Trends in Surface-Water Nitrate-N Concentrations and Loads from Predominantly-Forested Subwatersheds of the Chesapeake Bay Basin

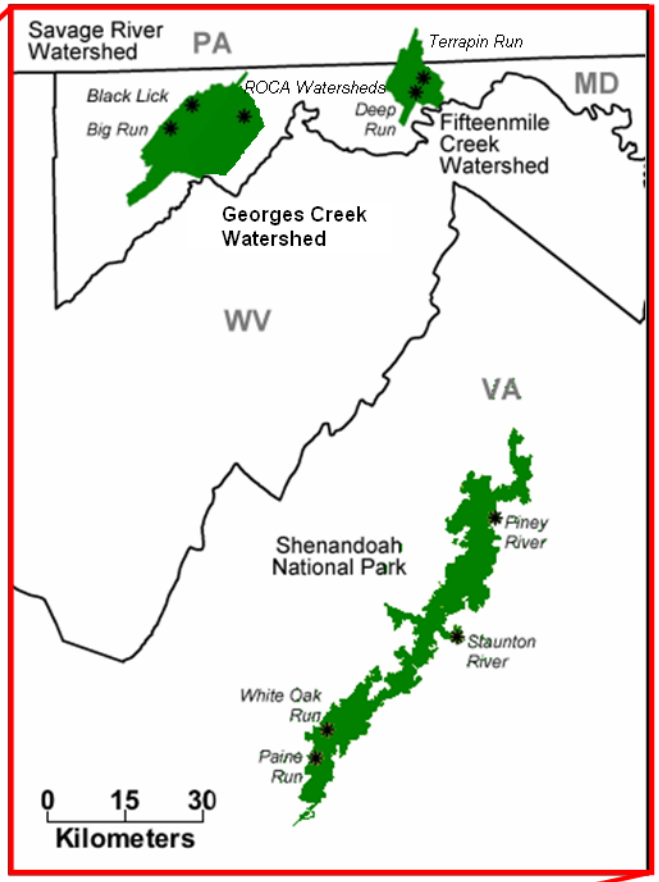
Keith N. Eshleman, Robert D. Sabo, Kathleen M. Kline

Appalachian Laboratory
University of Maryland Center for Environmental Science
Frostburg, MD 21532

STAC Healthy Watersheds Workshop, Buckeystown, MD

March 7, 2012

Chesapeake Bay Watershed



Water

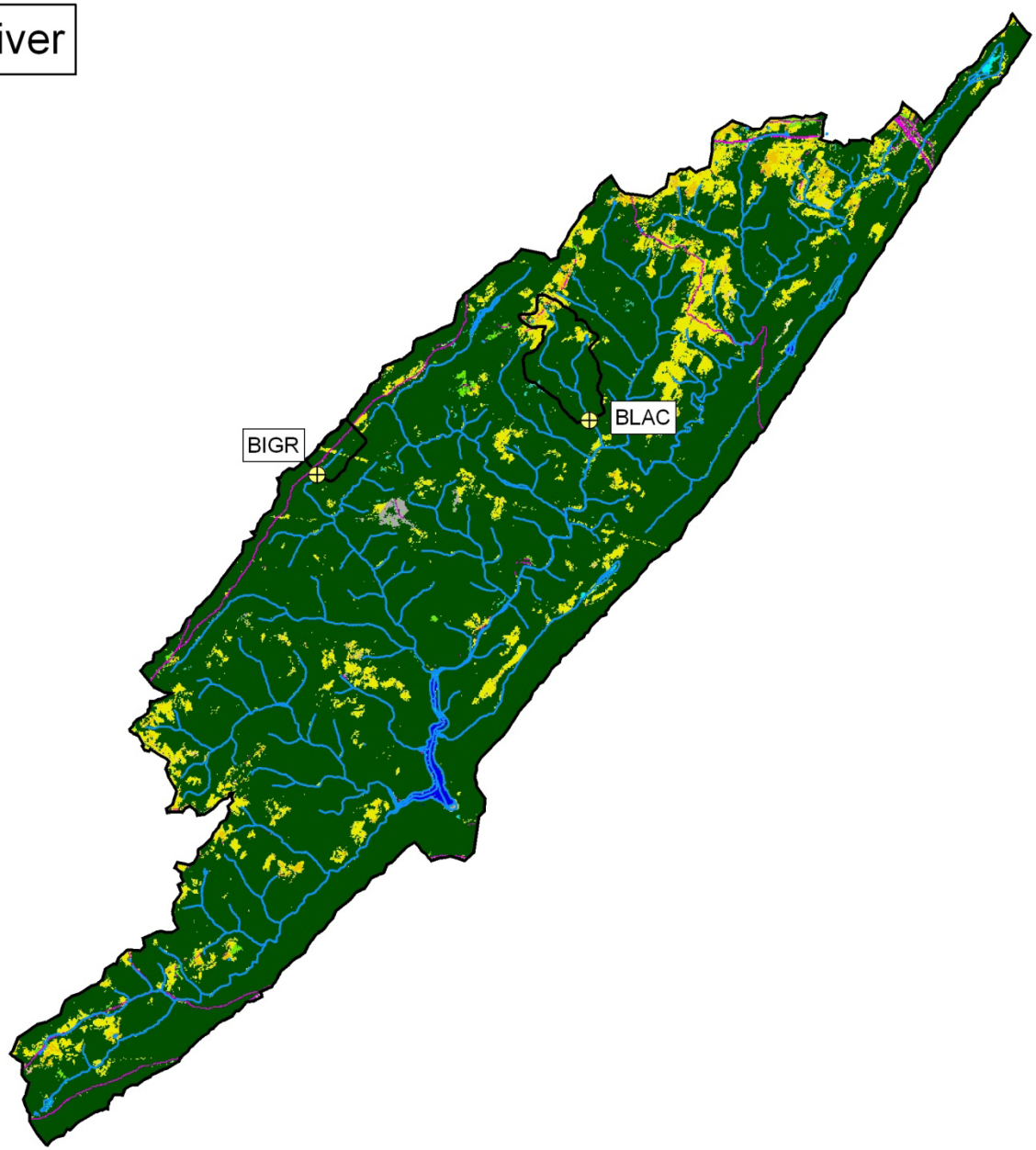
Urban/Built-up

Agriculture

Forest

Wetlands

Savage River



Legend

- Stream Gage
- NHD Streams
- Watershed Boundary
- Savage River Watershed
- No Data
- Open Water
- Low Int. Dev.
- Med Int. Dev.
- High Int. Dev.
- Transportation
- Urban Dec. Tree
- Urban Con. Tree
- Urban Mix Tree
- Urban Grass
- Extractive
- Barren
- Dec. Forest
- Con. Forest
- Mix Forest
- Pasture / Hay
- Croplands
- Natural Grass
- Dec. Wood. Wet.
- Con. Wood. Wet.
- Emergent Wet.
- Mixed Wet.

N

4 2 0 4 8 12 Kilometers

Chesapeake Bay Landcover from Mid Atlantic RESAC

Savage River

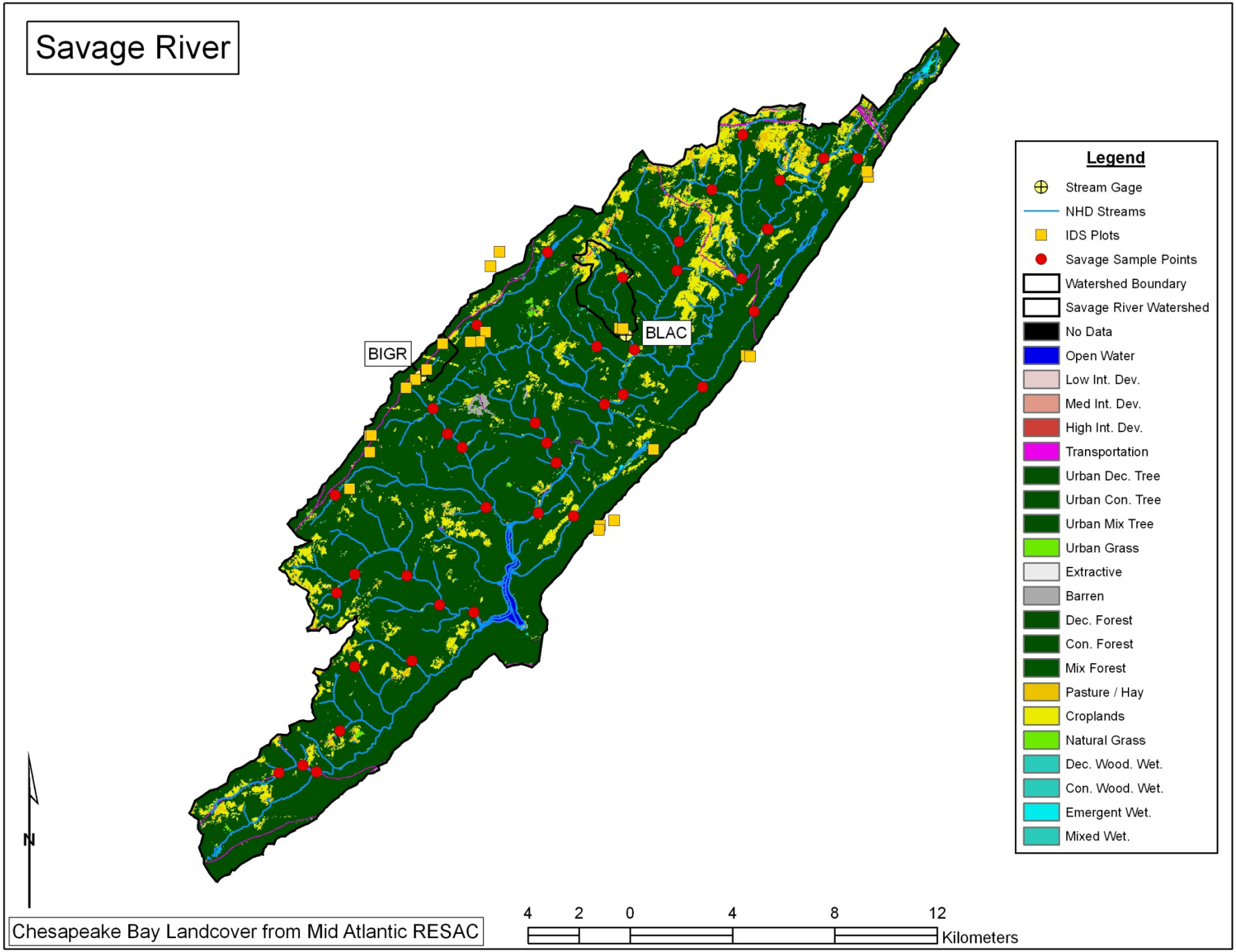
Legend

- Stream Gage
- NHD Streams
- Savage Sample Points
- Watershed Boundary
- Savage River Watershed
- No Data
- Open Water
- Low Int. Dev.
- Med Int. Dev.
- High Int. Dev.
- Transportation
- Urban Dec. Tree
- Urban Con. Tree
- Urban Mix Tree
- Urban Grass
- Extractive
- Barren
- Dec. Forest
- Con. Forest
- Mix Forest
- Pasture / Hay
- Croplands
- Natural Grass
- Dec. Wood. Wet.
- Con. Wood. Wet.
- Emergent Wet.
- Mixed Wet.

N

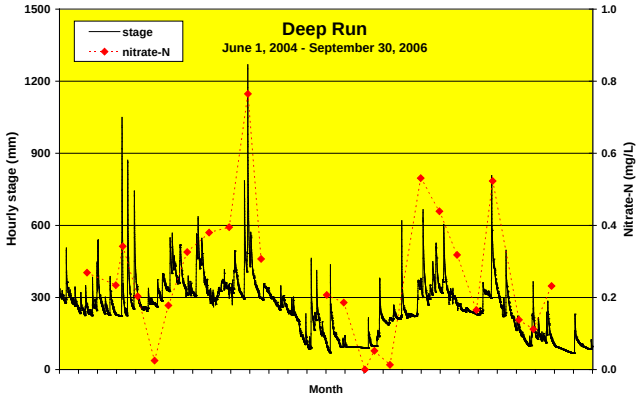
Chesapeake Bay Landcover from Mid Atlantic RESAC

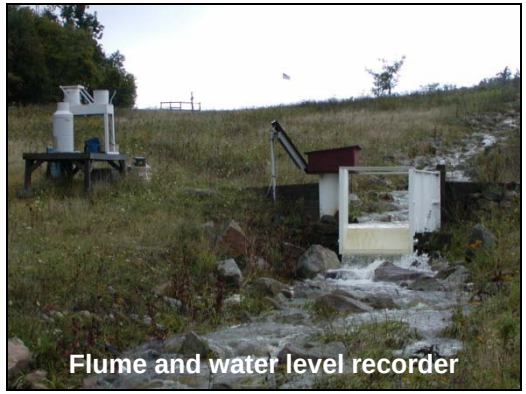
4 2 0 4 8 12 Kilometers

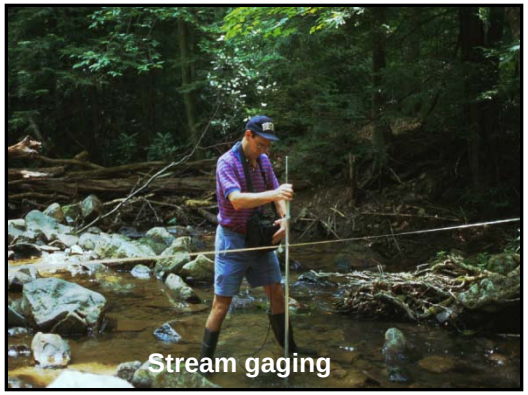

Savage River
BIGR
BLAC
Legend
Stream Gage
NHD Streams
IDS Plots
Savage Sample Points
Watershed Boundary
Savage River Watershed
No Data
Open Water
Low Int. Dev.
Med Int. Dev.
High Int. Dev.
Transportation
Urban Dec. Tree
Urban Con. Tree
Urban Mix Tree
Urban Grass
Extractive
Barren
Dec. Forest
Con. Forest
Mix Forest
Pasture / Hay
Croplands
Natural Grass
Dec. Wood. Wet.
Con. Wood. Wet.
Emergent Wet.
Mixed Wet.
N
Chesapeake Bay Landcover from Mid Atlantic RESAC
4 2 0 4 8 12
Kilometers

Network of Gaged Watersheds

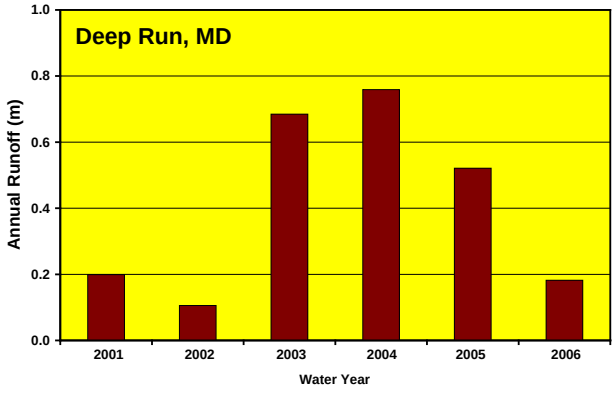
Raw Data





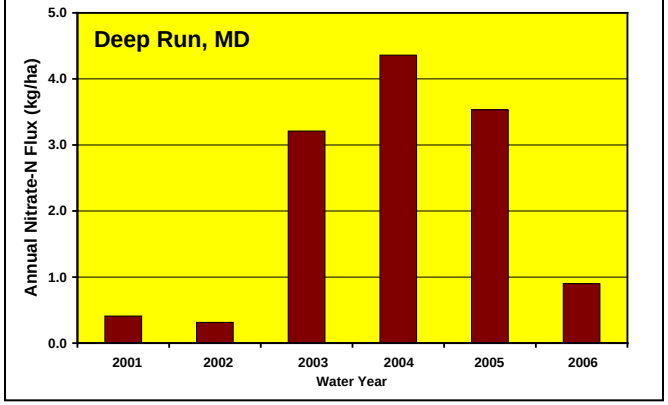


Annual Runoff

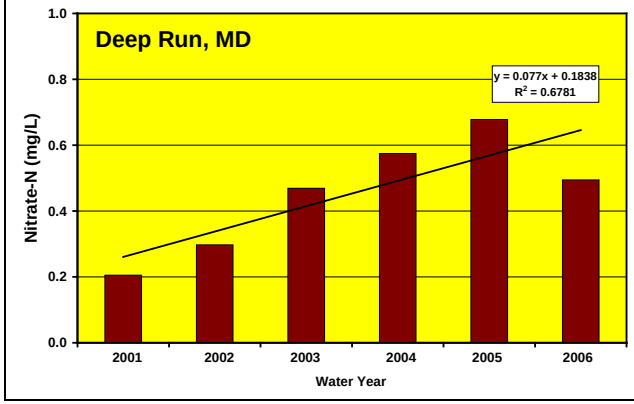


Models, rating curves → **WATFLOW LOADEST**

Annual Fluxes



Annual Flow-Weighted Concentrations



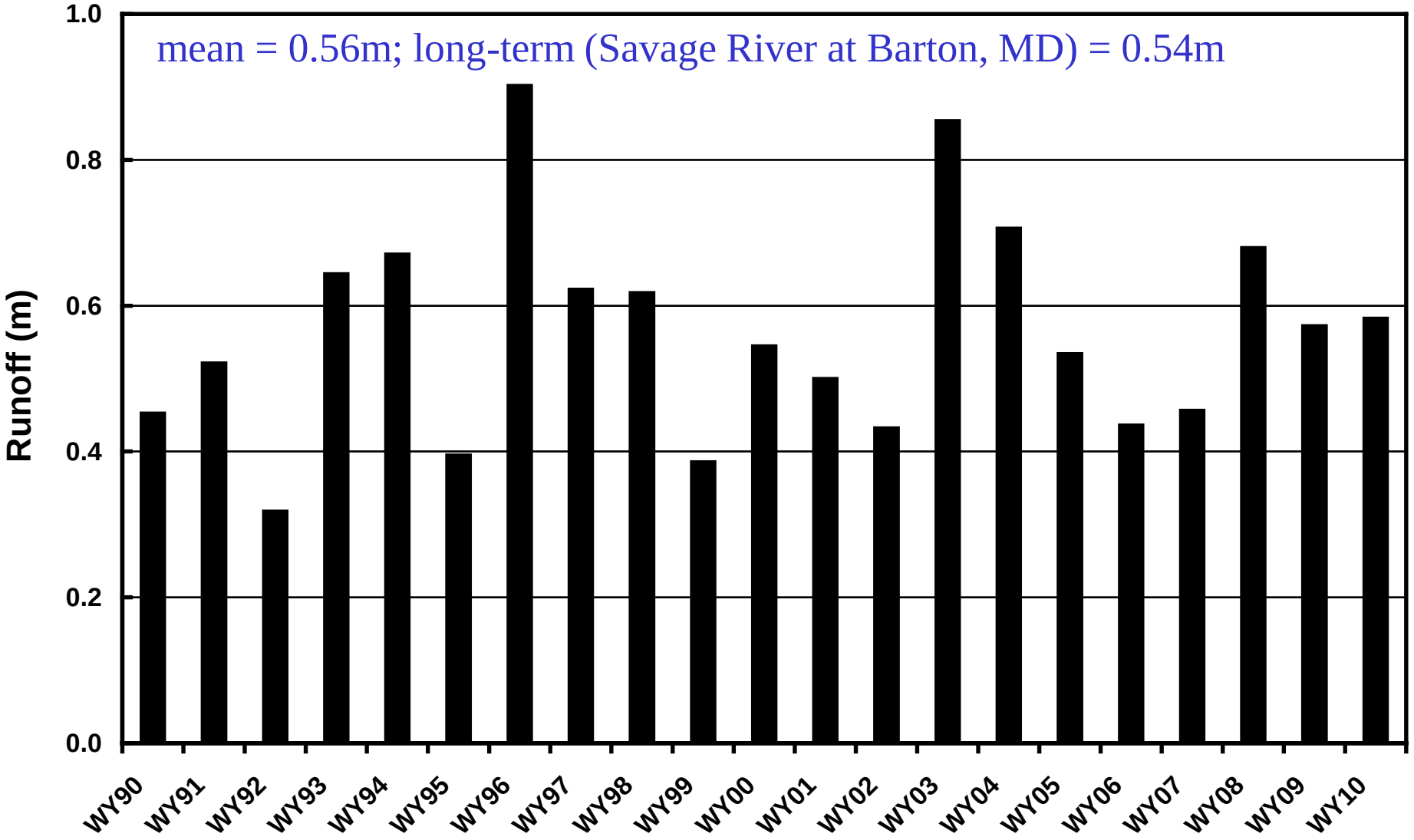
Research Questions

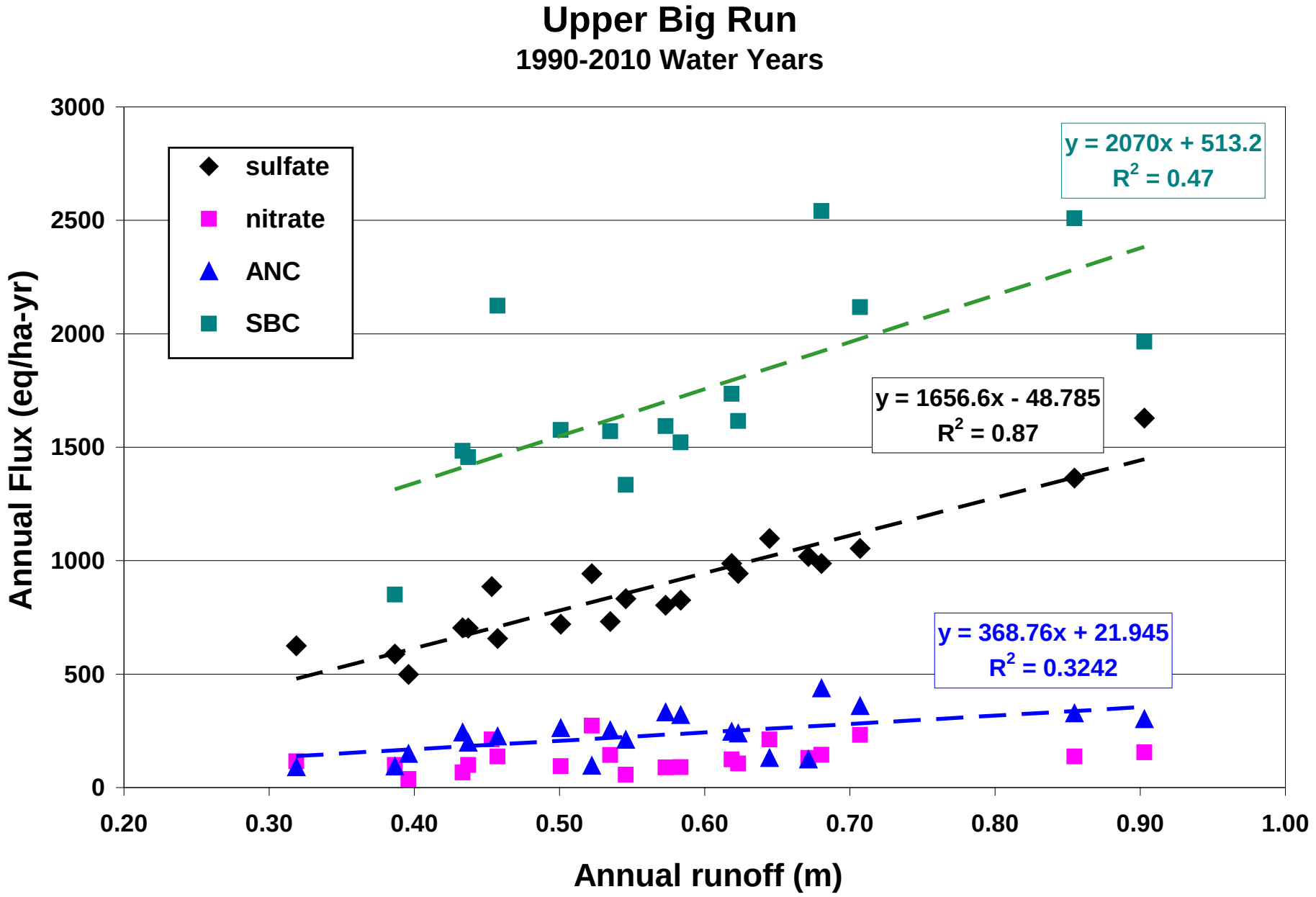
- What contemporary water quality changes are occurring in predominantly-forested watersheds of the Chesapeake Bay basin?
  - Acid-base conditions (i.e., acid neutralizing capacity)
  - Nutrient concentrations/loads
- What are the primary drivers of these changes?
  - Atmospheric deposition/emission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

