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# Linking Air Quality and Watershed Management Models:

# Handout to EPA Integrated Nitrogen Committee

Eladio Knipping

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Krish Vijayaraghavan, Christian Seigneur, Atmospheric & Environmental Research, Inc.
Joel Herr and Carl Chen, Systech Engineering, Inc.
Robert Goldstein and Eladio Knipping, Electric Power Research Institute

# Assessment Tools for Multimedia Linkages

feature

# Linking Air, Land, and Water Pollution for Effective Environmental Management

Since the passage of the National Environmental Policy Act in 1970, the U.S. Environmental Protection Agency (EPA), other federal agencies, and the states have made substantial progress in improving the nation's air and water quality. Traditionally, air, land, and water pollution control programs are managed independently of one another due, in part, to differing funding allocations and separate sets of rules and regulations. Even in a single-medium management paradigm, air programs have been addressing one pollutant at a time. Recognizing the complex interplay between meteorology and atmospheric chemistry, air quality managers are now beginning to pay attention to the development of multipollutant strategies under the "one-atmosphere" concept.

**Air quality managers are now beginning to pay attention to the development of multipollutant strategies under the "one-atmosphere" concept.**

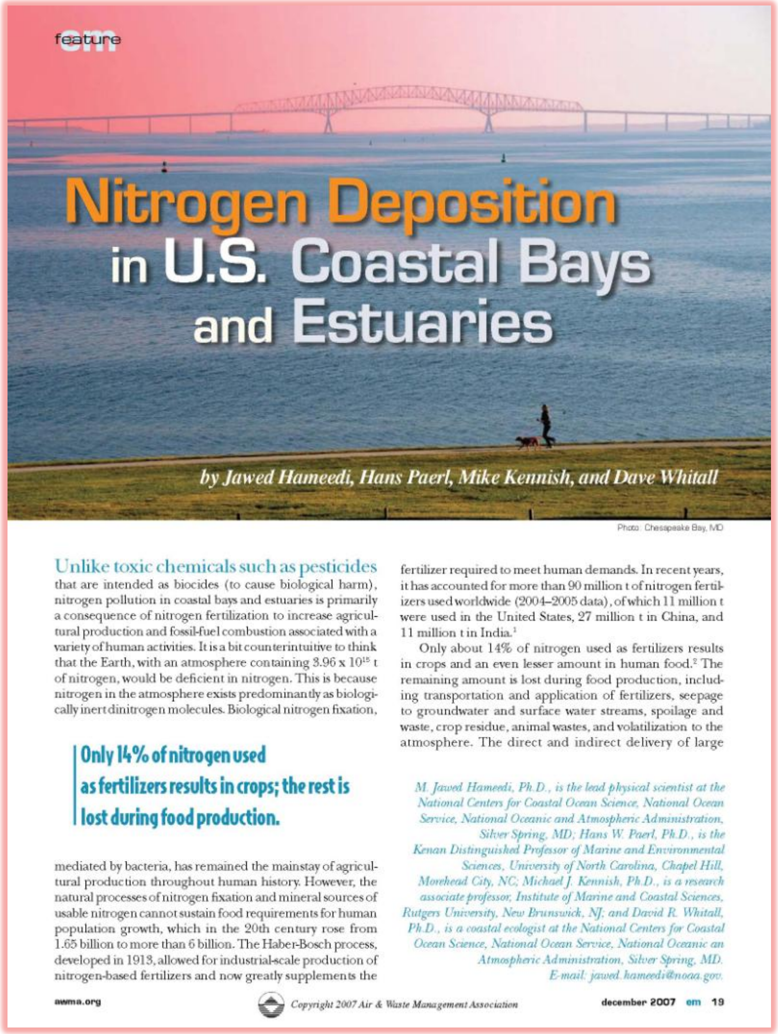
It is increasingly evident that air pollution control programs aimed at addressing issues such as acid rain, ozone, and fine particulate matter can also provide significant benefits to water quality. For example, reductions in nitrogen oxide emissions have helped reduce nitrogen eutrophication in coastal waters, while controls on mercury emissions into the atmosphere help reduce methylmercury concentrations in fish and wildlife.

Atmospheric deposition is the natural physical process by which airborne contaminants leave the atmosphere and are transferred to the land and water, contributing to multi-media pollution problems. Hence, policies dealing with excess greenhouse gases, nitrogen, sulfur, mercury, and other contaminants in the atmosphere must also consider multimedia issues to maximize the benefits of environmental regulations.

The articles that follow in this issue of *EM* discuss the need for integrated assessments of air, land, and water pollution and the resulting challenges confronting environmental managers. It should be noted that the views expressed in these articles do not necessarily reflect the views and policies of the U.S. Environmental Protection Agency, the National Oceanic and Atmospheric Administration, or any federal agency. em

*by S.T. Rao, Ph.D.*
*Director, Atmospheric Modeling Division*
*National Exposure Research Laboratory*
*U.S. Environmental Protection Agency;*
*and Director, Atmospheric Sciences Modeling Division*
*National Oceanic and Atmospheric Administration*
*E-mail: rao.st@epa.gov*



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# Nitrogen Deposition in U.S. Coastal Bays and Estuaries

*by Jawed Hameedi, Hans Paerl, Mike Kennish, and Dave Whitall*

Photo: Chesapeake Bay, MD

Unlike toxic chemicals such as pesticides that are intended as biocides (to cause biological harm), nitrogen pollution in coastal bays and estuaries is primarily a consequence of nitrogen fertilization to increase agricultural production and fossil-fuel combustion associated with a variety of human activities. It is a bit counterintuitive to think that the Earth, with an atmosphere containing $3.96 \times 10^{15}$ t of nitrogen, would be deficient in nitrogen. This is because nitrogen in the atmosphere exists predominantly as biologically inert dinitrogen molecules. Biological nitrogen fixation, mediated by bacteria, has remained the mainstay of agricultural production throughout human history. However, the natural processes of nitrogen fixation and mineral sources of usable nitrogen cannot sustain food requirements for human population growth, which in the 20th century rose from 1.65 billion to more than 6 billion. The Haber-Bosch process, developed in 1913, allowed for industrial-scale production of nitrogen-based fertilizers and now greatly supplements the fertilizer required to meet human demands. In recent years, it has accounted for more than 90 million t of nitrogen fertilizers used worldwide (2004–2005 data), of which 11 million t were used in the United States, 27 million t in China, and 11 million t in India.[1]

**Only 14% of nitrogen used as fertilizers results in crops; the rest is lost during food production.**

Only about 14% of nitrogen used as fertilizers results in crops and an even lesser amount in human food.[2] The remaining amount is lost during food production, including transportation and application of fertilizers, seepage to groundwater and surface water streams, spoilage and waste, crop residue, animal wastes, and volatilization to the atmosphere. The direct and indirect delivery of large

*M. Jawed Hameedi, Ph.D., is the lead physical scientist at the National Centers for Coastal Ocean Science, National Ocean Service, National Oceanic and Atmospheric Administration, Silver Spring, MD; Hans W. Paerl, Ph.D., is the Kenan Distinguished Professor of Marine and Environmental Sciences, University of North Carolina, Chapel Hill, Morehead City, NC; Michael J. Kennish, Ph.D., is a research associate professor, Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, NJ; and David R. Whitall, Ph.D., is a coastal ecologist at the National Centers for Coastal Ocean Science, National Ocean Service, National Oceanic an Atmospheric Administration, Silver Spring, MD. E-mail: jawed.hameedi@noaa.gov.*

  





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# Significance of Linkage between Air and Watershed Models

- Integrated Modeling Systems
- Multi-pollutant framework
- Effect of atmospheric loadings on water quality
- Comprehensive source attribution
- TMDL and critical load analysis and ecosystem management

# NARSTO 2008 Assessment

- **Technical Challenges of Applying Accountability-Based Air Quality Management with a Multi-Pollutant Framework**
  - Assess the technical challenges of implementing **“accountability”** within a multi-pollutant framework
  - Integrated multi-pollutant approach to controlling emissions that pose the most significant risks
  - The discussion of “Integrated Modeling Systems” is a key feature of this assessment.
  - Assessment is ongoing; due in 2008

# EPA's Watershed Deposition Tool (WDT)

- **Watershed Deposition Tool (WDT)**
  - Recent air/water linkage efforts by EPA
  - Released by the Atmospheric Sciences Modeling Division in September 2007

- Maps post-processed gridded deposition estimates from CMAQ to 8-digit HUCs within a watershed or region. **Static tool.**

- Deposition components:
  - Total Nitrogen: Dry and Wet; Oxidized and Reduced
  - Total Sulfur: Dry and Wet
  - Total Mercury: Dry and Wet

- CMAQ 3-Year averages (2001-2003) for nitrogen and sulfur and 1-Year (2001) for mercury currently available

# Air and Watershed Models Selected for Linkage in this Study

- **AMSTERDAM (a.k.a. CMAQ-MADRID-APT-Hg)**
  - **Advanced Modeling System for Transport, Emissions, Reactions and Deposition of Atmospheric Matter**
  - 3-D Eulerian air quality model to simulate ozone, PM, and the deposition of mercury and acidic and nitrogenous compounds
  - Hourly outputs of air concentrations and wet and dry deposition fluxes

- **WARMF**
  - **Watershed Analysis Risk Management Framework**
  - Decision support system for watershed planning and TMDL analysis

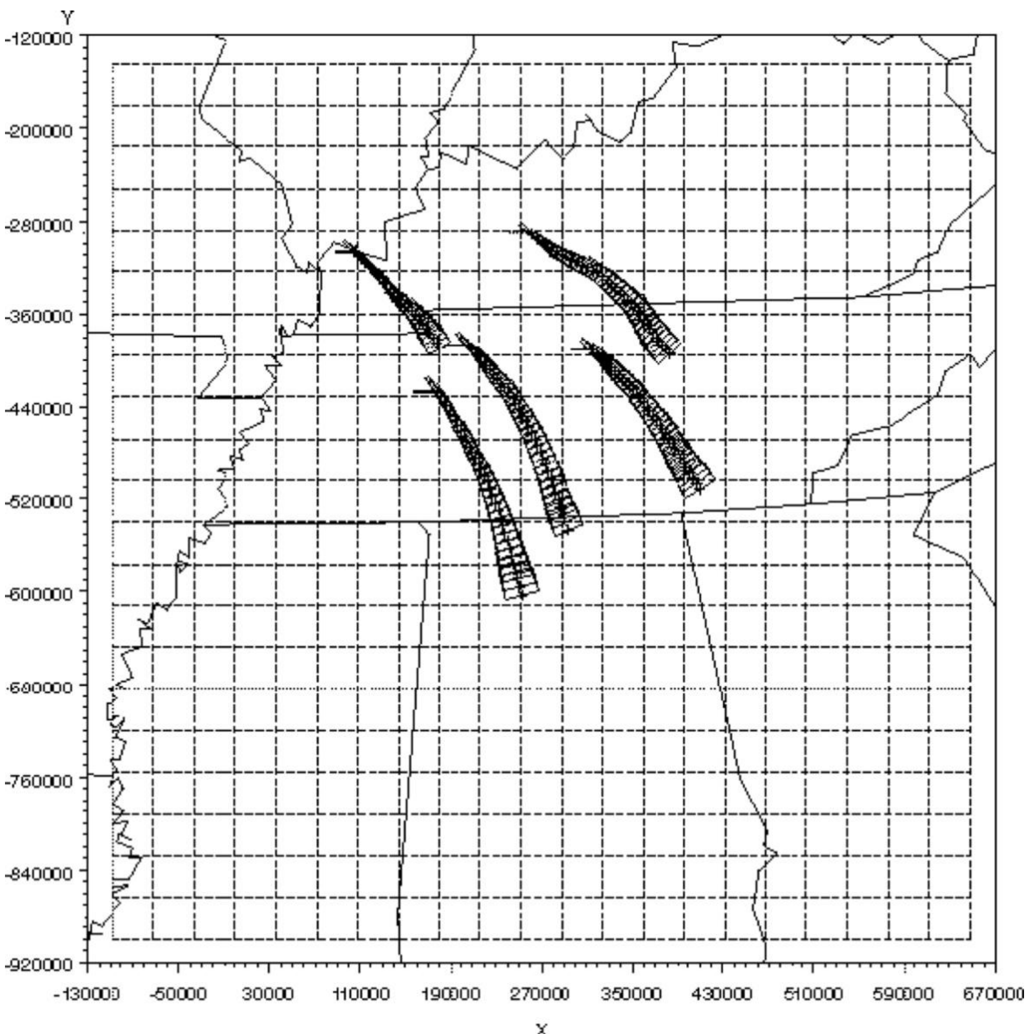
- Aim to synergize the capabilities of these two unique modeling systems developed separately under EPRI sponsorship into one dynamic system.

