Water Quality Analysis of the Lamprey River Watershed

Specific conductance, E. coli, and turbidity

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Importance of water quality in rivers

The preservation of high water quality in streams and rivers is critical for the health of ecosystems and human health. The Lamprey River drains into Great Bay, which is a vital estuarine ecosystem. Keeping the Lamprey clean preserves the ecology and ecosystem services that we rely on. The Lamprey River is also a source of drinking water and recreation for many people in southeastern New Hampshire. Water quality parameters such as specific conductance, *E. coli*, and turbidity indicate the chemical, biological, and physical state of the river. By analyzing the historical water quality data, scientifically-based conclusions can be made and action can be taken to solve the potential threats to this Wild and Scenic River.

Data analysis

To assess the past and current state of water quality in the Lamprey River watershed, analyses of historical data were carried out. Spatial and temporal trends were examined at 16 sites throughout the freshwater portion of the watershed. Other than specific conductance measurements which were taken throughout the year, samples were primarily taken by volunteers during the summer.

Results

In general, the specific conductance, *E. coli*, and turbidity measurements suggested relatively high water quality in the Lamprey River watershed. Specific conductance only exceeded the Class B New Hampshire surface water quality standard three times throughout the record. However, lower levels of specific conductance can still harm aquatic ecosystems. Higher measurements were seen at stations with closer proximity to areas of greater urban density, likely due to the rate of road salt application. *E. coli* seemed to be of more immediate concern.

Current watershed status and management implications

Despite the high quality of water indicated by the generally low specific conductance and turbidity measurements, management in the Lamprey River watershed is critical. Future land use changes in the watershed could increase specific conductance levels as more road salt is applied. Turbidity measurements may also increase with stronger, more frequent rain events. These factors can be mitigated through continued monitoring and suitable management responses. High measurements of *E. coli* should be the focus of future study and direct management. Increased sampling efforts could lead to more precise source identification. By identifying these sources, actions can be taken to ensure lower pathogenic activity in the Lamprey River. Specifically, working with policymakers and community members would make them aware of potential problems that may arise if these issues go unchecked.

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Introduction

Ensuring high quality water in rivers and streams is critical. Rivers are a source of economic, ecological, and aesthetic value when they are managed effectively. The first step in maintaining water quality is to monitor the various parameters that indicate the state of the water. It is useful to gather long-term data so that trends over time can be observed. Additionally, varying spatial data allows water quality parameters to be compared, which could indicate critically impaired parts of the river. For this analysis, historical data for specific conductance, *E. coli*, and turbidity were statistically analyzed. These parameters are directly impacted by natural and anthropogenic changes. By monitoring these spatial and temporal changes, the driving relationships can be better understood.

The New Hampshire Department of Environmental Services (NHDES) has set standards for certain rivers in the state. Class B rivers are considered acceptable for swimming, fishing, and other recreation purposes. To uphold this quality of water, certain standards have been established. The Class B New Hampshire surface water quality standards for each analyte of interest are described below.

The Lamprey River is designated as Class B by the NHDES. The watershed is approximately 214 square miles; it is the largest of the other rivers that drain into Great Bay. It is federally protected as a Wild and Scenic River under the National Wild and Scenic Rivers Act in 1968. Only two rivers in New Hampshire have that distinction. Historically, the Lamprey River has been intensely managed because of its importance to the ecosystems in Great Bay and the communities in southeastern New Hampshire. It is critical to continually monitor the water quality to ensure its wellbeing for future generations.

Specific conductance

Specific conductance measures how well water conducts an electrical current at a standard temperature of 25°C. The measurement increases when there are more cations or anions present. Essentially, by measuring how conductive the water is, the dissolved solids, such as chloride or sodium can be indirectly measured (Interpreting VRAP Water Quality Monitoring Parameters). Specific conductance is a good measure of the overall water quality. Polluted waters have higher specific conductance values because there are more ions in the water resulting from the breakdown of compounds.

There are several factors that affect specific conductance levels. Some areas have naturally higher amounts of ions due to the presence of more erosive rock types. In addition, elevated levels are typically seen as a result of anthropogenic sources. Road salt pollution, septic system leakage, wastewater treatment plant effluent, and agricultural runoff can all result in various ions entering a river. By understanding the spatial and temporal trends of specific conductance, it is easier to identify the potential sources causing more ions to enter the water.

Specific conductance can be measured relatively easily, which means it can be used as a surrogate for chloride concentrations. Chloride is primarily sourced by the application of road salt. The percentage of road pavement in a watershed controls sodium and chloride concentrations in the river, which suggests road salt is the main contributor to specific conductance (Daley et al, 2009). A statistically significant relationship (R2=0.97) between specific conductance and chloride concentrations has been shown (NHDES CALM, 2016). The statewide relationship established by the NHDES has a 95% confidence interval (±28 mg/L) for each prediction:

$$\text{Chloride (in mg/L)} = 0.289 * \text{Specific Conductance (in uS/cm)} - 11.7$$

From the chloride standards in Class B waters, the NHDES could establish critical values for specific conductance. The chronic criterion for chloride is 230 mg/L, which was found to be approximately equivalent to 835 µS/cm. Measurements that consistently exceed this value are considered to be impaired.

The typical range for specific conductance in New Hampshire rivers is 0-100 µS/cm. Low to moderate impact on aquatic ecosystems can occur from 101-500 µS/cm (Interpreting VRAP Water Quality Monitoring Parameters). Measurements above 500 µS/cm are considered high impact, and chronic measurements above 835µS/cm exceed the Class B New Hampshire surface water quality standard.

E. coli

Escherichia coli (*E. coli*) is a type of fecal coliform bacteria that lives in the intestine of most humans and animals. Its presence in surface water usually indicates sewage or animal waste contamination, which may contain disease-causing organisms. The presence of *E. coli* can also serve as a good predictor of gastrointenstinal illnesses (EPA 2017 Five-Year Review of the 2012 Recreational Water Quality Criteria).

E. coli levels can fluctuate considerably. For instance, rainstorms and low flow conditions may lead to elevated levels, but chronically high levels are typically observed in proximity to raw, untreated sewage or spots of frequent animal activity. The concentrations attenuate with increased distance from the source areas; this could be due to dying out in non-ideal conditions, or diluting as they move farther downstream.

When *E. coli* levels are abnormally high, there is a potential health risk to humans using the river for recreational activities. The New Hampshire Department of Environmental Services Class A NH Surface Water Quality Standard for *E. coli* states that three consecutive measurements made within sixty days should not exceed a geometric mean of 126 counts per 100 ml. A single measurement should not exceed 406 counts per 100 ml. Using the geometric mean uses the average of the logarithm-transformed values in order to "normalize" the scale. The count per 100 ml is the unit used to indicate the number of *E. coli* cells in 100 ml of water. This can also be expressed in colony-forming units (cfu). It should be emphasized that the *E. coli* count does not directly indicate the number of harmful bacteria. It simply represents the potential presence of other harmful pathogens in the water.

Turbidity

Turbidity is a water quality parameter that describes the amount of light that can pass through the water column. When materials such as clay, silt, or algae are present, light is scattered and absorbed rather than transmitted. Turbidity can be thought of as the "cloudiness" of the water. When water is more turbid than it should be, certain ecosystem functions may be threatened, and the aesthetic value of the river goes down. Colored dissolved organic matter (CDOM) can also increase turbidity. CDOM is the result of plants and leaves decaying underwater from the release of tannins and other molecules. High turbidity can negatively affect ecosystems in a few different ways. With more particles in the water, more heat is absorbed and elevated temperatures can decrease dissolved oxygen. Additionally, less light penetration leads to lower rates of photosynthesis. The particles may also disrupt natural ecosystem processes in fish and benthic macroinvertebrates. Suspended sediment can clog fish gills, which lowers disease resistance and reproduction rates. Once the sediment settles it can cover streambeds and harm benthic macroinvertebates. It should be noted that the total suspended sediment (TSS) in the water column is not a direct measurement of turbidity, but more TSS decreases the amount of light that can pass through the water.

Like *E. coli*, turbidity levels can spike dramatically because of natural occurrences. During storm events and periods of high flow, soil and other materials enter streams and rivers and temporarily raise suspended solid concentrations. Chronically high readings can be the result of human activities like deforestation and riparian zone disruptions.

It is important to monitor turbidity levels to maintain a healthy ecosystem. Water bodies with high turbidity are also much more susceptible to algal growth. The NHDES Class B NH Surface Water Quality Standard is 10 Nephelometric Turbidity Units (NTU). When measurements chronically exceed this standard, the river is considered too turbid.

Methods

Data collection and organization

There have been repeated water quality measurements throughout the freshwater portion of the Lamprey River Watershed from 1990 to present. Many parameters were measured including specific conductance, *E. coli*, and turbidity. The samples were obtained by various organizations (Kotowski, 2016). These grab samples were obtained by trained staff and volunteers who followed a quality assurance procedure. The standard methods for specific conductance (APHA 2510), *E. coli* (APHA 9213-D) and turbidity (2130-B) were used.

Water quality data for the Lamprey River and its tributaries were obtained from NH DES and EPA. The initial dataset was downloaded in March 2014, then filtered to exclude those 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. See Kotowski (2016) for additional information on the dataset. Additional observations from 2013-2016 at these sites were downloaded from the New Hampshire Environmental Monitoring Database on March 26, 2018. Sixteen sites had continuous specific conductance measurements, ten had *E. coli* measurements, and 12 had turbidity measurements.

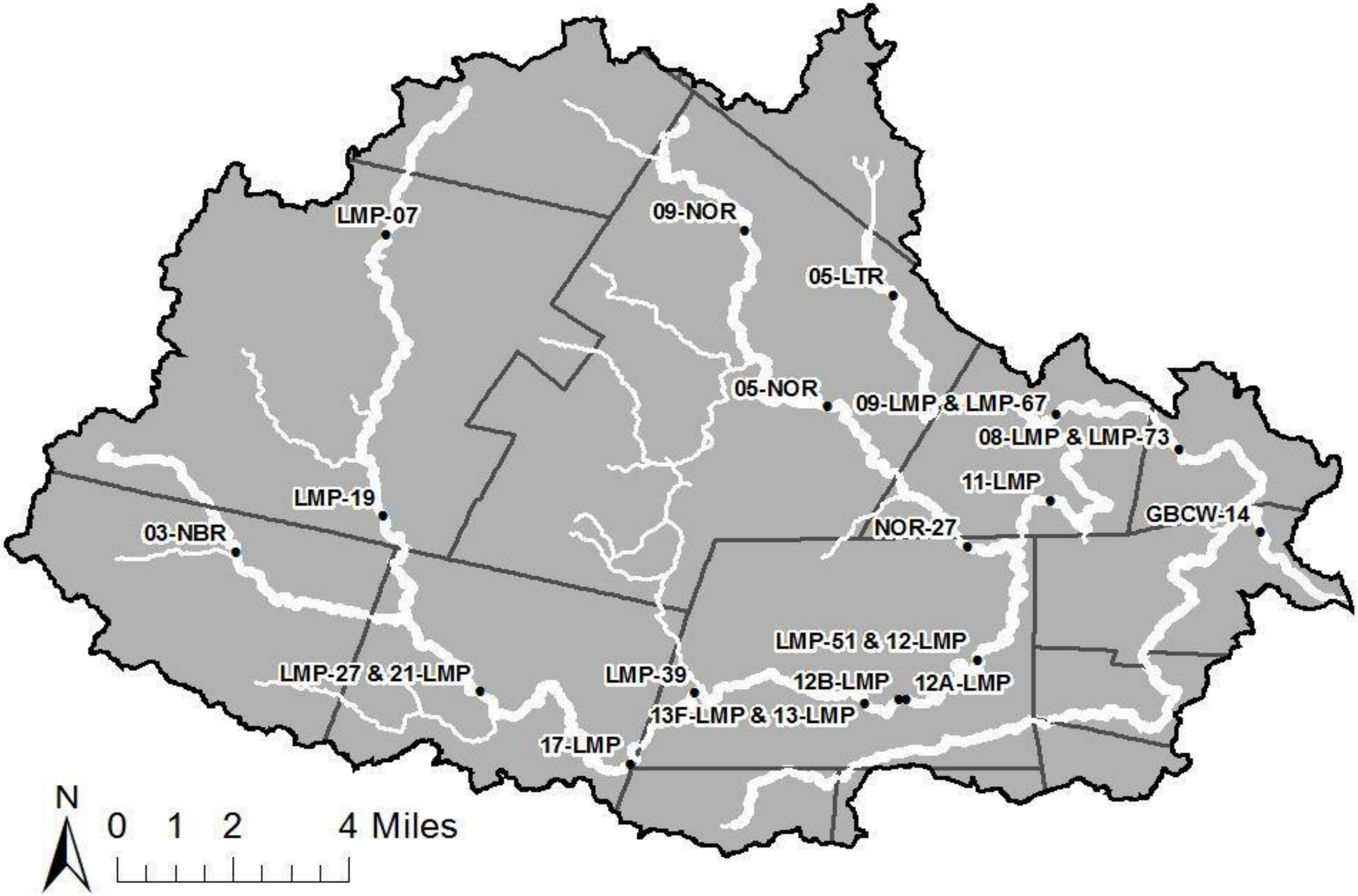


Figure 1: The Lamprey River watershed in southeast New Hampshire showing the main stem, major tributaries, and sampling site locations. Courtesy of Mark Kotowski (2016).

Analysis of spatial and temporal trends

Most of the measurements for turbidity and *E. coli* were obtained during the spring, summer, and fall. However, specific conductance measurements were measured year-round for some years. Discharge in the Lamprey River is much lower in the summer than the winter, which can increase specific conductance levels (Appendix A, Figure 25). To control for varying discharge, the mass flux of chloride was also calculated throughout the year; flux levels were more consistent throughout the year but showed more extreme high measurements in the summer months (Appendix A, Figure 26). Accordingly, the specific conductance data were divided into summer (June 1-October 31) and winter (November 1-May 31). These dates were chosen because measurements are visibly higher between the months of June and November (Appendix A, Figure 25).

Moreover, the summer data were separated by high-flow and low-flow conditions. Detailed discharge statistics spanning back to 1936 have been recorded at gaging stations throughout the United States by the U.S. Geological Survey. The median discharge on each day of the year was gathered at gaging station USGS 01073500 Lamprey River near Newmarket, NH. Subsequently, the discharge value recorded on the day of sampling was compared to the median discharge for that day of the year. If the discharge was lower than the median, that sample was considered to have been taken during low-flow conditions. If it was higher than the median, the sample was considered to have been taken during high-flow conditions.

For each parameter, a time series (1990-2016) using all measurements was created for each site. Each dataset was then tested for significant monotonic change over time using the

Mann-Kendall non-parametric test using MATLAB R2017b. If the p-value was lower than 0.05, it was concluded that the parameter significantly increased or decreased over time.

To observe the spatial trends for each of these parameters, the average value for each site was calculated and compared to the distances from the headwaters and river mouth. Distances from each site to the river mouth were measured. Subsequently, the distances to the headwaters, or point where the river begins, were measured. Since there are multiple points that can be considered the headwaters of the Lamprey River, the closest point was used in the measurement.

Additionally, ArcMap 10.5 was used to consider the land use upstream of each measurement location, using previously published land cover data (Rockingham and Strafford County Land Use 1998). Land cover was classified into four categories: Forest, water, urban, and agriculture. These classifications were produced using the NLCD 92 Land Cover Class definitions. Open water and wetlands were considered water. Residential, commercial, and industrial plots were considered urban. Deciduous, evergreen, and mixed forest, as well as shrublands were considered forest. Pasture/hay, row crops, small grain, and fallow were considered agricultural land cover. The parameter averages were then compared to the upstream land cover fractions using two different methods. The first method used the land cover fraction within a near-channel area. In ArcMap, a quarter-mile buffer was created around the entire Lamprey River and its major tributaries, which were then manually separated at each station. If two stations were combined in Kotowski (2016), they were combined for this analysis. After each station or station pair had a corresponding upstream buffer, the total area of the separated buffer, as well as the area of each land cover classification was calculated. The second method used the land cover fractions within the nested subwatersheds of each station. The area measurements from Kotowski (2016) were used. A digital elevation model (DEM) was used in that analysis to delineate each subwatershed for each station.

Results

Specific conductance

The overall average for all measurements of specific conductance throughout the entire record was 120 µS/cm. This is well below the Class B standard of 835 µS/cm.

There were some trends for individual stations over time. After the measurements from each station were grouped by summer low-flow, summer high-flow, or winter data, they were checked for significant increases or decreases over time. In total, there were four different stations that significantly increased (Mann-Kendall $p<0.05$) from 1990 to present (Appendix A, Table 1). Nine different sites significantly decreased over time (Appendix A, Table 1).

Using historical data spanning back to 1950 (Daley et al., 2009), a significant increase can be shown in the overall specific conductance averages from 1950 to 2013 ($p<0.05$). However, only using recent data (1990-2016) showed no overall significant change over time ($p>0.05$) (Appendix A, Figure 1).

The cause for the long-term increase in specific conductance levels is probably due to a wide variety of factors. One such factor may be the increase in road salt use over the past half-century. Road salt use in New Hampshire has nearly doubled over the past 40 years; there is now approximately 190,000 tons applied per year (Road Salt TMDLs and Road Salt Reduction Strategies in New Hampshire). During the winter, road salt application results in the delivery of chloride to nearby streams and rivers.

There were some notable spatial trends as well. In particular, specific conductance values were positively correlated with urban land cover fraction, both in the upstream quarter-mile buffers and the subwatersheds (Appendix D, Tables 2 and 3). A multivariate linear regression test showed that summertime specific conductance levels were controlled by urban land use throughout the entire subwatershed ($p=0.01$) rather than only the near channel area ($p=0.43$), suggesting that dissolved ions are loaded throughout the entire Lamprey River watershed.

There was a significant negative correlation between the discharge measured at Packers Falls and specific conductance values at each station (Appendix A, Figure 25). The measurements for specific conductance were inversely correlated with log-transformed discharge values (Kendall tau $p<0.0001$) (Figure 1). The negative correlation represents a dilution relationship. This was true for measurements taken in the winter and summer, during both high-flow and low-flow conditions. A consistent dilution relationship among all three of these datasets suggests that groundwater is the primary source for dissolved ions entering the Lamprey River.

Throughout the year, specific conductance values varied depending on the season (Appendix A, Figure 24). Overall, the summer measurements were 43 µS/cm higher than winter measurements (two-sample t-test, $\alpha=0.05$). Seventeen of twenty stations with year-round measurements had significantly higher specific conductance levels in the summer. This is likely a result of low discharge in the summer and high discharge during the winter and spring due to snowmelt. Lower flow means less volume of water and higher concentrations of ions.

E. coli

The overall average for all *E. coli* measurements throughout the entire record was 142 counts per 100 ml. This is greater than the Class B standard which states that three samples over the course of 60 days shall not exceed a geometric mean of 126 counts per 100 ml. However, a few very high *E. coli* measurements can skew this average. The median for all *E. coli* measurements was 60 counts per 100 ml.

