons between all pH measurements and the daily average discharge on the day of each of the pH measurements.

Appendix C – NO_3^- Summary

Site	Best-Fit Equation	R Value	Years of Data	Significance	Average NO_3^- (mg-N/L)
03-NBR	-	-	1	No	0.045
05-LTR	-	-	-	-	-
05-NOR	-	-	-	-	-
08-LMP	y = 0.0179x - 35.598	0.51	3	No	0.169
09-LMP	y = 0.0162x - 32.208	0.85	4	No	0.118
09-NOR	-	-	-	-	-
11-LMP	y = -0.0018x + 3.895	0.10	4	No	0.152
12-LMP	y = -0.0262x + 52.962	0.24	4	No	0.505
12A-LMP	-	-	-	-	-
12B-LMP	-	-	-	-	-
13-LMP	y = 0.0112x - 22.398	0.79	4	No	0.123
13F-LMP	-	-	-	-	-
17-LMP	y = -0.1049x + 210.149	0.77	4	No	0.413
21-LMP	y = 0.0158x - 31.524	0.86	4	No	0.124
GBCW-14	-	-	-	-	-
LMP-07	y = 0.0040x - 8.076	0.67	9	Yes	0.036
LMP-19	y = 0.0030x - 6.059	0.41	7	No	0.106
LMP-27	y = 0.0023x - 4.676	0.38	7	No	0.093
LMP-39	y = -0.0002x + 0.699	0.05	7	No	0.110
LMP-51	y = 0.0111x - 22.120	0.42	8	No	0.225
LMP-67	y = -0.0043x + 8.928	0.65	6	No	0.133
LMP-73	y = 0.0067x -13.461	0.84	11	Yes	0.113
NOR-27	y = 0.0010 - 2.100	0.44	8	No	0.051

Table C-1. Best-fit equations of annual average summer NO_3^- regressed against sampling year, linear correlation coefficient (r) value, number of years with measurements, significance at the 95% level, and the average NO_3^- value for each site.

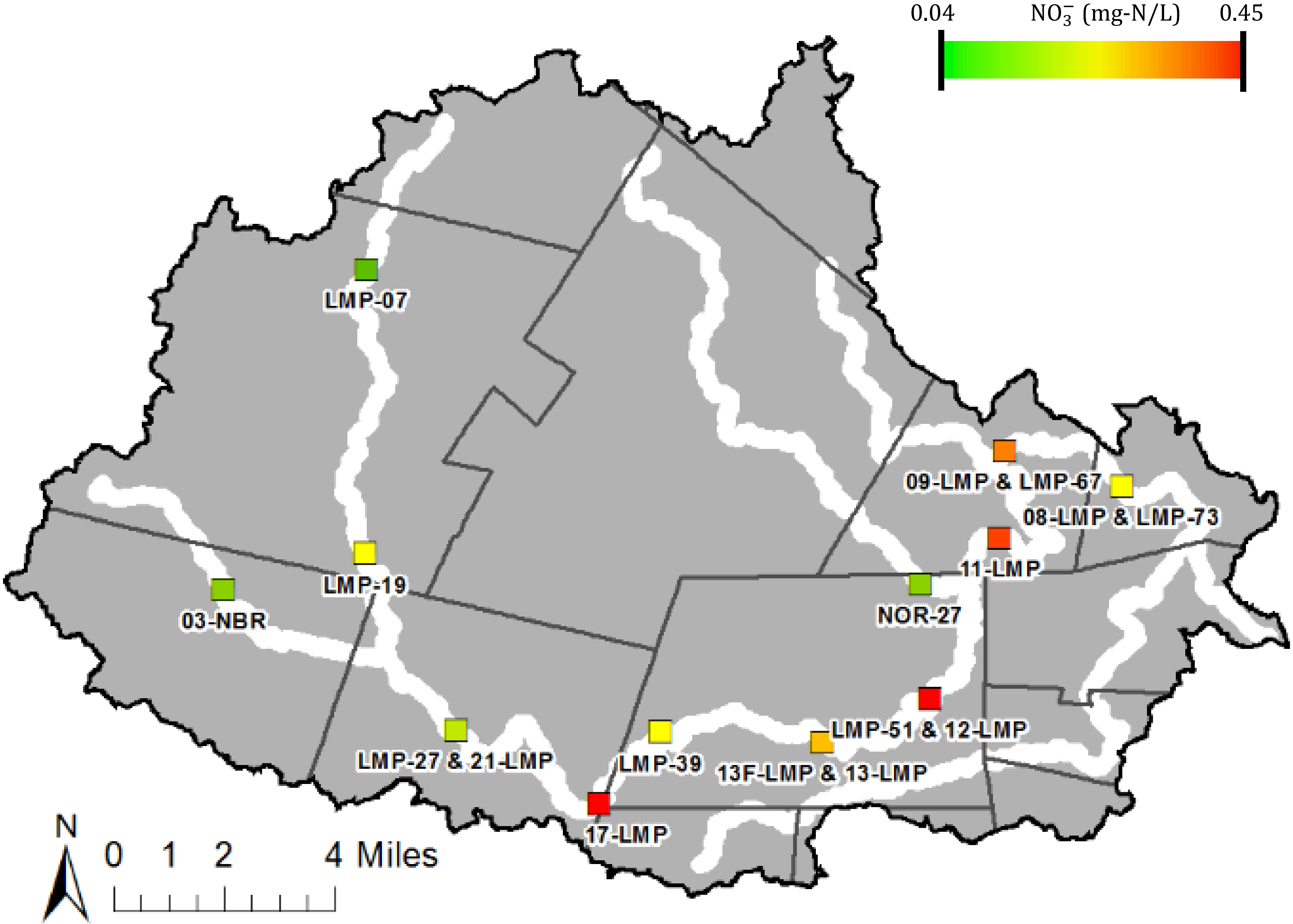

Figure C-1. Map of the Lamprey River watershed. Average summertime NO_3^- is shown for each site by the colored symbols.

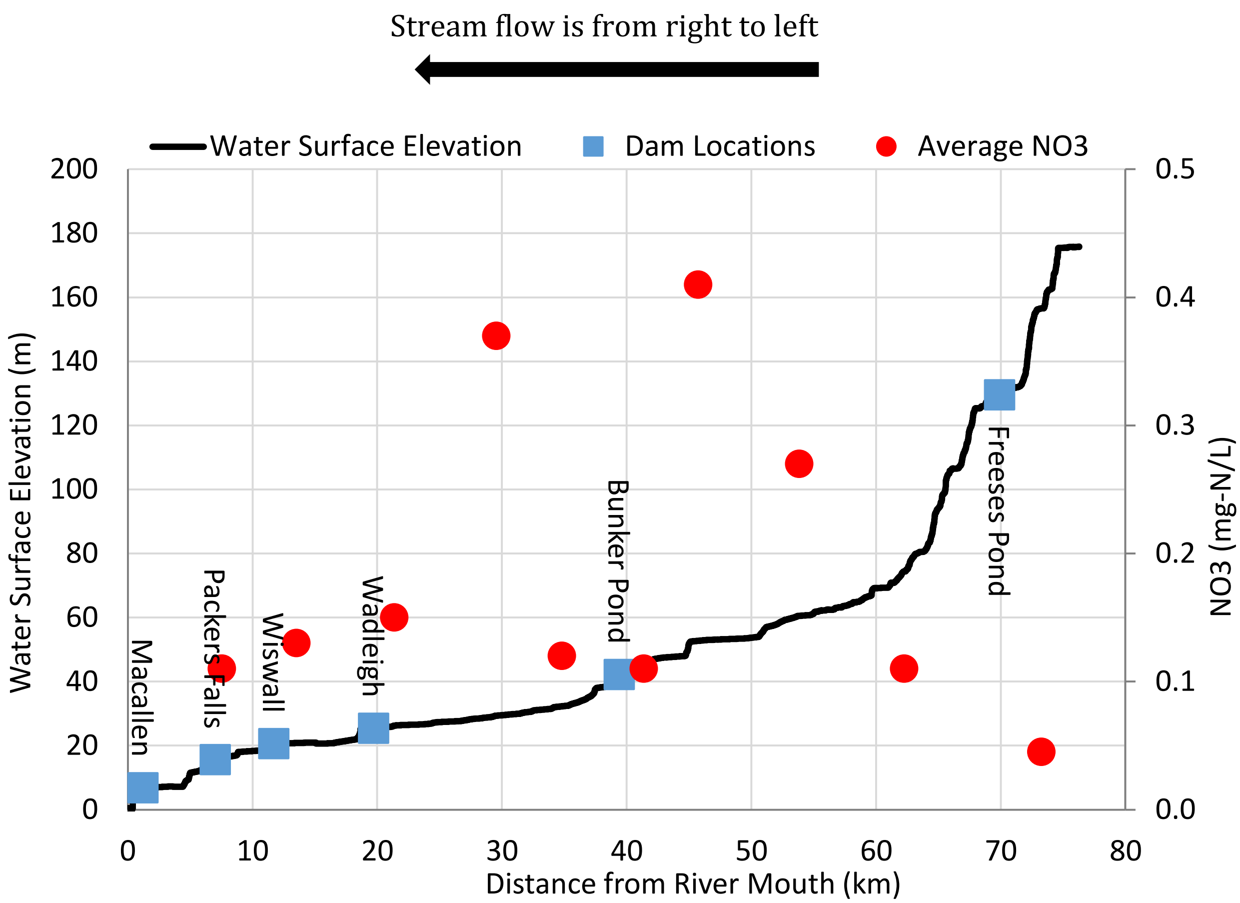

Figure C-2. Average summertime NO_3^- for sites along the Lamprey River main stem as a function of distance from the river mouth. No significant trends were found.

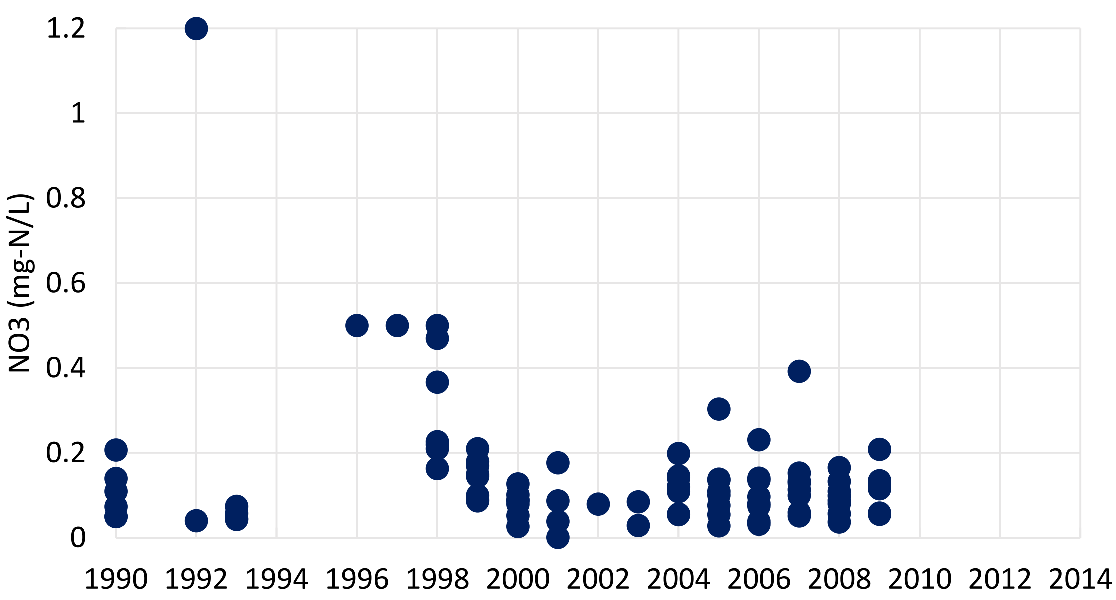

Figure C-3. Average annual NO_3^- over the entire record. No significant trend was found.

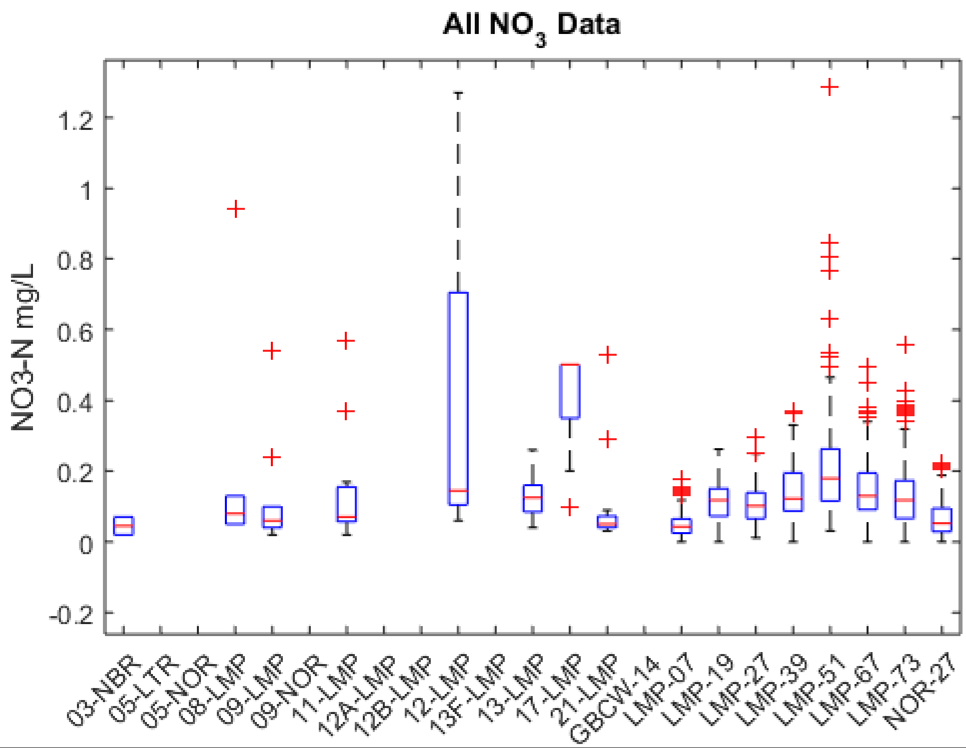

Figure C-4. Boxplot showing all NO_3^- data at each site, from the entire record. The top and bottom of each box represents the 25 and 75 percent quartiles, the red lines represent the median value, the whiskers represent the minimum and maximum values, and the red plus signs are outliers.

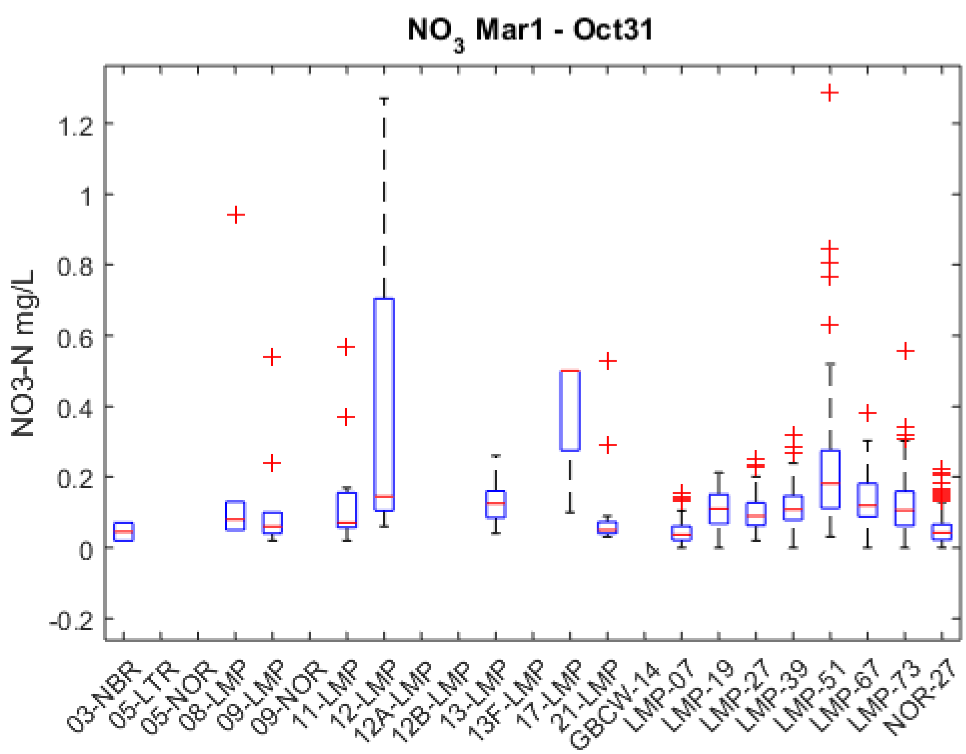

Figure C-5. Boxplot showing NO_3^- data from March 1 to October 31 at each site, from the entire record. The top and bottom of each box represents the 25 and 75 percent quartiles, the red lines represent the median value, the whiskers represent the minimum and maximum values, and the red plus signs are outliers.

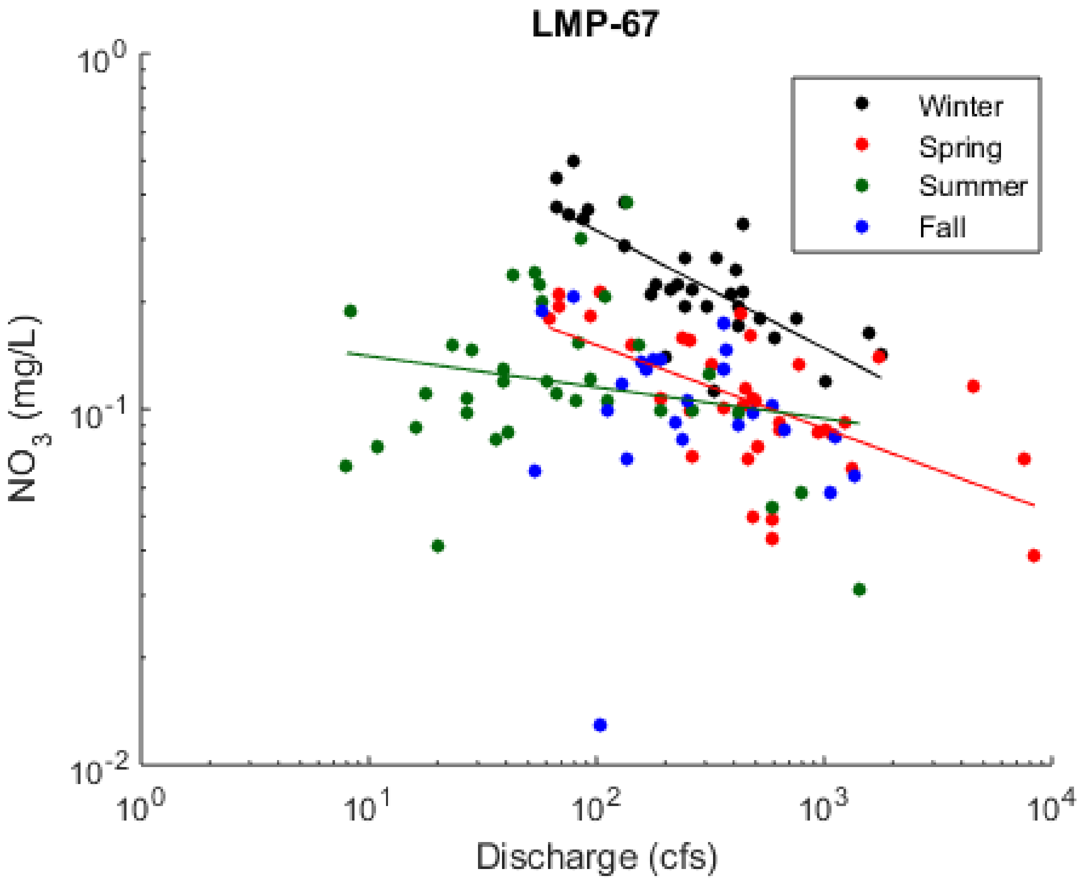

Figure C-6. Significant negative correlations for winter and spring between NO_3^- and the daily average discharge on the day of each of the NO_3^- measurements.

