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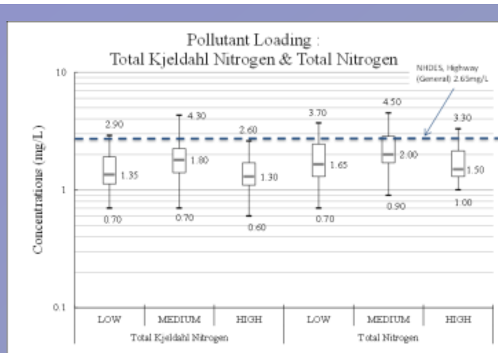

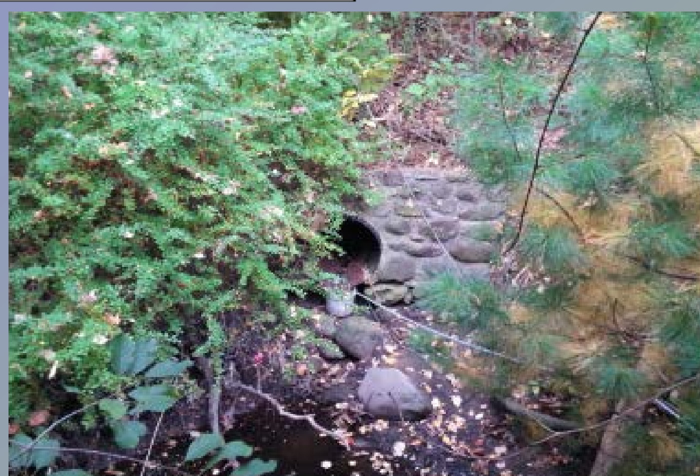

Validating Pollutant Load Estimates from Highways and Roads

Final Report

Prepared by the University of New Hampshire Department of Civil Engineering for the New Hampshire Department of Transportation in cooperation with the U.S. Department of Transportation, Federal Highway Administration

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16. Abstract

Rain and snowmelt that runs off of roadways carries pollutants. Pollutant event mean concentrations have been developed for various land uses to calculate annual pollutant loads. These were developed for total suspended solids, total phosphorus, and total nitrogen. NHDOT uses the Simple Method for estimating the pollutant load in runoff. This study collected real time in situ measurements to validate the concentrations used in Simple Method calculations for modeling pollutant loads from New Hampshire roadways. Three locations were picked to represent low, medium, and high traffic volume roadways. The actual measured amount of pollutants was compared to the loading predictions of the Simple Method. This study confirmed that using one modeling approach is effective for all New Hampshire roadways.

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Validating Pollutant Load Estimates from Highways and Roads

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PROJECT: Validating Pollutant Load Estimates from Highways and Roads

Final results and data analysis summary for UNHSC Highway Pollutant Load Study

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December 31, 2015

This document details research results of the New Hampshire State funded project, "Validating Pollutant Load Estimates from Highways and Roads" conducted by the University of New Hampshire Stormwater Center (UNHSC) and New Hampshire Department of Transportation (NH DOT). The project consisted of sampling stormwater runoff from three NH DOT owned roads with three different levels of average annual daily traffic counts (AADT). Monitoring was conducted over a two year period with storm samples collected during summer and fall only. The objective of the study was to investigate the relationship between AADT and pollutant concentrations in stormwater runoff.

The three sites selected for this project are detailed in Table 1 along with the total number of rainfall runoff events sampled at each location. The target number of storms monitored for each AADT scenario was 12-15 storms. Due to many uncontrollable elements such as offsite dependability of sampling locations, weather, and equipment damage (whether natural or otherwise), generation of 12-15 qualifying storms usually takes upwards of 24 months. These elements also make it difficult to sample each event at all three locations for the same storm date. Commonly 18-20 actual storm events need to be collected to accumulate reliable and defensible data on 12-15 qualifying events.

Table 1: Description of the three monitored locations and total number of rainfall events sampled.

Site	Description	Location	Number of Storms Sampled
1	High traffic count (>75,000 AADT)	Outfall located off I-95 draining a 32,670 sf section of highway with a 24" outfall. Access off of Edmond Avenue in Portsmouth, NH.	15
2	Moderate traffic count (> 35,000 AADT)	Outfall located off Route 16 draining a 13,500 sf section of the southbound highway with an 18" outfall. Accessed from the southbound lane off Rt. 108 across from Agway in Dover, NH.	23
3	Lower traffic count (< 15,000 AADT)	Outfall located off Route 4 draining a 10,080 sf section of highway with a 12" outfall. Accessed from the northbound lane of Rt. 108.	18

Literature Review

In partial fulfillment of the NH DOT funded project Validating Pollutant Load Estimates from Highways and Roads and in response to comments made by the Technical Advisory Group (TAG) a literature review was completed to summarize existing, similar research and data available in the region. The pollutants of interest for this study include total suspended solids (TSS), total nitrogen (TN), total phosphorous (TP), chloride (Cl), and zinc (Zn). These pollutants may enter natural waterways due to stormwater runoff from impervious surfaces and may result in severe damage to aquatic ecosystems or impaired waterways. Poor water quality may then lead to economic hardship for those industries which utilize the resources provided by these affected waterways. According to the US-EPA's *Technical Review of the Interactions Among Land Use, Transportation, and Environmental Quality*, urban-related stormwater runoff has led to the impairment of 858,186 acres of lakes, reservoirs, and ponds and 51,548 miles of rivers and streams (Kramer, M.G. 2013). These reported values are most likely much lower than actual values due to the difficulty of monitoring stormwater runoff as well as the fact that not all waterways are monitored. One of the largest sources of pollutants to water bodies is highway drainage, which typically contains high concentrations of TSS, ammonia, oil and grease, and metals (Kramer, M.G. 2013).

In the past, many studies have examined the production of these pollutants by automobiles in relation to air quality. The effects of air pollution on human health are severe and have led to an abundance of research into the relationship between vehicle emissions and air quality. Vehicle emissions are also important in relation to pollution of water bodies as the deposition of exhaust particles on impervious surfaces may lead to increased pollutant loads in stormwater runoff. Analyzing the tailpipe emissions of highway traffic provides valuable information about the types and quantities of pollutant appearing in highway drainage.

Cadle et al. (1999) investigated the composition of exhaust particulate matter (PM), but focused on the emissions of various vehicles within the light-duty motor vehicle category. The goal of vehicle selection was to choose an assortment of vehicles (diesel powered, gasoline powered, old, new, etc.). Following the Urban Dynamometer Driving Schedule (UDDS) of the Federal Test Procedure (FTP), which represents 85% of the driving in urban areas, the vehicles were evaluated through three driving phases: cold start, hot stabilized, and hot start. Vehicles were driven at an average speed of 19.6 mph with a top speed of 56.7 mph. The UDDS is a mandated dynamometer test utilizing the above set of parameters to evaluate tailpipe emissions. The results of the study reported the emission rates, in grams per mile, for hydrocarbons, carbon monoxide, nitrogen oxides, and PM (Table 2); sulfate and nitrate (Table 3); and various elements including Cl, P, and Zn (Table 4). Nitrate emissions were often below the detection limit of 0.04 mg/mi and concluded not to be a significant contributor to PM mass emissions from motor vehicles (Cadle et al, 1999). There was a high correlation between zinc and phosphorous emissions (R^2 = 0.90) which was attributed to the motor oil additive zinc diorgano dithiophosphate (ZDDP) used for its anti-wear and anti-oxidant properties (Cadle et al, 1999). The Cadle study showed that emissions tend to increase in older vehicles and during winter months due to cold starting. Light-duty diesel vehicles (LDDVs) also had much higher emissions rates than non-smoking gasoline vehicles but contribute to only a small portion of the overall highway exhaust emissions as LDDVs make up only a small portion (<1%) of the average "in-use fleet". Improvements in diesel technology have decreased PM emission rates because they must meet current the Federal Tier 1 FTP PM standard of 80 mg/mi, phased in from 1994-1996 (Cadle et al, 1999).

Table 2: The average PM and regulated emissions rates for the six categories of vehicles tested. Categories are based on the age of the vehicle. PM samples were analyzed for carbon, anions, and elements. (Cadle et al, 1999).

period	category	number	g/mi HC	g/mi CO	g/mi NOx	PM mg/mi
summer	1991–96	5	0.24	3.44	0.46	3.2
summer	1986–90	9	0.77	6.46	1.50	19.6
summer	1981–85	7	2.65	21.4	1.59	42.5
summer	1971–80	6	6.60	63.7	2.52	102
summer	smoker	7	8.43	44.7	2.21	351
summer	diesel	4	[a]	4.20	4.97	1176
winter	1991–96	5	1.39	17.0	0.73	39.9
winter	1986–90	6	1.17	14.9	1.38	25.0
winter	1981–85	6	4.05	45.3	2.07	62.3
winter	1971–80	6	4.42	59.6	1.82	109
winter	smoker	8	10.0	74.5	2.54	574
winter	diesel	11	1.14	1.80	1.64	538

[a] No data.

Table 3: Average Federal Test Procedure (FTP) Sulfate and Nitrate Emission Rates. Phase 1 – Cold Start Operation, Phase 2 – Hot Stabilized Operation, Phase 3 – Hot Start Operation (Cadle et al, 1999)

period	category	sulfate (mg/mi)	phase 1 SO_4^{2-} (mg/mi)	phase 2 SO_4^{2-} (mg/mi)	phase 3 SO_4^{2-} (mg/mi)	nitrate (mg/mi)
summer	1991–96	0.05	7.51 (0.69)[a]	0.13	0.20	0.00
summer	1986–90	0.15	0.27	0.08	0.11	0.02
summer	1981–85	0.14	0.28	0.15	0.24	0.00
summer	1971–80	1.67 (0.26)[a]	0.08	0.05	0.03	0.09
summer	smoker	0.34	0.33	0.20	0.34	0.04
summer	diesel	5.61 (1.54)[a]	9.19 (3.76)[a]	2.31 (0.81)[a]	9.16 (1.28)[a]	1.26 (0.25)
winter	1991–96	0.30	1.57	0.26	0.35	0.04
winter	1986–90	0.28	0.91	0.29	0.94	0.04
winter	1981–85	0.60	0.45	0.17	0.35	0.08
winter	1971–80	0.55	0.83	0.12	0.29	0.09
winter	smoker	1.80 (1.05)[a]	6.03 (2.24)[a]	0.61	0.94	[b]
winter	diesel	2.74	7.51	1.37	1.76	[b]

[a] Values in parentheses are the average with the highest emitter removed. [b] No data.

