Stream Health 201: Stream Stressors & The Stream Restoration Puzzle

Matthew J. Ehrhart
Director of Watershed Restoration

John K. Jackson, Ph.D.
Senior Research Scientist
&
Colleagues and Coworkers

Delaware River Watershed Forum Sept 2024

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Clean Water Act 1972
Safe Drinking Water Act 1974

2024 is the

52nd anniversary

Clean Water Act

76th anniversary
Federal Water Pollution Control Act – 1948

Protected Uses in the Clean Water Act

Impaired = protected uses are not sustained

Swimmable

Drinkable

Fishable

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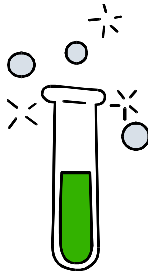
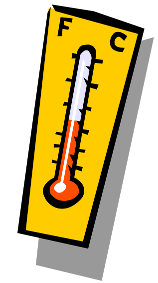
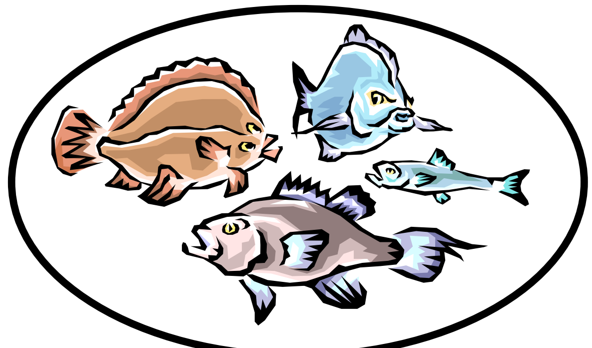
Chemical



Physical



Biological



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Aquatic Macroinvertebrates

Primarily aquatic insects, but non-insects too

Mayflies

Caddisflies

Stoneflies

Crayfish

Snails

Mussels

Pollution-Sensitive Species

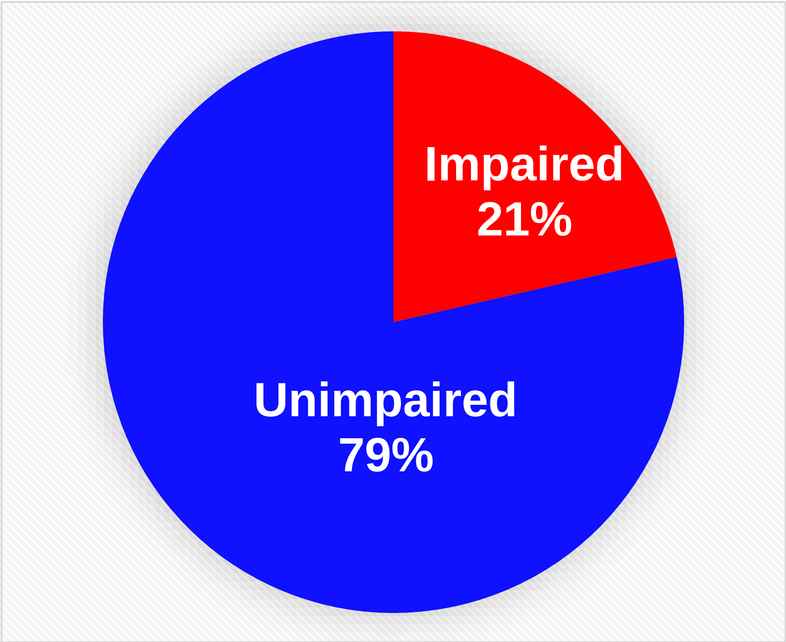
Ephemeroptera
Plecoptera
Trichoptera

2022 PA Integrative Report

https://www.dep.pa.gov/Business/Water/CleanWater/WaterQuality/IntegratedWatersReport/Pages/2022-Integrated-Water-Quality-Report.aspx

- 21% of Pennsylvania river and stream miles do not support healthy populations of aquatic life or other designated uses

27,883 miles



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We have a lot of polluted and clean streams

Chester County, PA

1020 miles impaired
(72%)

5,385,600 feet impaired
as of 2022

We have a lot of polluted and clean streams

Lancaster County, PA

1286 miles impaired

(89%)

6,790,080 feet impaired

as of 2022

Why are we not seeing streams delisted, or at least larger improvements?

1. Not Enough Time?

2. Not Enough Intensity?

3. Wrong Prescription?

4. Missed Something?

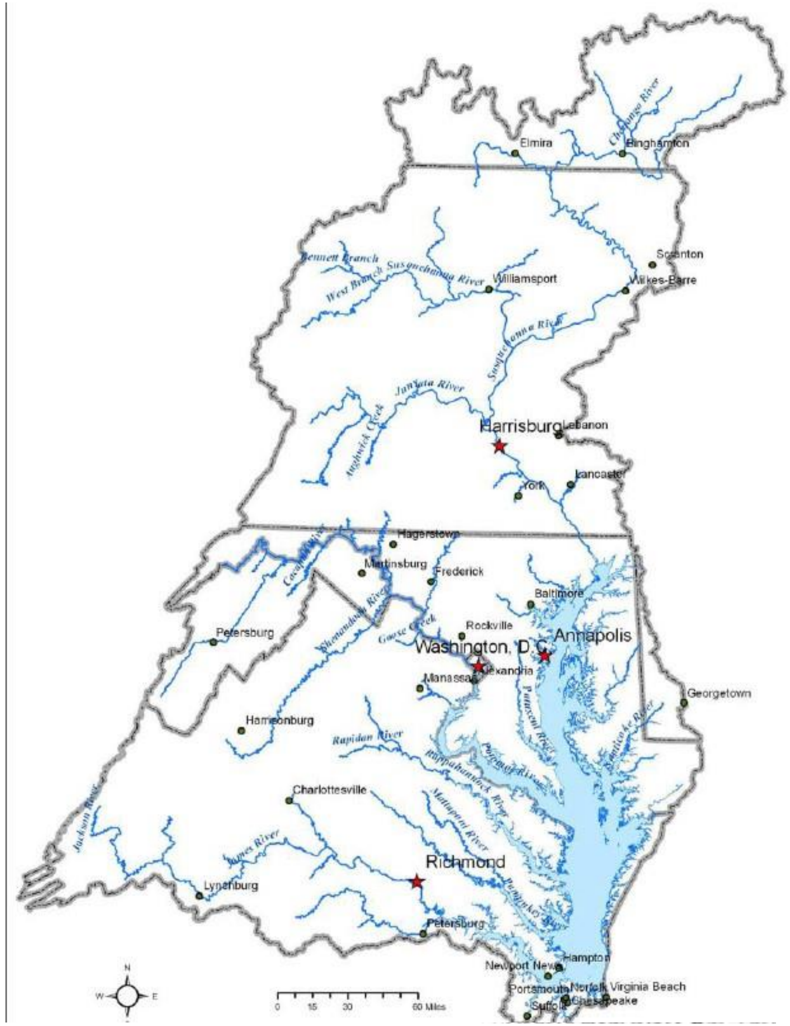
Chesapeake Bay Stressors ≠ Stream Stressors

Chesapeake Bay Stressors

- Nitrogen
- Phosphorous
- Sediment

Stream Stressors Are Different And More Complex

- Nitrogen is not typically a stressor in freshwater streams
- Sediment??



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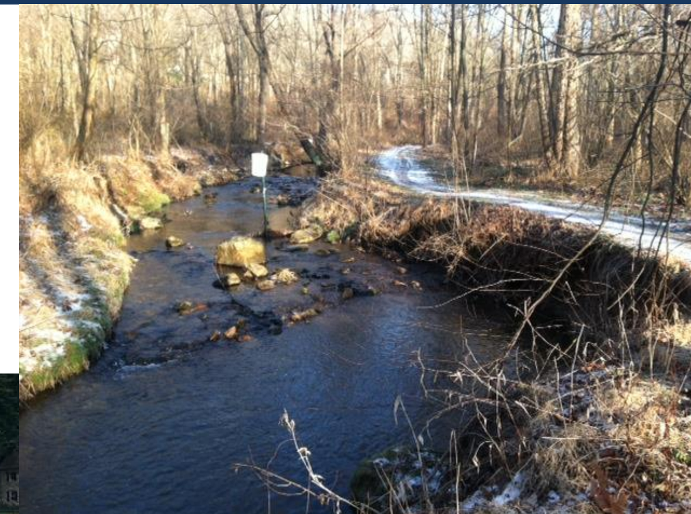
Wrong Prescription?

Focus on

excess sediment load

from

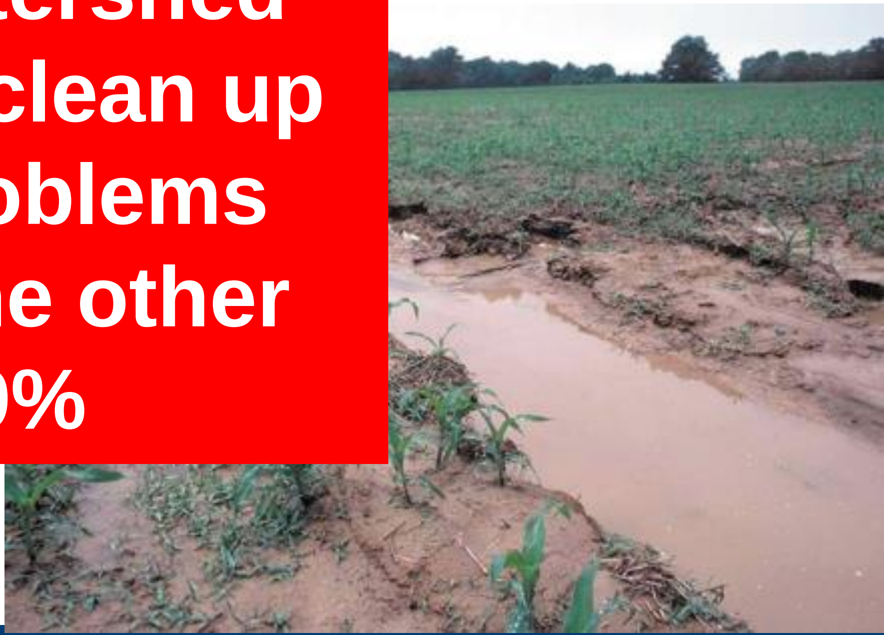
eroding stream banks



Wrong Prescription?

