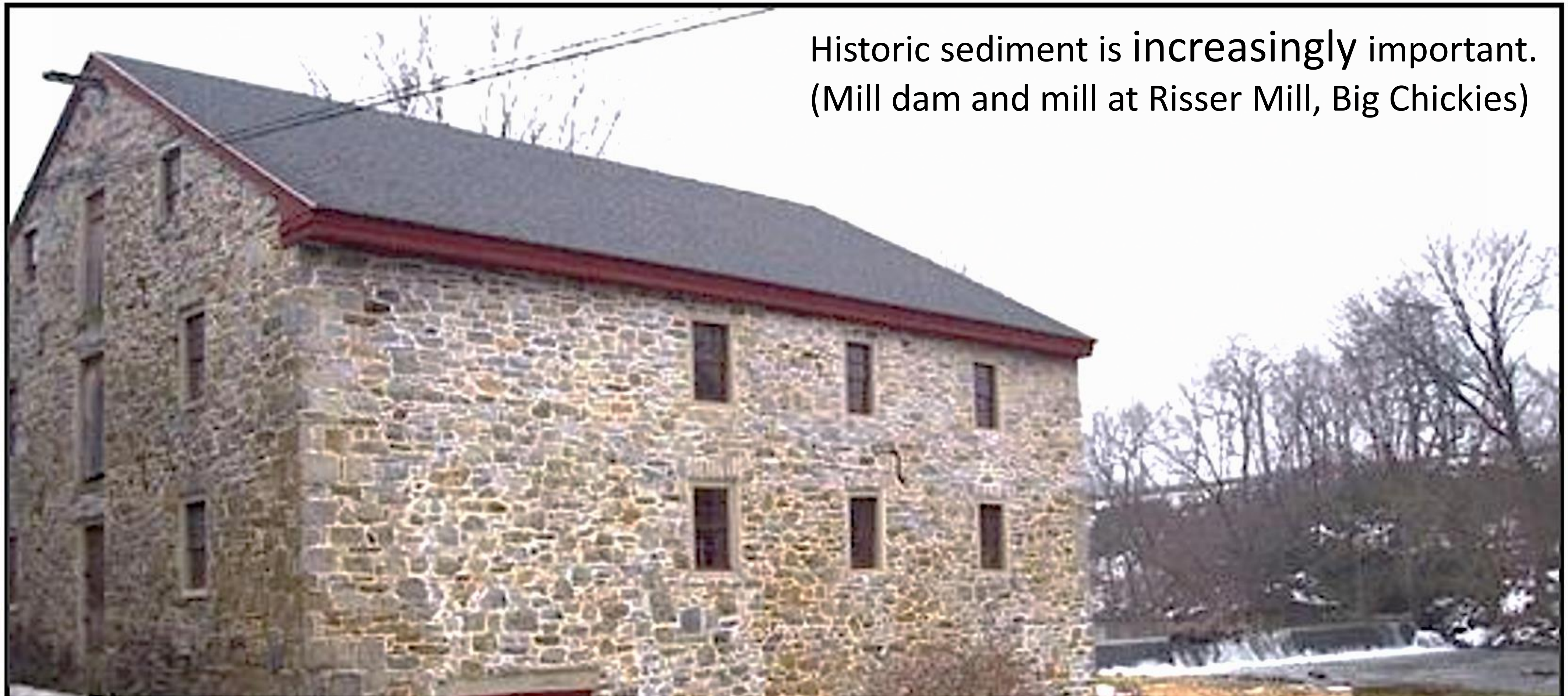
Questions for the Panel:

- How should legacy sediment be defined in the context of Chesapeake Bay management?
- **What is the importance of legacy sediments compared to other sediment sources?**
- To what extent do legacy sediments provide an important source of nutrient contributions in comparison with other sources?

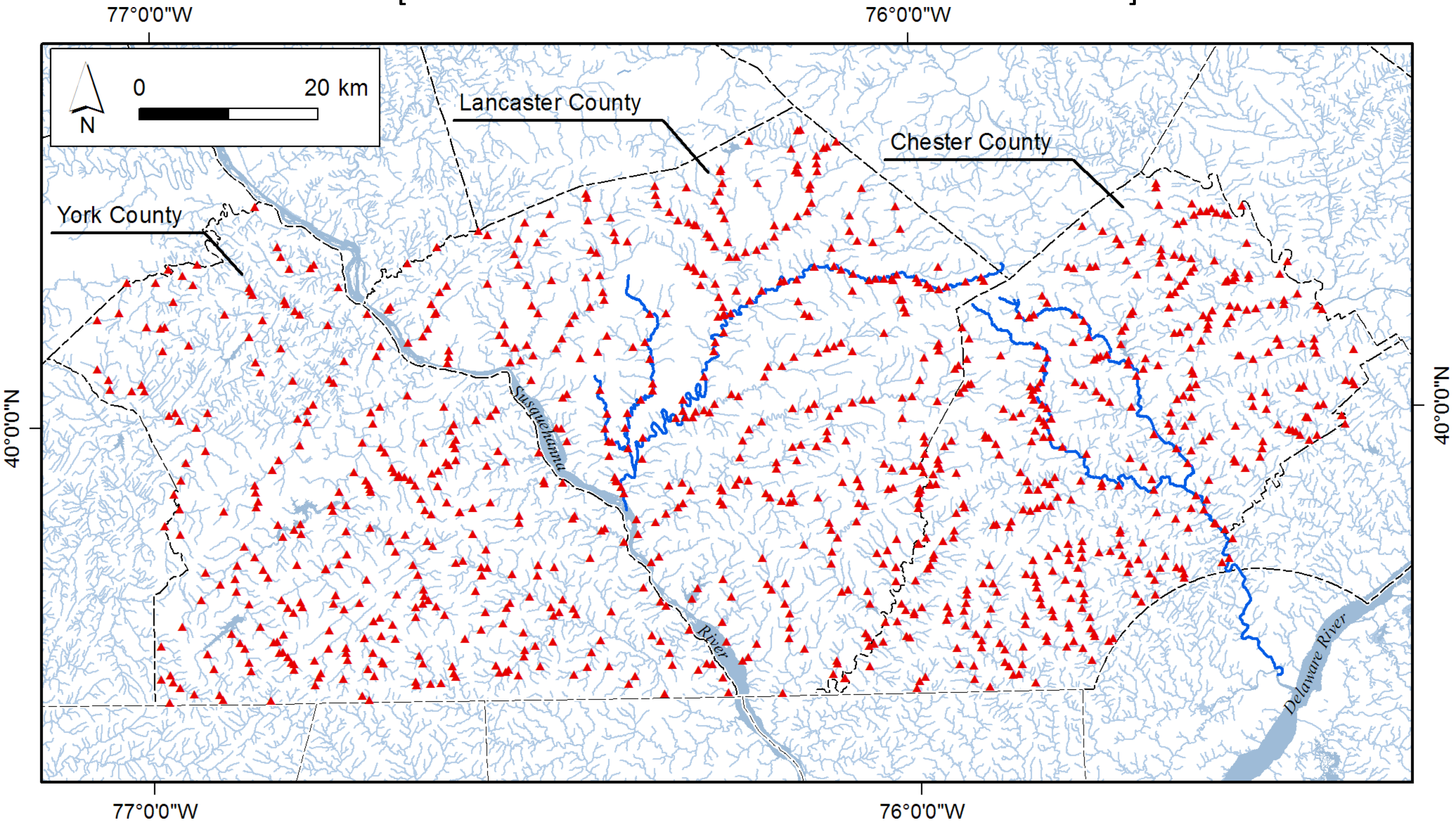
Prepared by D. Merritts, R. Walter, and M. Rahnis, based on collaborations with many partners.



1. Historic sediment is ubiquitous in Mid-Atlantic region.
2. Low-order (1^{st}, 2^{nd}, 3^{rd}) streams comprise 89% of Chesapeake Bay watershed area.
3. Low-order streams heavily milled and impacted by STORED historic sediment. **BASE LEVEL RISE**
4. Banks higher immediately upstream of dams and other grade control structures.
5. Bank erosion rates greatest after dam breaching. **BASE LEVEL FALL**
6. Much bank erosion occurs during winter months from freeze-thaw (Wolman, 1959; Merritts et al, 2013).

More than 1,000 mill dams in 19th C. Atlases of York, Lancaster & Chester Counties

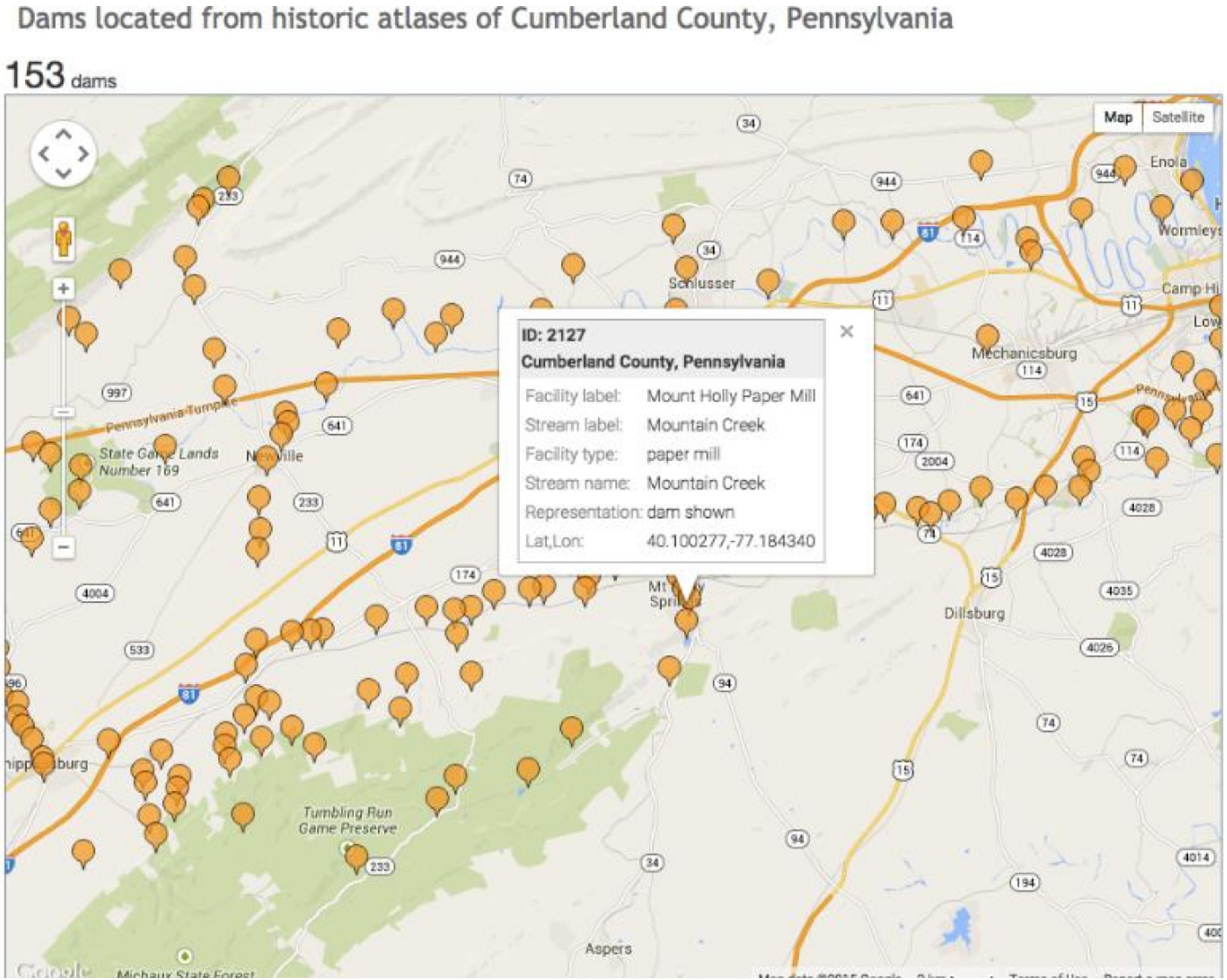
[Note: These dams are not in the NID database.]



