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Effect of the 2007 Heavy-Duty Highway Rule on pH Levels of Surface Waters in New York State

Bryan Comer

Abstract:

In this project, I intended to gain evidence that reduction in wet deposition of sulfate (SO_4^{2-}) and nitrate (NO_3^-), resulting from implementation of the 2007 Heavy-Duty Highway Rule, had led to an increase in pH levels of surface waters in New York State. Currently, some surface waters in New York State, especially in the Adirondack and Catskill regions, have pH levels low enough to damage aquatic ecosystems. The purpose of the 2007 Heavy-Duty Highway Rule is to both reduce sulfur (S) content in highway diesel fuel as well as reduce nitrogen oxide (NO_x) emissions from mobile sources. Reduction of NO_x is accomplished by allowing new heavy-duty diesel vehicles to make use of advanced pollution control technologies such as high-efficiency catalytic exhaust emission control devices which could not previously be used since S damages these devices. S and NO_x are precursors to acid deposition.

This project uses weekly data of SO_4^{2-} , NO_3^- , and pH concentrations over time from all active National Atmospheric Deposition Program (NADP) monitoring stations in New York State. Through regression analysis, I found that I cannot claim that the 2007 Heavy-Duty Highway Rule had any effect on concentrations of SO_4^{2-} , NO_3^- , or hydrogen ions (H^+) at the 95% confidence level. Since H^+ is directly related to pH, I also cannot claim that the 2007 Heavy-Duty Highway Rule had any effect on pH levels of surface waters in New York State at the 95% confidence level. If the 2007 Heavy-Duty Highway Rule does have any effect on pH levels of surface waters in New York State, more data and additional analysis will need to be conducted to confirm this.

Introduction

Sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are emitted into the atmosphere as a result of fossil-fuel combustion both from energy production, such as coal-burning power plants, and vehicle emissions. These pollutants are the precursors to acid deposition which can cause harm to aquatic ecosystems by lowering the pH of the water. A decrease in pH correlates to an increase in acidification. In particular, SO_2 emissions lead to wet deposition of sulfate (SO_4^{2-}) and NO_x emissions lead to wet deposition of nitrate (NO_3^-).

To combat acid rain, the EPA's Acid Rain Program uses a market-based approach to reduce SO_2 and NO_x emissions from coal-fired power plants. However, there is another rule that EPA has promulgated that may also help fight acid rain. EPA's 2007 Heavy-Duty Highway Rule could have positive external effects by decreasing the acidity of surface waters in New York State through reduction of SO_2 and NO_x emissions from on-road diesel vehicles.

The 2007 Heavy-Duty Highway Rule, finalized by the EPA in January 2001 and implemented beginning October 15, 2006, is a policy that mandates a 97% reduction in sulfur (S) content of highway diesel fuel from 500 parts per million (ppm) to 15 ppm through the use of ultra low-sulfur diesel fuel (ULSD) (*Heavy-duty Engine and Vehicle*, 2000). In 1999, transportation accounted for 6.9% of SO_2 emissions in the United States (Davis & Diegel, 2002). Decreases in S content, resulting from the 2007 Heavy-Duty Highway Rule, should lead to decreases in SO_2 emissions, thereby reducing wet

deposition of SO_4^{2-} . In 1999, transportation accounted for 53.4% of NO_x emissions in the United States (Davis & Diegel, 2002). ULSD will allow heavy-duty highway diesel vehicles to use advanced pollution control technologies, such as high-efficiency catalytic exhaust emission control devices, to meet new emission standards that will apply to all model year 2007 and later heavy-duty highway diesel engines and vehicles (*Heavy-duty Engine and Vehicle*, 2000). ULSD will also be used by light-duty diesel vehicles, such as passenger cars, as well. Use of advanced pollution control technologies should result in a decrease in NO_x emissions from heavy-duty diesel vehicles. Decreases in NO_x emissions, resulting from the 2007 Heavy-Duty Highway Rule, should lead to a decrease in wet deposition of NO_3^- . Reduction of SO_4^{2-} and NO_3^- deposition should lead to increases in pH of surface waters and, therefore, reduction of acidification.

Currently, many of the surface waters of New York State are acidified to degrees which strain aquatic ecosystems (Burns, Bode, & Murray, 2006; Burns, *et al*, 2005; Roy 2006; Sullivan, 2005). In this project, I intended to gain evidence that reduction in wet deposition of SO_4^{2-} and NO_3^- , resulting from the implementation of the 2007 Heavy-Duty Highway Rule, led to an increase in pH levels of surface waters in New York State. If increases in pH were accomplished by the 2007 Heavy-Duty Highway Rule, the acidified surface waters of New York State could see a faster recovery.

In order to determine how the pH of surface waters in New York State has changed over time, I analyzed data from eleven (11) monitoring stations run by the National Atmospheric Deposition Program (NADP). I looked at concentrations of SO_4^{2-} and NO_3^- as well as pH levels over time both before and after the implementation of the

2007 Heavy-Duty Highway Rule to determine what effect this rule had on those variables. However, as is shown in the Results section of this project, I cannot claim that the 2007 Heavy-Duty Highway Rule had an effect on the pH of surface waters in New York State or an effect on concentrations of SO_4^{2-} or NO_3^- , which are directly related to water acidification, at the 95% confidence level.

Literature Review

It is possible that the 2007 Heavy-Duty Highway Rule will reduce overall levels of wet deposition of SO_4^{2-} and NO_3^- and thereby lead to increases in pH of New York State surface waters over time. One area of New York State which is particularly susceptible to acid deposition is the Adirondack Mountain region. The Adirondack region is located directly downwind of Midwestern coal-burning power plants, resulting in the acidification of the surface waters in the area, particularly lakes (Mitchell, Raynal, & Driscoll, 2005; Raynal, Mitchell, & Driscoll, 2004; Roy, 2006).