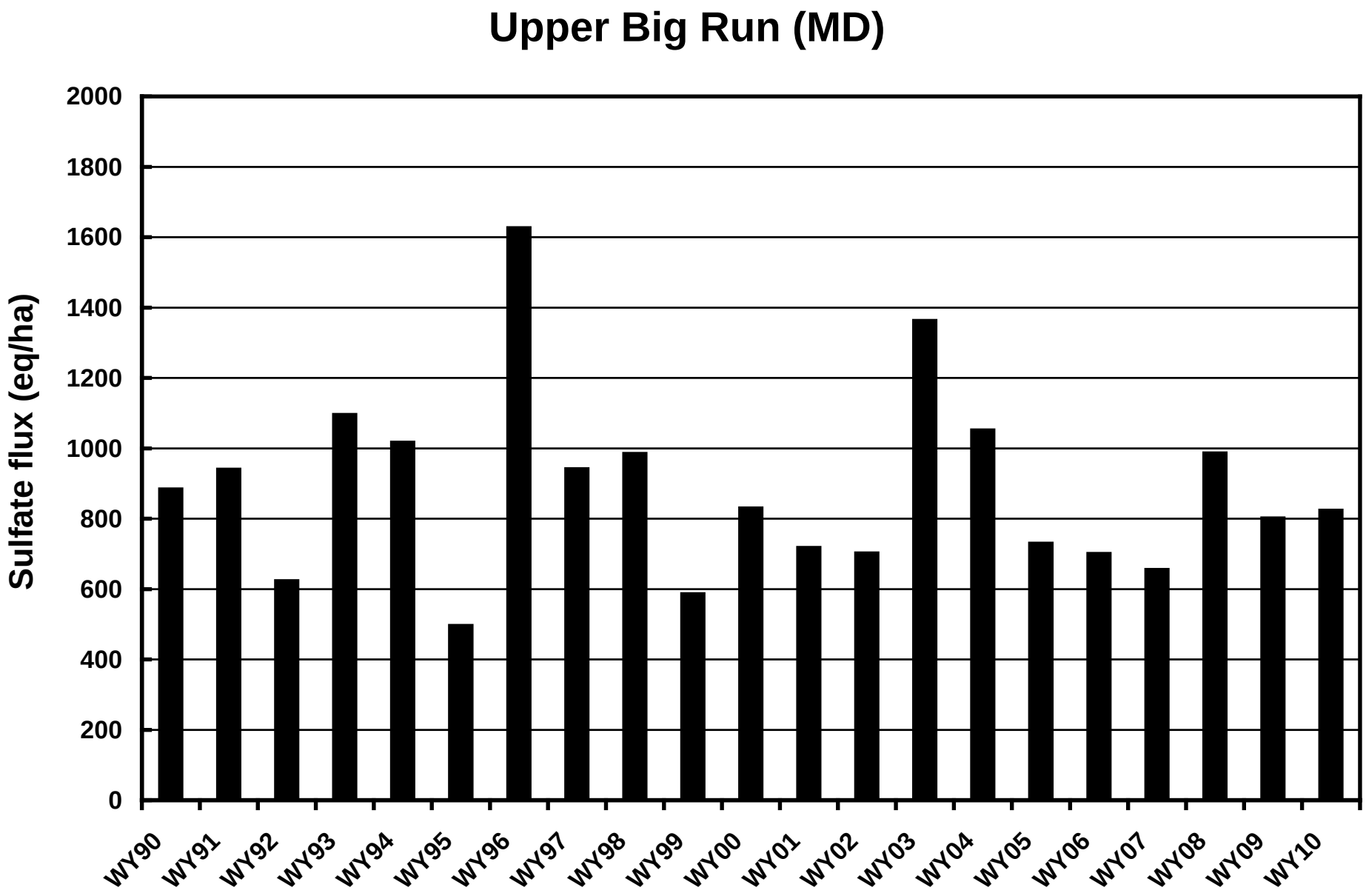
Outline

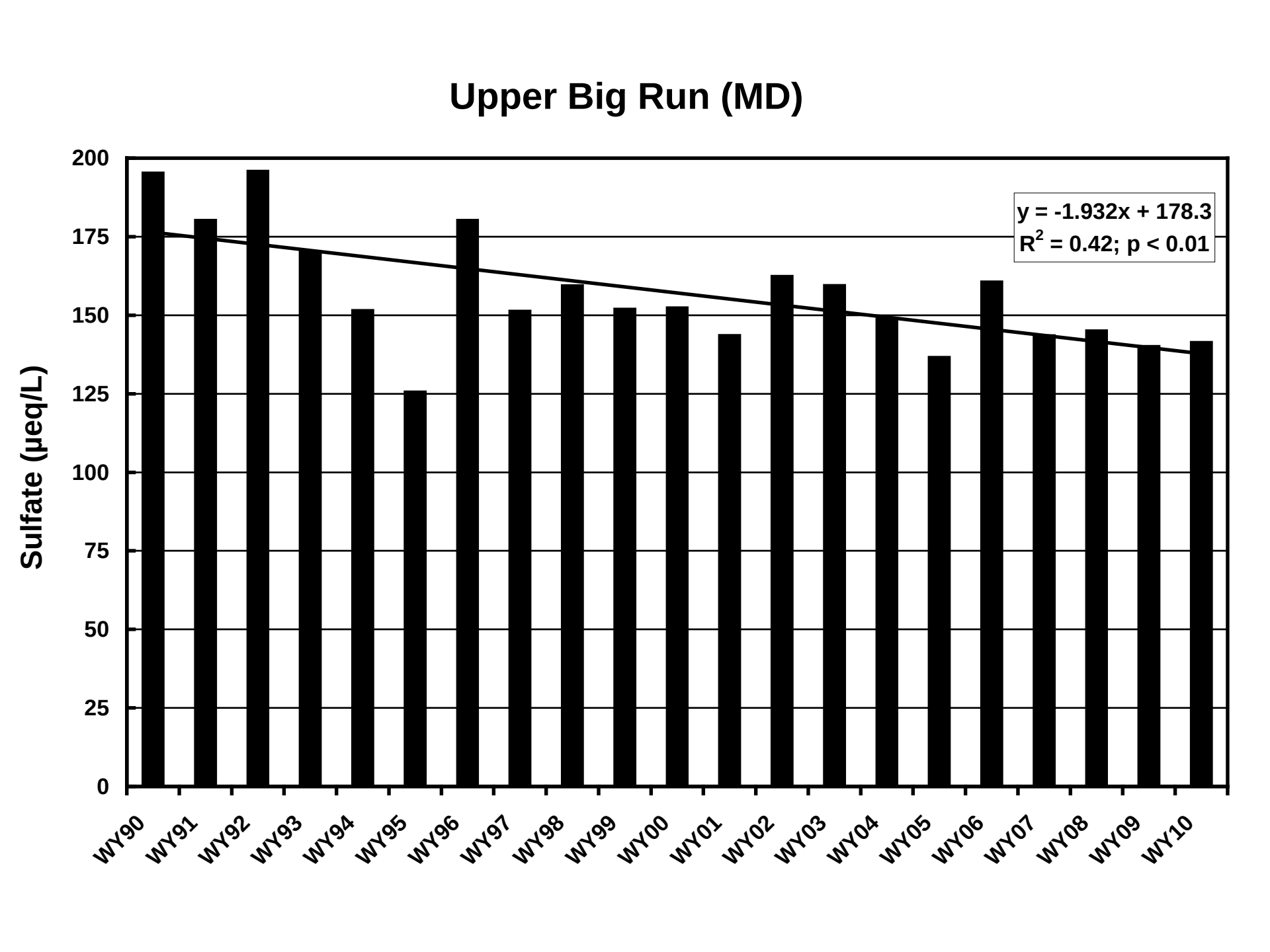
- Results from:
  - Long-term monitoring of gaged watersheds in western Maryland
  - Long-term synoptic water quality surveys in western MD
  - Other gaged, predominantly-forested watersheds in the Chesapeake Bay basin
  - Main-stem Potomac River stations and major tributaries
- Conclusions

Upper Big Run (MD)

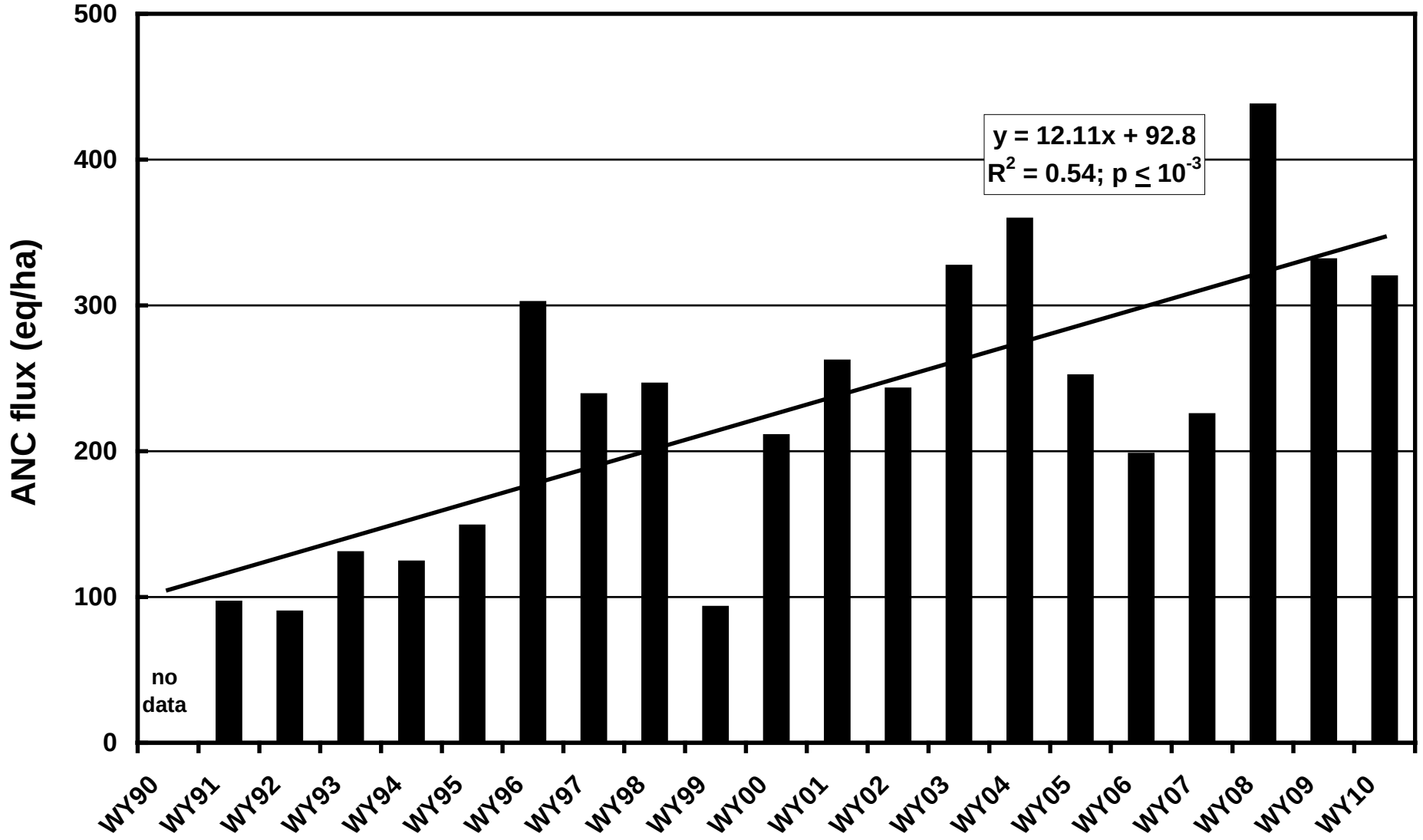


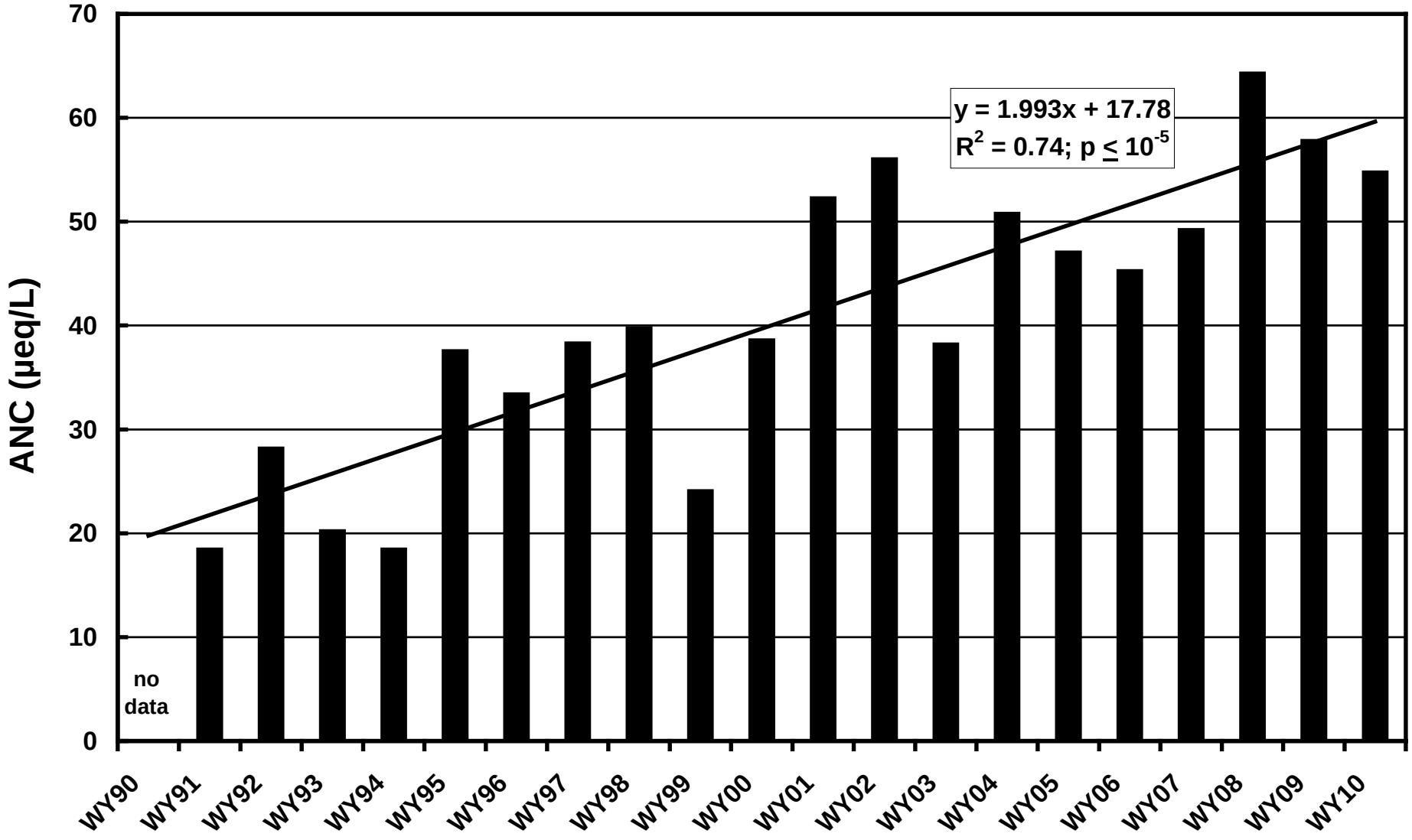

Upper Big Run
1990-2010 Water Years
sulfate
nitrate
ANC
SBC
y = 2070x + 513.2
R2 = 0.47
y = 1656.6x - 48.785
R2 = 0.87
y = 368.76x + 21.945
R2 = 0.3242
Annual Flux (eq/ha-yr)
3000
2500
2000
1500
1000
500
0
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Annual runoff (m)


Upper Big Run (MD)
Sulfate flux (eq/ha)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
WY90
WY91
WY92
WY93
WY94
WY95
WY96
WY97
WY98
WY99
WY00
WY01
WY02
WY03
WY04
WY05
WY06
WY07
WY08
WY09
WY10

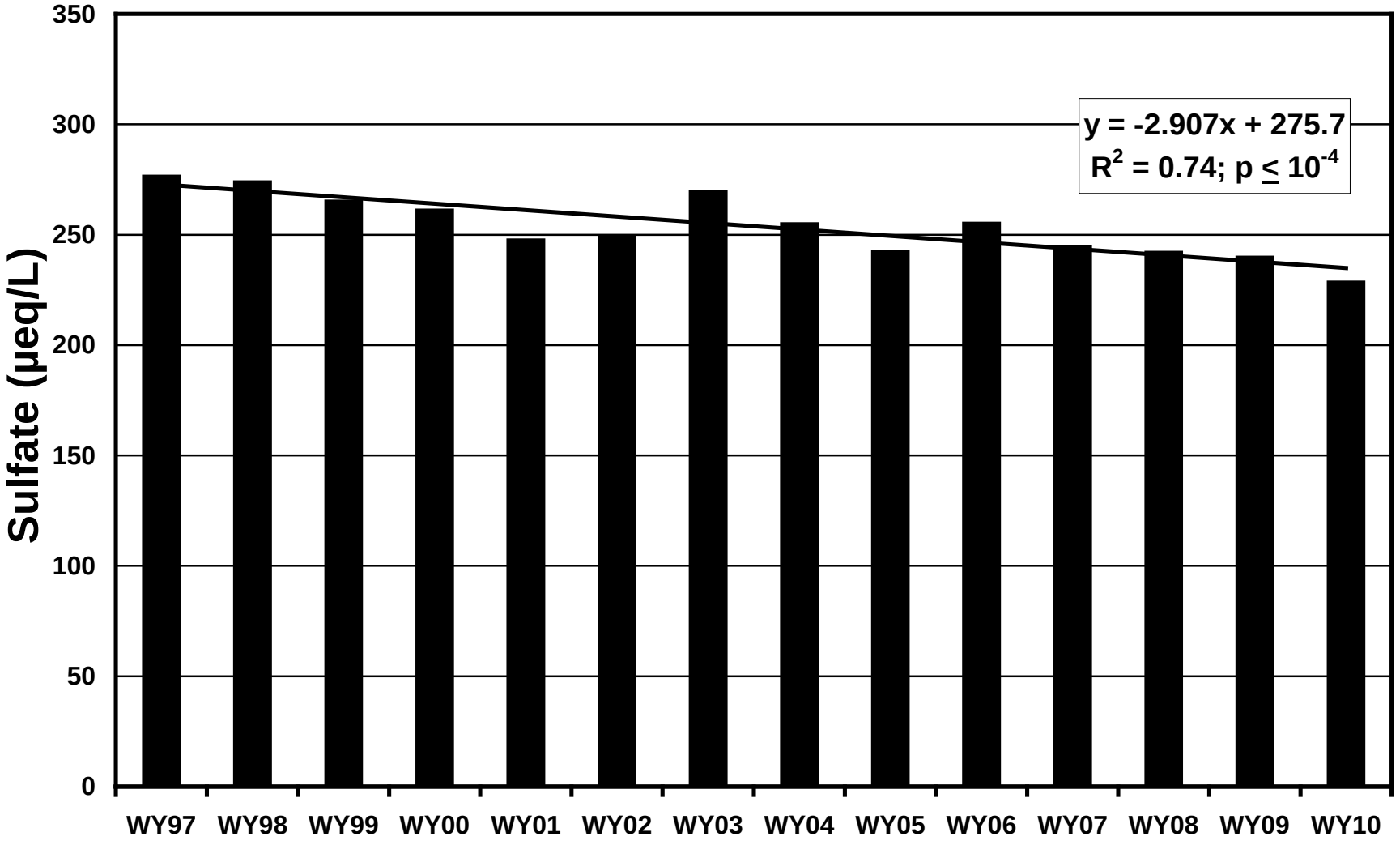

Upper Big Run (MD)
Sulfate (µeq/L)
200
175
150
125
100
75
50
25
0
y = -1.932x + 178.3
R2 = 0.42; p < 0.01
WY90
WY91
WY92
WY93
WY94
WY95
WY96
WY97
WY98
WY99
WY00
WY01
WY02
WY03
WY04
WY05
WY06
WY07
WY08
WY09
WY10

Upper Big Run (MD)



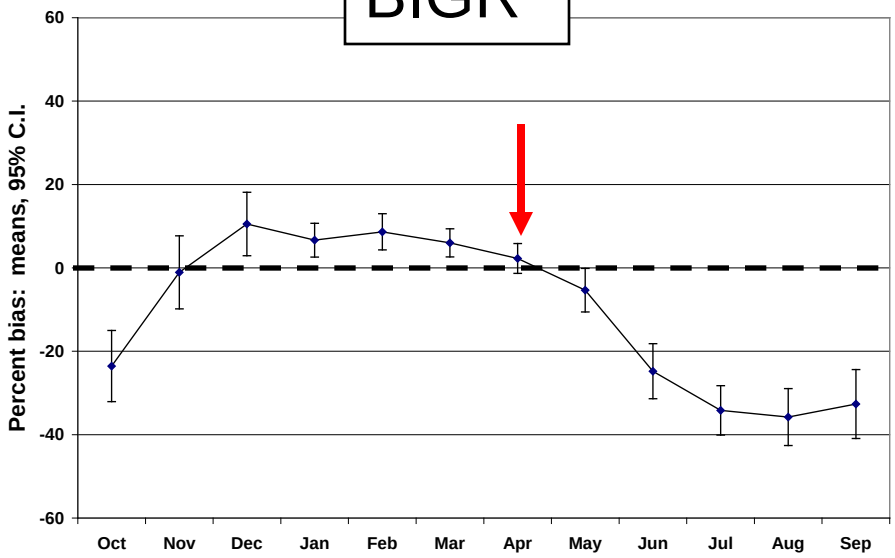

Upper Big Run (MD)
ANC (µeq/L)
70
60
50
40
30
20
10
0
y = 1.993x + 17.78
R2 = 0.74; p ≤ 10-5
no data
WY90
WY91
WY92
WY93
WY94
WY95
WY96
WY97
WY98
WY99
WY00
WY01
WY02
WY03
WY04
WY05
WY06
WY07
WY08
WY09
WY10

