New York State DEC

Total Maximum Daily Load (TMDL) for Acid Impaired Lakes in the Adirondack Park

NYS Forest Preserve
Adirondack Region, New York

September 2014
Developed in conformance with
Section 303(d) of the Clean Water Act

New York State Department of Environmental Conservation

Andrew M. Cuomo, Governor **Joseph Martens, Commissioner**

Technical Analysis Prepared by:
LimnoTech and Syracuse University
Under Contract to
Battelle, Duxbury MA

Prepared for:
NYSDEC
USEPA Region 2

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1 Introduction

Section 303(d) of the Clean Water Act and the United States Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 Code of Federal Regulations [CFR] Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are not meeting designated uses under technology-based controls. The TMDL process establishes the allowable loading of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and waterbody conditions. This allowable loading represents the maximum quantity of the pollutant that the waterbody can receive without exceeding water quality standards. The TMDL also takes into account a margin of safety (MOS), which reflects scientific uncertainty, as well as the effects of seasonal variation. By following the TMDL process, States can establish water quality-based controls to reduce pollution from both point and nonpoint sources, and restore and maintain the quality of their water resources (U.S.EPA 1991).

The 1998 (and subsequent) New York State Clean Water Act (CWA) Section 303(d) List of Impaired Waters identified approximately 400 waterbodies – including a number of lakes (and some streams) in the Adirondack Mountain Region of the state - as having designated uses (aquatic life support) impaired by low pH and associated impacts attributed to acidic deposition (acid rain). In this document information supporting the development of 51 TMDLs for parameters related to low surface water pH is presented, in order to achieve water quality standards associated with viability of the designated uses, such as aquatic life support. The scope of these 51 TMDLs covers 89 lakes and ponds in the Adirondacks. The report covers each step of the TMDL process and is organized as follows:

- Background
- Applicable Standards and Numeric Targets
- Water Quality Conditions
- Water Quality Modeling
- Source Assessment
- TMDL Development
- Reasonable Assurance and Implementation
- Post TMDL Monitoring

Blank page

2 Background

The Adirondack Park region is a protected area of 2.4 million hectares in the northern New York State, consisting of 1.0 million hectares of public land and 1.4 million hectares of private land. The region is characterized by dense, generally mature, mixed forest, cover and abundant surface waters including approximately 2,800 lakes and 9,400 km of streams (Jenkins et al. 2005). The Adirondack Park has long been a nationally important recreational area for fishing, hiking, boating and other outdoor activities.

The Adirondack region receives among the highest rates of atmospheric inputs of acid deposition in the United States (Driscoll et al. 2001a). This is due to the high amounts of precipitation the region receives annually (approximately 100 cm) in combination with the high concentrations of acidic substances in the atmosphere over the region (sulfate, nitrate; Burns et al. 2006; Driscoll et al. 1991). The bedrock of the Adirondack region is made up of granitic gneiss and meta-sedimentary rock which is overlain by thin glacial till (Driscoll et al. 1991). The till thickness varies, generally being thicker in the valley bottoms and becoming progressively thinner upslope. Soils developed from the glacial till are primarily Spodosols and are generally acidic. These soils are characterized by low pools of available base cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and limited ability to absorb and retain sulfate (Driscoll et al. 1991). Generally soils provide an important a buffering mechanism by which the strong acid anions inputs are neutralized by the supply of available base cations (Driscoll and Newton 1985; van Breemen et al. 1984). However, elevated inputs of acid deposition over the past century coupled with the geologic and soil characteristics which lack the capability to completely neutralize deposited acids make the Adirondacks highly vulnerable to acidic deposition (Driscoll et al. 1991).

New York's 1998 (and subsequent) Section 303(d) lists have identified a number of waterbodies in the Adirondack Mountain region as impaired by low pH and associated acid impacts. The majority of the acid-impaired lakes in the Adirondack Mountain region were added to the 303(d) list in 1998 based on chemistry and biologic data from the mid-1980s or earlier. The State of New York completed TMDLs for 143 of these acid-impaired lakes in 2006 (NYSDEC 2006). The 143 lakes included in the 2006 Acid Lakes TMDL are all located entirely within the New York State Forest Preserve. The Forest Preserve has expanded considerably in recent years through State land acquisition, adding to the number of ponded waters in the Forest Preserve. As a result, the ponded waters covered in the current TMDL have, for the most part, had been on the 303(d) List as private, but are now all located within the Forest Preserve. Thus the current TMDL is focused on some of the remaining affected lake waters on the 2012 303(d) List that now fall within the Forest Preserve lands.

2.1 Problem Statement

Anthropogenic activities, including the combustion of fossil fuels, have caused elevated levels of acid-generating compounds in the atmosphere. Specifically, the combustion of fossil fuels release sulfur dioxide (SO_2) and nitrogen oxides (NO_x) into the atmosphere where they react with water, oxygen and other chemicals to form various acidic compounds. These acidic compounds are deposited to the terrestrial and aquatic surfaces in both wet form (rain, snow and fog) and dry form (gases, aerosols and particles). Sulfuric acid (H_2SO_4) and nitric acid (HNO_3) are the primary agents of acid deposition. Acidic compounds can be transported long distances by prevailing winds, often across state and national borders, and affect ecosystems that are far away from emission sources.

Acidic deposition of atmospheric pollutants has caused widespread deleterious effects on forest and aquatic ecosystems across North America (U.S. EPA 2008a; Stoddard et al. 2003). In the Adirondacks, acidic deposition has led to a large number of lakes becoming impaired for aquatic life uses. Comprehensive monitoring and assessment of Adirondack lakes, ongoing since the 1980s has identified this region as one of the most affected by acidic deposition in North America.

2.2 Waterbodies, Pollutants, Sources, and Prioritization

2.2.1 Waterbodies and Watershed Description

The lakes that are the focus of this TMDL package comprise of 51 assessment units on New York's 303(d) list that lie in the Adirondack Region of New York State. This region includes portions of a number of larger drainage basins, many of which contain some of the 89 of the 128 acid rain-impacted lakes in this study. Table 2-1 tabulates the crosswalk of the 51 assessment units on the 303(d) that TMDLs are calculated to the acid-impacted lakes in this study. Table 2-2 listed the remaining 39 lakes considered in this study. These waterbodies are generally remote and subject to limited local sources of anthropogenic acidity.

Table 2-1 Waterbodies for which TMDLs are calculated

New York State 2012 Section 303(d) list						
Assessment Unit ID	AU Name	PWL	POND_NAME	POND #	LATITUDE	LONGITUDE
Ont 19- 40-15-4-P436	Sand Pond	0801-0055	Sand Pond	040436	-75.1596	43.948
Ont 19- 40-18-P443 thru P448	Pepperbox Pond, Spring Ponds, Tied Lake	0801-0076	Pepperbox Pond	040443	-75.0934	43.9361
			Lower Spring Pond	040444	-75.1387	43.9595
			Tied Lake	040446	-75.067	43.9797
Ont 19- 40-19-P456 thru P459	Minor Lakes Trib to Three Mile Cr Wshed	0801-0453	Unnamed	040457	-75.1295	43.9103
Ont 19- 40-P493- 2-P494,P496	Shallow Pond, Raven Lake	0801-0107	Raven Lake	040496	-75.0324	43.9282
Ont 19- 40-P493- 2-P498	Lyons Lake	0801-0109	Lyon Lake	040498	-75.0207	43.9458

New York State 2012 Section 303(d) list						
Assessment Unit ID	AU Name	PWL	POND_NAME	POND #	LATITUDE	LONGITUDE
Ont 19- 40- P493- 3-P499	Slim Pond	0801-0125	Slim Pond	040499	-75.0167	43.9246
Ont 19- 40- P493- 4-P500	Evergreen Lake	0801-0110	Evergreen Lake	040500	-75.0157	43.9183
Ont 19- 40- P493- 5-P502/6-P505	Peaked Mtn. Lake, Hidden Lake	0801-0111	Hidden Lake	040505	-74.994	43.9203
Ont 19- 40- P493- 6..P508.P511	Ginger Pond, Soda Pond	0801-0126	Ginger Pond	040508	-75.0034	43.9277
			Soda Pond	040511	-75.0097	43.9348
Ont 19- 40- P493- 6-P515	Dismal Pond	0801-0065	Unnamed P #4-513	040513	-74.9985	43.9467
Ont 19- 40- P493..P522 thru P535	Minor Lakes Trib to Red Horse Creek	0801-0068	Higby Twins E. Pond	040522	-74.9362	43.9597
			Higby Twins W. Pond	040523	-74.9408	43.9601
			Beaverdam Pond	040530	-74.8978	43.9705
Ont 19- 40- P493-19-P547 thru P565	Minor Lakes Trib to Shingle Shanty Brook	0801-0149	Lilypad Pond	040547	-74.7106	43.9827
			Mud Pond	040548	-74.7217	43.9799
			Little Salmon Lake	040549	-74.6989	43.9751
			Hardigan Pond	040551	-74.68	43.9743
Ont 19- 40- P493-21-1-P570	Terror Lake	0801-0018	Terror Lake	040570	-74.8232	43.8905
Ont 19- 40- P493-32-P578 thru 587	Minor Lakes Trib to Twitchell Creek	0801-0077	South Pond	040582	-74.8764	43.8466
Ont 19- 57- 5-P608,P610,P615	Evies Pond, Long Lake, Fish Pond	0801-0323	Evies Pond	040608	-75.2718	43.7796
			Long Lake	040610	-75.268	43.7793
			Fish Pond	040615	-75.2586	43.7787

New York State 2012 Section 303(d) list						
Assessment Unit ID	AU Name	PWL	POND_NAME	POND #	LATITUDE	LONGITUDE
Ont 19- 57- 7-P628,P630	Trout Pond, Bill's Pond	0801-0127	Bill's Pond	040630	-75.1496	43.8431
Ont 19- 57- 9-2-P632,P635,P638	Panther, Fifth Creek, Lennon Ponds	0801-0075	Panther Pond	040632	-75.1699	43.8202
			Upper Lennon Pond	045228	-75.1087	43.8169
Ont 19- 57-23-P647	Independence Lake	0801-0327	Unnamed P #4-646	040646	-75.0179	43.7541
Ont 19- 57-P651	Little Diamond Pond	0801-0153	Little Diamond Pond	040651	-74.933	43.8018
Ont 19- 60-P674 thru P684	Minor Lakes Trib to Upper Otter Creek	0801-0041	Black Foot Pond	040681	-75.0262	43.7442
Ont 19- 81- 7-1..P702 thru P708	Minor Lakes Trib to Upper Pine Creek	0801-0072	Lost Pond	040702	-75.1287	43.6843
			Middle Settlement Pond	040704	-75.0972	43.685
			Cedar Pond	040705	-75.0818	43.6929
			Grass Pond	040706	-75.061	43.6929
			Middle Branch Pond	040707	-75.0984	43.7014
			Little Pine Pond	040708	-75.1475	43.6824
Ont 19- 81-18-17. P753 to P767	Minor Lakes Trib to Big Moose Lake, NW	0801-0050	West Pond	040753	-74.8804	43.8109
			North Gull Lake	040762	-74.8233	43.8601
Ont 19- 81-18-17-P752, P760	Otter Pond	0801-0016	Otter Pond	040760	-74.7236	43.8551
Ont 19- 81-18-17-P752,P768, P769	Lower, Upper Sister Lakes	0801-0004	Lower Sister Lake	040768	-74.7706	43.875

New York State 2012 Section 303(d) list						
Assessment Unit ID	AU Name	PWL	POND_NAME	POND #	LATITUDE	LONGITUDE
Ont 19- 81-18-17-P775 to P779	Minor Lakes Trib to Big Moose Lake, SE	0801-0017	Chub Pond	040778	-74.7838	43.8289
			Pug Hole Pond	040775A	-74.8064	43.8208
Ont 19- 81-18-P782d, P788	Eagles Nest Lake	0801-0011	Eagles Nest Lake	040788	-74.7266	43.7653
Ont 19- 81-51- 2-P836, P837	Stink Lake, Balsam Lake	0801-0034	Stink Lake	040836	-74.8073	43.6323
			Balsam Lake	040837	-74.793	43.6297
Ont 19- 81-58-12-P854, P855	Horn Lake, Mountain Lake	0801-0052	Horn Pond	040854	-74.8192	43.6001
Ont 19- 81-58-22-2-3-P862 to P875	Minor Lakes Trib to Indian River	0801-0010	Deep Lake	040866	-74.6624	43.6182
			Twin Lake West	040869	-74.6391	43.6195
			Twin Lake East	040870	-74.6273	43.6215
			Northrup Lake	040875	-74.683	43.5785
Ont 19- 81-60-P876 thru P880	Minor Lakes Trib to Benedict Creek	0801-0029	Bear Pond	040880	-74.7012	43.708
Ont 19- 81-61- 4-P885	Falls Pond	0801-0399	Falls Pond	040885	-74.6853	43.6312
Ont 19-104-2-P951,-1-P952	Little Woodhull Lake, Lily Lake	0801-0070	Little Woodhull Lake	040951	-74.9916	43.5331
			Lily Lake	040952	-74.9969	43.5354
Ont 19-104-P981-1-P982,P984	Bloodsucker Pond	0801-0135	Bloodsucker Pond	040984	-75.0248	43.5972
Ont 19-114-P995, P996	Burp Lake, Black Creek Lake	0801-0139	Burp Lake	040995	-74.9018	43.461

New York State 2012 Section 303(d) list						
Assessment Unit ID	AU Name	PWL	POND_NAME	POND #	LATITUDE	LONGITUDE
Ont 19-128-6-P1003	Little Salmon Lk.	0801-0140	Little Salmon Lk.	041003	-74.843	43.4929
Ont 19-40-20-P473, P474	Sunday Lake, Sunday Creek Reservoir	0801-0195	Sunday Lake	040473	-75.1032	43.8583
Ont 19-40-22-P479 thru P492	Minor Lakes Trib to Moshier Creek	0801-0039	Upper Moshier Pond	040491	-75.0738	43.9415
SL- 1-P109-11-2-P120, P129	Rock Pond	0903-0003	Rock Pond, P-129	060129	-74.6436	43.9874
SL- 1-P109-11-P156, P168,P170	Halfmoon Pond	0903-0032	Halfmoon Pond	060170	-74.8251	44.0837
SL-25-101, P289	Crystal Lake	0905-0030	Crystal Lake	040289	-75.0683	44.1014
			Unnamed P #4-288e	040288E	-75.0446	44.0813
SL-25-73, P240 thru P247	Desert, Jakes, Buck, Hog Ponds	0905-0038	Desert Pond	040240	-75.1359	44.0181
			Jakes Pond	040245	-75.1259	43.9741
			Buck Pond	040246	-75.0665	43.9955
			Hog Pond	040247	-75.0667	43.9869
SL-25-73-26-38-P179 thru P186	Gregg Lk, Green, Twin, Loon Hollow Pds	0905-0035	Gregg Lake	040181	-75.0658	43.9627
SL-25-73-26-42-1-P195	Muskrat Pond	0905-0061	Muskrat Pond	040195	-75.0356	43.9412
SL-25-73-26-42-P196,P197	Bear Pond, Diana Pond	0905-0062	Diana Pond	040197	-75.0041	43.9528
SL-25-73-26-43-P198,P199,P200	Lower, Middle, Upper South Pond	0905-0057	Upper South Pond	040200	-75.0257	43.9908

New York State 2012 Section 303(d) list						
Assessment Unit ID	AU Name	PWL	POND_NAME	POND #	LATITUDE	LONGITUDE
SL-25-P309, P364 thru P381	Minor Lake Trib to Upper Oswegatchie	0905-0005	Hitchens Pond	040368	-74.9052	44.0103
SLC-32-61a-P217,-67-P221	Duck Pond, Benz Pond	0902-0021	Duck Pond	035219	-74.4637	44.5571
H-461, P582 thru P612	Minor Lakes Trib to Indian River/Lake	1104-0008	Bullhead Pond	050582	-74.243	43.807
			Cranberry Pond	050584	-74.1748	43.808
			Rock Pond	050586	-74.1827	43.7907
			Stonystep Pond	050587	-74.1864	43.7826
			Puffer Pond	050589	-74.1959	43.6756
			Center Pond	050593	-74.215	43.7425
			Clear Pond	050594	-74.2001	43.74
			Little Moose Pond	050607	-74.5432	43.5509
			Otter Pond	050608	-74.5634	43.5456
H-469, P624 thru P669	Minor Lakes Trib to Cedar River	1104-0003	Green Pond	050656	-74.2564	43.8282
			Unknown Pond	050658	-74.2841	43.8187
			Wakely Pond	050666	-74.4674	43.7397
H-503-P680/P682- 6, P687	Round Pond	1104-0073	Round Pond	050687	-74.2852	44.0588
H-240-144-44-P790,P790a	Big Alderbed Pd, Blind Mans Vly	1201-0002	Big Alderbed Pond	070790	-74.7052	43.3252
			Blind Mans Vly	070790A	-74.7008	43.3315

Table 2-2 Other waterbodies considered in the study but no TMDLs are calculated at this time			
POND_NAME	**POND #**	**LATITUDE**	**LONGITUDE**
East Copperas Pond,	020138	-74.3718	44.3131
St. Germain Pond	020201	-74.2627	44.3785
Benz Pond	030221	-74.455	44.5154
Green Pond	040184	-75.0599	43.9624
Unnamed P #4-201	040201	-74.9937	43.9681
Unnamed P #4-203	040203	-74.9825	43.9642
Oven Lake	040365	-74.9127	44.0201
Ike's Pond	040438	-75.1446	43.9028
Bear Pond	040458	-75.1173	43.9204
Unnamed P #4-484a	040484A	-75.0556	43.9258
Deer Pond	040485	-75.0574	43.9342
Shallow Pond	040494	-75.0382	43.9236
Unnamed P #4-497	040497	-75.0158	43.9394
Peaked Mtn. Lake	040502	-75.0037	43.9139
Unnamed P #4-510	040510	-74.9965	43.935
Summit Pond	040527	-74.9242	43.9925
Little Rock Pond	040534	-74.9104	43.9605
Frank Pond	040550	-74.691	43.9808
East Pond	040571	-74.863	43.8639
Pocket Pond	040581	-74.8811	43.834
Unnamed P #4-638	040638	-75.113	43.8154
Unnamed P #4-679	040679	-75.022	43.7643
Squash Pond	040754	-74.8884	43.8267

Little Chief Pond	040757	-74.8332	43.8446
Gull Lake South	040758	-74.8208	43.8564
Unnamed P #4-759	040759	-74.7548	43.8767
Constable Pond	040777	-74.7966	43.8334
Pigeon Lake	040779	-74.7621	43.8465
Kettle Pond	040841	-74.8211	43.6762
Unnamed P #4-863	040863	-74.721	43.5805
Wolf Lake	040873	-74.653	43.6297
Brooktrout Lake	040874	-74.6621	43.6033
Sly Pond	040888	-74.595	43.6709
Cellar Pond	040889	-74.5366	43.7243
Snyder Lake	041011	-74.8218	43.5703
Unnamed	045178	-75.1225	43.9006
Dishrag Pond	050665	-74.4906	43.7815
High Pond	060147	-74.6509	44.0864
Little Pine Pond	060148	-74.6578	44.1332

2.2.2 Pollutants of Concern

The TMDLs have been developed for pH. pH itself is not a pollutant. Violations of the pH criteria are typically caused by the addition of pollutants capable of changing the water chemistry such as sulfur oxides (SO_x) and nitrogen oxides (NO_x). The model was used to evaluate the responses of surface water ANC to reductions in atmospheric deposition of sulfate, nitrate and ammonium. Only sulfate is considered in the TMDL calculations because ANC is much more responsive to a unit decrease of sulfate deposition compared to nitrate or nitrate + ammonium combined. In fact, reducing atmospheric loading of sulfate plus nitrate and ammonium essentially yielded the same level of ANC increases that could be obtained with sulfate deposition alone (see Figure 5-11). These results were presented and discussed in section "5.6 Assessment of Lake Responses to Load Decreases". Therefore pollutants of concern for this study are atmospheric concentrations of sulfur oxides, expressed as SO_4^{2-}.

Oxides of sulfur (SO_x) and nitrogen (NO_x) can be deposited directly as gases or particles or react with water in the atmosphere to form dilute sulfuric and nitric acids and precipitate out of the atmosphere. These acid compounds are deposited onto watersheds and ultimately into streams and lakes. The specific water quality concern in these waterbodies is not the sulfuric/nitric acids or SO_4^{2-} and NO_3^- concentrations in surface waters, but rather with low pH, acid neutralizing capacity (ANC) and elevated aluminum concentrations that are the result of the atmospheric deposition of acidic compounds to the acid-sensitive region. A new US Government Accountability Office (GAO) report on water quality impacts of airborne pollutants states that "Atmospheric deposition, including from NO_x, SO_2, and mercury, is a contributing source of pollution to many waterbodies that the states have identified as impaired—that is, do not meet CWA water quality standards—according to our analysis of EPA's ATTAINS database" (U.S. GAO 2013). The GAO Report goes on to state that:

> *"Federal studies also show that atmospheric deposition associated with NOx, SO2, and mercury is polluting waters in the United States. For example, a 2011 report from the National Acid Precipitation Assessment Program (NAPAP)—a federal interagency program that coordinates acid rain research—summarized the most recent studies on acid rain and identified waters in several acid-sensitive ecosystems that are most vulnerable and that continue to receive harmful levels of acid rain. According to the report, from 2006 through 2008, over 550 lakes in the Adirondack Mountains ... continued to experience levels of acid rain that exceeded their ability to neutralize the acid."*

Specific research in the Adirondack Region has shown that lake water acidity also contributes to high mercury bioaccumulation in fish and wildlife (Evers et al. 2007, Yu et al. 2011). A report summarizing 1990 to 2000 data states that the mean pH of precipitation in New York State is 4.3 (U.S. EPA 2003). With the limited ability of soils to neutralize strong acid inputs, soil acidification will occur resulting in lower pH and the loss (depletion) of available base cations from soil. Lower soil pH, in turn, results in the mobilization of naturally occurring aluminum from soil and increase aluminum concentrations in surface waters. Elevated aluminum concentrations are toxic to certain native fish species. The selection of endpoints for this TMDL from amongst these water quality parameters are described in Section 3.3 below.