Table 4: Average emissions rates of elements across all 6 categories of vehicles tested (Cadle et al, 1999).

		mg/mi														
period	category	PM	Mg	Al	Si	P	S	Cl	Ca	Fe	Cu	Zn	Br	Pb	K	Cr	sum
summer	1991–96	3.0	0.0	0.01	0.183	0.005	0.019	0.002	0.003	0.036	0.001	0.006	0.0	0.003	[a]	[a]	0.27
summer	1986–90	85.8	0.046	0.041	0.129	0.115	0.225	0.012	0.17	0.088	0.025	0.186	0.0	0.027	[a]	[a]	1.07
summer	1981–85	42.5	0.009	0.01	0.211	0.071	0.147	0.007	0.136	0.06	0.011	0.108	0.0	0.006	[a]	[a]	0.78
summer	1971–80	102.2	0.029	0.018	2.516	0.094	0.512	0.23	0.071	0.113	0.012	0.099	0.012	0.043	[a]	[a]	3.75
summer	smokers	281.7	0.148	0.029	0.249	0.241	0.629	0.039	0.312	0.085	0.019	0.369	0.009	0.035	[a]	[a]	2.17
summer	diesel	1175	0.402	0.303	3.189	0.634	4.504	0.139	1.329	3.151	0.019	1.731	0.009	0.15	[a]	[a]	15.6
winter	1991–96	39.9	0.046	0.035	0.11	0.097	0.316	0.014	0.139	0.293	0.013	0.19	0.001	0.019	0.012	0.007	1.29
winter	1986–90	25.0	0.051	0.098	0.132	0.079	0.217	0.041	0.126	0.236	0.009	0.149	0.002	0.019	0.015	0.01	1.18
winter	1981–85	42.6	0.064	0.103	0.371	0.15	0.505	0.028	0.181	1.074	0.015	0.236	0.028	0.103	0.02	0.017	2.89
winter	1971–80	108.7	0.078	0.09	0.714	0.225	0.581	0.068	0.241	1.013	0.018	0.246	0.057	0.222	0.027	0.021	3.60
winter	smoker	574.1	[a]	[a]	[a]	[a]	2.114	0.127	0.401	1.885	0.064	[a]	0.036	0.282	[a]	[a]	4.91
winter	diesel	537.5	[a]	[a]	[a]	[a]	2.343	0.217	0.137	0.476	0.025	[a]	[a]	0.142	[a]	[a]	3.34

[a] Emission rate below detection limit.

Kittelson et al. (2003) performed a similar study to analyze the particulate emissions of gasoline spark ignition (SI) vehicles and compared this data with the particulate emissions of diesel engines. For this study both laboratory and on-road sampling were performed. The laboratory testing was performed in a similar manner to the previously described Cadle study, using a chassis dynamometer and dilution tunnel for sampling. The on-road sampling measured a variety of gaseous and particulate characteristics of exhaust and was performed on an interstate highway in the Minneapolis and Saint Paul metropolitan region. Test vehicles included compact cars, vans, and trucks with a range of low, medium and high mileages. Contaminant concentrations based off of traffic level were not analyzed as all sampling was performed during normal traffic conditions. Factors that significantly contributed to emissions rate were hard accelerations, high speeds, and cold starts. Most of the vehicle mass emissions rates were less than1.99 mg/mi (1.24 mg/km) on average during warm weather. Average emissions increased to between 1 and 7 mg/km during cold weather. Light-duty trucks had mass emission rates ranging from 6.92 mg/mi (4.3 mg/km) on start up to less than 0.1 mg/mi (0.062 mg/km) after fully warmed up. The current study does not include a traffic composition component, but all monitoring locations were along constant speed stretches and therefore could be considered to be receiving loading from vehicles that are operating while warmed-up.

Over the years, the list of known compounds emitted by automotive sources has grown extensively. The United States Environmental Protection Agency (US EPA) has reviewed the literature investigating these emission and developed a comprehensive database known as "The Master List of Compounds Emitted by Mobile Sources and Fuels" which contains the names, CAS numbers, emission types, and emission rates of over 700 different compounds which are emitted by vehicles. Creation of the list was divided into multiple phases during which one organization (Sierra Research, Inc.) reviewed 46 studies to create an initial database and a second company (Environ) reviewed 45 additional studies to update and add to the list. During the final stage of the project, Environ cross-referenced the list with the US EPA's Integrated Risk

Information System (IRIS) list of compounds (ENVIRON, 2006). The Master List project helped to characterize the chemical constituents in automobile emissions but did not provide information on the effects of traffic on contaminant emissions.

In 2008, Baldauf et al. performed a study to investigate the effects of traffic and environmental conditions on the concentrations and toxicity of near-road air pollutants by examining the temporal and spatial variations in gaseous and particulate emissions. Three primary categories of pollutants were analyzed using near-real-time measurements and integrated samples: US EPA regulated gases (CO, CO_2, NO_x, and total hydrocarbon (THC)), PM (coarse 10-2.5µm, fine 2.5µm – 0.1 µm, and ultrafine <0.1µm), and air toxics (benzene, toluene, formaldehyde, acrolein, polyaromatic hydrocarbons, etc.). Sampling and measurements were performed along a section of US Interstate 440 in Raleigh, NC. Using CO and black carbon (BC) as surrogates for gas emissions and PM, respectively, the study found that higher concentrations of gaseous and particulate pollutants were observed closer to the roadway and increased during high traffic periods (Figure 1). In addition, maximum concentrations of other pollutants (NO, ammonia, benzene, and naphthalene) frequently occurred during high traffic periods and when the winds from the road were the highest, both of which took place during the morning commuter period (Figure 2). The production and deposition of gaseous and particulate pollutants in the near-road microenvironment in relation to traffic volumes supports the theory that pollutant concentrations in stormwater runoff will also increase with higher AADT.

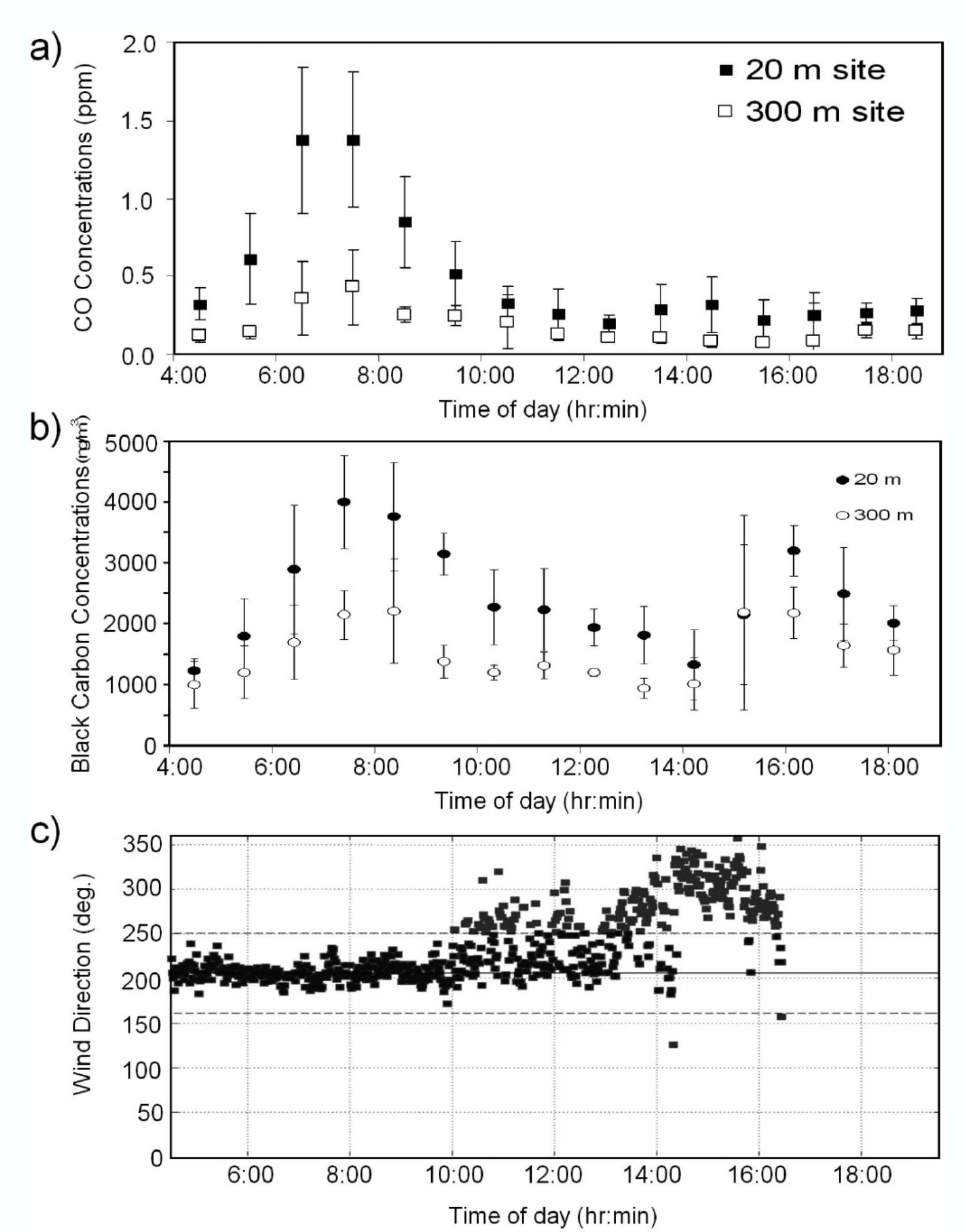

Figure 1: Comparison of (a) CO and (b) BC hourly average pollutant concentrations and measurement standard deviations by distance from the road on August 7, 2006. Panel c shows the 1-min average wind speed and direction profiles for this day on the basis of measurements from Sonic-20.6