Black Lick (MD)

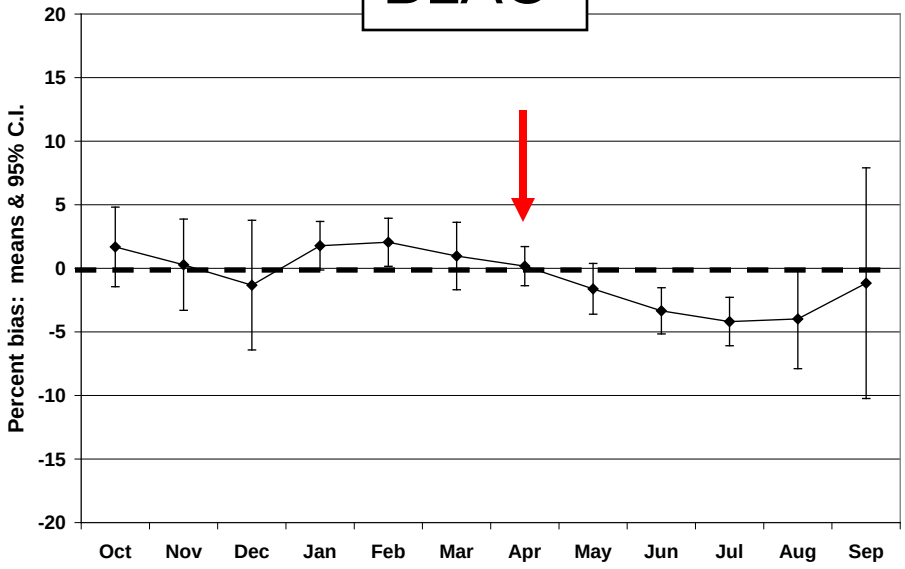


SO_4^{2-}

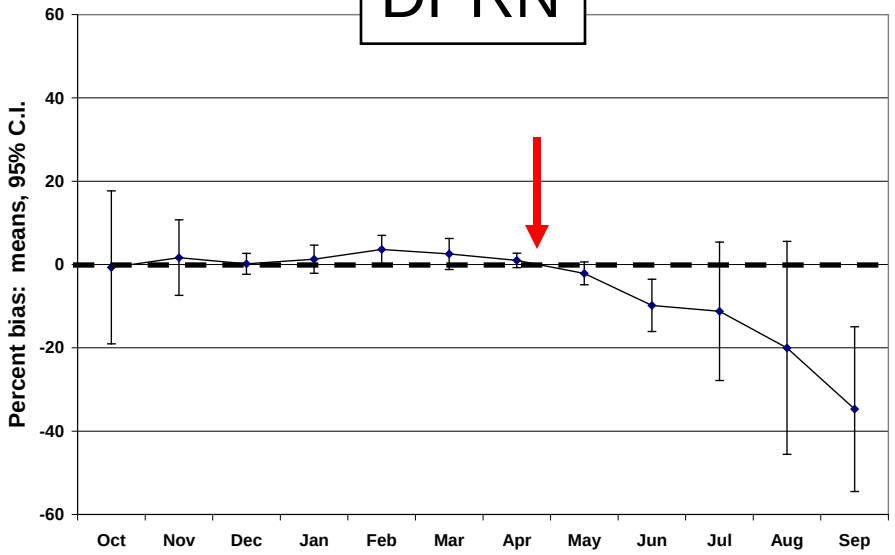
BIGR



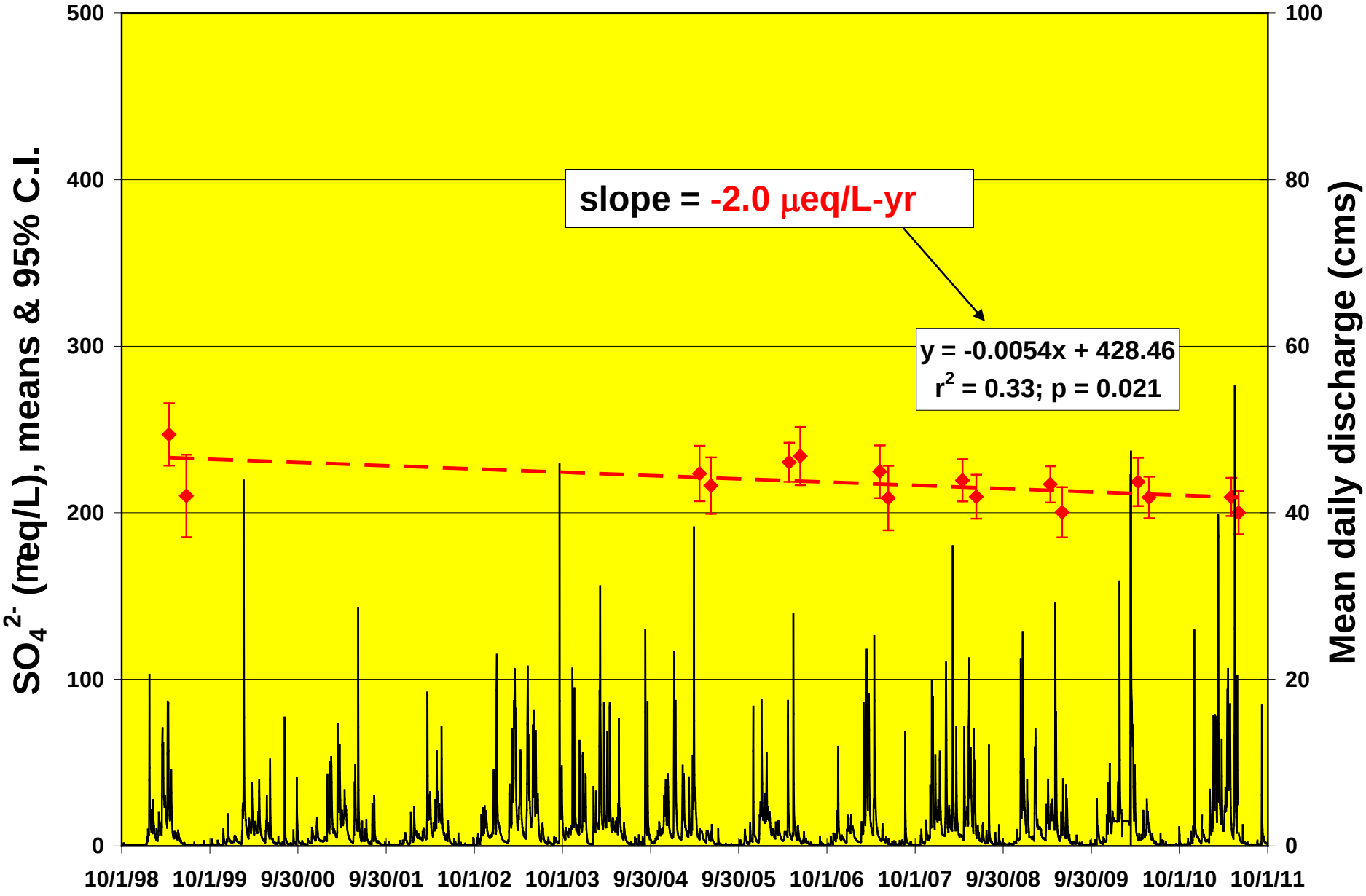
BLAC



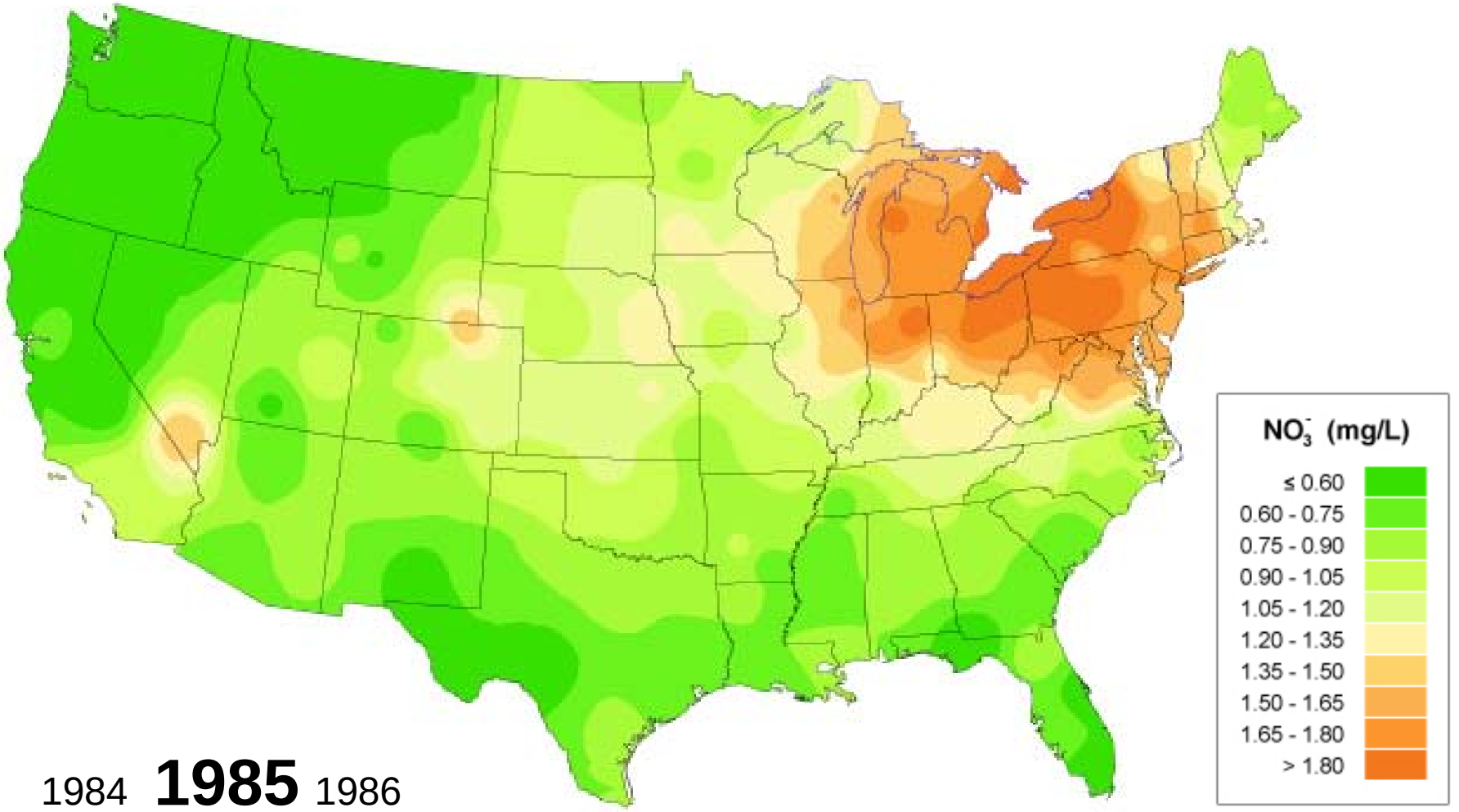
DPRN



All 40 Savage River stations: spring baseflow surveys

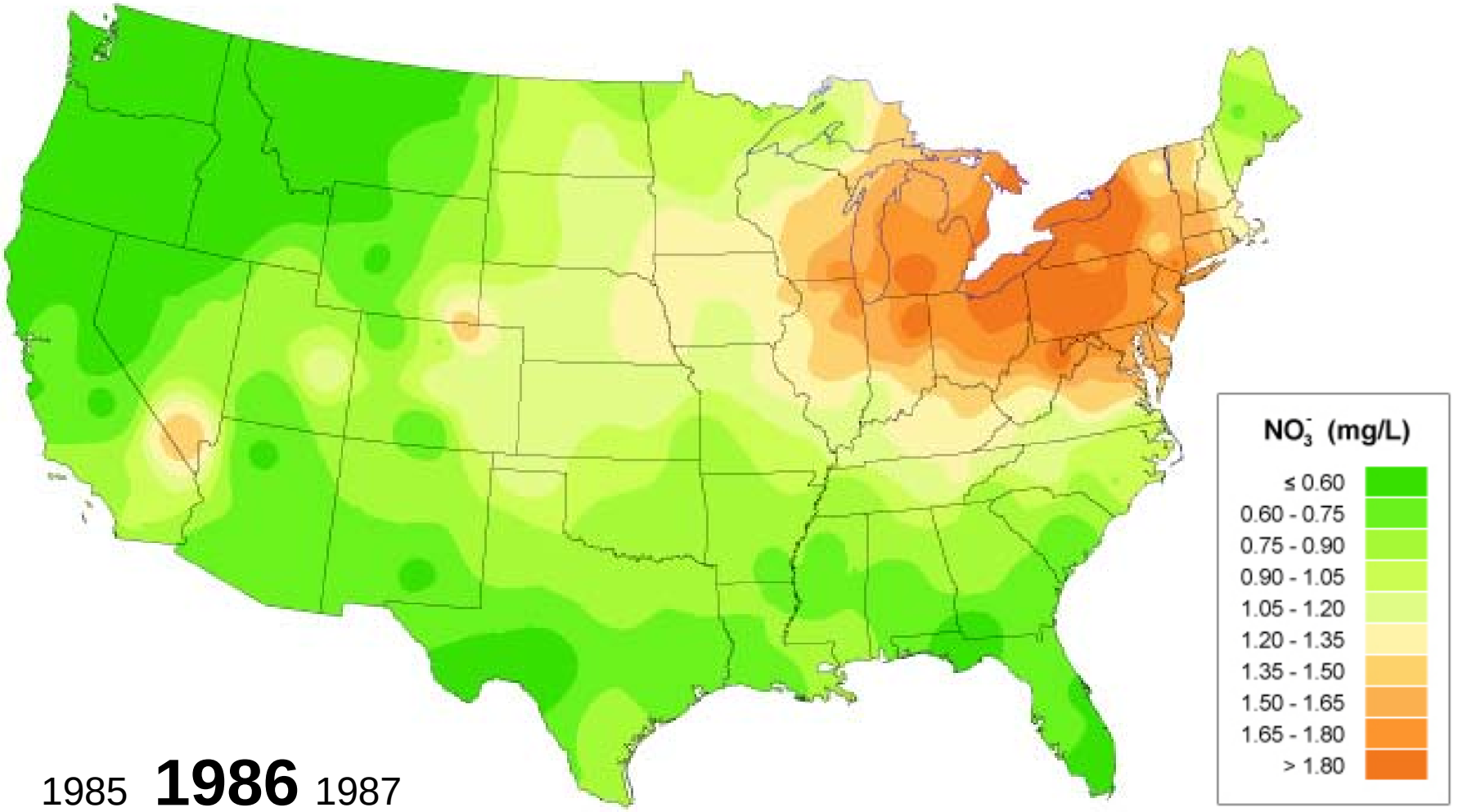


Nitrate Ion Concentrations 1985-2008



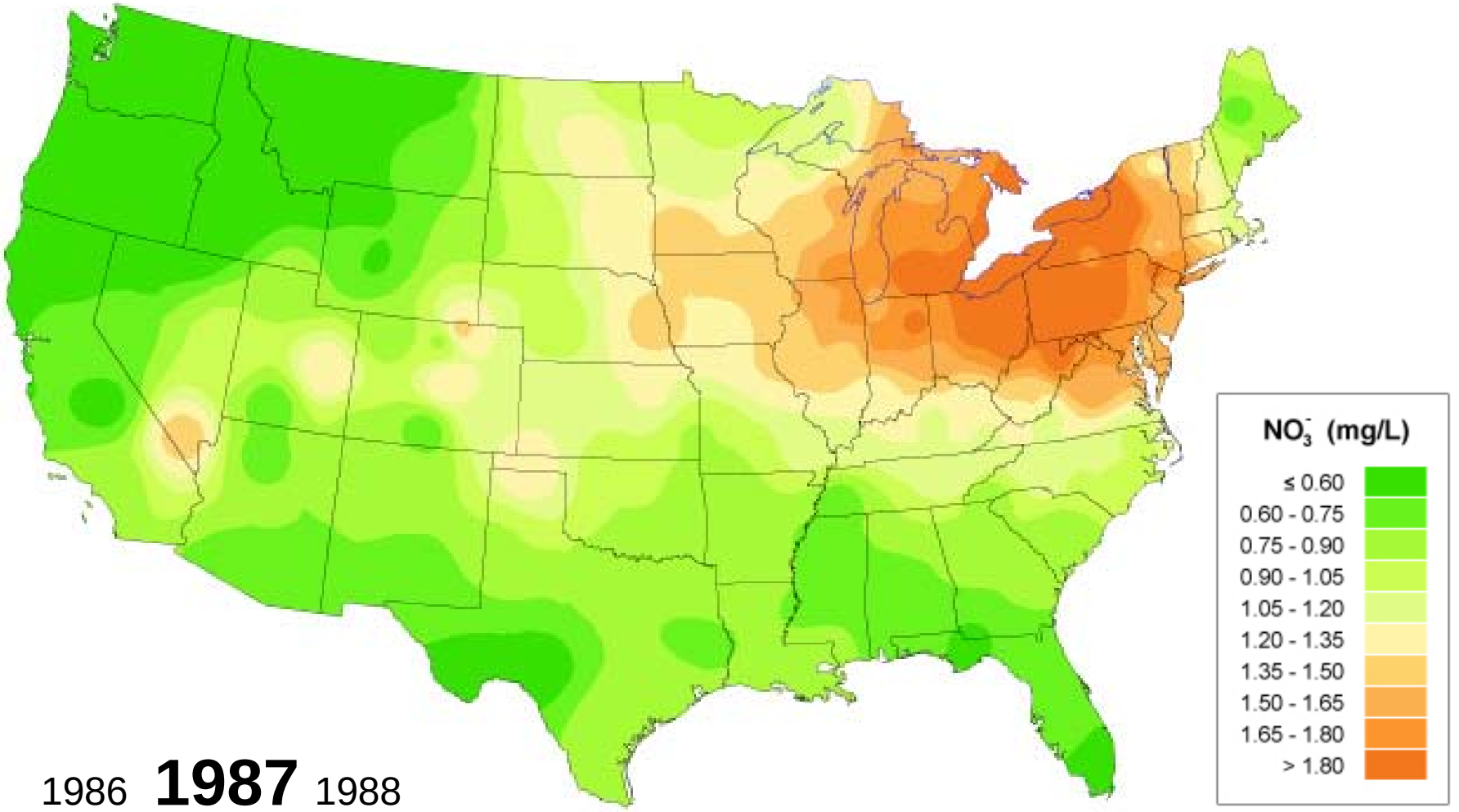
1984 **1985** 1986

Nitrate Ion Concentrations 1985-2008



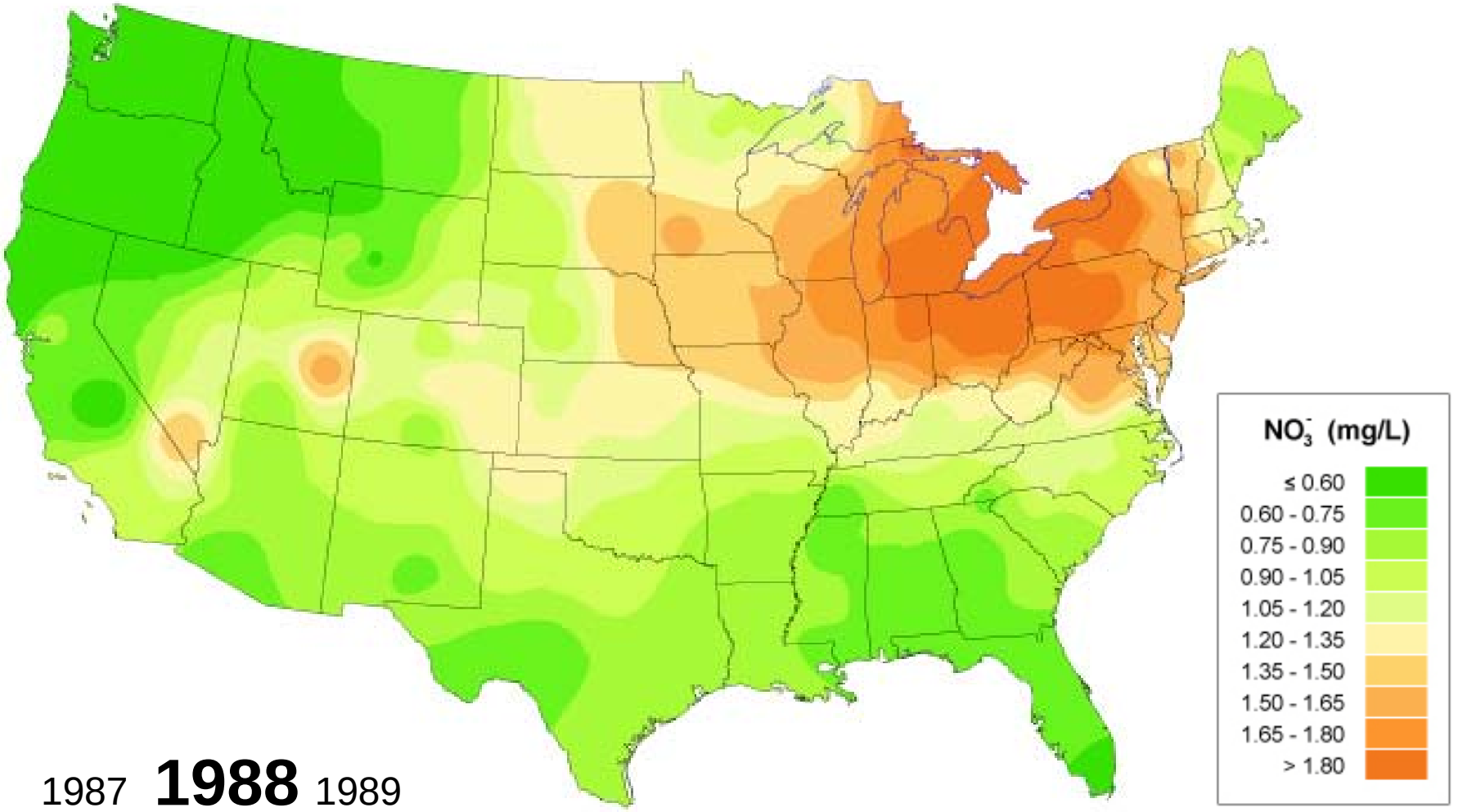
1985 **1986** 1987

Nitrate Ion Concentrations 1985-2008



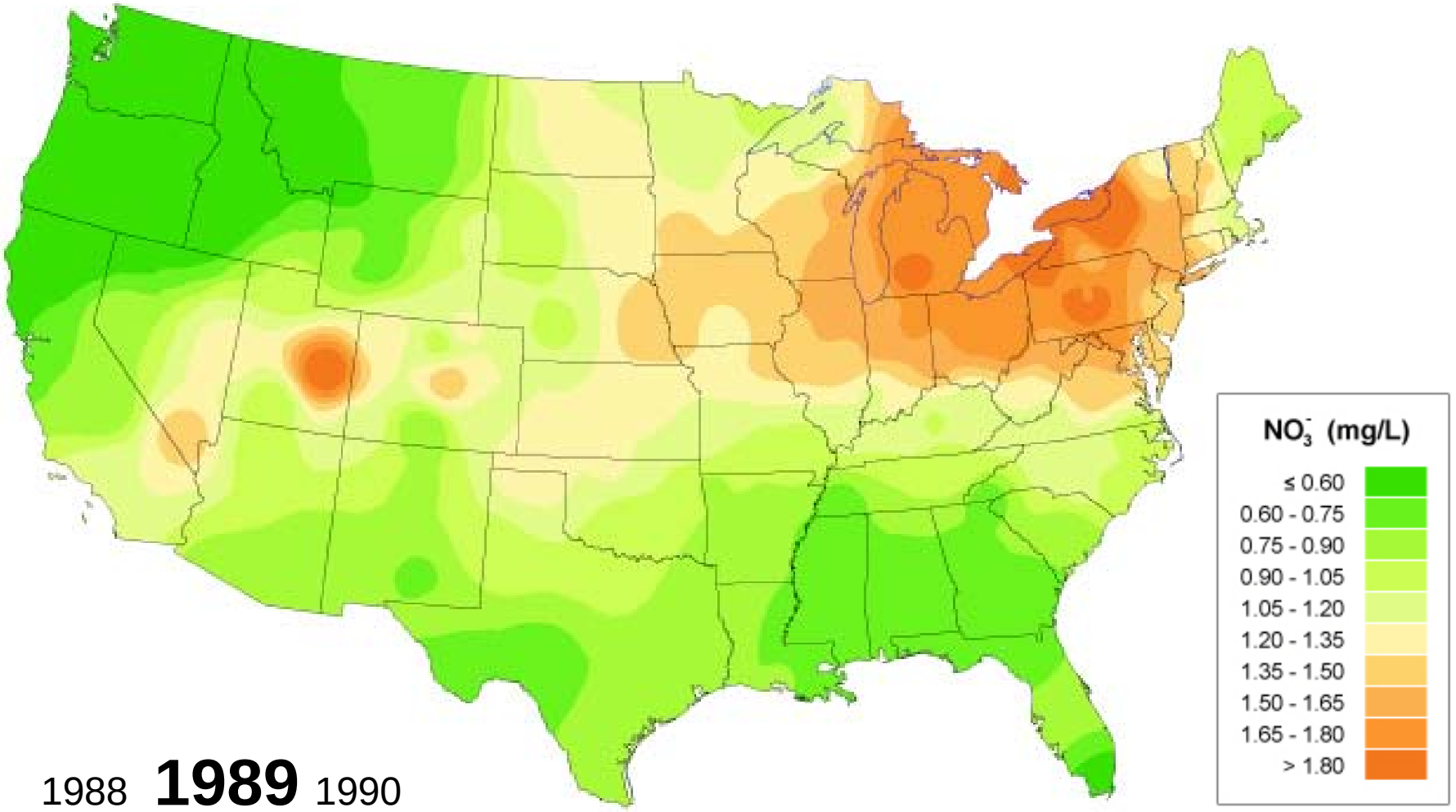
1986 **1987** 1988

Nitrate Ion Concentrations 1985-2008



