Can we remotely map streambank erosion hotspots from the sky?

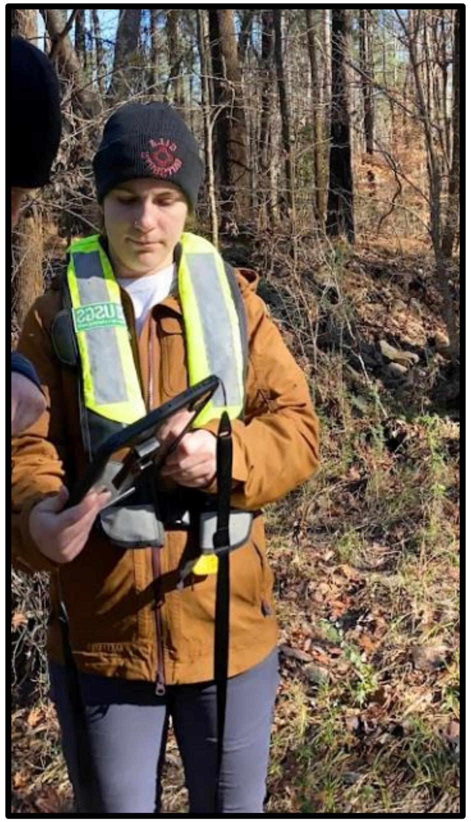
Krissy Hopkins
U.S. Geological Survey
WoW Webinar: September 20, 2023

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

USGS Project Team

Charlie Stillwell
Krissy Hopkins
Laura Gurley

Ryan Rasmussen



Deanna Hardesty

The problem

Excess sediment in surface waters can degrade habitat, cause sedimentation of reservoirs, and increase costs of water treatment

The problem

Streambanks are a leading source of sediment to downstream waterways, especially in the Piedmont

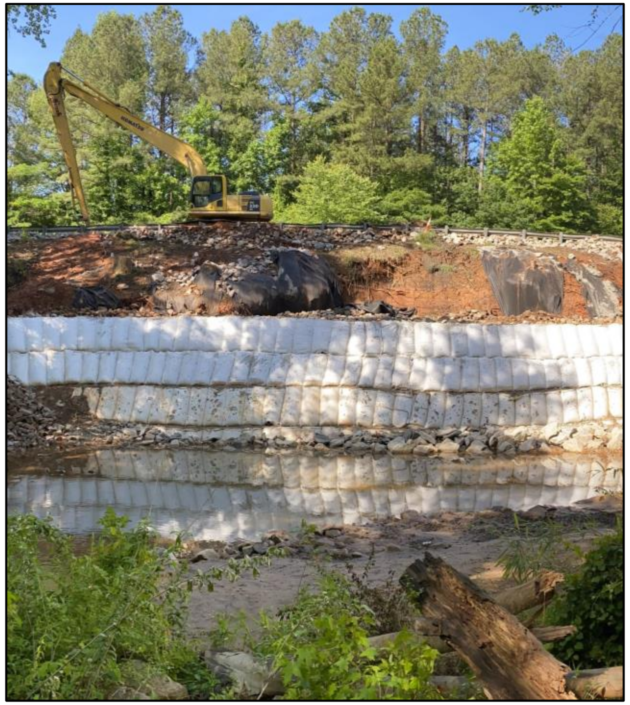
Bank collapse near hwy
Richland Creek, Raleigh, NC

Exposed sewer line
Walnut Creek Trib Adj Ivy Ln
Cary, NC

USGS

The problem

Streambanks are a leading source of sediment to downstream waterways, especially in the Piedmont



Bank collapse near hwy
Richland Creek, Raleigh, NC

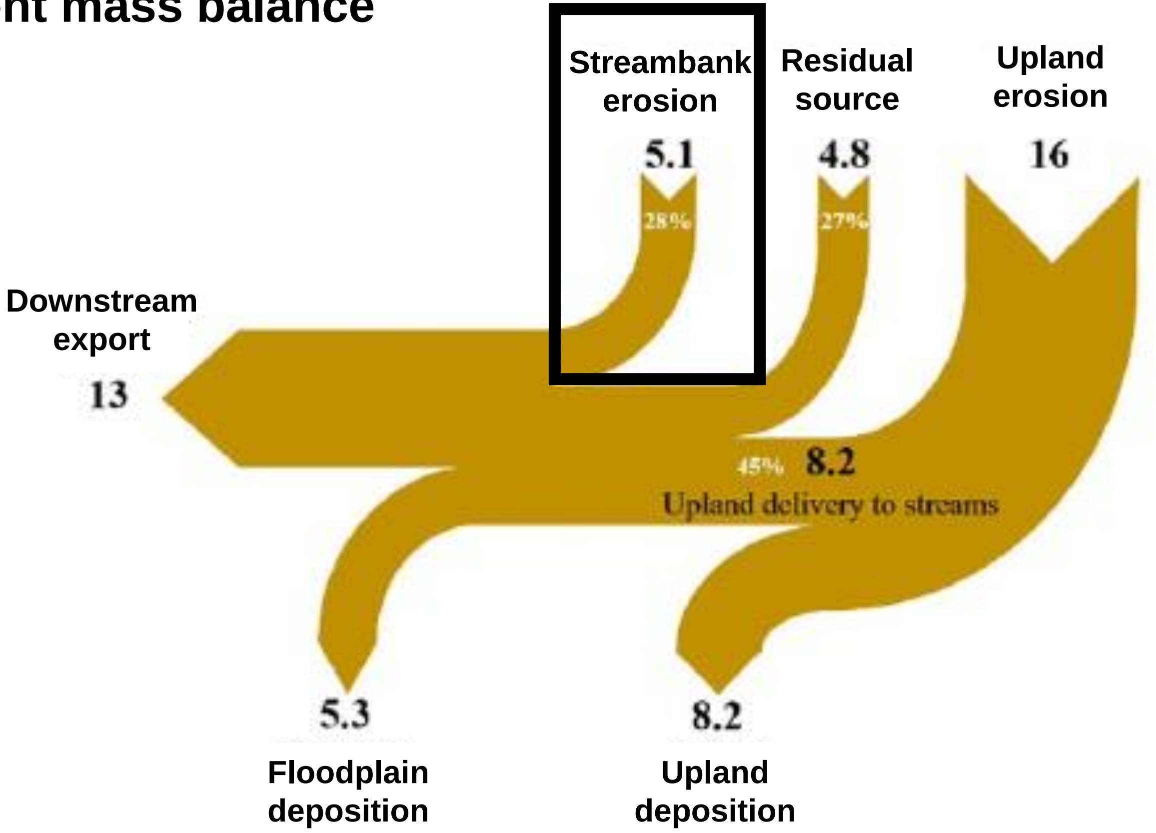
Exposed sewer line
Walnut Creek Trib Adj Ivy Ln
Cary, NC

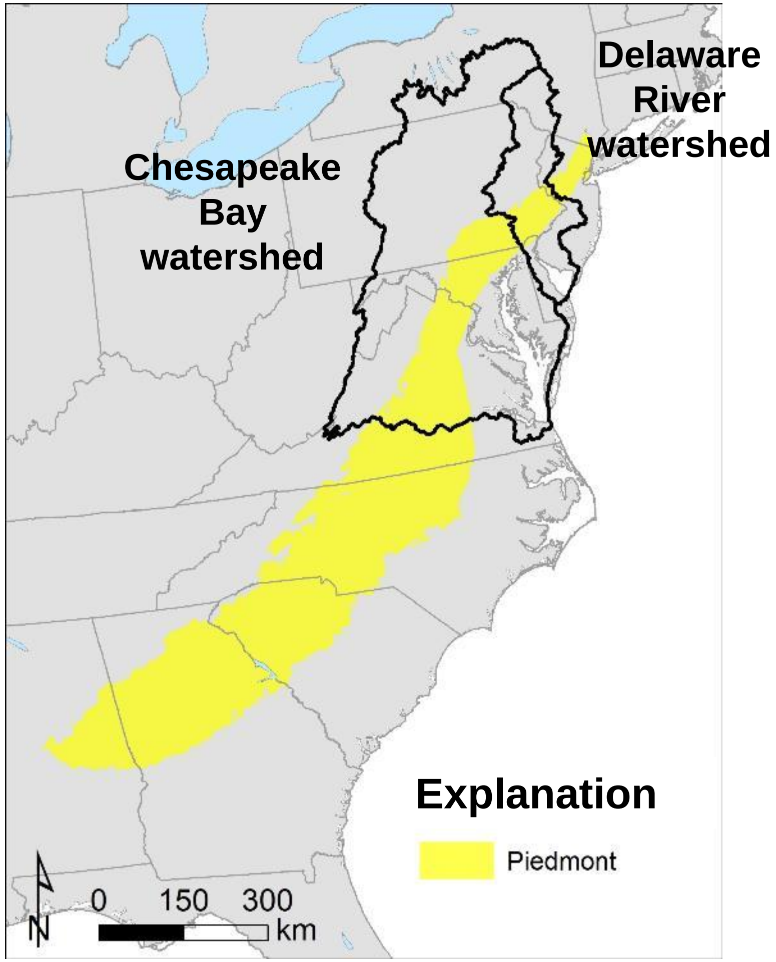
USGS

Watershed-scale sediment modeling

Streambank erosion contributes 28% of the sediment load in the Chesapeake and Delaware basins

Sediment mass balance (Tg/yr)





Noe et al. 2022 *Environ. Res. Lett.*

Watershed-scale sediment modeling

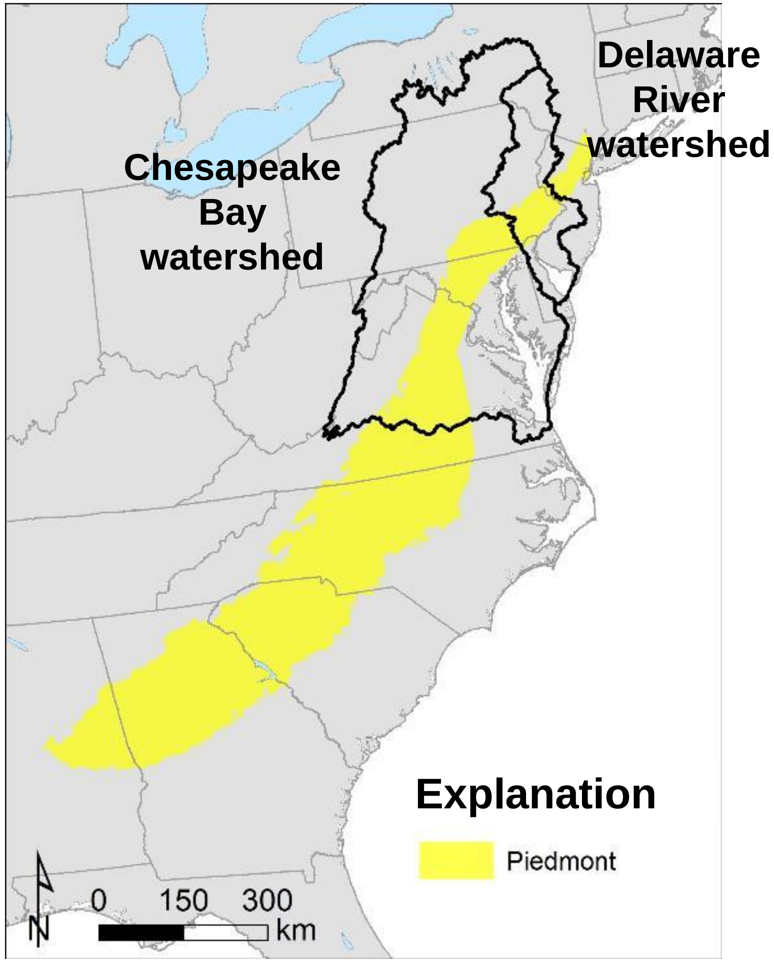
Streambank erosion contributes 28% of the sediment load in the Chesapeake and Delaware basins

Sediment mass balance
(Tg/yr)

Streambank erosion
equates to a cost of
$137 million annually
in Chesapeake and
Delaware Basins
Hopkins et al. 2023 *J. Env. Man.*

Floodplain deposition

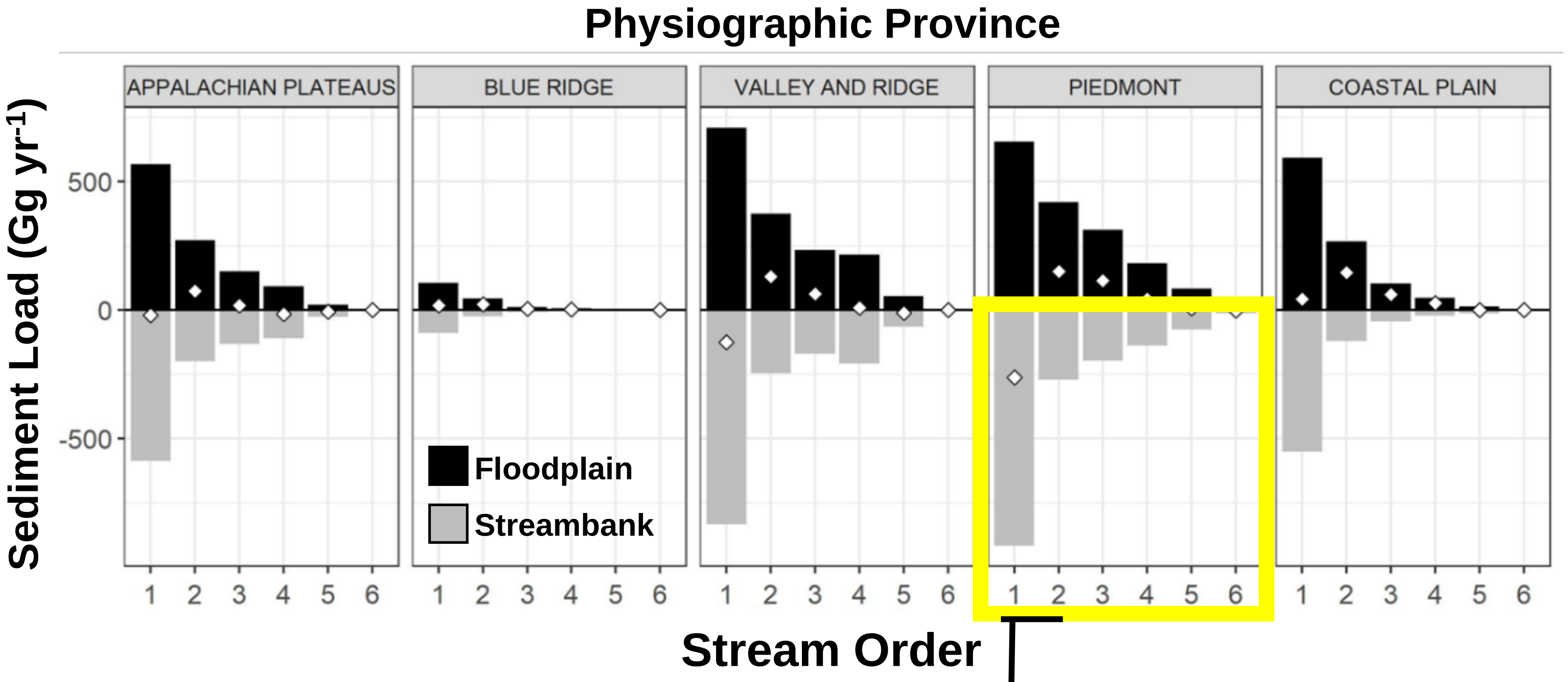
Upland deposition



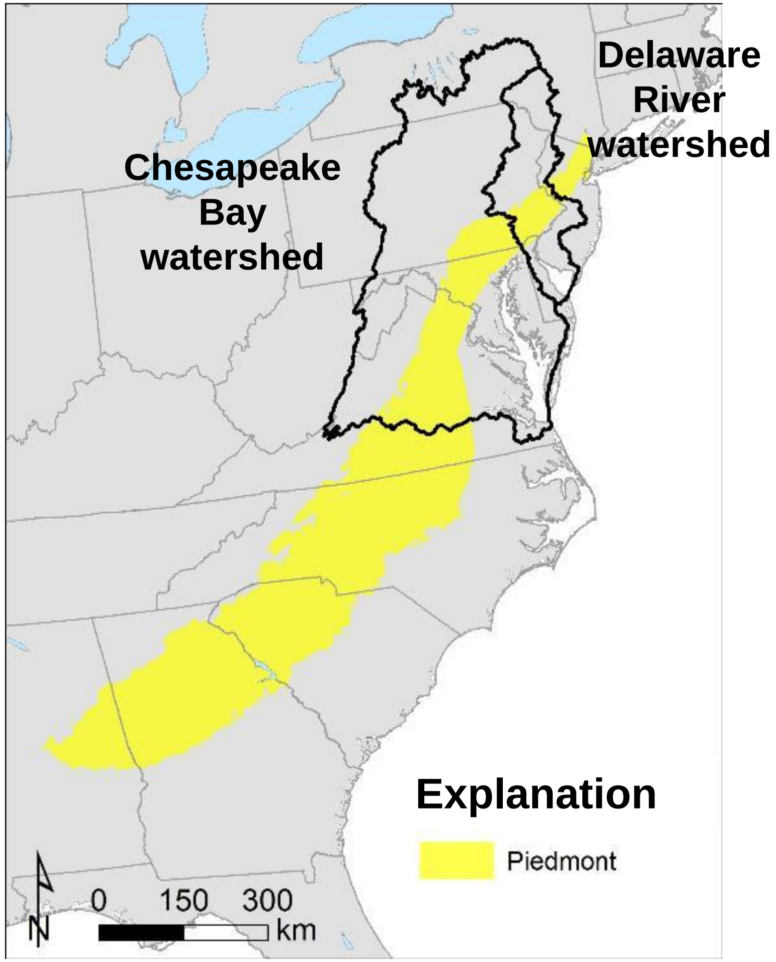
USGS

Watershed-scale sediment modeling

Zoom into the Piedmont and 75% of the streambank sediment export is from headwater (1-2 order) streams



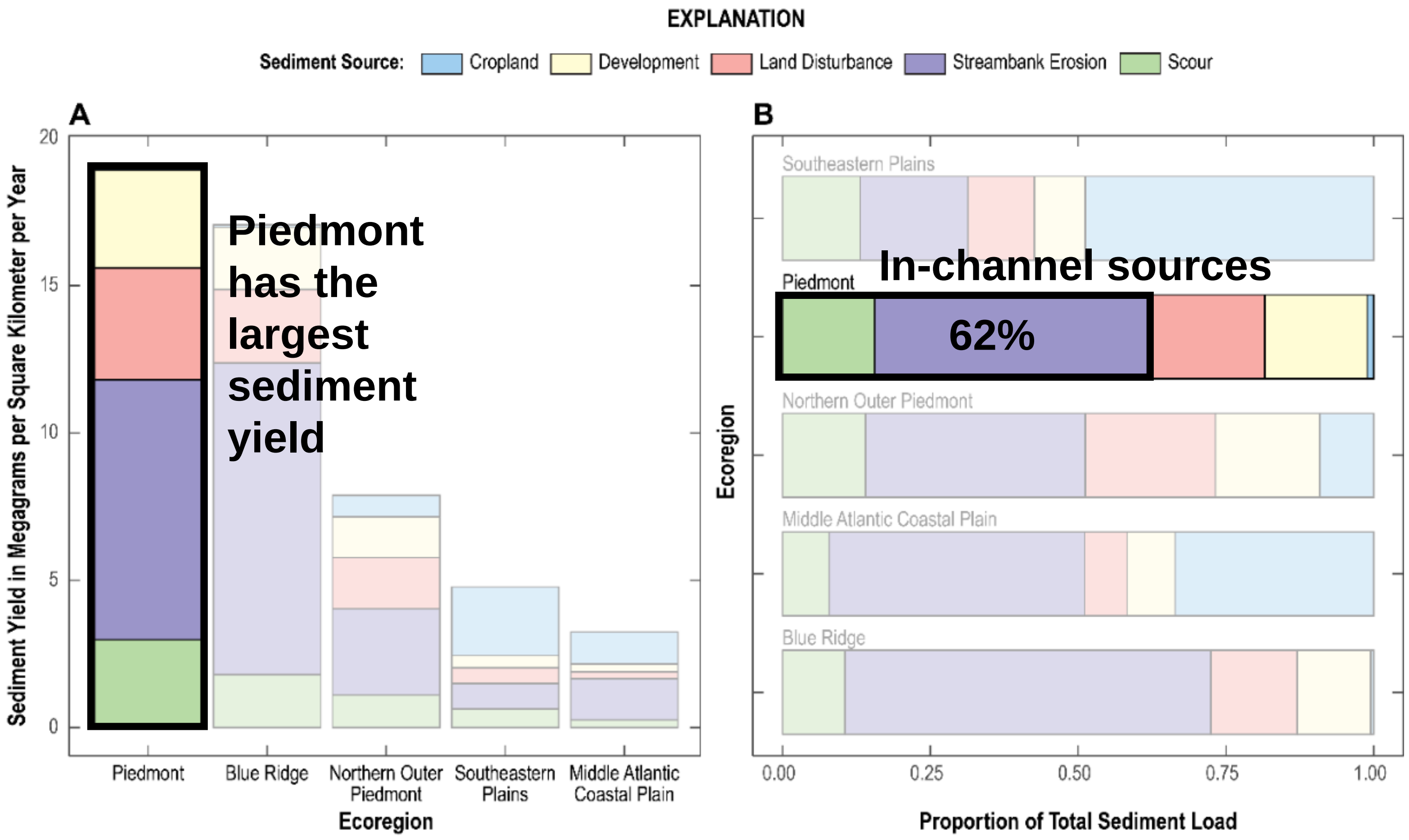
80% of total stream length is a headwater

