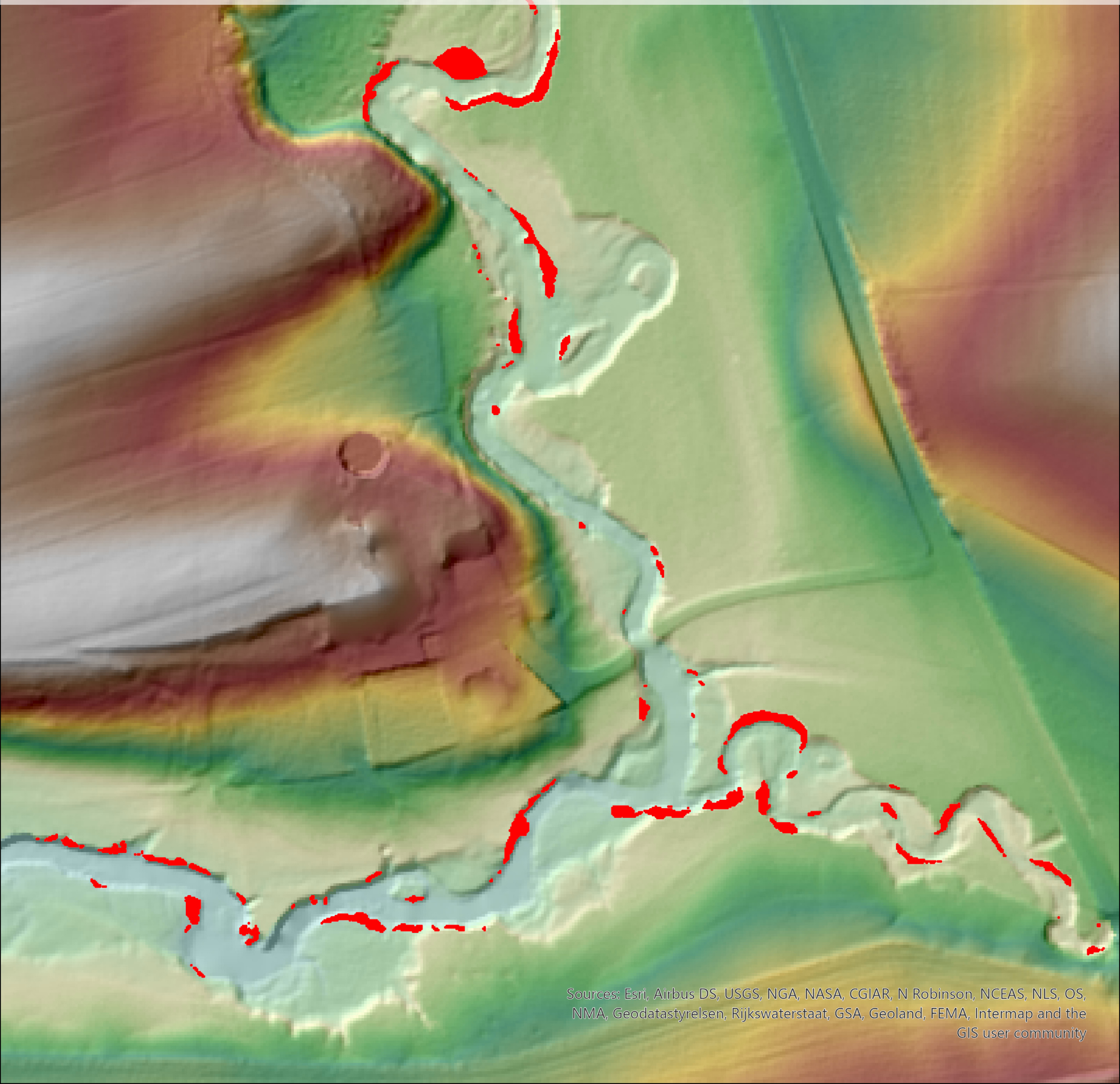
CRESCENDO IN COLLABORATION
LEGACY SEDIMENT 2.0 DECISION SUPPORT TOOL

FINAL REPORT AND USER GUIDE

A LANCASTER CLEAN WATER PARTNERS - WATER SCIENCE INSTITUTE PROJECT
UNDER AN MOU WITH THE CONSERVATION FOUNDATION OF LANCASTER COUNTY

Funded by the National Fish and Wildlife Foundation and the Steinman Foundation



CRESCENDO IN COLLABORATION

Final Report and User Guide

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Report Cover: a significant stretch of Little Beaver Creek experiencing rapid erosion, 2019 lidar DEM

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I. Introduction

The Lancaster Clean Water Partners (the Partners) have been exploring opportunities for identifying and prioritizing nutrient and sediment reductions to the Chesapeake Bay and achieving local clean water goals. Developing more precise decision-support tools that improve potential project site selection allows the Partners to make more efficient and cost-effective use of state and local resources required to implement best management practices (BMPs) for state TMDL reductions, municipal MS4 permit obligations, and local water quality improvements. Advanced tools will also increase the Partners technical support capacity needed to achieve collaborative goals, including the removal of 350 miles of Lancaster County streams from the Pennsylvania DEP list of impaired waterways. This removal or "delisting" is a significant element of the Partners approach to "clean, clear, water by 2040".