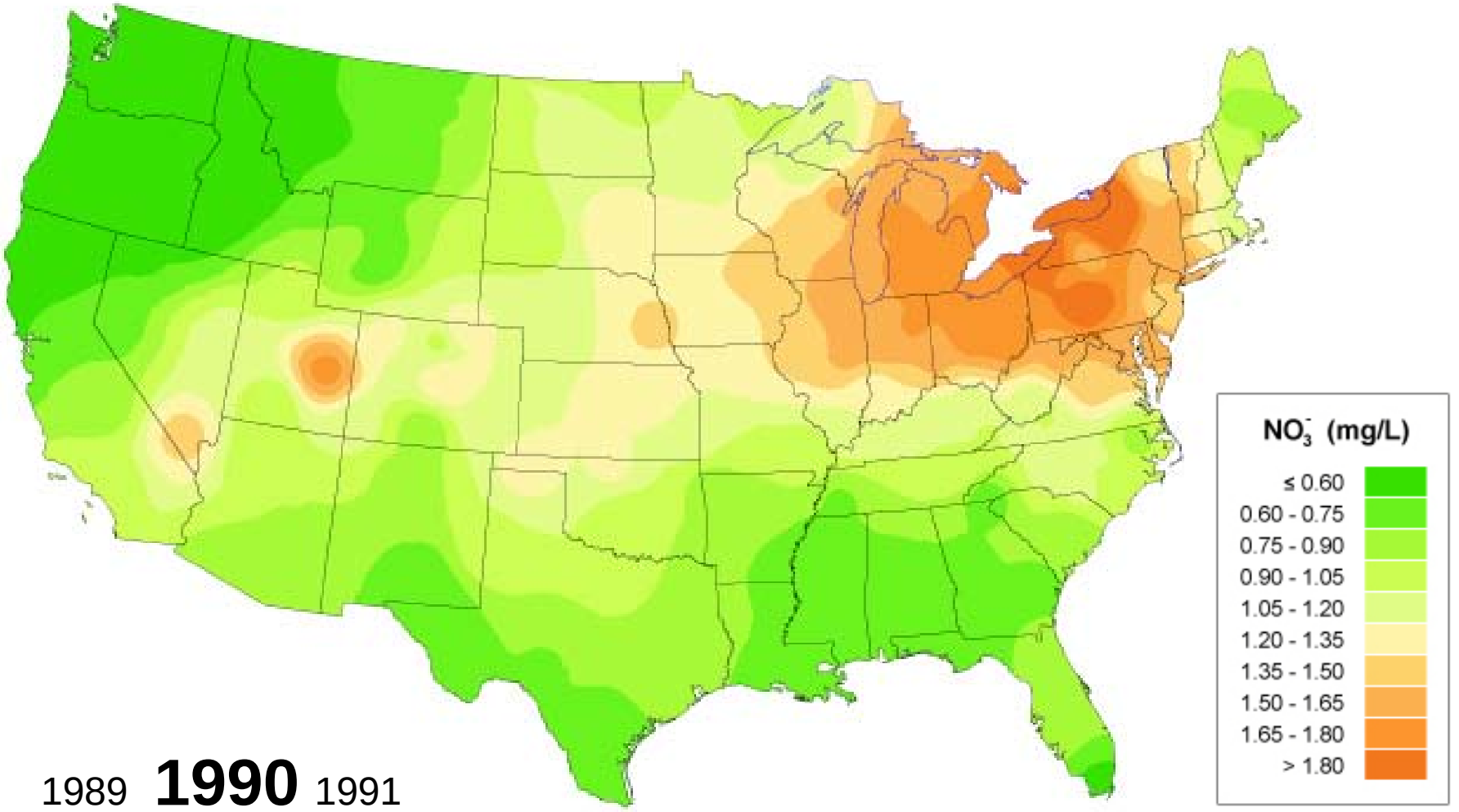
1987 **1988** 1989

Nitrate Ion Concentrations 1985-2008



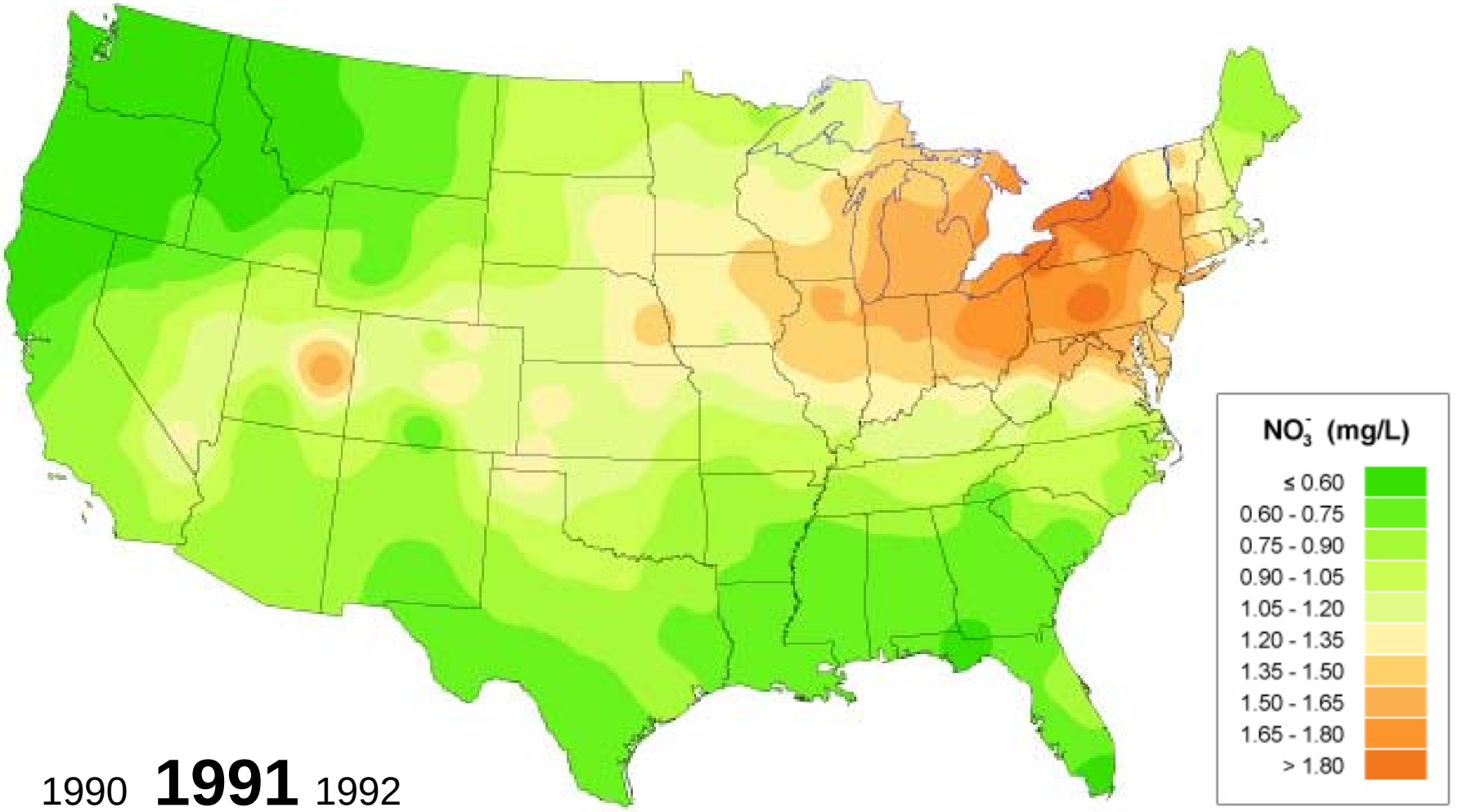
1988 **1989** 1990

Nitrate Ion Concentrations 1985-2008



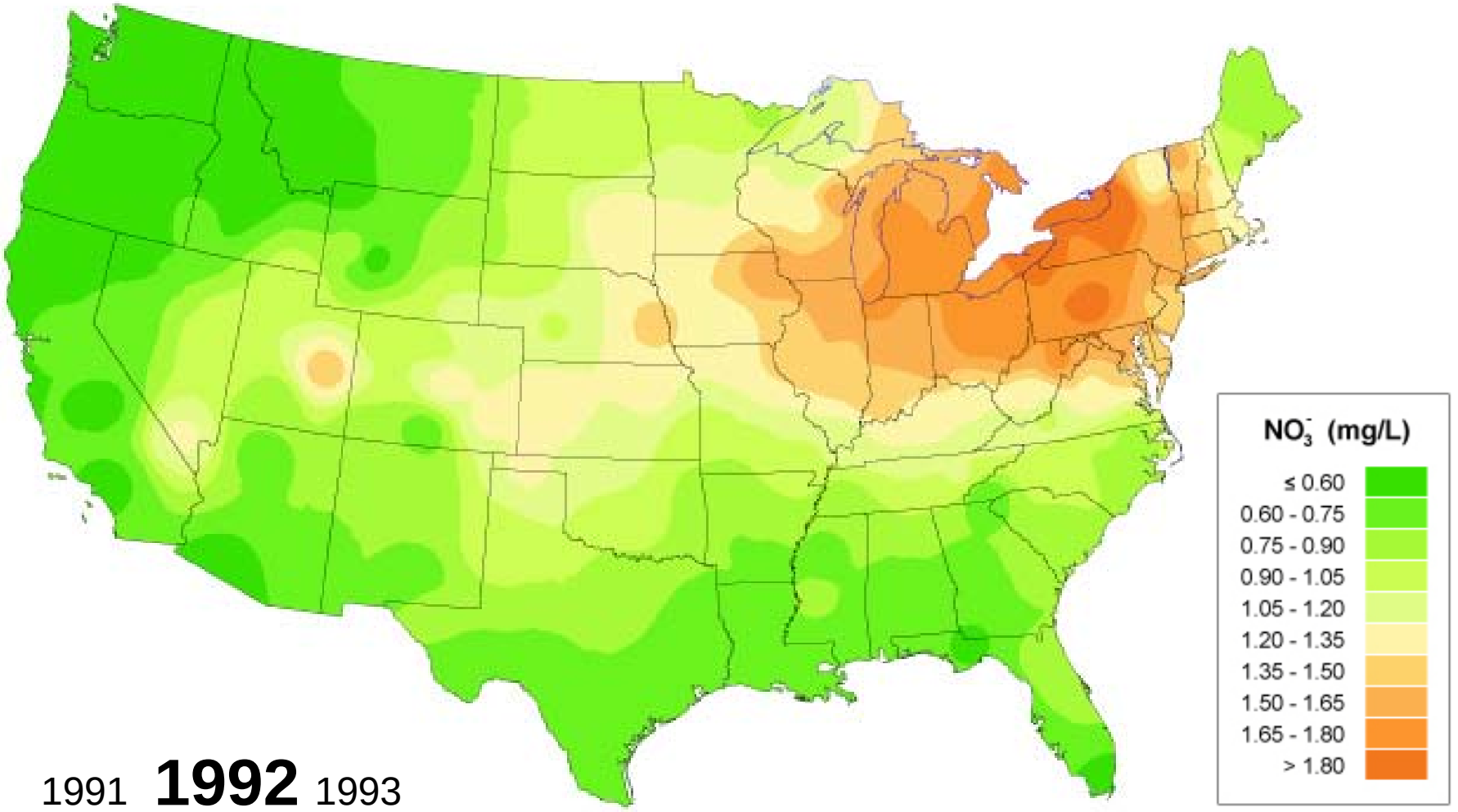
1989 **1990** 1991

Nitrate Ion Concentrations 1985-2008



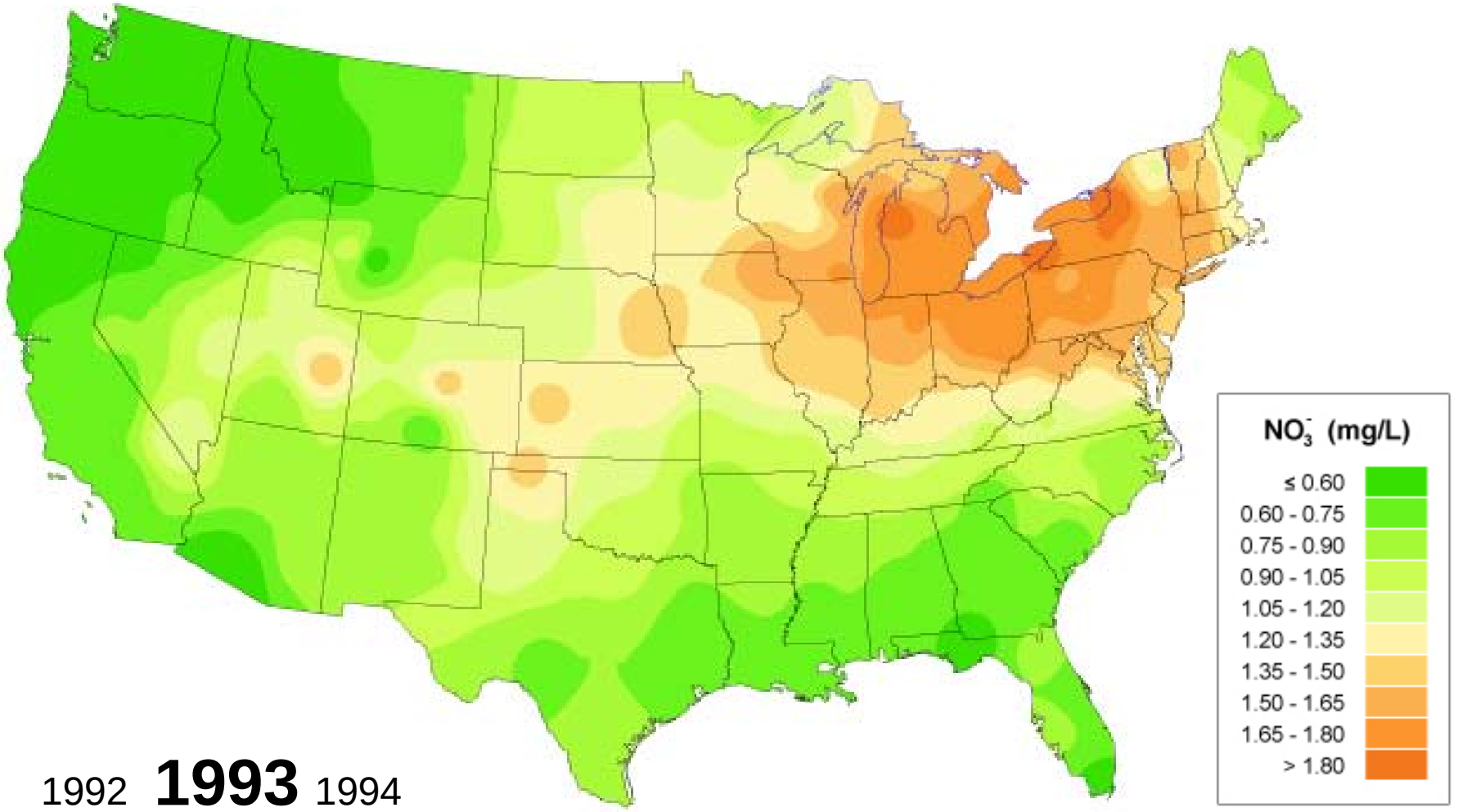
1990 **1991** 1992

Nitrate Ion Concentrations 1985-2008



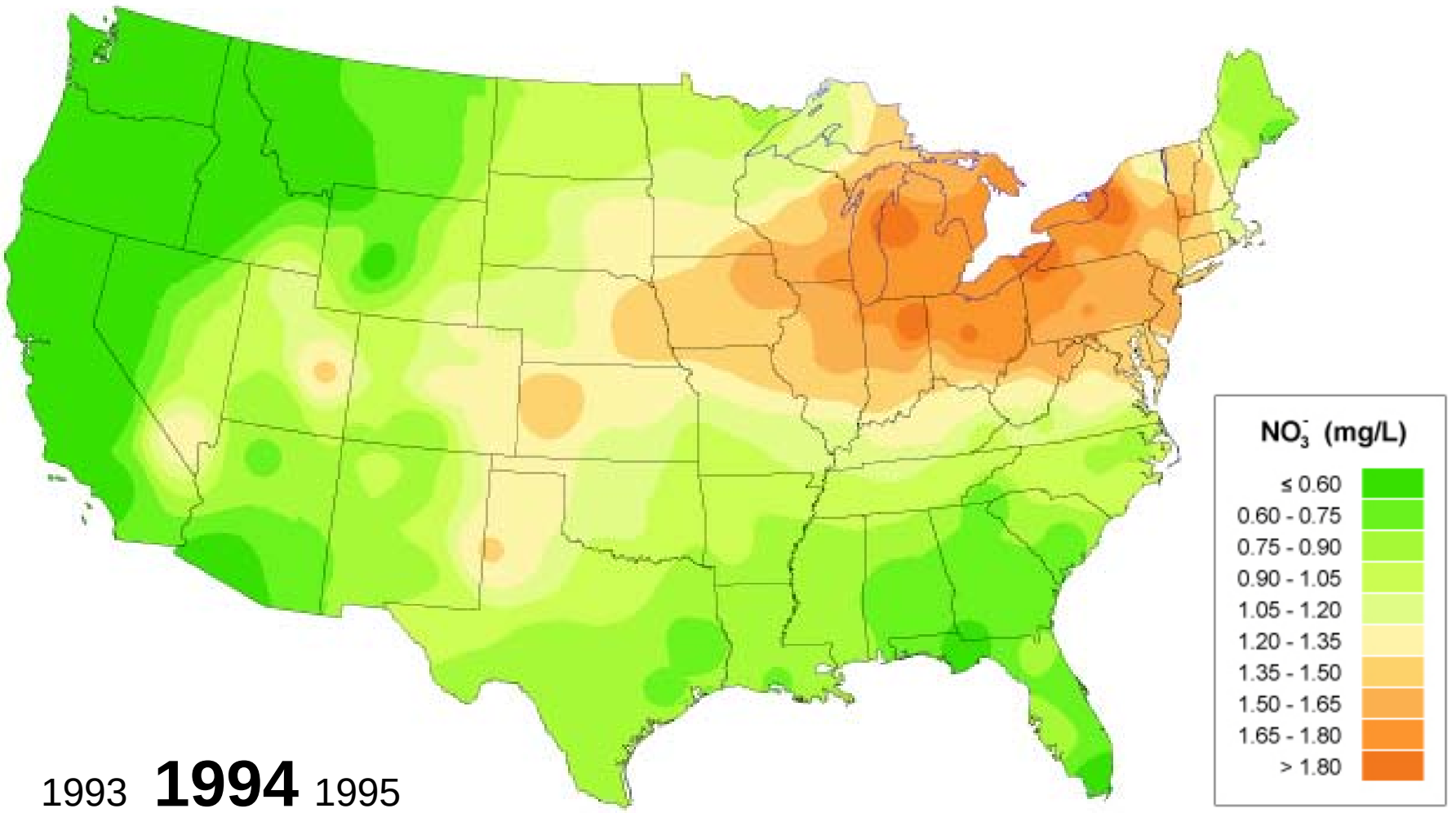
1991 **1992** 1993

Nitrate Ion Concentrations 1985-2008



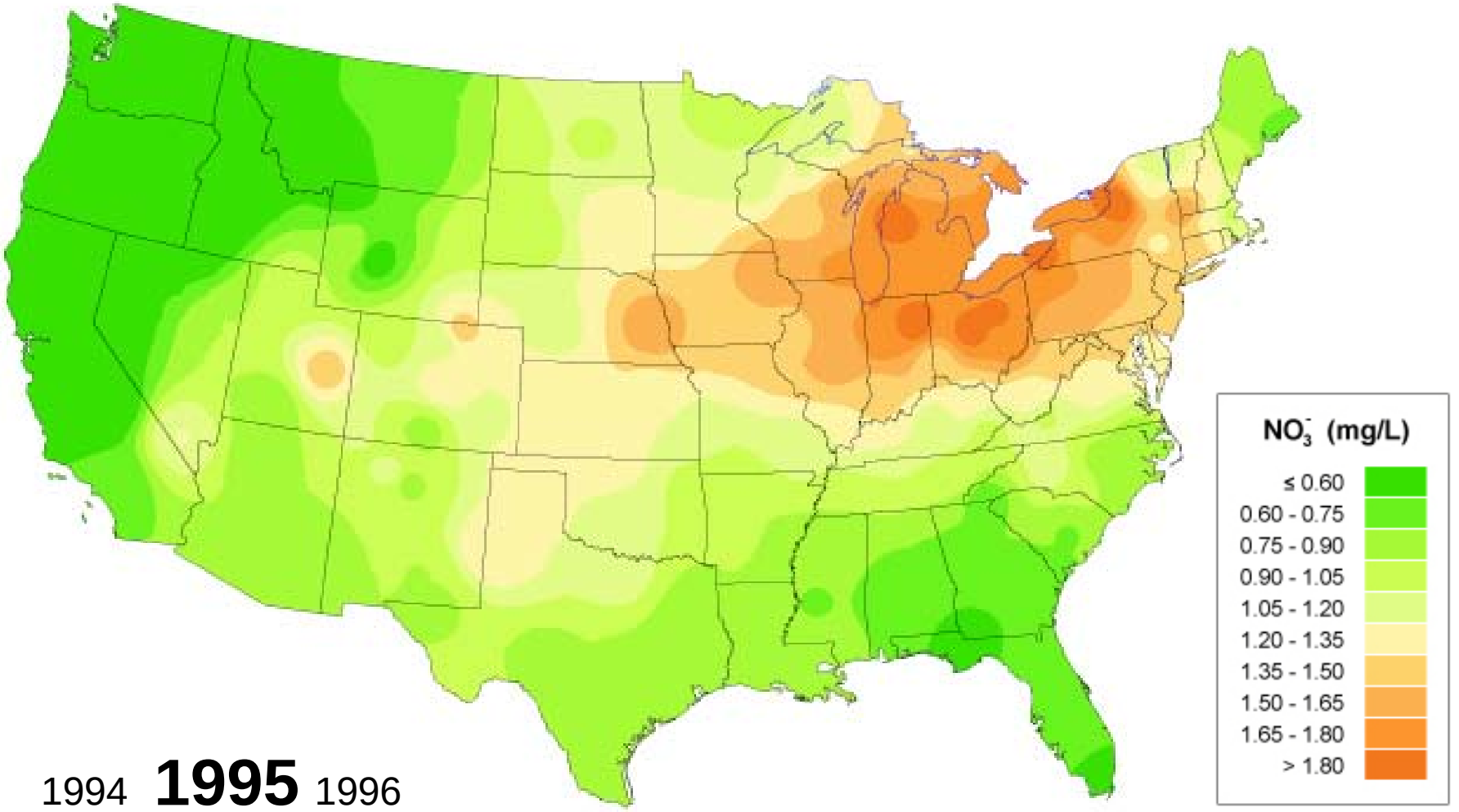
1992 **1993** 1994

Nitrate Ion Concentrations 1985-2008