There were no significant overall trends in *E. coli* observed at over time, or at any individual stations. Additionally, there were no significant seasonal trends throughout the year. When compared to discharge values at Packers Falls on the day of sampling, there were no significant correlations with *E. coli* measurements. There were also no significant correlations between average *E. coli* values and any four of the land cover classifications. However, the average *E. coli* value at each station was significantly negatively correlated with the distance from the headwaters (R2=0.53) (Appendix B, Figure 41). This could be due to *E. coli* cells dying or settling out as they move downstream. It should also be reiterated that detections of *E. coli* in the river are not necessarily harmful. *E. coli* is usually a good indicator of other pathogenic organisms. However, certain strains can be dangerous to human health (*E. coli O157:H7*). Testing for specific strains would require further investigation and more sophisticated sampling equipment.

Turbidity

The overall average for all turbidity measurements throughout the entire record was 1.4 NTU. This is well below the Class B water quality standard of 10 NTU.

There were significant decreases in turbidity levels at four of the twelve stations throughout the record spanning from 1990-2016 (Appendix C, Figures 42, 44, 47 and 49). No significant increases were observed. It was difficult to assess seasonal trends for turbidity since most measurements were taken during summer months. Generally, values were very low (<4 NTU) and only total three measurements exceeded the Class B standard of 10 NTU.

There was no significant relationship between the discharge at Packers Falls on the day of sampling and corresponding turbidity values.

Spatially, there were two land cover fractions that correlated with turbidity values using the two different methods. Agricultural land cover fraction within the upstream quarter-mile buffer was significantly positively correlated with average turbidity at the corresponding station (r2=0.60) (Appendix D, Table 2). Urban land cover fraction was significantly positively correlated with turbidity within the nested subwatershed of each station (r2=0.61) (Appendix D, Table 3).

Conclusions

A detailed historical data analysis of three water quality parameters in the Lamprey River watershed revealed some interesting findings. Overall, the quality of the Lamprey River's surface water is high. Specific conductance is often used as a general measure of water quality (National Aquatic Resource Surveys), and only one measurement throughout the entire record exceeded the Class B standard set by the NHDES. Turbidity is also a useful indicator for potential pollution of suspended solids in the water. Only three measurements were above the standard of 10 NTU, and most readings ranged from 0 to 4 NTU. E. coli measurements were much less consistent. Eighteen measurements exceeded the single measurement Class B surface water quality standard of 406 counts per 100 ml. However, E. coli measurements have been shown to have high spatial variability, even over the water column at a particular site (McDaniel et al., 2013).

Despite the high quality of water indicated by the generally low specific conductance and turbidity measurements, management in the Lamprey River watershed is critical. Future land use changes in the watershed could increase specific conductance levels as more road salt is applied. Turbidity measurements may also increase with stronger, more frequent rain events. These factors can be mitigated through continued monitoring and suitable management responses. Specifically, working with policymakers and community members to make them aware of potential problems that may arise if these issues go unchecked.

E. coli seems to be a more immediate concern. The measurements for this parameter were sparser than specific conductance and turbidity, but they showed the potential for the presence of pathogens. High *E. coli* levels have led to beach advisories in New Hampshire lakes, and although they are limited, the Lamprey River has spots designated for swimming. Monitoring *E. coli* is crucial for ensuring safe recreational areas since it can indicate the presence of fecal pollution and pathogenic organisms. It is recommended that more frequent and systematic *E. coli* measurements routines be implemented. By increasing the frequency and spatial variability of these measurements, potential sources can be identified and controlled. Sites near the Mill Street Bridge in Epping were found to have the highest consistent E. coli measurements; increased monitoring surrounding that site (13F-LMP) are recommended. Additionally, continued sampling in the upper watershed is suggested due to the greater impact of wildlife, which is a significant source of *E. coli* entering the river.

Through continued sample collection and data analysis, water quality problems can be solved. As a designated Wild and Scenic River, the health of the Lamprey is crucial for many ecosystems in the watershed and Great Bay. It is also a valuable resource for humans, both as a drinking water source and recreational destination. Increasing populations within the watershed make land use change is inevitable. Combined with climate change, seemingly healthy rivers like the Lamprey could become threatened in the upcoming century. Collective efforts by state organizations, watershed groups are crucial for preserving and improving the quality of water in our rivers.

Appendix A – Specific conductance

Table 1

Site	Seasonal flow condition	Significance	Trend	p-value
03-NBR	Low -flow	No	None	-
	High-flow	No	None	-
	Winter	No	None	-
05-LTR	Low -flow	No	None	-
	High-flow	No	None	-
	Winter	No	None	-
05-NOR	Low -flow	No	None	-
	High-flow	Yes	Positive	2.5×10^5
	Winter	No	None	-
08-LMP	Low -flow	Yes	Negative	0.0288
	High-flow	Yes	Negative	0.0078
	Winter	No	None	-
09-LMP	Low -flow	Yes	Positive	0.0026
	High-flow	Yes	Positive	0.0043
	Winter	No	None	-
09-NOR	Low -flow	Yes	Positive	0.022
	High-flow	Yes	Positive	1.07x10
	Winter	No	None	-
11-LMP	Low -flow	No	None	-
	High-flow	No	None	-
	Winter	No	None	-
12A-LMP	Low -flow	No	None	-
	High-flow	No	None	-
	Winter	No	None	-
12B-LMP	Low -flow	No	None	-
	High-flow	No	None	-
	Winter	No	None	-
12-LMP	Low -flow	No	None	-
	High-flow	Yes	Positive	0
	Winter	No	None	-
13F-LMP	Low -flow	No	None	-
	High-flow	No	None	-
	Winter	No	None	-
13-LMP	Low -flow	No	None	-
	High-flow	No	None	-

	Winter	No	None	-
17-LMP	Low -flow	No	None	-
	High-flow	No	None	-
	Winter	No	None	-
21-LMP	Low -flow	No	None	-
	High-flow	No	None	-
	Winter	No	None	-
LMP-07	Low -flow	No	None	-
	High-flow	No	None	-
	Winter	Yes	Negative	0
LMP-19	Low -flow	No	None	-
	High-flow	Yes	Negative	0
	Winter	Yes	Negative	0
LMP-27	Low -flow	No	None	-
	High-flow	Yes	Negative	0
	Winter	Yes	Negative	0
LMP-39	Low -flow	Yes	Negative	0
	High-flow	Yes	Negative	0
	Winter	Yes	Negative	0
LMP-51	Low -flow	No	None	-
	High-flow	Yes	Negative	0
	Winter	Yes	Negative	0
LMP-67	Low -flow	Yes	Negative	0
	High-flow	Yes	Negative	0
	Winter	Yes	Negative	0
LMP-73	Low -flow	Yes	Negative	0
	High-flow	Yes	Negative	0
	Winter	Yes	Negative	0
NOR-27	Low -flow	Yes	Negative	0
	High-flow	Yes	Negative	0
	Winter	No	None	-

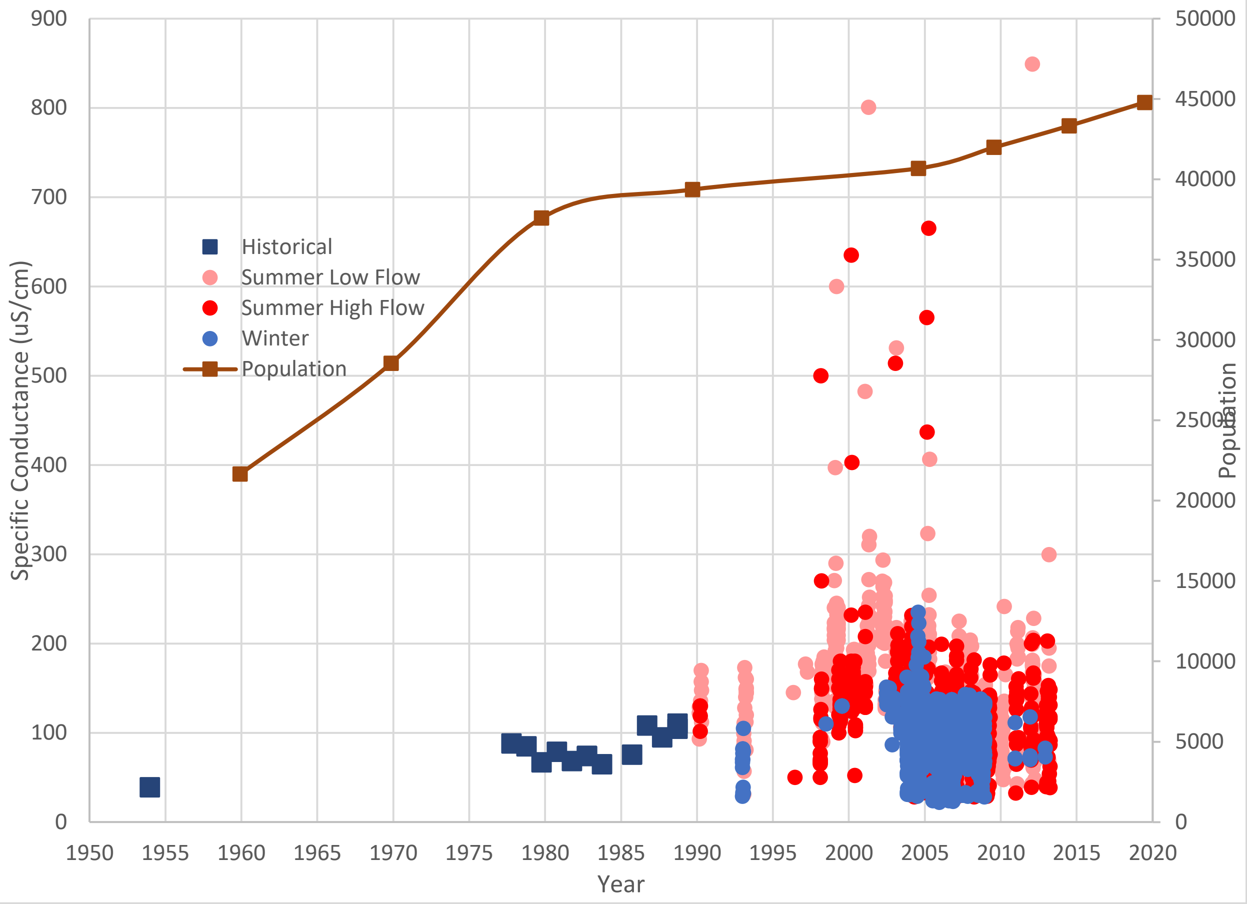


Figure 2: Historical specific conductance levels (1950-2013) compared to population within the Lamprey River watershed. Pre-1990 data courtesy of Daley et al. (2009). There was a significant increase in average specific conductance levels from 1950-2013, but not from 1990-2013.

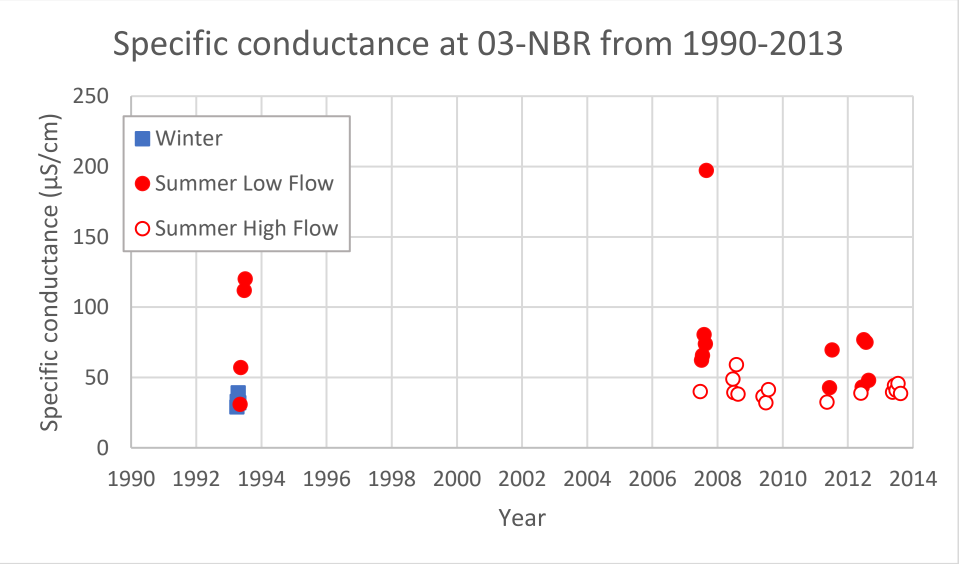


Figure 3

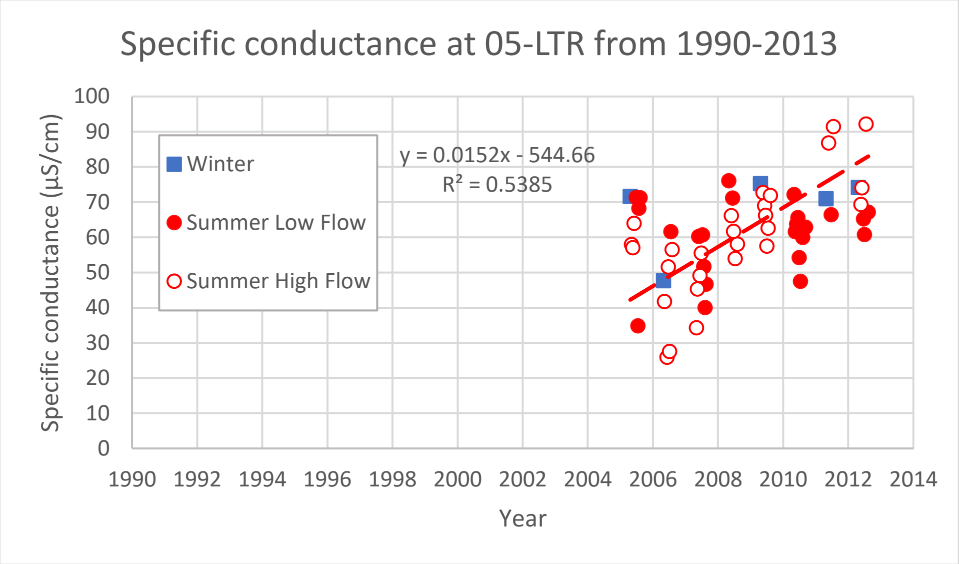


Figure 4: Summer high flow conditions showed significantly increasing trend over time

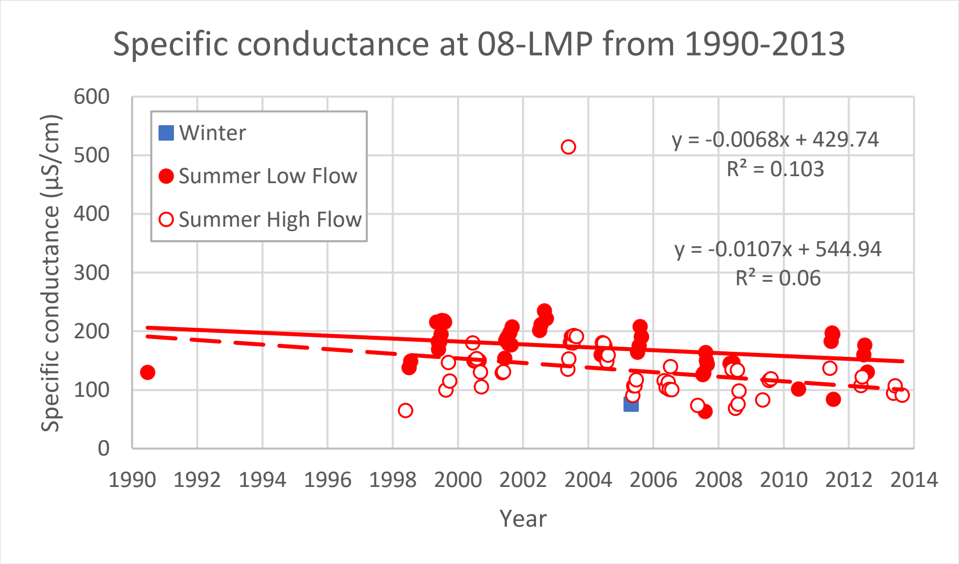


Figure 5: Summer low flow and high flow conditions showed significantly decreasing trends over time

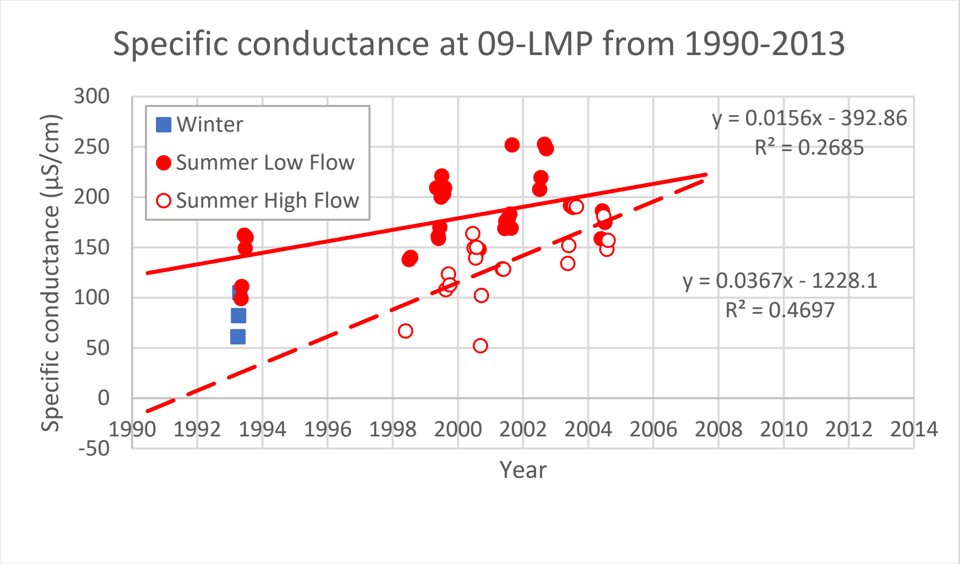


Figure 6: Summer low flow and high flow conditions showed significantly increasing trends over time

