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Chesapeake Sediment Synthesis

Reviewing sediment sources, transport, delivery, and impacts in the Chesapeake Bay watershed to guide management actions v3

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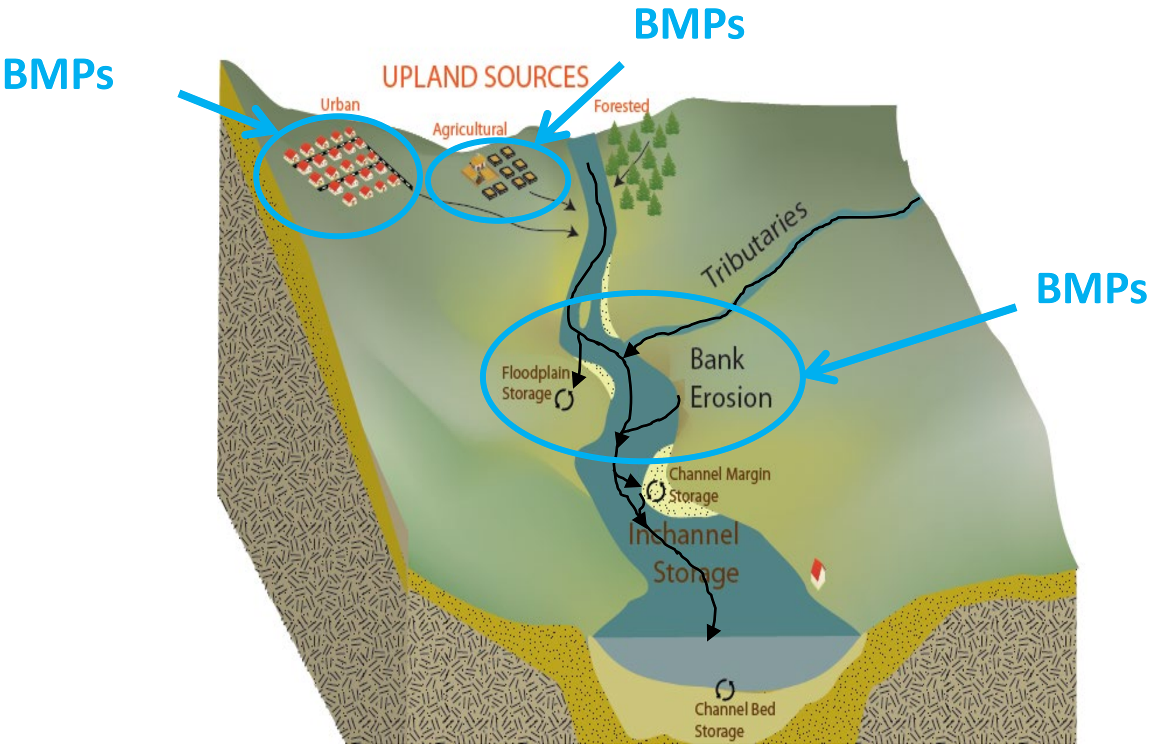
U.S. Department of the Interior
U.S. Geological Survey

https://doi.org/10.5066/P92JVLSP

Goal of the synthesis

To summarize the state of knowledge of sediment in the Chesapeake Bay watershed, in order to guide management actions on the landscape for the restoration of the watershed and estuary.



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Organization of the presentation

1. **Why care about sediment?**
   - Sediment characteristics
   - Impacts on biota, nontidal and tidal
   - Sediment as a vector for nutrients and contaminants
2. **The role of land use history**
   - Before Europeans
   - Historical eras of sediment
   - Land use and river management changes over time
3. **Sediment sources, transport, and delivery**
   - Sediment budget framework
   - Stream loads and yields
   - Stream load trends
   - Upland erosion
   - Upland storage
   - **Stream valley fluxes**
     - Bank erosion
     - Floodplain deposition
     - The balance of erosion and deposition
     - In-channel erosion and deposition
     - Stream valley storage
     - Reservoirs
5. **Integrative understanding of sources and delivery**
   - Fingerprinting to ID sources
   - Residence times and path lengths
   - Holistic pictures from watershed sediment budgets
   - Watershed delivery to the Bay
6. **BMP effects**
   - Tracking BMP implementation
   - Modeled BMP effects
   - Review of BMP efficiencies
   - Newer BMP examples
7. **Scientific tools**
   - Chesapeake Bay Program Phase 6 watershed model
   - New measurement capabilities
8. **State of the Science**
9. **Summary for watershed management**
   - How to guide management actions
   - Specific guidance for WIP and TMDL implementation
10. **References**

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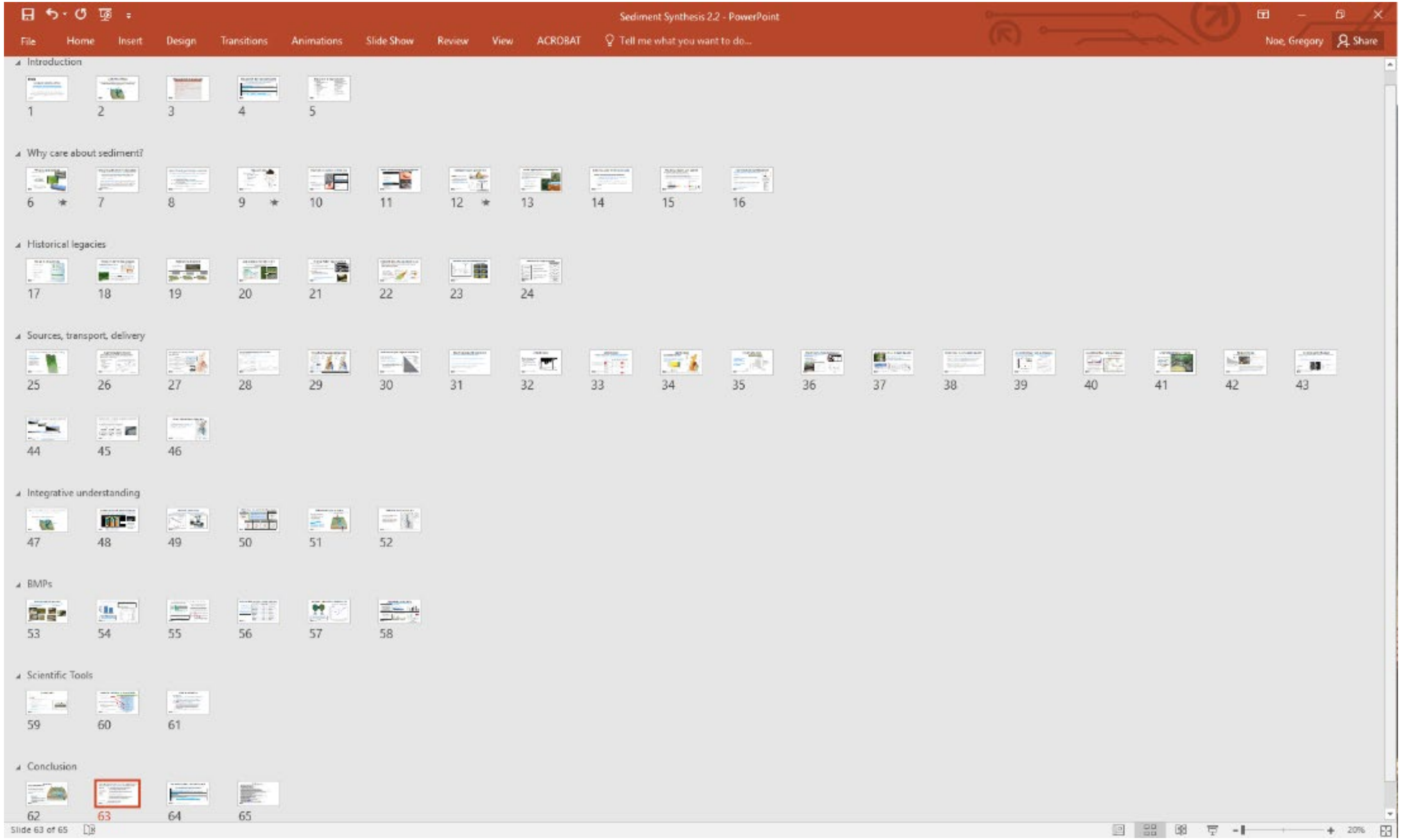
Organization of the presentation

A thorough identification of concepts, data, understanding, and management implications, with frequent summaries, to serve as a resource for the scientific and management communities.