Appendix D – DO Time Series

Lamprey main stem

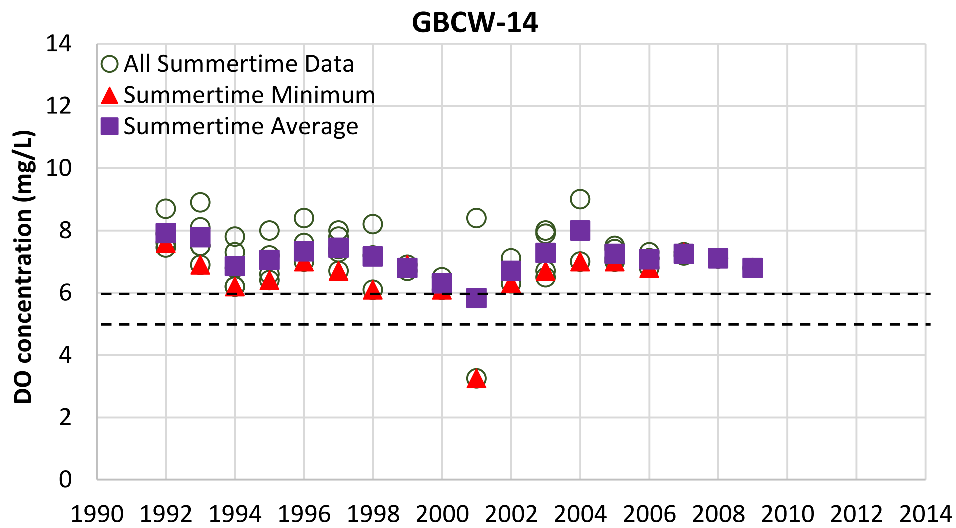

Figure D-1. Summertime average and minimum concentrations at Fowler's Dock in Newmarket (GBCW-14). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

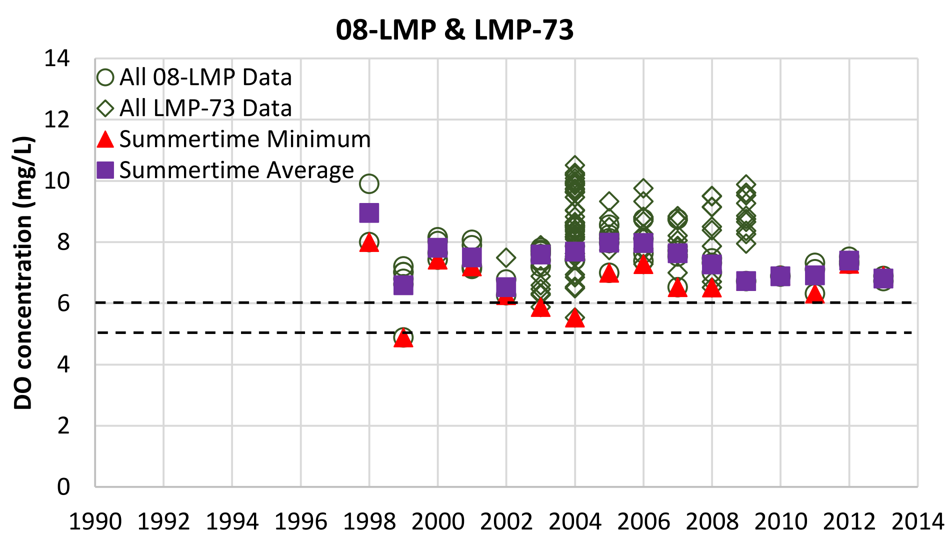

Figure D-2. Summertime average and minimum DO concentration at Wiswall Road Bridge and Packers Falls Road in Durham (08-LMP & LMP-73). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

Lamprey main stem

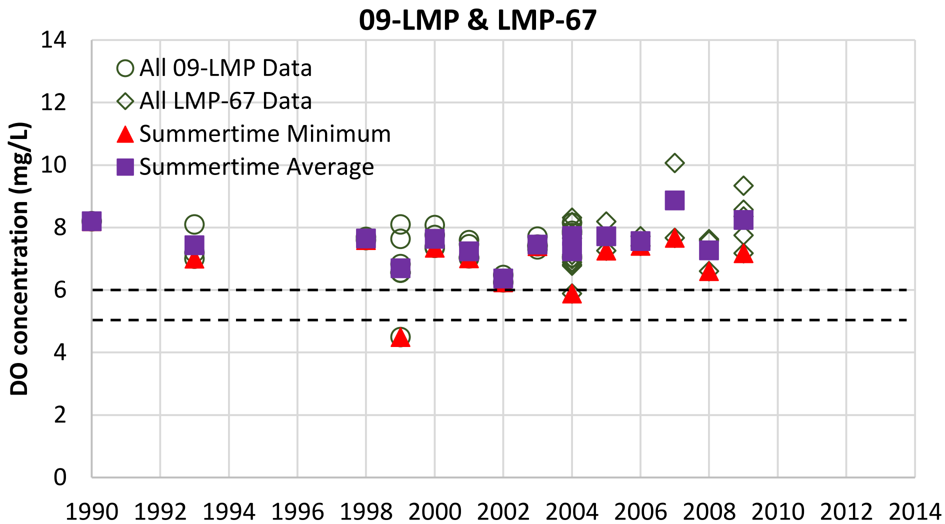

Figure D-3. Summertime average and minimum DO concentrations at Lee Hook Road in Lee (09-LMP & LMP-67). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

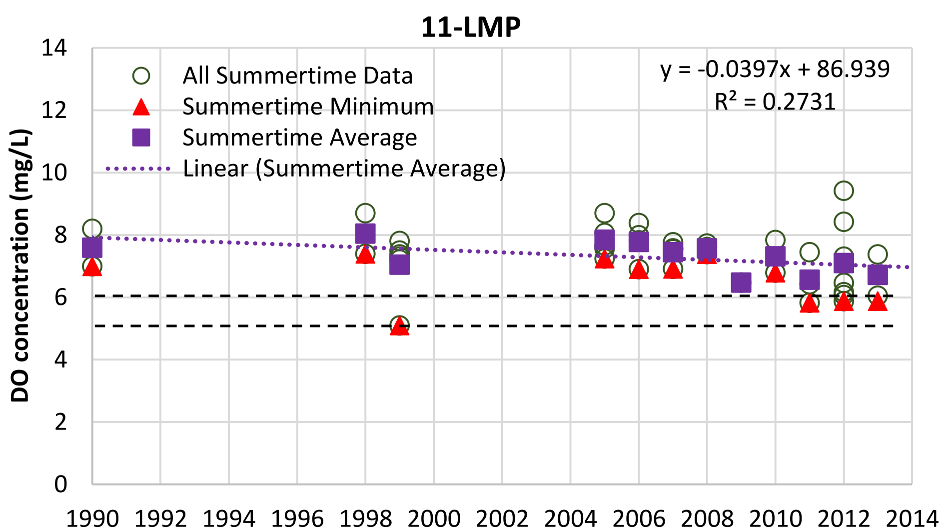

Figure D-4. Summertime average and minimum DO concentrations at Wadleigh Falls along Route 152 in Lee (11-LMP). A significant decrease was found for summertime average DO concentrations. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

Lamprey main stem

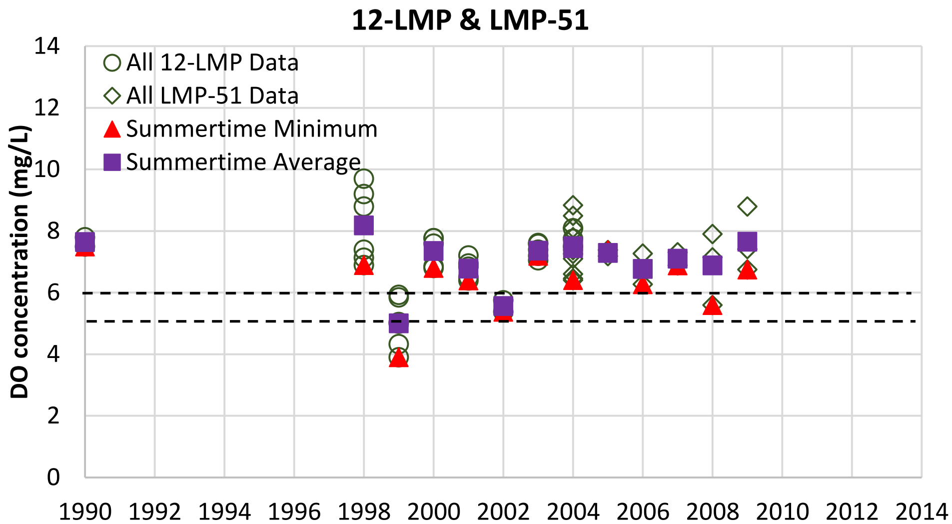

Figure D-5. Summertime average and minimum DO concentrations at the Route 87 Bridge in Epping (12-LMP & LMP-51). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

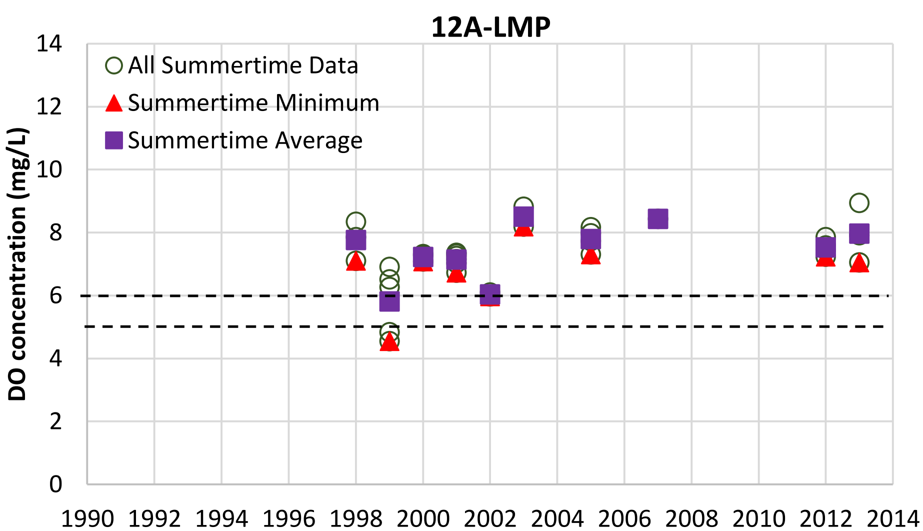

Figure D-6. Summertime average and minimum DO concentrations downstream of the Epping wastewater treatment facility in Epping (12A-LMP). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

Lamprey main stem

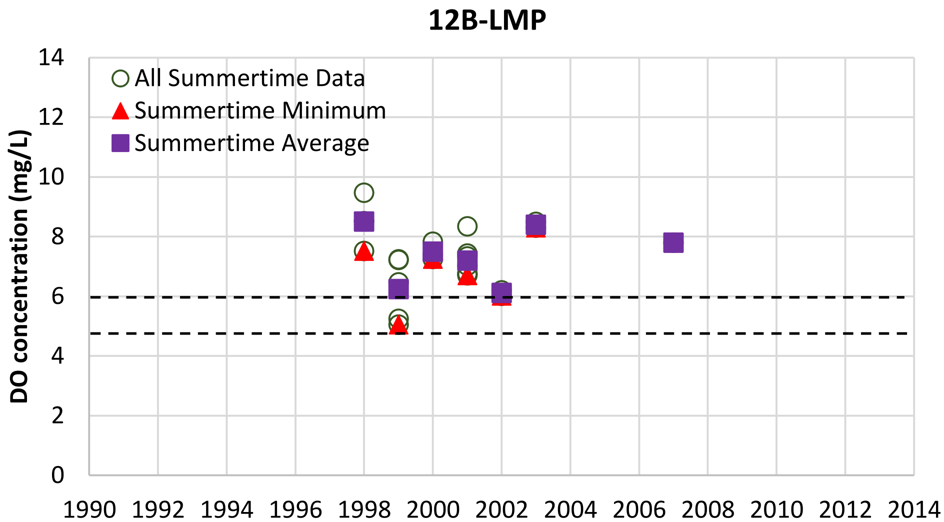

Figure D-7. Summertime average and minimum DO concentrations upstream of the Epping wastewater treatment facility in Epping (12B-LMP). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

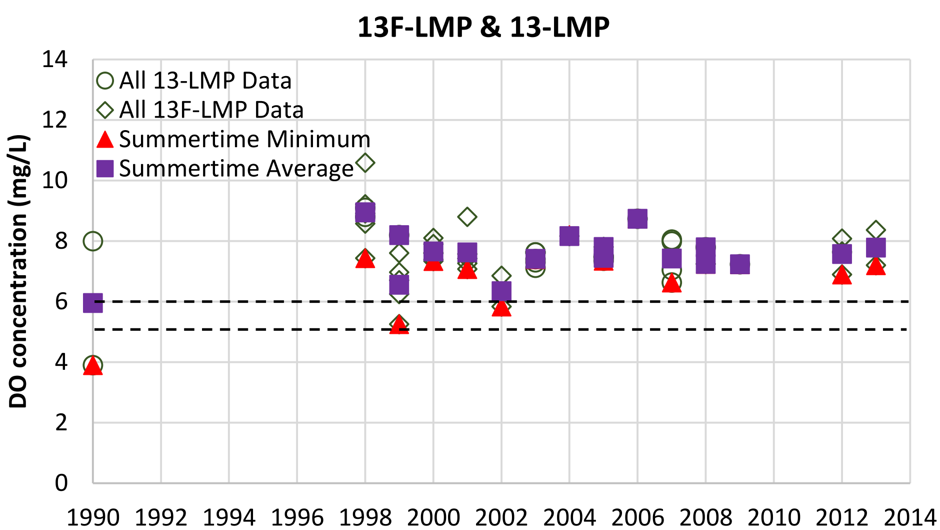

Figure D-8. Summertime average and minimum DO concentrations at the Mill Street Bridge in Epping (13F-LMP & 13-LMP). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

Lamprey main stem

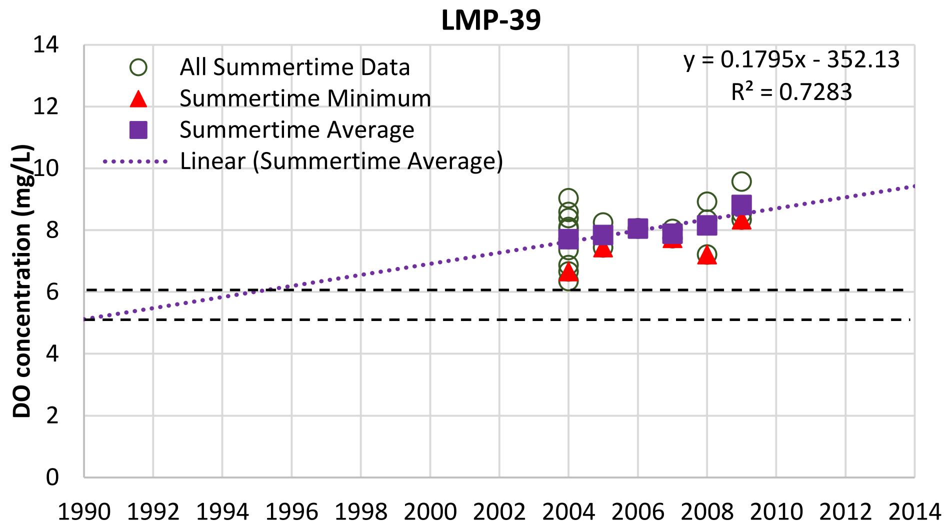

Figure D-9. Summertime average and minimum DO concentrations at Lamprey Lane in Epping (LMP-39). A significant increase was found for summertime average DO concentrations. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

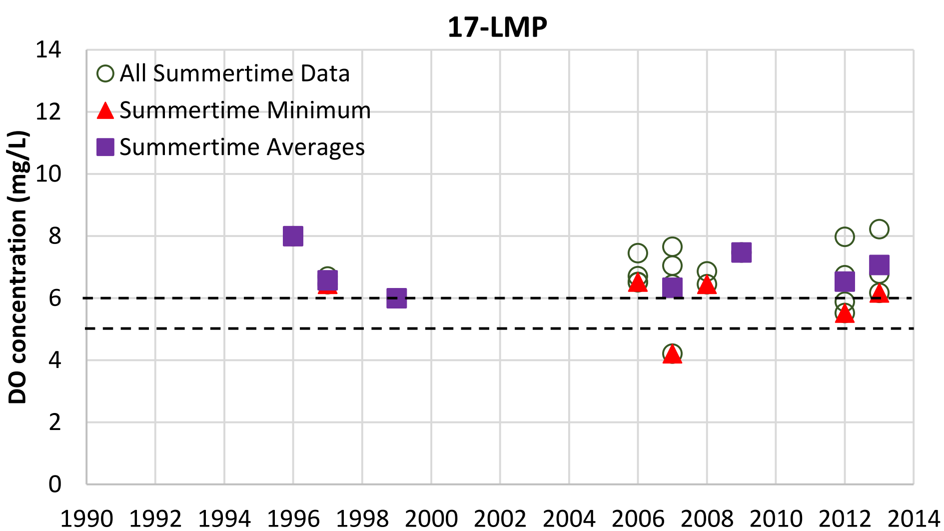

Figure D-10. Summertime average and minimum DO concentrations at the Prescott Road bridge in Raymond (17-LMP). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

Lamprey main stem

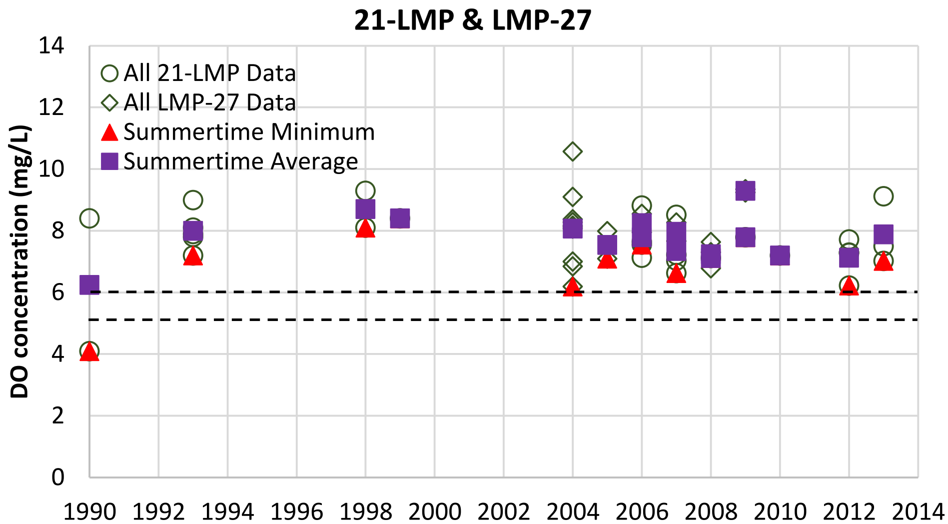

Figure D-11. Summertime average and minimum DO concentrations at Langford Road in Raymond (21-LMP & LMP-27). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

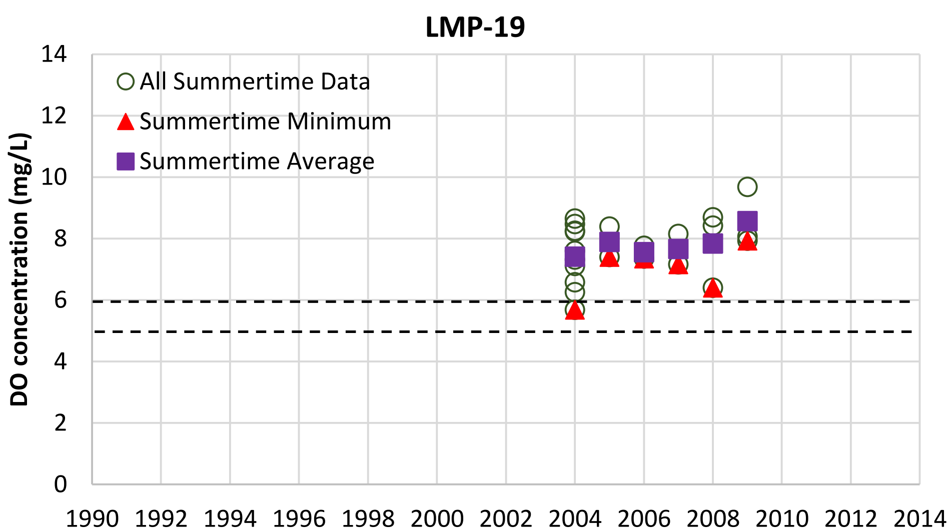

Figure D-12. Summertime average and minimum DO concentrations at Cotton Road in Deerfield (LMP-19). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

Lamprey main stem

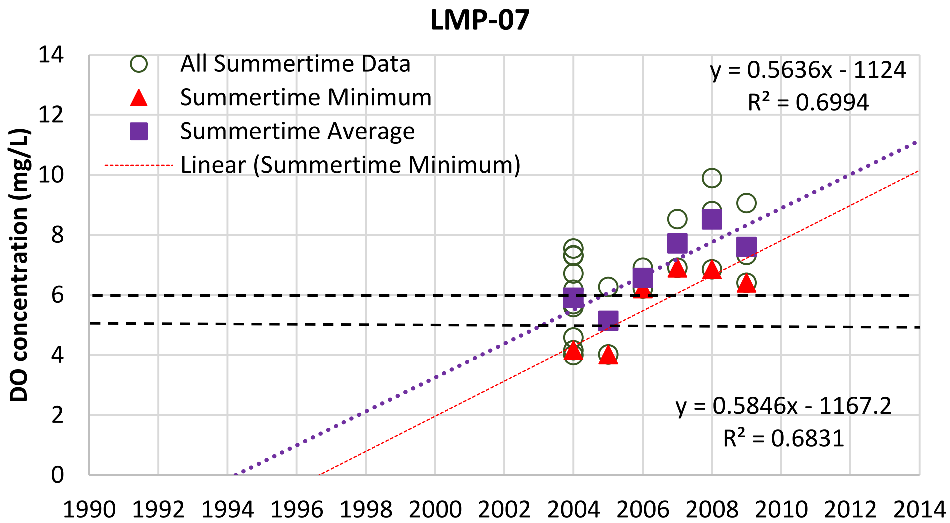

Figure D-13. Summertime average and minimum DO concentrations at Blakes Hill Road in Deerfield (LMP-07). A significant increase was found in both the summertime average DO concentration and the summertime minimum DO concentration. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

North River

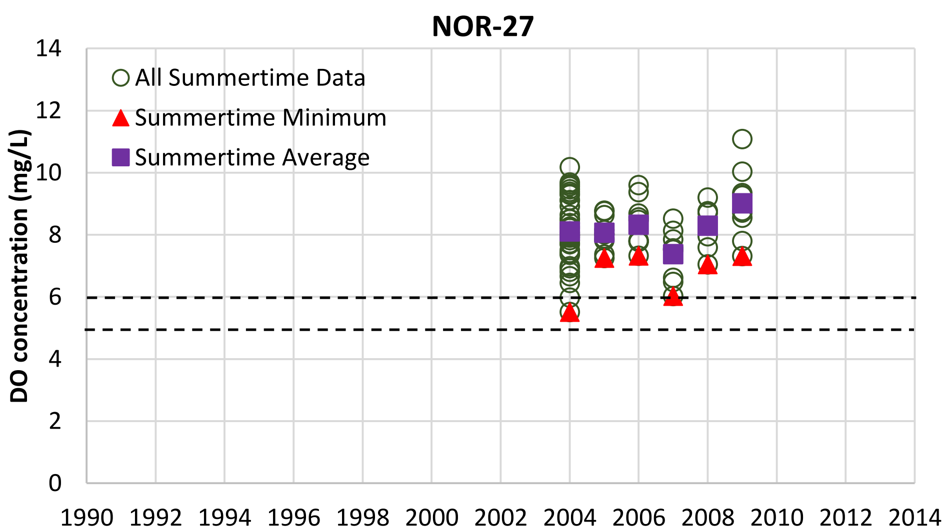

Figure D-14. Summertime average and minimum DO concentrations at Route 125 in Epping (NOR-27). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