Channel Modifications

"Fixing" 1% of the watershed cannot clean up the problems from the other 99%



Field Challenges Unaddressed

Wrong Prescription - Hydrology:
We are not learning from our failures

Emerson, C.H., C. Welty, and R.G. Traver. (2005)

Watershed-scale evaluation of a system of storm water detention basins.

Journal of Hydrologic Engineering 10:237-242.

little evidence for hydrologic improvements due to stormwater infrastructure

Detailed study
>100 BMPs
19 years ago

Miller, A.J., C. Welty, J.M. Duncan, M.L. Baeck, J.A. Smith. (2021)

Assessing urban rainfall-runoff response to stormwater management extent.

Hydrological Processes 35: e14287.

Same result
2021

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Wrong Prescription - geomorphology:
We are not learning from our failures

Bernhardt, E.S. and M.A. Palmer (2011).

River restoration: the fuzzy logic of repairing reaches to reverse catchment scale degradation.

Ecological Applications 21:1926-1931.

Literature Review
13 years ago

little evidence for ecological uplift after a stream's geomorphic attributes have been repaired

40 Streams
2020

Hilderbrand, R.H., J. Acord, T.J. Nuttle and R. Ewing (2020)

Quantifying the ecological uplift and effectiveness of differing stream restoration approaches in Maryland

Final Report - Chesapeake Bay Trust for Grant #13141

Wrong Prescription - geomorphology:

We are not learning from our failures

Stowe, Petersen, Rao, Walther, Freeman, Wenger (2023)

Stream restoration produces transitory, not permanent, changes to fish assemblages at compensatory mitigation sites

Restoration Ecology Vol. 31 (5): e13903,

little evidence for ecological uplift after a stream's geomorphic attributes have been repaired

23 "Natural Channel Design" projects, 53 sites in Georgia

Early "benefits" were not observed by the 7th year

Wrong Prescription - geomorphology:
We are not learning from our failures

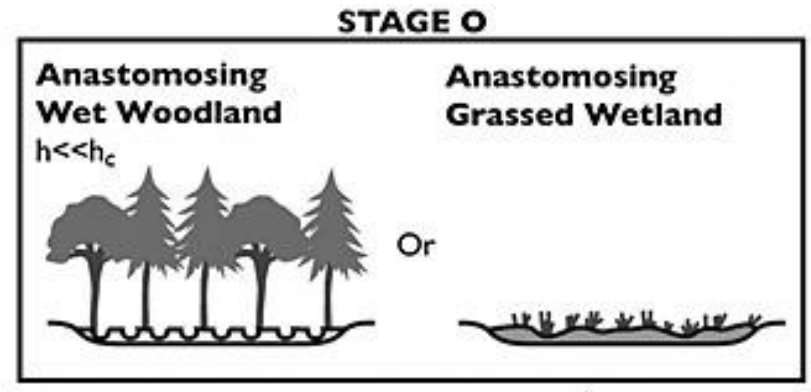
Smith, Neideigh, Rittle, Wallace (2020)

Assessing macroinvertebrate community response to restoration of Big Spring Run: Expanded analysis of before-after-control-impact sampling designs.

River Research and Applications 36:79-90

little evidence for ecological uplift after a stream's geomorphic attributes have been repaired

After 3 years: "restoration had no effect on the macroinvertebrate community due to poor in-stream conditions"



Wrong Prescription - geomorphology:

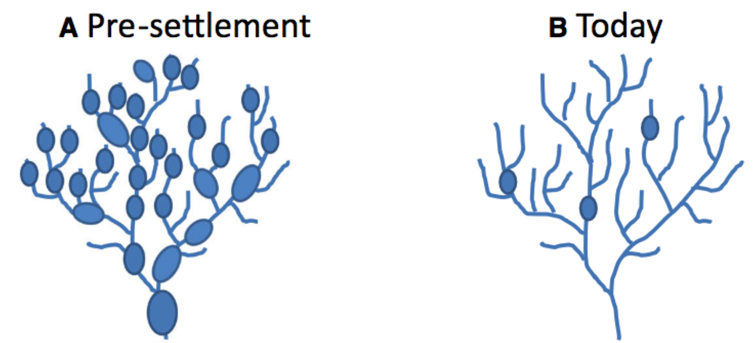
We are not learning from our failures

Wohl, Lininger, Scott. (2018)

River beads as a conceptual framework for building carbon storage and resilience to extreme climate events into river management.

Biogeochemistry 141:365-383.

"River beads refer to retention zones within a river network that typically occur within wider, lower gradient segments of the river valley."



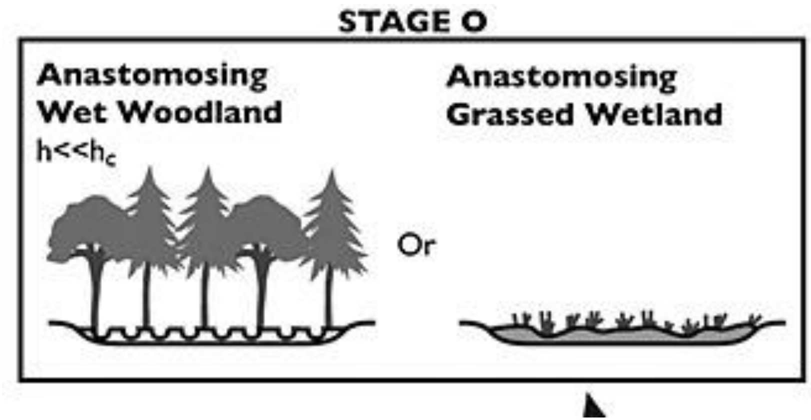
Wrong Prescription - geomorphology:

We are not learning from our failures

Pizzuto, Huffman, Symes. (2023)

Pre-and postsettlement depositional processes and environments of the 3rd-to 5th-order White Clay Creek watershed, Piedmont Province, Pennsylvania and Delaware, USA.

Geological Society of America Bulletin.



Based on 10 sites in 3rd – 5th order watersheds:
"*Instead of being dominated by wetlands*, presettlement river corridors are better described as a complex mosaic of riparian environments including … older colluvial landforms … floodplains …, primary (and possibly secondary) channels, … either localized or valley-spanning wetlands …"

Wrong Prescription - geomorphology:

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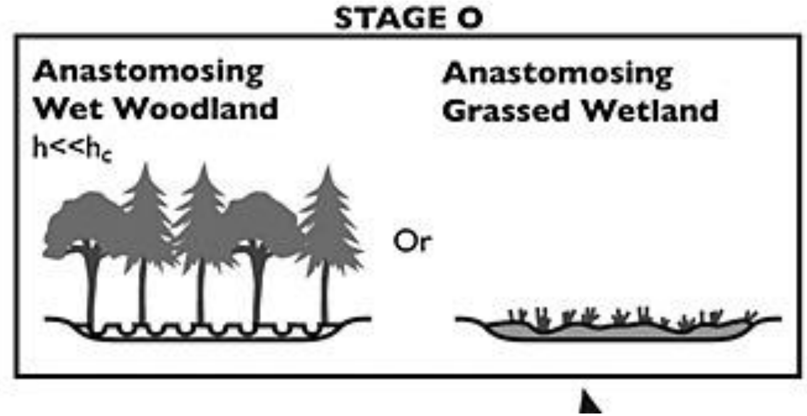

Based on 10 sites in 3rd – 5th order watersheds:
"millponds were important locally, but their deposits represent a minor component of the stratigraphic record."