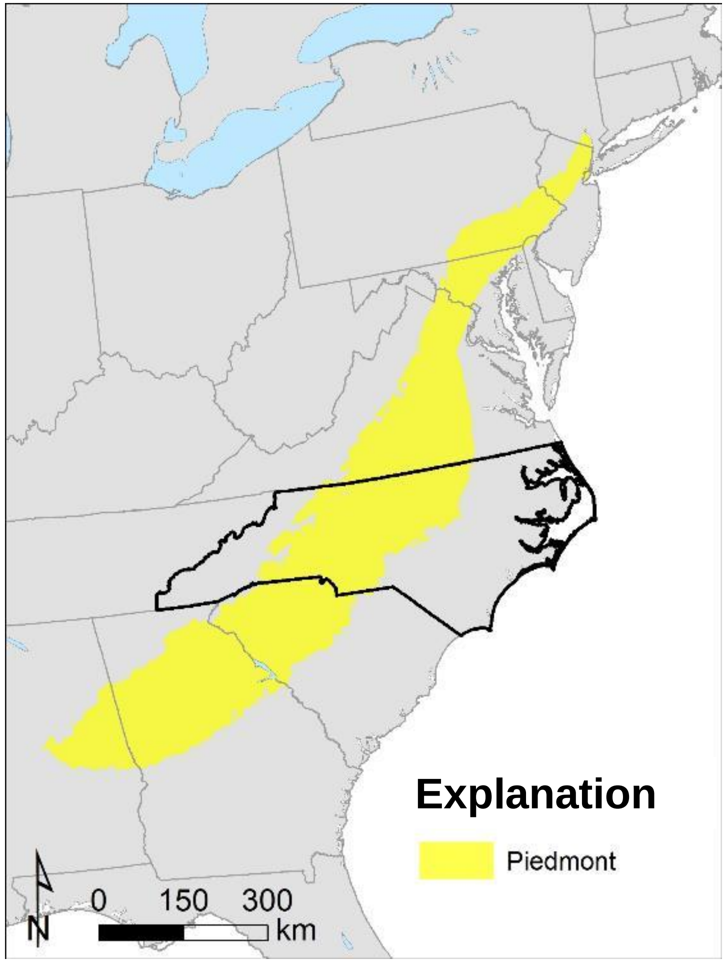


Hopkins et al. 2023 *J. Env. Man.*

SPARROW sediment modeling

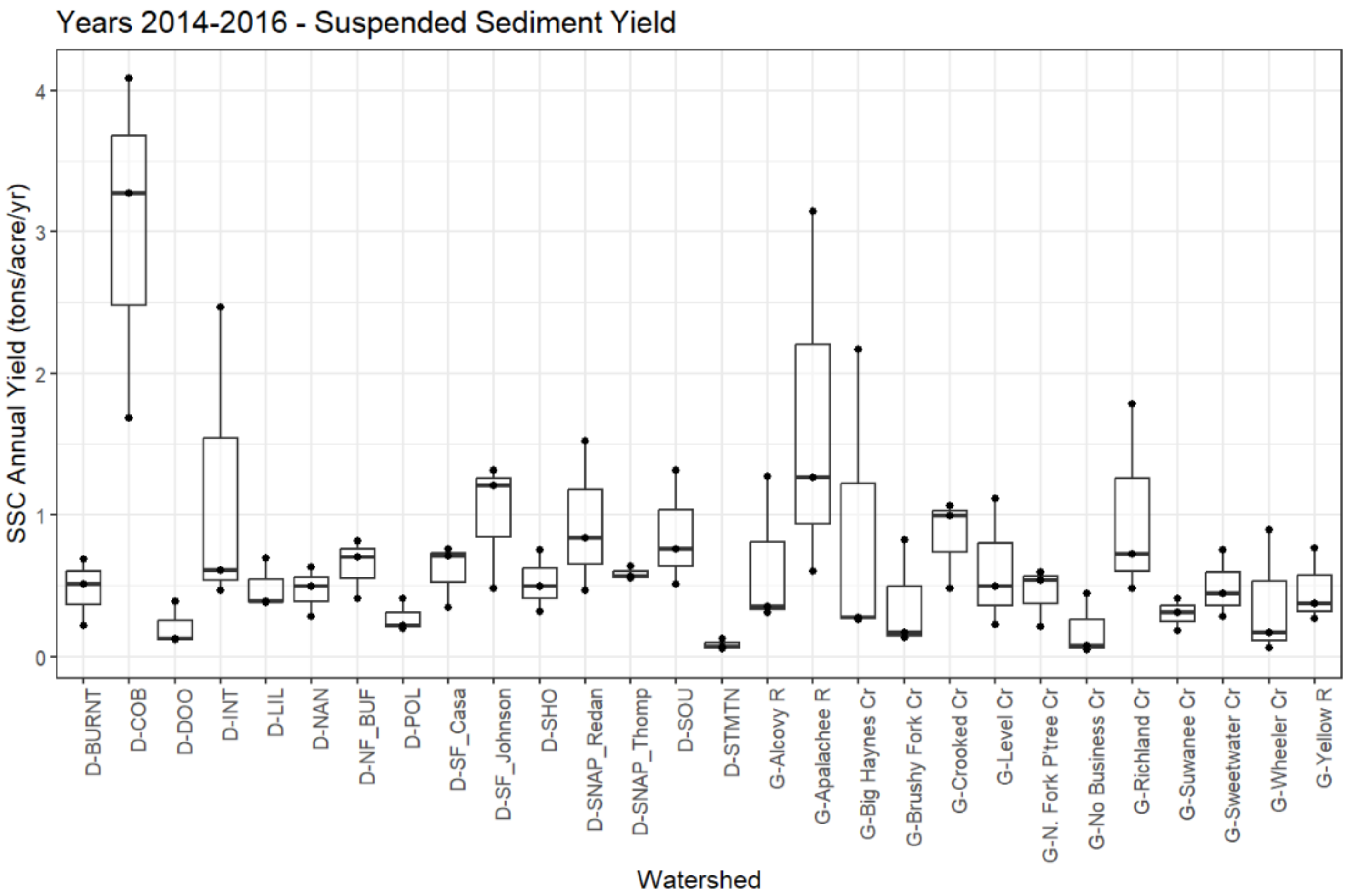
In North Carolina, 62% of the sediment load can be attributed to in-channel sources like streambank erosion





[Gurley et al. 2019 USGS ScienceBase]

In Atlanta: Sediment export is variable across urban watersheds and between years.



Aulenbach et al. 2022 USGS SIR 2023–5035

USGS

Working toward a solution

Assess streambank erosion hotspots along the City of Raleigh's stream network to support the City's efforts of prioritizing future stream mitigation projects.

Objectives

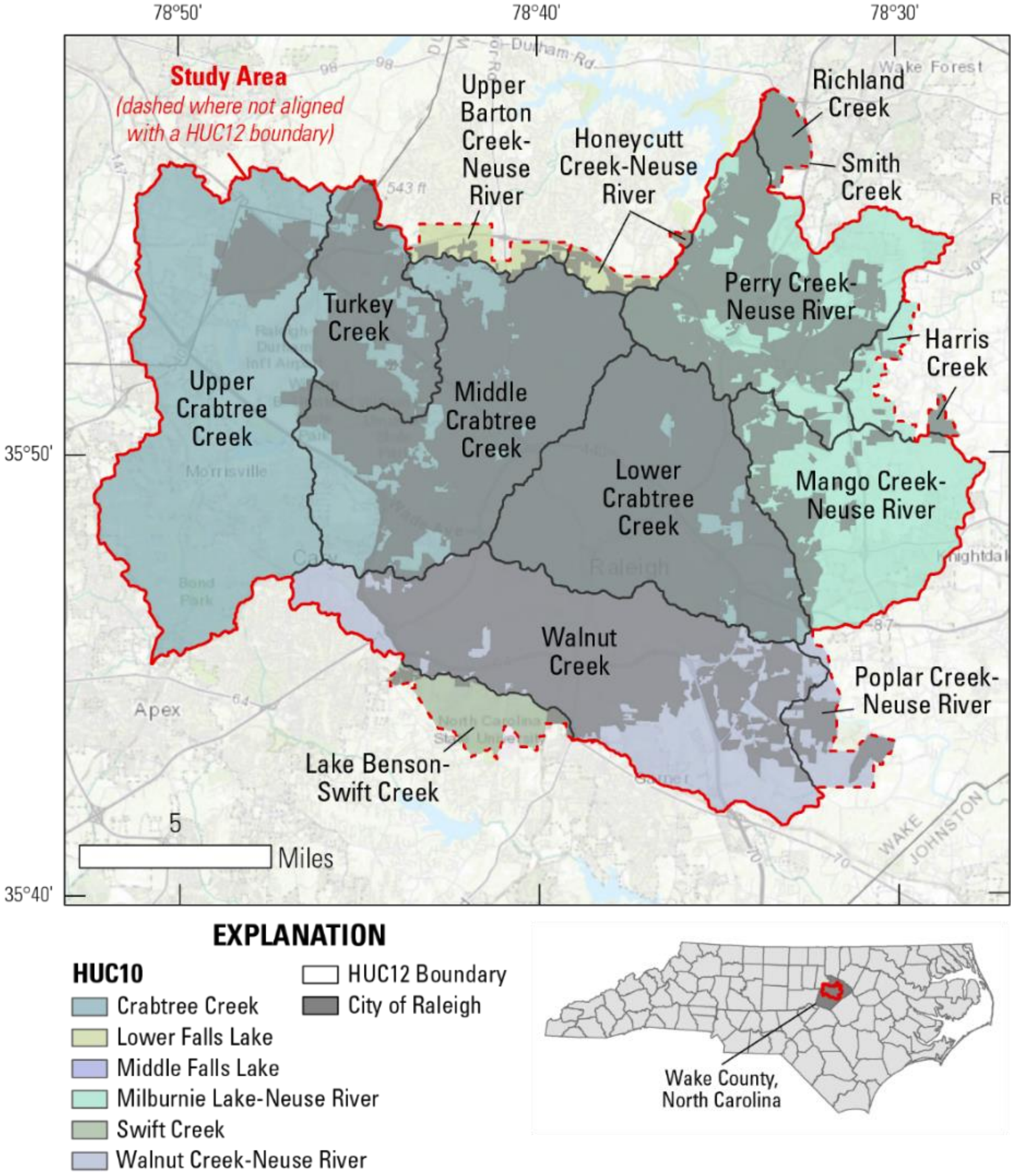
1. Conduct **field assessment** of streambank erosion potential at select stream reaches
2. Develop **geospatial datasets** that can be used as a proxy to map potential streambank erosion hotspots
3. Assess **proximity of infrastructure** to erosion hotspots
4. Develop **model to predict** streambank erosion potential using geospatial and field datasets

USGS Raleigh

Study area

- Encompasses the City of Raleigh
- Expanded to include major contributing watersheds and some parts of others that overlap with the City of Raleigh

Began with a rapid field assessment January and March 2022

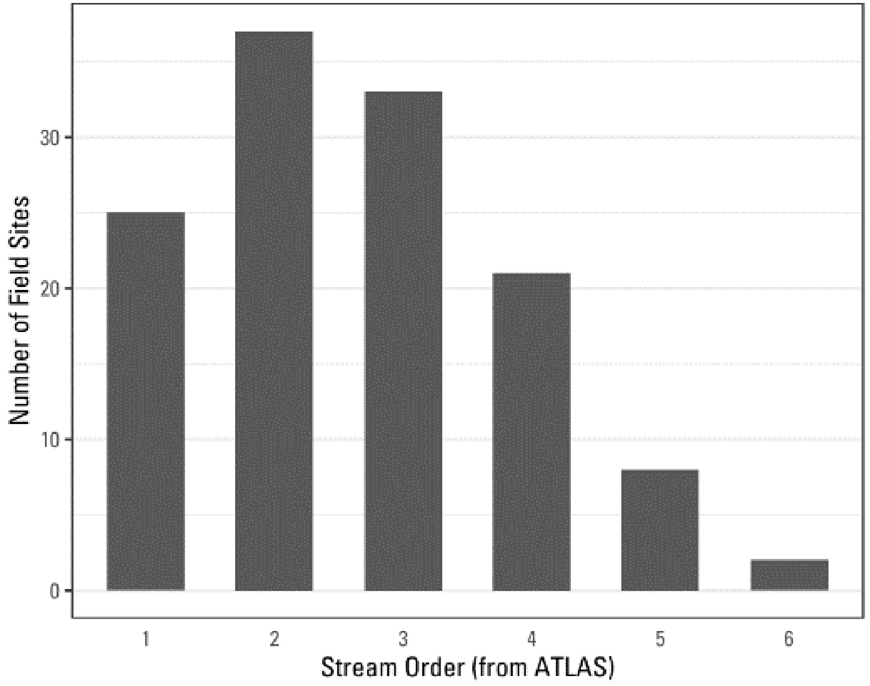


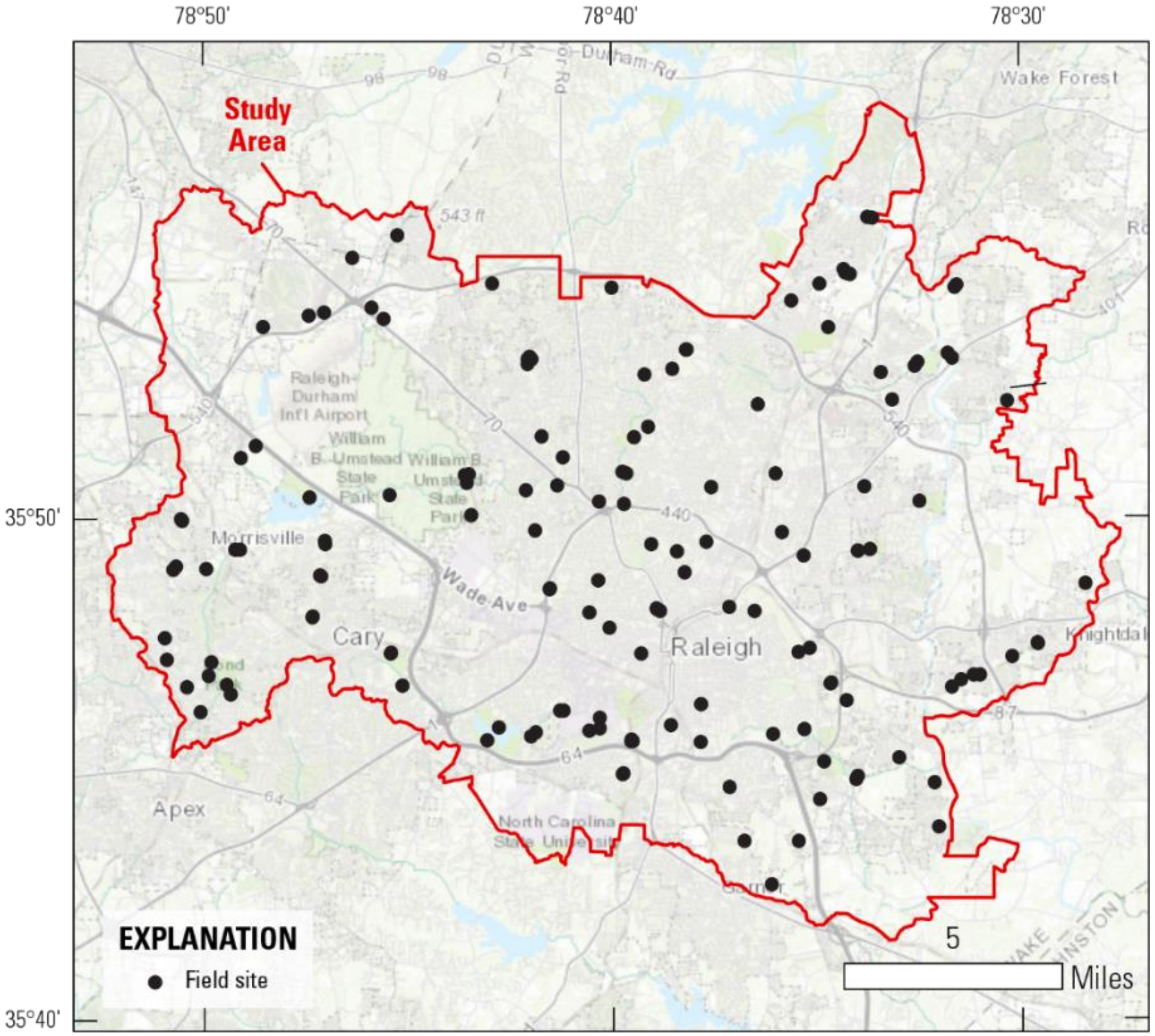
USGS

Field rapid assessment of stream conditions

124 sites across Raleigh

- Bank erosion hazard index (BEHI)
- Rapid geomorphic assessment (RGA)





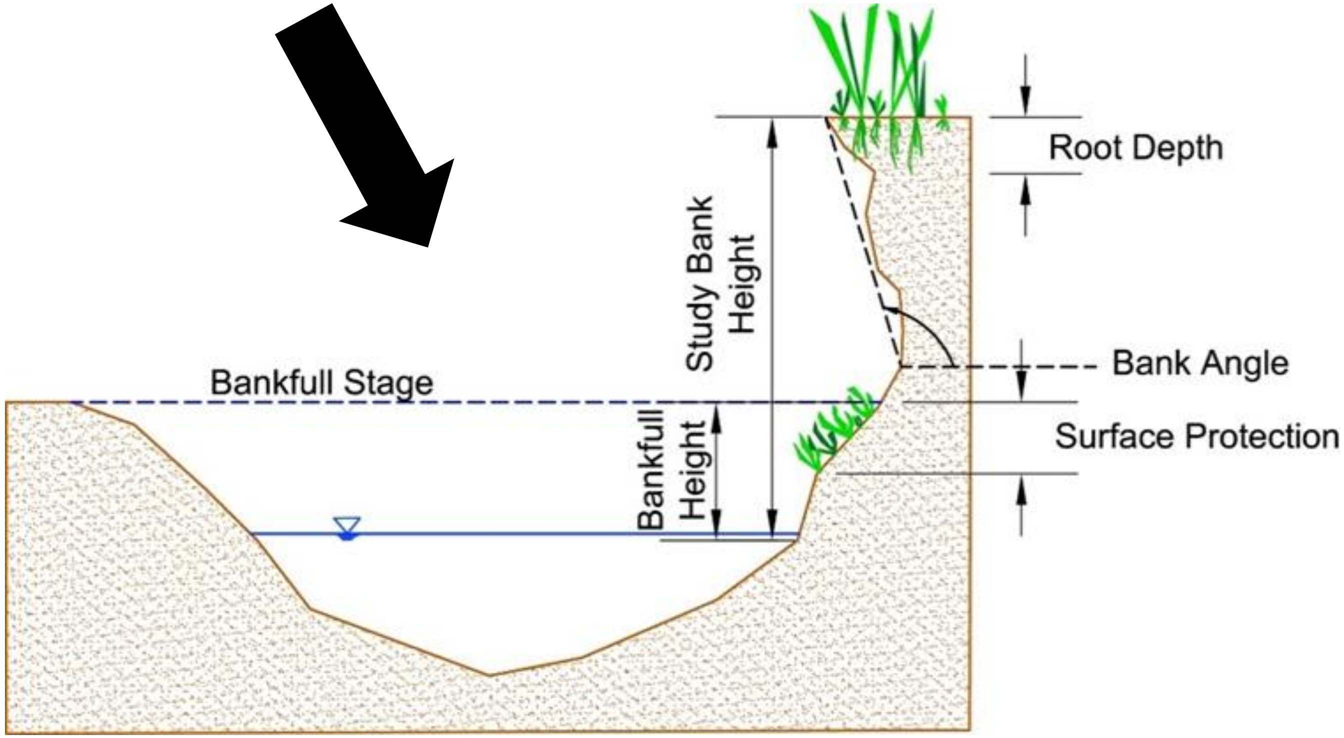
USGS

Stillwell et al. 2022 ScienceBase

Field Rapid Assessment

Bank Erosion Hazard Index (BEHI)

Rapid Geomorphic Assessment (RGA)



1. Primary bed material

Bedrock	Boulder/Cobble	Gravel	Sand	Silt Clay
0	1	2	3	4

2. Bed/bank protection

Yes	No	(with)	1 bank protected	2 banks
0	1		2	3

3. Degree of incision (Relative ele. Of "normal" low water; floodplain/terrace @ 100%)

0-10%	11-25%	26-50%	51-75%	76-100%
4	3	2	1	0

4. Degree of constriction (Relative decrease in top-bank width from up to downstream)

0-10%	11-25%	26-50%	51-75%	76-100%
0	1	2	3	4

…k erosion (Each bank)

	…ne	fluvial	mass wasting (failures)
Left	0	1	2
Right	0	1	2

6. Streambank instability (Percent of each bank failing)

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	0	0.5	1	1.5	2
Right	0	0.5	1	1.5	2

7. Established ripirian woody-vegetative cover (Each bank)

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	2	1.5	1	0.5	0
Right	2	1.5	1	0.5	0

8. Occurrence of bank accretion (Percent of each bank with fluvial deposition)

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	2	1.5	1	0.5	0
Right	2	1.5	1	0.5	0

9. Stage of channel evolution

I	II	III	IV	V	VI
0	1	2	4	3	1.5

10. Composition of adjacent side slope (circle)

	N/A	Bedrock	Boulders	Gravel-SP	Fines
Left	0	0.5	1	1.5	2
Right	0	0.5	1	1.5	2

11. Percent of slope (length) contributing sediment

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	0	0.5	1	1.5	2
Right	0	0.5	1	1.5	2