# AMSTERDAM Overview

- State-of-the-science 3-D Eulerian air quality model to simulate ozone, PM, and the deposition of mercury and acidic and nitrogenous compounds
- Advanced plume treatment of plumes from selected point sources such as power plant stacks (plume-in-grid modeling)
- Available at www.cmascenter.org

# AMSTERDAM Overview
# Importance of Plume-in-grid Modeling

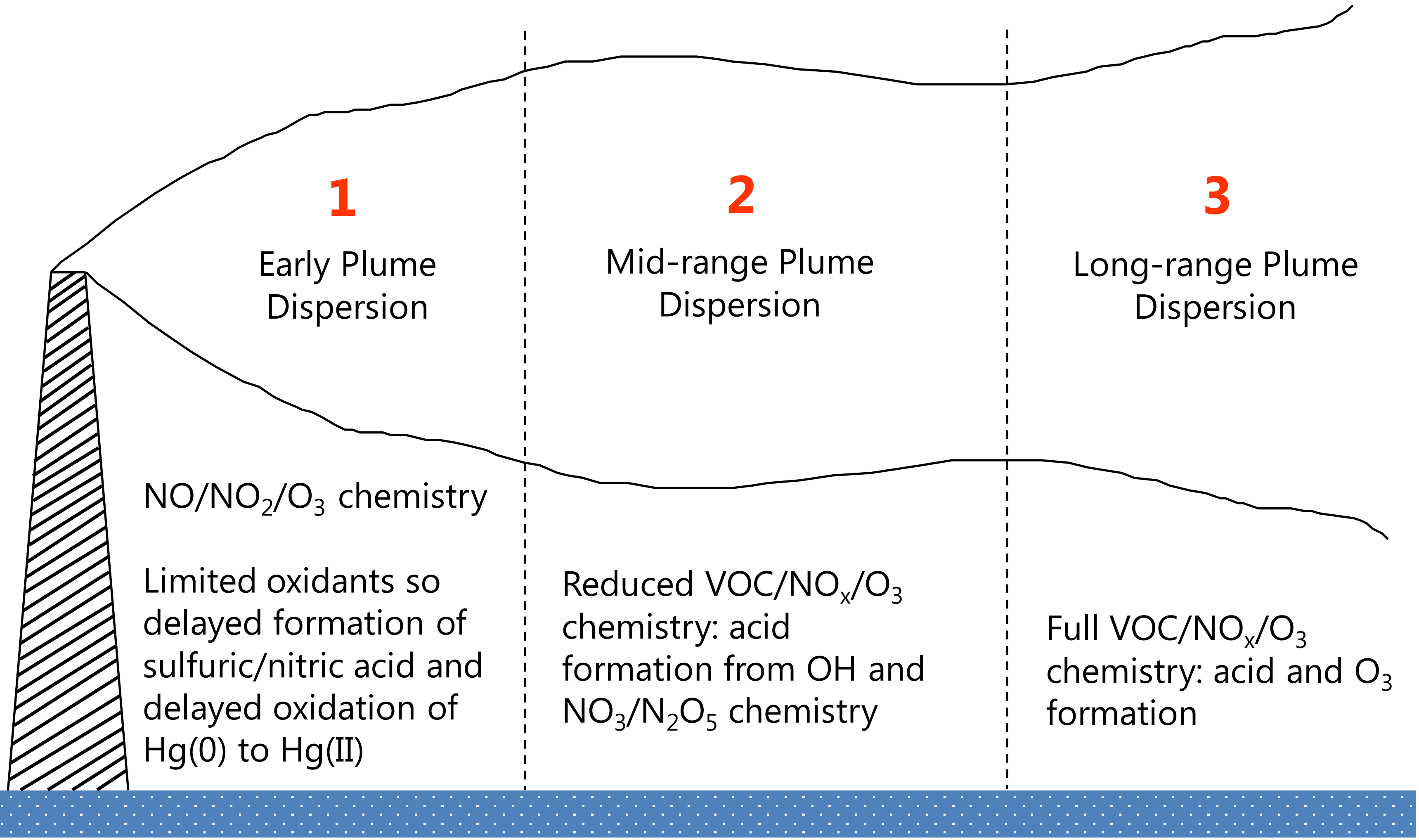
Plume Size vs Grid Size (from Godowitch, 2004)




## Limitations of Purely Grid-Based Approach

- Artificial dilution of stack emissions
- Unrealistic near-stack plume concentrations
- Incorrect representation of plume chemistry
- Incorrect representation of plume transport

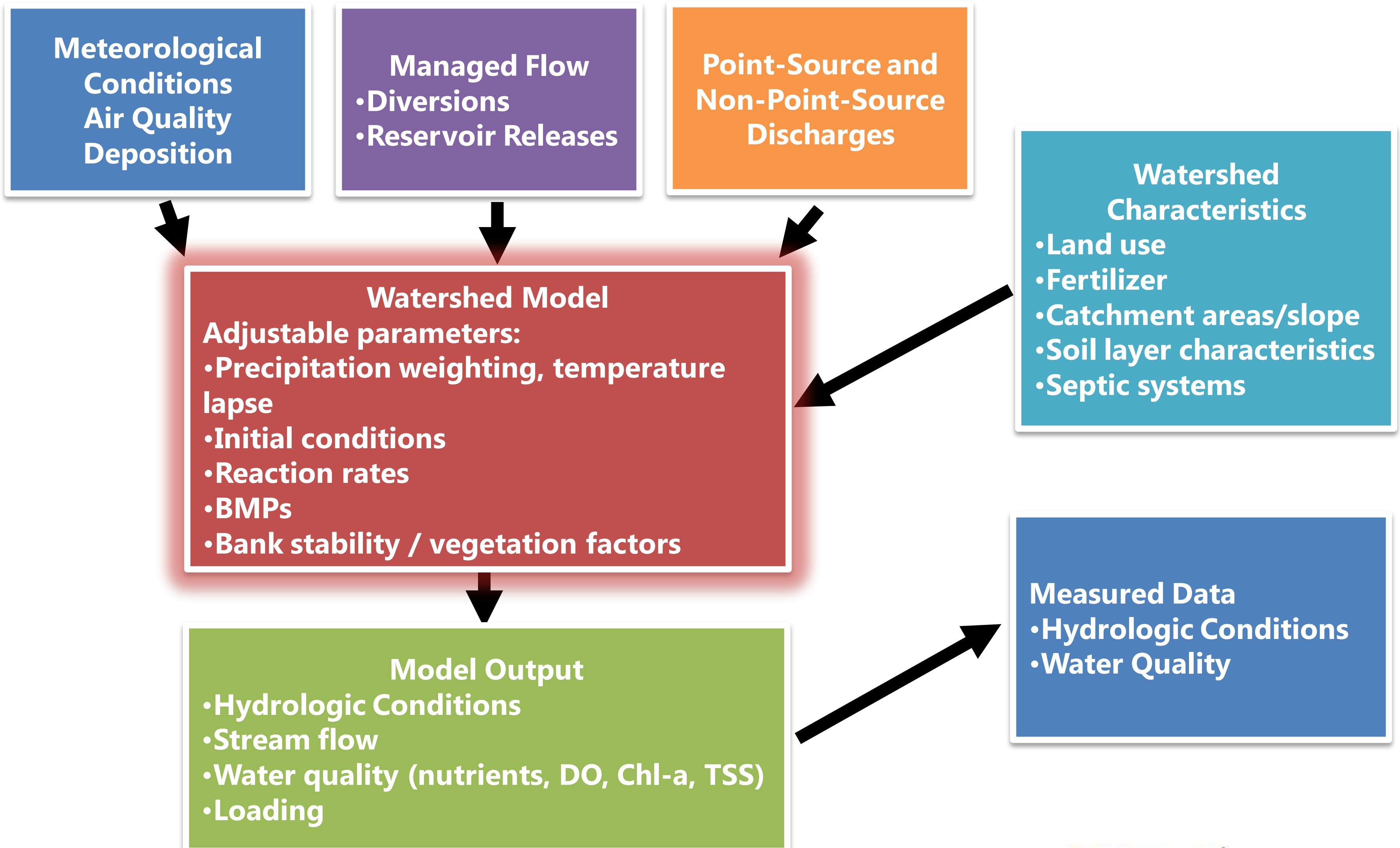
# Plume Chemistry and Relevance to Modeling of Nitrogen, Sulfur and Mercury Species



# WARMF Overview

- Comprehensive mechanistic watershed model, simulates flow, temperature, pH, nutrients, ions, sediment, algae, dissolved oxygen
- Divides watershed into land catchments, river segments, reservoirs
- Driven by meteorology, rain chemistry, gaseous and particulate concentrations in air

# Summary of the WARMF Watershed Model





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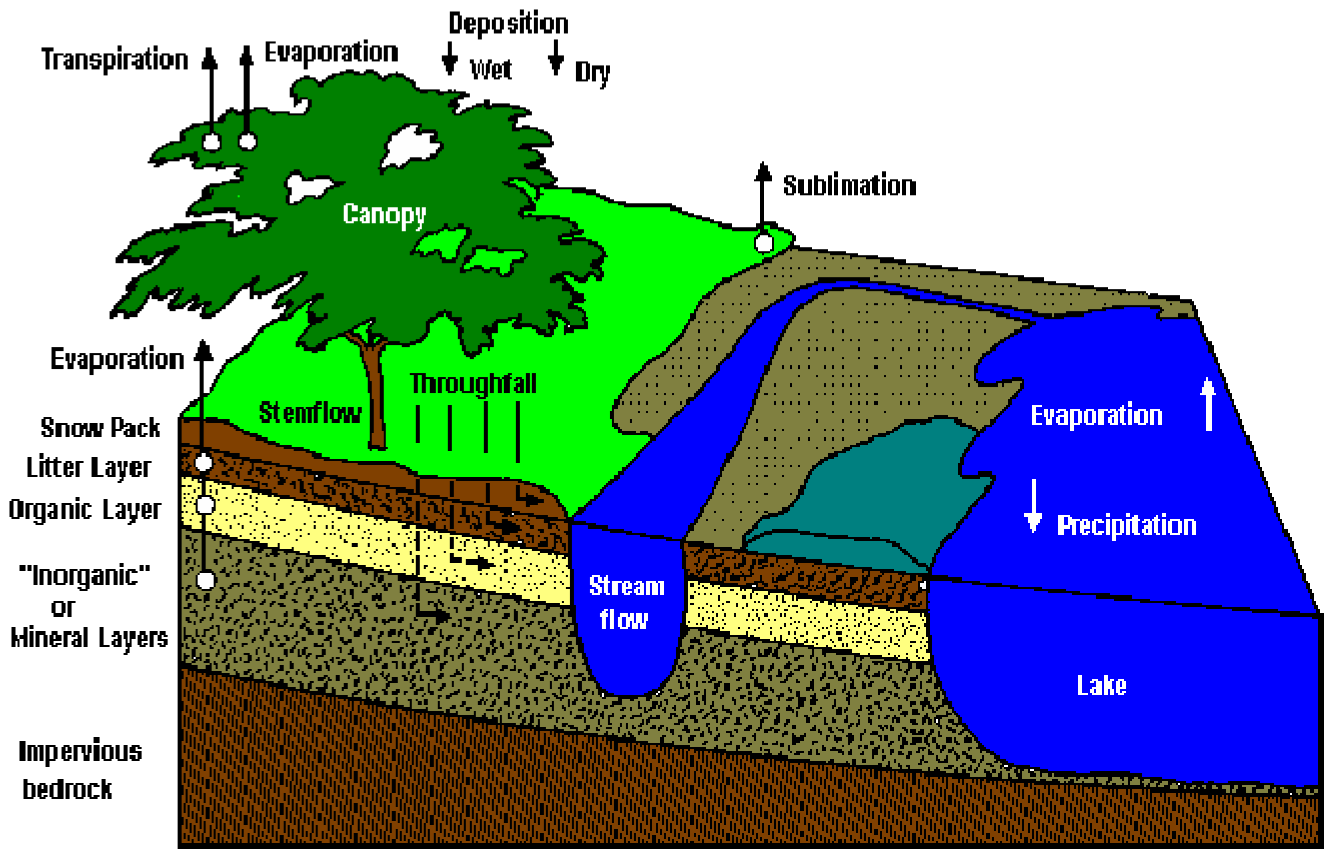
# Watershed Processes

**Subsurface Processes**

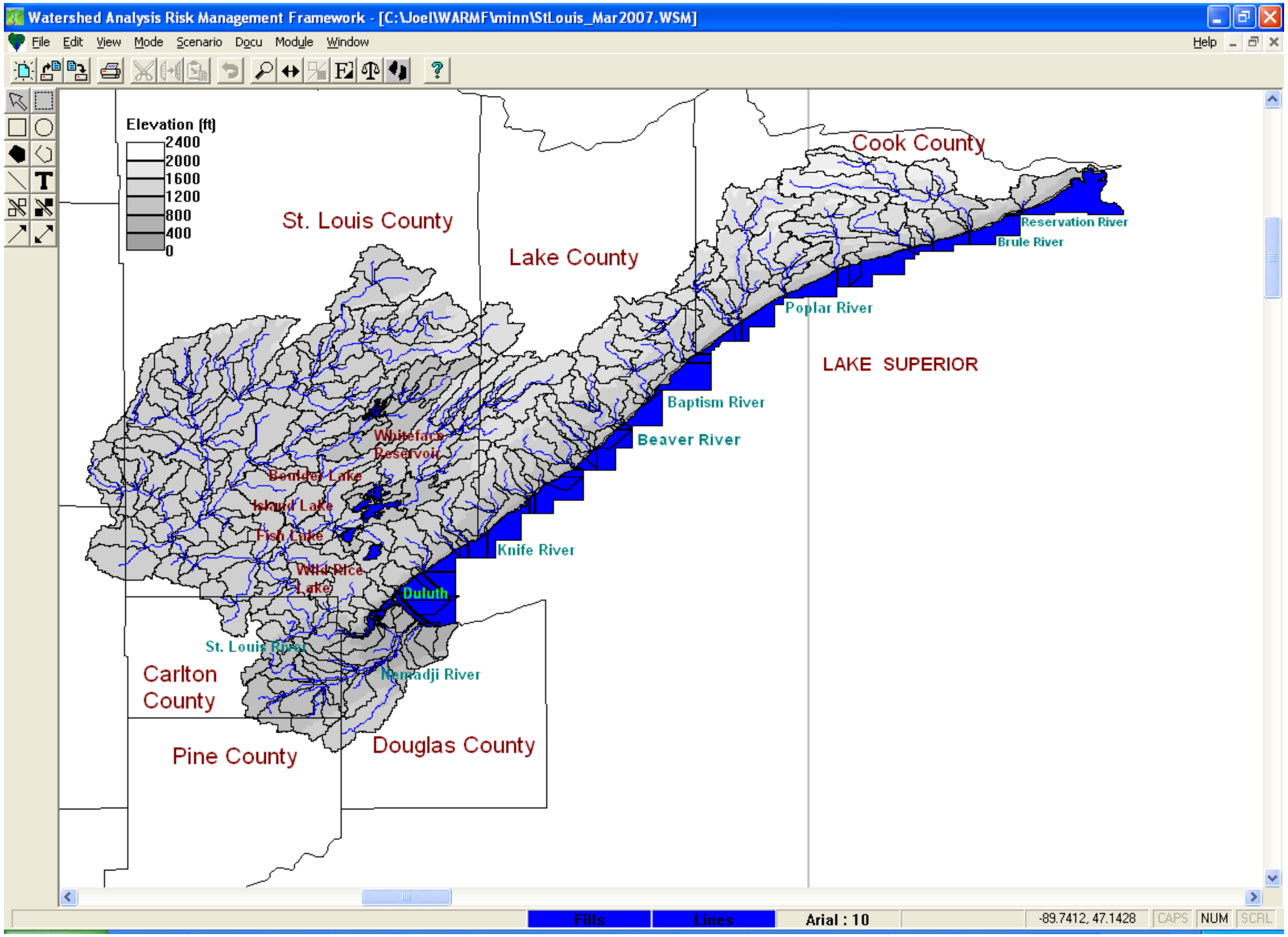
Mineral Weathering
AMD
Septic Systems
Organic Matter
Decay
Nitrification
Cation Exchange
Plant Uptake



# Descriptive Processes

- **Hydrology:** snow accumulation, snow melt, infiltration to soil, groundwater table, seepage to stream, flow routing in river, hydrodynamics of stratified lake.
- **Canopy:** wet deposition, dry deposition, throughfall, litter fall.
- **Soil:** weathering, organic matter decay, competitive cation exchange, etc.
- **River and lake:** fate and transport of pollutants, temperature, DO, nutrients, bioaccumulation of mercury in fish

# Interactive Watershed Map





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# Data Requirements of WARMF