Wrong Prescription - geomorphology:
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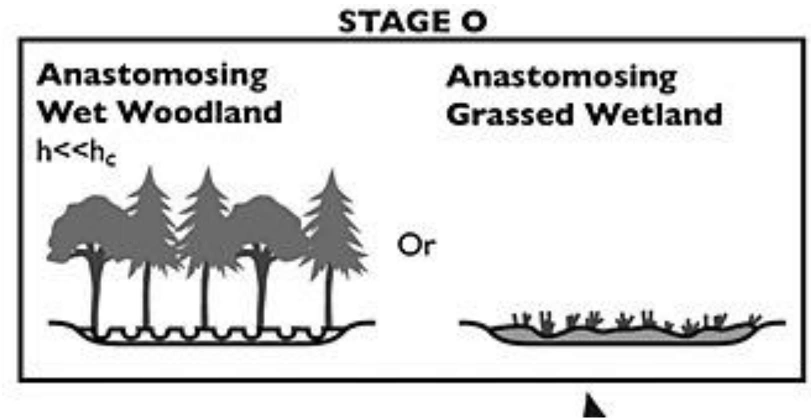

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There are new pollutants of concern today – some are roadway and parking lot pollutants tied to all of us …

Winter deicing salts
(2003)

PAHs in
coal tar seal coats
(2003)

6PPD-quinone
from tires
(2020)

Urban Runoff is a chemical cocktail

Environmental Science & Technology Article

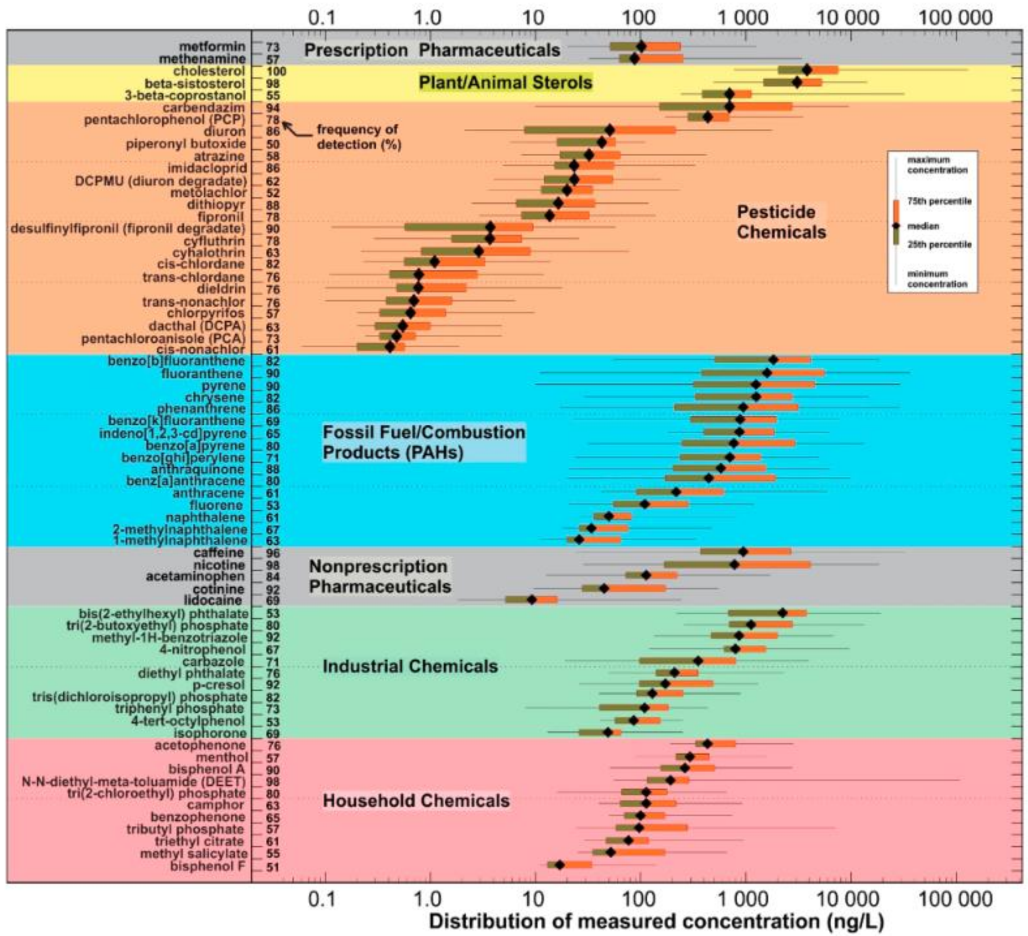


Figure 2. Box-plot distributions of measured concentrations for the 69 organic chemicals detected in 50% or more of 49 urban stormwater samples. Sorted alphabetically from top to bottom by chemical class and decreasing median concentrations.

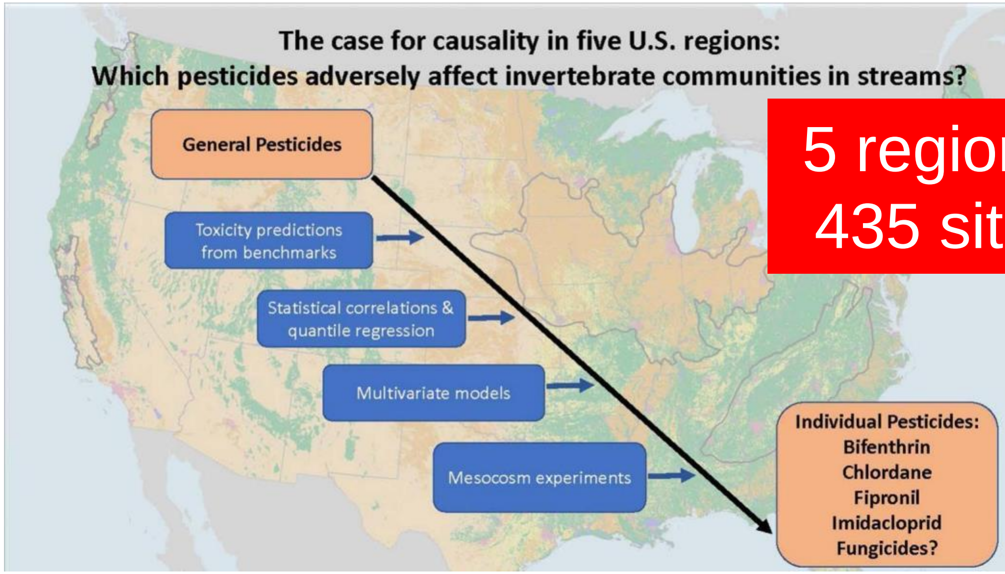
Median = 73 chemicals

- Pesticides
- PAHs

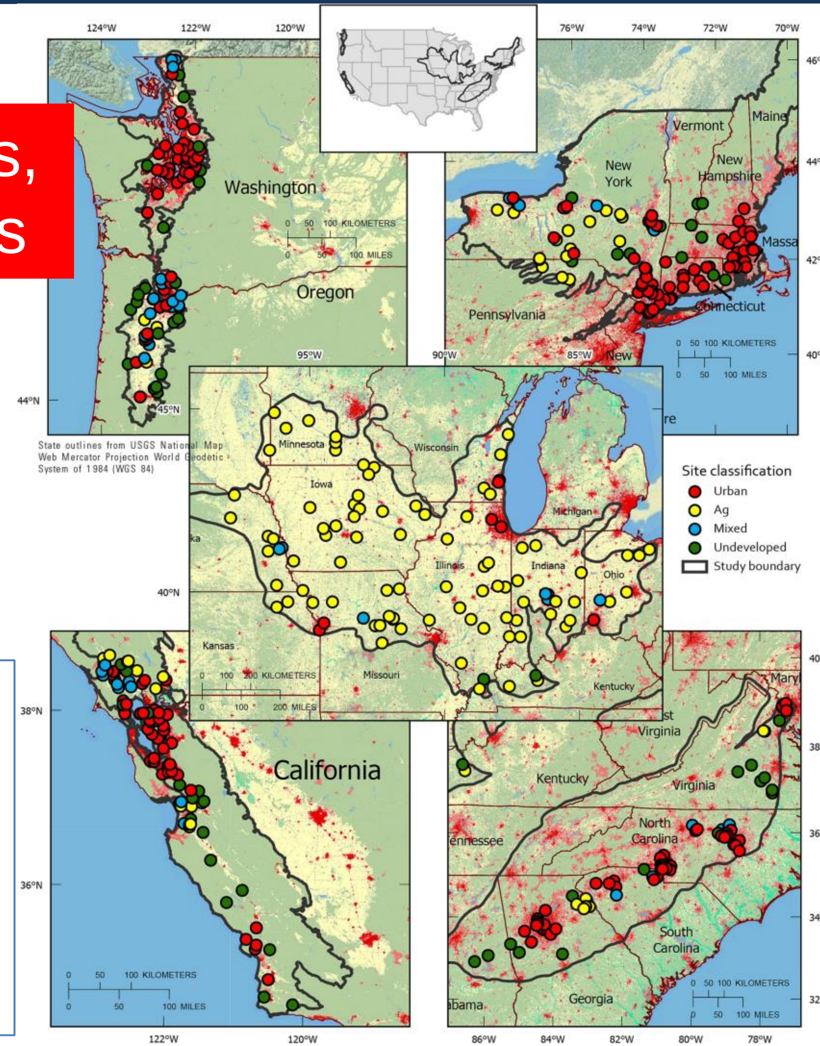
Plus Road Salt

https://sanantonioreport.org/commentary-will-san-antonio-re

Pesticides are everywhere, and important



5 regions, 435 sites



Novell, Moran, Waite, et al. (2024)

Multiple lines of evidence point to pesticides as stressors affecting invertebrate communities in small streams in five United States regions

Science of the Total Environment, 915, p.169634

Pesticides are everywhere, and important

Weight of evidence: insecticides are probable contributor to stream invertebrate impairment.

Bifenthrin, chlordane (1988), fipronil & imidacloprid were important regional stressors.