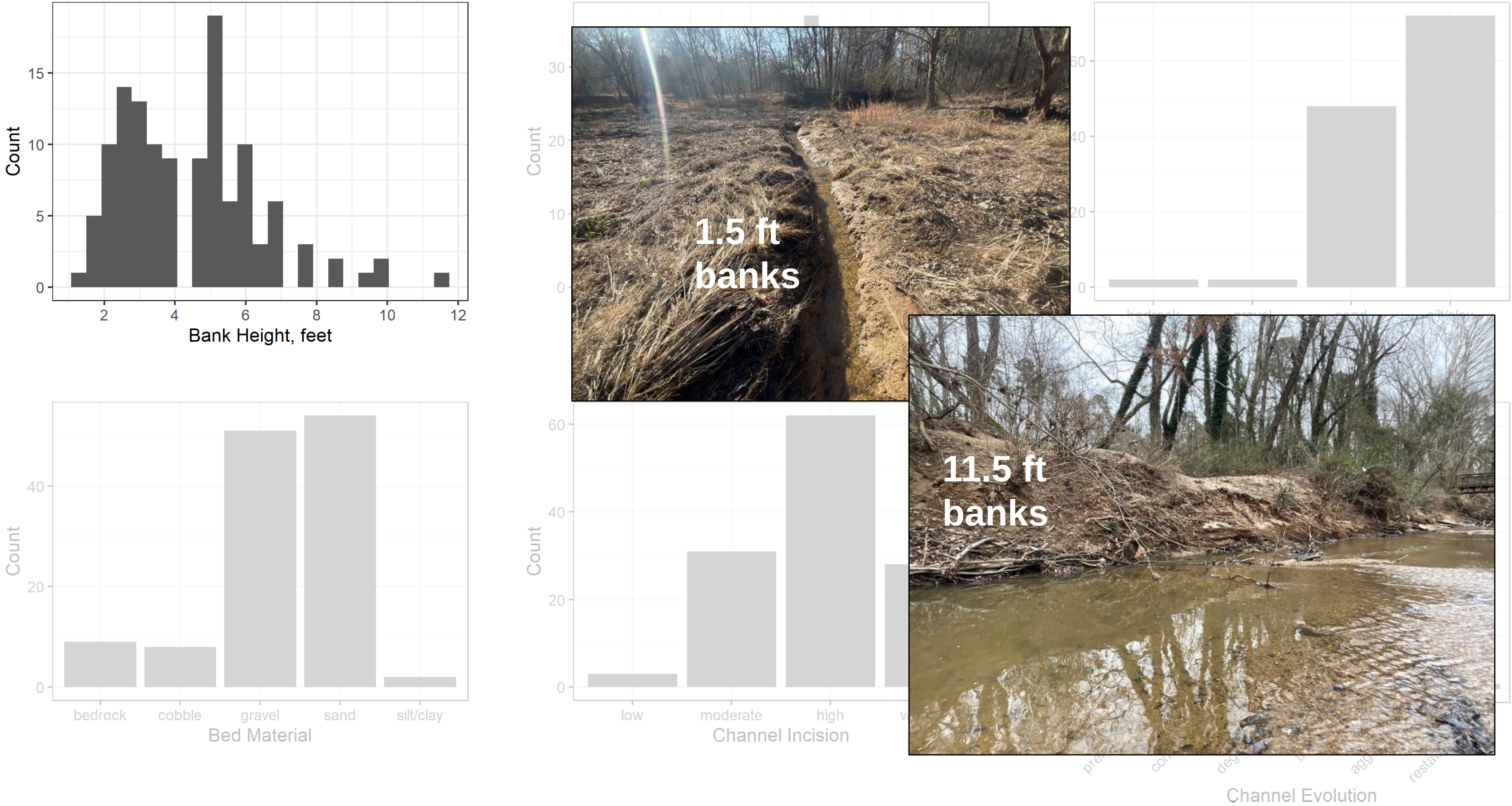
12. Severity of side-slope erosion

	None	Low	Moderate	High
Left	0	0.5	1.5	2
Right	0	0.5	1.5	2

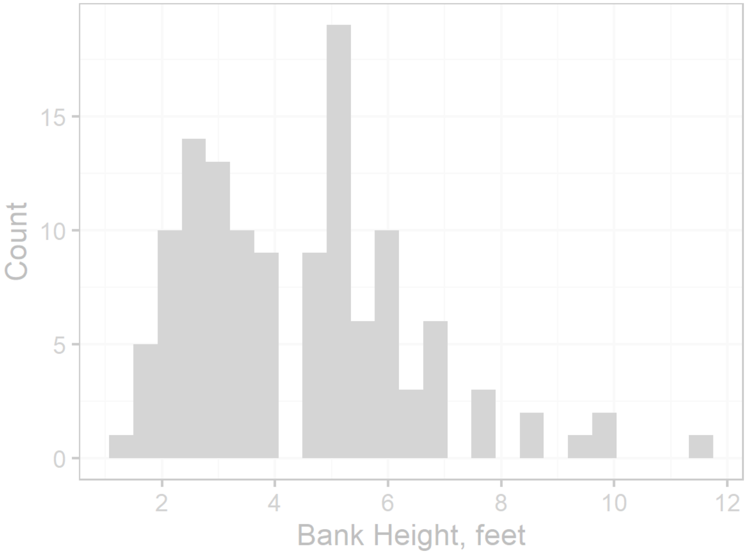
USGS

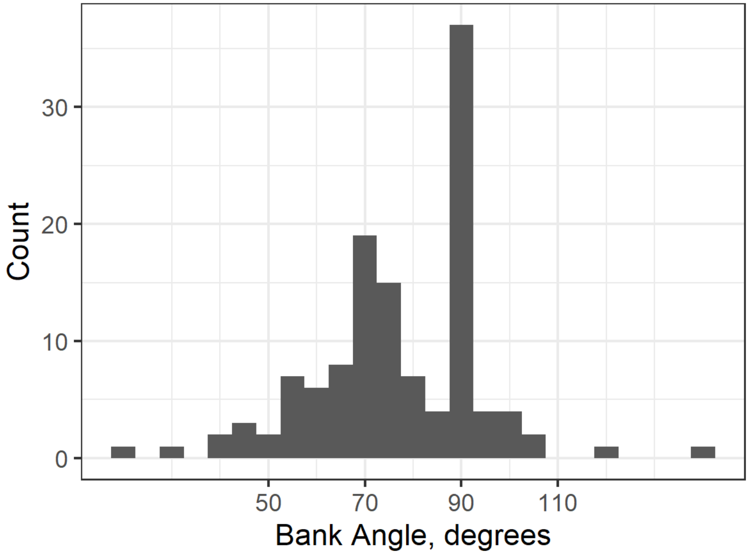
Stillwell et al. 2022 ScienceBase

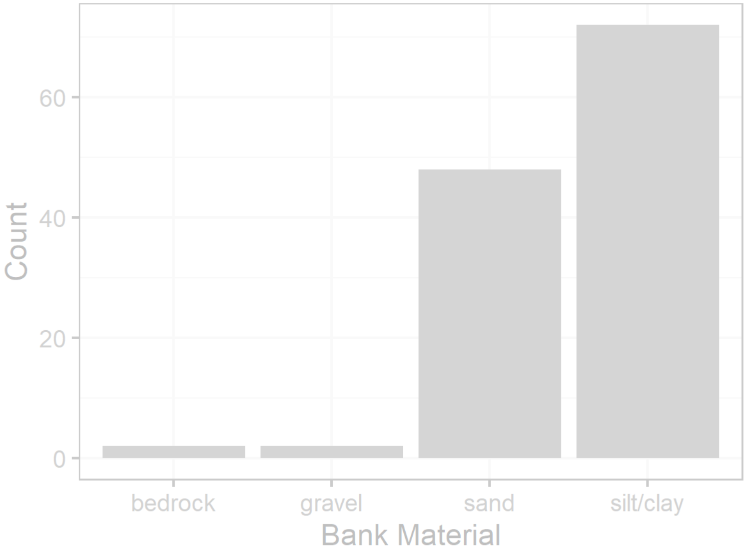
Histograms of some of the field data



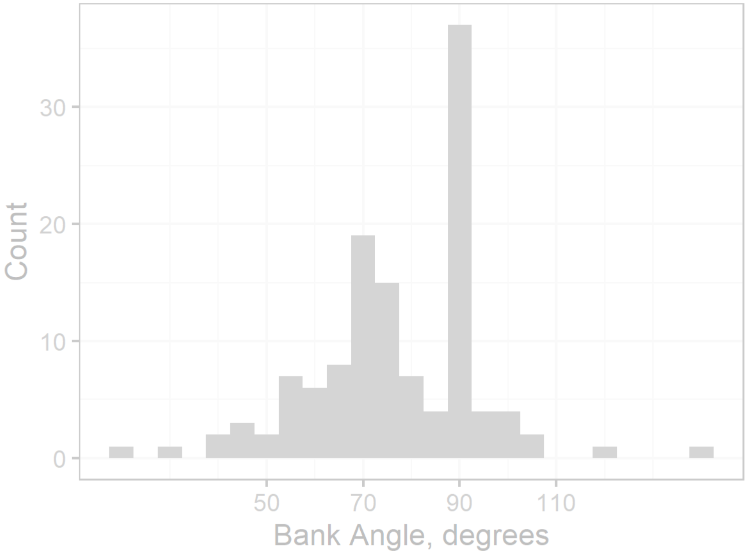
Histograms of some of the field data

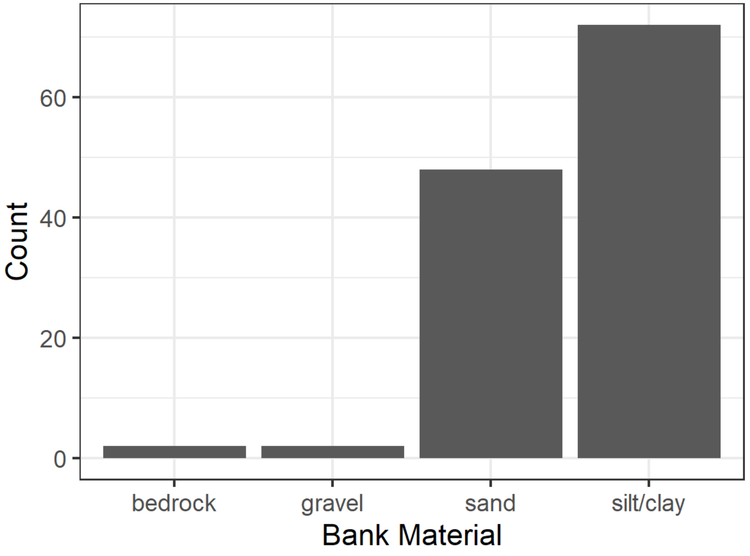


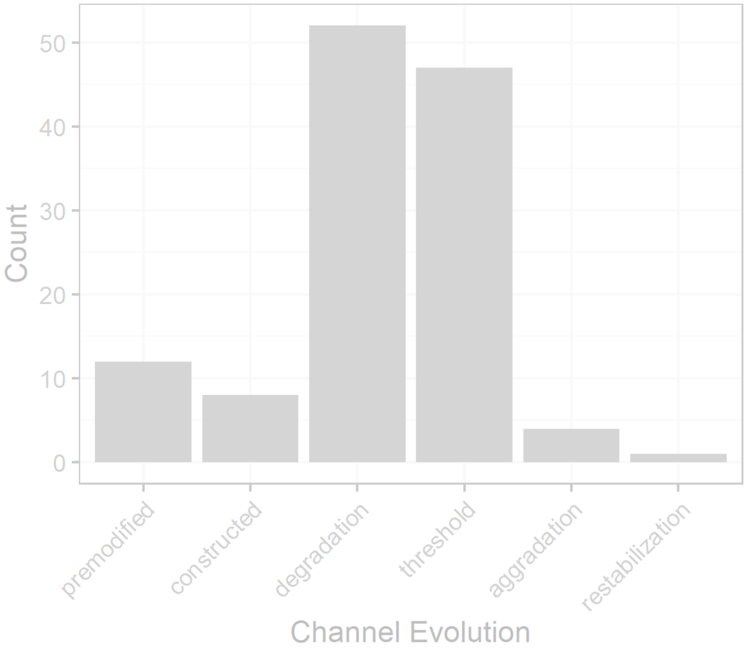




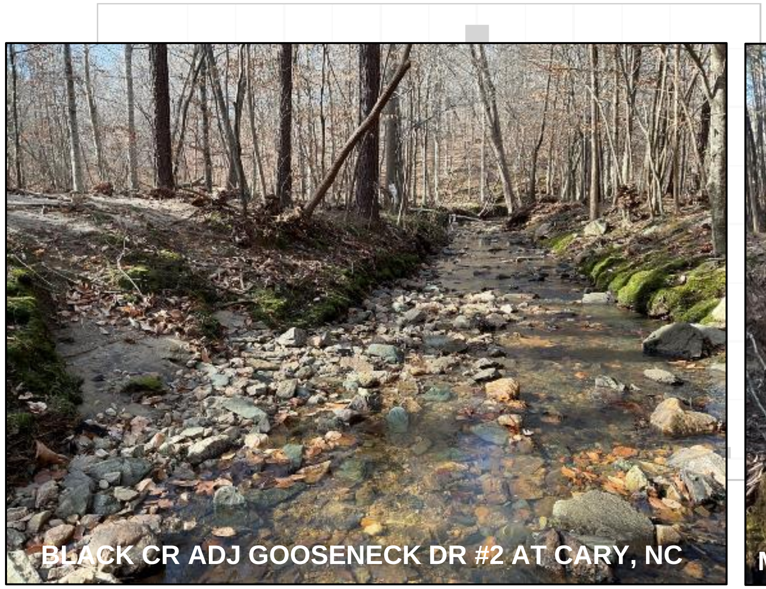
Histograms of some of the field data

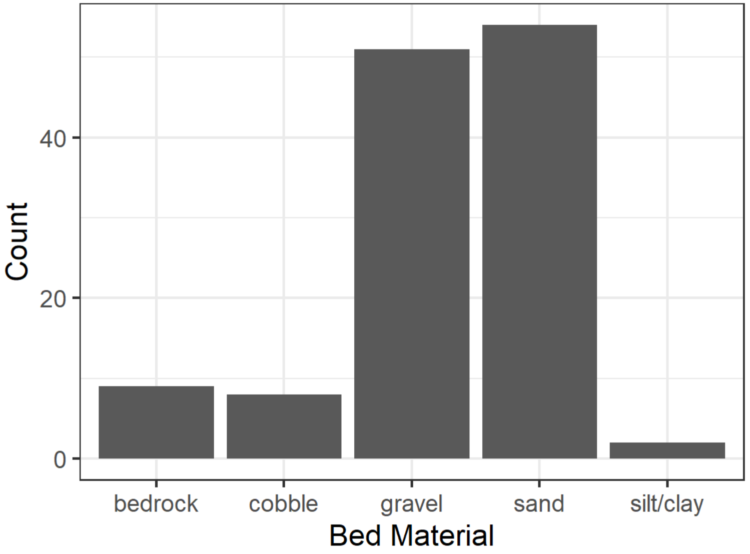






Histograms of some of the field data





BEHI: Extreme

MINE CR TRIB BLW CR DR AT RALEIGH, NC

MANGO CR TRIB ADJ STANWAY DR #1 AT KNIGHTDALE, NC

Headwater Streams

Drainage

< 0.1 mi^2

BEHI: Moderate

PIGEON HOUSE BR TRIB ABV GLENN AVE AT RALEIGH, NC

CRABTREE CR TRIB AT UMSTEAD FOREST AT RALEIGH, NC

BEHI: Extreme

RICHLAND CR ABV EBENEEZER CHURCH RD AT RALEIGH, NC
9.5 ft banks

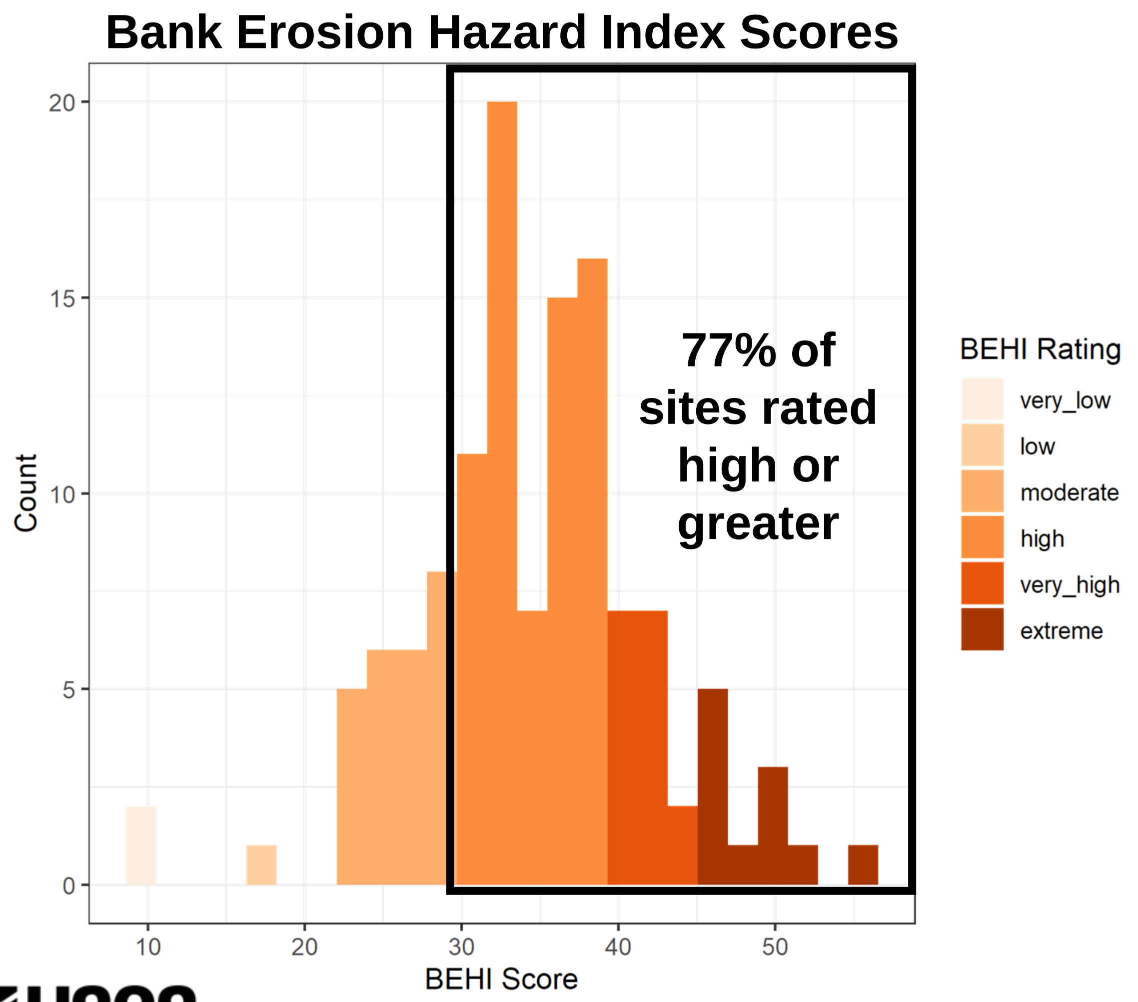
2-3 order streams

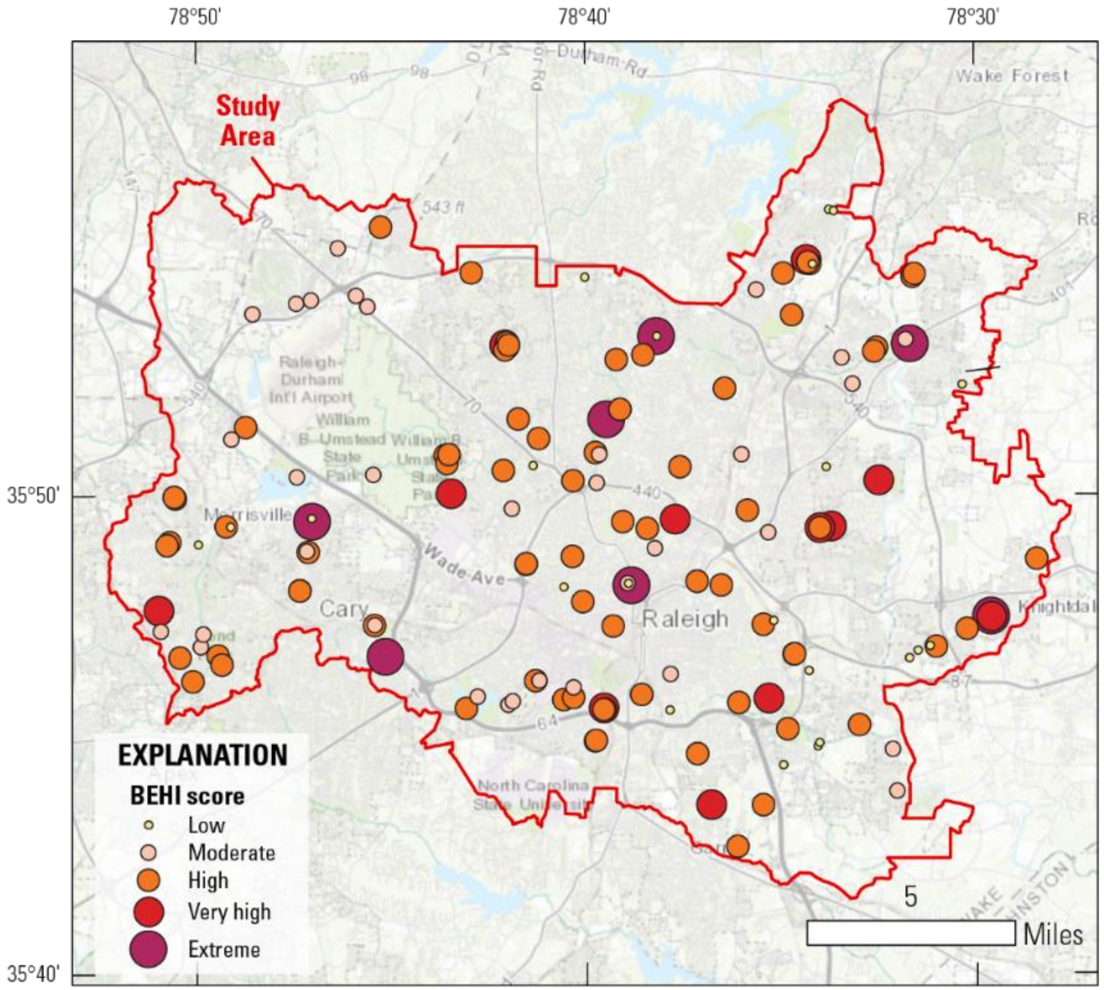
Drainage ~6 mi^2

BEHI: Moderate

WALNUT CR 0.3 MI BLW LAKE DAM RD AT RALEIGH, NC
4.5 ft banks

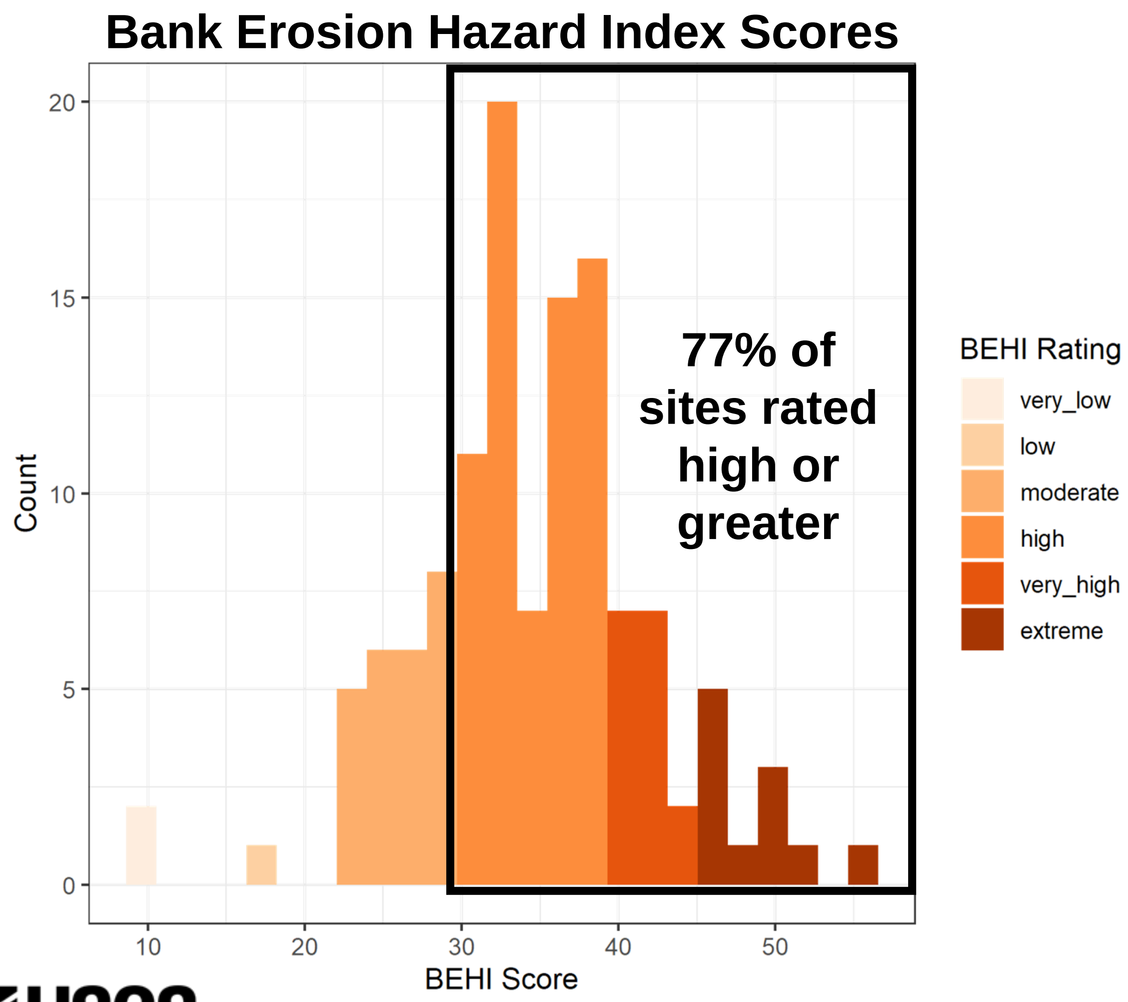
Field Rapid Assessment

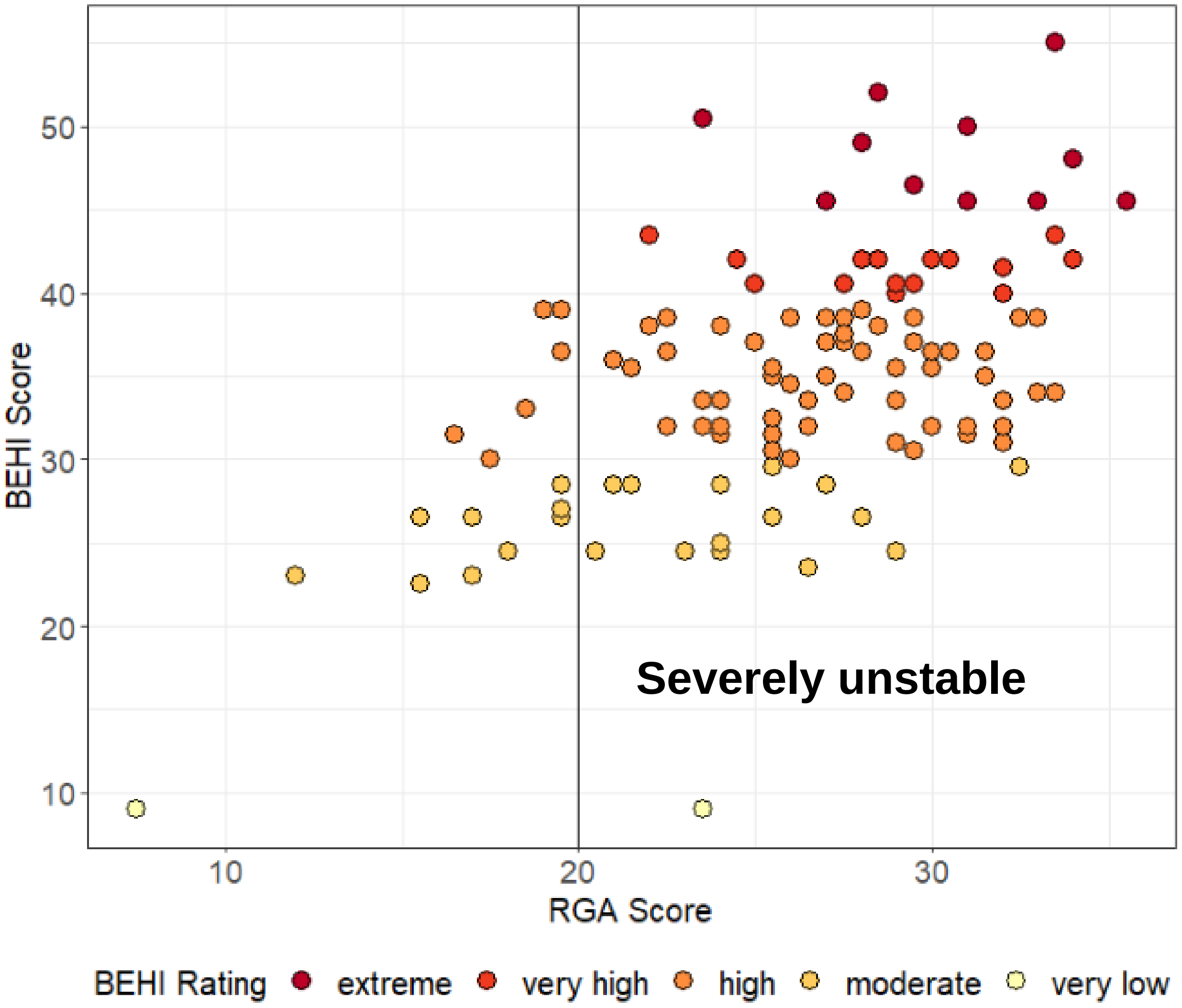




Stillwell et al. 2022 ScienceBase

Field Rapid Assessment





Stillwell et al. 2022 ScienceBase

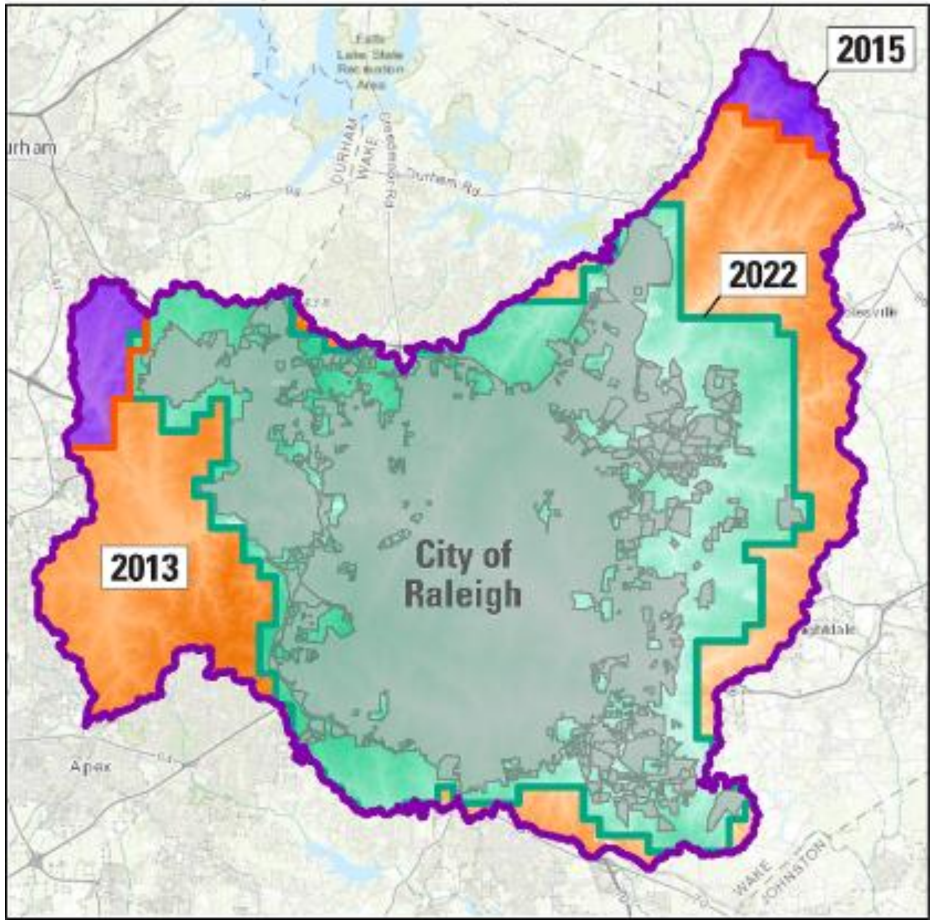
Working toward a solution

Assess streambank erosion hotspots along the City of Raleigh’s stream network to support the City’s efforts of prioritizing future stream mitigation projects.

Objectives

1. Conduct **field assessment** of streambank erosion potential at select stream reaches