North River

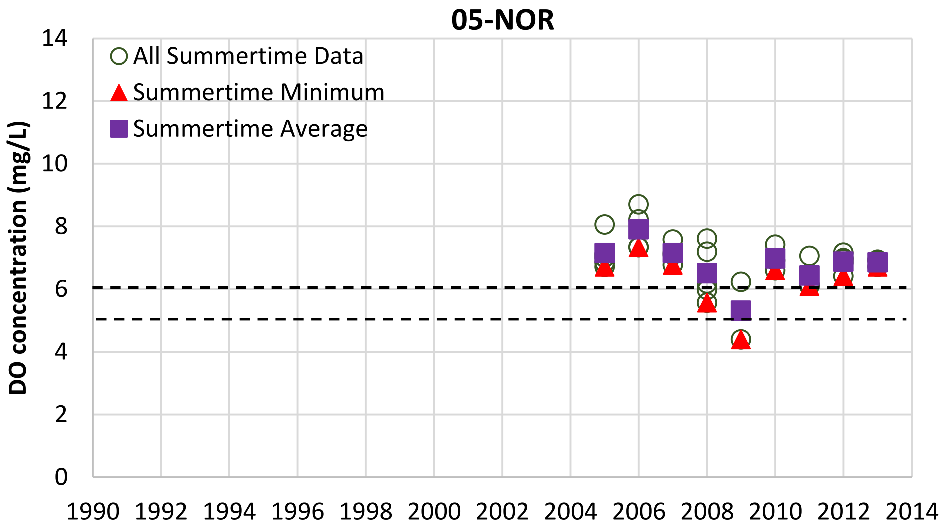

Figure D-15. Summertime average and minimum DO concentrations at the McCrillis Road Bridge in Epping (05-NOR). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

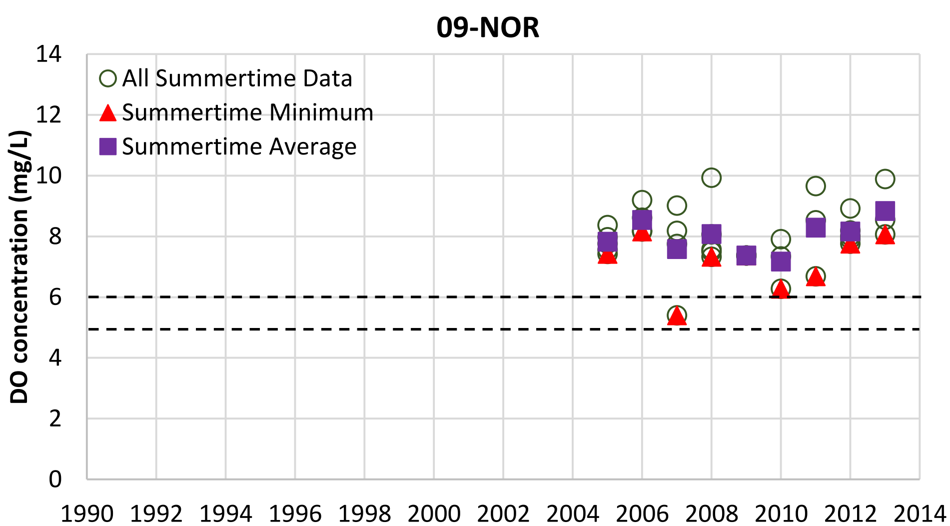

Figure D-16. Summertime average and minimum DO concentrations at the Freeman Hall Road bridge in Nottingham (09-NOR). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

Little River

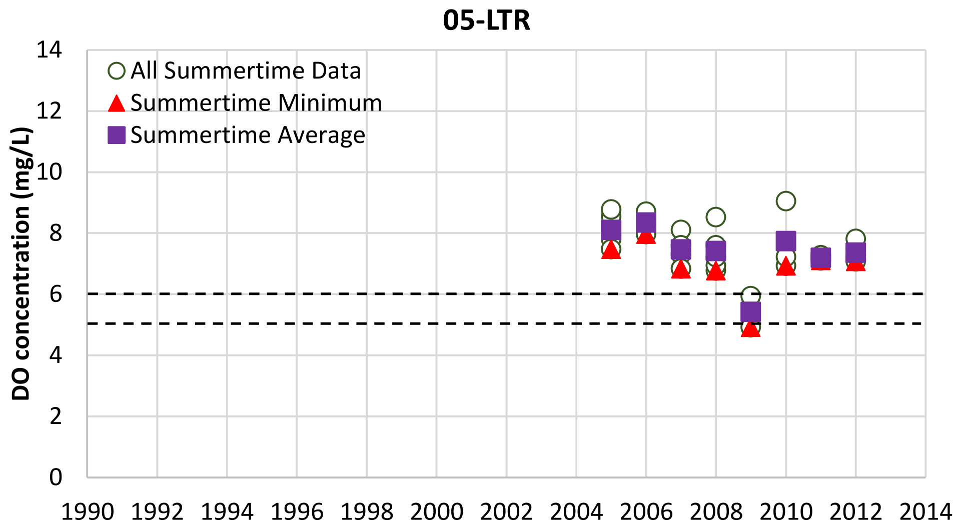

Figure D-17. Summertime average and minimum DO concentrations at the Smoke Street Bridge in Nottingham (05-LTR). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

North Branch River

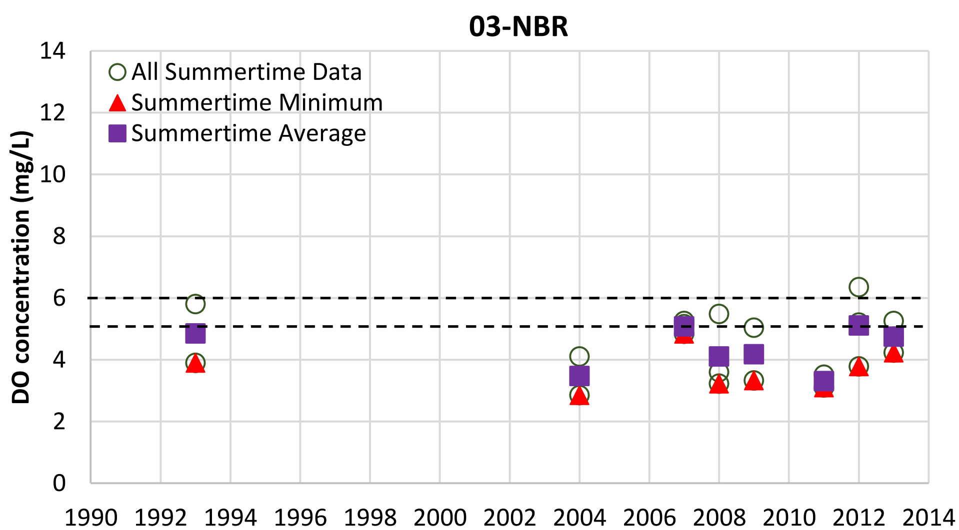

Figure D-18. Summertime average and minimum DO concentrations at New Boston Road in Candia (03-NBR). No significant change was found. The horizontal dashed lines represent the Class A and B DO standards (6 mg/L and 5 mg/L, respectively).

Appendix E – pH Time Series

Lamprey main stem

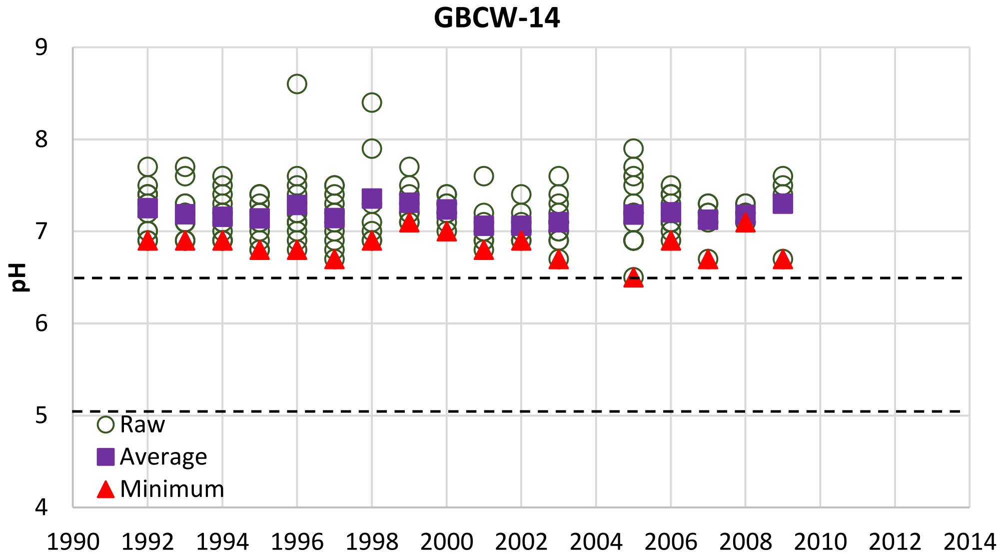

Figure E-1. Average and minimum pH at Fowler's Dock in Newmarket (GBCW-14). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant change was found.

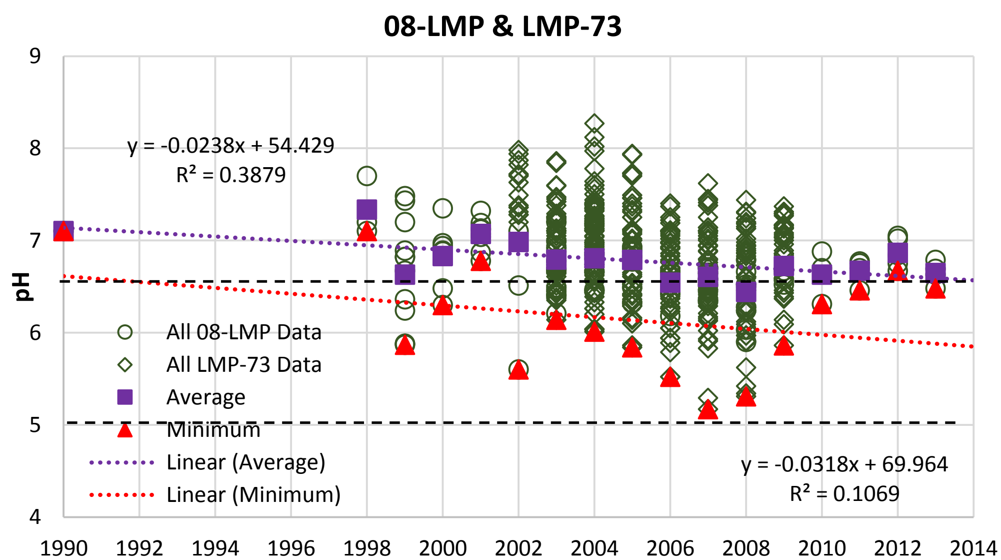

Figure E-2. Average and minimum pH at the Wiswall Road bridge and Packers Falls Road in Durham (08-LMP & LMP-73). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). Significant changes were found in both the average and minimum pH.

Lamprey main stem

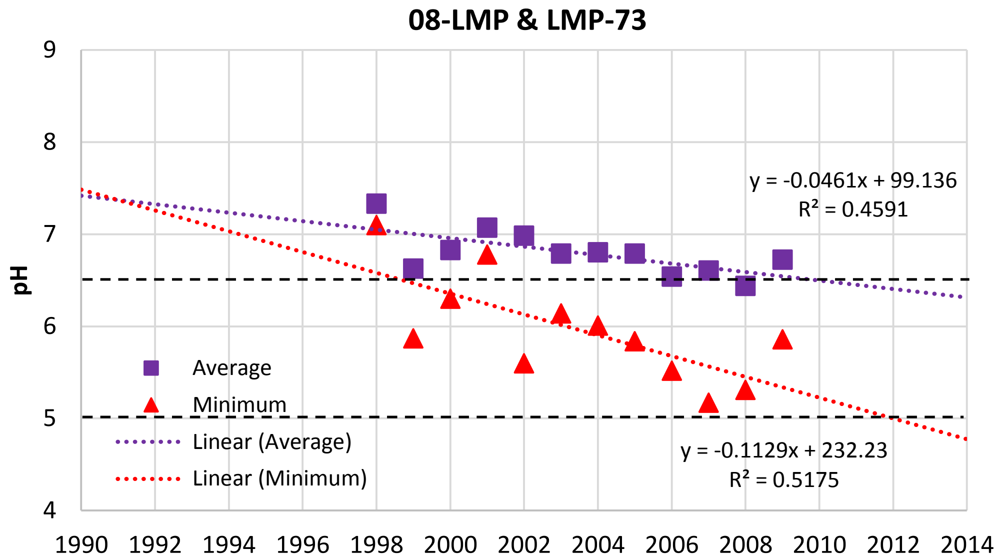

Figure E-3. Average and minimum pH at the Wiswall Road Bridge and Packers Falls Road in Durham (08-LMP & LMP-73) with isolated sampling years removed. The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). Significant changes were still found in both the average and minimum pH.

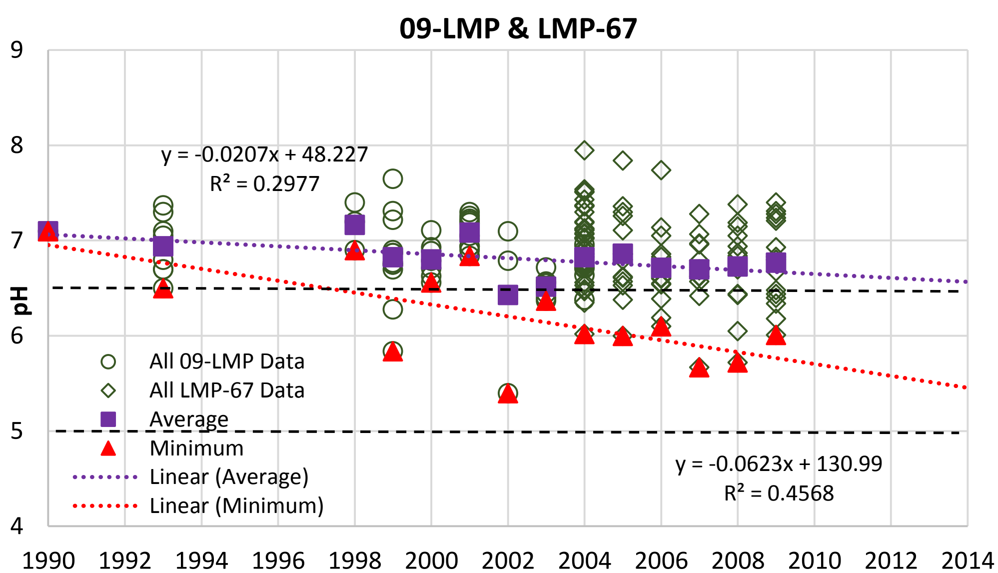

Figure E-4. Average and minimum pH at Lee Hook Road in Lee (09-LMP & LMP-67). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). Significant changes were found in both the average and minimum pH.

Lamprey main stem

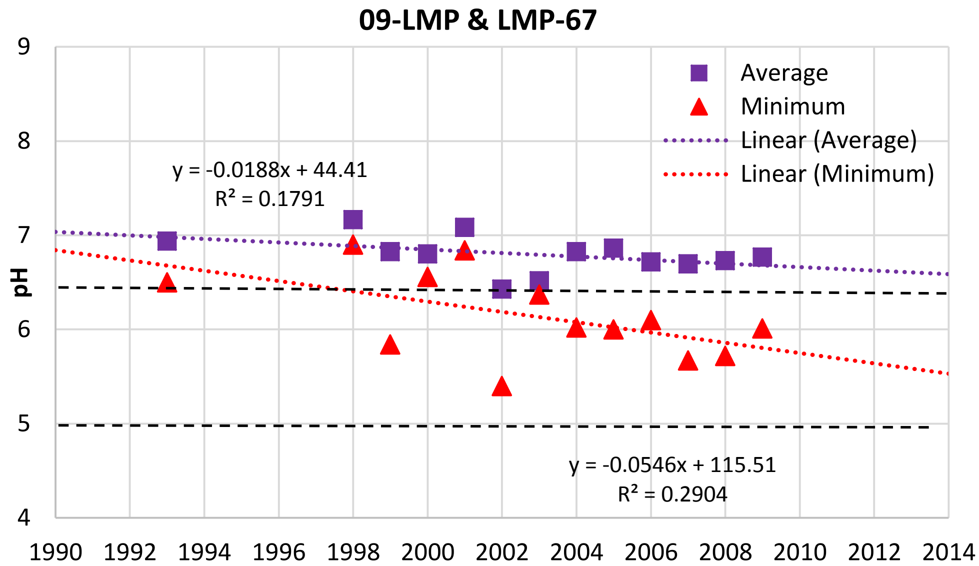

Figure E-5. Average and minimum pH at Lee Hook Road in Lee (09-LMP & LMP-67) with isolated sampling years removed. The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). A significant change was found in only the minimum pH.

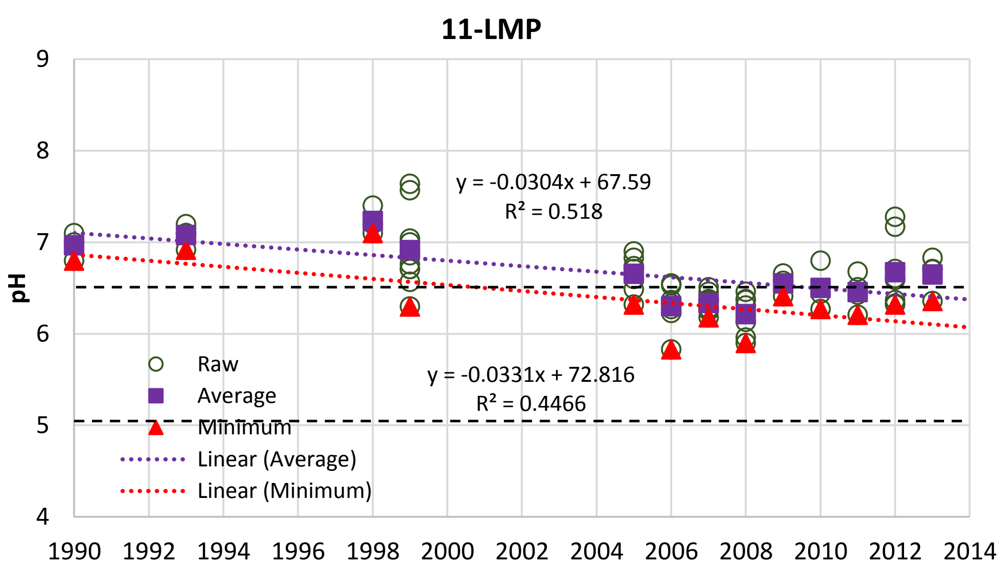

Figure E-6. Average and minimum pH at Wadleigh Falls along Route 152 in Lee (11-LMP). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). Significant changes were found in both the average and minimum pH.

Lamprey main stem

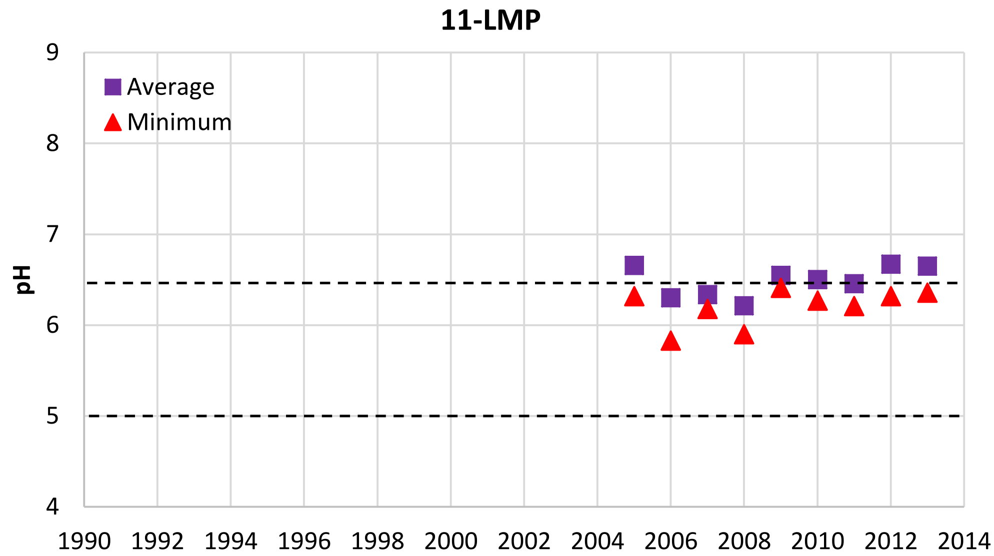

Figure E-7. Average and minimum pH at Wadleigh Falls along Route 152 in Lee (11-LMP) with isolated sampling years removed. The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant changes were found.