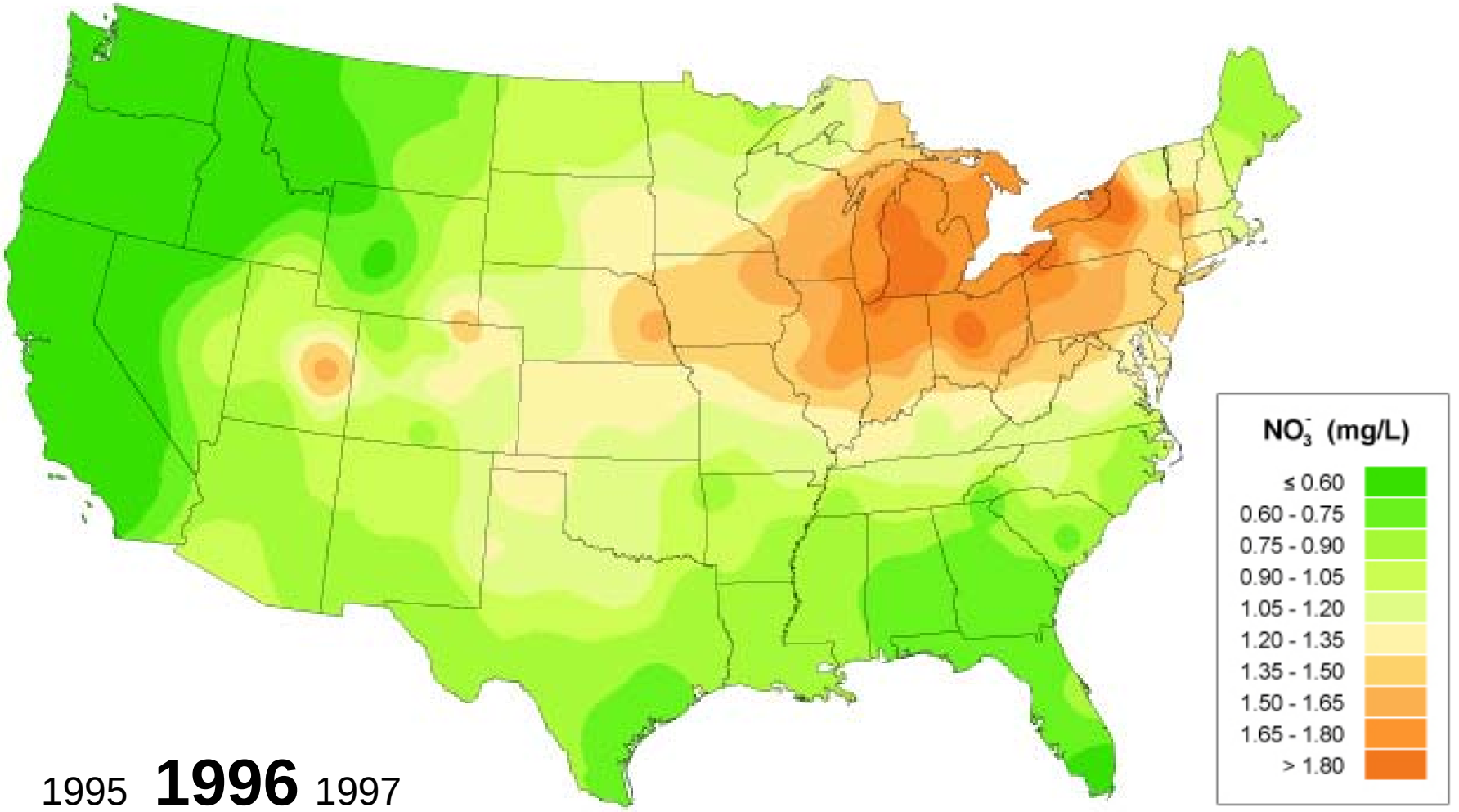
1993 **1994** 1995

Nitrate Ion Concentrations 1985-2008



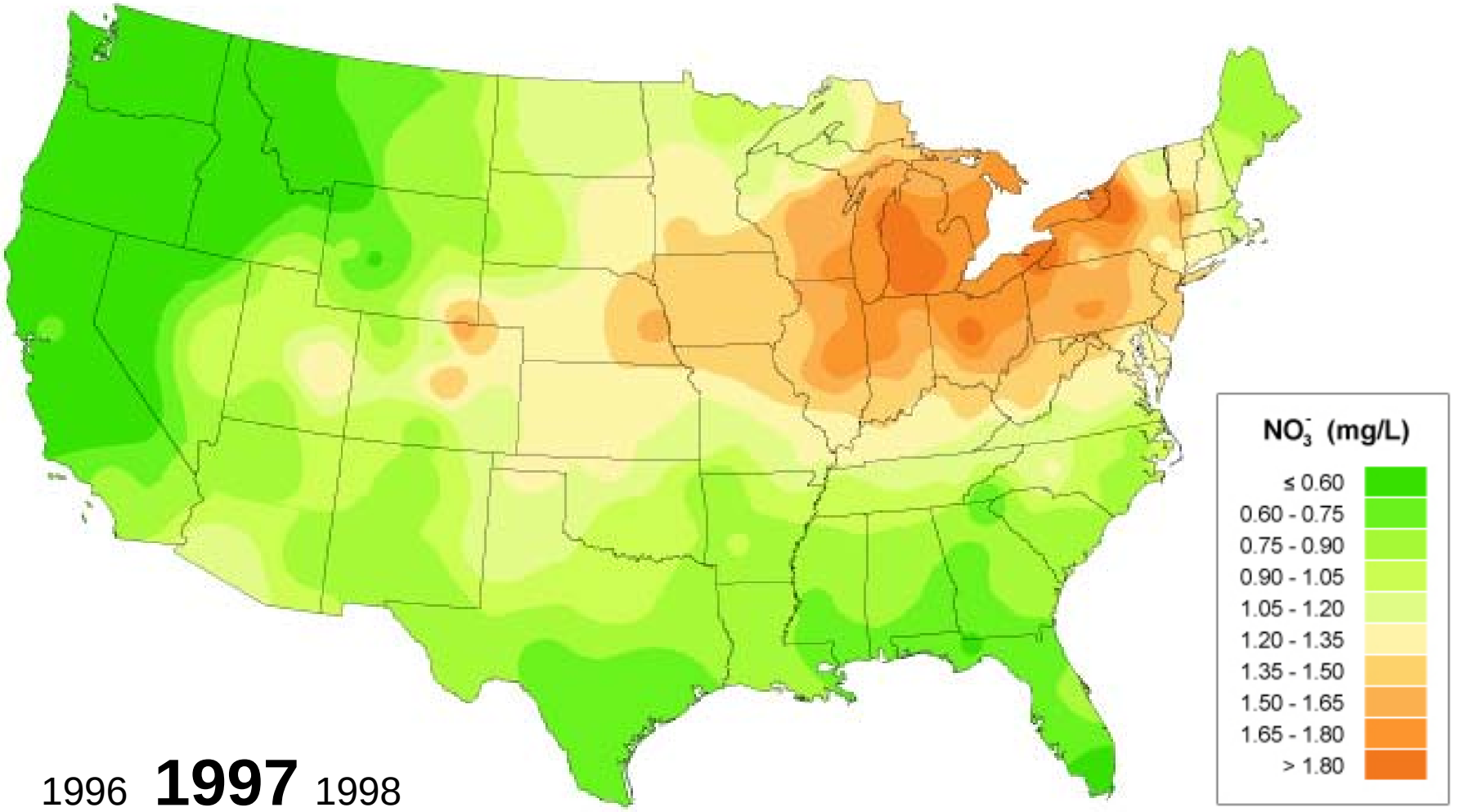
1994 **1995** 1996

Nitrate Ion Concentrations 1985-2008



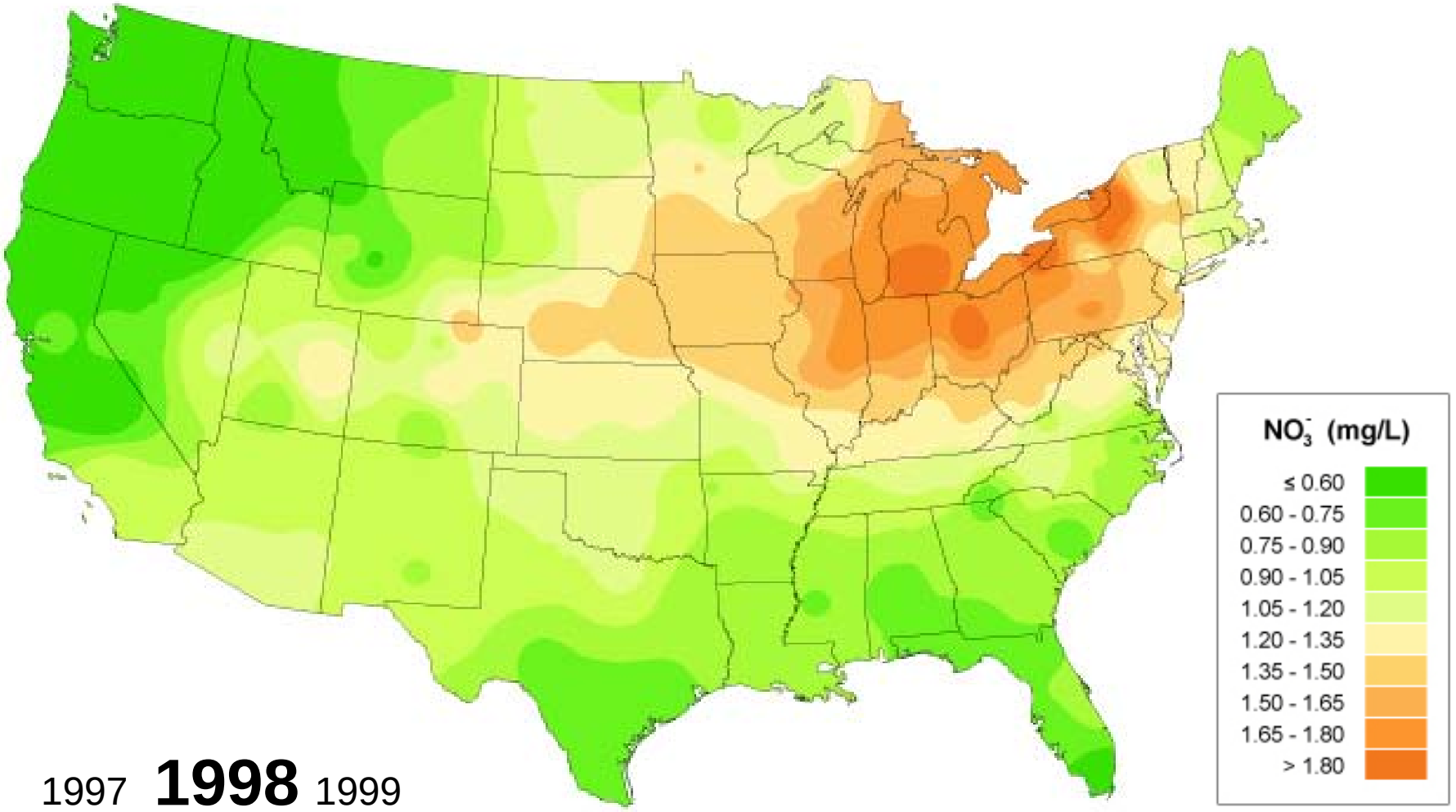
1995 **1996** 1997

Nitrate Ion Concentrations 1985-2008



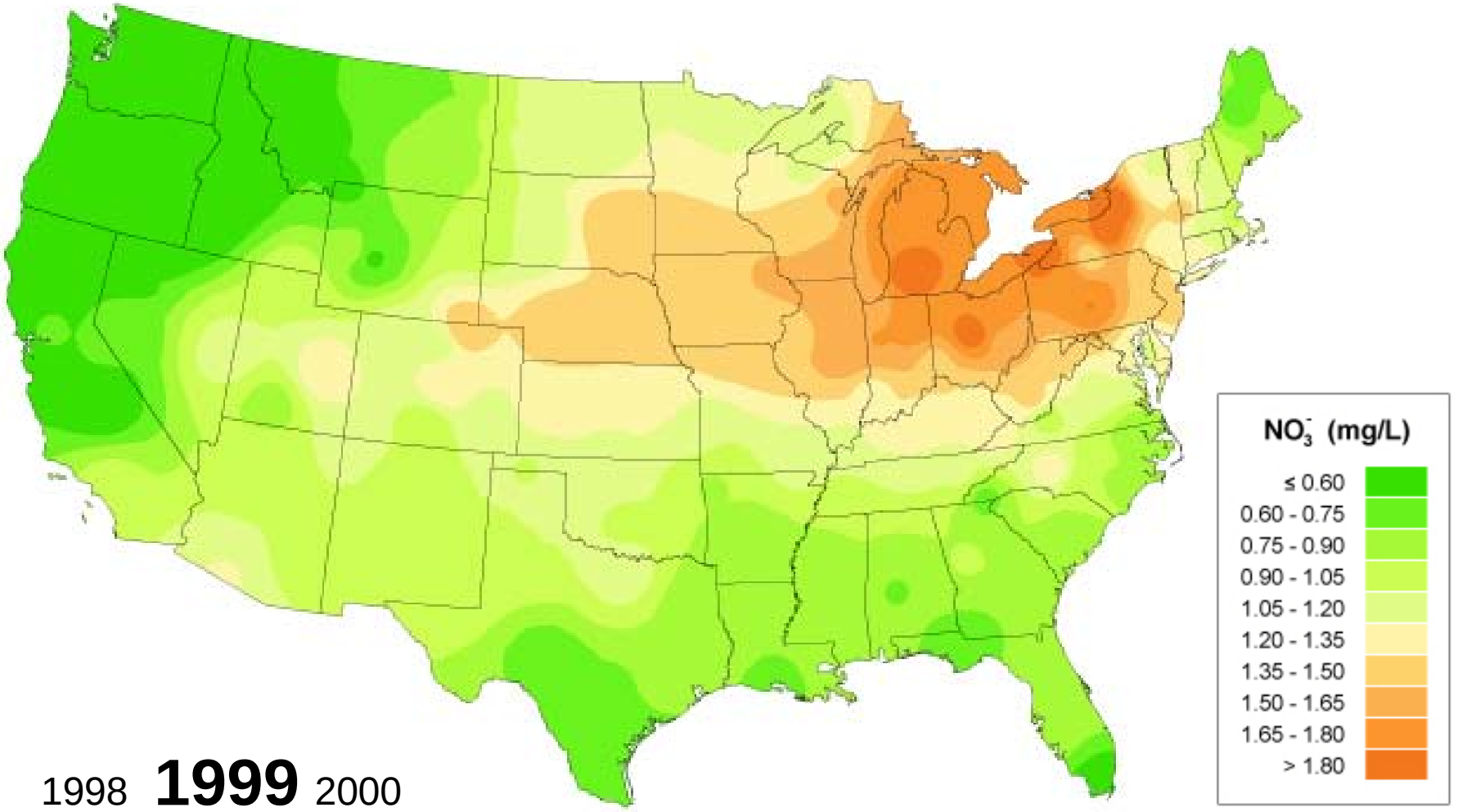
1996 **1997** 1998

Nitrate Ion Concentrations 1985-2008



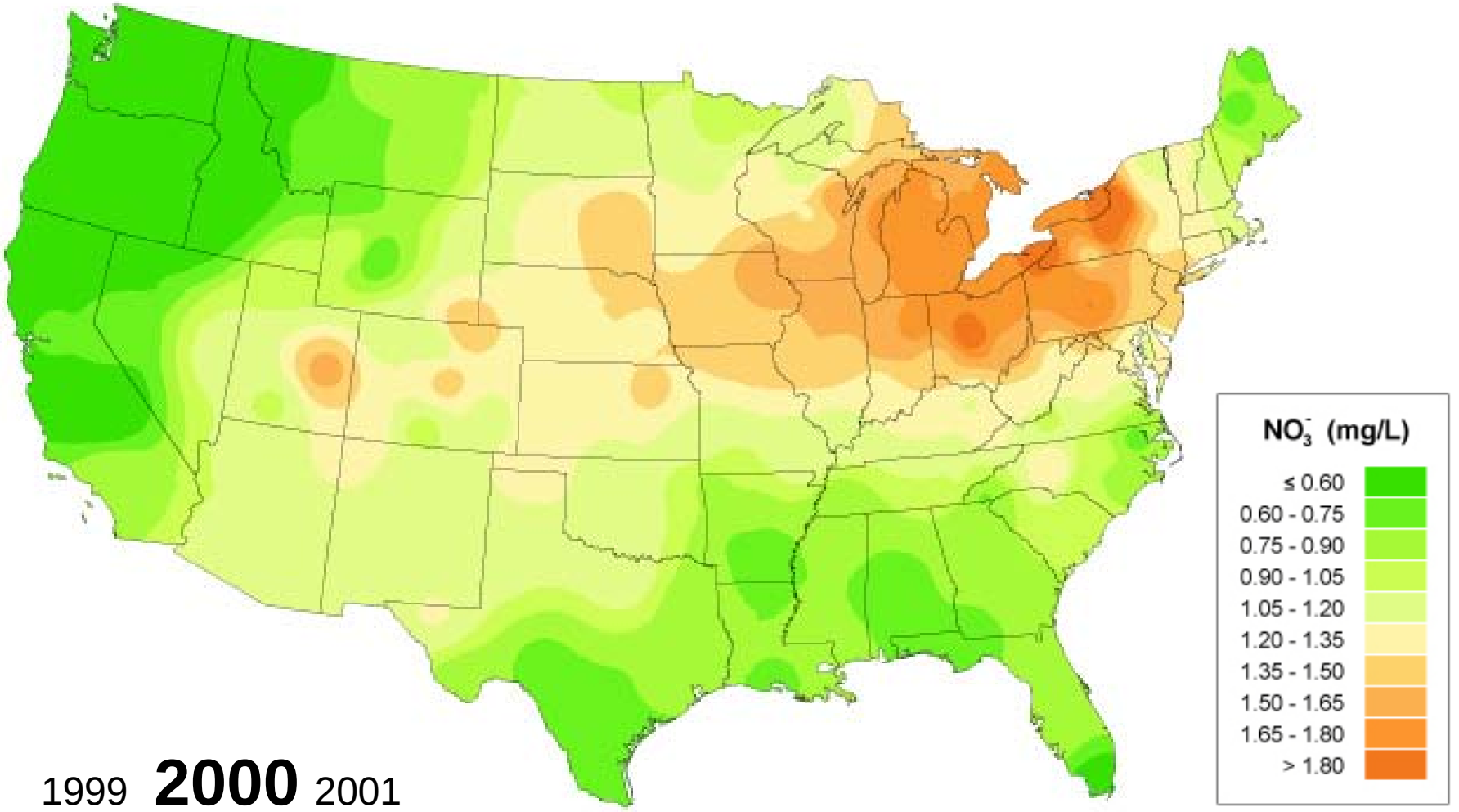
1997 **1998** 1999

Nitrate Ion Concentrations 1985-2008



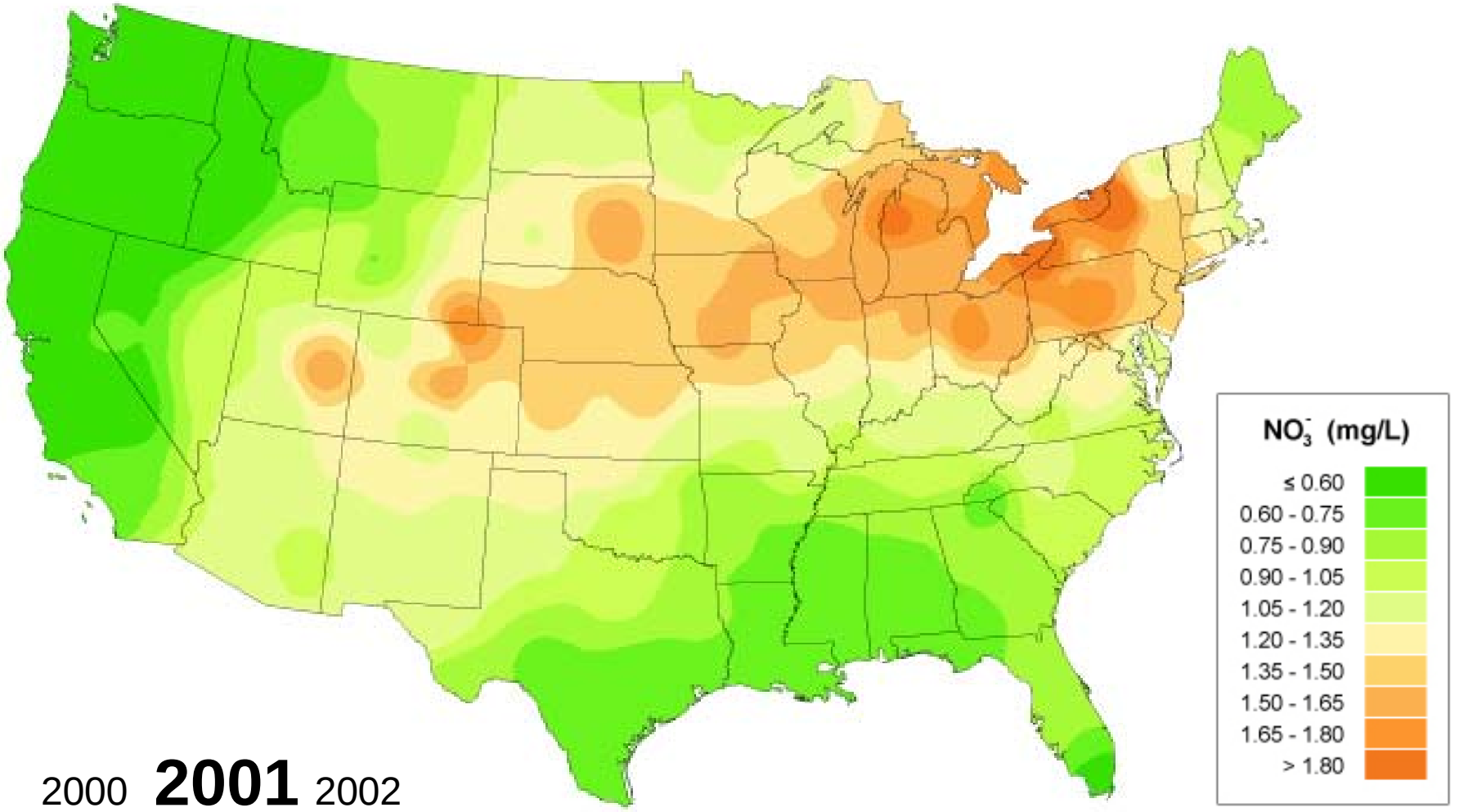
1998 **1999** 2000

Nitrate Ion Concentrations 1985-2008



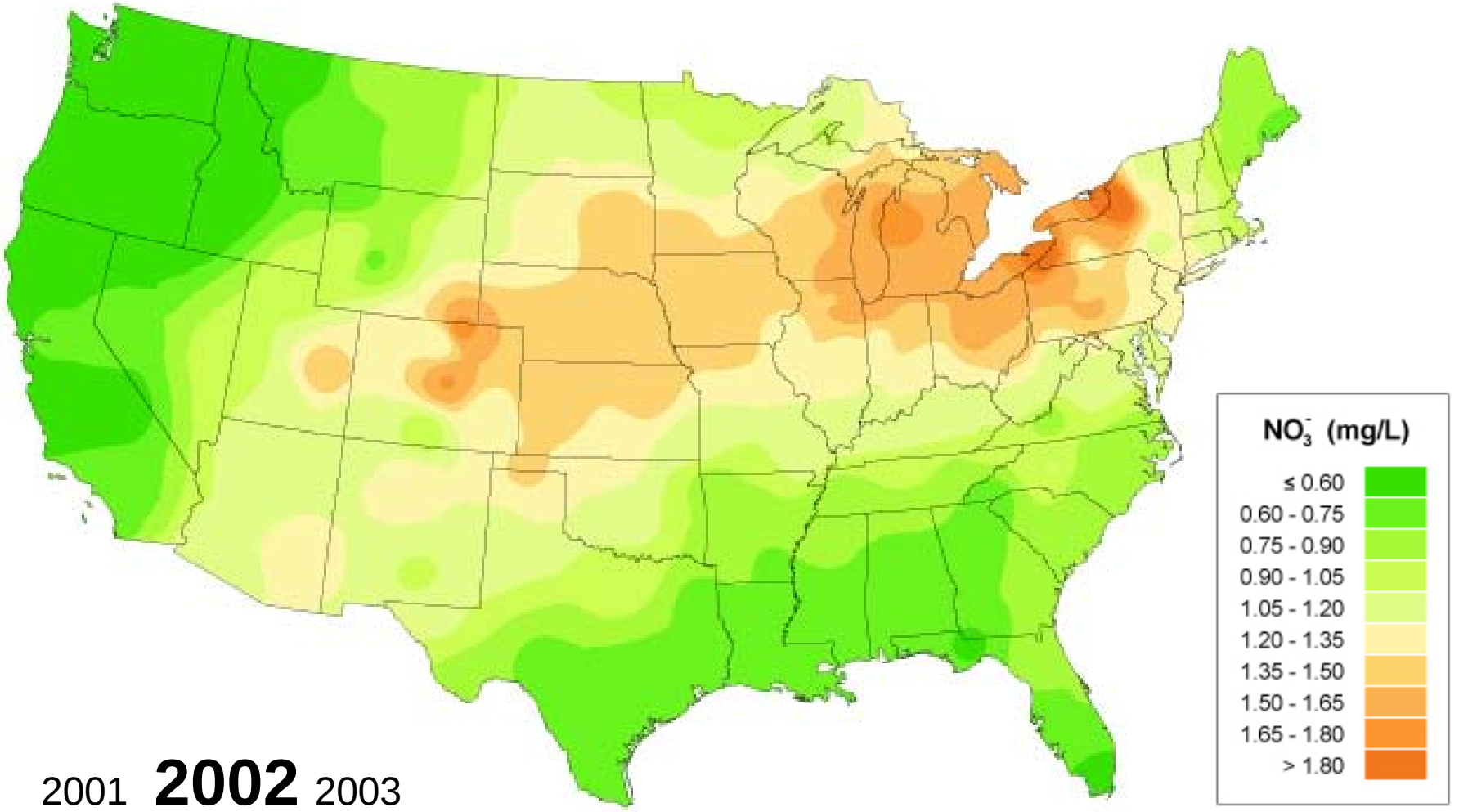
1999 **2000** 2001