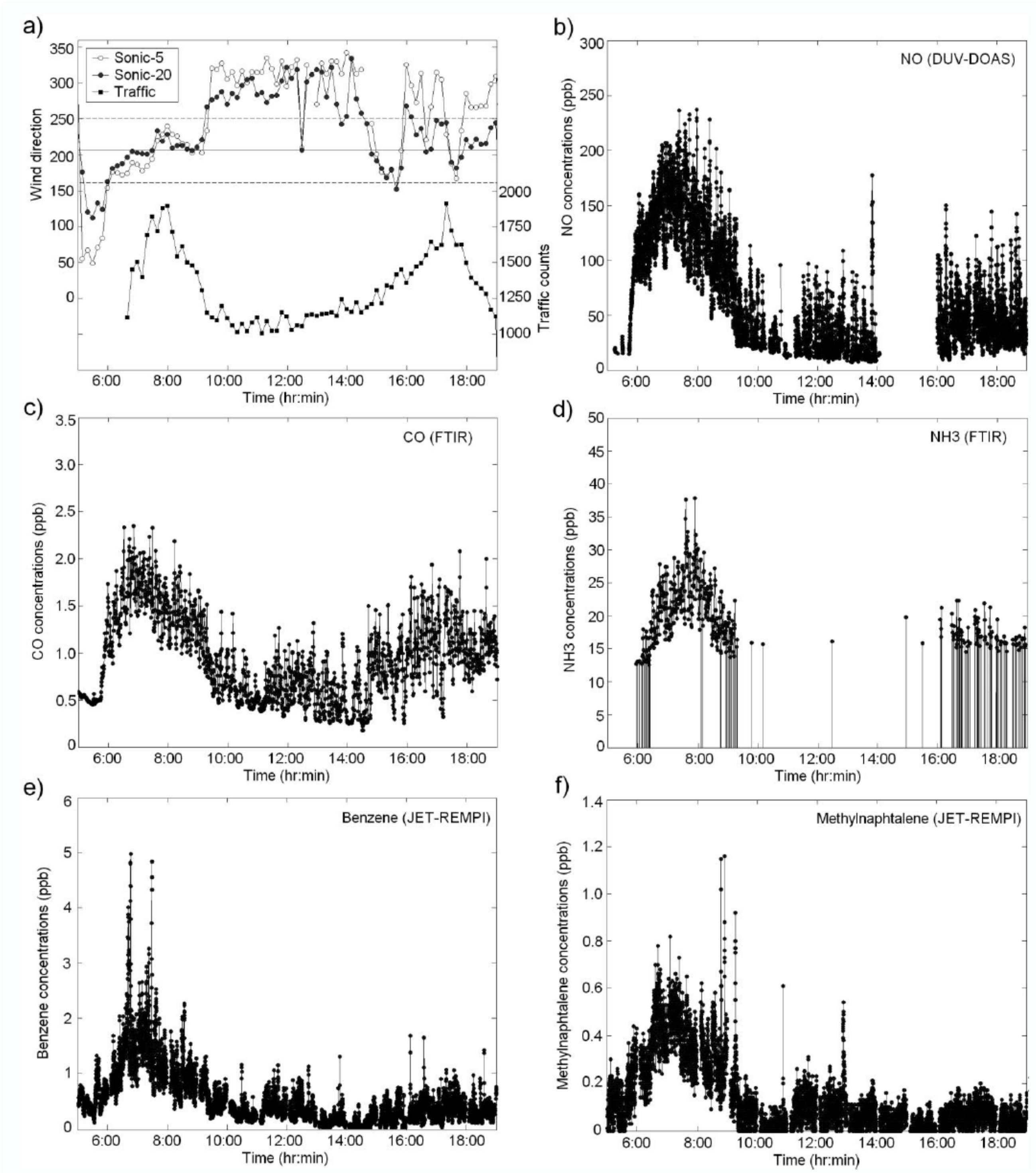

Figure 2: Comparison of measurements from on-site instrumentation (i.e. DUV-DOAs, FTIR, and Jet-REMPI) for August 3, 2006 for (a) wind direction, (b) NO, (c) CO, (d) NH3, (e) benzene, and (f) methylnapthelene.

To look into the link between deposition of ambient PM and water quality, the Desert Research Institute conducted the Lake Tahoe Source Attribution Study (LTSAS). Engelbrecht et al. (2009) used source-receptor modeling techniques to determine the chemical composition and origin for the PM data obtained during the Lake Tahoe Atmospheric Deposition Study (LTADS). The results supported the hypothesis that the majority of PM_{10} (particulate matter with diameter of 10 µm or less) in the lake basin (60%) was from re-suspended paved road dust while only about 23-33% of $PM_{2.5}$ (fine particles with diameter of 2.5 µm or less) was from motor vehicle tailpipe emissions. By finding a high correlation with soils in the PM_{10} range, the study also found that the major source of phosphorous was primarily soils. The contributions from tailpipe emissions were found to be very low in all cases as measured in $PM_{2.5}$. Atmospheric deposition of nitrogen to the lake was also found to be small with 0.26µg/m^3 in PM_{10} and 0.15µg/m^3 in $PM_{2.5}$. Figure 3 shows the seasonal origin and relative concentrations of various sizes of PM.

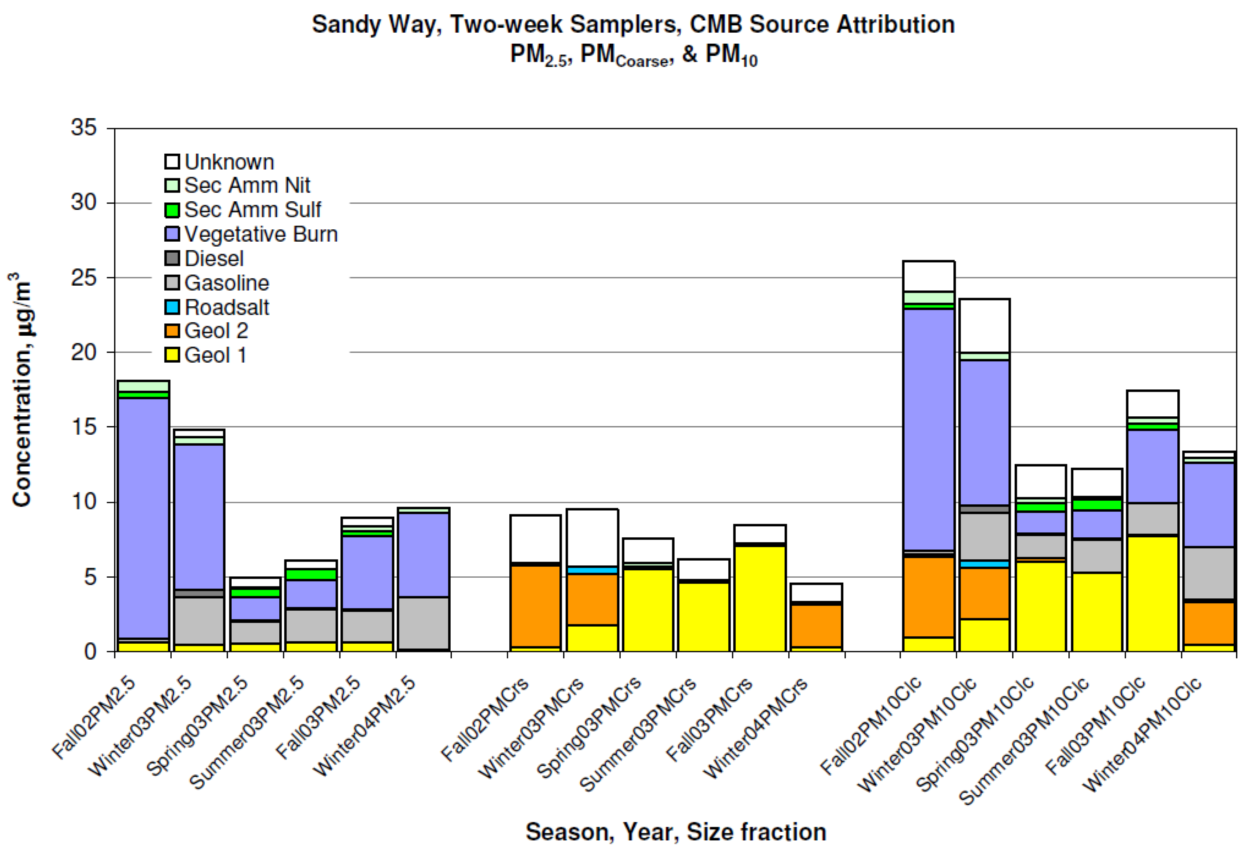

Figure 3: Lake Tahoe Source Attribution Study (Ref. 7) chart displays the various sources of particulate matter (PM) broken down by size fraction (PM2.5, PMcoarse, PM10) and season. Samples taken at the Sandy Way project site over a two week period.

The pollutant concentrations attributed to stormwater runoff in relation to highway activity was more thoroughly investigated by the US Department of Transportation Federal Highway Administration and the Massachusetts Department of Transportation from 2005 to 2007. During this study, data was collected from twelve locations along eight highways in Massachusetts. Four of the highways (Route119, Route 2, Interstate 495, and Interstate 95) were used for the primary and secondary monitoring locations while the other four (Route 8, Interstate 195, Interstate 190, and Interstate 93) were considered test sites and were only used to determine if the data could be transferable to other sites. Both continuous measurements and flow weighted samples were taken from the sampling sites along the four main highways. The results of the study showed that there was a statistically significant difference between median total nitrogen (TN) and total phosphorous (TP) concentrations for highways with different annual average daily traffic volumes (AADT). However, the study showed that 94% of phosphorous found in the highway runoff was related to highway-maintenance sand rather than tailpipe emissions. While there was no clear definition of highway maintenance sand provided it was assumed that this related to primarily winter maintenance activities. Maintenance sand, local soils, berm materials, and vegetation matter were found to be the primary sources of total-removable metals, such as iron and manganese. Copper and zinc in the runoff were assumed to primarily come from tire and brake wear.

In order to improve air and water quality around high traffic roadways, new standards for the quality and quantity of vehicle emissions are being developed. The *Federal and California Exhaust and Evaporative Emission Standards for Light-Duty Vehicles and Light-Duty Trucks* (2000) outlines the specific emission rate standards for various types of vehicles including light-duty vehicles, light-duty trucks, heavy light-duty trucks, and medium-duty vehicles. These standards are based off of the FTP driving schedule and the Evaporative and Onboard Refueling (ORVR) Test Procedure. Each type of vehicle fits within one of the standards depending on the extent of the vehicle's emissions. These include federal standard, federal National Low Emission Vehicle (NLEV) Program standards, federal Clean Fueled Vehicle (CFV) Program standards, and California standards. The information provided by these standards provides a base knowledge on the potential amount of contaminants being released by highway vehicles.

Aside from new standards, increases in alternative fuel vehicles (AFVs) and changes in motor oil composition have both led to changes in the emission rates and composition of automobile exhaust. Air pollution minimization programs have promoted the use of AFVs using compressed natural gas (CNG) or methanol 85 (M85) mixed gas. Durbin et al. (1998) compared the emissions of light-duty alternative fuel vehicles with light-duty vehicles using reformulated gasoline (RFG). The study examined exhaust emission rates and composition using in-lab sampling on a chassis dynamometer and dilution tunnel system. Overall the study reported an average particulate emission rate of 1.4 mg/mi for CNG vehicles and 0.7 mg/mi for M85 vehicles, which are low and comparable to standard gasoline vehicles. It is important to note that these studies did not include average emissions increases due to cold weather operation.

