U.S. Environmental Protection Agency
Clean Air Scientific Advisory Committee (CASAC)
Nitrogen Oxides and Sulfur Oxides Panel
Public Meeting

External Review Draft

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National Center for Environmental Assessment,
Office of Research and Development
Research Triangle Park, NC, May 24-25, 2017
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Documents Informing this Review

• Integrated Review Plan (IRP) OAR and ORD Product (final Jan’17)
  – Provides an overview of the history of the past reviews, decisions, and any relevant litigation
  – Highlights key policy-relevant science issues that will guide review
  – Outlines process and schedule for review
  – CASAC Panel reviewed and commented on the IRP

• Integrated Science Assessment (ISA) ORD Product
  – Concise evaluation and synthesis of the most policy-relevant science
  – Emphasis on integration of the science and on clear characterization of strengths and uncertainties of available scientific evidence
  – ISA provides the scientific foundation for:
    • Risk and Exposure Assessment (REA)
    • Policy Assessment (PA)
    • Agency decisions as reflected in proposed and final rules
  – CASAC reviews and comments on the ISA
    • Meetings are open to the public with opportunities for public comments
Risk and Exposure Assessment (REA) OAR Product

Prior to conducting an assessment, EPA prepares an REA planning document to assess the degree to which new evidence and tools support conducting a new quantitative REA.

- If an REA is warranted, the planning document also describes the scope and methods plan for the assessment.
- EPA consults with CASAC on the REA planning document.
- The REA draws upon information and conclusions presented in the ISA to conduct quantitative analyses of exposures and risks to ecosystems associated with the current standard(s) and, if appropriate, alternative standard(s) under consideration.
- The REA includes a characterization of the uncertainties associated with such estimates.
- CASAC reviews and comments on draft REAs, if conducted.
  - Meetings are open to the public with opportunities for public comments.
Documents Informing this Review (cont.)

• **Policy Assessment (PA)** *OAR Product*
  – Provides a transparent staff analysis of the scientific basis for policy options for consideration by senior management prior to rulemaking
  – Facilitates the CASAC’s advice to the Agency and recommendations to the Administrator on the adequacy of the existing standards or revisions that may be appropriate to consider
  – Intended to help “bridge the gap” between the Agency’s scientific assessments, presented in the ISA and REA(s), and the judgments required of the EPA Administrator in determining whether it is appropriate to retain or revise the NAAQS
    • The Administrator must set secondary standards that are requisite to protect public welfare (nether more nor less stringent than necessary) from any known or anticipated adverse effects associated with the presence of the pollutant in the ambient air
    – Focuses on the information most pertinent to evaluating the basic elements of the NAAQS: indicator, averaging time, form, and level
    – CASAC reviews and comments on draft PA
      • Meetings are open to the public with opportunities for public comments
Framework for Causal Determination

- Promote consistency and transparency
- Emphasize synthesis of evidence across scientific disciplines (e.g., geochemistry, physiology/toxicology, population, community and ecosystem-scale studies)
- Weight of evidence categories:
  - Causal relationship
  - Likely to be a causal relationship
  - Suggestive but not sufficient to infer a causal relationship
  - Inadequate to infer the presence or absence of a causal relationship
  - Not likely to be a causal relationship
- ISA Preamble describes this framework
  - Preamble is now stand-alone document (http://www.epa.gov/isa)
- CASAC has supported use of this framework in past ISAs
<table>
<thead>
<tr>
<th>Framework for Causal Determinations in the ISAs</th>
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<tbody>
<tr>
<td><strong>Causal relationship</strong></td>
</tr>
<tr>
<td>Evidence is sufficient to conclude that there is a causal relationship with relevant pollutant exposures. That is, the pollutant has been shown to result in effects in studies in which chance, confounding, and other biases could be ruled out with reasonable confidence. Controlled exposure studies (laboratory or small- to medium-scale field studies) provide the strongest evidence for causality, but the scope of inference may be limited. Generally, the determination is based on multiple studies conducted by multiple research groups, and evidence that is considered sufficient to infer a causal relationship is usually obtained from the joint consideration of many lines of evidence that reinforce each other.</td>
</tr>
</tbody>
</table>

| **Likely to be a causal relationship**          |
| Evidence is sufficient to conclude that there is a likely causal association with relevant pollutant exposures. That is, an association has been observed between the pollutant and the outcome in studies in which chance, confounding, and other biases are minimized but uncertainties remain. For example, field studies show a relationship, but suspected interacting factors cannot be controlled, and other lines of evidence are limited or inconsistent. Generally, the determination is based on multiple studies by multiple research groups. |