Location of mill dam

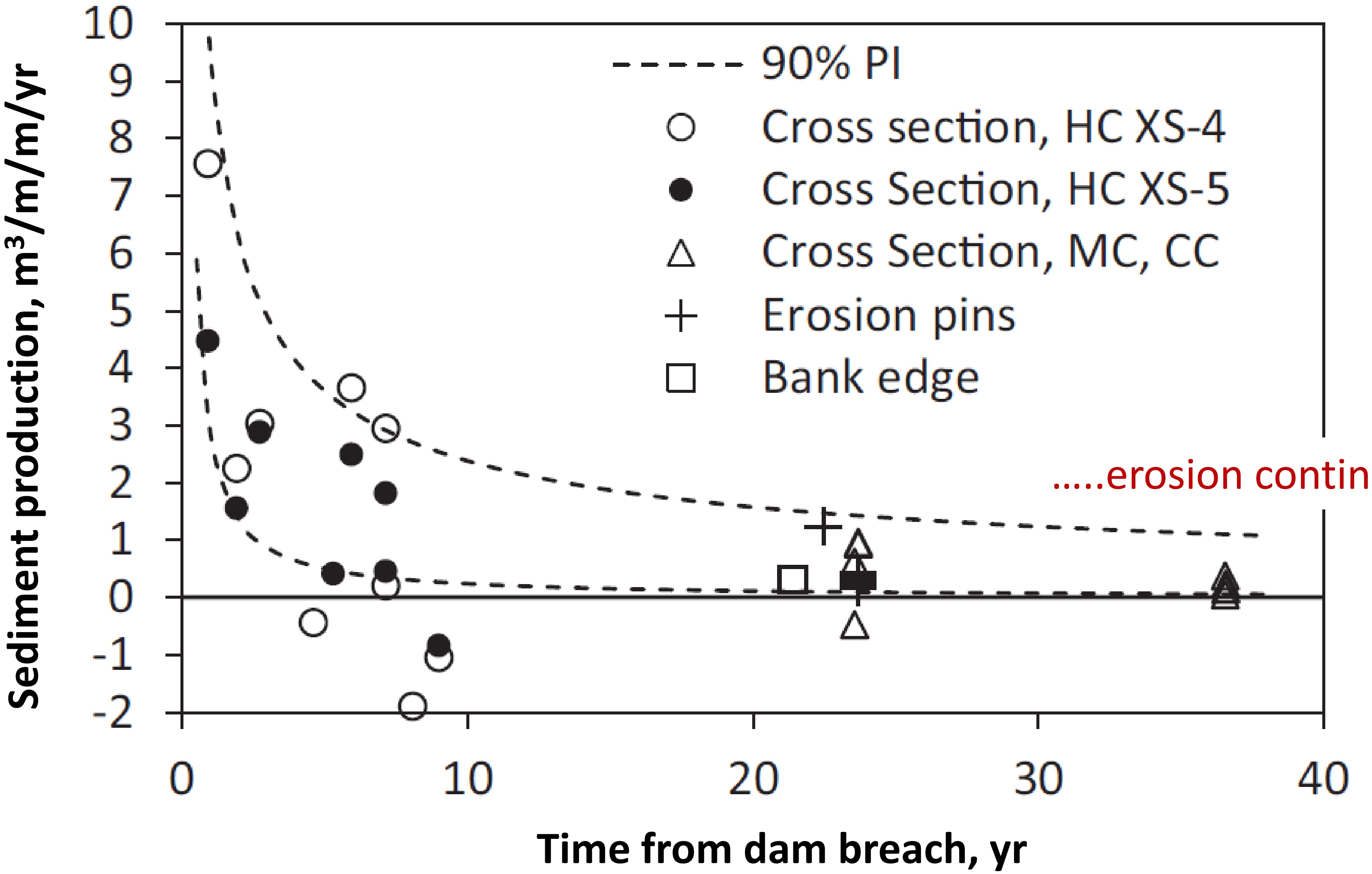
From Walter and Merritts, 2008

19th c. Milldams in Cumberland County PA



Web data link developed by Michael Rahnis, Franklin and Marshall College

Bank erosion rates greatest after dam breaching
Measured by repeat surveying and erosion pins; Merritts et al, 2013 (PA sites)

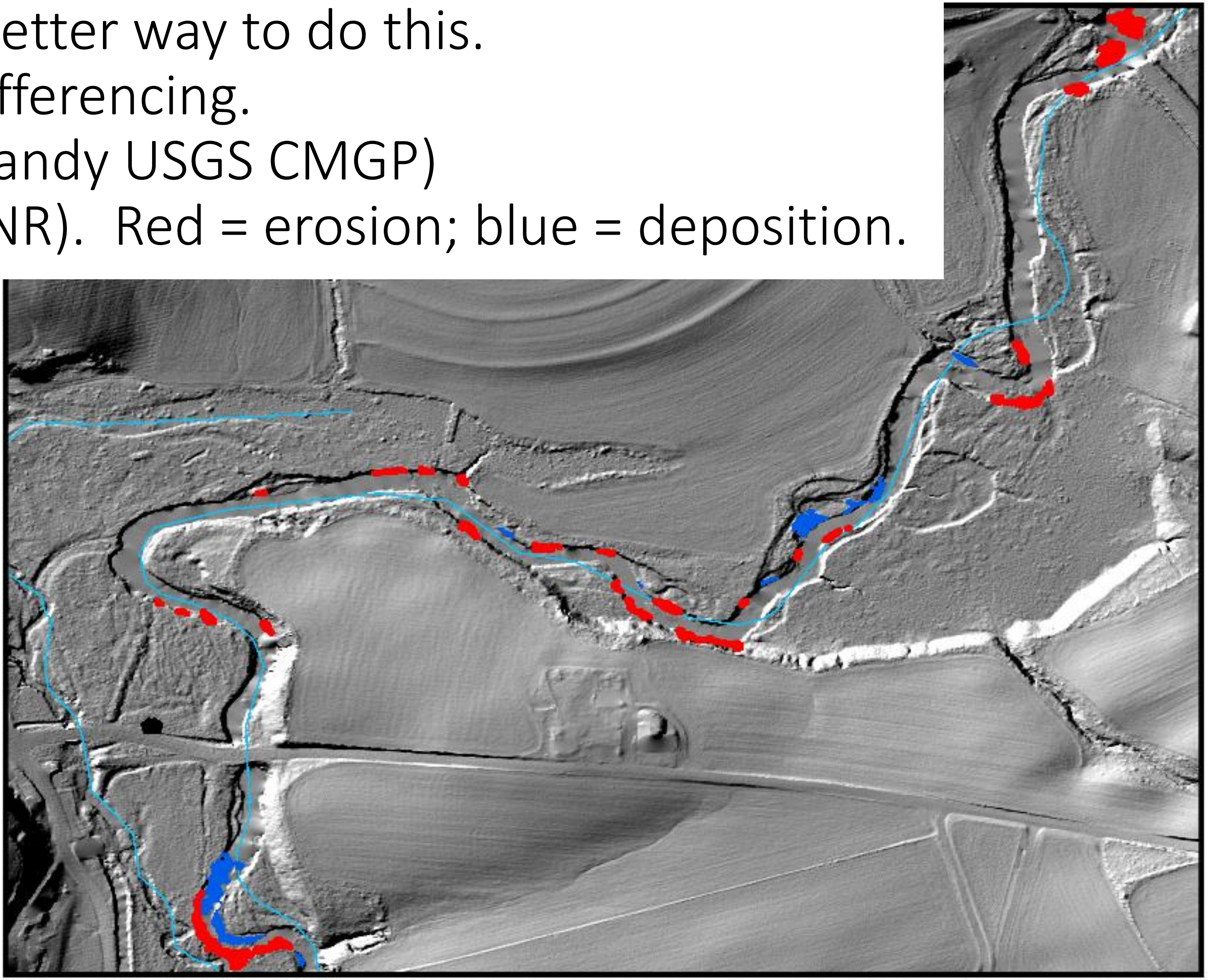


…..erosion continues for decades.

Negative power function fit to positive data (n = 26).

From: Merritts et al, 2013 (GSA Eng. Geo.)

A new and better way to do this.
Lidar DEM differencing.
2014 (post-Sandy USGS CMGP)
2008 (PA DCNR). Red = erosion; blue = deposition.



Methodology and Error for Lidar DEM-Differencing

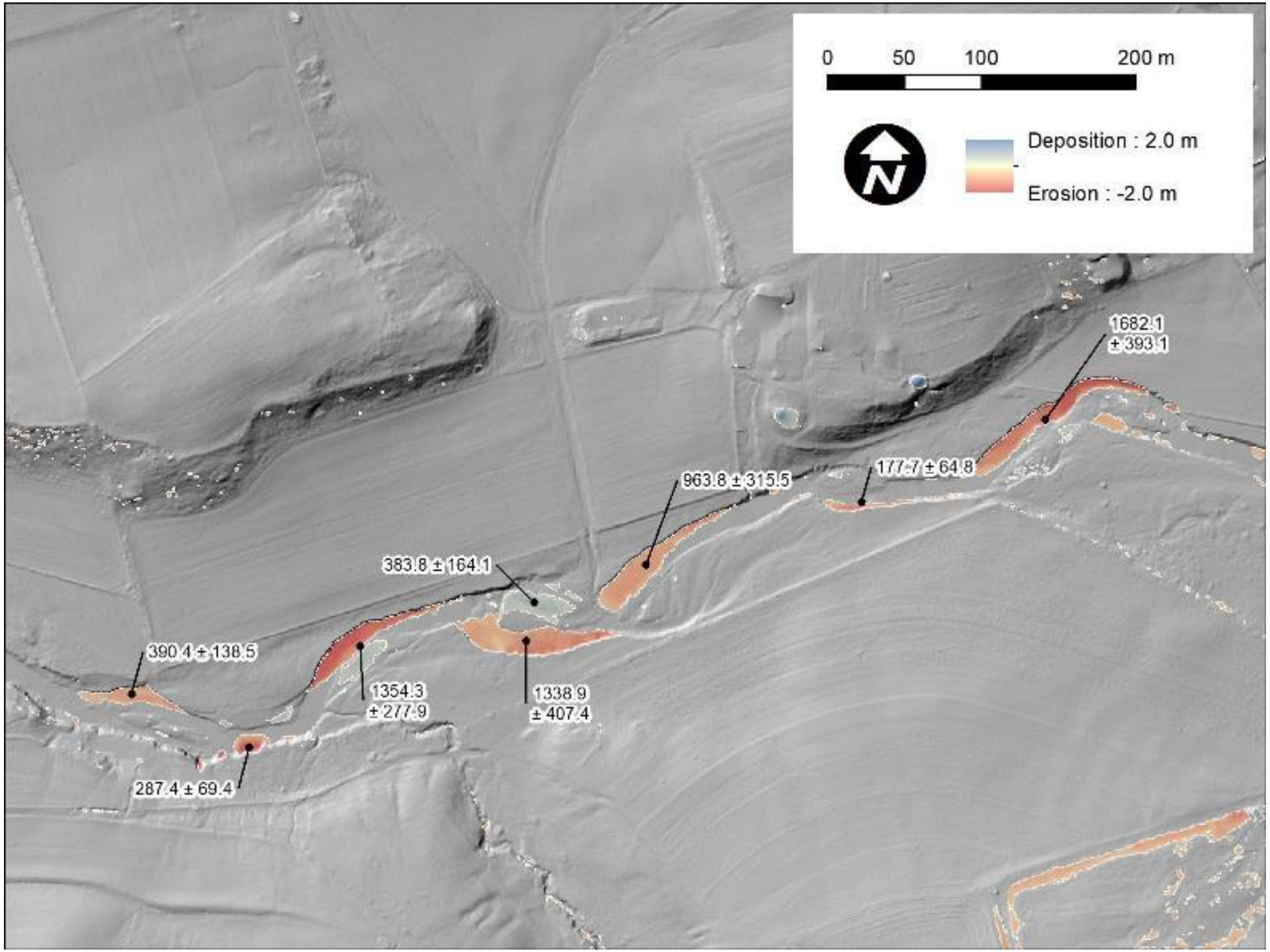
We analyzed LiDAR for changed areas (erosion and deposition) between April 2008 and December2014.