Changing requirements for motor oil composition have led to decreases in motor vehicle emissions of zinc, sulfur, and phosphorous. Modern three way catalytic converters, which are required for all new vehicles, reduce NO_x to nitrogen gas and oxidize CO and unburned hydrocarbons to improve the quality of tailpipe emissions. The life of these devices can be drastically shortened by zinc diorgano dithiophosphate (ZDDP) and sulfur, both of which can be found in motor oil (SynMax Performance Lubricants, 2009). Vehicles are now being required to use oils with lower concentrations of ZDDP (<0.08%) and sulfur (<0.5 or <0.7%). Not only does this extend the life and improve the durability of a vehicles emission control system, it also decreases zinc, phosphorous, and sulfur emissions (SynMax Performance Lubricants, 2009). Current specifications for motor oils based on vehicle type may be found on the Mobil 1 website in their Mobil 1 Engine Oils product table. (Mobile 1 Engine Oils, 2010).

In summary the analysis of existing literature indicates that there are more studies related to atmospheric pollutants emitted from tailpipes of various vehicles than there are from deposition related vehicle emissions by AADT. The existing literature would indicate that vehicle age, model and engine/fuel type have more of a bearing on anticipated pollutant loading potential than AADT. Preliminary findings from one study indicated that pollutant loads do increase with respect to vehicle count and seasonal operation. These studies further indicate a need for research particularly with respect to local atmospheric deposition and pollutant export rates associated with a range of AADT usage. Additional studies should also be performed with respect to emissions as influenced by the type of fuel burned with diesel being the potentially highest in pollutant concentrations and CNG vehicles being the potentially lowest.

Results

Automatic samplers were fitted to catch basin culverts that drained the study sites. Automatic samplers were programmed to collect flow-proportional samples when runoff began, and throughout the runoff event (storm). Table 4 provides information about the storm events sampled in this study. Following each storm, event runoff samples were collected and processed into 1 liter duplicate composite samples. Samples were preserved at 4°C until picked-up and transported to a third-party analytical lab, Absolute Resource Associates, Inc. in Portsmouth, NH. The samples were analyzed for total suspended sediments (TSS), heavy metals (zinc and copper), nitrogen species (total Kjeldahl nitrogen, nitrate, nitrite, and ammonia), dissolved phosphorus (PO_4), total phosphorus (TP), and chloride (Cl). Resultant pollutant concentrations (event mean concentrations) are listed in Table 6 through Table 8. Not all pollutants were analyzed for in each sample set in some cases due to low sample volume where priority was given to nutrients over sediments and metals. Italicized values in the tables indicate a resultant concentration was below the detection limit (BDL) of the analytical method; therefore for statistical methods a value of half the detection limit (DL) was entered. This is a standard approach used by UNHSC to provide a reasonable estimate that does not under or overestimate the pollutant concentration.

Descriptive statistics are included at the bottom of each table to help summarize each data set and ultimately compare them to other data sets. Figure 4 through Figure 9 display these statistics in box and whisker format which allow for the side-by-side comparison. Included on the TSS, TN and TP charts are reference lines indicating the pollutant loading concentrations found in the NHDES Simple Method model under the land use category of Highway (General).

Table 5: Storm characteristics for all monitored events.

Event Date	Total Rainfall (in)	Peak Intensity (in/5-min)	Rt. 4 Storm Volume (gal)	Rt. 16 Storm Volume (gal)	I-95 Storm Volume (gal)	Antecedent Dry Period	Season
5/16/2014	1.03	0.07	-	8,078	-	5	Spring
5/22/2014	0.25	0.01	-	1,961	-	4	Spring
5/27/2014	0.47	0.03	-	3,686	-	3	Spring
6/5/2014	0.16	0.02	-	1,255	-	5	Spring
6/13/2014	0.67	0.05	3,923	-	-	7	Spring
6/25/2014	0.77	0.11	-	6,039	-	11	Summer
7/7/2014	0.48	0.08	-	3,765	-	1	Summer
7/13/2014	0.11	0.02	-	863	-	3	Summer
7/23/2014	0.47	0.05	-	3,686	-	6	Summer
7/27/2014	0.39	0.02	-	3,059	-	3	Summer
7/28/2014	0.57	0.02	3,338	-	-	1	Summer
7/31/2014	0.11	0.03	644	863	-	3	Summer
8/7/2014	0.41	0.27	-	3,216	-	5	Summer
8/13/2014	2.46	0.19	14,406	-	-	5	Summer
9/6/2014	0.13	0.01	761	-	-	3	Summer
9/13/2014	0.11	0.01	644	-	-	5	Summer
10/1/2014	0.22	0.02	1,874	1,725	-	9	Fall
10/4/2014	0.22	0.03	1,230	1,725	6,720	2	Fall
10/16/2014	0.65	0.14	3,338	5,098	15,477	11	Fall
10/21/2014	2.05	0.09	10,951	16,078	38,081	4	Fall
11/1/2014	0.48	0.01	2,050	3,765	7,128	8	Fall
11/6/2014	0.32	0.02	-	2,510	5,295	4	Fall
12/2/2014	0.39	0.02	2,284	-	7,942	5	Fall
6/9/2015	0.33	0.11	1,581	2,588	-	6	Spring
6/15/2015	0.31	0.02	-	2,431	8,349	5	Spring
6/20/2015	1.05	0.05	-	8,235	-	5	Spring
6/23/2015	0.38	0.05	-	-	7,738	1	Summer
7/1/2015	0.40	0.03	2,167	3,137	8,146	2	Summer
7/9/2015	0.12	0.01	703	-	3,055	1	Summer
7/15/2015	0.21	0.13	1,464	1,647	4,277	4	Summer
7/30/2015	0.27	0.13	-	-	5,498	7	Summer
8/21/2015	1.14	0.15	6,676	-	-	2	Summer
9/10/2015	0.36	0.08	2,167	2,823	7,331	17	Summer
10/9/2015	0.74	0.07	-	-	15,070	8	Fall
10/28/2015	1.72	0.10	-	-	35,027	5	Fall

Table 6: Pollutant concentrations and descriptive statistics of stormwater runoff from NH Route 4 (Low AADT) monitoring location for each recorded event. Italicized values indicate a result that was below detection limit and a value of half the detection limit has been entered.

NH DOT Low Traffic (< 15,000 ADT)											
Durham, NH Rt. 4 overpass over Rt. 108. Outfall on north side of Rt. 4 and east side of Rt. 108											
Date	TSS (mg/L)	Copper (mg/L)	Zinc (mg/L)	TKN (mg/L)	NO3 (mg /L)	NO2 (mg/L)	NH3 (mg/L)	TN (mg/L)	PO4 (mg/L)	TP (mg/L)	Cl (mg/L)
5/16/2014	No Samples										
5/22/2014	No Samples										
5/27/2014	No Samples										
6/5/2014	No Samples										
6/13/2014	100			1.1	0.1	*0.05*	*0.25*	1.3	0.004	0.04	9.1
6/25/2014	No Samples										
7/7/2014	No Samples										
7/13/2014	No Samples										
7/23/2014	No Samples										
7/27/2014	No Samples										
7/28/2014	35			0.9	0.1	*0.05*	*0.25*	1	0.002	0.04	1.4
7/31/2014	45			2.9	0.8	*0.05*	1.3	3.7	0.038	0.12	10
8/7/2014	No Samples										
8/13/2014	12			0.7	*0.05*	*0.05*	*0.25*	0.7	0.005	*0.005*	1.1
9/6/2014	20			2.2	0.5	*0.05*	0.8	2.7	0.048	0.12	260
9/13/2014	17			1.9	0.4	*0.05*	1	2.2	0.039	0.1	100
10/1/2014	20	*0.025*	0.15	1.9	0.4	*0.05*	1.6	2.3	0.022	0.07	11
10/4/2014	36	*0.025*	0.14	2.1	0.4	*0.05*	1	2.5	0.007	0.05	14
10/16/2014	86	*0.025*	0.08	1.4	*0.05*	*0.05*	*0.25*	1.5	0.014	0.03	3.7
10/21/2014	24	*0.025*	0.12	1.2	*0.05*	*0.05*	*0.25*	1.3		0.04	3.1
11/1/2014	19	*0.025*	0.15	1.3	0.1	*0.05*	0.6	1.4	0.005	0.02	86
11/6/2014	No Samples										
12/2/2014	71	*0.025*	0.36	1.7	1.2	*0.05*	*0.25*	2.9	*0.05*	0.1	2300
6/9/2015		*0.025*	0.18	1.2	0.4	*0.05*	0.5	1.6	0.1	0.08	15
6/15/2015	No Samples										
6/20/2015	No Samples										
6/23/2015	No Samples										
7/1/2015	34	*0.025*	0.09	0.7	0.2	*0.05*	0.6	0.9	0.2	0.02	6.8
7/9/2015	19	*0.025*	0.18	1.2	0.6	*0.05*	0.6	1.8	0.2	0.09	27
7/15/2015	100	*0.025*	0.3	1.4	0.3	*0.05*	0.5	1.7	*0.05*	0.15	18
7/30/2015	No Samples										
8/21/2015	17		0.07	0.7	0.2	*0.05*	*0.25*	0.9	*0.05*	0.05	6.7
9/10/2015	28		0.22	2.3	0.4	*0.05*	1.1	2.7		0.06	14
10/9/2015	No Samples										
10/28/2015	No Samples										
Descriptive Statistics											
Count	17	10	12	18	18	18	18	18	16	18	18
Minimum	12	0.025	0.07	0.7	0.05	0.05	0.25	0.7	0.002	0.005	1.1
25th Percentile	19	0.025	0.1125	1.125	0.1	0.05	0.25	1.3	0.0065	0.04	6.725
Median	28	0.025	0.15	1.35	0.35	0.05	0.55	1.65	0.0385	0.055	12.5
75th Percentile	45	0.025	0.19	1.9	0.40	0.05	0.95	2.45	0.05	0.0975	24.75
Maximum	100	0.025	0.36	2.9	1.2	0.05	1.6	3.7	0.2	0.15	2300
Average	40.2	0.025	0.170	1.5	0.3	0.05	0.6	1.8	0.052	0.066	160
Standard Dev.	29.0	0.000	0.084	0.6	0.3	0.00	0.4	0.8	0.061	0.039	522.5

Table 7: Pollutant concentrations and descriptive statistics of stormwater runoff from NH Route 16 (Medium AADT) monitoring location for each recorded event. Italicized values indicate a result that was below detection limit and a value of half the detection limit has been entered.