2.2.3 Sources

EPA's 2008 National Emissions Inventory (U.S. EPA website at:

http://www.epa.gov/ttnchie1/net/2008inventory.html)

as summarized in GAO (2013) cites domestic transportation (including on-road vehicles, such as cars and trucks, and off-road transportation, such as commercial fishing vessels, passenger trains, and commercial aircraft) as the largest source of NO_x, and states that these sources contributed approximately 63 percent of the total estimated 17.4 million tons of NO_x emissions in the United States. EPA documents another major source of NO_x emissions as fuel combustion, mainly from power plants and industrial boilers, which accounted for an estimated 28 percent of total estimated NO_x emissions. The document also summarizes a statement from an EPA official stating that the only international sources of NO_x emissions of any note that reach the United States are in Canada and Mexico, and, in general, emissions from these sources do not impact U.S. waters.

The National Emissions Inventory cites domestic power plants as the source of approximately 87 percent of the total estimated 10.4 million tons of SO_2 emissions in the United States – primarily from fuel combustion (National Emissions Inventory, as cited in GAO 2013). Industrial processes and transportation contributed approximately 8 percent and 3 percent of these emissions, respectively.

As described in the 2006 TMDL document (Battelle 2006) "emissions from these common and widespread sources originate virtually everywhere. Some of the emissions originate within New York State; and some component of the pollutant load is from sources worldwide. But the waters of the Northeast and Adirondacks are most affected by sources from Southeast to Midwest United States and Canada."

2.2.4 Priority Ranking

The NYSDEC includes these Forest Preserve lakes on the Section 303(d) List on the part of the List designated as *Part 2a - Multiple Segment/Categorical Impaired Waterbodies Segments (atmospheric deposition)*. It is noted that these waters might be addressed by a pollutant/source-specific TMDL. Waterbodies on this part of the list that are also in the Forest Preserve are also noted as being high priority waters, i.e., waters scheduled for TMDL/restoration strategy development within the next two years. The location of 128 lakes included in the State's 303(d) List for acid impairment is shown in Figure 2-1.

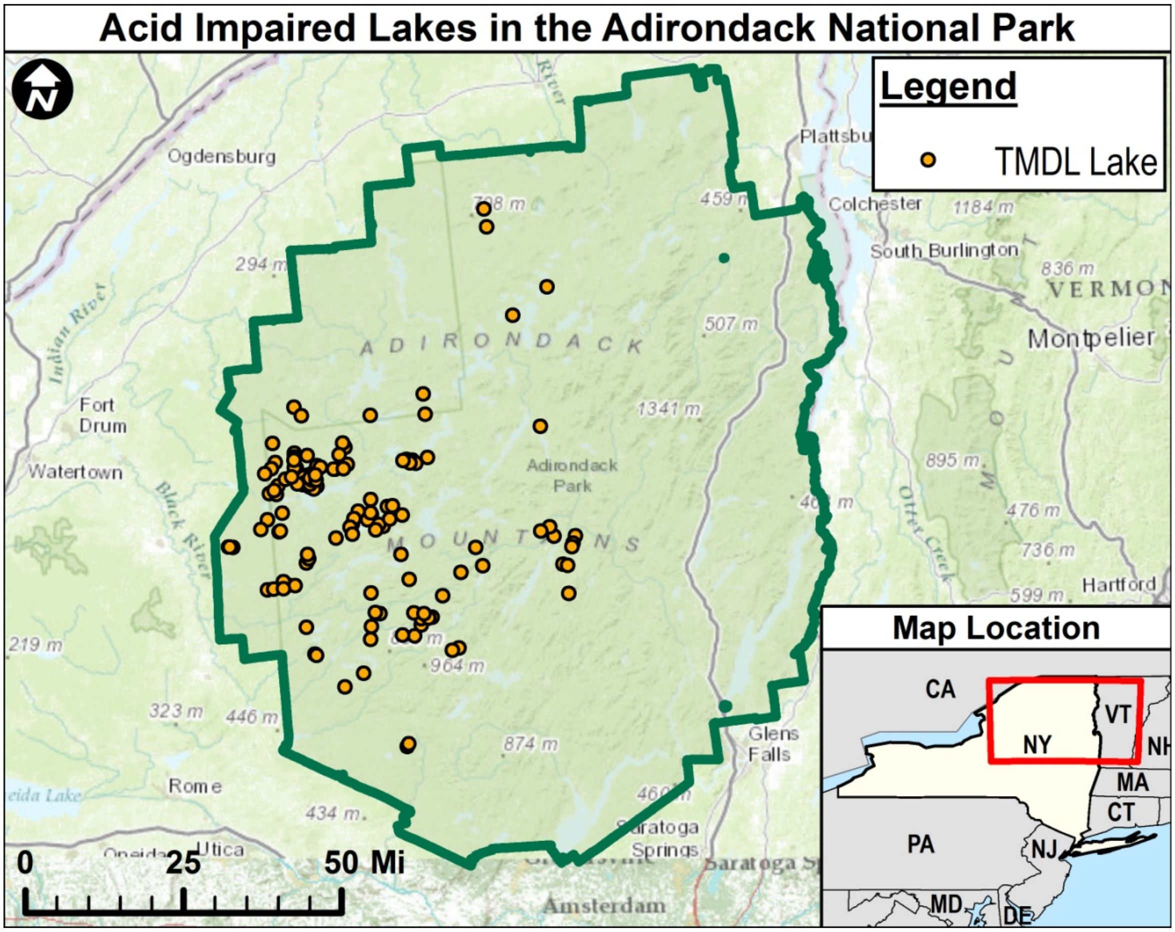

Figure 2-1. Location of acid impaired lakes in Adirondack Park.

The identification of priorities for TMDL development is a function of various factors, including severity of problem, availability of monitoring data, local support, availability of funding, applicability/availability of modeling tools, and identification of appropriate endpoint (i.e., water quality standards). Additionally, circumstances regarding many of these factors change over time. Consequently USEPA has agreed that states may limit the prioritizing of waters on the list to identification of those waters where TMDL development is a high priority for the next two year period (i.e., until the next Section 303(d) List is published). This flexibility allows states to respond to changing landscape, take advantage of other strategies and approaches, and direct TMDL development to where it will have the greatest benefit.

2.3 Data Collection

Several long-term monitoring programs have been developed in the Adirondacks to study the effects of acid deposition and also to evaluate the response of forest and aquatic ecosystems to changes in acid deposition over time. Large synoptic surveys have also been conducted to assess the extent of ecological impairment caused by acid deposition. Much of the monitoring and research conducted through these programs have contributed considerably to an understanding of the relationships between acid deposition and responses of Adirondack lakes and watersheds. As part of the data collection effort, an integrated access database containing all water quality data available for the Adirondack lakes to date was developed. Available dataset from various long-term monitoring programs and surveys were obtained for database development. The dataset contains information on both physical (e.g., location, watershed and lake surface area, lake depth, lake volume, hydraulic residence time) and chemical characteristics (lake water chemistry). A brief description of various monitoring programs and surveys from which water lake datasets are obtained is provided below.

- *The Adirondack Lake Survey (ALS)*: The Adirondacks Lake Survey (ALS) is an extensive baseline survey of fisheries and water chemistry of 1,469 Adirondack lakes conducted from 1984 – 1987 by the Adirondack Lake Survey Corporation (ALSC). The extensive data collected through these surveys including baseline chemistry, location and fish species are maintained in the ALSC database and made available to the public (http://www.adirondacklakessurvey.org/). The ALS dataset was obtained from Karen M. Roy (NYSDEC).
- *Eastern Lake Survey (ELS)*: The Eastern Lake Survey, conducted 1984 (ELS Phase 1) and then in 1986 (ELS Phase II) was the first part of a long-term effort by EPA known as the National Surface Water Survey. It was designed to quantify synoptically the acid-base status of surface waters in the United States in areas that are sensitive to acid deposition. In the "Adirondack Region", the ELS sampled 155 lakes that are 4 hectares or larger (Driscoll et al. 1991).
- *Adirondacks Long Term Monitoring Program (ALTM)*: The Adirondacks Long Term Monitoring (ALTM) program was initiated in 1982 by the Adirondack Lake Survey Corporation to evaluate chemistry of Adirondack lakes. The ALSC was formed as a cooperative effort of the New York State Department of Environmental Conservation and New York State Energy Research and Development Authority (NYSERDA) to better characterize the chemical and biological status of Adirondack lakes. The ALTM program has routinely sampled a total of 52 lakes on a monthly basis since 1992. Results are updated in the database through 2011. The ALTM dataset was provided by Charles T. Driscoll (Syracuse University).
- *Temporally Integrated Monitoring of Ecosystems (TIME)*: The Temporally Integrated Monitoring of Ecosystems (TIME) began in 1991 as a special study within the EPA Environmental Monitoring and Assessment Program (EMAP; http://www.epa.gov/airmarkt/assessments/TIMELTM.html). The purpose of EMAP is to evaluate ecological conditions across broad geographic expanse throughout the U.S. In the Adirondacks, the regional EMAP random sampling consisted of 115 lakes and their watersheds (Sullivan et al. 2006). TIME is a statistically-based sampling program developed to study the acid sensitive lakes in the Northeast and the streams in the mid-Appalachians. Currently, TIME program samples 43 lakes in the Adirondacks, once every year during late summer/early fall to evaluate water chemistry (Waller et al. 2012). Of the 43 TIME lakes, six lakes overlap with the ALTM program. The TIME dataset was provided by Charles T. Driscoll (Syracuse University).
- *NYSDEC Water Quality Dataset*: As part of the monitoring plan for the 2006 TMDL, NYSDEC conducts routine sampling of the lake chemistry on an annual basis to assess post-TMDL condition of lakes within the Adirondack Park. Roughly 35 – 40 lakes are sampled each year. The NYSDEC surface

water dataset covered 244 Adirondack lakes sampled during 2007 – 2012. The NYSDEC dataset was provided by Scott Quinn (NYSDEC).

- *Adirondacks Effects and Assessment Program (AEAP)*: EPA established the Adirondacks Effects and Assessment Program (AEAP) to conduct a synoptic chemical and biological sampling program on 30 lakes and ponds in the Adirondacks during 1994 - 2007. The AEAP was designed to assess various trophic levels with respect to ecosystem health and to gather baseline data and evaluate long-term changes of lake communities as indicators of ecosystem health (Momen et al. 2006). The project has continued since 2007, using funding from NYSERDA's Environmental Monitoring, Evaluation and Protection (EMEP) Program, but now covers a smaller number of lakes and ponds (16). http://www.rpi.edu/dept/DFWI/research/aeap/aeap_chem_biota_database.html
- *Direct/Delayed Response Project (DDRP) Resurvey 2001*. The Direct/Delayed Response Project (DDRP) was originally designed and implemented by EPA in 1984 to estimate the then-current and future effects of acidic deposition of surface waters in three regions: the Northeast; the middle Appalachian; and the southern Blue Ridge. As part of the DDRP, 145 lake watersheds in the northeast were surveyed. Among these 145 sites, 38 watersheds were located in the Adirondacks (Warby et al. 2005; Chen and Driscoll 2004).

  During the summer of 2001, 130 of the original 145 DDRP watersheds were resampled to investigate the changes in soil and surface waters that might have occurred since the original sampling in 1984. Twenty-five of the original 38 DDRP watersheds in the Adirondacks were included in the resurvey (Warby et al. 2005 and 2009). Surface water chemistry and soil analysis conducted during the original 1984 survey were repeated in the resurvey. Financial support for the resurvey was provided by the W.M. Keck foundation. DDRP resurvey data was provided by Charles T. Driscoll (Syracuse University).
- *Paleoecological Investigation of Recent Lake Acidification (PIRLA)*. The PIRLA project conducted in the 1980s used diatoms and chyrsophytes in sediment cores as ecological indicators to reconstruct historical changes in lake water chemistry across the eastern U.S. The PIRLA dataset contained 60 lakes for which sediment cores were used to reconstruct chemical histories of these lakes (Charles and Smol 1988; Church et al. 1989). PIRLA dataset was provided by Donald F. Charles (Drexel University). These data were augmented by diatom core data provided by Chandler Rowell (NYSDEC).

Blank

3
Applicable Standards, Criteria and Numeric Targets

3.1 Designated Uses and Use Support

Waters located in Forest Preserve Lands are not covered by New York State Water Classifications. Instead, these waters are protected under Article XIV of the New York State Constitution and are to be maintained as "forever wild." The "forever wild" provisions of Article XIV, §1 of the New York State Constitution reads in part as follows: "The lands of the state, now owned or hereafter acquired, constituting the forest preserve as now fixed by law, shall be forever kept as wild forest lands." A reasonable and generally accepted interpretation of the State Constitution language suggests that the waters of the Forest Preserve are to be maintained in their natural condition. This level of protection is consistent with the protection of high quality waters which constitute Outstanding National Resource Waters (ONRW) or "Tier 3" waters under 40 CFR 131.12(a)(3).

3.2 Water Quality Criteria

As with designated uses, waters located in Forest Preserve Lands are not covered by New York State Water Quality Standards. While these lakes are not covered by state water quality standard (WQS), New York State has derived a numeric TMDL endpoint that provides an appropriate level of aquatic life protection for Forest Preserve lakes categorized as "forever wild" (see Appendix 9 for derivation). The TMDL endpoint is derived for the organic acid adjusted ANC (ANC_{OAA}) to protect aquatic life from the adverse effects (e.g., pH and aluminum (Al) toxicity) that may result from anthropogenic acidification of acid-sensitive surface waters. This TMDL endpoint represents a minimum ANC_{OAA} threshold of 11 μeq L^{-1}, above which water quality is considered suitable for aquatic life propagation.

ANC is a measure of the ability of a waterbody to neutralize inputs of strong acid. ANC is the most widely used measure of acid sensitivity, acidification effects and chemical recovery of surface waters in response to changes in acidic deposition (e.g., Stoddard et al. 2003; Driscoll et al. 2007). ANC of natural waters is often evaluated as a key water quality parameter in regional water quality surveys and intensive watershed studies as well as the primary output of several watershed acidification models, rather than pH or inorganic Al (Driscoll et al. 1991; Thornton et al. 1990). The relationship of ANC with pH and inorganic Al are discussed further in Section 4.2 (see Figures 4.4 and 4-5).

The derivation of ANC_{OAA} threshold of 11 μeq L^{-1} is based on the work conducted by Lydersen et al. (2004) in Scandinavian lakes. Lydersen et al. (2004) proposed an ANC_{OAA} value of 11 μeq L^{-1} to protect arctic char (*Salvelinus alpinus*) in Scandinavian lakes. Arctic char represent fish species that are relatively more sensitive to acidification (compared to brown trout or yellow perch), so it takes a larger ANC to protect them. The brook trout (*Salvelinus fontinalis*) is chosen as the appropriate indicator species for setting the endpoint for these TMDLs, because it represents an important fish species indigenous to surface waters throughout New York State. The brook trout is also closely related to the arctic char (Doiron et al. 2002) as both are within the same Genus with analogous habitat and environmental requirements (Scott and Crossman 1973).

3.3 Numeric TMDL Targets

TMDL targets are established at a level that attains and maintains the applicable WQS, including designated uses, numeric and narrative criteria, and antidegradation policy [40 CFR §130.7(c)(1)]. TMDL submittals must include a description of any applicable water quality standard, and must also identify numeric water quality targets, which are quantitative values used to measure whether or not applicable WQS are being attained. Depending on the designated use being addressed, a TMDL target may be based on human health, aquatic life, or wildlife criteria (U.S. EPA 2008b).

The protection of the Forest Preserve lands and waters is governed by the language of the State Constitution, rather than the parameter-specific numeric water quality standards. As a result, NYSDEC does not have a numeric water quality criterion for these forest preserve lakes. In order to establish TMDLs to protect these lakes, NYSDEC must interpret the applicable narrative standard contained in the New York State Constitution and establish numeric water quality targets and TMDL endpoints sufficient to achieve that interpretation. These targets would be used to determine whether or not recovery has been attained and appropriate uses are protected.

A minimum ANC value of 11 μeq L^{-1} was chosen as the target for this TMDL and the derivation of this endpoint is described in Appendix 9.

4
Water Quality Conditions

The Adirondack region receives among the highest rates of atmospheric inputs of acid deposition in the United States (Driscoll et al. 2001). This is due to the high amounts of precipitation the region receives annually (approximately 100 cm) in combination with the high concentrations of acidic substances in the atmosphere over the region (Burns et al. 2006; Driscoll et al. 1991). Elevated inputs of acid deposition coupled with geologic characteristics of the soils which lack the capability to completely neutralize acid inputs, makes the Adirondacks highly vulnerable to acid deposition.

The ALS survey remains as one of the extensive inventory of water quality to date of Adirondack lakes (Baker et al. 1993). The survey focused on the collection of detailed chemical, physical and biological data from 1,469 Adirondack lakes and ponds ranging in size from about 0.2 to 283 hectares. The survey concluded that acidic waters were found throughout the Adirondacks but were most common in western and south western Adirondacks. About 26% of the survey lakes were strongly acidic (pH of less than 5.0). The survey also concluded that approximately half of the waters surveyed had mid-summer ANC of less than 50 μeq L^{-1} and can be classified as sensitive to acidic deposition. Sulfate was found to be the major strong acid anion in Adirondack lakes. Several lakes also exhibited high concentrations of dissolved organic carbon (DOC). These lakes were probably acidic under natural conditions, but have been made more acidic by acidic deposition (Baker et al. 1993).

Paleoecological techniques and modeling studies have been used to reconstruct chemical history of lakes in the Adirondacks. Evidence from these suggests that many lakes became acidic during the decades when air pollution and acidic deposition levels were highest in the U.S.

There have been substantial declines in the atmospheric deposition of SO_4^{2-} and NO_3^- in North America since the Clean Air Act Amendments (CAAA) of 1970 and 1990 (U.S. EPA 2008; NAPAP 2005) and the U.S. EPA Nitrogen Budget Program. Several studies have evaluated the progress of recovery of surface waters and soils in the Adirondacks and across the northeastern U.S. (Stoddard et al. 2003; Driscoll et al. 2003 and 2007; Warby et al. 2009). Studies involving ALTM and TIME lakes have shown that concentrations of SO_4^{2-} and NO_3^- in surface waters have shown a decline trend in the Adirondacks (Driscoll et al. 2007; Stoddard et al. 2003; Waller et al. 2012). In conjunction with declines in strong acid anions, the concentrations of base cations have also been declining in surface waters. Despite improvements in surface water chemistry, these studies suggest it would take several decades for the acid impacted lakes to attain chemical recovery thresholds.

4.1 Classification of TMDL Lakes

Based on the comprehensive 1984–87 survey of Adirondack lakes, the ALSC developed a lake classification scheme to group lakes depending on their chemical and hydrological characteristics (Newton and Driscoll 1990). The ALSC classification scheme provides a means to categorize lakes into groups that are likely to respond in similar ways to changes in atmospheric deposition. The ALSC classification scheme was applied to the TMDL lakes. Classification of the TMDL lakes was conducted by applying the chemical criteria described in the ALSC scheme.

First, the presence or absence of a lake outlet was used to separate drainage and seepage lakes (Figure 4-1). Based on calcium (Ca) concentration, drainage lakes were separated into thick deposits of glacial till (Ca ≥ 75 µmol L^{-1}), medium till (75 µm < Ca > 50 µmol L^{-1}) thin till (Ca ≤ 50 µmol L^{-1}) lakes. Then, based on a DOC criterion, each of these categories was sub-divided into high DOC (DOC ≥ 500 µmol L^{-1}) and low DOC (< 500 µmol L^{-1}) lakes. Similarly, using a Ca concentration of 25 µmol L^{-1}, seepage lakes were classified as either mounded seepage (Ca ≤ 25 µmol L^{-1}) or flow-through seepage (Ca > 25 µmol L^{-1}) lakes. The seepage lakes are further divided into high-DOC and low-DOC classes.

