Surface Water Quality is Improving due to Declining Atmospheric N Deposition*

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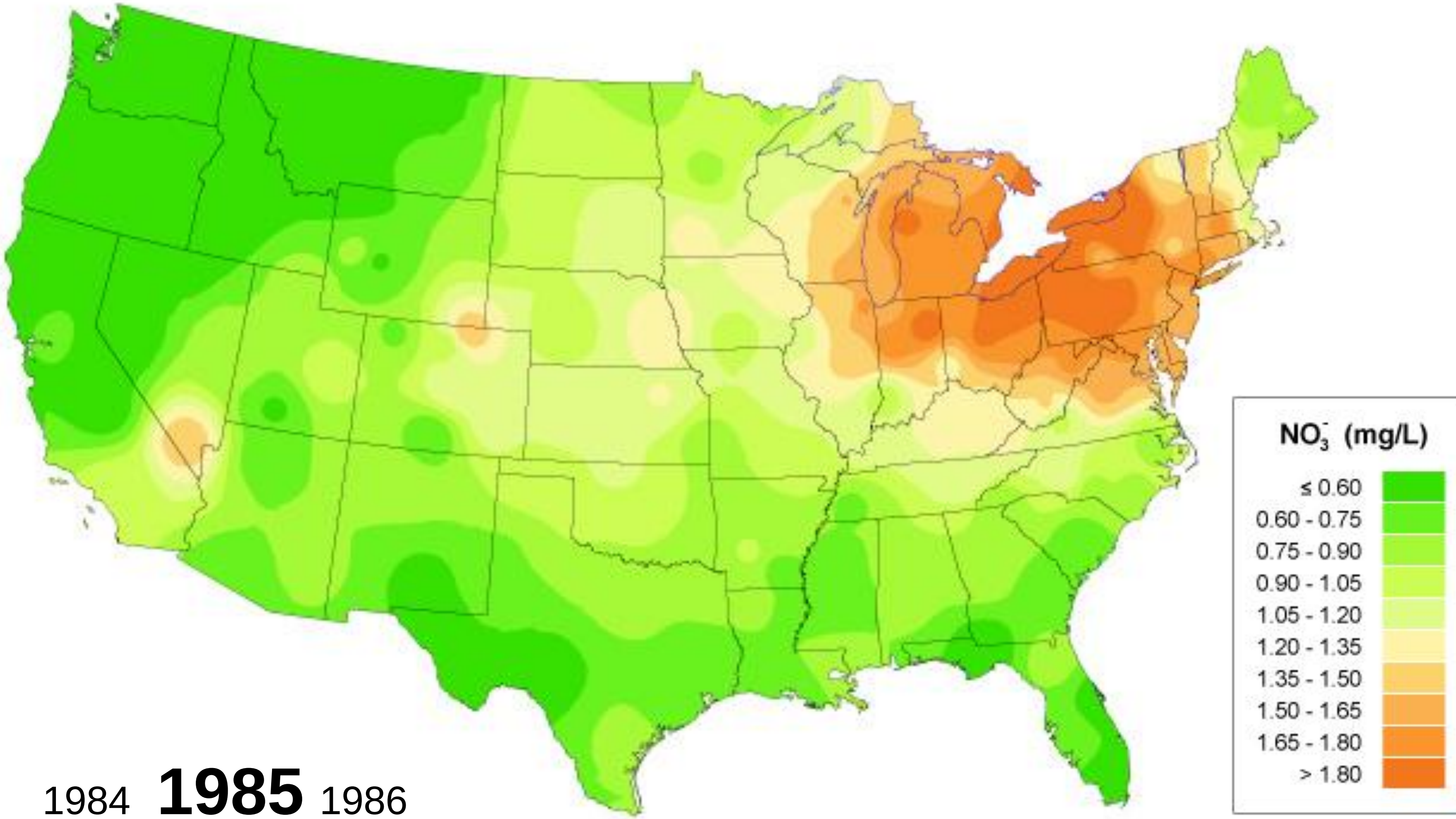
Research Questions

- What contemporary water quality changes are occurring in predominantly-forested watersheds of the Chesapeake Bay basin?
  - Acid-base conditions (i.e., acid neutralizing capacity)
  - Nutrient (esp. N) concentrations/loads
- What are the primary drivers of these changes?
  - Atmospheric deposition/emission controls
  - Forest disturbances
  - Land management
- How can the results of the research be used to inform water quality management at the river basin scale?

Data/Methods

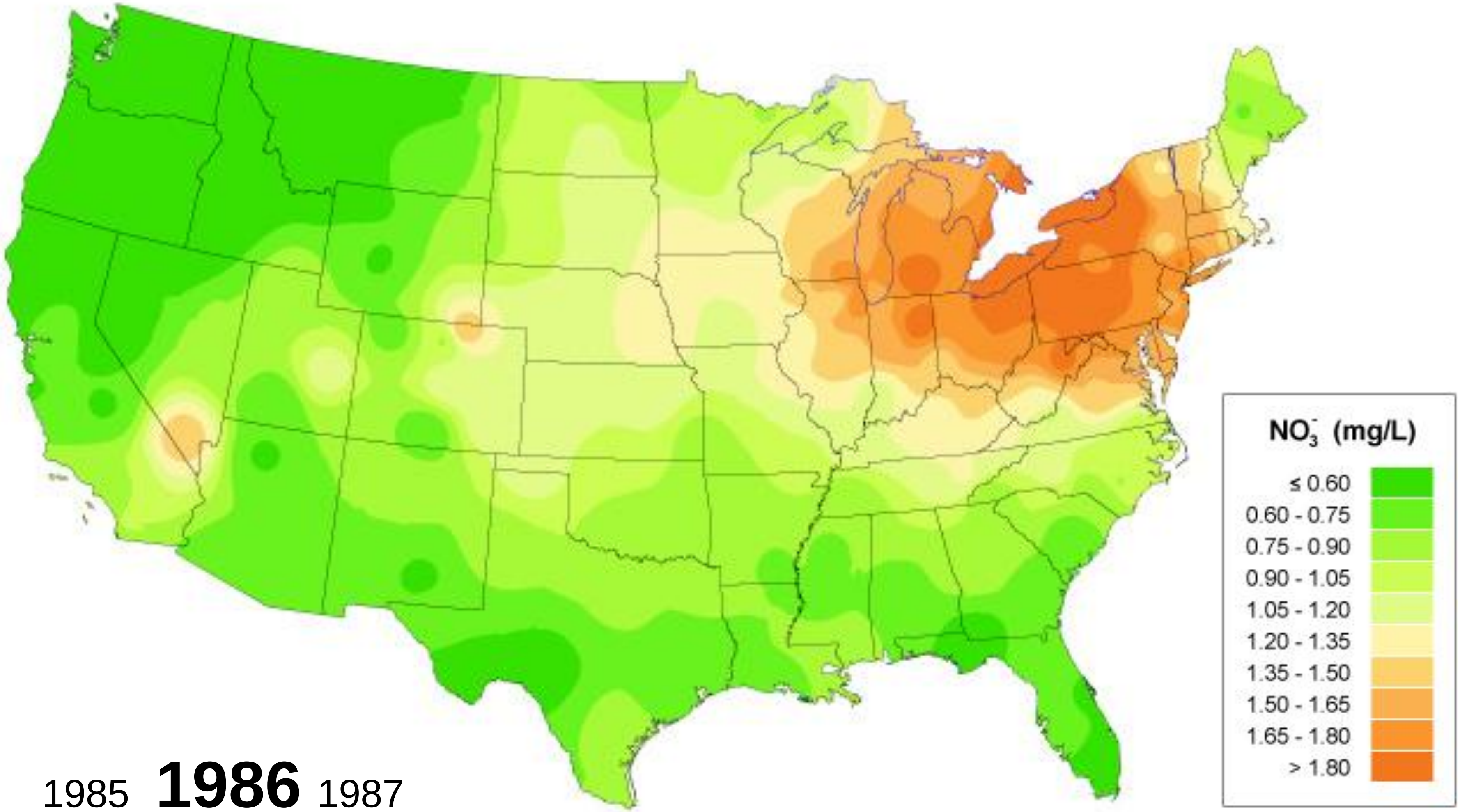
- Long-term nitrate-N concentration (mostly from state databases) and daily discharge (mostly USGS NWIS) data
- LOADEST model: 7-parameter regression model to estimate continuous daily loads (standard method)
- Computation of annual average loads and discharge-weighted concentrations (*not* flow-adjusted concentrations)
- NADP: extracted annual areal N deposition for each watershed
- Simple linear regression to estimate trends (slopes) and p levels