Nitrate Ion Concentrations 1985-2008



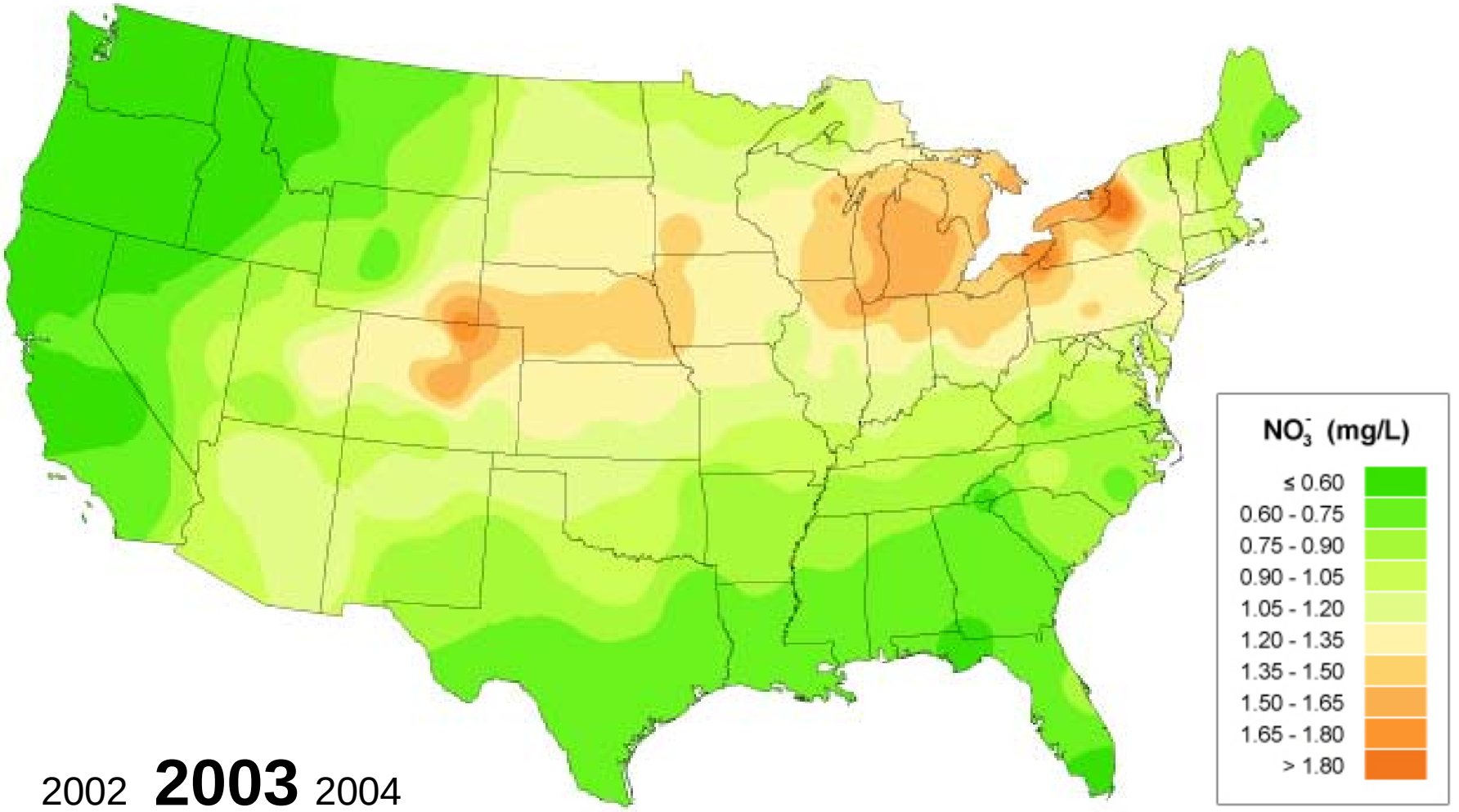
2000 **2001** 2002

Nitrate Ion Concentrations 1985-2008



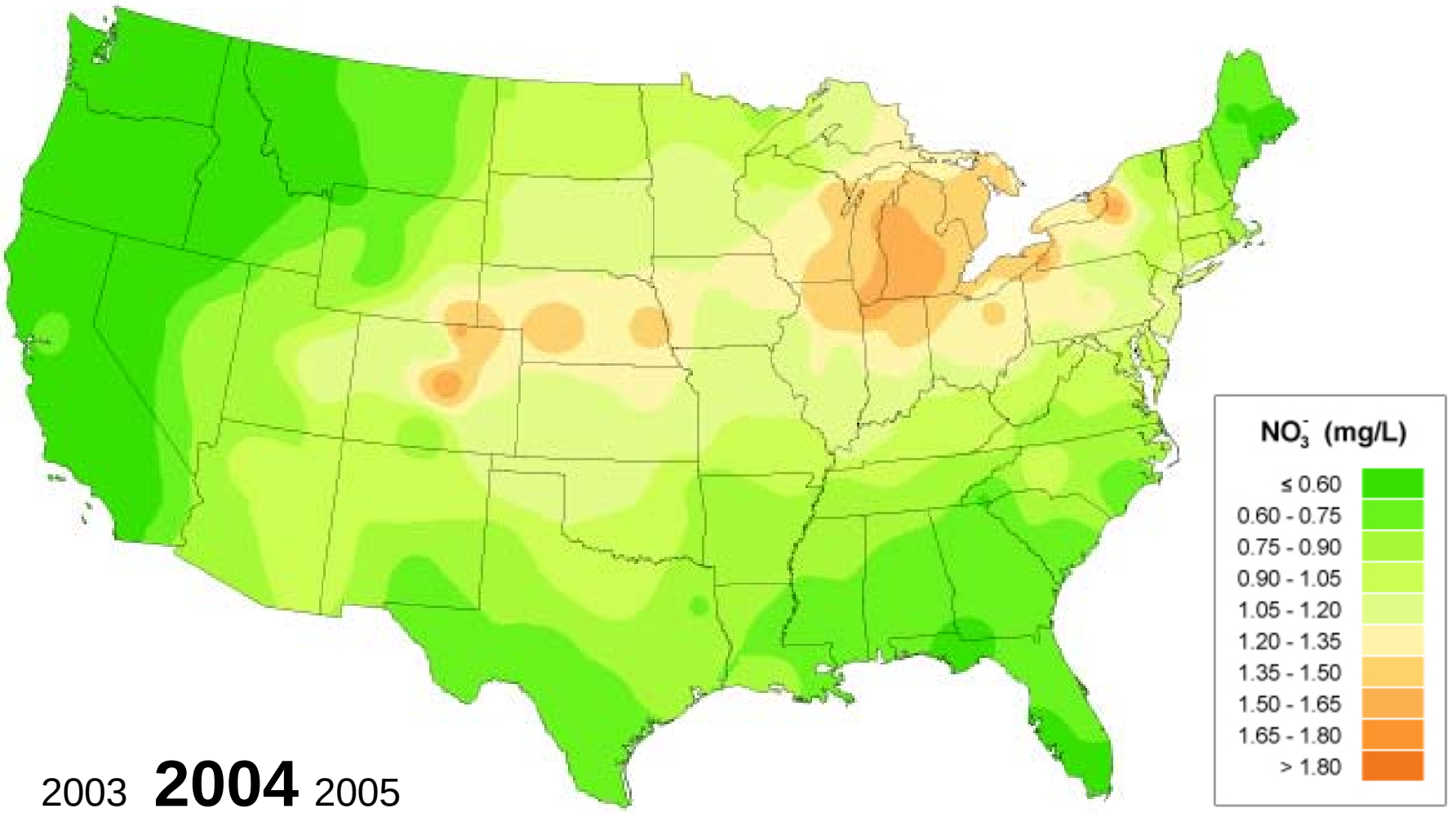
2001 **2002** 2003

Nitrate Ion Concentrations 1985-2008



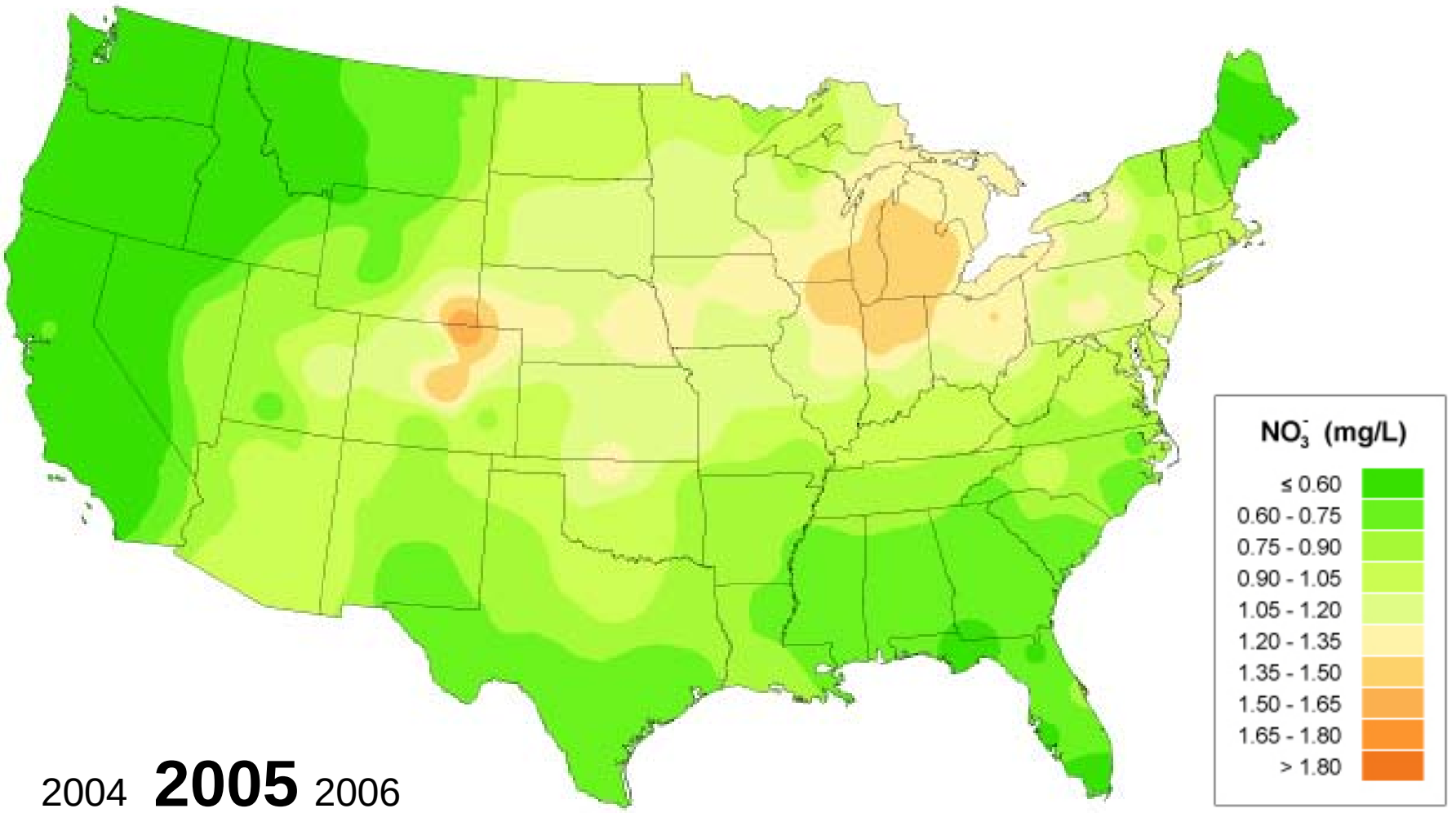
2002 **2003** 2004

Nitrate Ion Concentrations 1985-2008



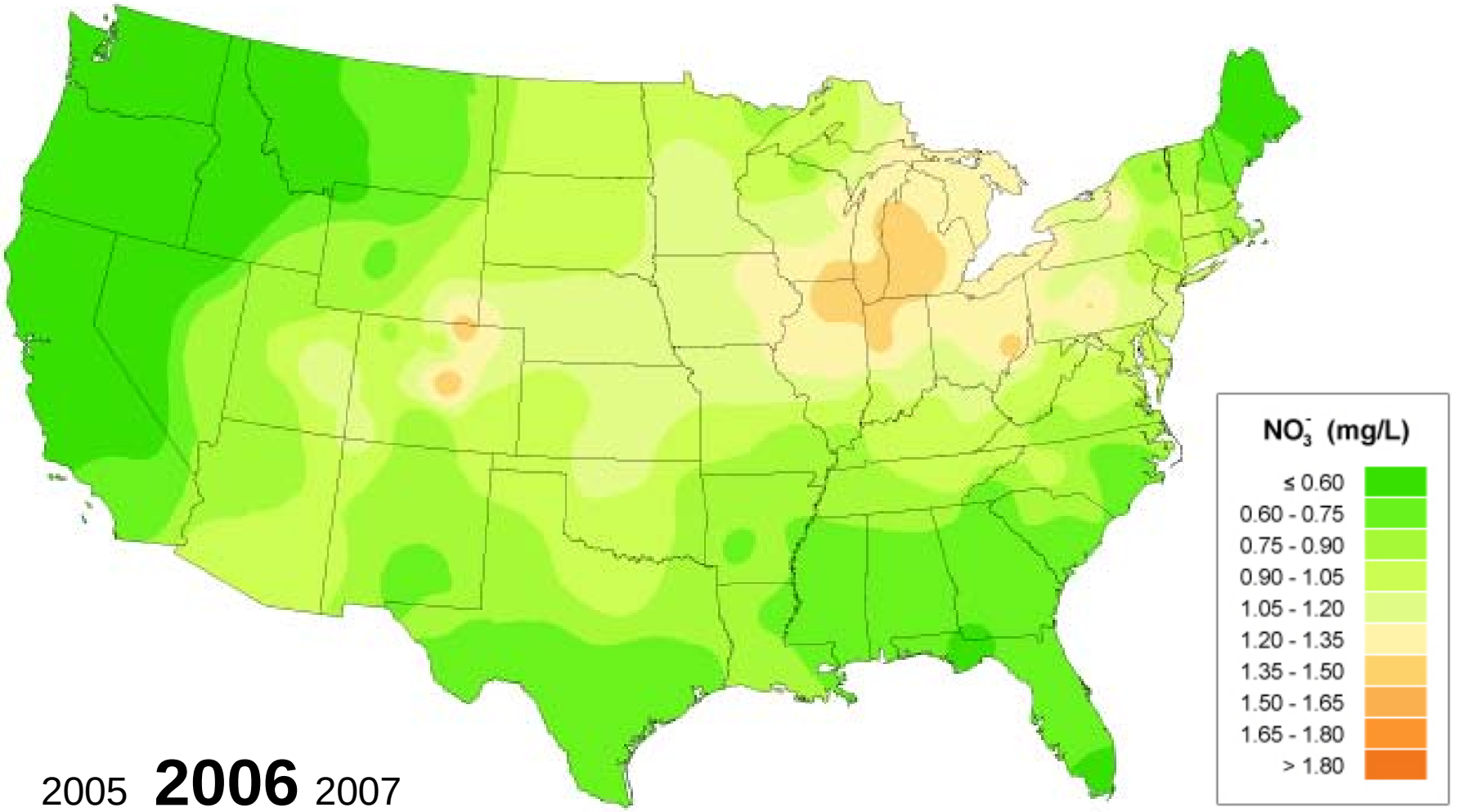
2003 **2004** 2005

Nitrate Ion Concentrations 1985-2008



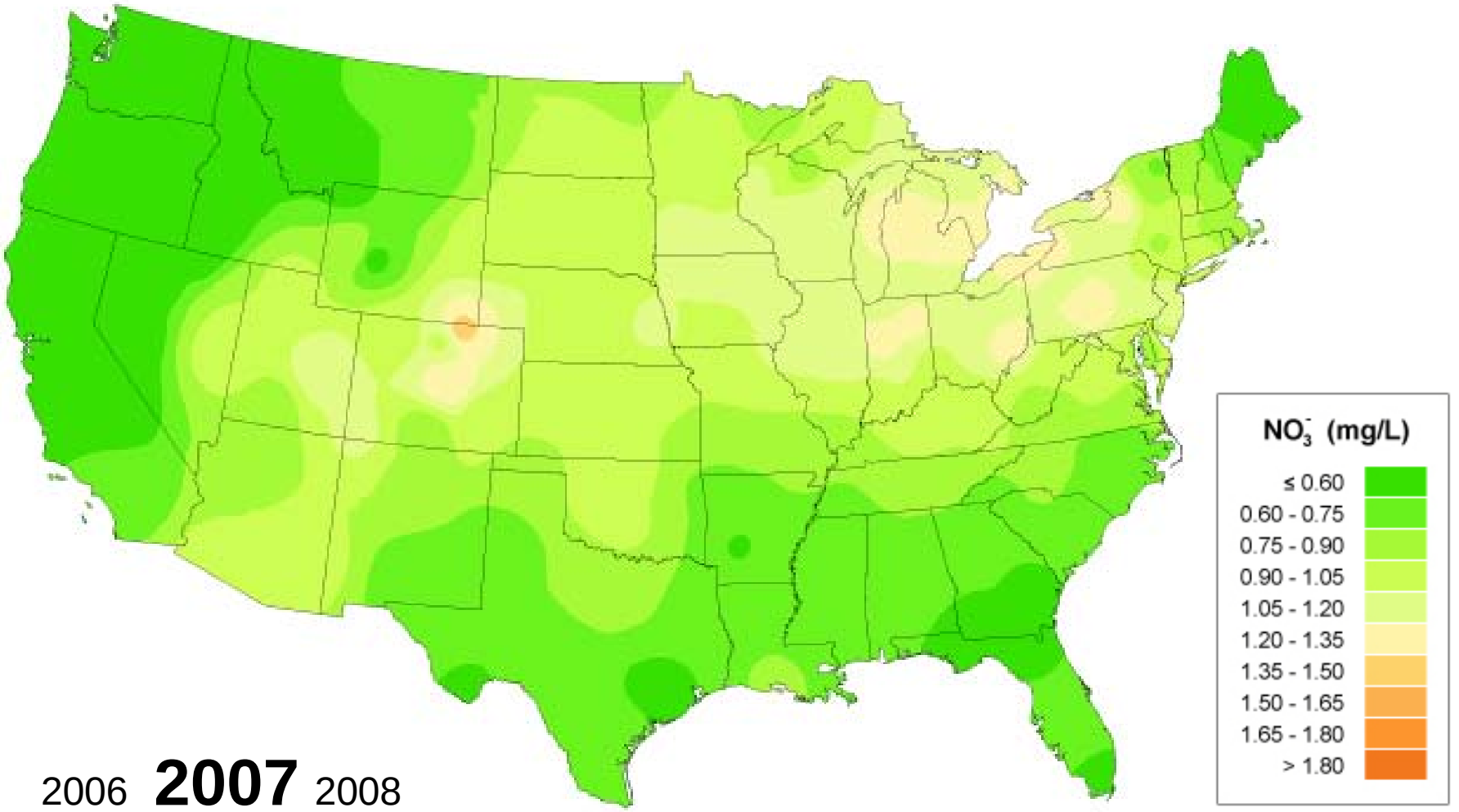
2004 **2005** 2006

Nitrate Ion Concentrations 1985-2008



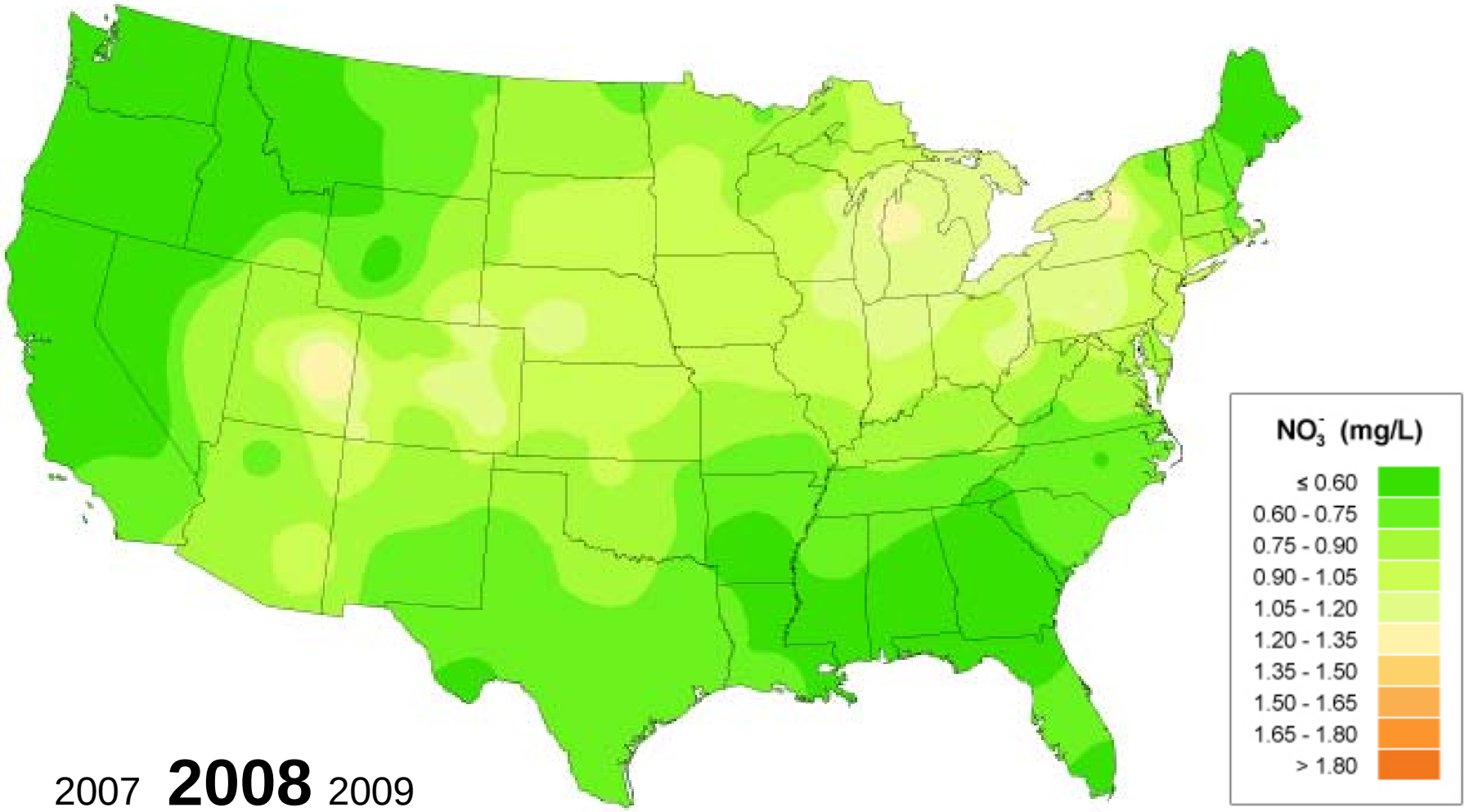
2005 **2006** 2007

Nitrate Ion Concentrations 1985-2008