Roy (2006) claims that the Adirondack region is one of the most sensitive areas to acidification in North America; Burns, Bode, & Miller (2006) claim that the Catskill Mountains of Southeastern New York State are also sensitive to acidification. Most research has been conducted in the Adirondack and Catskill regions of New York State because of their particular sensitivity to acid. The following literature has been written on the topic of acid deposition in New York State.

A study conducted by Raynal, Mitchell, and Driscoll (2005) focused on evaluating surface water chemistry and atmospheric deposition of Arbutus Lake watershed in the Adirondacks. This study illustrated both the cause and effects of acid

deposition in the Adirondacks, as well as uncovered reasons why recovery of lakes in the Adirondacks from acidification has slowed over time. The researchers claim, as previously stated, that the cause of increased acid deposition in the Adirondacks is due to its location downwind of Midwest coal-burning power plants. The study points to ongoing measurements that reveal that the wet deposition of SO_4^{2-} has decreased within the past two decades which can be attributed to the regulations set in place by the Clean Air Act Amendments of 1990 (CAAA). However, they note that there has been little change in deposition of NO_3^- . The study found that acid deposition has occurred over the last 150 years and, as a result, acidification of both soil and water in the Adirondacks has occurred. Limited recovery has been seen over the last 30 years despite emission regulations. The researchers note that their projections indicate that if the lakes continue to be exposed to acid deposition at the current rates, they will either continue to become more acidic or recover at a very slow rate. The researchers acknowledge that further emission regulations need to be implemented in order to improve the recovery of the Adirondack lakes.

Another study conducted by Burns, *et al* (2005) focused not only on the Adirondack region, but the Catskill region as well. Their intent was to gain insight to the effects of acid deposition across various regions of New York State. The researchers began by explaining that fossil-fuel combustion leads to SO_2 and NO_x which are the precursors to acid deposition. The researchers claim that aquatic biota are likely to be harmed when water pH is less than 5.5 and acid-neutralizing capacity (ANC) is below 50 microequivalents per liter ($\mu\text{eq/L}$). The study found that the pH of precipitation had increased on average 0.02 units in the Adirondack and Catskill regions from 1984 to

2001. A positive increase in pH indicates that the precipitation is becoming less acidic. Three-fourths of the increase in pH was determined to be from decreased levels of SO_4^{2-} and one-fourth from decreased levels of NO_3^- . The researchers drew a direct link between the decreased levels of SO_4^{2-} and NO_3^- and similar decreases in SO_2 and NO_x emissions from power plants. Overall, the study found that surface waters in the Adirondacks and Catskills are recovering, albeit slowly, due in part to the CAAA. This group joins with Raynal, Mitchell, and Driscoll (2005) in recognizing that further reductions in SO_2 and NO_x beyond those mandated in the CAAA may be necessary to speed recovery of the surface waters in the Adirondacks and Catskills.

Another study, conducted by Burns, McHale, Driscoll, and Roy (2005), investigated the relationship between surface water chemistry and reduced levels of acid precipitation in the Adirondacks and Catskills between 1984 and 2001. The researchers noted that the Adirondacks and Catskills were “two of the most acid-sensitive regions in North America” because they have a low ANC. This study found that there was significant reduction in SO_4^{2-} and NO_3^- between 1984 and 1991 but not many significant trends reduction of SO_4^{2-} and NO_3^- from 1991 to 2001. This suggests that most of the change occurred between 1984 and 1991. The study also found that pH increased in the precipitation at the sites near the Adirondacks and Catskills from 1984 to 2001. The researchers found an increase in ANC in sites located in both regions. Decreases in the acidity of the precipitation of the Adirondacks and the Catskills were attributed to increased controls such as the CAAA and better pollution removal technologies and energy conservation.

A study conducted by Burns, Bode, and Murray (2006), focused on changes in stream chemistry related to decreased acidity of atmospheric deposition in the Neversink River Basin of the Catskill Mountains by comparing data collected in 1983 and 2003. The researchers claim that “the Neversink River is the most acid-sensitive watershed in the Catskills region...” They point out that fossil-fuel combustion is the major source of SO₂ and NO_x which lead to acid deposition. This group of researchers had a more stringent cutoff of a pH of 6 being potentially harmful to aquatic biota as compared to the study conducted by Burns, *et al* (2005) which claimed that a pH of 5.5 or less was the threshold for harm to aquatic biota. Since Burns is the common denominator here, the proclamation in the report that a pH of 6 or less is potentially harmful to aquatic biota *may* be an indication that over time, scientists have found that a pH of less than 6, as opposed to less than 5.5, is potentially harmful. This is important because pH is measured on a logarithmic scale so a small increase in pH is a large increase in the concentration of hydrogen ions (H⁺). The researchers agree with Burns, *et al* (2005) that an ANC of less than 50µeq/L also presents a risk to aquatic biota. Though this study focused on biological implications of increased pH, it does recognize that there has been an increase in the pH in the Neversink River Basin which the researchers link to decreased emissions of SO₂ from coal-fired power plants as mandated by the CAAA.