Nitrate Ion Concentrations
1985-2008



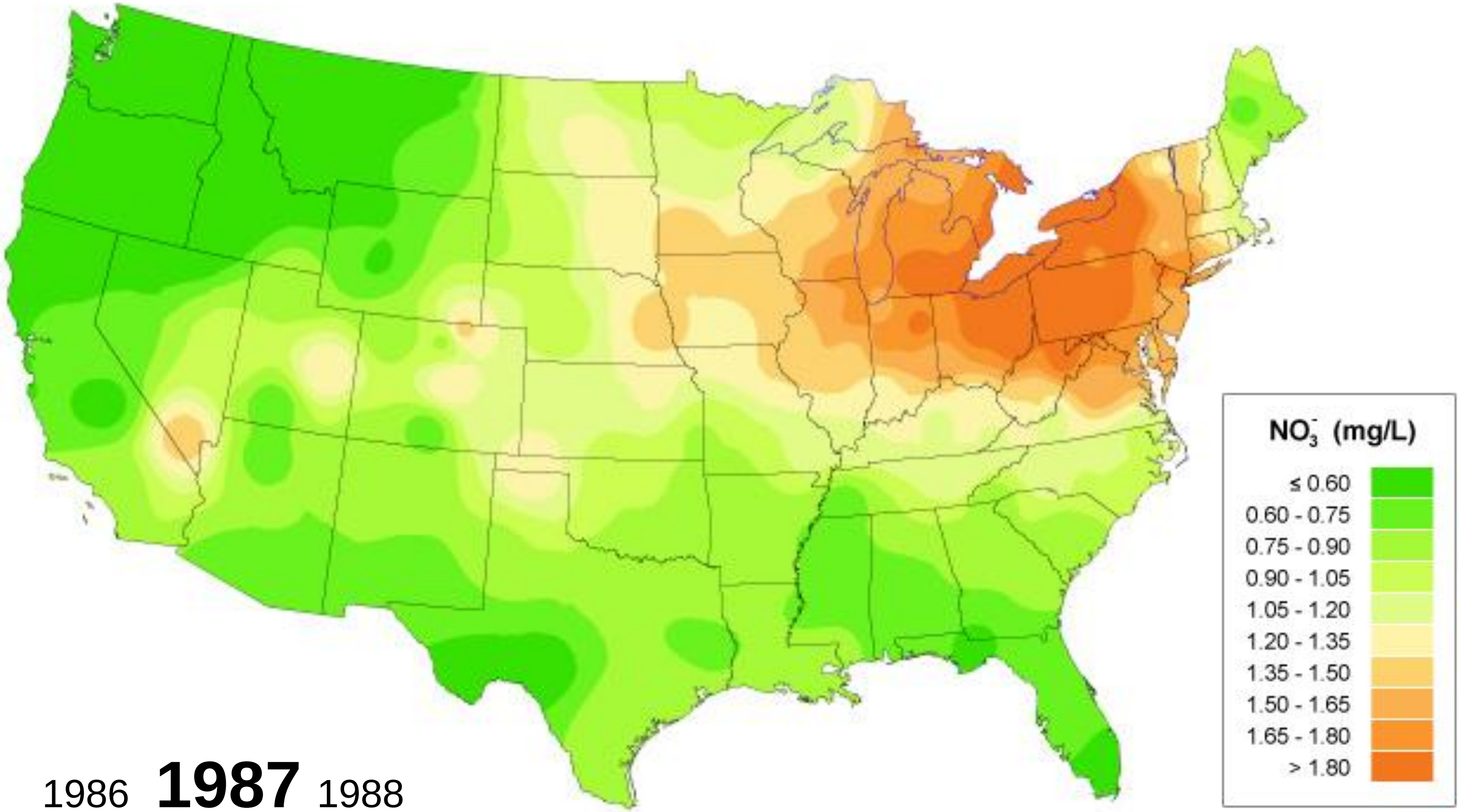
1984 **1985** 1986

Nitrate Ion Concentrations
1985-2008



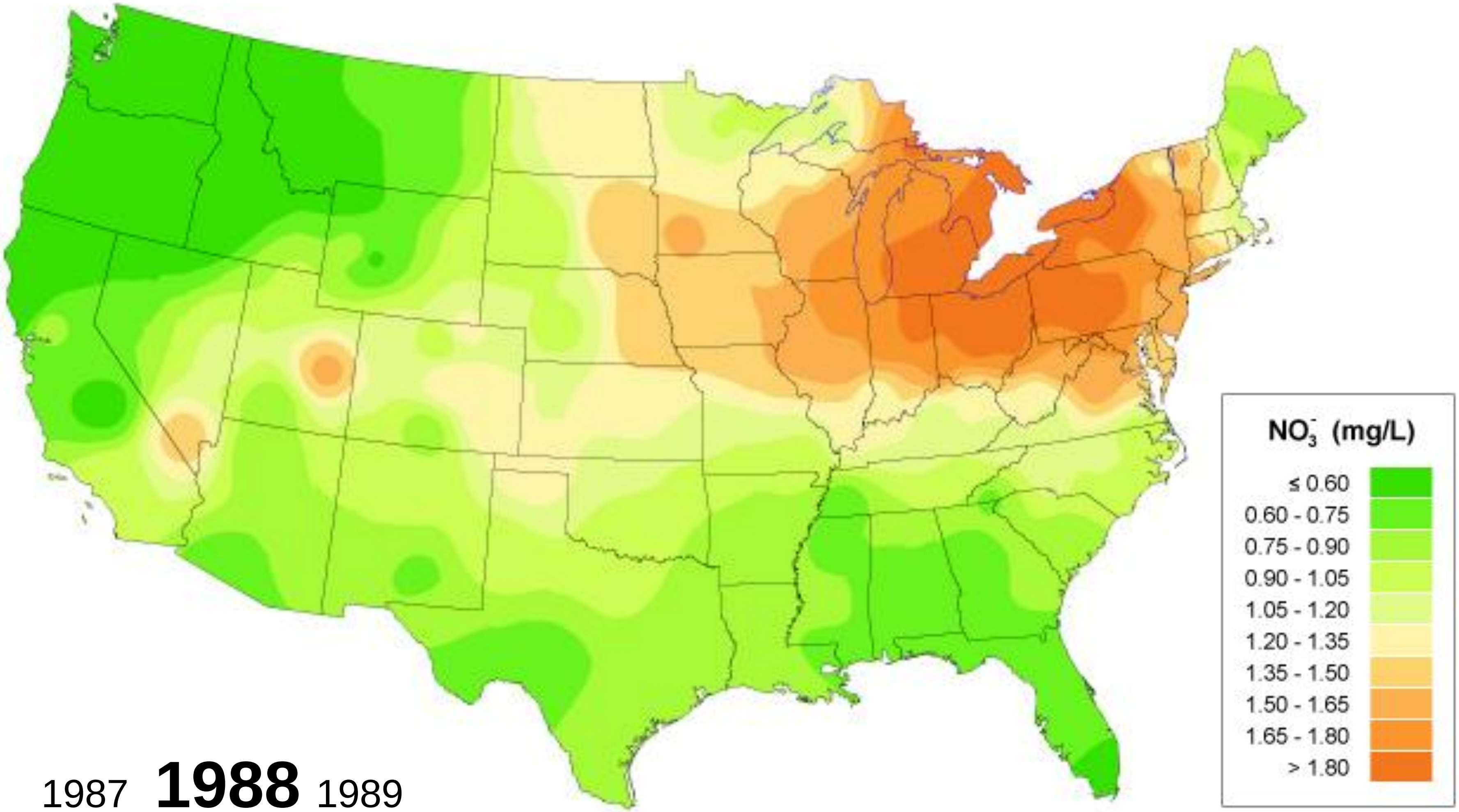
1985 **1986** 1987

Nitrate Ion Concentrations 1985-2008



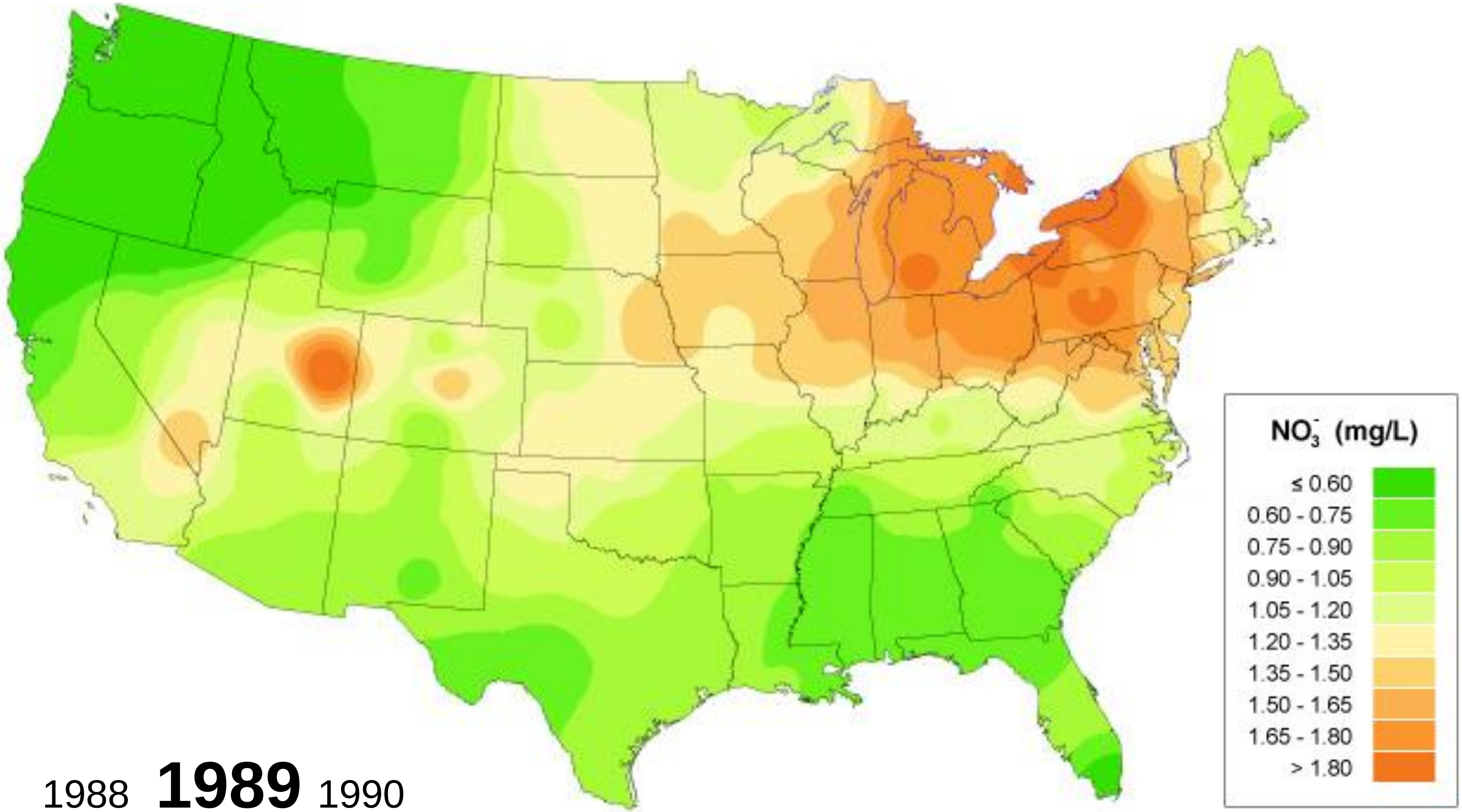
1986 **1987** 1988

Nitrate Ion Concentrations
1985-2008



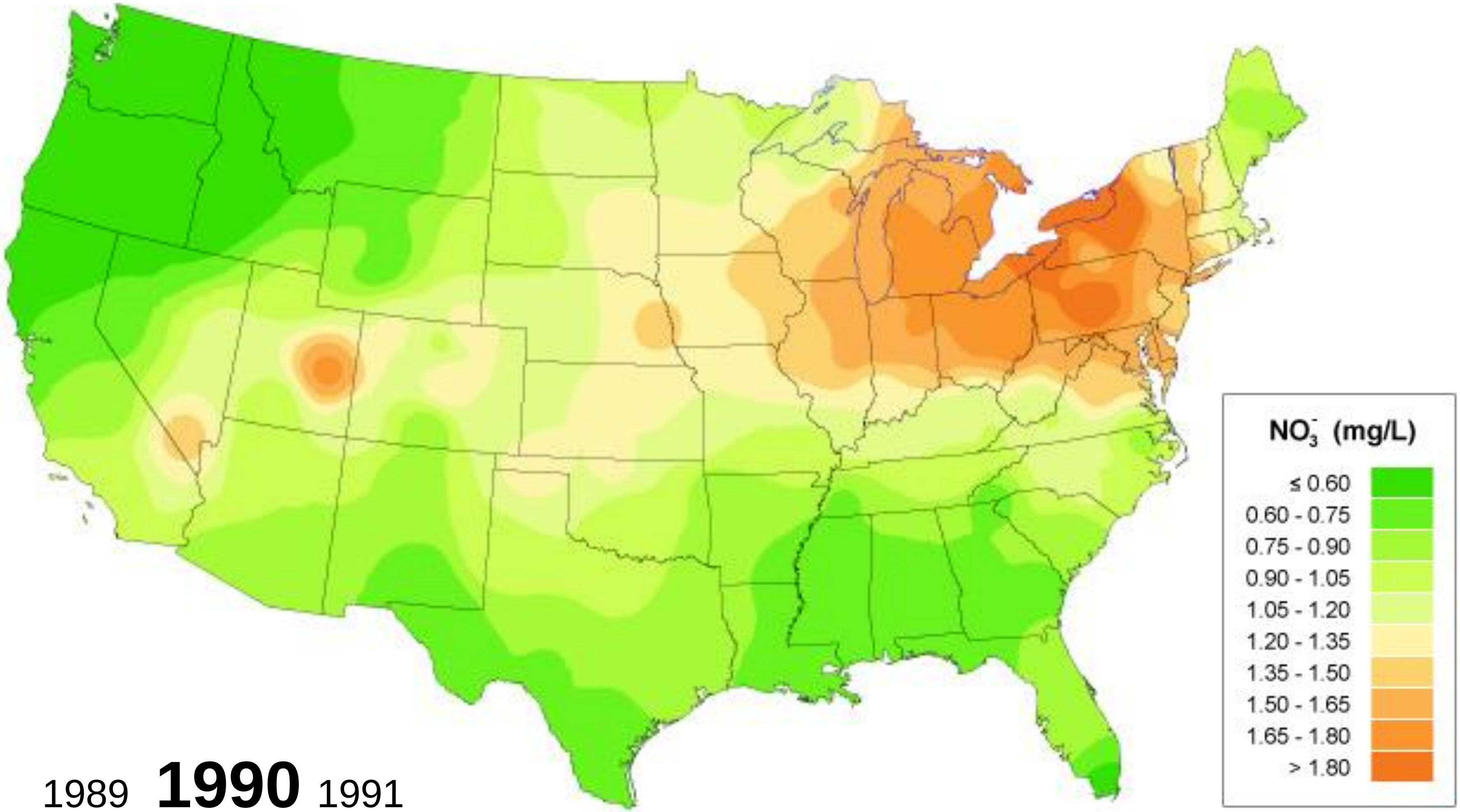
1987 **1988** 1989

Nitrate Ion Concentrations 1985-2008



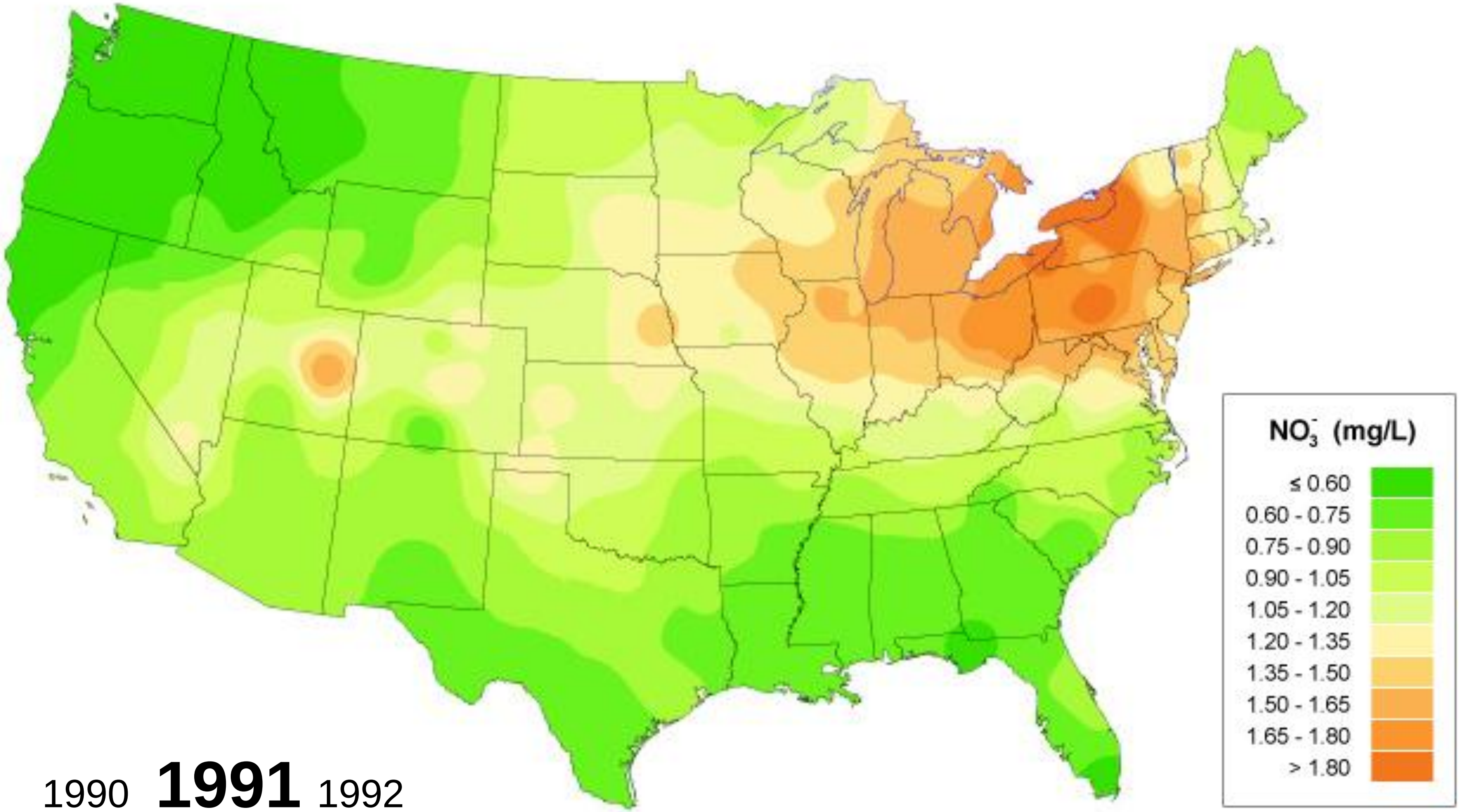
1988 **1989** 1990

Nitrate Ion Concentrations 1985-2008



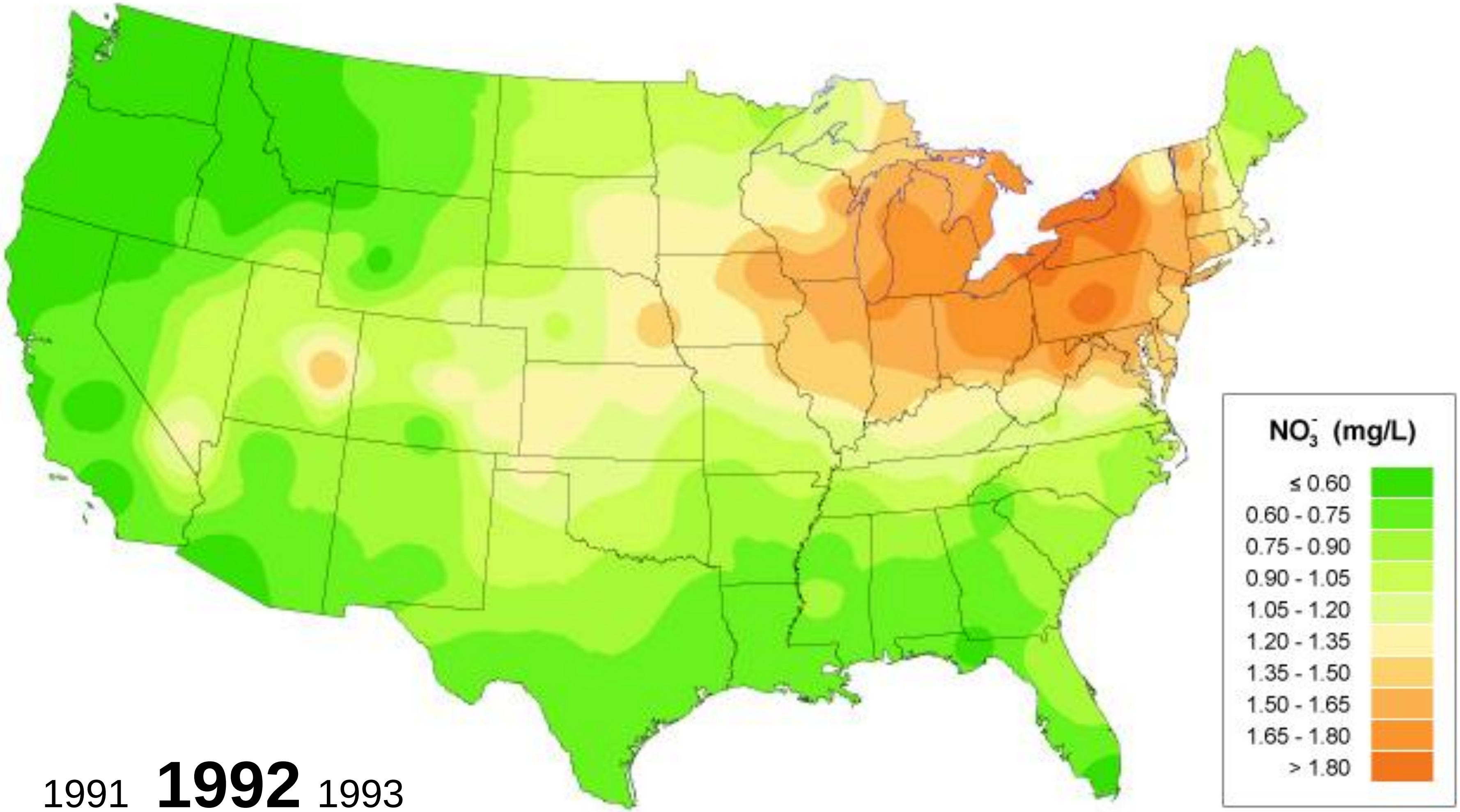
1989 **1990** 1991