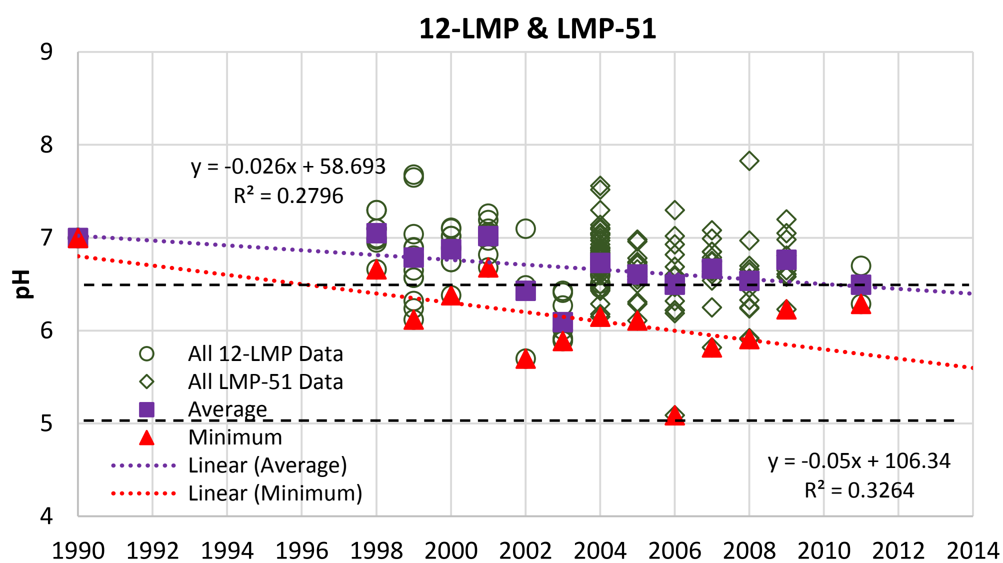

Figure E-8. Average and minimum pH at the Route 87 bridge in Epping (12-LMP & LMP-51). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). Significant changes were found in both the average and minimum pH.

Lamprey main stem

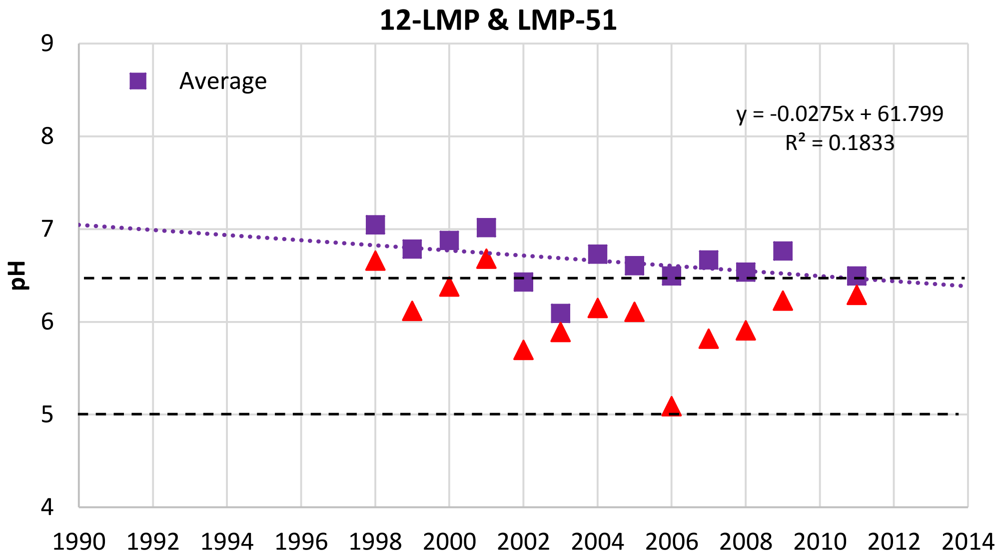

Figure E-9. Average and minimum pH at the Route 87 Bridge in Epping (12-LMP & LMP-51) with isolated sampling years removed. The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). A significant change was still found in the average pH.

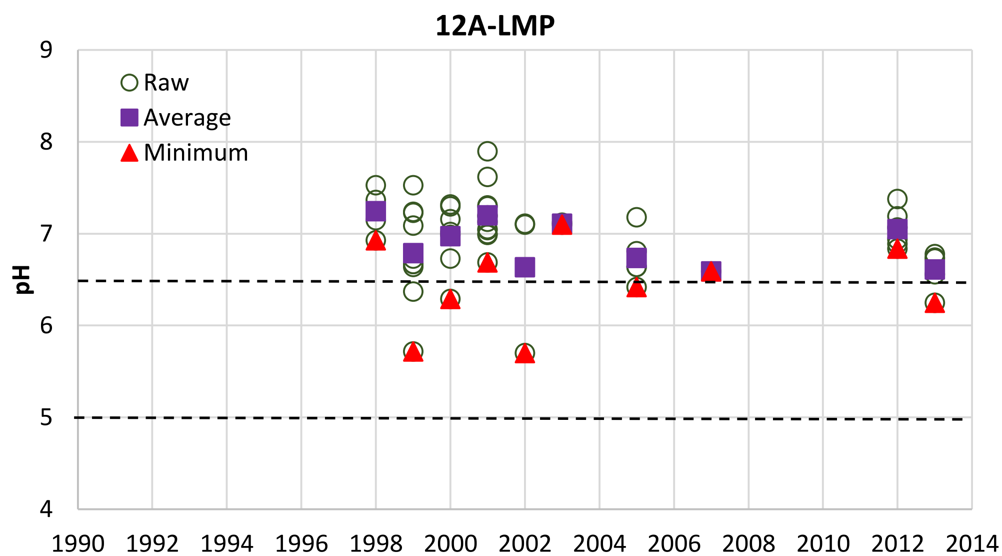

Figure E-10. Average and minimum pH from downstream of the Epping wastewater treatment facility in Epping (12A-LMP). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant changes were found.

Lamprey main stem

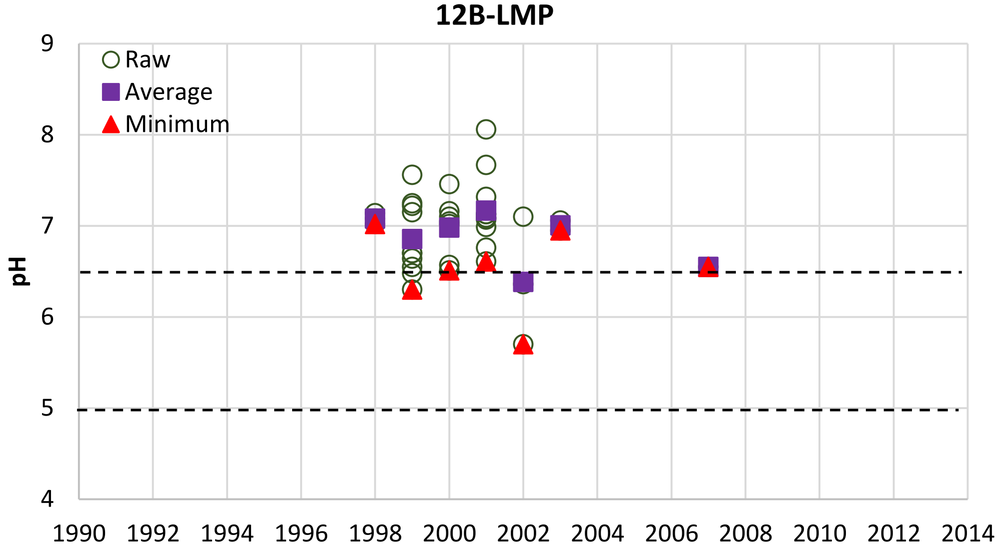

Figure E-11. Average and minimum pH from upstream of the Epping wastewater treatment facility in Epping (12B-LMP). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant changes were found.

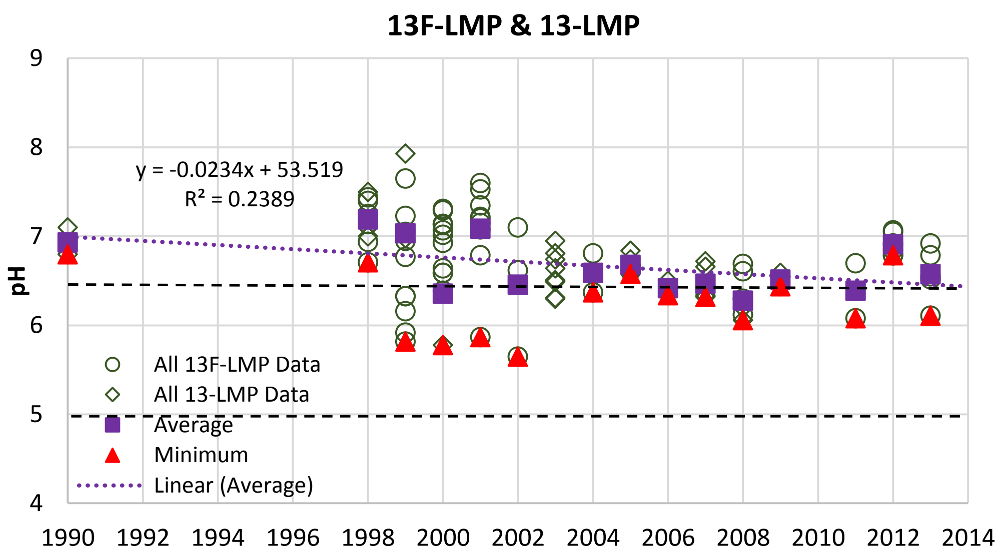

Figure E-12. Average and minimum pH at the Mill street Bridge in Epping (13F-LMP & 13-LMP). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). A significant change was found in the average pH.

Lamprey main stem

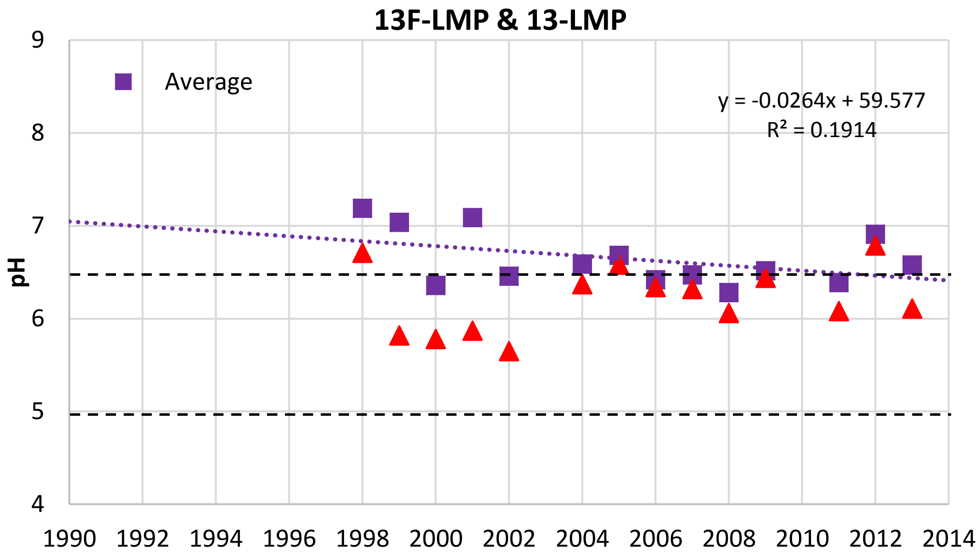

Figure E-13. Average and minimum pH at the Mill street bridge in Epping (13F-LMP & 13-LMP) with isolated sampling years removed. The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant changes were found.

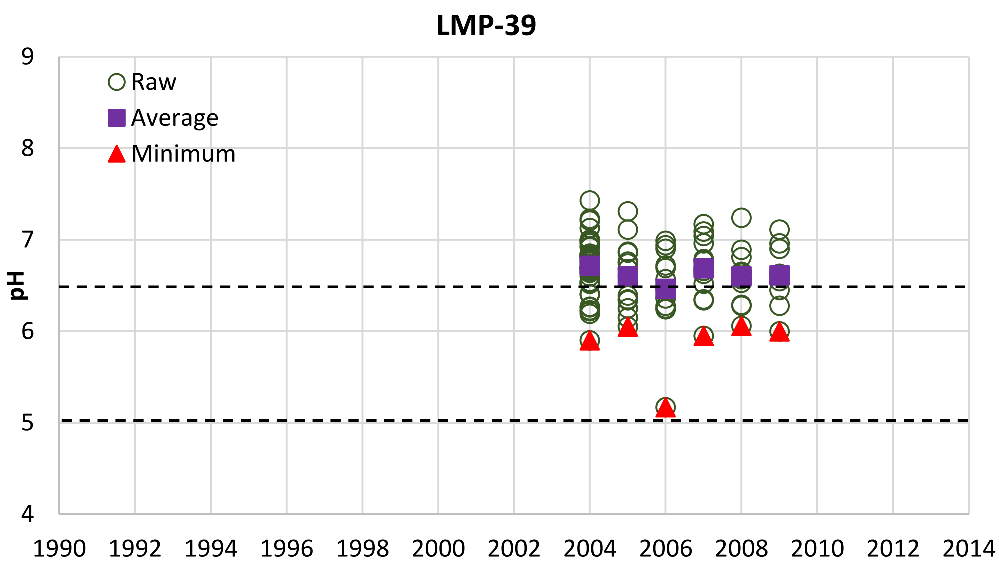

Figure E-14. Average and minimum pH at Lamprey Lane in Epping (LMP-39). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant changes were found.

Lamprey main stem

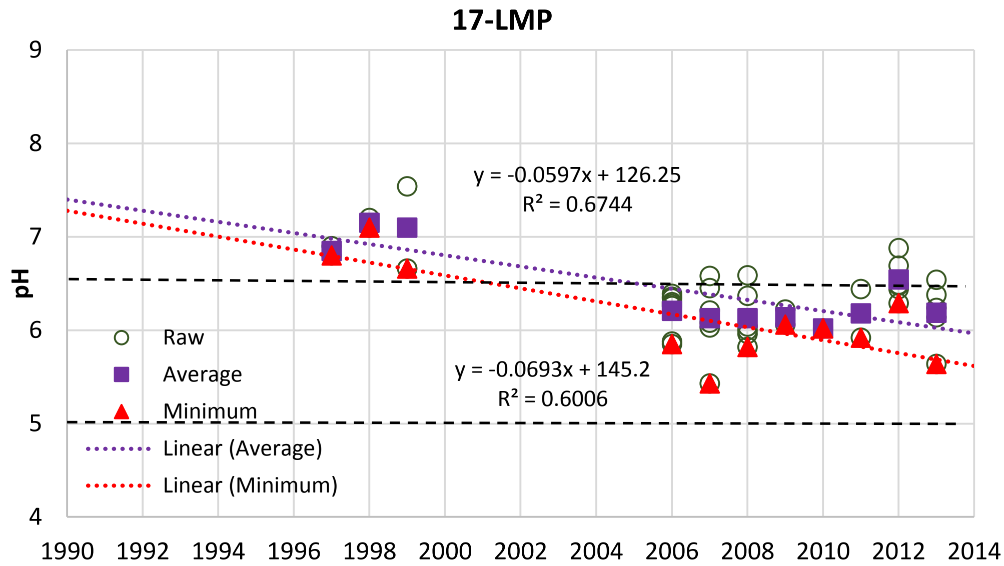

Figure E-15. Average and minimum pH at the Prescott Road bridge in Raymond (17-LMP). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). A significant change was found in both the average and minimum pH.

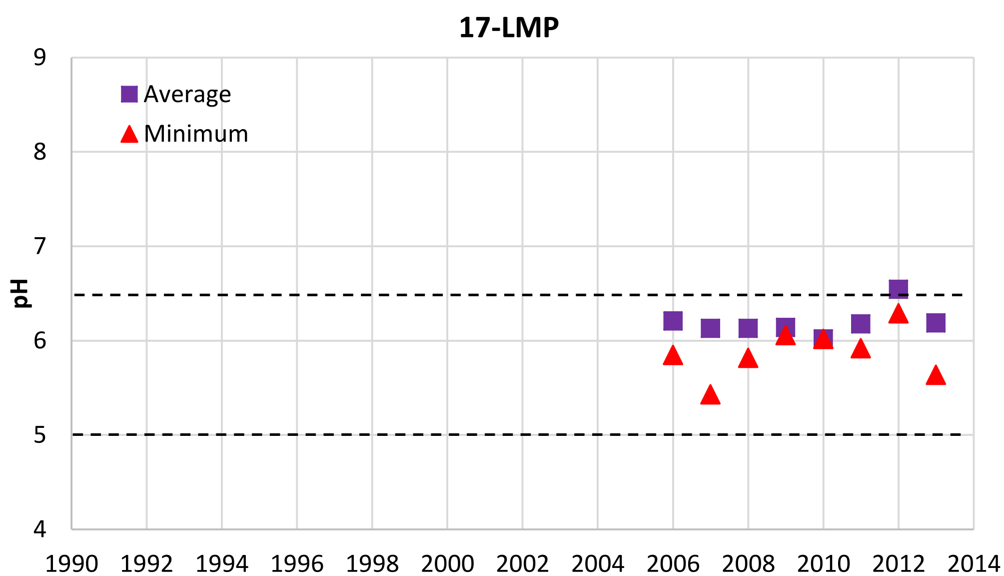

Figure E-16. Average and minimum pH at the Prescott Road bridge in Raymond (17-LMP) with isolated sampling years removed. The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant changes were found.

Lamprey main stem

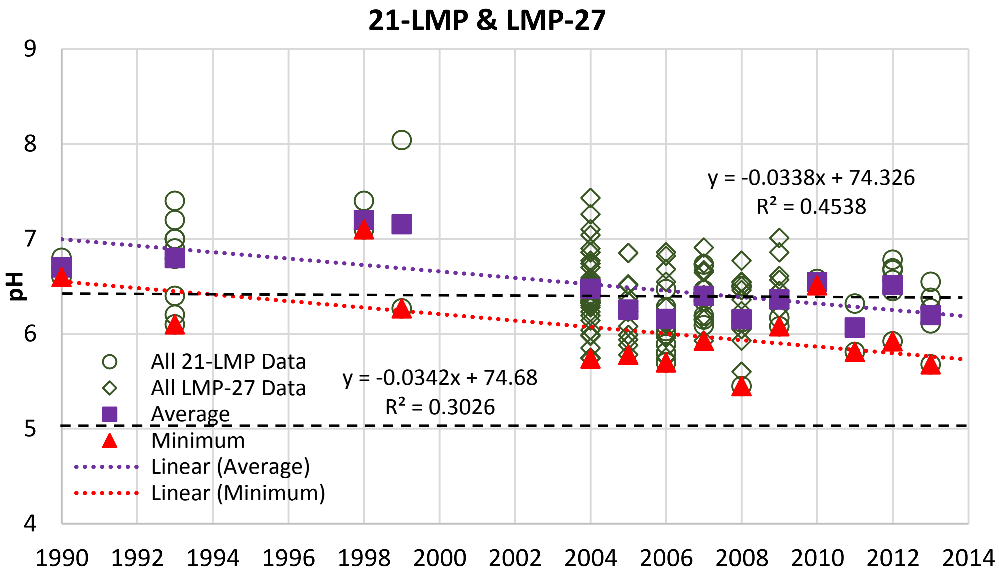

Figure E-17. Average and minimum pH at Langford Road in Raymond (21-LMP & LMP-27). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). A significant change was found in both the average and minimum pH.

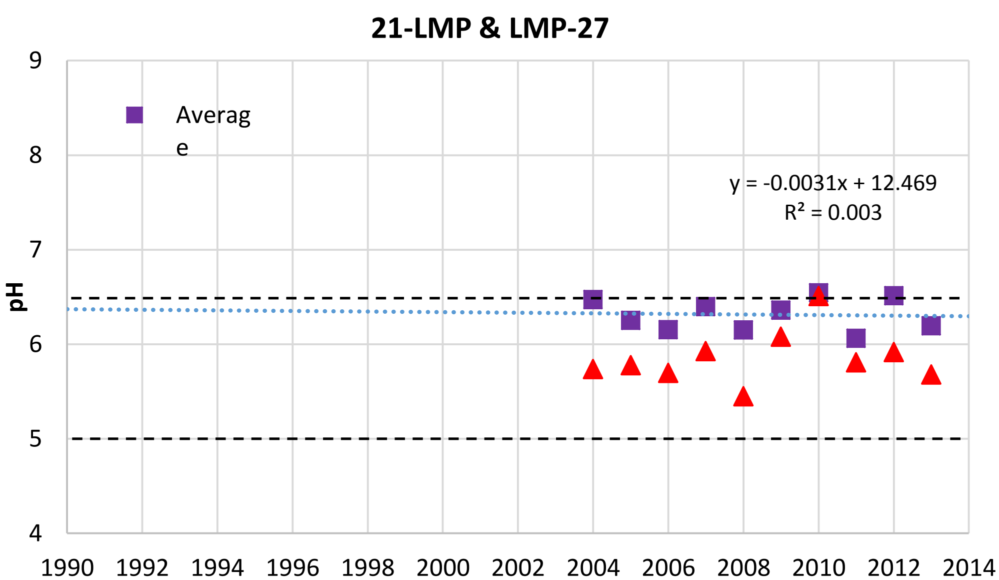

Figure E-18. Average and minimum pH at Langford Road in Raymond (21-LMP & LMP-27) with isolated sampling years removed. The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant changes were found.