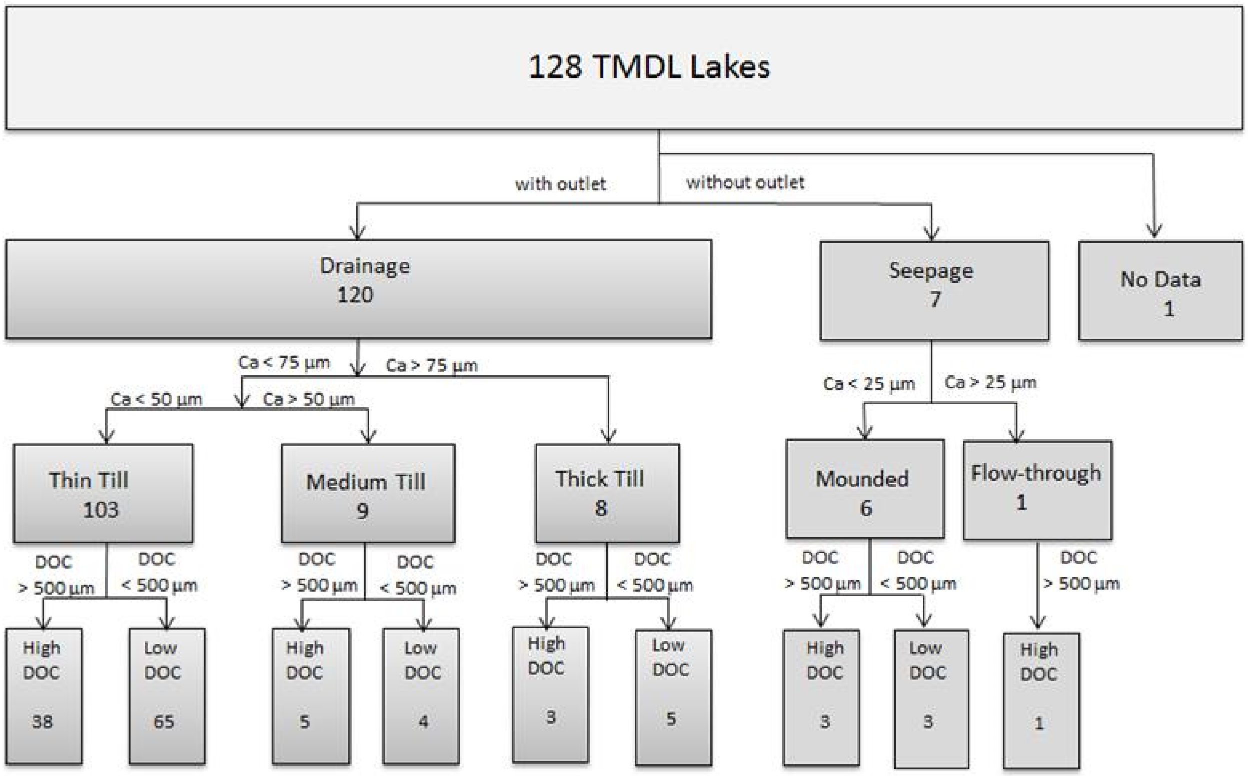

Figure 4-1. Classification of the TMDL lakes based on ALSC classification scheme.

For one of the TMDL lakes (045178 – Unnamed Pond) chemistry data were not available and therefore it was excluded from the classification. However, for modeling purpose (see Section 5.5) the Unnamed Pond (045178) was modeled with the thin-till category. The vast majority of the TMDL lakes (94%) are drainage lakes. A majority of the TMDL lakes (80%) belong to the thin till drainage lake category. Drainage lakes located in thin till watersheds are sensitive to acidic deposition due to shallow surficial deposits (Driscoll et al. 1998). About 7.5% of the drainage lakes belong the medium till category and can be characterized as moderately sensitive to acidic deposition, while 6.5% of drainage lakes belong to thick till category and are relatively less sensitive to acidic deposition than are thin and medium-till lakes. A small proportion of the TMDL lakes (5%) are seepage lakes of which most are mounded seepage lakes. Mounded seepage lakes, which receive most of their water from direct precipitation, are sensitive to acidic deposition (Driscoll and Newton 1985).

4.2 Data Analysis

To assess the chemical conditions of impaired lakes in the 303(d) list, water quality parameters measured for these lakes were evaluated. Measured values of ANC (measured by Gran Titration, or ANC_G), pH and inorganic monomeric aluminum (Al_{IM}) were evaluated for 127 of 128 TMDL lakes (as noted above, no water chemistry data were available for one of the TMDL lakes). For each parameter, an average value was calculated when more than one measurement was available.

A distribution of measured ANC values for the 127 TMDL lakes are shown in Figure 4-2. Water bodies classified as thick-till and medium-till lakes exhibit relatively high ANC values (> 50 μeq L^{-1}). Thin till and seepage lakes exhibit ANC values that are typically less than <50 μeq L^{-1}. Of the 127 TMDL lakes with observed data, 98 lakes have ANC values below 20 μeq L^{-1}.

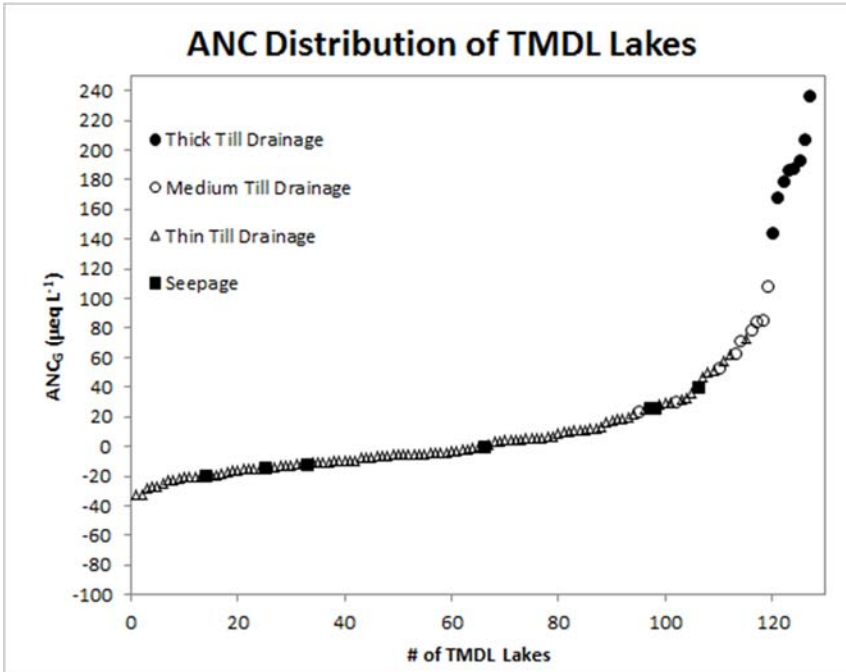

Figure 4-2. Distribution of ANC values for the 127 impaired lakes included in the 303(d) list.

A similar distribution plot of pH was developed for the TMDL lakes (Figure 4-3). The distribution pattern of pH is similar to ANC. Lakes in the thick till and medium till class generally exhibit pH values > 6. Majority of the lakes in the thin till and seepage lakes class are characterized by pH values less < 5.5, although a few thin till lakes have measured pH values > 6. Of the 127 TMDL lakes with observed data, 23 lakes have pH > 6. Correspondingly, these 23 lakes also have ANC > 20 μeq L^{-1}.

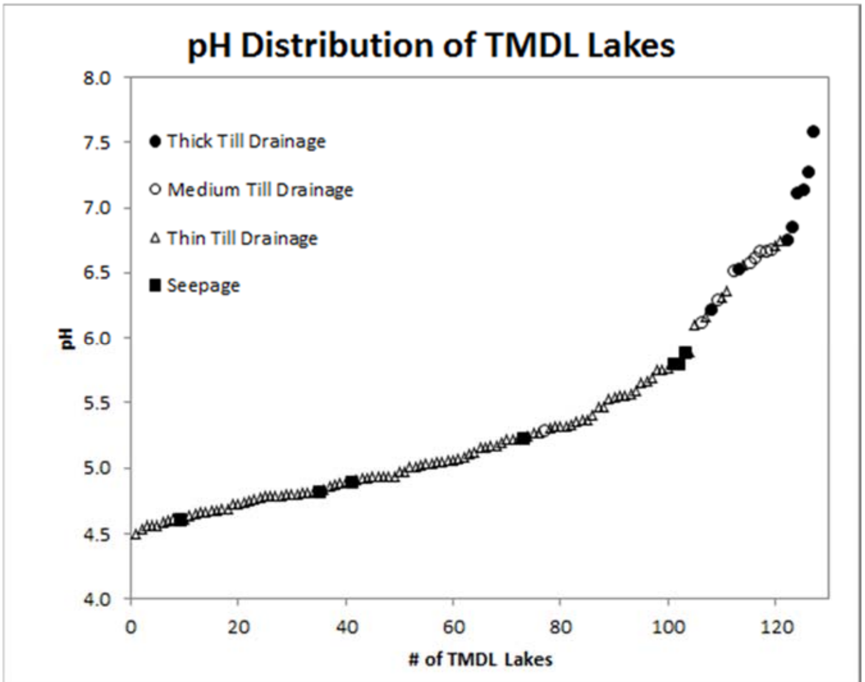

Figure 4-3. Distribution of pH values for the 127 impaired lakes included in the 303(d) list.

The pH-ANC relationship of the Adirondack lakes was examined using the observed values from various datasets (Figure 4-4). As shown in Figure 4-4, pH has a non-linear relationship with ANC. Weak acids, including organic acids, are an important component of acid-base system in the Adirondack lakes. The presence of weak acids can suppress the pH without changing the ANC (Driscoll et al. 1994). The effect of weak acids on pH appears to be the greatest in waters with ANC values between 0 and 60 μeq L^{-1}. An ANC value of 20 μeq L^{-1} roughly corresponds to a pH value of 6.

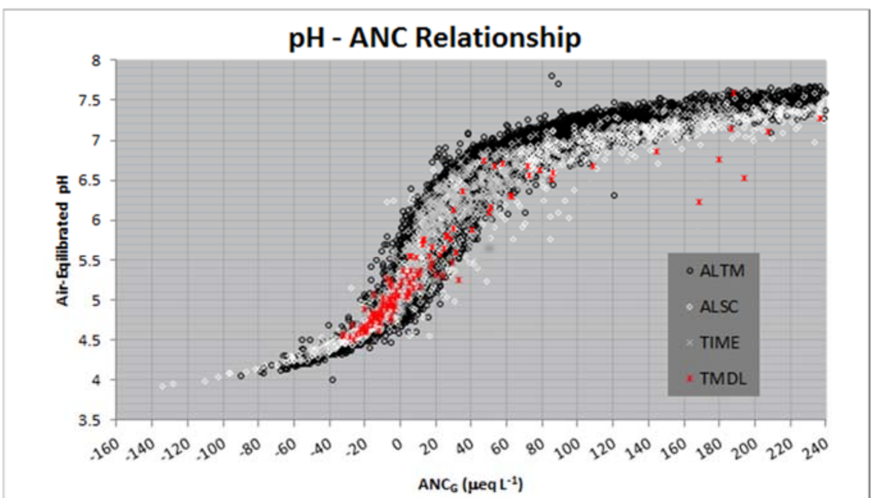

Figure 4-4. Relationship between pH and ANC in Adirondack lakes.

One of the ecologically important consequences of acid deposition is the mobilization of inorganic monomeric aluminum (Al_{IM}) from watershed soil to surface waters. Concerns regarding Al_{IM} in surface waters are related to its toxicity to fish and other forms of aquatic wildlife. Many researchers have identified that the presence of Al_{IM} in surface water as an important indication of acid deposition effects (e.g., Baker et al. 1993; Driscoll et al. 2001; Lawrence et al. 2007). An Al_{IM} concentration of 2 μmol L^{-1} (54 μg L^{-1}) is suggested as the threshold above which toxic effects of Al are evident to fish and other aquatic biota (Driscoll et al. 2001; Baldigo et al. 2007). The relationship between Al_{IM} and ANC for the ALTM and the TMDL lakes are shown in Figure 4.5. At ANC values of > 20 μeq L^{-1}, concentrations of Al_{IM} are generally low and below the toxic threshold value. At ANC values < 0 μeq L^{-1}, concentrations of Al_{IM} increases significantly as a function of decrease in ANC (Figure 4-5).

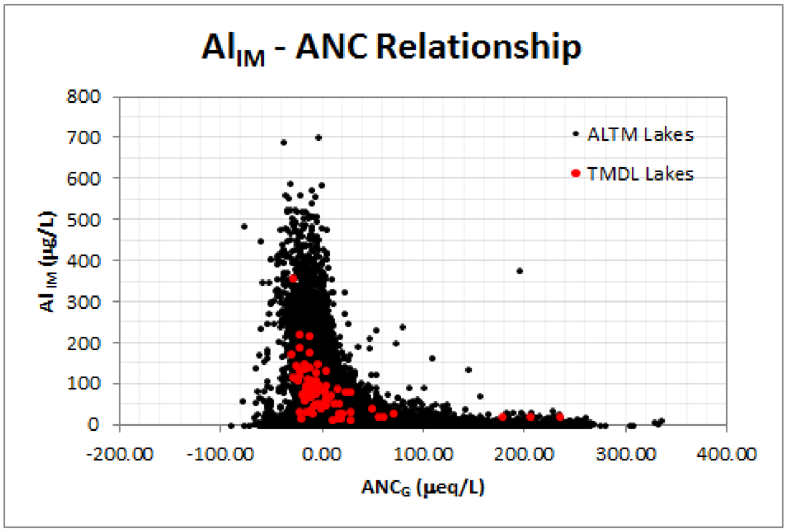

Figure 4-5. Relationship between Al_{IM} and ANC in Adirondack lakes.

Blank page

5 Water Quality Modeling

The modeling framework chosen for this TMDL includes the key watershed processes that regulate the acid-base status of the Adirondack lake-watersheds. As part of model selection process, a comprehensive evaluation of two model frameworks PnET-BGC (Gbondo-Tugbawa et al. 2001) PWM-PHREEQC (Battelle, 2006) was conducted relative to their ability to simulate watershed processes (DePinto et al. 2012). Model evaluation informed that PnET-BGC model simulates the major biogeochemical processes that regulate the acid-base status of soil and water including atmospheric deposition, hydrology, weathering, soil chemical processes (e.g., cation exchange and anion adsorption/desorption), biological transfer (e.g., vegetation uptake, element mineralization, and nitrification), and wetland/lake retention of sulfate and nitrate. PnET-BGC is a processes-based dynamic model that can be applied to assess the time-variable response of forest and interconnected aquatic systems to changes in atmospheric inputs of acid deposition. The model has previously been applied to several Adirondack lake watersheds and other sites in the United States to investigate the long-term effects of acidic deposition in forest watersheds and also to make projections regarding the recovery of surface waters in response to decreases in acidic deposition.

Therefore, PnET-BGC was selected as the appropriate model for this TMDL development. The model was applied to each of the impaired lake watersheds to develop the TMDL.

5.1 Model Description

PnET-BGC is a fully integrated, time-variable biogeochemical model developed to simulate the response of soil and surface waters of forest ecosystems to atmospheric deposition, climate change and land disturbance. As a lumped-parameter model it utilizes a set of average physical and chemical parameters to describe effectively the response of the whole watershed. The model was developed by linking two submodels: PnET-CN (Aber and Driscoll 1997) and BGC (Gbondo-Tugbawa et al. 2001). PnET-CN is a simple generalized model of water, carbon (C), and nitrogen (N) balances, which provides estimates of net primary productivity, N uptake and water balances. BGC expands PnET to include biogeochemical interactions of major elements (i.e., Ca, Mg, K, Na, Si, S, P, Al, Cl, N, C) within forested watersheds. The main processes in PnET-BGC include tree photosynthesis, growth and productivity, litter production and decay, mineralization of organic matter, immobilization of nitrogen, nitrification, vegetation and organic matter interactions of major elements, abiotic soil processes, solution speciation, and surface water processes (Gbondo-Tugbawa et al. 2001).

Recently, the PnET-BGC algorithm has been modified by adding two subroutines; a CO_2 uptake subroutine and a lake solute retention algorithm. The CO_2 uptake subroutine takes to account the effects of increases atmospheric CO_2 concentration on forest ecosystem processes (Pourmokhtarian et al. 2012). The lake solute retention algorithm simulates the mass transfer of major elements from the water column of lakes to sediments. This process is important in lakes with relatively long hydrologic residence times and can be important in the removal of nitrate and sulfate in lakes and the in-lake production of ANC (Kelly et al. 1987). The lake solute retention algorithm requires knowledge of lake mean depth, water residence time and mass transfer coefficients to predict in-lake removal or generation of major ions (Kelly et al. 1987).

The model requires inputs of atmospheric deposition (wet and dry), meteorological data (solar radiation, temperature and precipitation), land disturbance history and element weathering rates as input data, and soil, hydrological and vegetation parameters (Table 5-1). The model predicts time-series concentrations and fluxes of major solutes in surface water, concentrations and pools of exchangeable cations and adsorbed sulfate in soil, and fluxes of major solutes from soil and forest vegetation. The overall structure of the PnET-BGC model is shown in Figure 5-1.

The PnET-BGC model framework is designed to utilize relatively few and generally available input data, to run quickly, and to produce outputs that can be validated against available field data. The input requirements are limited so that the models can be run with the types of summary data generally available for most long-term forest watershed studies. Whenever possible, generalized relationships are used so that many parameters remain the same for all runs within a broad vegetation type. This means that these general inputs could be applied across many sites. Generic parameter files for broad-leaved deciduous, spruce-fir and other vegetation classes, along with site-specific climate drivers, obtain robust predictions of carbon and water balance and soil and surface water chemistry.

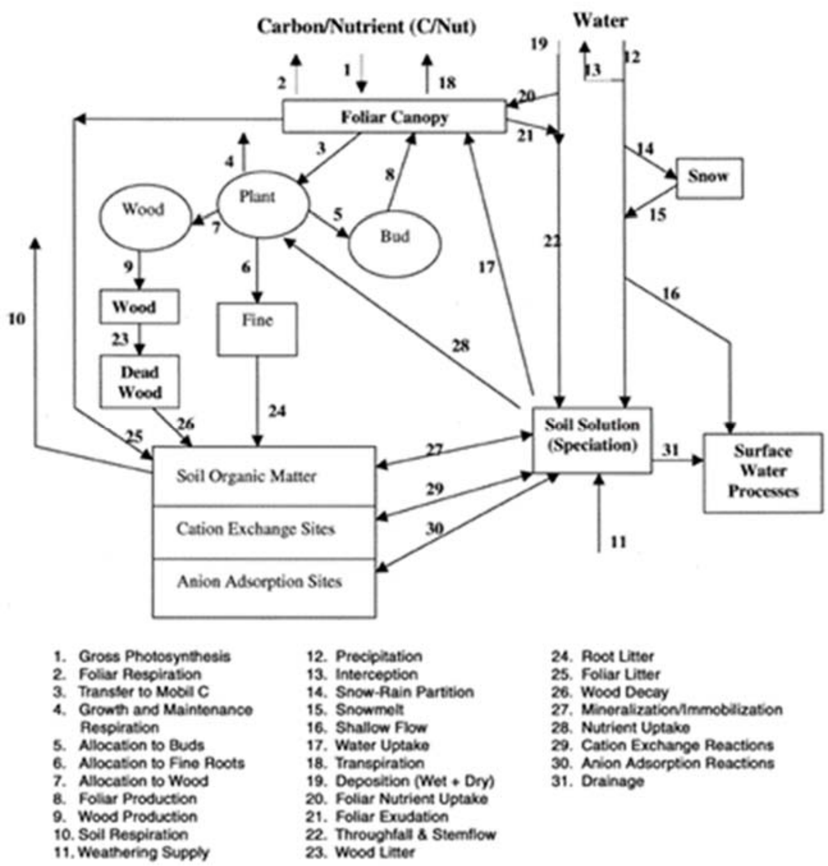

Figure 5-1. Structure of PnET-BGC illustrating the compartments of flowpaths of carbon, nutrients and water within the model. From Gbondo-Tugbawa et al. (2001).

The model is typically run with a monthly time-step under "background" conditions of climate and atmospheric deposition and without any land disturbance starting in the year 1000 and running to 1850 as a spin-up period. This allows the model to come to steady-state prior to hindcasts. Hindcast projections are typically initiated starting in the year 1850 and include consideration of historical climate, atmospheric deposition and land-disturbance. Early values for these inputs are recreated from historical records (Aber and Federer 1992; Driscoll et. al. 2001b) and matched with measured values later in the record. Assessments of model performance are made by evaluating measured surface water time series data relative to modeled results.

Table 5-1 Model Inputs and Parameters for the PnET-BGC Model

MEASUREMENT	BASIS	USE
INPUTS		
Max-min air temperature	°C; Monthly or finer timescale; long time series	Model input
Precipitation quantity	cm/mo; Monthly or finer timescale; long time series	Model input
Incident solar radiation (PAR)	Monthly or finer (mmol/m^2-s)	Model input
Soil bulk density (Soil mass per unit area)	Once (kg m^{-2})	Model input
Wet deposition	g/m^2-mo; all major solutes; Monthly or finer; long time series	Model input
Dry to wet ratio	Molar ratio; all major solutes; once	Model input
Forest disturbance (logging, fire, storm)	*Year; Intensity:* the fraction of the watershed that is disturbed by the disturbance event; *Removal Fraction:* the fraction of the forest biomass removed from the watershed during the disturbance event; *Soil loss fraction:* Quantity of soil forest floor removal during disturbance event	Model input
Watershed area and latitude	m^2	Model calculations
Major tree species	e.g., Northern Hardwoods, Spruce-Fir, Red Oak-Red Maple, Red Pine	Model calculations
Weathering	g / m^2 – mo obtained by calibration; Once	Model Input
PARAMETERS		
Vegetation chemistry	Vegetation stoichiometry (Element Organic Content and Element Plant Tissue) g/g DW; g/g N; Once	
Cation selectivity coefficients	Soil (eg/kg) and soil solution (µmol/L); Once	Cation exchange
Anion adsorption isotherms	Once	Anion adsorption
Foliar exchange/uptake (H, Mg, K, Ca, NH4)	Once	Regulating net throughfall flux

PnET-BGC is an open source model and the source code is available online http://www.lcs.syr.edu/faculty/driscoll/personal/PnET%20BGC.asp. The model has been extensively tested against field observations and applied to assess the long-term effects of acidification on forest watersheds in the Adirondacks and other sites in the northeastern United States (Zhai et al. 2008; Sullivan et al. 2006; Chen and Driscoll 2005a; Chen and Driscoll 2004; Chen et al. 2004; Gbondo-Tugbawa and Driscoll 2003). PnET-BGC has also been applied to evaluate the efficacy of various environmental policies and emission reduction scenarios with regard to Adirondack lake acid-base conditions (Wu and Driscoll 2010; Wu and Driscoll 2009; Chen and Driscoll 2005b; Gbondo-Tugbawa and Driscoll 2002a, 2002b; Driscoll et al. 2001). Therefore, the model has been utilized both as a research and management tool.