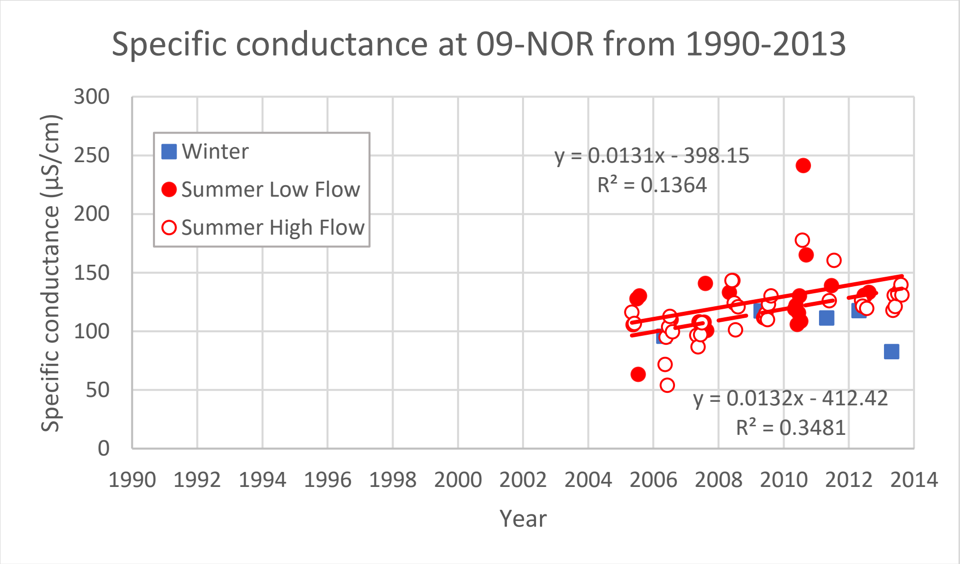


Figure 7: Summer low flow and high flow conditions showed significantly increasing trends over time

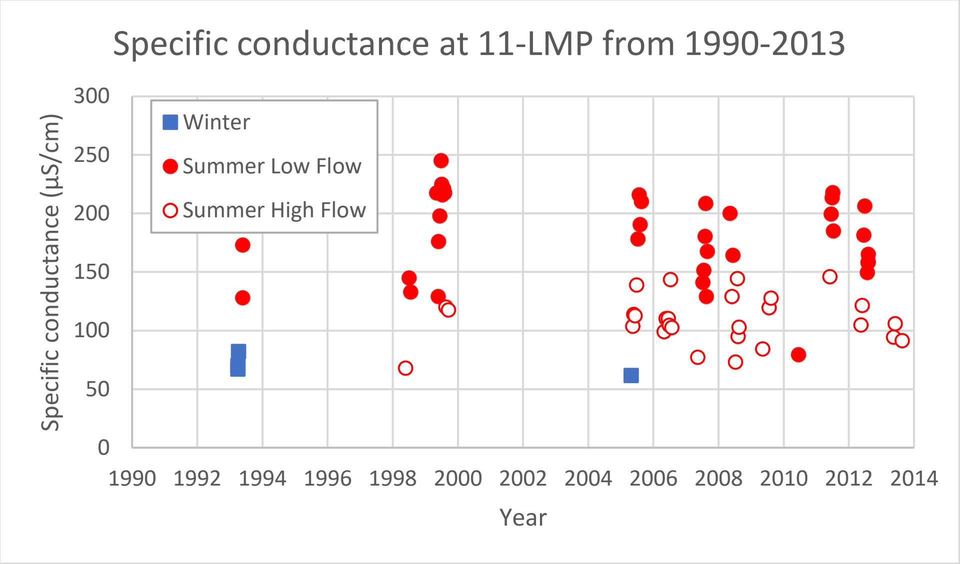


Figure 8

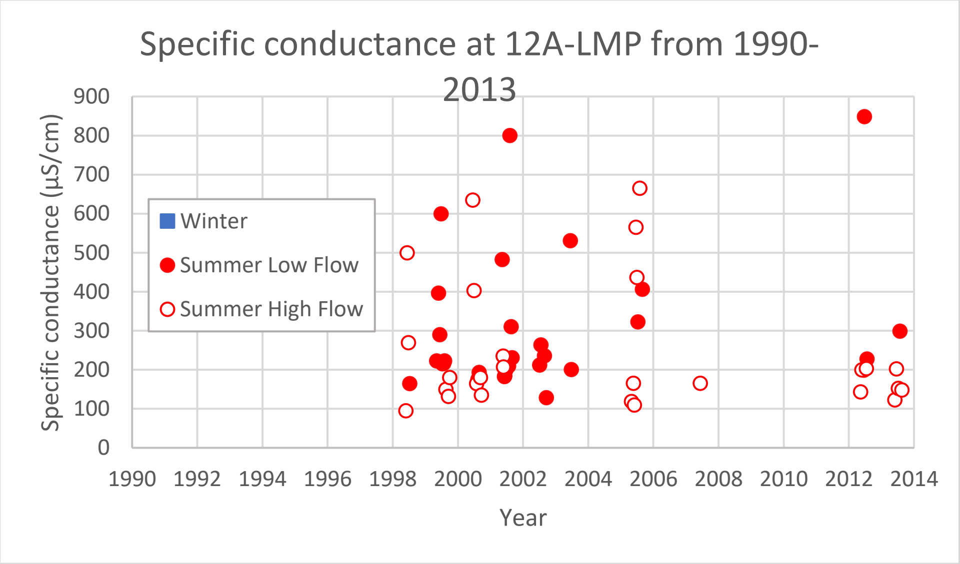


Figure 9

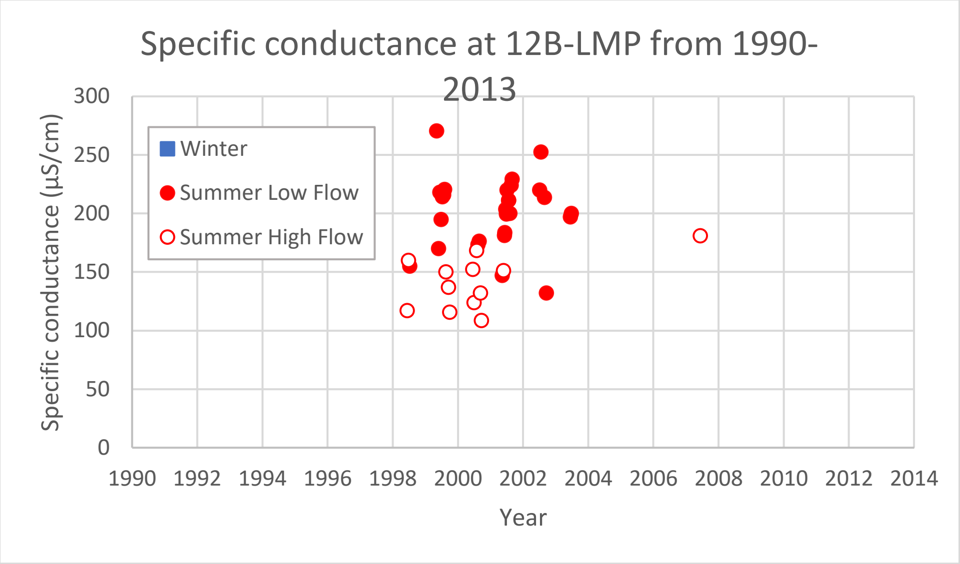


Figure 10

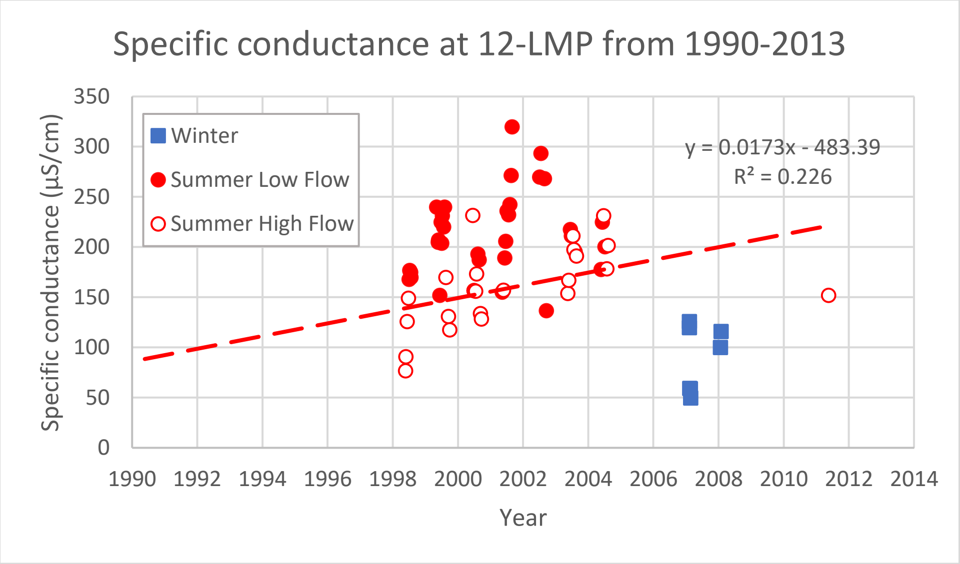


Figure 11: Summer high flow conditions showed significantly increasing trend over time

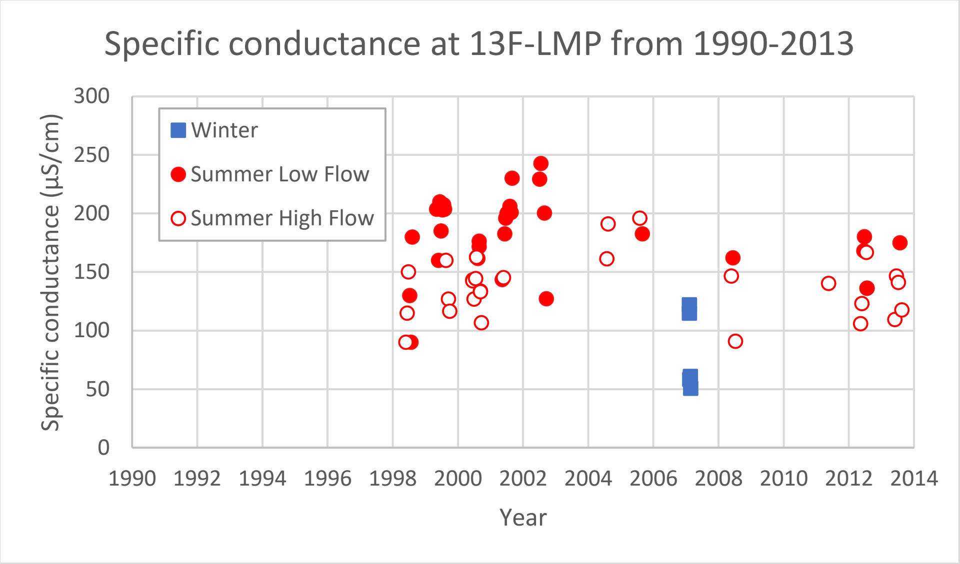


Figure 12

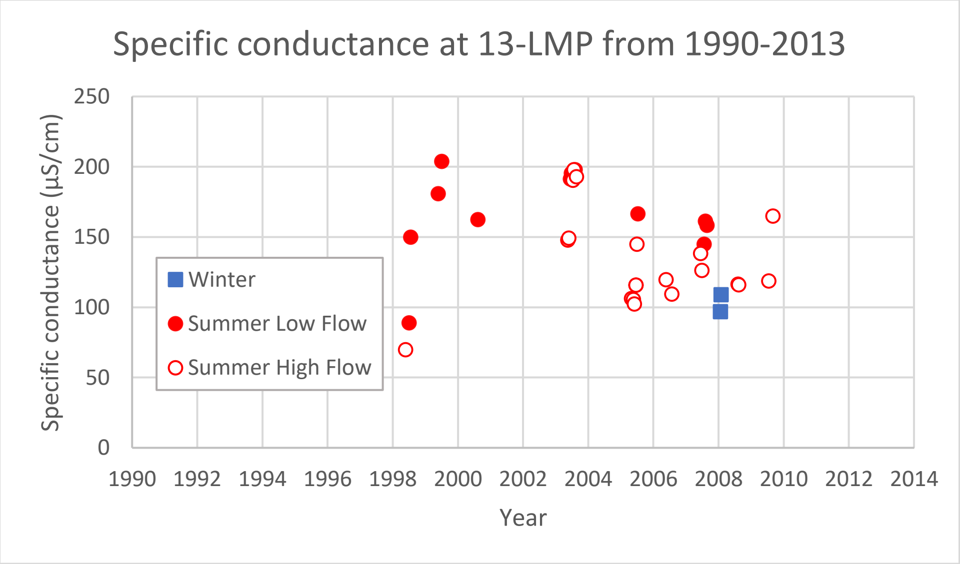


Figure 13

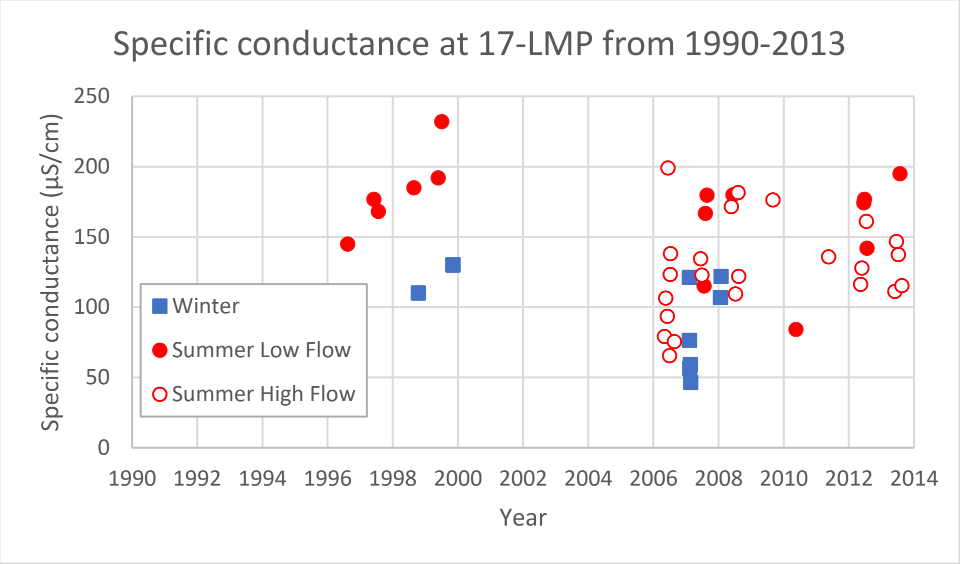


Figure 14

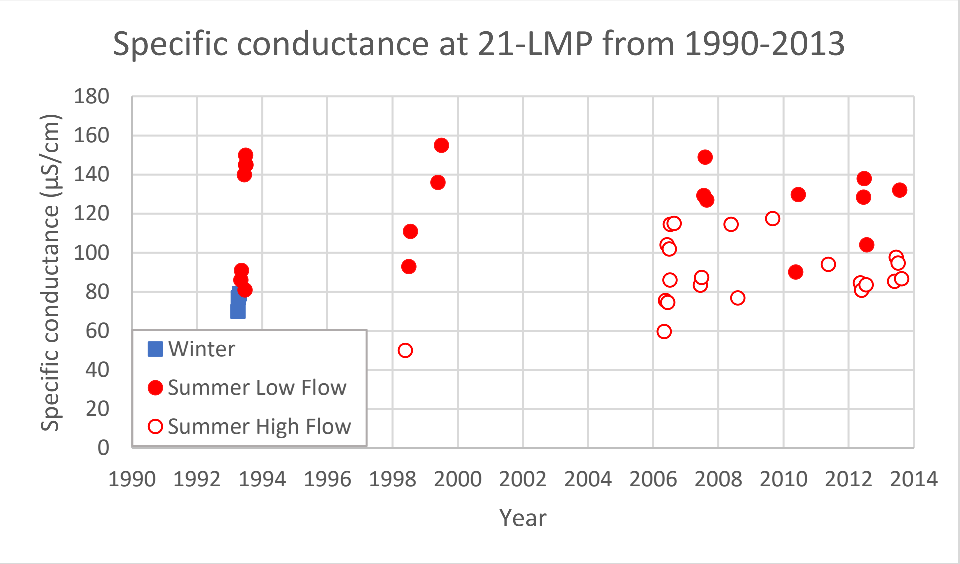


Figure 15

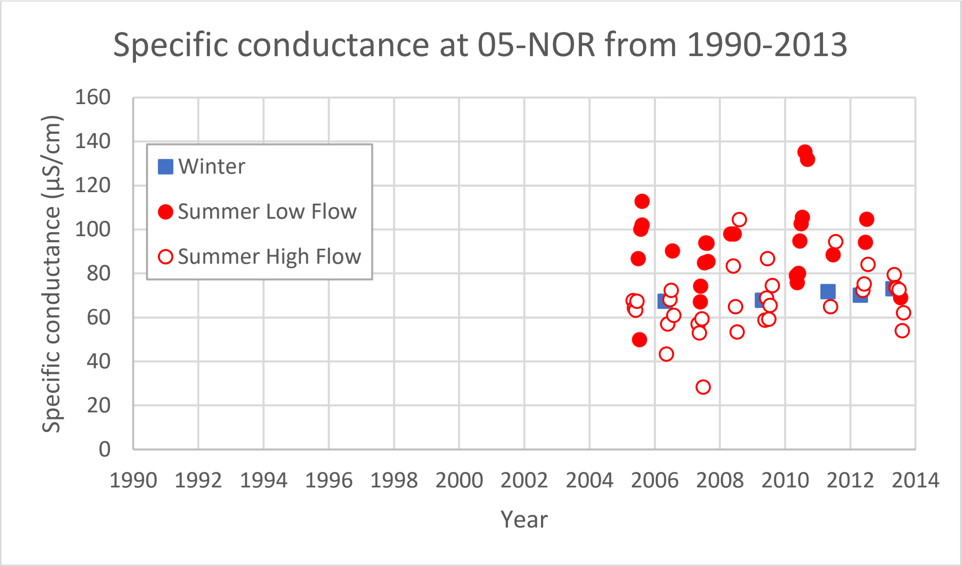


Figure 16

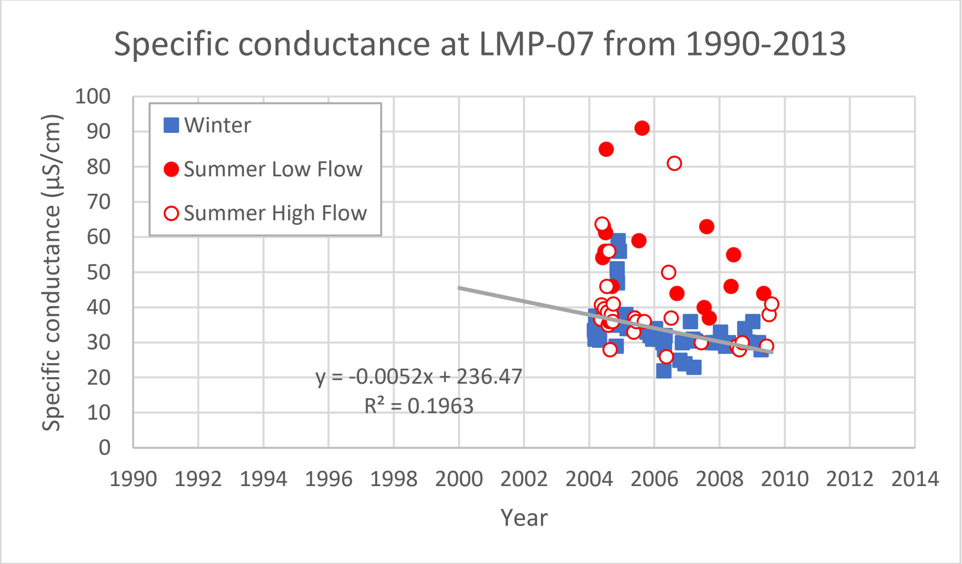


Figure 17: Winter specific conductance levels showed significantly decreasing trend over time