- Topographic data (DEM) to delineate a watershed into catchments, rivers, lakes

- Site specific data
  - Land Use, Meteorology, Air Quality, Rain Chemistry, Point Sources, Managed Flow (diversions & releases), Observed Flow and Water Quality Data

- Model Outputs
  - Time series of state variables, i.e. pollutant concentrations of each CSTR
  - GIS maps with bar charts for pollution loads from various sub regions
  - Color coded GIS maps showing areas meeting or violating criteria
  - Annual fluxes between compartments



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# Peer Review

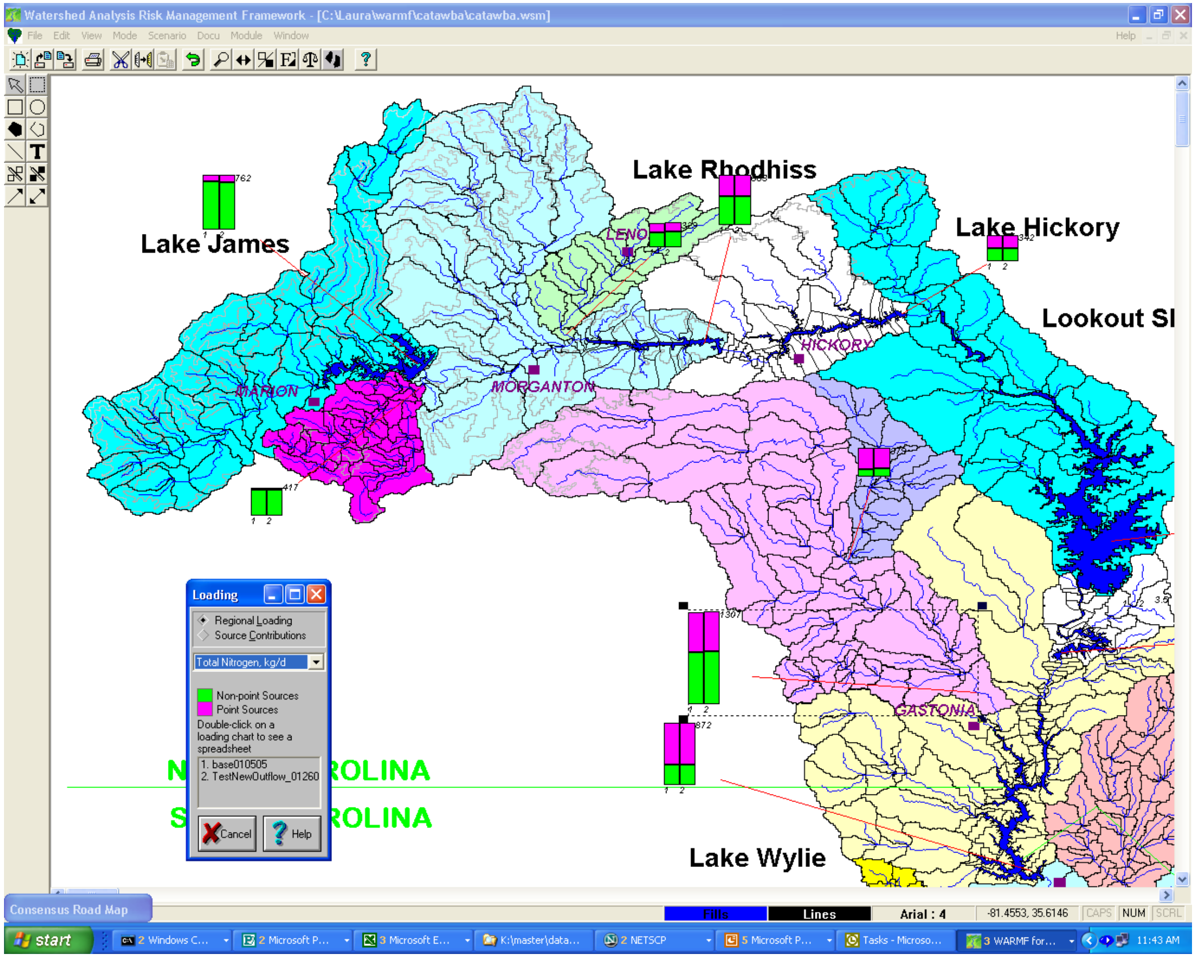
- Solicited by U.S. EPA and Followed EPA Guidelines

- Peer Reviews
  1. General Purpose Use and TMDLs: August 2000
  2. Acid Mine Drainage: July 2001
  3. Onsite Wastewater (Septic) Systems: May 2003
  4. Mercury Transport: March 2004

- Reviewers included Local / National Experts
  - EPA regional and headquarters
  - State WQ agencies
  - Research institutes and universities
  - Electric utilities and stakeholders

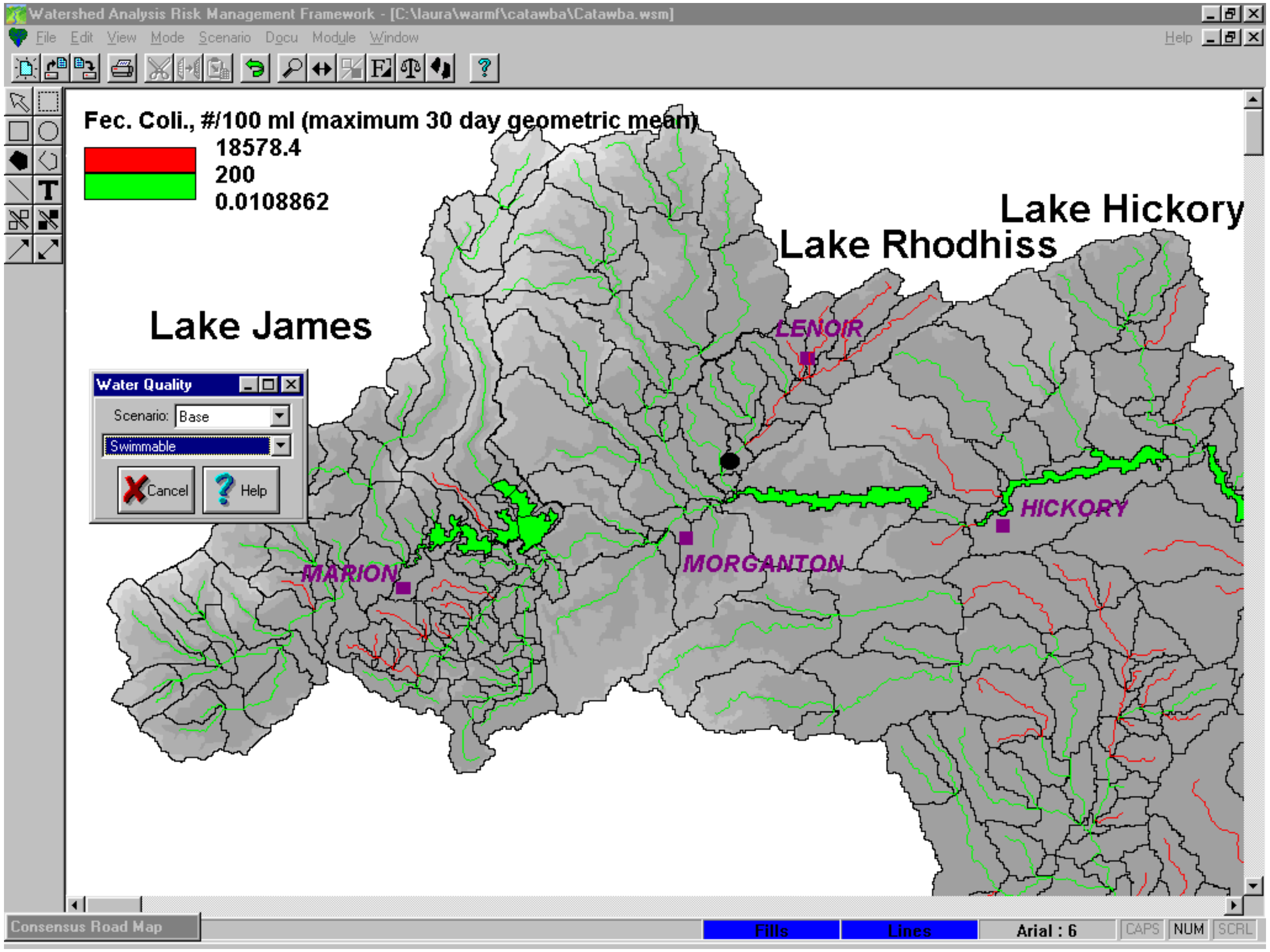
- **WARMF modified to incorporate reviewer recommendations**

# GIS Bar Charts to Show Sources of Pollutants




Systech Engineering, Inc

# GIS Map to Display WQ Violations





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# WARMF Applications


International:
Kyungan River, Korea
Techi Reservoir, Taiwan

# Components of the Interface

**AMSTERDAM**

**Linkages**

- Common Meteorology
- Spatial and Temporal Mapping
- Air Concentrations
- Wet Deposition
- Dry Deposition

**WARMF**

# Atmospheric Species of Interest in Ecosystem Modeling

- **Acidification of soils and water bodies**
  - Acidic species (sulfate, nitrate, chloride)
  - Neutralizing species (Na, K, Mg, Ca)
  - Complex impact of NHx

- **Eutrophication**
  - Nitrogenous species (NOx, nitrous and nitric acids, nitrate, organic nitrogen, ammonia, ammonium)
  - Phosphorus (atmospheric deposition << direct discharges)

- **Bioaccumulation**
  - Mercury species; other metals
  - Persistent organic pollutants (POPs)
  - Complex impact of nutrients

- **Ozone damage to plants**

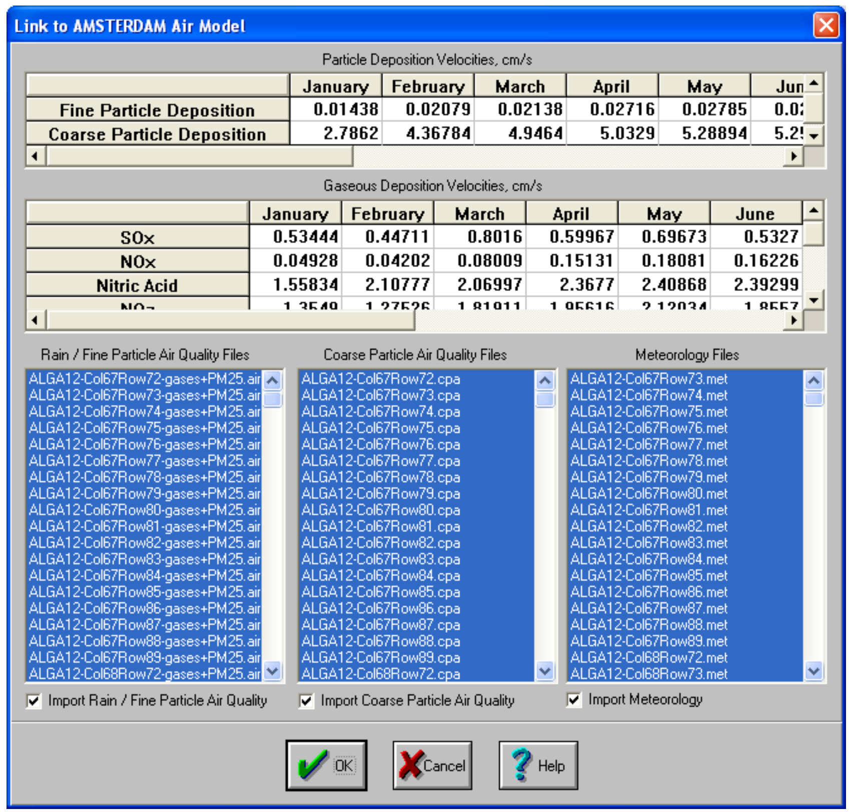
# Testing the Linkage

- AMSTERDAM output from two scenarios:
  - 2002 Base scenario
  - "Beyond 2009" $NO_x/SO_2/Hg$ future-year scenario

- Catawba watershed

# Modifications to WARMF

Linkage function to import all AMSTERDAM output and MCIP meteorology





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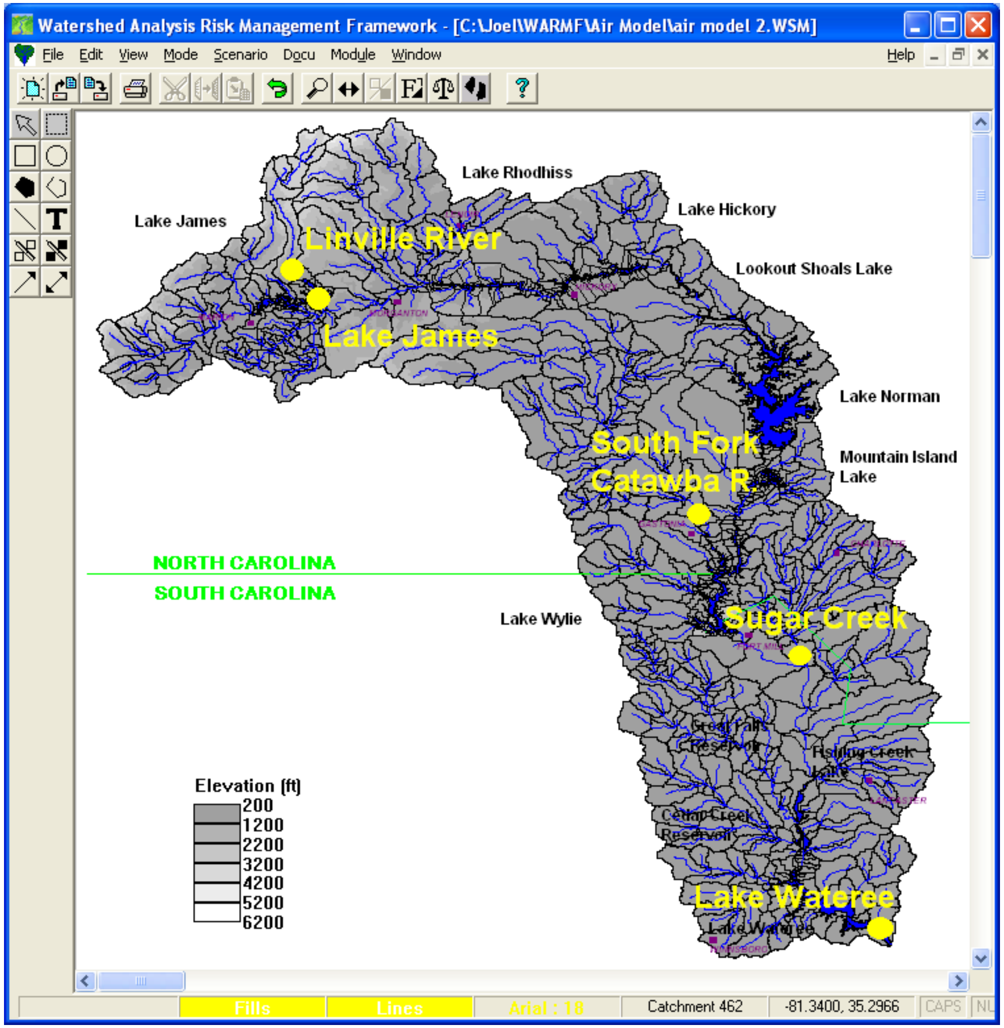
# WARMF Testing Locations