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The Sediment Story: take home points for management

Excessive sediment harms fish and wildlife in the Chesapeake Bay and its watershed

Three important geomorphic principles to guide management:

Scale

Sediment starts in the uplands and moves through stream storage compartments

Sediment processes differ in headwater streams than in larger rivers

Sediment (and attached nutrients) 'hops and rests' downstream, in and out of different storage zones (like floodplains) where it can rest from days to thousands of years, **causing delayed response to management actions**

Time

Historical legacy matters for understanding current sediment issues, and may impact BMP and management effects on loads in the future

Land Use

Nutrients and other pollutants are attached to sediment

Agricultural, developed land, and **stream banks** are all **important sources of sediment**, but locally and temporally variable

Based on models, **BMPs are thought to have reduced the 2014 sediment load to streams by about 23%** in the Chesapeake Bay watershed

New scientific advances continue to improve our ability to understand and guide management of local and regional sediment problems

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Why care about sediment?

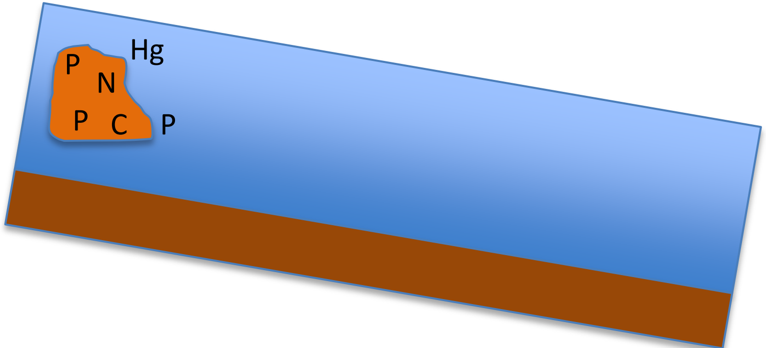
Sediment characteristics

Impacts on biota

- Tidal and nontidal
- Grain size matters
- Multiple mechanisms

Associated contaminants

- Phosphorus and nitrogen
- Other chemicals



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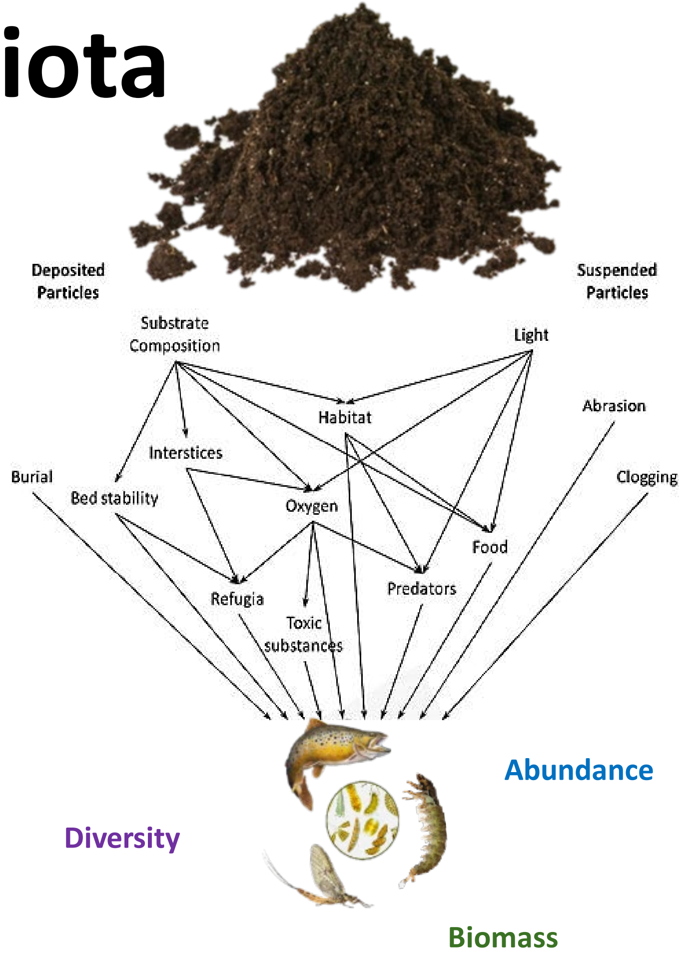
Impacts on biota

Nontidal watershed

- General effects, foodwebs
- Fish and amphibians
- Spawning fish

Chesapeake Bay

- SAV
- Oysters / benthos



Modified from Jones et al. 2012

Sediment negatively affects estuarine organisms

Watershed sediment delivered in floods has a dramatic short-term impact on water clarity (Cerco and Noel 2016, Fabricius et al. 2016)

In some areas, internal resuspension may be more important on average than contemporary inputs (Wang et al. 2013)

Effect of sediment inputs varies regionally (Wang et al. 2013)

Negative effects on biota:

- **Seagrass** (light attenuation, burial)

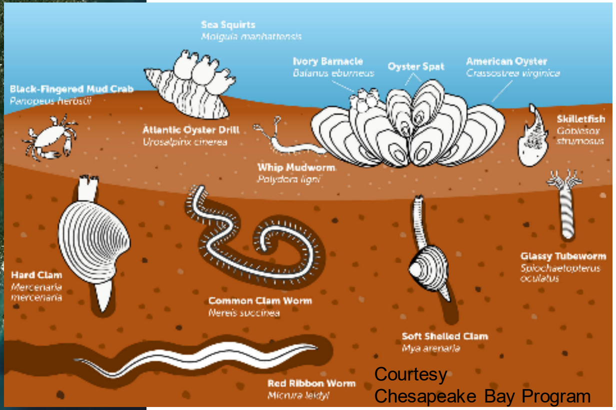
  (Cabaço et al. 2008, Burbisz et al. 2016)

- **Phytoplankton** (light stress)

  (Cloern 1987, Buchanan et al. 2005)

- **Macrobenthic** community biomass and structure (burial, contaminants)

  (Hinchey et al. 2006, Colden et al. 2015, Comeau et al. 2017)



USGS *Impacts on biota*

Sediment is a vector for other contaminants

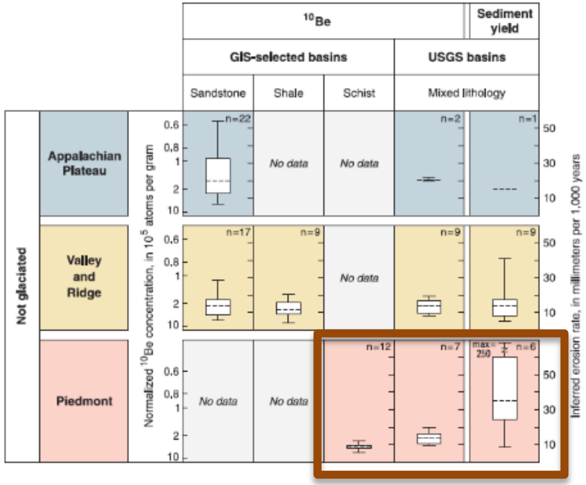
Managing sediment may help with other contaminants

- Phosphorus: **77% of TP load to the Bay is attached to sediment (particulate)** (Zhang et al. 2015)
- Nitrogen: 18% of TN load is attached to sediment (Zhang et al. 2015)
- Metals, pesticides, PCBs, and organic contaminants, for example

The role of history: before Europeans

Geologic rates of erosion vary across the Chesapeake watershed (Gellis et al. 2009)

The Piedmont had low natural sediment yields, in contrast to its current high yields



Gellis et al. 2009

Pre-European Holocene condition: very different than today

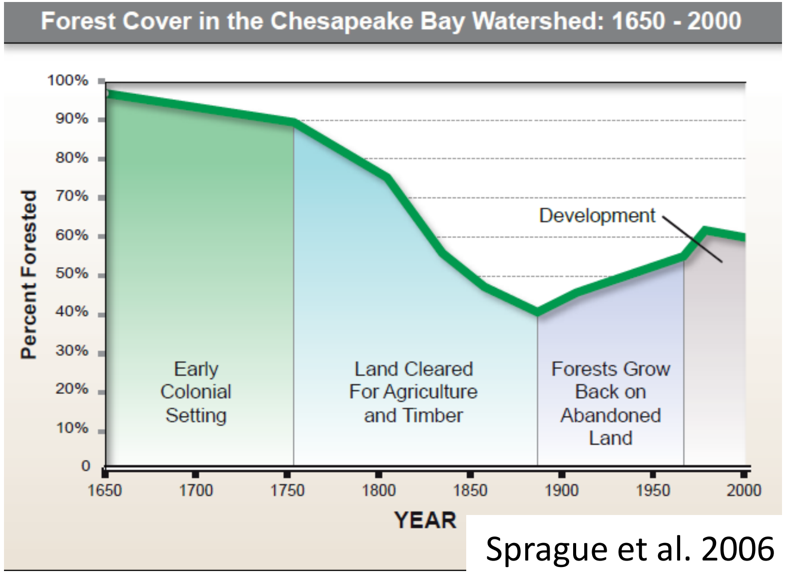
USGS *History*

In some locations, <u>headwater</u> streams (likely not the larger streams and rivers) may have had low banks, anastomosing channels, and wetland marsh and swamp floodplains (Elliott et al. 2013), with much beaver influence (Ruedemann and Schoonmaker 1938, Brush 2009), … but more research is needed.