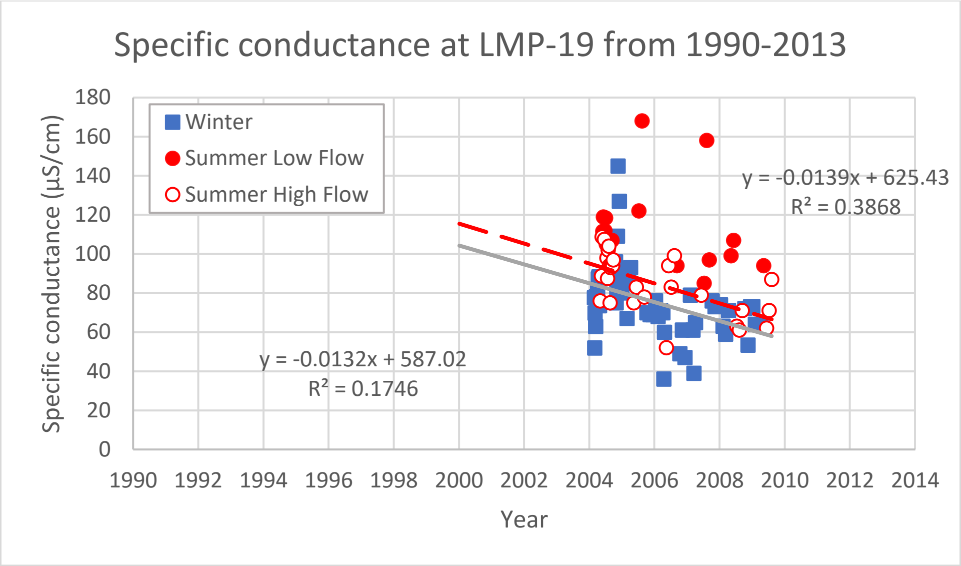


Figure 18: Summer high flow conditions and winter levels showed significantly decreasing trends over time

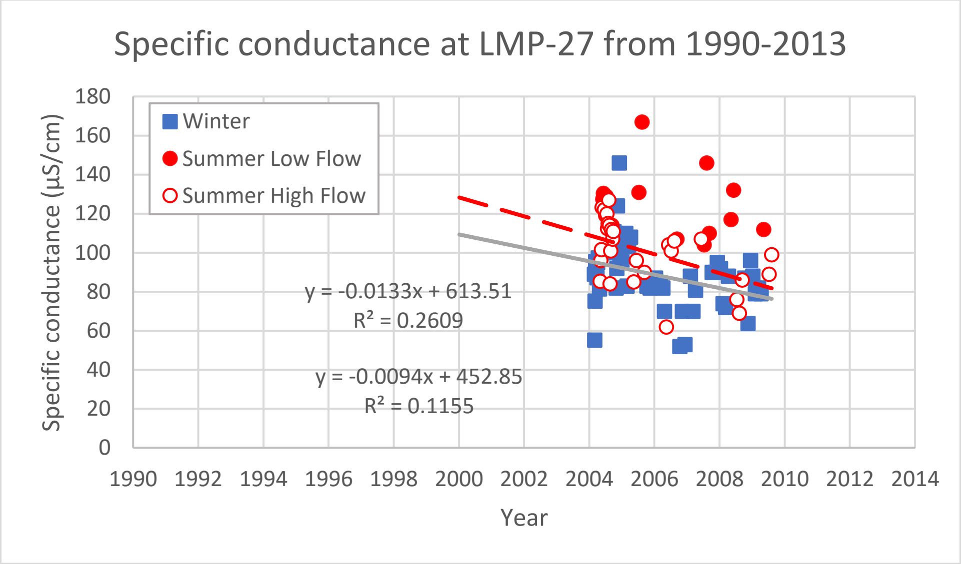


Figure 19: Summer high flow conditions and winter levels showed significantly decreasing trends over time

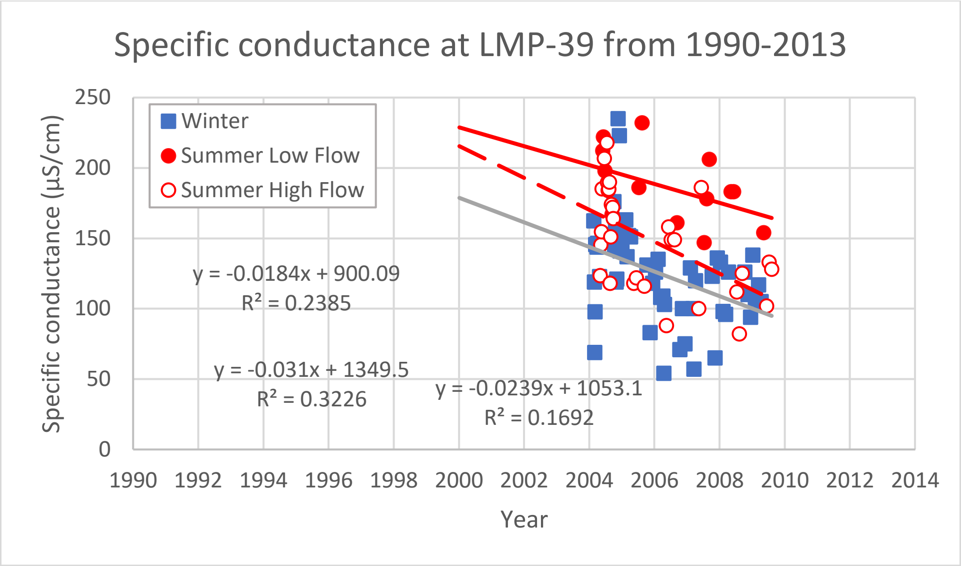


Figure 20: Summer low flow and high flow conditions and winter levels showed significantly decreasing trends over time

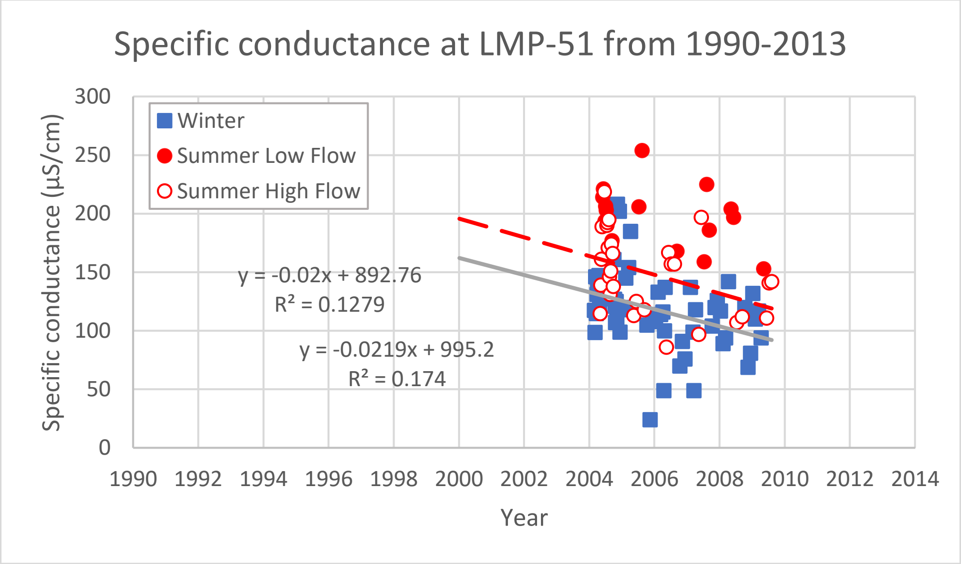


Figure 21: Summer high flow conditions and winter levels showed significantly decreasing trends over time

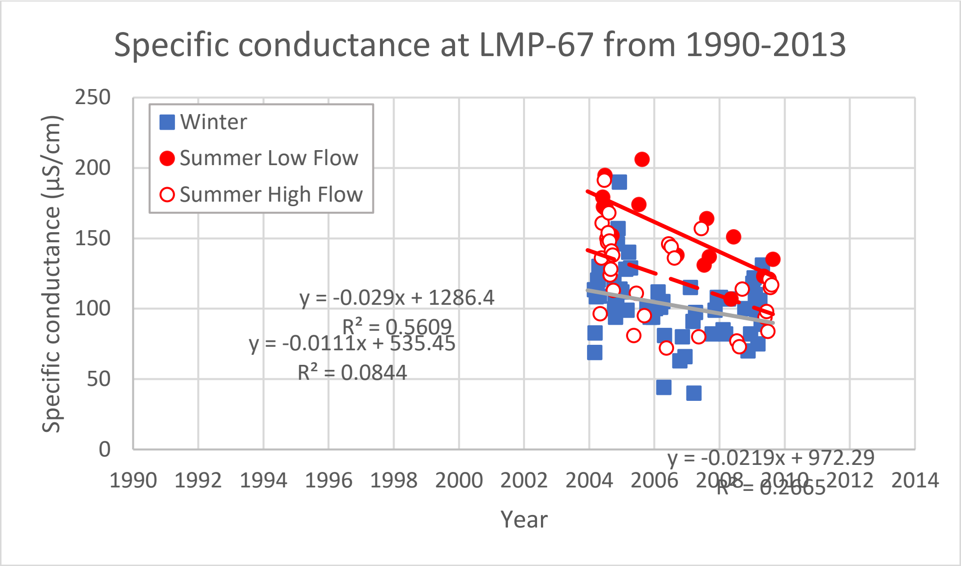


Figure 22: Summer low flow and high flow conditions and winter levels showed significantly decreasing trends over time

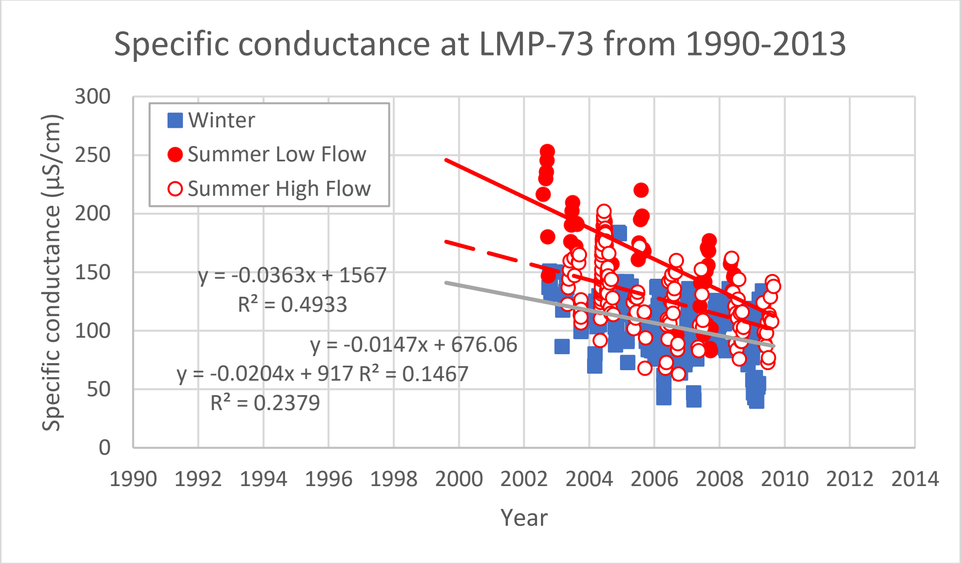


Figure 23: Summer low flow and high flow conditions and winter levels showed significantly decreasing trends over time

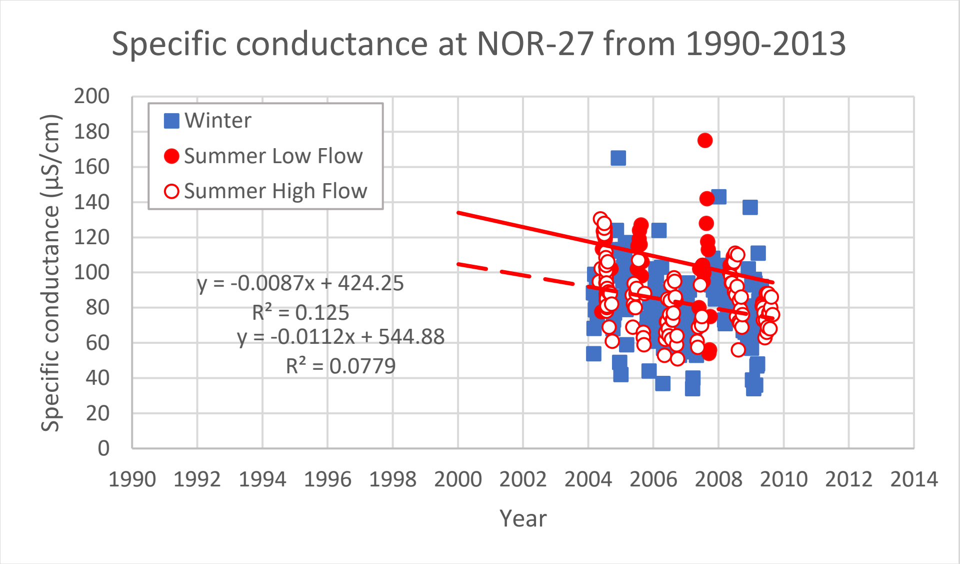


Figure 24: Summer low flow and high flow conditions showed significantly decreasing trends over time

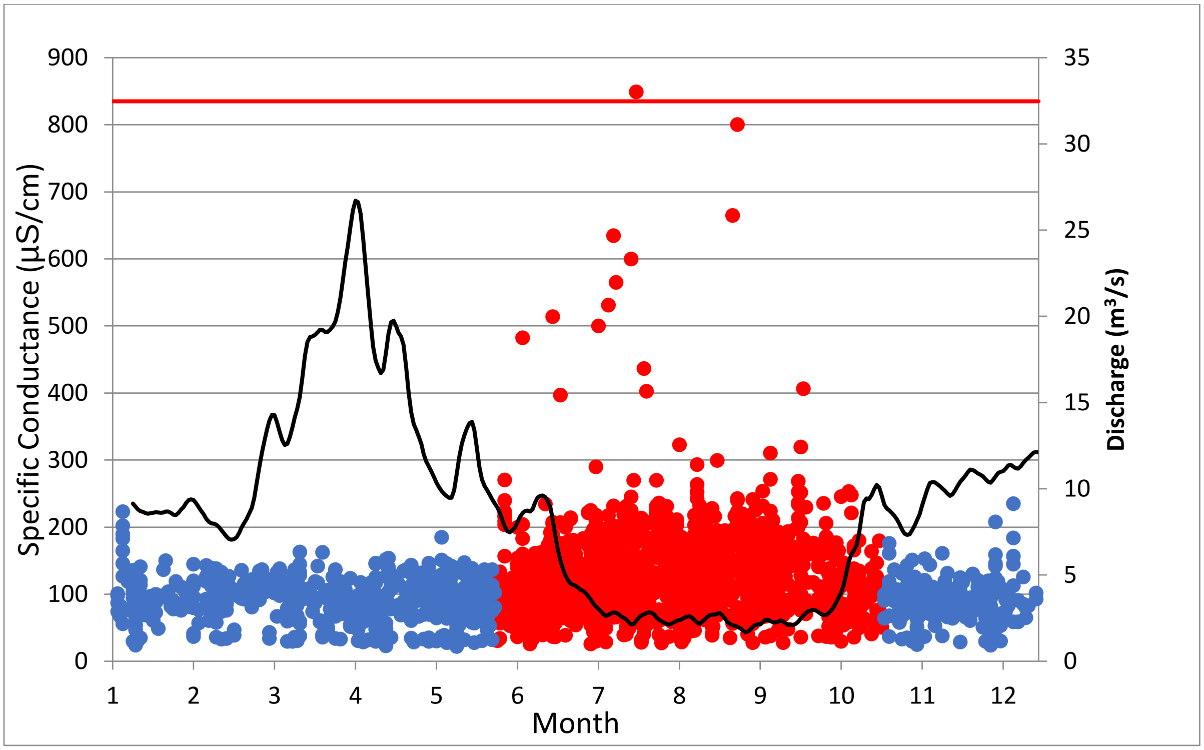


Figure 25: Seasonal specific conductance at all Lamprey River stations (1990-2013). Average daily discharge at Packers Falls (1934-2013) is shown on the secondary axis.

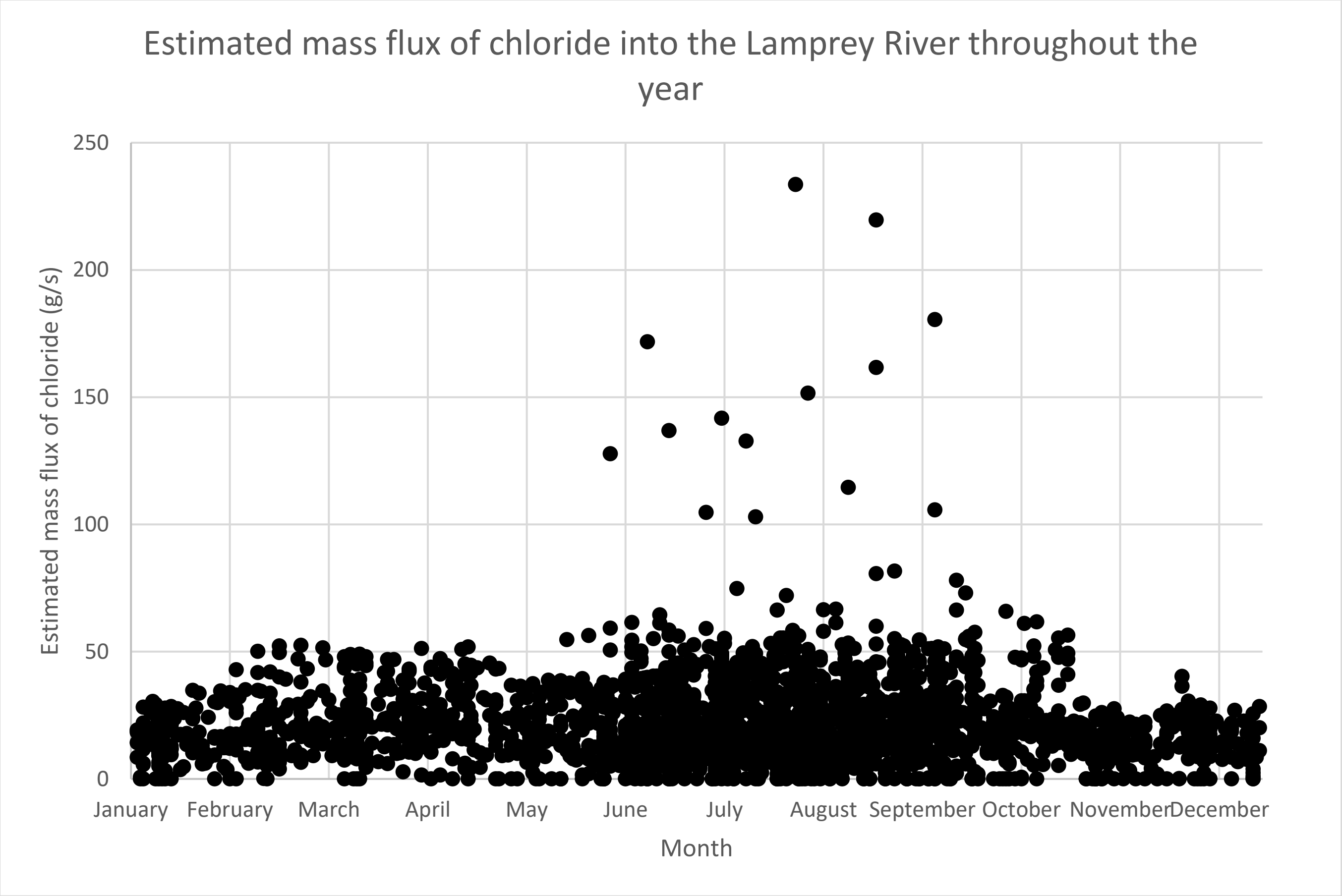


Figure 26: Estimated mass flux (see pg. 6) throughout the year. Mass flux was calculated by converting measured specific conductance values to chloride equivalent, then multiplying by the discharge recorded at Packers Falls on the day of sampling.