Pyrethroid, organochlorine, phenylpyrazolen, neonicotinoid

Novell, Moran, Waite et al. (2024)

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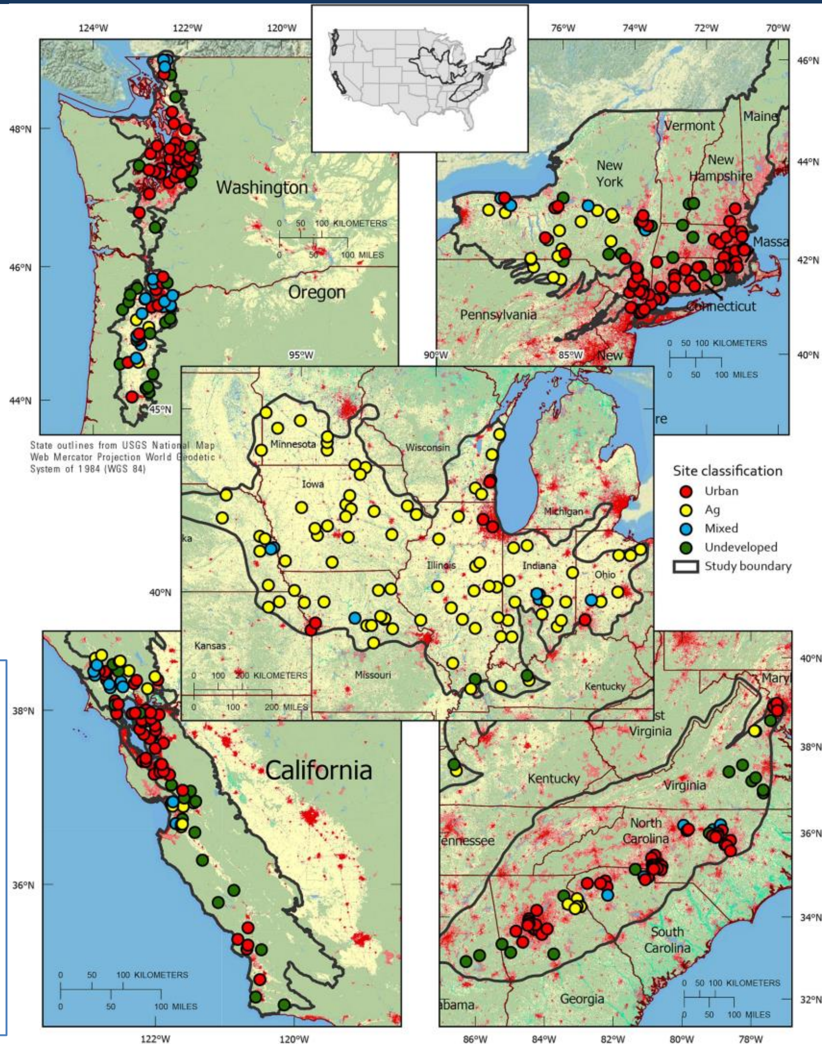
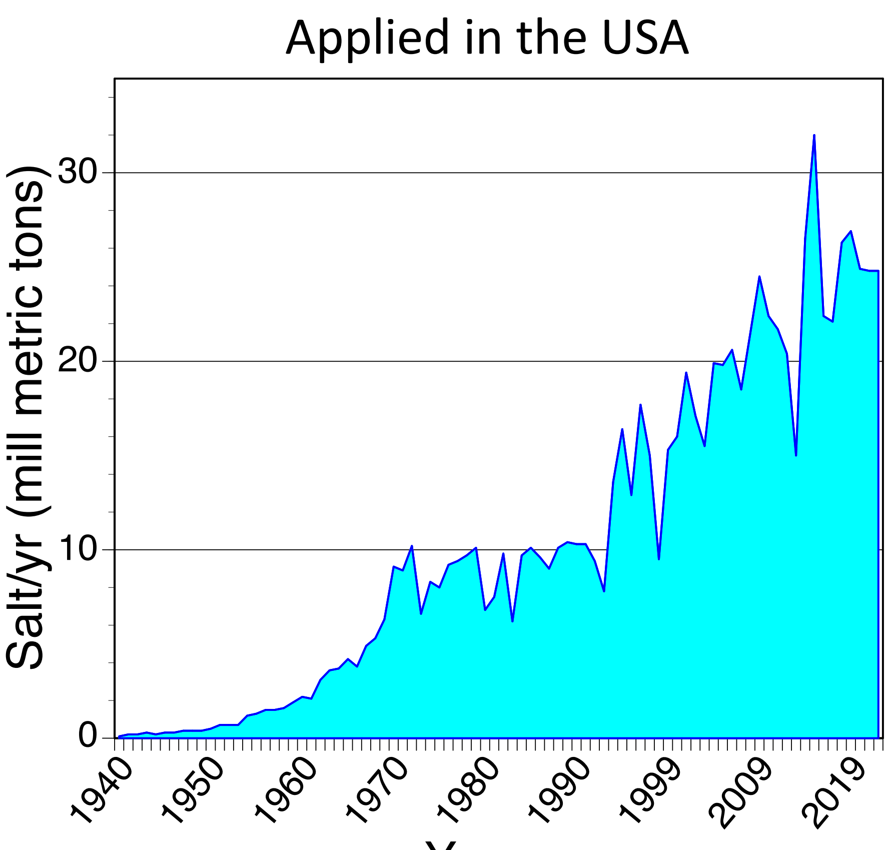
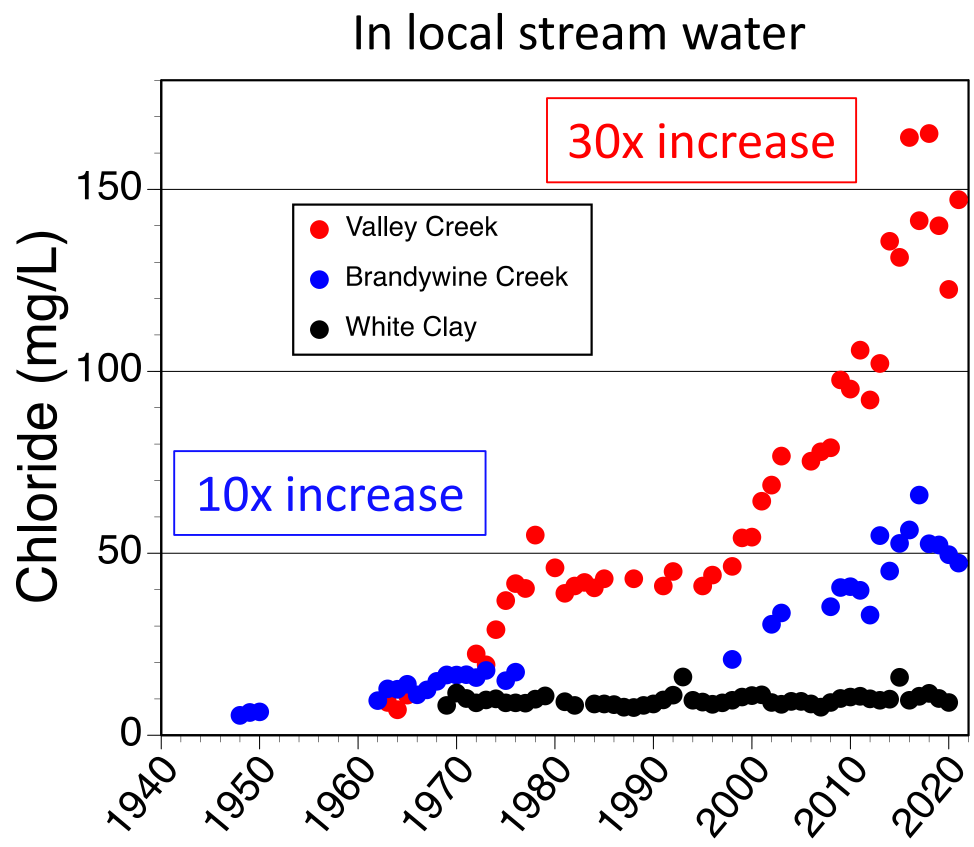


Road salt use is much greater than decades ago. That salt is contaminating our streams