| **Suggestive of, but not sufficient to infer, a causal relationship** |
| Evidence is suggestive of a causal relationship with relevant pollutant exposures, but chance, confounding, and other biases cannot be ruled out. For example, at least one high-quality study shows an effect, but the results of other studies are inconsistent. |

| **Inadequate to infer a causal relationship**   |
| Evidence is inadequate to determine that a causal relationship exists with relevant pollutant exposures. The available studies are of insufficient quality, consistency, or statistical power to permit a conclusion regarding the presence or absence of an effect. |

| **Not likely to be a causal relationship**      |
| Evidence indicates there is no causal relationship with relevant pollutant exposures. Several adequate studies examining relationships with relevant exposures are consistent in failing to show an effect at any level of exposure. |

**Rule out chance, confounding, and other biases**
**Consistency, coherence, biological plausibility, high-quality studies**

**Multiple, high-quality studies show effects**
**Uncertainty remains**

**Association found in at least one high-quality study**
**Or, results are inconsistent**

**Evidence is of insufficient quantity, quality, consistency**

**Multiple studies consistently show no effect across exposure concentrations**

Modified from Table II of the Preamble to the ISA
NO\textsubscript{X}-SO\textsubscript{X}-PM Ecology ISA Team

**NCEA-RTP Team**
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**Contributing Authors**

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- *Aquatic Acidification*: Tim Sullivan *, Jason Lynch
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**Ecosystem Services:**
- George Van Houtven *, Jessie Allen *, Jana Compton

**Case Studies:**
- Marion Deerhake *, Tim Sullivan *, Tamara Blett

*under contract with RTI International
Secondary NAAQS for oxides of nitrogen and oxides of sulfur

- Standards set to protect against direct effects of gaseous oxides of nitrogen and sulfur on vegetation
- Current NO₂ and SO₂ secondary standards
  - NO₂: Annual average at a level of 53 ppb
  - SO₂: 3-hr avg, not to exceed 0.5 ppm more than once a year
- No new standards were set in the 2012 review to provide protection against potentially adverse deposition-related effects

Secondary NAAQS for particulate matter

- Standards set to protect against ecological effects, visibility impairment, effects on materials, and climate impacts
- Current PM_{2.5} secondary standards
  - Annual: mean, averaged over 3 years at a level of 15 ug/m³
  - 24-hr: 98th %tile averaged over 3 years at a level of 35 ug/m³
- Current PM_{10} secondary standard
  - 24-hr avg, not to exceed 150 ug/m³ more than once per year on average over a 3-year period
Contents of the Draft NO$_x$-SO$_x$-PM ISA for Ecological Criteria

Includes review of literature through December 2015

- ISA Preamble: now an online stand-alone companion document as part of an effort to streamline this and future ISAs ([http://www.epa.gov/isa](http://www.epa.gov/isa))
- Preface: Legislative requirements, history of secondary NAAQS review
- Executive Summary
- Chapter 1: Integrative synthesis: summary of subsequent chapters
- Chapter 2: Source to deposition
- Chapter 3: Gas phase biological effects
- Chapter 4: Soil biogeochemistry
- Chapter 5: Biological effects of terrestrial acidification
- Chapter 6: Biological effects of terrestrial eutrophication
- Chapter 7: Aquatic biogeochemistry
- Chapter 8: Biological effects of freshwater acidification
- Chapter 9: Biological effects of freshwater nitrogen enrichment
- Chapter 10: Biological effects of nitrogen enrichment in estuaries
- Chapter 11: Wetland eutrophication
- Chapter 12: Non-acidifying sulfur effects
- Chapter 13: Climate modification of ecological response
- Chapter 14: Ecosystem services
- Appendices
Chemical species included in the criteria pollutants categories for the NOxSOxPM-ECO ISA

• Oxides of nitrogen
  • Total oxidized nitrogen (NOy) includes the transformation products from emissions of oxides of nitrogen (e.g., nitric acid and particulate nitrate)

• Oxides of sulfur
  • Total oxidized sulfur (SOx) includes particulate sulfate (SO$_4^{2-}$) combined with sulfur dioxide (SO$_2$)

• Particulate matter (PM)
  • PM can be emitted directly as well as formed in the atmosphere. Major components of PM that are formed in the atmosphere include nitrate (NO$_3^{-}$), sulfate (SO$_4^{2-}$), and ammonium (NH$_4^{+}$)