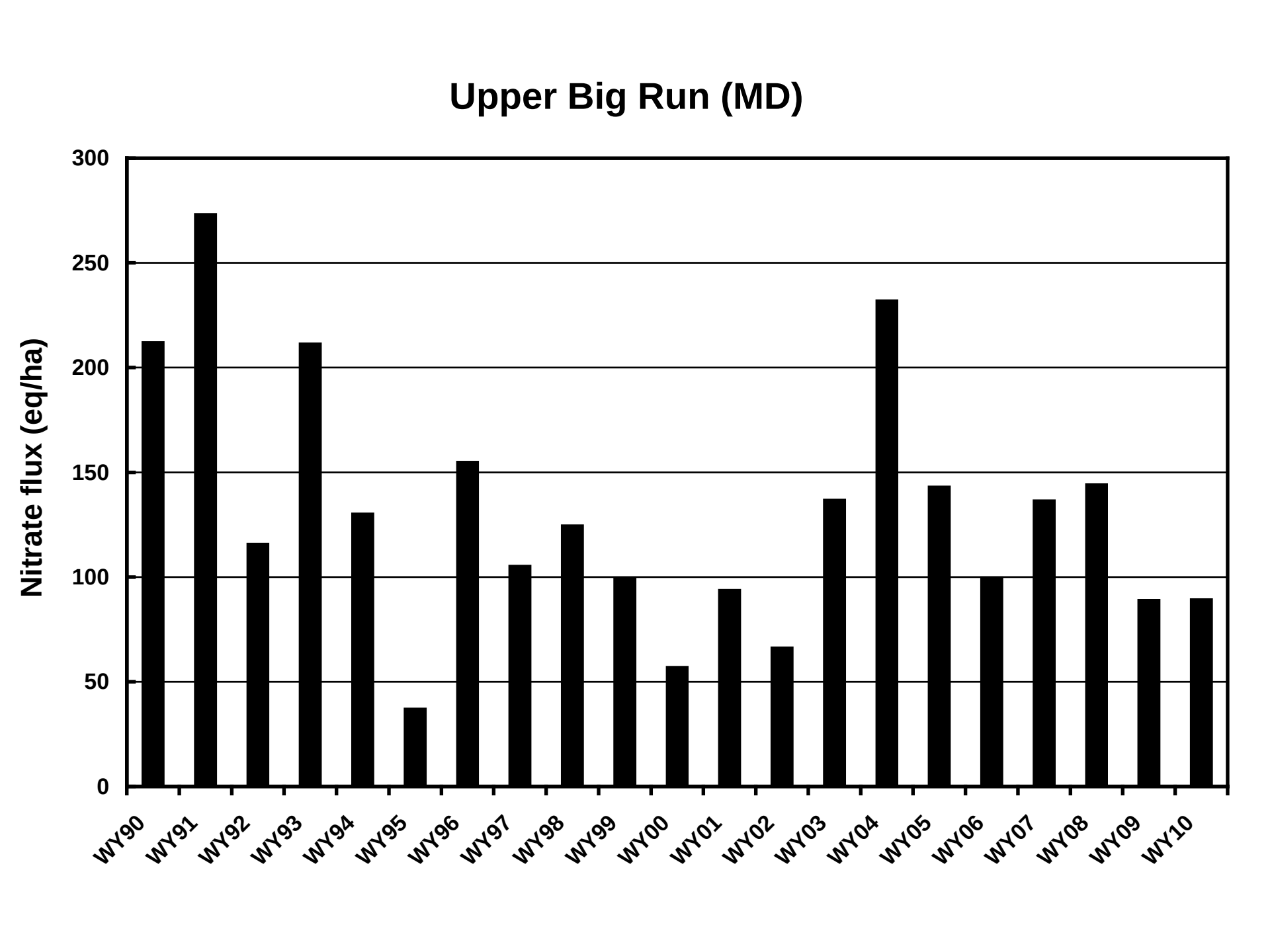


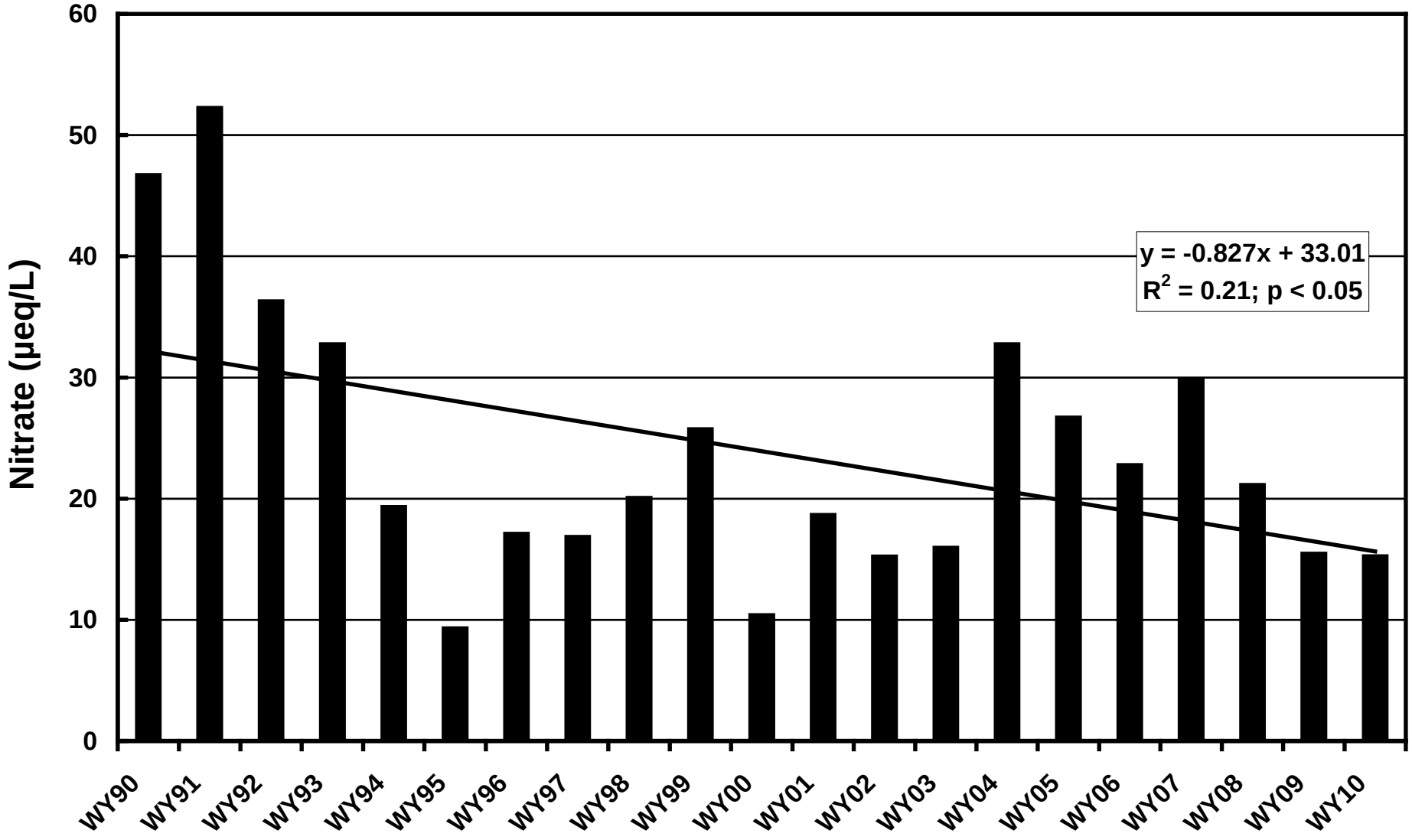
2006 **2007** 2008

Nitrate Ion Concentrations 1985-2008

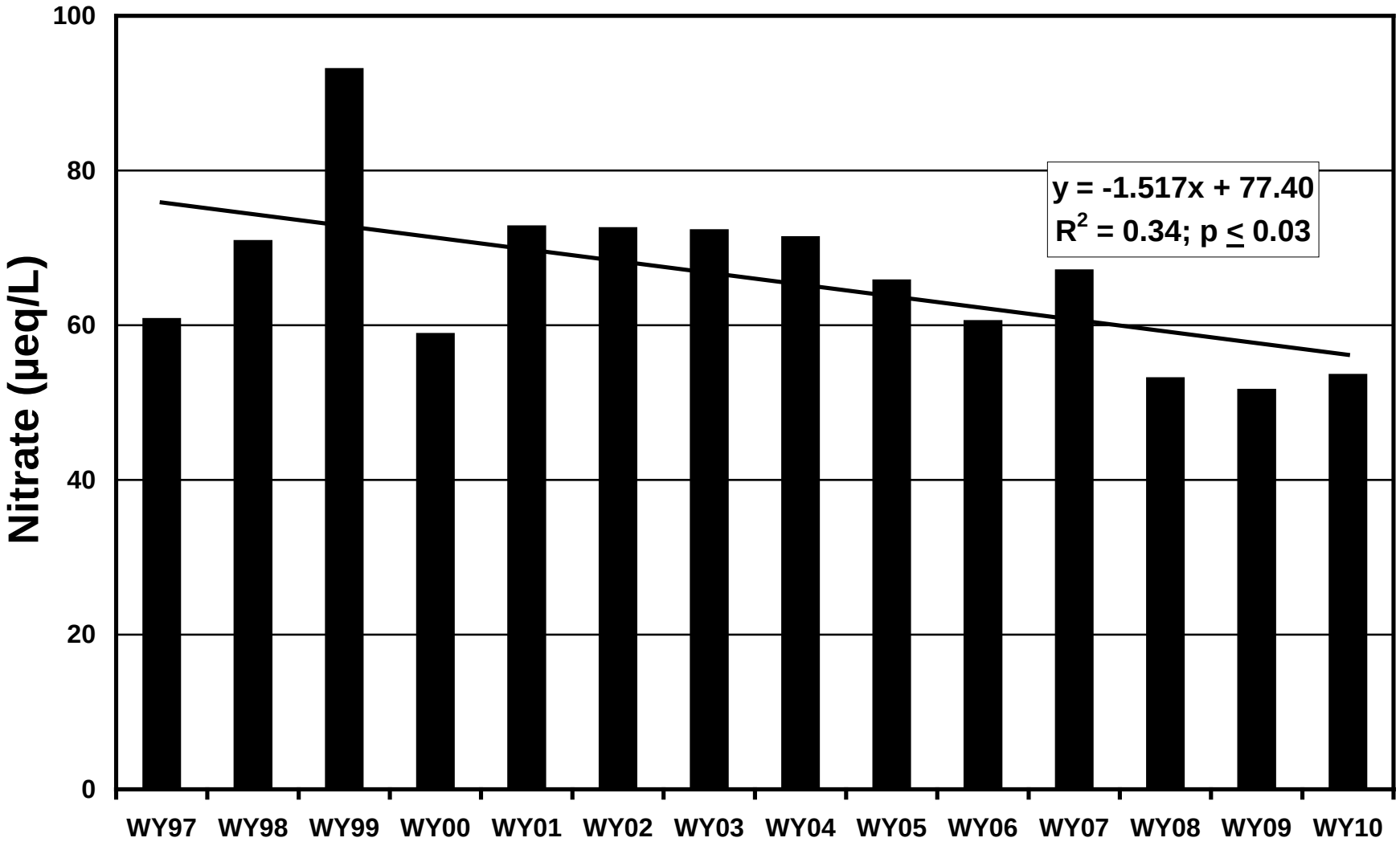


2007 **2008** 2009


Upper Big Run (MD)
Nitrate flux (eq/ha)
300
250
200
150
100
50
0
WY90
WY91
WY92
WY93
WY94
WY95
WY96
WY97
WY98
WY99
WY00
WY01
WY02
WY03
WY04
WY05
WY06
WY07
WY08
WY09
WY10

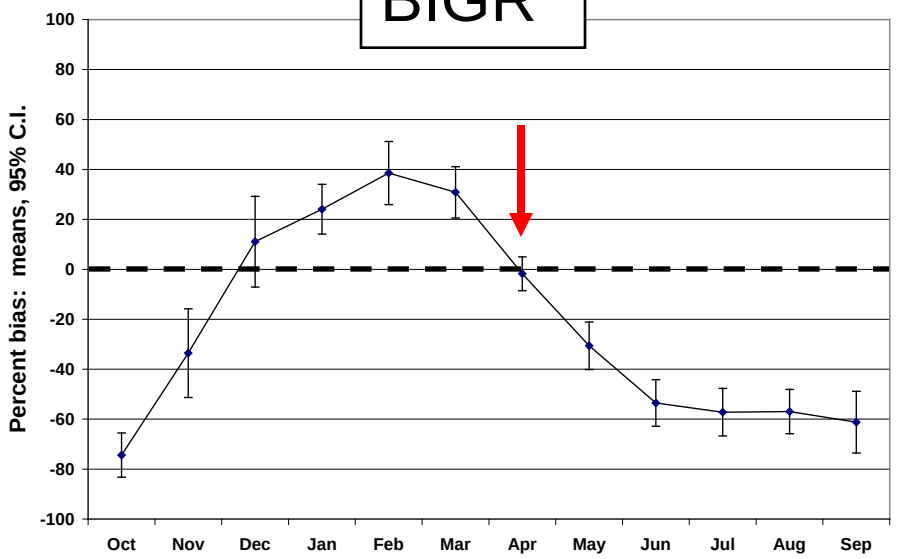

Upper Big Run (MD)
Nitrate (µeq/L)
60
50
40
30
20
10
0
y = -0.827x + 33.01
R2 = 0.21; p < 0.05
WY90
WY91
WY92
WY93
WY94
WY95
WY96
WY97
WY98
WY99
WY00
WY01
WY02
WY03
WY04
WY05
WY06
WY07
WY08
WY09
WY10

Black Lick (MD)