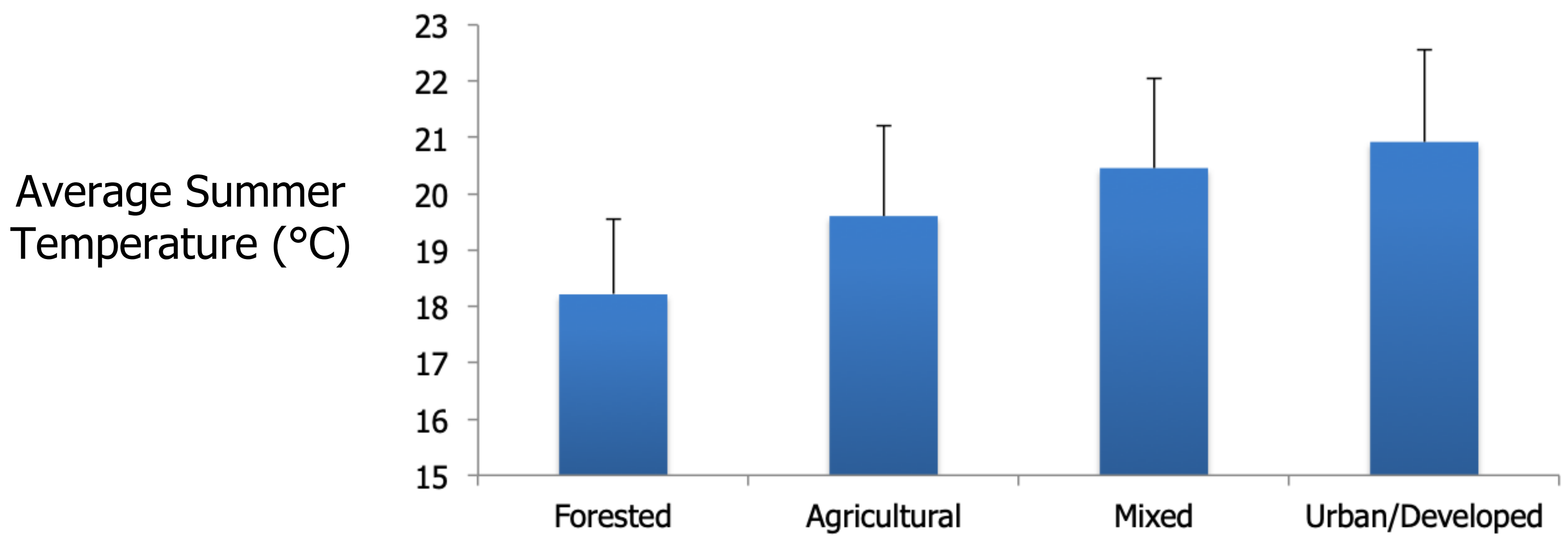


USGS

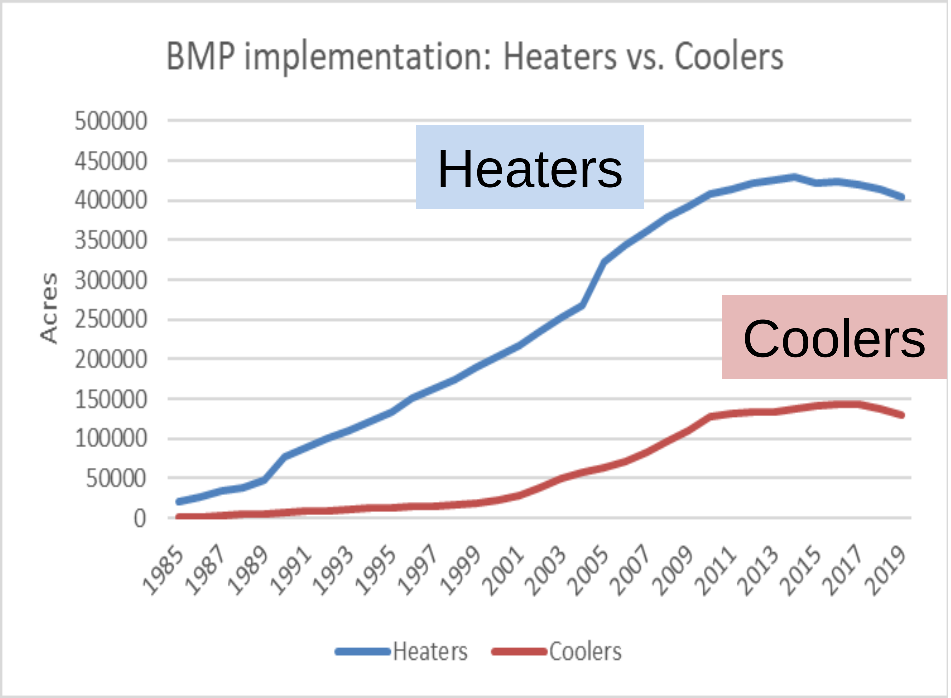
Chester County Water Resources Authority
CHESTER COUNTY – PENNSYLVANIA

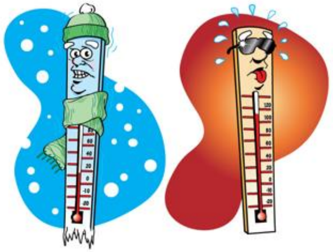
Some of today's pollutants were also an issue in 1972 – Thermal Pollution – stream temperature as a function of land & water use

39 Delaware River watersheds of different size with varying land uses



Pollution-reduction/stormwater BMPs act as "Heaters" or "Coolers"





3x more Heaters in Chesapeake watershed

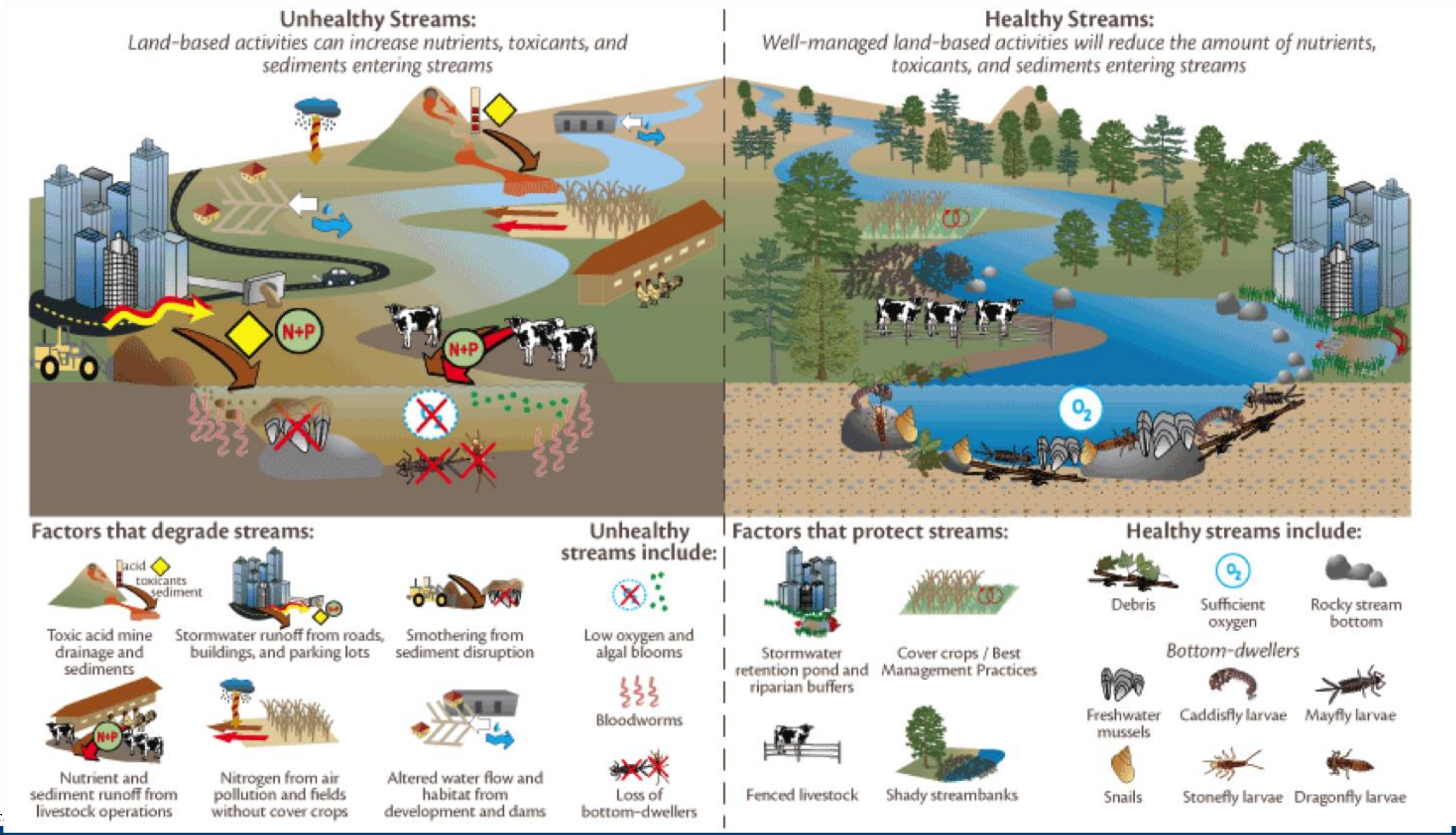
"Heaters" include stormwater retention ponds, floating treatment wetlands and vegetated open channels.

"Coolers" include riparian forest buffers, upstream tree planting, urban stormwater infiltration, and wetlands restoration, enhancement and rehabilitation.

Unhealthy Stream = Unhealthy Watershed

– generally with many concurrent stressors –

Vary spatially and temporally, with cumulative/additive effects



https://wheatleyriver.

Why are we not seeing streams delisted, or at least larger improvements?

