Henson Creek, Coweeta LTER, North Carolina

A synoptic survey of ecosystem services from headwater catchments in the United States

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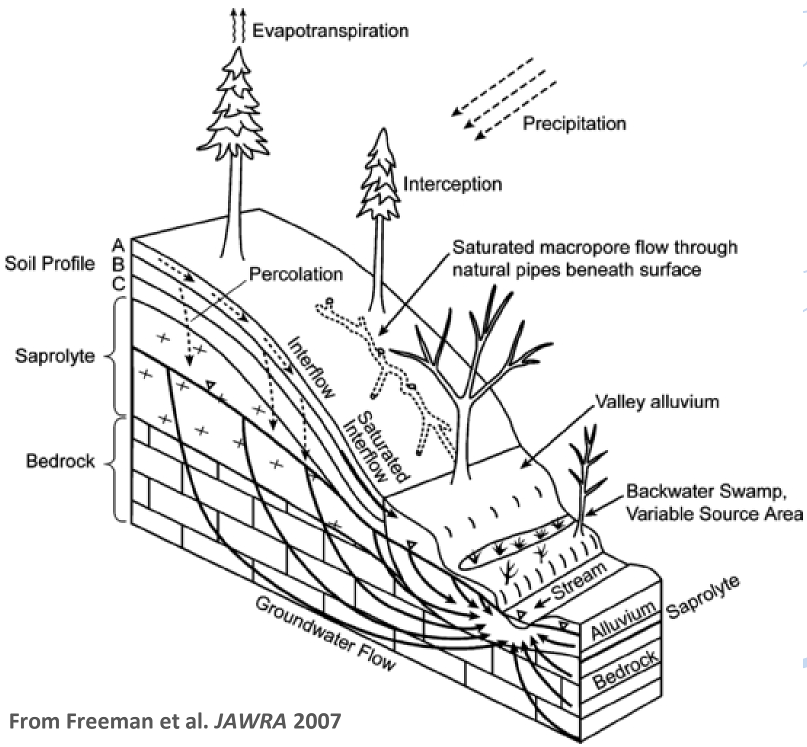
Outline—
our path through this thicket

McRae Ck, HJ Andrews LTER, Oregon

- **What is a headwater stream?**
  - Geomorphological definition
  - Legal definition
- **Extent & connectivity**
  - Spatial extent & scale
  - Influences on downstream ecosystems
- **Threats to HW**
  - Agriculture
  - Urbanization
  - Mining
- **Ecosystem goods & services**
  - Examples from NRSA

What is a headwater stream?

Tributary to West Fork Smith River, Oregon



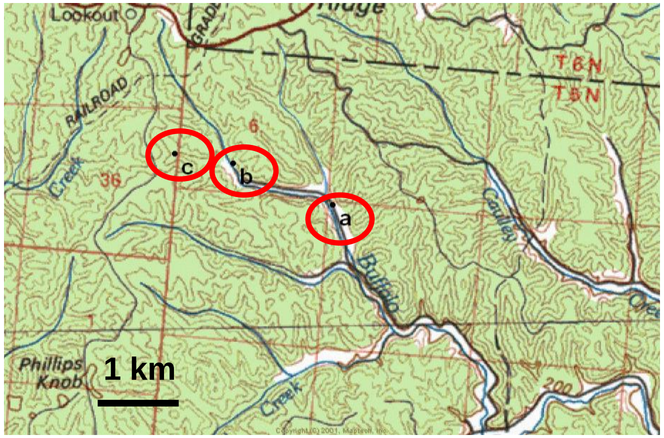
From Freeman et al. *JAWRA* 2007

- **The uppermost streams in a watershed —** Nadeau & Rains *JAWRA* 2007
- **1st & 2nd order streams—** Nadeau & Rains *JAWRA* 2007
- **Streams draining watersheds ≤ 32 km^2—** Ohio EPA
- **Streams <10m wide—** Peterson et al. *Science* 2001
- **Primary land-water interface—** Freeman et al. *JAWRA* 2007
- **Begins where surface runoff is sufficiently concentrated to cause scour and distinct banks—** Dietrich & Dunne *Channel Network Hydrology* 1993
- **and continues downstream to the colluvial-alluvial transition point—** MacDonald & Coe *Forest Science* 2007

Map resolution matters

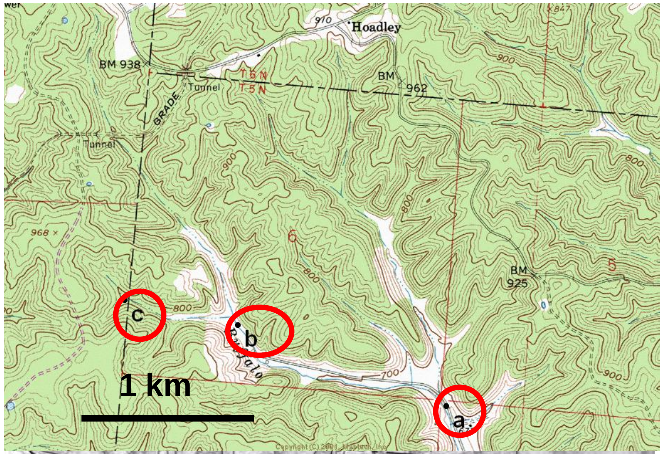
1:100K

- 1st orders above **“a”**: **2**
  - **a** = 2nd order
  - **b** = 1st order
  - **c** = nothing



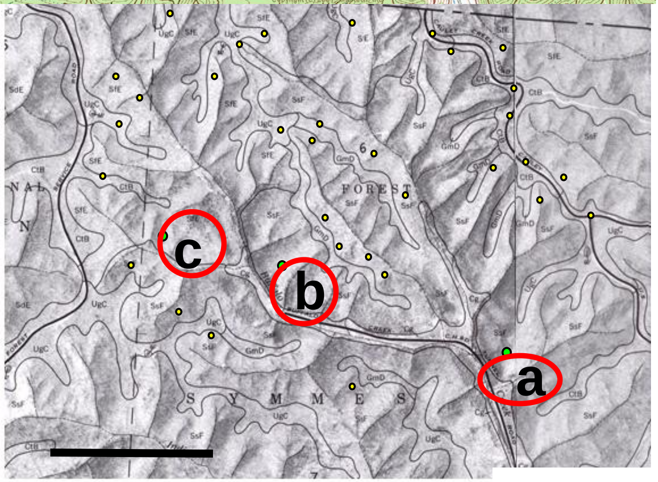
1:24K

- 1st orders above **“a”**: **5**
  - **a** = 3rd order
  - **b** = 2nd order
  - **c** = 1st order



1:16K (USDA/NRCS)

- 1st order above **“a”**: **41**
  - a = 4th order
  - b = 3rd order
  - c = 2nd order



Compiled by Ken Fritz, USEPA/NERL-Cincinnati

Carabell/Rapanos Decision

(Just what is included in the waters to the US?)

Rapanos v. United States, 547 U.S. 715, 2006

(4-1-4 Plurality)

○ **Jurisdiction over the following waters** (Scalia waters)

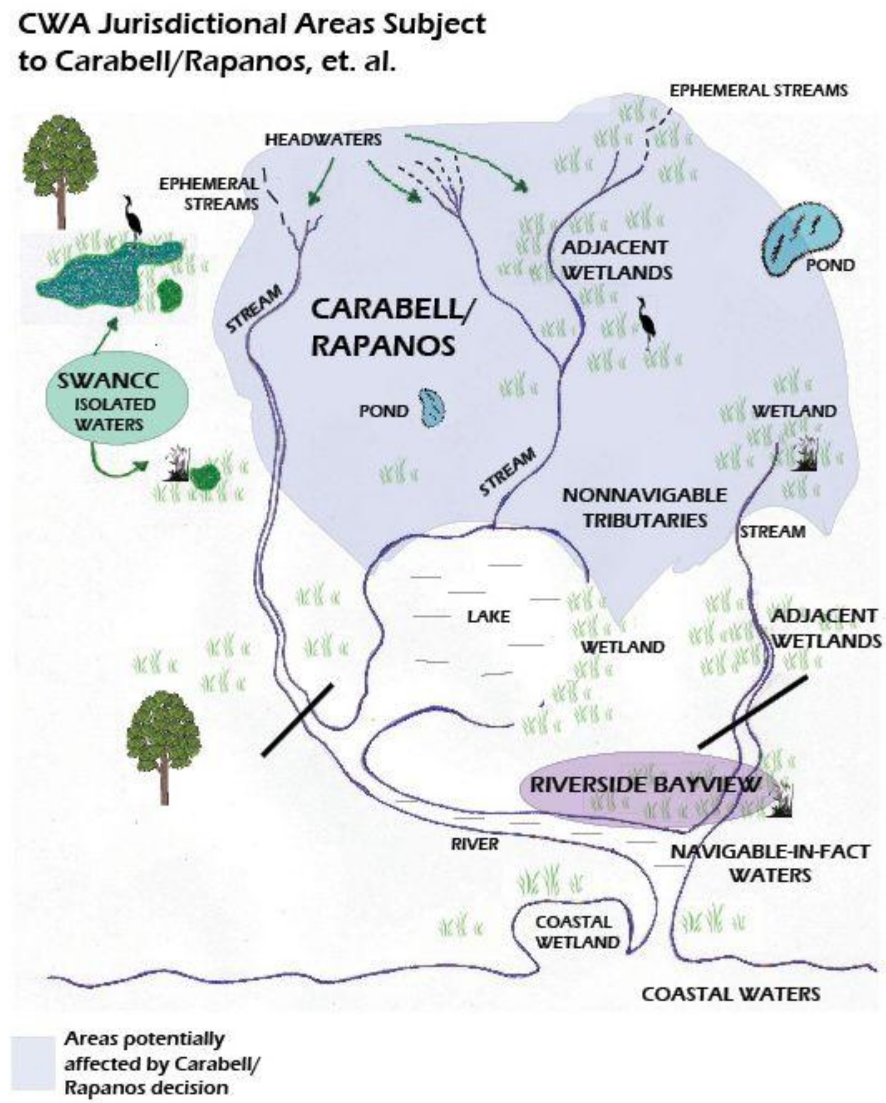
•traditional navigable waters
•wetlands adjacent to traditional navigable waters
•non-navigable tributaries of traditional navigable waters that are relatively permanent
•wetlands that directly abut such tributaries

○ **Jurisdiction based on a significant nexus** (Kennedy waters)

•tributaries that are not relatively permanent
•wetlands adjacent to non-navigable tributaries
•wetlands adjacent to but not directly abutting a relatively permanent non-navigable tributary

○ **What constitutes a *significant nexus?***

•an assessment of the flow characteristics and functions of the tributary itself and the functions performed by all wetlands adjacent to the tributary to determine if they significantly affect the chemical, physical and biological integrity of downstream traditional navigable waters
•significant nexus includes consideration of hydrologic and ecologic factors



