Beta-Version of ArcGIS-Based Hand Analysis for Mopan River, Belize

Leila Donn, December 2017

Abstract

By 2015 over half of the world's population will live in the tropics, so it is important that we understand how humans interact with natural climate changes to drive landscape formation in these areas. Flood inundation location can reflect both these natural and human-driven changes, so I aim to generate a series of flood inundation maps, and eventually a set of flood recurrence intervals for the Mopan River. I successfully delineated the Mopan River stream network using sub-meter accurate LiDAR imagery. I then used this stream network to design my own beta-method of HAND mapping completely within ArcGIS Pro. My method has potential, but there are a number of issues that I need to work out with the help of those more knowledgeable about GIS than I am.

Introduction

By 2050 over half of the world's population will live in the tropics (Roberts et al. 2017). However, tropical watersheds are still poorly understood, despite millennia of human interaction and land use. Evidence exists for human use of the Belize River Valley watershed across the last four millennia, from the Maya Archaic to the present: some of the most politically influential Maya cities in Central America were located in this watershed, and today intensive agriculture supports modern populations throughout the valley. For my thesis, I seek to quantify long-term anthropogenic drivers of landscape change and associated flooding in the watershed. Humans interact with natural climate changes to drive landscape formation, partially through flooding, and so flood inundation location can reflect both these natural and human-driven changes. For this project, I completed a beta-version of a method of height above nearest drainage (HAND) flood inundation mapping using LiDAR, for an area that has almost no hydrological data available. I will continue to develop this model over the next semester, and plan to use it to develop flood recurrence intervals for the region. This kind of research can inform environmental management systems and resource use during the present day.

Project Goal

The goal of this project was to delineate and produce a HAND map of the Mopan River watershed of the Belize River Valley from LiDAR imagery acquired by the University of Texas of San Antonio. I achieved this goal, albeit not using the method originally anticipated. I wasn't able to successfully execute the method of HAND mapping covered in class, but instead developed a beta-version of HAND for an approximately three-mile-long reach of the Mopan River (Figure 1) delineated from my LiDAR imagery.

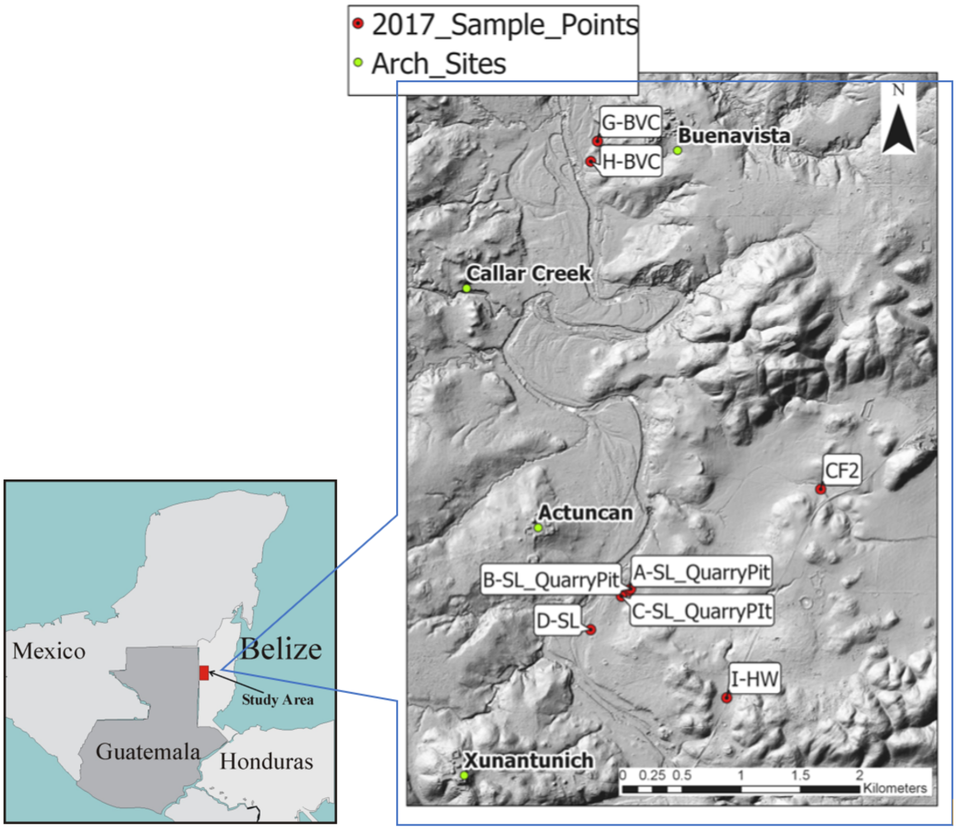

Figure 1: Research location

Site background: Geology, Climate, Soils

The Belize River Valley is a clay floodplain fluvial karst watershed located in central-west Belize (Figure 1). I'm focusing on the fluvial system, and am currently basing my thesis on data collected from near the Mopan River, which has its headwaters in the Maya Mountains. The region experiences abundant rainfall at 1500-2000 millimeters per year; ninety percent of this occurs from May to December because the climate is tropical wet/dry (Beach 2015). The area is subject to several natural hazards including flooding, drought, and extreme temperatures, with hurricanes occurring approximately once every six years. The soils of the region have very well-developed B-horizons and are likely Alfisols, however we are currently in the process of analysis of soil samples collected this past summer.

Methods

Initially I had planned to complete my stream delineation and HAND mapping using the methods presented in class, however these methods didn't work with my data. I therefore attempted to follow directions that I found online for another method of HAND mapping in which all analyses were completed in ArcGIS. This method also did not work for me. At this point, I created my own method, all within ArcGIS. I am calling it a beta-method because there are some kinks to be worked out, and some of the steps still need to be further refined. I will begin here with details of this final method that I designed myself, and then I will include details about the first two methods I attempted that were unsuccessful.

Beta Method of HAND Mapping in ArcGIS

For my analyses, I used a sub-meter accurate LiDAR DEM acquired by the University of Texas at San Antonio, with whom I am working on my thesis. The imagery had a number of no data values within the stream channel, which would have been a problem for delineation and mapping. Therefore, I began by researching ways that I could assign the no data cells values that were calculated averages of the elevations of the cells surrounding them. I found the “Elevation Void Fill” tool which takes the average elevation of the eight cells closest to the cell with no data and assigns it that value. I ran the tool and was pleased with the result, and so this void filled LiDAR DEM is what I used for all my analyses (Figure 2).

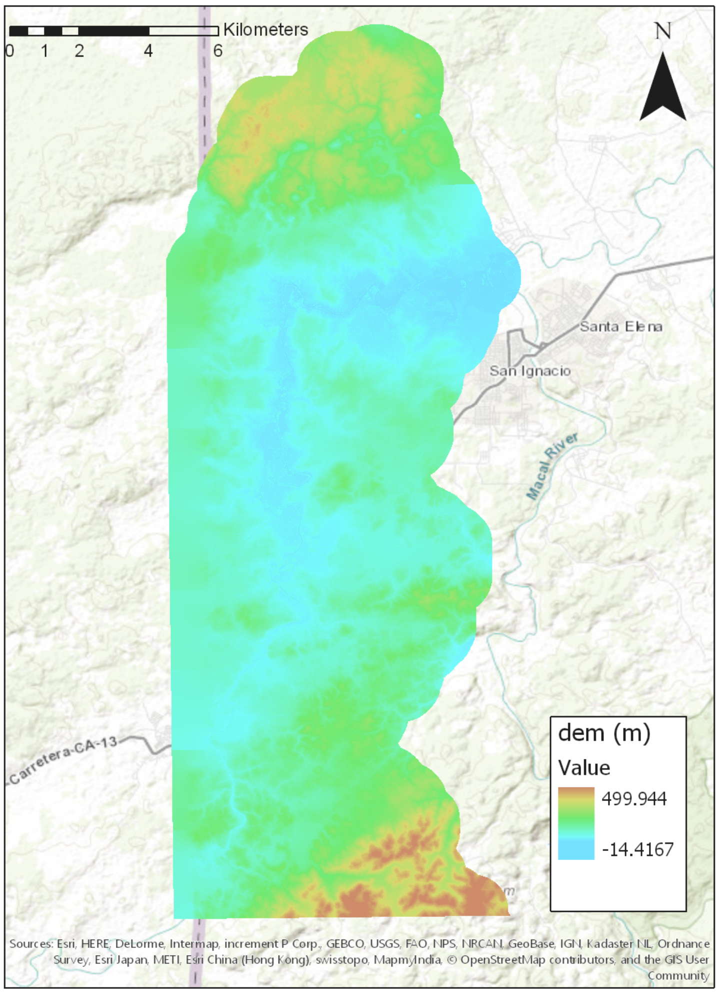

Figure 2: Void-filled DEM

I began my analyses by delineating the stream network shown in my LiDAR imagery using the procedure presented in class. My LiDAR imagery does not include the entire watershed, so I delineated the streams shown in the imagery that are part of the Mopan River watershed. First, I manually determined the decimal degree coordinates of the outlet of the Mopan River and used these coordinates to create my point feature, from which I delineated my watershed using the “Ready-To-Use Watershed” tool. I made sure to set the projection of my point feature, and the projection of all the layers I created, to the projection of my DEM: WGS 1984 UTM Zone 16N. Then I added my void-filled DEM to the map and created a one-kilometer buffer around it. From there, I extracted only the portion of the DEM that included my delineated streams using the “Extract by Mask” tool. From here, since there is no available stream network dataset for Belize, I began hydrologic terrain analysis.