Nitrate Ion Concentrations
1985-2008



1990 **1991** 1992

Nitrate Ion Concentrations 1985-2008



1991 **1992** 1993

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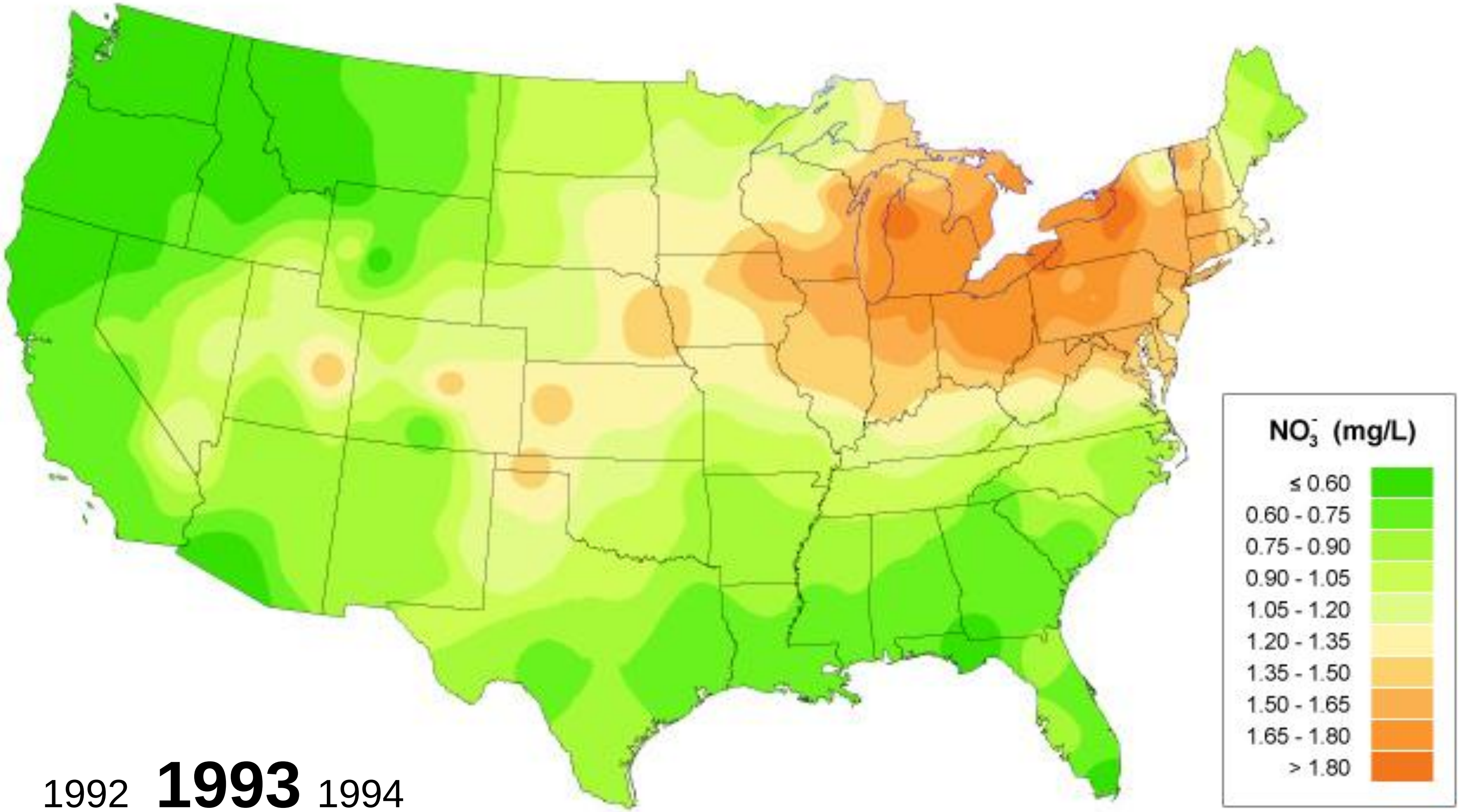
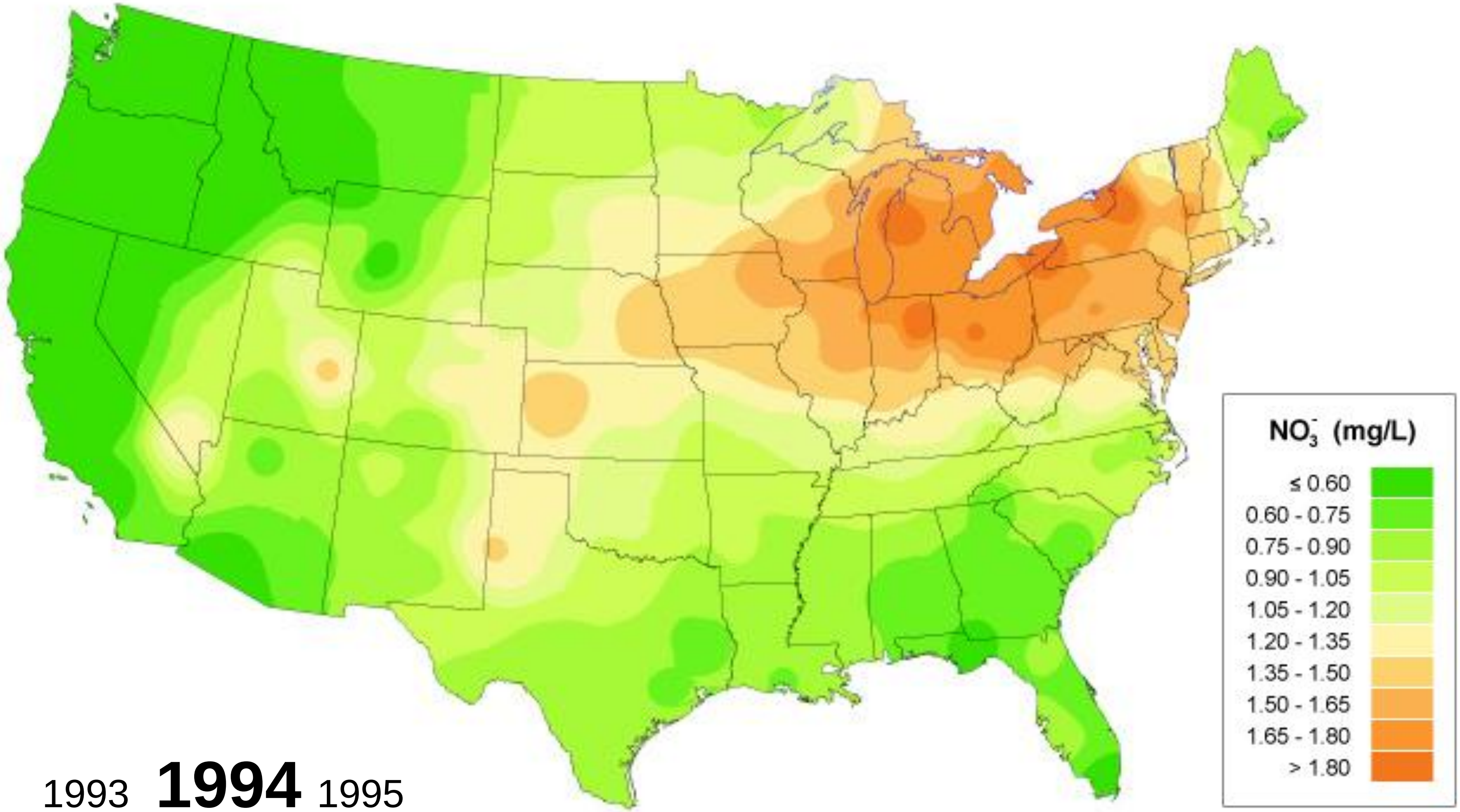


1992 **1993** 1994

Nitrate Ion Concentrations 1985-2008



1993 **1994** 1995

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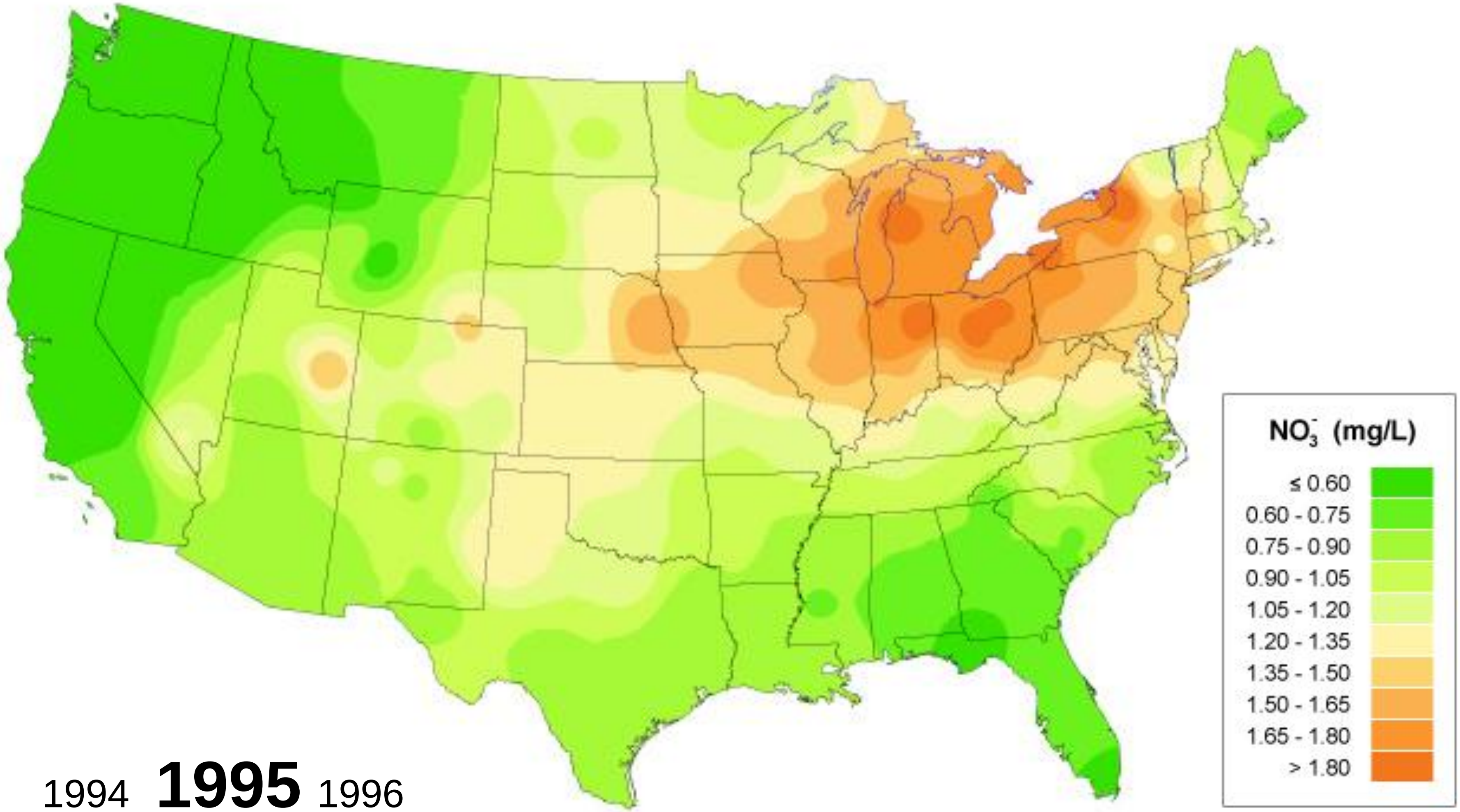
1985-2008



1994 **1995** 1996

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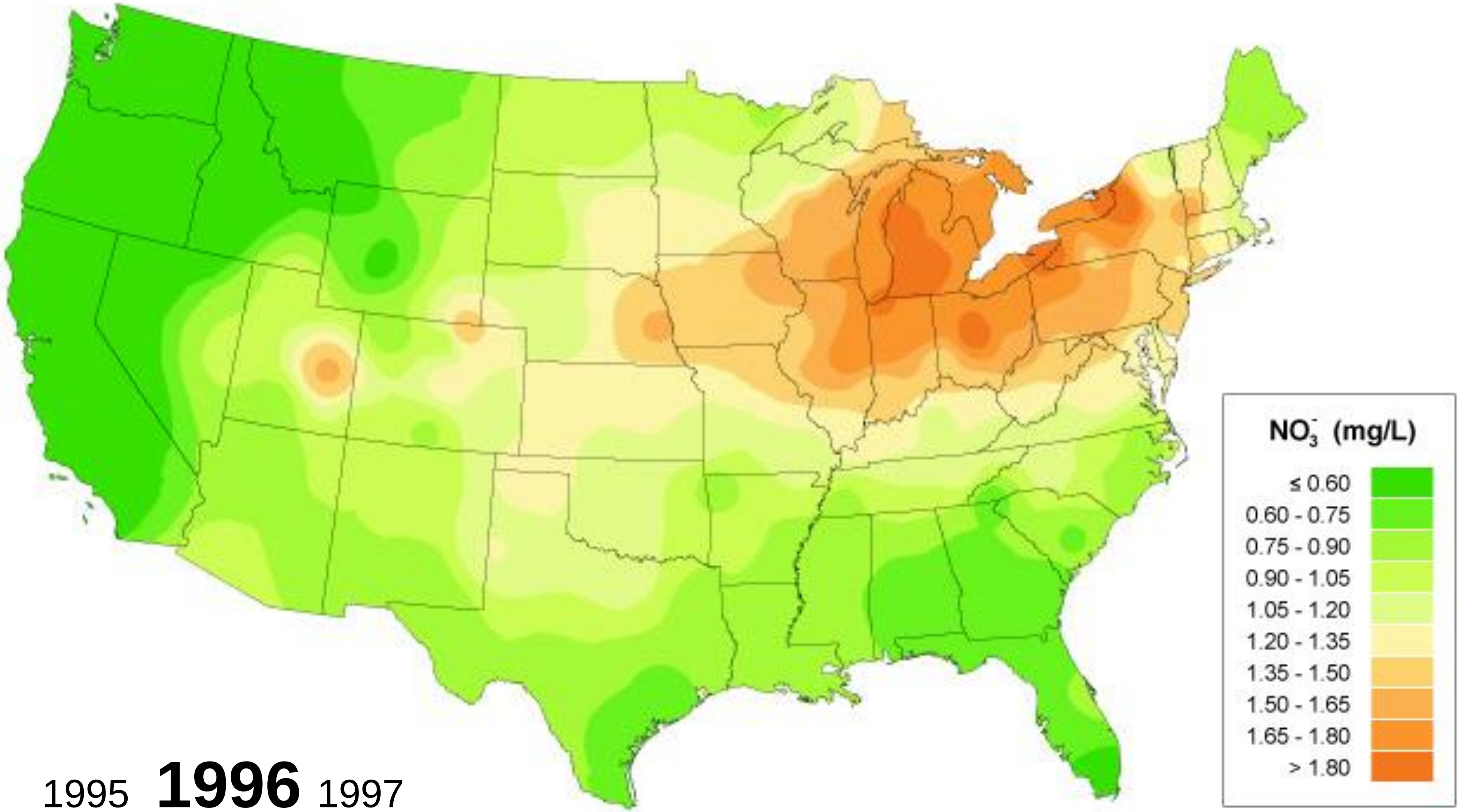
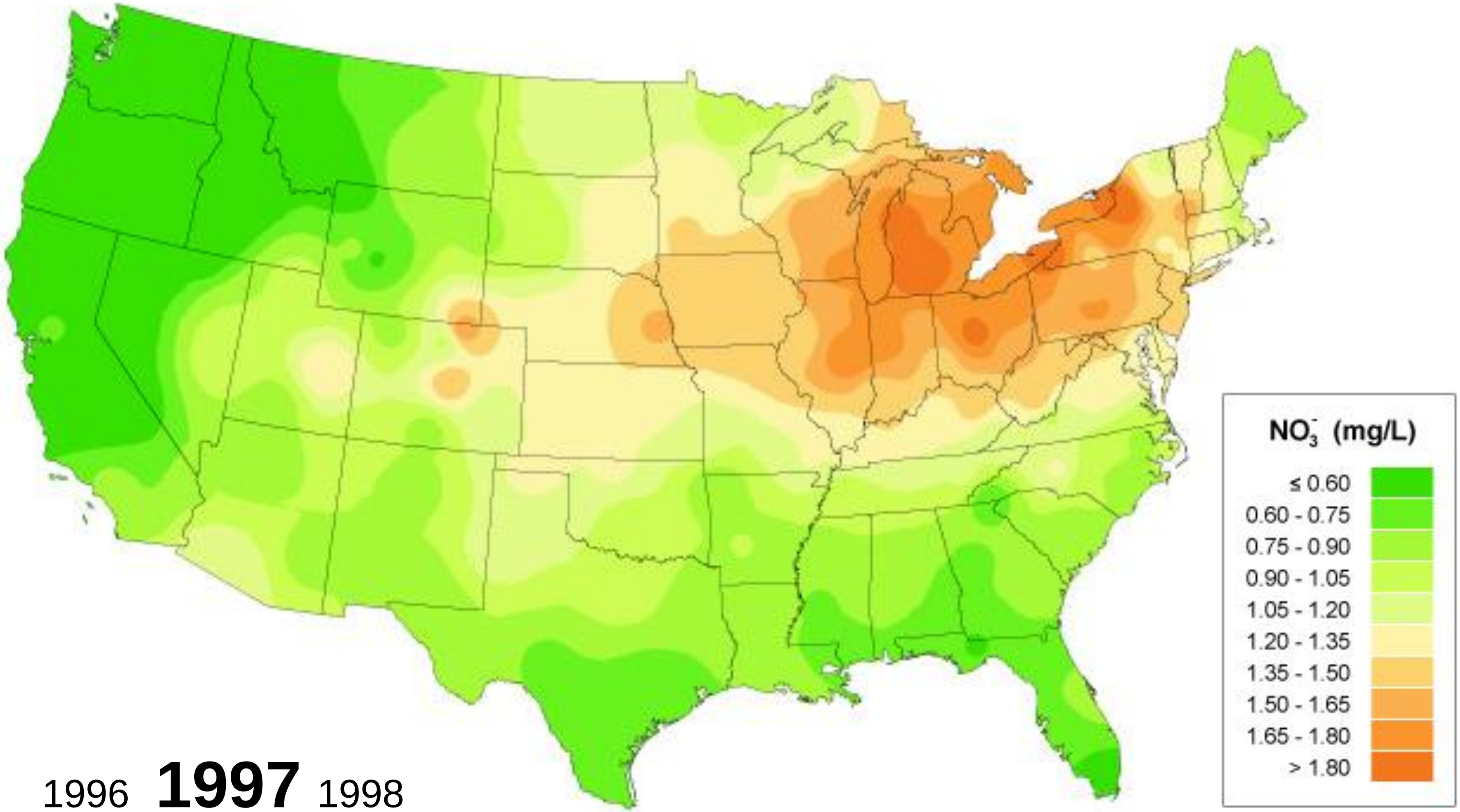