Sediment (S) reduction is a central element of these improvement strategies, in part because it can be a direct measure of BMP success. Sediment also serves as a placeholder for Nitrogen (N) and Phosphorus (P) nutrient loads to streams. Together S, N, and P are significant pollutants that collectively affect the chemistry and shape public perception of local water's health, economic, recreational and aesthetic value. In the Chesapeake Bay, sedimentation and turbidity loads play a vital role in defining the health of ecosystems supporting submerged aquatic vegetation (SAV) and native oysters. Due to historical land use practices and radical anthropogenic alteration of valley bottoms, primarily from milldam construction and operation, immense quantities of fine sediment were trapped behind dams and deposited atop wetlands that had functioned for thousands of years prior to European settlement (Walter and Merritts, 2008). This sediment, commonly known as legacy sediment (LS) because it is a legacy of earlier generations, was deposited in newly formed slack water environments (mill ponds) that typically stretched for several miles behind individual impoundments. The Chesapeake Bay Program's Scientific and Technical Advisory Committee (STAC) defines legacy sediment as "sediment stored in upland and lowland portions of the Bay's tributary watersheds as a byproduct of accelerated erosion caused by landscape disturbance following European settlement, most prominently in the Piedmont and Coastal Plain provinces" (Miller et al., 2019). From historical records, it is estimated that an average density of 0.14 to 0.15 dams per km^2 in Pennsylvania was present by the mid-nineteenth century (Walter and Merritts, 2008). Similar densities in other mid-Atlantic states demonstrate that the deposition of LS behind stream impoundments is ubiquitous in the Chesapeake Bay watershed. Once a milldam is breached, the former impoundment drains, exposing the trapped sediment to erosive conditions and forms a single channel stream that continues to erode LS at significant rates for decades (Merritts et al., 2013). Legacy sediment is most often found morphologically in stream system valley bottoms as paired fill terraces; flat on the surface and roughly the height of the former milldam that was the limit of sediment deposition in the slack water environments. Today, due to improved land use practices, the erosion of upland sediment into streams has decreased while the contribution of fine legacy sediment from stream bank erosion has dramatically increased. Today, stream bank erosion is the primary source of sediment, and associated nitrogen and phosphorus, contributing 50-90% of the total load for watersheds flowing into the Chesapeake Bay (Gellis and Sanisaca, 2018; Langland et al., 2020). Given the significant role that sediment plays in "listing" impaired streams, identification of areas with high stream bank erosion is part of the Partners' comprehensive initiative for data acquisition and capacity building.

The Water Science Institute (WSI) has been an advocate and innovator in applying accurate and advanced techniques for site specific and regional data mapping projects in the Chesapeake Bay watershed. The focus of our mapping efforts is providing conservation practitioners with comprehensive data analysis to support BMP strategies that address holistic edge-of-stream and in-stream conservation and restoration plans. As a leader in practical applications of lidar (Light Detection and Ranging), we utilize precise, three-dimensional datasets to interpret landscape change that informs resource prioritization strategies. Using digital elevation models (DEMs) generated from 2014-2019 public lidar datasets of Lancaster County, we quantified differences in stream bank elevations between the two datasets to identify where the rate and volume of bank retreat and erosion is occurring. Mapping the entire county allows users to compare the relative rate of erosion by area and identify “hotspots” that can be prioritized for further investigation.

Our partners at the Pennsylvania Natural Resource Conservation Service (NRCS) and the Steinman Foundation of Lancaster County have supported these local watershed initiatives including the development of more refined and enhanced lidar differencing techniques for prioritizing potential restoration locations. The Partners, with funding from the National Fish and Wildlife Foundation administered by the Conservation Foundation of Lancaster County, also support WSI’s mapping and field work to collaboratively promote County strategic water quality goals associated with stream delisting, data capacity building, and identification of potential restoration catchments. These datasets will be incorporated with additional WSI data layers into the Partner’s Collaborative Watershed Mapping Tool 2.0. WSI deliverables include: 2019 Lancaster lidar DEM, canopy data, stream bank erosion polygons, legacy sediment terrace polygons, hotspot and heat map capability, and historical milldam locations.

II. Descriptions of Deliverables

1) 2019 Lancaster lidar

- The 2019 Lancaster County lidar dataset was funded by NRCS and is part of the USGS 3D Elevation Program (3DEP). This project's 2014 and 2019 lidar datasets were accessed using the Pennsylvania Spatial Data Access (PASDA) public geospatial data portal. The goal of the 3DEP program is to acquire consistent high-resolution nationwide lidar datasets that help inform critical county-wide decisions that depend on elevation data. This current dataset for Lancaster County complements earlier datasets (2008 and 2014) and surpasses them in quality. Compared with our original DEM differencing data, using 2008 and 2014 lidar, provided to the Partners for Collaborative Watershed Mapping Tool 1.0, the latest dataset has significantly higher resolution and reduced uncertainty. When mapping landscape change, determining uncertainty is an important consideration in remote sensing applications, particularly at a county-wide scale since it allows practitioners to compare potential opportunities relative to one another. By contrast, field scale mapping is less efficient, comprehensive, accurate and more expensive to perform at the county level.

2) Canopy data

- The canopy DEM was generated from the 2014 lidar point cloud dataset and displays canopy height and cover throughout the county. Each raster cell can be individually selected to collect and display canopy height.

3) Stream bank erosion polygons

- DEMs were created using lidar datasets from 2014 and 2019 to determine the ~ 4-year rate of change along stream channels to evaluate bank erosion within Lancaster County watersheds. From the DEMs, we created a difference raster to locate changes in elevation between 2014 and 2019. We performed a level of detection (LoD) change analysis at a 95% confidence interval with a variable, roughness-dependent level of uncertainty. We turned the difference raster dataset into 146,520 individual 2D shapefile polygons representing 3D change of stream banks. In the ~ 4-year study period, the average surface area of all erosion polygons is 36 ft.^{2} and the average volume loss is 2.6 tons (~5,200 lbs.), which equates to an annual erosion rate of 0.61 tons/yr. (~1,200 lbs./yr.) for all polygons. The total volume loss from all polygons, which represents our estimated average annual sediment load from bank erosion for Lancaster Co., equals ~80,000 tons/yr. (~160,000,000 lbs./yr). The attribute table contains data for individual polygons, including surface area (expressed in ft.^{2}), volume of sediment lost in the 2014-19 period (expressed in tons, cubic yards, and lbs.), annual erosion rate (expressed in tons/yr., cubic yards/yr., and lbs./yr.), and an erosion rate uncertainty percent (expressed in decimal form).