5.2 Input Development

This section provides a description of model input development. Model simulations were conducted for total of 141 lakes of which 128 were TMDL lakes and the remaining 13 lakes were selected for model calibration/confirmation purposes. Model was run on a monthly time step and required monthly values of atmospheric deposition of all major elements and meteorological data (minimum and maximum temperature, precipitation, solar radiation) for entire simulation period.

The model inputs of atmospheric deposition of chemical constituents and climate variables of precipitation, temperature and solar radiation were derived from available regression models (Ollinger et al. 1993; Ito et al. 2002). These spatial regression models were developed from the meteorological, National Climatic Data Center (NCDC), and wet deposition monitoring sites (NADP/NTN or NYS-ADMN) inside and near the Adirondack Park. Long-term meteorological variables and wet deposition measured since 1978 at the Huntington Forest (HF), located in central Adirondacks, were scaled to estimate deposition for the 141 model application sites. It was assumed that the deposition time series at TMDL sites were proportional to the values at the HF. Wet deposition data prior to 1978 were reconstructed based on historical emissions for the Adirondack source region described by Driscoll et al. (2001), assuming values for background deposition based on measurements in remote areas (Gbondo-Tugbawa et al. 2002; Gbondo-Tugbawa and Driscoll 2003, Figure 5-2). PnET-BGC utilizes dry deposition data in the form of dry to wet deposition ratios for each element. A uniform ratio for each species was obtained from experimental data at the HF (Shepard et al. 1989).

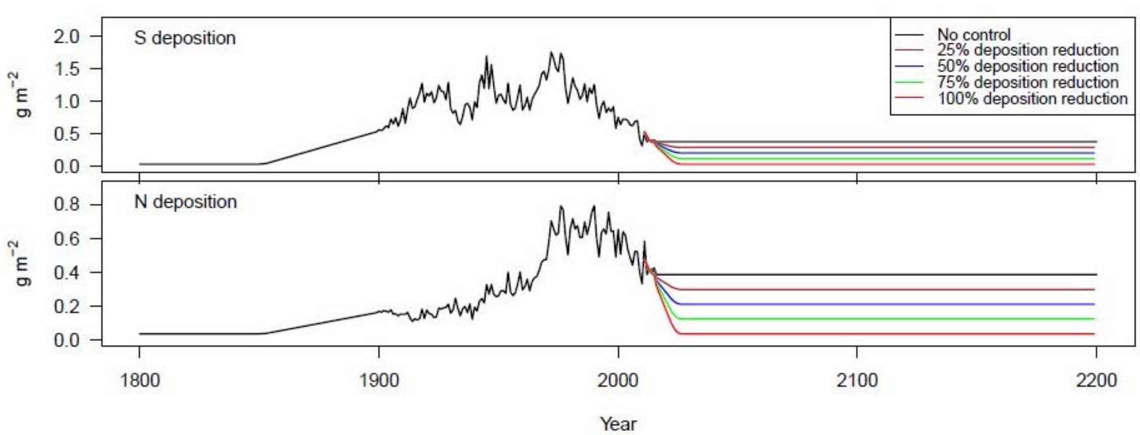

Figure 5-2. Historical and projected atmospheric deposition of S and N for Arbutus Lake located near Huntington Forest.

The model also required monthly inputs of meteorology starting from the year 1000 A.D., including minimum and maximum temperature, PAR (Photosynthetic Active Radiation), and the amount of precipitation. The monthly minimum and maximum temperature and precipitation amounts for each site were derived from the spatial model of Ito et al. (2002). Solar radiation was derived from a regional regression model developed by Aber and Freuder (2000). For forecast scenarios, average meteorological values (2001 – 2010) were used.

For vegetation inputs, there are four sets of parameters corresponding to four types of vegetation: northern hardwood, spruce fir, red maple-red oak mixture and pine. The parameters for the area-weighted average of the dominant vegetation type (northern hardwood and spruce fir as representative of deciduous and coniferous type, respectively) were used for each site. Land cover data for each watershed were obtained through a geographic information system (GIS) data layer for the region.

The lake solute retention algorithm requires specification of water column-sediment mass transfer coefficients for major elements. To quantify coefficients, a mass balance analysis was conducted on each element for Arbutus Lake. Arbutus Lake, located in central Adirondacks, is the only lake with detailed hydrology and chemistry measurements at both inlet and outlet of the lake. Element mass transfer coefficients developed at Arbutus Lakes were utilized in the model simulations by assuming all lakes exhibit the same in-lake retention coefficients.

Soil parameters including element weathering rate, cation exchange capacity, sulfate adsorption capacity and partial pressure of CO_2 were obtained through calibration and held constant throughout model simulations.

5.3 Model Performance Metrics

The PnET-BGC model calibration and performance were evaluated using statistical indicators of normalized mean error (NME) and the normalized absolute mean error (NMAE) (see Gbondo-Tugbawa et al. 2001) which are described according to the following equations.

$$NME = \frac{\bar{P} - \bar{O}}{\bar{O}} \qquad and \qquad NMAE = \frac{\sum_{i=1}^{n} (|P_i - O_i|)}{n\bar{O}}$$

Where:

P_i is predicted value;

O_i is the measured or observed value;

$\bar{O}$ and $\bar{P}$ are the mean values of individual observations of O_i and P_i, respectively; and

n is the number of observations.

NME provides a comparison of predictions and observations on an average basis (i.e., over the entire time series). NME thus expresses the bias in average values of model predictions and observations and gives a rough measure of overestimation (NME>0) or underestimation (NME<0) by the model relative to observed values. The NMAE is an absolute indicator for the discrepancy between model predictions and observations. The NMAE does not allow compensation of positive and negative discrepancies. An NMAE of zero is considered optimal. The smaller the values of NME and NMAE, the closer model simulations are to the measured values. The focus of model performance evaluation was on minimizing NME and NMAE to the extent possible based on iterative adjustments to the model coefficients. Model performance metrics are discussed below and shown in Table 5-3.

5.4 Model Calibration and Confirmation

Model calibration/confirmation was performed and model performance was evaluated prior to application of the model for TMDL development. A set of 26 Adirondack lakes with long long-term monitoring data was selected for model calibration and confirmation (Table 5-2). All but one lake (Sunday Lake) has time-series chemistry data starting either from 1982 or 1991. Sunday Lake was monitored from 2002 – 2006. Each lake was classified based on the ALSC classification scheme. These lakes represent a range of sensitivities to acidic deposition, although the list tends toward more sensitive lakes.

The model runs were started in 1000 A.D. and run under constant background deposition and no land disturbance until 1850 to achieve steady state. Changes in atmospheric deposition and land disturbance events were initiated after 1850. Current forest cover was assumed to remain constant over the simulation period. Calibration was performed by adjusting model parameters within acceptable range until simulated output closely matched with observed data. A total of 6 different sets of inputs parameters representing different lake classes were developed during the calibration processes. Model predicted and observed time-series of chemical constituents for Constable Pond are shown in Figure 5-3.

Comparisons of average measured and model simulated concentrations of major ions, pH and ANC for all 12 lakes included in the calibration are provided in Table 5-3. Gran Titration measured values of ANC (ANC_G) were compared with the model predicted ANC. The ANC calculated by the model is the organic adjusted ANC (Driscoll et al. 1994; Kohler et al. 2000), referred to as ANC_{OAA}. However, note that various investigators have used slightly different approaches and coefficients to estimate the contribution of acidity by organic acids.

Model predictions of major ions, pH and ANC are generally in good agreement with the observed values as evidenced from the performance criteria (Table 5-4). The model was able to successfully capture the declining temporal trends in surface water SO_4^{2-} observed across all sites. Model predicted Ca^{2+} concentrations generally agreed well with observed values. However, Ca^{2+} concentrations were under predicted at sites where observed concentrations were greater than 100 μeq L^{-1}. This in turn caused under prediction of ANC at sites where observed values were greater than 70 μeq L^{-1}. This problem in model behavior has limited impacts for the TMDL application since majority of the impaired lakes are characterized by low ANC values (ANC < 50 μeq L^{-1}).

The model was less successful in accurately depicting the markedly high temporal changes in NO_3^- concentrations. The model represents major processes in N cycle including mineralization, nitrification plant N uptake leaching losses and within-lake retention of NO_3^{2-}. However, nitrogen undergoes complex biogeochemical interactions in forest watersheds and interconnected lakes. For example, short-term climatic fluctuations could affect mineralization and photosynthesis, thereby altering the balance between production and uptake of nitrate (Aber et al. 2002; Campbell et al. 2009). These changes can influence short-term NO_3^- losses. Alternately, physical disturbances caused by forest logging, fire and storm damages could influence long-term N cycling that can affect NO_3^{2-} loss for decades to centuries (Aber and Driscoll 1997). Finally as watersheds recover from effects of acidification, there may be an associated increase in in-lake primary productivity which in-turn would likely increase in-lake retention of N (Kelly et al. 1990). Climate variability, uncertainties associated with land use disturbance and lack of field data complicates modeling the mechanisms that regulate nitrate concentrations in surface waters.

Table 5-2. List of Lakes Used in Model Calibration/Confirmation

Lake	ID	Application	Lake Type	TMDL Lake	Monitoring Program
Brooktrout Lake	040874	Calibration	Thin till drainage low DOC	YES	ALTM
Constable Pond	040777	Calibration	Thin till drainage low DOC	YES	ALTM
West Pond	040753	Calibration	Thin till drainage low DOC	YES	ALTM
Middle Settlement Lake	040704	Calibration	Thin till drainage low DOC	YES	ALTM
Middle Branch Lake	040707	Calibration	Thin till drainage low DOC	YES	ALTM
Squash Pond	040754	Calibration	Thin till drainage high DOC	YES	ALTM
East Copperas Pond	020138	Calibration	Thin till drainage high DOC	YES	TIME
Grass Pond	040706	Calibration	Medium till drainage low DOC	YES	ALTM
Clear Pond	050458	Calibration	Thick till drainage low DOC	NO	ALTM
Carry Pond	050669	Calibration	Mounded seepage lake low DOC	NO	ALTM
Arbutus Lake	050684	Calibration	Medium till drainage low DOC	NO	ALTM
Raquette Lake Reservoir	060315A	Calibration	Medium till drainage high DOC	NO	ALTM
Lower Beech Ridge Pond	040203	Confirmation	Thin till drainage low DOC	YES	TIME
Big Alderbed Pond	070790	Confirmation	Thin till drainage low DOC	YES	TIME
Rock Pond	060129	Confirmation	Thin till drainage low DOC	YES	TIME
Little Moose Pond	050607	Confirmation	Thin till drainage low DOC	YES	TIME
Sunday Lake	040473	Confirmation	Thin till drainage high DOC	YES	AEAP
Willys Lake	040210	Confirmation	Thin till drainage low DOC	NO	ALTM
Indian Lake	040852	Confirmation	Thin till drainage low DOC	NO	ALTM
Jockeybush Lake	050259	Confirmation	Thin till drainage low DOC	NO	ALTM
North Lake	041007	Confirmation	Thin till drainage low DOC	NO	ALTM
Queer Lake	060329	Confirmation	Thin till drainage low DOC	NO	ALTM
Bubb Lake	040748	Confirmation	Thin till drainage low DOC	NO	ALTM
Limekiln Lake	040826	Confirmation	Medium till drainage low DOC	NO	ALTM
Willis Lake	050215	Confirmation	Medium till drainage low DOC	NO	ALTM
Sagamore Lake	060313	Confirmation	Medium till drainage high DOC	NO	ALTM

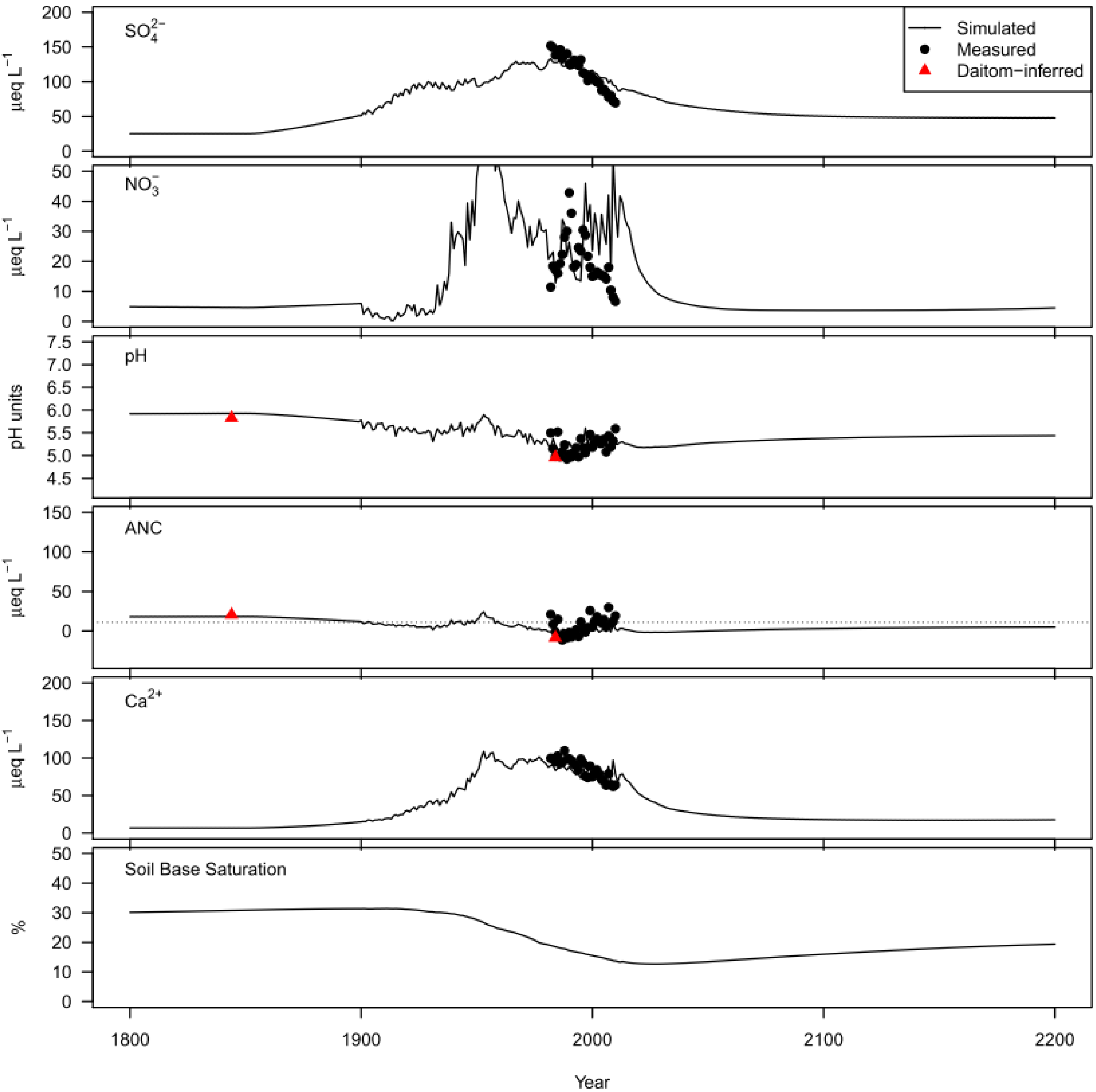

Figure 5-3. A comparison of measured and model-predicted values of concentrations SO_4^{2-}, NO_3^-, pH, ANC, Ca^{2+} and soil percent base saturation at Constable Pond. Measured values are shown for comparison. Diatom inferred pH and ANC_G are shown in red triangles.

Table 5-3 Measured and Model Simulated Values of Major Ions, pH and ANC. Model Performance Metrics of NME and NMAE are Provided.[1]

	Lake	Measured		Simulated		Model Performance	
	Constituent	Mean	Std. Deviation	Mean	Std.Deviation	NME	NMAE
Calibrated lakes (12 lakes)	pH	5.55	0.75	5.62	0.73	0.01	0.03
	ANC	24.0	39.4	22.6	41.4	-0.06	0.38
	SO_4^{2-}	46.1	14.1	45.7	11.4	-0.01	0.11
	NO_3^-	10.9	8.0	10.7	10.5	-0.01	0.52
	Ca^{2+}	41.4	21.0	37.8	19.5	-0.09	0.13

[1]All values are expressed as $\mu eq\ L^{-1}$, except pH, NME and NMAE. NME is normalized mean error; NMAE is normalized mean absolute error.

Model calibration was followed by model application to 14 lakes in order to independently confirm the calibrated parameters. Each of the 14 confirmation lakes was simulated using appropriate calibrated parameters and site specific input data (i.e., climate, atmospheric deposition, land disturbance history).

A comparison of measured and model predicted average values for chemical constituents are shown in Figure 5-4. It shows that the model predicted ANC and pH compare quite closely with the observed values for the calibration/confirmation lakes. Nitrate does not compare as favorably because of the reasons discussed above. Model predicted time-series (1800 - 2200) plots of surface water chemistry and soil percent base saturation for each of the 12 calibration and 14 confirmation lakes are shown in Appendix 1.

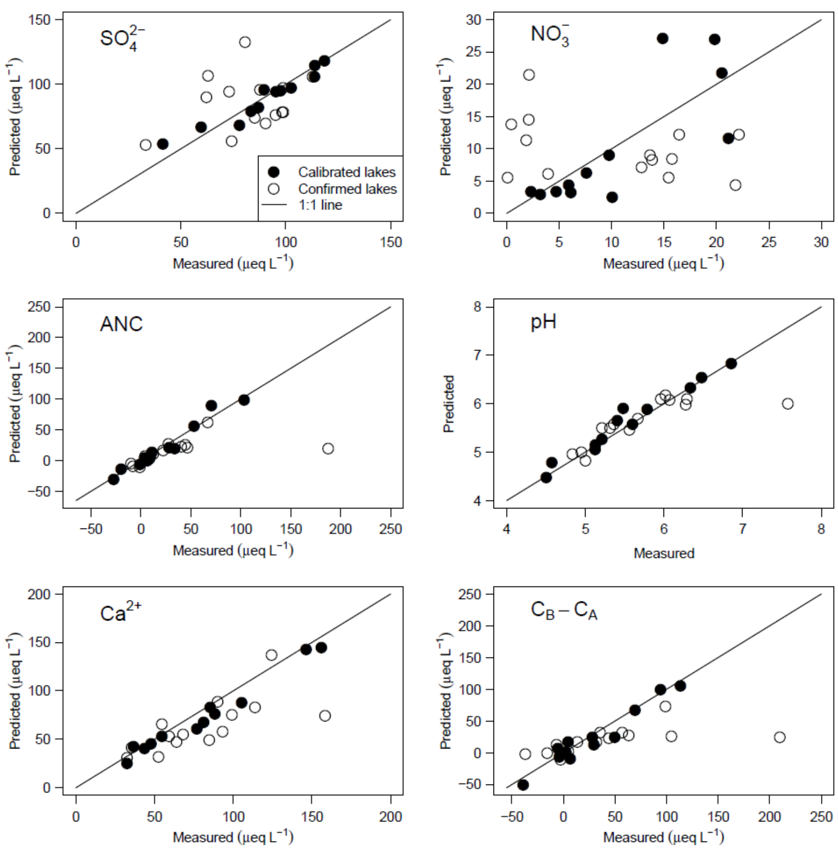

Figure 5-4. Model simulated average concentrations of SO_4^{2-}, NO_3^-, Ca^{2+}, C_B - C_A (base cations – acid anions), pH and ANC for calibration (solid circles) and confirmation (open circles) compared to average observed values.

5.5 Model Application to the TMDL Lakes

Following calibration and confirmation, the model was applied to all the TMDL lakes. Model inputs (i.e., precipitation, climate, vegetation and deposition) were developed for each site as described in section 5.2. Initially, based on the lake classification scheme, each of the TMDL lakes was assigned to one of the six parameter sets developed from the calibration. However, preliminary simulations suggested that the model parameters derived through calibration for the thin-till category were not adequate to simulate the wide range of thin-till lakes in the TMDL list. Therefore, additional parameter sets were developed, primarily by adjusting the Ca^{2+} weathering rate and the soil partial pressure of CO_2, resulting in 9 different sets (classes) of model parameters. The different model parameter classes are provided in Appendix 2. For each TMDL lake, model simulations were then performed iteratively using all 9 parameter classes and simulated results were compared to the measured values. A final parameter class was assigned for a given lake by determining the parameter class that resulted in least relative error for model predicted values compared to the measured results. The parameter class assigned for each TMDL lake was retained for model forecast of load reduction scenarios (see Section 5.1.2). Model simulated time-series of chemical constituents for a TMDL lake (Higby Twins E. Pond) is shown in Figure 5-5. Similar model output for all 128 TMDL lakes is provided in Appendix 3. Comparisons of annual average measured and model simulated concentrations of major ions, pH and ANC for all TMDL lakes included in the calibration are provided in Table 5.4.