• The ISA evaluates both the **gas phase** and **deposition effects** on ecosystems
**U.S. Emissions of NH$_3$, SO$_2$, and NO$_X$**

- NH$_3$ mainly from agriculture*
- SO$_2$ mainly from electric utilities (decreasing)
- NO$_X$ from a mixture of sources, with highway and off-highway vehicles the largest sources

*NH$_3$ is a particulate matter precursor*
Nitrogen Deposition Conclusions

- Recent N deposition presented by the map below
- Nitrogen deposition relatively constant over the last 25 years.
- Decreases in NO$_3^-$ and HNO$_3$ deposition are largely offset by increases in NH$_4^+$ and NH$_3$ deposition across the U.S. (based on NADP/NTN and TDEP).

Three-year (2011 to 2013) average annual dry + wet deposition of NO$_Y$ and NH$_X$ species.
Sulfur Deposition Conclusions

- Recent S deposition presented in the map below
- Large decreases in S deposition mainly in the eastern U.S. (based on NADP/NTN and TDEP) over the last 25 years

**Total Wet and Dry Sulfur Deposition in the U.S. from 2011-2013**

Total S Deposition (kg-S/ha) for 3-Yr. Avg. Between 2011-2013
Acidifying Deposition Conclusions

H+ Equivalents of Total Nitrogen and Sulfur Deposition in the U.S. from 2011-2013
Acidifying deposition by N+S (shown in equivalents below) decreased markedly in the east and has remained relatively constant in the west (with small localized increases) over the last 25 years.

- Increased acidifying deposition in the central U.S. driven by reduced forms of N (NH₃, NH₄⁺), which contribute to acidification when converted to nitrate by soil microbes.
There are 19 determinations in the NOx-SOx-PM-Eco ISA

- 14 determinations that remain causal from 2008 NOx-SOx ISA
  - In each case there is new science adding weight of evidence and/or broader application

- 5 determinations are new:
  - 3 causal
  - 1 likely causal
  - 1 suggestive of a causal relationship
## Summary of Causal Determinations

### ECOLOGICAL EFFECTS

<table>
<thead>
<tr>
<th>ISA</th>
<th>2017 NOx SOx PM - Eco</th>
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</thead>
<tbody>
<tr>
<td><strong>Indicator</strong></td>
<td>Gases*</td>
</tr>
<tr>
<td>Class of Pollutant Effect</td>
<td>Direct phytotoxic</td>
</tr>
<tr>
<td>Ecosystem</td>
<td>Terrestrial</td>
</tr>
</tbody>
</table>

**Scale of Ecological Response**
- Ecosystem
  - Water cycling
  - Carbon sequestration
  - Productivity
- Community
  - Biodiversity
- Population
  - Individual Growth rate
- Individual
  - Physiological alteration, stress or injury
- Geochemistry
  - Soil or sediment chemistry
  - Surface water chemistry

**Causal** | **Likely causal** | **Suggestive** | **Inadequate** | **Not likely** | **Not evaluated in the causality framework**

*Includes: NO, NO2, HNO3, SO2 and PAN | Hg=mercury
Gas-phase Effects
Chapter 3
Phytotoxic Effects of Gas-phase NO	extsubscript{y} & SO	extsubscript{x}

• Acute and chronic exposures to SO	extsubscript{2} have phytotoxic effects on vegetation, which include foliar injury, decreased photosynthesis, and decreased growth.

• Acute exposures to some species of NO	extsubscript{y} (e.g., NO	extsubscript{2}, NO, PAN & HNO	extsubscript{3}) cause plant foliar injury and decreased growth.

• The majority of controlled exposure studies over the past several decades used concentrations of gas-phase NO	extsubscript{y} and SO	extsubscript{x} above ambient concentrations currently observed in the US.

• There is little information on exposures and effects reflecting the more recent lower pollutant concentrations.
Terrestrial N Enrichment and Acidification Chapters 4-6
Terrestrial N Enrichment Effects

Sensitivity across the US
All terrestrial ecosystems are vulnerable to N enrichment; sensitivity varies with historical loading

N deposits
• On the biota directly
• To the soil with transport to the biota

Physiological effects
• Higher growth rates of opportunistic species
• Documented effects on hundreds of species

Community/Ecosystem effects
• Loss of species richness and decreases in biodiversity in communities of:
  • lichens, herbaceous plants, mycorrhizal fungi
Example of N Enrichment Effects: Herbaceous Plant Biodiversity Nitrogen Critical Loads

Herbaceous plants (e.g., forbs, grasses, etc.) represent a large portion of plant diversity.