2. Develop **geospatial datasets** that can be used as a proxy to map potential streambank erosion hotspots
3. Assess **proximity of infrastructure** to erosion hotspots
4. Develop **model to predict** streambank erosion potential using geospatial and field datasets

Dataset footprints based on year of lidar collection

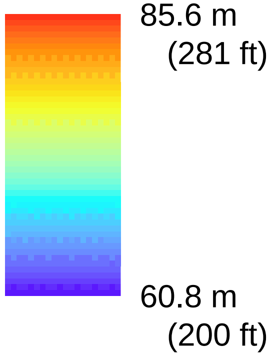


USGS Raleigh

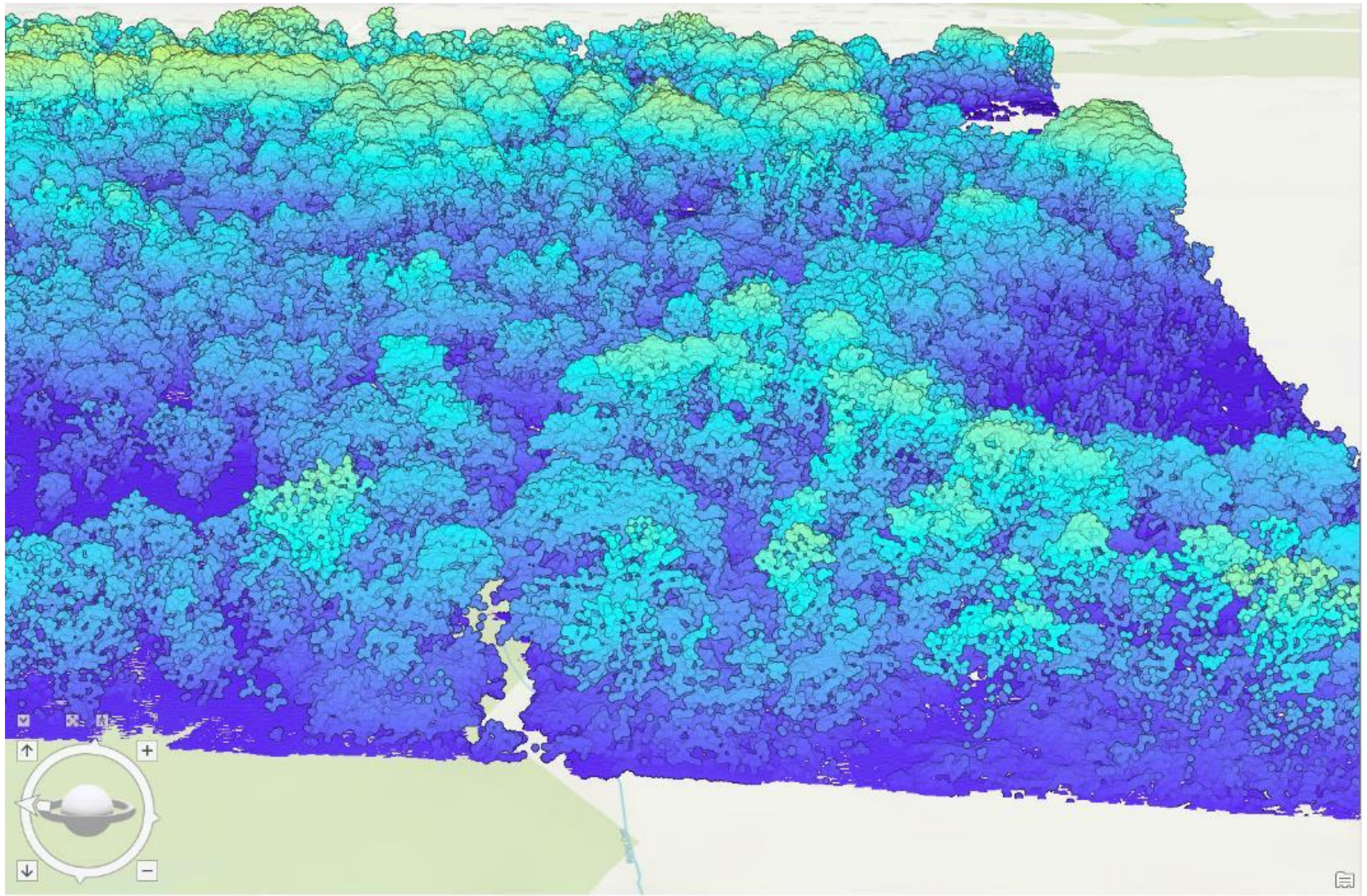
Geospatial datasets generated from lidar for years 2013, 2015, 2022

Processing lidar

- Interpolate a bare earth surface
- Exclude building and vegetation lidar points
- QL2 = 1-m cell size
- Snap grids



Walnut Creek near S States St



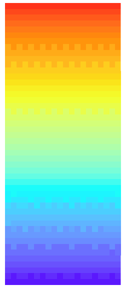
USGS

Gurley et al. 2023 ScienceBase

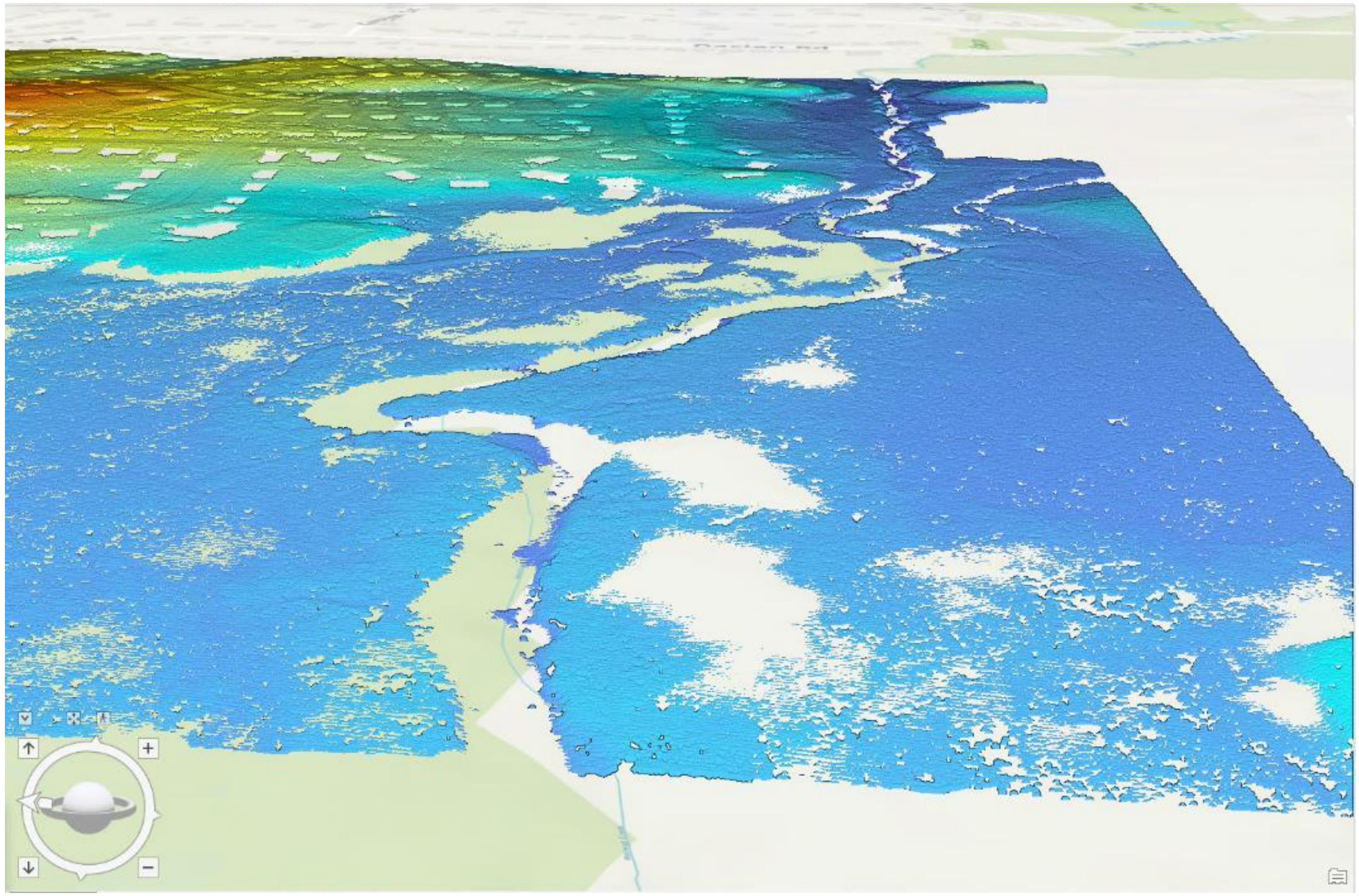
Geospatial datasets generated from lidar for years 2013, 2015, 2022

Processing lidar

- Interpolate a bare earth surface
- Exclude building and vegetation lidar points
- QL2 = 1-m cell size
- Snap grids



Walnut Creek near S States St



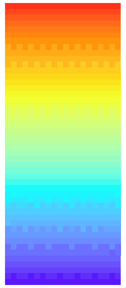
USGS

Gurley et al. 2023 ScienceBase

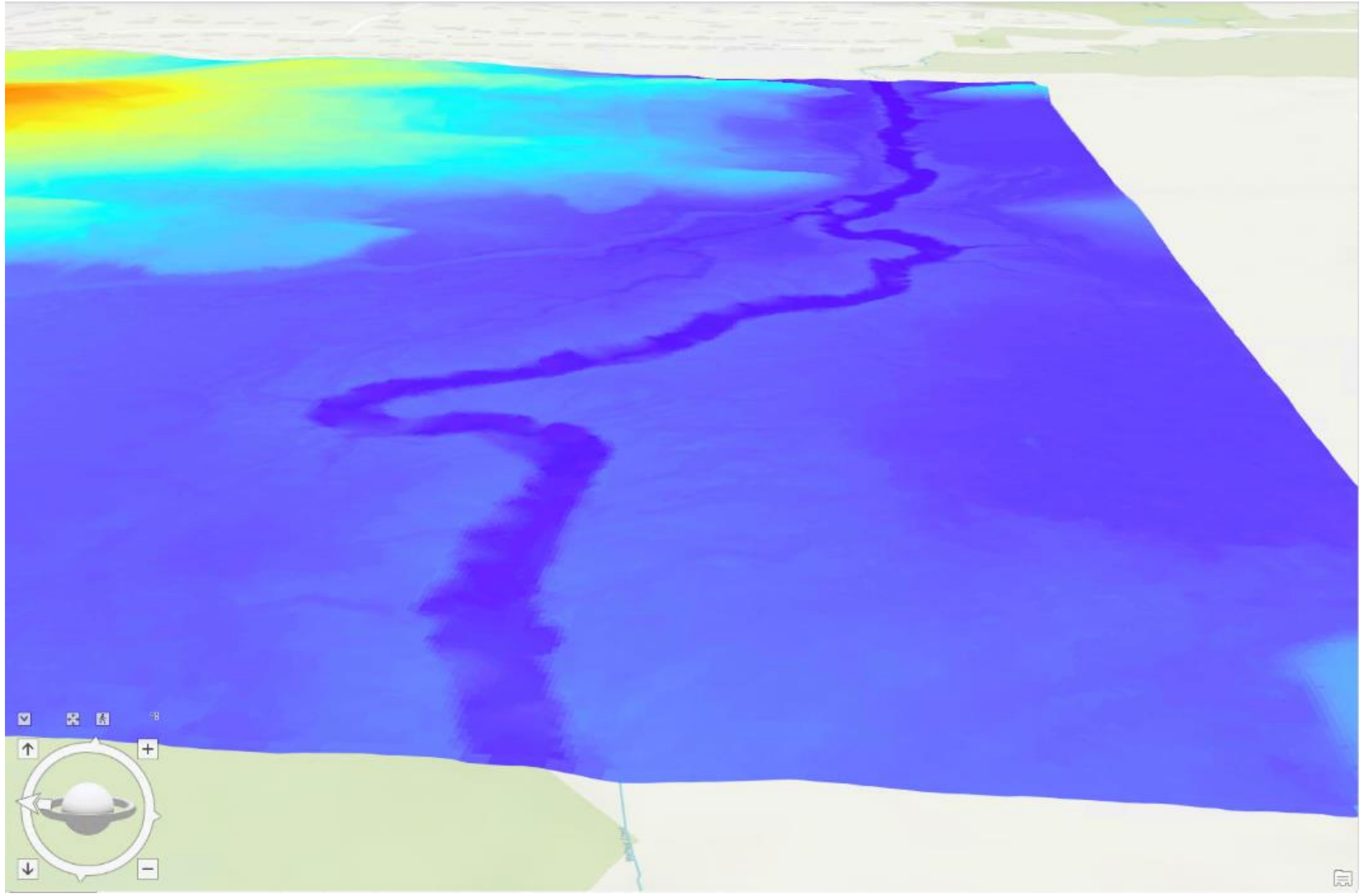
Geospatial datasets generated from lidar for years 2013, 2015, 2022

Processing lidar

- Interpolate a bare earth surface
- Exclude building and vegetation lidar points
- QL2 = 1-m cell size
- Snap grids



Walnut Creek near S States St

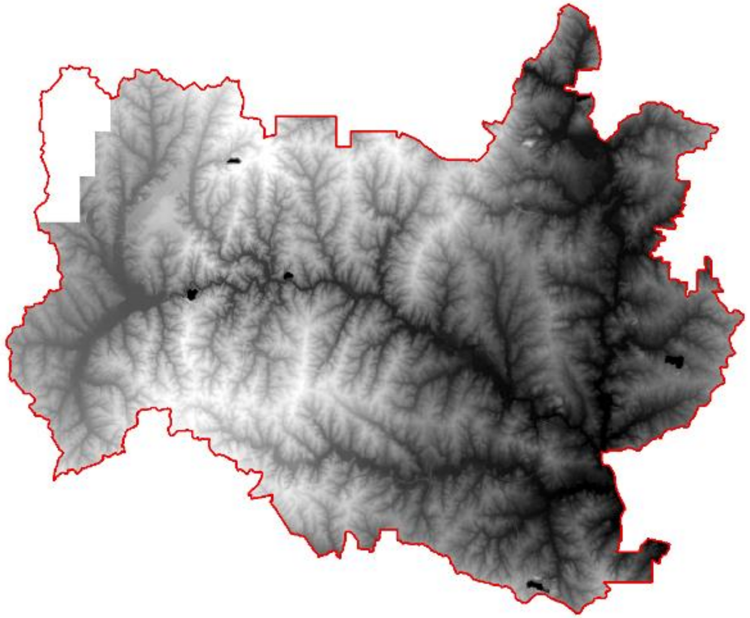


USGS

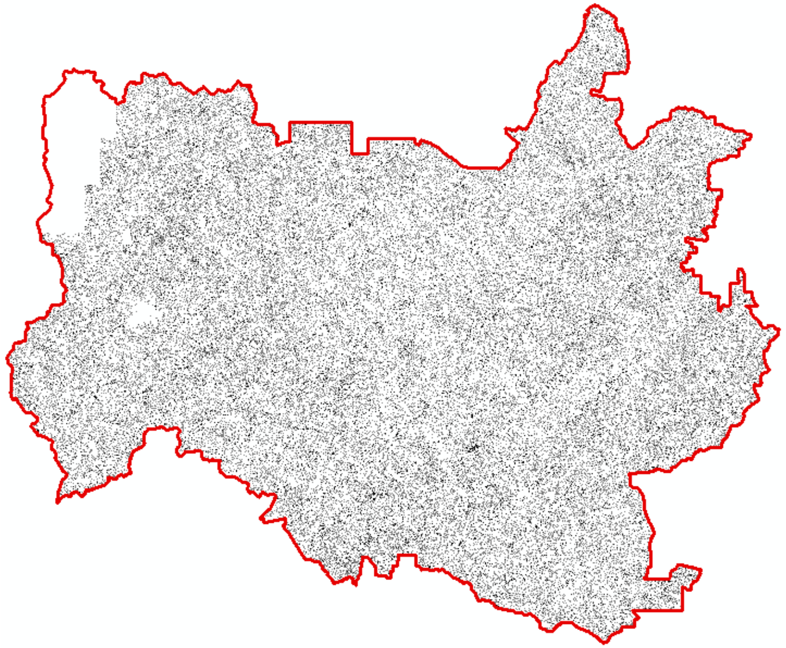
Gurley et al. 2023 ScienceBase

Geospatial datasets generated from lidar for years 2013, 2015, 2022

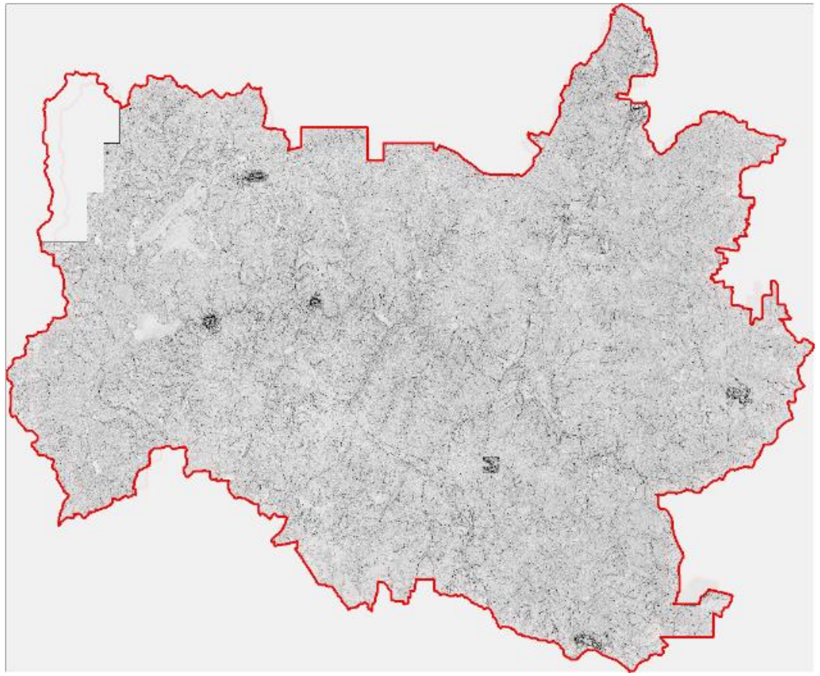
1-m DEM



Point density



Landscape openness

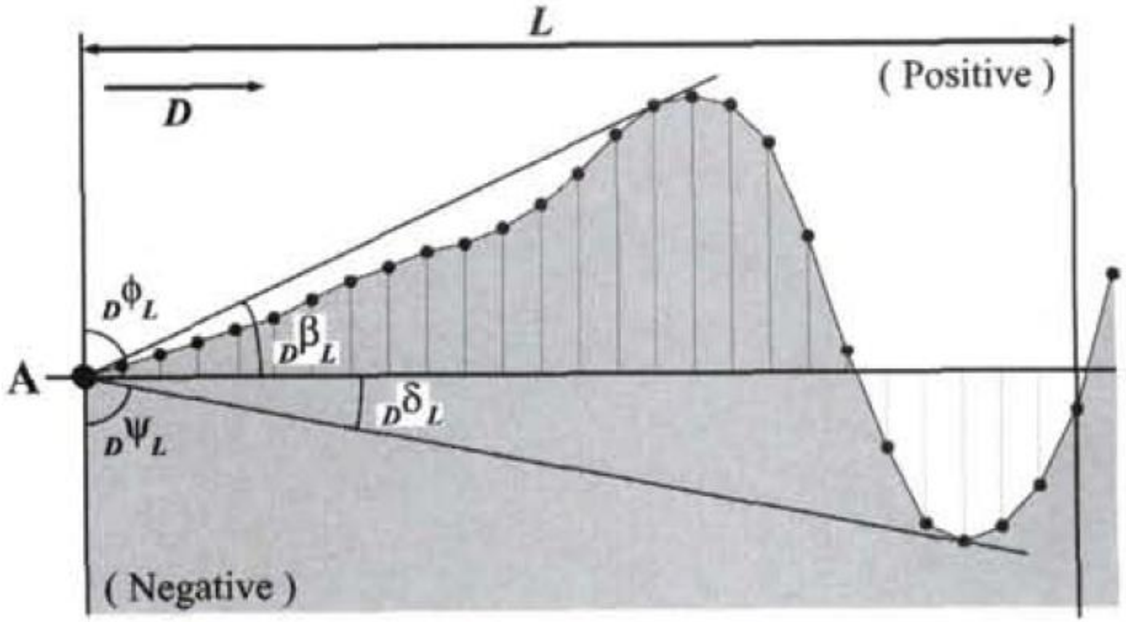


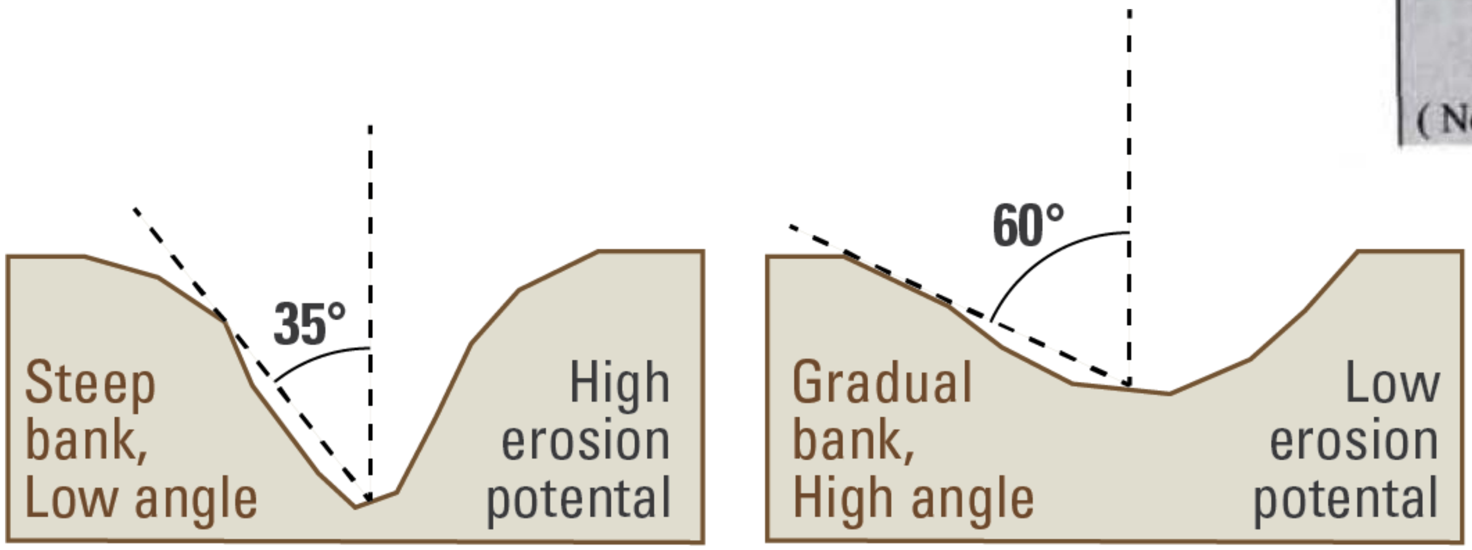
USGS

[Gurley et al. 2023 ScienceBase]

What is positive openness?