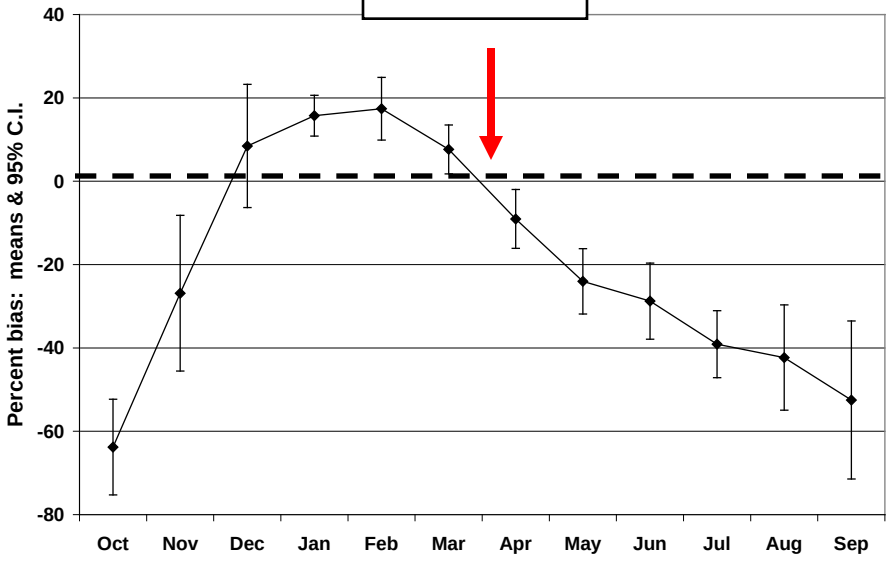


NO_3-N

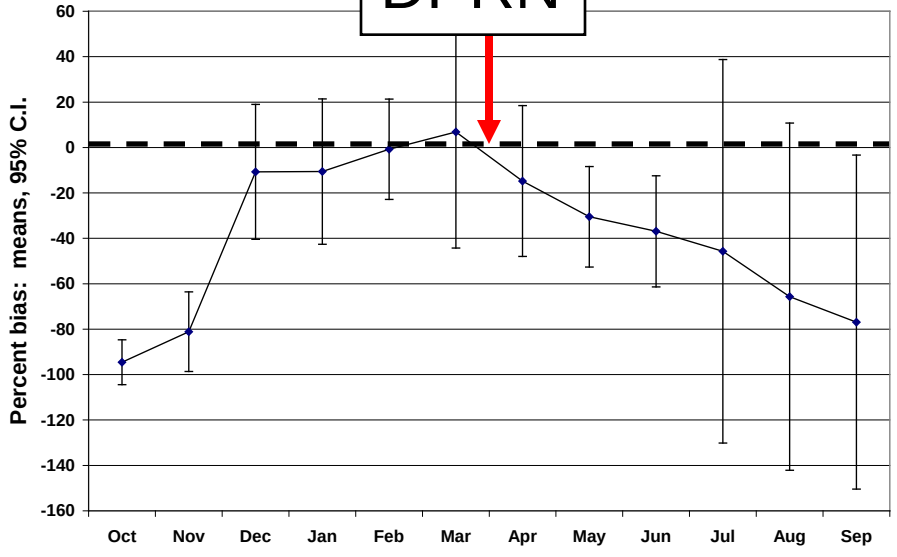
BIGR

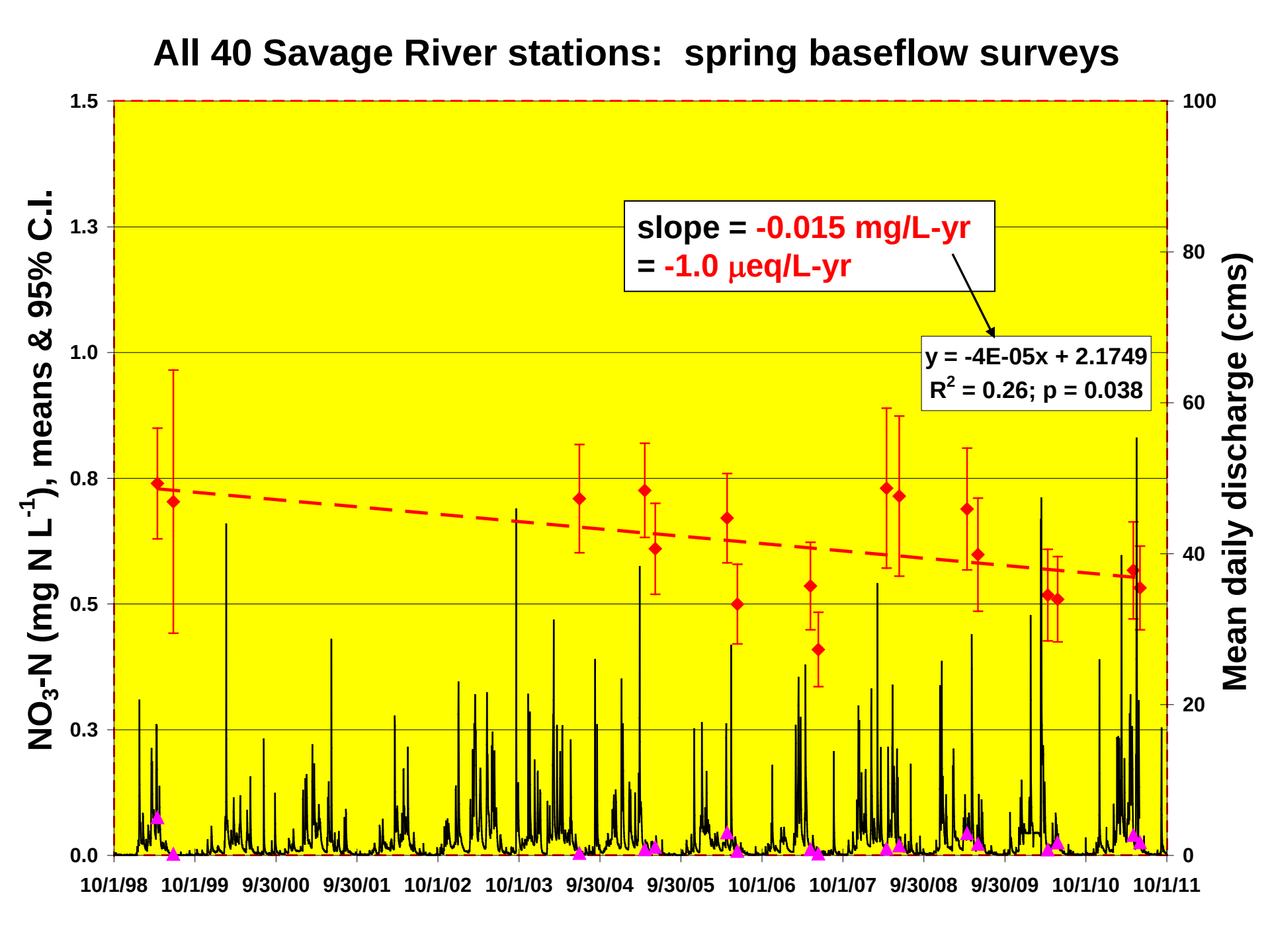


BLAC



DPRN




All 40 Savage River stations: spring baseflow surveys
slope = -0.015 mg/L-yr
= -1.0 μeq/L-yr
y = -4E-05x + 2.1749
R2 = 0.26; p = 0.038
NO3-N (mg N L-1), means & 95% C.I.
Mean daily discharge (cms)
1.5
1.3
1.0
0.8
0.5
0.3
0.0
100
80
60
40
20
0
10/1/98
10/1/99
9/30/00
9/30/01
10/1/02
10/1/03
9/30/04
9/30/05
10/1/06
10/1/07
9/30/08
9/30/09
10/1/10
10/1/11

Conclusions

- Acid-sensitive watersheds in western MD are exhibiting signs of recovery from acid deposition (Eshleman *et al.*, 2008)
  - Decreasing streamwater sulfate concentrations
  - Decreasing nitrate-N concentrations
  - Increasing ANC (very acid-sensitive systems only)
- Changes consistent with dramatic decreases in acid deposition due to 1990 Clean Air Act Amendments ("acid rain program")
  - H_2SO_4/SO_2 deposition (~50% reduction)
  - HNO_3 deposition (~40% reduction)

Ancillary monitoring stations

- Comprise a small subset of 108 stations identified by Langland *et al.* (1995)
  - Potomac River at Washington DC at Chain Bridge: *downstream* station
  - Potomac River at Hancock (MD): *upstream* station (75% forested)
  - 4 other Potomac River tributaries
  - 6 predominantly-forested (> 75%) basins in VA and PA

Chesapeake Bay watershed load stations used in the current study

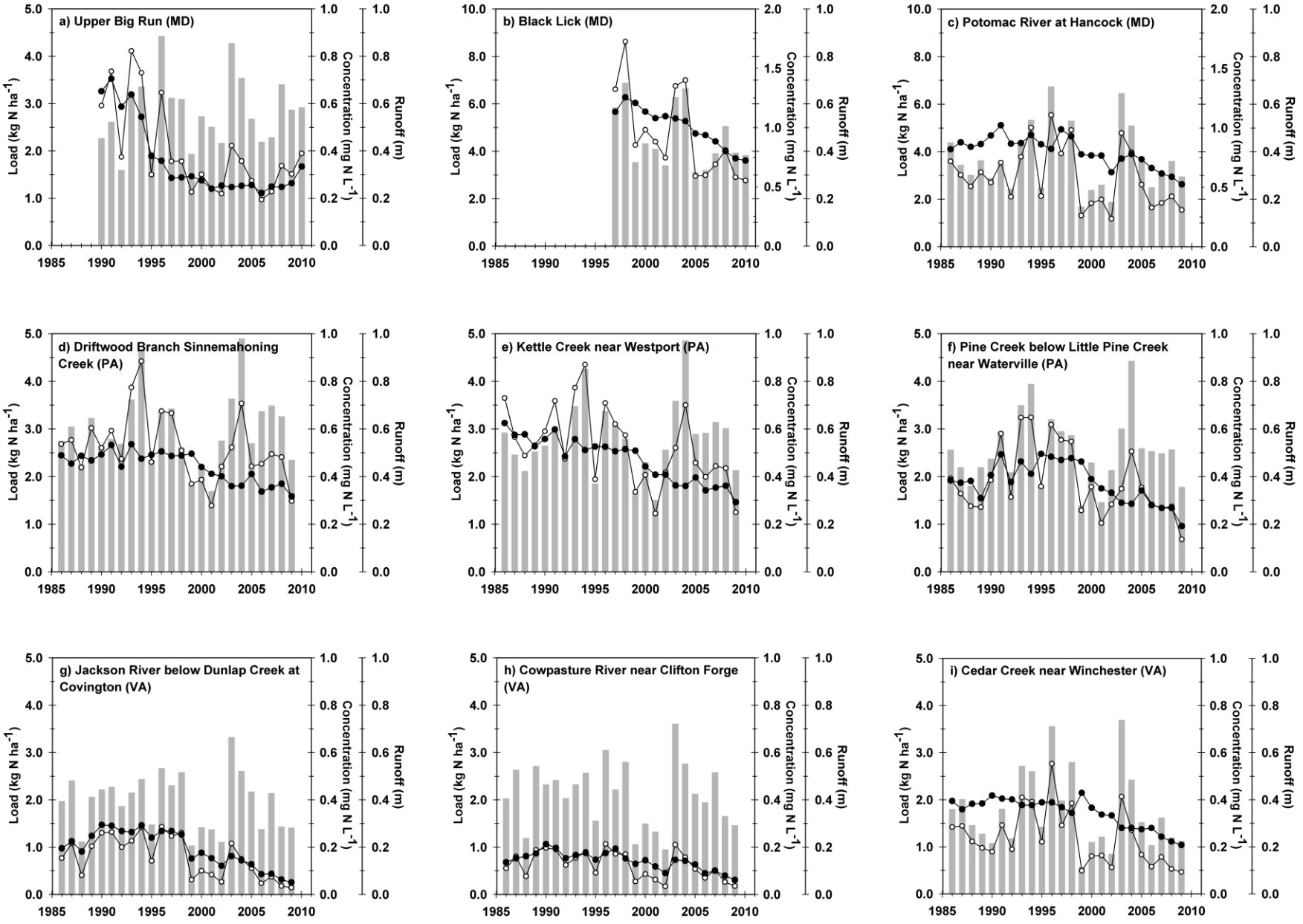
Watershed/ station (abbr.)*	Watershed/station description	WQ station	Watershed area (mi^2)	% forest
BIGR (1990-2010)	Upper Big Run, MD	BIGR	0.63	91.7
BLAC (1997-2010)	Black Lick, MD	BLAC	2.18	78.5
POTH	Potomac River at Hancock, MD	POT2386[1]	4073	75.4
DBSC	Driftwood Branch Sinnemahoning Creek at Sterling Run, PA	WQN420[2]	272	92.9
KCWP	Kettle Creek near Westport, PA	WQN434[2]	233	94.9
PCLP	Pine Creek below Little Pine Creek near Waterville, PA	WQN410[2]	944	98.2
JRDC	Jackson River below Dunlap Creek at Covington, VA	2JKS023.61[3]	614	81.0
CRCF	Cowpasture River near Clifton Forge, VA	2CWP002.58[3]	461	81.8
CCWV	Cedar Creek near Winchester, VA	1BCDR013.29[3]	103	85.6
ANTC	Antietam Creek near Sharpsburg, MD	ANT0044[1]	281	32.2
CATC	Catoctin Creek near Middletown, MD	CAC0148[1]	66.9	51.5
CONC	Conococheague Creek at Fairview, MD	CON0180[1]	494	41.1
MONR	Monocacy River at Bridgeport, MD	MON0528[1]	173	19.7
POTW (1986-2008)	Potomac River near Washington, DC	POT1184[4]	11570	57.9

*Data available for water years 1986 through 2009 (unless otherwise indicated)
[1]Data from Maryland Department of Natural Resources
[2]Data from Pennsylvania Department of Environmental Protection
[3]Data from Virginia Department of Environmental Quality
[4]Data from Hirsch *et al.* (2010)

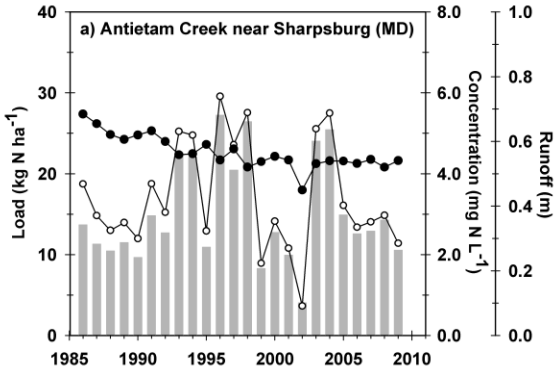
Data/Methods

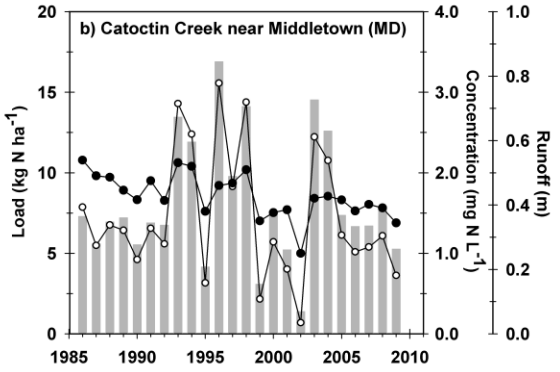
- Long-term nitrate-N concentration (various sources) and daily discharge (mostly USGS NWIS) data: 1986-2009
- LOADEST model: 7-parameter regression model to estimate loads (standard method)
- Computation of annual average flow-weighted concentrations from loads and runoff values (***not*** flow-adjusted concentrations; FACs)
- Simple linear regression to estimate trends (slopes) and p levels

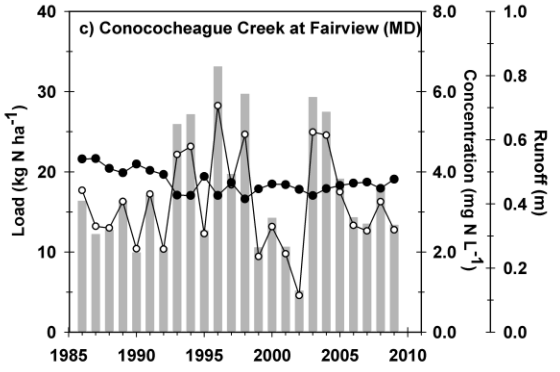
Nine predominantly-forested (>75%) watersheds

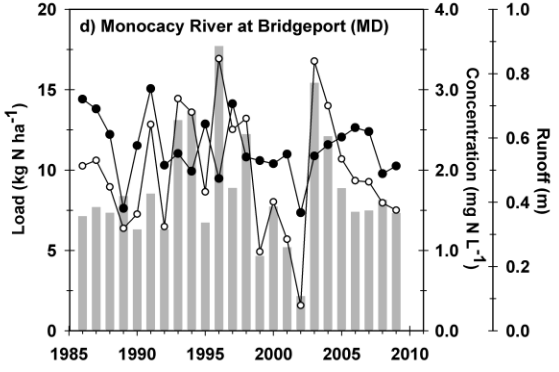


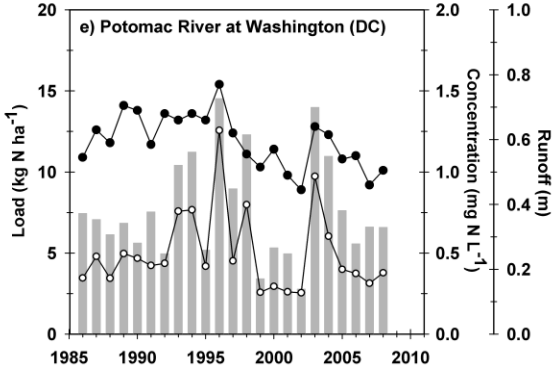
Four major Potomac River tributaries and downstream station





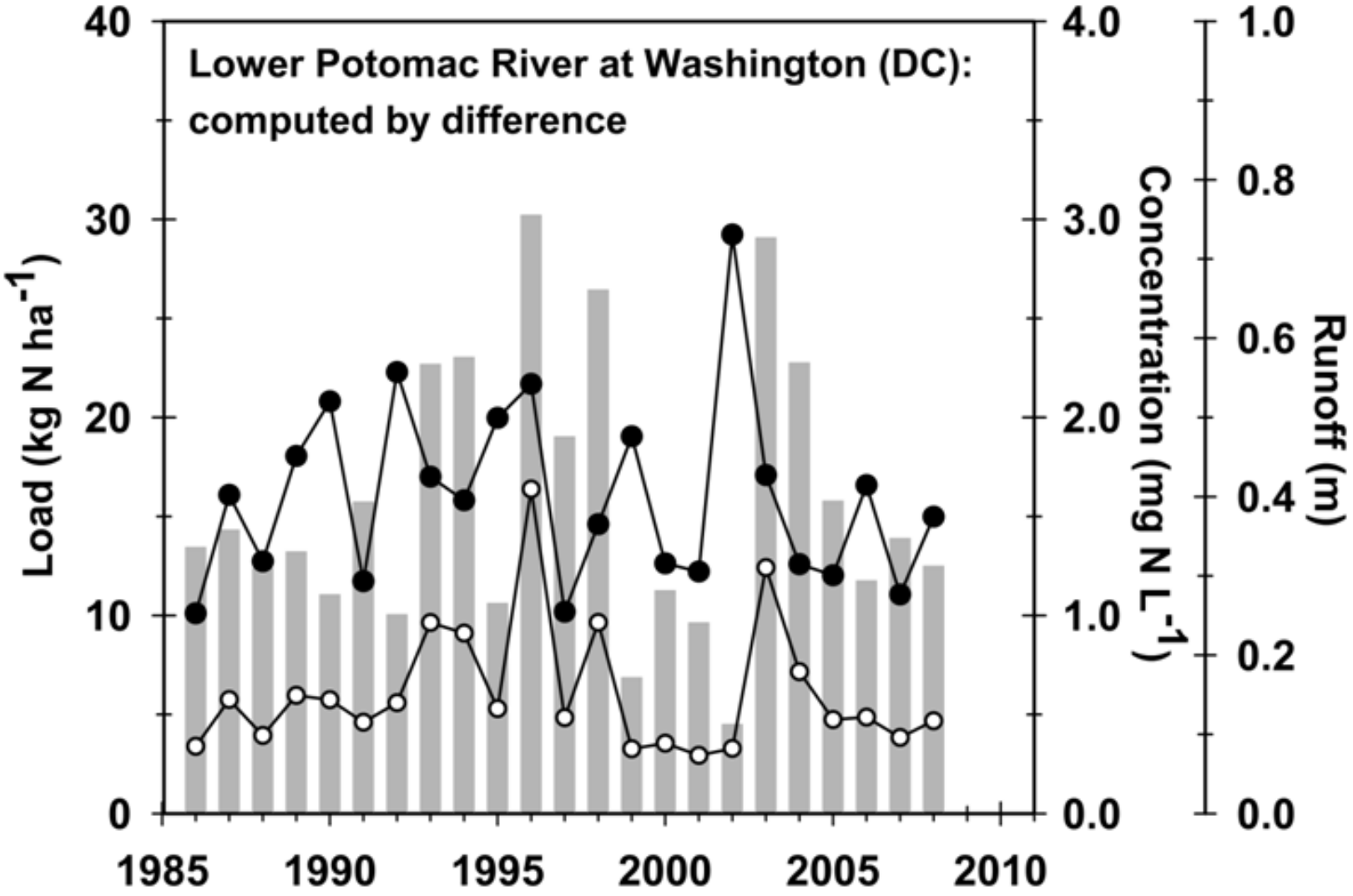






Analysis of trends (1986-2009 water years)

Watershed/ station	Mean annual runoff (m)	Slope (runoff)	Mean annual nitrate-N load (kg ha^{-1} yr^{-1})	Slope (load)	Mean annual nitrate-N (mg N L^{-1})	Slope (conc.)	Change in nitrate-N concentration (%)
BIGR (1990-2010)	0.564	0.003	2.00	**-0.097**	0.360	**-0.021**	**-72.6**
BLAC (1997-2010)	0.457	-0.012	4.67	**-0.295**	1.004	**-0.039**	**-40.0**
POTH	0.363	-0.001	2.95	-0.056	0.801	**-0.014**	**-33.5**
DBSC	0.596	0.002	2.62	-0.036	0.442	**-0.007**	**-31.9**
KCWP	0.562	0.003	2.63	**-0.059**	0.472	**-0.013**	**-46.9**
PCLP	0.509	0.001	1.92	-0.034	0.374	**-0.007**	**-35.4**
JRDC	0.391	-0.002	0.79	**-0.037**	0.192	**-0.009**	**-67.9**
CRCF	0.423	-0.002	0.63	**-0.019**	0.143	**-0.004**	**-48.8**
CCWV	0.350	-0.002	1.20	-0.032	0.343	**-0.008**	**-40.4**
ANTC	0.379	0.001	17.10	-0.093	4.533	**-0.047**	**-21.1**
CATC	0.406	0.000	7.26	-0.081	1.713	**-0.024**	**-27.4**
CONC	0.437	0.002	16.08	-0.018	3.752	**-0.024**	**-13.8**
MONR	0.439	-0.000	9.91	-0.040	2.267	-0.014	ns
POTW (1986-2008)	0.383	0.000	5.02	-0.026	1.191	**-0.013**	**-21.8**


Lower Potomac River at Washington (DC):
computed by difference
Load (kg N ha-1)
Concentration (mg N L-1)
Runoff (m)
0
10
20
30
40
0.0
1.0
2.0
3.0
4.0
0.0
0.2
0.4
0.6
0.8
1.0
1985
1990
1995
2000
2005
2010

More Conclusions

- Decreasing trends in surface water nitrate-N concentrations are a largely untold CB "success story"
- ……but the "where" and "why" are very important
  - Headwaters of the basin
  - Largest percentage changes in heavily forested subwatersheds
  - Forest dynamics (aggradation, climate change response, decline in nitrate-N deposition under 1990 CAAA) are primary drivers
  - May have less to do with land/water management actions to date
- Obvious need to account for forest N dynamics in TMDL process
- "Good news": the lag time of forest N response appears to be relatively short (years), not long (Galloway *et al.,* 2003)
- Preventing future degradation of forested subwatersheds (i.e., "doing nothing") may be more cost-effective than 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
- Graduate students and research assistants
  - Sarah Hypio
  - Tim Negley
  - Chris Welcker
  - Jer Sawma
  - Jeff Griffith
  - Geoff Frech
  - Jim Garlitz
  - Michael Snyder
  - James Morgan
  - Brian McCormick
  - Adam Eshleman
- Sponsors
  - Maryland DNR
  - EPA STAR
  - NSF Ecosystems
  - NASA Interdisciplinary Science
  - NASA Terrestrial Ecology
  - NASA Decision Support Systems
  - The Nature Conservancy
- Data sources
  - Maryland DNR (Tony Prochaska)
  - Pennsylvania DEP
  - Virginia DEQ
  - USGS NWIS
  - NADP/NTN