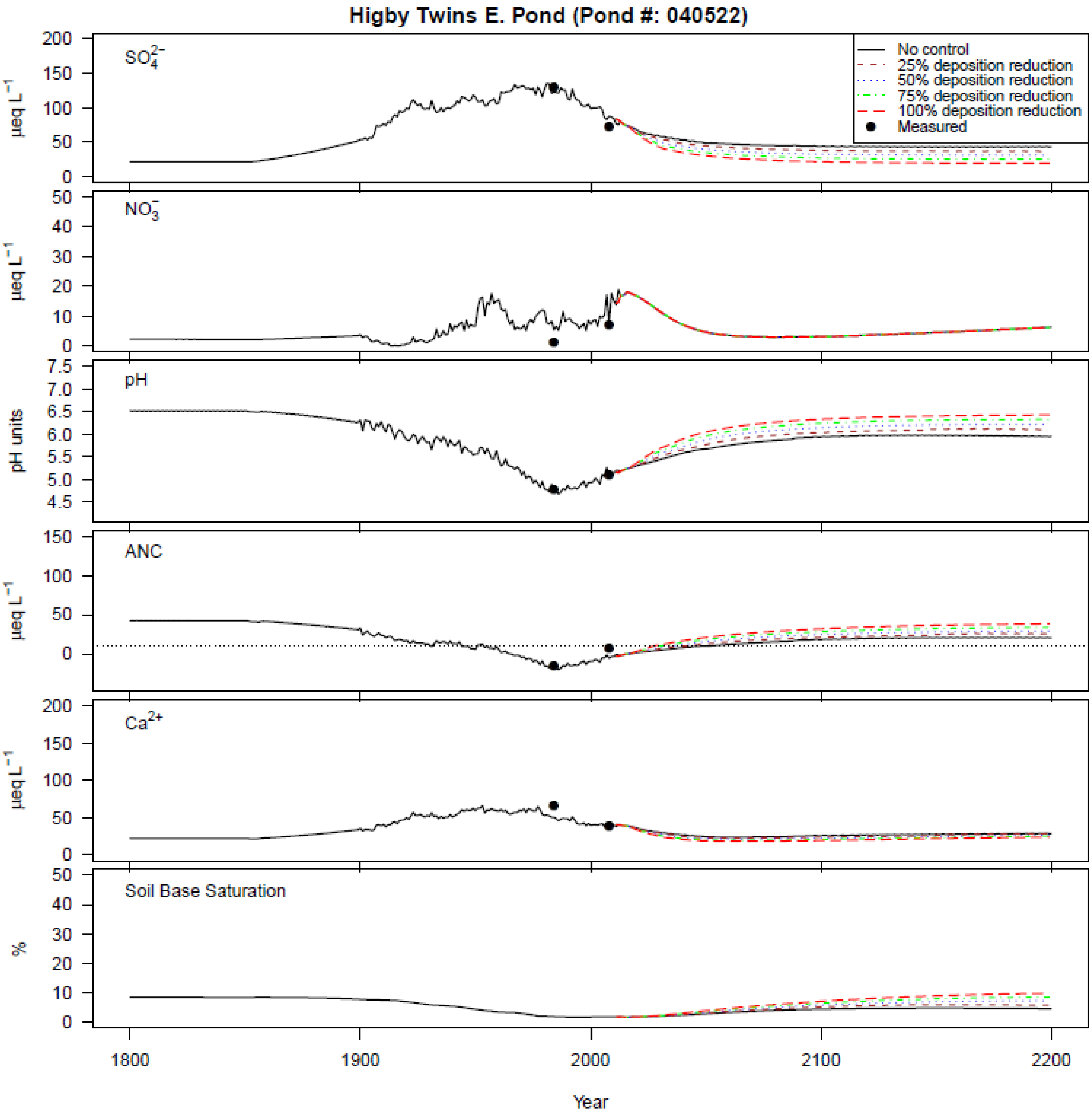

Figure 5-5. A comparison of measured and model-predicted values of concentrations of SO_4^{2-}, NO_3^- pH, ANC, Ca^{2+} and soil percent base saturation at Higby Twins E. Pond. Measured values are shown for comparison.

Table 5-4 Measured and Model Simulated Values of Major Ions, pH and ANC. Model Performance Metrics of NME and NMAE are Provided.[1]

	Lake	Measured		Simulated		Model Performance	
	Constituent	Mean	Std. Deviation	Mean	Std. Deviation	NME	NMAE
TMDL lakes (128 lakes)	pH	5.26	0.60	5.36	0.58	0.02	0.04
	ANC	8.1	32.6	5.9	26.0	-0.27	1.28
	SO_4^{2-}	40.7	15.1	41.6	11.2	0.02	0.21
	NO_3^-	6.5	8.2	9.8	8.5	0.50	1.06
	Ca^{2+}	29.9	14.4	28.1	12.1	-0.06	0.21

[1]All values are expressed as μeq L^{-1}, except pH, NME and NMAE. NME is normalized mean error; NMAE is normalized mean absolute error.

5.5.1 Model Performance of Pre-industrial pH and ANC

Pre-industrial estimates of pH and ANC_G for several Adirondack Lakes were inferred from the PIRLA diatom database. Paleolimnological estimates are available for 12 lakes for pH and 9 lakes for ANC_G that are included in this TMDL. Most of these TMDL waterbodies have inferred pre-industrial ANC_G values above zero μeq L^{-1}. The PnET-BGC model predictions for pre-industrial pH and ANC_{OAA} generally agreed well with the diatom inferred values (Figure 5-6; Appendix 1) thus providing confidence in the model hindcast results for remaining lakes with no inferred data. Model hindcast results are important for TMDL development because it reveals the cause of impairment for a given lake; specifically, whether the impairment existed even in the pre-industrial period (due to natural conditions) or it was caused by acidic deposition.

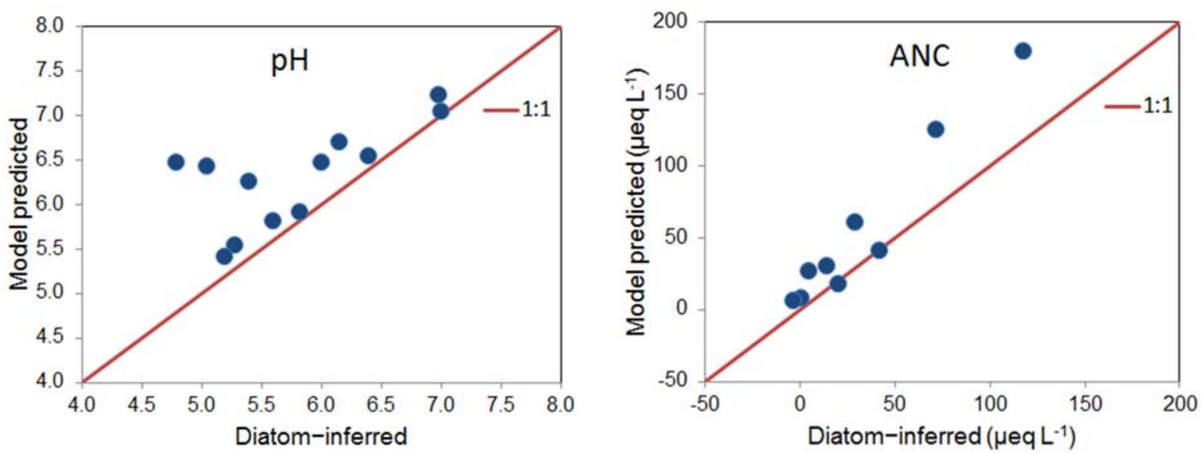

Figure 5-6. A comparison of model hind cast of pre-industrial (~ 1850) pH and ANC with values inferred from paleoecological studies

NYSDEC obtained sediment depth diatom-based inferences for ANC_G and pH for three of the PnET-BGC modeled lakes - Constable Pond, Brook Trout Lake, and Indian Lake (NYSDEC unpublished data). The data support the conclusion that prior to about 1930 the model hindcast values and paleo-inferences generally agree (ANC R^2 = 0.43, pH R^2 = .45, n = 18; vs. ANC R^2 = 0.20, pH R^2 = .22, n = 36 for the data set as a whole). Indian Lake shows agreement between the hindcast and inferences throughout its sediment profile (Figure 5-7). Constable Pond and Brook Trout Lake will be dealt with separately from this TMDL (see Section 5-6 below), but for the 14 Adirondack lakes which have pre-industrial period inference data available, none of the results appear to contradict the TMDL model hindcasts.

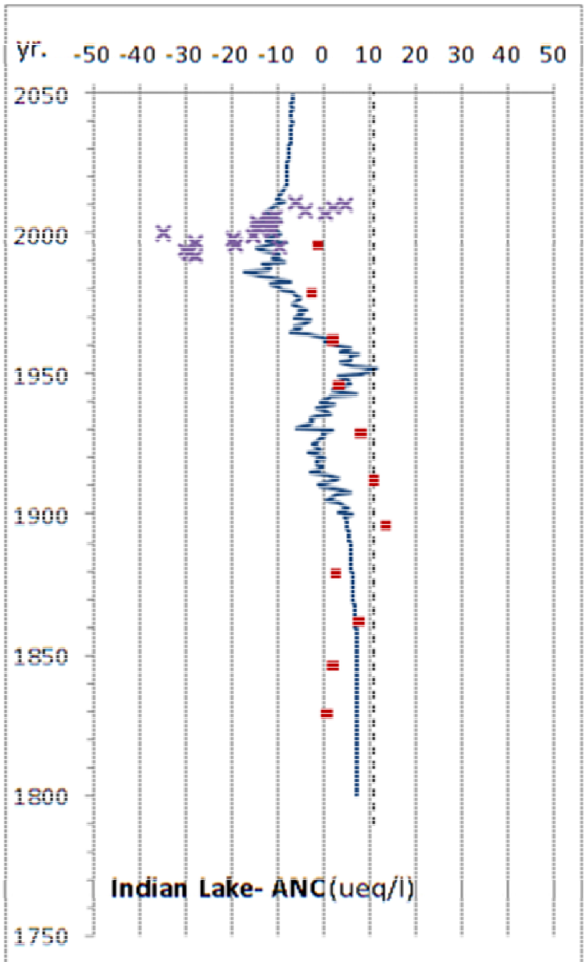

Figure 5-7. Sediment Depth Profile of ANC from Indian Lake (line = hindcast model; squares = inference model; x = growing season averages from 1992 to 2011; dashed line = ANC of 11 μeq/L)

5.5.2 Development of Load Reduction Scenarios

Following application of the model to each of TMDL lakes, the long-term response of surface water chemistry to various decreases in atmospheric loads of SO_4^{2-}, NO_3^- and ammonium (NH_4^+) was evaluated. The following approaches were considered in developing load reduction scenarios: (1) reduction in atmospheric deposition of SO_4^{2-} only, (2) reduction in atmospheric deposition of NO_3^- + NH_4^+ only, and (3) reduction in atmospheric deposition of SO_4^{2-} + NO_3^- + NH_4^+. A total of 25 possible scenarios were developed by considering various levels of atmospheric load reductions involving SO_4^{2-}, NO_3^-+NH_3^- and a combination of the two (Figure 5-8). A 100% decrease scenario is essentially equal to the assumed pre-industrial background conditions.

The baseline was considered as the average atmospheric deposition during 2009 – 2011 estimated at each site. Load reductions scenarios were developed relative to this baseline load. Load decreases were initiated during the year 2013. For each scenario considered, baseline load was decreased linearly for the first 10 years (from 2013 – 2023), and was then held constant until the end of the simulation period in 2200.

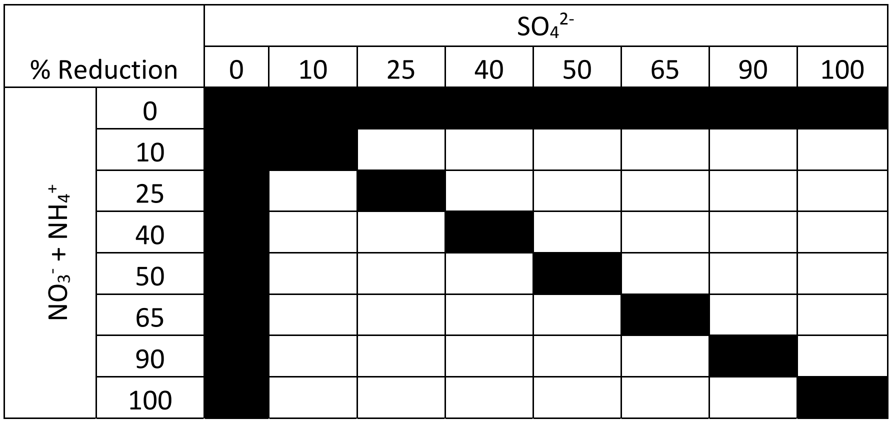

Figure 5-8. Schematic representation of various combinations of load reduction scenarios (black shaded) that were considered

5.6 Assessment of Lake Responses to Load Decreases

The response of surface water to load reductions of S and N were evaluated at two targeted future dates: 2050 and 2200. The ANC values at 2050 and 2200 corresponding to the 25 load reduction scenarios are provided in Appendix 4. Model outputs for each lake were evaluated by developing load response and cumulative distribution plots. Load response plots were developed by plotting percent reduction along the x-axis and the corresponding ANC on the y-axis. The load-response plots for the 128 TMDL lakes for various scenarios involving SO_4^{2-}, NO_3^-+NH_4^+ and the combined SO_4^{2-}+ NO_3^-+NH_4^+ are shown in Appendices 5, 6 and 7.

Model simulations suggest that the TMDL lakes exhibit a range of recovery characteristics in response to the assumed decreases in acidic deposition. The response characteristics can be grouped into three major categories: 1) lakes that will attain target ANC by year 2200, which is essentially a steady-state condition of the watershed with respect to the decrease in atmospheric deposition (although many lakes in this category attain target much earlier than 2200), with the TMDL equal to the baseline level; 2) lakes that will require some level of load reduction from baseline to attain the target ANC by 2200; and 3) lakes that will never attain the target ANC even with 100% decrease in acid deposition. Load-response plots of ANC values in response to decrease in atmospheric SO_4^{2-} deposition for select TMDL lakes are shown in Figure 5-9 as an example of each response category. Duck Pond is an example of a lake that will attain ANC target by the year 2050 without requiring any additional load reduction. According to the model Constable Pond will require some level of load reduction to attain the ANC target, but the timeframe for recovery is a function of percent reduction of current deposition levels. Constable Pond will require approximately 97% reduction in sulfate deposition from current levels to achieve ANC target in 2100, but the same target can also be attained in year 2200 with only 60% reduction.

According to the PnET-BGC model forecasts, Constable Pond and Brooktrout Lake both require substantial SOX and NOX reductions to achieve the TMDL endpoint. Both diatom paleolimnological data and the ANC inference model indicate that at least one point in the past both waterbodies met the ANC endpoint. The issue with Brooktrout Lake is that it was stocked by DEC in 2005 with Horn Lake heritage strain brook trout and now has a naturally sustaining brook trout population. The presence of a viable fish population is a contradiction with the PnET-BGC results, which forecast a lack of recovery under existing US air emissions policy. Not as much is known about the present biological condition of Constable Pond, but during the growing season, the ANC has been hovering near and just below the ANC endpoint. ALSC netting results (1999) for Constable Pond indicate the presence of several fish species, including brook trout. This apparent anomaly, based on PnET-BGC results, may be due to the fact that Constable Pond is embedded in a chain of lakes where seasonal migration of fish is probable as water quality conditions change. For one reason or another, the PnET-BGC model will need additional refinement, in order to properly develop a TMDL for these waterbodies. Hence, TMDLs will be developed for these two waterbodies as part of a future effort by NYSDEC.

Peaked Mountain is an example of a lake that will not attain the ANC target by 2200 even with a 100% decrease in atmospheric sulfate deposition. Hindcast results suggest that this lake and most of the lakes in this category exhibited ANC below the target even during the pre-industrial period.

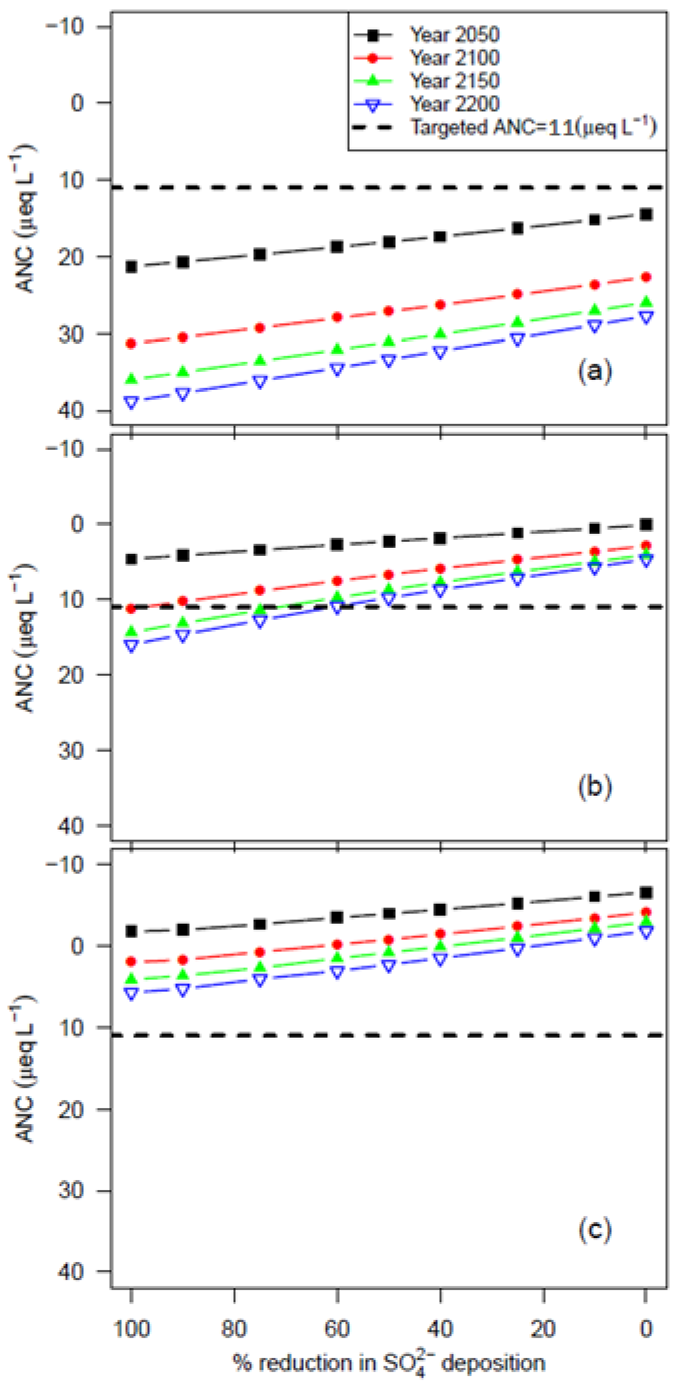

Figure 5-9. Load-response curves for (a) Duck Pond, (b) Constable Pond and (c) Peaked Mountain Lake, corresponding to reductions in atmospheric sulfate deposition.

Model forecast simulations also suggest that surface waters vary in their response to reductions in SO_4^{2-} compared to NO_3^-+NH_4^+ deposition. A cumulative distribution of model predicted ANC by year 2200 in response to 100% reductions in atmospheric deposition of SO_4^{2-}, NO_3^-+NH_4^+, and combined SO_4^{2-} plus NO_3^-+NH_4^+ is shown in Figure 5-10. Results suggest that surface water ANC is much more responsive to a unit decrease in SO_4^{2-} deposition compared to NO_3^-+NH_4^+ deposition. The scenario involving combined load reduction in SO_4^{2-} plus NO_3^-+NH_4^+ achieved essentially the same level of recovery in lake ANC compared to SO_4^{2-} only load reduction.

Several lakes also exhibited decreases in lake ANC in response to scenarios involving decreases in loading of NO_3^-+NH_4^+ (for example see Benz Pond in Appendix 6). The decrease in ANC with N load reductions is counterintuitive since ANC is expected to increase in response to decreases in acid loading. This negative response can be explained by within-lake processing of NO_3^-. In-lake retention of nitrate (or denitrification) is an important mechanism of ANC generation (Kelly et al. 1987), especially in lakes with relatively long residence times. Decreases in N deposition will limit watershed supplies of NO_3^- to lakes, thereby limiting some of the lake's ability of in-lake alkalinity generation.