Lamprey main stem

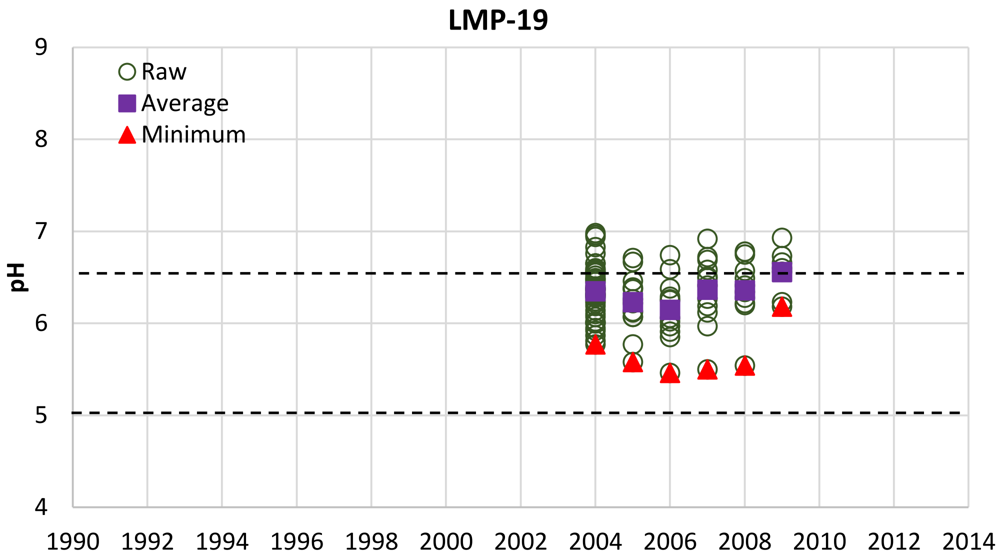

Figure E-19. Average and minimum pH at Cotton Road in Deerfield (LMP-19). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant changes were found.

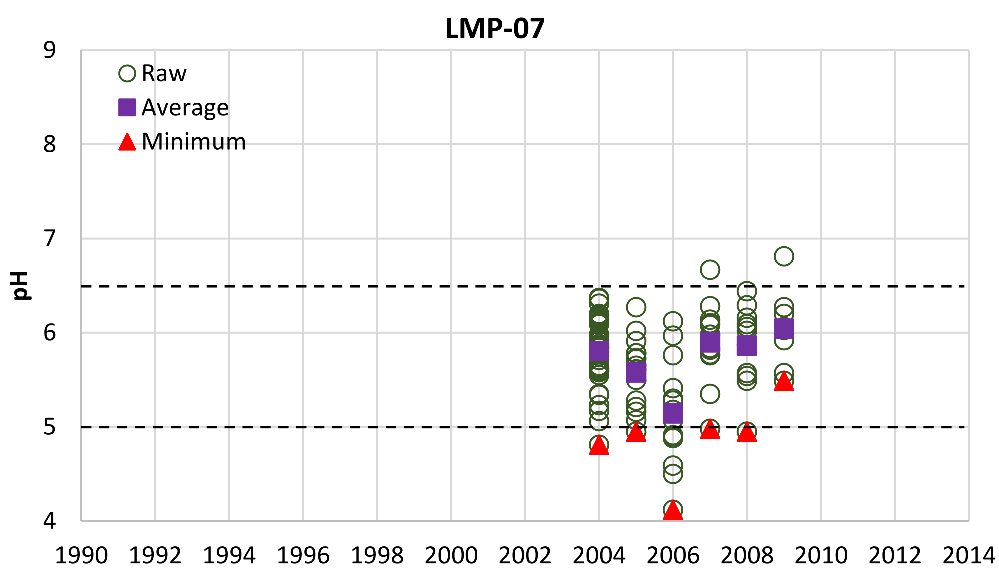

Figure E-20. Average and minimum pH at Blakes Hill Road in Deerfield (LMP-07). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant changes were found.

North River

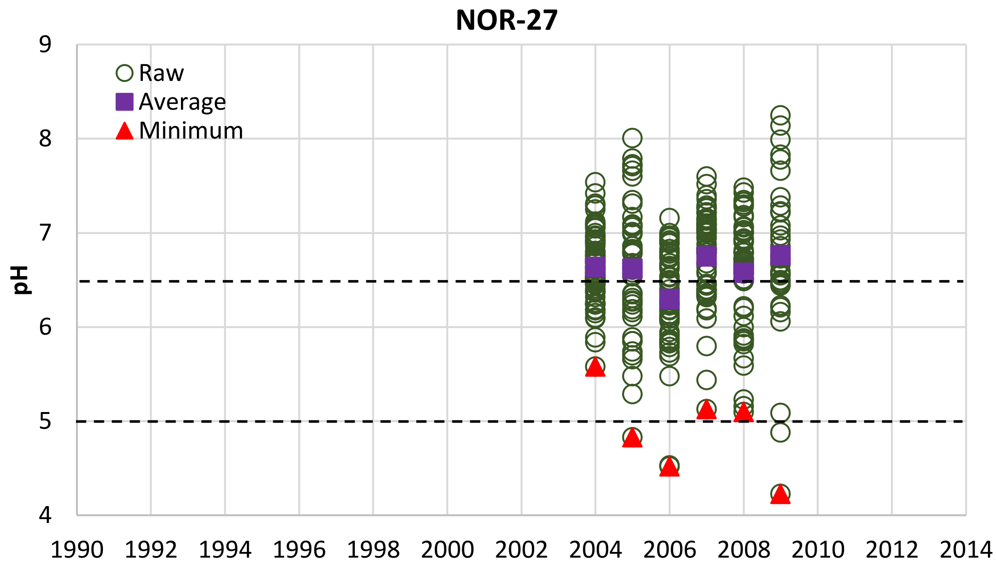

Figure E-21. Average and minimum pH at Route 125 in Epping (NOR-27). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant changes were found.

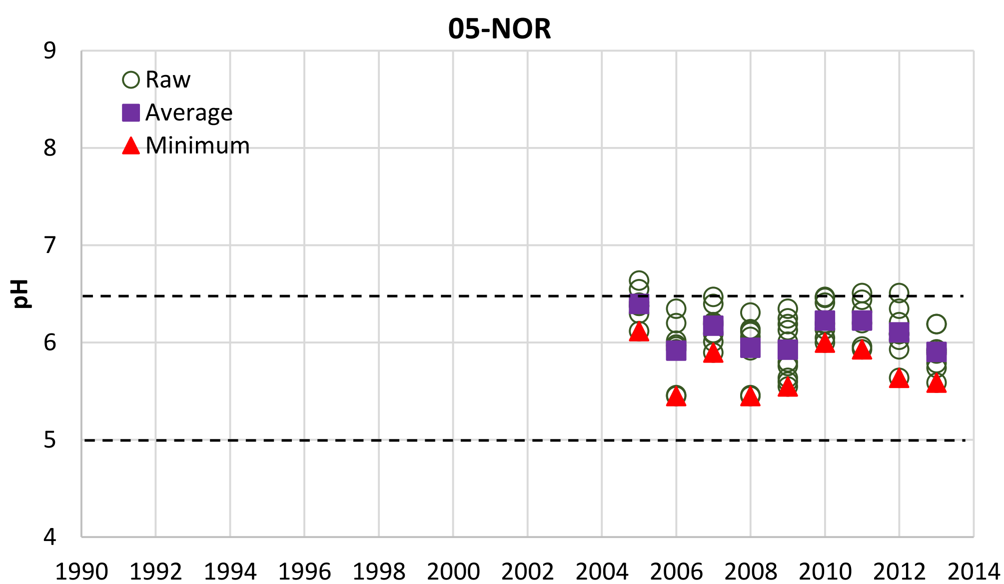

Figure E-22. Average and minimum pH at the McCrillis Road bridge in Epping (05-NOR). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant changes were found.

North River

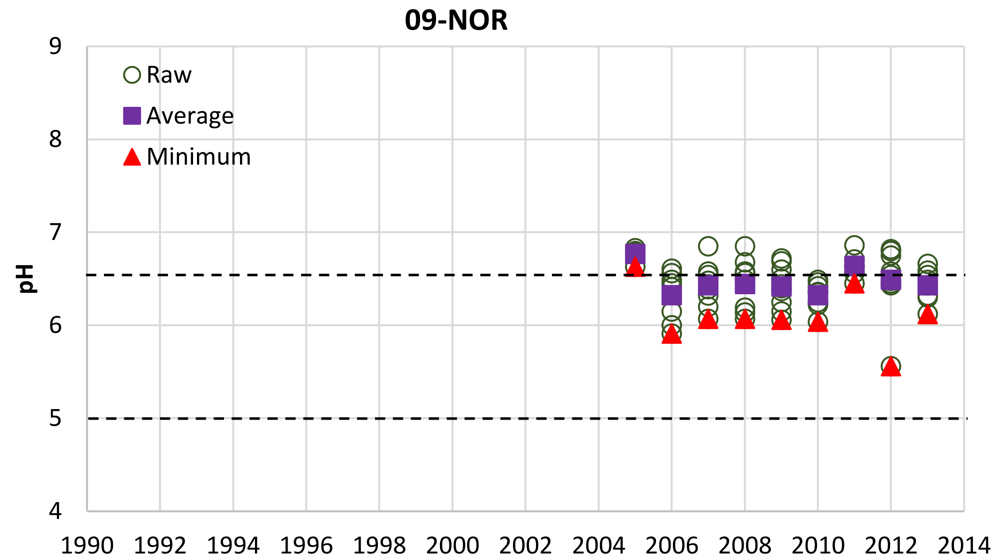

Figure E-23. Average and minimum pH at the Freeman Hall Road bridge in Nottingham (09-NOR). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant changes were found.

Little River

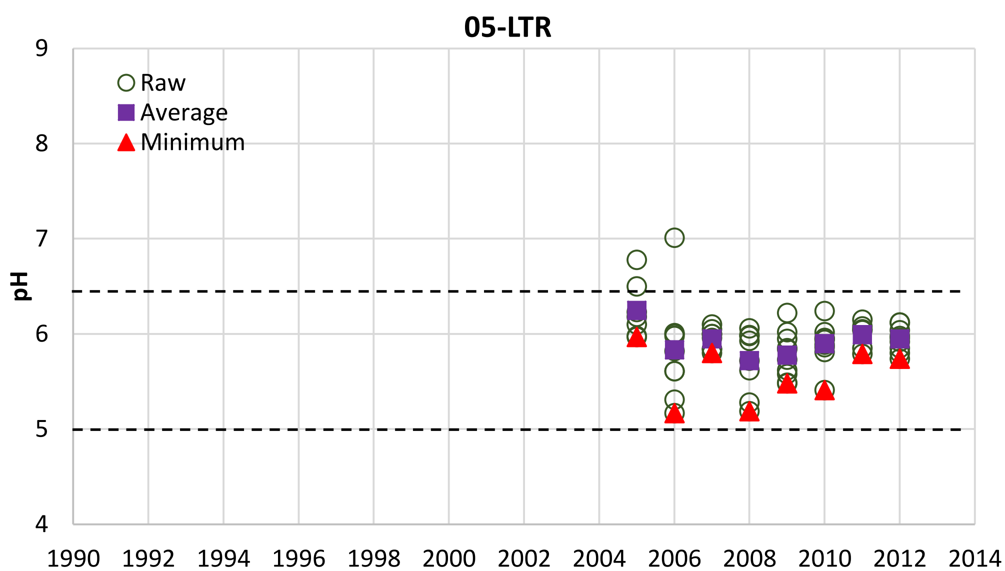

Figure E-24. Average and minimum pH at the Smoke street bridge in Nottingham (05-LTR). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). No significant changes were found.

North Branch

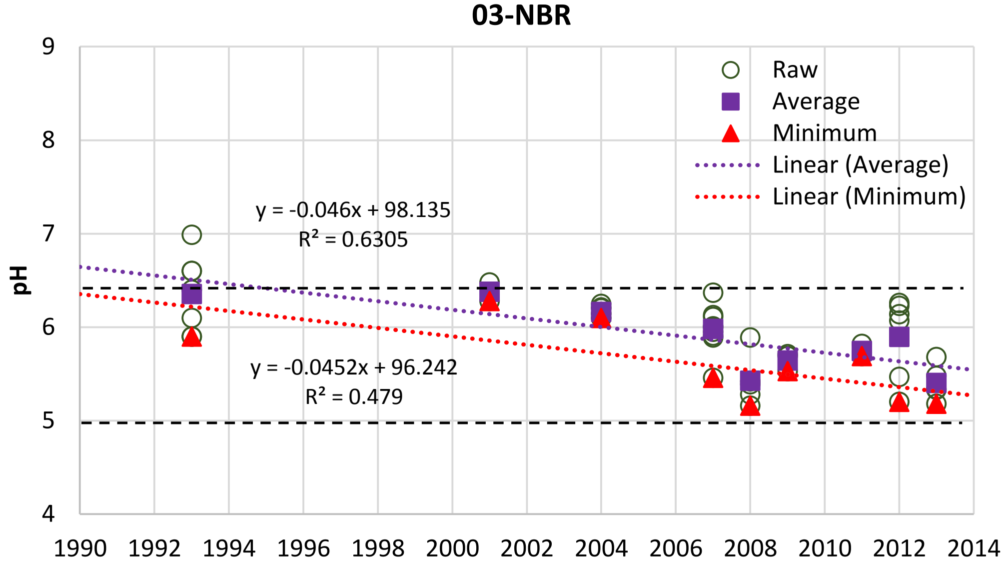

Figure E-25. Average and minimum pH at New Boston Road in Candia (03-NBR). The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). A significant change was found in both the average and minimum pH.

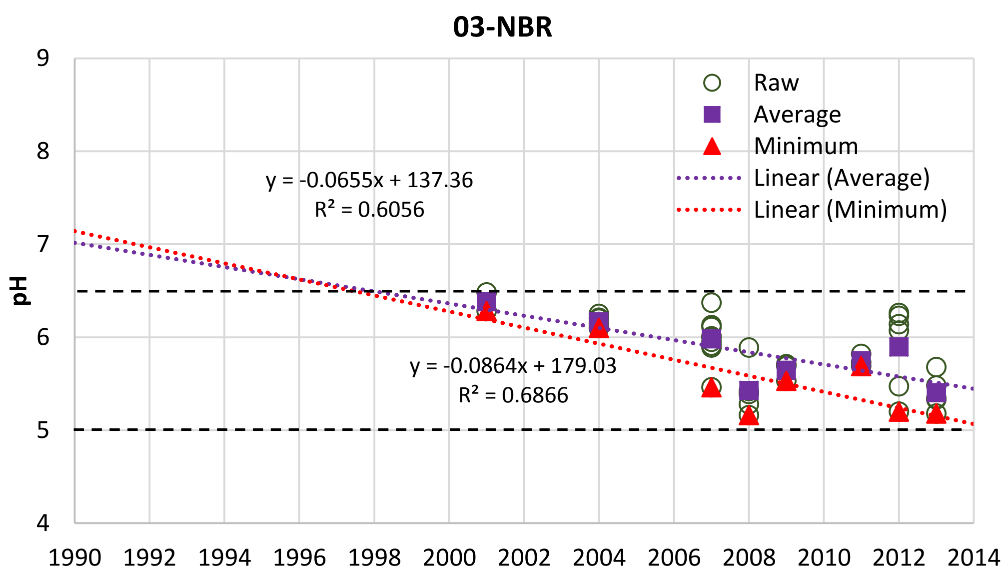

Figure E-26. Average and minimum pH at New Boston Road in Candia (03-NBR) with isolated sampling years removed. The horizontal dashed lines represent the NHDES pH standards of 5 (below which is a high impact on water quality) and 6.5 (above which is considered normal). A significant change was still found in both the average and minimum

Appendix F – NO_3^- Time Series

Lamprey main stem

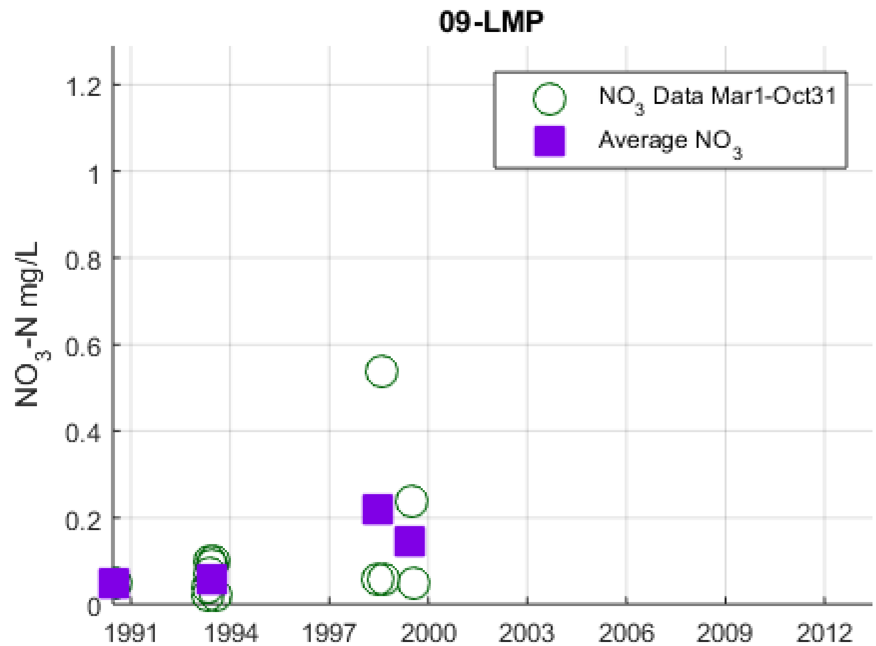

Figure F-1. Summertime average NO_3^- concentrations at Lee Hook Road in Lee (09-LMP). No significant change was found.

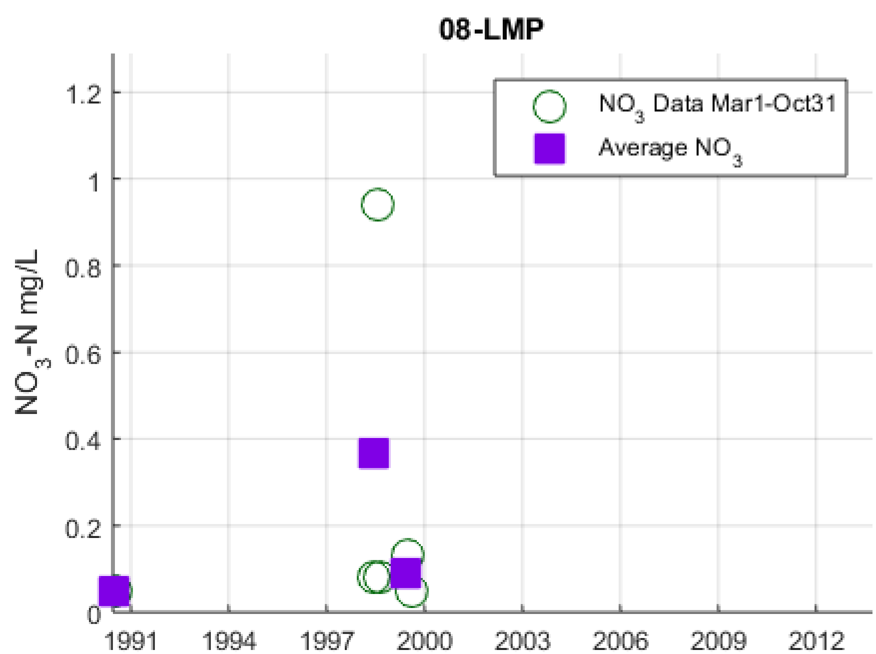

Figure F-2. Summertime average NO_3^- concentrations at the Wiswall Road Bridge in Durham (08-LMP). No significant change was found.

Lamprey main stem

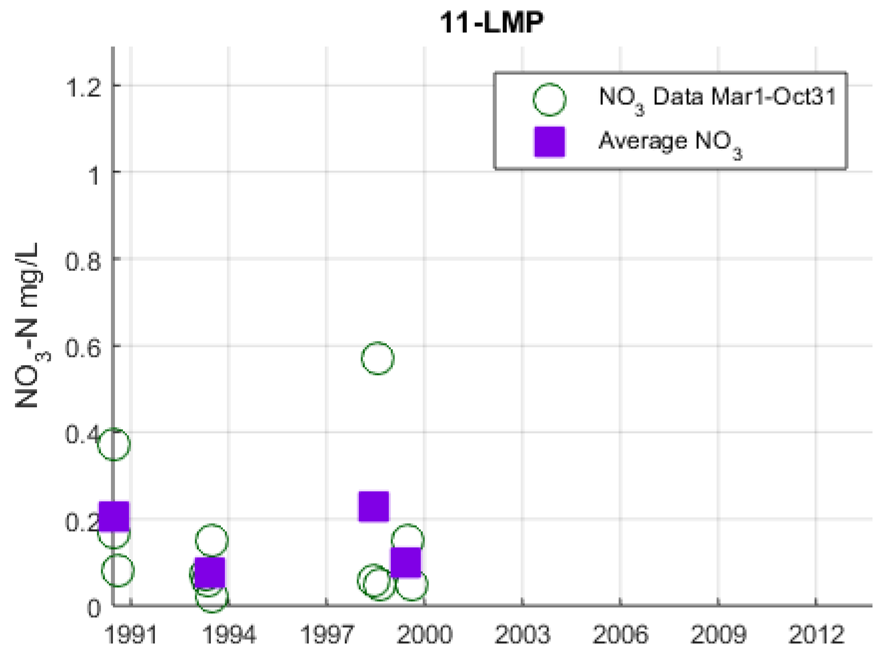

Figure F-3. Summertime average NO_3^- concentrations at Route152 at Wadleigh Falls in Lee (11-LMP). No significant change was found.