NH DOT Medium Traffic (> 35,000 ADT)											
Dover, NH Spaulding Turnpike / Rt. 16 overpass over Rt. 108.											
Date	TSS (mg/L)	Copper (mg/L)	Zinc (mg/L)	TKN (mg/L)	NO3 (mg /L)	NO2 (mg/L)	NH3 (mg/L)	TN (mg/L)	PO4 (mg/L)	TP (mg/L)	Cl (mg/L)
5/16/2014	40			0.7	0.1	*0.05*		0.9		0.11	36
5/22/2014	28			1.2	0.2	*0.05*	*0.25*		0.096	0.19	49
5/27/2014	38			1.3	0.3	*0.05*	0.6	1.7	0.063	0.16	27
6/5/2014	47			2	0.2	*0.05*	0.6	2.3	0.068	0.22	26
6/13/2014	No Samples										
6/25/2014	65			1	0.1	*0.05*	*0.25*	1.2	0.044	0.14	7.2
7/7/2014	96			1.5	0.4	*0.05*	*0.25*	1.9	0.063	0.22	23
7/13/2014	24			1.3	0.4	*0.05*	*0.25*	1.7	0.075	0.14	9.9
7/23/2014	46			2.6	0.4	*0.05*	*0.25*	3	0.083	0.23	15
7/27/2014	52			2.1	0.4	*0.05*	0.6	2.5	0.048	0.2	22
7/28/2014	No Samples										
7/31/2014	36	*0.025*		2.1	0.8	*0.05*	0.5	2.9	0.056	0.11	24
8/7/2014	130			2.3	0.5	*0.05*	*0.25*	2.8	0.066	0.17	14
8/13/2014	No Samples										
9/6/2014	No Samples										
9/13/2014	No Samples										
10/1/2014	44	*0.025*	0.1	2.2	0.4	*0.05*	1	2.6	0.1	0.35	18
10/4/2014	150	*0.025*	0.09	1.7	0.2	*0.05*	0.9	1.9	0.1	0.18	8.3
10/16/2014	280	*0.025*	0.13	1.9	0.1	*0.05*	*0.25*	2	0.038	0.19	9.8
10/21/2014	65	*0.025*	0.06	1.8	0.1		*0.25*	1.9		0.11	5.8
11/1/2014	150	*0.025*	0.06	1.7	0.2	*0.05*	0.6	1.9	*0.0005*	0.01	7
11/6/2014	71	*0.025*	0.06	1.7	0.4	*0.05*	0.8	2.1	0.01	0.05	9.7
12/2/2014	No Samples										
6/9/2015		0.12	0.69	4.3	*0.05*	*0.05*	*0.25*	4.3	0.1	0.7	61
6/15/2015		*0.025*	0.13	3.1	0.2	*0.05*	0.5	3.3	*0.05*	0.18	100
6/20/2015		*0.025*	0.07	3.7	*0.05*	*0.05*	0.8	3.7	0.1	0.15	20
6/23/2015	No Samples										
7/1/2015	300	*0.025*	0.16	1.1	0.3	*0.05*	0.6	1.4	*0.05*	0.2	25
7/9/2015											
7/15/2015	140	0.06	0.44	3.9	0.6	*0.05*	1.2	4.5	0.2	0.44	92
7/30/2015	No Samples										
8/21/2015	No Samples										
9/10/2015	40		0.21	1.5	0.2	*0.05*	0.5	1.7		0.15	14
10/9/2015	No Samples										
10/28/2015	No Samples										
Descriptive Statistics											
Count	20	12	12	23	23	22	22	22	20	23	23
Minimum	24	0.025	0.06	0.7	0.05	0.05	0.25	0.9	0.0005	0.01	5.8
25th Percentile	40	0.025	0.0675	1.4	0.15	0.05	0.25	1.75	0.0495	0.14	9.85
Median	58.5	0.025	0.115	1.8	0.2	0.05	0.5	2.05	0.0645	0.18	20
75th Percentile	132.5	0.025	0.1725	2.25	0.40	0.05	0.60	2.875	0.097	0.21	26.5
Maximum	300	0.12	0.69	4.3	0.8	0.05	1.2	4.5	0.2	0.7	100
Average	92.1	0.036	0.183	2.0	0.3	0.05	0.5	2.4	0.071	0.200	27
Standard Dev.	77.2	0.027	0.183	0.9	0.2	0.0	0.3	0.9	0.041	0.137	25.0

Table 8: Pollutant concentrations and descriptive statistics of stormwater runoff from NH Interstate 95 (High AADT) monitoring location for each recorded event. Italicized values indicate a result that was below detection limit and a value of half the detection limit has been entered.

NH DOT High Traffic (> 75,000 ADT)											
Portsmouth, NH I-95 south bound. North of traffic circle, south of exit 6.											
Date	TSS (mg/L)	Copper (mg/L)	Zinc (mg/L)	TKN (mg/L)	NO3 (mg /L)	NO2 (mg/L)	NH3 (mg/L)	TN (mg/L)	PO4 (mg/L)	TP (mg/L)	Cl (mg/L)
5/16/2014	No Samples										
5/22/2014	No Samples										
5/27/2014	No Samples										
6/5/2014	No Samples										
6/13/2014	No Samples										
6/25/2014	No Samples										
7/7/2014	No Samples										
7/13/2014	No Samples										
7/23/2014	No Samples										
7/27/2014	No Samples										
7/28/2014	No Samples										
7/31/2014	No Samples										
8/7/2014	No Samples										
8/13/2014	No Samples										
9/6/2014	No Samples										
9/13/2014	No Samples										
10/1/2014	No Samples										
10/4/2014	90	*0.025*	0.17	1.5	0.2	*0.05*	0.7	1.7	0.011	0.04	5.9
10/16/2014	79	*0.025*	0.14	1.1	*0.05*	*0.05*	*0.25*	1.2	*0.0025*	0.02	9
10/21/2014	43	*0.025*	0.08	1	*0.05*	*0.05*	0.5	1.1		0.03	3.1
11/1/2014	34	*0.025*	0.1	1.2	0.2	*0.05*	*0.25*	1.5	0.053	*0.005*	53
11/6/2014	38	*0.025*	0.12	1.2	0.2	*0.05*	0.7	1.4	0.002	0.02	
12/2/2014	74	*0.025*	0.26	1.8	0.2	*0.05*	*0.25*	2	*0.05*	0.11	470
6/9/2015	No Samples										
6/15/2015		*0.025*	0.26	2.3	0.4	*0.05*	0.8	2.7	0.2	0.11	35
6/20/2015	No Samples										
6/23/2015		*0.025*	0.11	0.6	0.4	*0.05*	0.5	1	*0.05*	0.04	8.1
7/1/2015	83	*0.025*	0.2	1.3	0.4	*0.05*	0.8	1.7	*0.05*	0.1	14
7/9/2015	28	*0.025*	0.28	2.6	0.7	*0.05*	1.4	3.3	*0.05*	0.13	31
7/15/2015	58	*0.025*	0.2	1.1	0.4	*0.05*	*0.25*	1.5	*0.05*	0.1	11
7/30/2015	100		0.4	2.6	0.6	*0.05*	0.7	3.2	*0.05*	0.32	
8/21/2015	No Samples										
9/10/2015	100		0.09	1.3	0.2	*0.05*	*0.25*	1.5		0.11	8.4
10/9/2015	140		0.2	1.6	0.7	*0.05*	1.2	2.3		0.09	
10/28/2015	33		0.11	0.9	*0.05*	*0.05*	*0.25*	1		0.05	
Descriptive Statistics											
Count	13	11	15	15	15	15	15	15	11	15	11
Minimum	28	0.025	0.08	0.6	0.05	0.05	0.25	1	0.002	0.005	3.1
25th Percentile	38	0.025	0.11	1.1	0.2	0.05	0.25	1.3	0.0305	0.035	8.25
Median	74	0.025	0.17	1.3	0.2	0.05	0.5	1.5	0.05	0.09	11
75th Percentile	90	0.025	0.23	1.7	0.40	0.05	0.75	2.15	0.05	0.11	33
Maximum	140	0.025	0.4	2.6	0.7	0.05	1.4	3.3	0.2	0.32	470
Average	69.2	0.025	0.181	1.5	0.3	0.05	0.6	1.8	0.052	0.085	59
Standard Dev.	32.4	0.000	0.086	0.6	0.2	0.0	0.4	0.7	0.051	0.074	130.8

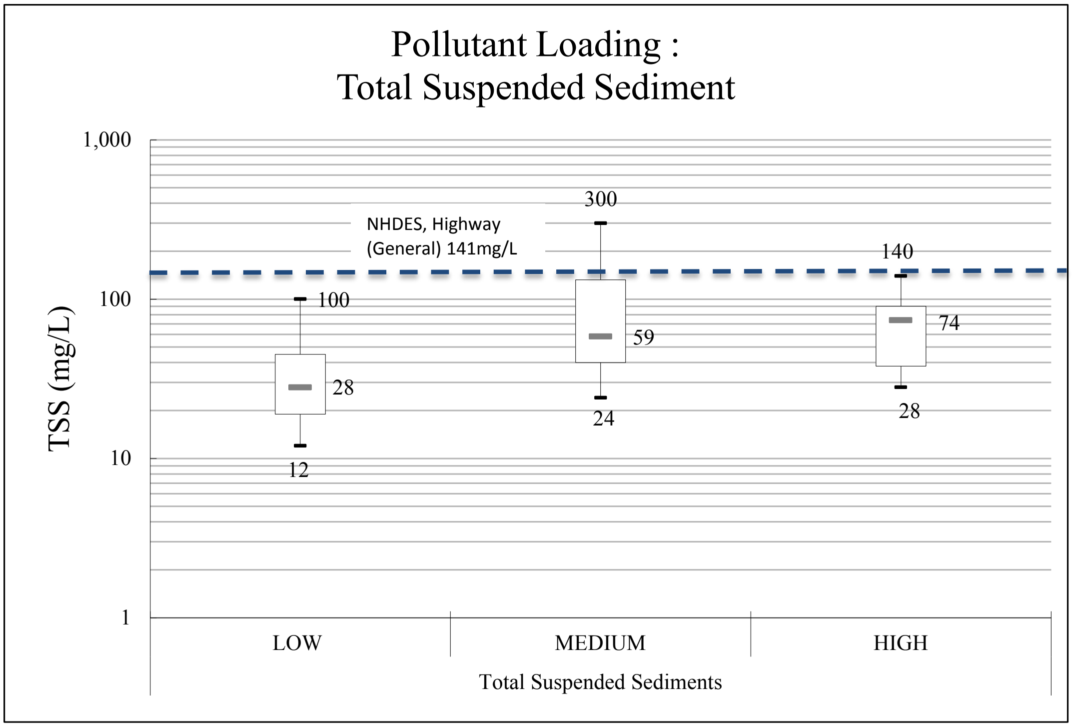

Figure 4: Box and whisker plot of total suspended sediment (TSS) results for each of the monitored locations. The dotted line is the EMC value for TSS used in the NHDES Simple Method calculations.