Watershed graphic prepared by Assoc. of State Wetland Managers

Critical Needs for Headwater Streams—
responding to Carabell-Rapanos

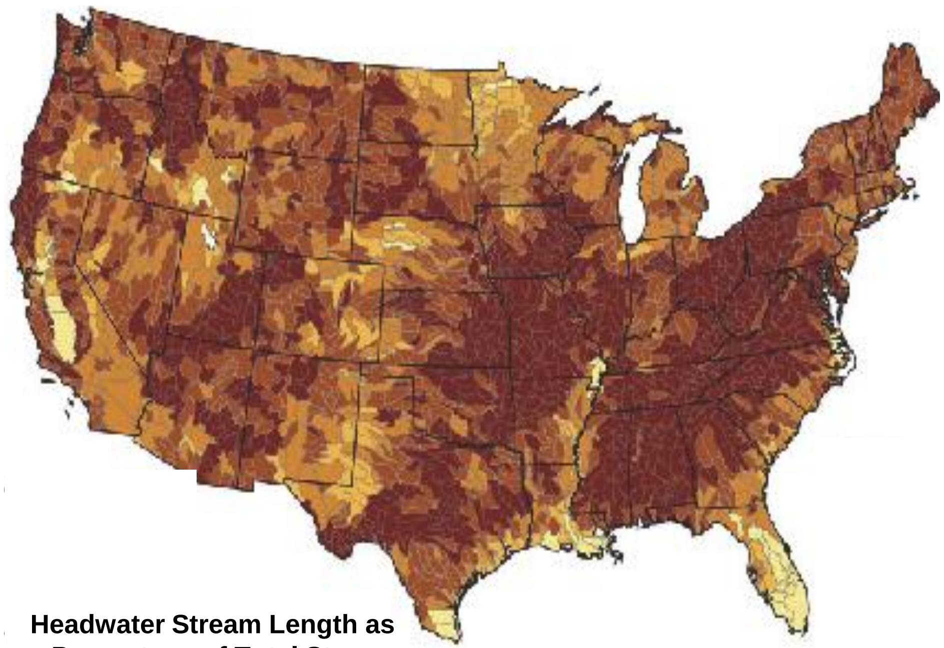
Little Lost Man Ck, northern California

- **Spatial extent and connectivity**
  - Mapping & classifying
- **Cumulative contribution to navigable waters**
  - Determining functions/services
- **Protection and restoration**
  - Determining priorities

Headwater streams—an overlooked resource

"The very foundation of our Nation's great rivers is a vast network of unknown, unnamed, and under appreciated headwater streams."

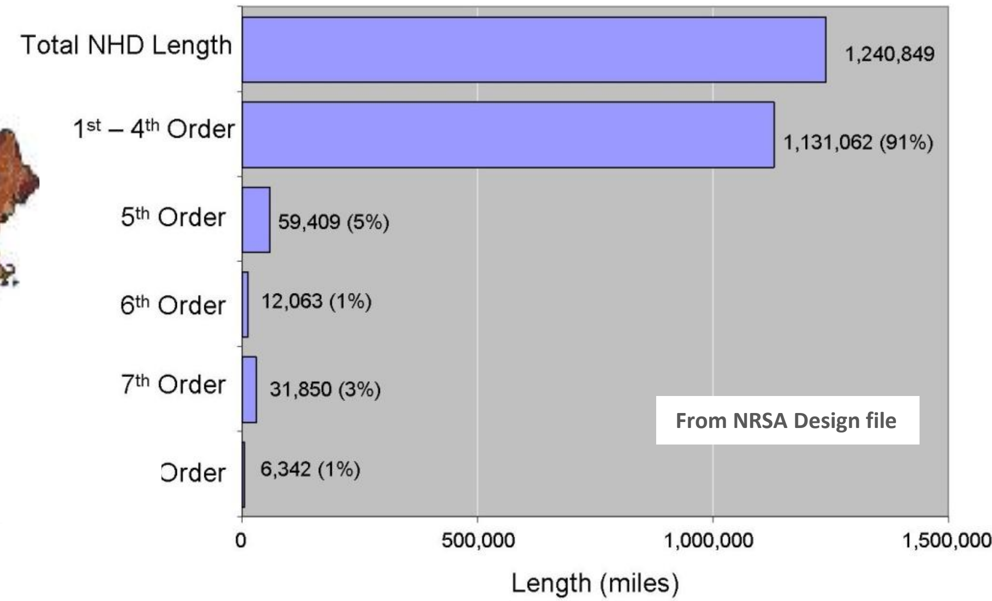
Meyer et al. *Where rivers are born* 2003



Headwater Stream Length as a Percentage of Total Stream Length

% Headwater Streams

- 0
- 1-19
- 20 -36
- 37-48
- 49-57
- 58-100
- State boundary



National extent (1st & 2nd order)—

- **50-70% of US stream miles**

State monitoring and assessment efforts usually under-emphasize headwater streams—

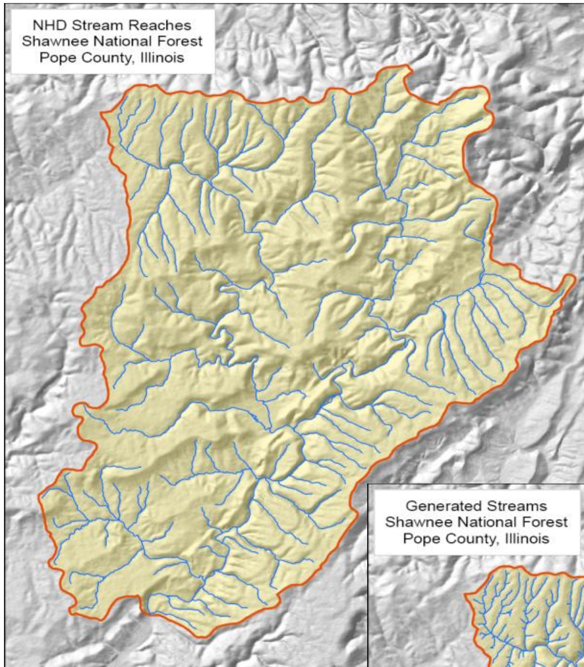
- **Ohio – 261 of 8179 assessed length (3%)**
- **Kentucky – 171 of 2767 assessed length (6%)**

Provide critical ecosystem services and influence the condition of downstream and adjacent ecosystems?

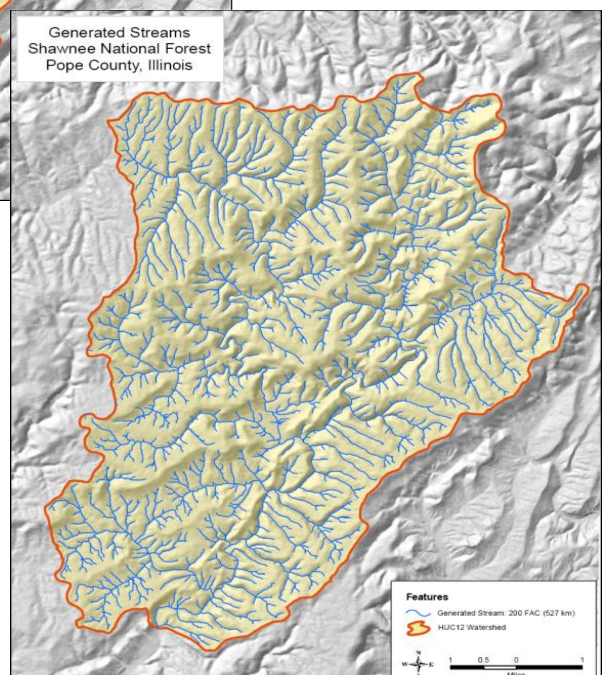
From Ken Fritz, USEPA/NERL

from Nadeau & Rains *JAWRA* 2007

Extent of Headwater Streams—
where are they on the landscape?



National Hydrographic Database (NHD, 1:100,000) measured stream length : *233 km*



Flow Accumulation Model predicted total stream length: *527 km*

K Fritz & B Johnson, unnamed tributary, Shawnee National Forest, Illinois

- **Field surveying the position of channel origins & hydrologic transition zones**
- **Estimate extent of headwater streams within surrounding HUC based on field determined *Flow Accumulation Coefficients***
- **Comparisons to existing resource databases**

From Ken Fritz, USEPA/NERL

What is the significance of headwater streams on downstream water quality?