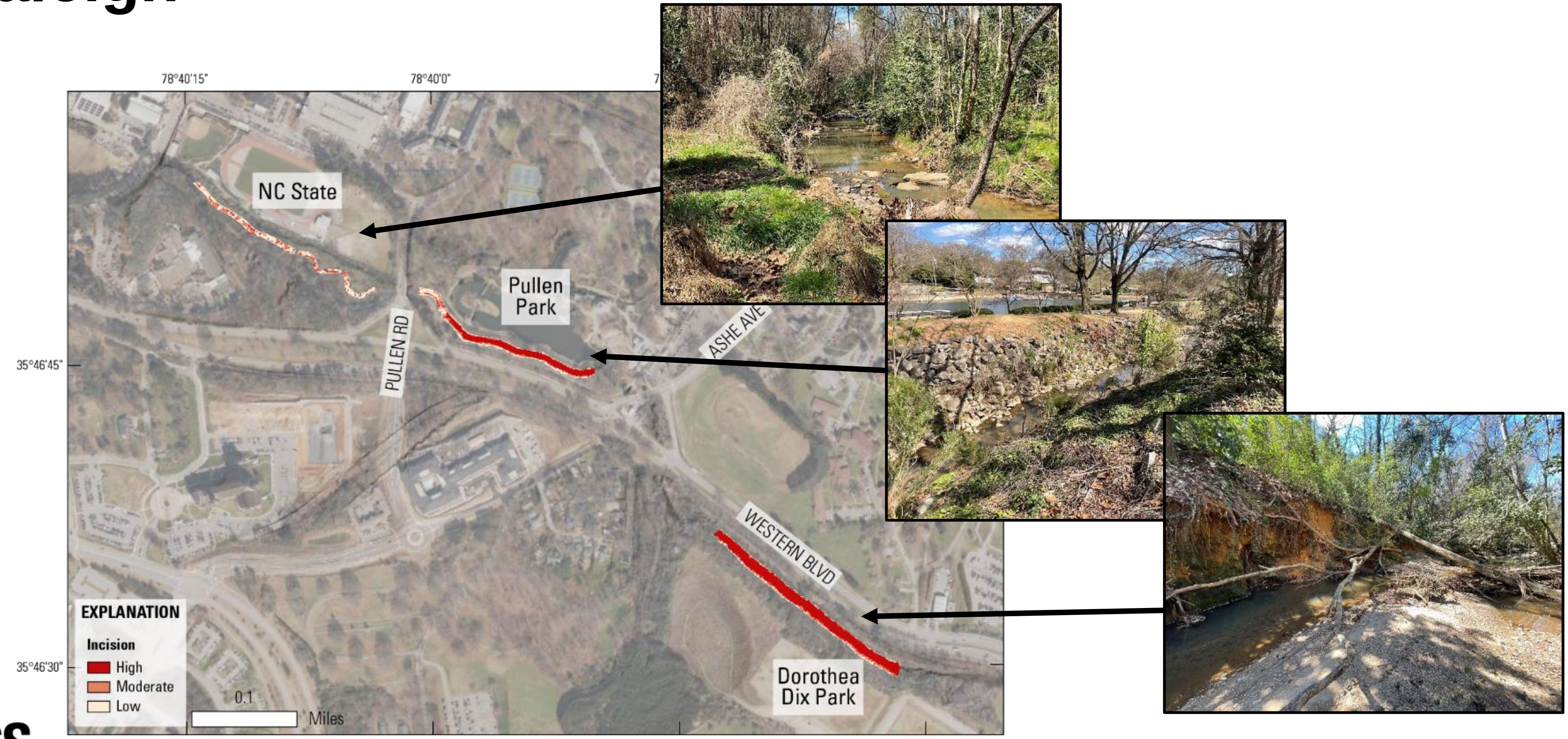
- Calculates mean horizon elevation angle
- 16 directions, search radius of 60ft
- Low values indicate a steep bank
- High values indicate gradual sloped bank





Yokoyama 2002 *PE&RS*

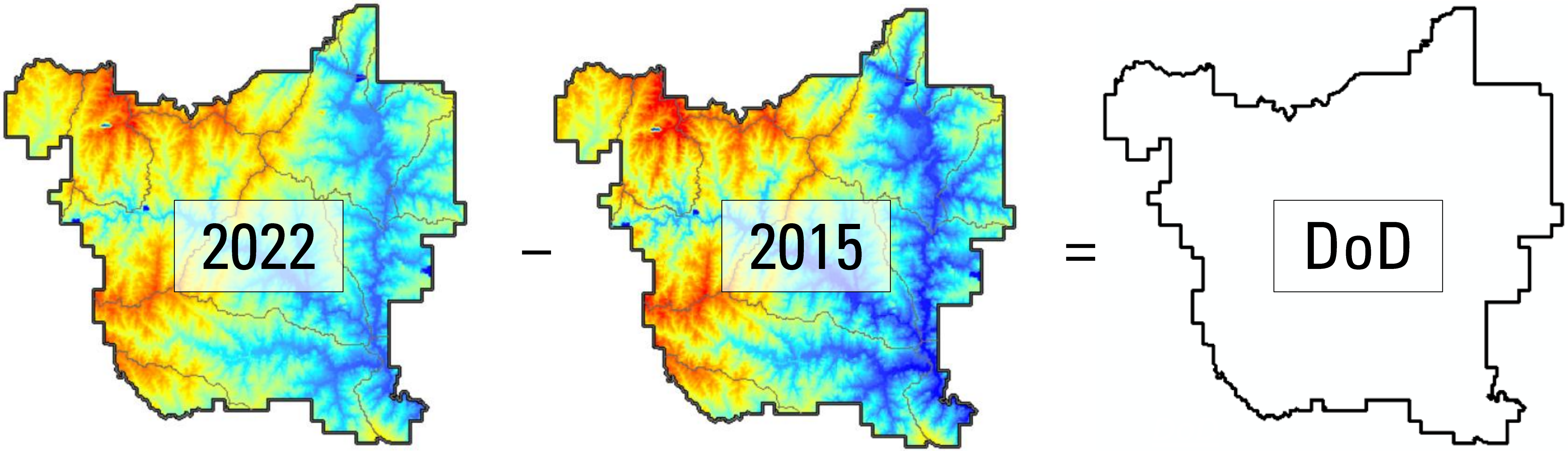
Positive landscape openness along Rocky Branch in Raleigh



USGS

Generating a DEM of Difference (DoD)

- Subtract elevation in the 2015 DEM from the 2022 DEM
- Propagated error from both datasets and removed differences within error



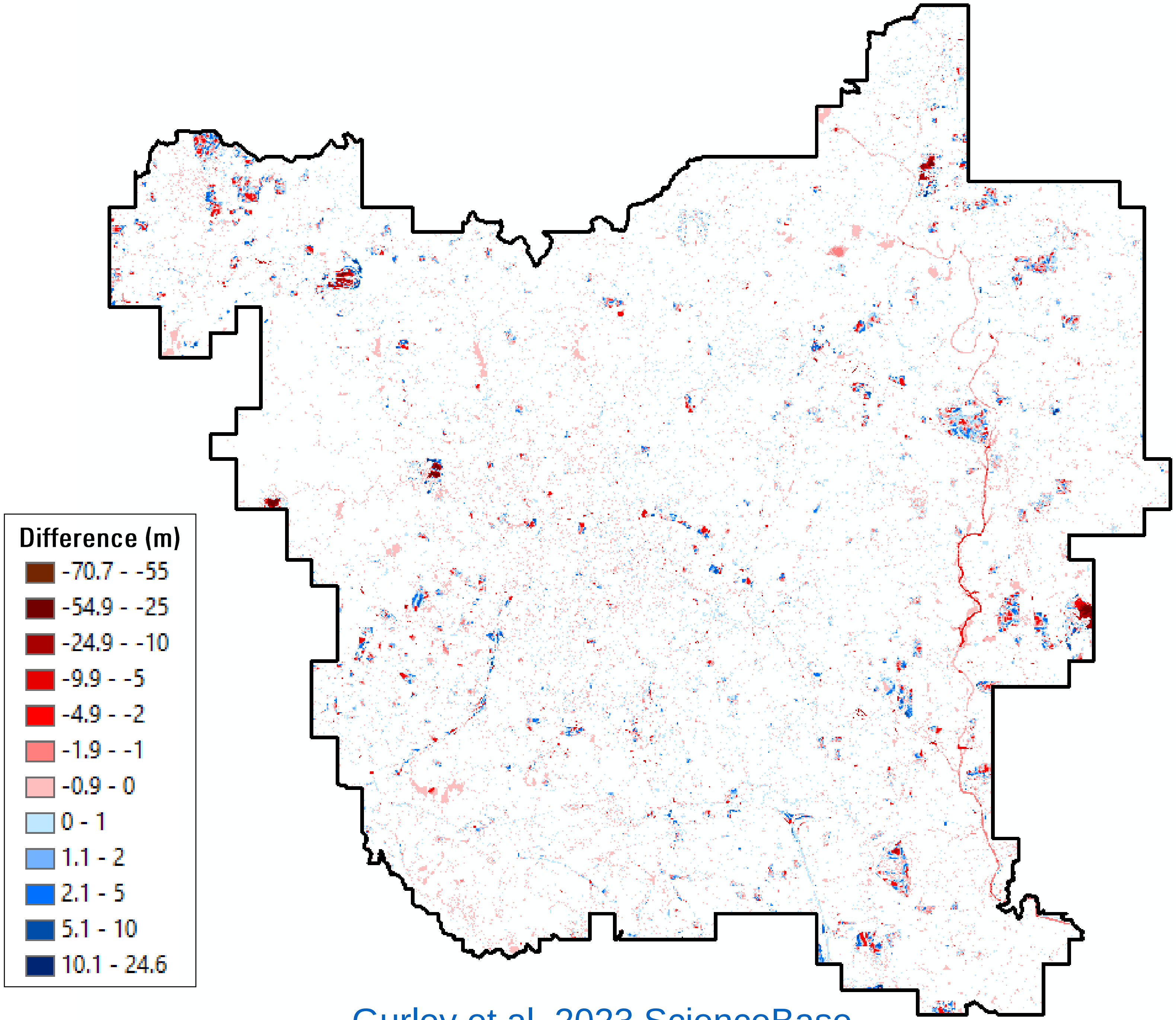
- negative result = erosion
- positive result = deposition

USGS

DEM of Difference

Overall

- Elevation decreasing – erosional – Red
- Elevation increasing – depositional – Blue
- Stand out features

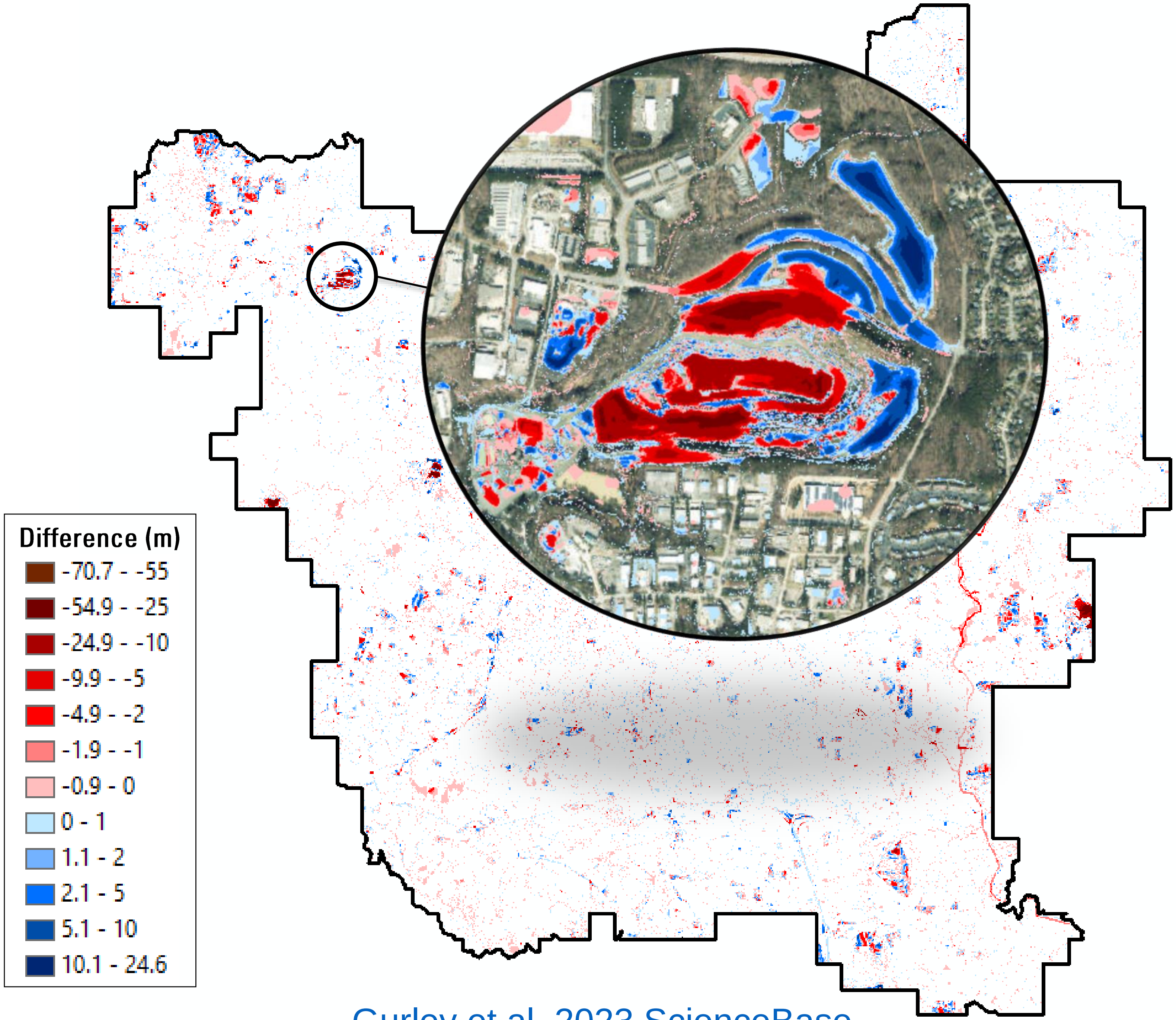


Gurley et al. 2023 ScienceBase

DEM of Difference

Overall

- Elevation decreasing – erosional – Red
- Elevation increasing – depositional – Blue
- Stand out features
  - Quarries

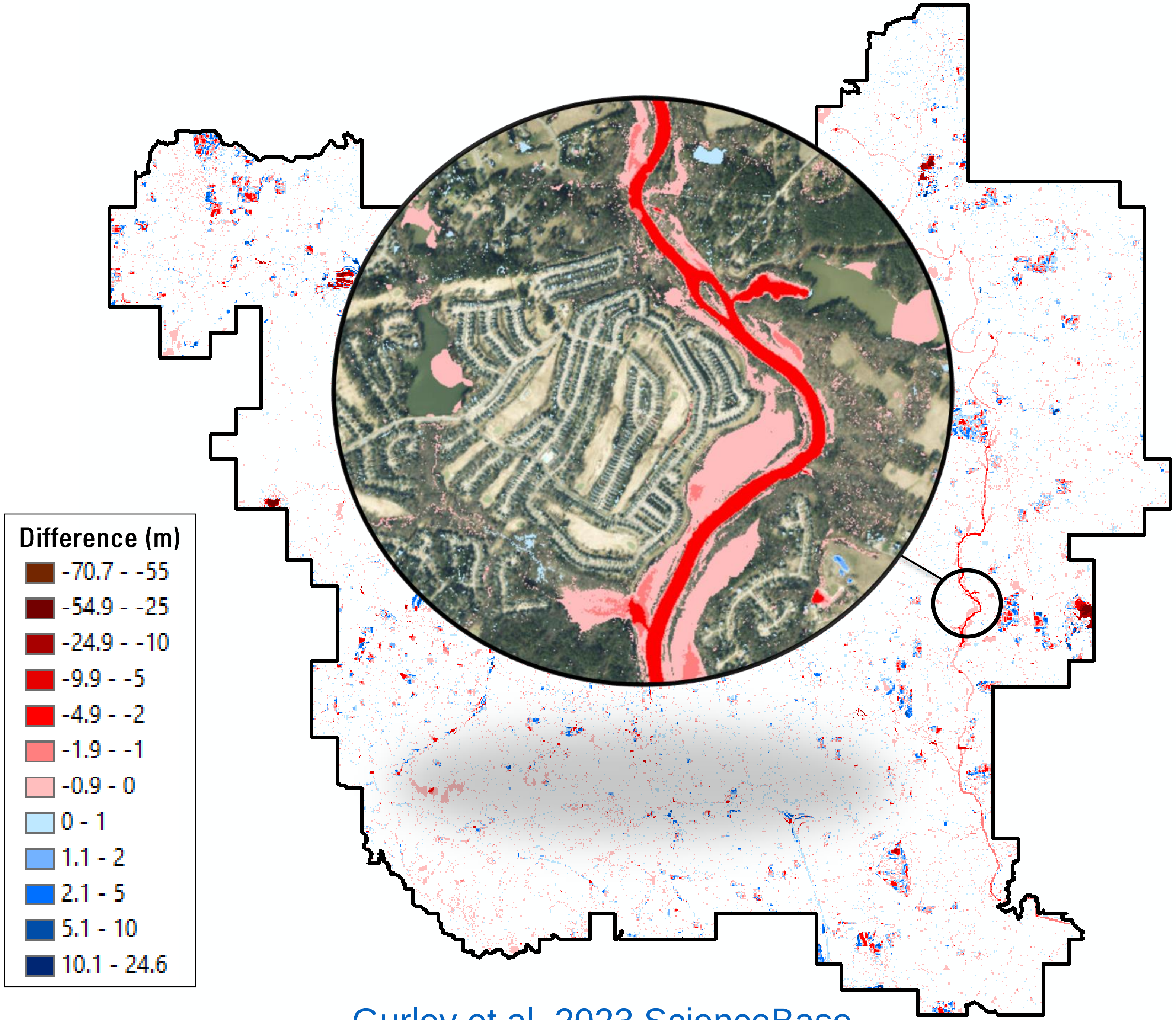


Gurley et al. 2023 ScienceBase

DEM of Difference

<u>Overall</u>

- Elevation decreasing – erosional – Red
- Elevation increasing – depositional – Blue
- Stand out features
  - Quarries
  - Water level



[Gurley et al. 2023 ScienceBase]()

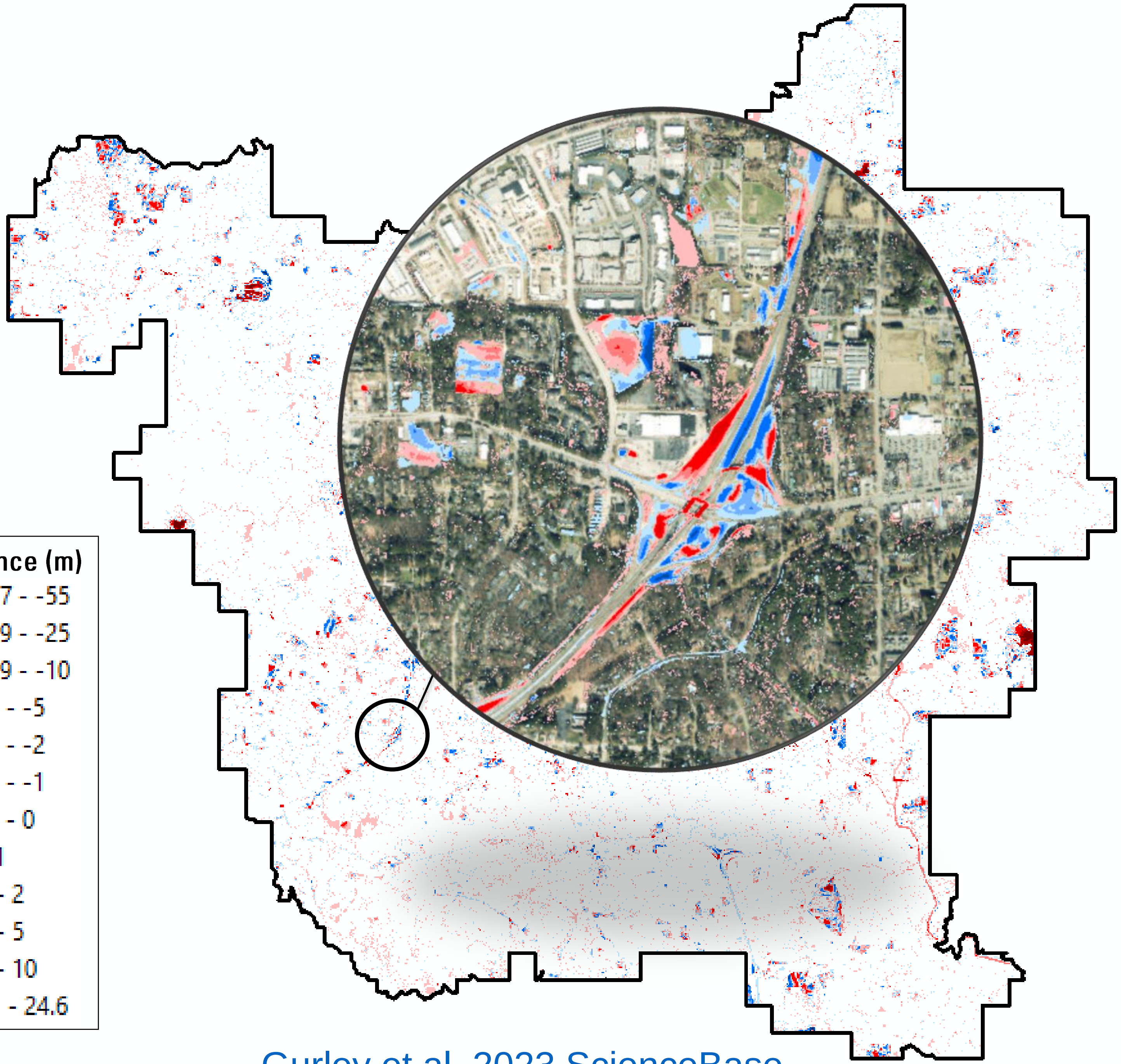
USGS

DEM of Difference

Overall

- Elevation decreasing – erosional – Red
- Elevation increasing – depositional – Blue
- Stand out features
  - Quarries
  - Water level
  - Construction