4) Legacy sediment terrace polygons

- Since legacy sediment terraces are nearly flat, it is possible to confidently map these surface areas and quantify how much sediment is contained in an area of interest. legacy sediment terraces were identified and mapped, sediment thickness was calculated for each lidar raster cell from the difference between the elevation of the terrace and the elevation of the water in the adjacent stream channel. Each terrace could then be given a value for total volume of sediment by adding all the sediment thickness measurements within each individual terrace polygon. This methodology is similar to what is detailed in Johnson et al. 2019 for mapping similar watersheds in the mid-Atlantic. We mapped legacy sediment terraces adjacent to all 3rd order and larger stream channels in Lancaster County. 2nd and 1st order streams were also mapped, but not as extensively, However, these smaller order stream polygons can be individually quantified by WSI on a parcel-by-parcel basis. The average surface area of a terrace polygon is ~80,000 ft.^{2} (~1.8 acres), the average sediment volume is ~8,700 tons (~17,000,000 lbs.), and the average sediment thickness is 2.8 ft. The total mapped LS volume for the county is ~57,000,000 tons (~110,000,000,000 lbs.) and covers ~13,000 acres (~20 square miles) of surface area in valley bottoms. The attribute table contains data for each terrace polygon, including its surface area (expressed in ft.^{2} and acres), volume of sediment (expressed in tons, cubic yards, and lbs.), and average sediment thickness (expressed in ft.).

5) Hotspot maps

- Hotspot maps were created by attaching our stream bank erosion polygons to a boundary feature. We used HUC12 watersheds in Lancaster County as the primary boundary feature, but this can be adapted to include any boundary feature of interest. Hotspot maps are useful to help prioritize potential sites and field visits by identifying larger areas that are contributing relatively more suspended sediment to streams than other areas. We also attached the enhanced Lancaster stream centerlines to these maps so erosion rate per foot of stream length can also be evaluated. The attribute table includes the area of the boundary feature (expressed in square miles), stream length inside the boundary feature (expressed in miles), volume of sediment erosion between 2014-2019 (expressed in tons, cubic yards, and lbs.), annual erosion rate (expressed in tons/yr., cubic yards/yr., and lbs./yr.), annual erosion rate per stream length (expressed in tons/ft./yr., cubic yards/ft./yr., and lbs./ft./yr.), and an erosion rate uncertainty percent (expressed in decimal form).

6) Block statistics heatmap

- A density analysis takes quantities of some known event and spreads it across a landscape based on the quantity that is measured at each event and the spatial distribution of the locations of the event. The result is a density surface showing where a feature is more and less concentrated. We mapped the density of stream bank erosion in Lancaster County to identify where the highest concentration of erosion is occurring. The heatmap's primary measurement takes the form of several blocks that are ~2,000 ft. X ~2,000 ft. and contains the sum of all erosion polygons inside the bounds of each block. A total of 3,345 blocks were generated based on the location and amount of erosion measured in each polygon. The size of the blocks was selected for identifying relatively large stretches of stream that could host a significant restoration project(s). The attribute table contains data for each heatmap block, including volume of sediment lost between lidar flights (expressed in tons, cubic yards, and lbs.), annual erosion rate (expressed in tons/yr., cubic yards/yr., and lbs./yr.), and an erosion rate uncertainty percent (expressed in decimal form).

7) Historical milldam locations

- Historic milldam locations were mapped using several historical maps from different times, primarily the Bridgens' Atlas of Lancaster County (H.F. Bridgen, 1864) and the Combination Atlas Map of Lancaster County (Everts & Stewart, 1875). The attribute table contains data for each historical milldam location, including type of mill present, mill name, how the dam is represented on the map, breach status (0 = breached, 1 = intact), and source map and year. To learn more about the mapping process, visit https://anabranch.blogspot.com/.

III. Steps to Select and Develop a Stream Bank Erosion BMP Strategy

Step 1: Wide focus

Since stream bank erosion and legacy sediment terraces are a prevalent source of Lancaster County nutrient and sediment loads, we can break up our data by selecting a large boundary feature to narrow the focus for identifying potential projects. We can initially use HUC12 watersheds to quantify erosion and terrace datasets at a county-wide scale. Each mapped watershed in Lancaster County has an attribute table that includes the name of the watershed, watershed area (expressed in square miles), total stream length (expressed in miles), legacy sediment volume (expressed in tons, cubic yards, and lbs.), volume of bank sediment lost between 2014-2019 (expressed in tons, cubic yards, and lbs.), annual stream bank erosion rate (expressed in tons/yr., cubic yards/yr., and lbs./yr.), annual stream bank erosion rate per stream length (expressed in tons/ft./yr., cubic yards/ft./yr., and lbs./ft./yr.), and an erosion uncertainty percent (expressed in decimal form).