Next, an ongoing study being conducted by Mitchell, Raynal, and Driscoll (2005) is determining the relationship between atmospheric deposition and surface water chemistry at the Arbutus Lake watershed in the Adirondacks. The main goal of the project is to study the relationship between drainage losses of nitrogen (N) and S in relation to changes in climate and atmospheric deposition. The researchers echo

previously discussed literature in saying that fossil-fuel combustion is the major source of SO_2 and NO_x which lead to acid deposition. Also, that acid deposition causes the acidification of surface waters such as lakes and rivers. Recent findings indicate that concentrations of SO_4^{2-} in discharge from the lakes have decreased significantly in the 1990s. No clear trend for NO_3^- has been established in lake discharges in the 1990s. The group concludes that their recent results indicate that much can be learned about the effectiveness of clean air policies including the CAAA by studying the effects of acid deposition on the lakes of the Adirondacks. They note that some recovery from acidification is present but that their research shows that “current regulations are likely inadequate to protect the most sensitive waters in the region from its [acid deposition’s] effects.”

Another ongoing study, which is being conducted by Sullivan (2005) is making an effort to “extrapolate” results from some of the lakes that are “intensively studied” and see if they are representative of the lakes of the Adirondack region in general. Sullivan is a member of the same camp as Burns, *et al* (2005) in claiming that a pH of less than 5.5 and an ANC of less than $50\mu\text{eq/L}$ are potentially harmful to aquatic biota. Sullivan explains that it is important for resource managers and policymakers to understand the impact that future emission reductions will have on the recovery of Adirondack ecosystems from acidification. He sees a problem with assessing progress by studying only a few lakes in the region and is attempting to provide a bigger picture to policymakers. The goal of the study is to provide information that can help set future emission standards to aid in the recovery of a greater number of Adirondack lakes.

Finally, an ongoing study is being conducted by Roy (2006). This study intends to assess changes in water chemistry in the Adirondacks and to provide policymakers with findings to make policy decisions to aid in the recovery of acidified lakes in the region. This study is identifying changes in water chemistry over time in Adirondack lakes. Roy agrees with the parameters of aquatic biota risk set in the Burns, Bode, and Murray (2006) study. Roy claims that a pH of less than 6 and an ANC of less than $50\mu\text{eq/L}$ are potentially harmful to aquatic biota. The primary goal of the study is to assess the effectiveness of the CAAA. Preliminary findings from data collected from 1982 to 1991 of 17 Adirondack Long Term Monitoring (ALTM) lakes indicated a decrease in SO_4^{2-} in most lakes, but an increase of NO_3^- in over half the lakes and no improvements in ANC or pH. The second analysis of 52 lakes from 1992 to 2000 showed decreased levels of SO_4^{2-} in most lakes, variable levels of NO_3^- , increase of ANC in 29 out of 48 lakes, and increase in pH in 18 lakes. Roy believes that recovery will take decades without further regulation of emissions. Roy advocates further reductions in SO_2 and NO_x in order to speed the recovery of the lakes.

The common theme throughout all the literature is that without further mandates for reduction of SO_2 and NO_x , recovery for the acidified surface waters of New York State will take decades. Though its emphasis is not on acid rain, the 2007 Heavy-Duty Highway Rule implemented by the EPA beginning October 15, 2006, may result in a reduction in SO_2 and NO_x emissions and correlate to a reduction in acid deposition and an increase in pH levels of surface water in New York State over time.

Methodology

Analysis Technique

I have collected data from 11 National Atmospheric Deposition Program (NADP) monitoring sites listed in the Data Collection section and seen in Figure 5. The data include weekly concentrations of SO_4^{2-} , NO_3^- , and pH. My project will use data analysis tools, such as regression, to determine if there have been any changes in wet deposition of SO_4^{2-} , NO_3^- , and pH after the implementation of the 2007 Heavy-Duty Highway Rule. The 2007 Heavy-Duty Highway Rule was implemented by the EPA beginning October 15, 2006.

In general, I performed a regression for concentrations of SO_4^{2-} , NO_3^- , and hydrogen ions (H^+) both pre and post 10/15/06 and compare the slopes of the resulting linear regression lines at the 95% confidence level. If the slope of the linear regression line prior to 10/15/06 was statistically significantly different from the slope after 10/15/06, then I could claim that the trend changed after the date of implementation of the 2007 Heavy-Duty Highway Rule. If that was the case, then I would determine if the amount of SO_4^{2-} , NO_3^- , or pH was trending higher or lower after the implementation of the rule. However, as is explained in the Results section, I could not claim that the slopes of the trendlines before and after 10/15/06 were statistically significantly different at the 95% confidence level for SO_4^{2-} , NO_3^- , or H^+ at any of the monitoring locations. In the following steps, I explain why I used H^+ instead of pH for my regression analysis.

I used Microsoft Excel as my analysis software. Appendix A consists of the Excel file containing my data analysis. The steps of my analysis are as follows:

Step 1: Convert pH to H+. Since pH is measured on a logarithmic scale, I decided to convert pH into concentrations of hydrogen ions (H+) to make it easier to perform a regression analysis. To convert pH to H+, I used the following equation:

$$H^+ = 10^{-pH}$$

Step 2: Obtain descriptive statistics for SO₄²⁻. Using Excel's "Descriptive Statistics" data analysis tool, I obtained the mean and standard deviation for SO₄²⁻ from the first monitoring site (NY01) data (see highlighted rows in Figure 1). This information allowed me to identify and eliminate outliers in the data from my analysis. I considered any data point less than or greater than two standard deviations from the mean to be an outlier.