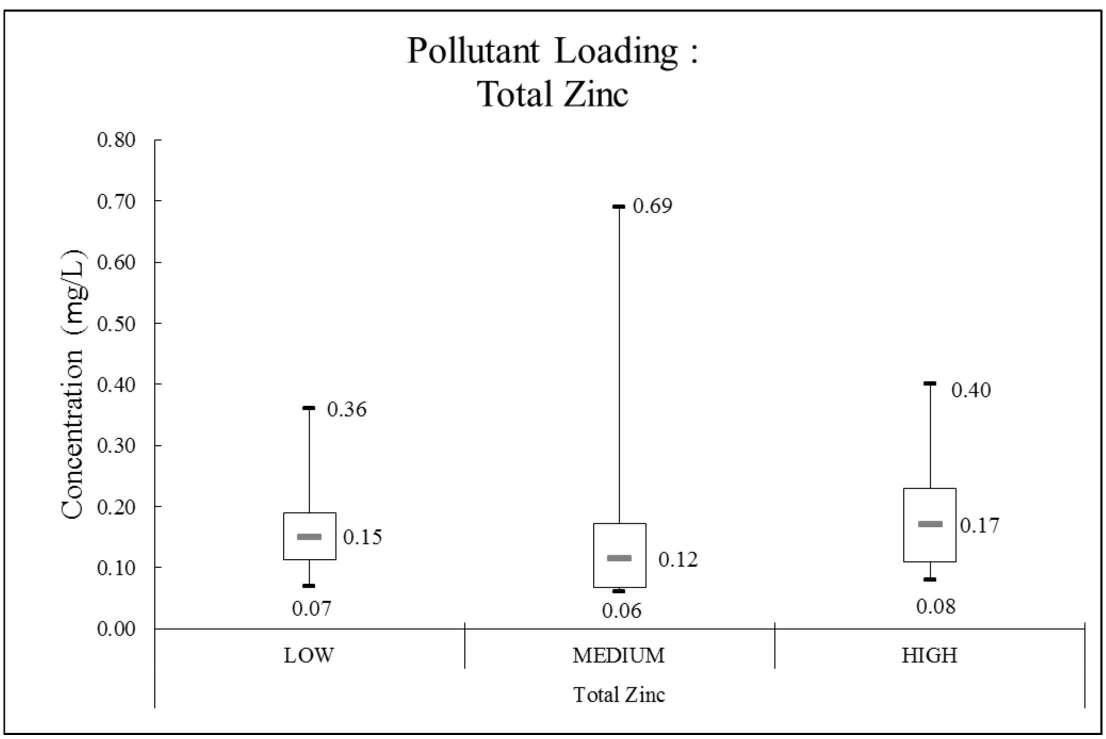

Figure 5: Box and whisker plot of heavy metal results for each of the monitored locations. Only zinc is included in this plot because copper was consistently below detectable limits of the analytical method.

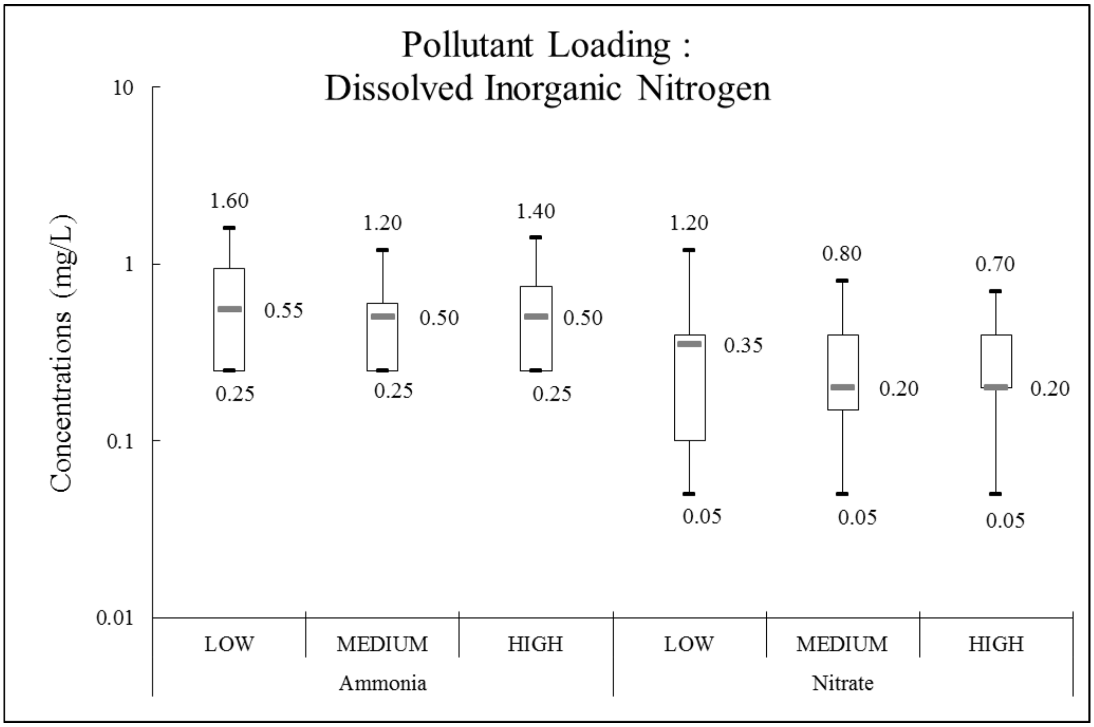

Figure 6: Box and whisker plot of dissolved inorganic nitrogen results, Ammonia (NH_3) and Nitrate (NO_3), for each of the monitored locations. Nitrite (NO_2) was consistently below detectable limits of the analytical method.

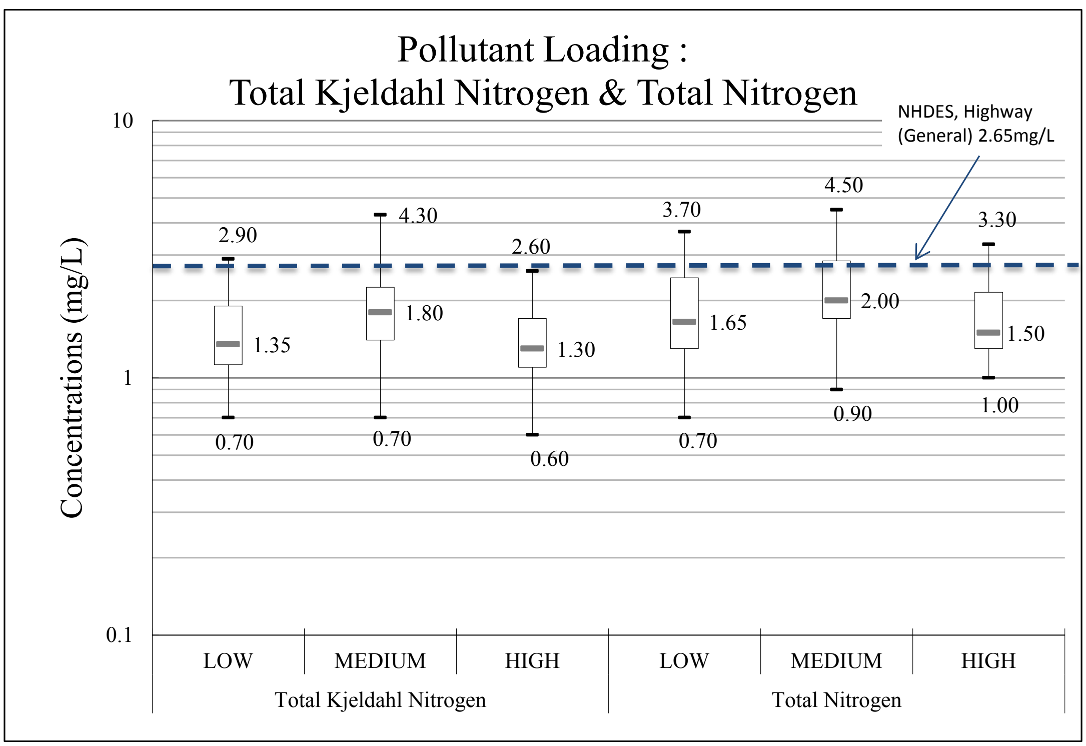

Figure 7: Box and whisker plot of Total Kjeldahl Nitrogen (TKN) and Total Nitrogen (TN) results for each of the monitored locations. The dotted line is the EMC value for TN used in the NHDES Simple Method calculations.

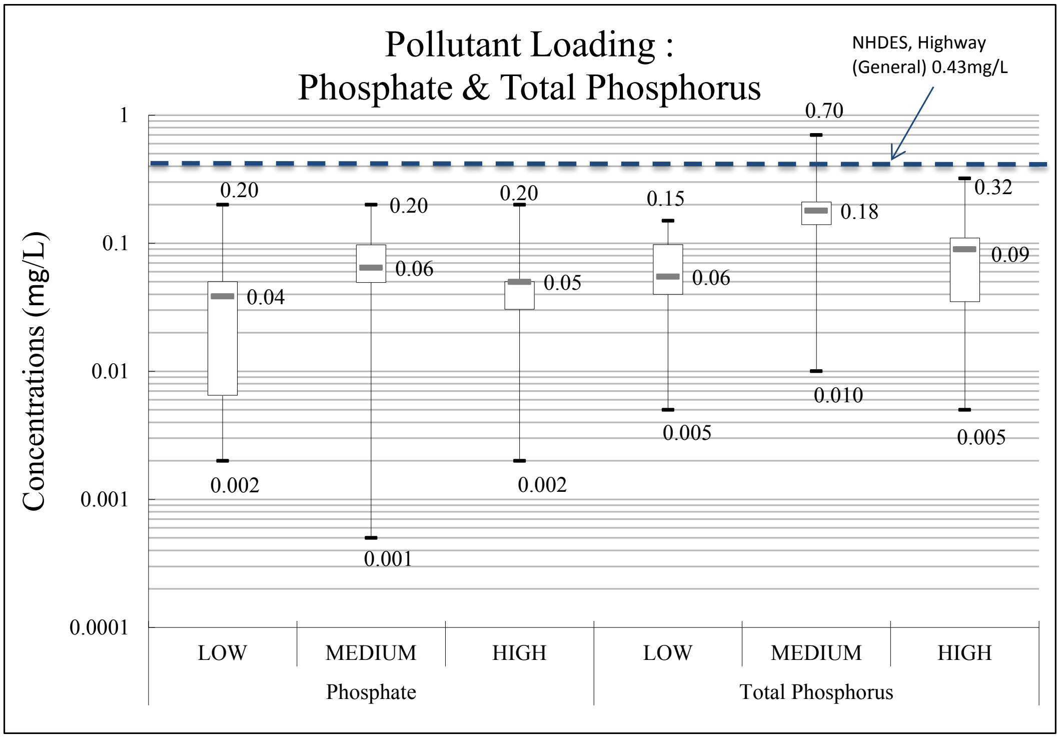

Figure 8: Box and whisker plot of Phosphate (PO_4) and Total Phosphorus (TP) results for each of the monitored locations. The dotted line is the EMC value for TP used in the NHDES Simple Method calculations.