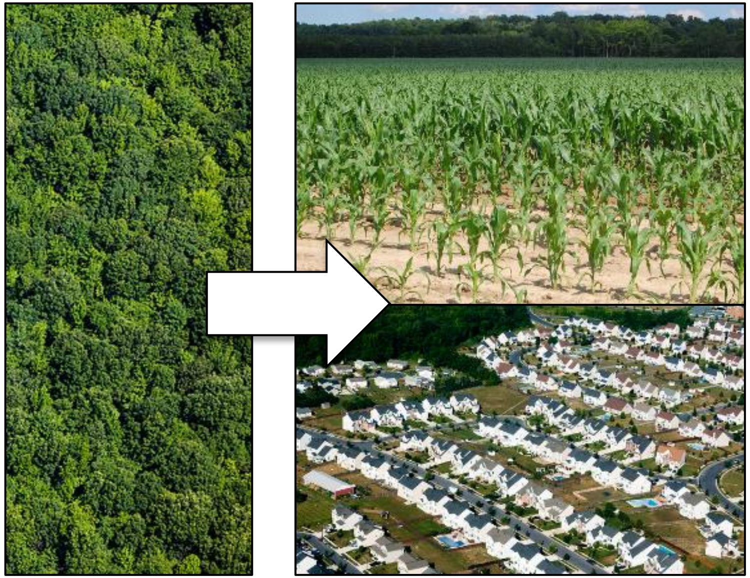
Land use change from 1650 to now

Forest conversion to agriculture and urbanization

increased soil erosion



Sprague et al. 2006



The role of history: legacy sediment

Definition (2017 STAC workshop)

"For the purposes of the Chesapeake Bay management effort, we would define legacy sediment as sediment stored in the landscape as a byproduct of accelerated erosion caused by landscape disturbance following European settlement."

What it means for landscape processes and restoration

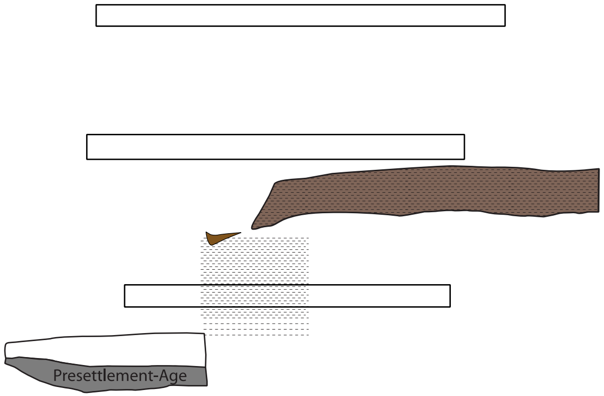
There is a large amount of sediment stored in the fluvial landscape that sets the current impaired conditions and processes that need to be measured and managed to influence stream habitat and downstream loads

How much and where

- Legacy sediment thickness varies
- Some stored sediment is pre-colonial (Pizzuto et al. 2017)
- New remote sensing and GIS tools can estimate local storage

Important because legacy sediment can:

- **Increase sediment loads as it is mobilized**
- **Create long lag times of stream response to upland BMPs** (see later slides)
- **Impair a local waterway even if current landuse may make it seem like it should be a reference "undisturbed" site**

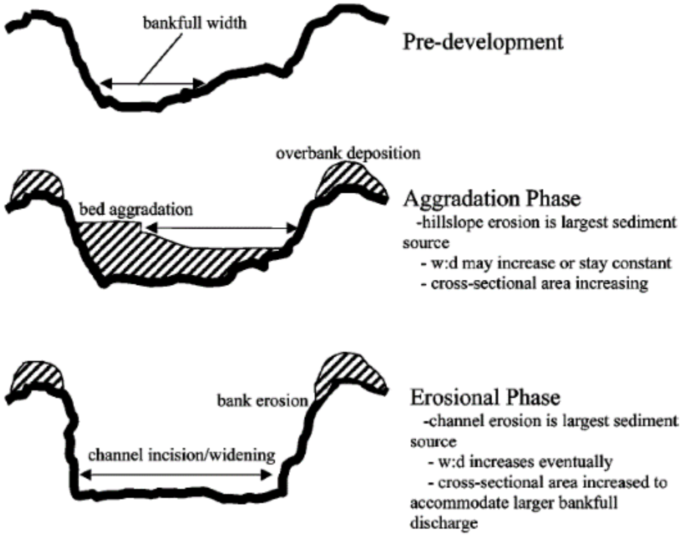


Donovan et al. 2015,
modified from Jacobson and Coleman 1986

Historic plank road buried under floodplain sediment

Urbanization can change channel form

Channel changes with urbanization



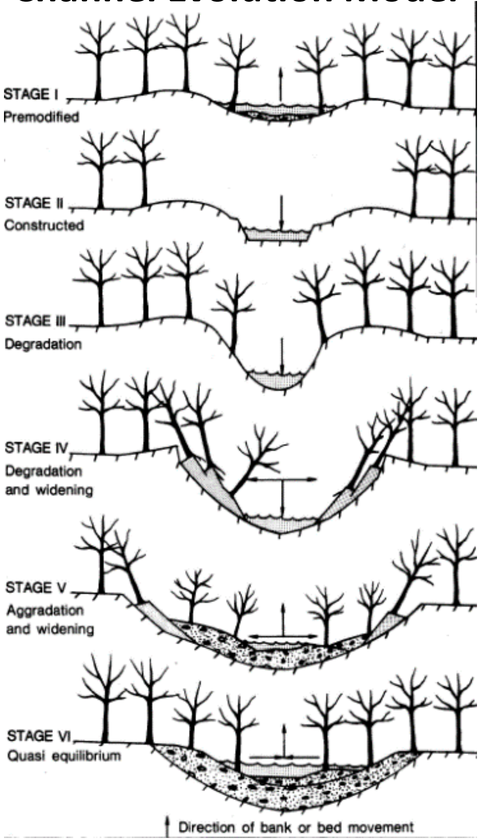
Paul and Meyer 2001

Stream channels are dynamic and can change over time

Understanding the stage of channel evolution can be important for stream and sediment management

Incised channels, which are found throughout the Chesapeake, often go through a progression of changes

Channel Evolution Model



Hupp and Simon 1991

USGS *History*

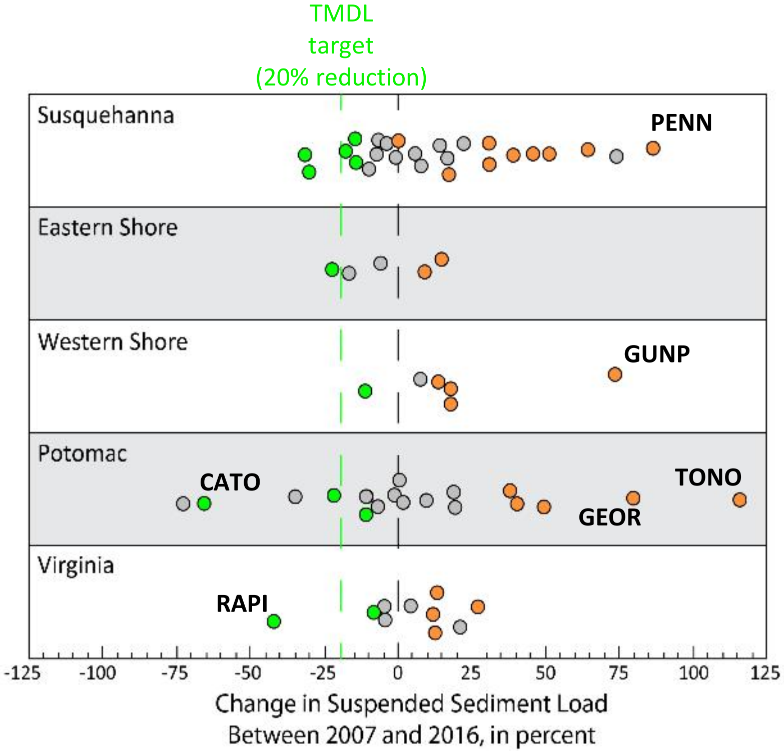
Conceptual model of sediment sources, transport, and delivery