<i>SO4</i>	
Mean	1.676593
Standard Error	0.103756
Median	1.416
Mode	0.98
Standard Deviation	1.22766
Sample Variance	1.507149
Kurtosis	7.452862
Skewness	2.268375
Range	7.325
Minimum	0.135
Maximum	7.46
Sum	234.723
Count	140
Confidence Level(95.0%)	0.205144

Figure 1: Example of SO₄²⁻ Descriptive Statistics at NY01

Step 3: Create a scatter plot of SO_4^{2-} over time. The scatter plot allows me to graphically identify outliers. Figure 2 below is an example; the data points colored red are outliers.

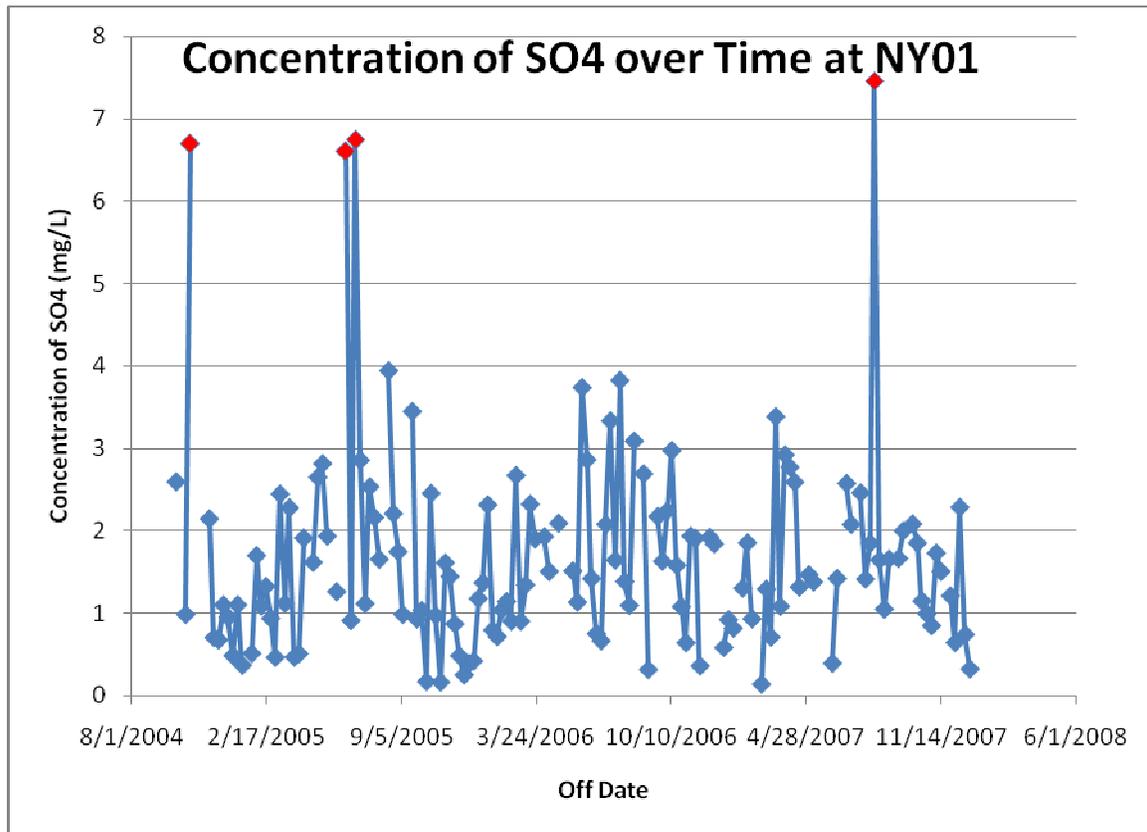


Figure 2: Example of Scatter Plot to Identify Outliers Prior to Regression

Step 4: Remove outliers and missing data for SO_4^{2-} . In preparation for performing a regression analysis on the data, I removed the outliers I identified in Step 3 as well as any rows with missing data.

Step 5: Perform regression for SO_4^{2-} data prior to 10/15/06. Since 10/15/06 is when the 2007 Heavy-Duty Highway Rule was implemented, I want to determine the slope of the trendline prior to its implementation so that I can compare it with the slope of the trendline after its implementation. As an example, the highlighted cell in Table 1 is the slope of the trendline for SO_4^{2-} at NY01 prior to 10/15/06.

Table 1: Example of Regression Output for SO_4^{2-} prior to 10/15/06 at NY01

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	1.14957753	0.20480241	5.61310525	2.44E-07	0.7423754	1.5567796
Week	0.00727218	0.00325342	2.235237951	0.0280	0.0008035	0.013740876

Step 6: Perform regression for SO_4^{2-} data after 10/15/06. This will give me the slope of the trendline after the rule's implementation. As an example, the highlighted cell in Table 2 is the slope of the trendline for SO_4^{2-} at NY01 after 10/15/06.

Table 2: Example of Regression Output for SO_4^{2-} after 10/15/06 at NY01

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	1.3954112	0.7636485	1.827295138	0.07400847	-0.1408514	2.93167387
Week	0.0005456	0.0054801	0.099570684	0.92110866	-0.0104789	0.01157027

Step 7: Create a scatterplot that graphically depicts the trend of SO_4^{2-} concentrations before and after 10/15/06. This allows for a visual comparison of the slope of the trendline before and after 10/15/06 to determine how the concentration of SO_4^{2-} has changed. Figure 3 below is an example.