New critical load estimates for the onset of species loss (shown right).

Source: Simkin et al. 2016; 113:4086-4091

Source: Pardo et al., 2011
Terrestrial Nitrogen Critical Loads Update from Pardo et al. 2011

Bars = critical loads developed by USDA-FS/ Pardo et al. 2011

Circles = new critical loads (CL) published

Gold = herbaceous plants and shrubs
- New CLs on decreasing species richness and biodiversity

Green = lichens
- New CL on decreased species richness and declining thallus condition

Grey = mycorrhizae
- New CL on declining biodiversity

Blue = trees
- New CL on saturation canopy-level photosynthesis for conifers
- 10% change in community including trees

The onset of most effects is below 10 kg/ha/yr
Terrestrial Acidification Effects (N+S dep)

Sensitive ecosystems
Historical deposition and geology are major factors.

Soil biogeochemical effects and indicators of adverse effects on plant life
• Calcium to Aluminum ratio (Ca:Al) < 1.0
• Base cation to Aluminum ratio (BC:Al) < 10

Plant physiological effects
• Crown dieback, decrease tree growth, suppress tree seedling regeneration, and increase tree mortality rates.

Community effects
• Evidence pointing to changes in forest composition in areas affected by soil acidification.
• Changes found in forest understory plant community composition, grass and forb diversity.
Critical loads (as H⁺ equivalents) for soil indicator (BC:Al and Ca:Al) values that link to adverse effects on plants (dark red = more sensitive)
Aquatic N Enrichment and Acidification Chapters 7-11
Sensitive ecosystems

Historical deposition and geology are major factors

Physiological effects

Effects are primarily attributable to low pH and high inorganic Al, although acid neutralizing capacity (ANC) is often used as a proxy

Community effects

Loss of species richness/biodiversity and abundance:

- Primary Producers
- Zooplankton
- Benthic Invertebrates
- Fish (threshold ANC 0-100)

Number of fish species per lake versus acidity status, expressed as ANC, for Adirondack lakes. (Sullivan et al. 2006)
Current critical loads for acidification (dark red = more sensitive)
Sensitive ecosystems

Sensitivity to deposition varies with the fraction of N from deposition to total N loading. Other sources of N loading include wastewater effluent and agricultural/urban runoff.

• Freshwaters: high altitude lakes/remote headwater streams are the most sensitive freshwater systems.

• Wetlands: Bogs and fens are most sensitive of the wetlands.

• Estuaries: Atmospheric deposition typically contributes ≤ 40% of total N loading.
Sensitive ecosystems
Varies according to the amount of N from deposition vs total loading. High altitude lakes/remote headwater streams are most sensitive.

Example water quality indicators
Surface water NO$_3^-$

Physiology/population growth rate effects
N stimulates phytoplankton growth.

Community effects
Primary producers: Increased productivity, altered species composition, reduced phytoplankton biodiversity. Form of N impacts algal species community composition.
Zooplankton: Limited evidence for declines in zooplankton biomass.
Invertebrates: Limited evidence for taxonomic shifts, trophic interaction effects.

Nitrogen Critical Loads for High Elevation Lakes and Streams

<table>
<thead>
<tr>
<th>Location</th>
<th>Deposition (kg N/ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western high elevation lakes</td>
<td>1.0-1.2</td>
</tr>
<tr>
<td>Eastern high elevation lakes</td>
<td>3.5-6.0</td>
</tr>
</tbody>
</table>

References:
- Nanus et al. 2012
- Saros et al. 2011
- Sheibley et al. 2014
- Baron et al. 2011
- Pardo et al. 2011
- Sheibley et al. 2014
- Saros et al. 2011
- Nanus et al. 2012
- Pardo et al. 2011
N Enrichment/Eutrophication in Wetlands

Most sensitive

- Bog
- Fen
- Riparian
- Freshwater tidal

Low hydrological connectivity
N loads from deposition
Critical Loads 2.7-14 kg N/ha/y

Less sensitive

- Mangrove
- Salt marsh

High hydrological connectivity
N loads from runoff, wastewater
Critical Loads 63-400 kg N/ha/y

Bog Ecosystem

Fens in Massachusetts

Carnivorous Pitcher Plant
Atmospheric deposition typically constitutes ≤40% of total N loading to estuaries, although it can be higher in some locations.