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# Watersheds of Testing Locations

| Land Use | Linville River | Lake James | South Fork Catawba R. | Sugar Creek | Lake Wateree |
|---|---|---|---|---|---|
| Deciduous Forest | 41.58% | 42.05% | 25.81% | 14.81% | 30.43% |
| Evergreen Forest | 21.12% | 21.26% | 18.81% | 7.52% | 22.89% |
| Mixed Forest | 29.06% | 28.48% | 14.32% | 2.64% | 11.84% |
| Grassland | 0.00% | 0.00% | 0.00% | 1.22% | 2.14% |
| Shrub / Scrub | 0.00% | 0.00% | 0.00% | 0.17% | 0.30% |
| Wetlands | 0.15% | 0.31% | 0.53% | 0.65% | 0.76% |
| Herbaceous Wetland | 0.00% | 0.00% | 0.00% | 0.03% | 0.00% |
| Pasture | 2.66% | 2.29% | 16.39% | 4.56% | 11.98% |
| Cultivated | 1.59% | 1.73% | 14.01% | 1.06% | 5.17% |
| Recr. Grasses | 0.96% | 0.29% | 0.84% | 26.29% | 4.74% |
| Low Intensity Developed | 1.56% | 1.96% | 5.13% | 23.26% | 5.21% |
| Med. Intensity Developed | 0.00% | 0.00% | 0.00% | 6.74% | 0.75% |
| High Intensity Developed | 0.03% | 0.06% | 0.85% | 6.89% | 1.04% |
| Commercial / Industrial | 0.67% | 0.72% | 2.57% | 3.44% | 1.42% |
| Barren | 0.47% | 0.73% | 0.43% | 0.38% | 0.47% |
| Water | 0.16% | 0.12% | 0.31% | 0.32% | 0.87% |

# Modeled vs Measured Inputs to WARMF

- Run baseline simulation using measured meteorology (NCDC), air & rain chemistry (NADP)

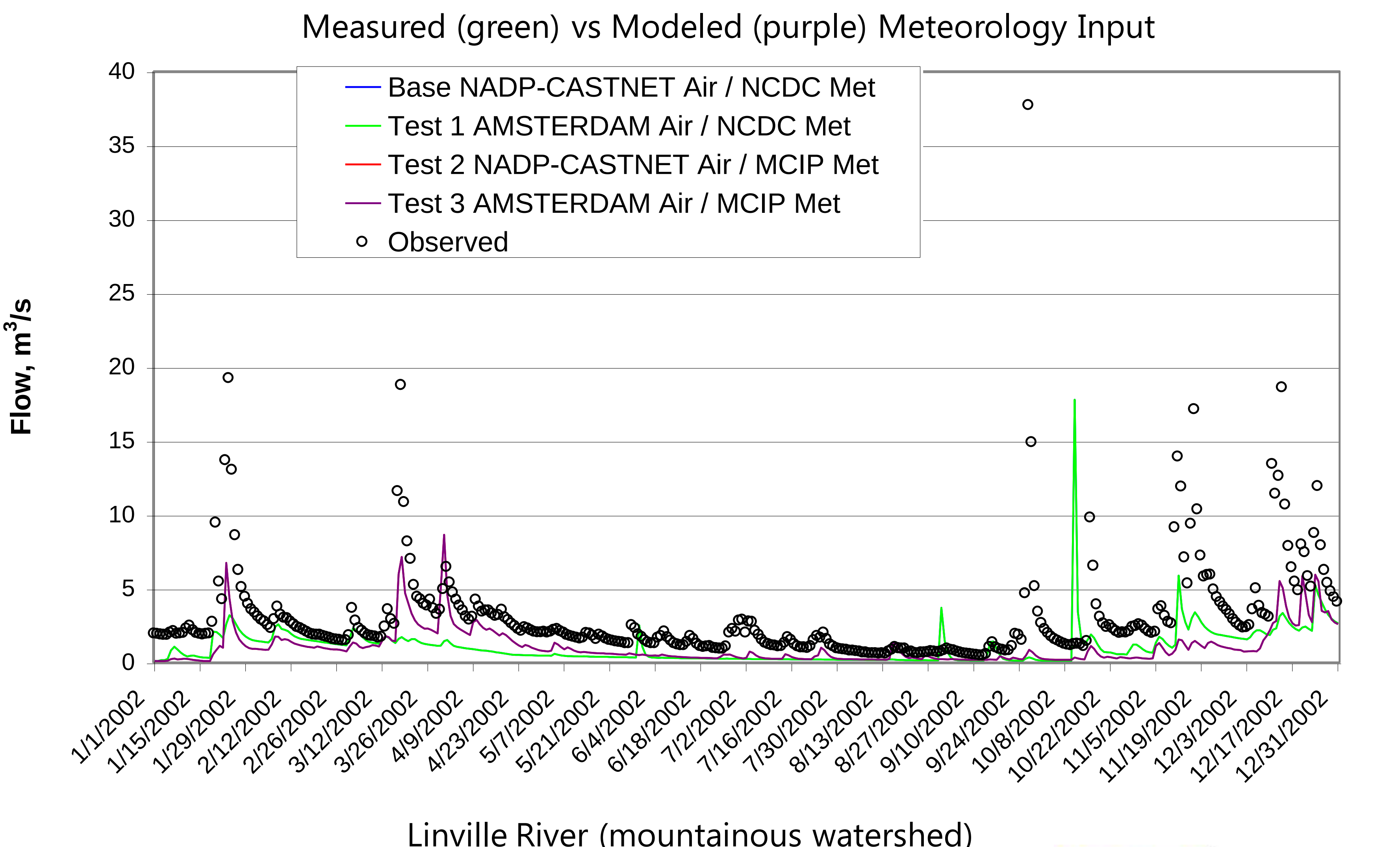
- Run test simulations using modeled meteorology (MCIP) and/or air & rain chemistry (AMSTERDAM)

- Compare tests to baseline
  - flux from atmosphere to land
  - time series of simulated water quality in lakes and rivers

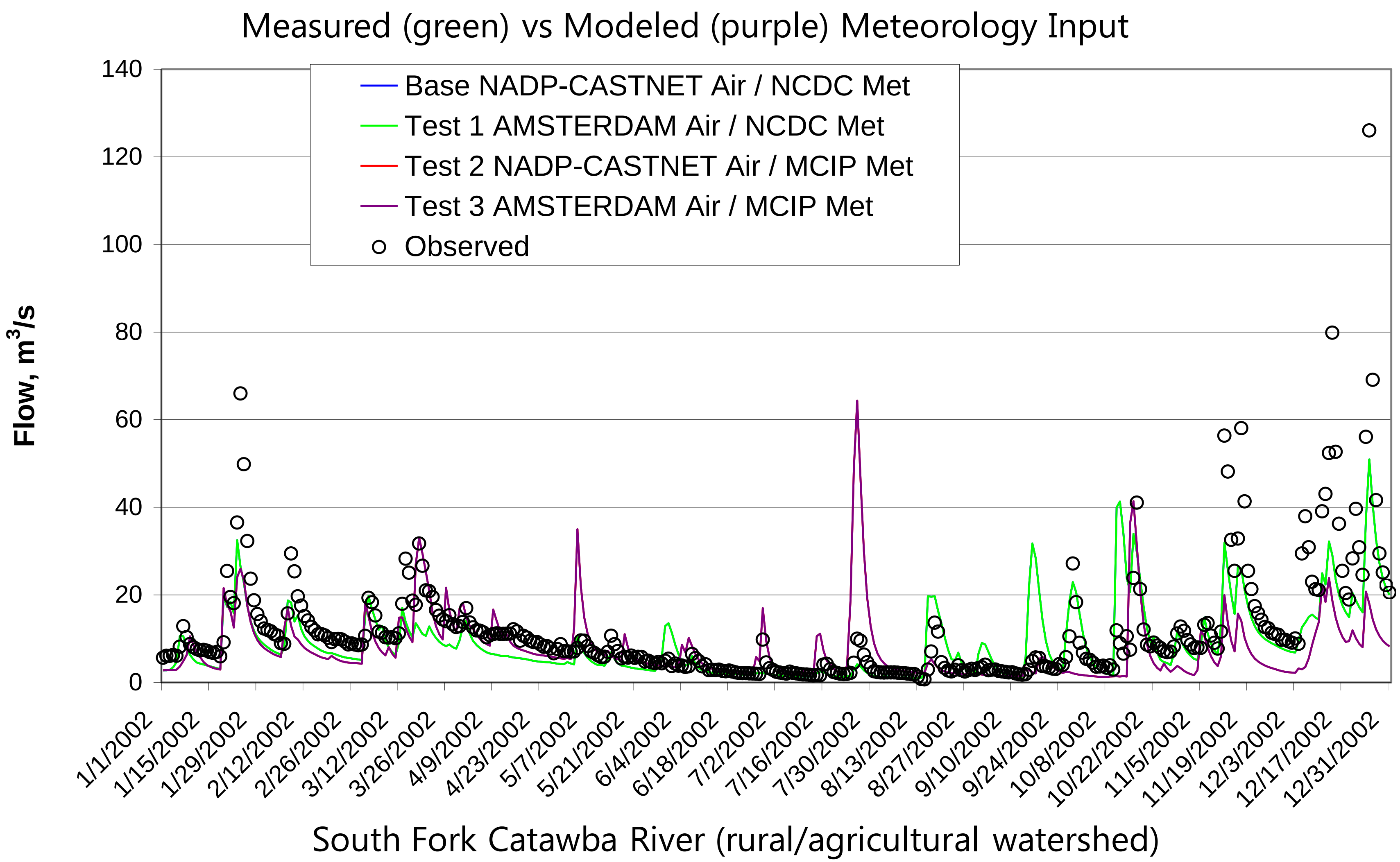
# WARMF Test Simulations

| Simulation | Air and Rain Concentration Input | Meteorology Input | What is tested |
|---|---|---|---|
| Baseline | NADP / CASTNET Measured | NCDC Measured | Compared against test scenarios |
| Test 1 | AMSTERDAM | NCDC Measured | AMSTERDAM vs NADP air & rain concentrations |
| Test 2 | NADP / CASTNET Measured | MCIP | Modeled MCIP vs measured NCDC meteorology, change in flow |
| Test 3 | AMSTERDAM | MCIP | Full implementation of linkage, flux comparison vs AMSTERDAM |

# Simulated Flow (Linville River)



# Simulated Flow (South Fork Catawba River)





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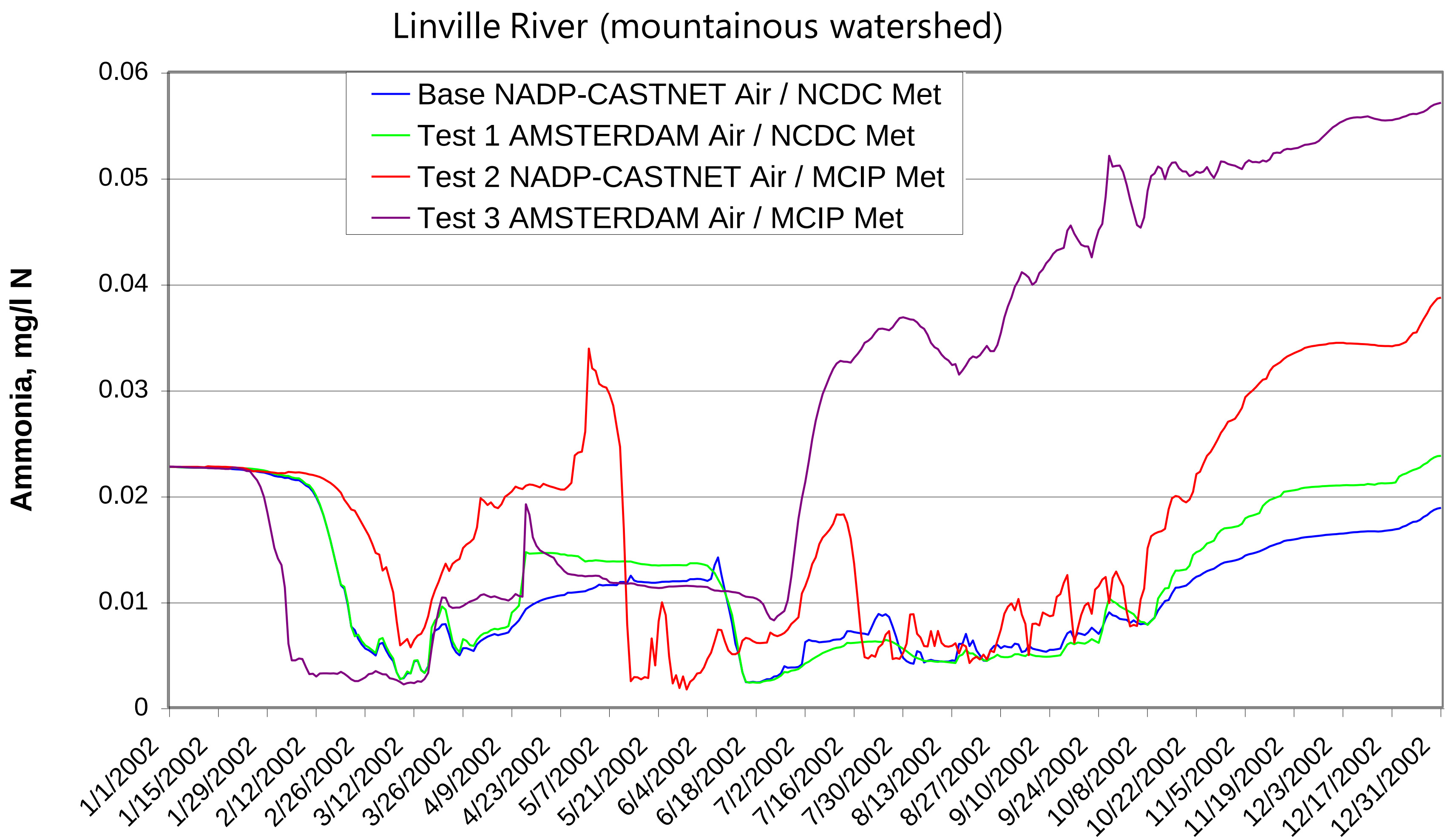
# Results of Simulated Flow Testing

- MCIP has greater spatial resolution than NCDC (106 stations vs. 17 stations), hourly values