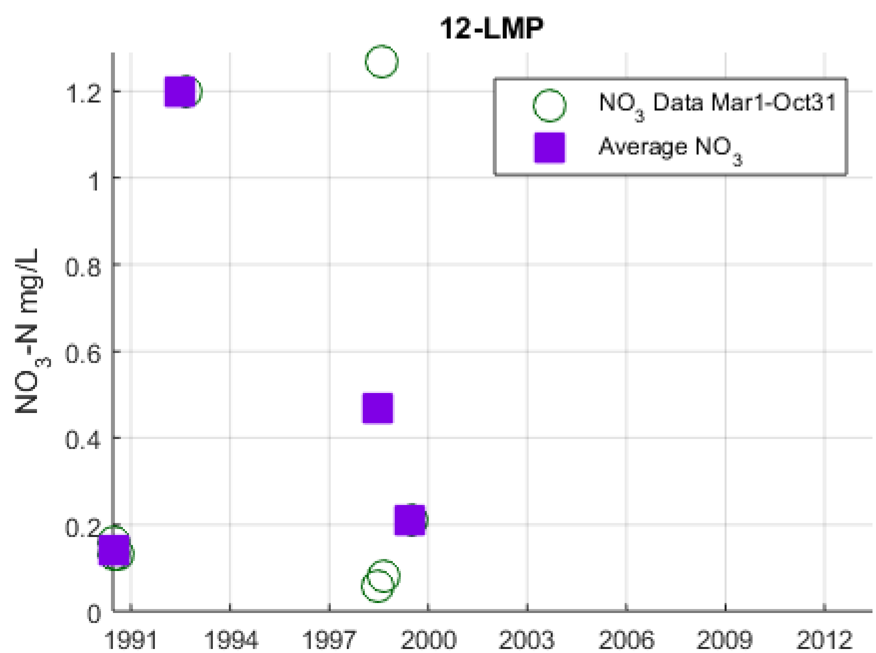

Figure F-4. Summertime average NO_3^- concentrations at the Route 87 bridge in Epping (12-LMP). No significant change was found.

Lamprey main stem

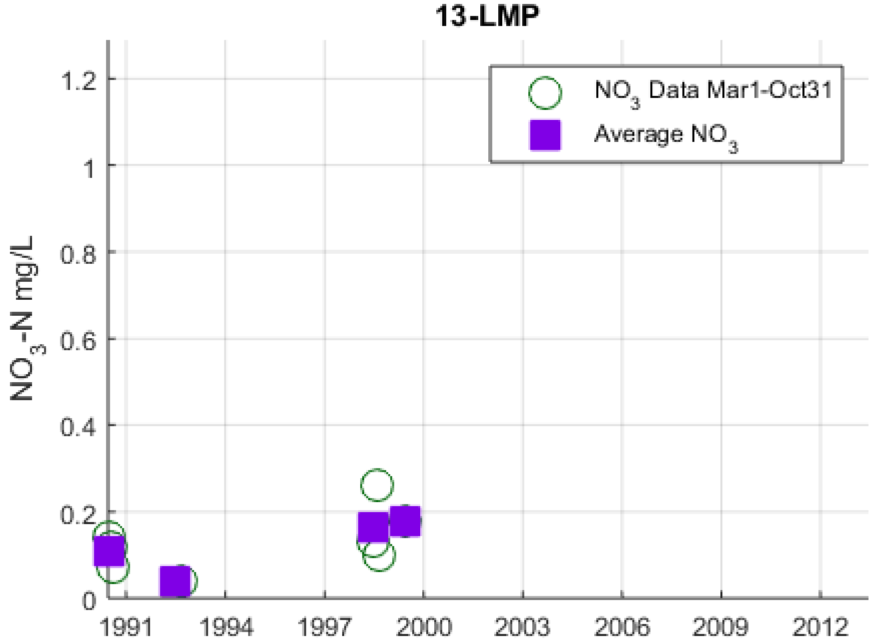

Figure F-5. Summertime Average NO_3^- concentrations at the Mill Street bridge in Epping (13-LMP). No significant change was found.

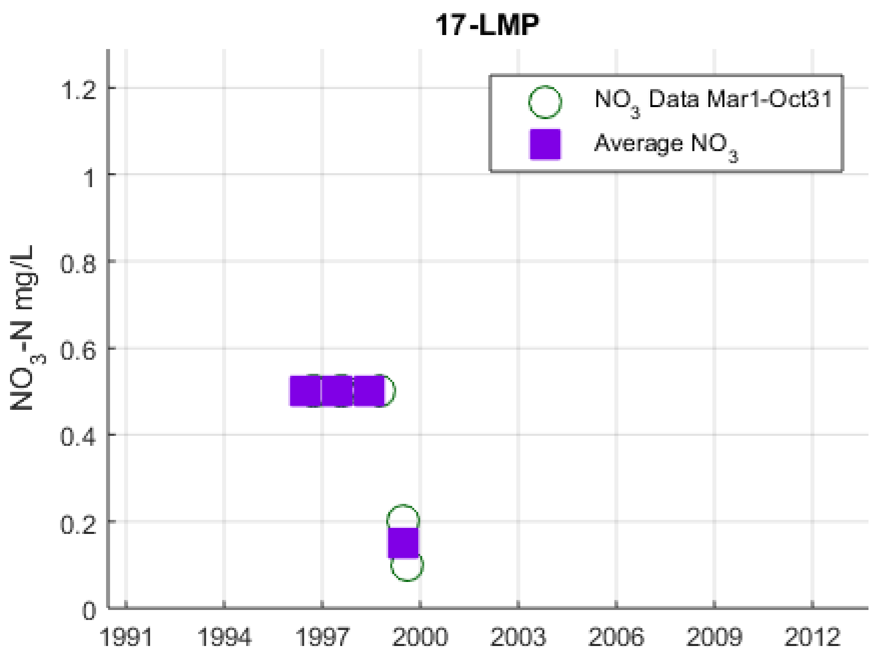

Figure F-6. Summertime average NO_3^- concentrations at Prescott Road bridge in Epping (17-LMP). No significant change was found.

Lamprey main stem

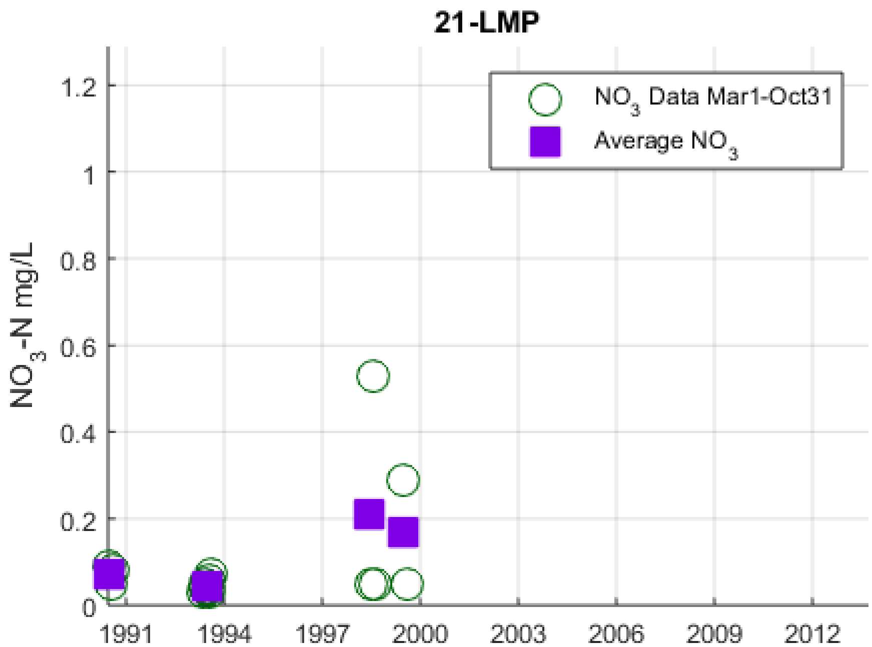

Figure F-7. Summertime average NO_3^- concentrations at the Langford Road bridge in Raymond (21-LMP). No significant change was found.

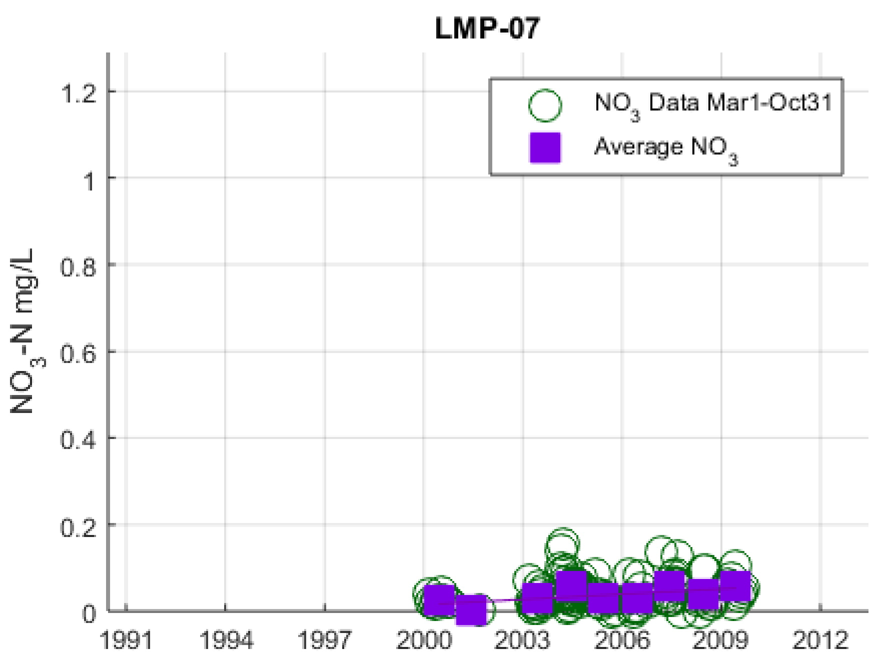

Figure F-8. Summertime average NO_3^- concentrations at Blakes Hill Road in Deerfield (LMP-07). A significant increase was found in the annual average NO_3^-.

Lamprey main stem

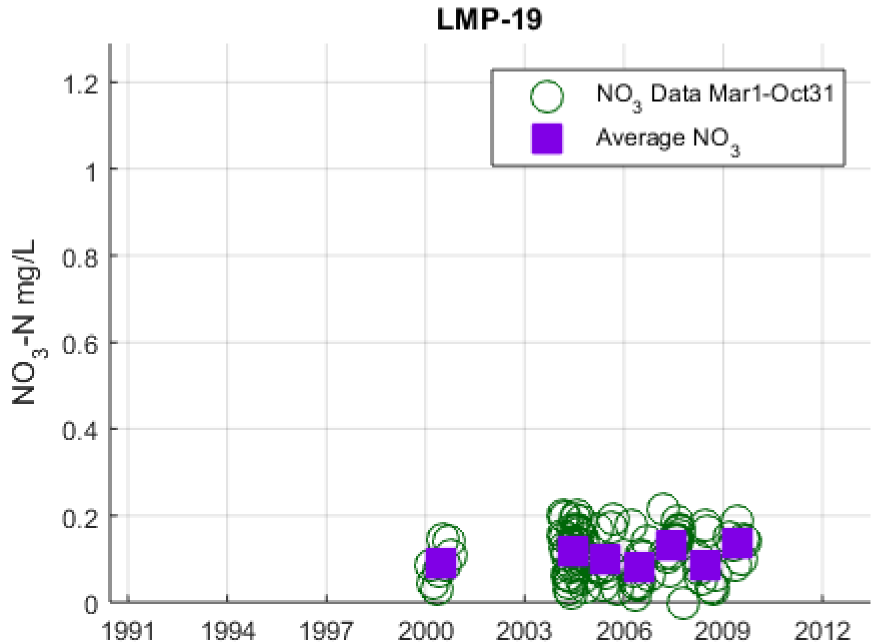

Figure F-9. Summertime average NO_3^- concentrations at Cotton Road in Deerfield (LMP-19). No significant change was found.

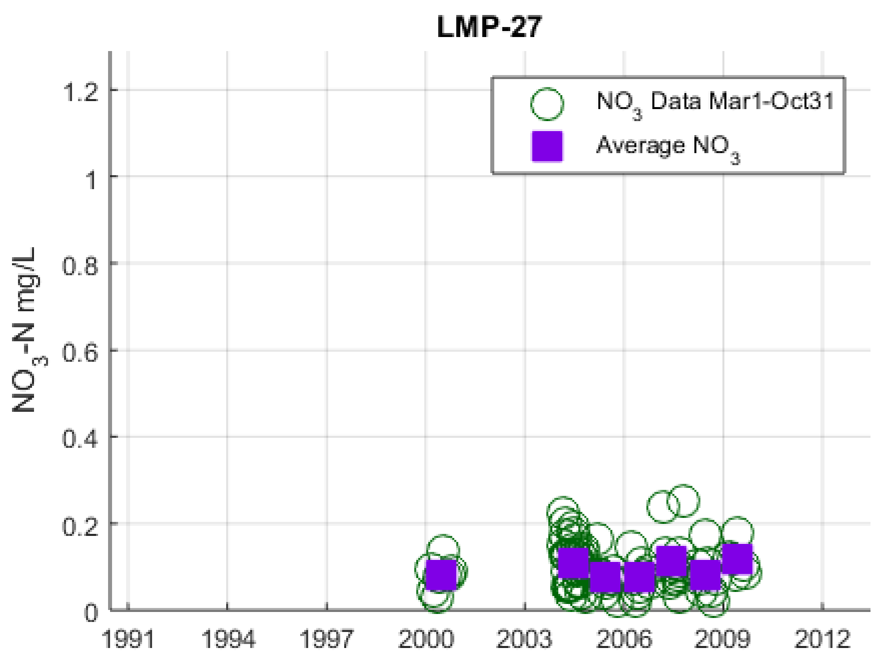

Figure F-10. Summertime average NO_3^- concentrations at Langford Road in Raymond (LMP-27). No significant change was found.

Lamprey main stem

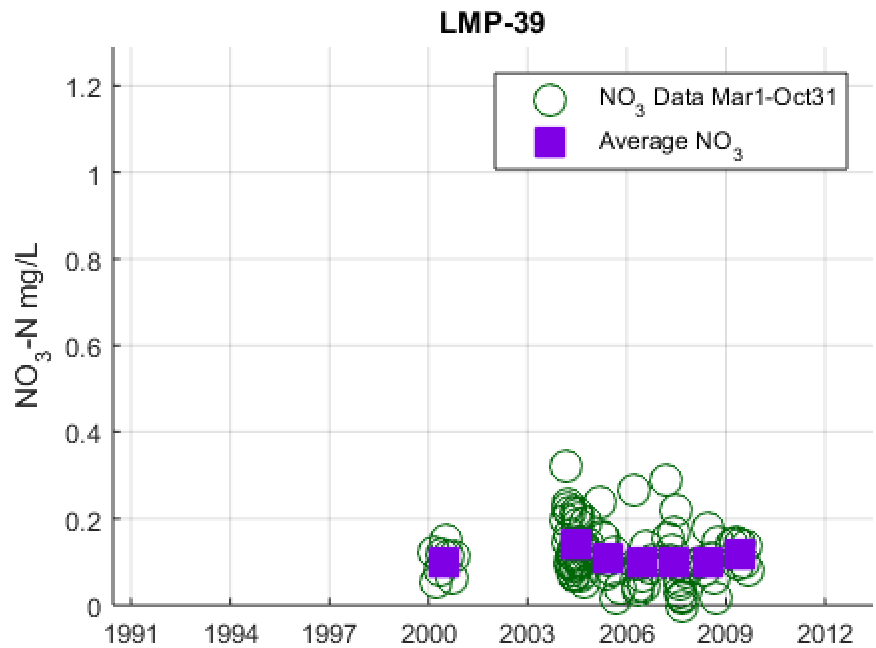

Figure F-11. Summertime average NO_3^- concentrations at Lamprey Lane in Epping (LMP-39). No significant change was found.

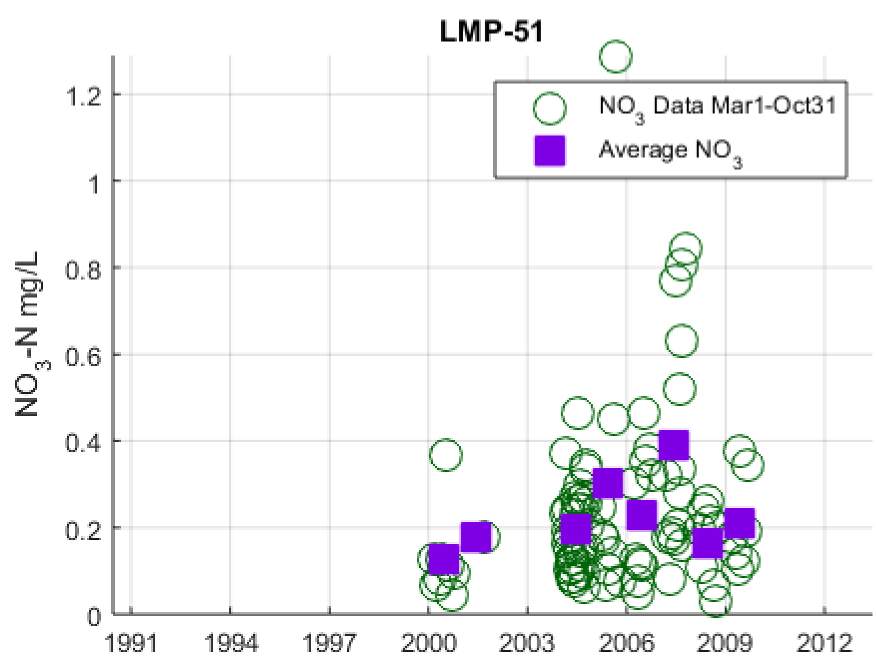

Figure F-12. Summertime average NO_3^- concentrations at the Route 87 bridge in Epping (LMP-51). No significant change was found.

Lamprey main stem

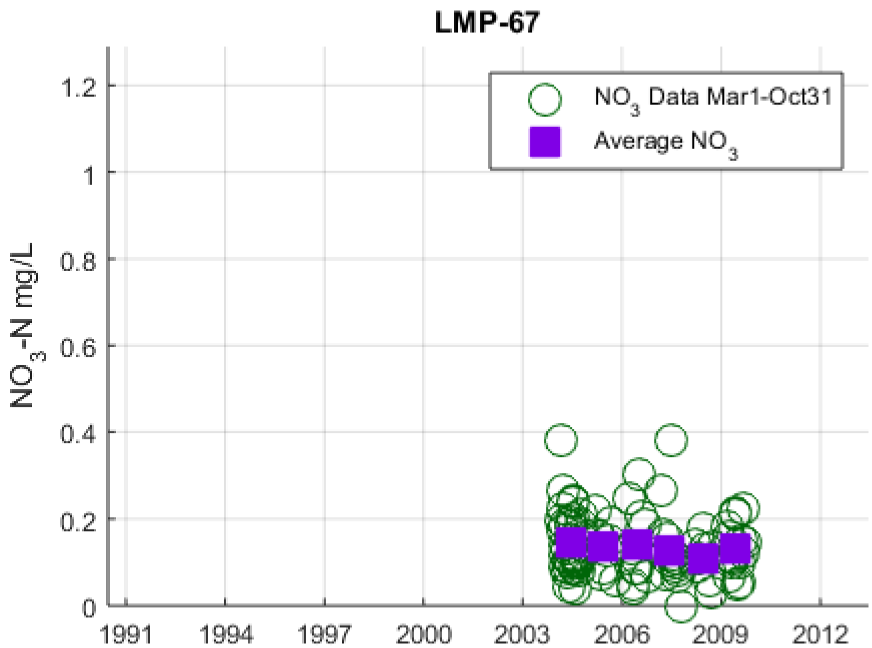

Figure F-13. Summertime average NO_3^- concentrations at Lee Hook Road in Lee (LMP-67). No significant change was found.

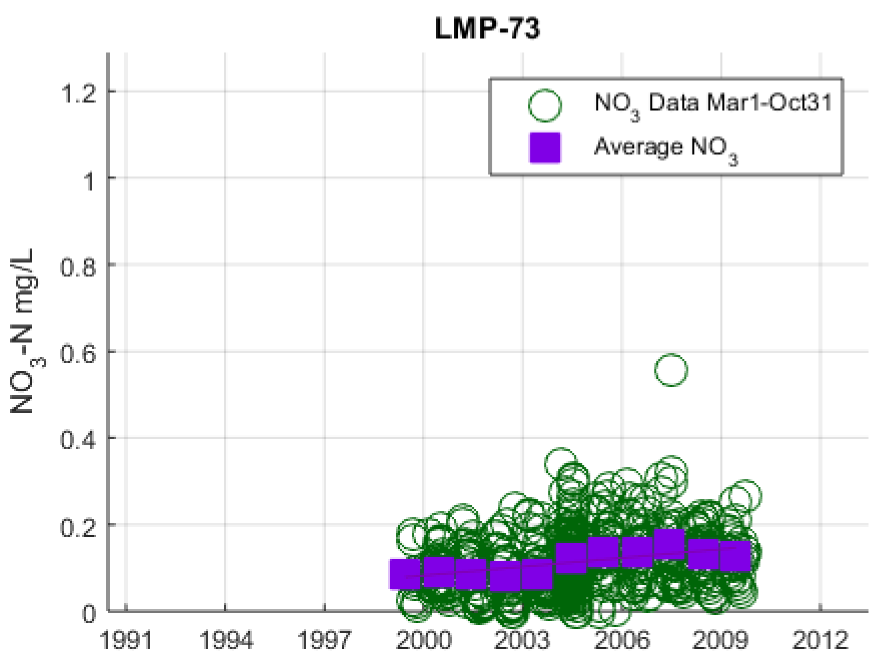

Figure F-14. Summertime average NO_3^- concentrations at Packers Falls Road in Durham (LMP-73). A significant increase was found in the annual average NO_3^-.