1. Not Enough Time?
2. Not Enough Intensity?
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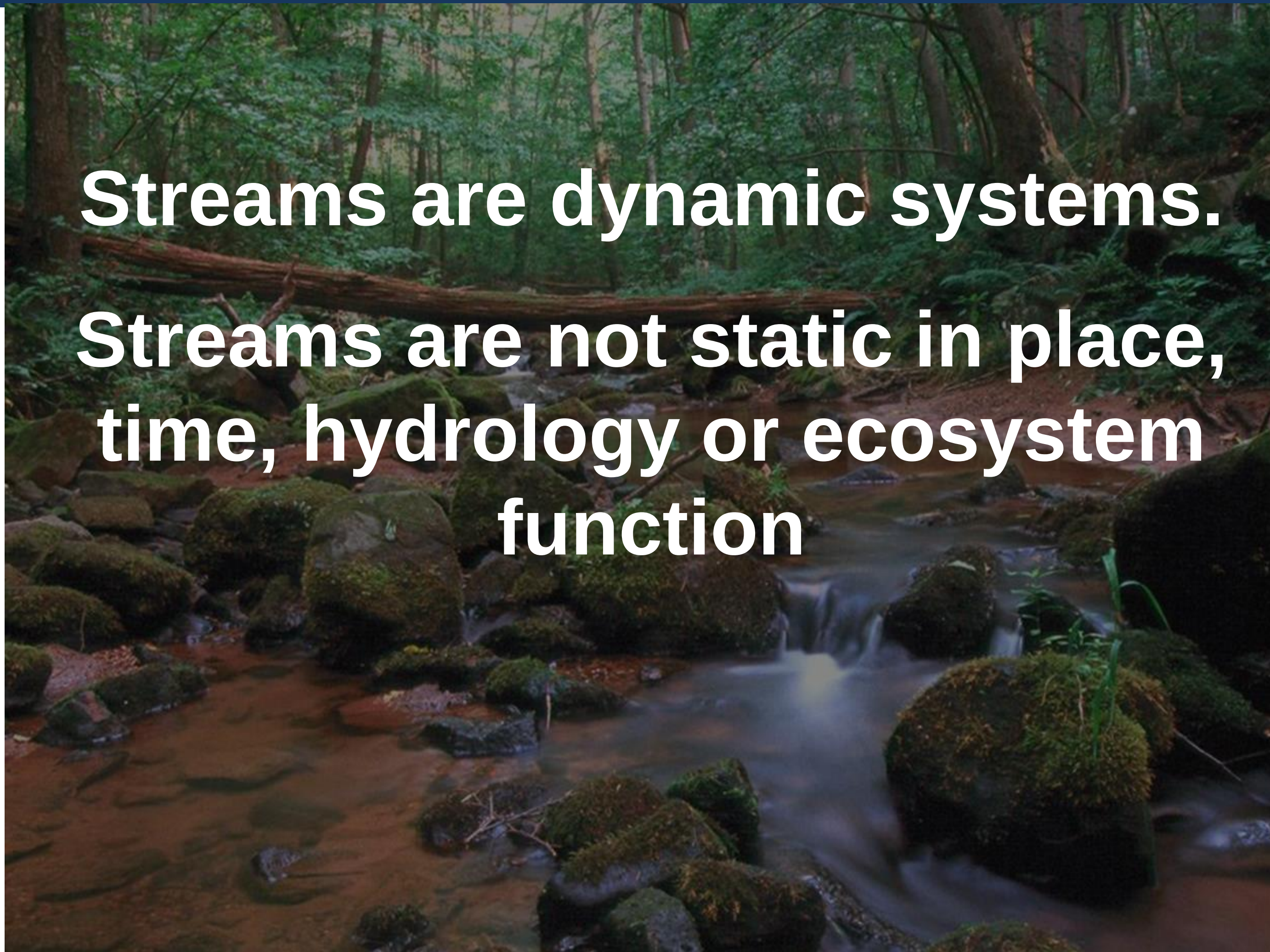
Restoration Approach:
Mimic or Restore Natural Function

Inconvenient Resiliency



Streams are dynamic systems.

Streams are not static in place, time, hydrology or ecosystem function

Where Do We Start?

- Accept that restoration efforts will have to scale with the problem and the watershed size
- Consider and address multiple stressors
- Recognize and plan for the human dimension aspect of the work
- Be prepared to critically evaluate the work and adapt
- Use Models as planning tools and for perspective, but don't let them limit your efforts

We know wide, setback fences help

Before & after cows removed

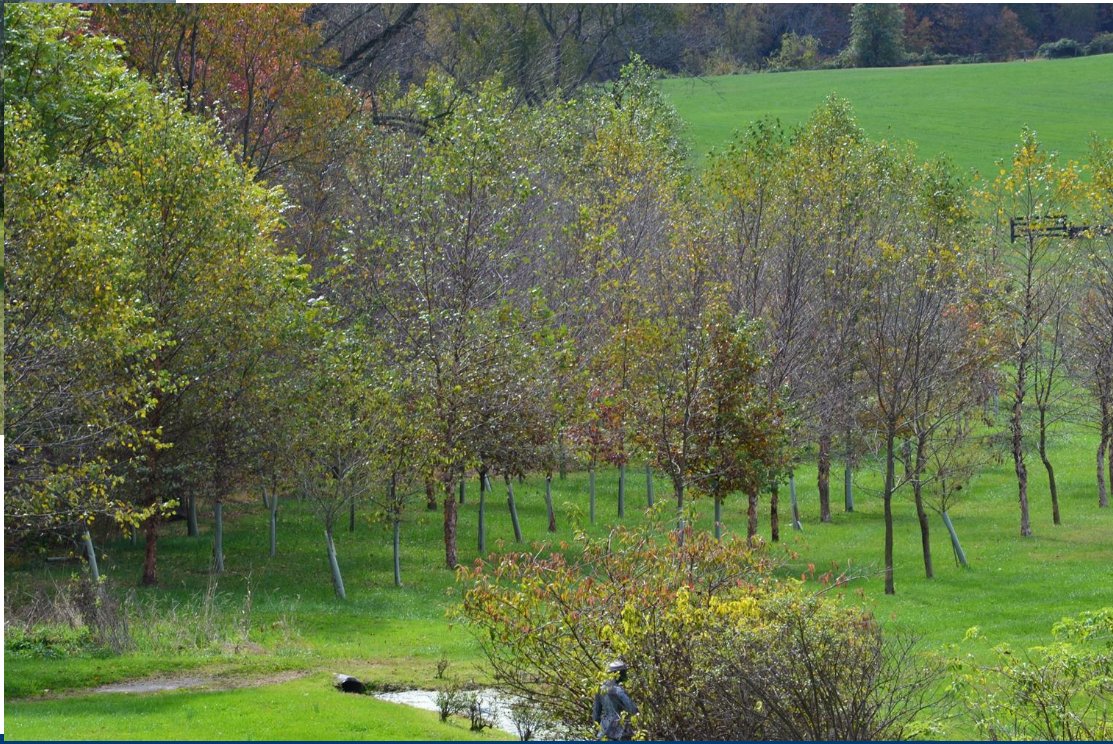
Photo courtesy of Lancaster Co. Conservation District

We know managed barnyards help

Before & After

We know wide, forested buffers help

Before & After



We know wide, forested buffers help

Stream functions we are changing:

Flow

Runoff

Erosion

Temperature

Geomorphology

Food Resources

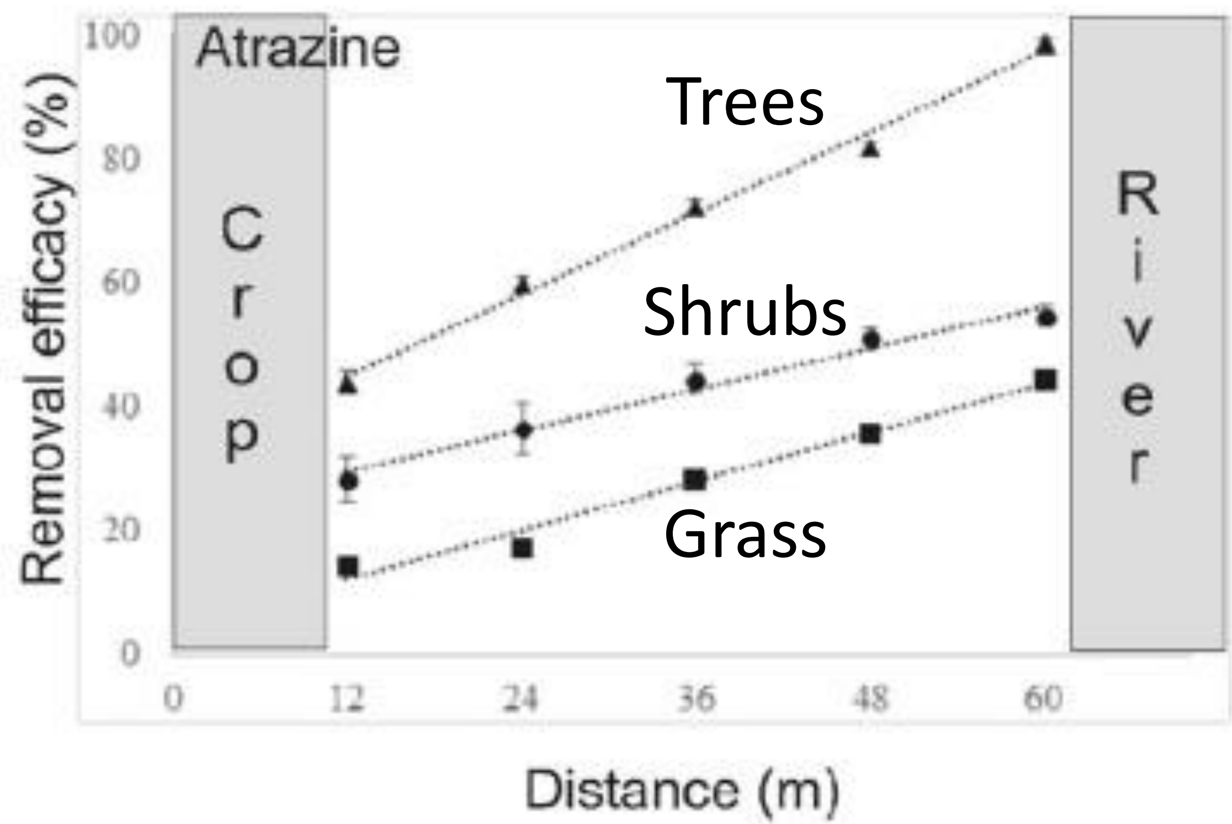
Nutrient Processing

Organic Matter Processing

All without channel & floodplain "restoration" projects

Riparian Forest Buffers – filters – trap or process pollutants

We know wide, forested buffers help



Aguiar Jr., T. R., F. R. Bortolozo, F. A. Hansel, K. Rasera, and M. T. Ferreira. 2016. Riparian buffer zones as pesticide filters of no-till crops. Environ Sci Pollut Res 22:10618–10626.

We know wide, forested buffers help

Streamside forest buffer width needed to protect stream water quality, habitat, and organisms: a literature review.

Sweeney, BW and JD Newbold. 2014. Journal of the American Water Resources Association 50:560-584.