Sediment sources, transport, and storage zones in watersheds vary as a result of land use, management practices, and geology, from headwaters to the Bay

USGS *Source, transport, delivery*

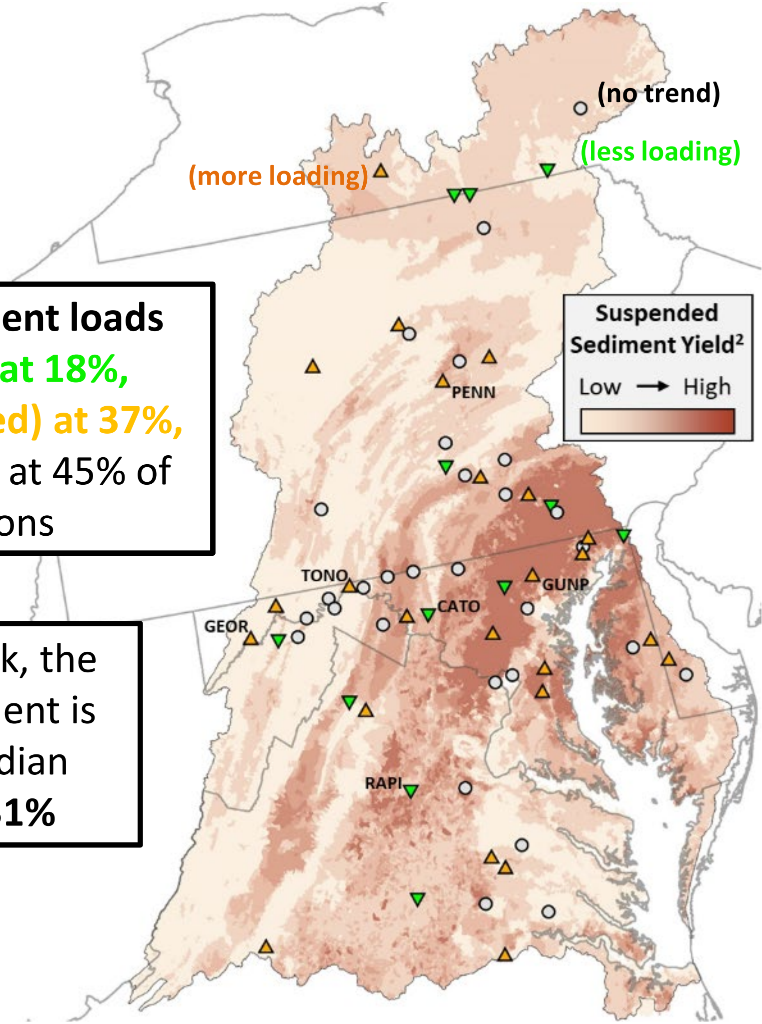
Trends in suspended sediment load,

in the most recent ten year period, 2007-2016[1]:



Suspended sediment loads
have improved at 18%,
degraded (increased) at 37%,
and have no trend at 45% of the 65 stations

Across the network, the median improvement is **20%** and the median degradation is **31%**



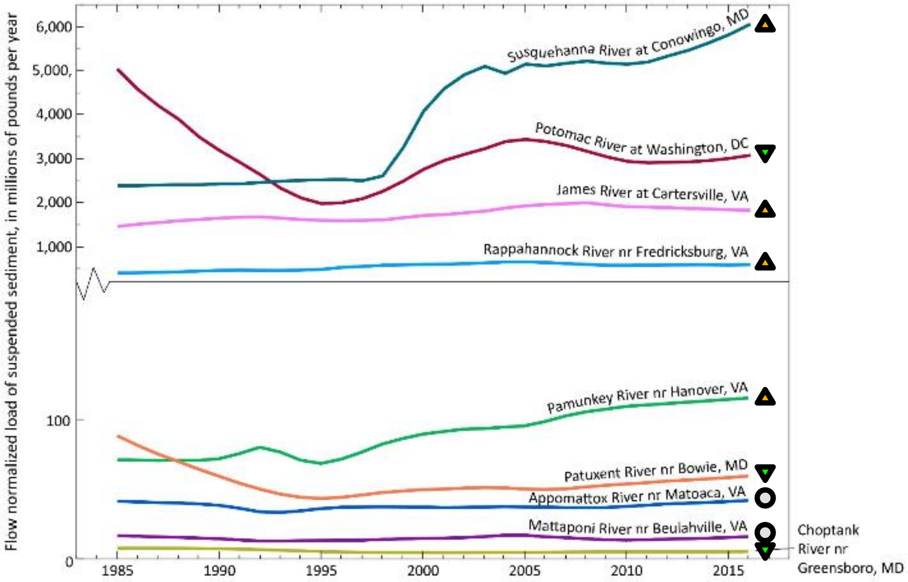
USGS *Source, transport, delivery*

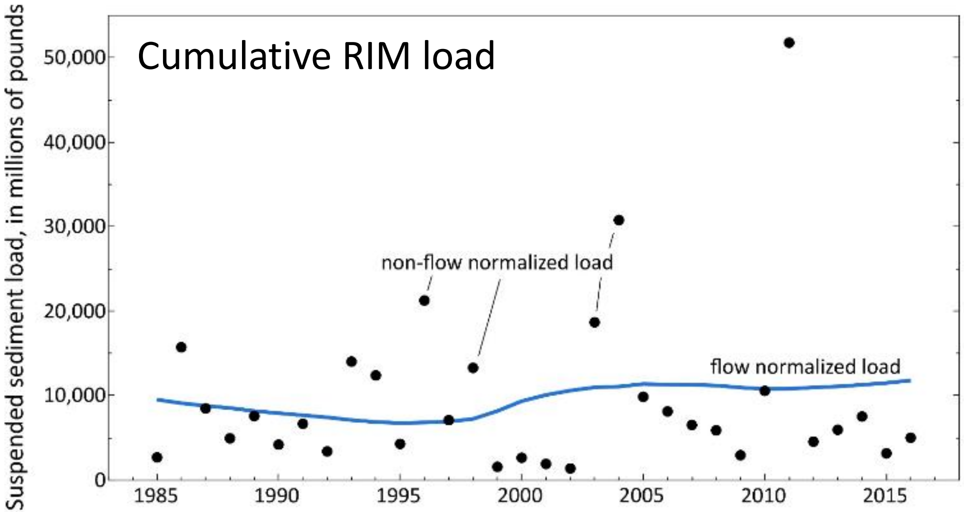
[1]Moyer et al. 2017, [2]Brakebill et al. 2010 http://cbrim.er.usgs.gov/maps.html

Long-term suspended sediment yield to the Bay from RIM stations

Moyer et al. 2017

Most of the rivers with high sediment loads have increasing loads over the past 30 years