Figure 1 shows all HUC12 watersheds in Lancaster County ranked by their annual stream bank erosion rates (expressed in tons/yr.). Five data classes were categorized using the Jenks natural breaks classification method which highlights the differences between data in the five classes (de Smith, Goodchild, and Longley, 2007). In the WSI analysis, HUC12 watersheds with the highest annual bank erosion rates include Little Chiques Creek, Eshelman Run-Pequea Creek, Conowingo Creek, West Branch Octoraro Creek, Muddy Run-East Branch Octoraro Creek, and Tweed Creek-Octoraro Creek. HUC12 watersheds with the lowest relative erosion rates include Donegal Creek, Millers Run-Little Conestoga Creek, Lititz Run, and Middle Conestoga River. While watersheds with the highest relative erosion rates are the primary factor for this search, Step 2 will detail how it is still possible to search potential high stream bank erosion restoration sites using location instead of watershed scale erosion rates as the primary factor.

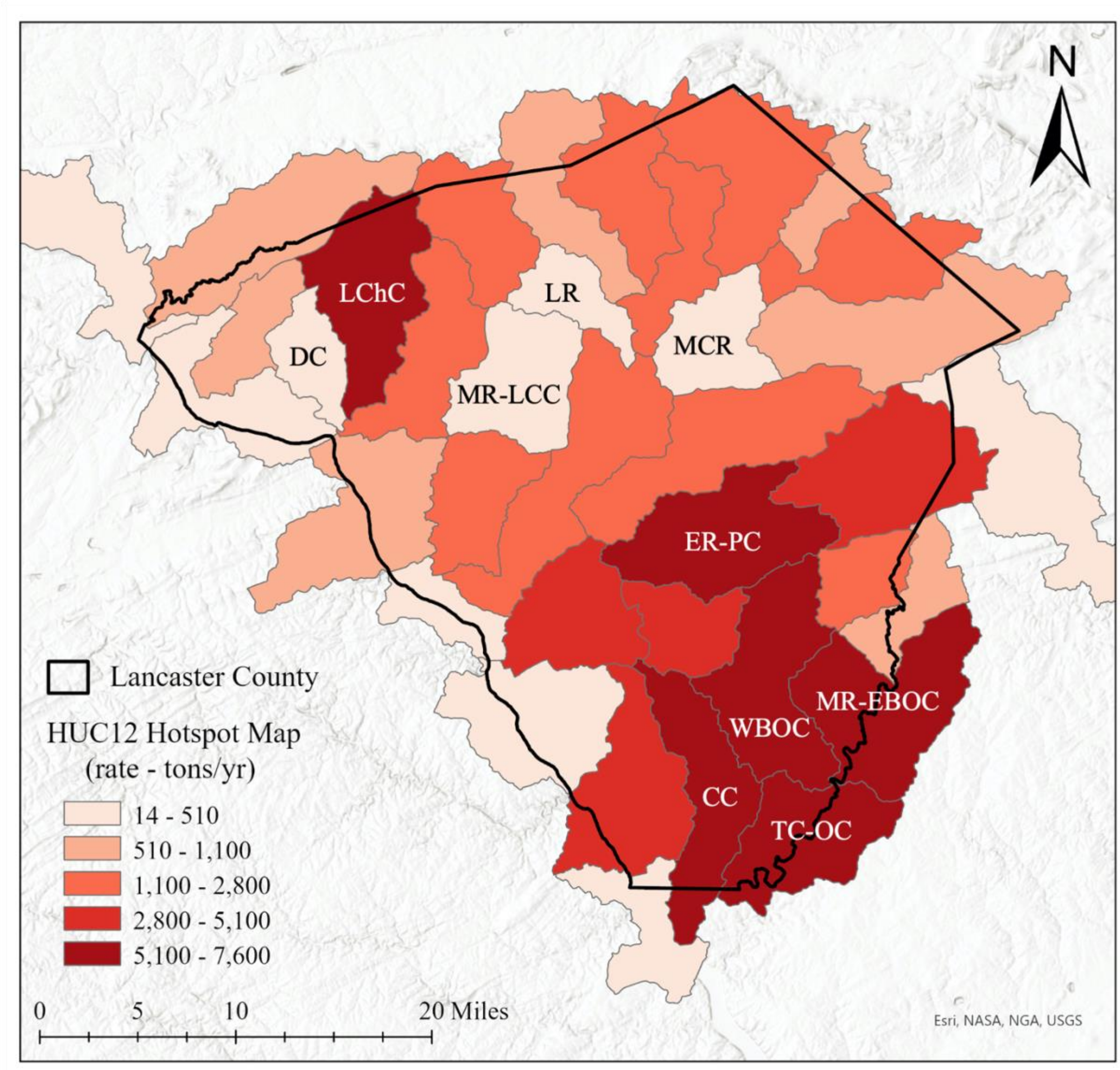

Figure 1. HUC12 hotspot map of watersheds inside the bounds of Lancaster County ranked by average annual stream bank erosion sediment load (expressed in tons/yr.). DC = Donegal Creek; LChC = Little Chiques Creek; MR-LCC= Muddy Run-Little Conestoga Creek; LR = Lititz Run; MCR = Middle Conestoga River; ER-PC = Eshelman Run-Pequea Creek; CC = Conowingo Creek; WBOC = West Branch Octoraro Creek, MR-EBOC = Millers Run-East Branch Octoraro Creek; and TC-OC = Tweed Creek-Octoraro Creek.

Step 2: Narrowing focus

After HUC12 watershed(s) are selected, we perform a block statistics density analysis to begin focusing on smaller stream areas eroding at relatively more rapid rates. Remember, each valley bottom block includes the volume of sediment eroded between lidar flights (expressed in tons, cubic yards, and lbs.), annual erosion rate (expressed in tons/yr., cubic yards/yr., and lbs./yr.), and an erosion rate uncertainty. In addition to the density analysis, it is helpful to begin examining the historic milldam table and how dams may affect areas of high or low erosion.