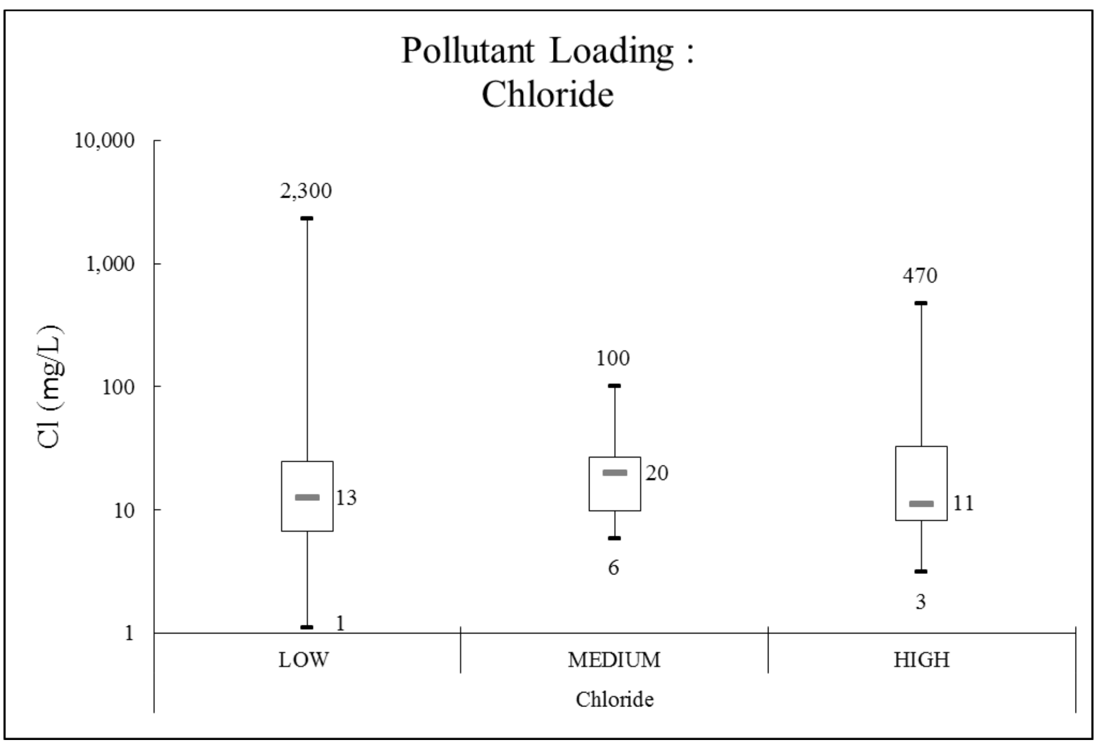

Figure 9: Box and whisker plot of Chloride (Cl) results for each of the monitored locations.

Data Comparison

The data generated in this study is compared between each monitoring location, results from a previous study conducted along Massachusetts Interstate 93 (MA DOT, 2010), as well as values used in the NHDES Simple Method modeling calculations (NHDES, 2008; CDM, 2004). The median values of the reported constituents are listed in Table 9 and displayed graphically in the bar charts in Figure 10 through Figure 14. Additionally, comparative results of the annual pollutant loading calculations using the simple method are listed in Table 10 and the pollutant export rates in Table 11.

Table 9: Median values for constituent concentrations in highway runoff collected from MA I-93 '99-'00, MA I-93 '06-'07, NH Rt. 4, NH Rt. 16, and NH I-95 '14-'15, and NHDES Simple Method land use category Highway (General).

Constituent	Interstate 93 (1999–2000) median	Interstate 93 (2006–07) median	NH Rt 4 (2014) median	NH Rt 16 (2014) median	I-95 (2014) median	NHDES HWG General
Total nitrogen, unfiltered, mg/L	2.54	2.09	1.65	2	1.5	2.65
Phosphorus, unfiltered, mg/L	0.44	0.34	0.055	0.18	0.09	0.43
Chloride, filtered, mg/L	76	31.2	12.5	20	11	-
Copper, unfiltered, µg/L	140	178	25	25	25	-
Zinc, unfiltered, µg/L	575	613	150	115	170	-
Suspended sediment, mg/L	426	714	28	58.5	74	141

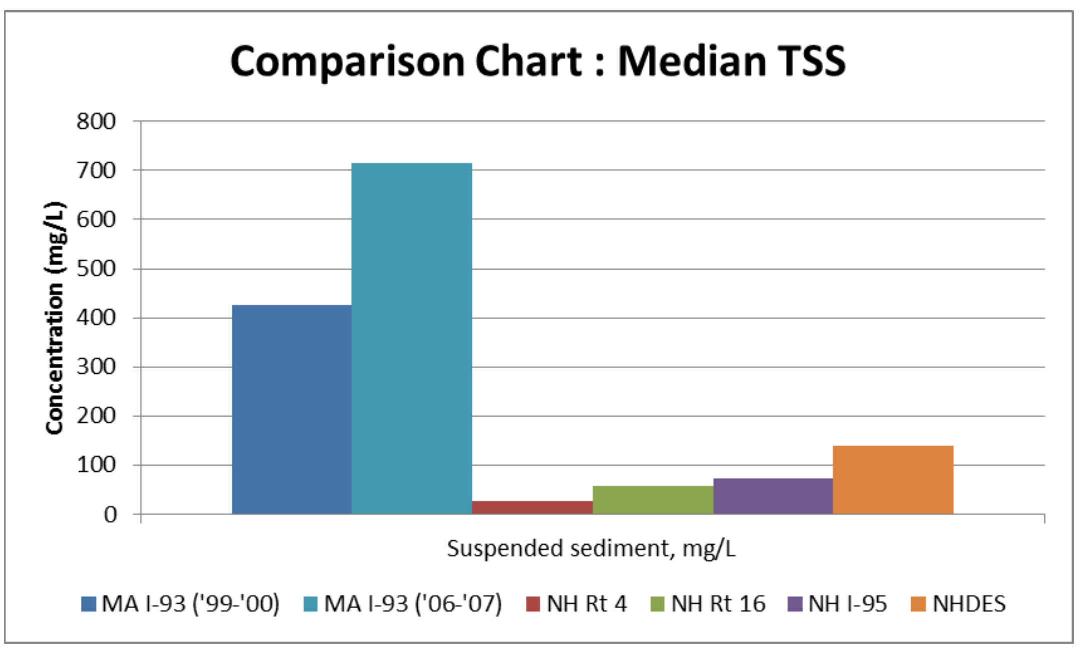

Figure 10: Comparison of median total suspended sediment (TSS) values from Massachusetts Interstate 93, New Hampshire Route 4, Route 16, and Interstate 95, and NHDES Simple Method pollutant loading calculations.

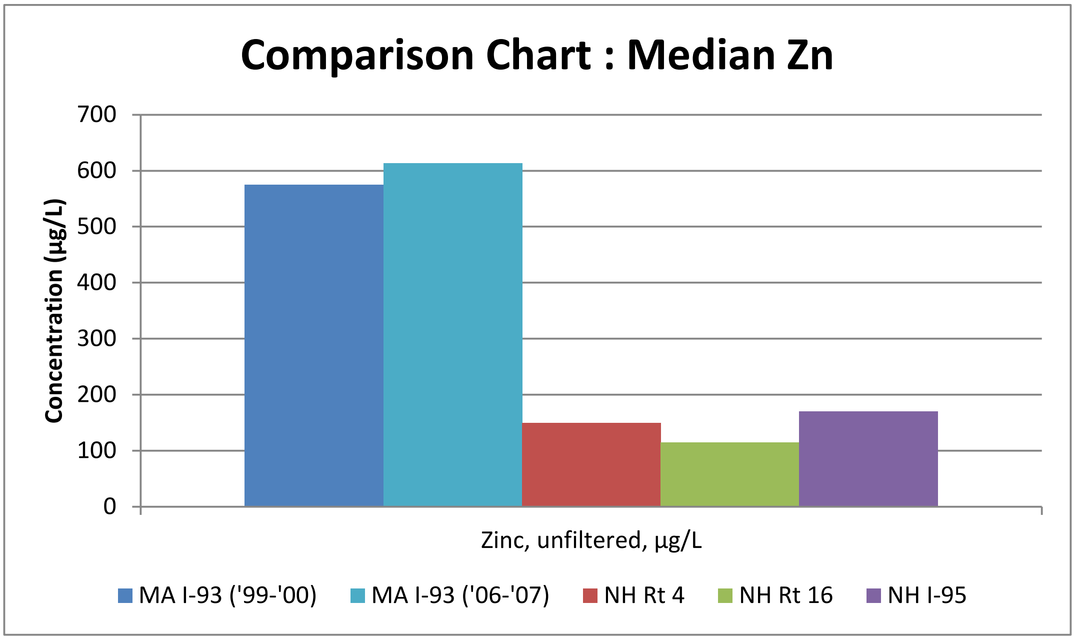

Figure 11: Comparison of median zinc (Zn) values from Massachusetts Interstate 93, New Hampshire Route 4, Route 16, and Interstate 95.