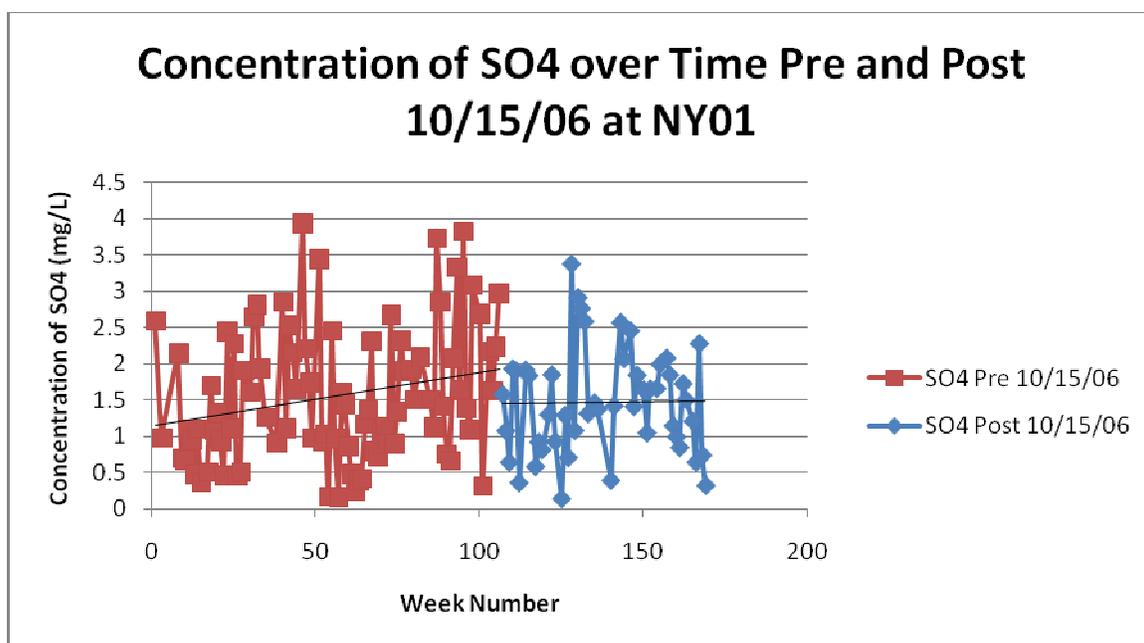


Figure 3: Example of Scatterplot Showing Concentration of SO_4^{2-} over Time Pre and Post 10/15/06

Step 8: Compare the slope of the trendline before 10/15/06 to the slope of the trendline after 10/15/06 at the 95% confidence level. I compared the two slopes to determine if they were statistically significantly different at the 95% confidence level. After running the regression pre and post 10/15/06, I noted the 95% confidence interval for potential slopes of two trendlines. If the intervals do not overlap, then I can claim that the slope of the trendline prior to 10/15/06 is different than the slope of the trendline after 10/15/06 at the 95% confidence

level. This would indicate that the concentration of SO_4^{2-} had changed after the implementation of the 2007 Heavy-Duty Highway Rule. Alternatively, if the intervals *do* overlap, then I cannot claim that the slopes are statistically significantly different at the 95% confidence level. See the highlighted cells in Figure 4 which are examples of 95% confidence intervals derived from a regression performed on SO_4^{2-} data for NY01. Note that the intervals overlap so, in this case, I cannot claim that the slopes are different at the 95% confidence level.

SO4 Pre 10/15/06
NY01

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	1.1495775	0.2048024	5.6131052	2.4417E-07	0.7423754	1.5567796
Week	0.0072721	0.0032534	2.2352379	0.0280234	0.0008035	0.0137408

SO4 Post 10/15/06
NY01

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	1.3954112	0.7636485	1.8272951	0.0740084	0.1408514	2.9316738
Week	0.0005456	0.0054801	0.0995706	0.9211086	0.0104789	0.0115702

Figure 4: Example of 95% Confidence Interval Comparison to Determine if the Slopes of Two Linear Trendlines are Statistically Significantly Different

Step 9: Repeat Steps 2 – 8 for NO_3^- and H^+ . Also repeat the process for data collected from all 11 monitoring sites.

Data Collection

Quality assured data on SO_4^{2-} , NO_3^- , and pH levels from National Atmospheric Deposition Program (NADP) monitoring stations throughout New York State are easily accessed from their website (<http://nadp.sws.uiuc.edu/>). There is typically a five to six month delay in posting recorded data because of the quality assurance process. I am interested in data recorded both before and after the implementation of the 2007 Highway Rule which took effect October 15, 2006. By April 2008, data on SO_4^{2-} , NO_3^- , and pH levels up to and including October 2007 should be available for analysis. This data will be essential in evaluating trends in pH levels related to changes in SO_4^{2-} and NO_3^- . I will collect data from all active monitoring stations located in New York State. Figure 5 below is a map of NADP monitoring sites in New York; the blue dots are active sites.