First, I ran the “Fill” tool on my DEM. Next, I ran the “Flow Accumulation” tool, which took three hours to run. From here, I defined my streams based on a flow accumulation threshold. First, I delineated my streams based on a threshold of 5,000, but it looked like there were many more streams than there should be (Figure 3), so I reran my delineation using a flow accumulation threshold of 10,000 (Figure 4). Though I like this product better, I think that I need to refine my method of determining the flow accumulation threshold. Then I clipped my streams to my basin. Last, I created a stream links layer which I then converted into a vector representation. My stream network delineation looks fairly good, however there is some edge contamination present at the western edge of my DEM. This is another part of my method that will need to be further refined.

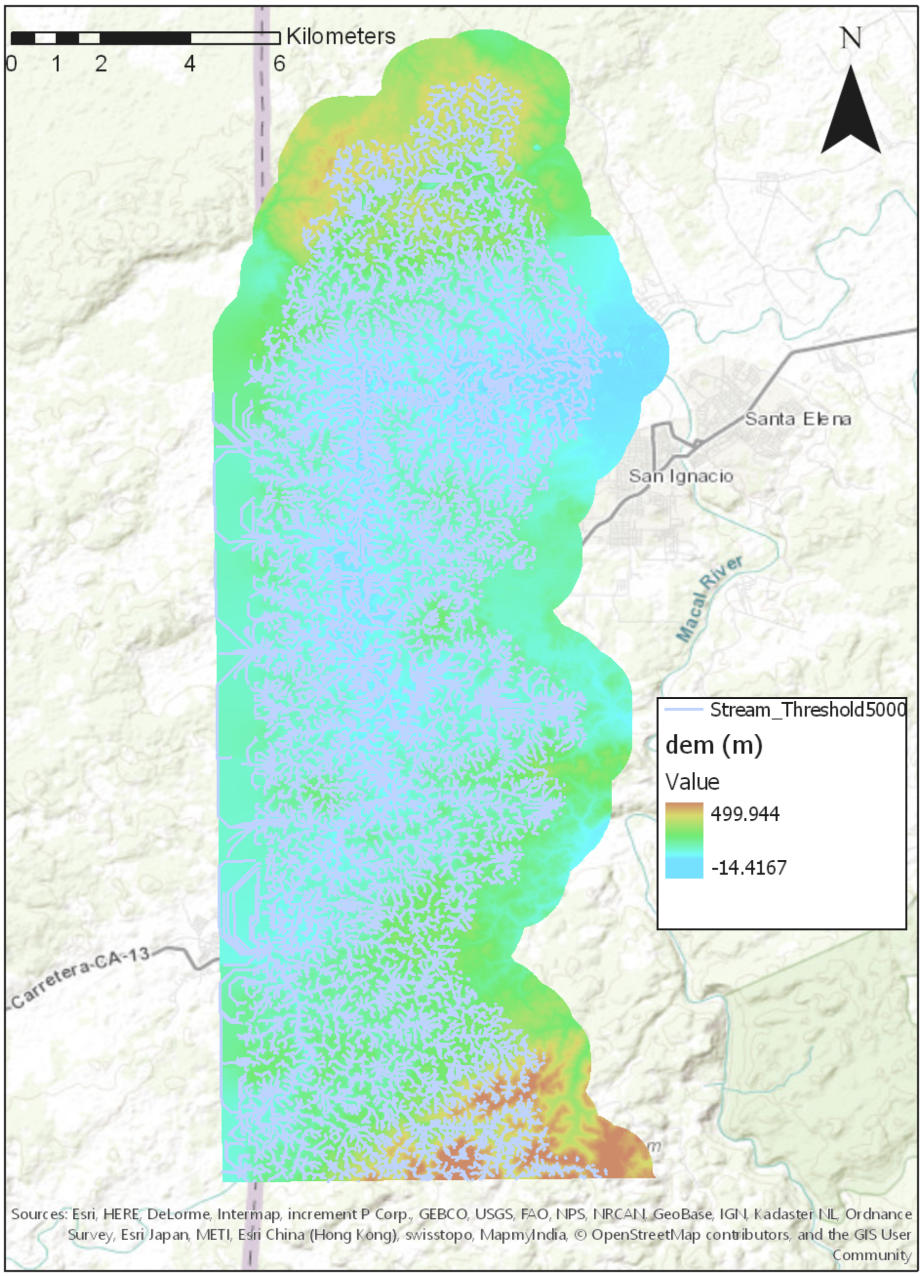

Figure 3: Stream network with threshold of 5,000

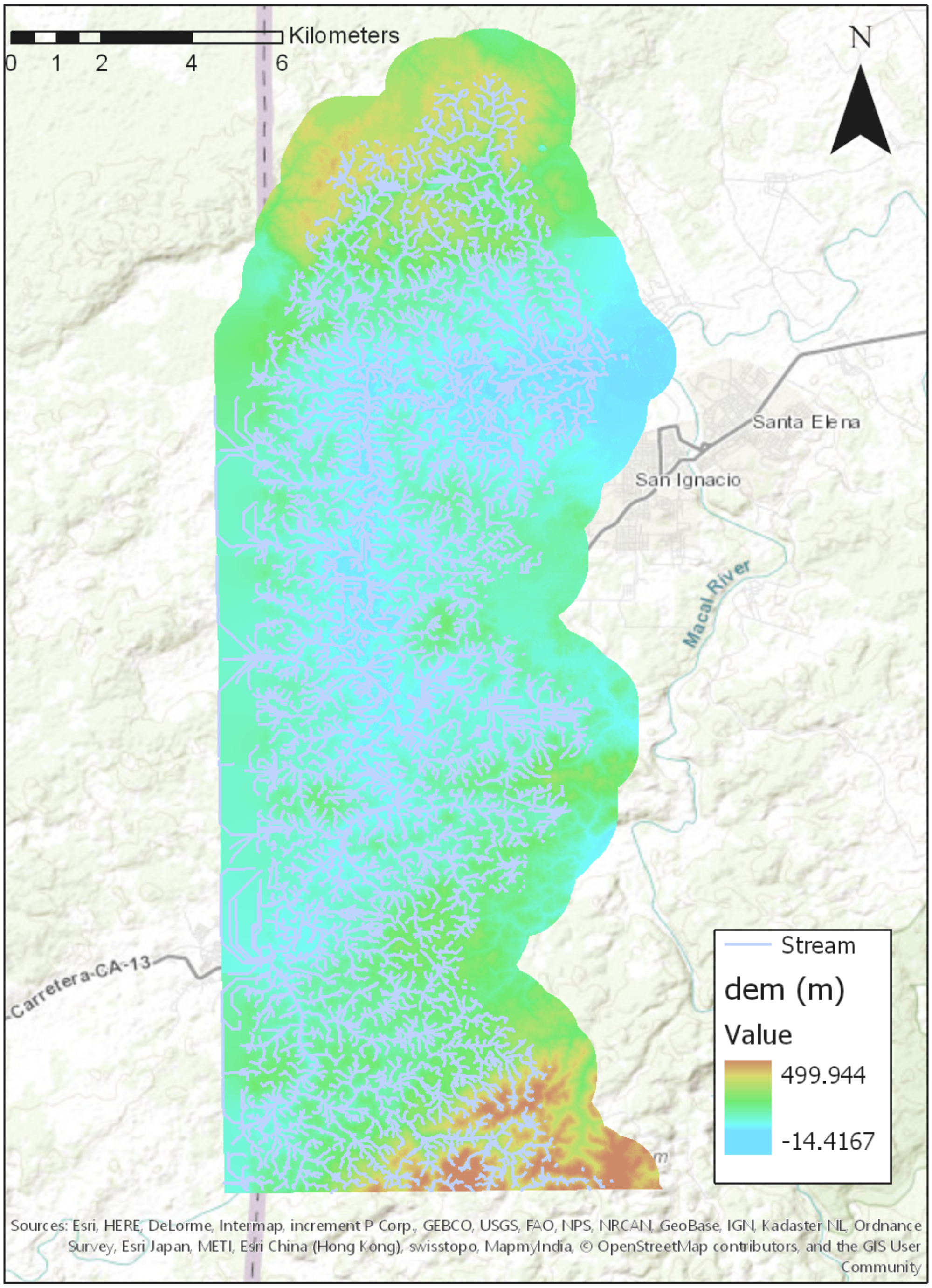

Figure 4: Stream network with threshold of 10,000

At this point I began HAND analysis. First, I added elevation information from my DEM to the stream network vector file just created. I did this by right clicking on "Map" at the top of the Contents pane and adding an elevation surface in "Properties." Then I ran a tool called "Add Surface Information" that allowed me to calculated elevation (Z) values for my stream network for my DEM. I had the option of calculating minimum, maximum, or mean Z values and chose to use mean Z values. Next, I ran the "Topo to Raster" tool, which converted the elevation values for my stream network into an elevation raster. I then subtracted this from my DEM. This produced a HAND raster with some values that were less than zero (Figure 5); I'm not totally sure what these values represent, but my guess is that they have something to do with the elevation of the stream channels. I then set a manual interval in symbology that displays only values that are greater than zero (Figures 6 and 7). Both of these rasters are very pixelated.

I'm not sure why that is, but the HAND patterns shown on them make sense to me. At this point, I generated a series of flood inundation maps by using the less-than-or-equal-to command in "Raster Calculator" to isolate a variety of stage values on the HAND map that displays only values greater than zero.