Wider buffers (>30 m) on small streams have positive impacts on these functions:

- Subsurface nitrate removal
- Sediment trapping
- Stream channel width
- Channel meandering and bank erosion
- Temperature
- Large woody debris
- Macroinvertebrates and fish

Riparian Forest Buffers Provide Critical Habitat

Complex instream habitat

- Channel geomorphology
- Large woody debris
- Stream bank stabilization
- Leaf packs and small wood
- Coarse sediment
- Shade
- Stream is dynamic

Sweeney et al. 2004. PNAS

Riparian deforestation, stream narrowing, and loss of stream ecosystem services.

Riparian deforestation, stream narrowing, and loss of stream ecosystem services

Bernard W. Sweeney*[†], Thomas L. Bott*, John K. Jackson*, Louis A. Kaplan*, J. Denis Newbold*, Laurel J. Standley*, W. Cully Hession[‡], and Richard J. Horwitz[§]

*Stroud Water Research Center, Avondale, PA 19311; [‡]Department of Civil and Environmental Engineering, University of Vermont, Burlington, VT 05405; and [§]Academy of Natural Sciences of Philadelphia, Philadelphia, PA 19103

Communicated by M. Gordon Wolman, The Johns Hopkins University, Baltimore, MD, August 12, 2004 (received for review December 17, 2003)

A study of 16 streams in eastern North America shows that riparian deforestation causes channel narrowing, which reduces the total amount of stream habitat and ecosystem per unit channel length and compromises in-stream processing of pollutants. Wide forest reaches had more macroinvertebrates, total ecosystem processing of organic matter, and nitrogen uptake per unit channel length than contiguous narrow deforested reaches. Stream narrowing nullified any potential advantages of deforestation regarding abundance of fish, quality of dissolved organic matter, and pesticide degradation. These findings show that forested stream channels have a wider and more natural configuration, which significantly affects the total in-stream amount and activity of the ecosystem, including the processing of pollutants. The results reinforce both current policy of the United States that endorses riparian forest buffers as best management practice and federal and state programs that subsidize riparian reforestation for stream restoration and water quality. Not only do forest buffers prevent nonpoint source pollutants from entering small streams, they also enhance the in-stream processing of both nonpoint and point source pollutants, thereby reducing their impact on downstream rivers and estuaries.

Deforestation, which annually averaged ≈14.6 million hectares (ha) worldwide between 1990 and 2000 (1), will continue as long as humans assign a higher value to wood products and agriculture than to "ecosystem services" (2) provided by the forest, such as watershed protection, wildlife conservation, and carbon sequestration (3). The deforestation of riparian areas not only reduces wildlife habitat and corridors but also directly impacts the stream itself by lowering water and habitat quality due to (*i*) loss of woody debris, leaf litter, and dissolved organic carbon inputs (4); (*ii*) lack of shade, which causes very high levels of photosynthetically active radiation (5), solar UV radiation (6), and temperature (7); and (*iii*) less buffering against nonpoint source pollutants (8). Although the deforestation that denuded most of eastern North America in the 19th century was reversed in upland areas decades ago, debate continues about whether riparian areas of that region and elsewhere should remain treeless (9, 10). Although recent U.S. legislation (11) has emphasized the use of forested buffers to keep nonpoint source pollutants out of streams (8), grass buffers can also intercept pollutants (12). Ultimately, the debate may turn on how buffers affect the structure and function of the stream itself and especially its ability to impede the downstream transport of pollutants to larger rivers, estuaries, and oceans. Here we test the hypothesis that the narrowing of small streams caused by riparian deforestation leads to a significant decline in (*i*) the amount and functional quality of stream ecosystem and (*ii*) the ability of that ecosystem to process water pollutants.

The conceptual basis of our hypothesis is that unnatural channel narrowing caused by riparian deforestation results in less wetted bottom (i.e., benthic) habitat per unit of channel length, increased water velocity, and lower bed roughness. By reducing the total amount of benthic stream ecosystem per unit of channel length, these physical changes compromise in-stream ecosystem function and the processing of pollutants. Our idea builds on an earlier hypothesis that riparian deforestation lowers water and habitat quality in streams (13) and on scientific research that has demonstrated more biological and biogeochemical activity on or in the bottoms of small streams than in their water columns (14). We show that, when averaged across many streams, important ecosystem services and both structural and functional ecosystem parameters (e.g., levels of nitrogen and phosphorus processing, dissolved organic matter processing, pesticide degradation, net stream metabolism, and the abundance of macroinvertebrates and fish) in forested reaches equaled or exceeded those in deforested reaches per unit of length of stream.

Methods

We studied contiguous (paired) forested and deforested reaches of 16 temperate streams in rural Piedmont watersheds in eastern North America (Fig. 1). Streams ranged from first to fifth order, with watershed areas of 0.1–123 km^2. The forested reaches were upstream from the deforested reach at 11 sites and downstream at 5. Similar topographic gradients and riparian soils and lack of tributaries characterized most pairs of reaches. To avoid factors that might confound the primary study variable (presence or absence of forest), all deforested reaches lacked the typical anthropogenic disturbance common in the region (e.g., disturbance from equine, bovine, or row crop agriculture or urbanization). We studied geomorphology, biodegradable dissolved organic matter (BDOM), macroinvertebrates, and fish in all 16 streams. Because of time and budget constraints, we studied gross primary production (GPP), community respiration (CR), nutrient processing, and pesticide degradation in 8–14 streams. We sampled macroinvertebrates five times a year and BDOM, GPP, CR, nutrient processing, and pesticide degradation twice (summer and winter, with multiple measurements per season for GPP and CR). We measured all other parameters once and used quantitative methods (see below) to study most parameters.

Geomorphology. A global positioning system with differential correction was used to locate the top and bottom of each of the experimental reaches, which were ≈100–200 m in length. A laser level was used to quantify the longitudinal profile of each reach. Along this profile, we measured bankfull elevation, channel bottom and water surface elevations, width of the water surface, and width of bank at 10-m intervals as well as at important features, such as top of riffle, top of pool, and deepest point in pool. At every third equal interval (i.e., 30, 60, 90 m, etc., from the top of the reach), we used a laser level to survey a detailed channel cross-section orthogonal to the flow. Stream substratum

Freely available online through the PNAS open access option.

Abbreviations: ha, hectare; DOM, dissolved organic matter; BDOM, biodegradable DOM; GPP, gross primary production; DOC, dissolved organic carbon; CR, community respiration; NDM, net daily metabolism.

[†]To whom correspondence should be addressed. E-mail: sweeney@stroudcenter.org.

www.pnas.org/cgi/doi/10.1073/pnas.0405895101

Forested vs not forested (meadow)

Forested streams have more area per length (= more habitat)

Forested

Deforested (grass)

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Forested vs not forested (meadow)

- 1.5 to 3x wider
- Up to 2.5 slower (longer residence time)
- Up to 5x more biological activity

Leading to:

- Up to 9x more N uptake (4x typical)
- Often 2-5x more P uptake (highly variable)
- Up to 3x atrazine degradation

Riparian Forest Buffers
– cannot be the only BMP, stop all pollutants

Concentrated overland flow through a wide, grass buffer

Whole Farm Approach at Watershed Scale

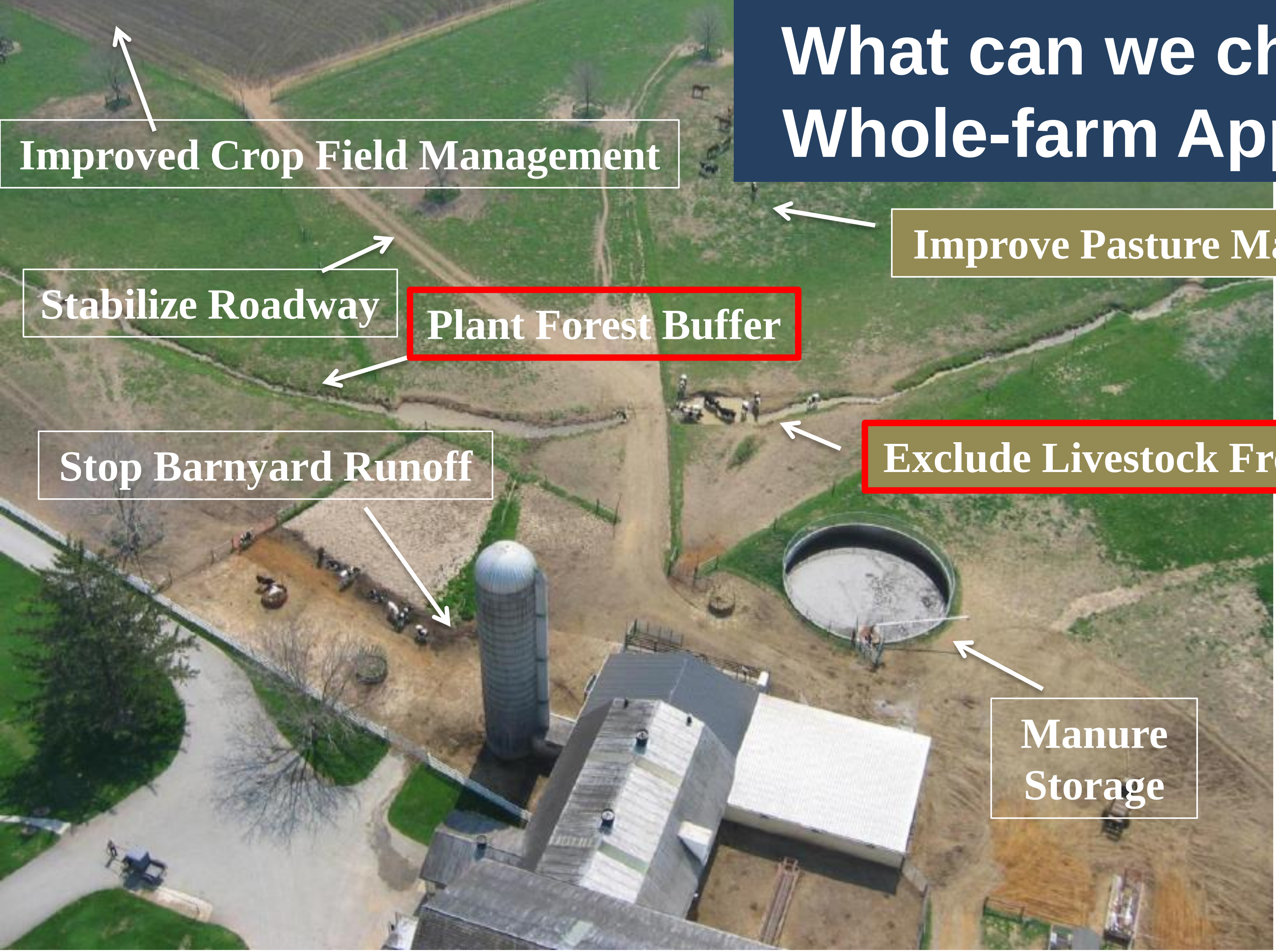
1. Get farm animals and farm practices out of stream/floodplain (replant a wide riparian forest)