We rasterize LiDAR survey data for the years 2008 (PA DCNR) and 2014 (USGS) to create digital elevation models (DEMs) covering all of Lancaster County at 0.5-meter pixel size. This is a higher resolution DEM than the 1-m DEM provided, for example, by PASDA to the public.

Differencing these high-resolution DEMs that we generate produces a map of elevation change during the 6.7-yr interval between acquisition of the 2008 and 2014 lidar datasets.

We calculated a pair of error rasters based on instrumental uncertainty and surface roughness, and then used the error rasters to threshold the change raster at a given probability. We thresholded the change raster at the 90% probability of detection for further study. Thresholding removes small apparent differences that are not measurable using airborne LiDAR and allows us to focus on measurable changes.

We converted the thresholded change raster to polygon geometries and calculated volume of erosion or deposition for each polygon along with a range of uncertainty. The resulting product allows us to query specific places where detectable bank retreat occurred during the interval from 2008 to 2014.



Big Beaver Creek west of Big Beaver Pike, Lancaster PA (Longitude, Latitude: -76.210999, 39.937545).

Elevation change detected at the 90% probability level shown in red (erosion or lowering) and blue (deposition or raising), draped over a DEM calculated from an aerial LiDAR survey flown in 2014. Call-outs identify areas of significant detectable change with volume in cubic meters ± 1 standard deviation uncertainty.

Indian Run, PA – Stobers Dam breach, 2011
Height 14 ft (4.3 m)

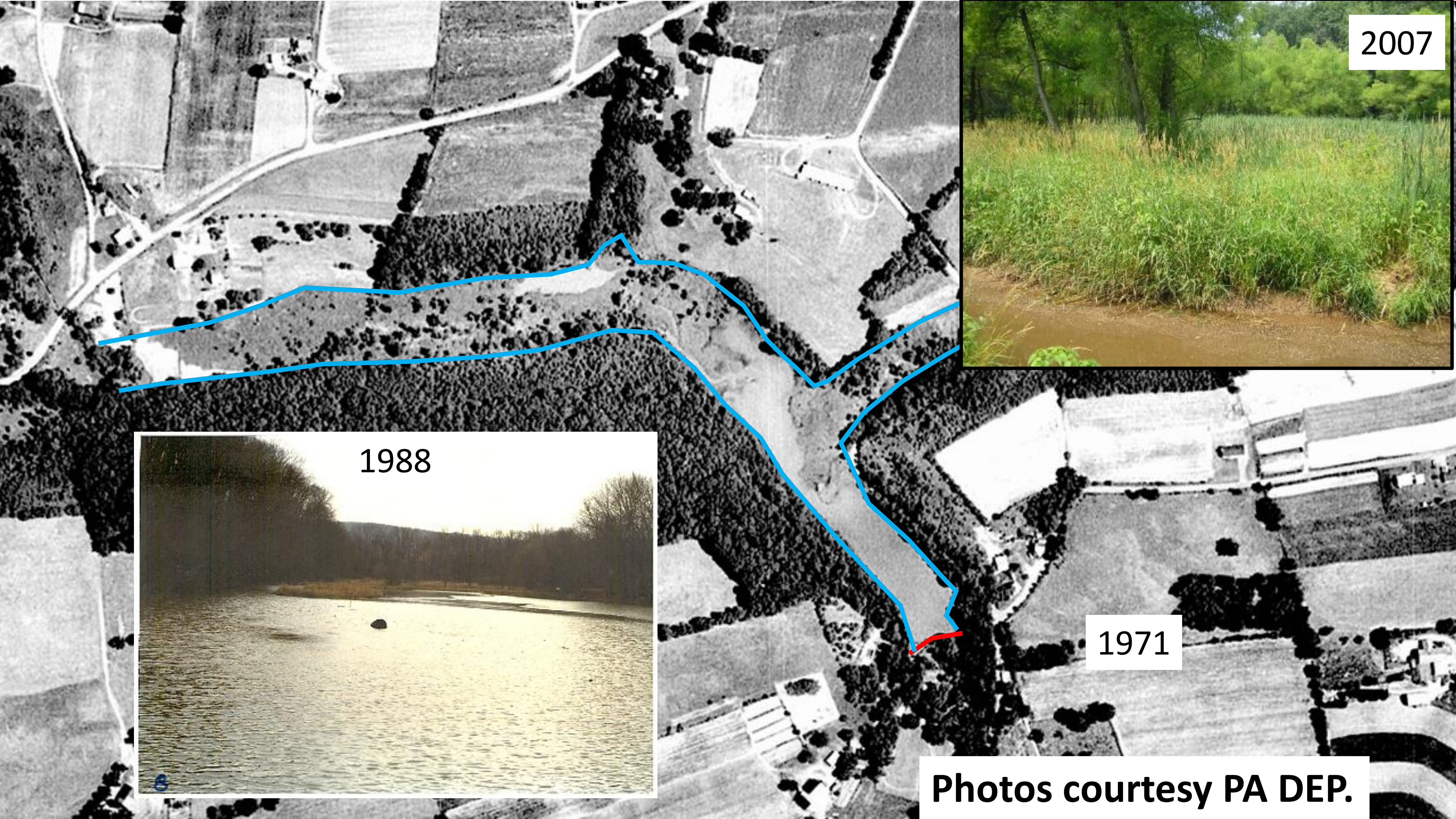
Photos courtesy PA DEP.

Hurricane Agnes, 1972

1864

2007

Photos courtesy PA DEP.

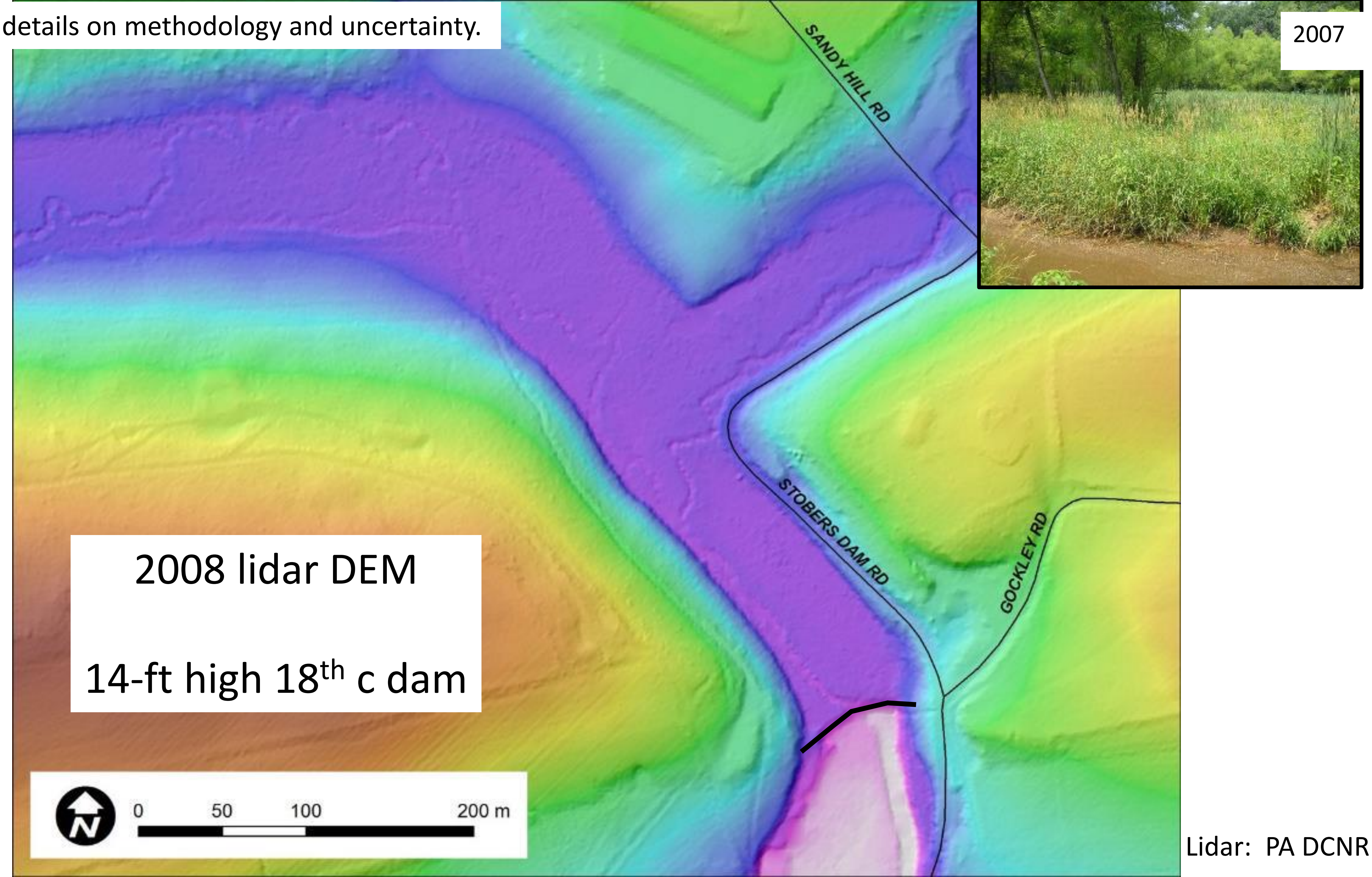


Photos courtesy PA DEP.

Indian Run, PA – Stobers Dam breach, 2011

Indian Run, PA – Stobers Dam breach, 2011
Knickpoint in 2012---**BASE LEVEL FALL**

See slide 7 for details on methodology and uncertainty.