- NCDC is accurate at meteorology stations with daily data; MCIP is modeled

- Neither meteorology data source superior for flow prediction
  - R-squared and volume balance used for comparison
  - MCIP did better in mountains
  - NCDC did better in lowlands
  - Only one year used: hard to generalize

# Simulated Ammonia Concentration



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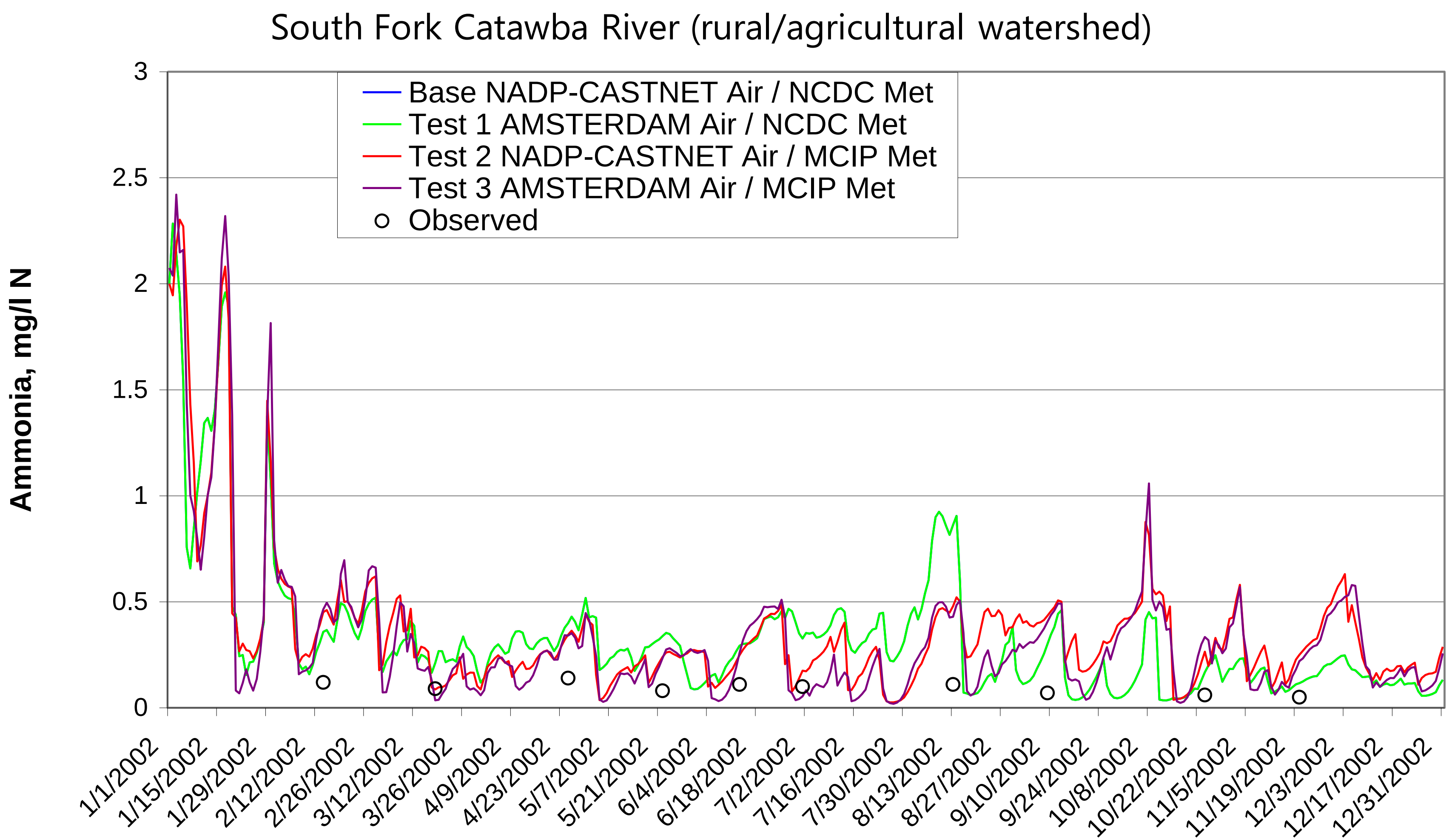

# Simulated Ammonia Flux

Wet Deposition Flux from Atmosphere to Land, kg/ha/year as N

| Watershed | WARMF Baseline | WARMF Test 3 | AMSTERDAM |
|---|---|---|---|
| Linville River | 0.74 | 1.66 | 1.68 |
| Lake James | 0.65 | 1.66 | 1.63 |
| S. Fork Catawba R. | 0.83 | 1.71 | 1.78 |
| Sugar Creek | 0.80 | 2.14 | 2.22 |
| Lake Wateree | 0.79 | 1.82 | 1.90 |

Dry Deposition Flux from Atmosphere to Land, kg/ha/year as N

| Watershed | WARMF Baseline | WARMF Test 3 | AMSTERDAM |
|---|---|---|---|
| Linville River | 0.62 | 0.40 | 0.34 |
| Lake James | 0.61 | 0.46 | 0.36 |
| S. Fork Catawba R. | 0.54 | 1.40 | 0.90 |
| Sugar Creek | 0.36 | 2.60 | 1.47 |
| Lake Wateree | 0.55 | 1.64 | 1.14 |





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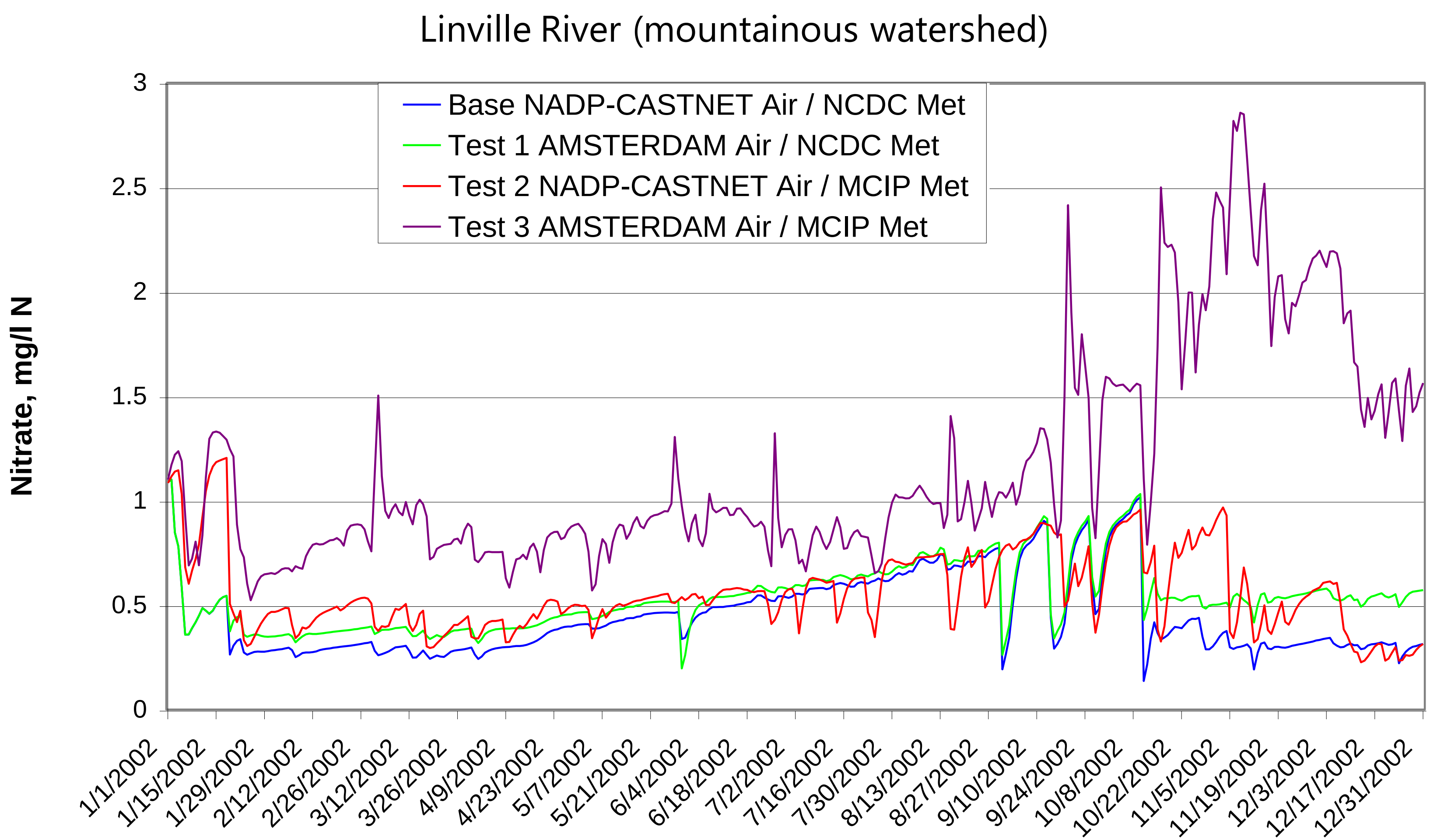
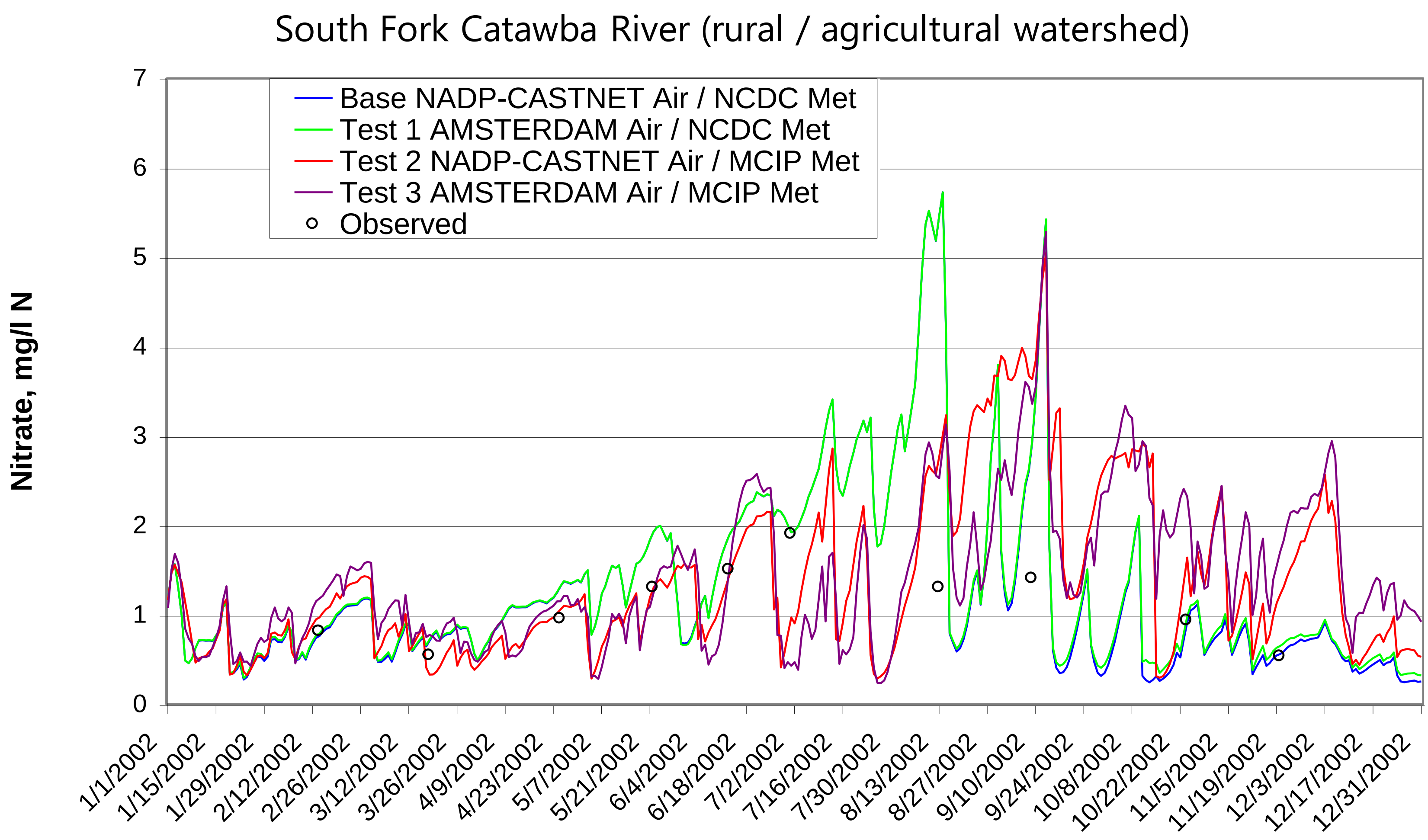
# Simulated Nitrate Concentration