USGS *Source, transport, delivery*

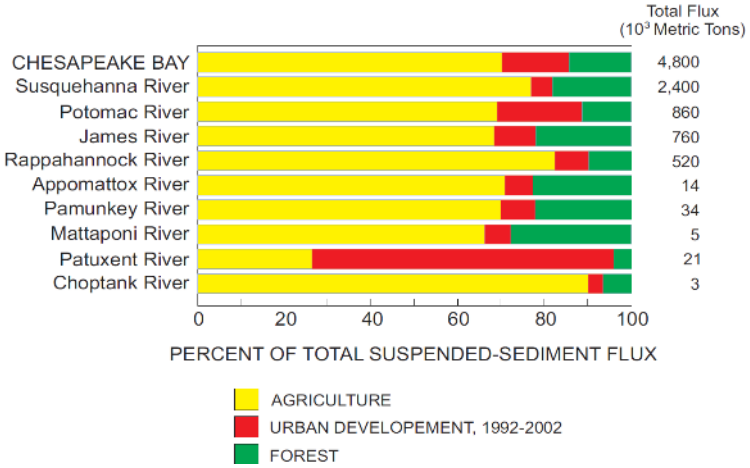
Upland erosion

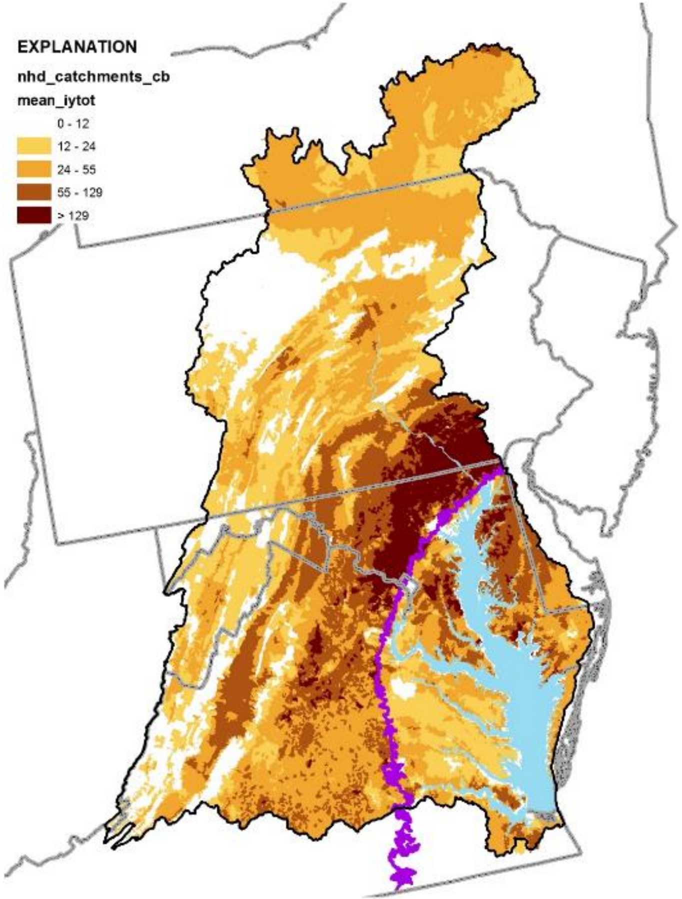
(Brakebill et al. in preparation)

SPARROW suggests that local suspended sediment yields are highest in the developed Piedmont, but that

agriculture is widespread and contributes ~69% of the suspended sediment to Chesapeake Bay

(Brakebill et al. in 2010)





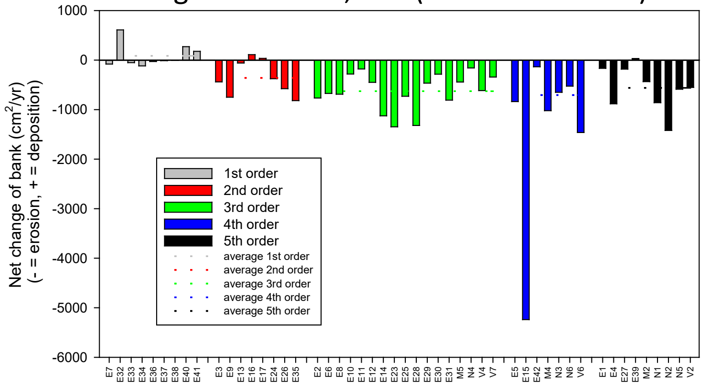
Source, transport, delivery

Stream internal fluxes: Bank erosion

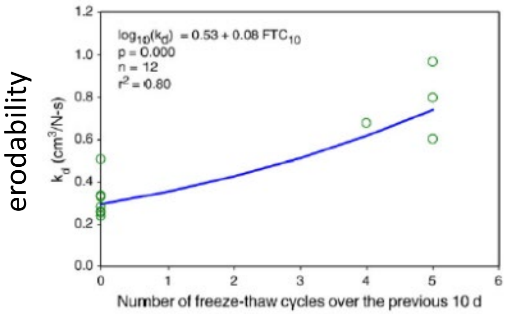
Bank erosion rates are highly variable, and typically increase:

- with stream drainage area (Gellis et al. 2015, Gellis et al. 2017, Hopkins et al. 2018)
- with large floods (Gellis et al. 2017)
- with freeze-thaw cycles (Wynn et al. 2008)
- with warmer water and more acidic and saltier water (Hoomehr et al. 2018)
- with wider channel relative to floodplain (Schenk et al. 2013)
- with less dense soil (Wynn and Mostaghimi 2006)
- with less woody vegetation and less roots (Wynn and Mostaghimi 2006)

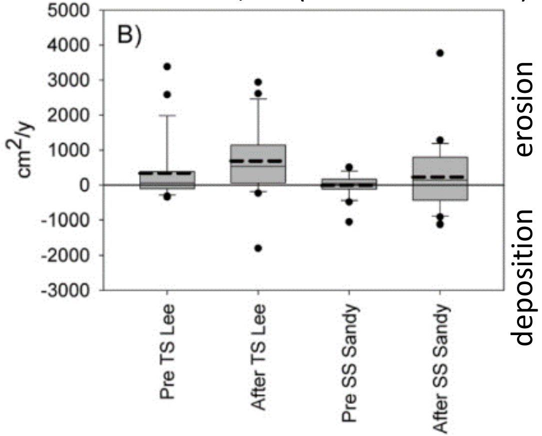
Linganore Creek, MD (Gellis et al. 2015)



Stroubles Creek, VA (Wynn et al. 2008)



Difficult Run, VA (Gellis et al. 2017)



USGS *Source, transport, delivery*

Stream internal fluxes: floodplain deposition

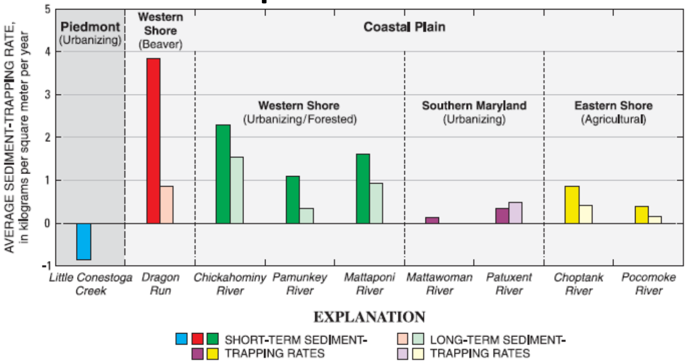
Floodplain trapping is spatially and temporally variable depending on watershed land use, geology, geomorphology, and hydrologic connectivity
(also see Noe and Hupp 2005, Hupp et al. 2013, Wolf et al. 2013, Gillespie et al. 2018)

Piedmont

Watershed	Floodplain sedimentation (kg m^{-2} yr^{-1})
Difficult Run	6.5
Little Conestoga Creek	4.9
Linganore Creek	9.8

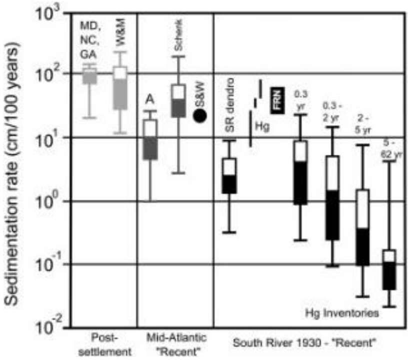
Schenk et al. 2013

Chesapeake watershed



Gellis et al. 2009

Blue Ridge / Valley and Ridge



Pizzuto et al. 2016

USGS *Source, transport, delivery*

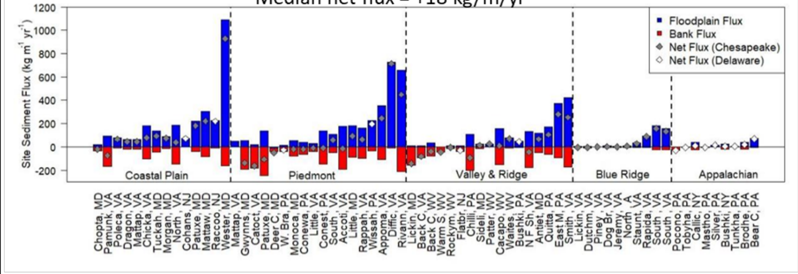
Stream internal fluxes: banks and floodplains