Figure 2 demonstrates how narrowing the search focus is represented. In this example the focus area is in the southern portion of Lancaster County, which includes the HUC12 watersheds of Conowingo Creek, West Branch Octoraro Creek, and Tweed Creek-Octoraro Creek (see inset image in Figure 2 for location of these watersheds relative to Lancaster County). Mapped stretches of stream in these watersheds indicate high rates of bank erosion relative to other county stream segments. Using the Jenks method, the five classes of data were applied and analyzed. Significantly, historic milldam locations are also mapped near many of the valley bottom blocks with elevated erosion rates. While Figure 2 displays some of the highest erosion rates in the county, it is possible to further narrow the search using location instead of erosion as the primary indicator. Since small areas in the valley bottom experiencing active erosion are identified using the block statistics method, it enables the identification of stream stretches experiencing high erosion rates in watersheds that DON'T have the highest relative erosion rates. So, if location is your primary goal when searching for potential BMP implementation, sites with legacy sediment, rapid erosion rates, and relatively high sediment loads can be incorporated into successful project design.

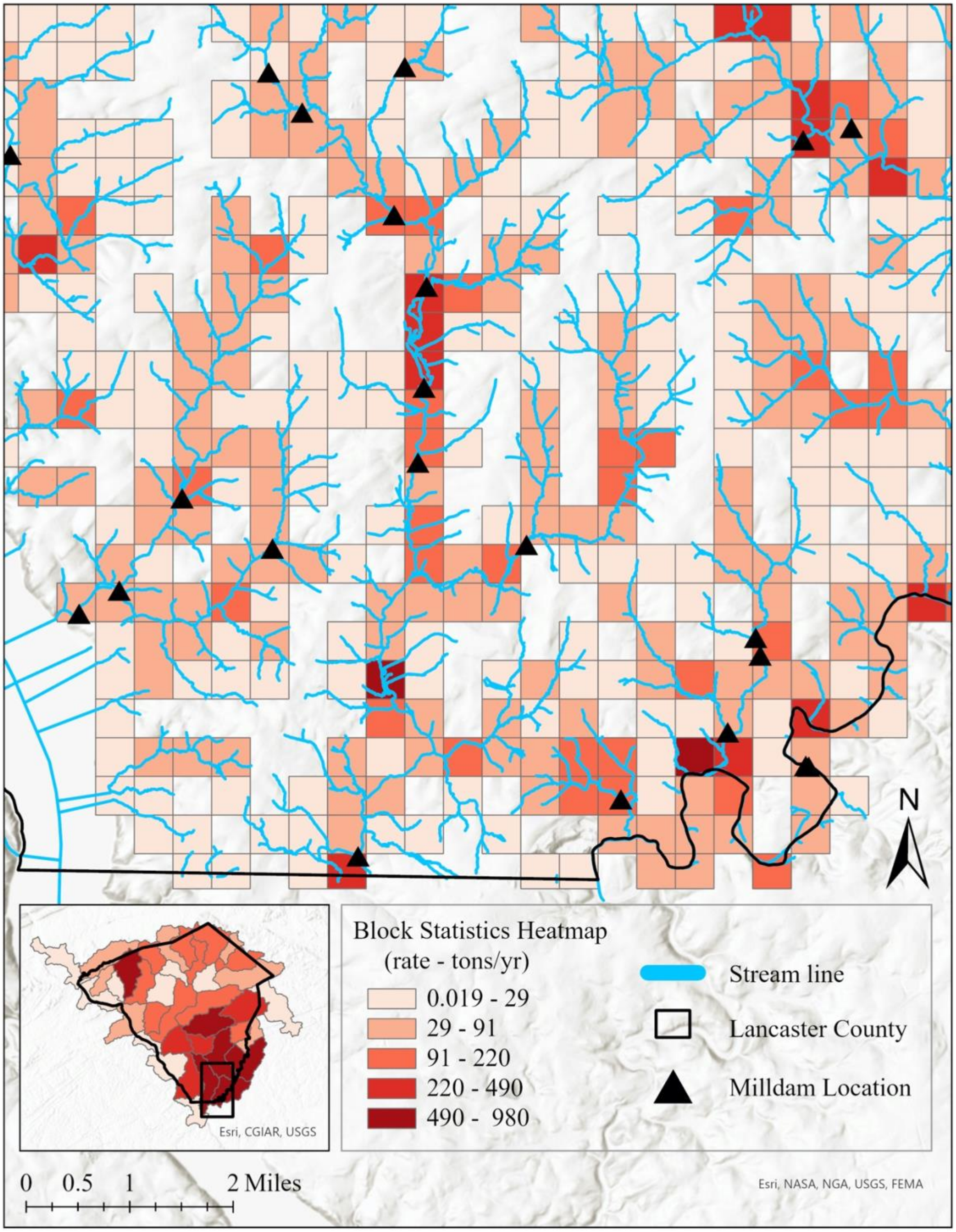

Figure 2. Block statistics heatmap of the southern portion of Lancaster County ranked by annual stream bank erosion rates, including parts of the HUC12 watersheds of Conowingo Creek, West Branch Octoraro Creek, and Tweed Creek-Octoraro Creek. Inset image shows HUC12 hotspot map from figure 1 and the location of this heatmap relative to other watersheds in the county.

Step 3: Sharp focus

With a few blocks selected, zoom in and we can begin examining individual stream bank erosion polygons, legacy sediment terrace polygons, and canopy heights. Each erosion and terrace polygon can be selected and includes the previously mentioned metrics. Canopy heights can also be developed by selecting where the dataset is present. Now that we have identified a project scale area, we can apply the datasets at a scale that is the focus of your BMP strategy.