Difference (m)
- -70.7 - -55
- -54.9 - -25
- -24.9 - -10
- -9.9 - -5
- -4.9 - -2
- -1.9 - -1
- -0.9 - 0
- 0 - 1
- 1.1 - 2
- 2.1 - 5
- 5.1 - 10
- 10.1 - 24.6



Gurley et al. 2023 ScienceBase

USGS

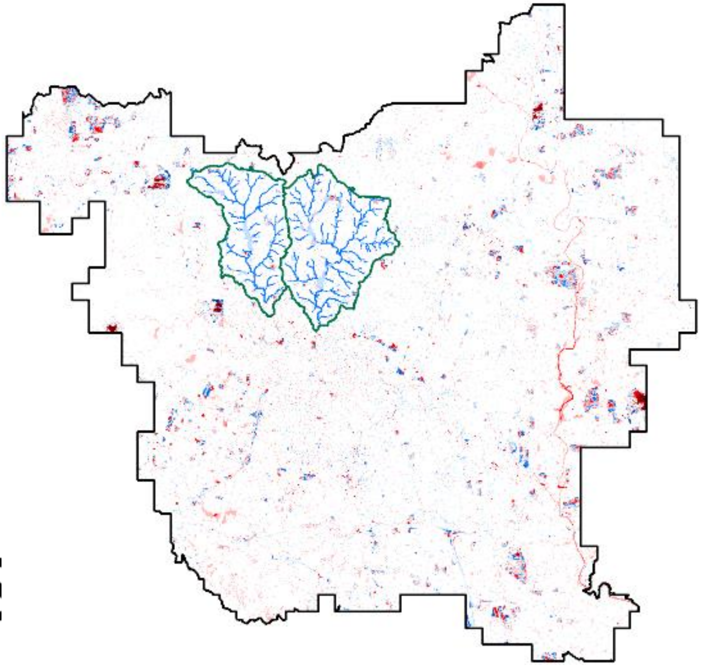
DEM of Difference

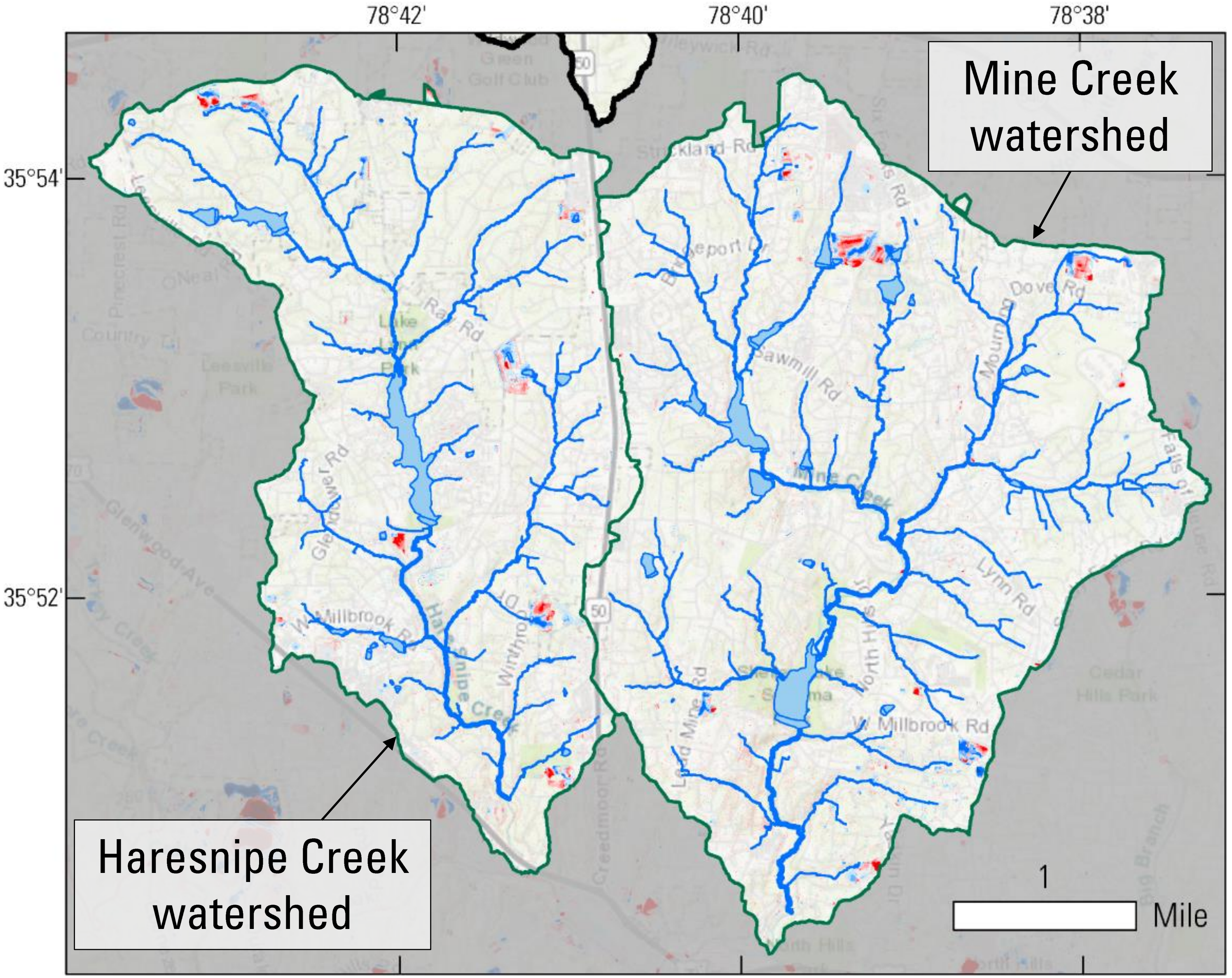
Focusing in on streambanks

• Haresnipe and Mine Creek watersheds

•Stream segments break at confluences (n=335)

•Buffered stream segments and quantified erosion





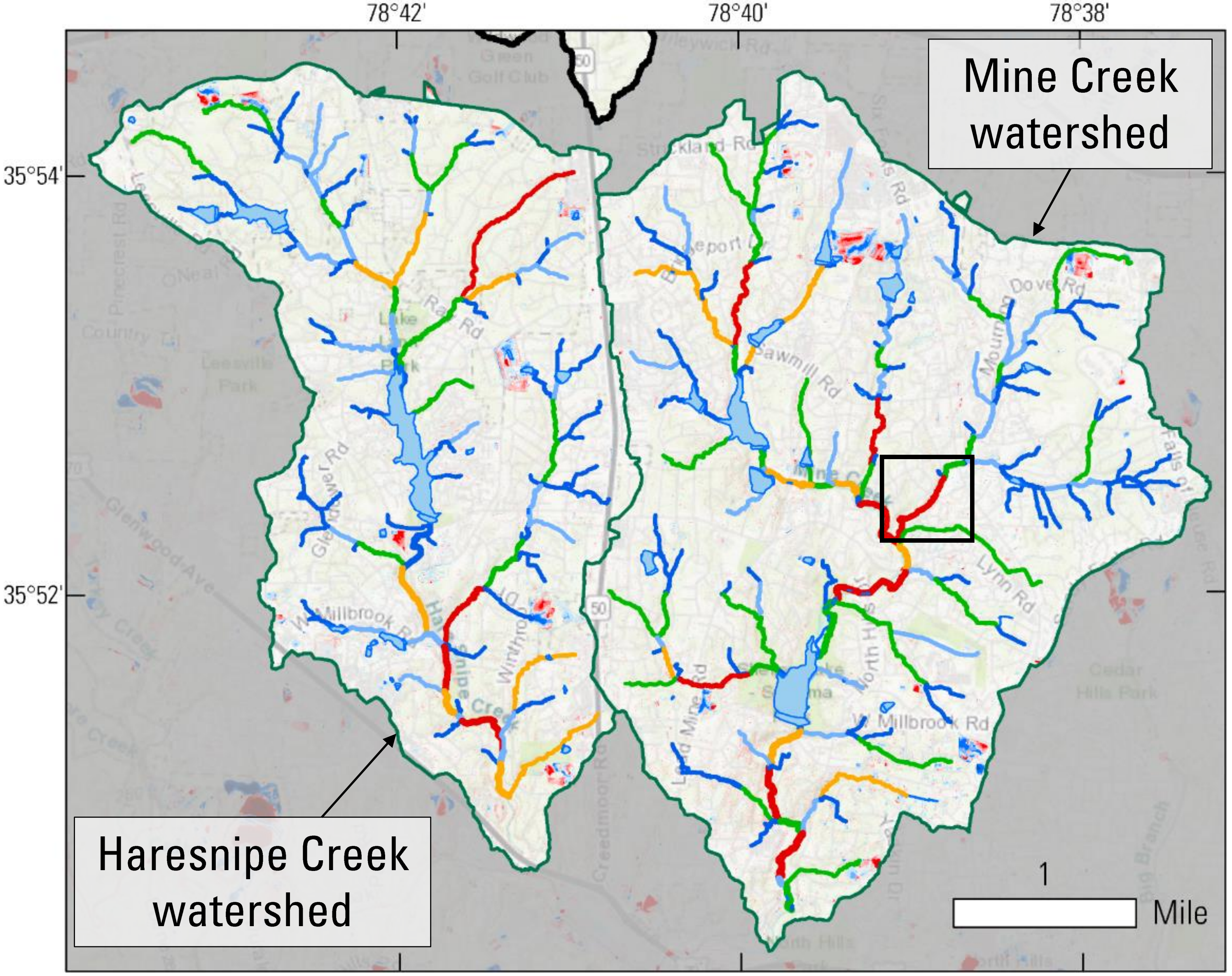
USGS

Preliminary Information-Subject to Revision. Not for Citation or Distribution.

DEM of Difference

Focusing in on streambanks

- Volume of sediment erosion within stream buffers
- Up to ~2,500 m^3 → approximately could fill an Olympic size swimming pool
- Hotspots tended to be longer stream segments – more bank to erode



Volume of sediment erosion (meters)

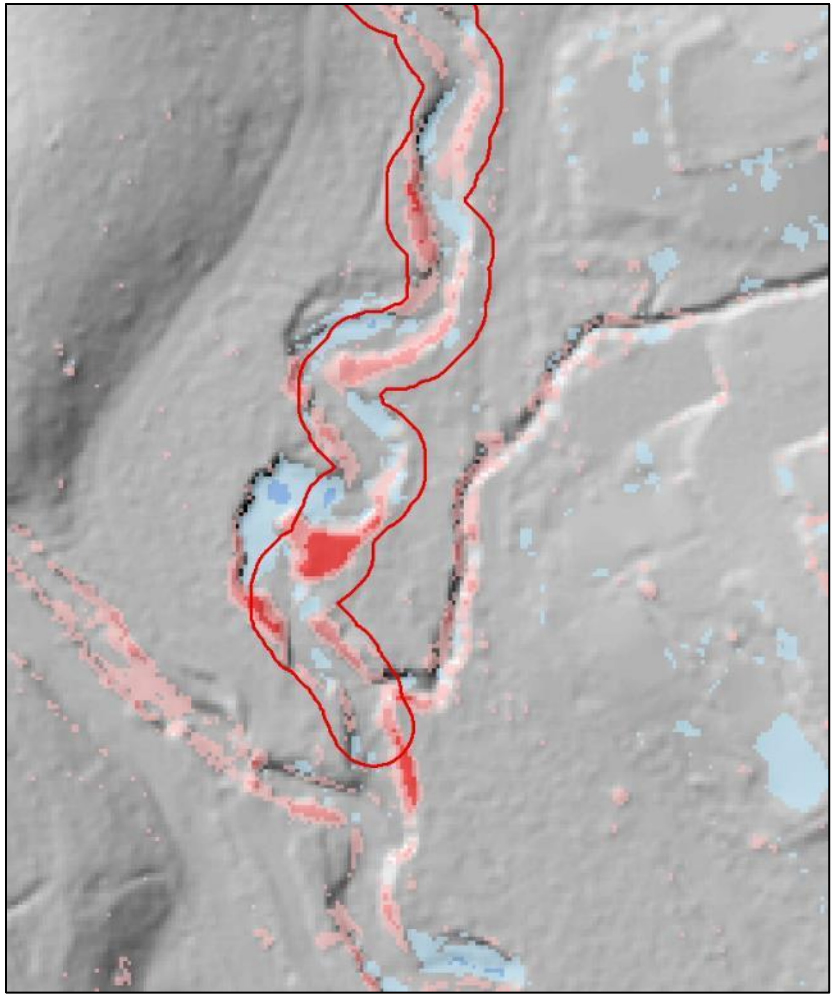
- -2592.8 - -1500
- -1499.9 - -1000
- -999.9 - -500
- -499.9 - -250
- -249.9 - 0

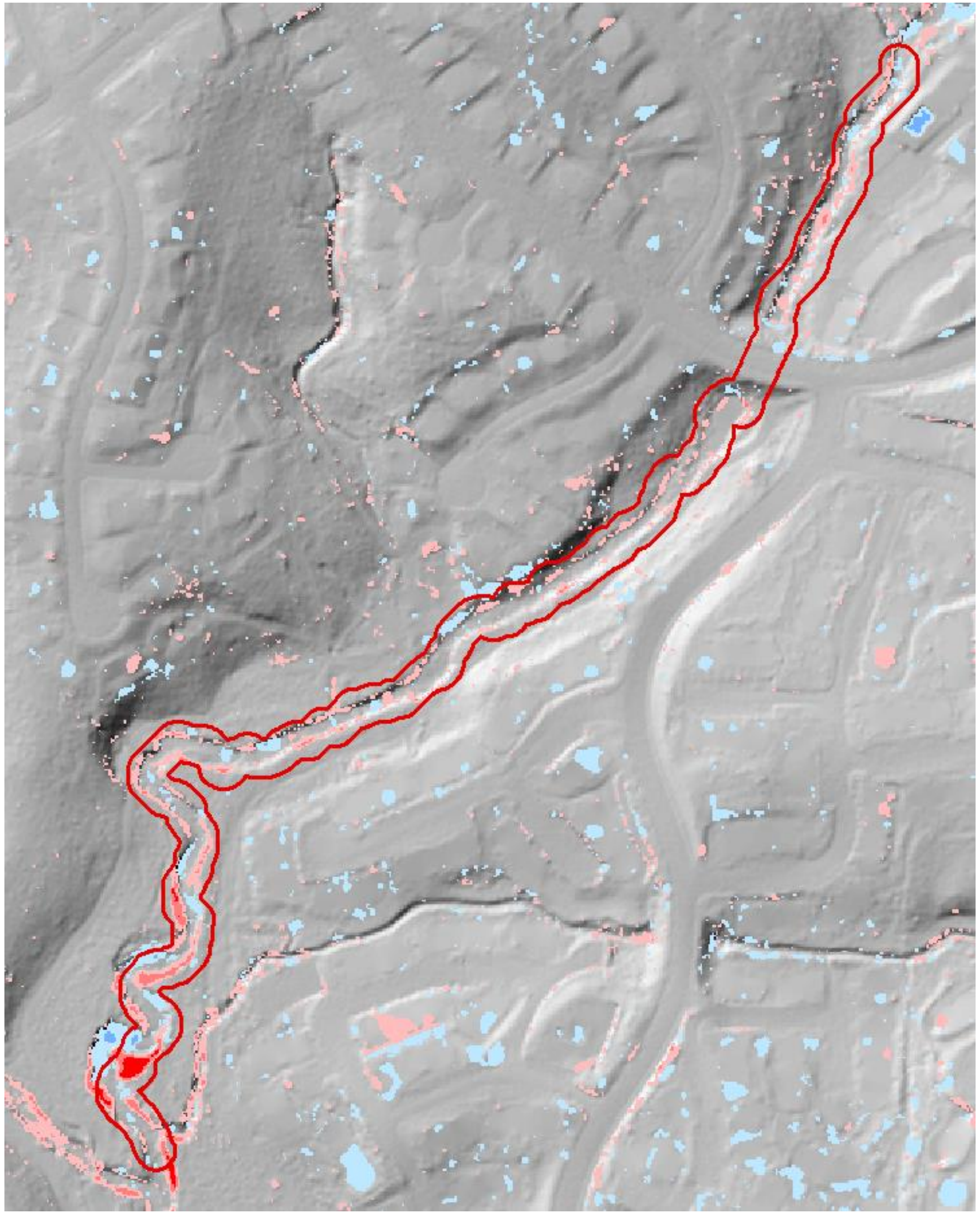
USGS

DEM of Difference

Focusing in on streambanks

- Volume of sediment erosion within stream buffers



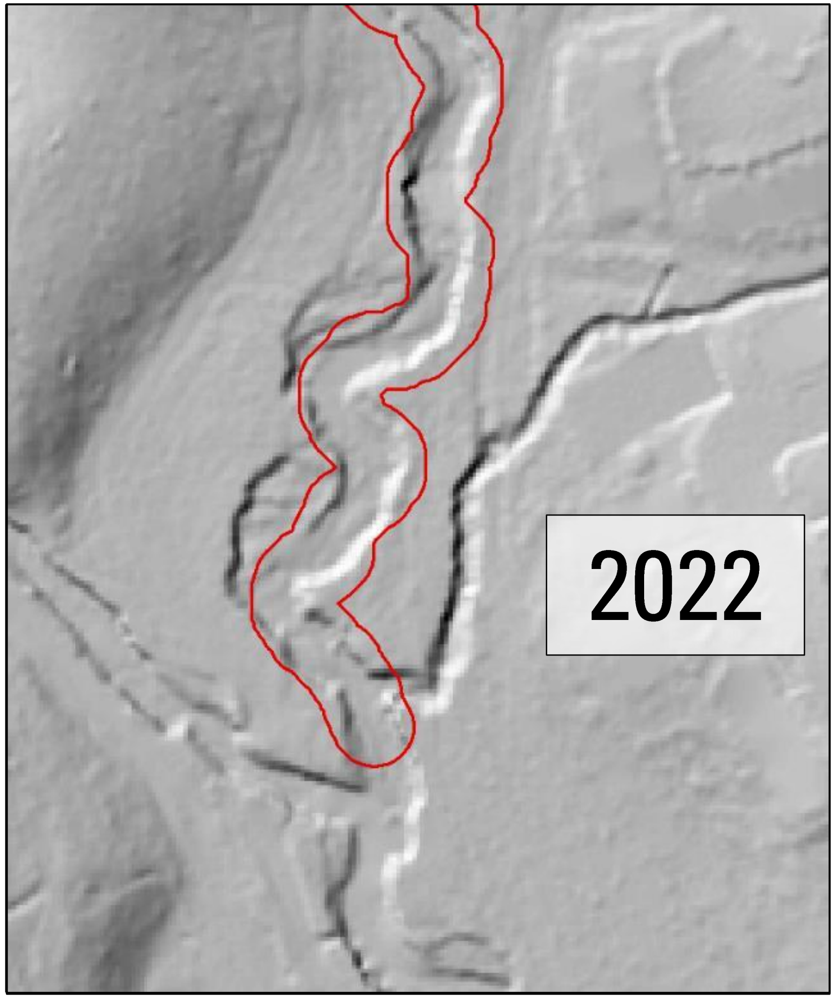


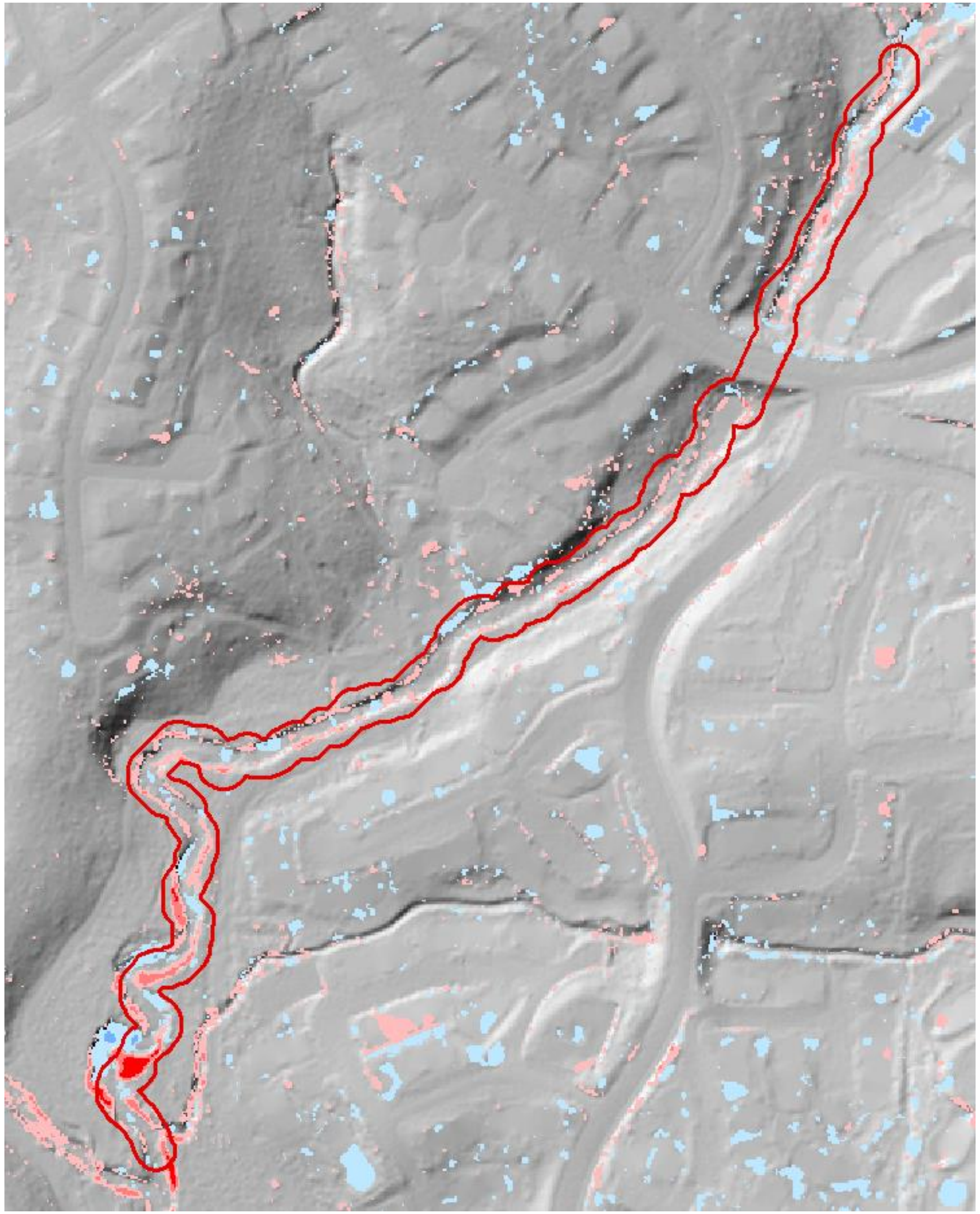
Preliminary Information-Subject to Revision. Not for Citation or Distribution.