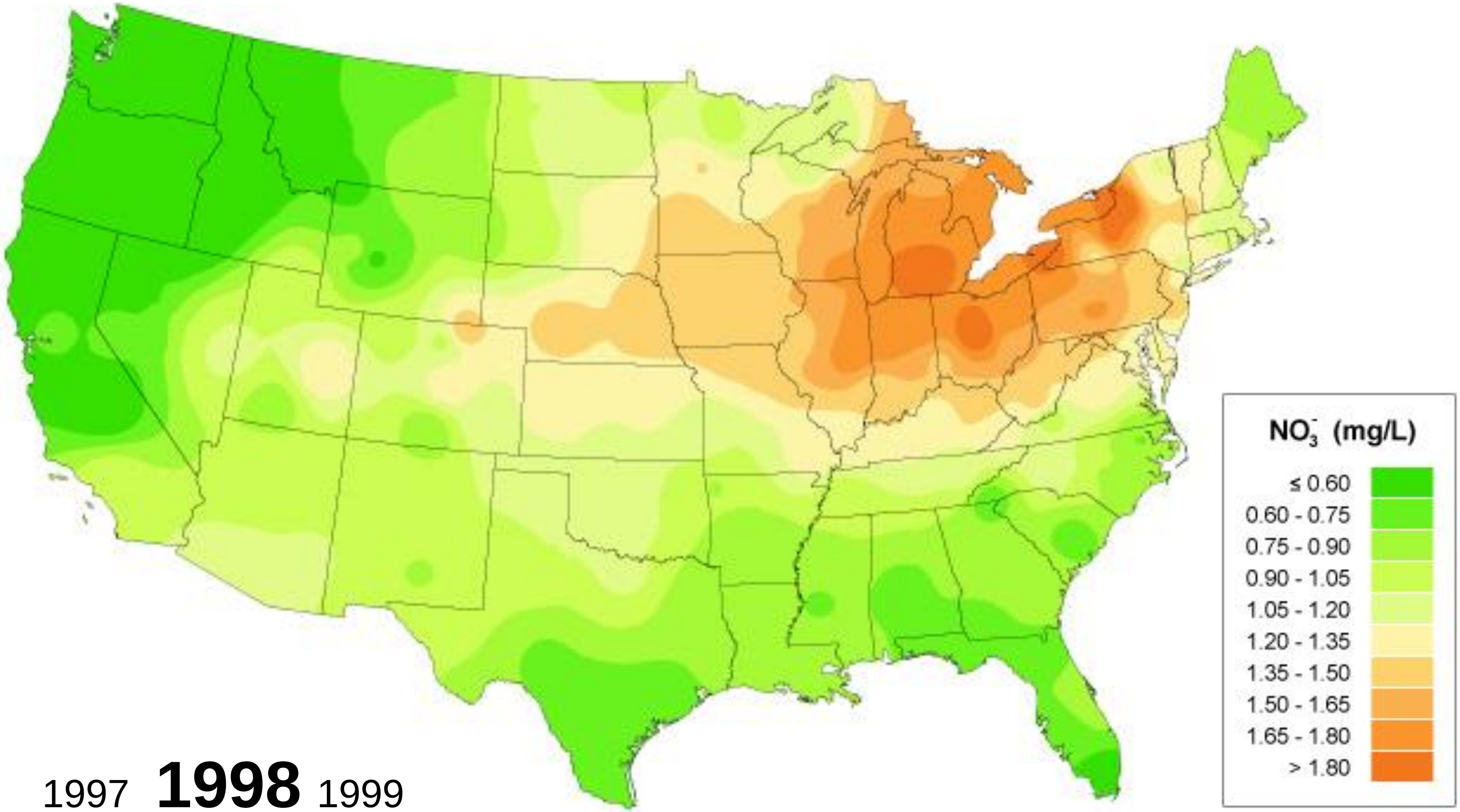
1995 **1996** 1997

Nitrate Ion Concentrations 1985-2008



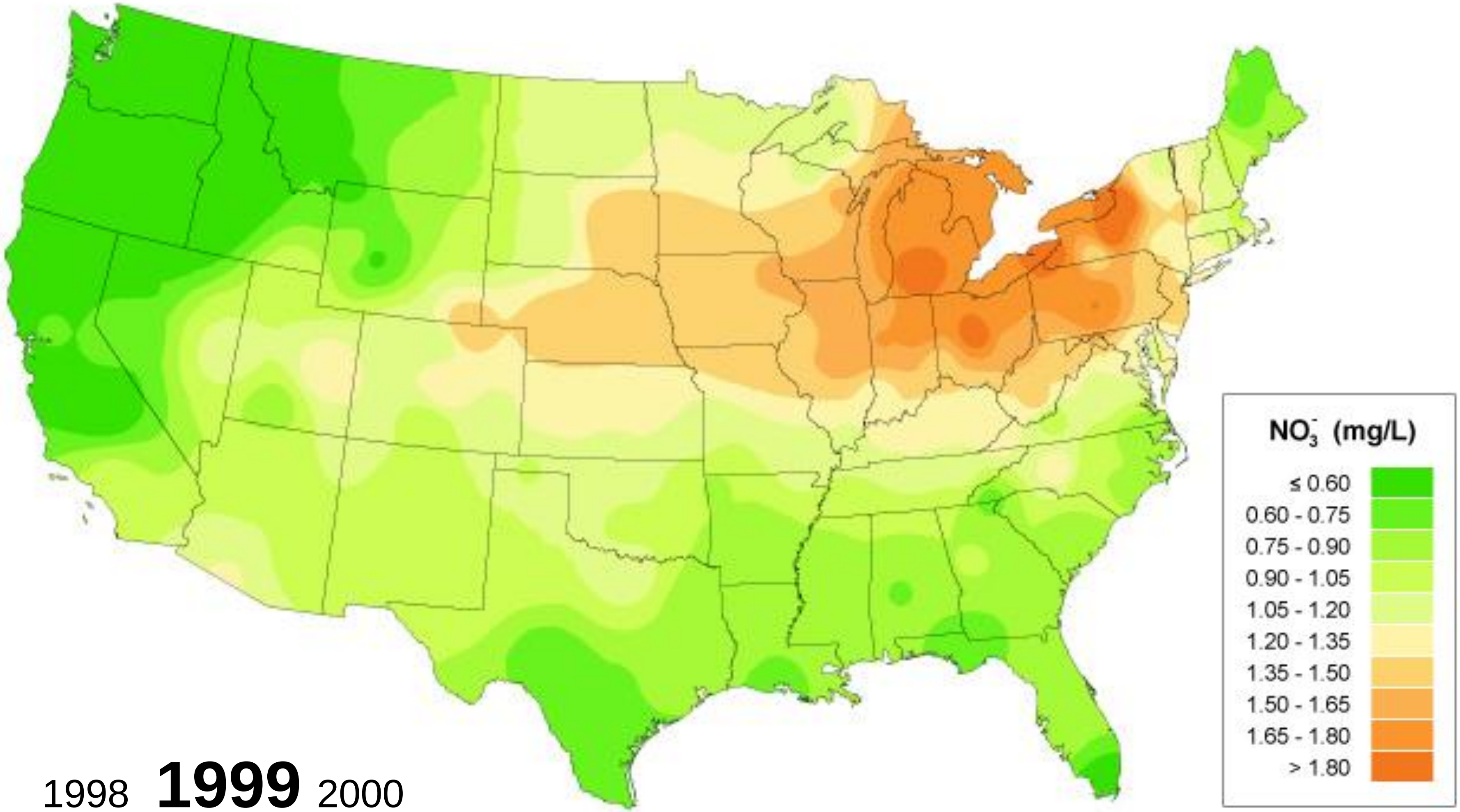
1996 **1997** 1998

Nitrate Ion Concentrations 1985-2008



1997 **1998** 1999

Nitrate Ion Concentrations 1985-2008



1998 **1999** 2000

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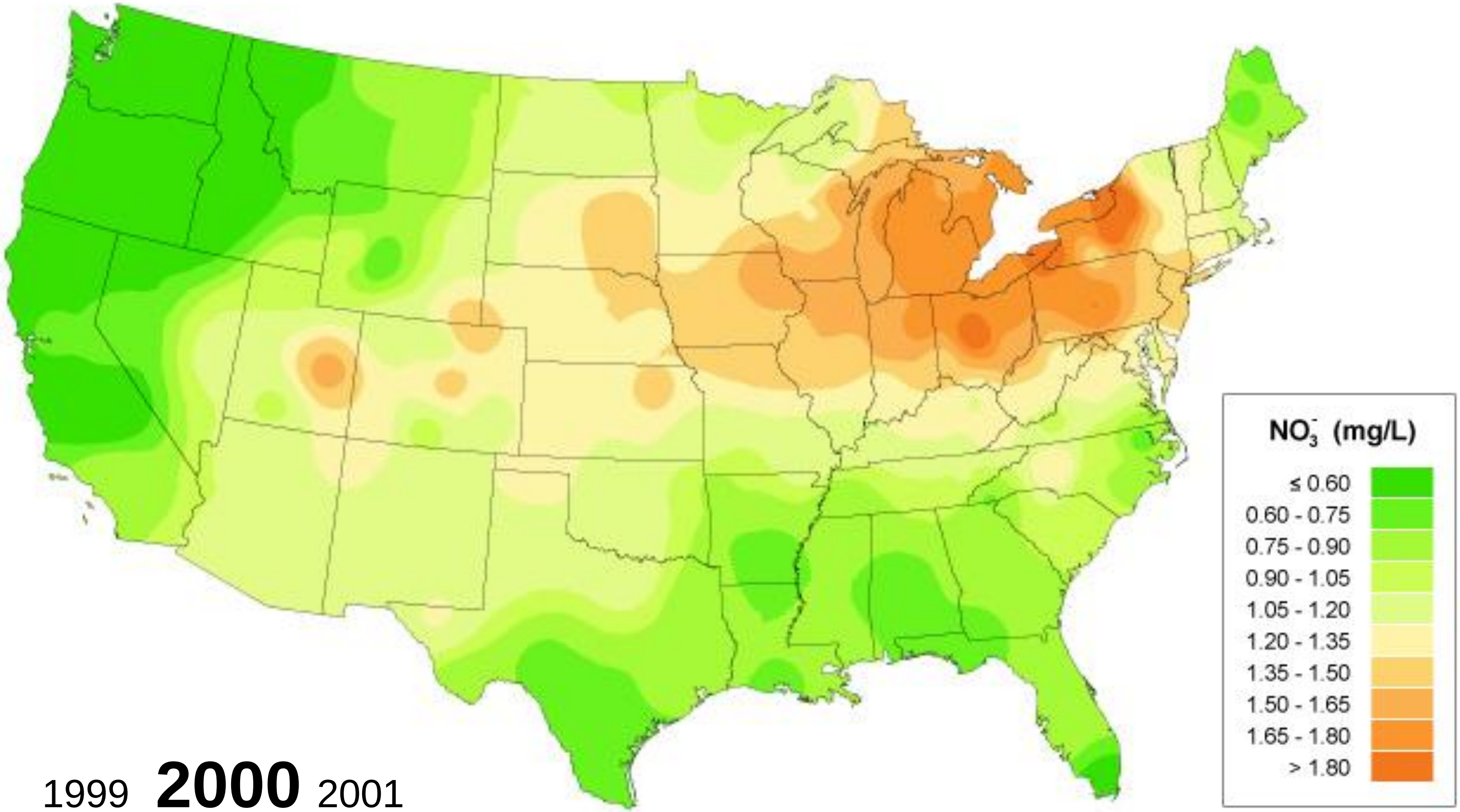
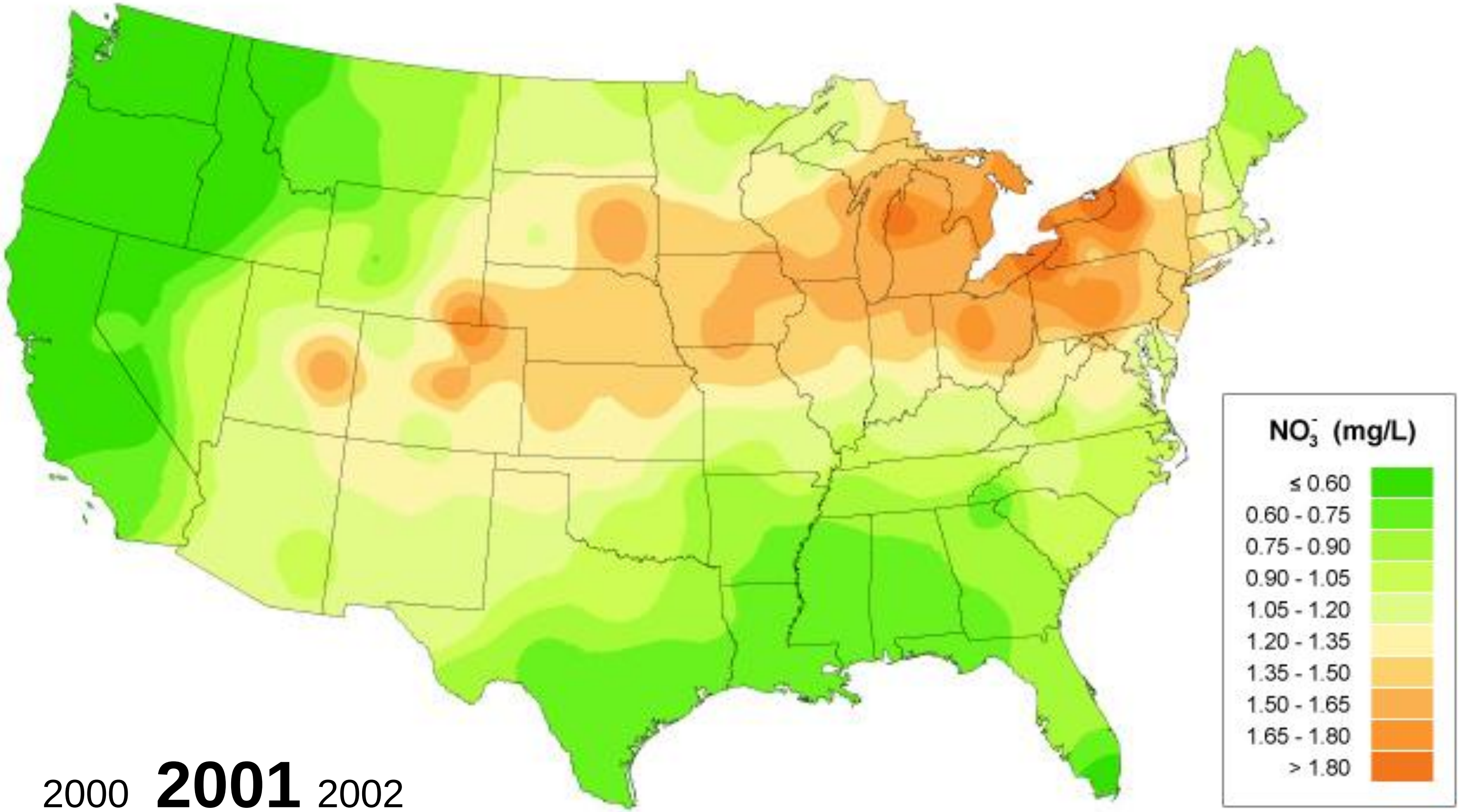
1985-2008