Figures 3-6 details a parcel scale stretch of stream (~1,000 ft.) on Little Chiques Creek using all available datasets which collectively create the larger scale datasets outlined in Steps 1 and 2. In Figure 3 several stream bank erosion polygons and their metrics are shown. This stretch of stream is experiencing rapid bank retreat and was identified using the county wide block statistics heatmap in Step 2. Figure 4 shows legacy sediment terraces, and their metrics, mapped adjacent to the stream. Restoration practices that may involve removing legacy sediment can benefit from having an estimate of the site soil volume prior to field investigation. Figure 5 displays canopy heights present along the same stretch of stream. Knowledge of site canopy height and cover density can be helpful when determining what type of BMP strategy to implement. Individual stream bank erosion polygons, legacy sediment terrace polygons, and canopy data can all be selected to gather associated metrics. Figure 6 shows all three of those datasets together on a single map. Together, these three datasets comprise the triage approach WSI uses to identify BMP sites with high potential legacy sediment volume, stream bank erosion rates, and nutrient loads.

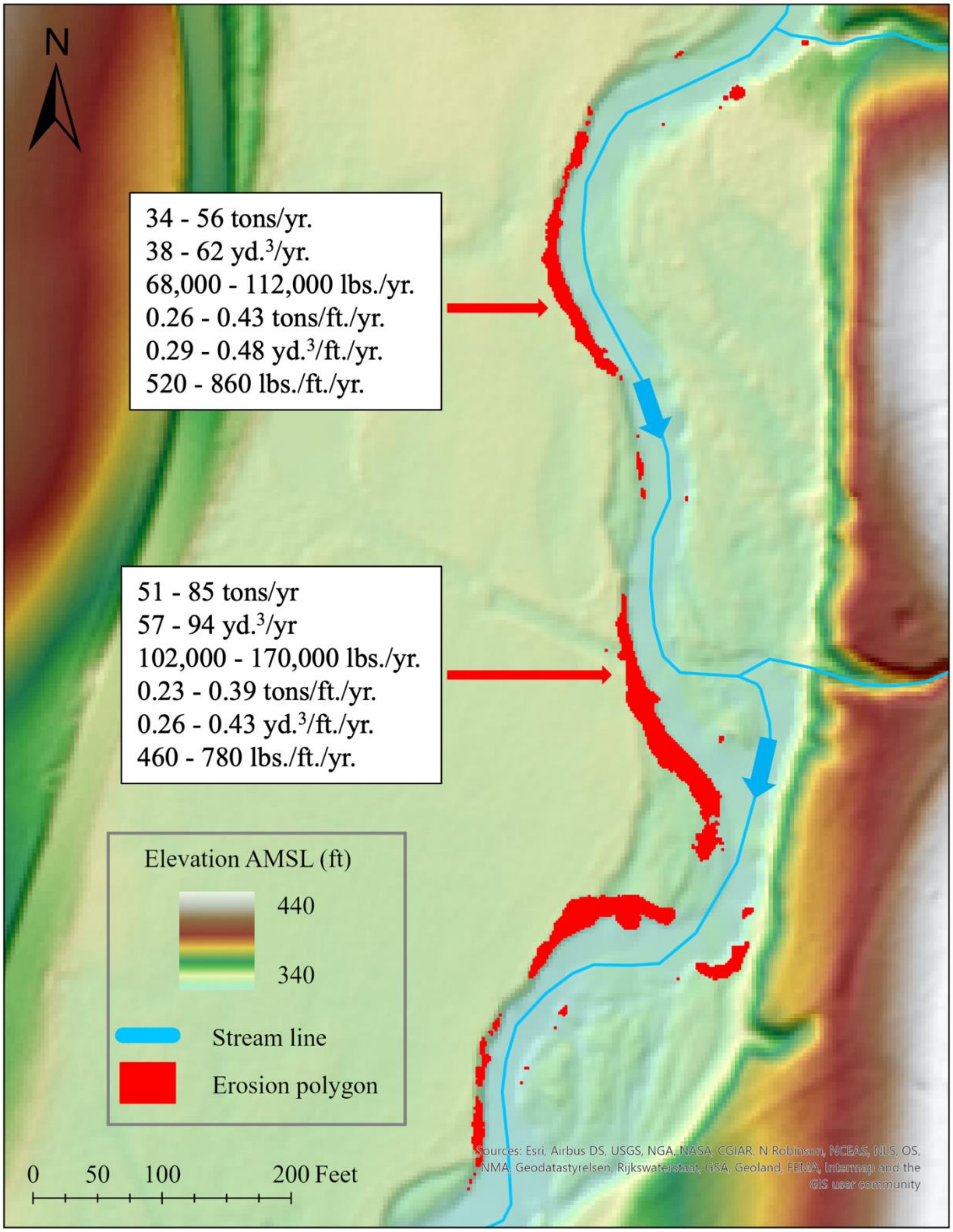

Figure 3. Map of a stream reach (~1,000 ft) on Little Chiques Creek, in northwest Lancaster County, that is eroding at a rapid rate relative to the rest of the watershed. Specified bank erosion rates and metrics in the figure pertain to individual polygons that are being pointed to.