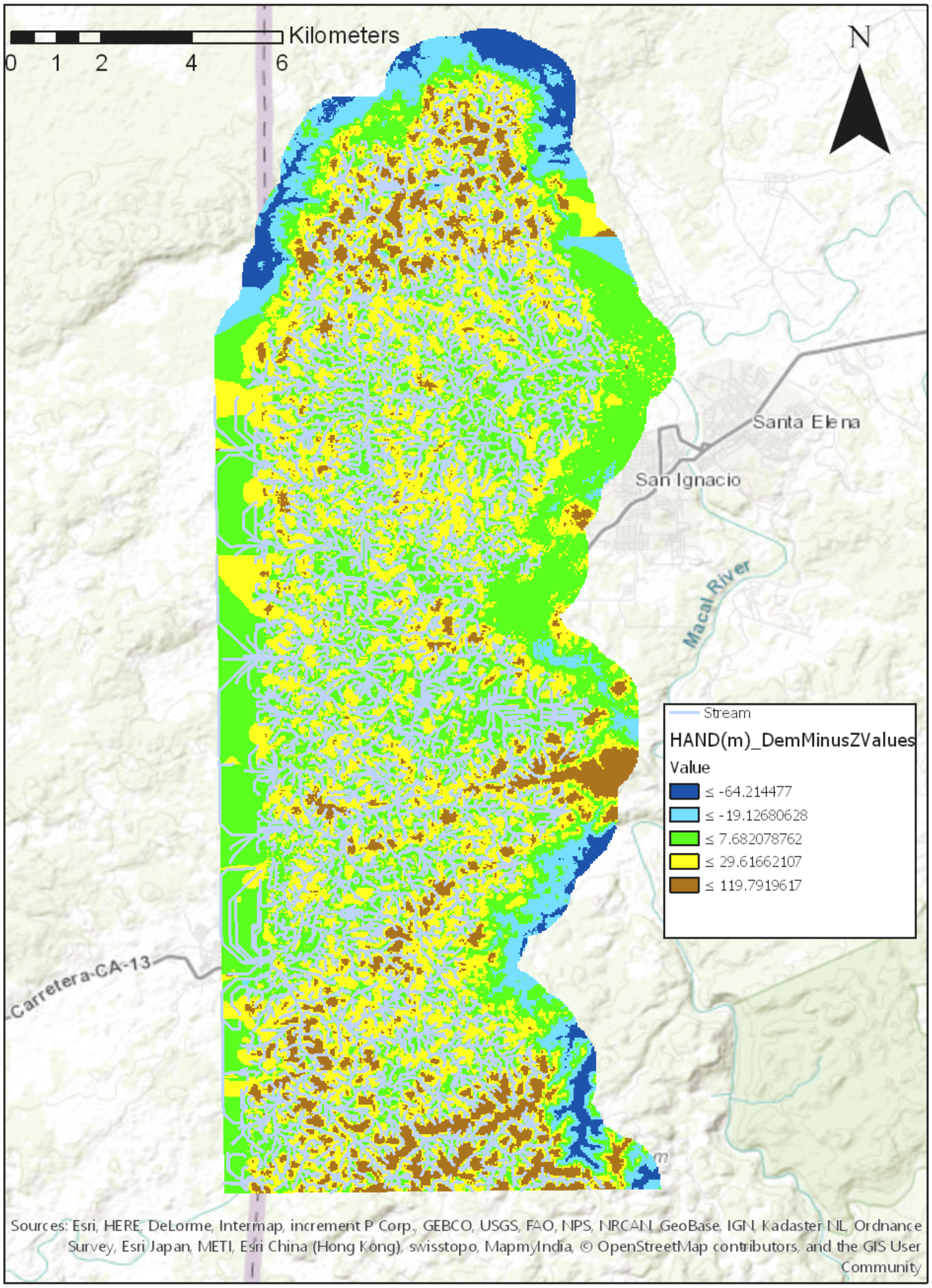

Figure 5: Beta method of HAND mapping, including values less than 0

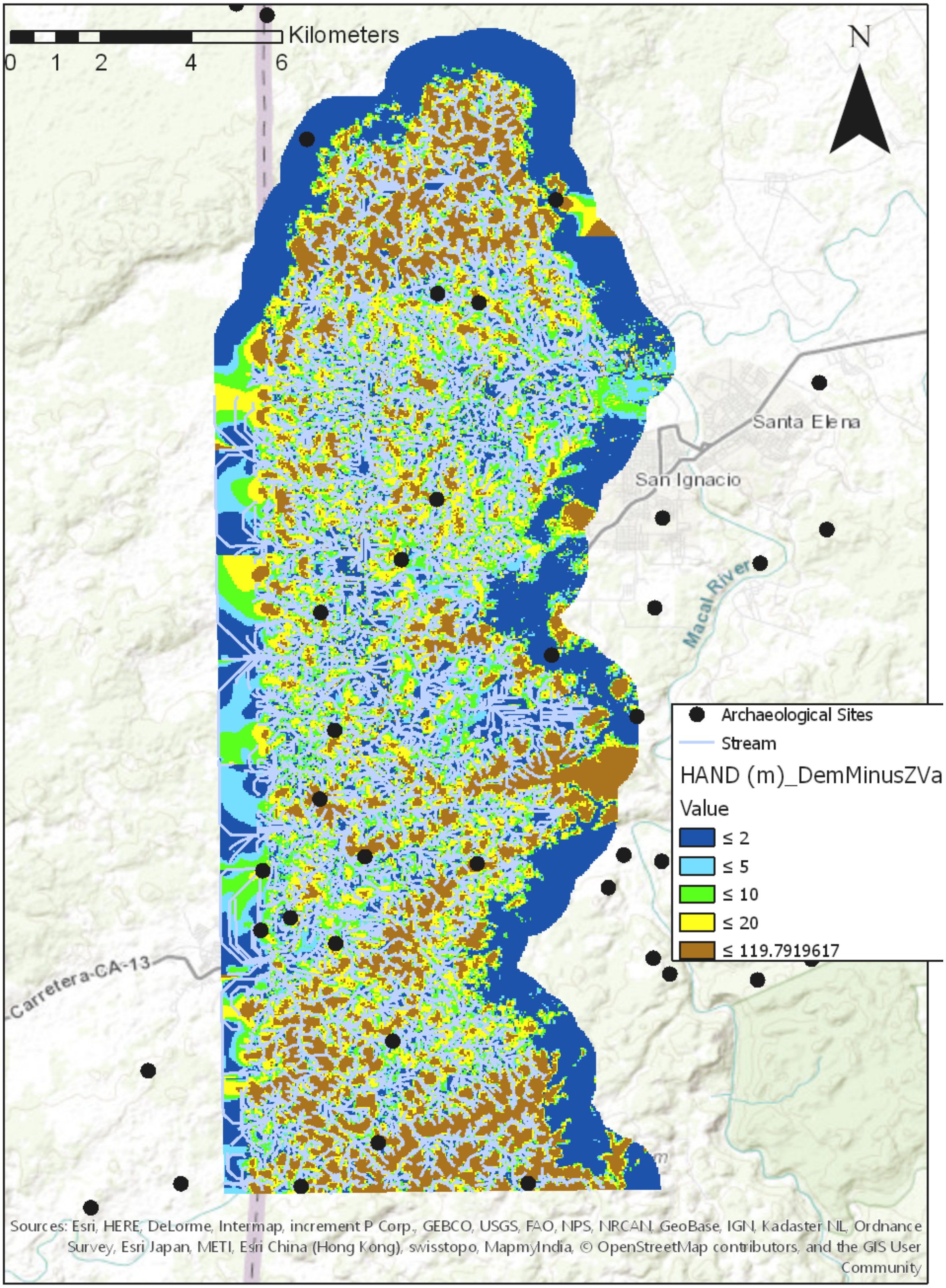

Figure 6: Beta method of HAND mapping, including only values greater than 0

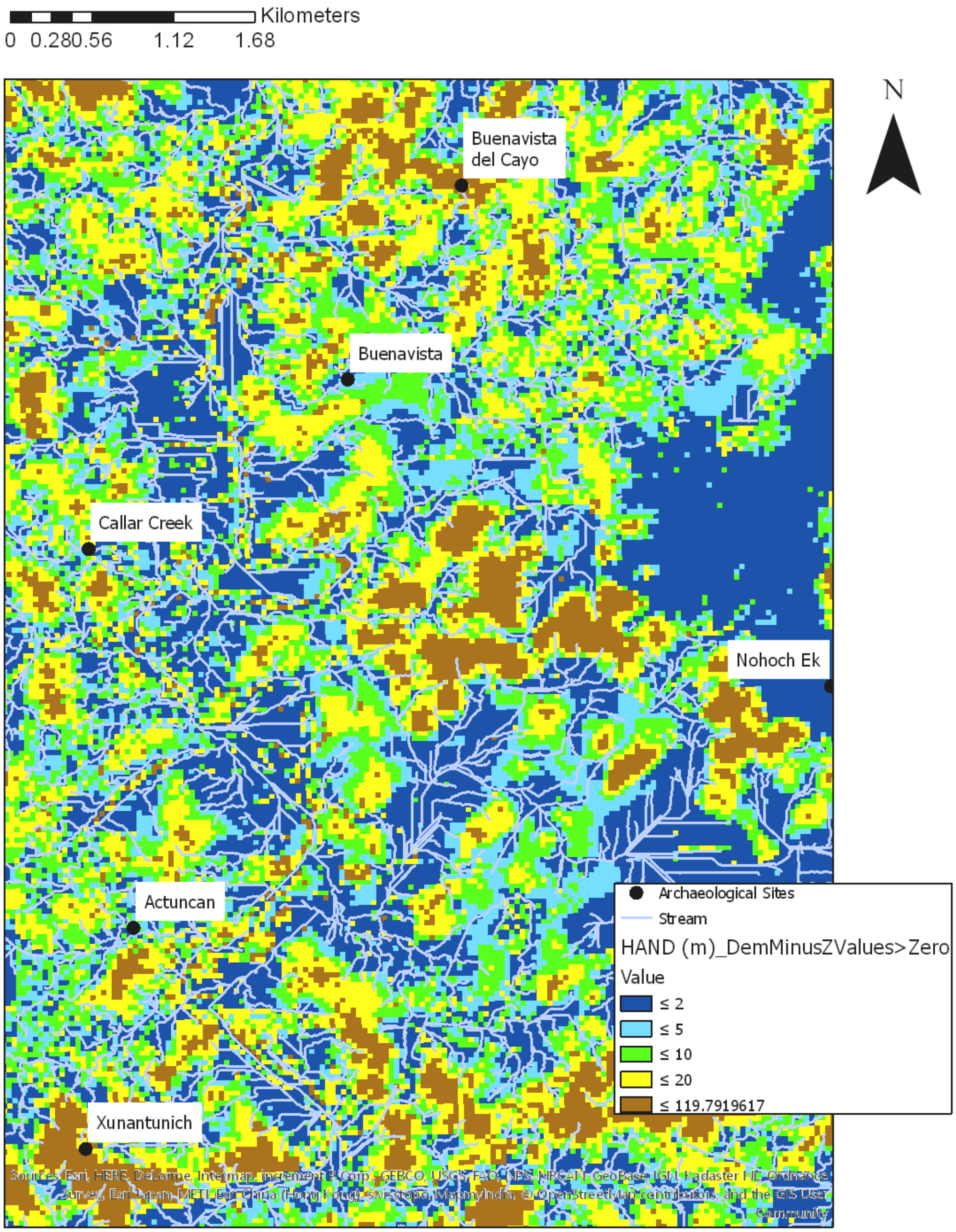

Figure 7: Zoomed in view of beta method of HAND mapping, including only values greater than 0

Once I had done this, I also generated an additional HAND map using a slightly different method to see if I could correct the odd pixilation. For this map, I set all of my stream network Z values to zero, reran the "Topo to Raster" tool, and subtracted this raster from the DEM. This produces a much prettier file (Figures 8 and 9), however there are some issues with this particular method of generating HAND that I will discuss in the next section of this paper.

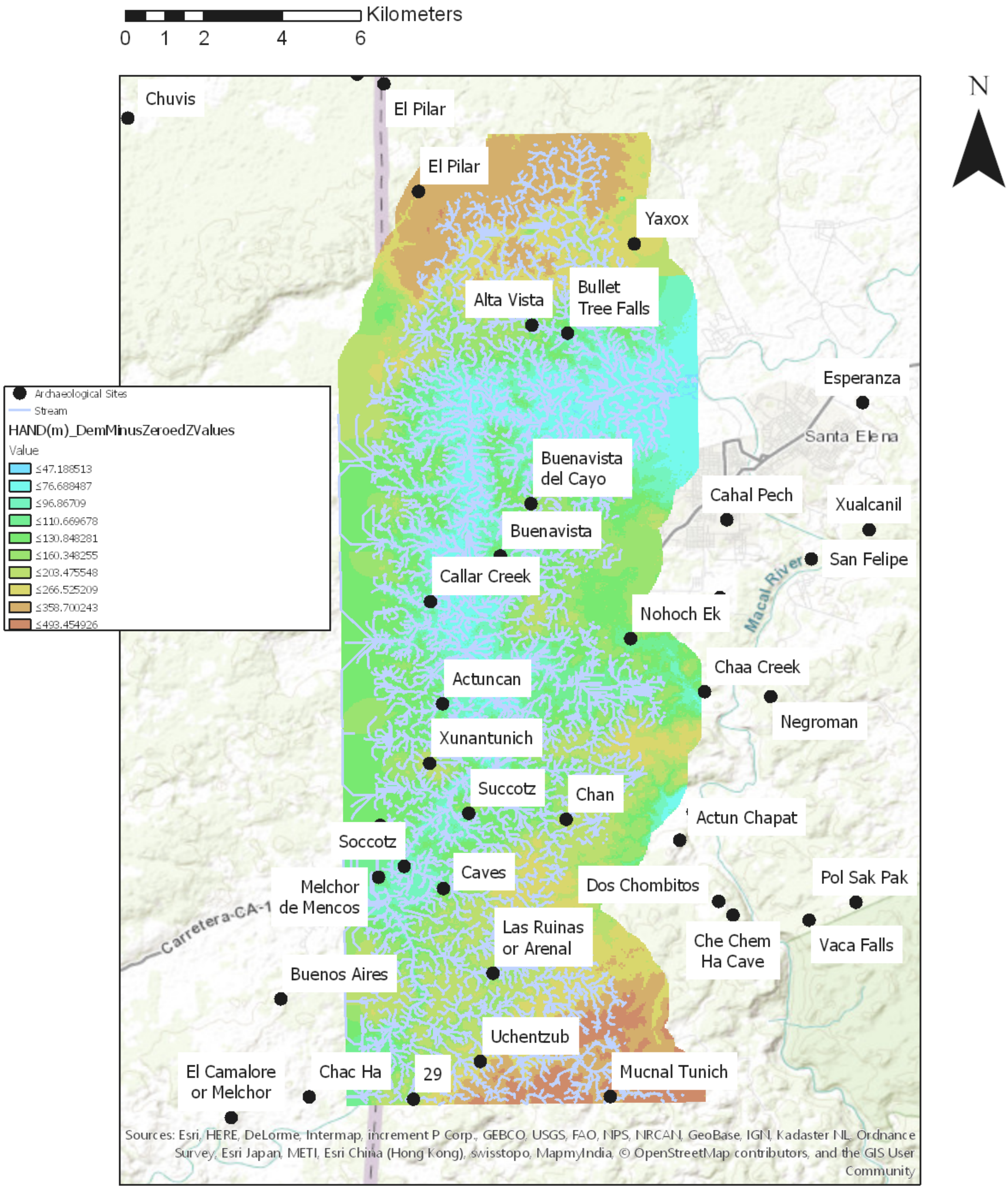