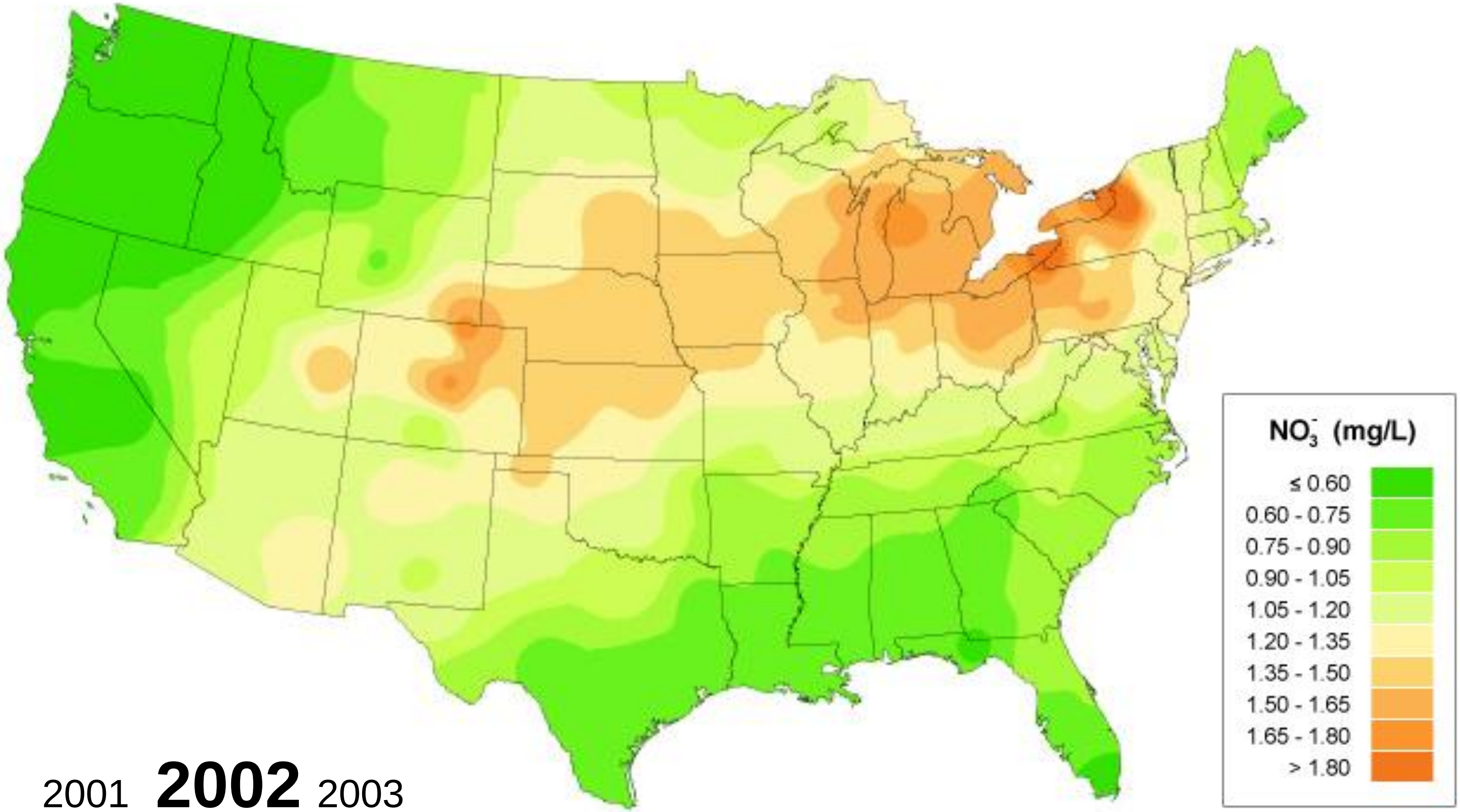
1999 **2000** 2001

Nitrate Ion Concentrations
1985-2008



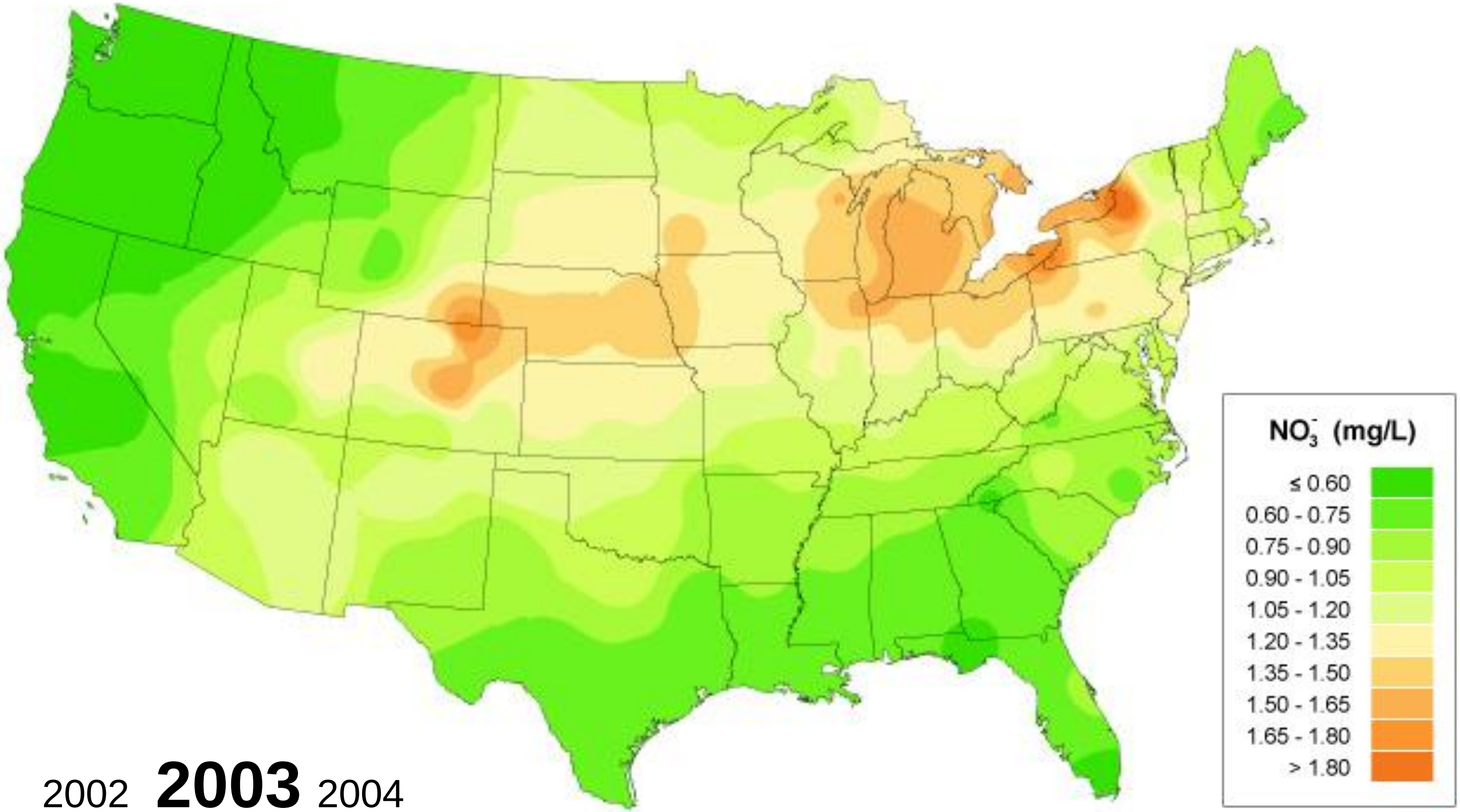
2000 **2001** 2002

Nitrate Ion Concentrations 1985-2008



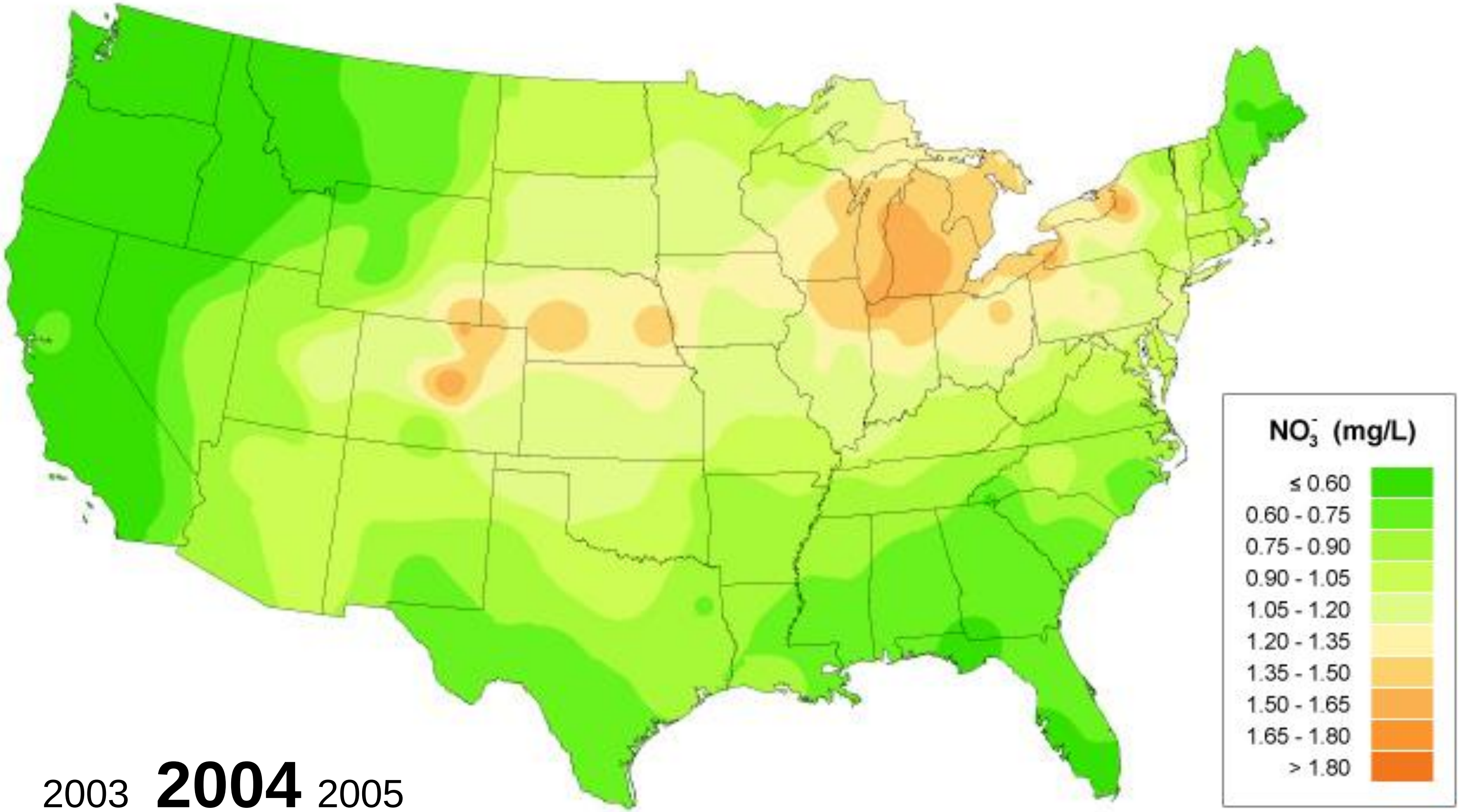
2001 **2002** 2003

Nitrate Ion Concentrations
1985-2008



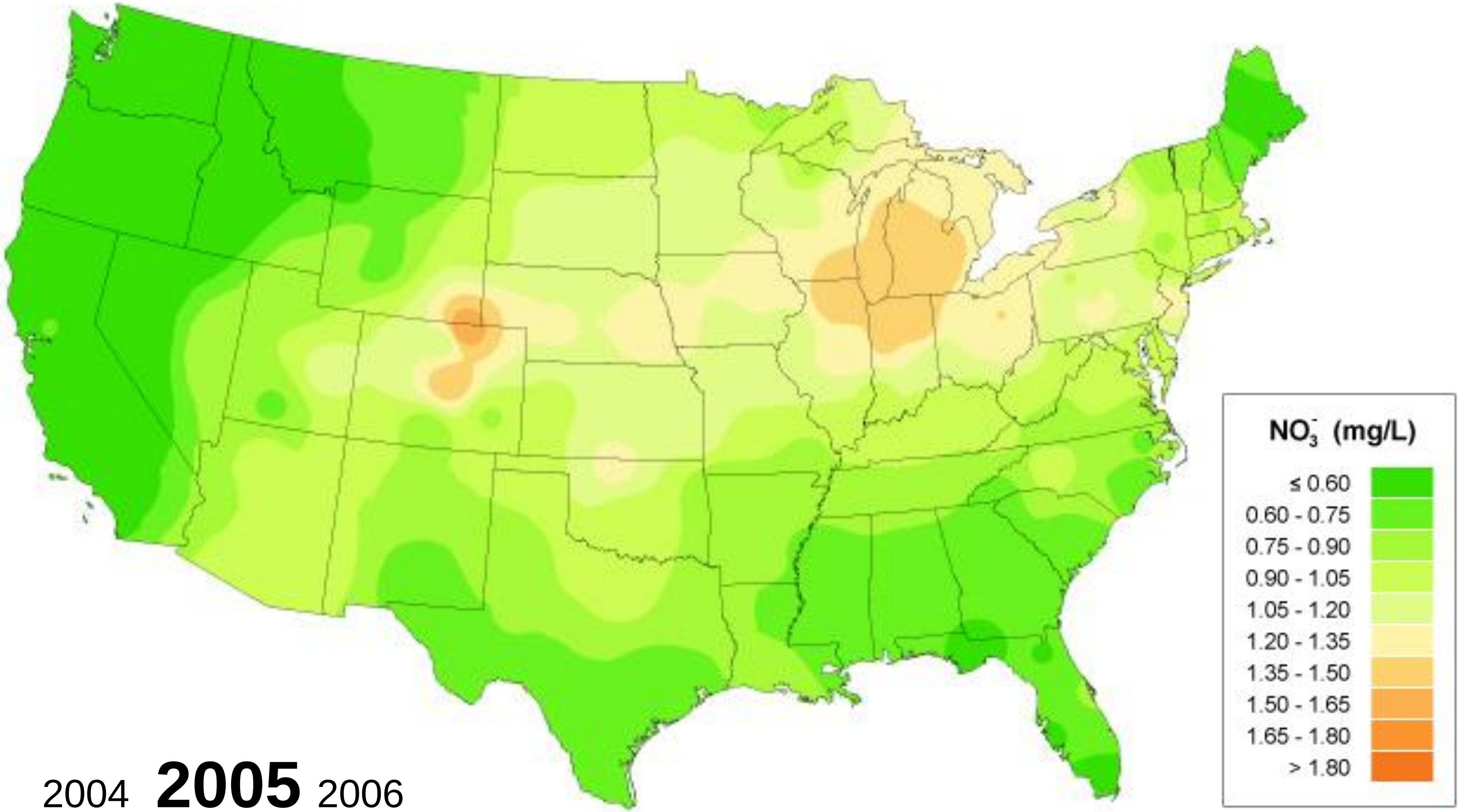
2002 **2003** 2004

Nitrate Ion Concentrations 1985-2008



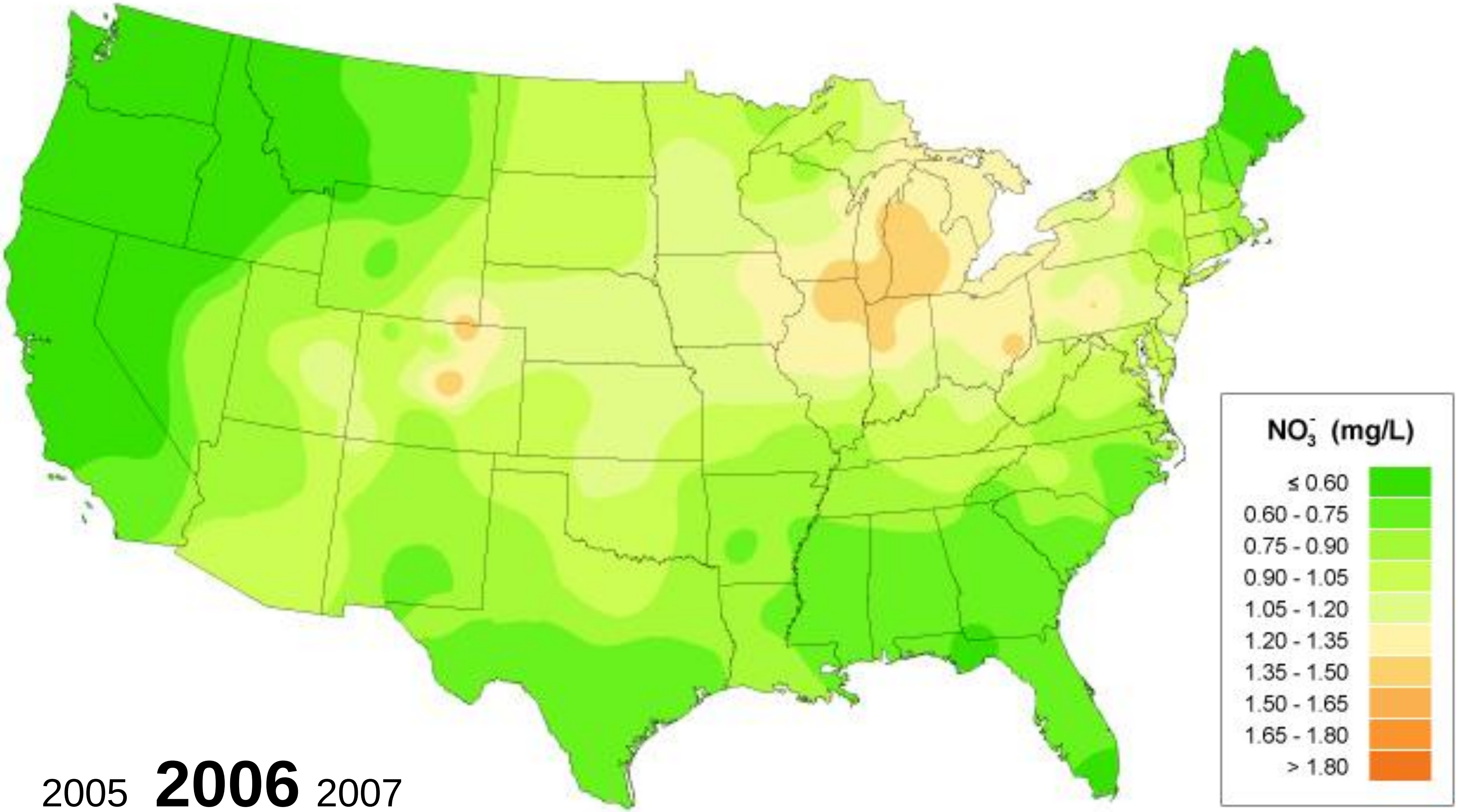
2003 **2004** 2005