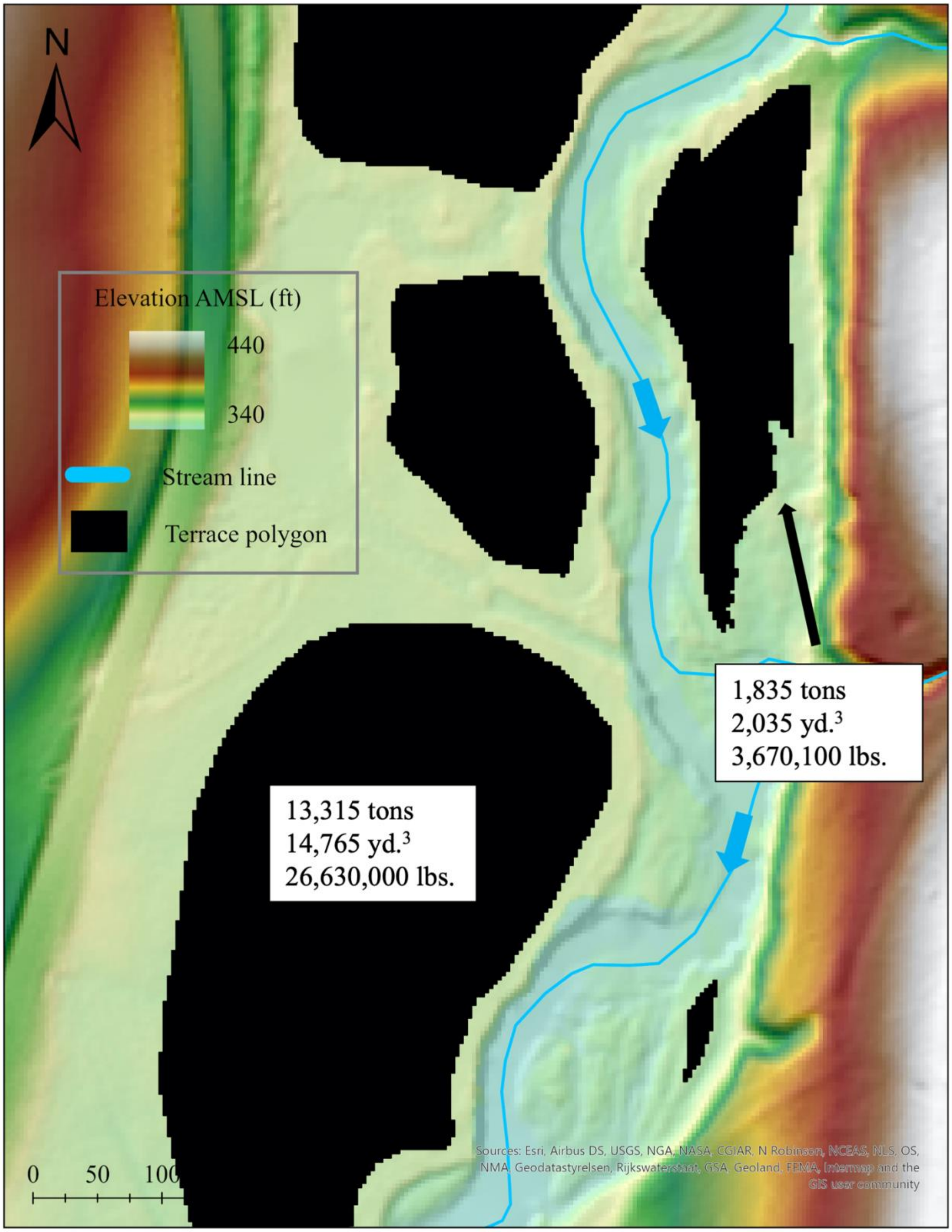

Figure 4. Legacy sediment terraces mapped adjacent to a stretch of Little Chiques Creek.