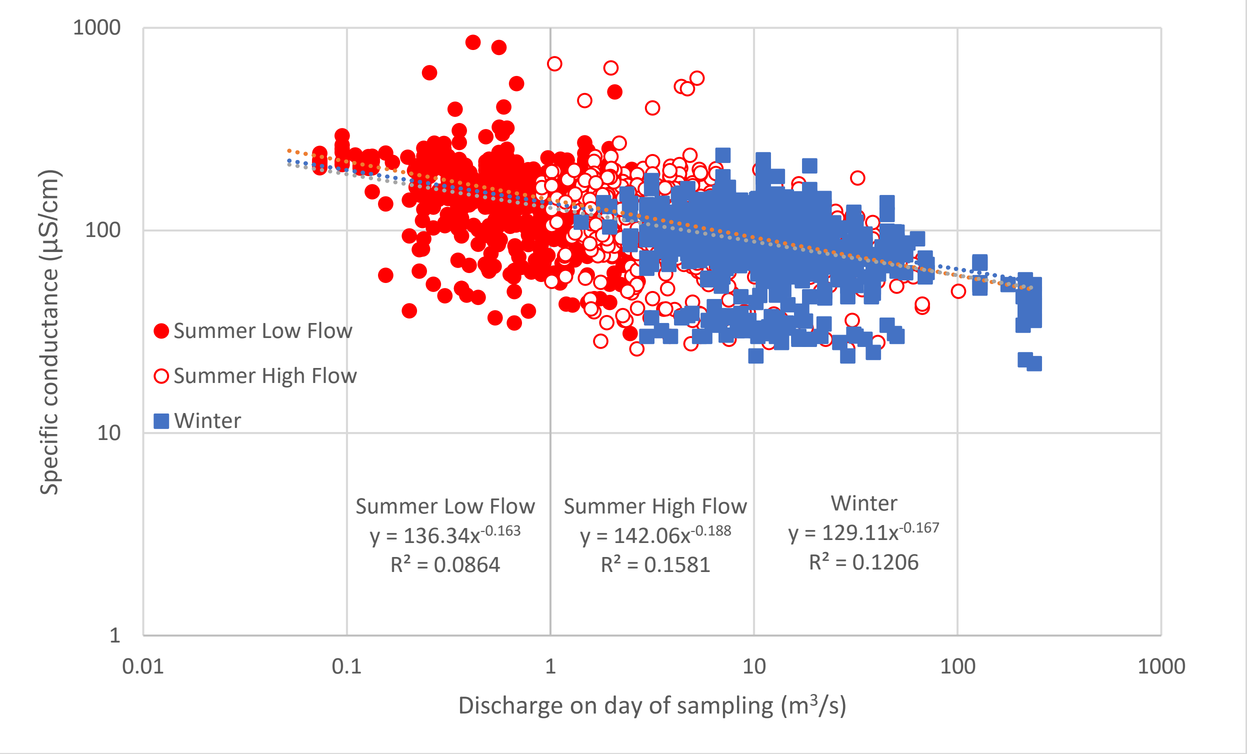


Figure 27: Relationship between discharge and specific conductance in the Lamprey River (1990-2013)

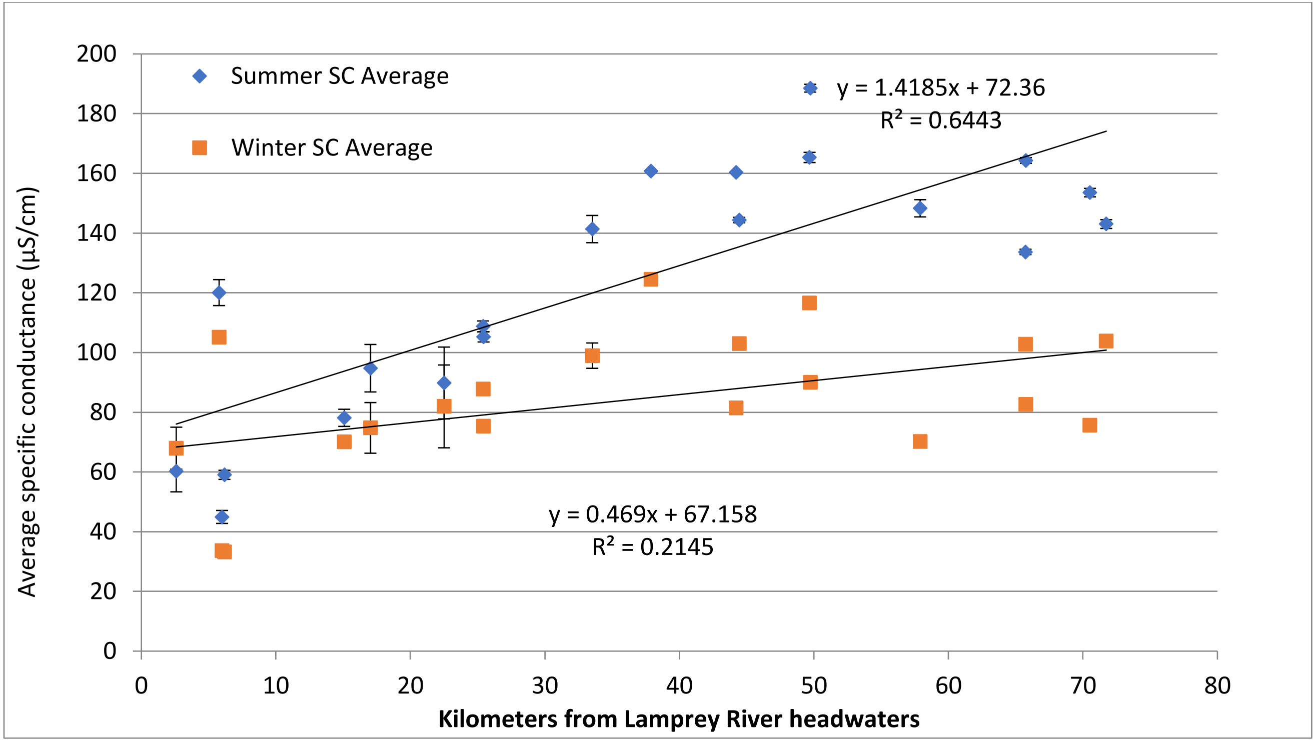
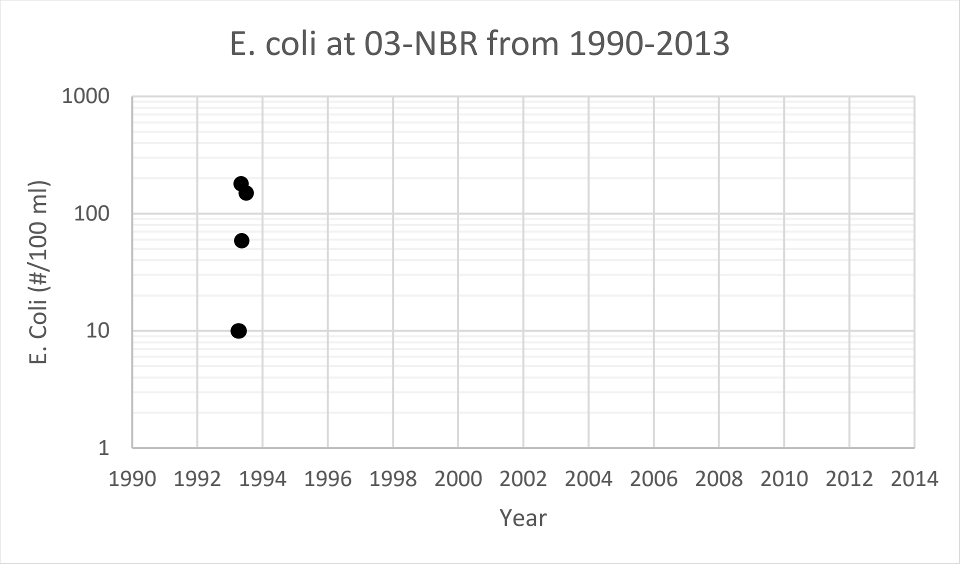


Figure 28: Average summer and winter specific conductance at each station compared to kilometers from headwaters

Appendix B – E. coli



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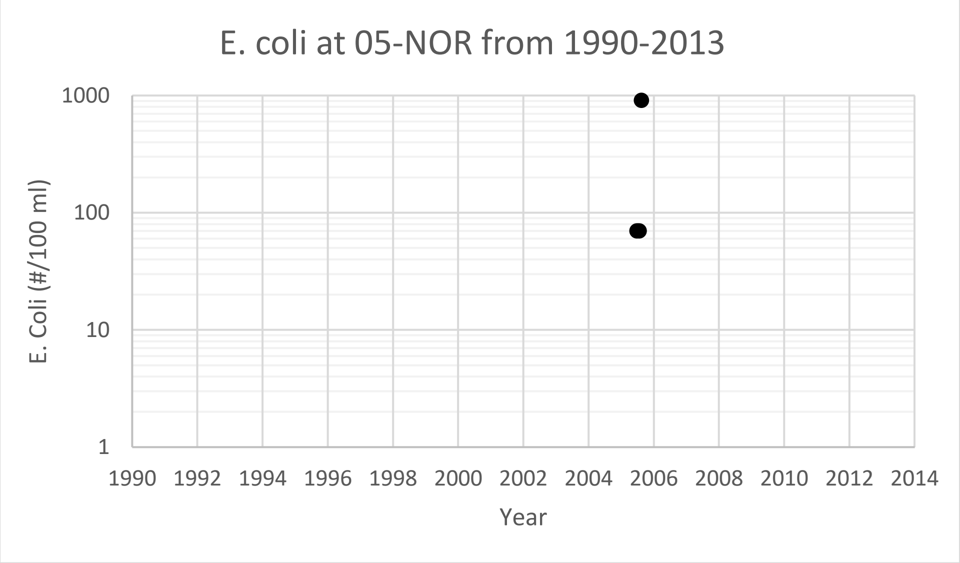

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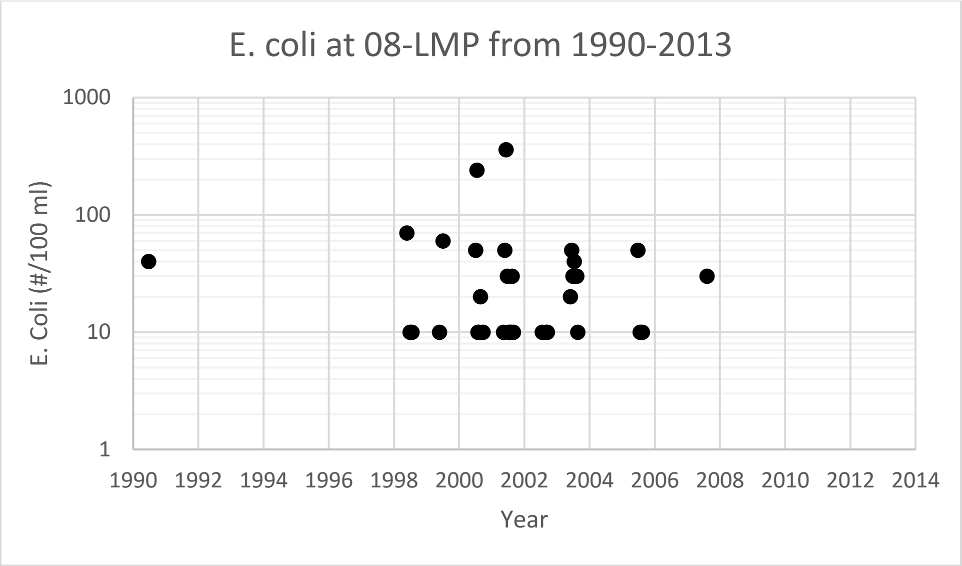

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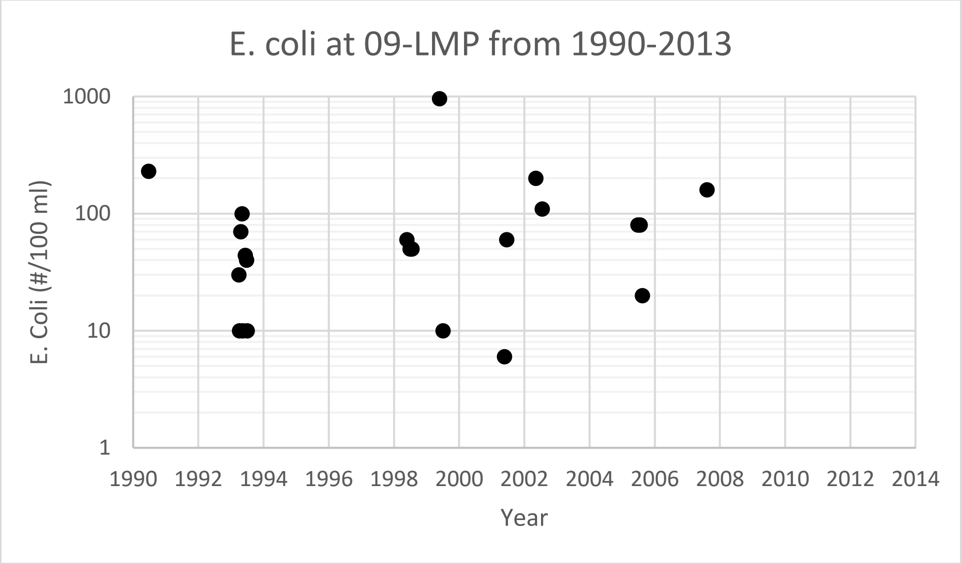

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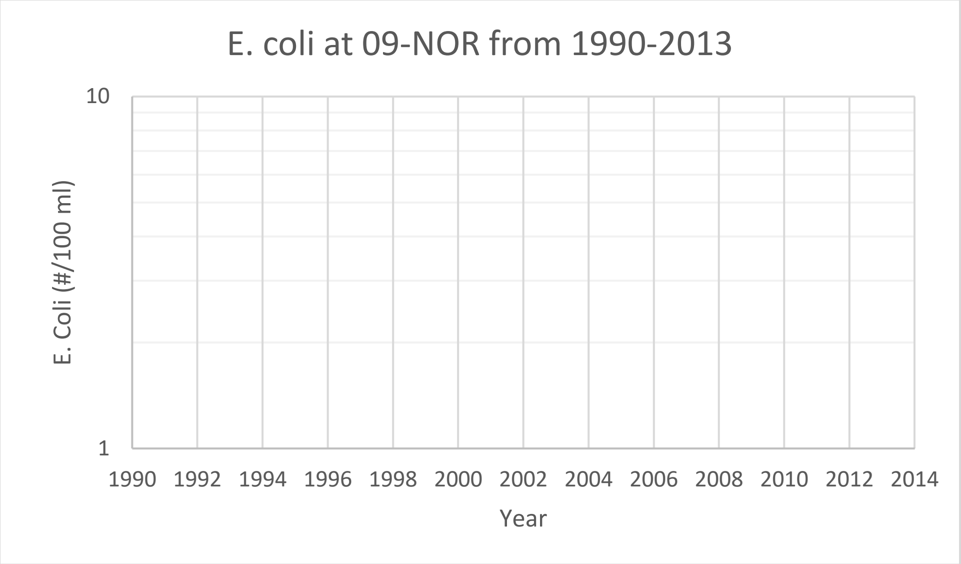

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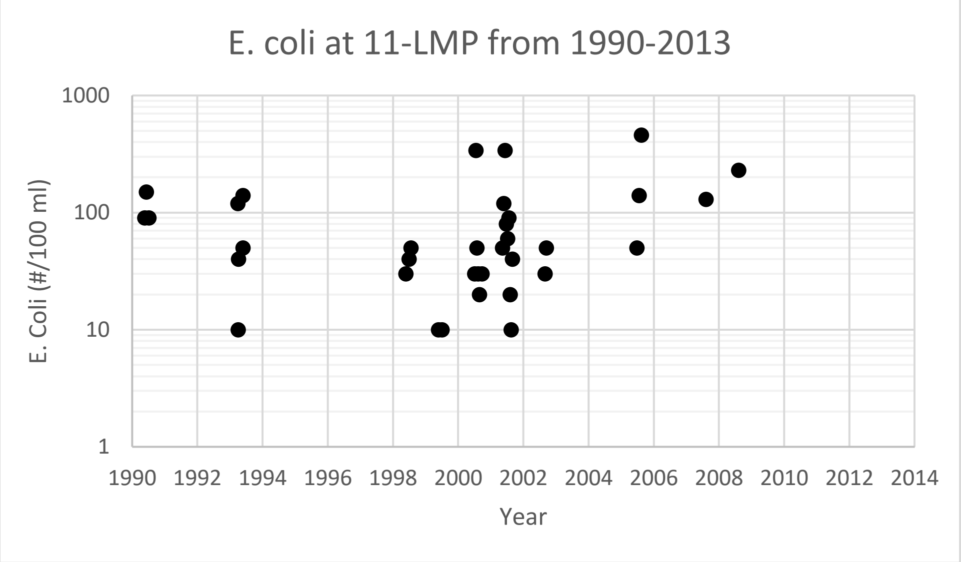