Figure 8: Beta method of HAND mapping, stream elevations set to 0

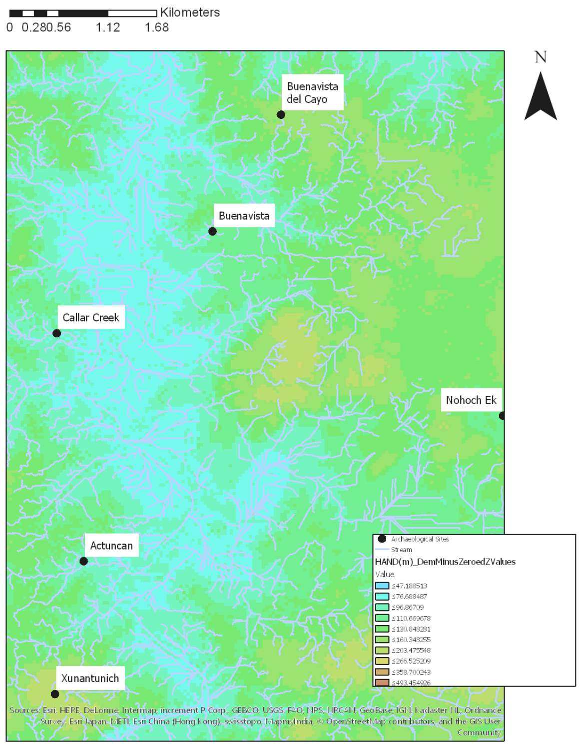

Figure 9: Zoomed in view of beta method of HAND mapping, stream elevations set to 0

Unsuccessful Attempts at Stream Delineation and HAND Mapping

I first began these analyses by trying to delineate my stream network with 3-arc-second DEM imagery from the Shuttle Radar Topography Mission (STRM). I successfully delineated my stream network using the procedure outlined in class (Figure 10), however when I overlaid my LiDAR DEM onto my delineated stream network it became clear that the SRTM data was too coarse to be used with my sub-meter accurate LiDAR because my delineated streams did not match particularly well with the streams shown in the LiDAR imagery (Figure 11). Therefore, I delineated my stream network using the LiDAR imagery as outline above.