# Simulated Nitrate Concentration





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# Simulated Nitrate Flux

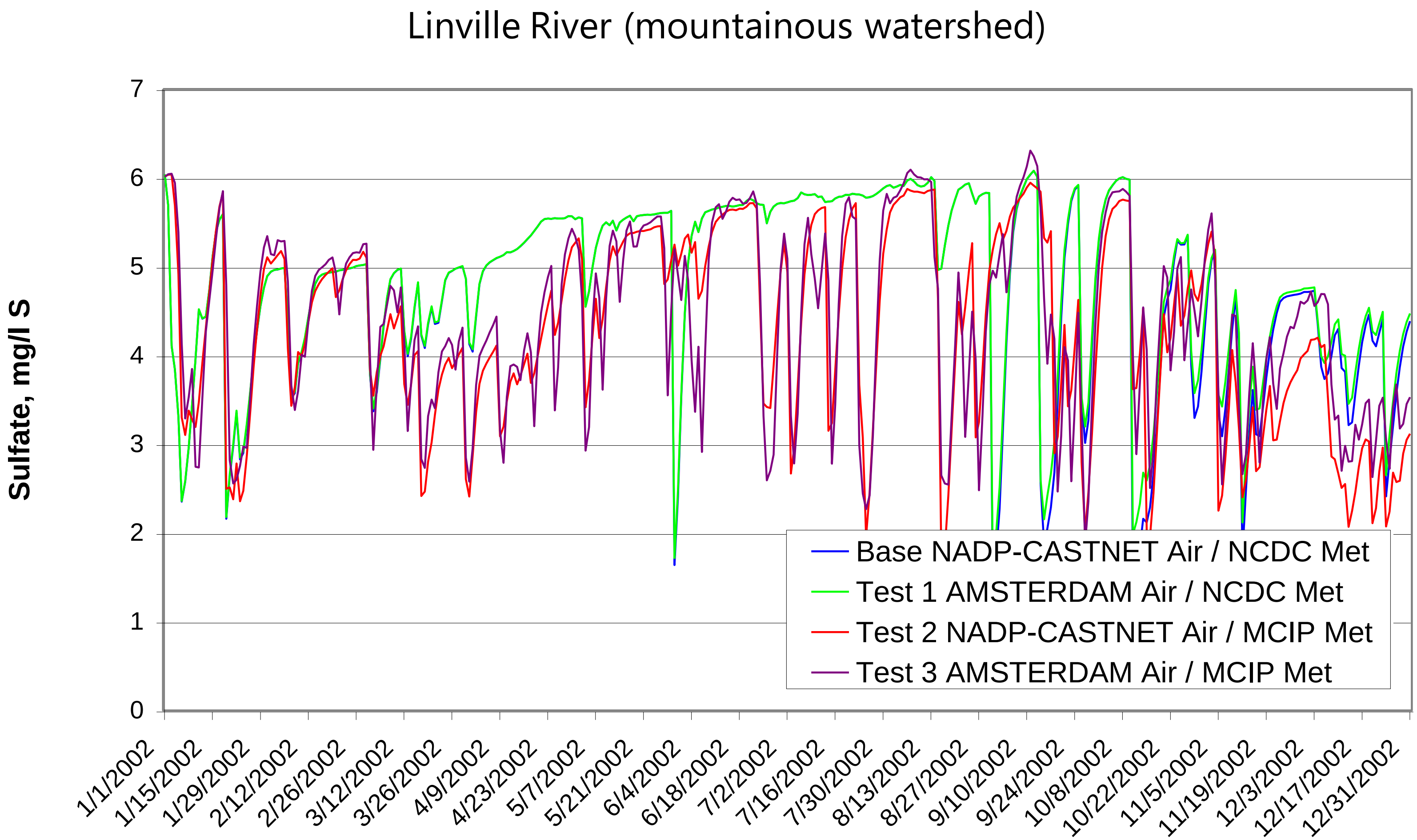
Wet Deposition Flux from Atmosphere to Land, kg/ha/year as N

| Watershed | WARMF Baseline | WARMF Test 3 | AMSTERDAM |
|---|---|---|---|
| Linville River | 1.02 | 1.93 | 2.10 |
| Lake James | 0.88 | 2.00 | 2.04 |
| S. Fork Catawba R. | 1.18 | 2.17 | 2.30 |
| Sugar Creek | 1.10 | 2.14 | 2.28 |
| Lake Wateree | 1.09 | 2.03 | 2.17 |

Dry Deposition Flux from Atmosphere to Land, kg/ha/year as N

| Watershed | WARMF Baseline | WARMF Test 3 | AMSTERDAM |
|---|---|---|---|
| Linville River | 0.05 | 5.09 | 5.38 |
| Lake James | 0.05 | 5.35 | 5.40 |
| S. Fork Catawba R. | 0.04 | 6.99 | 5.47 |
| Sugar Creek | 0.03 | 8.62 | 7.77 |
| Lake Wateree | 0.04 | 6.34 | 5.87 |

# Simulated Sulfate Concentration





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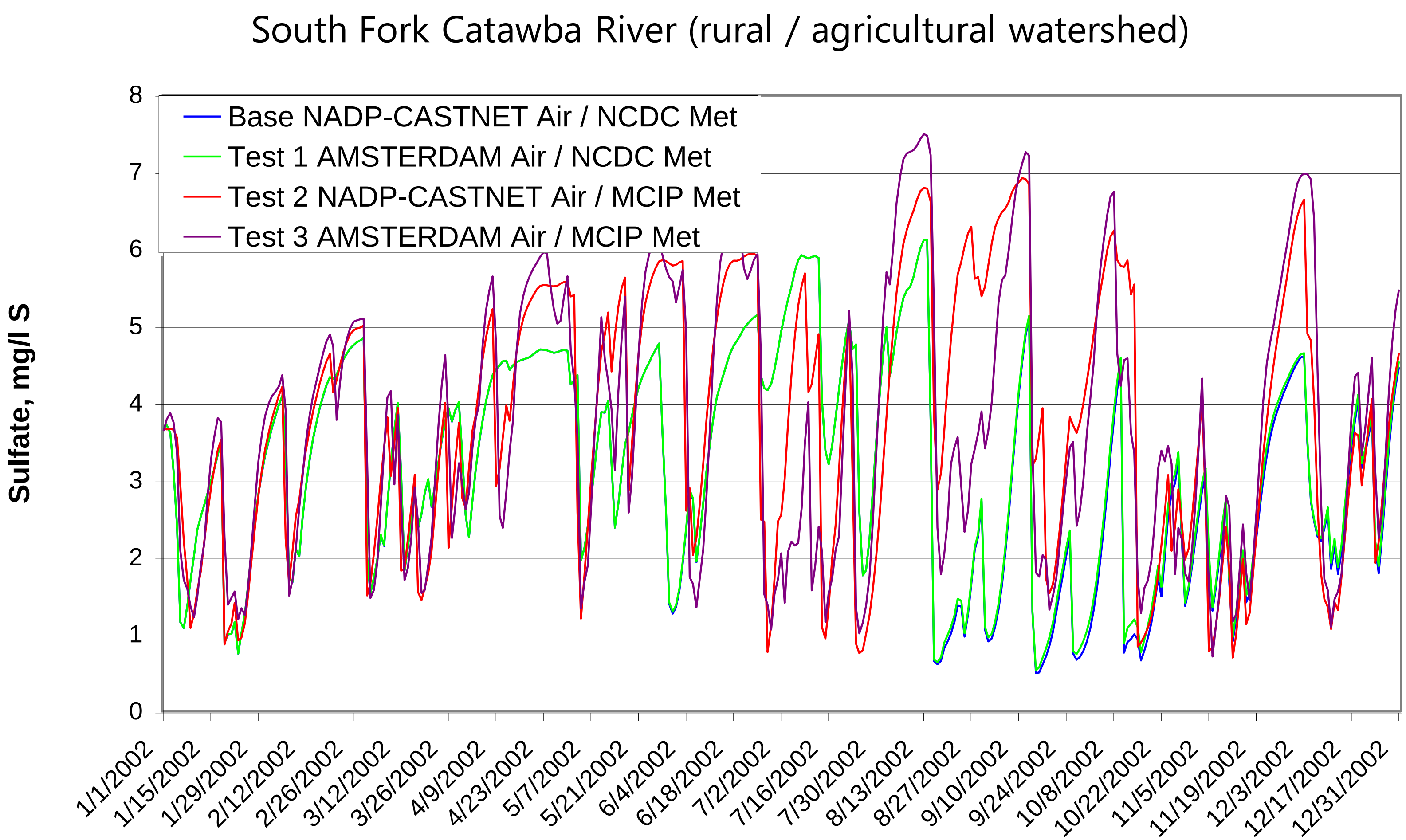
# Simulated Sulfate Concentration



# Simulated Sulfate Flux

Wet Deposition Flux from Atmosphere to Land, kg/ha/year as S

| Watershed | WARMF Baseline | WARMF Test 3 | AMSTERDAM |
|---|---|---|---|
| Linville River | 2.29 | 5.32 | 5.37 |
| Lake James | 2.00 | 4.72 | 4.95 |
| S. Fork Catawba R. | 2.69 | 4.89 | 5.31 |
| Sugar Creek | 2.49 | 5.57 | 6.16 |
| Lake Wateree | 2.48 | 4.86 | 5.35 |

Dry Deposition Flux from Atmosphere to Land, kg/ha/year as S

| Watershed | WARMF Baseline | WARMF Test 3 | AMSTERDAM |
|---|---|---|---|
| Linville River | 0.19 | 2.40 | 4.40 |
| Lake James | 0.19 | 2.50 | 4.07 |
| S. Fork Catawba R. | 0.17 | 3.43 | 4.56 |
| Sugar Creek | 0.11 | 5.58 | 8.77 |
| Lake Wateree | 0.17 | 3.59 | 5.44 |

# Simulated Air Emission Reduction

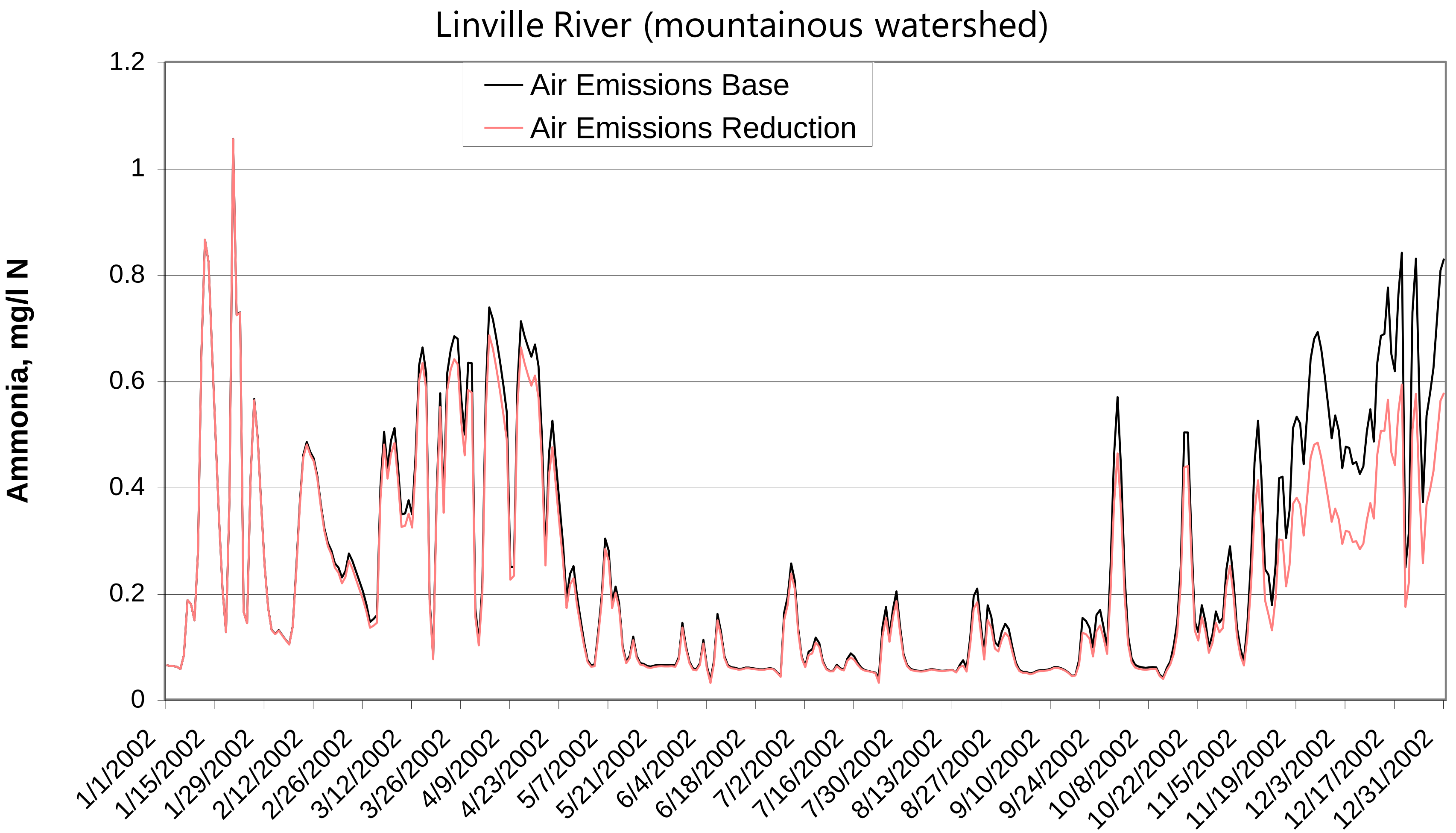
- Domainwide Values

- Total $SO_2$ Emissions (Base Case, 2002): 21,594 tons/year
- Total $SO_2$ Emissions (Beyond 2009 scenario): 16,354 tons/year

- Total NOx Emissions (Base Case, 2002): 28,253 tons/year
- Total NOx Emissions (Beyond 2009 scenario): 20,544 tons/year

- Absolute and relative reductions in emissions:
  - $SO_2$: 5240 tons/year (24%)
  - NOx: 7709 tons/year (27%)

# Effect due to Air Emission Reduction



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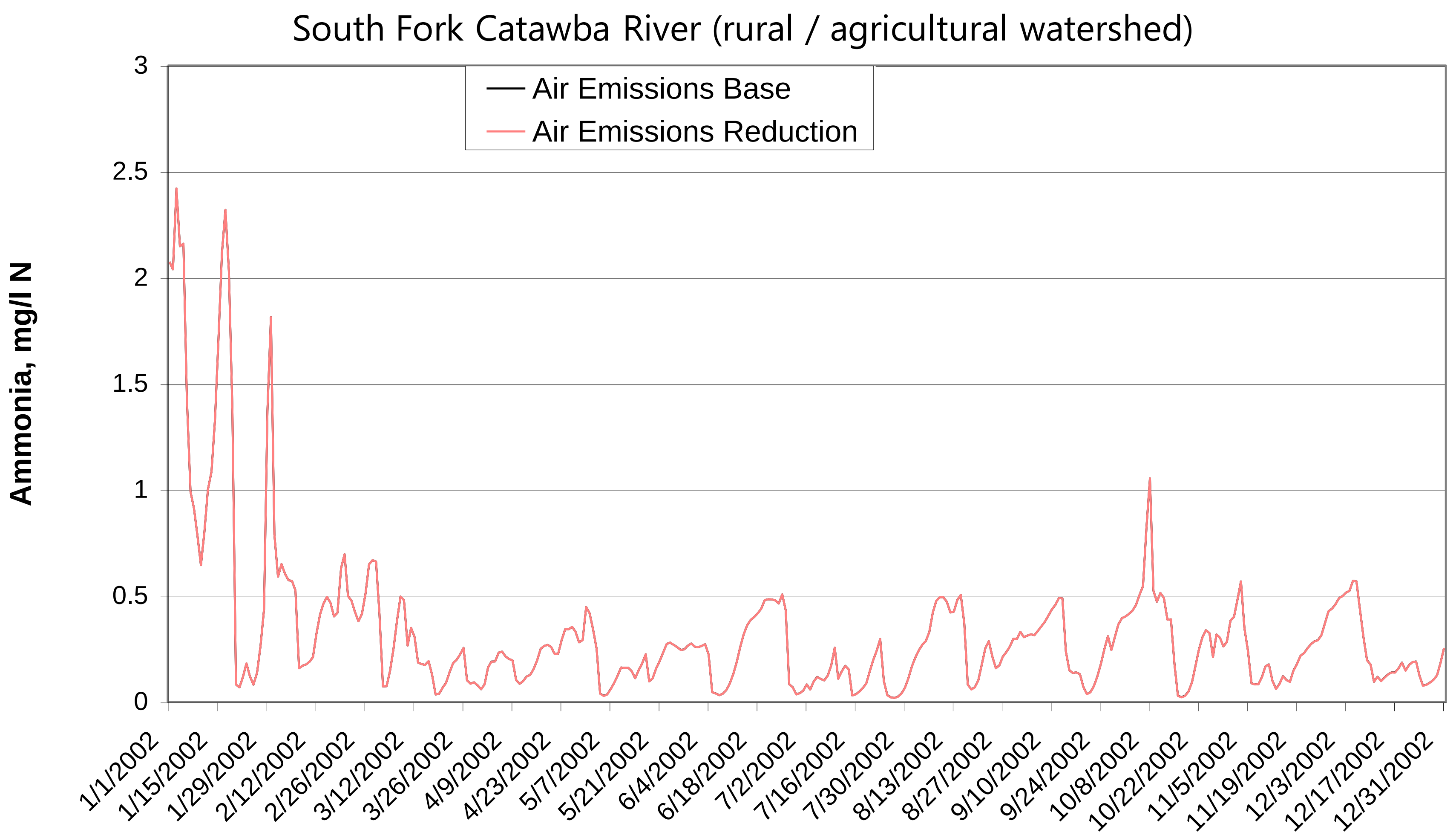