McRae Ck, HJ Andrews LTER, Oregon

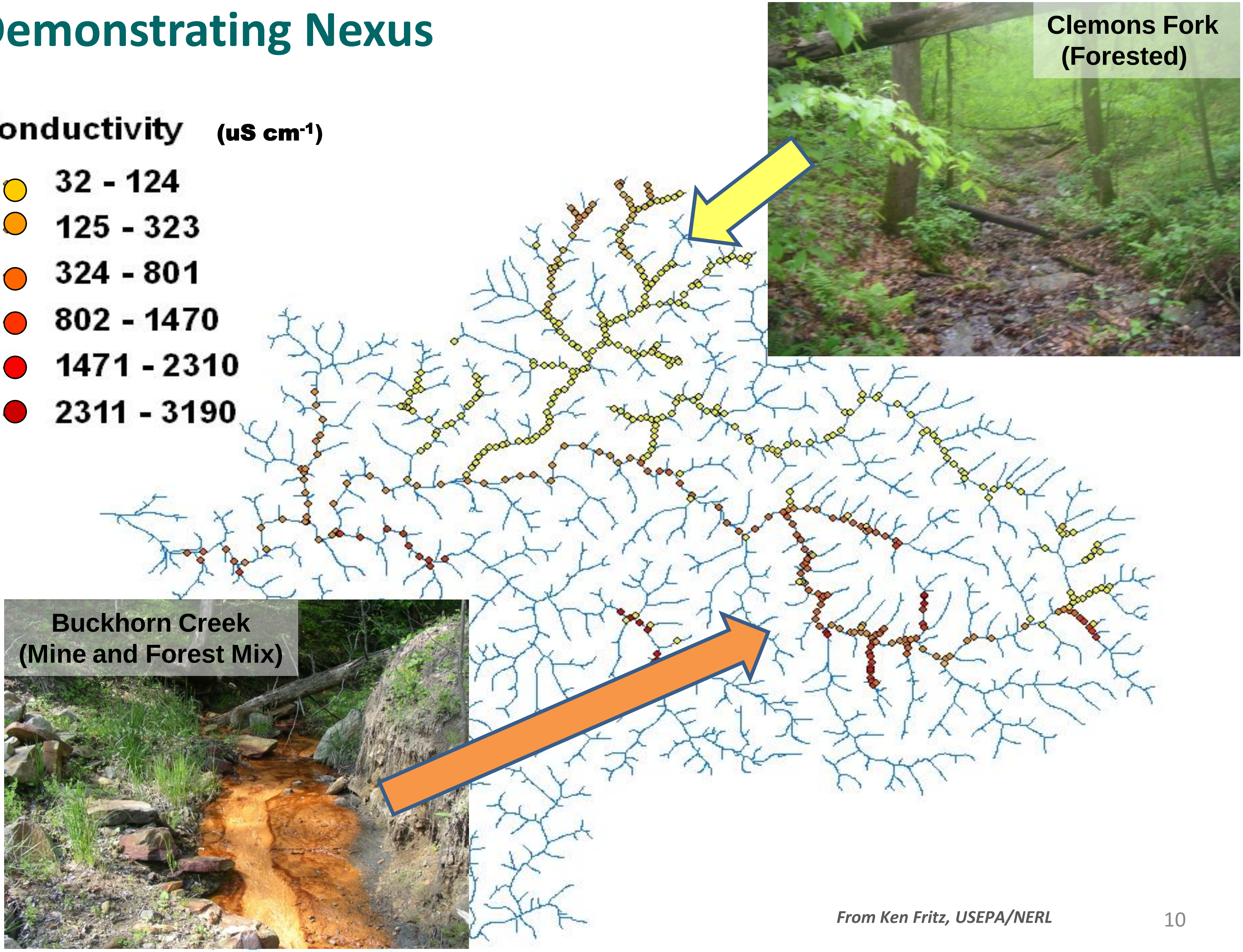
Blue River, HJ Andrews LTER, Oregon

Willamette River, Corvallis, Oregon
(http://www.epa.gov/wed/pages/facilities/corvallisfacilities.htm)

Demonstrating Nexus

Conductivity (uS cm^{-1})

- 32 - 124
- 125 - 323
- 324 - 801
- 802 - 1470
- 1471 - 2310
- 2311 - 3190

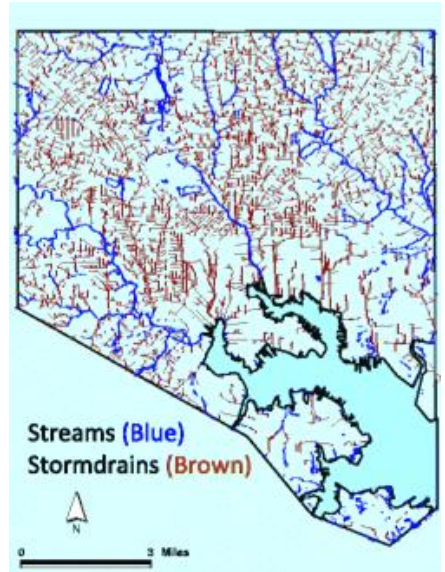


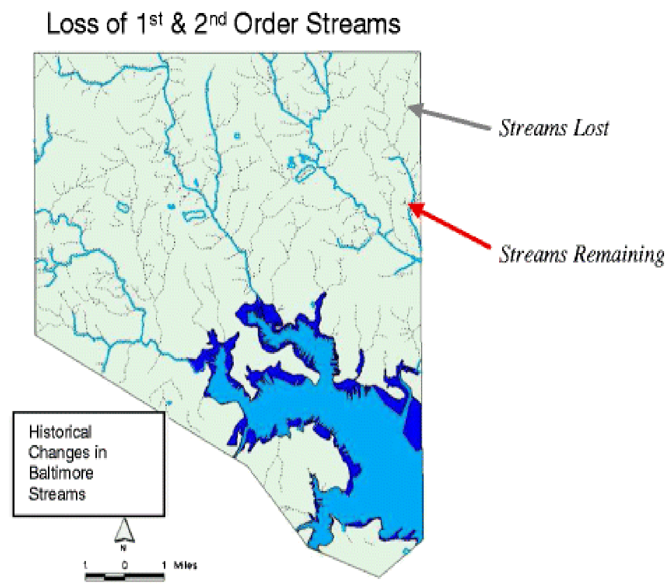
From Ken Fritz, USEPA/NERL

Headwater streams—
where have they gone?

Amberly Ck, Cincinnati, Ohio
(Jake Beaulieu, EPA-NRMRL)

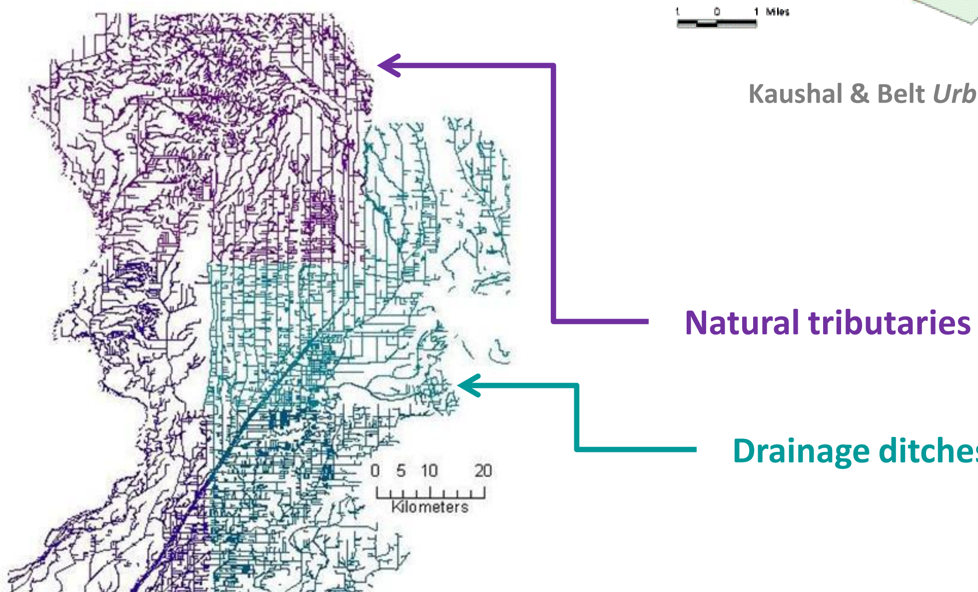
An urban story
(Baltimore County)





Kaushal & Belt *Urban Ecosystems* 2012

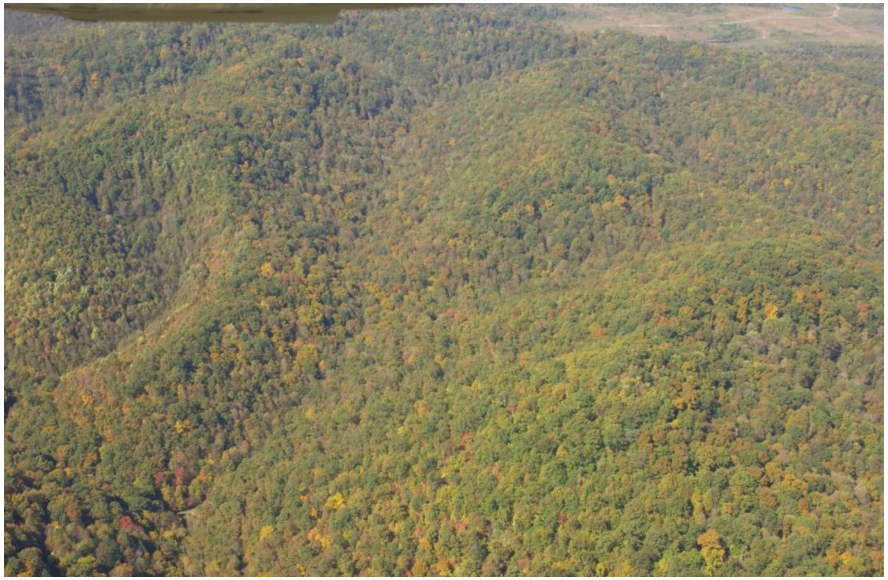
An agriculture story
(Mississippi Alluvial Valley)



Pierce et al. *Biology* 2012

Moving Mountains—

An Appalachian story

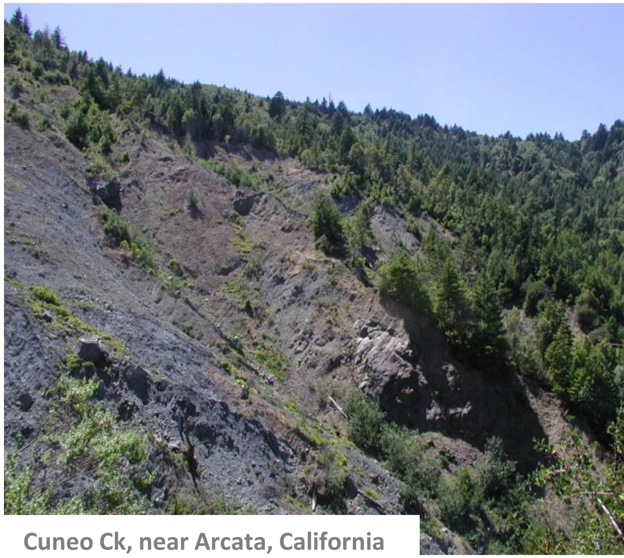


- 10% of US coal is produced in the Appalachian Mountains, mostly by mountaintop removal/valley fill mining.
- > 35,000 km^2 of valley fills in WV, KY, VA & TN.
- 1,200 - 2000 km (4%) of HW streams buried 1992-2002

US EPA, *EPA/600/R-09/138F* 2011

Visit http://www.kentuckycoal.org to get the industry spin on this

So what?