**Biological Effects**

**Excess growth of primary producers** can lead to increased harmful algal bloom (HAB) outbreaks, hypoxia, block light to submerged aquatic vegetation (SAV), reduce SAV extent.

**Shifts in phytoplankton community structure**, increased reduced N relative to oxidized N favors some HAB species.

**Shifts in bacteria and archaea community structure** affected by N availability and form.

**Shift in benthic invertebrate community structure** linked to hypoxia. Some evidence for growth effects and shifts in taxonomic assemblages in shellfish. Shellfish can filter out N, possibly providing remediation.

**Fish reproduction and behavior**: Many species absent in conditions of low dissolved oxygen. Alteration of reproductive and behavioral endpoints associated with hypoxia/eutrophic conditions.
N-nutrient Enhanced Coastal Acidification

New topic since the 2008 ISA

Biogeochemical effects

- Dissolution of anthropogenic atmospheric CO$_2$ in coastal waters decreases pH.
- CO$_2$ produced by organic matter decomposition in eutrophic waters can contribute CO$_2$ to the water column, also decreasing pH.
- Contribution of N-nutrient enhanced vs. atmospheric anthropogenic CO$_2$ to decreasing pH is not known.

Biological effects

**Invertebrates**: Decreased calcification/increased dissolution of organisms that produce calcium carbonate shells (mollusks, bivalves, corals)

**Oyster production**: Documented declines on west coast linked to ocean acidification.

There was limited empirical evidence linking nutrient loading to coastal acidification in the most recent literature review, but this is a rapidly expanding area of research.
Sulfur
Non-acidifying Effects
Chapter 12
**S-nutrient Effects**

| S deposition and increased sulfide phytotoxicity in freshwater wetland plant species. |
| Increased injury, mortality in plants: *wild rice in MN*  
  *freshwater marsh in NY*  
  *sawgrass in Everglades* |
| Increased sulfide in water or wet soils |
| Increased [SO₄] in water or wet soil |
| Increased sulfur-reducing microbe abundance/activity |

**S deposition and increased methylation of Hg in wetland and aquatic ecosystems**

| Increased [MeHg] or %MeHg in water, wet soil, or aquatic plants:  
  *wetlands, reservoirs, lakes, streams, rivers* |

**Increased Hg in food web**

| Increased Hg in invertebrates  
  *Mn bog, WI lake* |
| Increased Hg in rice  
  *FW marsh, CA* |
| Increased Hg in birds  
  *USGS report* |
| Increased Hg in fish  
  *Everglades marsh, TX reservoirs, SD lakes, WI lake, Isle Royale lakes, Voyageurs NP lakes* |

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**2008 ISA**  
Causal relationship

**Current Draft ISA**  
Causal relationship

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**S deposition and increased methylation of Hg in wetland and aquatic ecosystems where the value of other factors is within adequate range for methylation.**

**Not included**  
Causal relationship
Chapter 13 describes how climate, specifically temperature and precipitation, alter ecosystem response to nitrogen and sulfur deposition.

- CASAC made the suggestion to include this topic in their comments on the draft Integrated Review Plan in April 2016.

Chapter 14 is a summary of recent advances in ecosystem services frameworks, studies that evaluate the effects of anthropogenic nitrogen on ecosystem services and several “profiles” of threatened and endangered species for which nitrogen is listed as a stressor.
Appendices

Include:

• Case studies at five locations in the U.S. (Southern California, Northeastern U.S., Rocky Mountain National Park, Southern Appalachia, Tampa Bay) are included in Appendix C to support the Risk and Exposure Assessment and the Policy Assessment.

• Review of evidence for effects of particulate matter (PM) on ecological receptors
## Next Steps

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<th>NOxSOxPM-ECO NAAQS review</th>
<th>Timeline</th>
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<td>1&lt;sup&gt;st&lt;/sup&gt; draft Integrated Science Assessment (ISA) public release</td>
<td>March 30, 2017</td>
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<td>Clean Air Scientific Advisory Committee (CASAC) meeting to review 1&lt;sup&gt;st&lt;/sup&gt; draft</td>
<td>May 24-25, 2017</td>
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<td>Risk and Exposure Assessment (REA) planning document</td>
<td>2018</td>
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<td>2&lt;sup&gt;nd&lt;/sup&gt; draft ISA targeted for public release</td>
<td>2018</td>
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<tr>
<td>Final ISA targeted for public release</td>
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