DEM of Difference

Focusing in on streambanks

- Volume of sediment erosion within stream buffers





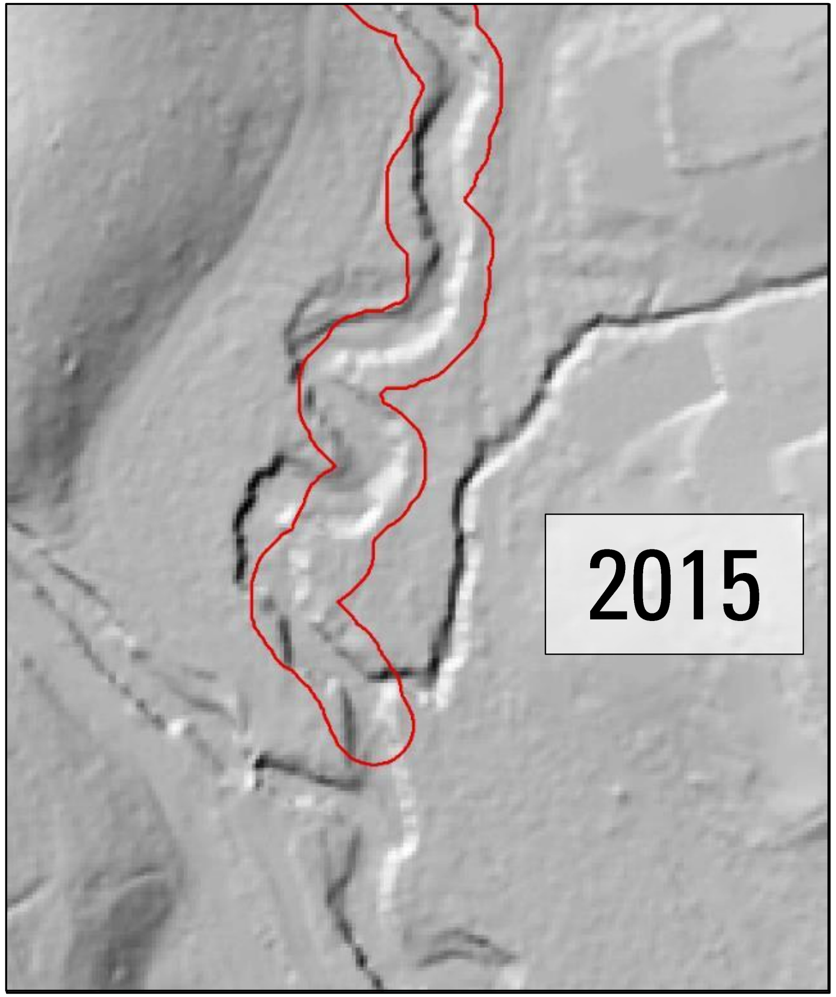
USGS

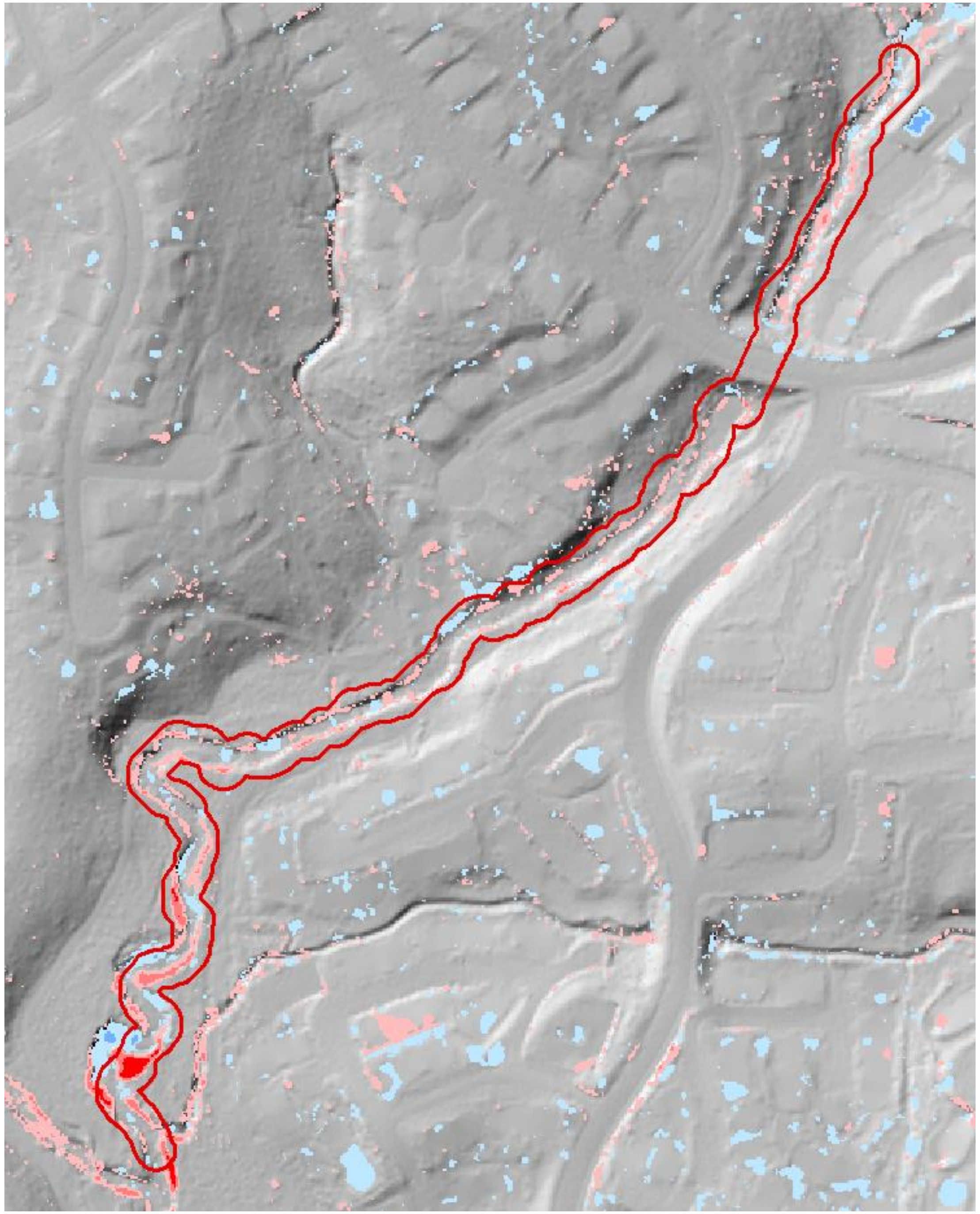
Preliminary Information-Subject to Revision. Not for Citation or Distribution.

DEM of Difference

Focusing in on streambanks

- Volume of sediment erosion within stream buffers



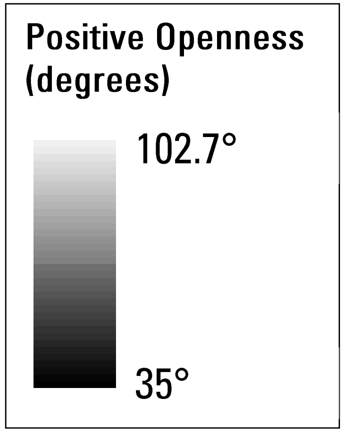


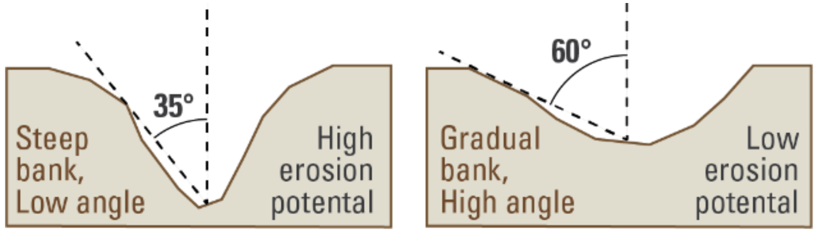
Preliminary Information-Subject to Revision. Not for Citation or Distribution.

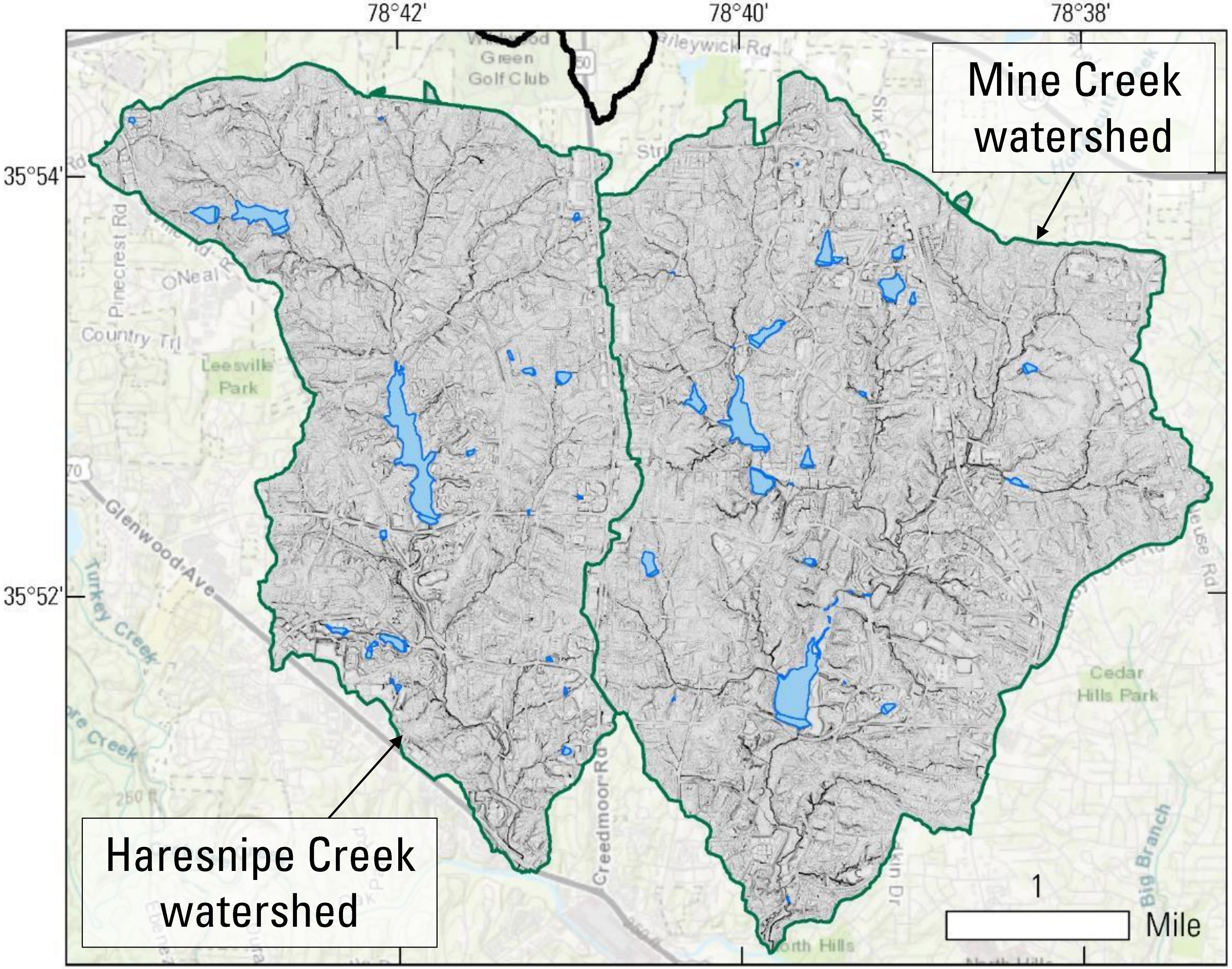
Positive Openness

Focusing in on streambanks

- Map of positive openness
- Darker = lower openness = more incised







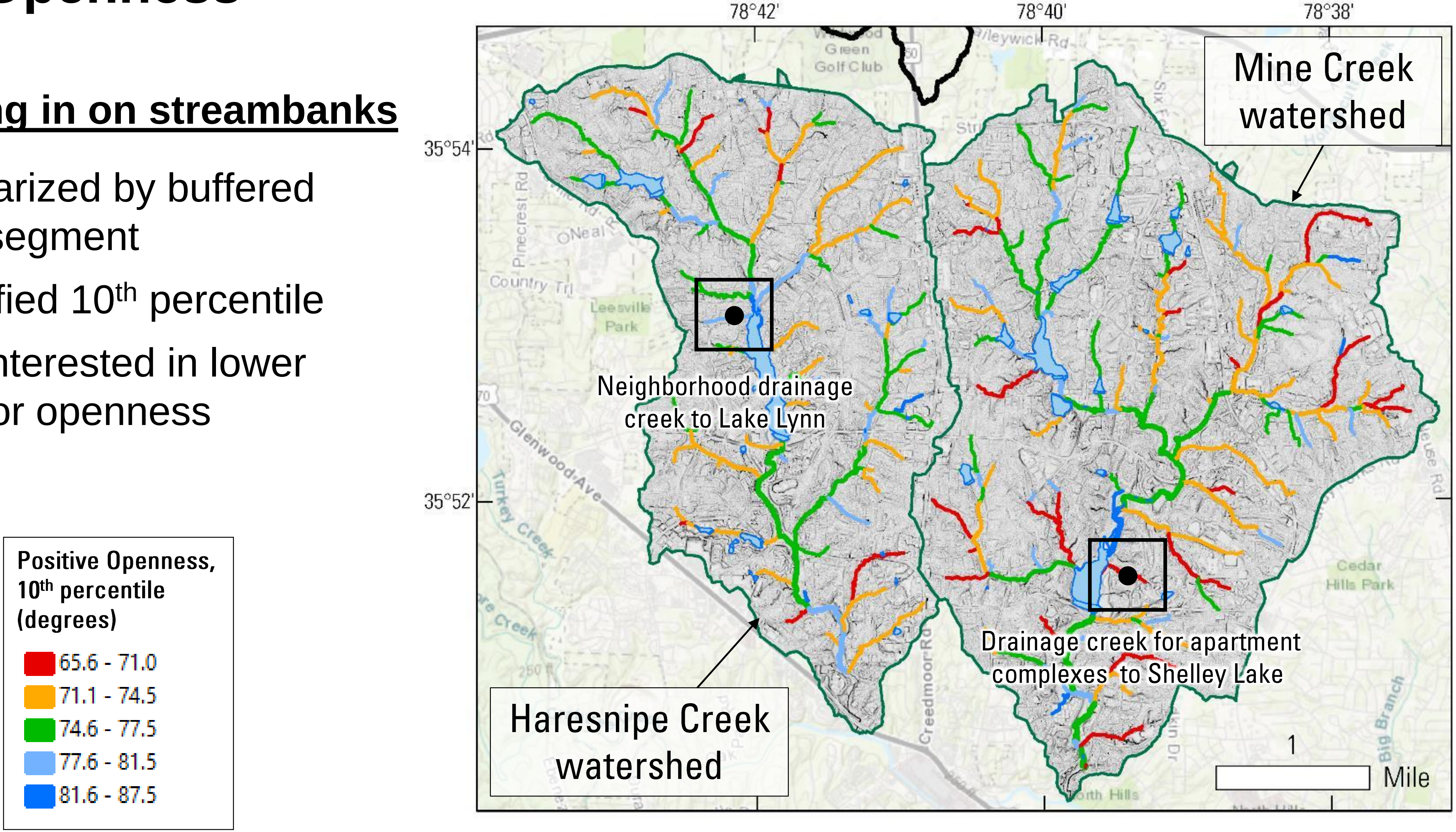
USGS

Preliminary Information-Subject to Revision. Not for Citation or Distribution.

Positive Openness

Focusing in on streambanks

- Summarized by buffered stream segment
- Quantified 10th percentile
- More interested in lower values for openness



USGS

Examples of openness along a stream reach

Higher Openness

Lower Openness

USGS

Gurley et al. 2023 ScienceBase

Working toward a solution

Assess streambank erosion hotspots along the City of Raleigh's stream network to support the City's efforts of prioritizing future stream mitigation projects.

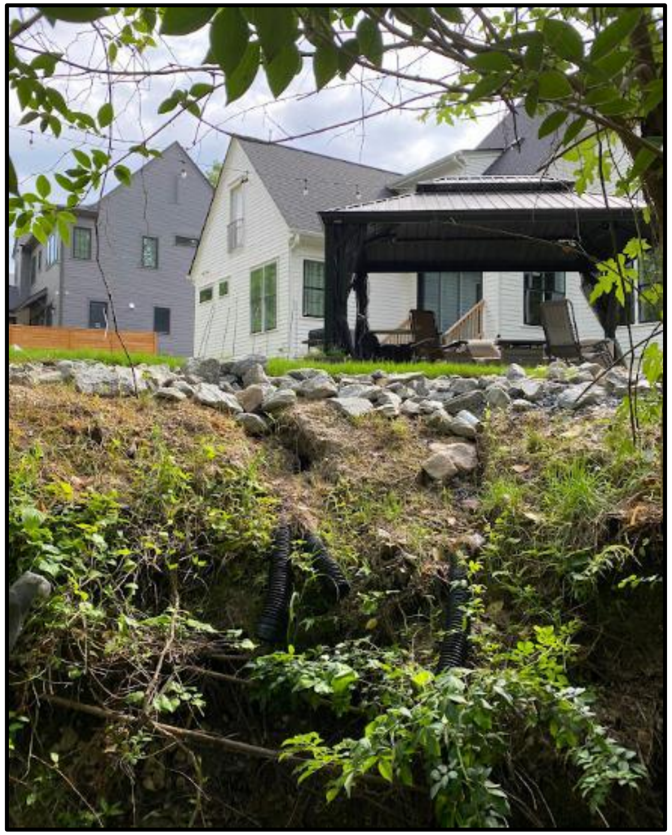
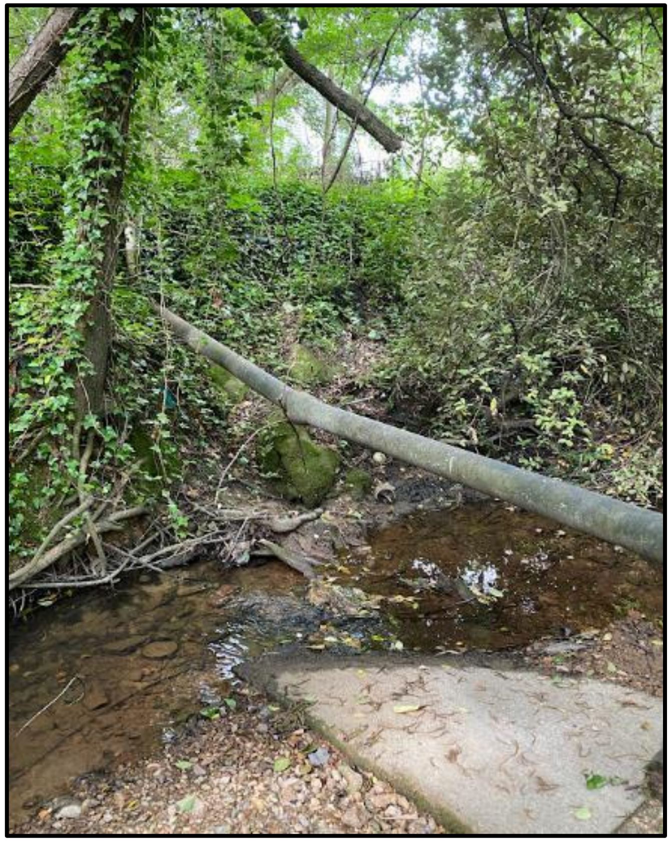
Objectives

1. Conduct **field assessment** of streambank erosion potential at select stream reaches
2. Develop **geospatial datasets** that can be used as a proxy to map potential streambank erosion hotspots
3. Assess **proximity of infrastructure** to erosion hotspots
4. Develop **model to predict** streambank erosion potential using geospatial and field datasets

USGS Raleigh

Reach level to targeted infrastructure

- What infrastructures should we consider?
- Assess the proximity of those infrastructure features to erosion hotspots

Developed list of potential applications for infrastructure assessment

BRAINSTORM

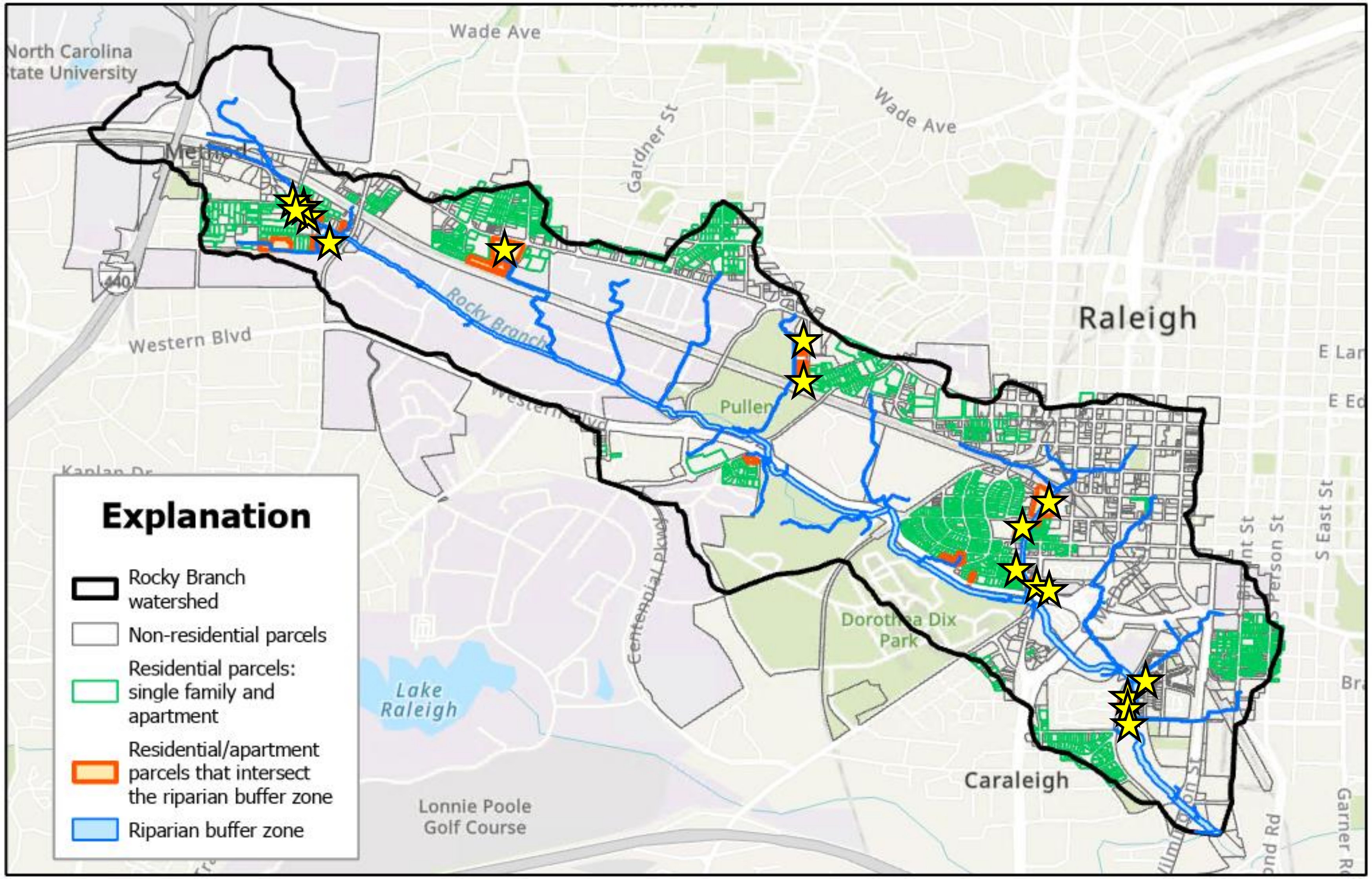
- Backyard stream stabilization
- Park trails and greenways
- Road transportation infrastructure
- Culverts
- Major stormwater outfalls
- Sewer mains
- Other utility infrastructure (gas, water, etc.)