Cuneo Ck, near Arcata, California

Boone County, North Carolina
(US EPA, *EPA/600/R-09/138F* 2011)

St Kevin's Gulch, Leadville, Colorado
(http://co.water.usgs.gov/toxics/gallery/stkev/)

Washington, DC
(US EPA, *EPA/600/R-09/138F* 2011)

WS 1, HJ Andrews LTER
(http://andrewsforest.oregonstate.edu/images/)

Two-stage ditch near Delaware, Ohio

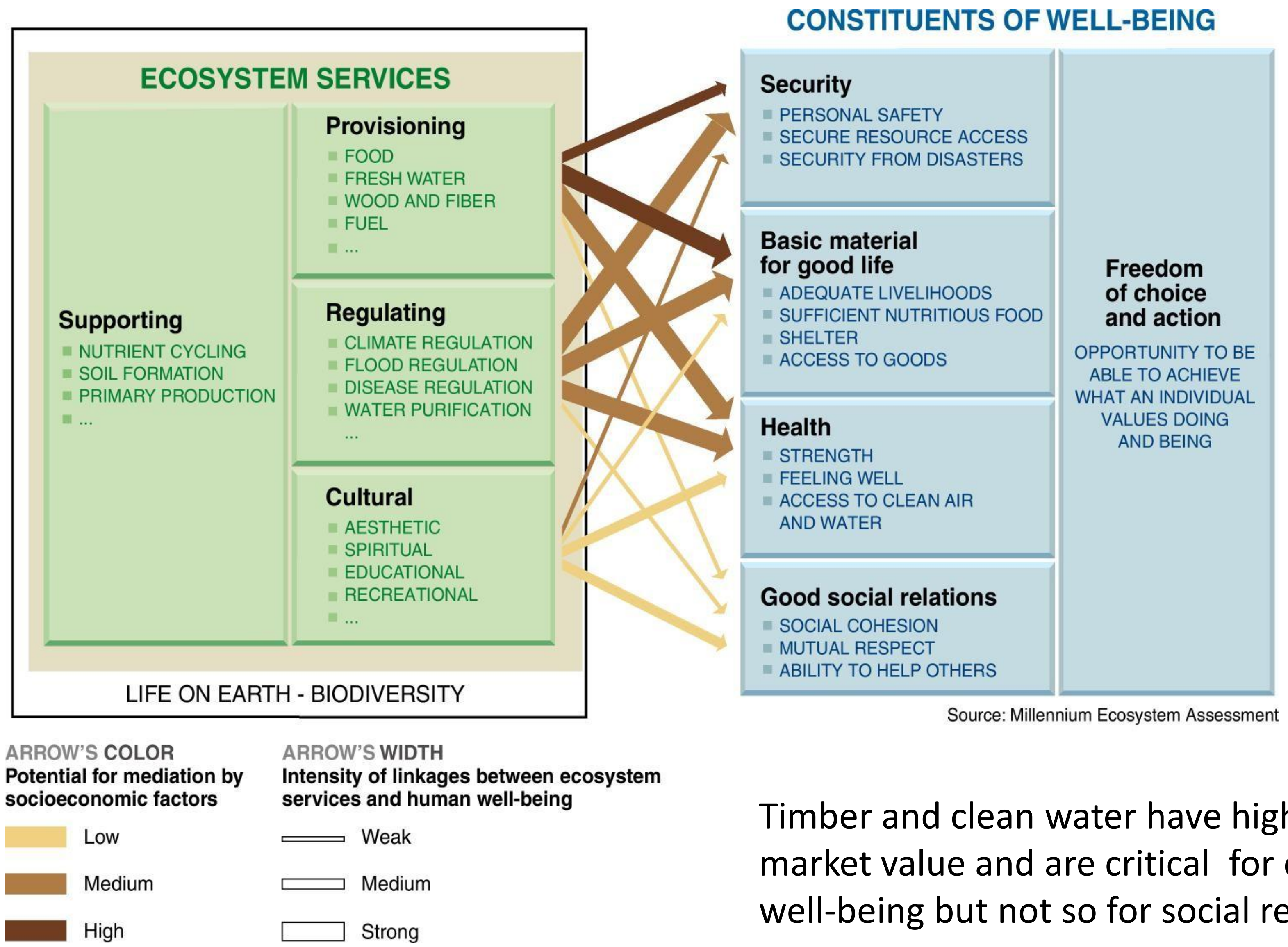
Ecosystem goods and services—

some examples

Ecosystem good or service	Ecosystem function	Example
Climate regulation	Regulation of global temperature, precipitation	Greenhouse gas distribution, water cycle
Nutrient cycling	Storage, processing, acquisition of nutrients	N, P, S, etc cycles
Erosion control and sediment retention	Retention of soils within an ecosystem	Prevention of excess soil loss and siltation
Recreation	Individual and community physical and mental health	hunting, fishing, nature observations
Cultural	Non-commercial uses of natural space or resources	Aesthetics, artistic expression, educational experience
Food production	Extractable primary production as food stuff	Production of fish, meat, grains, fruits, etc
Disturbance regulation	Capacitance of ecosystem response to environmental fluctuations	Storm surge protection, flooding control, drought recovery, fire resistance

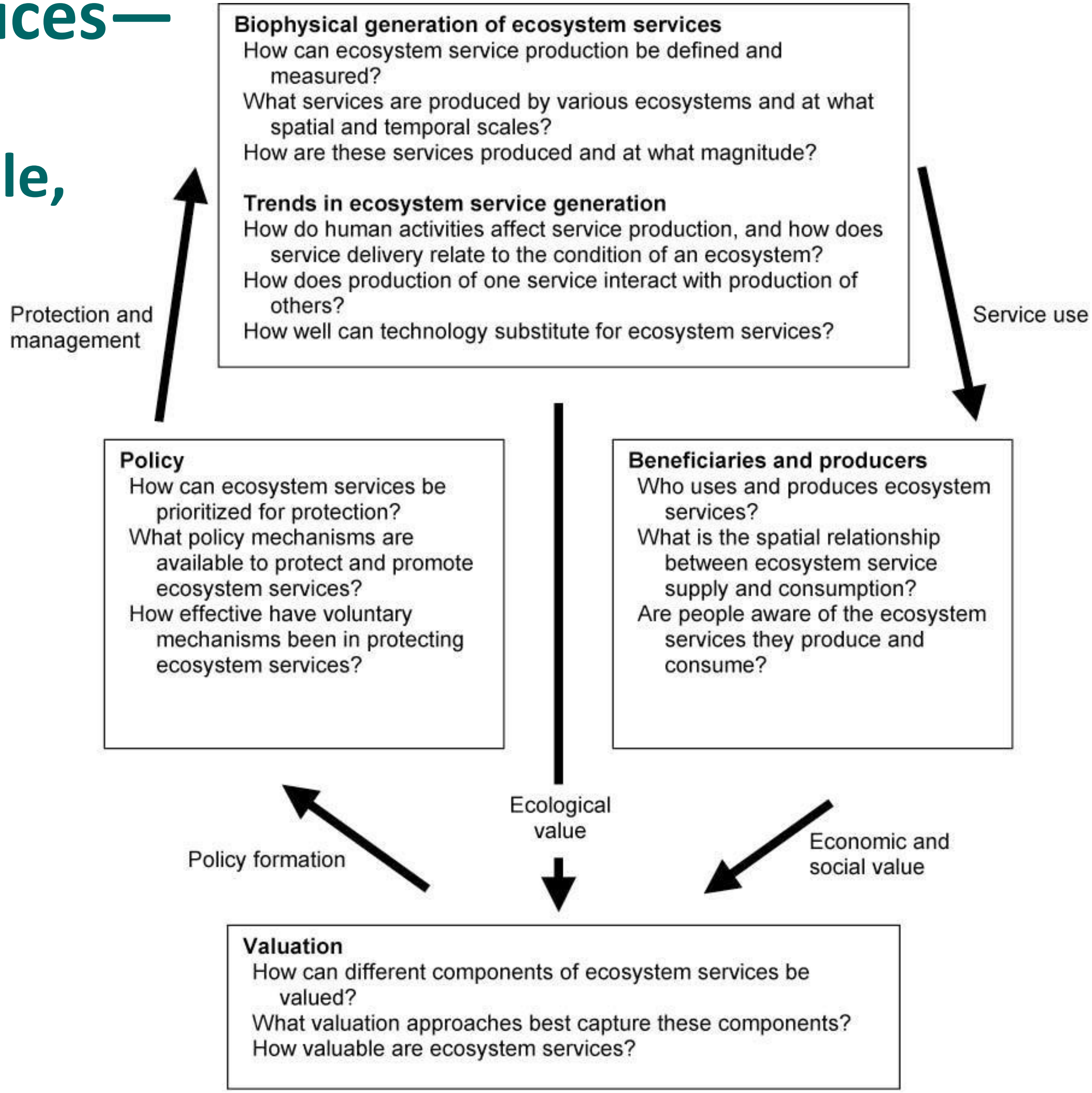
Costanza et al. *Nature* 1997

Ecosystem services & environmental, social, economic well-being



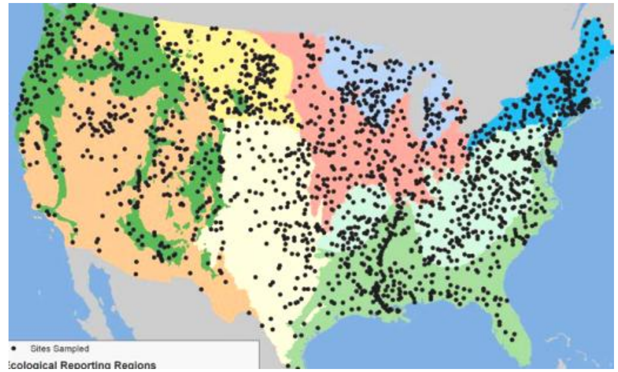
Timber and clean water have high market value and are critical for our well-being but not so for social relations.

Ecosystem services—the link between ecosystems, people, and policy



Brauman et al. *Annual Review of Environmental Resources* (2007)

Data sources—



Ecoregion	Length (Km)	% HW
NAP	190,550	81
SAP	504,387	82
CPL	282,416	82
NPL	43,563	74
SPL	58,550	79
TPL	363,227	80
UMW	153,827	79
WMT	241,560	83
XER	71,958	80
NRSA	1,910,038	81

○Stream data— 568 HW catchments

- US EPA National Rivers and Streams Assessment (2008-2009)

○Land cover data—

- 2006 NLCD attributed to NHD+ catchments

○Mean annual ppt, runoff—

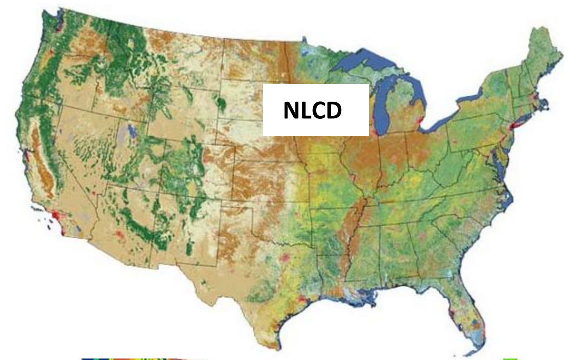
- NHD+, unit runoff method (based on 30y ppt, RO record)

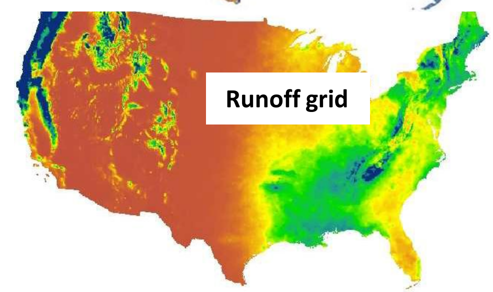
○Forest, crop, soil C, N & P—

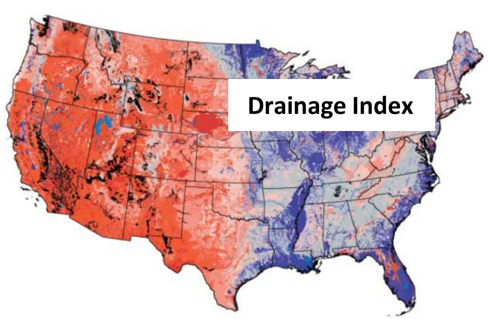
- Forest & Timber C (USFS FIA)
- Forest & Timber N & P (Schade et al. 2005)
- Crop C, N & P (Vitousek et al. 2009)
- Soil C (SSURGO & STATSGO)
- Soil N & P (Cleveland & Liptzin 2007)