Nitrate Ion Concentrations
1985-2008



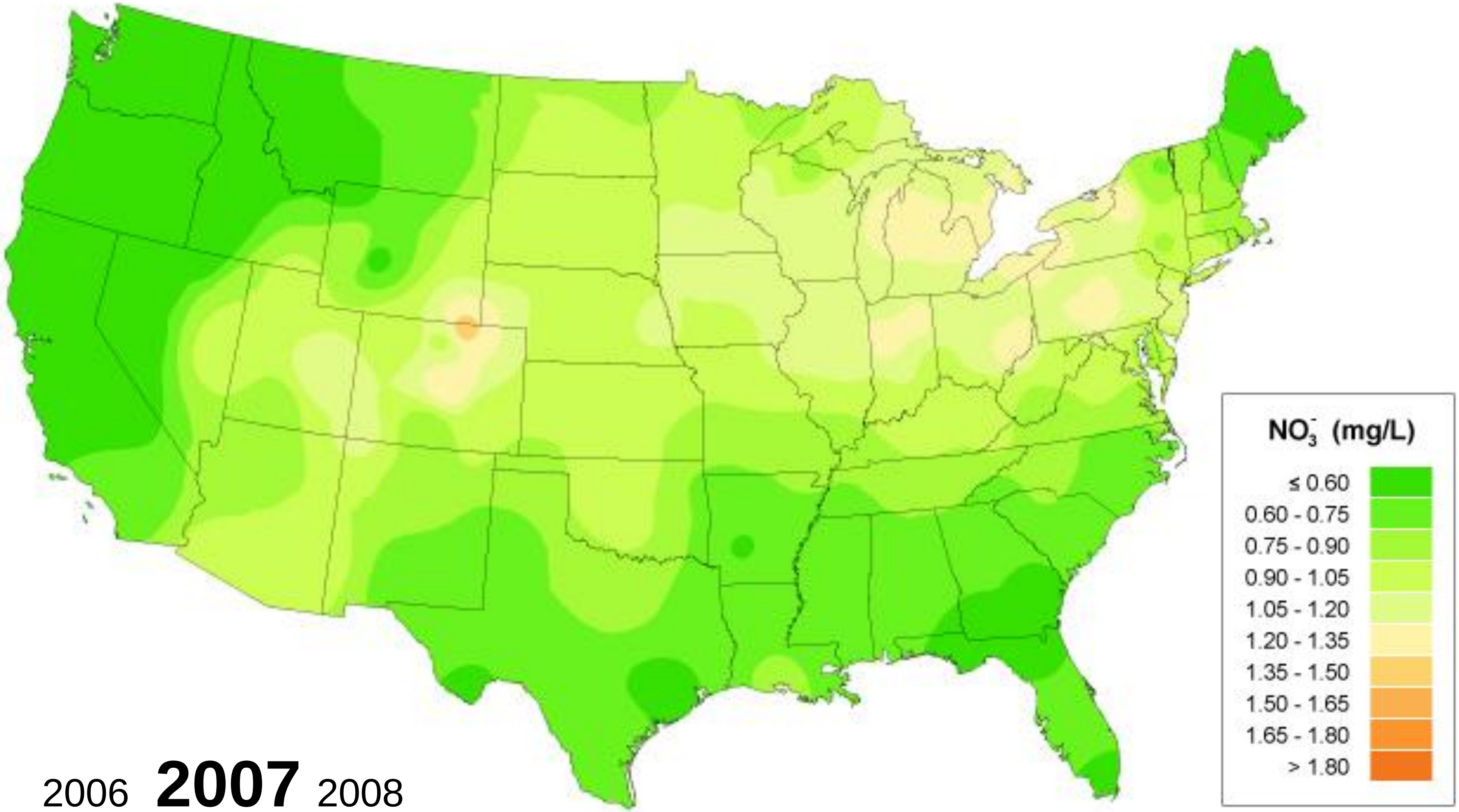
2004 **2005** 2006

Nitrate Ion Concentrations
1985-2008



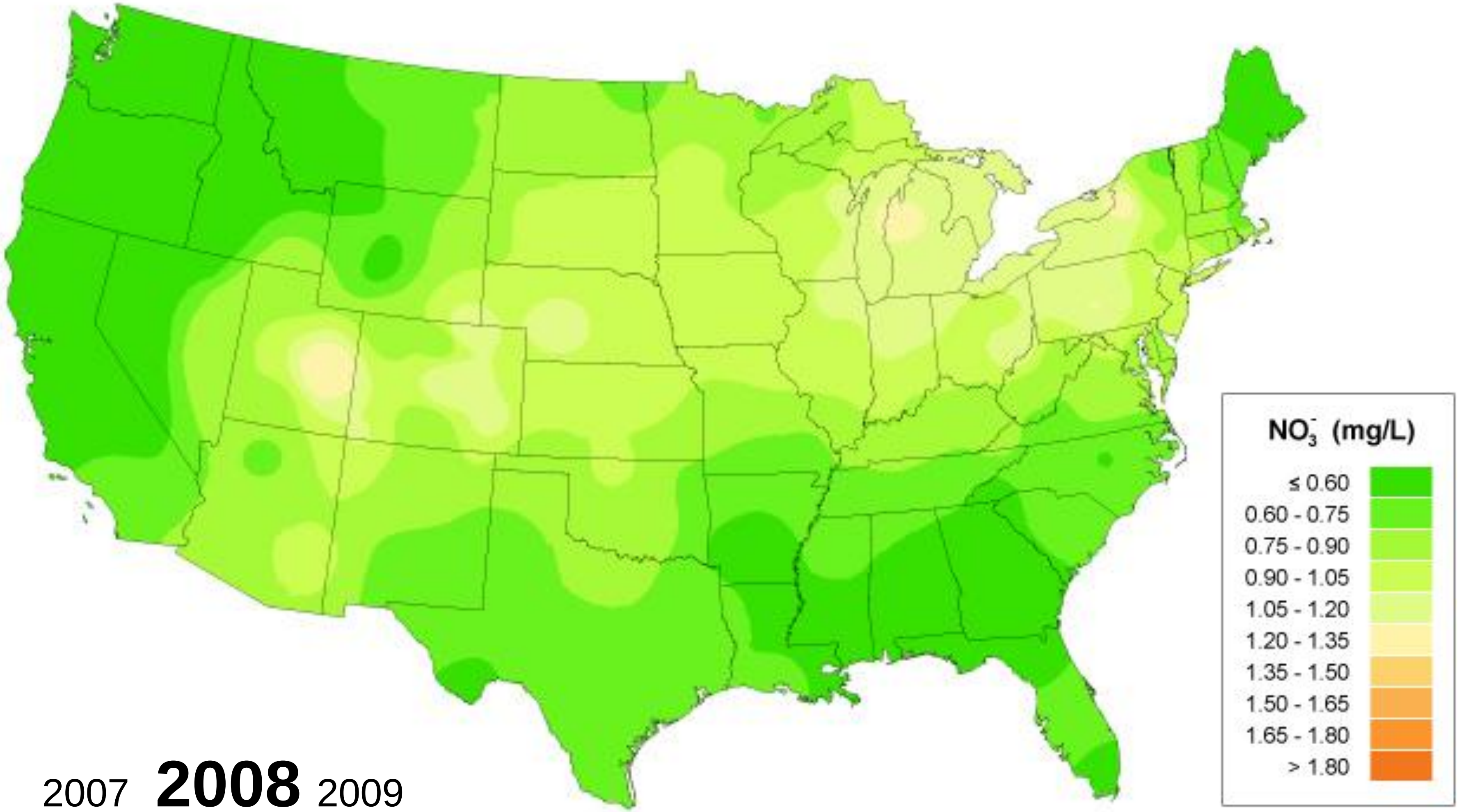
2005 **2006** 2007

Nitrate Ion Concentrations 1985-2008



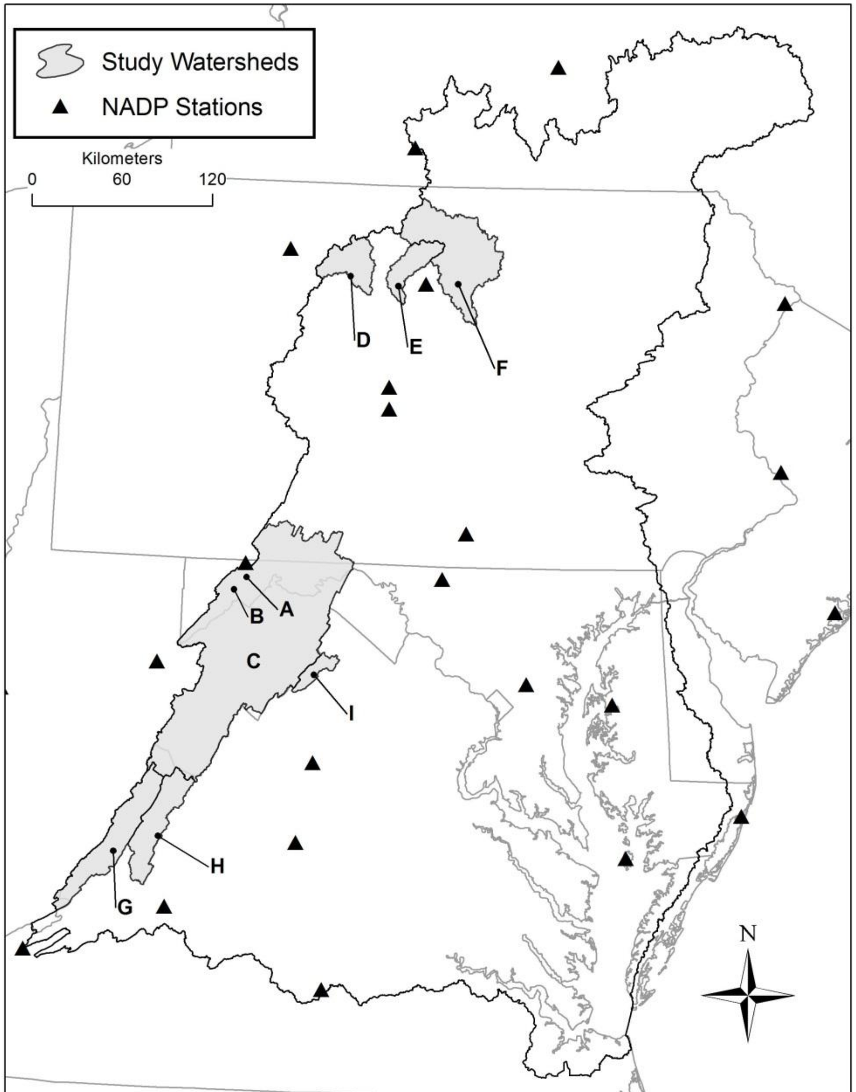
2006 **2007** 2008

Nitrate Ion Concentrations
1985-2008



2007 **2008** 2009

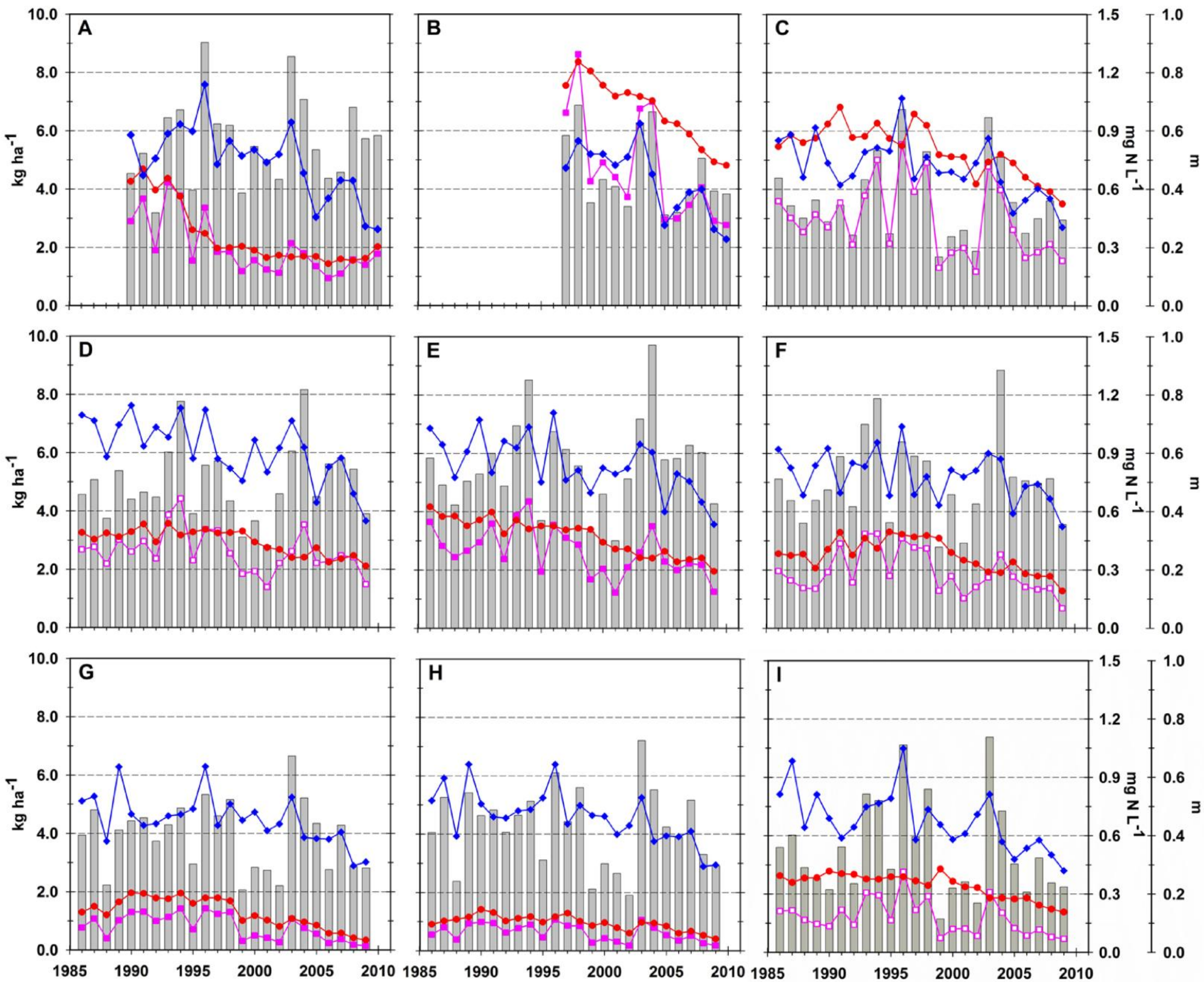
Study Sites: Nine Predominantly (>75%) Forested Watersheds and NADP Stations