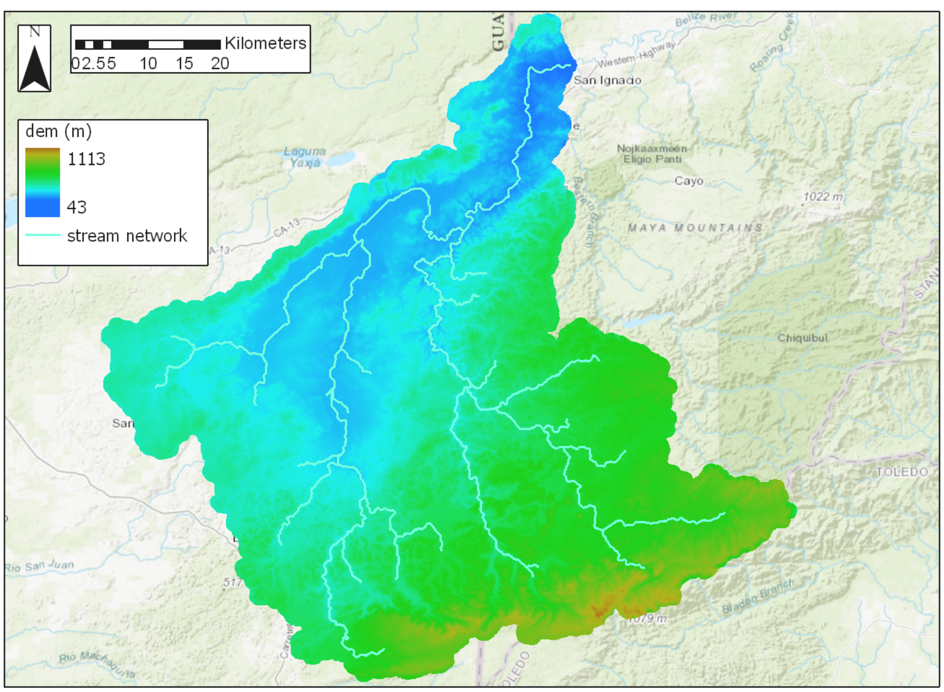

Figure 10: Stream delineation from SRTM imagery

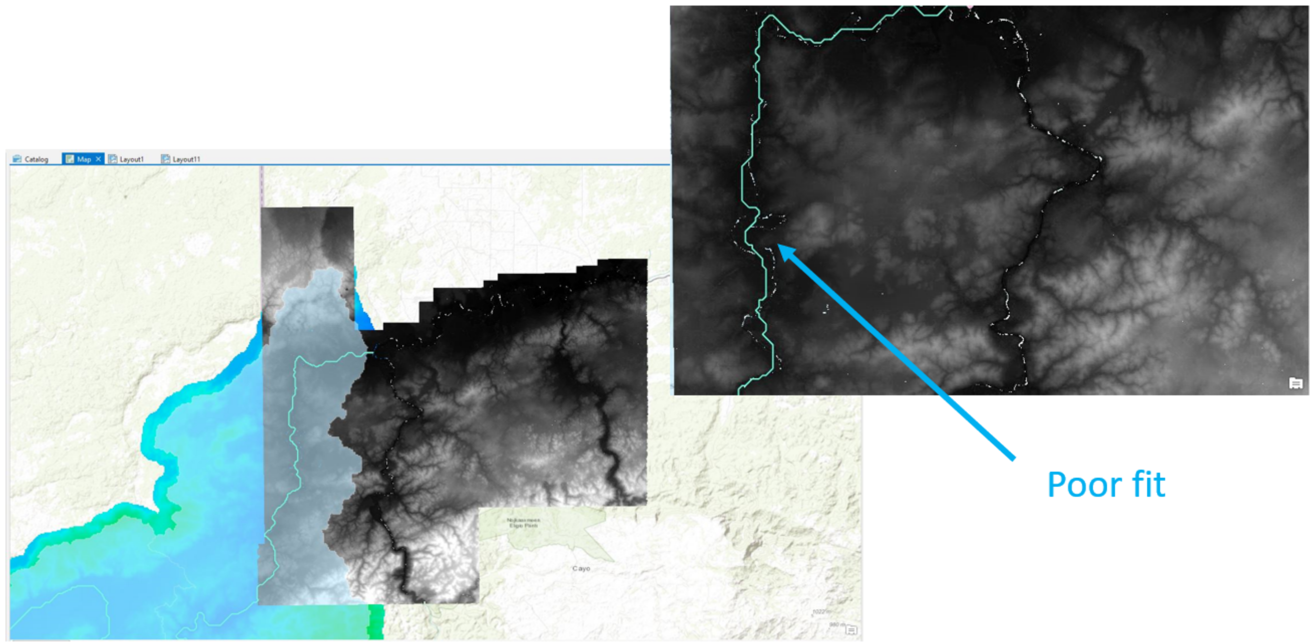

Figure 11: Poor agreement between streams delineated from SRTM imagery and my LiDAR DEM

After delineating my streams using LiDAR, I did not progress directly to designing my own HAND mapping method. First, I tried to execute the method presented in class. The first issue I ran into was that when I ran the “Features to Point” tool to generate a dangling vertices file, no “Start Flag” field with all values equal to one was generated in the attribute table. Therefore, I manually added a “Start Flag” column and set all values equal to one. Then I converted this feature to a raster file with the same dimensions as my DEM, and reclassified this raster to values zero, one, and “no data.” From here, I attempted to use HydroShare and CyberGIS to run my HAND analysis, but my reclassified Start.tif and Dembasin.tif files were much too large. Therefore, I compressed them in ArcGIS by exporting the raster as a tif file using compression type LZW. These files were still much too large to upload onto HydroShare, so I used the iRODS server to upload my two tif files onto HydroShare, which took two hours. Once my files were uploaded, I attempted to run analyses with CyberGIS. I tried two separate times, and both times a green coffee cup showed up in the progress bar for a long time, and after about two hours the analysis stopped running but didn’t produce any maps whatsoever. Therefore, I abandoned this particular method of generating HAND maps.

Before I resorted to designing my own method of generating HAND maps, I did some internet research and found a procedure for generating HAND maps outlined on a GIS blog (https://gis.stackexchange.com/questions/173101/correcting-errors-in-height-above-nearest-drainage-hand-model?noredirect=1&lq=1). I attempted to follow this procedure, first running the “Zonal Statistics” tool using my drainage network and DEM. This tool seemed to generate elevations of my streams. Then I tried to run the “Euclidean Allocation” tool to calculate, for each cell, the zone of the closest source location in Euclidean distance (Figure 12). From there, I subtracted the map that was produced from the DEM and got a product that made no sense (Figure 13). Since I didn't understand this method well, and wasn't sure where I had gone wrong, this is the point at which I decided that I needed to design my own method to produced HAND maps.

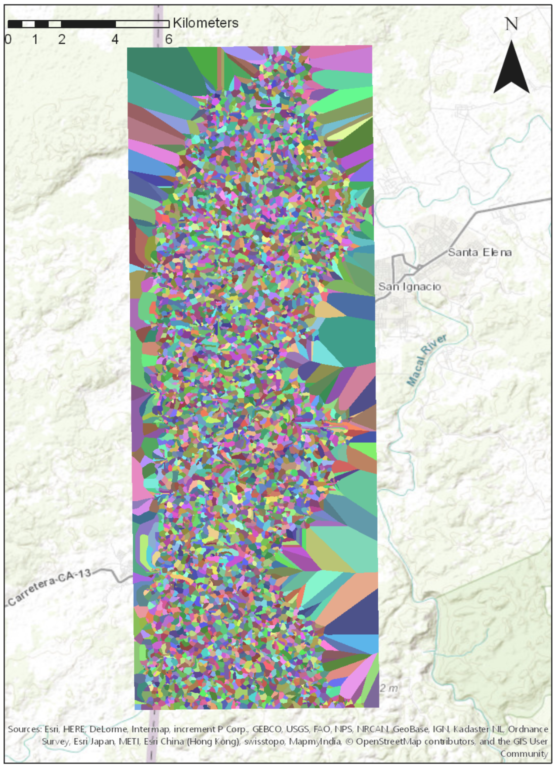

Figure 12: Product of Euclidean Allocation tool

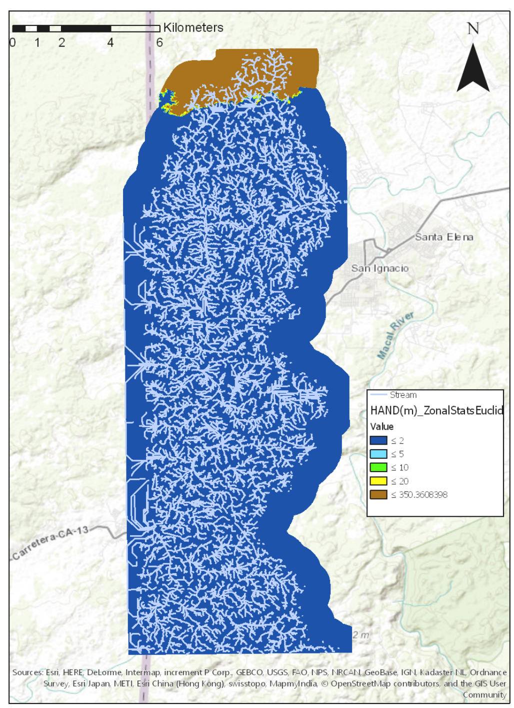

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Figure 13: Incorrect HAND map produced from Zonal Statistics and Euclidean Allocation

Discussion

My final HAND maps are those that were produced using the HAND method that I designed. The HAND map that was generated by setting the stream channel Z values to zero (Figure 8) is more attractive than the first HAND map I generated (Figure 6), in which Z values reflect the elevations assigned to the streams from the DEM. However, there is an issue with the more attractive HAND map that makes it unusable: it doesn't appear to be representing HAND values that are less than 50 meters or so (Figures 14 and 15). As a result, it is completely useless for my flood inundation maps since all of the flood stages I am interested in are less than 50 meters. I'm not totally sure what the problem is here, but since my other method of HAND mapping (Figure 6) works just fine for displaying lower stages, this is the map that I moved forward with to produce a series of flood inundation maps.