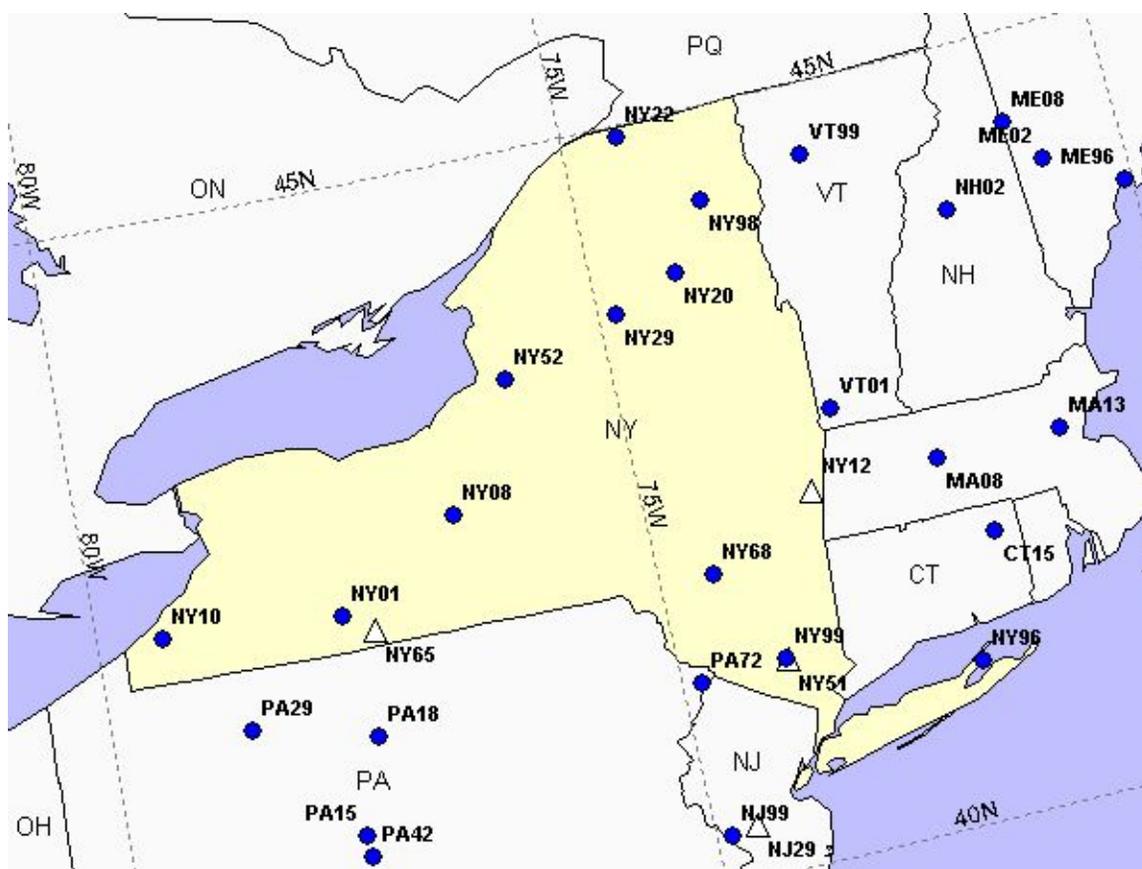


Figure 5: Map of New York State National Atmospheric Deposition Monitoring Sites

Source: <http://nadp.sws.uiuc.edu/sites/sitemap.asp?state=ny>

The monitoring stations are as follows:

Table 3: Summary of Monitoring Station Names, Locations, Proximity to Interstates, and Dates of Operation

Station Name	Location	Closest NY Interstate (approx mileage)	Dates of Operation
Alfred (NY01)	Allegany County	86 (10 mi)	08/17/2004 - Present
Aurora Research Farm (NY08)	Cayuga County	90 (20 mi)	04/17/1979 - Present
Chautauqua (NY10)	Chautauqua County	90 (5 mi)	06/10/1980 - Present
Huntington Wildlife (NY20)	Essex County	87 (25 mi)	10/31/1978 - Present
Akwesasne Mohawk-Fort Covington (NY22)	Franklin County	87 (50 mi)	08/18/1999 - Present
Moss Lake (NY 29)	Herkimer County	81 (45 mi)	07/29/2003 - Present
Bennett Bridge (NY52)	Oswego County	81 (5 mi)	06/10/1980 - Present
Biscuit Brook (NY68)	Ulster County	87 (25 mi)	10/11/1983 - Present
Cedar Beach, Southold (NY96)	Suffolk County	495 (20 mi)	11/25/2003 - Present
Whiteface Mountain (NY98)	Essex County	87 (15 mi)	07/03/1948 - Present
West Point (NY99)	Orange County	87 (10 mi)	09/13/1983 - Present

The Bennett Bridge and monitoring station is located east of Lake Ontario and the Chautauqua monitoring station is located east of Lake Erie. Measurements taken from these monitoring stations may be influenced by lake effect precipitation. The Cedar Beach, Southold monitoring station is located on the coast of Long Island which may impact its measurements due to its proximity to the Atlantic Ocean. The Akwesasne Mohawk-Fort Covington and Moss Lake monitoring stations are the furthest from New York interstates and may receive lower concentration of pollutants from heavy-duty

highway diesel vehicles than other stations. From this analysis, I will be able to determine if geographic location has any effect on results. Figure 6 below is a photo of one of the Huntington Wildlife monitoring station.



Figure 6: Photo of Huntington Wildlife Monitoring Site (NY20)

Source: <http://nadp.sws.uiuc.edu/sites/siteinfo.asp?id=NY20&net=NTN>

Results

In this section, I will discuss the findings of my analysis. I will go through each of the 11 monitoring sites and explain the difference in the slope of the linear regression lines before and after 10/15/06. For example, I will compare the “pre” and “post” slope and indicate whether or not they are statistically significantly different at the 95% confidence level. Appendix A contains the data analysis that led to these results.

After comparing the slope of the linear regression trendlines pre and post implementation of the 2007 Heavy-Duty Highway Rule, I was unable to claim that any were statistically significantly different at the 95% confidence level. This means that at the 95% confidence level, I cannot say for certain that the 2007 Heavy-Duty Highway Rule had any effect on the trend of SO_4^{2-} , NO_3^- , or H^+ concentrations at the 11 monitoring sites throughout New York State. Table 4,

below compare the trends of SO_4^{2-} , NO_3^- , and H^+ concentrations pre and post 10/15/06 (the date of implementation for the rule) at each monitoring site. Table 7 explains the instances where the post slope was less than the pre slope indicating that after the implementation of the 2007 Heavy-Duty Highway Rule, the concentrations of SO_4^{2-} , NO_3^- , or H^+ tended to decrease. A decrease in SO_4^{2-} , NO_3^- , and H^+ can lead to lower acidification, but again, I cannot be certain of these results at the 95% confidence level.