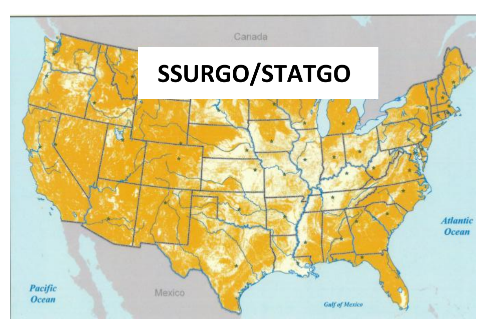
○N removal

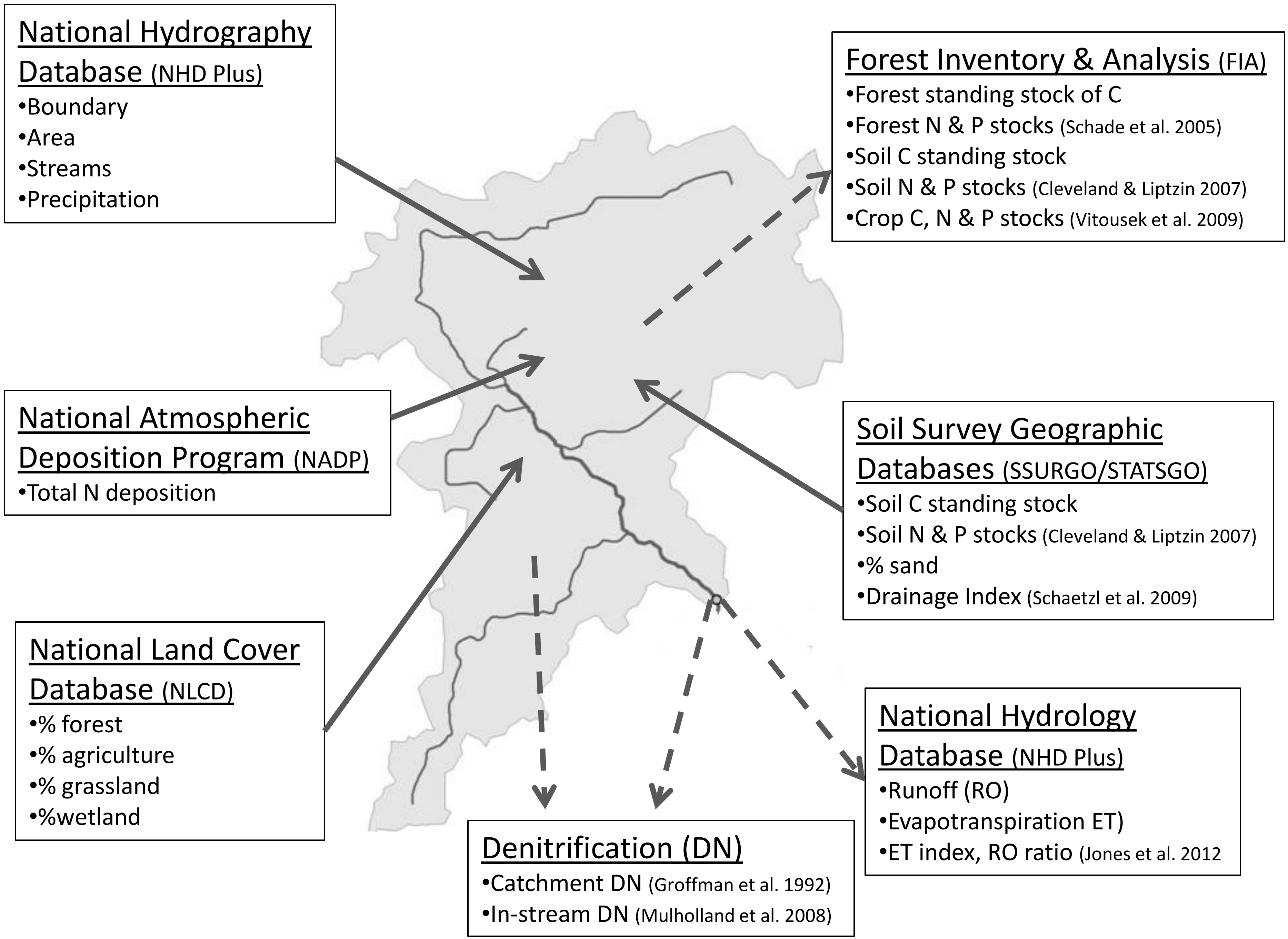
- Catchment denitrification (Groffman et al. 1992)
- Stream channel dentrification (Wollheim et al. 2006; Mulholland et al. 2008)