2. Control pollution from barnyards, manure management, private and public roads

3. Improve croplands and pastures (soil health, nutrient management)

4. Aggregate projects to improve watershed & stream

What can we change? Whole-farm Approach



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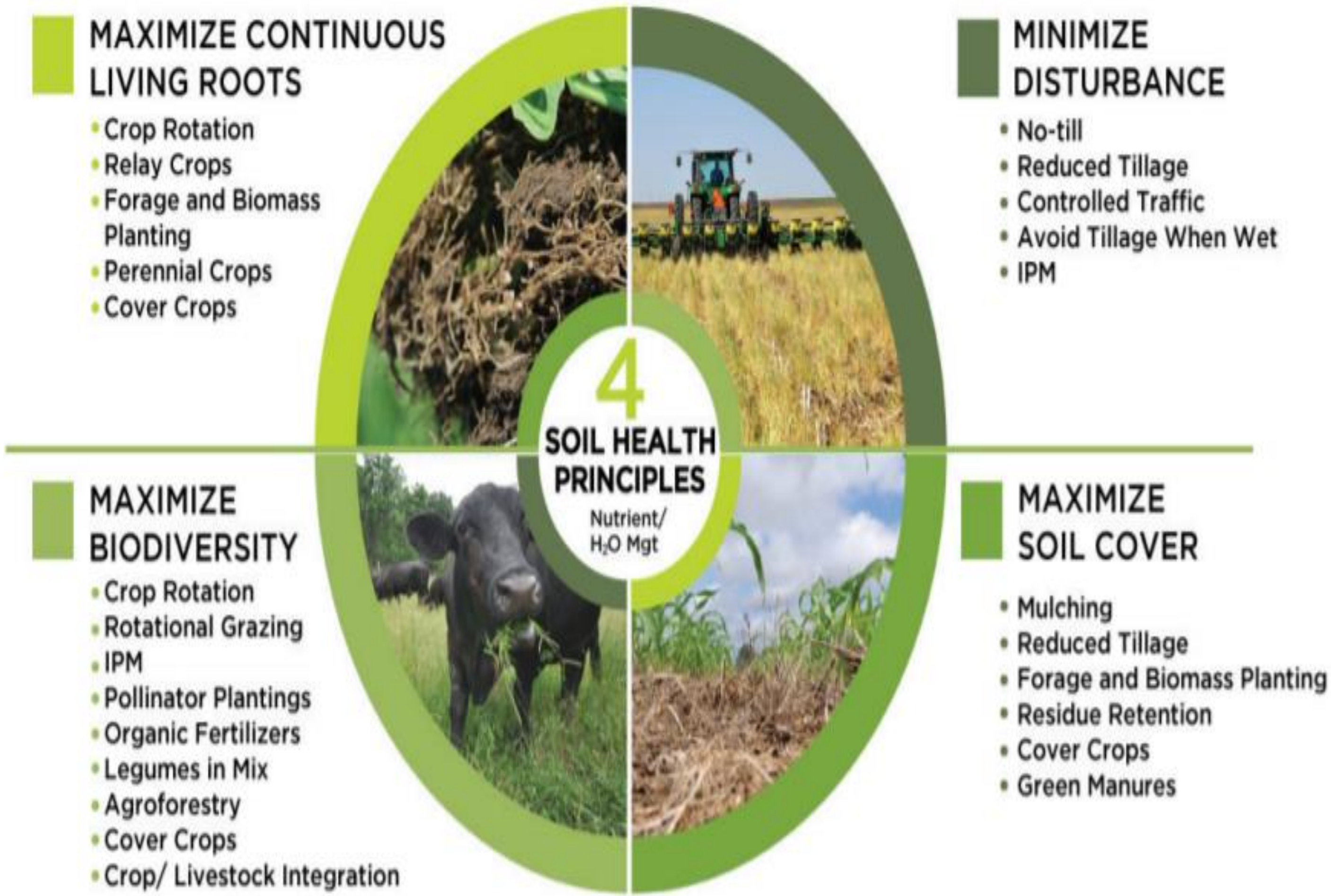
We know improved soil health helps



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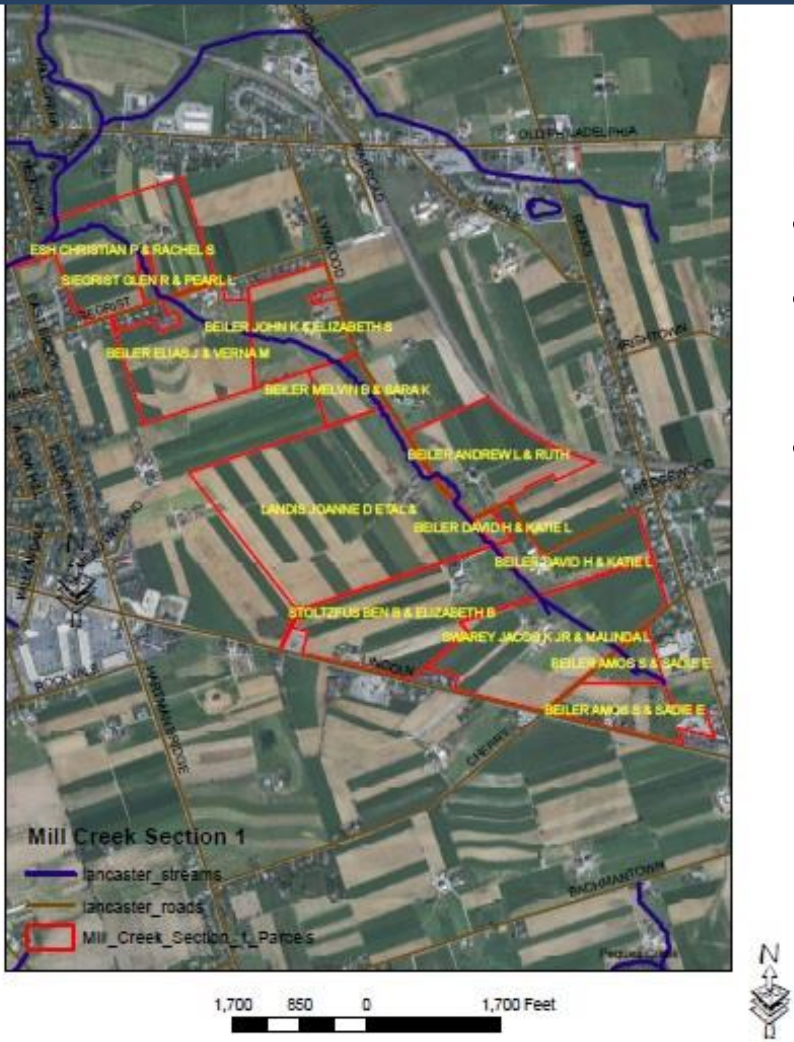
Watershed Scope and Scale



Beiler Run

- Approximately 1500 acres
- 13 Parcels (11 farms) stream adjacent
- 19 total farms in the watershed

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Whole Farm Approach at Watershed Scale

1. Get farm ... ut of stream/f ...
2. Control ... re manage ...
3. Improve ... ealth, nutrient ...
4. Aggrega ... ed & stream

Whole Farm Approach

=

Passive Stream & Watershed Restoration

Cost Effectiveness of Passive Restoration

6 Lancaster County, PA farms: Stream miles = 2.38, buffer acres = 26..3, crop acres = 295	Nitrogen ($/lb • yr)	Phosphorus ($/lb • yr)	Sediment ($/lb • yr)
Riparian Forest Buffer ($6260 per acre) cost effectiveness ($/lb per yr)	$39.62	$2790.47	$1.37
RFB w/ Livestock Exclusion cost effectiveness ($/lb per yr)	$55.89	$251.48	$0.32
Cover crop / No-Till on Crop Acres cost effectiveness ($/lb per yr)	$4.95	$202.98	$0.12
"Stream Restoration” $500,000/mile cost effectiveness ($/lb per yr)	**$1322.08**	**$1324.43**	**$0.38**
"Stream Restoration” $5,000,000/mile cost effectiveness ($/lb per yr)	**$13,220.75**	**$13,244.30**	**$3.81**

Questions?

STROUD WATER RESEARCH CENTER