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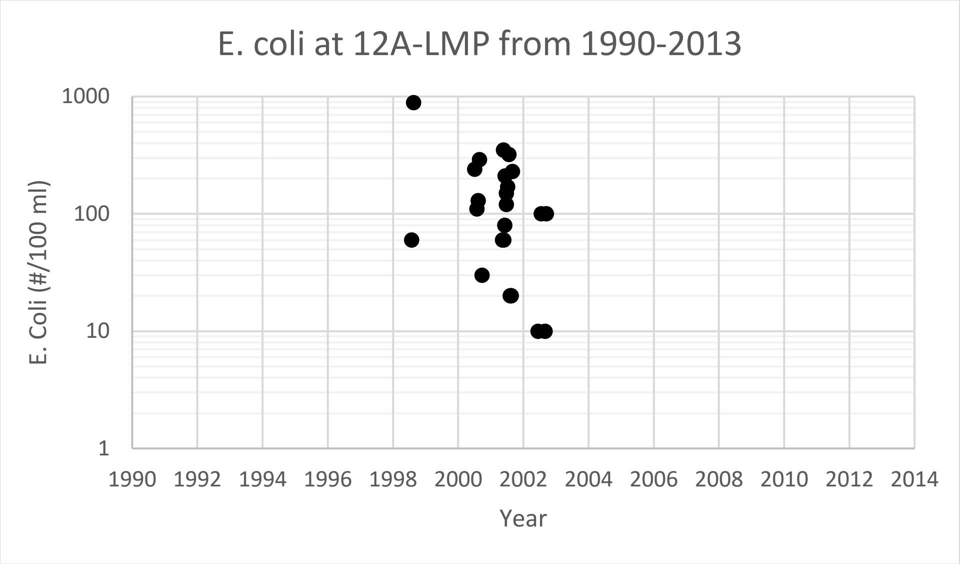

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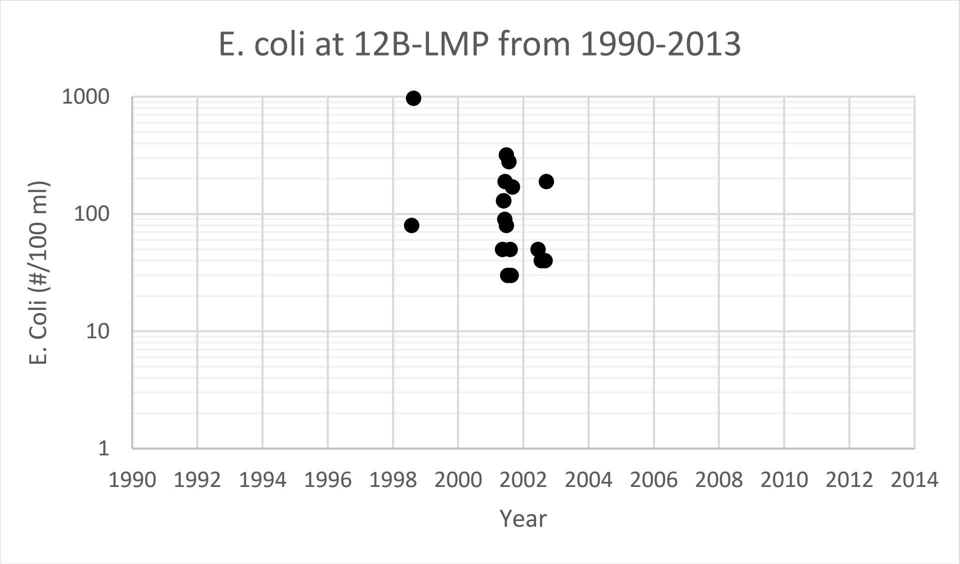

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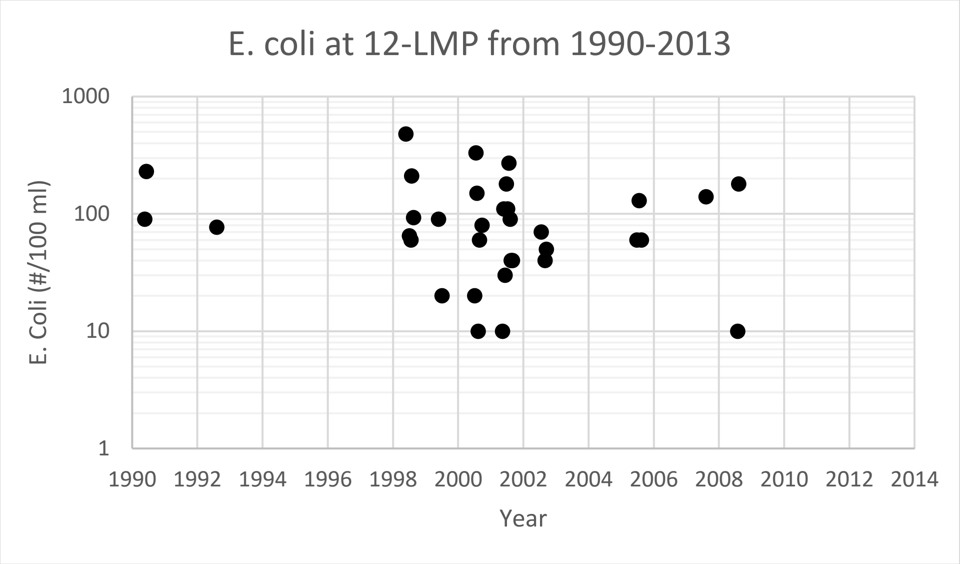

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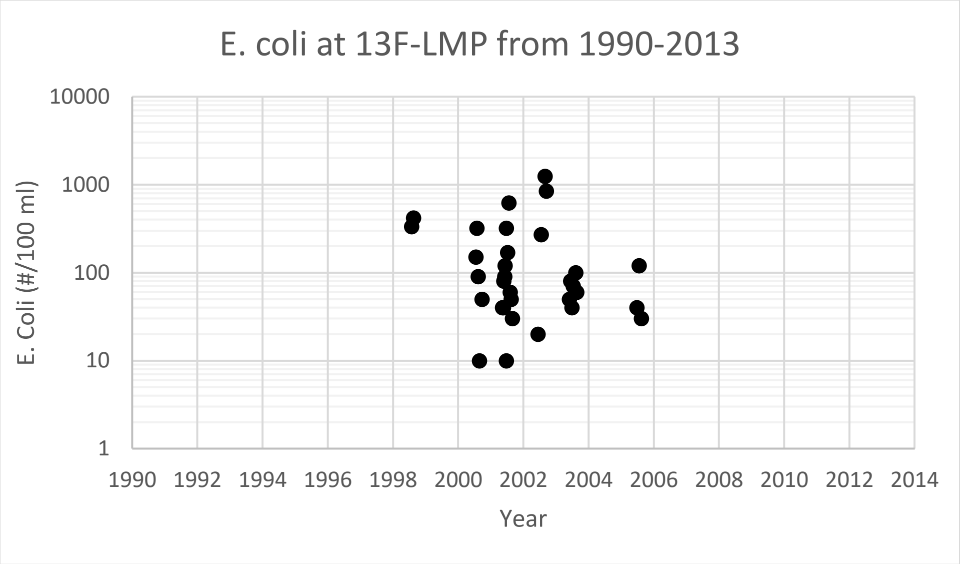

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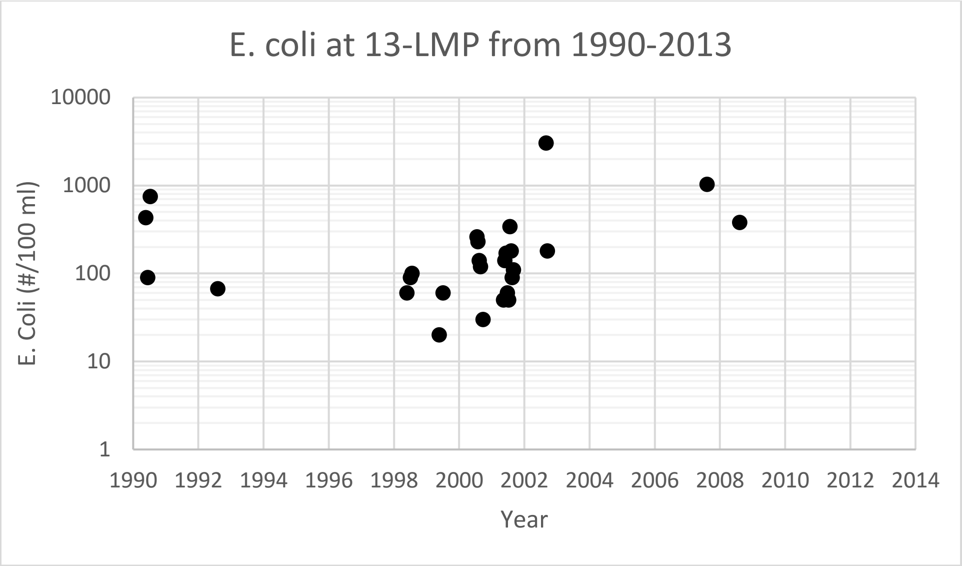

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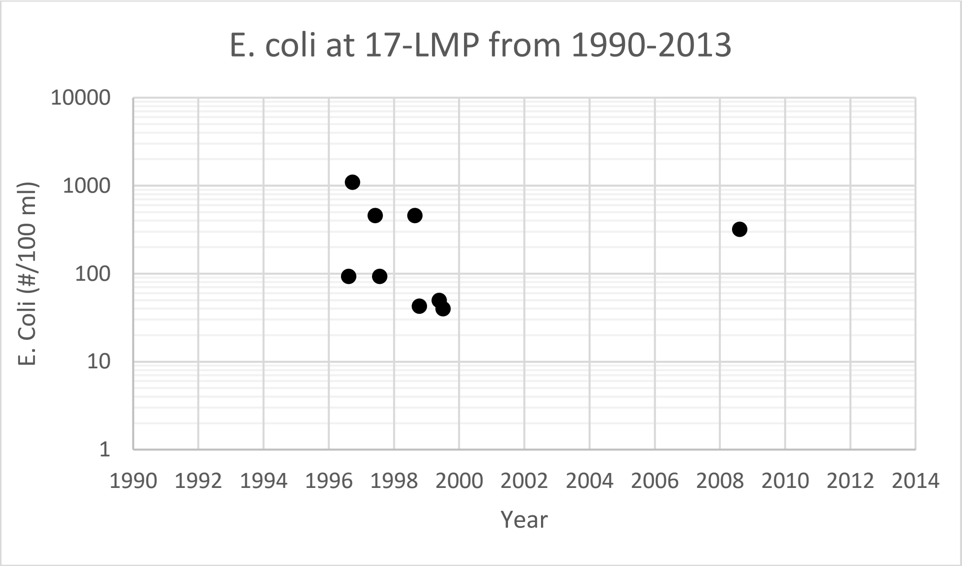

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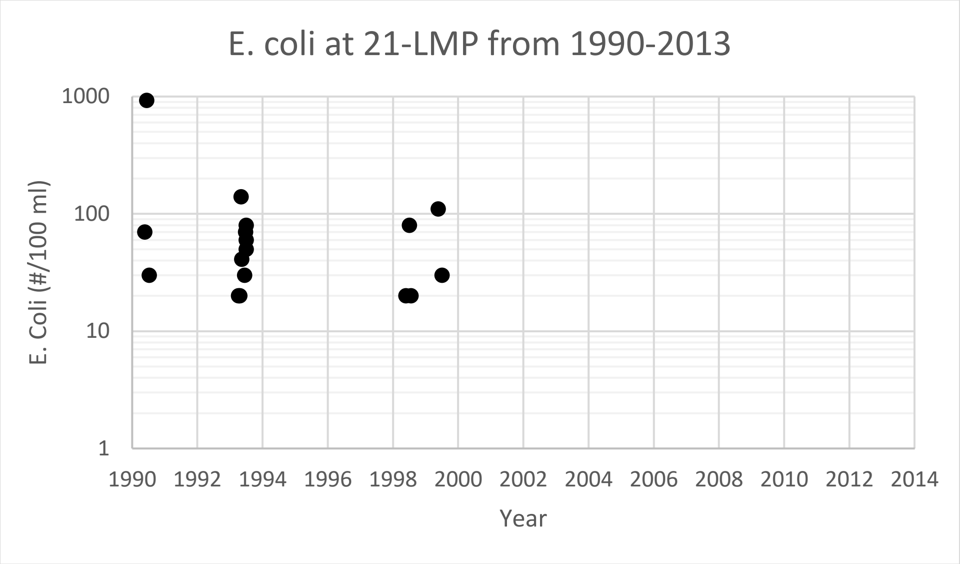

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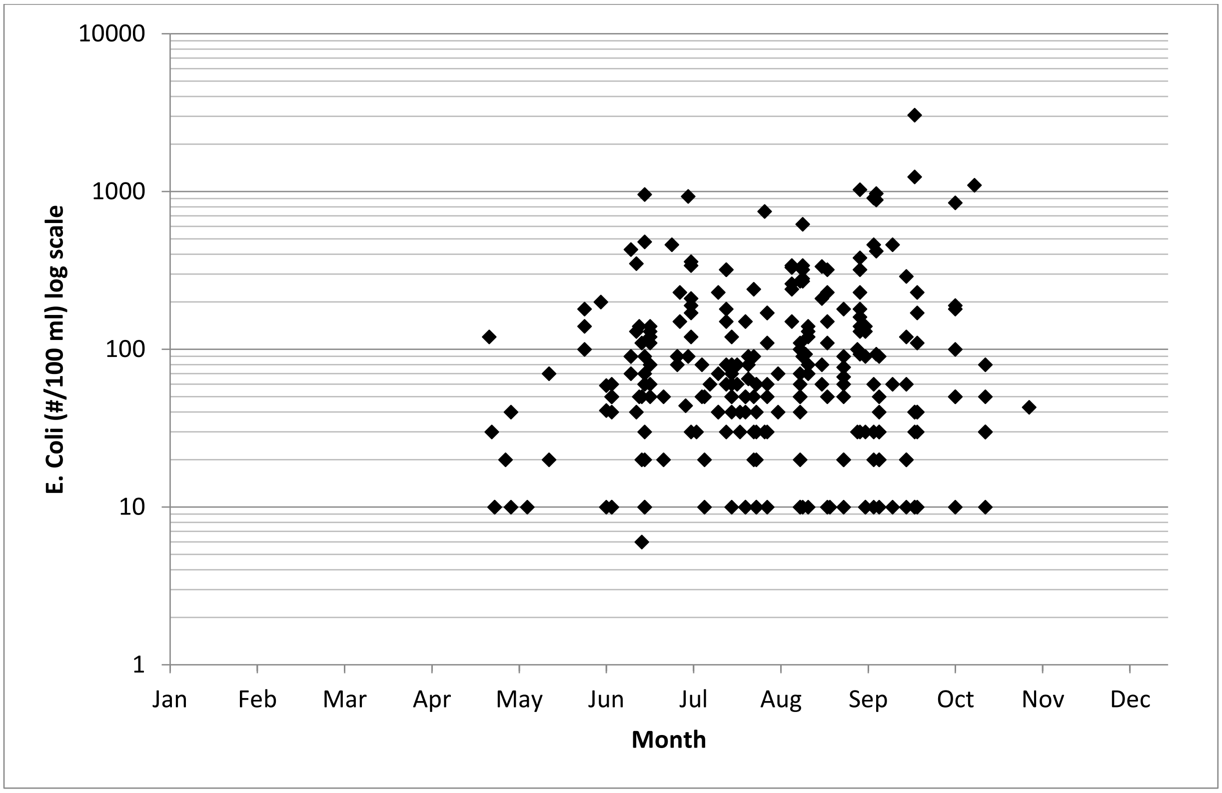


Figure 42: E. coli count at all Lamprey River stations (1990-2013). Shown on log scale.

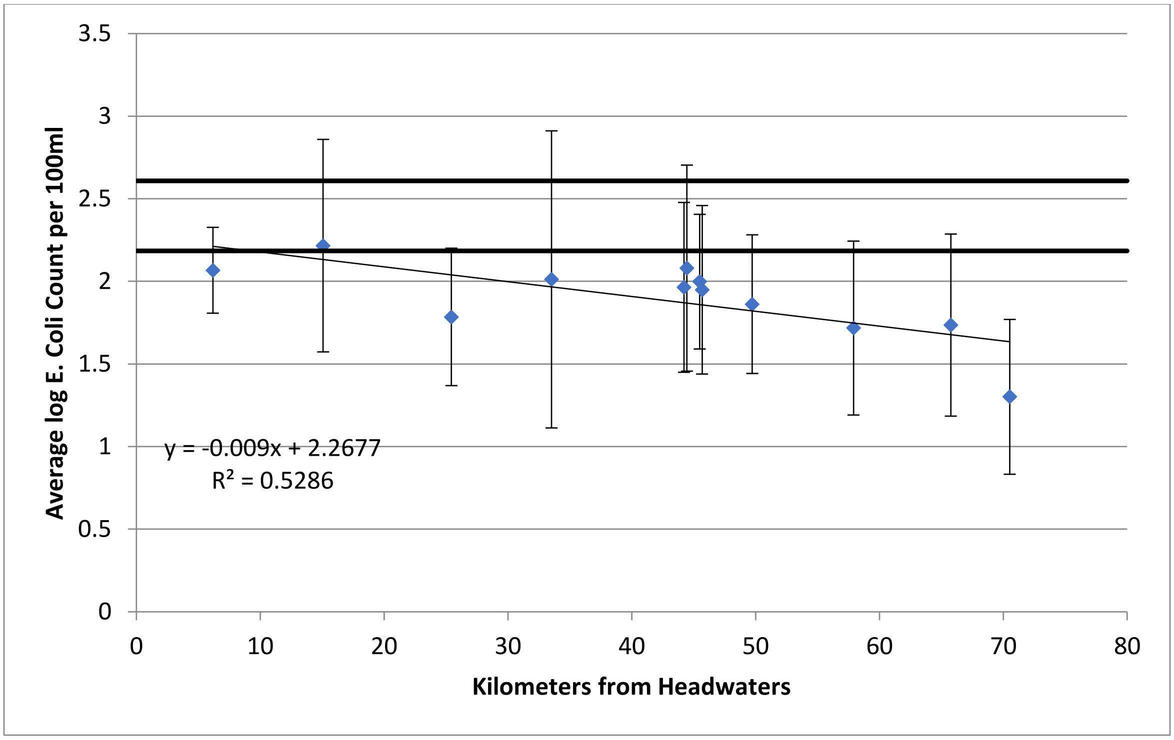


Figure 43: Average E. coli count (log-transformed) at each station compared to distance from Lamprey River headwaters