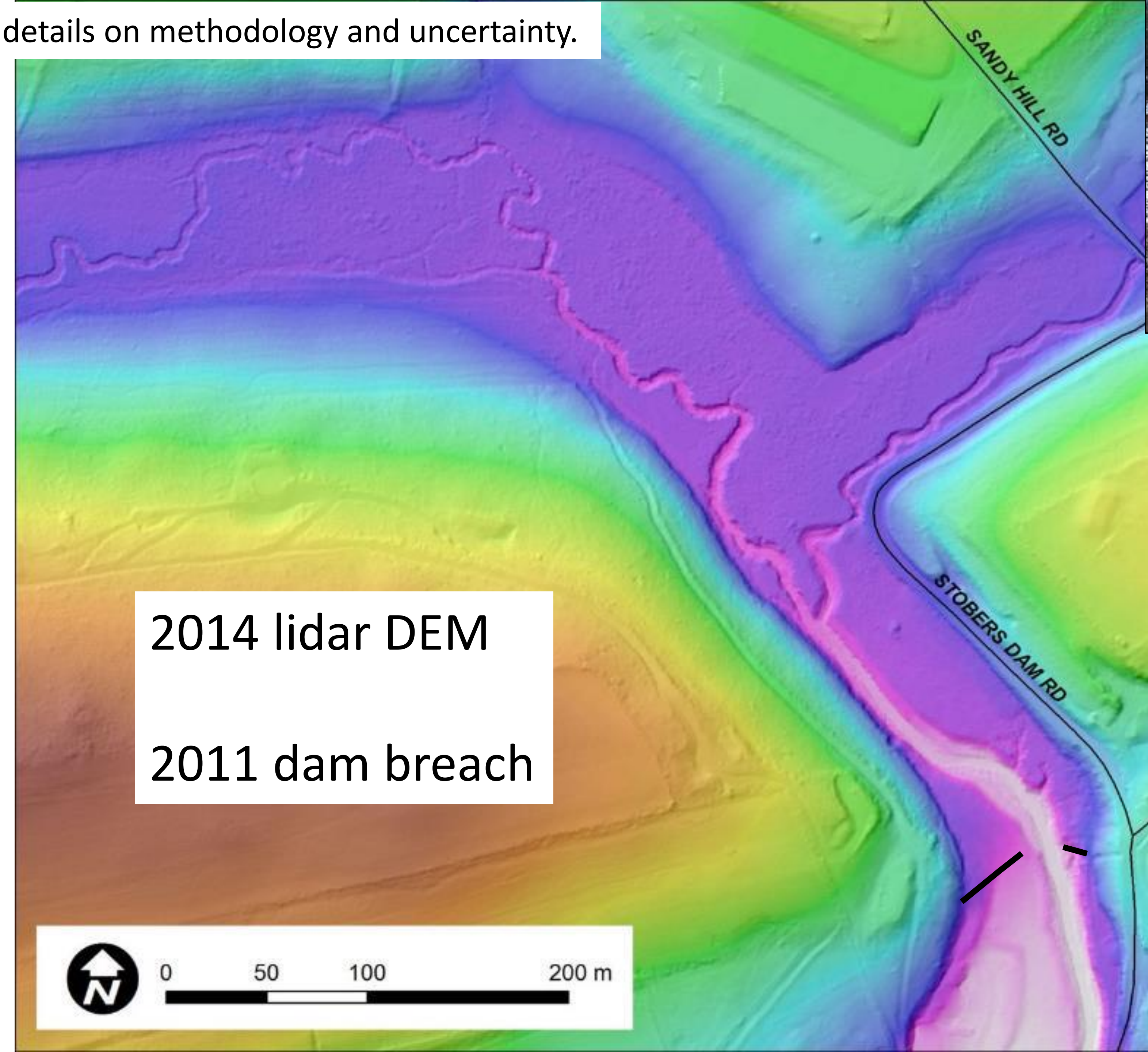


2008 lidar DEM

14-ft high 18th c dam

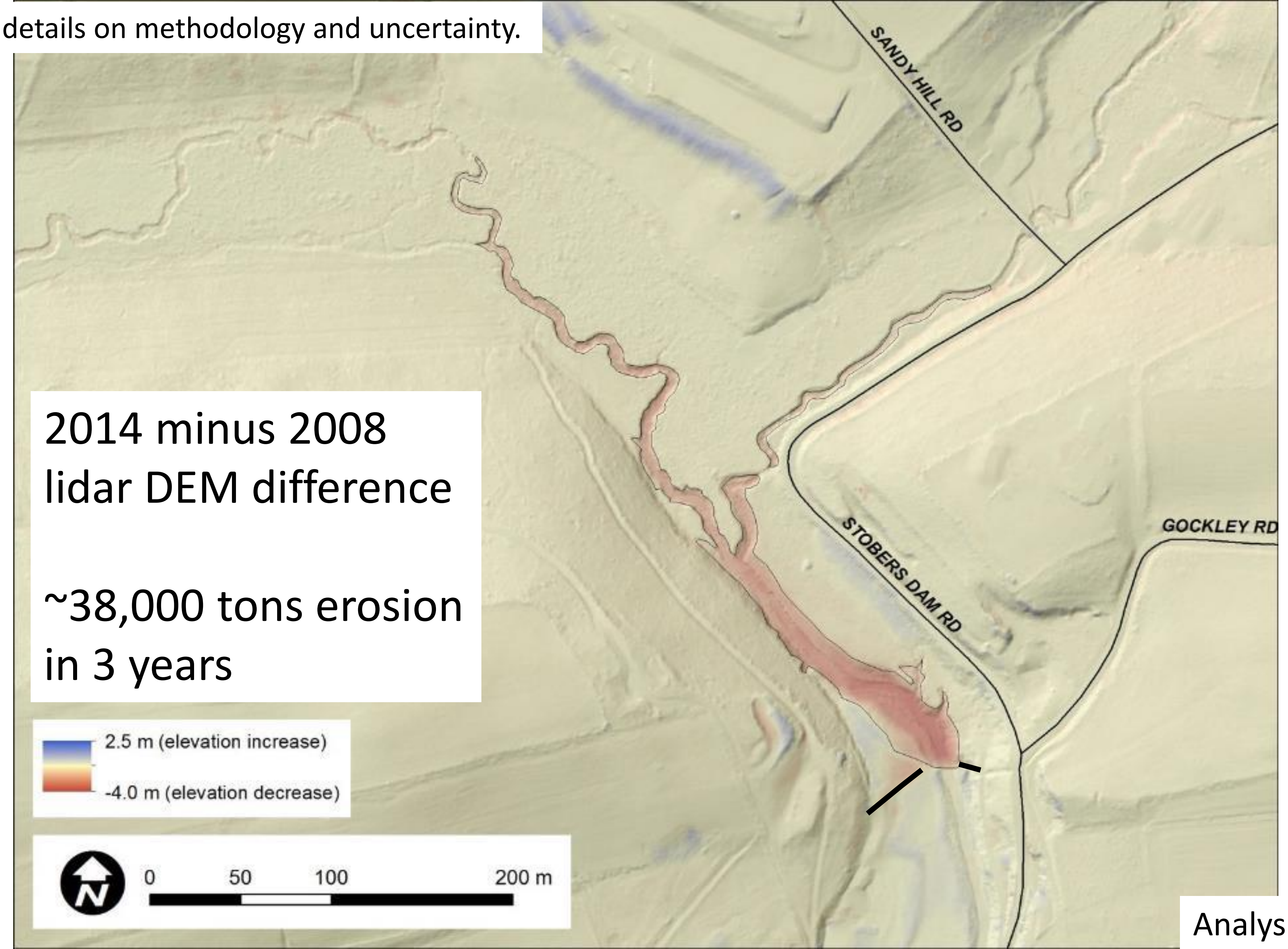
Lidar: PA DCNR

See slide 7 for details on methodology and uncertainty.



Lidar: USGS CMGP

See slide 7 for details on methodology and uncertainty.