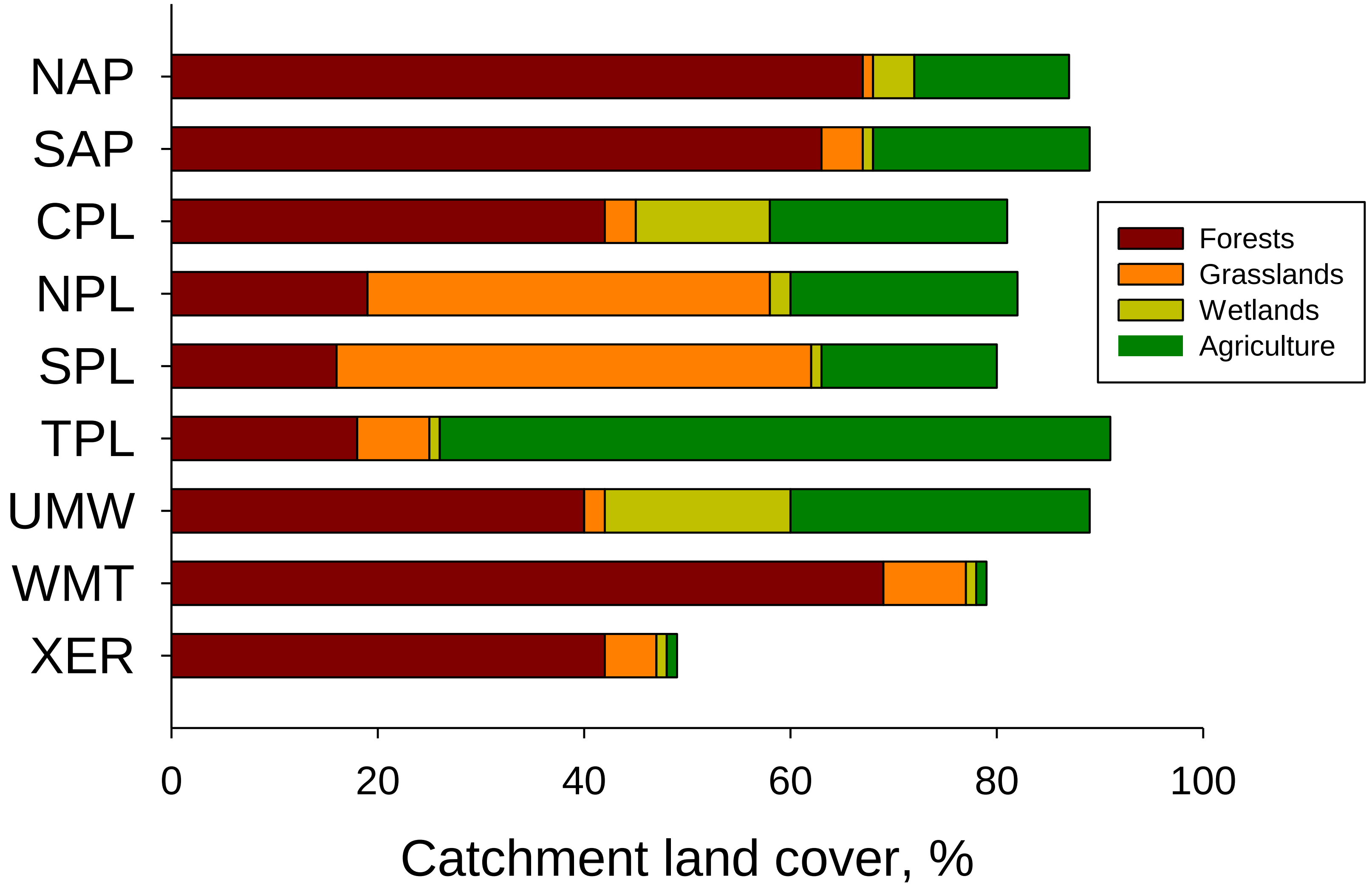




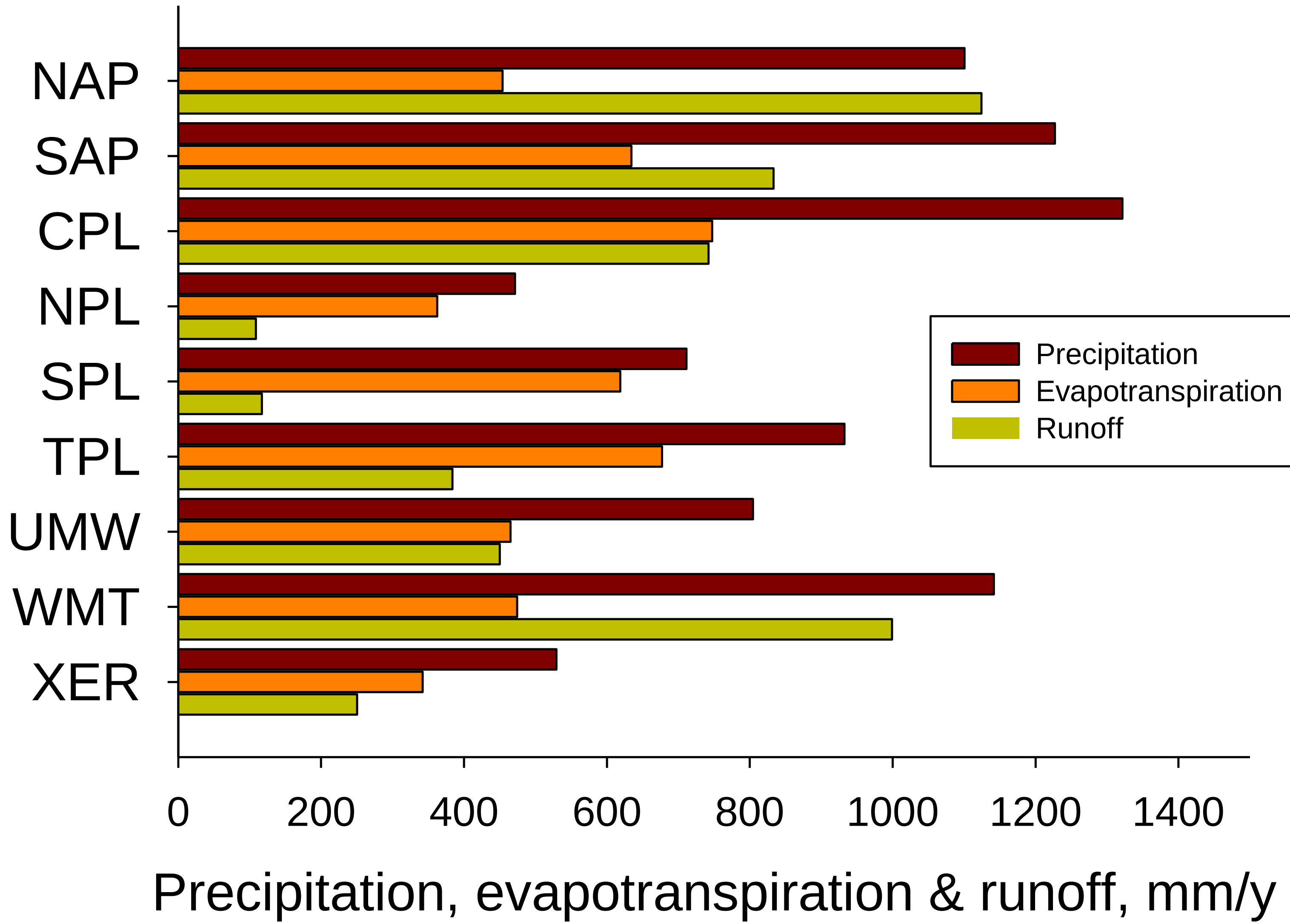



National Hydrography Database (NHD Plus)
•Boundary
•Area
•Streams
•Precipitation
Forest Inventory & Analysis (FIA)
•Forest standing stock of C
•Forest N & P stocks (Schade et al. 2005)
•Soil C standing stock
•Soil N & P stocks (Cleveland & Liptzin 2007)
•Crop C, N & P stocks (Vitousek et al. 2009)
National Atmospheric Deposition Program (NADP)
•Total N deposition
Soil Survey Geographic Databases (SSURGO/STATSGO)
•Soil C standing stock
•Soil N & P stocks (Cleveland & Liptzin 2007)
•% sand
•Drainage Index (Schaetzl et al. 2009)
National Land Cover Database (NLCD)
•% forest
•% agriculture
•% grassland
•%wetland
National Hydrology Database (NHD Plus)
•Runoff (RO)
•Evapotranspiration ET)
•ET index, RO ratio (Jones et al. 2012
Denitrification (DN)
•Catchment DN (Groffman et al. 1992)
•In-stream DN (Mulholland et al. 2008)

Catchment land cover

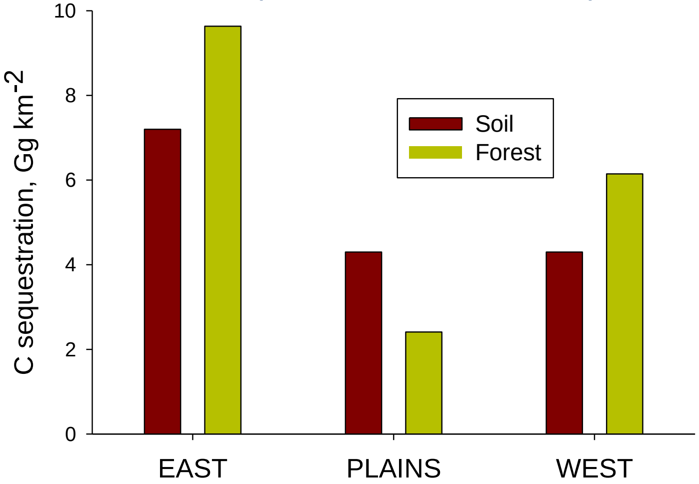


Catchment water supply—



Catchment C sequestration—

Regional C sequestration
(FIA & SSURGO/STATSGO)



Eastern forest C = 1.59 Gg km^{-2} * % forest

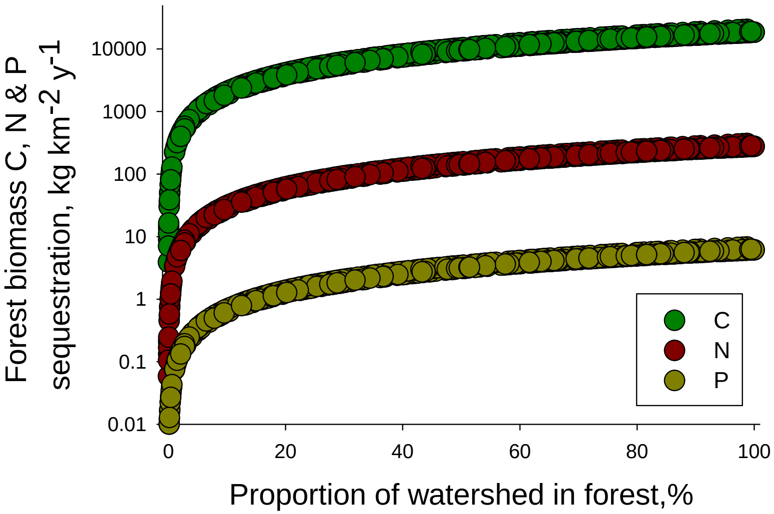
Plains & Western forest C = 1.02 Gg km^{-2} * % forest

USDA (2008) *US Agriculture and Forestry Greenhouse Gas Inventory: 1990-2005*. USDA Technical Bulletin No. 1921

USEPA (2011) *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2009*. EPA 430-R-11-005

Soil C –from USDA SSURGO/STATSGO database

Modeled watershed C, N & P sequestration



C:N:P stoichiometry

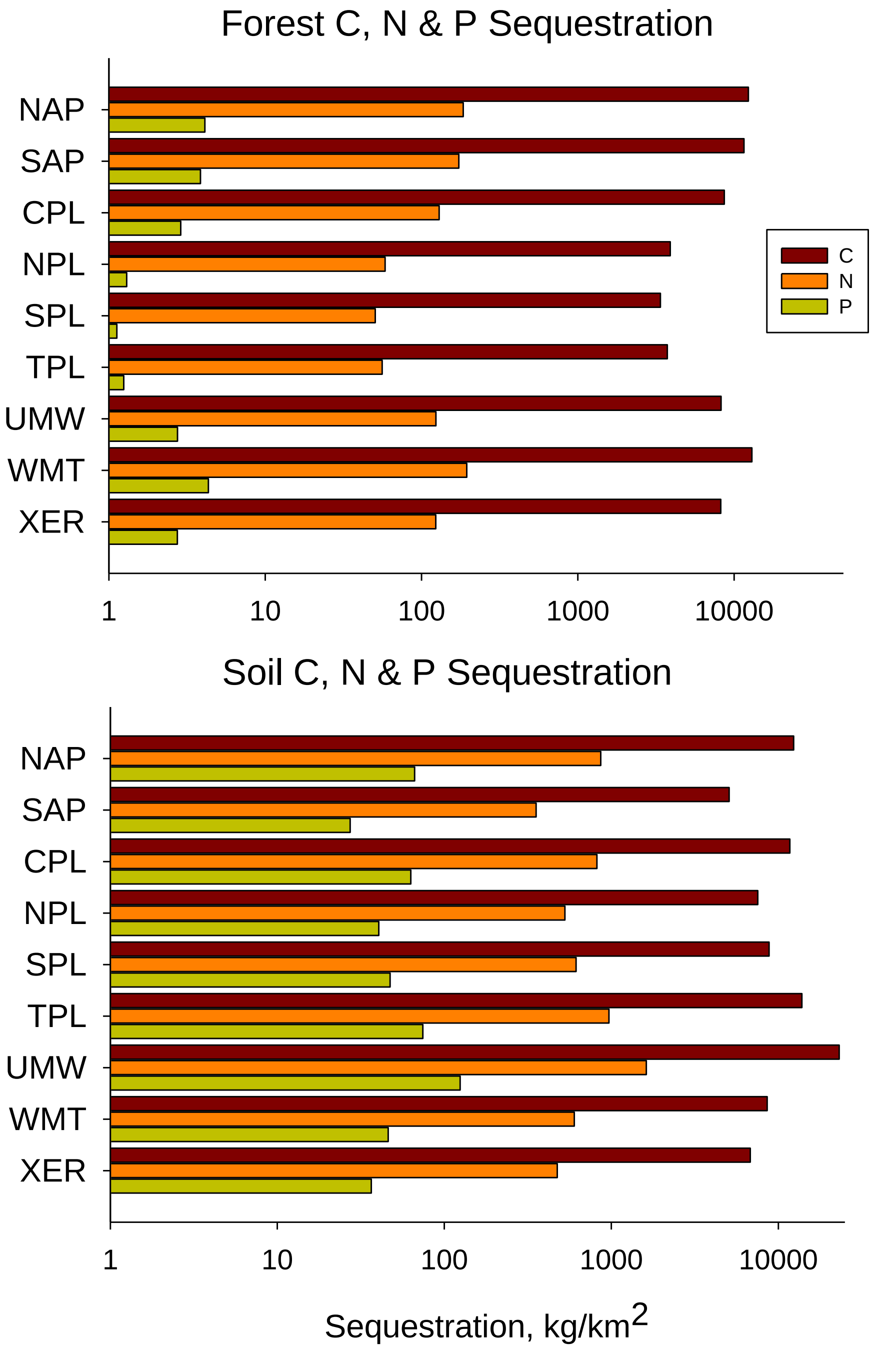
Forest **3000:45:1**

(Schade et al. *Oikos* (2005)

Soil **186:13:1**

(Cleveland & Liptzin *Biogeochemistry* (2006)

C, N & P sequestration—forests & soils



Jacoby Creek, Arcata, California

N removal via denitrification—

N removal by catchment soils

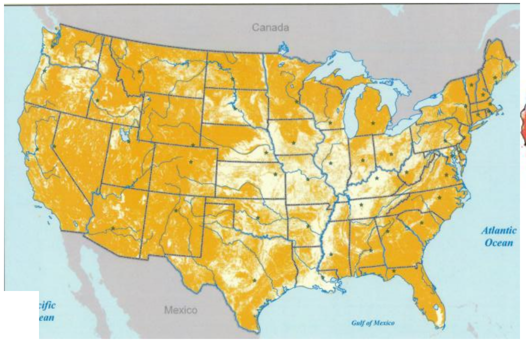
$$NR = [0.34*(DI)] – [0.40*(\%Sand)] + 11.81$$