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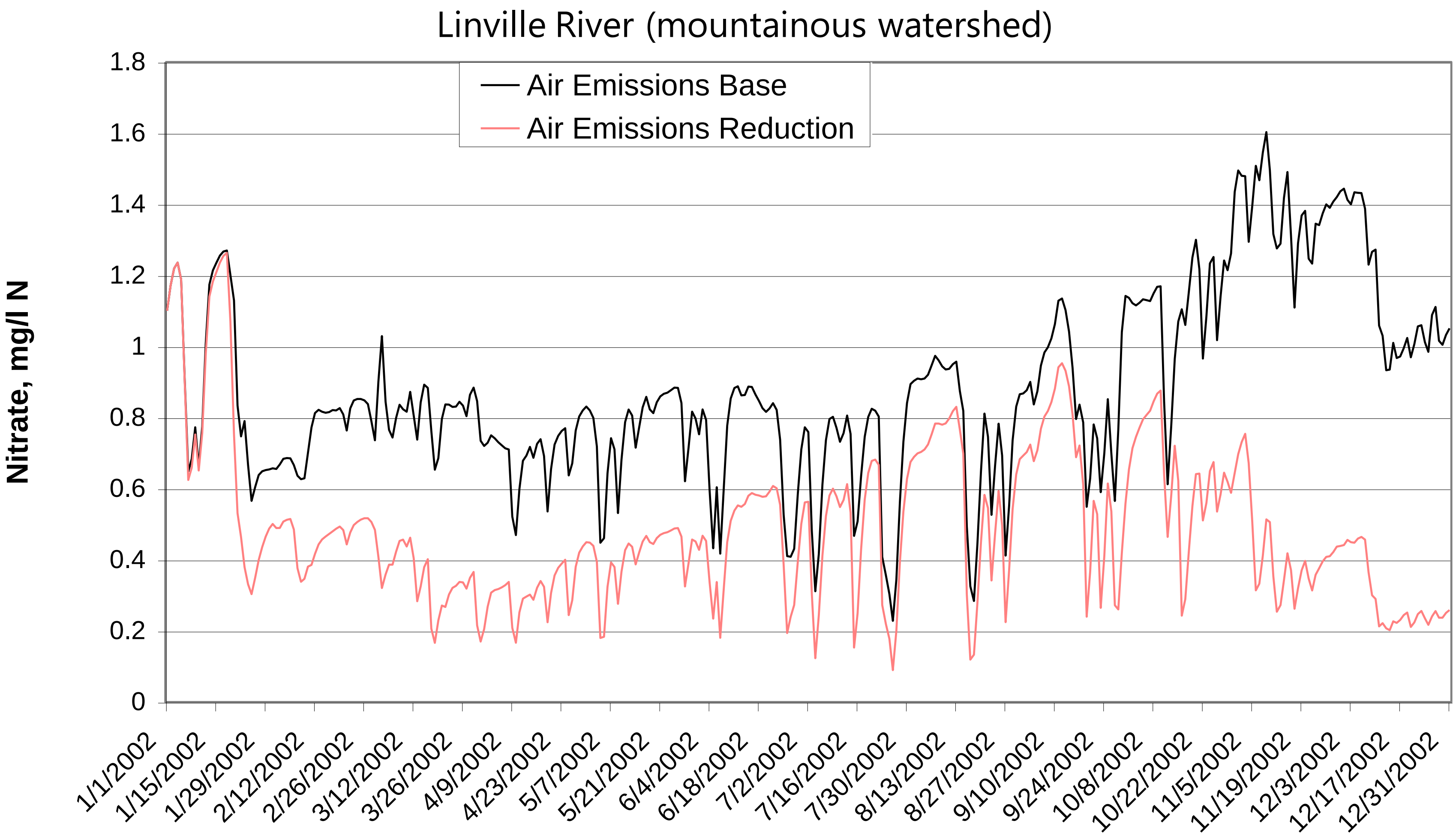






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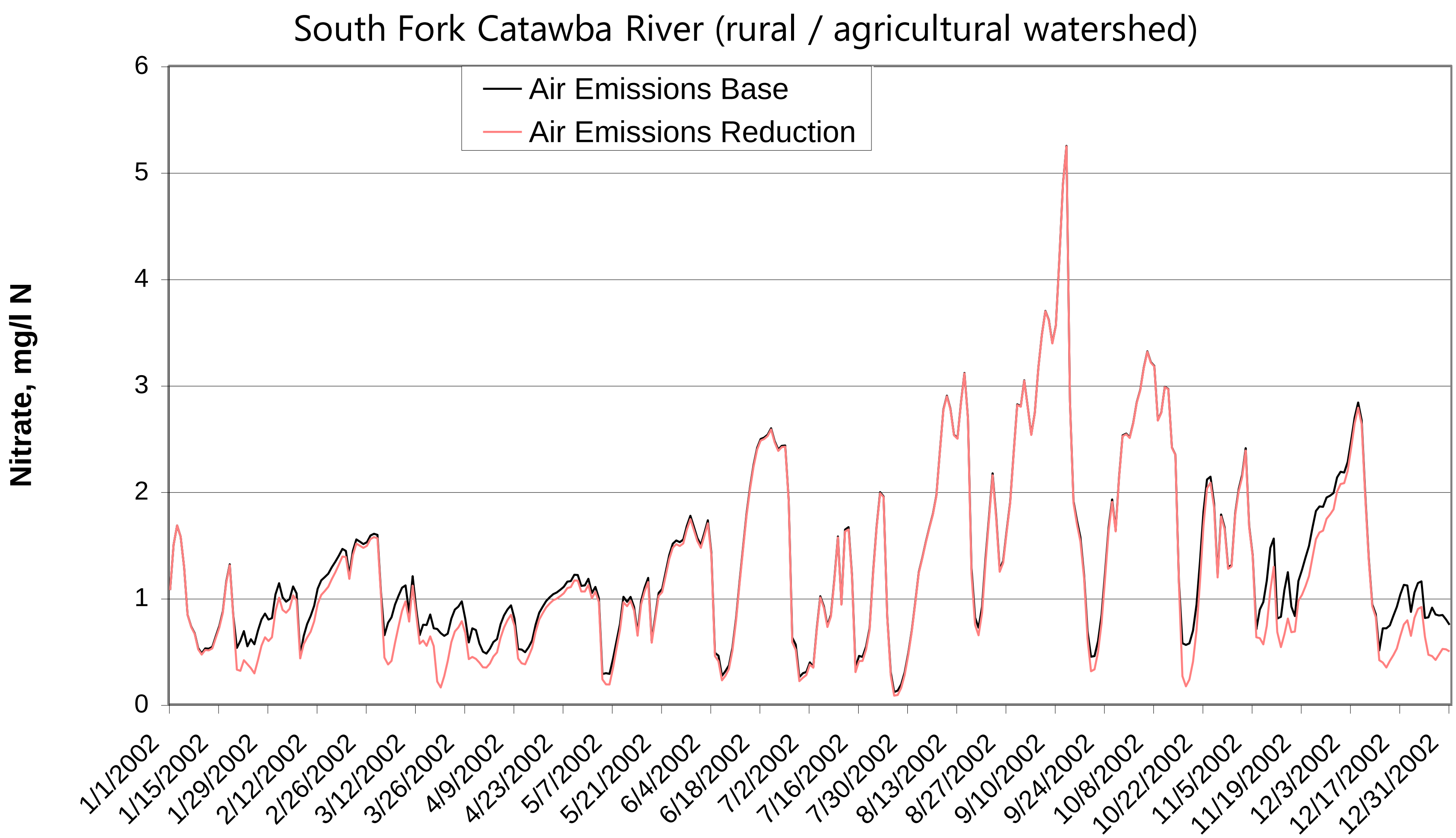
# Effect due to Air Emission Reduction



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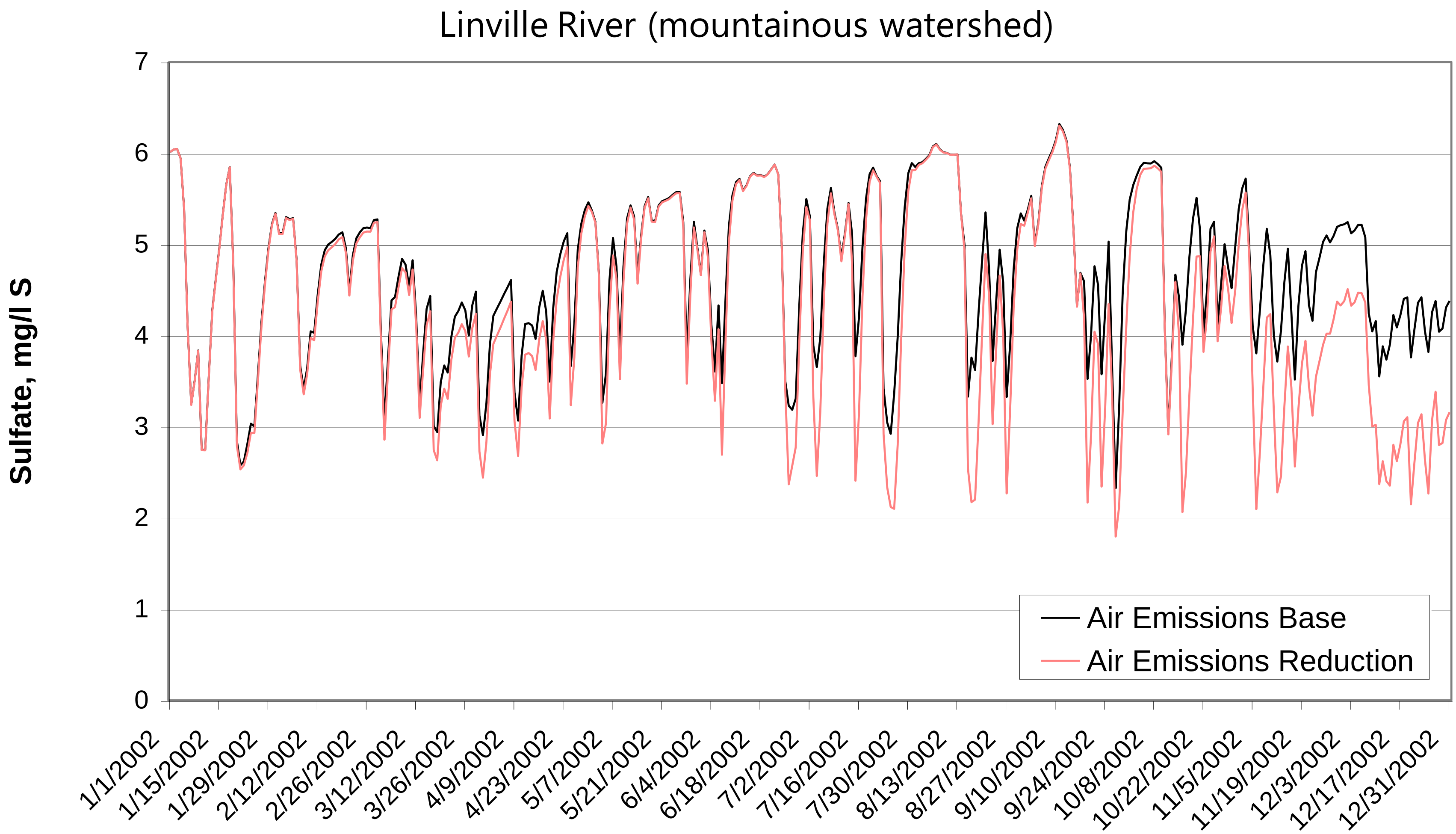