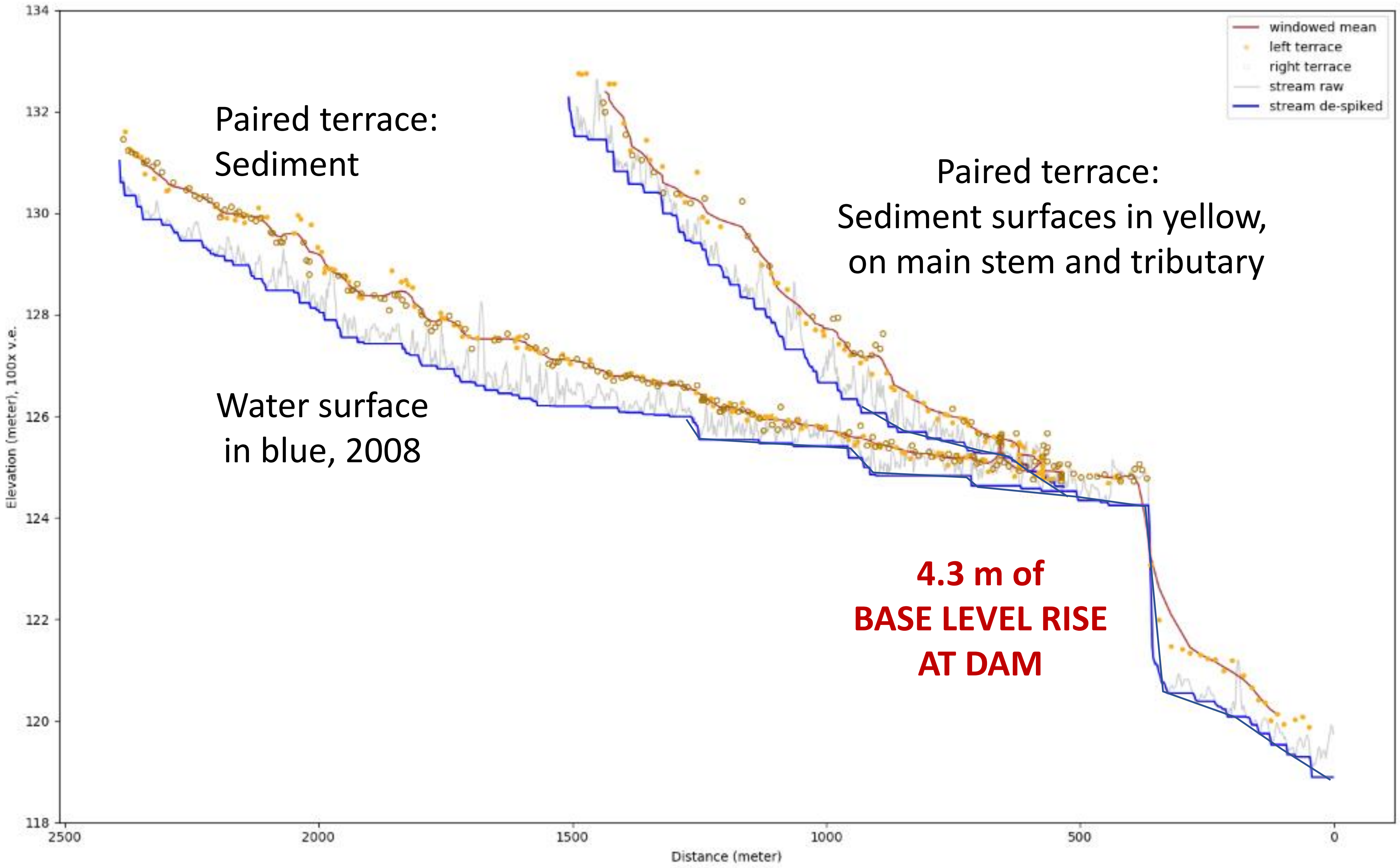


2014 minus 2008
lidar DEM difference

~38,000 tons erosion
in 3 years

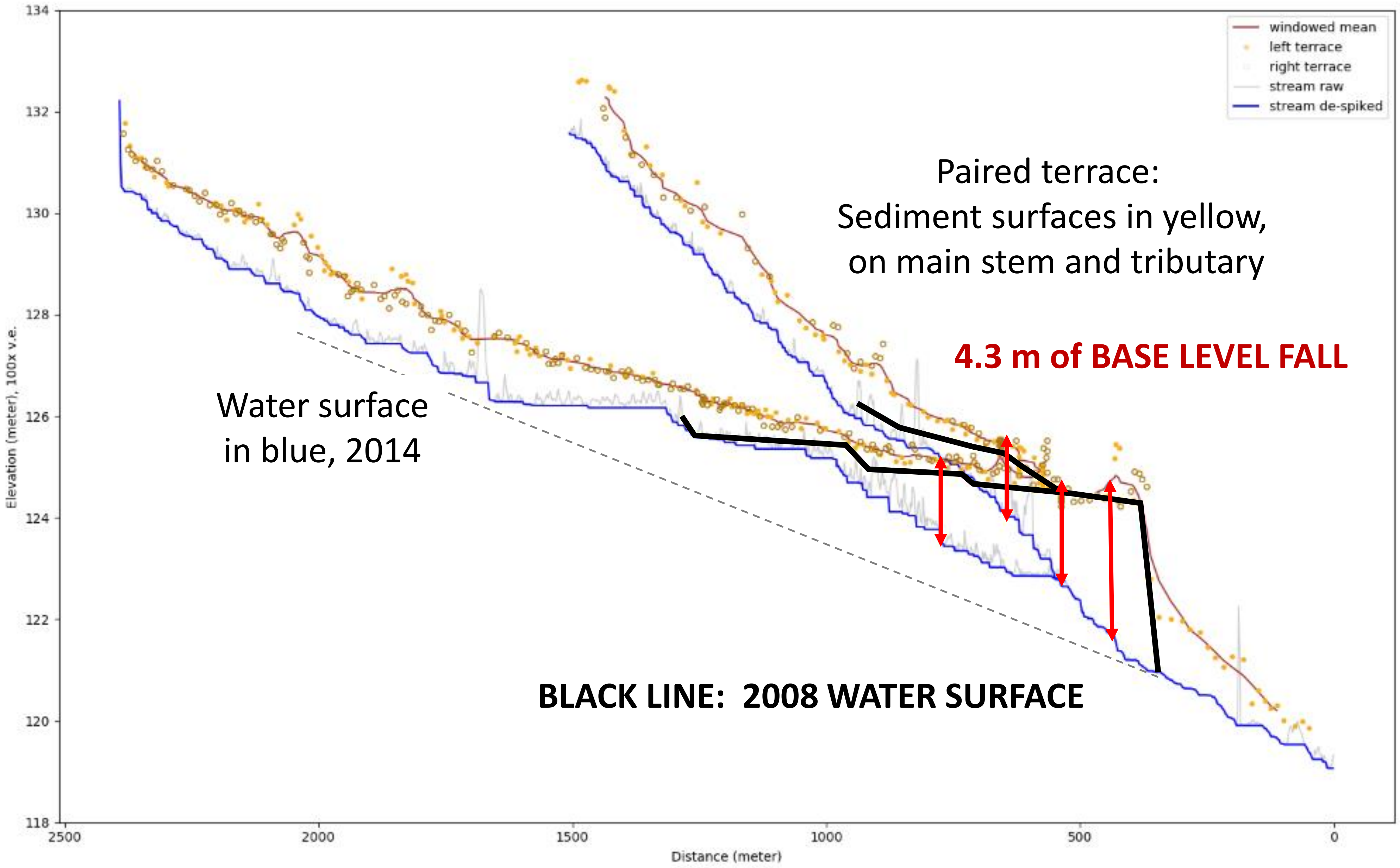
Analysis: M. Rahnis

See slide 7 for details on methodology and uncertainty.



Analysis: M. Rahnis

See slide 7 for details on methodology and uncertainty.



Analysis: M. Rahnis

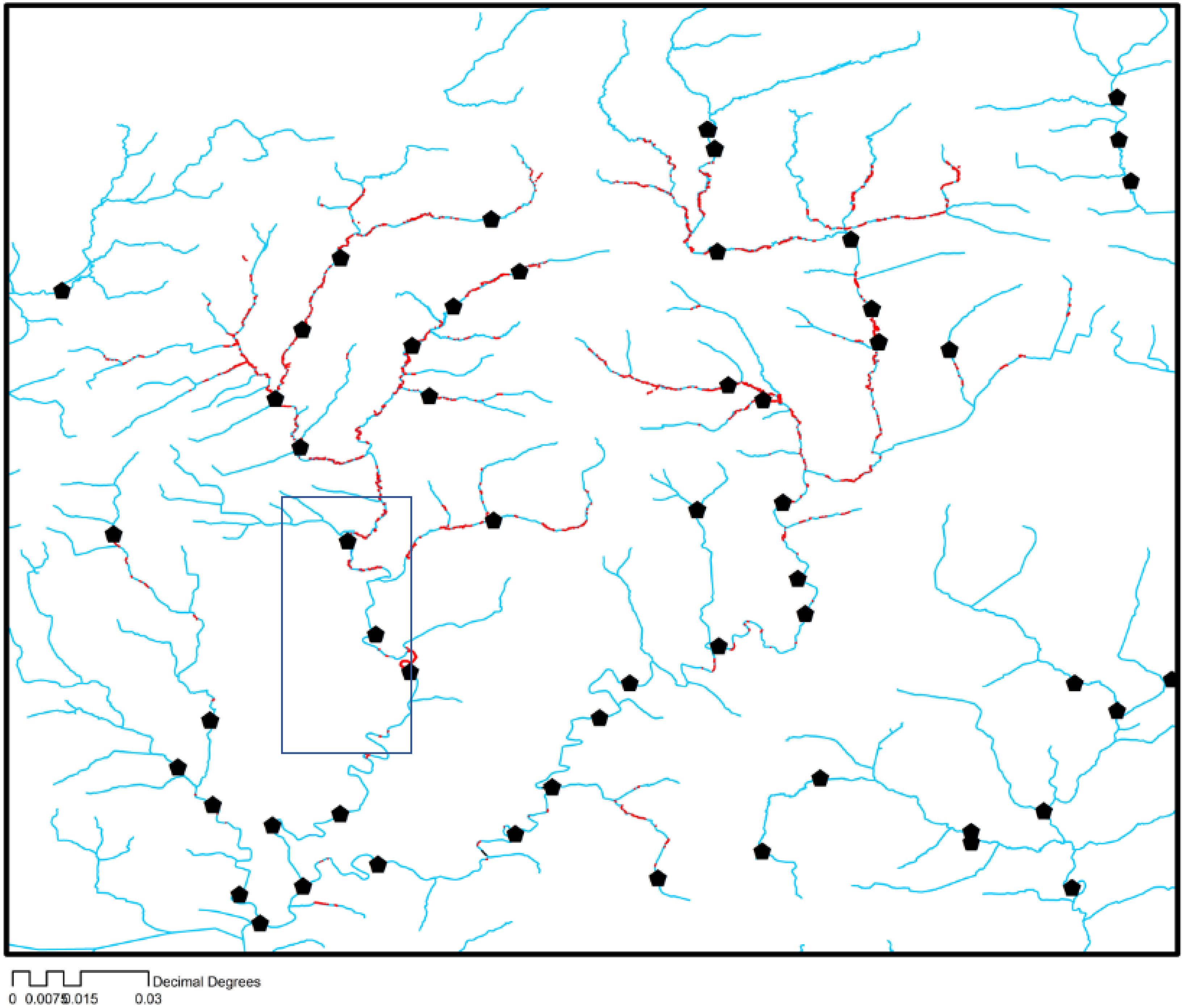
Chiques Creek Watershed, PA

Lidar DEM differencing 2008-2014

See slide 7 for methodology.

Red: Erosion hot spots along stream banks at sites of millpond reservoir sedimentation.

Analysis: M. Rahnis



Chiques Creek Watershed, PA

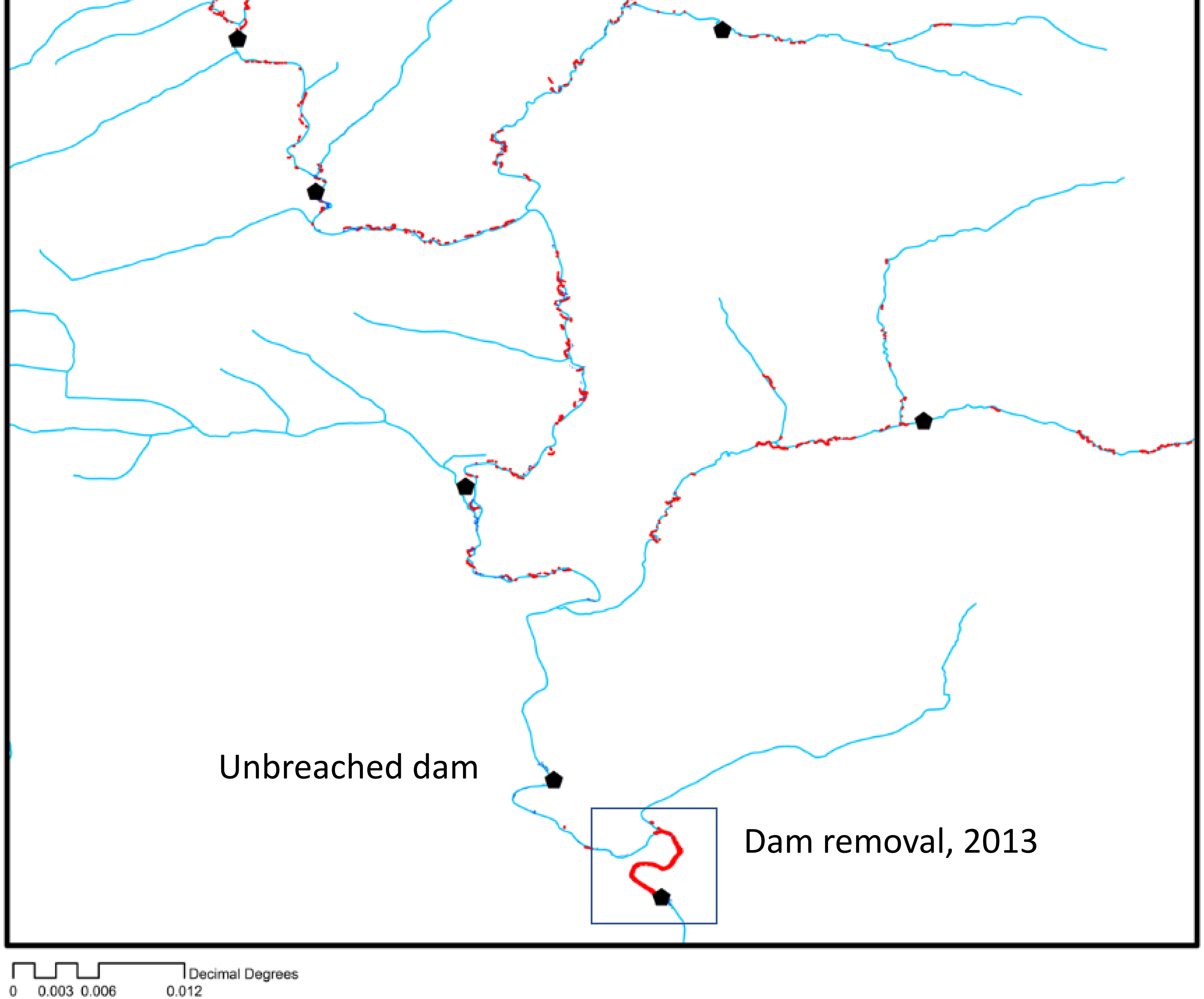
Lidar DEM differencing 2008-2014

Red is bank erosion in 6.7 yrs

See slide 7 for details on methodology.

Erosion hot spots in hot moments after dam breaching or removal.