Groffman et al. *Landscape Ecology* (1992)

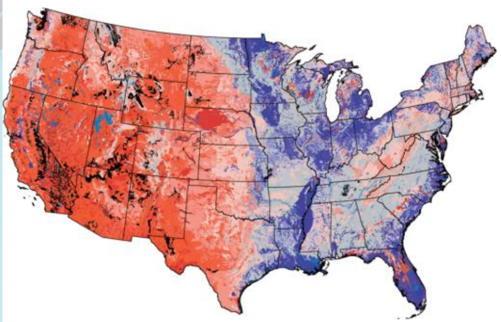
N removal by stream channels

$$NR = 1\text{-}Exp\ (V_f\text{-}N/HL)$$

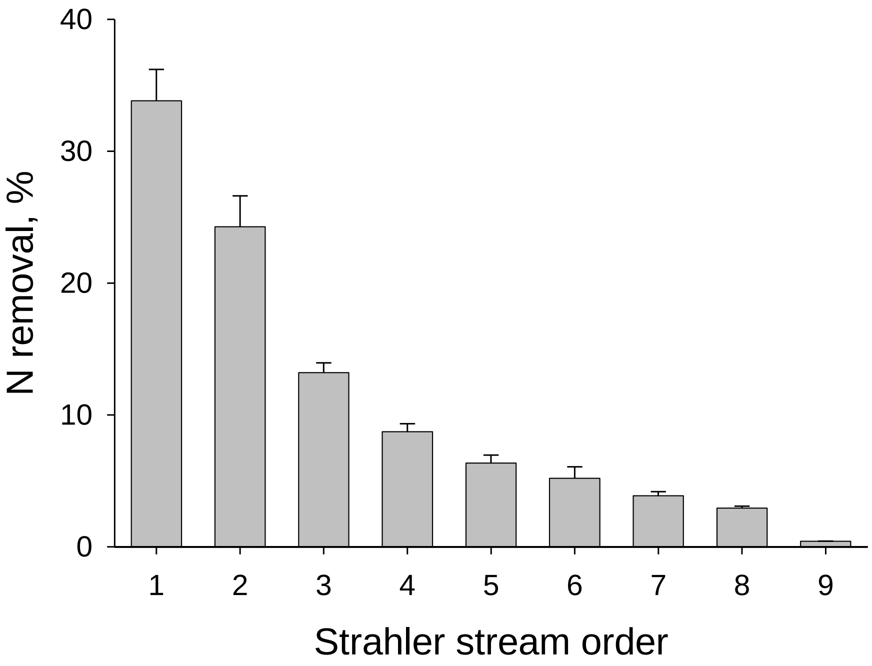
Wollheim et al. *Geophysical Research Letters* (2006)
Mulholland et al. *Nature* (2008)
Hill & Bolgrien *Biogeochemistry* (2011)

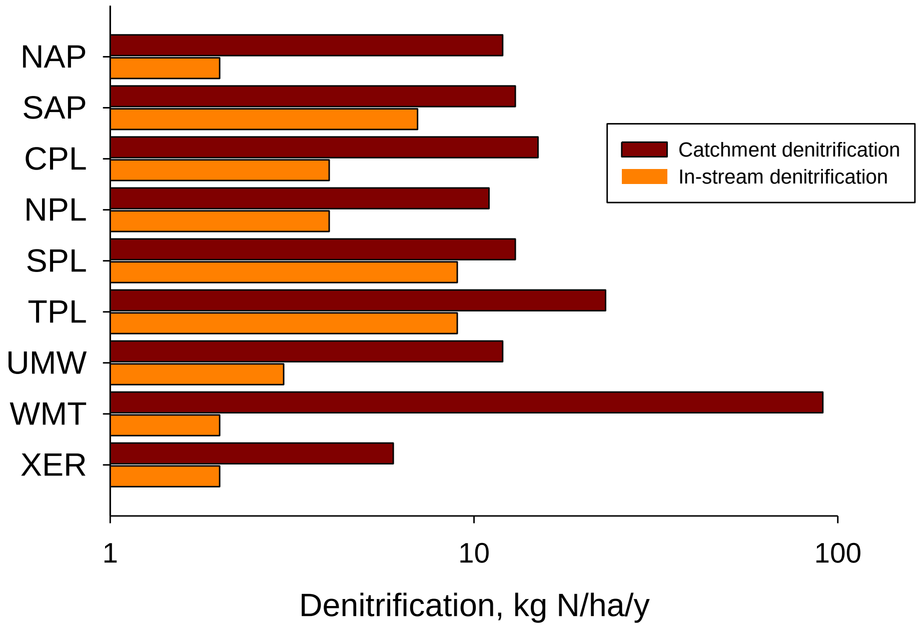


% sand in soil column
SSURGO/STATSGO



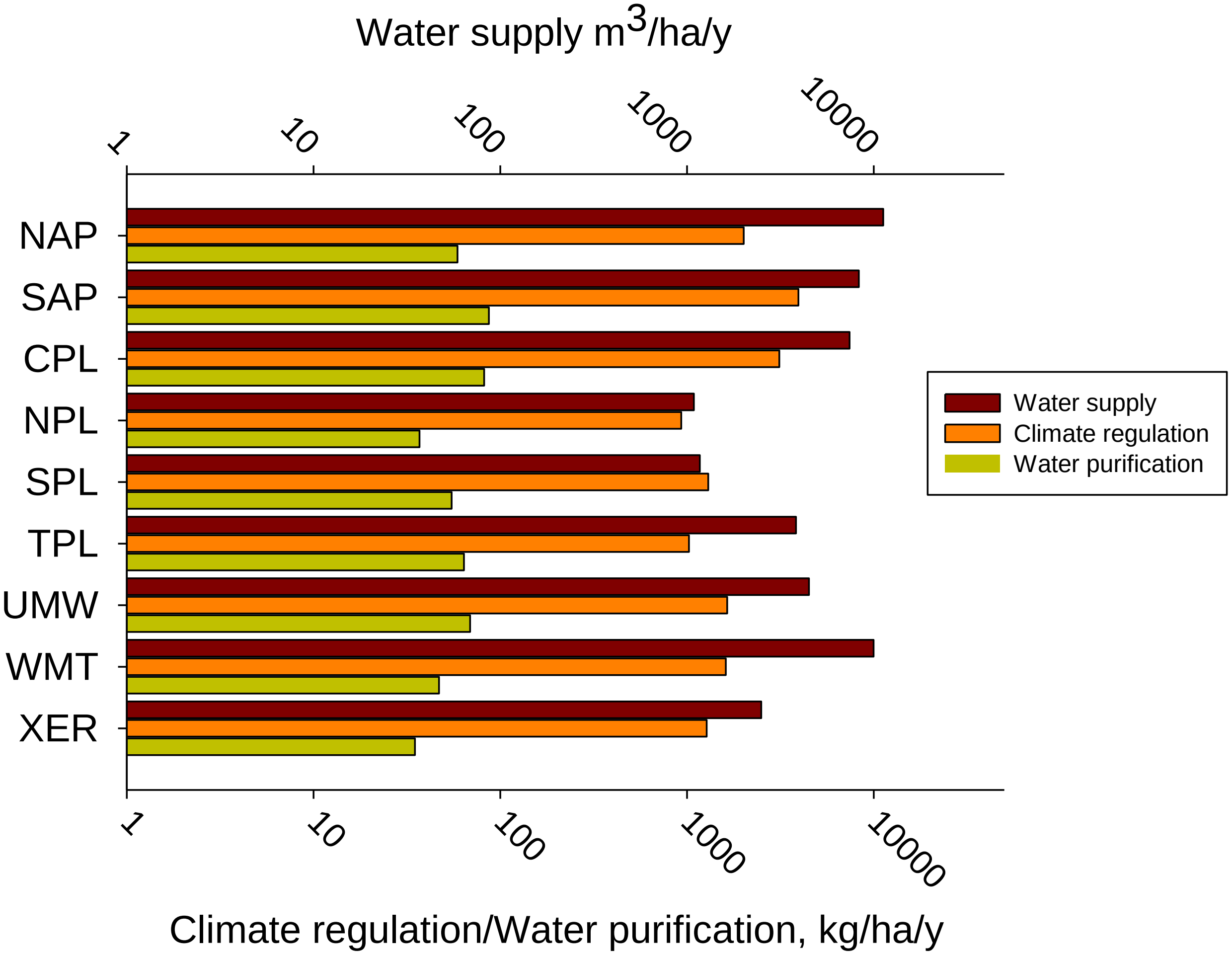
Drainage Index (DI) Map
F Krist (USFS) & R Schaetzl (Mich St Univ)
unpublished





Ecosystem service production functions—

Amity CK, Duluth, Minnesota



From production functions to economics—

Value = production function * unit value

Ecosystem service	Unit value
Water supply[a]	$0.035/m^3
Climate regulation[b]	
C sequestration	$0.12/Mg C
Water Purification[c]	
N sequestration	$160/Mg N
Denitrification	$160/Mg N
P sequestration	$1600/Mg P