(Noe et al. 2020, Noe et al. in review)

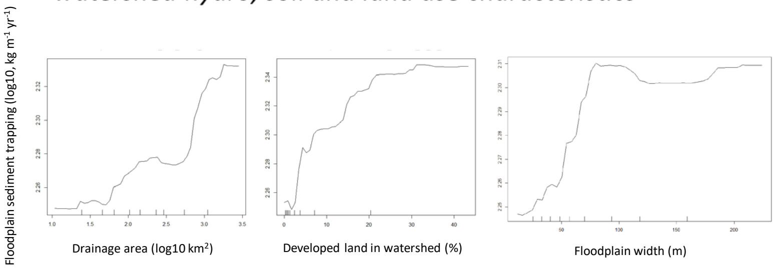
1. *The long-term balance of bank erosion and floodplain deposition varies greatly*

Mean net flux = +68 kg/m/yr

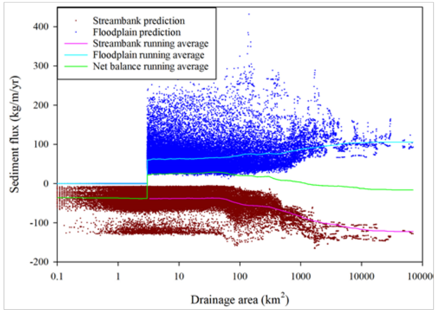
Median net flux = +18 kg/m/yr

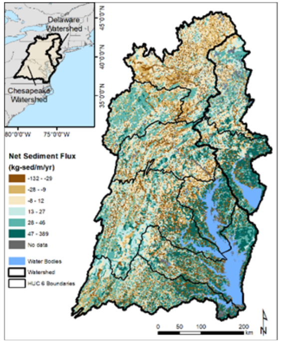


2. *But is predictable from reach geomorphology and watershed hydro, soil and land use characteristics*

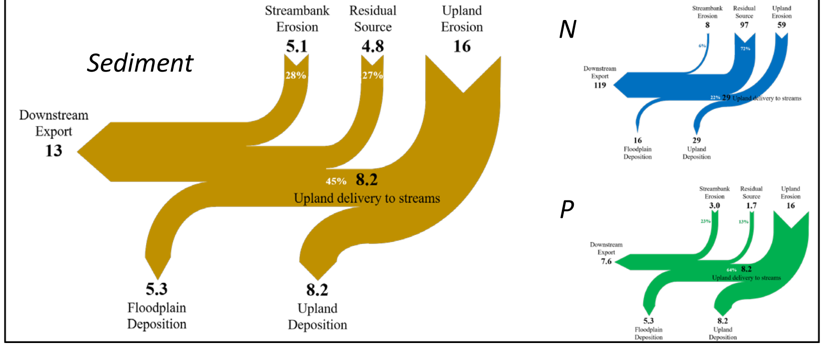


3. *Allowing prediction of fluxes for each of the 74,133 nontidal NHD+ stream reaches in the entire mid-Atlantic*





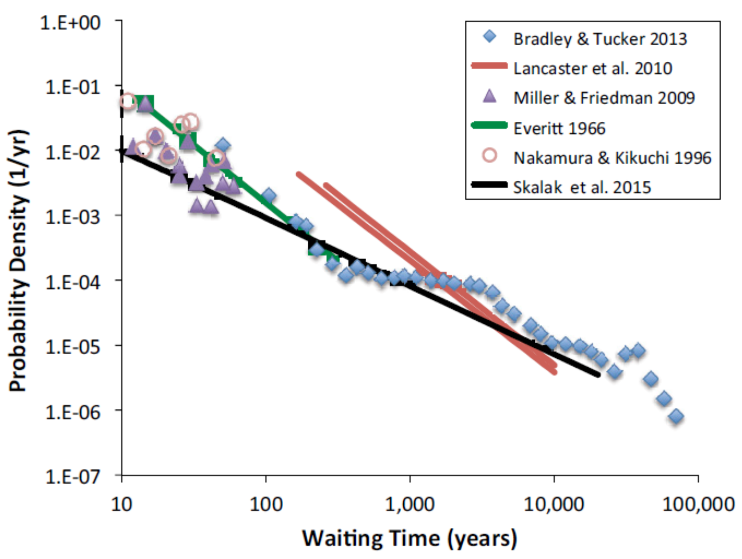
4. *Summed for the entire Chesapeake watershed, and compared to other models, to generate a sediment and N/P budget*



USGS *Source, transport, delivery*

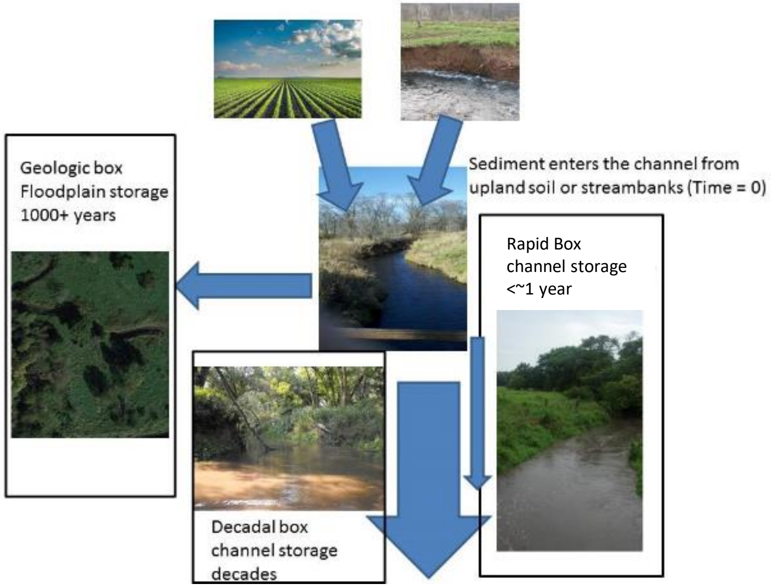
Sediment transit times

Sediment transit times, from erosion to storage zones, can be thought of as a 3-box model:
geologic, decadal, and rapid, each with different management implications



Pizzuto et al. 2017

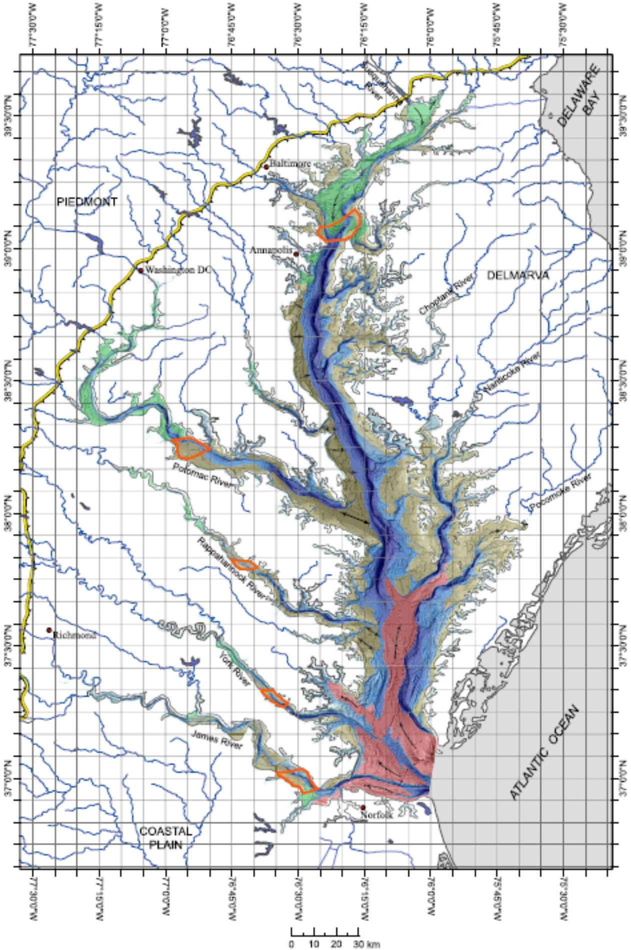
Gellis et al. 2017

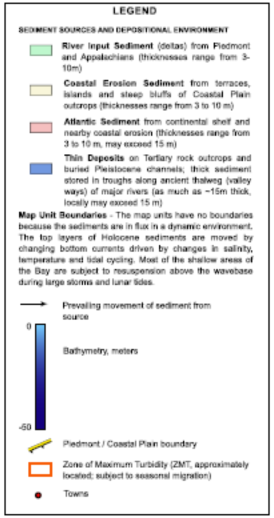


USGS *Lag times*

Watershed delivery to the Bay

Sources of sediment within the Chesapeake Bay include river inputs, coastal erosion, and marine inputs, depending on location