Analysis:
M. Rahnis



Chiques Creek Watershed, PA
(Location is left bank near center of image in Slide 6)

Freeze-Thaw Processes and Stream Bank Erosion

[AMERICAN JOURNAL OF SCIENCE, VOL. 257, MARCH, 1959, P. 204-216]

FACTORS INFLUENCING EROSION OF A COHESIVE RIVER BANK

M. GORDON WOLMAN

Dept. of Geography, Johns Hopkins University, Baltimore, Maryland

ABSTRACT. The sinuous channel of Watts Branch in Montgomery County, Maryland, traverses a grassy meadow nearly devoid of trees. The creek has a drainage area of four square miles and the river bank is composed primarily of cohesive silt. Resurveys of cross sections during the five years 1953-1957 have revealed as much as seven feet of lateral erosion. Over the past two years, additional measurements of the amount of erosion around rows of steel pins driven horizontally into the bank have been made at frequent intervals. These observations indicate several combinations of factors primarily responsible for the progressive recession.

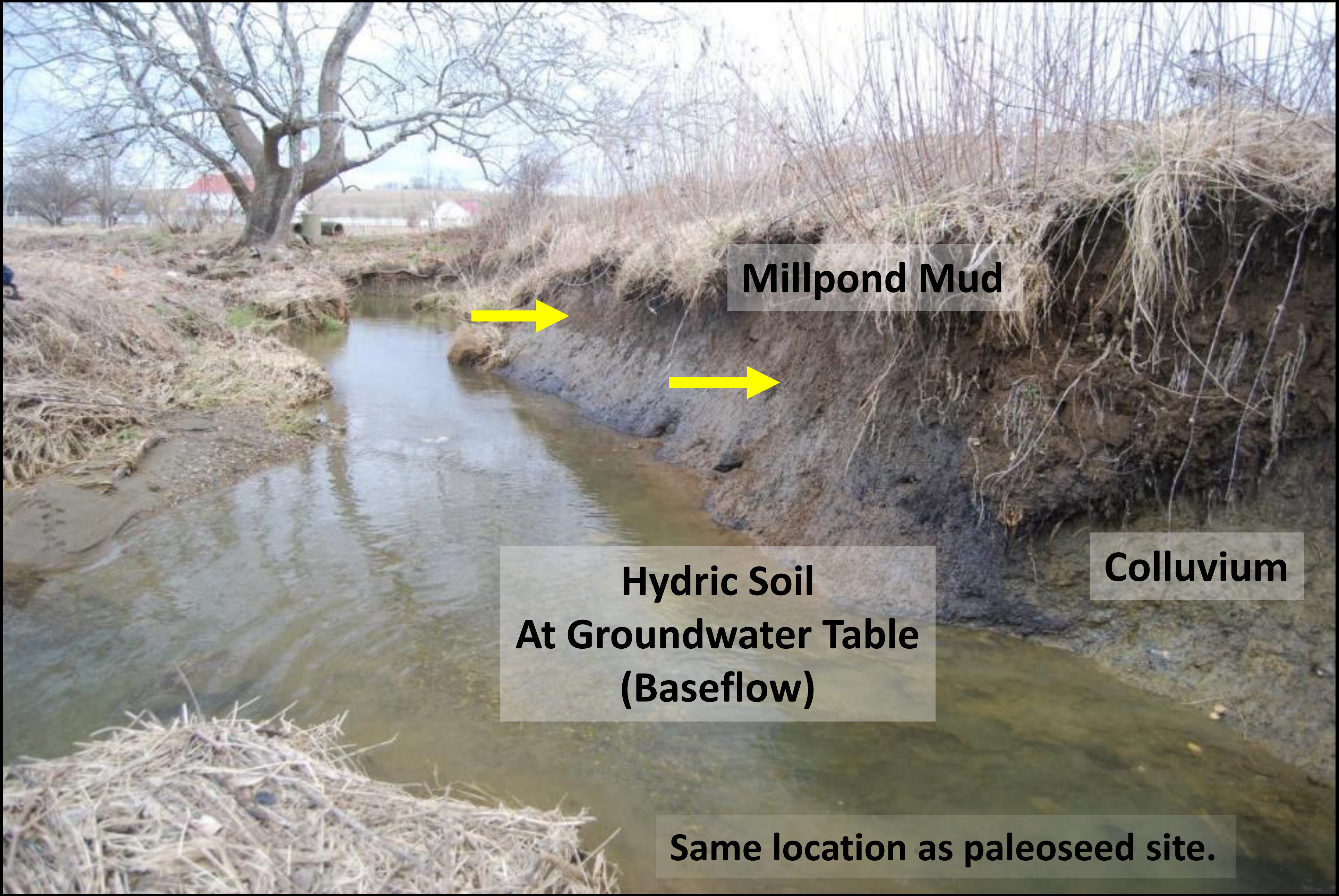
Approximately 85 percent of the observed erosion occurred during the winter months of December, January, February, and March. A thickness of as much as 0.4 feet of sediment was eroded from the bank at specific points in a period of several hours during which a bankfull flow attacked banks which had previously been thoroughly wetted. Erosion was most severe at the water surface. Little or no erosion was observed during the summer despite the occurrence of the highest flood on record in July, 1956.

Second in erosion effectiveness were cold periods during which wet banks, frost action, and low rises in stage combined to produce 0.6 foot of erosion in six weeks during the winter of 1955-56. Significant erosion also resulted from the combination of moist banks and low rises in stage. Lastly, crystallization of ice and subsequent thawing, without benefit of changes in stage, also produced some erosion as did flashy summer floods even on hard, dry banks. Inasmuch as such summer floods constitute the rare and "catastrophic" events on small drainage basins in this region, present observations suggest that the cumulative effect of more moderate climatic conditions on this process of erosion exceeds the effect of rarer events of much greater magnitude.

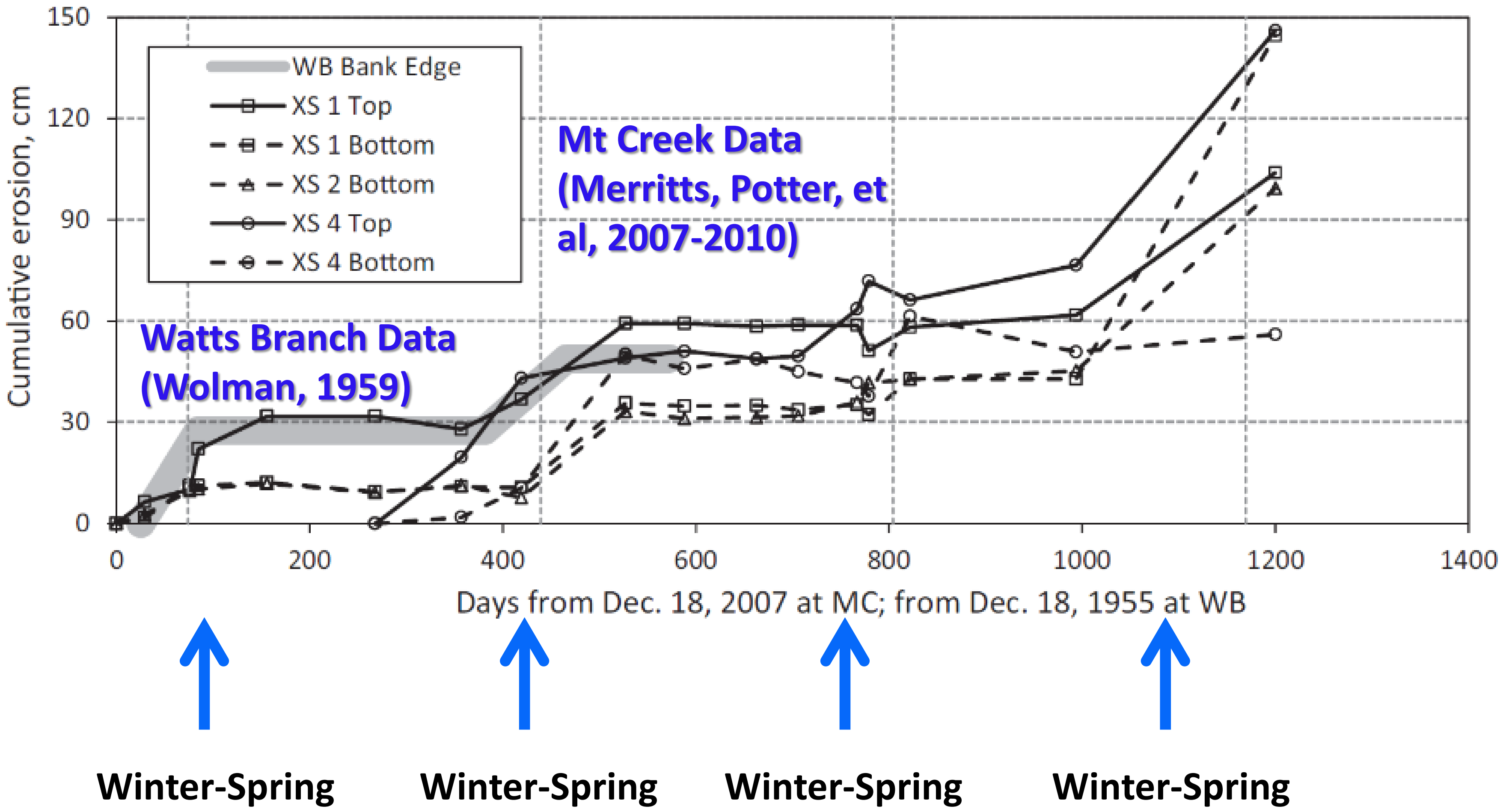
This preliminary analysis of several factors responsible for erosion of the cohesive