Table 4: Comparison of SO_4^{2-} Trends Pre and Post 10/15/06 at each Monitoring Site

Monitoring Site	Approx. Distance from Nearest Interstate (mi)	Pre Slope	Post Slope	Statistically Significantly Different?
NY01	10	0.0073	0.0005	No
NY08	20	-0.0009	0.0132	No
NY10	5	0.0020	0.0030	No
NY20	25	-0.0018	0.0041	No
NY22	50	-0.0016	0.0097	No
NY29	45	0.0005	0.0063	No
NY52	5	0.0010	0.0117	No
NY68	25	0.0047	0.0083	No
NY96	20	0.0061	0.0063	No
NY98	15	0.0002	0.0049	No
NY99	10	0.0053	0.0134	No

Table 5: Comparison of NO₃⁻ Trends Pre and Post 10/15/06 at each Monitoring Site

Monitoring Site	Approx. Distance from Nearest Interstate (mi)	Pre Slope	Post Slope	Statistically Significantly Different?
NY01	10	-0.0047	-0.0058	No
NY08	20	-0.0063	0.0020	No
NY10	5	-0.0073	-0.0081	No
NY20	25	-0.0024	-0.0012	No
NY22	50	-0.0047	-0.0042	No
NY29	45	-0.0037	-0.0028	No
NY52	5	-0.0056	-0.0006	No
NY68	25	-0.0013	0.0015	No
NY96	20	-0.0001	0.0022	No
NY98	15	-0.0047	-0.0037	No
NY99	10	0.0021	0.0111	No

Table 6: Comparison of H+ Trends Pre and Post 10/15/06 at each Monitoring Site

Monitoring Site	Approx. Distance from Nearest Interstate (mi)	Pre Slope	Post Slope	Statistically Significantly Different?
NY01	10	-1.63E-08	-14.98E-08	No
NY08	20	-7.90E-08	4.77E-08	No
NY10	5	6.68E-08	-23.26E-08	No
NY20	25	-7.04E-08	-1.83E-08	No
NY22	50	-9.31E-08	-17.34E-08	No
NY29	45	-7.08E-08	-0.15E-08	No
NY52	5	-6.05E-08	3.50E-08	No
NY68	25	5.74E-08	17.07E-08	No
NY96	20	4.34E-08	9.96E-08	No
NY98	15	-3.90E-08	-8.68E-08	No
NY99	10	3.49E-08	23.97E-08	No

Table 7: Instances where Post Slope was less than Pre Slope

Monitoring Site	Approx. Distance from Nearest Interstate (mi)	SO ₄ ²⁻ , NO ₃ ⁻ , or H+?	Pre Slope	Post Slope	Magnitude of Difference
NY01	10	SO ₄ ²⁻	0.0073	0.0005	0.0068
NY01	10	NO ₃ ⁻	-0.0047	-0.0058	0.0011
NY01	10	H+	-1.63E-08	-14.98E-08	13.35E-08
NY10	5	NO ₃ ⁻	-0.0073	-0.0081	0.0007
NY10	5	H+	6.68E-08	-23.26E-08	29.94E-08
NY22	50	H+	-9.31E-08	-17.34E-08	8.03E-08
NY98	15	H+	-3.90E-08	-8.68E-08	4.78E-08

Table 7 above depicts instances where one may find evidence that the 2007 Heavy-Duty Highway Rule led to a reduction in SO_4^{2-} , NO_3^- , or H^+ . We see that at NY01, the slopes of the trendlines after the implementation of the rule for SO_4^{2-} , NO_3^- , and H^+ were all less than the slopes of the trendlines prior to implementation. This indicates that the overall concentrations of SO_4^{2-} , NO_3^- , and H^+ were decreasing compared to their concentrations prior to implementation of the rule. This is an interesting result since NY01 is only about 10 miles away from the nearest interstate; so perhaps the station's close proximity to a highway played a role in these results. Also concentrations of NO_3^- and H^+ at NY10, which is only about 5 miles away from the closest interstate, tended to decrease after implementation; however, as mentioned earlier, this site may be impacted from lake-effect precipitation as well. For NY22 and NY98, H^+ concentrations tended to decrease after implementation but without a decrease in SO_4^{2-} or NO_3^- , it would be difficult to link this reduction with the 2007 Heavy-Duty Highway Rule. However, it is important to note that I could not claim that any of the slopes were statistically significantly different at the 95% confidence level.

Possible Reasons for Obtaining Inconclusive Results

In general, I cannot claim that the 2007 Heavy-Duty Highway Rule had any effect on concentrations of SO_4^{2-} , NO_3^- , H^+ , and pH since it is directly related to H^+ , over time. In Appendix A, under any of the "...Beta Comparisons" tabs, one can see that the 95% confidence intervals are very large, often including both positive and negative numbers as potential "true values" for the slopes of the linear regression trendlines. These large confidence intervals make it difficult to claim that two linear regression trendlines are actually different from each other statistically. Next, I will discuss possible reasons for inconclusive data.

Lack of Data

More data both before and after the implementation of the rule may be required to observe any meaningful trends over time. It could be that the actual impact on acid rain from the 2007 Heavy-Duty Highway Rule may take years or even a decade to become clear.