	Watershed	Area (km²)
A	Upper Big Run, MD	1.63
B	Black Lick, MD	5.64
C	Potomac River at Hancock, MD	10,550
D	Driftwood Branch Sinnemahoning Creek at Sterling Run, PA	704
E	Kettle Creek near Westport, PA	603
F	Pine Creek below Little Pine Creek near Waterville, PA	2,440
G	Jackson River below Dunlap Creek at Covington, VA	1,590
H	Cowpasture River near Clifton Forge, VA	1,190
I	Cedar Creek near Winchester, VA	267

Eshleman *et al.*, 2013

Results: trends in nitrate-N concentration, nitrate-N yield, IN deposition, and runoff in nine watersheds



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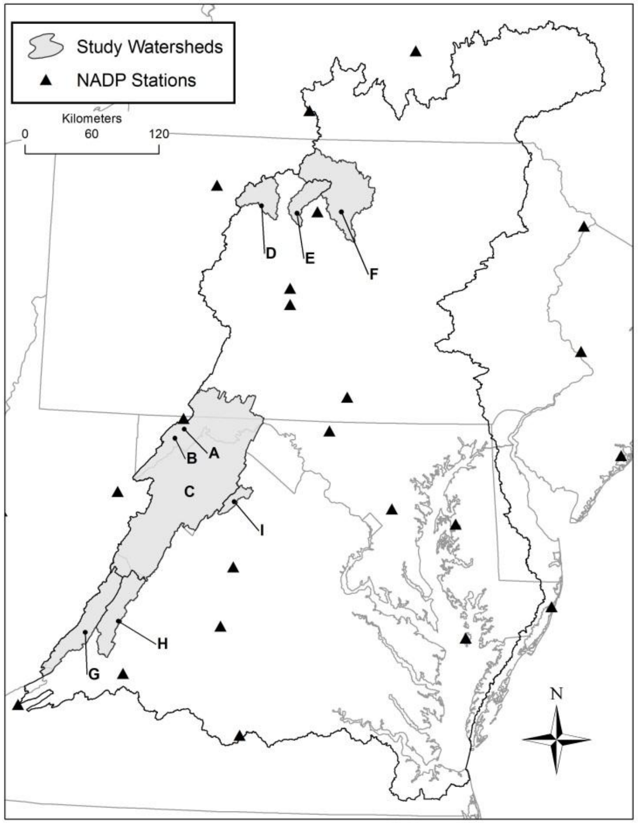
Percentage changes (1986-2009)

Watershed	Annual nitrate-N yield	Annual nitrate-N concentration	Annual wet N deposition
A	-65.4	-72.6	-43.1
B	-58.1	-40.0	-50.2
C	-35.8	-33.5	-34.3
D	-27.0	-31.9	-32.0
E	-41.1	-46.9	-29.6
F	-33.7	-35.4	-20.0
G	-69.5	-67.9	-29.3
H	-51.7	-48.8	-34.4
I	-46.8	-40.4	-36.4
Mean	***-47.7***	***-46.4***	***-34.4***



Eshleman *et al.*, 2013

Conceptual kinetic N saturation model

[after Lovett and Goodale (2011)]

(1) $D - V - S = Y + G$

[*D* is N deposition, *V* is net incorporation of N into vegetation, *S* is net incorporation of N into soil, *Y* is the yield or export of N to surface waters, and *G* is gaseous N loss; all are **rates**]

(2) $Y = D - A$

[Neglect the *G* term (assumed small relative to *Y*), combine *V* and *S* into one term, $A = V + S$, and rearrange]

(3) $Y = Y_0 + D - A$

[Y_0 term added to represent N sources from non-forested land uses]

(4) $A = aD$

[Make *A* a linear function of *D* where *a* ($0 \leq a \leq 1$) represents the (assumed constant) proportion of *D* that is taken up and stored in vegetation and soil]

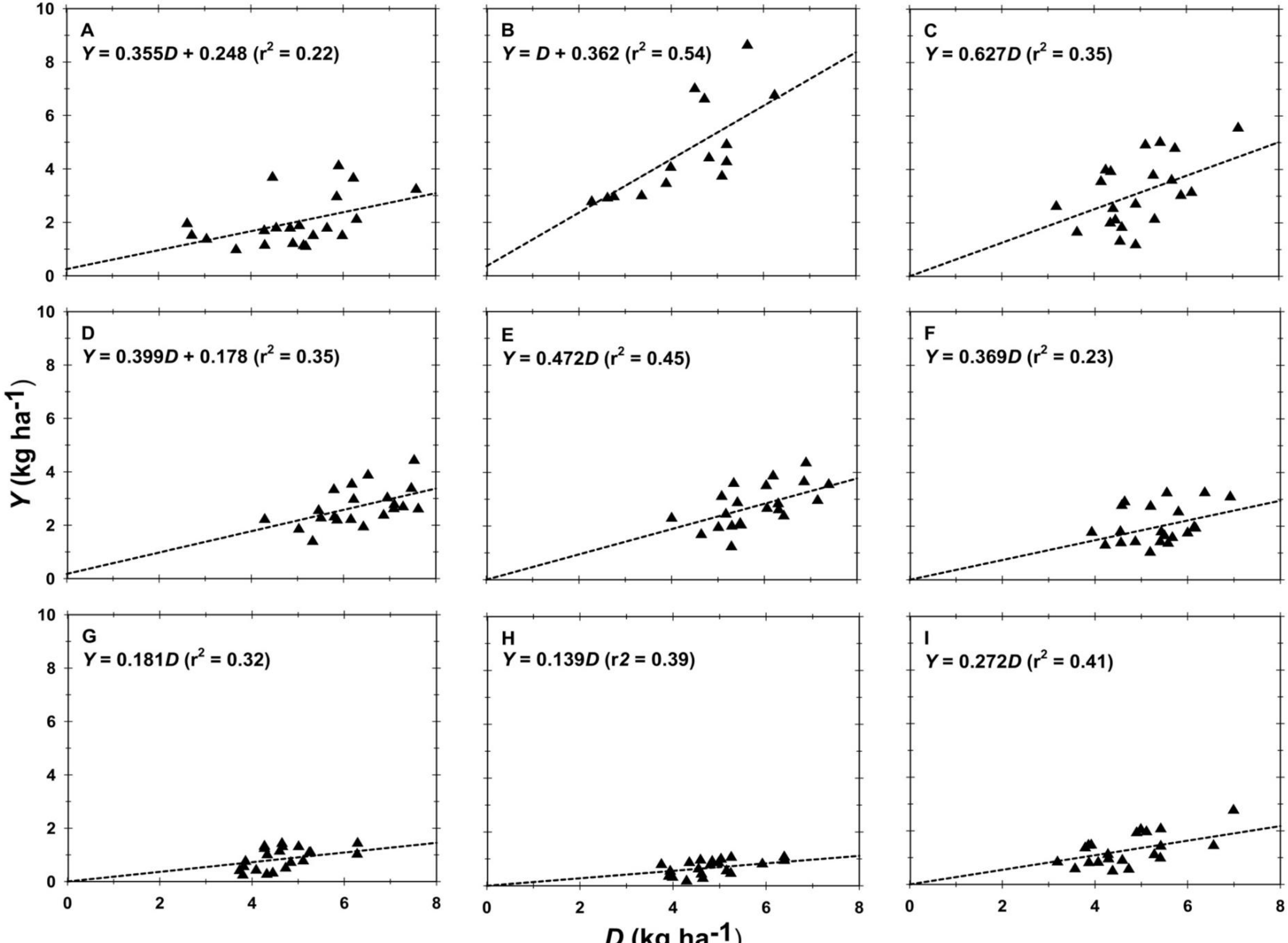
(5) $Y = Y_0 + (1 - a)D$

[Substitute for *A* in (3) and simplify]

Solve for *a* and Y_0 using Sigmaplot Dynamic Fit Wizard (subject to constraints *a* and $Y_0 \geq 0$); note that a graph of *Y* on *D* has slope of $(1 - a)$ and intercept Y_0

Eshleman *et al.*, 2013

Model fits: nitrate-N yields (*Y*) vs. N deposition (*D*)



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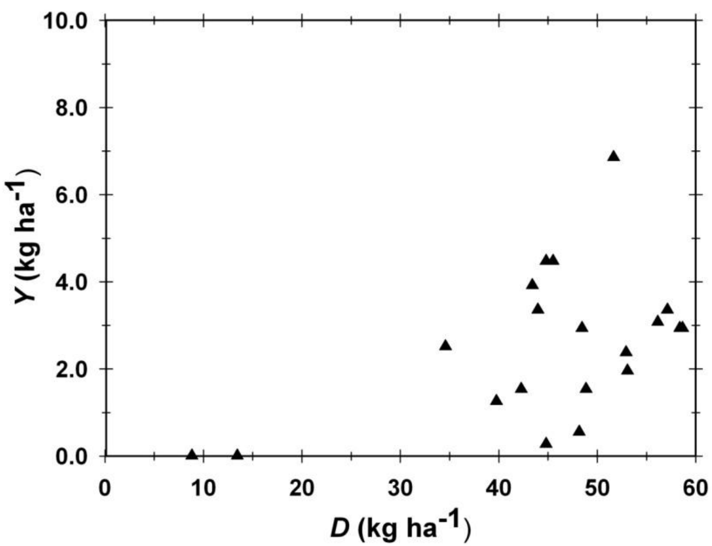
Values of a and (1 - a)

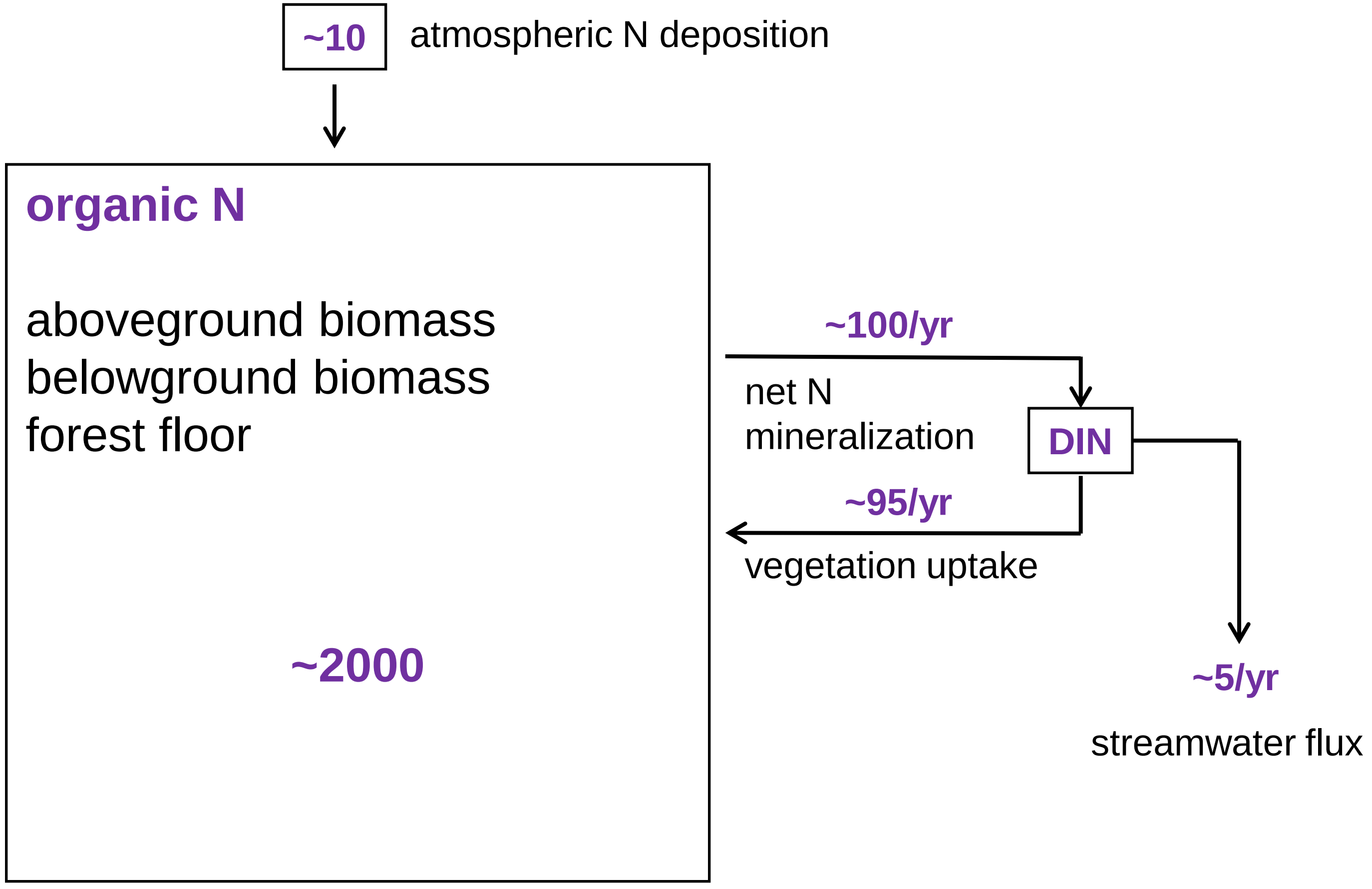
- a is an "aggradation coefficient" and (1 – a) is the first derivative, dY/dD
- Estimated values of (1 – a) from this study ranged from 0.14 to 1.00:
  - PA: 0.41, MD: 0.66, VA: 0.20
- Pan *et al.* (2004): regional value of 0.25 for CBW forests using PnET-CN
- Shank (2013, pers. comm.): assumed as 0.10



Moldan and Wright (2011**):** a small (0.5 ha) watershed in Sweden was subjected to 19 years of experimental additions of ammonium nitrate using a sprinkler system (NITREX)

Hubbard Brook Experimental Forest, NH

(conventional simplified model of forest N cycle)