Freeze-thaw Apron January 2010; Big Spring Run pre-restoration

After High Flow Event 2010; Big Spring Run pre-restoration

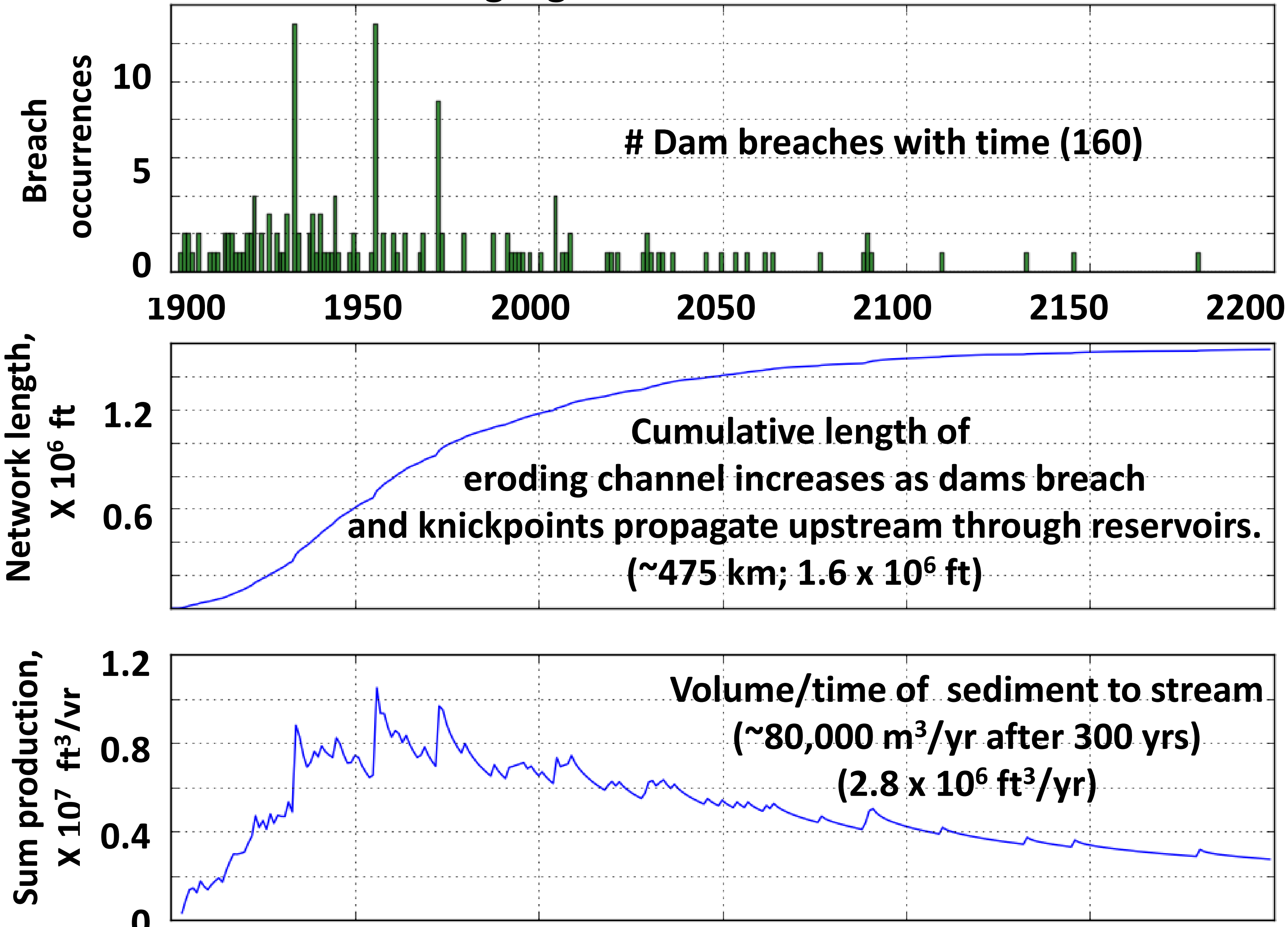


Freeze-thaw Drives Bank Retreat During December-March



Data collected by Merritts, Potter, Jenschke, et al. See Merritts et al. in GSA Eng. Geo, 2013.
See Wolman, 1959, Factors influencing erosion of a cohesive river bank (Amer. Jnl of Science).
Also works by Lawler, Wynn, et al.

Simulating 300 yrs Post-breach sediment loading to streams
Modeling lag times in sediment fluxes



Big Spring Run Before Wetland Restoration

April 2005

Big Spring Run After Wetland Restoration

Restoration completed by Land Studies, Inc., November 2011

Big Spring Run Floodplain Wetland Restoration

June 2012 (Six Months Later)

Big Spring Run Floodplain Wetland Restoration

August 2016

Big Spring Run Floodplain Wetland Restoration

June 2013

Before

General Definition Legacy Sediment - Sediment that was eroded from upland areas after the arrival of early Pennsylvania settlers and during centuries of intensive land uses; that was deposited in valley bottoms along stream corridors, burying pre-settlement streams, floodplains, wetlands, and valley bottoms; and that altered and continues to impair the hydrologic, biologic, aquatic, riparian, and water quality functions of pre-settlement and modern environments.

Legacy sediment often accumulated behind ubiquitous low-head mill dams … resulting in thick accumulations of fine- grained sediment with significant amounts of nutrients.

From Technical Definition - Widespread indicators of impaired streams and watersheds due to legacy sediments include high banks, rapid rates of bank erosion, high sediment loads in streams, habitat degradation (aquatic and riparian), and diminished recharge of groundwater and denitrification capability.

Historic sediment

”Pompeii effect”

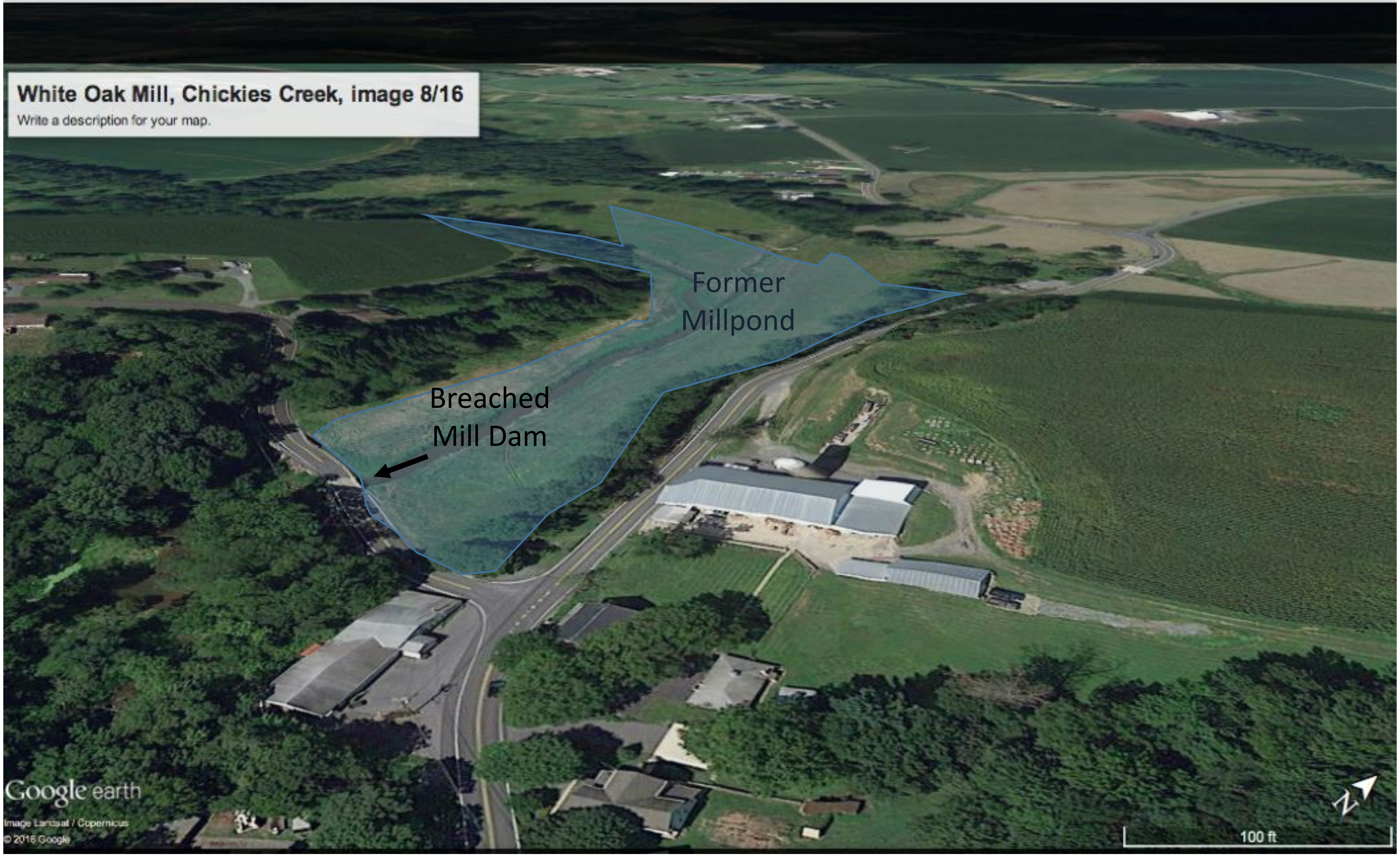
Sediment wedges in reservoirs

Released by dam breaching and other causes of base level fall that lead to incision

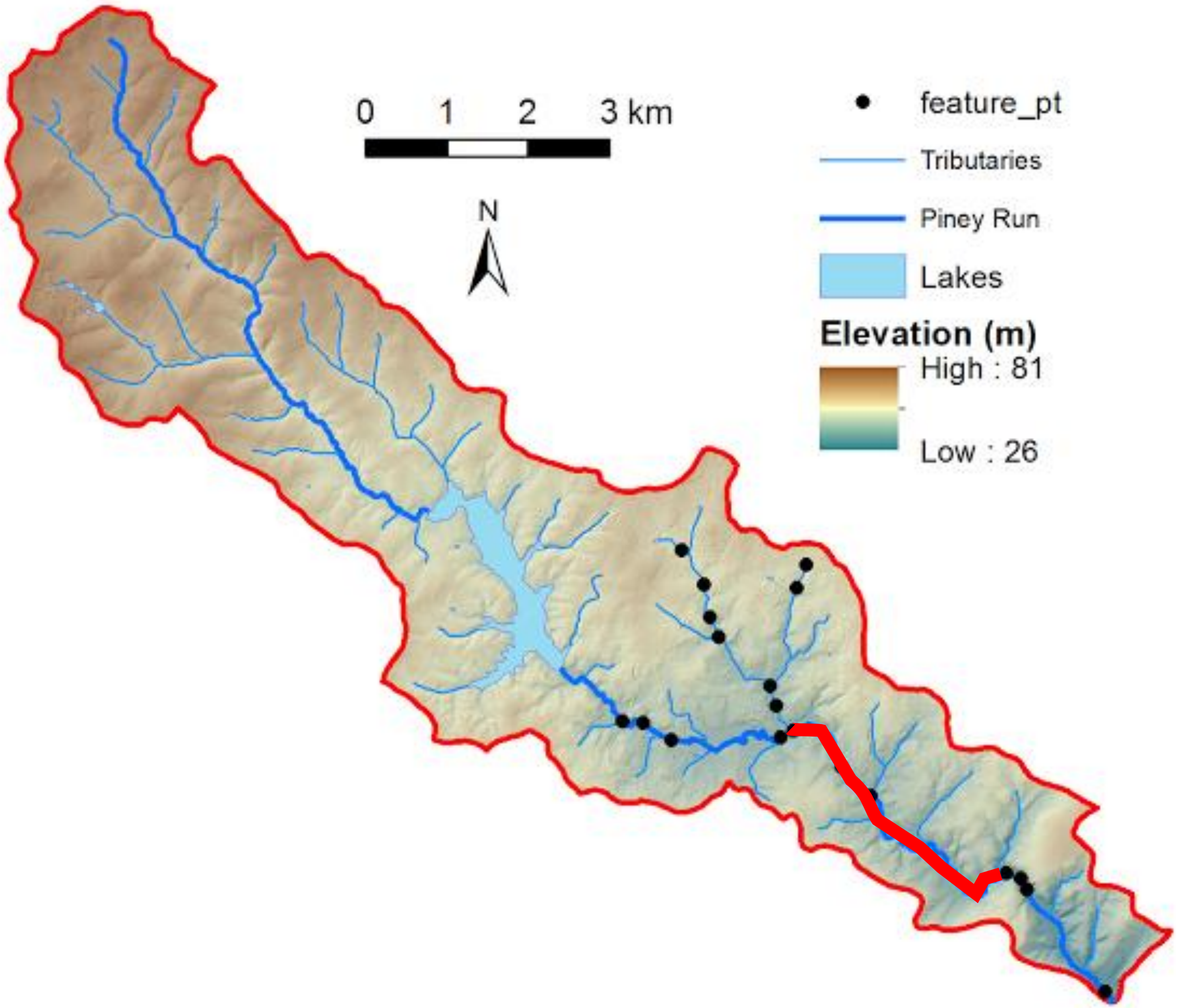
From PADEP (Legacy Sediment Workgroup) Definition:
http://www.dep.pa.gov/PublicParticipation/AdvisoryCommittees/WaterAdvisory/ChesapeakeBayManagementTeam/Documents/legacy_sediment_definitions.pdf