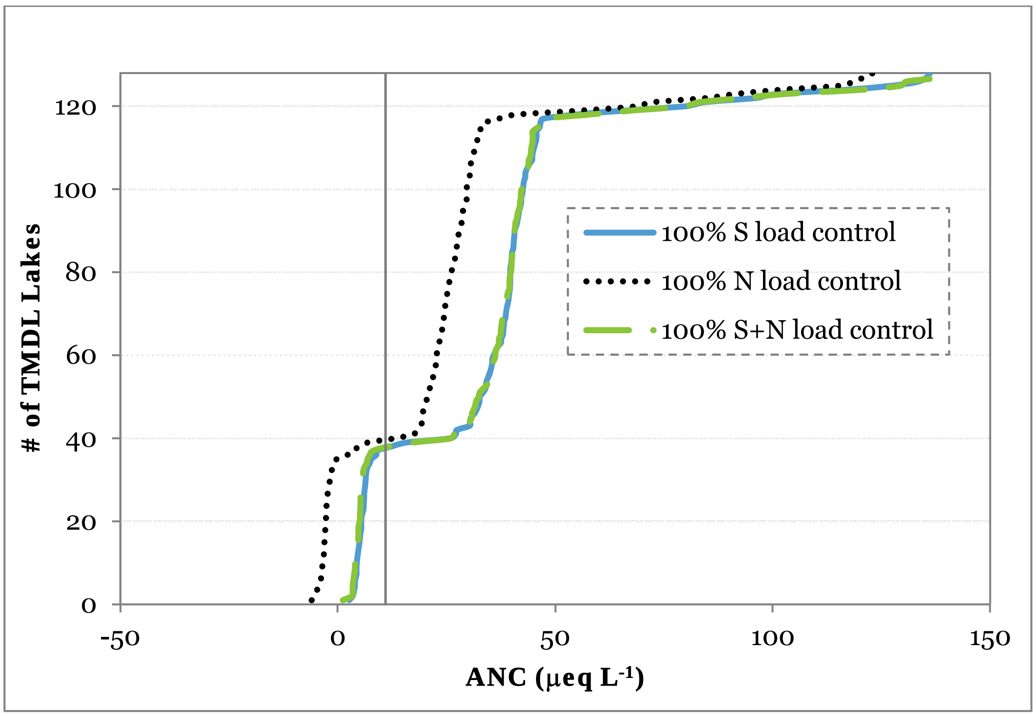

Figure 5-10. Cumulative distribution of model predicted ANC values for the 128 TMDL lakes in 2200 corresponding to following scenarios: 100% reduction in SO_4^{2-} deposition, 100% reduction in NO3- + NH4+ deposition and 100% reduction in combined deposition of SO_4^{2-} and NO_3^-+NH_4^+. Target ANC of 11 μeq L^{-1} is show for comparison (vertical dashed line).

Model forecast simulations suggest that the combined load reduction scenarios involving SO_4^{2-} plus NO_3^- +NH_4^+ could counter some of the ANC increases that can be achieved through SO_4^{2-} loading alone. For this reason, the TMDL for impaired lakes were developed solely based on atmospheric deposition of sulfate. It is useful to evaluate the recovery of surface waters in response to 100% reduction in sulfate loading since it represents the background conditions (pre-industrial ~ 1850). A cumulative distribution plot of model predicted ANC for years 2050 and 2200 in response to a 100% reduction in sulfate loading for the 128 TMDL lakes is shown in Figure 5-11. Model hindcast of pre-industrial ANC values are also included in Figure 5-11. The cumulative distribution representing 2050 ANC shows that the Adirondack lakes during this period are more acidic than either under pre-industrial conditions or in 2200, suggesting that the lake-watersheds are still responding to reductions in atmospheric loading and continue on the recovery path. The 2200 cumulative distribution of ANC for the TMDL lakes suggests that the lakes are approaching ANC values that correspond to the pre-industrial values. Therefore, the year 2200 represents the conditions where the watersheds have stabilized relative to the atmospheric deposition to the point where the lake chemistry can be considered to be at steady-state. For the purpose of the TMDL analysis, the response to load reduction will be assessed by evaluating ANC in the year 2200 when the lake is assumed to have attained steady-state condition.

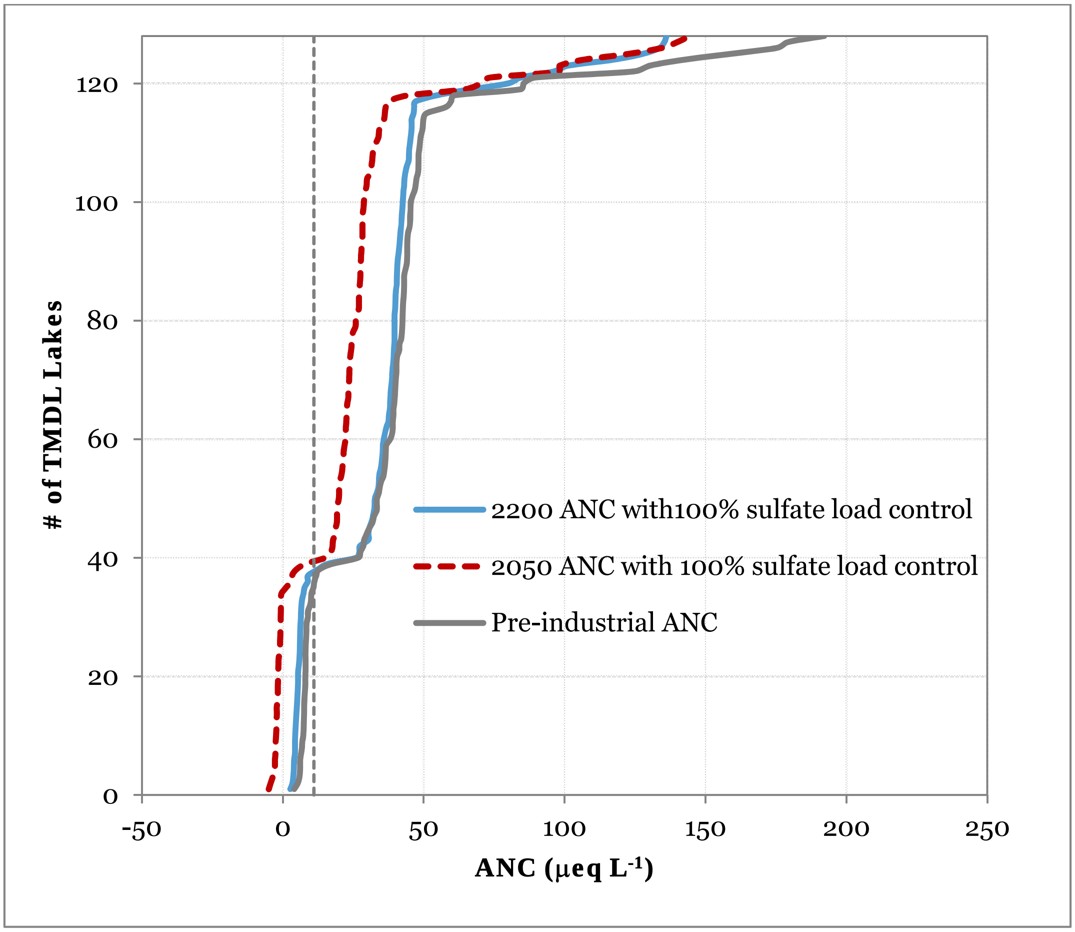

Figure 5-11. Cumulative distribution of model predicted ANC values for the 128 TMDL lakes in 2050, 2200 and pre-industrial period corresponding to 100% control in SO_4^{2-} deposition. Target ANC of 11 μeq L^{-1} is show for comparison (vertical line).

Model simulations suggest that by 2200, 37 of the 128 impaired lakes will not attain the ANC target of 11 μeq L^{-1} (Figure 5-11). The majority of these lakes (35 of 37) also exhibited pre-industrial ANC less than 11 μeq L^{-1}. Since the 37 lakes will likely not attain the ANC target even with complete elimination of acidic deposition, recovery of these water bodies cannot be addressed by an acid deposition TMDL alone. Additional site specific management options may be necessary to recover the ANC of these sites.

A summary of status of the 128 impaired lakes at future years 2050 and 2200 is provided in Figure 5-12. With the TMDLs equal to baseline sulfate loadings, 89 lakes will attain the ANC target in 2200. The modeling shows that two additional lakes, Brooktrout Lake and Constable Pond, can attain the ANC target with some level of reduction in baseline sulfate loading. The remaining 37 of the 128 lakes will not attain the ANC target even after 100% elimination of sulfate loading.

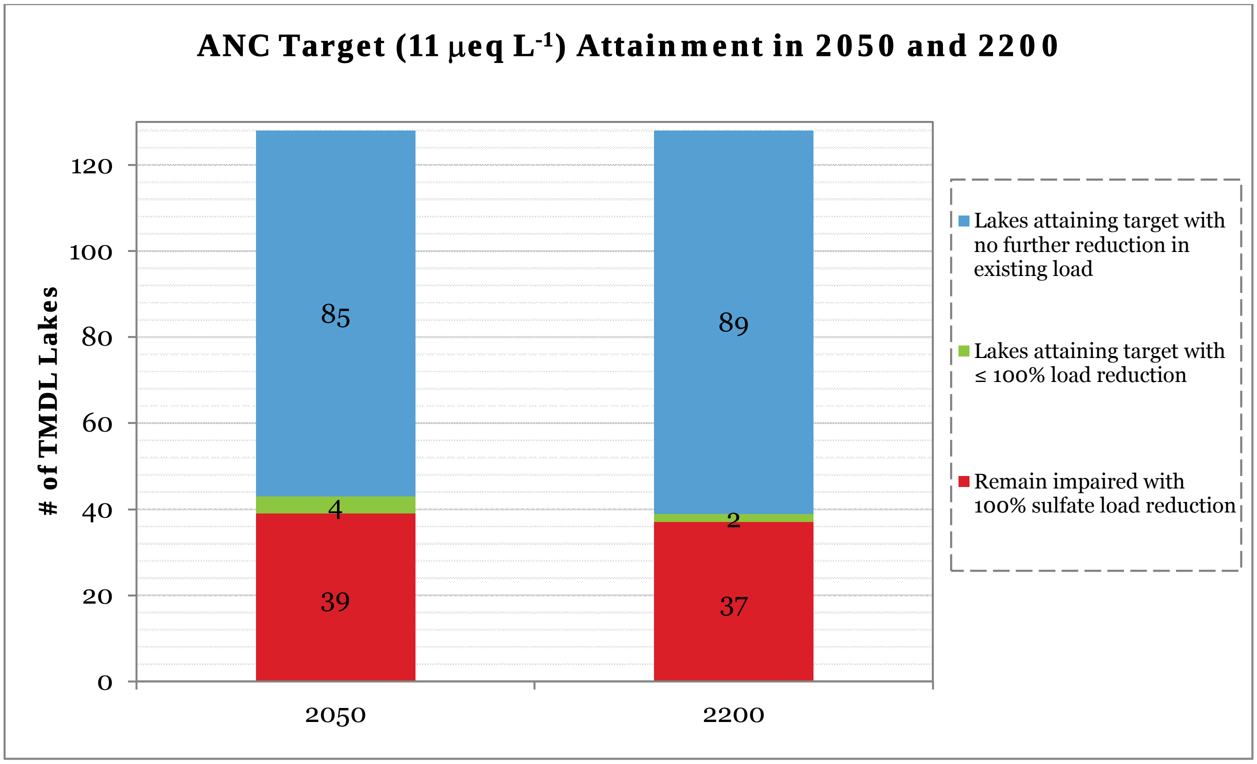

Figure 5-12. Summary of the ANC target attainment status for the 128 TMDL lakes in years 2050 and 2200.

Blank page

6
Source Assessment

Due to the remote location and the general prohibition of discharges to waters within the Forest Preserve, the primary (in fact, the lone significant) source of impairment to these waters is atmospheric deposition. SOx and NOx can be transported long distances by atmospheric transport before deposition to the surface of the watershed.

While naturally occurring watershed conditions can influence water quality in these lakes, current control efforts focus on impacts from atmospheric deposition due to anthropogenic sources. Many of these specific sources lie outside the borders of New York State. Because of this (and other factors), meeting this TMDL will require implementation efforts on a regional scale. In fact, this situation was recognized when these waters were first included on the New York State Section 303(d) List in 1998:

> The extensive studies which have been conducted on the "acid rain" waterbodies have shown that the water quality problem and resulting aquatic life impairment is not the result of wastewater discharges subject to control under the Clean Water Act. Therefore, a TMDL analysis in the classical sense may not be appropriate. Since the problem and its solution is a national issue requiring implementation under the Clean Air Act, the Department is requesting that USEPA take the lead in developing the TMDL for all states that are affected by this water quality problem.

The 1998 List also noted that:

> Efforts are underway on a national level to reduce pollutant emissions required by the Clean Air Act. New York and other northeast states have taken legal action against EPA to accelerate implementation of controls, particularly in the Midwest. Monitoring of these waters will be continued to assess changes in water quality resulting from implementation of the Clean Air Act. These changes are expected to occur only slowly over the time.

The U.S. GAO Report (U.S. GAO 2013) also notes the focus on interstate air pollution as part of the issue in Adirondack lakes. The GAO report states:

> According to state officials, over the last two decades the state has reduced in-state emissions of SO_2 by about 90 percent and reduced instate emissions of NO_x to a lesser extent[1]. This in turn has reduced acid rain and improved water quality in the Adirondack lakes. However, state officials said that reducing acid rain to the levels called for in the TMDL remains a challenge because almost all of the NO_x, SO_2, and other sulfur oxides contributing to acid rain in the region can be attributed to out-of state sources—mostly from the Southeast, and Midwest United States and Canada. Specifically, data compiled by the NYSDEC in the mid- 1980s estimated that 83 to 87 percent of acid rain came from emissions of NO_x, SO_2, and other sulfur oxides originating out-of-state, and NYSDEC officials stated that this percentage is now likely higher as a result of the in-state reductions. According to NYSDEC officials, meeting the TMDL goals for acid rain is dependent on emissions reductions in other states, but they said the department will continue to

[1] According to the GAO document, NO_x emissions decreased from 30 percent to 90 percent depending on the emission source but there is not reliable data on the precise reduction of overall emissions.

> address its responsibilities for improving air and water quality within the state through implementation of federal programs under the CAA, as well as state air programs, such as its Acid Deposition Reduction Program. According to NYSDEC officials, the state has not used other non-regulatory tools available under the CWA to help address acid deposition, such as petitioning for conferences with other states, but they said that this is an option that needs to be considered.

The "National Acid Precipitation Assessment Program Report (NAPAP) to Congress 2011: An Integrated Assessment" summarizes information and analysis of the environmental effectiveness of the Acid Rain Program (ARP), which was mandated under Title IV of the 1990 Clean Air Act Amendments (CAAA) to reduce SO_2 and NO_x emissions from electric generating sources. The Report states that "since the implementation of the ARP, scientists have measured changes in some lakes and streams in the eastern United States and found signs of recovery in many, but not all, regions and waterbodies." The study evaluated trends from 1990 to 2008 for 50 Adirondack Mountain lakes, and finds that 90 percent of the study lakes had improving trends for sulfate, 32 percent had improving trends for nitrate, and 58 percent had improving trends for ANC. However, Title IX of the 1990 CAAA requires NAPA to report quadrennially on "the reduction in deposition rates that must be achieved in order to prevent adverse ecological effects. The Report finds that additional emission reductions are still needed for ecological recovery, especially in acid-sensitive areas. The Report goes on to state that "reduction of SO2 to 0.44 million tons/ year from the power sector would result in nearly full protection of lakes in the Northeast and the Adirondack Mountains." This recommendation was developed using a more stringent endpoint for ANC, as the endpoint was designed to also protect flowing waters, which are more sensitive to episodic events than the vast majority of waters assessed in this TMDL modeling effort.

While the U.S. Court of Appeals for District of Columbia decides when to lift the stay on the Cross State Air Pollution Rule (CSAPR), the Clean Air Interstate Rule (CAIR) remains in effect. The CAIR is thought to have contributed to a general reduction in power SO2 emissions and corresponding Sulfate depositions as is illustrated by the chart below.

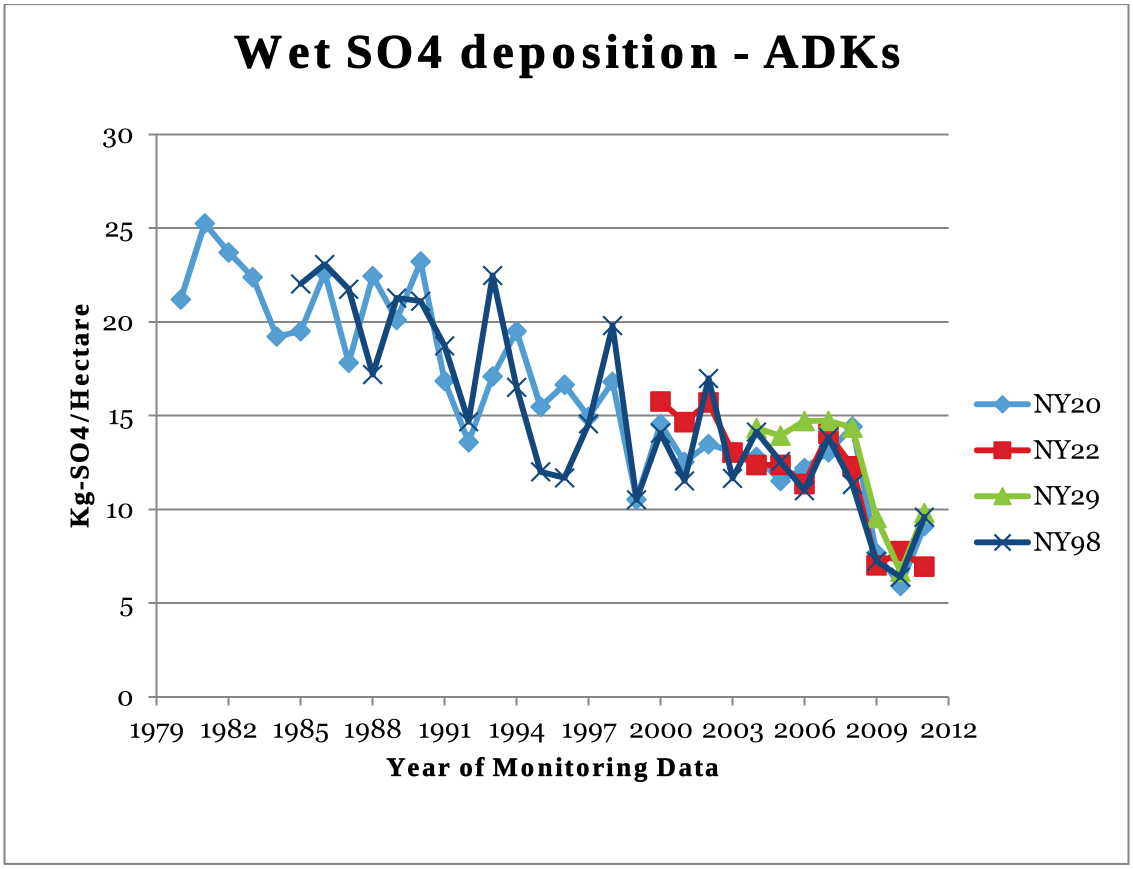

Figure 6-1 indicates the trends in wet sulfate deposition in time, in kg-SO4/ha.

Three of the Figure 6-1 sites (Huntington Wildlife, NY20; Moss Lake, NY29; and Whiteface Mountain, NY98) are within the boundary of Adirondack Park, while one is just a few miles north (Akwesasne Mohawk/Ft Covington, NY22). Data from these and other sites are available from the National Atmospheric Deposition Program/National Trends Network (NADP/NTN; please see http://nadp.sws.uiuc.edu/ntn). Trends in wet deposition of SO4 and NO3 are generally consistent with regional SO2 and NOx emissions reductions and improvements in overall air quality across New York (e.g. Civerolo et al. 2012).

Blank page

7
TMDL Development

A TMDL calculates the maximum amount of a pollutant allowed to enter a water body so that the water body will meet water quality standards for that particular pollutant. In this case, there is no applicable water quality standard, so the TMDL will be developed to meet the ambient water quality value. The TMDL allocates the maximum allowable load to point sources (Wasteload Allocation or WLA), and nonpoint sources (Load Allocation or LA), which include both anthropogenic and natural background sources of the pollutant. TMDLs must also include a margin of safety (MOS) to account for uncertainty in the relationship between pollutant loading and receiving water quality.

The TMDL is therefore defined by the equation:

$$TMDL = \Sigma LA + \Sigma WLA + MOS$$

Where

TMDL = total maximum daily load (i.e., the loading capacity (LC) of the receiving water)

ΣLA = sum of all load allocation for non-point sources

ΣWLA = sum of all wasteload allocation for point sources

MOS = Margin of safety

In general, waterbodies become impaired due to excessive loading of particular pollutants that result in exceedance of water quality standards. A TMDL establishes the maximum daily load that can be assimilated by the waterbody, without violating standards, and allocates portions of this load to point and non-point sources. This normally involves reductions in loading (both point and non-point sources) from existing levels.

The most significant source of acidity to lake watersheds in the Adirondack Park is from atmospheric deposition of sulfur and nitrogen compounds. Because the majority of the impaired waters share common pollutant sources and the origin of these sources lie both within and outside state boundary, a regional TMDL approach is deemed appropriate rather than setting TMDL targets for individual lakes. Other regional TMDLs dealing with atmospheric deposition, such as the atmospheric mercury deposition TMDLs developed for Minnesota (MPCA 2007) and the Northeastern United States (NEIWPCC 2007), have taken similar approaches, and thus are good templates for this TMDL. The regional TMDL is also less resource intensive in terms of measuring compliance than developing TMDLs for each individual lake.

As explained in section 5-6, model simulations suggest that the recovery of lake watersheds is more responsive to controls on atmospheric deposition of sulfur rather than decreases in nitrogen or nitrogen and sulfur combined. Therefore, the TMDL was developed for atmospheric deposition of sulfate.

As a result of this TMDL 89 of the 128 acid impaired Adirondack lakes are expected to attain TMDL endpoint by the year 2200 in response to load reductions that have already occurred in 2013. Two of the lakes are not adequately addressed by the modeling. The remaining 37 lakes are not expected to achieve the TMDL endpoint by the year 2200 even with complete elimination of acid deposition, Hindcast simulations suggest that the majority of these 37 lakes were acidic during pre-industrial time. Because the AWQV for these lakes cannot be achieved through this TMDL processes, these lakes are not included within the TMDL. The load reductions called for in this TMDL will benefit these 37 lakes by improving water to some extent, but additional site-specific management options may be necessary to attain AWQV. A list of these 37 lakes summarized by lake type, watershed area and lake surface area are provided in Appendix 10.