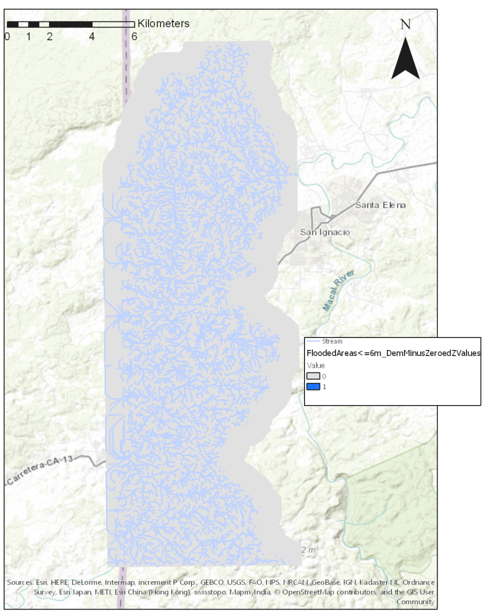

Figure 14: Incorrect flood inundation map for flood stage of 6m using beta method of HAND mapping, stream elevations set to 0

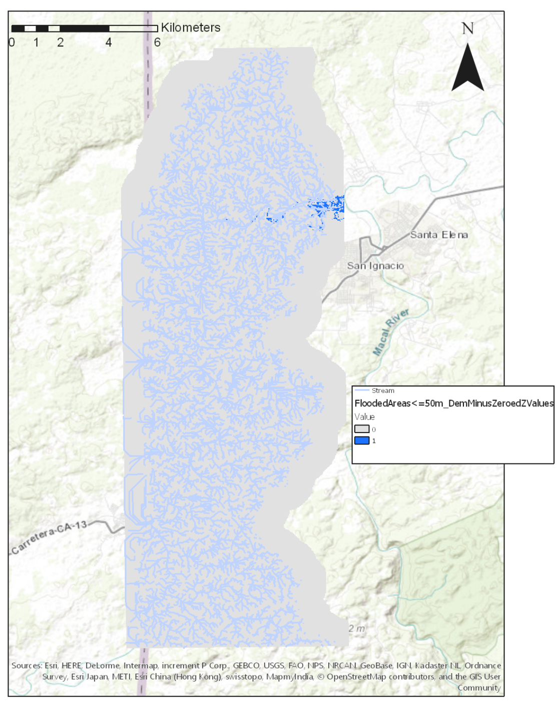

Figure 15: Incorrect flood inundation map for flood stage of 50m using beta method of HAND mapping, stream elevations set to 0

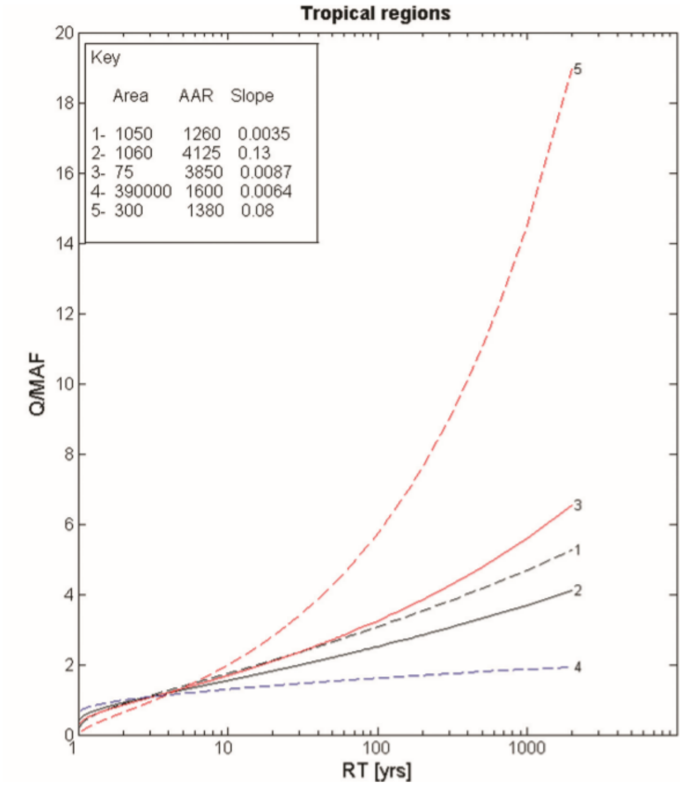

Figure 16: Regional Flood Frequency Analysis from Smith et al. 2014

I was hoping to use the Regional Flood Frequency Analysis (RFFA) presented in Smith et al. (2014) to determine the stage for the 1-year flood, the 5-year flood, the 25-year flood, and the 100-year flood. Smith et al.'s RFFA enables the estimation of return period discharges anywhere in the world based only on Köppen–Geiger climate classification, upstream area, and annual rainfall. Based on the annual precipitation for my region and the slope of my stream network, I used Smith et al.'s figure (Figure 16) to determine that I need to use RFFA curve five. However, while RFFA curve five provides discharge values for a sequence of floods, I am not sure how to get stage height from this. Discharge is equal to velocity x channel area. I attempted to solve this equation for stage (or height of channel at a given flood stage). To get channel width I measured the width of the Mopan River at ten separate locations in Google Earth and then took the average since all channel widths are fairly similar along the channel reach I am looking at. I calculated the channel to have an average width of 31.81 meters. At this point, I still had two variables in my discharge equation: velocity and channel height. I tried to use Manning's equation to calculate bankfull depth, since according to Smith et al. bankfull is typically assumed to be equal to the annual flood stage. I used a roughness coefficient of 0.035 for my channel and was able to solve for bankfull, but I got an answer that didn't make sense (0.01 meters). Clearly this is another area that I need to work on.

Therefore, I generated a series of flood inundation maps that are not associated with any particular recurrence interval, using the HAND map that includes all values greater than zero. The flood inundation maps I generated represent conditions at stages of three meters (Figure 17), six meters (Figure 18), ten meters (Figure 19), 15 meters (Figure 20), 20 meters (Figure 21), and 35 meters (Figure 22). There does seem to be something strange going on with the buffer at the edge of the stream network, but that's another issue that I will need to get help with. Archaeological sites are shown on each of these maps to give an idea of how flooding would have affected ancient peoples.

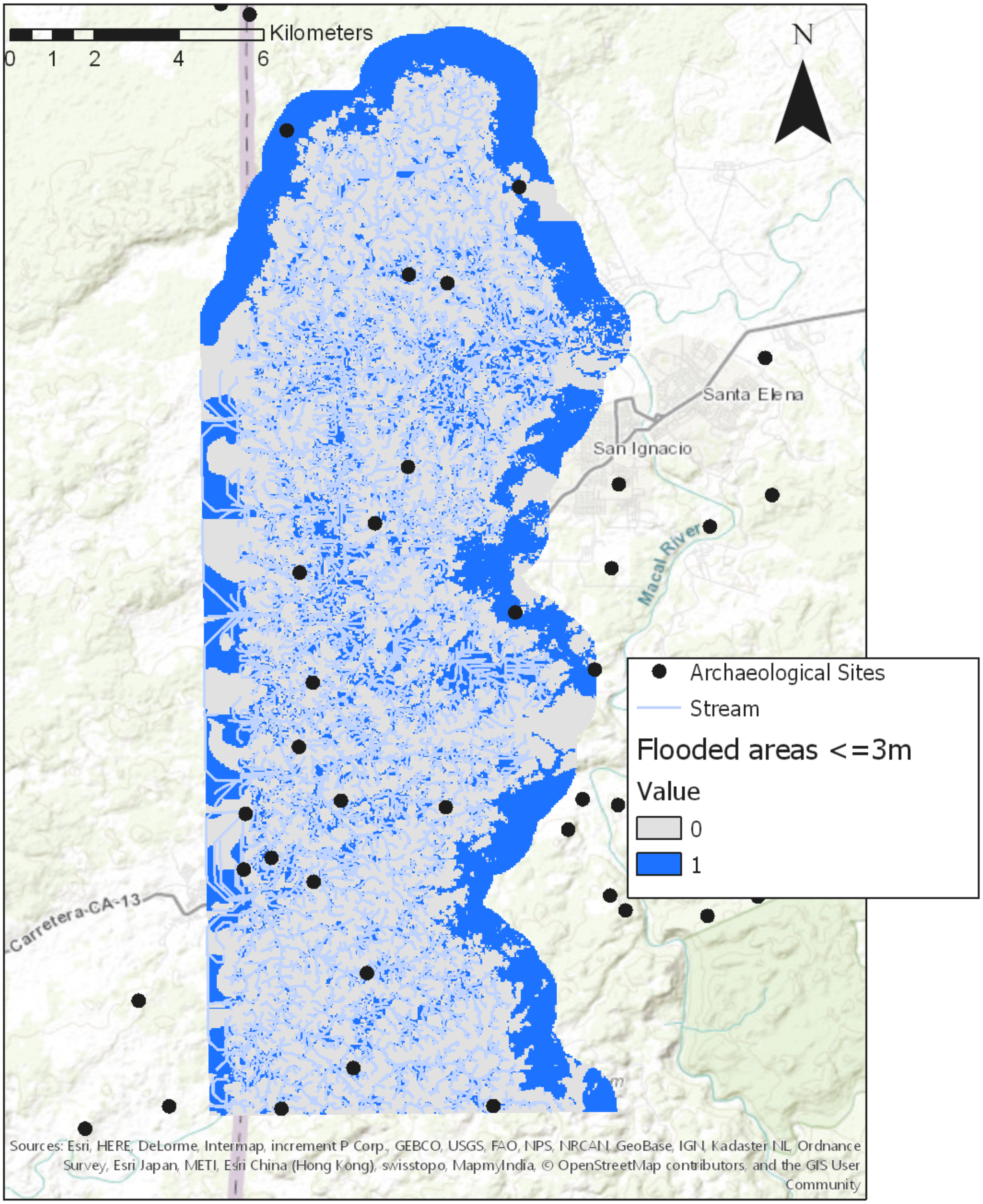

Figure 17: Flood inundation map for flood stage of 3m using beta method of HAND mapping, including only values greater than zero