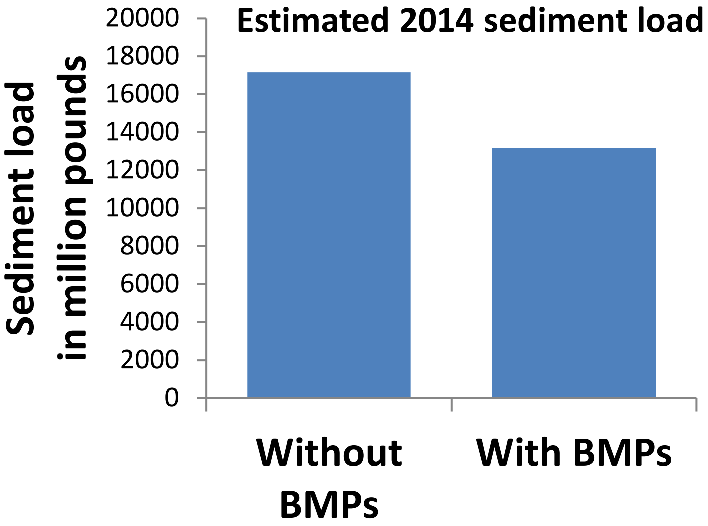


Newell et al. 2004

USGS *Delivery to Bay*

Best management practices in the Chesapeake Bay watershed

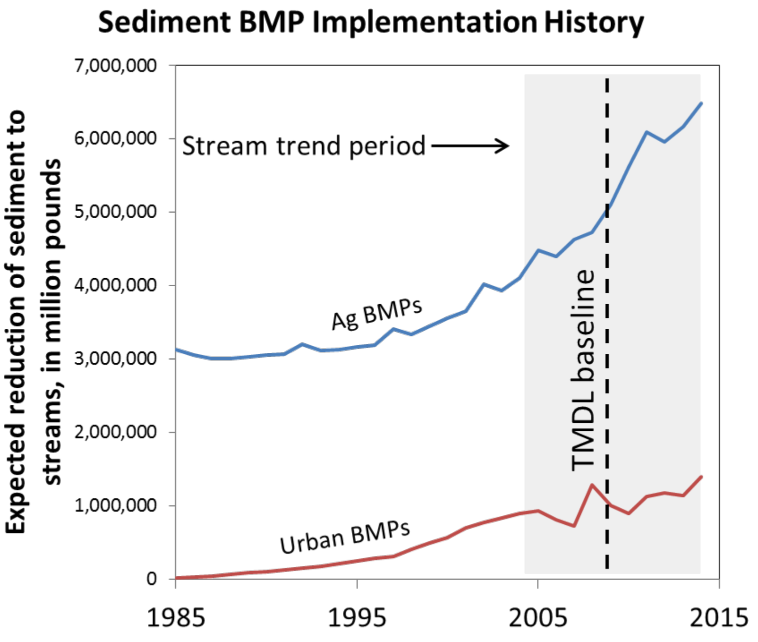
Results from the Chesapeake Bay Watershed Model v5.3.2



BMPs are estimated to have reduced the sediment load to streams in the Chesapeake Bay watershed by about 23% in 2014.

Ag BMP implementation has accelerated from 1985 to 2014, and is expected to reduce total sediment load to streams by 19%.

Urban BMP implementation is expected to reduce total sediment load to streams by 4%.

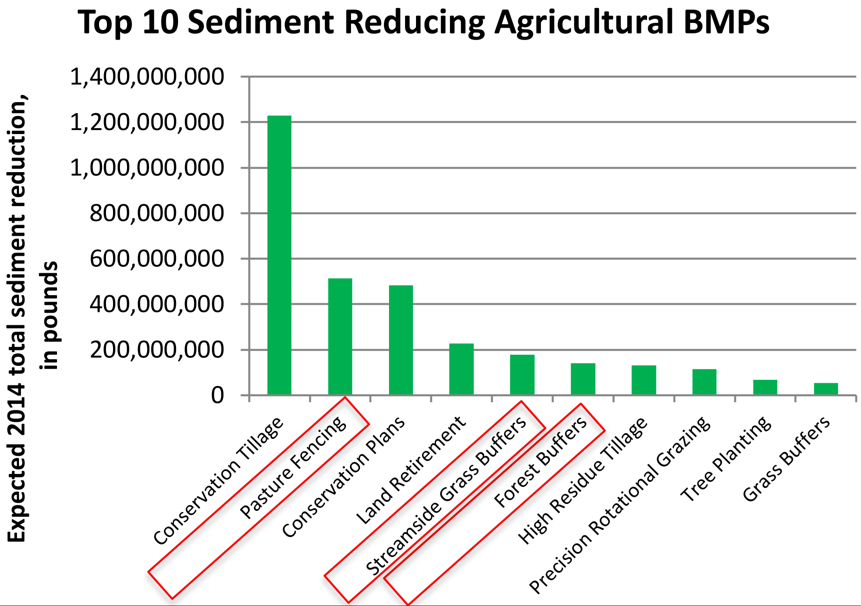


USGS *BMPs*

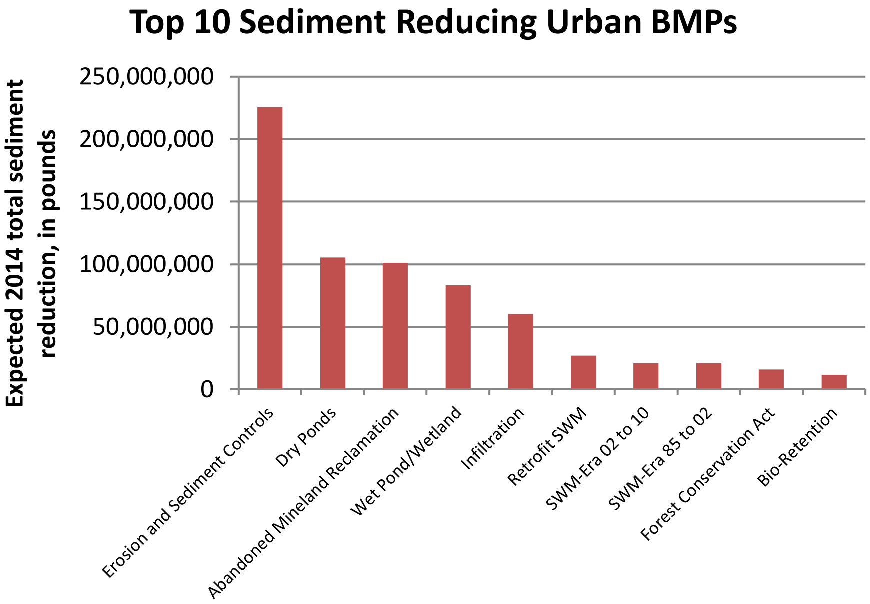
Sekellick et al. in review

Best management practices in the Chesapeake Bay watershed

Results from the Chesapeake Bay Watershed Model v5.3.2



The two urban BMPs with the greatest reduction in sediment loadings rely on intercepting sediment and reducing erosion.



The principal BMPs for reducing agricultural sediment loads to streams have a wide variety of modes of action.