The process to determine the TMDL for 89 lakes for which decrease in atmospheric acid deposition will likely result in attainment of water quality standards includes:

1. Determine the maximum allowable atmospheric sulfate load to each TMDL lake (i.e., the maximum pollutant load that the water body can assimilate and attain water quality standards - or, in this case, the AWQV).
2. Identify the lake with lowest existing atmospheric sulfate load among the 89 lakes being assessed. We can therefore assume that this load will be as protective of all other TMDL lakes.
3. Establish the lowest existing sulfate load as the critical load (the TMDL) at which the 89 impaired lakes will attain the target ANC endpoint by year 2200 (steady-state).

The baseline load atmospheric sulfate load is defined as the average load to the waterbodies for the 2009 - 2011 period. The baseline load represents the current levels of atmospheric sulfate deposition. The average baseline atmospheric sulfate load derived for each impaired lake is provided in Appendix 8. Estimated sulfate deposition ranges from 19.7 meq/m^2-yr to 33.6 meq/m^2-yr across the impaired sites with an average value of 23.8 meq/m^2-yr.

The PnET-BGC model was applied at each site to provide the link between sulfate deposition and lake ANC by quantifying the maximum amount of sulfate deposition the watershed can receive and maintain the desired ANC endpoint selected for this TMDL. Model simulations suggest that at current levels of sulfate deposition the majority of the lakes will attain ANC endpoint of 11 μeq L^{-1} within year 2200 (Figure 5-13). For these lakes the load allocation is equal to the existing baseline load. For each of the 89 lakes, the baseline and maximum allowable load is shown in Figure 7-1. The lowest existing load among these 89 lakes is 19.7 meq/m^2-yr for Clear Pond(050594). The lowest maximum allowable load of 19.7 meq/m^2-yr therefore represents the TMDL below which all 89 lakes will attain the target ANC of 11 μeq L^{-1}.

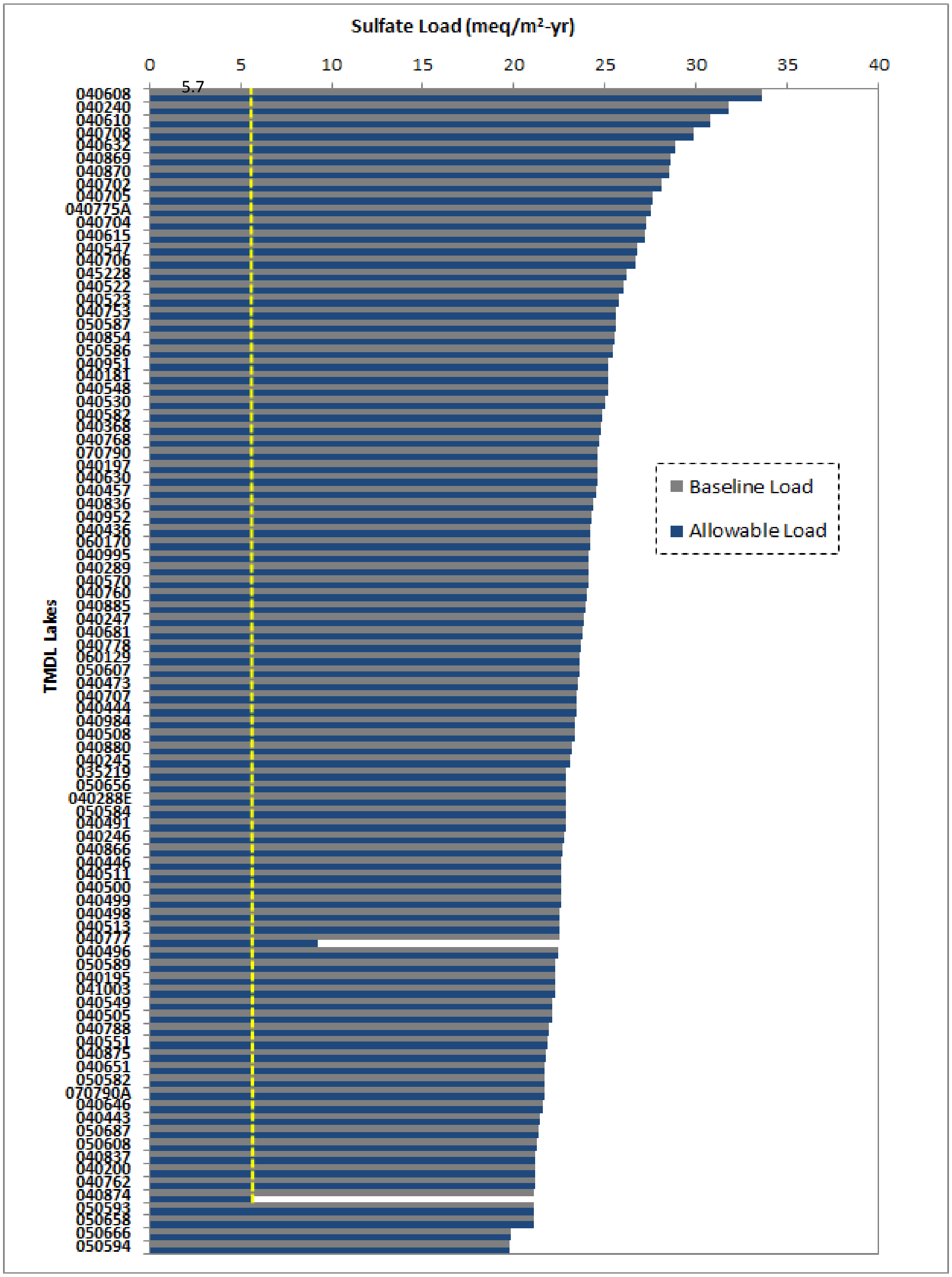

Figure 7-1. Estimated baseline (annual average: 2009 - 2011) atmospheric SO_4^{2-} load (light bar) and the maximum annual allowable SO_4^{2-} load (dark bar) to each TMDL lake. The vertical yellow line corresponds to the lowest maximum allowable load that can sustain ANC endpoint across all impaired lakes. This plot does not include the 37 lakes that will not meet 11 μeq L^{-1} ANC target even 100% reduction in acid deposition. Also note that for reasons noted in Section 5.6, Lakes 040777 (Constable Pond) and 040874 (Brook Trout Lake) are not used in the determination of the TMDL for the remaining 89 lakes.

7.1 Waste Load Allocation

As discussed in Section 3.1, the Adirondack lakes are remote waters that are regulated by the New York State Constitution as being "forever wild." Consequently, there are no point sources (i.e., permitted discharges) of significant acidity loading in these watersheds now or expected in the future. Therefore, a wasteload allocation of zero is allotted to point sources to these waterbodies.

7.2 Load Allocation

The final TMDL allocations for the 89 Adirondack Lakes covered under this TMDL are summarized in Table 7-1. The TMDL also incorporates the required MOS (discussed in Section 7.3), which reduces the allowable load allocations by 10 %. These 89 lakes will attain target ANC by year 2200, which is essentially a steady-state condition of the watershed with respect to the decrease in atmospheric deposition (although many lakes in this category attain target much earlier than 2200), with 10% load reductions from the baseline level.

The maximum allowable sulfate loading rate (meq/m^2-yr) at each site (Figure 7-1) is converted to annual mass loading (eq/yr) by multiplying loading rate with the respective watershed area. The annual load is divided by 365.25 and converted to daily load (eq/day). The unit conversion of 105.8892 lb/meq is used for Table 7.1. The TMDL, LA and MOS in milliequivalents of each watershed are provided in Appendix 11.

Table 7-1. TMDL Allocation for Atmospheric SO_4^{2-} Deposition for the 89 Acid Impaired Adirondack Lakes.

PWL #	Pond #	Pond Name	TMDL	LA	WLA	Explicit MOS (10%)
			(lb/day)	lb/day)	(lb/day)	(lb/day)
0902-0021	035219	Duck Pond	0.802	0.722	0	0.080
0905-0035	040181	Gregg Lake	37.836	34.053	0	3.784
0905-0061	040195	Muskrat Pond	4.356	3.921	0	0.436
0905-0062	040197	Diana Pond	4.200	3.780	0	0.420
0905-0057	040200	Upper South Pond	2.613	2.351	0	0.261
0905-0038	040240	Desert Pond	4.599	4.139	0	0.460
0905-0038	040245	Jakes Pond	3.141	2.827	0	0.314
0905-0038	040246	Buck Pond	2.268	2.041	0	0.227
0905-0038	040247	Hog Pond	3.027	2.725	0	0.303
0905-0030	040289	Crystal Lake	1.024	0.921	0	0.102
0905-0005	040368	Hitchens Pond	21.849	19.664	0	2.185
0801-0055	040436	Sand Pond	19.893	17.904	0	1.989
0801-0076	040443	Pepperbox Pond	4.522	4.070	0	0.452
0801-0076	040444	Lower Spring Pond	14.391	12.952	0	1.439
0801-0076	040446	Tied Lake	2.607	2.346	0	0.261
0801-0453	040457	Unnamed Pond	21.407	19.267	0	2.141
0801-0195	040473	Sunday Lake	88.017	79.215	0	8.802
0801-0039	040491	Upper Moshier Pond	16.375	14.738	0	1.638
0801-0107	040496	Raven Lake	45.528	40.975	0	4.553

PWL #	Pond #	Pond Name	TMDL	LA	WLA	Explicit MOS (10%)
			(lb/day)	lb/day)	(lb/day)	(lb/day)
0801-0109	040498	Lyon Lake	10.817	9.735	0	1.082
0801-0125	040499	Slim Pond	2.461	2.215	0	0.246
0801-0110	040500	Evergreen Lake	4.425	3.983	0	0.443
0801-0111	040505	Hidden Lake	1.462	1.315	0	0.146
0801-0126	040508	Ginger Pond	25.537	22.984	0	2.554
0801-0126	040511	Soda Pond	2.309	2.079	0	0.231
0801-0065	040513	Unnamed Pond	7.196	6.476	0	0.720
0801-0068	040522	Higby Twins E. Pond	8.283	7.454	0	0.828
0801-0068	040523	Higby Twins W. Pond	3.404	3.063	0	0.340
0801-0068	040530	Beaverdam Pond	33.346	30.011	0	3.335
0801-0149	040547	Lilypad Pond	245.913	221.322	0	24.591
0801-0149	040548	Mud Pond	227.087	204.378	0	22.709
0801-0149	040549	Little Salmon Pond	181.792	163.613	0	18.179
0801-0149	040551	Hardigan Pond	11.357	10.222	0	1.136
0801-0018	040570	Terror Lake	17.465	15.719	0	1.747
0801-0077	040582	South Pond	12.582	11.323	0	1.258
0801-0323	040608	Evies Pond	1.519	1.367	0	0.152
0801-0323	040610	Long Lake	6.577	5.919	0	0.658
0801-0323	040615	Fish Pond	65.584	59.026	0	6.558
0801-0127	040630	Bills Pond	6.483	5.834	0	0.648
0801-0075	040632	Panther Pond	7.981	7.183	0	0.798
0801-0327	040646	Unnamed Pond	4.894	4.405	0	0.489
0801-0153	040651	Little Diamond Pond	0.953	0.857	0	0.095
0801-0041	040681	Blackfoot Pond	12.761	11.485	0	1.276
0801-0072	040702	Lost Lake	1.771	1.594	0	0.177
0801-0072	040704	Middle Settlement Lake	9.002	8.102	0	0.900
0801-0072	040705	Cedar Pond	40.904	36.814	0	4.090
0801-0072	040706	Grass Pond	19.807	17.826	0	1.981
0801-0072	040707	Middle Branch Lake	17.021	15.319	0	1.702
0801-0072	040708	Little Pine Lake	79.280	71.352	0	7.928
0801-0050	040753	West Pond	7.534	6.781	0	0.753
0801-0016	040760	Otter Pond	9.185	8.266	0	0.918
0801-0050	040762	North Gull Lake	7.166	6.449	0	0.717
0801-0004	040768	Lower Sister Lake	118.259	106.433	0	11.826
0801-0017	040778	Chub Lake	17.091	15.382	0	1.709
0801-0011	040788	Eagles Nest Lake	9.420	8.478	0	0.942
0801-0034	040836	Stink Lake	25.253	22.728	0	2.525
0801-0034	040837	Balsam Lake	2.052	1.847	0	0.205

PWL #	Pond #	Pond Name	TMDL (lb/day)	LA lb/day)	WLA (lb/day)	Explicit MOS (10%) (lb/day)
0801-0052	040854	Horn Lake	5.814	5.232	0	0.581
0801-0010	040866	Deep Lake	4.286	3.857	0	0.429
0801-0010	040869	Twin Lake West	19.168	17.251	0	1.917
0801-0010	040870	Twin Lake East	11.149	10.034	0	1.115
0801-0010	040875	Northrup Lake	3.018	2.716	0	0.302
0801-0029	040880	Bear Pond	11.904	10.714	0	1.190
0801-0399	040885	Falls Pond	6.877	6.189	0	0.688
0801-0070	040951	Little Woodhull Lake	83.196	74.876	0	8.320
0801-0070	040952	Lily Lake	5.291	4.762	0	0.529
0801-0135	040984	Bloodsucker Pond	0.433	0.390	0	0.043
0801-0139	040995	Burp Lake	2.166	1.949	0	0.217
0801-0140	041003	Little Salmon Lake	12.177	10.959	0	1.218
0801-0075	045228	Upper Lennon Pond	1.981	1.783	0	0.198
1104-0008	050582	Bullhead Pond	9.381	8.443	0	0.938
1104-0008	050584	Cranberry Pond	7.333	6.600	0	0.733
1104-0008	050586	Rock Pond	1.437	1.293	0	0.144
1104-0008	050587	Stonystep Pond	4.046	3.642	0	0.405
1104-0008	050589	Puffer Pond	16.647	14.983	0	1.665
1104-0008	050593	Center Pond	11.420	10.278	0	1.142
1104-0008	050594	Clear Pond	3.007	2.706	0	0.301
1104-0008	050607	Little Moose Pond	44.410	39.969	0	4.441
1104-0008	050608	Otter Lake	37.910	34.119	0	3.791
1104-0003	050656	Green Pond	3.032	2.729	0	0.303
1104-0003	050658	Unknown Pond	27.654	24.888	0	2.765
1104-0003	050666	Wakely Pond	5.488	4.939	0	0.549
1104-0073	050687	Round Pond	97.313	87.582	0	9.731
0903-0003	060129	Rock Pond	225.082	202.574	0	22.508
0903-0032	060170	Halfmoon Pond	4.439	3.995	0	0.444
1201-0002	070790	Big Alderbed Pond	114.935	103.441	0	11.493
0905-0030	040288E	Unnamed Pond	33.954	30.558	0	3.395
0801-0017	040775A	Pug Hole Pond	4.885	4.396	0	0.488
1201-0002	070790A	Blind Mans Vly Pond	8.925	8.033	0	0.893

7.3 Critical Condition

The lowest areal deposition load among these 89 lakes is 19.7 meq/m^2-yr for Clear Pond (050594 in PWL 1104-0008). This is lowest maximum load that allows for all 89 lakes to attain the target ANC of 11 μeq L^{-1} (TMDL endpoint) by year 2200 (steady-state). While converted to pounds per day for the area of the watershed of each lake, all the TMDL allocations in Table 7.1 are equal or above this areal deposition rate expressed as milliequivalents in Appendix 11.

Table 7-2. Critical TMDL Allocation for Atmospheric SO_4^{2-} Deposition for the 89 Acid Impaired Adirondack Lakes.

TMDL (Critical Load) meq/m^2-yr	Wasteload Allocation (meq/m^2-yr)	Load Allocation (meq/m^2-yr)	Explicit Margin of Safety (10%)
19.7	0	17.7	2.0

7.4 Margin of Safety

The TMDL regulations (40CFR §130.7(c)(1)) require that a TMDL include a margin of safety to account for any lack of knowledge concerning the relationship between loading and attainment of water quality standards. The MOS can be either explicit (e.g., stated as an additional percentage load reduction) or implicit (i.e., conservative assumptions in the TMDL calculations or overall approach) in the calculations of the TMDL, or a combination of the two.

This TMDL has incorporated an explicit 10% allocation to account for any uncertainty in TMDL determination. The 10% MOS was recommended by USEPA-R2 with the consensus of NYSDEC.

7.5 Seasonal Variations

Like MOS, seasonal variation should be considered in TMDL calculations in order to assure that standards are met during all anticipated conditions. Due to the long-term nature of acid deposition and the slow response of watershed and in-lake processes to changes in deposition load, it is appropriate to express the critical load on an annual basis rather than daily. Critical load expressed as the daily limit has limited practical use in-terms of implementation and long-term monitoring.

Due to the slow response of the watershed and in-lake processes to decreases in atmospheric deposition of sulfate, there are no specific critical conditions specified in this TMDL.

The design of the monitoring component to support the restoration of these waters will take into account the seasonal variation during spring freshet to better ensure that water quality standards and restoration goals are met under all conditions.

8 Reasonable Assurance and Implementation

EPA guidance calls for reasonable assurances when TMDLs are developed for waters impaired by both point and nonpoint sources. In such cases, waste load allocations for point sources are dependent on assumptions about controls on nonpoint source loads; EPA requires reasonable assurance that the assumed reduction of nonpoint sources will occur in order for the TMDL to be approved. However in waters impaired solely by nonpoint sources, as is the case for this TMDL, reasonable assurances regarding load reductions are not required in order for a TMDL to be approved.

The reductions outlined in this restoration strategy/TMDL are based upon federal/regional requirements that are already in place and being implemented. These include the Clean Air Interstate Rule (CAIR) that was put into place in 2005, as well as reductions that were included in the 1990 Clean Air Act Amendments and other state and local measures. CAIR has replaced the U.S. EPA Nitrogen Oxides Budget Program (NBP) and the New York State Acid Deposition Reduction Program (ADRP) that provided additional reductions not accounted for in the loading calculations. Together the NBP and the ADRP required certain electric generators in the State to reduce emissions of SOx and NOx to 50 percent below Phase 2 levels of the federal acid rain program in order to protect sensitive areas of the state, including the Adirondack and Catskill mountains. While CAIR required a relatively small amount of additional SO2 and NOx reductions beyond the NBP and ADRP in New York, it required similar overall reductions in SO2 and NOx from electric generators in 27 additional eastern States to address transport of ozone and PM2.5. It should be noted that CAIR, while still in place, has been remanded back to EPA by the U. S. Court of Appeals for the District of Columbia Circuit to correct several deficiencies found by the court. For this TMDL, the analysis shows that further enforcement of Clean Air Act (CAA) requirement that assure recent levels of sulfate deposition would restore those lakes that are projected to be capable of restoration. To cover the 10 percent Margin of Safety, further reductions are needed. NYSDEC will assure that New York State's CAA reductions are achieved, as well as an additional state requirements, but to assure that reductions of emissions well outside its borders will be achieved, New York State must rely on USEPA to insure that other states meet their CAA reduction obligations. Also, further reductions in deposition will hasten the recovery for most of the lakes.

EPA has identified the Acid Rain Program as the key regulation or program contributing to these reductions. The Acid Rain Program was designed, in part, to address the effect of NOx and SO2 on waterbodies. The program implements CAA requirements for significant decreases in the emissions of NOx and SO2 from power plants to improve air quality and protect ecosystems that have suffered damage from acid rain, including aquatic ecosystems. According to the 2011 NAPAP report, the mandated emission reductions have been achieved, and thus no additional controls in emissions can be expected from this program.

However, two broad trends—recent environmental regulations and changing market conditions—could affect emissions from power plants. Regarding environmental regulations, beginning in June 2010, EPA proposed or finalized two key regulations, the Cross-State Air Pollution Rule (CSAPR) and the Mercury Air Toxics Standards (MATS), that would, among other things, reduce emissions of NOx and SO2 from coal-burning power plants. Still, the requirements and deadlines that these regulations may establish for power plants are uncertain. In particular, both regulations have been challenged in federal court. For example, EPA finalized the CSAPR in August 2011. The regulation requires reductions if certain emissions of air pollutants, including NOx and SO2, in 28 states. The Supreme Court overturned the U.S Court of Appeals for the District of Columbia decision to vacate the CSAPR. While EPA is waiting for the Court of Appeals to decide when to lift the stay for the CSAPR, CAIR remains in effect.

The MATS rule, as noted by EPA in its response to a GAO report, is expected to reduce SO_2 emissions by 1.5 million tons in 2017. The court challenges to MATS are on-going.

Regarding broader market conditions, important market drivers have been weighing on the viability of coal burning power plants. Key among these has been the recent decrease in the price of natural gas, which has made it more attractive for power companies to use natural gas instead of coal to generate electricity. Power plants that use natural gas instead of coal to produce electricity generally emit less NOx and SO2 per unit of electricity generated. Nevertheless, coal is likely to continue to be a key fuel source for electricity generation in the United States, although its share as a source of electricity is expected to decline.

Additionally, there have recently been key mobile source standards, like the 2010 Emissions Control Area and the 2011 Heavy Duty Vehicle GHG standards, which provide large reductions in both NOx and SOx from ocean-going ships and heavy-duty trucks, respectively. In addition, the proposed Tier 3 vehicle standards, which are scheduled to be proposed in 2013, would reduce SOx emissions from vehicles by 51% by 2030. Because vehicle emissions are only 3% of total SOx emissions, the reductions in Sulfate deposition would be minimal in the western Adirondacks.