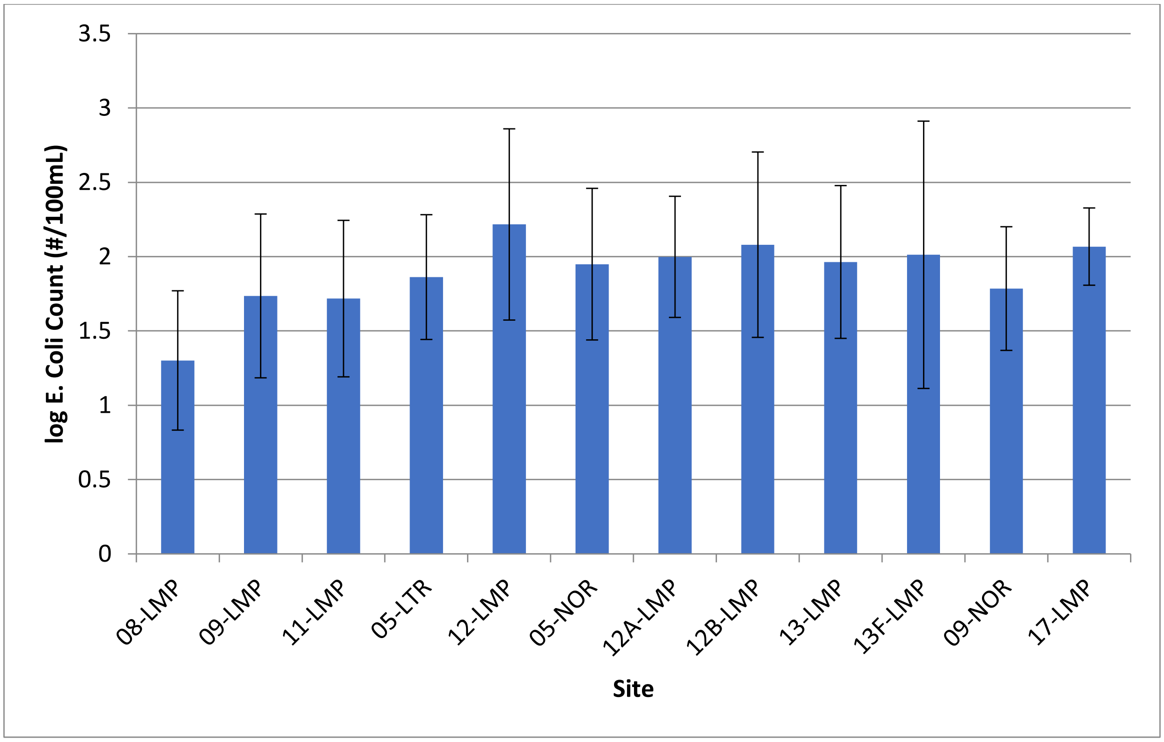


Figure 44: ***Average summer E. coli count at each station***

Appendix C - Turbidity

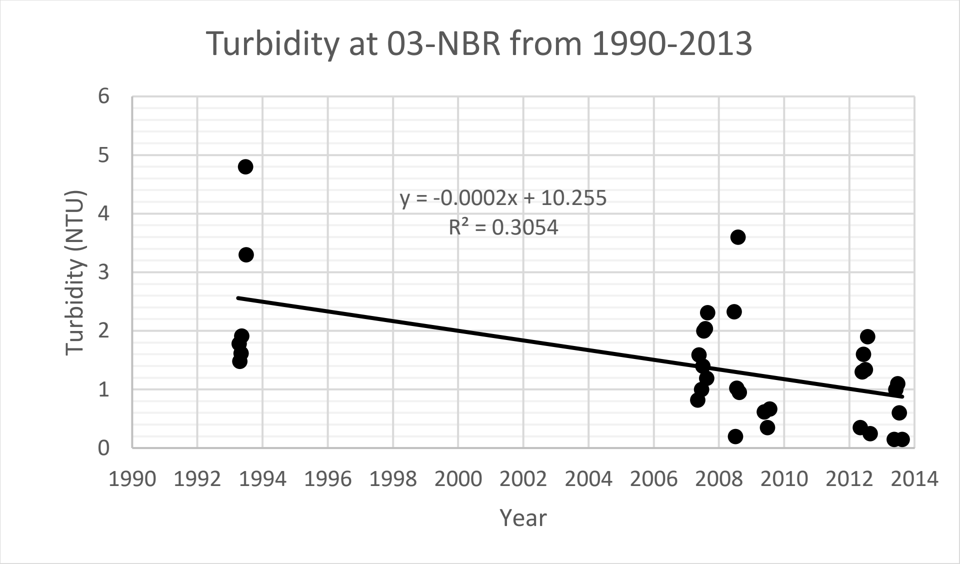


Figure 45: Significantly decreasing trend over time

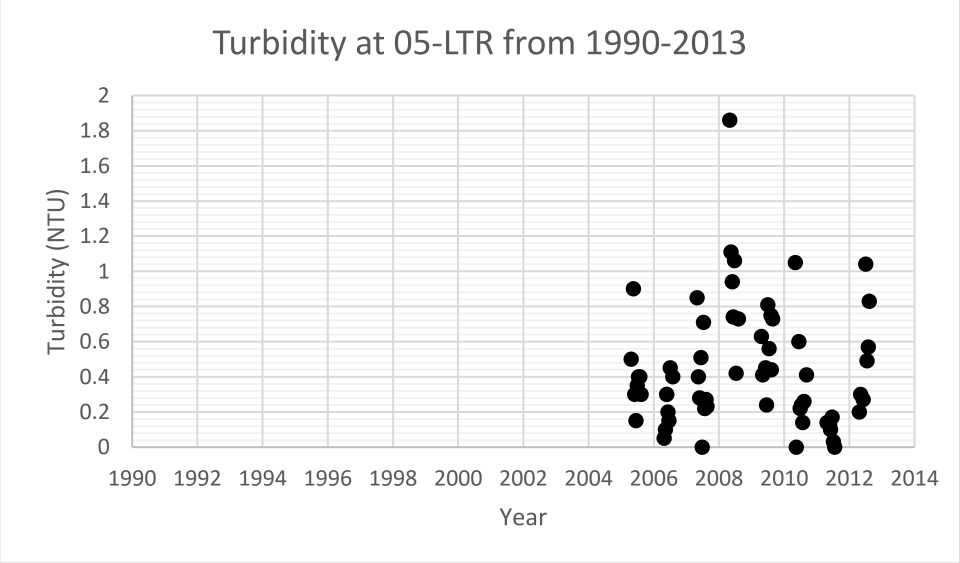


Figure 46

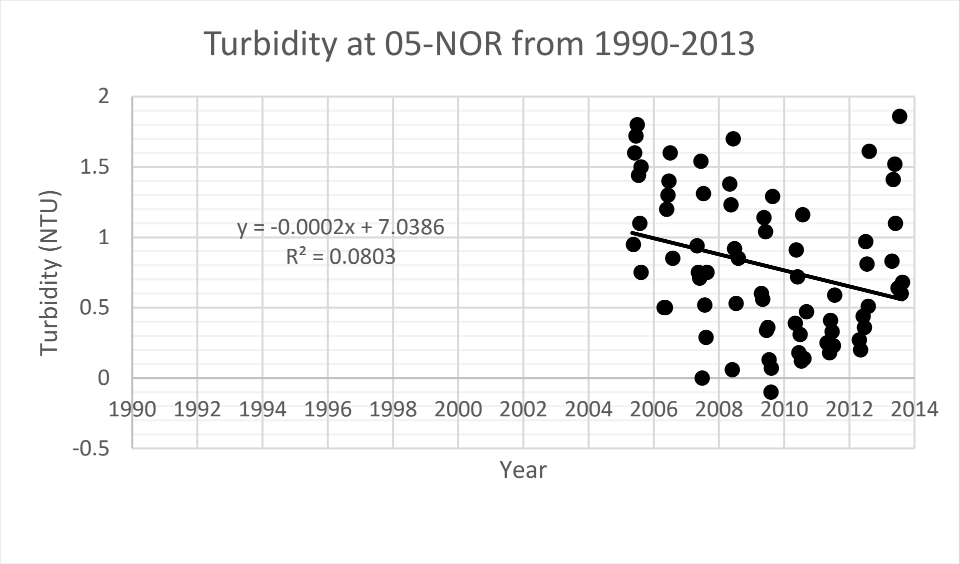
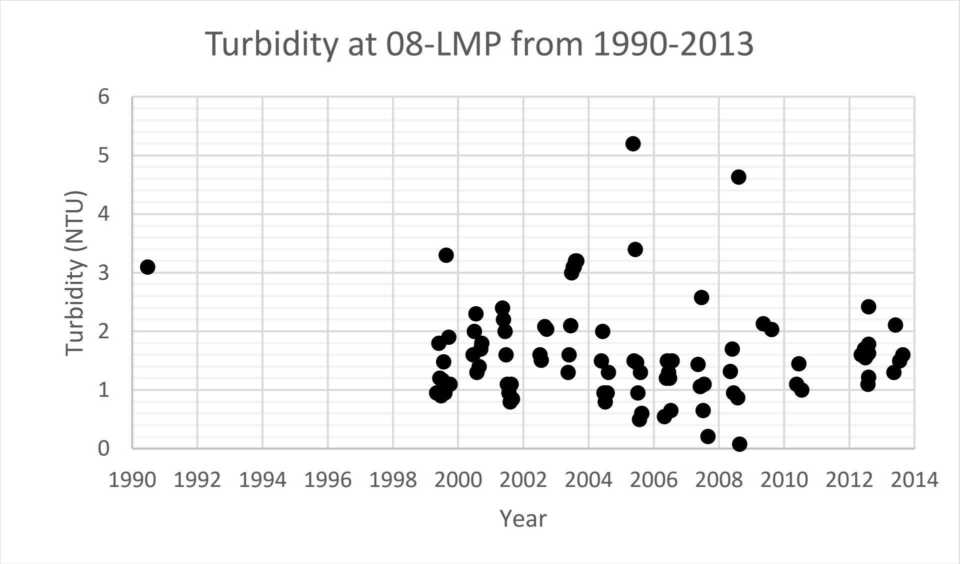


Figure 47: Significantly decreasing trend over time



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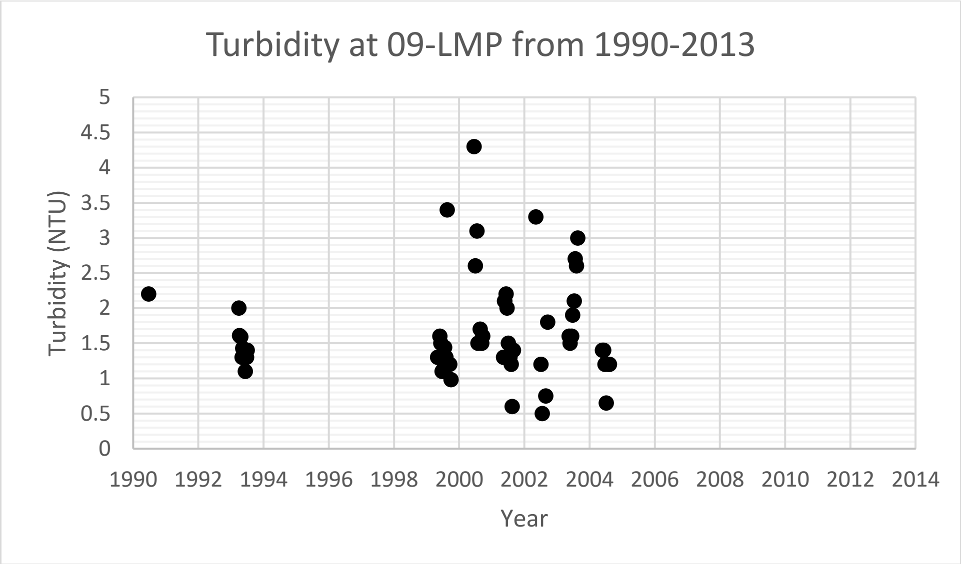

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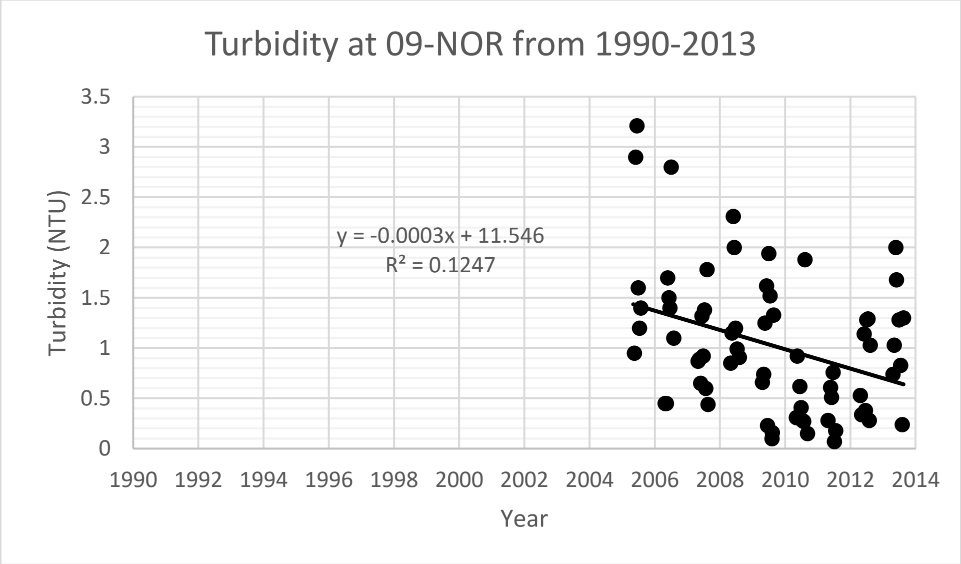
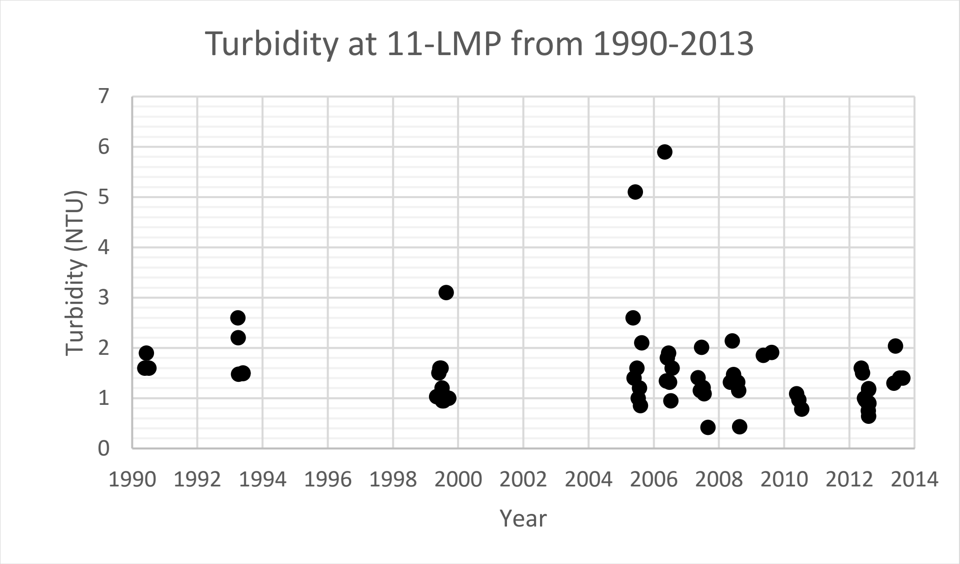


Figure 50: Significantly decreasing trend over time



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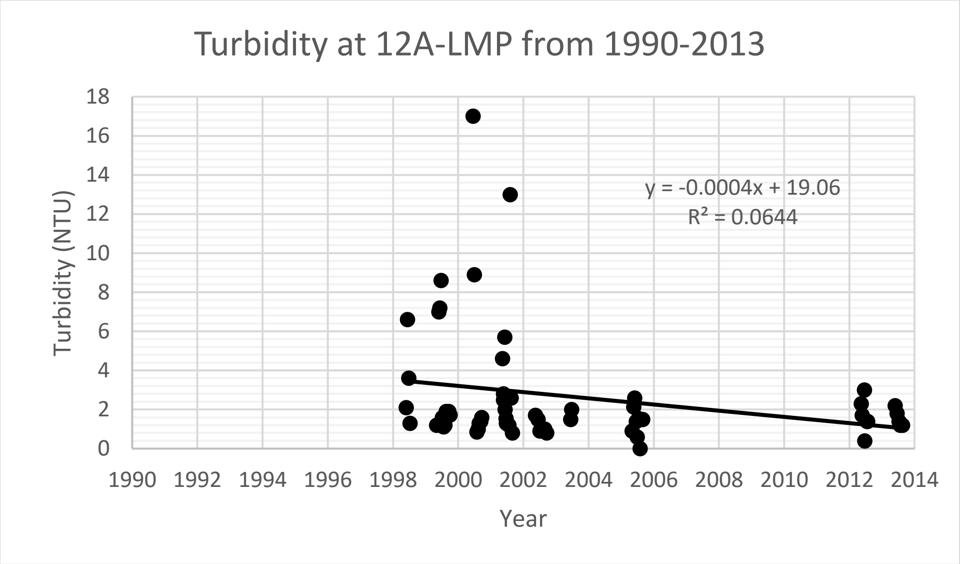
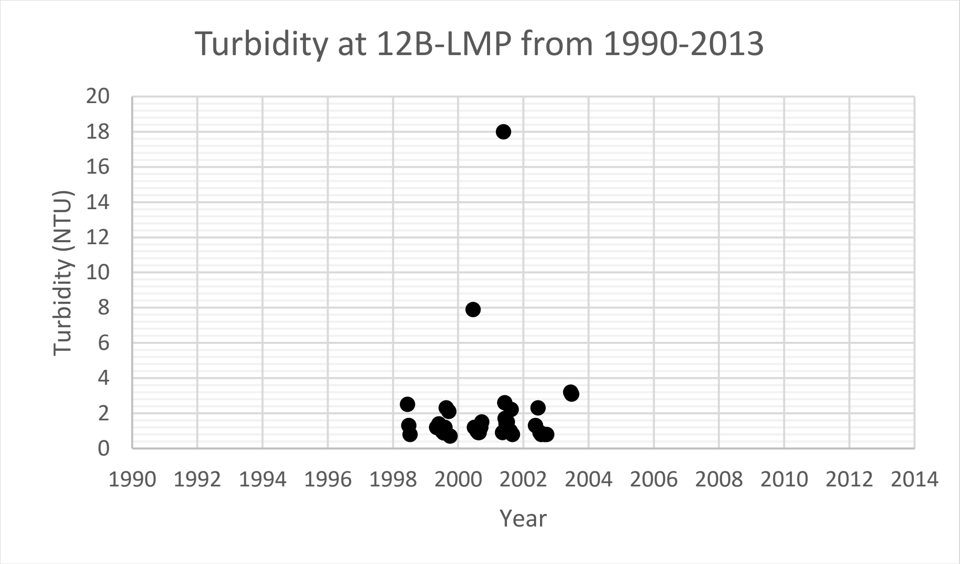