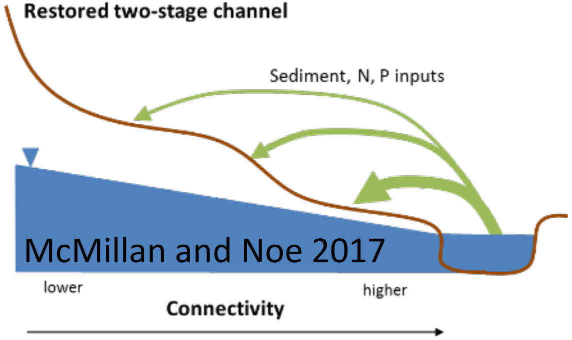
USGS *BMPs*

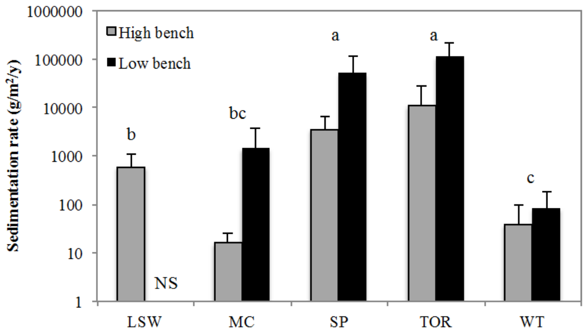
Sekellick et al. in review

Case study: stream BMPs

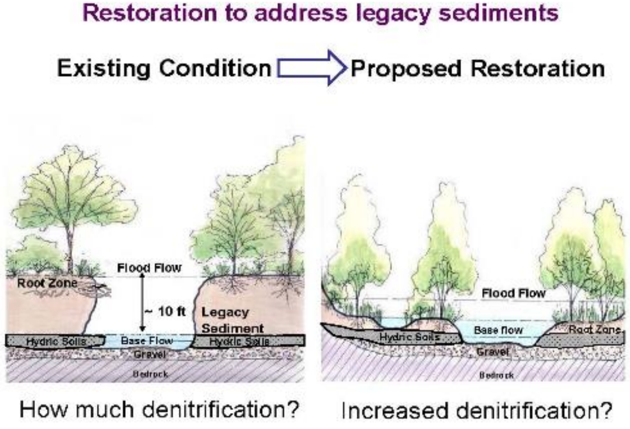
Preventing bank erosion and reconnecting floodplains works

Stream geomorphic ‘restoration’ (e.g. Natural Channel Design) can be effective at increasing sediment trapping through floodplain creation (Charlotte, NC example)

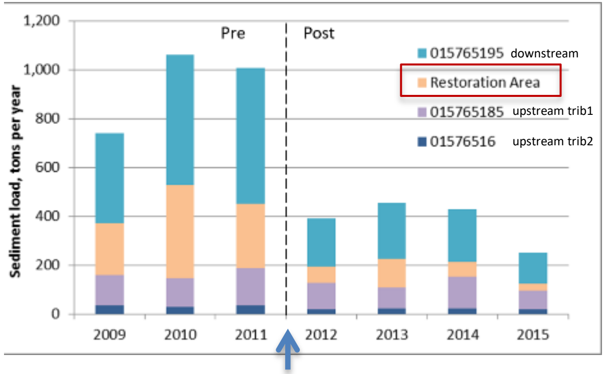




Removal of legacy sediment reduces downstream sediment load (Big Spring Run, PA example)



Langland et al. in review



USGS *BMPs*

Scientific tools

Data

- Suspended sediment, bedload, rates of sediment erosion and trapping

Sediment fingerprinting

- SED_SAT

Sediment budgets

- Individual studies of erosion and deposition rates across watersheds
- Combined inference with fingerprinting

Models

- CB Watershed Model (now Phase 6)
- SPARROW
- SWAT
- 1-D Transport and storage
- Chesapeake Floodplain (and Bank) Network

Geomorphic characterization

- LIDAR and LIDAR change, SFM, FACET, surveying, bathymetry, photogrammetry, visual assessments, etc.

A robust toolkit is growing and refining … applying it to observe and model your watershed will help you to implement management actions to reduce sediment loading and impacts!

Erosion Hotspot Mapping with Structure from Motion

Summary

How to guide management actions:

Scale, Time, and Land Use

Geology and historical land use generated a physical template that current land use, and climate, in addition to management, are acting upon to control the sediment delivery to the Chesapeake Bay.

Variations in the temporal and spatial scale of these factors and landscape processes interact in complex ways and require further study to improve predictability of sediment sources, transport, fate and BMP effectiveness.

Scale-dependent factors influencing management action choices:

Sediment sources

- **Piedmont, urban and agriculture land use, headwater streams are all important**

Transport times and lags

- **Active sediment storage can delay detection of effects of BMPs on sediment loads**

BMPs

- **Wide range in efficiencies, but many are effective, although trends in stream loads are not consistent**
- **Improving knowledge of sources and lags can help target BMP type and locations**

Lane et al. 2007

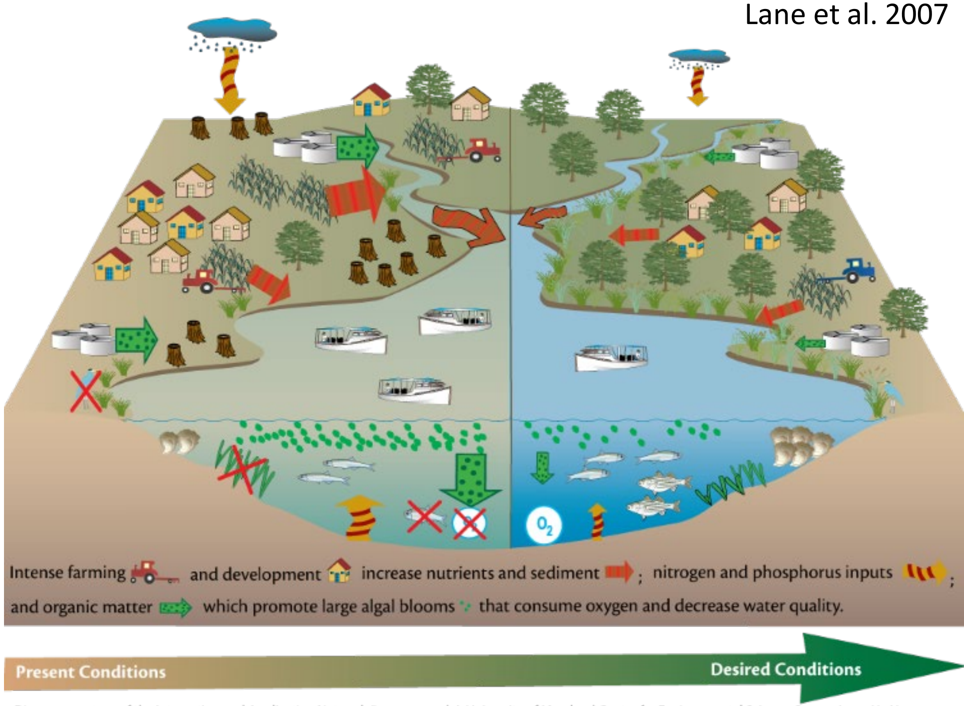


Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: Lane, H., J.L. Woerner, W.C. Dennison, C. Neill, C. Wilson, M. Elliott, M. Shively, J. Graine, and R. Jeavons. 2007. Defending our National Treasure: Department of Defense Chesapeake Bay Restoration Partnership 1998-2004. Integration and Application Network, University of Maryland Center for Environmental Science, Cambridge: MD.

Specific guidance for WIP and TMDL implementation

The state of the science points to urban, Piedmont, and headwater streams as having the greatest rates of sediment yield in the Chesapeake watershed, whereas agricultural streams generally have lower rates but are more widespread

Headwater streams: *1st and 2nd order channels erode their streambanks but typically have minimal active floodplains*

TMDL implications: consider practices associated with stream restoration to prevent bank erosion

Co-benefit considerations: improve stream health and fish habitat and increase fish passage

Larger streams and rivers: *If well connected to channels, floodplains can trap much of the sediment eroded upstream*

TMDL implications: conserve and restore hydrologic connectivity to floodplains

Co-benefit considerations: improve wildlife and fish habitat and biodiversity, and mitigate flooding

Urban areas: *Bank erosion is the dominant source of sediment export*

TMDL implications: consider stormwater control in the uplands with stream restoration to prevent bank erosion

Co-benefit considerations: improve stream health, fish habitat, and recreation

Agricultural areas: *Both bank erosion and upland soil erosion are important sediment sources in agricultural areas; the two can often be visually assessed*

TMDL implications: consider practices to reduce soil erosion and implement stream buffers

Co-benefit considerations: improve stream health and fish habitat and forest buffer

TMDL implications: legacy sediment removal can prevent bank erosion and restore floodplain connectivity

Co-benefit considerations: improve wetland and fish and wildlife habitat

Not all sediment is equal: *Contaminated sediment can be targeted for management*

Coarse sediment is needed for stream habitat, whereas fine sediment has the largest impact on stream biota

USGS *Summary for watershed management*