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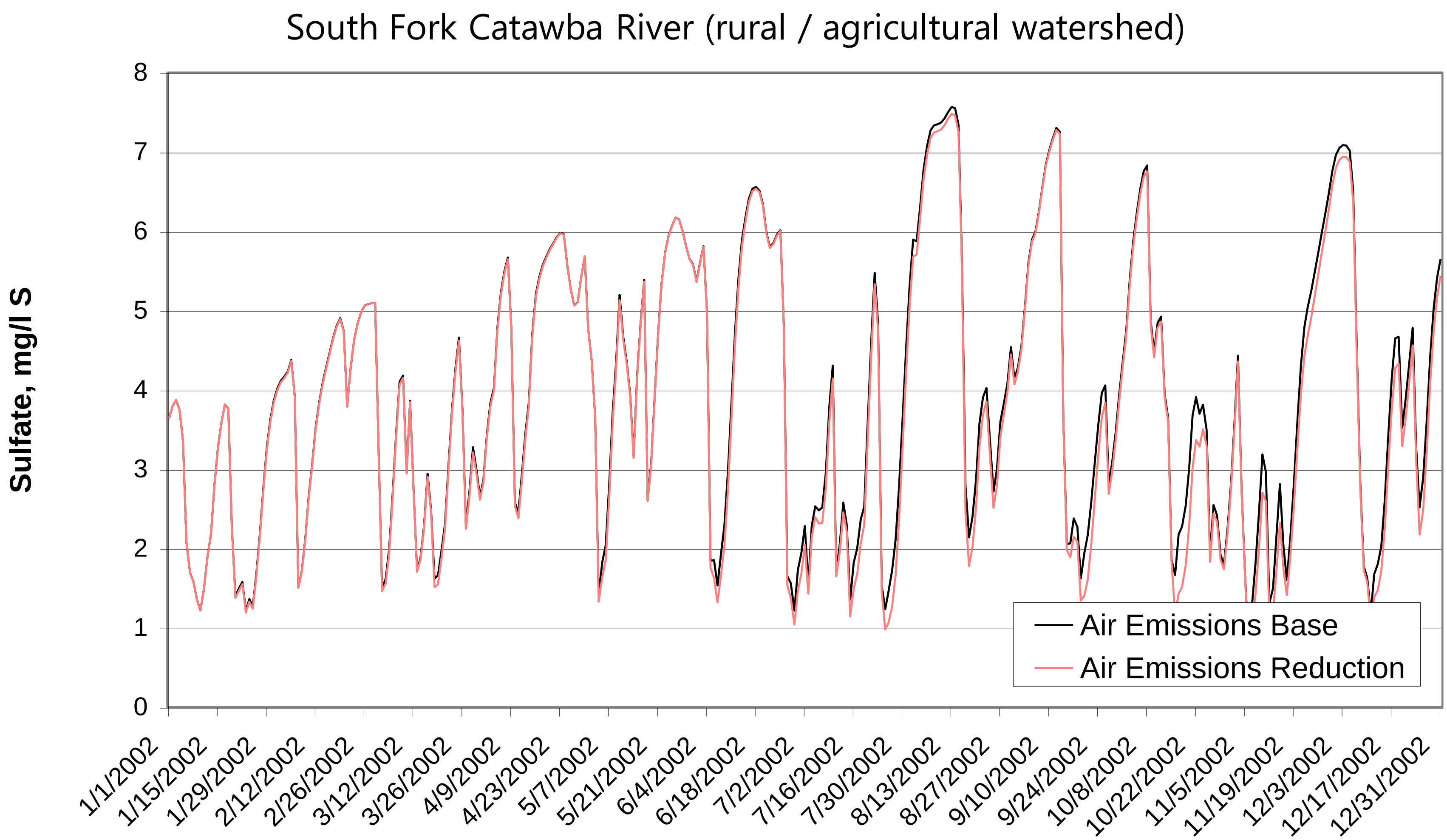
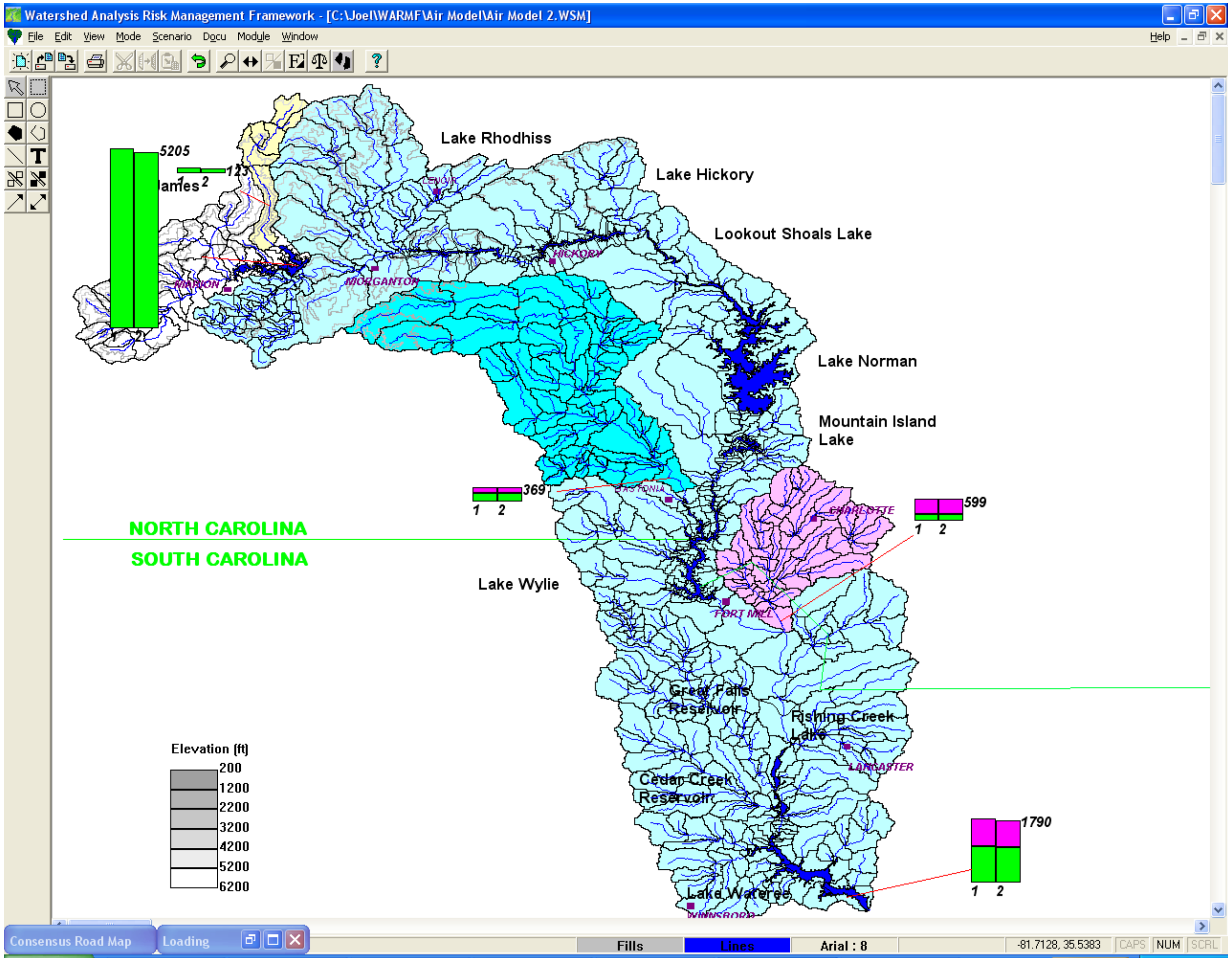
# Effect due to Air Emission Reduction



# Ammonia Loading from Watershed





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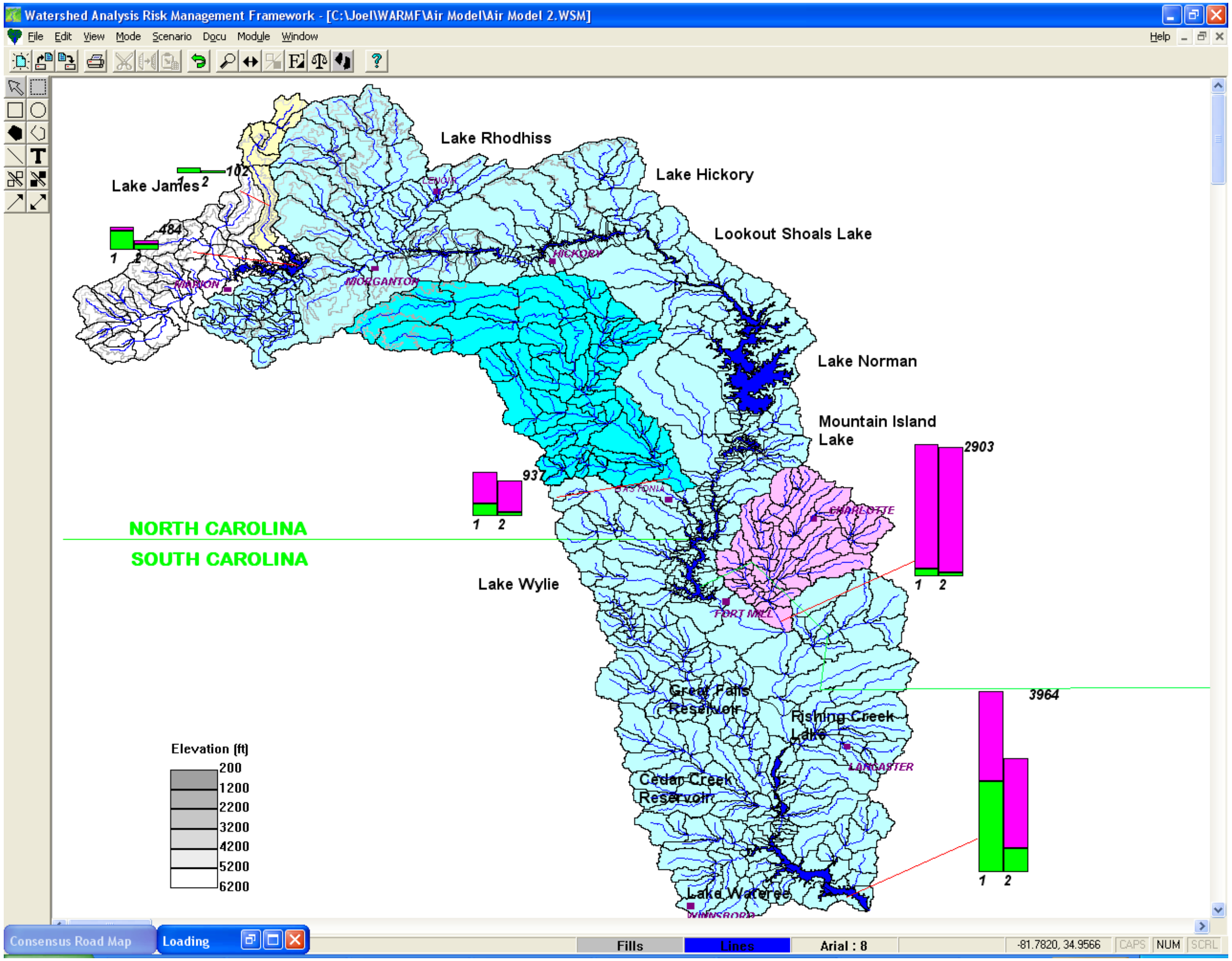
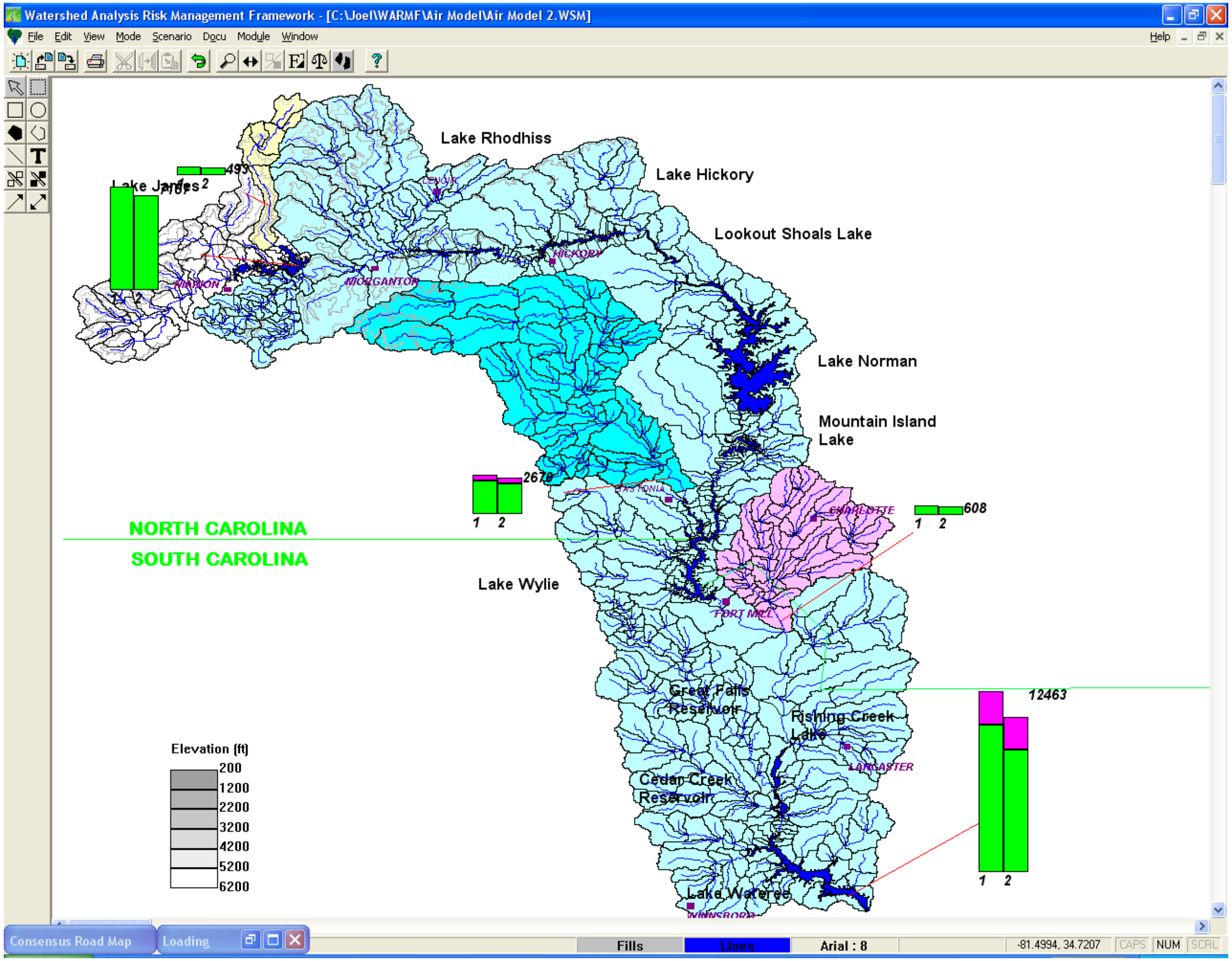
# Nitrate Loading from Watershed



# Sulfate Loading from Watershed





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# Effect of Air Emission Reduction

| Location | Ammonia Reduction, % | Nitrate Reduction, % | Sulfate Reduction, % |
|---|---|---|---|
| Linville River | 12.0% | 63.5% | 17.8% |
| Lake James | 5.0% | 42.2% | 5.6% |
| South Fork Catawba R. | 0.5% | 19.8% | 7.3% |
| Sugar Creek | 0.2% | 2.7% | 13.7% |
| Lake Wateree | 1.4% | 11.0% | 6.8% |

Surface Water Load Reduction

# Linkage Summary

- AMSTERDAM output provides high resolution inputs of rain, gaseous, fine particulate, and coarse particulate concentrations
- MCIP provides high resolution meteorology but with somewhat lower accuracy than measured data
- Sensitivity to atmospheric load varies by land use
- WARMF can predict water quality improvement resulting from air emissions reductions
- The linkage provides a tool to estimate emissions source contributions to atmospheric deposition and understand how that contribution affects water quality and other watershed variables
- Improvements in emissions, meteorological and air quality models will translate into better linked data

# Contact Information

Eladio M. Knipping
Electric Power Research Institute (EPRI)
2000 L Street NW Suite 805, Washington, DC 20036 USA
Email: eknippin@epri.com
Phone: 202.293.2691

Joel Herr
Systech Water Resources, Inc.
1200 Mount Diablo Blvd., Suite 102, Walnut Creek, CA 94596
Email: joel@systechwater.com
Phone: 925.355.1780 ext. 1

Krish Vijayaraghavan
AER, Inc.
388 Market St, Suite 750, San Francisco, CA 94111
Email: krish@aer.com
Phone: 415.268.8634