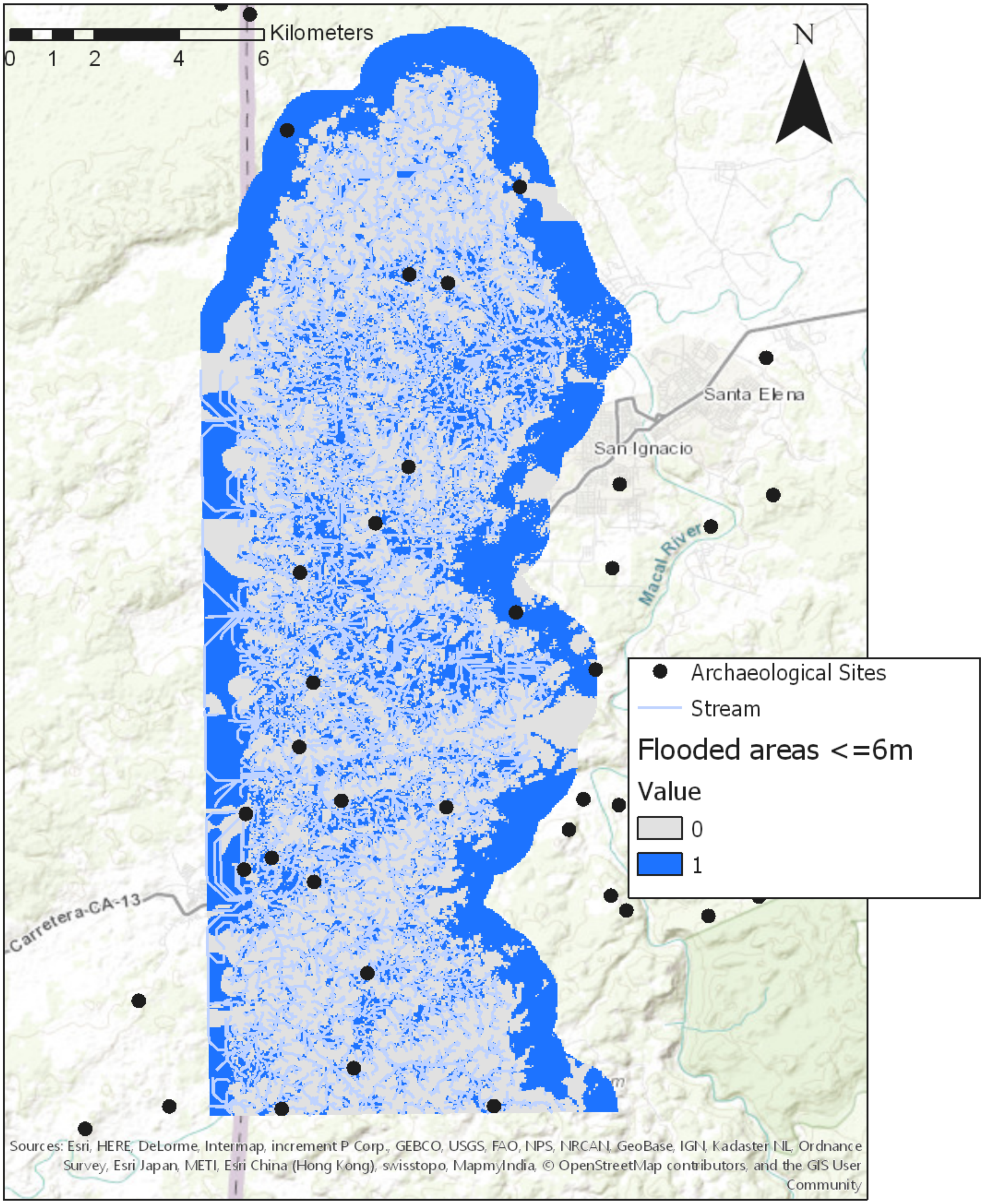

Figure 18: Flood inundation map for flood stage of 6m using beta method of HAND mapping, including only values greater than 0

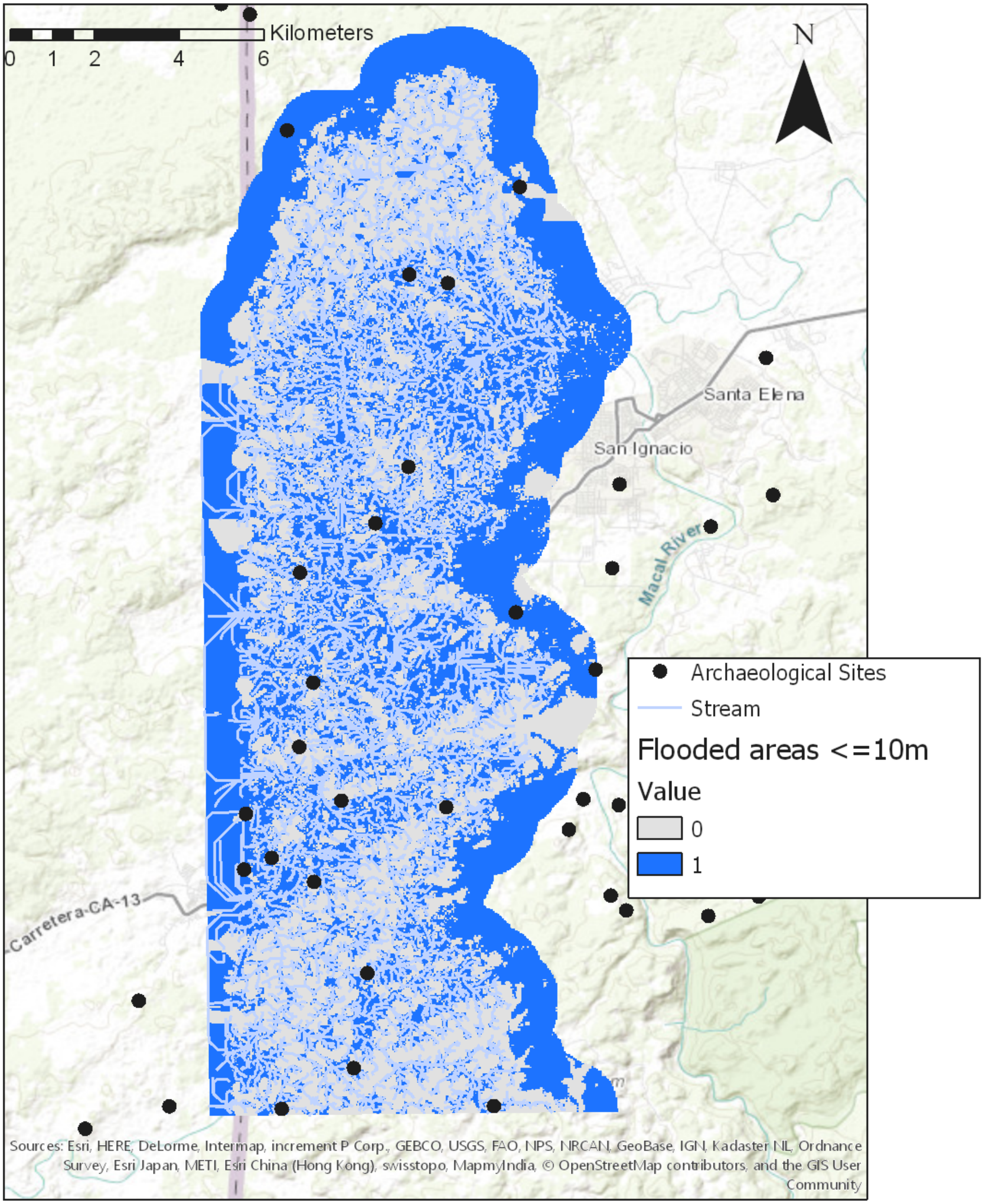

Figure 19: Flood inundation map for flood stage of 10m using beta method of HAND mapping, including only values greater than 0

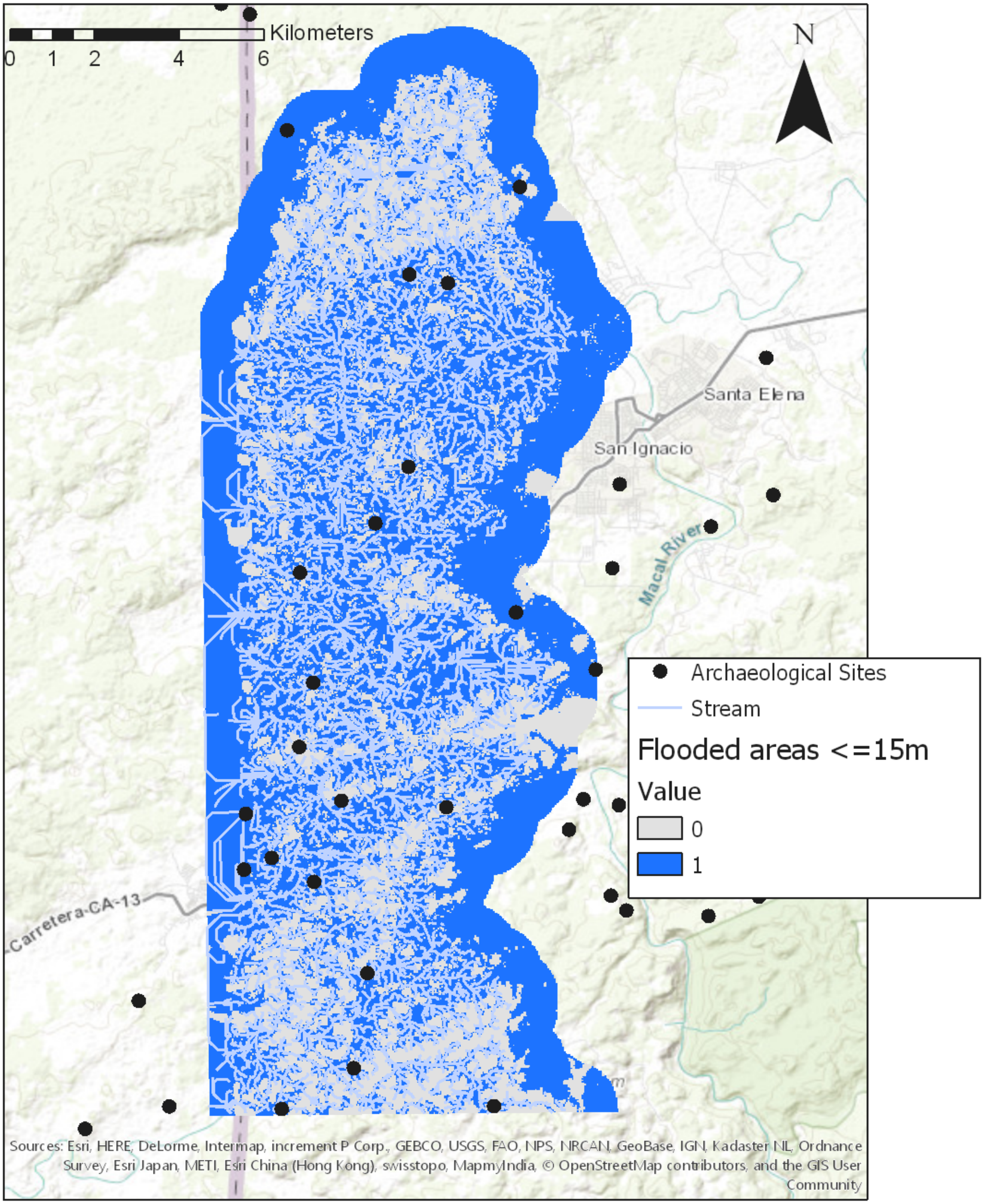

Figure 20: Flood inundation map for flood stage of 15m using beta method of HAND mapping, including only values greater than 0