1925
Aerial Photo
White Oak Mill
Chiques Creek, PA
Millpond
Mill Dam
(~10 ft high)

2016

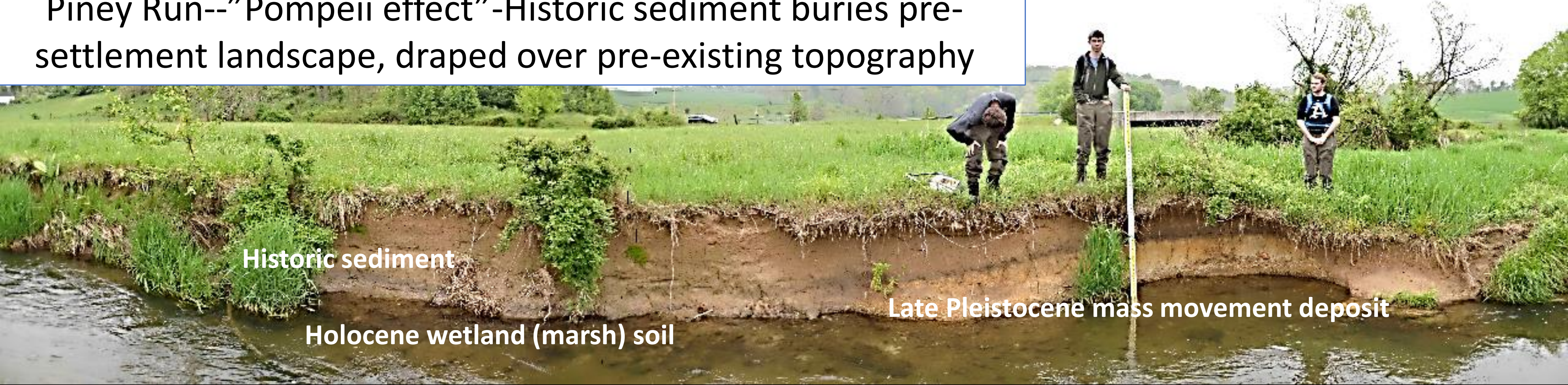


White Oak Mill, Chickies Creek, image 8/16
Write a description for your map.
Former Millpond
Breached Mill Dam
Google earth
Image Landsat / Copernicus
© 2016 Google
100 ft

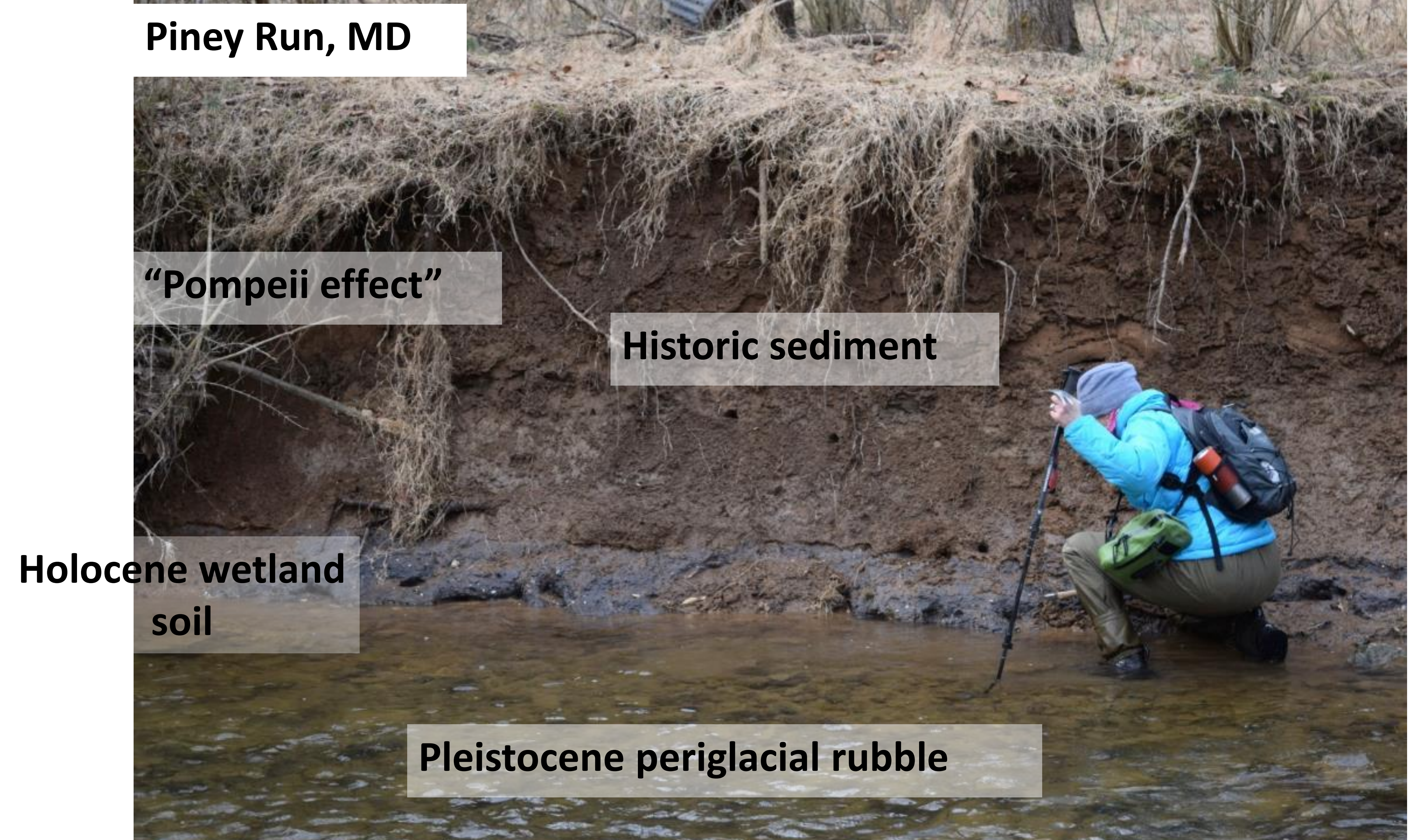


Along Piney Run, MD, from Browns Mill (Slacks Rd) to De Vries Mill (Arrington Rd)

Piney Run--"Pompeii effect"-Historic sediment buries pre-settlement landscape, draped over pre-existing topography




Piney Run, MD
MD DNR and US FWS
Brown: <300 yrs BP
Historic sediment
Black: Holocene
wet meadow
300-11,200 yrs BP


Piney Run, MD
"Pompeii effect"
Historic sediment
Holocene wetland soil
Pleistocene periglacial rubble

Piney Run—Buried debris fans at toe-of-slope; to right is buried black marsh soil in original topographic low area

John B. Devries' Paper Mill on Piney Falls, Arrington Road, near soapstone quarry. Site of an older mill. 1850 census of manufactures listed John B. Devries paper mill with 4 male and 1 female employees, water power, 2 engines. The "Devries Flour and Paper Mills . . . 3 miles from Sykesville" were damaged in the flood, July 29, 1868. Mill extinct. (From J. McGrain, Mills of Marylalnd.)

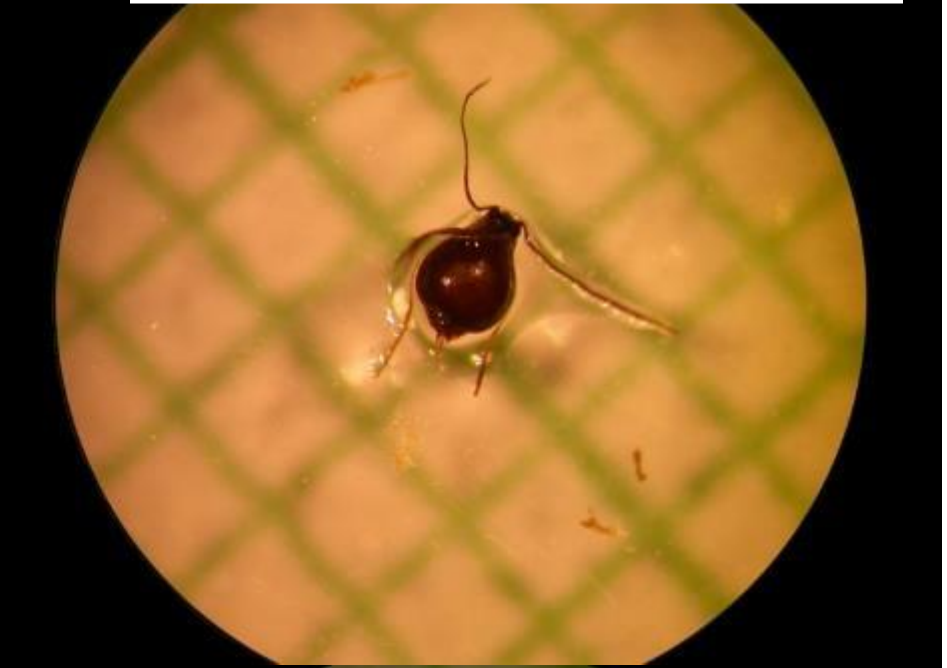
Piney Run Radiocarbon Dates
Base of Buried Hydric Soil

Nut (11,060-11,035 Cal BP)
Hemlock cone (11,070-10,710 Cal BP)

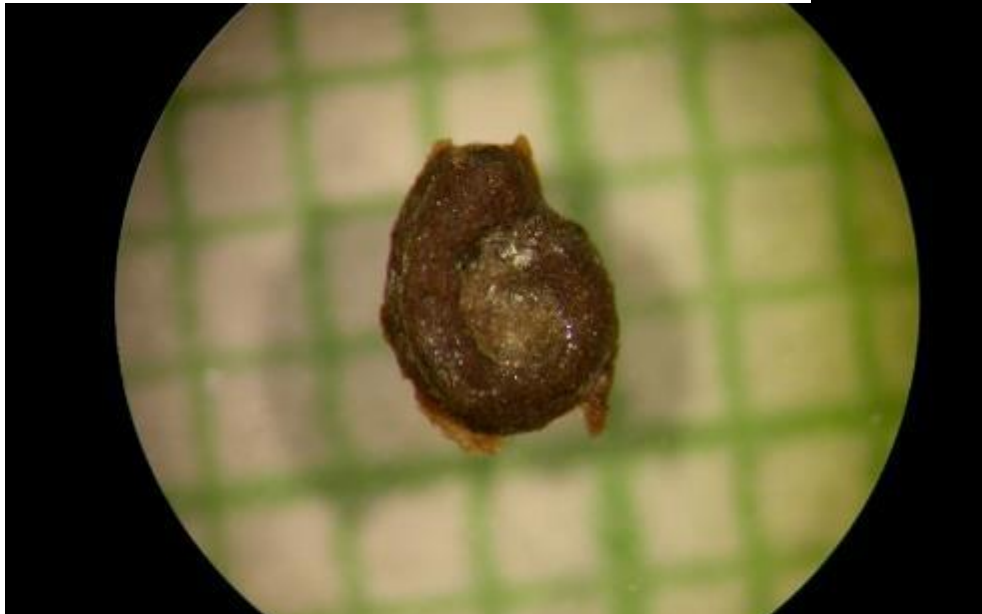
Hemlock cone (11,065-10,695 Cal BP)

Dulichium –marsh, wet meadow

Eleocharis—marsh, wet meadow



Potomogetan—submerged aquatic



Carex scoparia—marsh, wet meadow

Elliott, S. J., Wilf, P., Walter, R. C., & Merritts, D. J. (2013). Subfossil leaves reveal a new upland hardwood component of the pre-European Piedmont landscape, Lancaster County, Pennsylvania. PloS one, 8(11).