North River

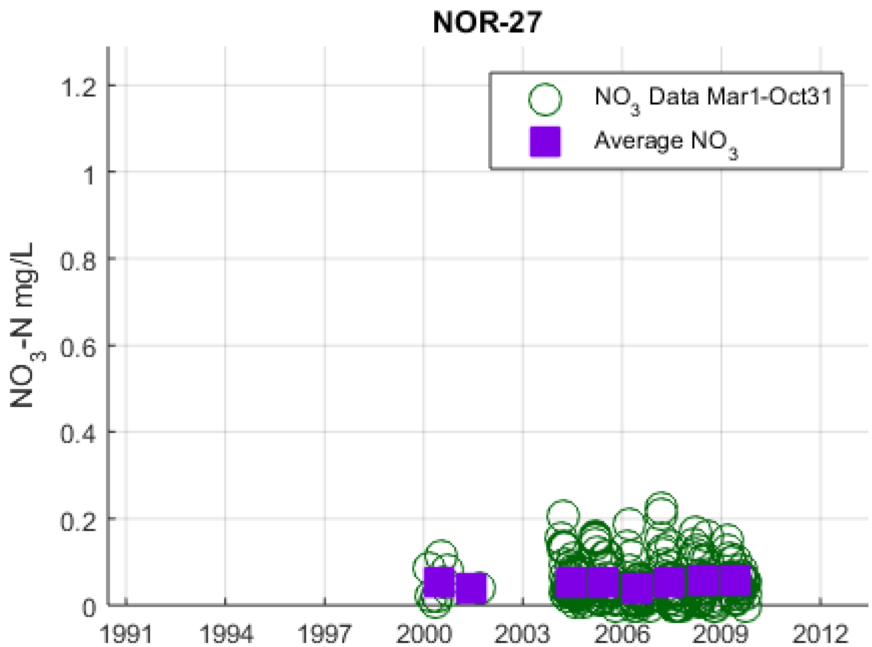

Figure F-15. Summertime average NO_3^- concentrations at Route 125 in Epping (NOR-27). No significant change was found.

Appendix G – Discharge Correlations

DO - Winter		Q1		Q7 Average		Q7 Median		Q7 Maximum	
Site ID	N	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log
03-NBR	-	-	-	-	-	-	-	-	-
05-LTR	-	-	-	-	-	-	-	-	-
05-NOR	-	-	-	-	-	-	-	-	-
08-LMP	-	-	-	-	-	-	-	-	-
09-LMP	-	-	-	-	-	-	-	-	-
09-NOR	-	-	-	-	-	-	-	-	-
11-LMP	-	-	-	-	-	-	-	-	-
12-LMP	-	-	-	-	-	-	-	-	-
12A-LMP	-	-	-	-	-	-	-	-	-
12B-LMP	-	-	-	-	-	-	-	-	-
13-LMP	-	-	-	-	-	-	-	-	-
13F-LMP	-	-	-	-	-	-	-	-	-
17-LMP	-	-	-	-	-	-	-	-	-
21-LMP	-	-	-	-	-	-	-	-	-
GBCW-14	-	-	-	-	-	-	-	-	-
LMP-07	29	0.179	0.262	0.322	0.318	0.350	0.313	0.269	0.290
LMP-19	29	0.210	0.356	0.372	0.403	0.406	0.404	0.313	0.376
LMP-27	29	0.233	0.374	0.356	0.404	0.380	0.398	0.304	0.367
LMP-39	29	0.257	0.382	0.424	0.438	0.460	0.439	0.342	0.391
LMP-51	27	0.237	0.355	0.432	0.460	0.460	0.455	0.358	0.427
LMP-67	31	0.267	0.461	0.383	0.477	0.399	0.467	0.354	0.467
LMP-73	89	0.097	0.180	0.178	0.244	0.177	0.239	0.157	0.217
NOR-27	75	0.155	0.265	0.214	0.279	0.234	0.287	0.187	0.257

Table G-1. For the winter season (1/1-3/31), the number of years of data (N), the linear correlation coefficient for untransformed and log-transformed DO concentration and daily average discharge on the day of the measurement (Q1), and the seven day average (Q7 Average), median (Q7 Median), and maximum (Q7 Maximum) discharge leading up to the day of the measurement.

DO - Spring		Q1		Q7 Average		Q7 Median		Q7 Maximum	
Site ID	N	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log
03-NBR	16	0.464	0.488	0.383	0.433	0.374	0.413	0.301	0.395
05-LTR	19	0.428	0.538	0.441	0.483	0.433	0.482	0.444	0.459
05-NOR	21	0.489	0.458	0.537	0.496	0.526	0.495	0.575	0.500
08-LMP	23	0.558	0.315	0.428	0.280	0.445	0.272	0.447	0.310
09-LMP	14	0.089	0.002	0.027	-0.059	0.033	-0.043	0.016	-0.078
09-NOR	21	0.489	0.495	0.481	0.491	0.501	0.514	0.504	0.486
11-LMP	21	0.444	0.321	0.314	0.308	0.344	0.322	0.292	0.301
12-LMP	13	0.317	0.548	0.224	0.484	0.214	0.464	0.218	0.471
12A-LMP	10	0.619	0.711	0.665	0.726	0.665	0.719	0.627	0.699
12B-LMP	4	0.860	0.819	0.914	0.796	0.925	0.798	0.766	0.753
13-LMP	9	0.549	0.497	0.306	0.453	0.315	0.457	0.228	0.431
13F-LMP	10	0.315	0.730	0.214	0.668	0.180	0.625	0.234	0.677
17-LMP	9	0.255	0.209	0.222	0.237	0.211	0.261	0.211	0.212
21-LMP	17	-0.036	0.078	-0.141	0.066	-0.110	0.088	-0.188	0.022
GBCW-14	76	0.433	0.413	0.449	0.349	0.371	0.321	0.430	0.357
LMP-07	32	0.112	0.338	0.270	0.437	0.407	0.514	0.220	0.413
LMP-19	30	0.186	0.472	0.298	0.514	0.393	0.545	0.256	0.492
LMP-27	29	0.555	0.529	0.349	0.486	0.256	0.413	0.371	0.500
LMP-39	32	0.255	0.437	0.252	0.373	0.266	0.348	0.242	0.371
LMP-51	32	0.253	0.467	0.266	0.424	0.249	0.413	0.227	0.395
LMP-67	36	0.448	0.610	0.432	0.546	0.300	0.443	0.432	0.564
LMP-73	114	0.339	0.573	0.393	0.539	0.376	0.511	0.305	0.513
NOR-27	80	0.211	0.345	0.185	0.253	0.190	0.223	0.123	0.230

Table G-2. For the spring season (4/1 – 6/30), the number of years of data (N), the linear correlation coefficient for untransformed and log-transformed DO concentration and daily average discharge on the day of the measurement (Q1), and the seven day average (Q7 Average), median (Q7 Median), and maximum (Q7 Maximum) discharge leading up to the day of the measurement.

DO - Summer		Q1		Q7 Average		Q7 Median		Q7 Maximum	
Site ID	N	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log
03-NBR	25	0.053	-0.077	0.163	-0.024	0.188	0.048	0.179	-0.058
05-LTR	35	-0.412	-0.369	-0.419	-0.357	-0.396	-0.351	-0.377	-0.356
05-NOR	39	-0.569	-0.476	-0.546	-0.453	-0.509	-0.448	-0.528	-0.451
08-LMP	72	0.150	0.394	0.239	0.372	0.231	0.362	0.196	0.366
09-LMP	39	0.487	0.582	0.500	0.564	0.392	0.523	0.509	0.578
09-NOR	37	-0.018	0.275	0.083	0.344	0.099	0.366	0.066	0.322
11-LMP	50	0.189	0.306	0.270	0.304	0.265	0.303	0.215	0.282
12-LMP	43	0.468	0.683	0.529	0.665	0.466	0.644	0.513	0.671
12A-LMP	42	0.417	0.565	0.473	0.550	0.423	0.533	0.509	0.560
12B-LMP	29	0.472	0.630	0.575	0.621	0.531	0.613	0.536	0.631
13-LMP	26	0.108	0.034	0.219	0.037	0.188	0.018	0.217	0.053
13F-LMP	43	0.280	0.401	0.215	0.364	0.173	0.355	0.242	0.362
17-LMP	28	0.094	0.125	0.292	0.136	0.321	0.146	0.227	0.122
21-LMP	32	-0.118	-0.146	0.042	-0.108	0.061	-0.084	-0.016	-0.135
GBCW-14	79	0.030	0.194	0.034	0.207	0.032	0.223	0.016	0.171
LMP-07	29	0.606	0.552	0.603	0.472	0.417	0.330	0.642	0.516
LMP-19	28	0.321	0.345	0.406	0.382	0.339	0.320	0.413	0.409
LMP-27	27	-0.189	-0.055	-0.113	0.058	-0.040	0.133	-0.104	0.090
LMP-39	28	0.233	0.196	0.289	0.244	0.208	0.169	0.313	0.283
LMP-51	28	0.080	0.135	0.049	0.191	0.000	0.166	0.102	0.229
LMP-67	31	-0.052	-0.015	-0.058	0.009	-0.060	0.003	-0.025	0.065
LMP-73	134	0.166	0.319	0.171	0.251	0.171	0.245	0.169	0.245
NOR-27	106	0.215	0.420	0.261	0.422	0.251	0.403	0.272	0.430

Table G-3. For the summer season (6/1 – 9/30), the number of years of data (N), the linear correlation coefficient for untransformed and log-transformed DO concentration and daily average discharge on the day of the measurement (Q1), and the seven day average (Q7 Average), median (Q7 Median), and maximum (Q7 Maximum) discharge leading up to the day of the measurement.

DO - Fall		Q1		Q7 Average		Q7 Median		Q7 Maximum	
Site ID	N	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log
03-NBR	-	-	-	-	-	-	-	-	-
05-LTR	-	-	-	-	-	-	-	-	-
05-NOR	-	-	-	-	-	-	-	-	-
08-LMP	5	0.893	0.794	0.949	0.924	0.949	0.934	0.919	0.929
09-LMP	5	0.937	0.866	0.971	0.940	0.977	0.964	0.951	0.936
09-NOR	-	-	-	-	-	-	-	-	-
11-LMP	-	-	-	-	-	-	-	-	-
12-LMP	5	0.974	0.952	0.921	0.950	0.909	0.938	0.889	0.903
12A-LMP	5	0.835	0.771	0.824	0.854	0.802	0.821	0.783	0.834
12B-LMP	5	0.590	0.718	0.353	0.558	0.304	0.473	0.266	0.365
13-LMP	-	-	-	-	-	-	-	-	-
13F-LMP	6	0.843	0.717	0.892	0.838	0.869	0.801	0.914	0.942
17-LMP	3	0.879	0.841	0.886	0.891	0.913	0.923	0.880	0.859
21-LMP	-	-	-	-	-	-	-	-	-
GBCW-14	46	0.169	0.503	0.261	0.612	0.313	0.641	0.170	0.518
LMP-07	25	0.247	0.497	0.436	0.563	0.450	0.586	0.376	0.541
LMP-19	25	0.159	0.483	0.326	0.580	0.351	0.616	0.261	0.537
LMP-27	24	0.030	0.297	0.238	0.412	0.290	0.492	0.155	0.349
LMP-39	25	0.145	0.371	0.362	0.480	0.403	0.548	0.306	0.441
LMP-51	24	0.201	0.488	0.386	0.583	0.421	0.637	0.315	0.537
LMP-67	25	0.108	0.421	0.325	0.549	0.365	0.619	0.243	0.492
LMP-73	109	0.240	0.501	0.342	0.570	0.354	0.594	0.254	0.516
NOR-27	64	0.102	0.418	0.248	0.478	0.294	0.528	0.140	0.412

Table G-4. For the fall season (10/1 – 12/31), the number of years of data (N), the linear correlation coefficient for untransformed and log-transformed DO concentration and daily average discharge on the day of the measurement (Q1), and the seven day average (Q7 Average), median (Q7 Median), and maximum (Q7 Maximum) discharge leading up to the day of the measurement.

pH - Winter		Q1		Q7 Average		Q7 Median		Q7 Maximum	
Site ID	N	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log
03-NBR	-	-	-	-	-	-	-	-	-
05-LTR	-	-	-	-	-	-	-	-	-
05-NOR	-	-	-	-	-	-	-	-	-
08-LMP	-	-	-	-	-	-	-	-	-
09-LMP	-	-	-	-	-	-	-	-	-
09-NOR	-	-	-	-	-	-	-	-	-
11-LMP	-	-	-	-	-	-	-	-	-
12-LMP	-	-	-	-	-	-	-	-	-
12A-LMP	-	-	-	-	-	-	-	-	-
12B-LMP	-	-	-	-	-	-	-	-	-
13-LMP	-	-	-	-	-	-	-	-	-
13F-LMP	-	-	-	-	-	-	-	-	-
17-LMP	-	-	-	-	-	-	-	-	-
21-LMP	-	-	-	-	-	-	-	-	-
GBCW-14	-	-	-	-	-	-	-	-	-
LMP-07	25	-0.554	-0.803	-0.568	-0.784	-0.507	-0.760	-0.634	-0.788
LMP-19	24	-0.645	-0.738	-0.631	-0.727	-0.584	-0.706	-0.694	-0.715
LMP-27	24	-0.555	-0.769	-0.577	-0.701	-0.530	-0.677	-0.603	-0.714
LMP-39	25	-0.428	-0.819	-0.417	-0.817	-0.390	-0.820	-0.399	-0.778
LMP-51	24	-0.337	-0.695	-0.447	-0.718	-0.413	-0.717	-0.438	-0.678
LMP-67	25	-0.284	-0.693	-0.365	-0.774	-0.347	-0.770	-0.305	-0.734
LMP-73	80	-0.307	-	-0.404	-	-0.389	-	-0.386	-
NOR-27	72	-0.364	-	-0.365	-	-0.352	-	-0.371	-

Table G-5. For the winter season (1/1 – 3/31), the number of years of data (N), the linear correlation coefficient for untransformed and log-transformed pH and daily average discharge on the day of the measurement (Q1), and the seven day average (Q7 Average), median (Q7 Median), and maximum (Q7 Maximum) discharge leading up to the day of the measurement.

pH - Spring		Q1		Q7 Average		Q7 Median		Q7 Maximum	
Site ID	N	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log
03-NBR	16	-0.402	-	-0.112	-	-0.006	-	-0.188	-
05-LTR	22	-0.472	-	-0.470	-	-0.457	-	-0.492	-
05-NOR	24	-0.595	-	-0.569	-	-0.565	-	-0.578	-
08-LMP	22	-0.170	-	0.075	-	0.058	-	0.083	-
09-LMP	15	-0.196	-	0.038	-	0.024	-	0.088	-
09-NOR	24	-0.410	-	-0.342	-	-0.337	-	-0.337	-
11-LMP	22	-0.291	-	-0.025	-	-0.029	-	-0.043	-
12-LMP	13	-0.057	-	0.307	-	0.326	-	0.301	-
12A-LMP	10	-0.500	-	-0.603	-	-0.597	-	-0.590	-
12B-LMP	4	0.008	-	-0.416	-	-0.282	-	-0.584	-
13-LMP	9	0.254	-	0.364	-	0.359	-	0.379	-
13F-LMP	10	-0.317	-	-0.065	-	0.021	-	-0.176	-
17-LMP	9	-0.658	-	-0.586	-	-0.536	-	-0.599	-
21-LMP	17	-0.304	-	0.230	-	0.376	-	0.050	-
GBCW-14	73	-0.233	-	-0.297	-	-0.262	-	-0.273	-
LMP-07	29	-0.634	-0.803	-0.732	-0.784	-0.441	-0.760	-0.758	-0.788
LMP-19	27	-0.807	-0.738	-0.803	-0.727	-0.414	-0.706	-0.853	-0.715
LMP-27	26	-0.503	-0.769	-0.425	-0.701	-0.235	-0.677	-0.566	-0.714
LMP-39	28	-0.791	-0.819	-0.734	-0.817	-0.346	-0.820	-0.803	-0.778
LMP-51	30	-0.745	-0.695	-0.717	-0.718	-0.369	-0.717	-0.781	-0.678
LMP-67	32	-0.557	-0.693	-0.583	-0.774	-0.340	-0.770	-0.588	-0.734
LMP-73	112	-0.544	-	-0.516	-	-0.384	-	-0.539	-
NOR-27	78	-0.599	-	-0.501	-	-0.349	-	-0.548	-

Table G-6. For the spring season (4/1 – 6/30), the number of years of data (N), the linear correlation coefficient for untransformed and log-transformed pH and daily average discharge on the day of the measurement (Q1), and the seven day average (Q7 Average), median (Q7 Median), and maximum (Q7 Maximum) discharge leading up to the day of the measurement.

pH - Summer		Q1		Q7 Average		Q7 Median		Q7 Maximum	
Site ID	N	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log
03-NBR	31	-0.613	-	-0.687	-	-0.632	-	-0.661	-
05-LTR	44	-0.547	-	-0.561	-	-0.534	-	-0.597	-
05-NOR	49	-0.639	-	-0.711	-	-0.691	-	-0.718	-
08-LMP	74	-0.477	-	-0.471	-	-0.368	-	-0.507	-
09-LMP	38	-0.437	-	-0.461	-	-0.382	-	-0.453	-
09-NOR	46	-0.352	-	-0.352	-	-0.349	-	-0.365	-
11-LMP	50	-0.390	-	-0.387	-	-0.298	-	-0.431	-
12-LMP	42	-0.225	-	-0.172	-	-0.136	-	-0.189	-
12A-LMP	40	-0.335	-	-0.368	-	-0.342	-	-0.402	-
12B-LMP	29	-0.282	-	-0.135	-	-0.014	-	-0.234	-
13-LMP	22	-0.349	-	-0.362	-	-0.324	-	-0.401	-
13F-LMP	46	-0.402	-	-0.456	-	-0.415	-	-0.473	-
17-LMP	31	-0.356	-	-0.533	-	-0.509	-	-0.516	-
21-LMP	35	-0.480	-	-0.537	-	-0.452	-	-0.576	-
GBCW-14	76	-0.140	-	-0.098	-	-0.068	-	-0.131	-
LMP-07	28	-0.326	-	-0.351	-	-0.269	-	-0.365	-
LMP-19	27	-0.387	-0.886	-0.408	-0.791	-0.323	-0.558	-0.427	-0.806
LMP-27	25	-0.601	-0.704	-0.608	-0.582	-0.427	-0.308	-0.639	-0.598
LMP-39	27	-0.607	0.008	-0.665	0.132	-0.505	0.352	-0.675	0.086
LMP-51	27	-0.516	-0.717	-0.550	-0.748	-0.417	-0.589	-0.564	-0.721
LMP-67	29	-0.503	-0.317	-0.389	-0.281	-0.167	-0.091	-0.466	-0.275
LMP-73	122	-0.486	-	-0.485	-	-0.401	-	-0.536	-
NOR-27	106	-0.268	-	-0.131	-	-0.041	-	-0.216	-

Table G-7. For the summer season (6/1 – 9/30), the number of years of data (N), the linear correlation coefficient for untransformed and log-transformed pH and daily average discharge on the day of the measurement (Q1), and the seven day average (Q7 Average), median (Q7 Median), and maximum (Q7 Maximum) discharge leading up to the day of the measurement.

pH - Fall		Q1		Q7 Average		Q7 Median		Q7 Maximum	
Site ID	N	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log
03-NBR	-	-	-	-	-	-	-	-	-
05-LTR	-	-	-	-	-	-	-	-	-
05-NOR	-	-	-	-	-	-	-	-	-
08-LMP	5	-0.090	-	-0.321	-	-0.328	-	-0.399	-
09-LMP	5	0.034	-	-0.237	-	-0.252	-	-0.355	-
09-NOR	-	-	-	-	-	-	-	-	-
11-LMP	-	-	-	-	-	-	-	-	-
12-LMP	5	0.054	-	-0.131	-	-0.121	-	-0.269	-
12A-LMP	5	0.300	-	0.271	-	0.307	-	0.194	-
12B-LMP	5	0.148	-	0.000	-	0.020	-	-0.114	-
13-LMP	-	-	-	-	-	-	-	-	-
13F-LMP	6	-0.228	-	-0.382	-	-0.361	-	-0.473	-
17-LMP	-	-	-	-	-	-	-	-	-
21-LMP	-	-	-	-	-	-	-	-	-
GBCW-14	44	-0.116	-	-0.012	-	-0.034	-	0.015	-
LMP-07	22	-0.418	-	-0.302	-	-0.176	-	-0.444	-
LMP-19	22	-0.609	-	-0.498	-	-0.385	-	-0.620	-
LMP-27	22	-0.598	-0.679	-0.363	-0.585	-0.211	-0.473	-0.537	-0.641
LMP-39	23	-0.589	-0.299	-0.437	-0.159	-0.323	-0.014	-0.549	-0.242
LMP-51	23	-0.589	-0.859	-0.563	-0.850	-0.483	-0.772	-0.638	-0.855
LMP-67	22	-0.223	-	-0.248	-	-0.184	-	-0.326	-
LMP-73	97	-0.380	-	-0.459	-	-0.439	-	-0.455	-
NOR-27	60	-0.465	-	-0.557	-	-0.531	-	-0.533	-

Table G-8. For the fall season (10/1 – 12/31), the number of years of data (N), the linear correlation coefficient for untransformed and log-transformed pH and daily average discharge on the day of the measurement (Q1), and the seven day average (Q7 Average), median (Q7 Median), and maximum (Q7 Maximum) discharge leading up to the day of the measurement.