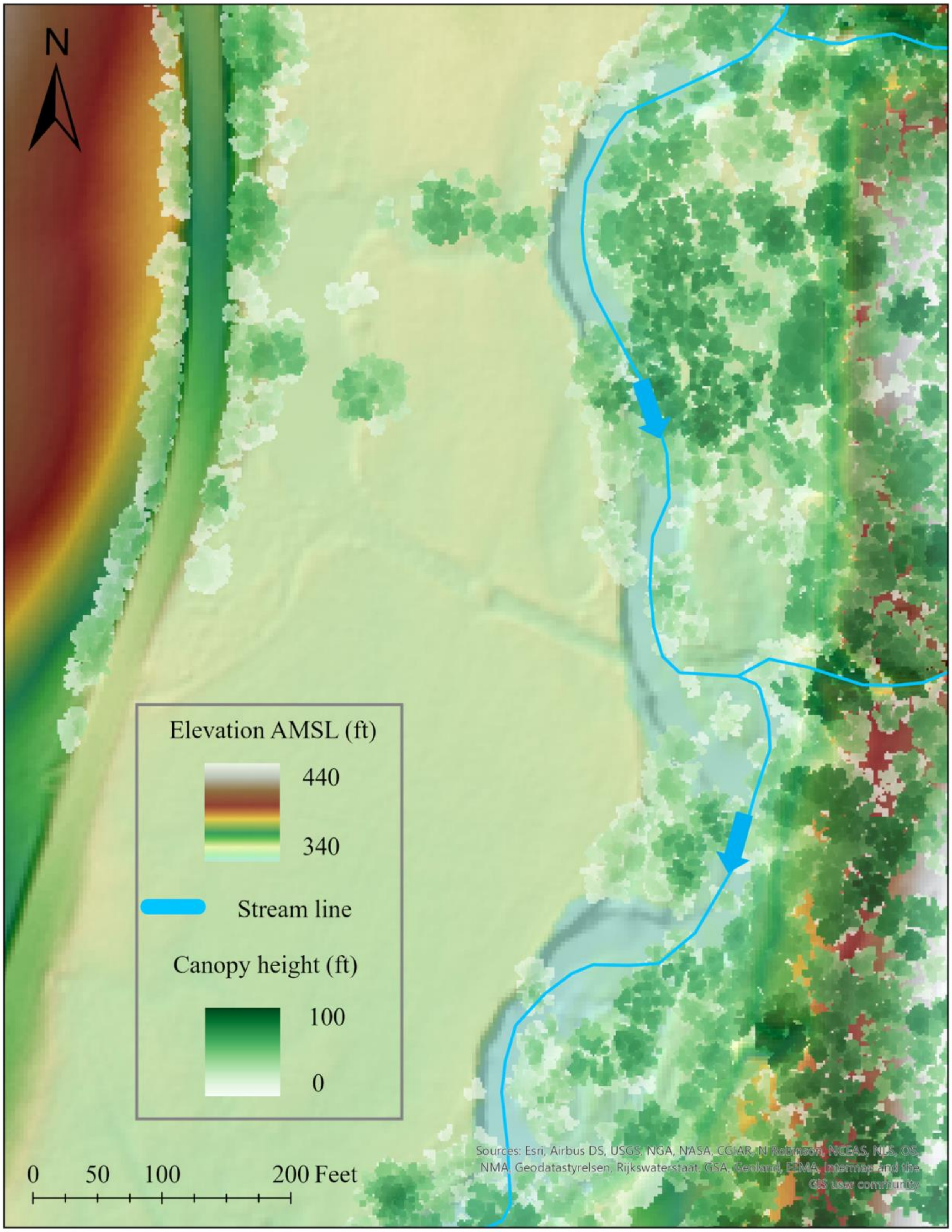

Figure 5. Canopy height and cover adjacent to a stretch of Little Chiques Creek.

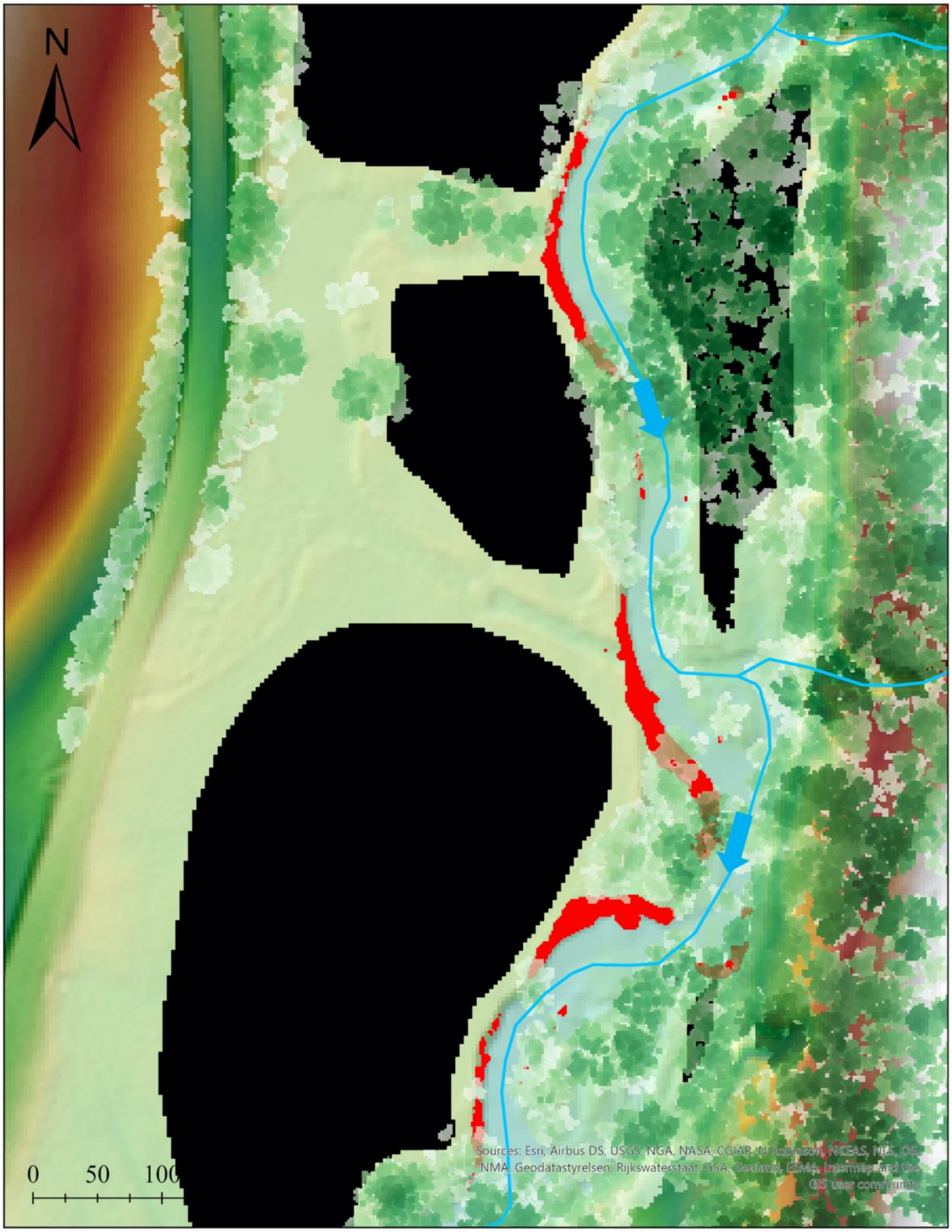

Figure 6. Erosion polygons, legacy sediment terraces, and canopy data combined from Figures 3-5. Refer to previous figures 3-5 for legend information.

IV. References

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