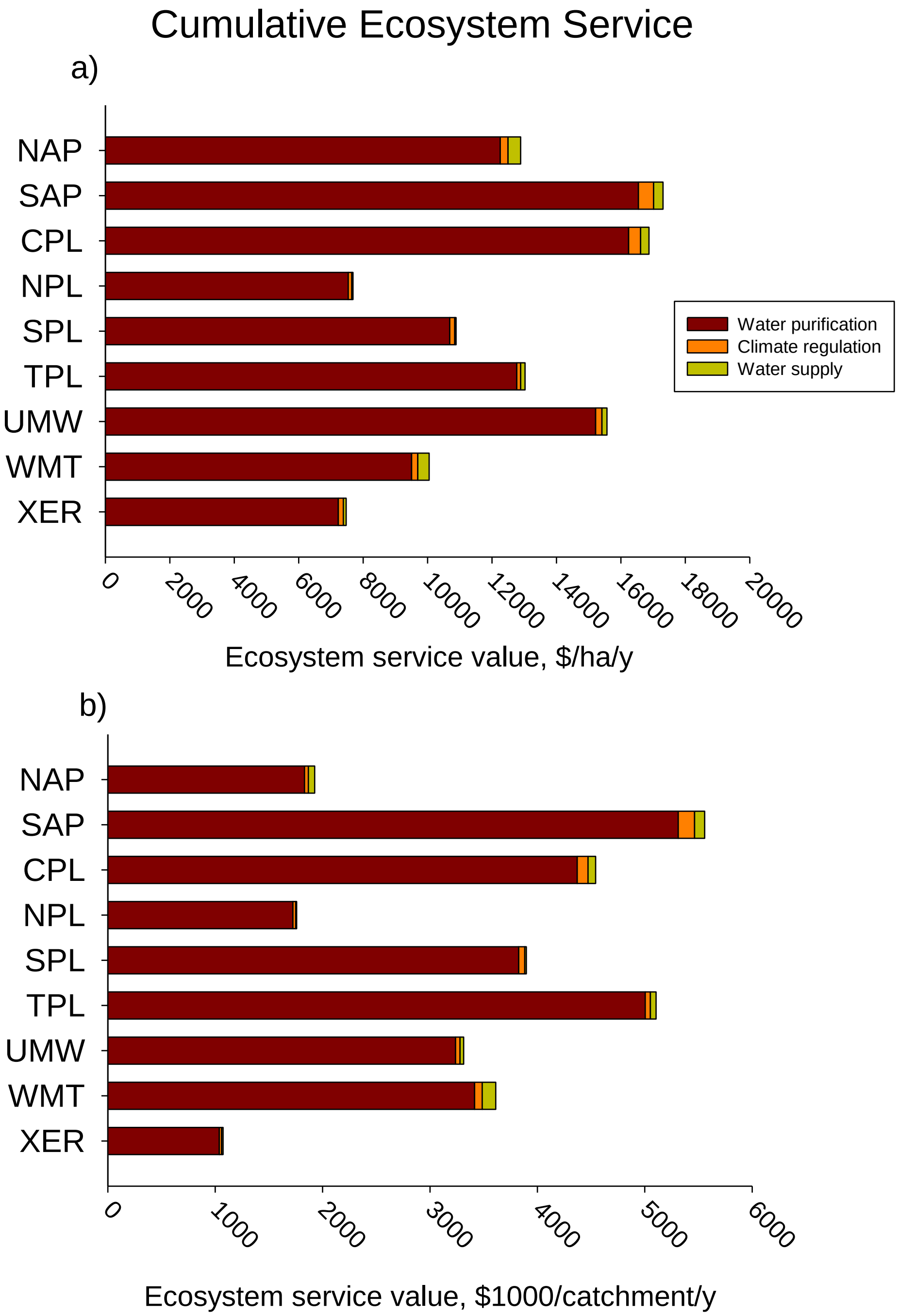
East Fork Trinity River, Van Alstyne, Texas

[a]Krieger, 2001; Nunes et al., 2006; Watanabe and Ortega, 2011
[b]Intercontinental Exchange, 2012
[c]Keplinger et al., 2003; Sano et al., 2005; USEPA, 2007; Dodds et al., 2009; Turpie et al., 2010; Compton et al., 2011; Watanabe and Ortega, 2011

Cumulative ecoregional ecosystem services value—

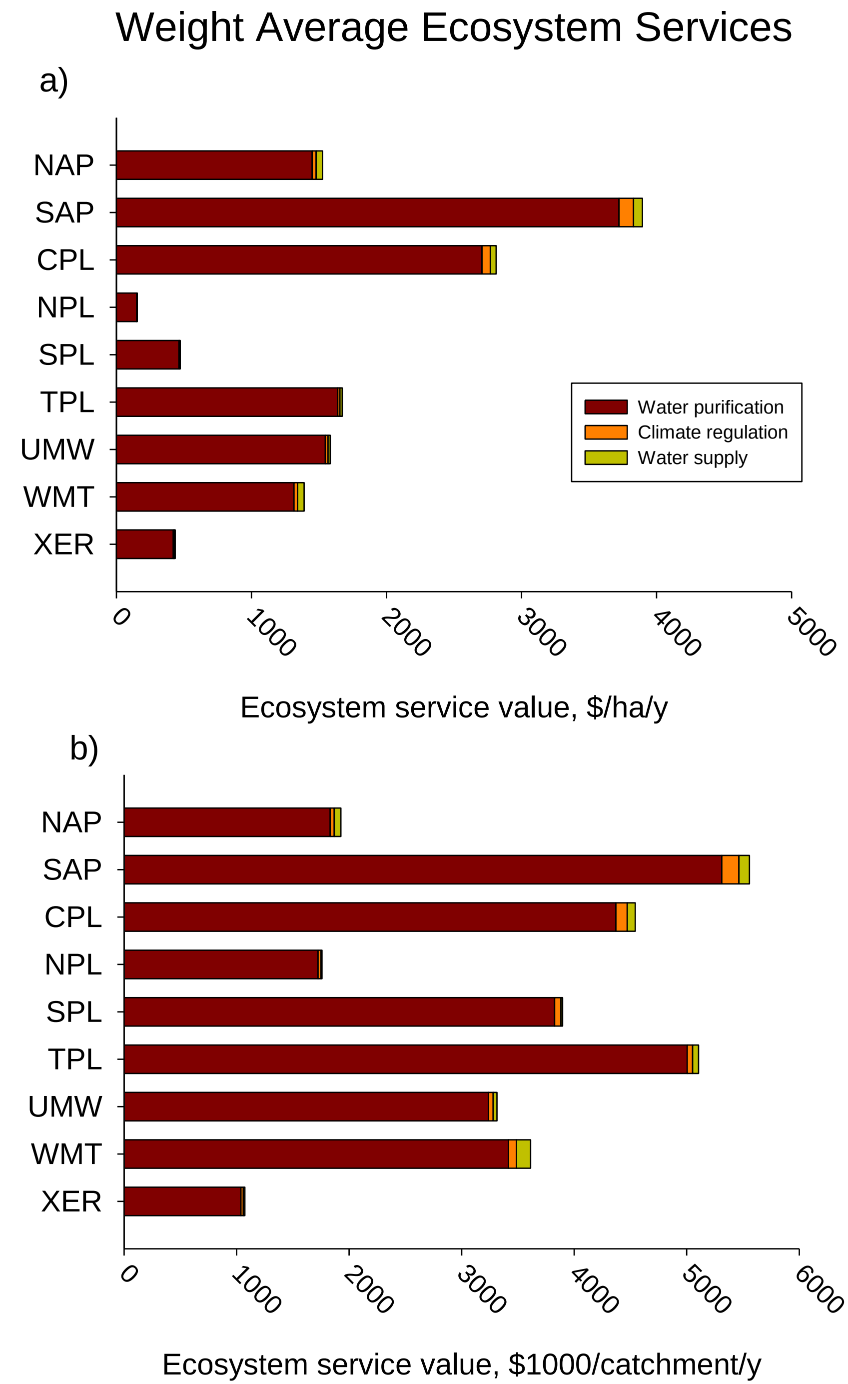
bundled ecosystem services for the 568 study catchments

Amity Ck, Duluth, Minnesota

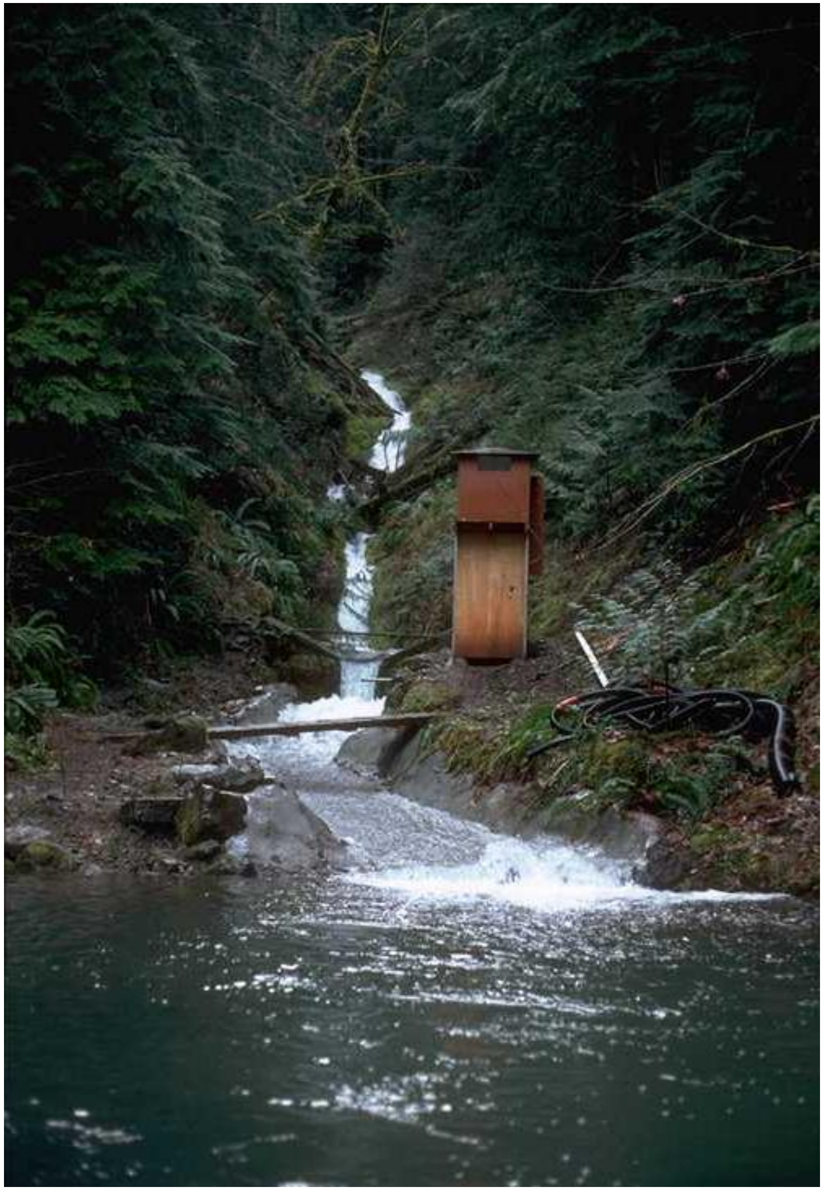


US average ecosystem services value—
bundled ecosystem services

Mack Creek, HJ Andrews LTER, Oregon



Economic value—



Watershed 2, HJ Andrews LTER, Oregon

- Our 568 1st and 2nd order stream catchments are a statistical representation of >2 million HW catchments in the continental US
- These HW streams represent 80% of total stream length, but still may be significantly under-estimated
- The headwater catchments are, on average, 52% forested
- The average value of ecosystem services from a single headwater catchment is:
    - Water supply—$470,000 y^{-1}
    - Climate regulation—$553,000 y^{-1}
    - Water purification –$29,759,000 y^{-1}
    - ❑ TOTAL CATCHMENT VALUE—$30,782,000 y^{-1}
- Extrapolation of these ecosystem services to all headwater catchments suggest that protection of these catchments from unsustainable uses is warranted