NO3 - Winter		Q1		Q7 Average		Q7 Median		Q7 Maximum	
Site ID	N	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log
03-NBR	-	-	-	-	-	-	-	-	-
05-LTR	-	-	-	-	-	-	-	-	-
05-NOR	-	-	-	-	-	-	-	-	-
08-LMP	-	-	-	-	-	-	-	-	-
09-LMP	-	-	-	-	-	-	-	-	-
09-NOR	-	-	-	-	-	-	-	-	-
11-LMP	-	-	-	-	-	-	-	-	-
12-LMP	-	-	-	-	-	-	-	-	-
12A-LMP	-	-	-	-	-	-	-	-	-
12B-LMP	-	-	-	-	-	-	-	-	-
13-LMP	-	-	-	-	-	-	-	-	-
13F-LMP	-	-	-	-	-	-	-	-	-
17-LMP	-	-	-	-	-	-	-	-	-
21-LMP	-	-	-	-	-	-	-	-	-
GBCW-14	-	-	-	-	-	-	-	-	-
LMP-07	37	-0.654	-0.838	-0.658	-0.828	-0.627	-0.816	-0.677	-0.820
LMP-19	33	-0.594	-0.708	-0.595	-0.703	-0.578	-0.691	-0.594	-0.685
LMP-27	33	-0.636	-0.763	-0.618	-0.726	-0.601	-0.715	-0.621	-0.720
LMP-39	33	-0.695	-0.844	-0.750	-0.847	-0.748	-0.851	-0.706	-0.811
LMP-51	32	-0.498	-0.746	-0.563	-0.769	-0.562	-0.772	-0.526	-0.732
LMP-67	31	-0.545	-0.768	-0.652	-0.829	-0.652	-0.825	-0.603	-0.799
LMP-73	129	-0.497	-0.668	-0.535	-0.679	-0.513	-0.668	-0.513	-0.665
NOR-27	79	-0.286	-0.334	-0.344	-0.403	-0.346	-0.408	-0.318	-0.373

Table G-9. For the winter season (1/1 – 3/31), the number of years of data (N), the linear correlation coefficient for untransformed and log-transformed NO_3^- concentrations and daily average discharge on the day of the measurement (Q1), and the seven day average (Q7 Average), median (Q7 Median), and maximum (Q7 Maximum) discharge leading up to the day of the measurement.

NO3 - Spring		Q1		Q7 Average		Q7 Median		Q7 Maximum	
Site ID	N	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log
03-NBR	-	-	-	-	-	-	-	-	-
05-LTR	-	-	-	-	-	-	-	-	-
05-NOR	-	-	-	-	-	-	-	-	-
08-LMP	-	-	-	-	-	-	-	-	-
09-LMP	7	-0.553	-0.783	-0.372	-0.732	-0.389	-0.733	-0.321	-0.723
09-NOR	-	-	-	-	-	-	-	-	-
11-LMP	8	-0.482	-0.264	-0.396	-0.253	-0.408	-0.241	-0.353	-0.266
12-LMP	3	-0.899	-0.990	-0.876	-0.996	-0.878	-0.996	-0.870	-0.996
12A-LMP	-	-	-	-	-	-	-	-	-
12B-LMP	-	-	-	-	-	-	-	-	-
13-LMP	3	-0.732	-0.952	-0.698	-0.938	-0.700	-0.936	-0.689	-0.939
13F-LMP	-	-	-	-	-	-	-	-	-
17-LMP	-	-	-	-	-	-	-	-	-
21-LMP	7	-0.350	-0.728	-0.244	-0.598	-0.249	-0.602	-0.223	-0.572
GBCW-14	-	-	-	-	-	-	-	-	-
LMP-07	40	-0.117	-	-0.197	-	-0.218	-	-0.148	-
LMP-19	35	-0.084	-0.331	-0.181	-0.298	-0.220	-0.292	-0.128	-0.299
LMP-27	33	-0.139	-0.447	-0.232	-0.393	-0.213	-0.353	-0.173	-0.400
LMP-39	35	-0.284	-0.473	-0.269	-0.393	-0.187	-0.322	-0.239	-0.390
LMP-51	34	-0.370	-0.724	-0.429	-0.632	-0.358	-0.557	-0.373	-0.625
LMP-67	36	-0.371	-0.615	-0.443	-0.579	-0.359	-0.515	-0.373	-0.546
LMP-73	199	-0.303	-	-0.311	-	-0.301	-	-0.247	-
NOR-27	85	0.006	-	-0.126	-	-0.139	-	-0.102	-

Table G-10. For the spring season (4/1 – 6/30), the number of years of data (N), the linear correlation coefficient for untransformed and log-transformed NO_3^- concentrations and daily average discharge on the day of the measurement (Q1), and the seven day average (Q7 Average), median (Q7 Median), and maximum (Q7 Maximum) discharge leading up to the day of the measurement

NO3 - Summer			Q1		Q7 Average		Q7 Median		Q7 Maximum	
Site ID	N	Critical R	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log
03-NBR	-	-	-	-	-	-	-	-	-	-
05-LTR	-	-	-	-	-	-	-	-	-	-
05-NOR	-	-	-	-	-	-	-	-	-	-
08-LMP	-	-	-	-	-	-	-	-	-	-
09-LMP	-	-	-	-	-	-	-	-	-	-
09-NOR	-	-	-	-	-	-	-	-	-	-
11-LMP	-	-	-	-	-	-	-	-	-	-
12-LMP	-	-	-	-	-	-	-	-	-	-
12A-LMP	-	-	-	-	-	-	-	-	-	-
12B-LMP	-	-	-	-	-	-	-	-	-	-
13-LMP	-	-	-	-	-	-	-	-	-	-
13F-LMP	-	-	-	-	-	-	-	-	-	-
17-LMP	-	-	-	-	-	-	-	-	-	-
21-LMP	-	-	-	-	-	-	-	-	-	-
GBCW-14	-	-	-	-	-	-	-	-	-	-
LMP-07	44	0.29	-0.331	-	-0.316	-	-0.236	-	-0.331	-
LMP-19	36	0.32	-0.743	-0.839	-0.758	-0.749	-0.586	-0.567	-0.767	-0.753
LMP-27	35	0.33	-0.557	-0.435	-0.478	-0.333	-0.297	-0.129	-0.520	-0.347
LMP-39	36	0.32	-0.202	-	-0.108	-	0.010	-	-0.155	-
LMP-51	37	0.32	-0.330	-0.539	-0.391	-0.543	-0.331	-0.437	-0.378	-0.511
LMP-67	36	0.32	-0.335	-0.203	-0.328	-0.168	-0.241	-0.038	-0.338	-0.159
LMP-73	194	0.14	-0.107	-	-0.094	-	-0.081	-	-0.106	-
NOR-27	115	0.18	-0.082	-	-0.029	-	0.009	-	-0.044	-

Table G-11. For the summer season (6/1 – 9/30), the number of years of data (N), the linear correlation coefficient for untransformed and log-transformed NO_3^- concentrations and daily average discharge on the day of the measurement (Q1), and the seven day average (Q7 Average), median (Q7 Median), and maximum (Q7 Maximum) discharge leading up to the day of the measurement.

NO3 - Fall			Q1		Q7 Average		Q7 Median		Q7 Maximum	
Site ID	N	Critical R	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log	Linear	Log-Log
03-NBR	-	-	-	-	-	-	-	-	-	-
05-LTR	-	-	-	-	-	-	-	-	-	-
05-NOR	-	-	-	-	-	-	-	-	-	-
08-LMP	-	-	-	-	-	-	-	-	-	-
09-LMP	-	-	-	-	-	-	-	-	-	-
09-NOR	-	-	-	-	-	-	-	-	-	-
11-LMP	-	-	-	-	-	-	-	-	-	-
12-LMP	-	-	-	-	-	-	-	-	-	-
12A-LMP	-	-	-	-	-	-	-	-	-	-
12B-LMP	-	-	-	-	-	-	-	-	-	-
13-LMP	-	-	-	-	-	-	-	-	-	-
13F-LMP	-	-	-	-	-	-	-	-	-	-
17-LMP	-	-	-	-	-	-	-	-	-	-
21-LMP	-	-	-	-	-	-	-	-	-	-
GBCW-14	-	-	-	-	-	-	-	-	-	-
LMP-07	32	0.34	-0.307	-	-0.135	-	-0.081	-	-0.183	-
LMP-19	28	0.37	-0.404	-	-0.251	-	-0.206	-	-0.289	-
LMP-27	27	0.38	-0.458	-0.490	-0.312	-0.441	-0.257	-0.352	-0.340	-0.494
LMP-39	28	0.37	-0.430	-0.206	-0.237	-0.097	-0.172	0.029	-0.302	-0.176
LMP-51	29	0.36	-0.331	-0.348	-0.316	-0.416	-0.292	-0.378	-0.314	-0.440
LMP-67	25	0.39	-0.226	-	-0.134	-	-0.095	-	-0.182	-
LMP-73	149	0.16	-0.089	0.079	-0.015	0.123	-0.002	0.116	-0.061	0.102
NOR-27	69	0.23	-0.042	-	0.039	-	0.080	-	-0.039	-

Table G-12. For the fall season (10/1 – 12/31), the number of years of data (N), the linear correlation coefficient for untransformed and log-transformed NO_3^- concentrations and daily average discharge on the day of the measurement (Q1), and the seven day average (Q7 Average), median (Q7 Median), and maximum (Q7 Maximum) discharge leading up to the day of the measurement.

Appendix H – Land Cover Correlations

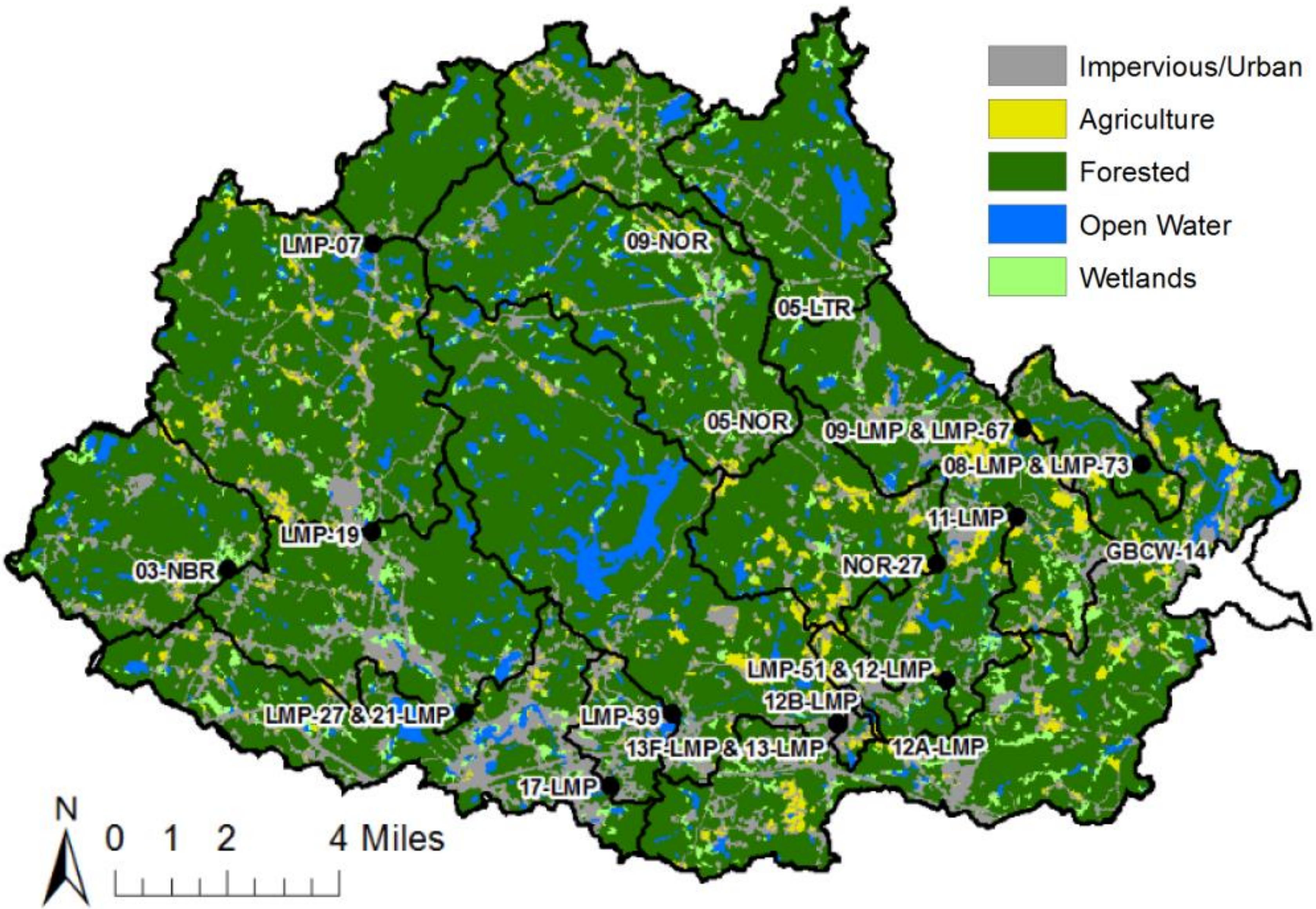

Figure H-1. Map of the Lamprey River watershed showing the delineation of the nested subwatersheds of each sampling site. Also, different land cover types are shown.

Watershed	Average DO	Average pH	Average NO_3	% Urban	% Agriculture	% Forested	% Open Water	% Wetlands
LMP-07	6.9	5.72	0.036	4.05	1.15	89.91	2.88	2.01
03-NBR	4.4	5.89	0.045	12.57	1.58	77.36	5.48	3.01
LMP-19	7.8	6.33	0.106	11.15	3.08	80.63	3.28	1.86
LMP-21/17-LMP	7.9	6.5	0.268	13.22	2.32	78.09	3.99	2.38
17-LMP	6.8	6.42	0.413	16.01	2.16	74.40	4.57	2.85
LMP-39	8.1	6.61	0.110	16.92	2.14	73.54	4.59	2.81
13-LMP/13F-LMP	7.7	6.66	0.123	15.10	2.23	73.97	6.25	2.45
12B-LMP	7.4	6.86	-	15.21	2.27	73.80	6.27	2.44
12A-LMP	7.4	6.89	-	7.74	2.50	80.26	6.85	2.66
12-LMP/LMP-51	7.1	6.68	0.365	15.45	2.43	73.43	6.20	2.48
09-NOR	8	6.47	-	12.27	3.53	76.36	5.48	2.35
05-NOR	6.8	6.09	-	10.92	2.34	78.06	5.39	3.29
NOR-27	8.2	6.61	0.051	11.03	3.74	77.33	5.00	2.90
05-LTR	7.4	5.92	-	7.84	0.43	80.01	8.25	3.46
09-LMP/LMP-67	7.6	6.5	0.125	14.41	3.01	73.88	5.85	2.85
08-LMP/LMP-73	7.8	6.8	0.113	14.66	3.20	73.52	5.71	2.91
11-LMP	7.3	6.66	0.152	14.57	2.91	74.01	5.88	2.63
GBCW-14	7.1	7.19	-	14.94	3.42	72.97	5.57	3.11

Table H-1. Average DO, pH, and NO_3^- for each sampling site, as well as the percent area of urban, agriculture, forested, open water, and wetlands for each subwatershed.

Appendix I – Candia Logger Data

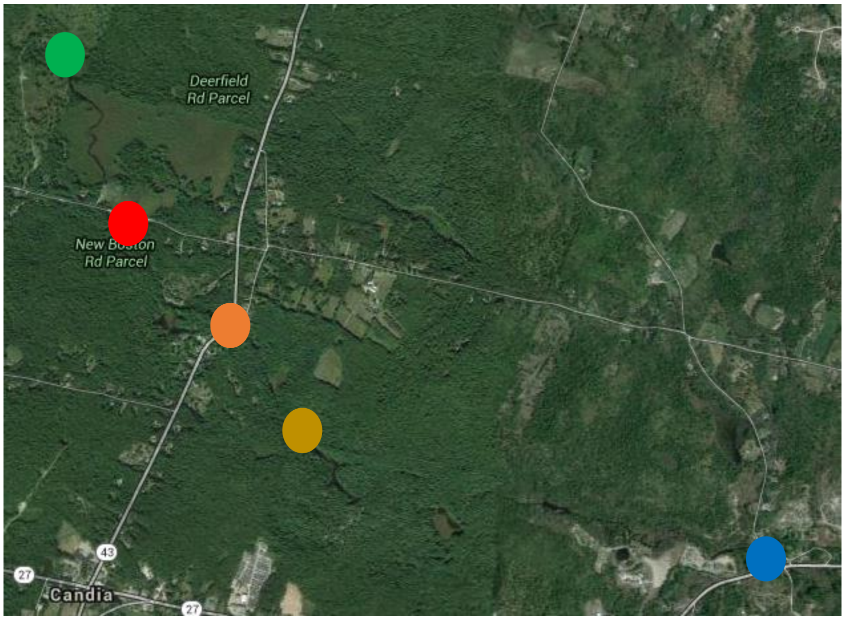

Figure I-1. Image showing data logger locations near New Boston Road in Candia (03-NBR). Loggers were deployed at, upstream and downstream of the usual sampling location.

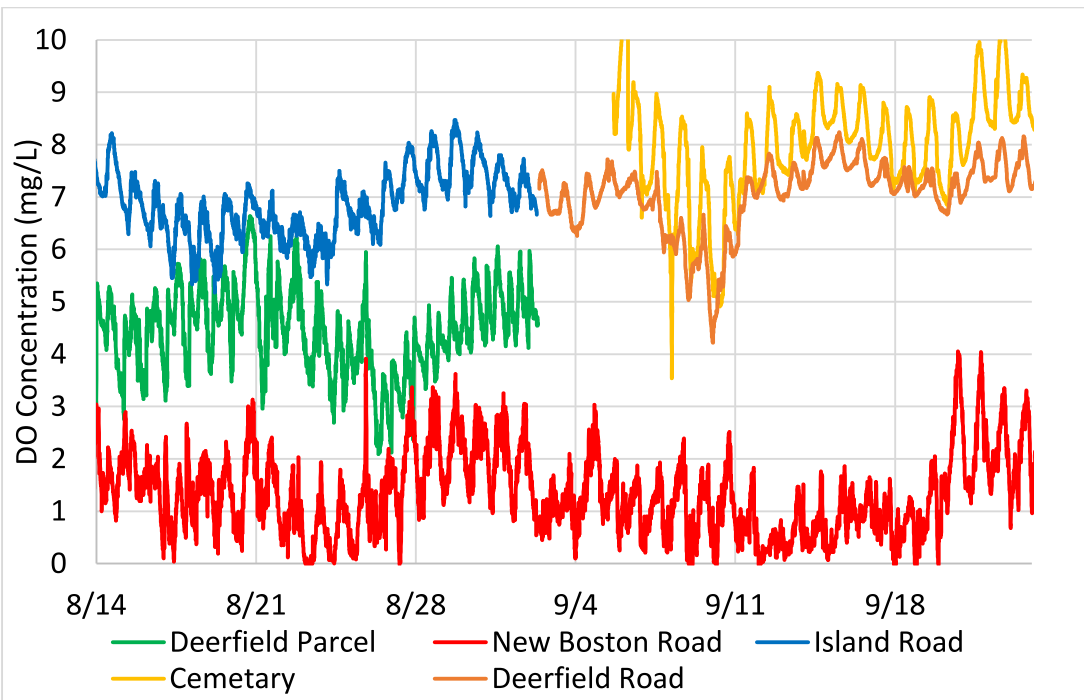

Figure I-2. A graph showing DO concentration adjacent to New Boston Road during six weeks in 2015 from the multiple sampling locations.

Sources

Chapra, Steven C. 1997. *Surface Water-Quality Modeling*. New York: McGraw-Hill.

Lamprey River Advisory Committee. 2013. Summary of Water Quality Monitoring in the Lamprey River 2012-2013.
http://www.lampreyriver.org/UploadedFiles/Files/Summary_of_Water_Qual_Monitoring_in_the_Lamprey_2012,3.pdf

Langmuir, Donald. *Aqueous Environmental Geochemistry*. Upper Saddle River, NJ: Prentice Hall, 1997.

Piscataqua Region Estuaries Partnership (PREP). State of Our Estuaries. 2013.

State of New Hampshire Department of Environmental Services (NHDES). Acid Rain Status and Trends in New Hampshire Lakes, Ponds, and Rainfall. 2015.

State of New Hampshire Department of Environmental Services (NHDES). Environmental Fact Sheet. Nitrate and Nitrite in Drinking Water. 2010.

State of New Hampshire Department of Environmental Services (NHDES). Great Bay Nitrogen Non-Point Source Study. 2014.

State of New Hampshire Department of Environmental Services (NHDES). Lamprey River Nomination Committee.

State of New Hampshire Department of Environmental Services (NHDES). Numeric Nutrient Criteria for the Great Bay Estuary. 2009.

State of New Hampshire Department of Environmental Services (NHDES). 2012 Section 305(b) and 303(d) Consolidated Assessment and Listing Methodology.

State of New Hampshire Department of Environmental Services (NHDES). 2012 Section 305(b) and 303(d) Surface Water Quality Report.

Strock, Kristin E., Sarah J. Nelson, Jeffrey S. Kahl, Jasmine E. Saros, and William H. McDowell. "Decadal Trends Reveal Recent Acceleration in the Rate of Recovery from Acidification in the Northeastern U.S." *Environmental Science & Technology Environ. Sci. Technol.* (2014): 4681-689.

Table of Regulated Drinking Water Contaminants. *EPA*. Environmental Protection Agency. Web. 03 May 2016.

Taylor, John R. 1997. *An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements*. 2nd ed. Sausalito, Calif.: University Science Books.

Waller, Kristin, Driscoll, C., Lynch, J., Newcomb, D., Roy, K. 2012. Long-term recovery of lakes in the Adirondack region of New York to decreases in acidic deposition. Atmospheric Environment 46, 56-64.

Water Quality Legislative History - Water Quality Standards Advisory Committee - NH Department of Environmental Services. Web. 02 May 2016.

Wilderotter, Sophie, Lightbody, A., Sheehan, K. Distribution of fluvial wetland area and river slope along the Lamprey River. 2014.