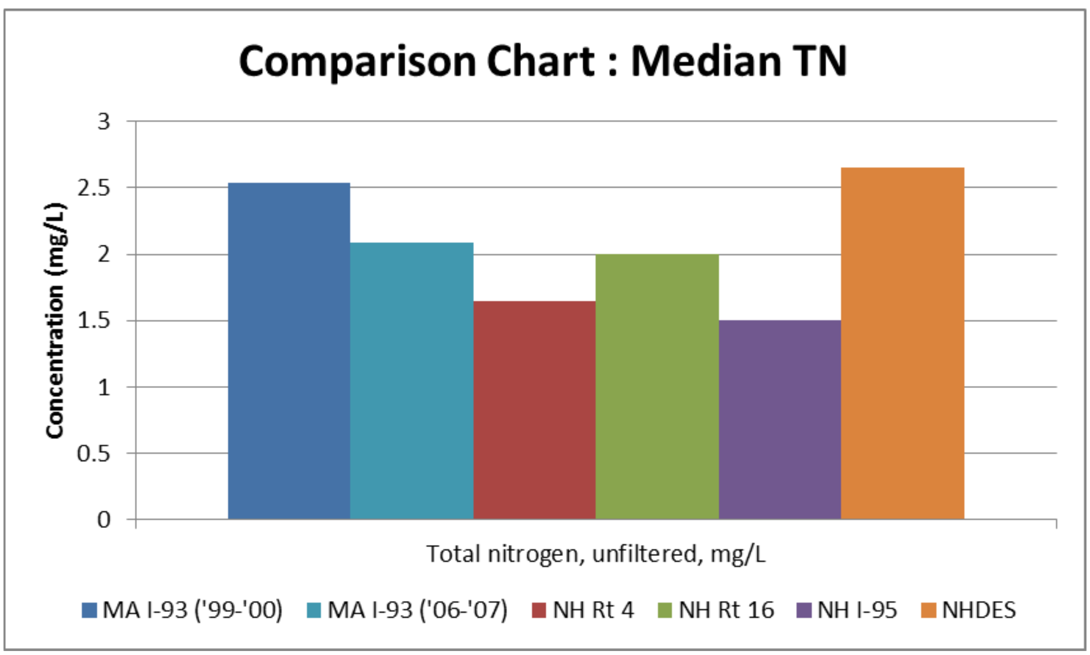

Figure 12: Comparison of median total nitrogen (TN) values from Massachusetts Interstate 93, New Hampshire Route 4, Route 16, and Interstate 95, and NHDES Simple Method pollutant loading calculations.

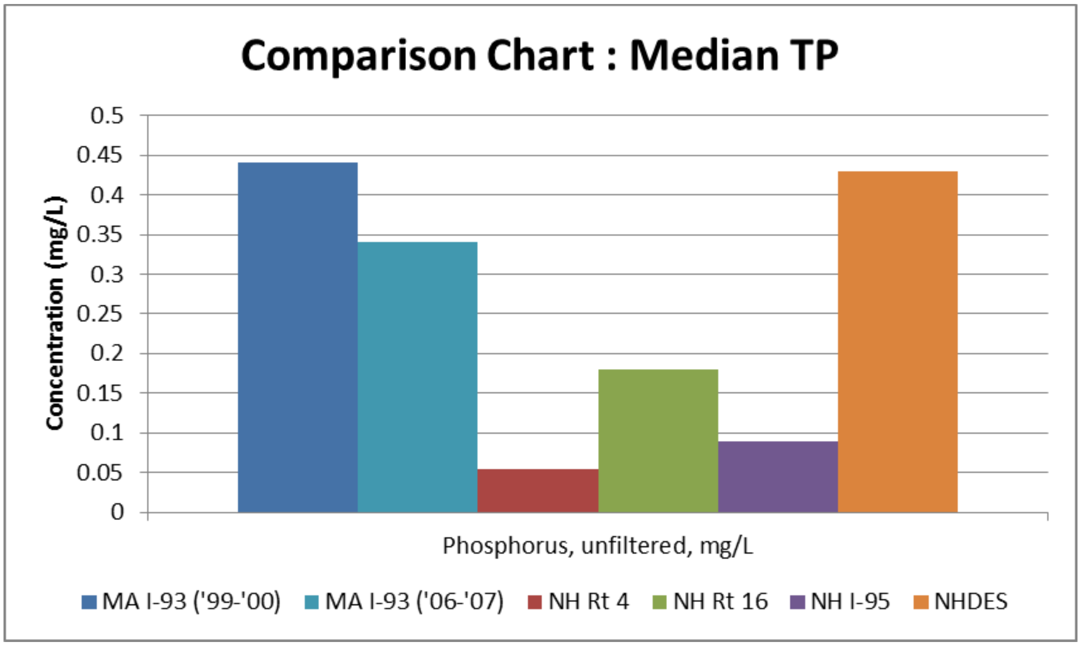

Figure 13: Comparison of median total phosphorus (TP) values from Massachusetts Interstate 93, New Hampshire Route 4, Route 16, and Interstate 95, and NHDES Simple Method pollutant loading calculations.

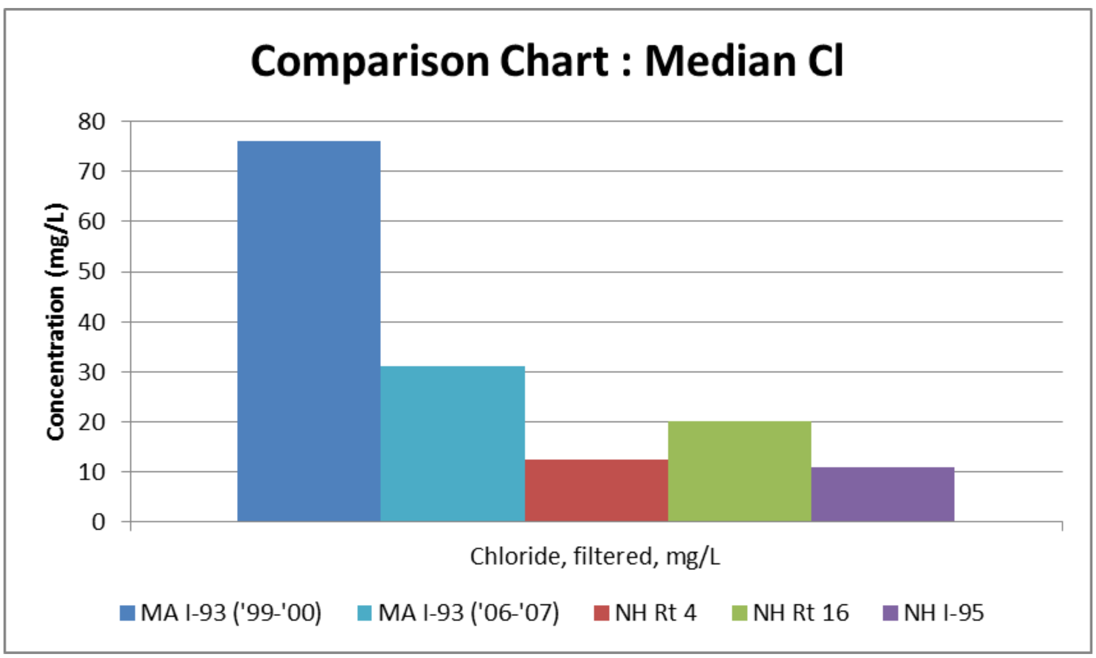

Figure 14: Comparison of median chloride (Cl) values from Massachusetts Interstate 93, New Hampshire Route 4, Route 16, and Interstate 95. (Note – NH sites only sampled in non-winter months)

Table 10: Comparison results of annual pollutant loading export rates using the NHDES Simple Method with the average and median constituent concentrations from the current study compared to the pollutant loading concentration for the General Highway land use category.

		Pollutant Export Rates					
Pollutant	Concentration	DOT Low		DOT Med		DOT High	
		(lb/ac/yr)	(Kg/ha/yr)	(lb/ac/yr)	(Kg/ha/yr)	(lb/ac/yr)	(Kg/ha/yr)
TSS	Average*	372.0	416.9	852.7	955.8	641.0	718.5
	Median*	259.2	290.6	541.6	607.1	685.2	768.0
	Modeled**	1305.5	1463.3	1305.5	1463.3	1305.5	1463.3
TP	Average*	0.61	0.68	1.85	2.08	0.79	0.88
	Median*	0.51	0.57	1.67	1.87	0.83	0.93
	Modeled**	3.98	4.46	3.98	4.46	3.98	4.46
PO_4	Average*	0.48	0.54	0.65	0.73	0.48	0.54
	Median*	0.36	0.40	0.60	0.67	0.46	0.52
TN	Average*	17.0	19.1	21.6	24.2	16.7	18.7
	Median*	15.3	17.1	18.5	20.8	13.9	15.6
	Modeled**	24.5	27.5	24.5	27.5	24.5	27.5
NO_3	Average*	3.2	3.6	2.7	3.0	2.9	3.3
	Median*	3.2	3.6	1.9	2.1	1.9	2.1
TKN	Average*	13.8	15.5	18.8	21.1	13.6	15.3
	Median*	12.5	14.0	16.7	18.7	12.0	13.5
NH_3	Average*	5.8	6.5	4.8	5.4	5.4	6.1
	Median*	5.1	5.7	4.6	5.2	4.6	5.2
Zn	Average*	1.6	1.8	1.7	1.9	1.7	1.9
	Median*	1.4	1.6	1.1	1.2	1.6	1.8
Cl	Average*	1485.0	1664.4	251.1	281.4	545.9	611.8
	Median*	115.7	129.7	185.2	207.6	101.8	114.2
*Empirically derived EMC values from UNHSC project monitoring							
**EMC values from NHDES Simple Method: Highway (General)							

Table 11: Comparison of annual pollutant export rates (PER) between the average of the three NHDOT sites monitored for this study, USEPA Region 1 MS4 Permit recommendations (USGS, Mass DOT, 2012), and NHDES Simple Method calculations.

Summary Pollutant Export Rates (Kg/ha/yr)			
Pollutant	**DOT (avg)***	**EPA**	**NHDES**
Total Suspended Sediments	697	1,659	1,463
Total Zinc	1.8	2.0	-
Total Nitrogen	20.7	11.4	27.5
Total Phosphorus	1.2	1.5	4.5
*Average PER from all three NHDOT monitored locations			

Conclusions

Results of this study indicate that there is limited variability between pollutant load exports from NH highways with various AADT. While there may be increases in pollutant load export due to other variables such as season, traffic congestion, and other transportation related variables, this study concludes that AADT alone does not warrant distinction between NH highways. In this study annual average pollutant load export rates were generated using all three highway classes assessed. Pollutant load export rates measured in this study are generally consistent with those reported and used by NHDES and EPA Region 1. In most instances the export rates measured are lower than those used by NHDES and EPA Region 1 indicating a factor of safety or conservative modeling approach which offers an additional level of confidence in the modeling approach as environmental pollution sources are dynamic and highly variable. The lone exceptions are with respect to total phosphorus and total nitrogen. In the case of total phosphorus the export rate measured in this study is consistent with the EPA Region 1 modeled values whereas the NHDES values are 3-3.75 times greater. For total nitrogen the export rate measured in this study is consistent with the NHDES modeled values whereas the EPA Region 1 values are 1.9-2.4 times lower.

This study provides verification that the modeled approaches available from NHDES and EPA Region 1 provide representative estimates of anticipated pollutant loads from all NH highways.

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