Other Potential Variables

In my regression analysis, I am holding all other variables constant which certainly have an impact and are definitely not constant. For example, weather patterns matter a great deal when dealing with wet deposition of SO_2 and NO_x . Also, what if there are more or less vehicles travelling on the interstates? What if the coal-fired power plants in the Midwest increase production? The truth is that all of these variables have the ability to impact my results.

Policy Alternatives

If I cannot claim that the 2007 Heavy-Duty Highway Rule is affecting the pH of surface waters in New York State at the 95% confidence level, what does this mean for public policy solutions to acid deposition and the acidification of surface waters in New York State? To be fair, the 2007 Heavy-Duty Highway Rule was never intended to combat acid rain in the first place, but I

see the potential for positive externalities at some level over time. To address the problem more directly, I have come up with a few public policy options that could be implemented to address the problem of acidified surface waters in New York State.

Regulations

The EPA already has a cap-and-trade program for SO₂ emissions from coal-fired power plants under its Acid Rain Program. If the cap were reduced, acid deposition would decrease. Another regulatory option would be to abolish the Acid Rain Program's cap-and-trade program and replace it with a command and control system forcing coal-fired power plants to reduce their emissions of SO₂ and NO_x and fine those who do not comply. However, typically non-market based solutions are less popular.

Power plants can reduce SO₂ emissions by burning fuel with lower sulfur content or installing other control technologies such as scrubbers. To reduce NO_x, power plants can use low-NO_x burners. Regulations requiring low-sulfur fuel and the use of better control technologies could reduce acid deposition.

For diesel vehicles, the reduction of sulfur content in diesel fuel will allow the use of advanced emission control technologies which will reduce NO_x. The government could mandate the use of these control technologies on all diesel vehicles that operate on on-road diesel fuel.

Taxes

Though politically unpopular, taxes could be levied on generators of SO₂ and NO_x, charging them for each unit of each pollutant they discharge. It's important to realize that such a policy would increase government tax revenue but those being taxed would likely pass any additional costs to the consumers of the goods and services they produce. If energy producers are taxed, people will likely be charged more for their energy use.

Subsidies

The government could subsidize alternative energy sources which can dramatically reduce SO₂ and NO_x emissions associated with energy production.

Liming Acidified Lakes

One temporary solution to acidified lakes is the application of lime (as in limestone). This reduces the acidity of the lake but needs to be reapplied as the lake becomes more acidified again. Though liming is usually seen as a low cost solution, there are many lakes in New York State that would require treatment on an ongoing basis which would increase cost.

Education

The EPA provides tips on steps to reduce acid deposition that ordinary citizens can take on their website at <http://www.epa.gov/acidrain/reducing/index.html#take>. These tips include conserving energy, insulating your home, and purchasing energy efficient appliances. Through energy conservation, less electricity is used which reduces demand for energy production which is a main cause of acid deposition.

Conclusion

The surface waters in New York State have a real problem with acid deposition. Out of the over 1000 data points for pH levels I have collected, only 18 were above a pH of 5.5, the threshold at which aquatic biota are likely to be negatively affected. With current data, I cannot claim at the 95% confidence level that the 2007 Heavy-Duty Highway Rule had any effect on pH levels of surface waters in New York State. I also cannot claim at the 95% confidence level that the rule had any effect on concentrations of SO₄²⁻ and NO₃⁻ which have a direct relationship to water acidity. Over time, the 2007 Heavy-Duty Highway Rule may result in decreased acidification of surface waters in New York State as a positive externality to the regulation; however, this remains to be seen.

It is clear that the policies in place now that specifically deal with reducing acid deposition are insufficient at protecting the surface waters in New York State. This is especially true when we consider the harm acid deposition causes ecologically sensitive areas of the state such as the Adirondack region. Possible policy options to help reduce acid deposition and its effects include (1) new regulations on the generators of acid deposition precursors, such as coal-fired power plants, (2) taxation on generators of acid deposition precursors, (3) subsidies for alternative energy production, (4) liming of acidified lakes, and (5) greater public education on the importance of energy conservation and its relationship to acid deposition.

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APPENDIX A

This appendix includes the data analysis I conducted using Microsoft Excel to arrive at my results and conclusions. The Excel file is found in an attachment to this document under the title “Data Analysis and Results.” Below, I will provide definitions for each of the tab labels in the Excel file. Please note that NY** simply means that it could be any of the monitoring stations (NY01, NY08, etc.).

NY Data** – Data from the National Atmospheric Deposition Program for NY** monitoring station.

NY H+ SP w Out** – Scatterplot of H+ containing outliers at NY**.

NY H+ DS w Out** – Descriptive Statistics for H+ data with outliers at NY**. This description is used throughout the file but H+ is substituted for SO_4^{2-} and NO_3^- .

NY H+ Data no Out for Reg** – Data for H+ to be used for regression that contains no outliers or missing data at NY**.

NY H+ DS no Out** – Descriptive Statistics for H+ without outliers at NY**.

NY H+ PRE Reg** – Regression analysis for H+ data at NY01 prior to the implementation of the 2007 Heavy-Duty Highway Rule on 10/15/06.

NY H+ POST Reg** – Regression analysis for H+ data at NY01 prior to the implementation of the 2007 Heavy-Duty Highway Rule on 10/15/06.

NY H+ SP TL PRE and POST** – Scatterplot comparing H+ data trends both before and after 10/15/06 including trendlines at NY**.

NY H+ Beta Comparisons** – Comparing the slope of the trendlines before and after 10/15/06 for H+ at NY**