Selected infrastructures

1. **Residential backyard streambank erosion**
2. Greenway trails
3. Sewer mains

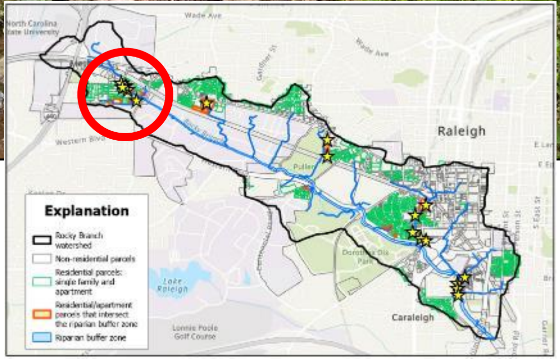
Backyard residential: Rocky Branch

- Assessed residential riparian buffer
- 55 parcels were within the buffer zone
- Summarized negative change in the DoD within the riparian buffer
- **17 properties had at least one pixel with more than 0.5 m erosion**

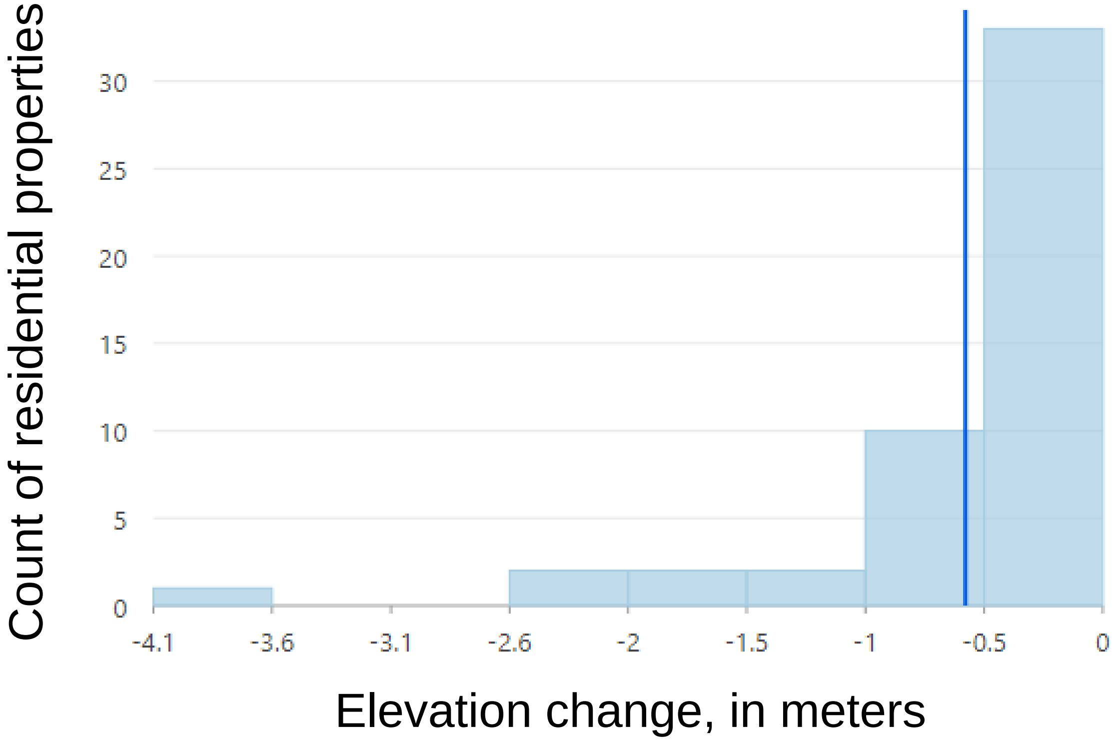


Backyard residential: Rocky Branch

- Example of erosion detected at Royal St property
- Approx. 2 meters elevation change



Distribution of minimum elevation change detected in the riparian zone of residential property



Working toward a solution

Assess streambank erosion hotspots along the City of Raleigh’s stream network to support the City’s efforts of prioritizing future stream mitigation projects.

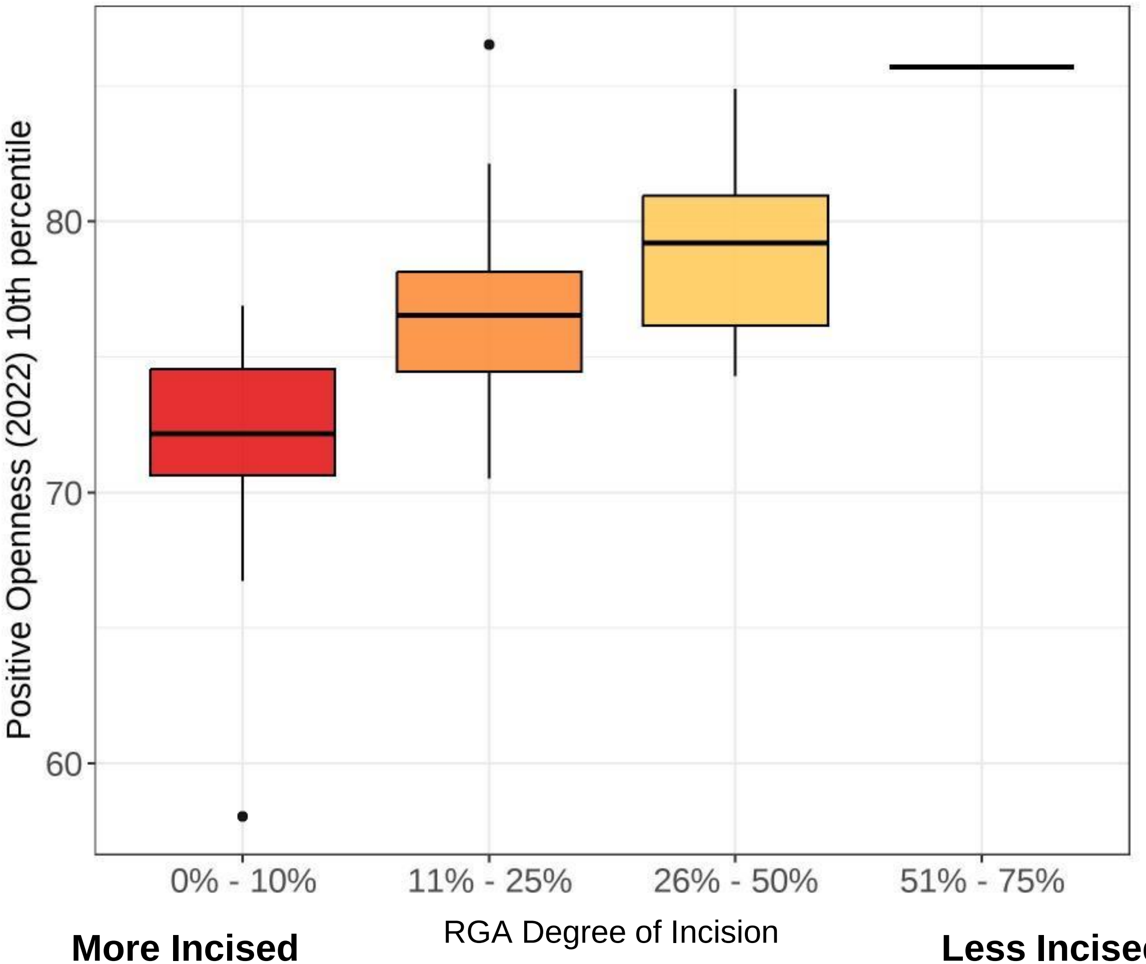
Objectives

1. Conduct **field assessment** of streambank erosion potential at select stream reaches
2. Develop **geospatial datasets** that can be used as a proxy to map potential streambank erosion hotspots
3. Assess **proximity of infrastructure** to erosion hotspots
4. Develop **model to predict** streambank erosion potential using geospatial and field datasets

USGS Raleigh

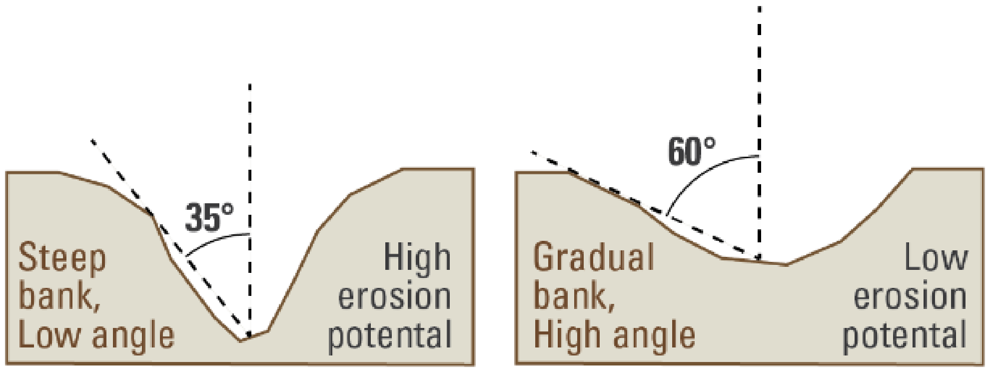
Openness and incision

Exploring patterns between field and geomorphic variables



More Incised **Less Incised**

Positive Openness



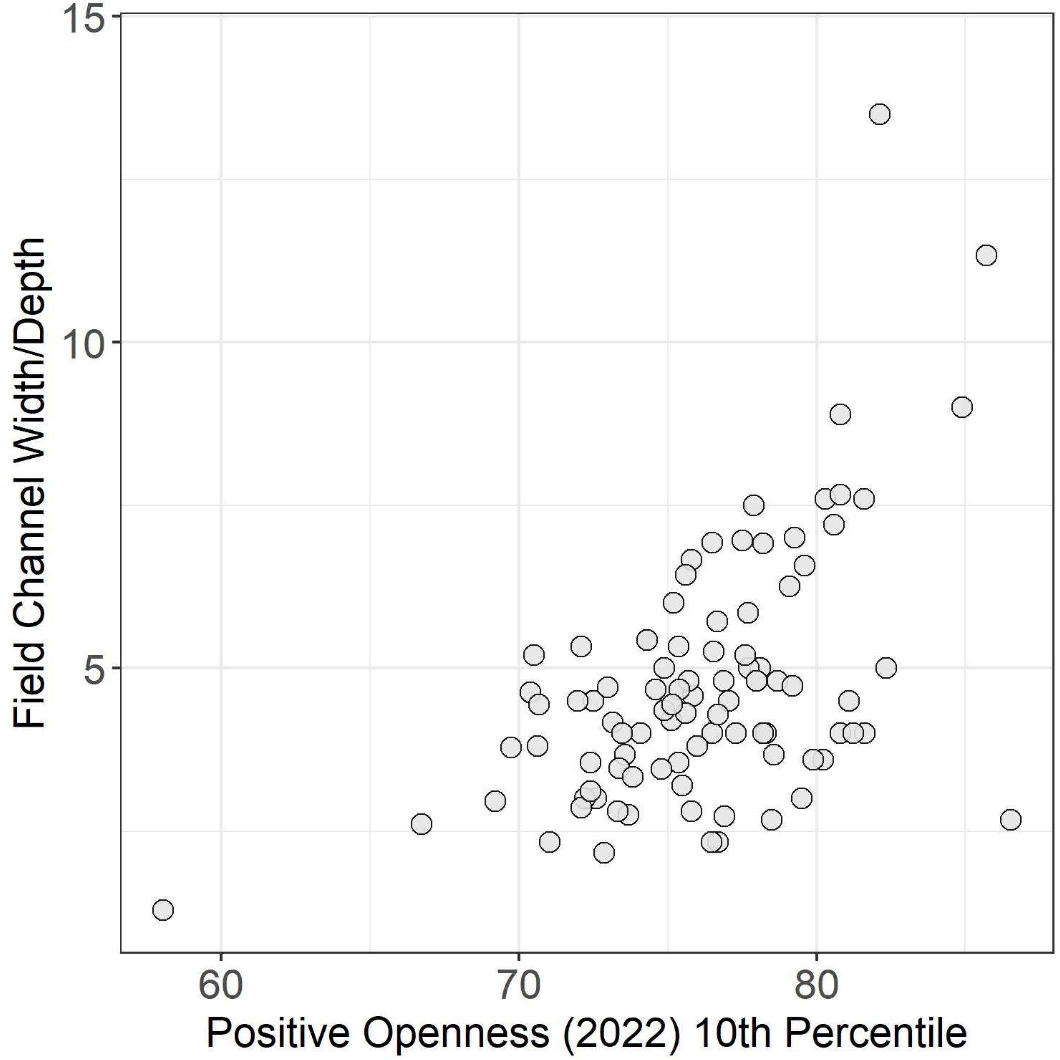
Rocky Branch along Dorothea Dix Park

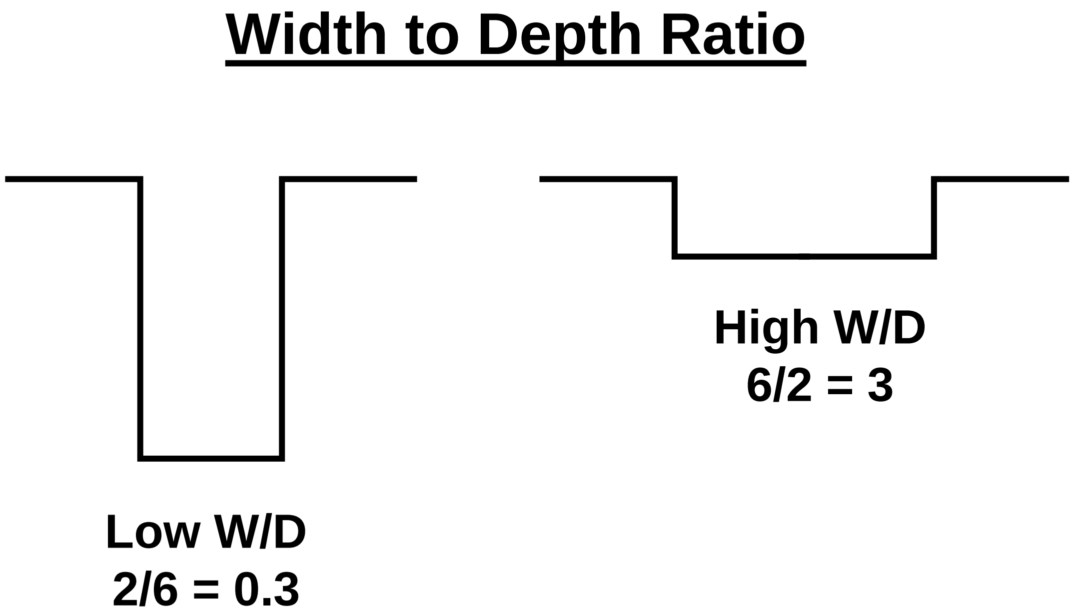
Rocky Branch through NC State

Preliminary Information-Subject to Revision. Not for Citation or Distribution.

Openness and incision

Exploring patterns between field and geomorphic variables

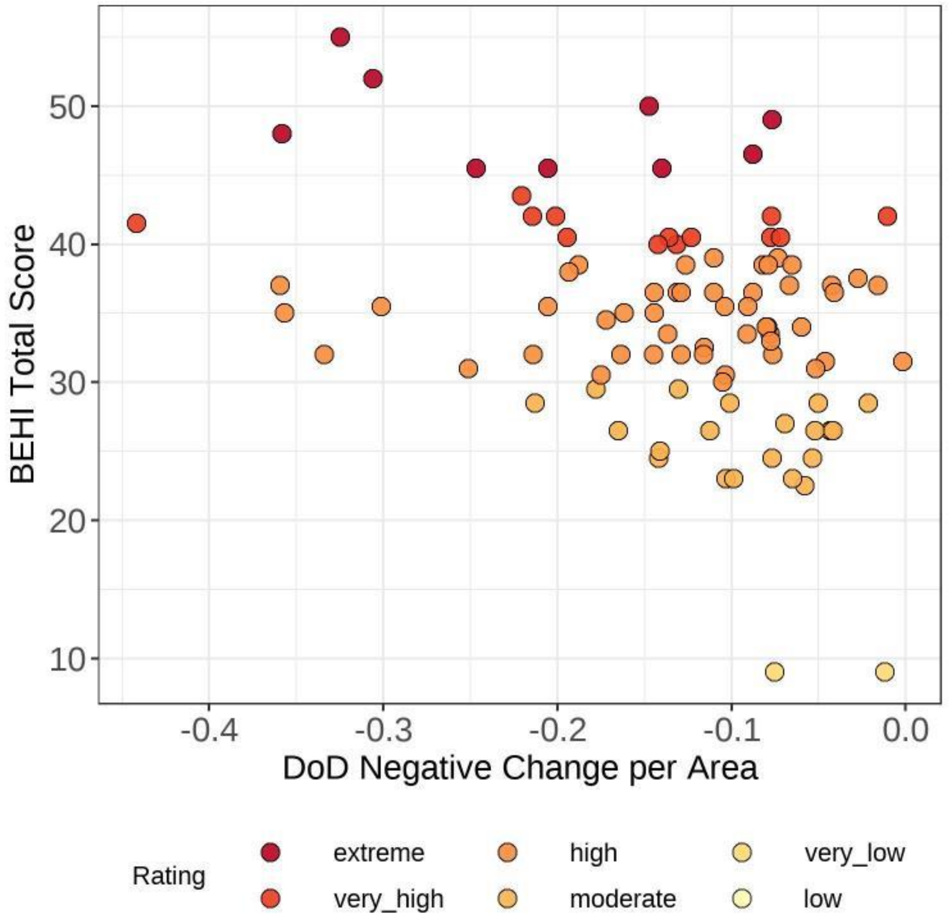




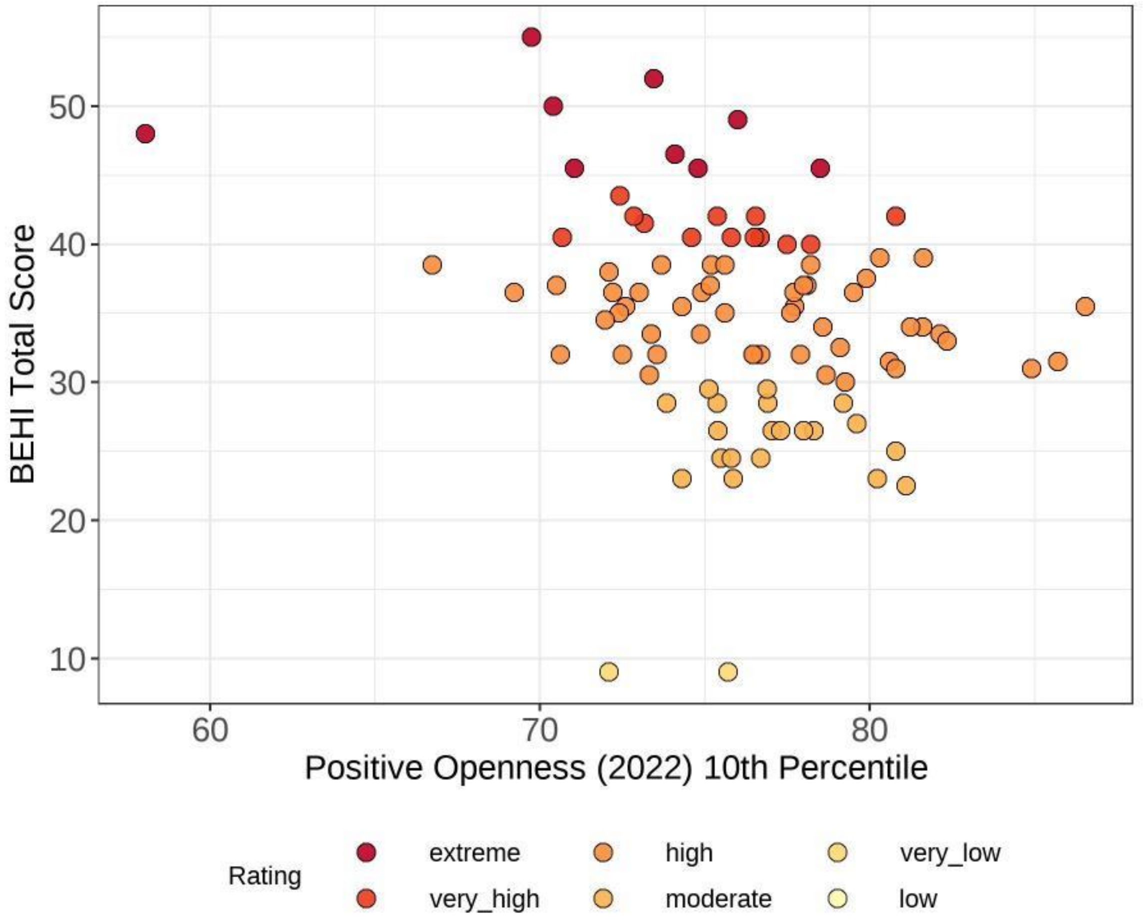
Preliminary Information-Subject to Revision. Not for Citation or Distribution.

BEHI scores and geospatial proxies

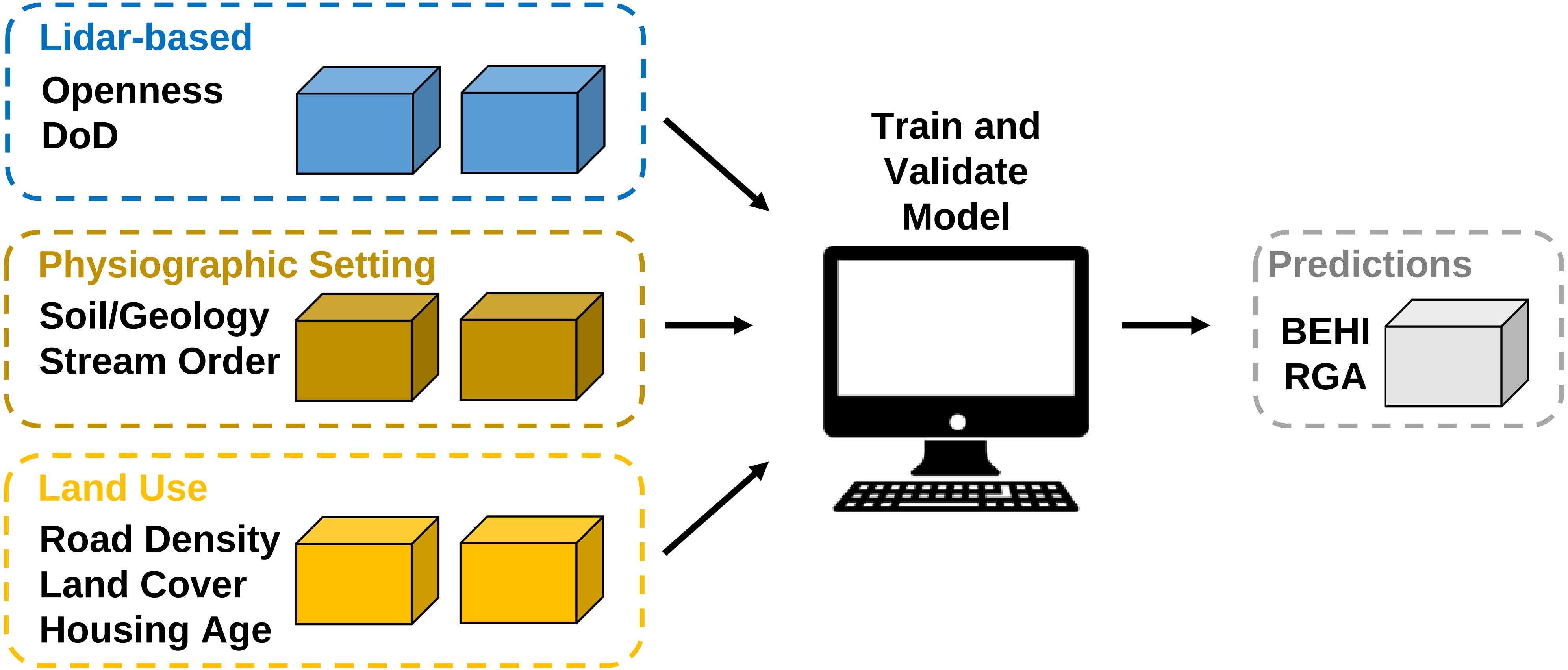
Higher BEHI scores more negative change in the DEM of difference



Less correlation between BEHI and openness



Next Steps: Machine Learning Model Development



Preliminary Information-Subject to Revision. Not for Citation or Distribution.

Summary

Can we remotely map streambank erosion hotspots from the sky?

- We know streambank erosion is a problem in the Piedmont.
- DoD/openness **shows where** erosion is happening, the model should help us **understand why**.
- Interested to explore methods in **other settings** and see if there a links to **water quality patterns.**

QR link to project page

Krissy Hopkins
khopkins@usgs.gov

USGS