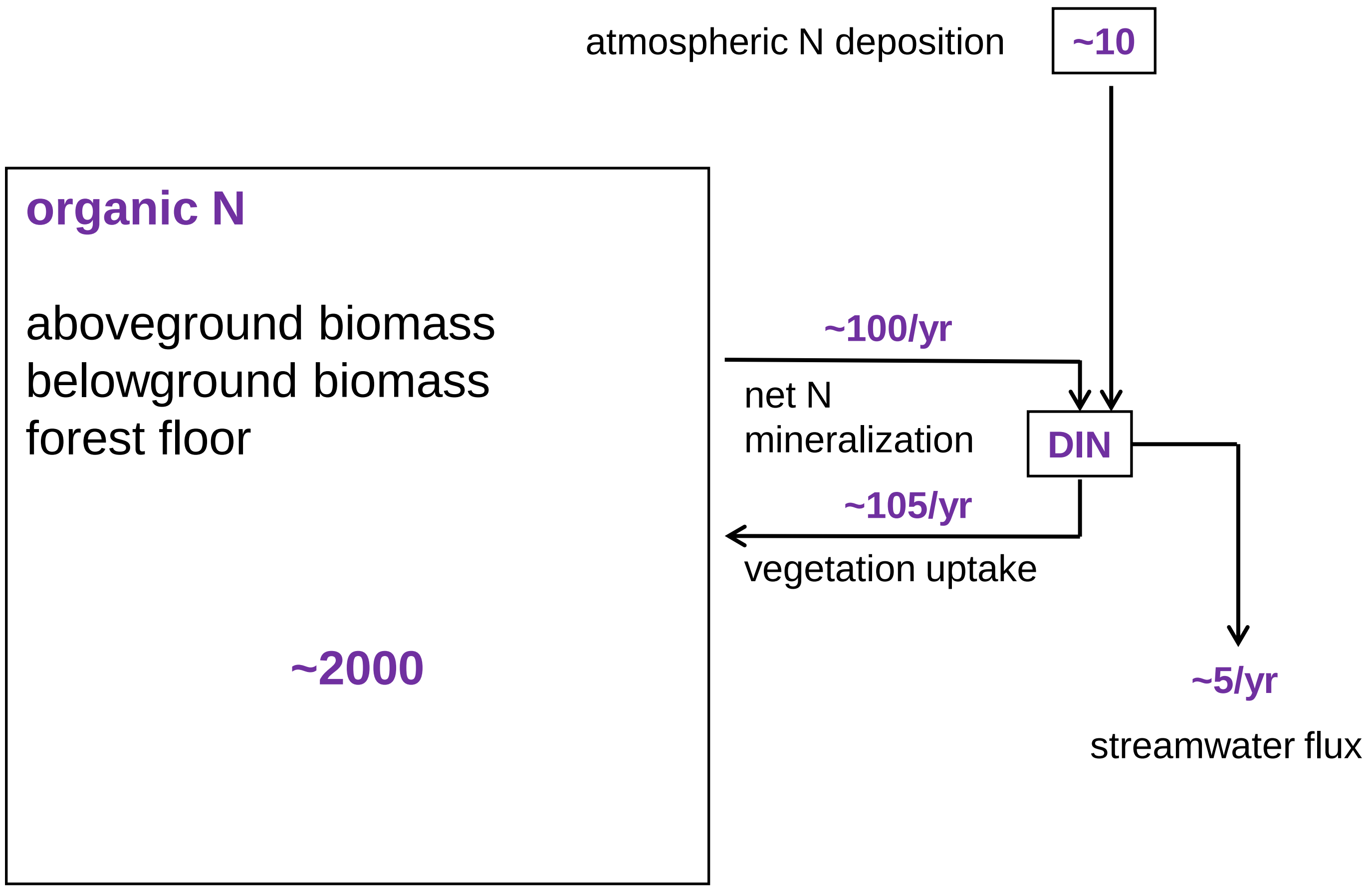


units: kg N/ha

Data from Likens *et al.*, 1977

Hubbard Brook Experimental Forest, NH

(*modified* simplified model of forest N cycle)

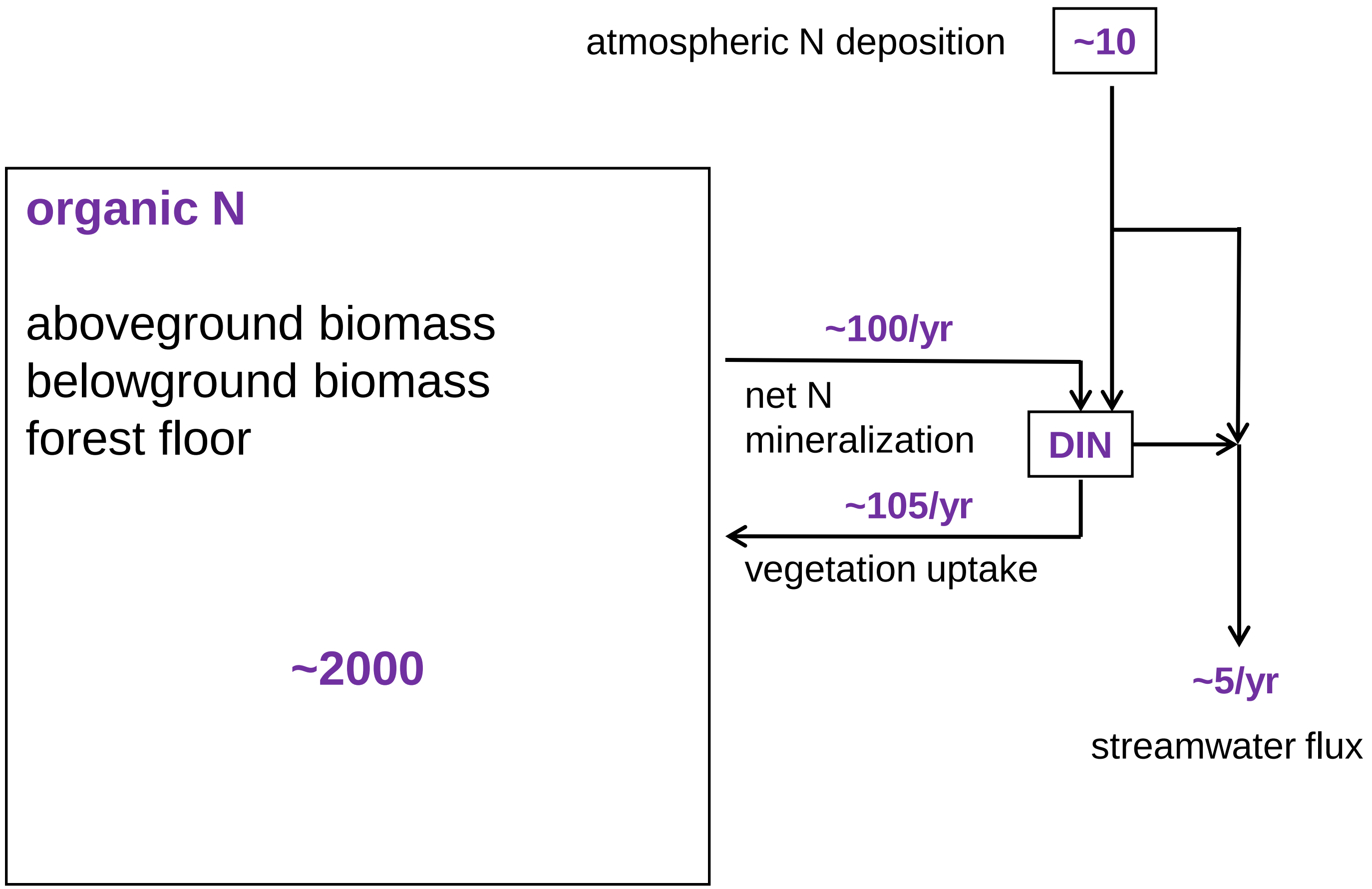


units: kg N/ha

Data from Likens *et al.*, 1977

Hubbard Brook Experimental Forest, NH

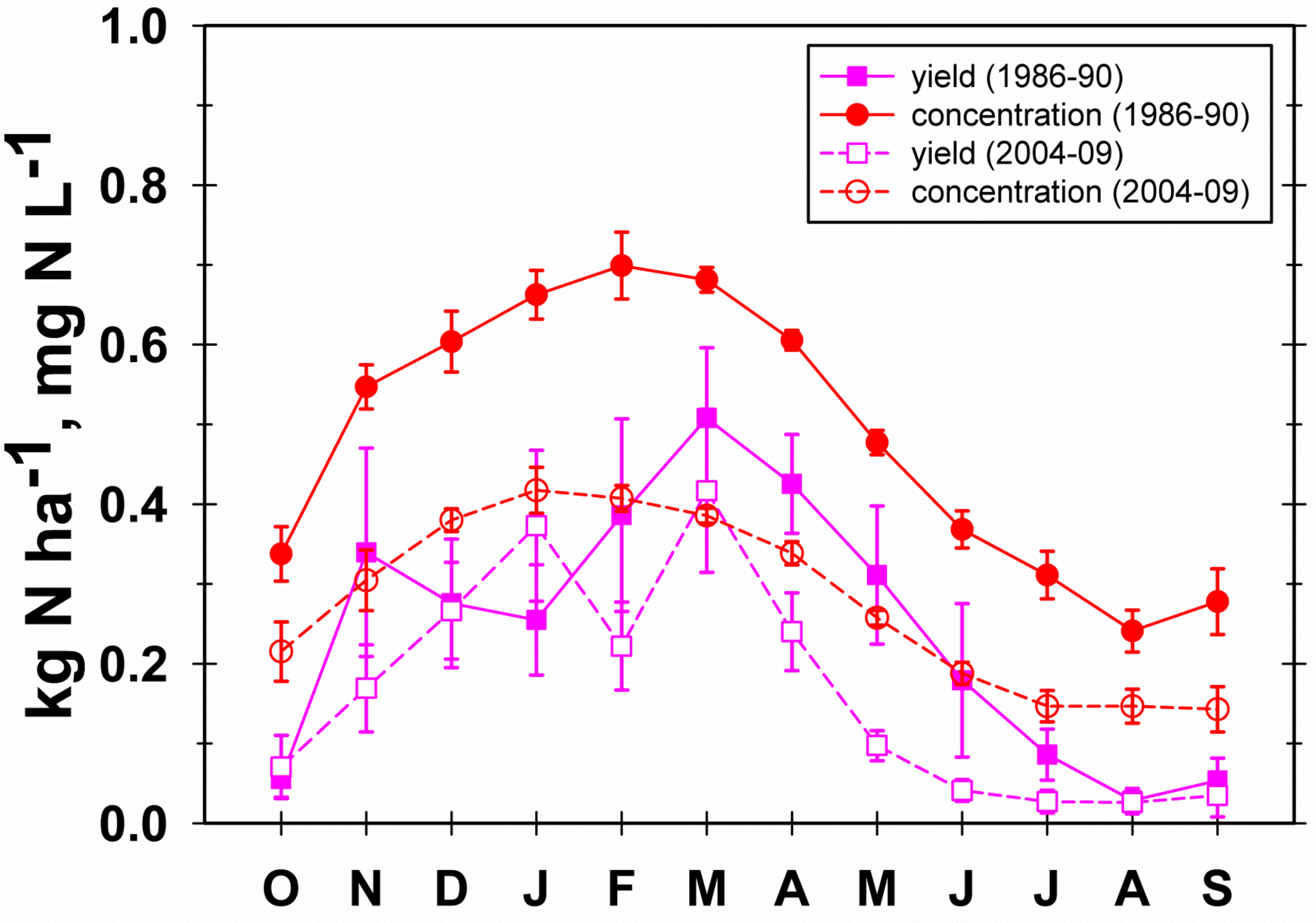
(*modified* simplified model of forest N cycle)



units: kg N/ha

Data from Likens *et al.*, 1977

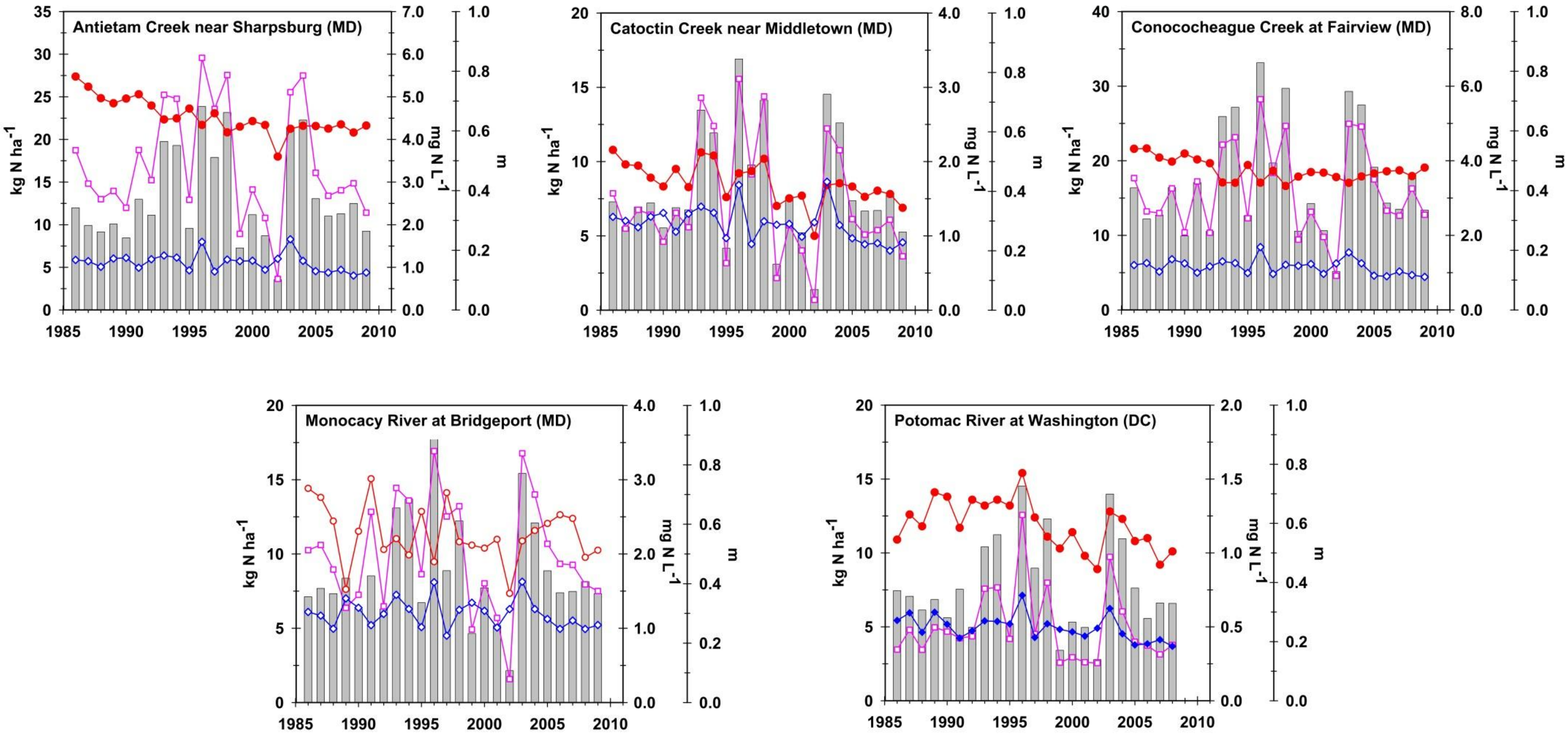
Kettle Creek, PA



Eshleman *et al.*, 2013

Next steps

- Comparable analysis of mixed-land use sub-watersheds (i.e., major tribs of Potomac River basin) and RIM station



Conclusions

- Decreasing surface water nitrate-N concentrations and yields are a largely untold CB “success story”
- “Good news”, but the “where” and “why” are important
  - Forested headwaters of the basin
  - “Co-benefit” of 1990 CAAA, not Clean Water Act
  - Responses to atmospheric S and N deposition reductions similar
  - Unknown importance relative to land management actions
- Must account for forest N dynamics in TMDL process (N yields from atmospheric deposition previously considered “uncontrollable”)
- Additional water quality improvements likely with > N deposition control
- In-stream N processing can be neglected
- Lag time of forest N response appears to be relatively short (< a year or so), suggesting that a significant portion of atmospheric N bypasses the soil
- Preventing future degradation of forested subwatersheds (i.e., “doing nothing”) may be very cost-effective relative to restoring highly degraded parts of the watershed
  - Greater forest protection and preservation
  - Local water quality and recreational benefits

Acknowledgments

- Principal collaborators
  - Phil Townsend
  - Brenden McNeil
  - Ray Morgan
  - Dave Nelson
- Graduate students and lab assistants
  - Sarah Hypio
  - Tim Negley
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  - Jeff Griffith
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  - Michael Snyder
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  - Maryland DNR
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  - NASA Terrestrial Ecology
  - NASA Decision Support Systems
- Data sources
  - Maryland DNR
  - Pennsylvania DEP
  - Virginia DEQ
  - USGS NWIS
  - NADP/NTN