Figure 52: Significantly decreasing trend over time



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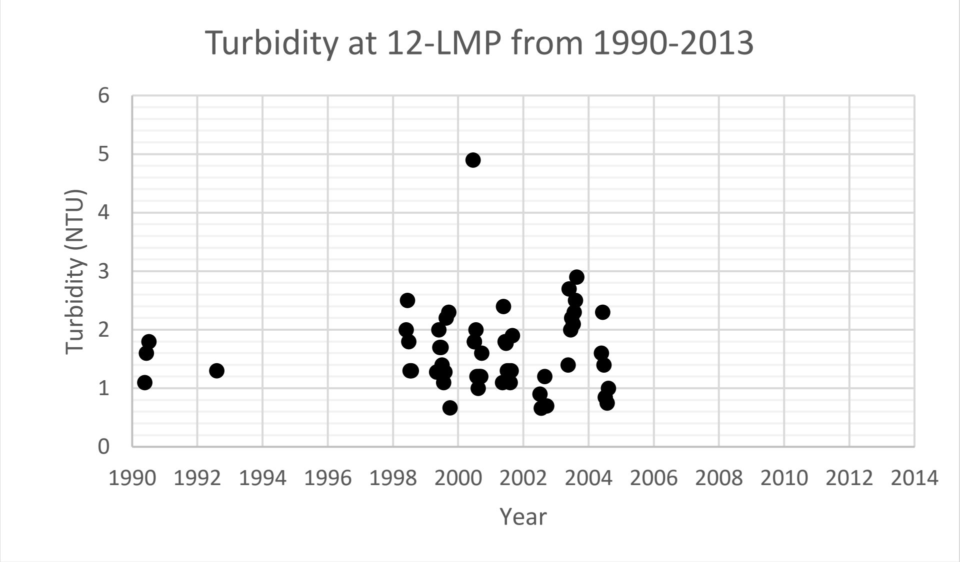

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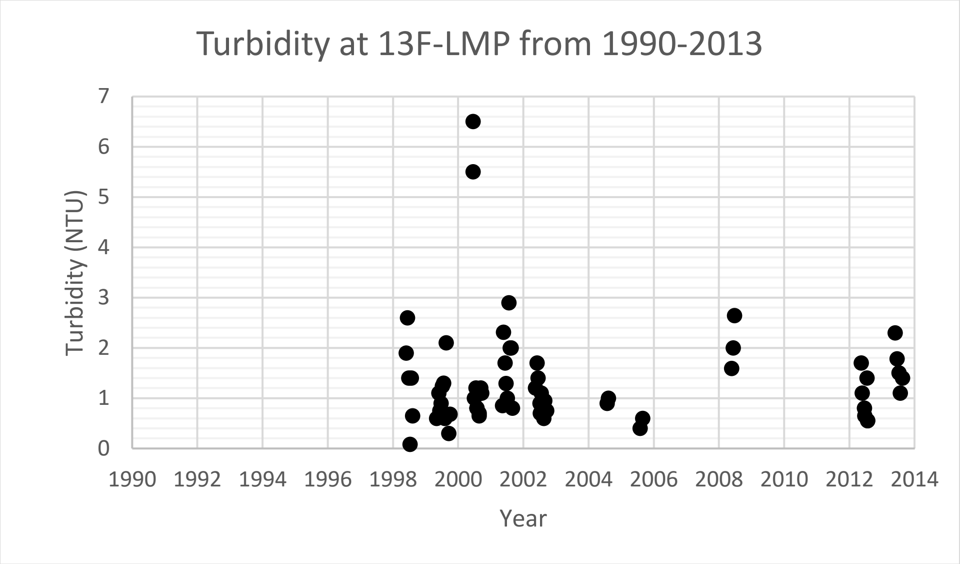

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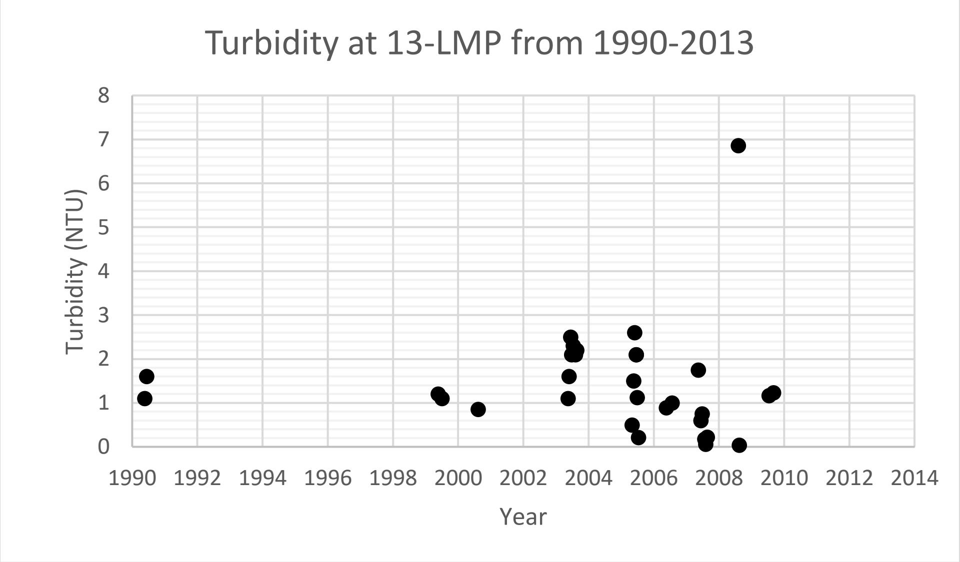

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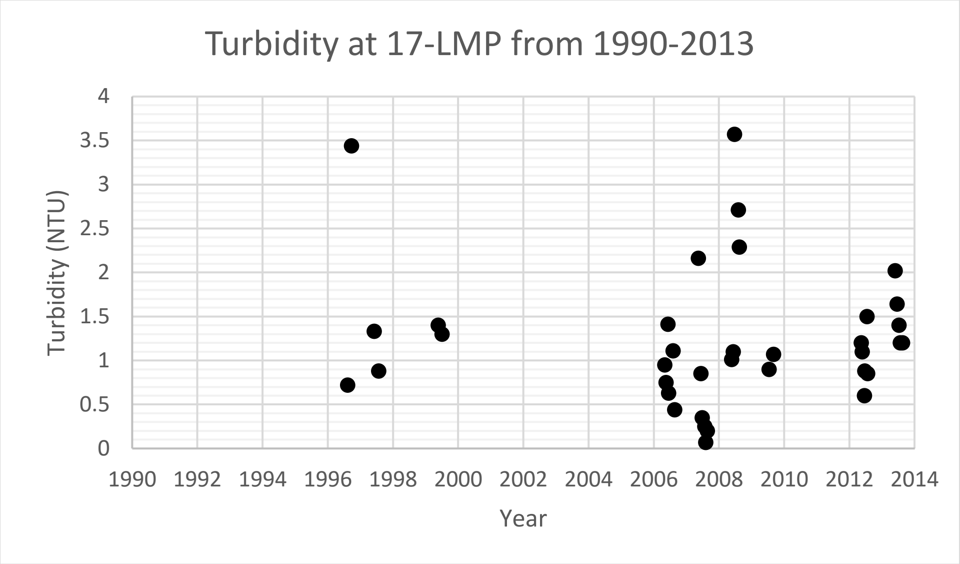

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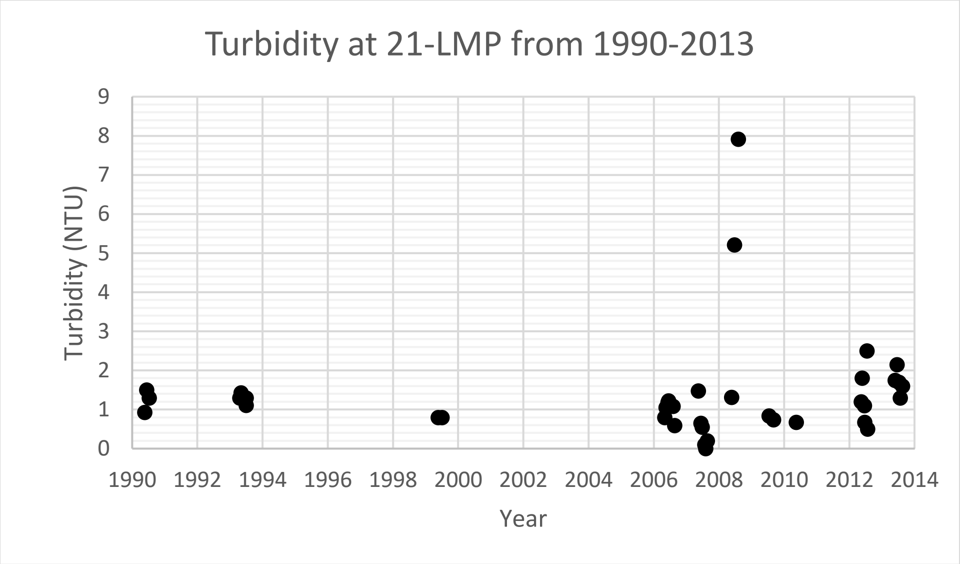

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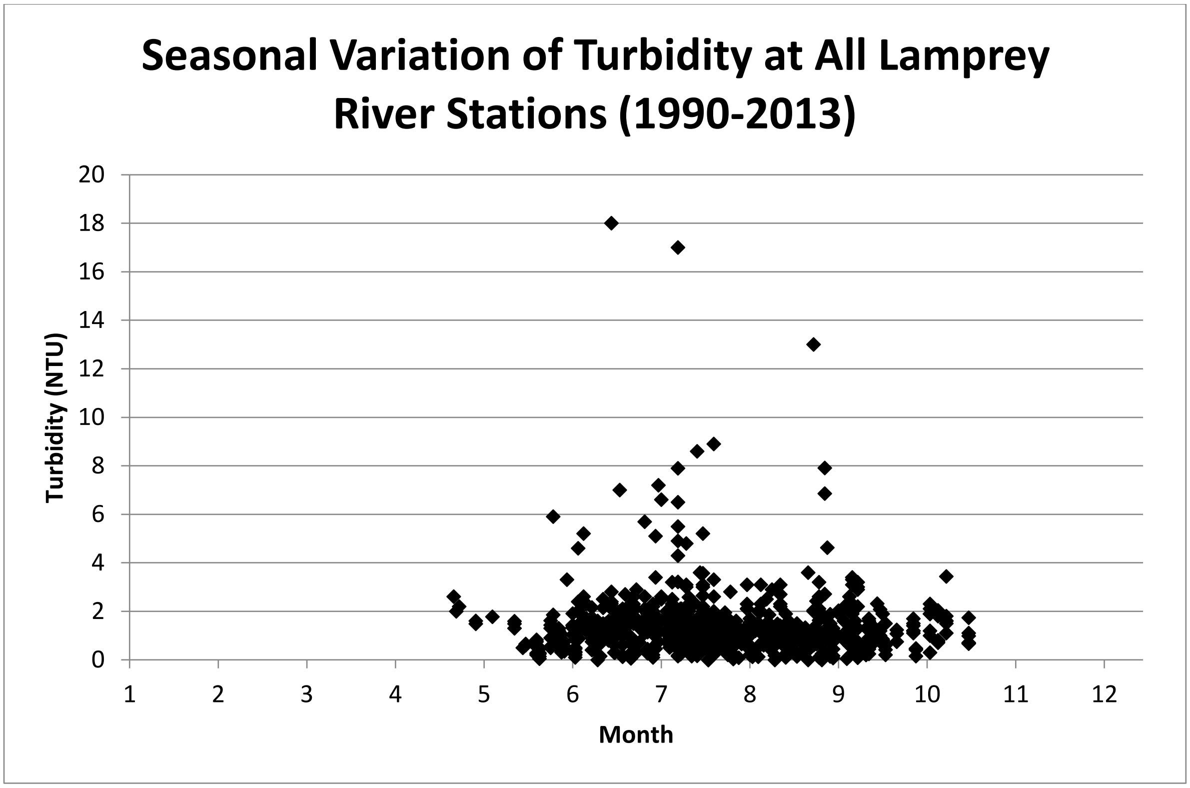

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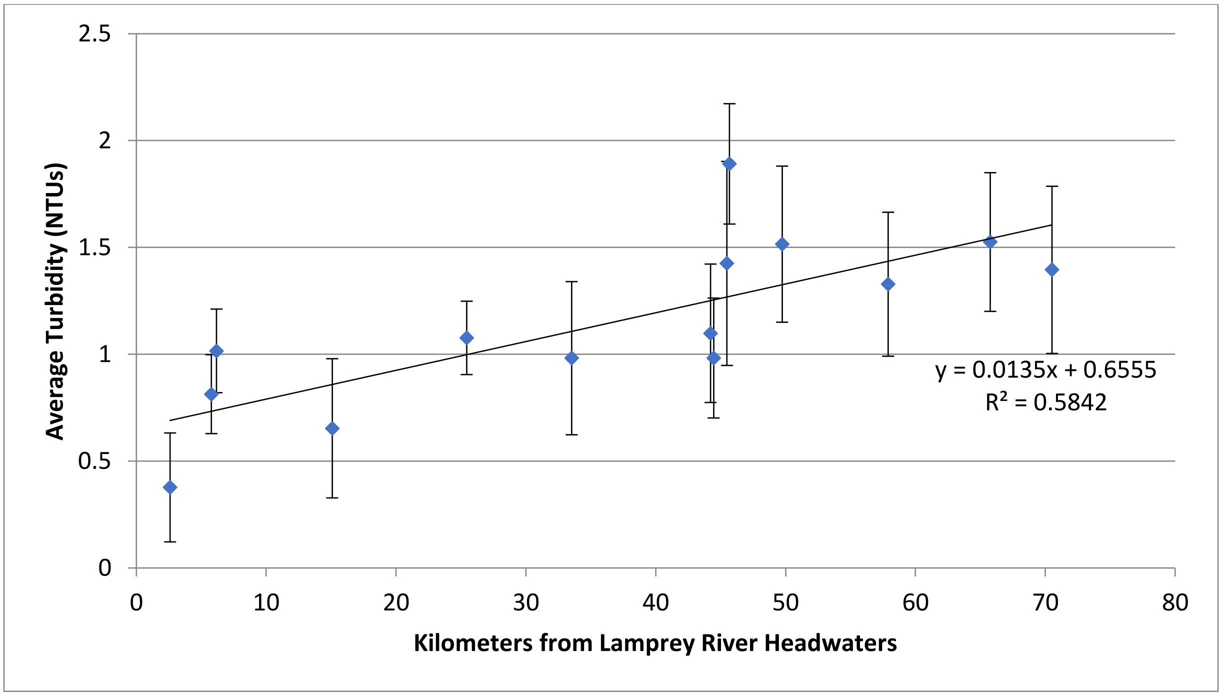

Figure 60: Average turbidity at each site compared to distance from headwaters

Appendix D – Land Cover

Table 2: Correlation coefficient r between land cover type and parameter in near-stream quarter-mile buffer to next station

Correlation	Forest	Water	Urban	Agriculture
Summer SC	-0.69625	-0.52987	0.6565755	0.54574496
Winter SC	-0.64866	-0.52545	0.7157114	0.17466441
E. Coli	-0.27294	0.023214	0.4226316	-0.3040278
Turbidity	-0.46858	-0.32982	0.2949784	0.77435689

Table 3: Correlation coefficient r between land cover type and parameter in nested subwatershed

Correlation	Forest	Water	Urban	Agriculture
Summer SC	-0.6530195	-0.1299126	0.79693048	0.36086294
Winter SC	-0.7201457	0.14494418	0.72819626	0.47877621
E. Coli	0.28032336	-0.0100193	-0.2476439	-0.3443065
Turbidity	-0.4989784	-0.7014511	0.78394976	0.44532379

Table 4: Location of each station with measurements in the Lamprey River watershed

Station ID	Station Name	Hydrologic Unit Code Name	River Name	Station Latitude	Station Longitude
03-NBR	NEW BOSTON RD	NORTH BRANCH RIVER	North Branch	43.0790610	-71.2853280
05-LTR	LITTLE RIVER SMOKE STREET BRIDGE	LITTLE RIVER	Little River	43.1459330	-71.0601970
05-NOR	MCCRILLIS ROAD BRIDGE	NORTH RIVER	North River	43.1166610	-71.0832780
08-LMP	WISWALL RD BRIDGE	LOWER LAMPREY RIVER	Lamprey mainstem	43.1045830	-70.9631560
09-LMP	LEE HOOK RD LEE	LOWER LAMPREY RIVER	Lamprey mainstem	43.1140110	-71.0050190
09-NOR	FREEMAN HALL ROAD BRIDGE	BEAN RIVER	North River	43.1634110	-71.1109080
11-LMP	RTE 152 - WADLEIGH FALLS	LOWER LAMPREY RIVER	Lamprey mainstem	43.0913530	-71.0070670
12A-LMP	DOWNSTREAM OF EPPING WWTF	MIDDLE LAMPREY RIVER	Lamprey mainstem	43.0391170	-71.0570420
12B-LMP	UPSTREAM OF EPPING WWTF	MIDDLE LAMPREY RIVER	Lamprey mainstem	43.0388970	-71.0594190
12-LMP	RTE 87 BRIDGE	MIDDLE LAMPREY RIVER	Lamprey mainstem	43.0496250	-71.0331780
13F-LMP	MILL ST BRIDGE	MIDDLE LAMPREY RIVER	Lamprey mainstem	43.0381420	-71.0709860
13-LMP	ROUTE 125 BRIDGE	MIDDLE LAMPREY RIVER	Lamprey mainstem	43.0367030	-71.0689310
17-LMP	PRESCOTT ROAD BRIDGE D.S. OF DEAD POND	MIDDLE LAMPREY RIVER	Lamprey mainstem	43.0225060	-71.1513780
21-LMP	LANGFORD RD	MIDDLE LAMPREY RIVER	Lamprey mainstem	43.0415610	-71.2020470
GBCW-14	FOWLERS DOCK ON THE LAMPREY RIVER	LOWER LAMPREY RIVER	Lamprey mainstem	43.0825000	-70.9358330
LMP-07	LAMPREY RIVER AT BLAKES HILL RD	HEADWATERS-LAMPREY RIVER	Lamprey mainstem	43.1627560	-71.2334490
LMP-19	LAMPREY RIVER AT COTTON RD	HEADWATERS-LAMPREY RIVER	Lamprey mainstem	43.0882760	-71.2346870
LMP-27	LAMPREY RIVER AT LANGFORD RD	MIDDLE LAMPREY RIVER	Lamprey mainstem	43.0417780	-71.2021930
LMP-39	LAMPREY RIVER AT LAMPREY LANE	MIDDLE LAMPREY RIVER	Lamprey mainstem	43.0410280	-71.1289670
LMP-51	LAMREY RIVER AT RTE 87	MIDDLE LAMPREY RIVER	Lamprey mainstem	43.0493070	-71.0326670
LMP-67	LAMPREY RIVER AT LEE HOOK RD	LOWER LAMPREY RIVER	Lamprey mainstem	43.1139090	-71.0052820
LMP-73	LAMPREY RIVER AT PACKERS FALLS RD	LOWER LAMPREY RIVER	Lamprey mainstem	43.1029650	-70.9521600
NOR-27	NORTH RIVER AT RTE 125	NORTH RIVER	North River	43.0793590	-71.0357590

References