The United States Government Accountability Office (GAO) was asked by members of Congress to examine EPA's efforts to address atmospheric deposition of pollutants that impair waterbodies. GAO found that:

> *"EPA has also sought to address atmospheric deposition through Clean Air Act (CAA) regulations but faces challenges in doing so. EPA issued regulations that reduced emissions of NOx, SO2, and mercury and in turn the amount of pollution in waterbodies. Even with reduced emissions, NOx, SO2, and mercury continue to pollute the nation's waterbodies. EPA's recent attempt to address atmospheric deposition by establishing secondary National Ambient Air Quality Standards (NAAQS)—standards to protect public welfare—targeting the effects of acid rain caused by NOx and SO2 on water bodies was not successful. EPA stated that uncertainty regarding atmospheric modeling and limitations in available data prevented determination of secondary NAAQS adequate to protect against the effects of acid rain, and the agency has not identified alternative strategies. EPA has begun a 5-year pilot program to gather additional scientific data, but it is unclear whether or when the agency will be able to address scientific uncertainties to enable adoption of a protective secondary NAAQS. EPA also did not set secondary NAAQS to address nutrient over-enrichment in aquatic ecosystems caused by NOx because of the limited available scientific data. Many sources of nitrogen can contribute to nutrient over-enrichment in a waterbody, including sources of nitrogen unrelated to atmospheric deposition. EPA recently announced an effort that is to lead to the development of an integrated nitrogen research strategy that includes approaches to reducing atmospheric deposition of NOx into waters impaired because of nutrient over-enrichment by nitrogen."*

GAO recommends that EPA determine whether EPA can obtain in a timely manner the data it needs to establish secondary NAAQS adequate to protect against the effects of acid rain and, if not, identify alternative strategies to do so. EPA agreed with GAO's recommendation.

Additionally, the adaptive/iterative nature TMDL implementation also influences the discussion of reasonable assurance. As noted below the emphasis on a monitoring component to measure actual water quality conditions, track the restoration of these waters and support model refinements provide additional assurance that water quality goals will eventually be achieved.

Blank page

9
Post-TMDL Monitoring

NYSDEC is committed to continuing the post-TMDL monitoring of all the 303(d) listed waters that was begun in 2007. All 303(d) listed waters will be monitored on an approximately 5-year rotation, subject to the availability of adequate funding and in compliance with NYSDEC management policies for the Adirondack Forest Preserve. Follow-up ambient water quality monitoring data will be used to periodically assess the recovery (or not) of acidified 303(d) listed waters resulting from state and federal programs to control anthropogenic sources of SO_2 and NO_x, thus reducing atmospheric deposition of acidifying substances to these acid-sensitive surface waters. Because the TMDL process is iterative, post-TMDL monitoring data are expected to provide much of the information necessary for updating and revising the current TMDL. In addition, we have included the New York State Energy Research and Development Authority's (NYSERDA) Research and Monitoring Plan for atmospheric deposition issues (Appendix 12); This Plan describes the priorities that NY has placed on funding these efforts. However, it should be noted that it is not possible with the present resources to fund every aspect of this Plan and that a more comprehensive approach would require additional federal funding from USEPA and other federal

10
Public Participation

Notice of availability of the Draft TMDL, Total Maximum Daily Load for Acid Impaired Lakes in the Adirondack Park, was made available to the public by publication in the DEC Region 5 and DEC Region 6 Environmental Notice Bulletin (ENB). The affected lakes are in these two DEC Regions. The Draft TMDL was public noticed August 13, 2014, and a 30-day public review period was established for soliciting written comments from stakeholders prior to the finalization and submission of the TMDL for USEPA approval. The ENB Notice read as follows:

"This notice announces the availability of a Draft total Maximum Daily Load (TMDL) document proposed by New York State Department of Environmental Conservation NYS DEC) to address the following waterbodies: ***89 Lakes of the Adirondack Park in New York State***

These Acid Lakes are impaired for the Acid Neutralizing Capacity resulting from the impairment effects of Acidification. The Draft TMDL document is available on the NYS DEC website at: http://dec.ny .gov/chemical/23835.html.

Background: States are required by Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (US EPA's) implementing regulations (40 CFR Part 130) to develop TMDL plans for waterbodies and pollutants where water quality standards are not being met. By definition, a TMDL specifies the allowable pollutant loading from all contributing sources (e.g., point sources, nonpoint sources, and natural background) at a level necessary to attain the applicable water quality standards with seasonal variations and a margin of safety that takes into account any lack of knowledge concerning the relationship between the sources of the pollutant and water quality. In essence, a TMDL defines the assimilative capacity of the waterbody to absorb a pollutant and still meet water quality standards.

The Acid Lakes Draft TMDL is based on New York collected data, a model developed by New York researchers, and a target point for Acid Neutralizing Capacity (ANC) prepared by the NYS DEC. The Draft TMDL addresses 89 lakes that the model predicts will attain the target by the year 2200. The model presumes continuation of the effect of the New York and interstate reductions of acidic depositions resulting from NOx and SOx reduction efforts already mandated.

Contact: Edward Anna, NYS DEC – Division of Water, 625 Broadway, 4th Floor, Albany, NY 12233, Phone: (518) 402-8245."

This comment period ended September 12, 2014 without any comments having been received.

11
References

Aber, J. D., and C. A. Federer. 1992. A Generalized, Lumped-Parameter Model of Photosynthesis, Evapotranspiration and Net Primary Production in Temperate and Boreal Forest Ecosystems. *Oecologia*, 92(4), 463-474, doi:10.1007/BF00317837.

Aber, J. D., and R. Freuder. 2000, Sensitivity of a forest production model to variation in solar radiation data sets for the eastern U. S. *Clim. Res.*, 15, 33– 43.

Aber, J.D., S. V. Ollinger, C. T. Driscoll, G. E. Likens, R.T. Holmes, R.J. Freuder, C.L. Goodale. 2002. Inorganic N losses from a forested ecosystem in response to physical, chemical, biotic and climatic perturbations. *Ecosystems* 5: 648–658.

Aber, J.D., C.T. Driscoll. 1997. Effects of land use, climate variation, and N deposition on N cycling and C storage in northern hardwood forests. *Global Biogeochemical Cycles* 11, 639–648.

Baker, J.P., W.J. Warren-Hicks, J. Galager, and S.W. Christensen. 1993. Fish population losses from the Adirondack lakes. *Water Resources Research* 29(4):861–874.

Battelle. 2006. *New York State Forest Preserve Lakes TMDL Support Document (DRAFT)*. EPA Contract Number 68-C-03-041. Duxbury, MA. February 2006.

Burns, D.A., M.R. McHale, C.T. Driscoll, and K.M. Roy. 2006. Response of Surface Water Chemistry to Reduced Levels of Acid Precipitation: Comparison of Trends in Two Regions of New York, USA. *Hydrological Processes* 20:1611–1627.

Campbell, J.L., L.E. Rustad, E.W. Boyer, S.F. Christopher, C.T. Driscoll, I.J. Fernandez,

P.M. Groff man, D. Houle, J. Kiekbusch, A.H. Magill, M.J. Mitchell, S.V. Ollinger,. 2009. Consequences of climate change for biogeochemical cycling in forests of northeastern North America. *Canadian Journal of Forest Research* 39: 264–284.

Charles, D.F. and J.P. Smol. 1988. New methods for using diatoms and chrysophytes to infer past pH of low-alkalinity lakes. *Limnology and Oceanography* 33:1451-1462.

Chen, L., and C. T. Driscoll. 2004. An evaluation of processes regulating spatial and temporal patterns in lake sulfate in the Adirondack region of New York. *Global Biogeochemical Cycles* 18:GB3024.

Chen, L., C. T. Driscoll, S. Gbondo-Tugbawa, M. J. Mitchell, and P. S. Murdoch. 2004. The application of an integrated biogeochemical model (PnET-BGC) to five forested watersheds in the Adirondack and Catskill regions of New York. *Hydrological Processes* 18:2631-2650.

Chen, L., and C.T. Driscoll. 2005a. Regional assessment of the response of the acid-base status of lake watersheds in the Adirondack region of New York to changes in atmospheric deposition using PnET-BGC. *Environmental Science and Technology* 39, 787– 794.

Chen, L., and C. T. Driscoll. 2005b. Strategies for emission controls to mitigate snowmelt acidification. *Geophysical Research Letters* 32:L20401, 4 pp

Church, M.R., K.W. Thorton, P.W. Shaffer, D.L. Stevens, B.P. Rochelle, R.G. Holdren, M.G. Johnson, J.J. Lee, R.S. Turner, D.L. Cassell, D.A. Lammers, W.G. Campbell, C.I. Liff, C.C. Brandt, L.H. Liegel, G.D. Bishop, D.C. Mortenson, and S.M. Pierson. 1989. Future effects of long-term sulfur deposition on surface water chemistry in the Northeast and Southern Blue Ridge Province (Results of the Direct/Delayed Response Project). U.S. Environmental Protection Agency Environmental Research Laboratory, Corvallis, OR.

Civerolo, K., O. Rattigan, and D. Felton, Long-term wet deposition, particulate, and gas-phase sulfur and nitrogen measurements in New York State, Fall 2012 NADP Annual Meeting and Scientific Symposium *The NADP Cooperative: State, Local, and Tribal Perspectives*, South Portland, ME, October, 2012.

DePinto, J.V., P. Selvendiran, and C.T., Driscoll. 2012. Technical Memorandum "*Comparison of PWM/PHREEQC and PnET-BGC model frameworks and recommendation for proceeding with the Adirondack Lake TMDL analysis*". LimnoTech, April 11, 2012.

Doiron, S., L. Bernatchez, P. Blier. 2002. A comparative mitogenomic analysis of the potential adaptive value of arctic char mtDNA introgression in brook char populations (Salvelinus fontinalis Mitchill). *Mol. Biol. Evol.* 19(11) 1902-1909.

Driscoll, C.T. and R.M. Newton. 1985. Chemical Characteristics of Adirondack Lakes. *Environmental Science and Technology* 19:1018–1024.

Driscoll, C.T., R.M. Newton, C.P. Gubala, J.P. Baker, and S.W. Christensen. 1991. Adirondack Mountains in *Acidic Deposition and Aquatic Ecosystems: Regional Case Studies*. Charles, D.F. (ed.). New York: Springer-Verlag. pp. 133–202.

Driscoll, C.T., M.D. Lehtinen, and T. J. Sullivan. 1994. Modeling the acid-base chemistry of organic solutes in Adirondack, NY, lakes. *Water Resources Research* 30:297-306.

Driscoll, C.T., K.M. Postek, D. Mateti, K. Sequeira, J.D. Aber, W.J. Krester, M.J. Mitchell, and D.J. Raynal. 1998. The response of lake water in the Adirondack region of New York to changes in acidic deposition. *Environmental Science and Policy* 1:185–198.

Driscoll, C.T., G.B. Lawrence, A.J. Bulger, T.J. Butler, C.S. Cronan, C. Eagar, K.F. Lambert, G.E. Likens, J.L. Stoddard, and K.C. Weathers.2001b. Acidic Deposition in the Northeastern United States: Sources and Inputs, Ecosystem Effects, and Management Strategies. *BioScience*, 51(3), 180-198.

Driscoll, C.T., K.M. Driscoll, K.M. Roy, and M.J. Mitchell. 2003. Chemical response of lakes in the Adirondack region of New York to declines in Acidic deposition. Environmental Science and Technology 37:2036–2042.

Driscoll, C.T., K.M. Driscoll, K.M. Roy, and J. Dukett. 2007. Changes in the chemistry of lakes in the Adirondack Region of New York following declines in acidic deposition. *Applied Geochemistry* 22:1181–1188.

Evers, D.C., Y.-J. Han, C.T. Driscoll, N.C. Kamman, W.M. Goodale, K.F. Lambert, T.M. Holsen, C.Y. Chen, T.A. Clair, and T.J. Butler. 2007. Biological mercury hotspots in the Northeastern United States and Southeastern Canada. *BioScience,* 57:1-15.

Gbondo-Tugbawa, S.S., C.T. Driscoll, J.D. Aber, G.E. Likens. 2001. Evaluation of an integrated biogeochemical model (PnET-BGC) at a northern hardwood forest ecosystem. *Water Resources Research* 37 (4), 1057–1070.

Gbondo-Tugbawa, S.S., and C.T. Driscoll. 2002a. Evaluation of the effects of future controls on sulfur dioxide and nitrogen oxide emissions on the acid-base status of a northern forest ecosystem. *Atmospheric Environment* 36:1631-1643.

Gbondo-Tugbawa, S.S., and C.T. Driscoll. 2002b. Retrospective analysis of the response of soil and stream chemistry of a northern forest ecosystem to atmospheric emission controls from the 1970 and 1990 Amendments of the Clean Air Act. *Environmental Science and Technology* 36:4714-4720.

Gbondo-Tugbawa, S.S., C.T. Driscoll, M.J. Mitchell, J.D. Aber, and G.E. Likens. 2002c. A model to simulate the response of a northern hardwood forest ecosystem to changes in S deposition. *Ecol. Appl.*, 12, 8– 23.

Gbondo-Tugbawa, S.S., C.T. Driscoll. 2003. Factors controlling long-term changes in soil pools of exchangeable basic cations and stream acid neutralizing capacity in a northern Harwood forest ecosystem. *Biogeochemistry* 63, 161–185.

Ito, M., M.J. Mitchell, and C.T. Driscoll. 2002. Spatial patterns of precipitation quantity and chemistry and air temperature in the Adirondack region of New York. *Atmos. Environ*., 36, 1051– 1062.

Jenkins, J., K. Roy, C. Driscoll, and C. Buerkett. 2005. *Acid Rain and the Adirondacks: A Research Summary*. Ray Brook, New York: Adirondacks Lakes Survey Corporation.

Kelly, C.A., J.W.M. Rudd, R.H. Hesslein, D.W. Schindler, P.J. Dillon, C.T. Driscoll, S.A. Gherini, and R.E. Hecky. 1987. Prediction of biological acid neutralization in acid sensitive lakes. *Biogeochemistry* 3:129–140.

Kelly, C.A., J.W.M. Rudd, and D.W. Schindler. 1990. Acidification by nitric-acid – Future considerations. *Water, Air and Soil Pollution* 50(1-2):49-61.

Lawrence, G.B., J.W. Sutherland, C.W. Boylen, S.A. Nierzwicki-Bauer, B. Momen, B. P. Baldigo, and H.A. Simonin. 2007. Acid rain effects on aluminum mobilization clarified by inclusion of strong organic acids." *Environmental Science and Technology* 41:93–98.

Lydersen, E., T. Larssen, E. Fjeld. The influence of total organic carbon (TOC) on the relationship between acid neutralizing capacity (ANC) and fish status in Norwegian lakes. *Sci. Total Environ*. 2004, 326, 63–69.

Minnesota Pollution Control Agency (MPCA). 2007. Minnesota Statewide Mercury Total Maximum Daily Load. Minnesota Pollution Control Agency. March 27, 2007. http://www.pca.state.mn.us/index.php/view-document.html?gid=8507

Momen B., G.B. Lawrence, S.A. Nierzwicki-Bauer, J.W. Sutherland, L. Eichler, J.P. Harrison, and C.W. Boylen. 2006. Trends in summer chemistry linked to productivity in lakes recovering from acid deposition in the Adirondack Region of New York. *Ecosystems* 9:1306–1317.

National Acid Precipitation Assessment Program [NAPAP]. 2005. National acid precipitation assessment program report to Congress: An integrated assessment. Silver Spring, MD: NAPAP Committee on Environment and Natural Resources (CENR) of the National Science and Technology Council (NSTC). http://www.esrl.noaa.gov/csd/aqrs/reports/napapreport05.pdf.

National Acid Precipitation Assessment [NAPA] Program. 2011. *National Acid Precipitation Assessment Program Report to Congress 2011: An Integrated Assessment.*

New England Interstate Water Pollution Control Commission (NEIWPCC). 2007. *Northeast Regional Mercury Total Maximum Daily Load*. October 2007.

New York Department of Environmental Conservation. 2006. *Impaired Waters Restoration Plan for Acid Rain Lakes (NYS Forest Preserve) Adirondack Region, New York and Proposed Total Maximum Daily Load (TMDL) for pH/Acid Rain Impacts.*

New York Department of Environmental Conservation. 2013. *New York State Aquatic Fact Sheet Ambient Water Quality Value for Protection of Aquatic Life.* Draft. January 10, 2013.

Ollinger, S.V., J.D. Aber, G.M. Lovett, S.E. Millham, R.G. Lathrop, and J.M. Ellis. 1993. A spatial model of atmospheric deposition for the northeastern U.S. *Ecol. Appl.*, 3, 459–472.

Pourmokhtarian, A., C.T. Driscoll, J.L. Campbell, and K. Hayhoe. 2012. Modeling potential hydrochemical responses to climate change and increasing CO2 at the Hubbard Brook Experimental Forest using a dynamic biogeochemical model (PnET-BGC), Water Resour. Res., 48, W07514, doi:10.1029/2011WR011228.

Roy, K.M., C. Driscoll, and C. Buerkett. 2005. *Acid Rain and the Adirondacks: A Research Summary*. Ray Brook, New York: Adirondacks Lakes Survey Corporation.

Scott, W.B., and E.J. Crossman. 1973. Freshwater Fishes of Canada. Bulletin 184. Fisheries Research Board of Canada 1973. 966 pp.

Shepard, J.P., M.J. Mitchell, T.J. Scott, Y.M. Zhang, and D.J. Raynal. 1989. Measurements of wet and dry deposition in a northern hardwood forest. *Water Air Soil Pollut*., 48, 225– 238.

Snyder, P. Chemist, Adirondack Lake Survey Corporation, Ray Brook, NY. Personal Communication to Howard Simonin. As cited in NYSDEC 2006.

Stoddard, J., J. Kahl, F. Deviney, D. DeWalle, C. Driscoll, A. Herlihy, J. Kellogg, P. Murdoch, J. Webb, and K. Webster. 2003. *Response of Surface Water Chemistry to the Clean Air Act Amendments of 1990*. Research Triangle Park, NC: U.S. Environmental Protection Agency.

Sullivan TJ, Charles DF, Smol JP, Cumming BF, Selle AR, Thomas DR, Bernert JA, Dixit SS (1990) Quantification of changes in lakewater chemistry in response to acidic deposition. Nature 345:54-58.

Sullivan, T.J., C.T. Driscoll, B.J. Cosby, I.J. Fernandez, A.T. Herlihy, J. Zhai, R. Stemberger, K.U. Snyder, J.W. Sutherland, S.A. Nierzwicki-Bauer, C.W. Boylen, T.C. McDonnell, and N.A. Nowicki. 2006. *Assessment of the Extent to Which Intensively Studied Lakes Are Representative of the Adirondack Mountain Region*. Albany, NY: New York State Energy Research and Development Authority.

Thornton, K., D. Marmorek, P. Ryan. 1990. State-of-Science/ Technology Report 14. National Acid Precipitation Assessment Program.

U.S.EPA, 1991. Guidance for Water Quality-based Decisions: The TMDL Process. EPA 440/4-91-001. Office of Water, Washington, DC.

U.S. EPA. 2003. *Response of Surface Water Chemistry to the Clean Air Act Amendments of 1990*. EPA 620/R-03/001, Research Triangle Park, NC.

U.S. EPA. 2008a. *Integrated Science Assessment for Oxides of Nitrogen and Sulfur – Environmental Criteria*. EPA/600/R-08/082F.

U.S. EPA. 2008b. TMDLs Where Mercury Loadings Are Predominantly From Air Deposition. http://www.epa.gov/owow/tmdl/pdf/document_mercury_tmdl_elements.pdf.

U.S. Government Accounting Office. 2013. Water Quality: *EPA Faces Challenges in Addressing Damage Caused by Airborne Pollutants*. GAO 13-39, January 2013.

van Breeman N., C.T. Driscoll, and J. Mudler. 1984. "Acidic Deposition and Internal Proton Sources in Acidification of Soils and Waters." *Nature* 307:599–604.

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

Warby, R.A.F., C.E. Johnson, and C.T. Driscoll. 2005. Chemical Recovery of Surface Waters across the Northeastern United States from Reduced Inputs of Acidic Deposition: 1984–2001. *Environmental Science and Technology,* 39(17):6548–6554.

Warby R.A.F., C.E. Johnson, and C.T. Driscoll. 2009. Continuing Acidification of Organic Soils across the Northeastern USA: 1984–2001. *Soil Science Society of America Journal*, 73:274–284.

Wu, W., and C.T. Driscoll. 2009. Application of PnET-BGC - an integrated biogeochemical model - to assess the surface water ANC recovery at Adirondacks under three multi-pollutant proposals. *Journal of Hydrology*. 378: 299 – 312.

Wu, W., and C.T. Driscoll. 2010. Impact of Climate Change on Three-Dimensional Dynamics Critical Load Functions. *Environmental Science and Technology*, 44: 720 – 726.

Yu, X., C.T. Driscoll, M. Montesdeoca, D. Evers, M. Duron, K. Williams, N. Schoch, and N.C. Kamman. 2011. Spatial patterns of mercury in biota of Adirondack, New York lakes. *Ecotoxicology*, 20:1543-1554.

Zhai, J, C.T. Driscoll, T.J. Sullivan, and B.J. Cosby. 2008. "Regional application of the PnET-BGC model to assess historical acidification of Adirondack Lakes." *Water Resources Research* 44 doi:10.1029/2006WR005532.