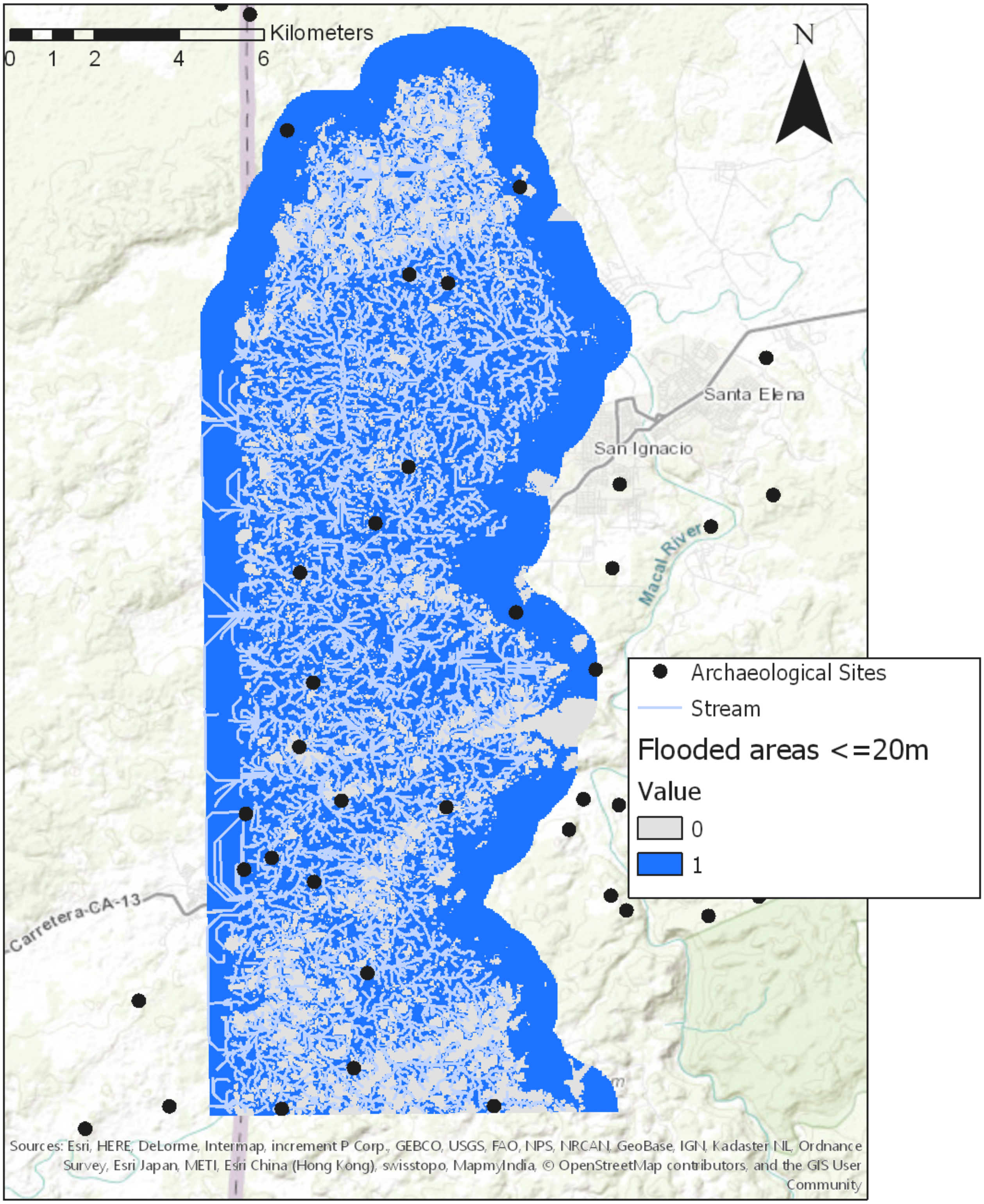

Figure 21: Flood inundation map for flood stage of 20m using beta method of HAND mapping, including only values greater than 0

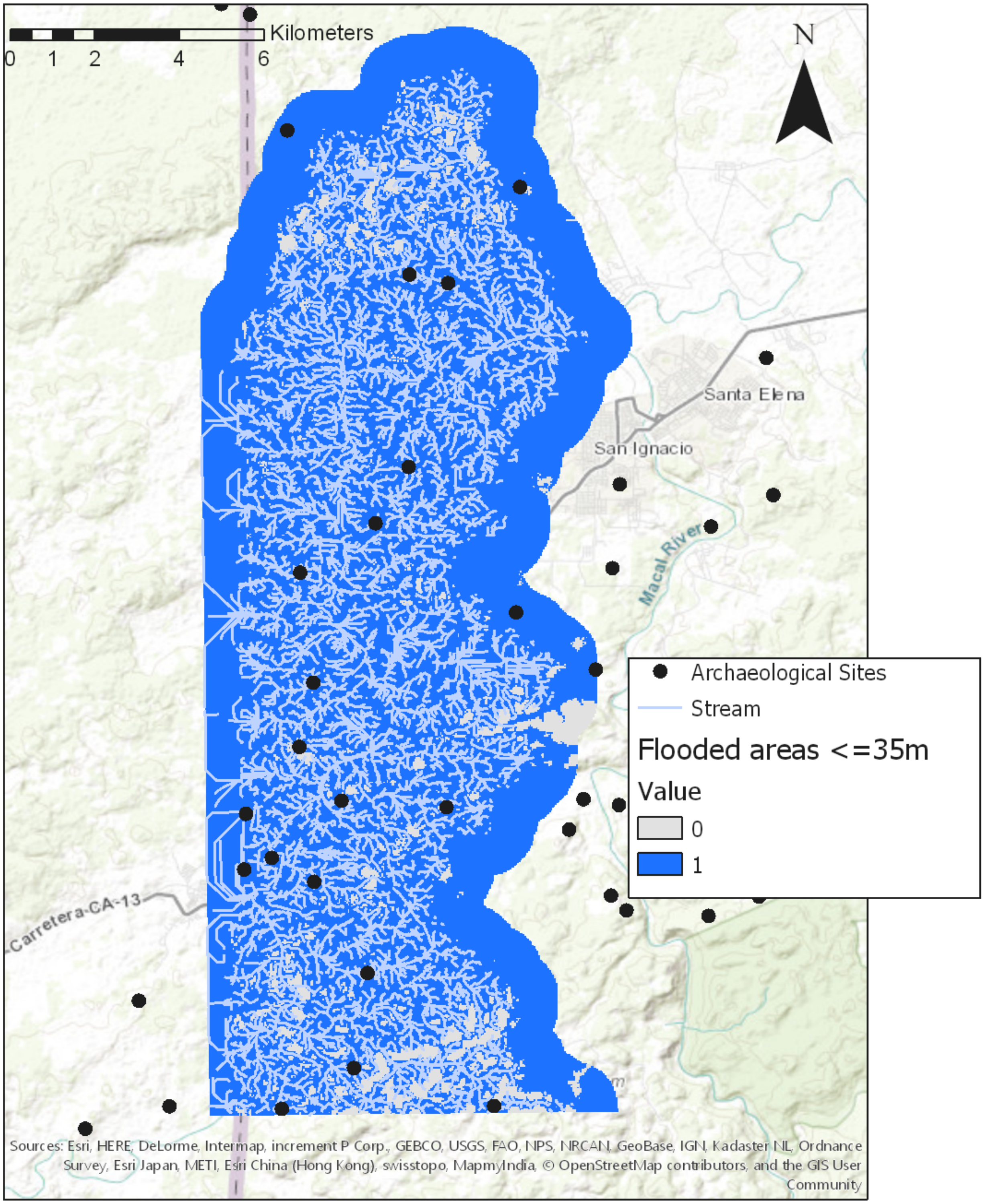

Figure 22: Flood inundation map for flood stage of 35m using beta method of HAND mapping, including only values greater than 0

Conclusions and Future Work

I was able to design a HAND map, and an associated series of flood inundation maps using a method that I designed myself. However, I am very new to GIS and therefore there are doubtless a number of issues that need to be worked out with this method, some of which I have covered. I will discuss these issues and work toward further refinement of my method with other members of my lab group that are experienced ArcGIS users. I do think that creating HAND maps completely within ArcGIS is a valuable skill because it offers a streamlined, relatively user-friendly method of mapping that does not necessarily require the internet.

After I have refined this method, I would like to create a paleoflood inundation map by dropping my elevation surfaces down by four meters, which would put the floodplain at the elevation it was at during the height of ancient Maya use. I also hope to use this method on the entire watershed, but for that I need more high-resolution imagery: either more LiDAR or some other type of satellite data that has finer resolution than what is currently available for SRTM in Belize.

These maps will contribute to my thesis research by offering insight into flood-related landscape formation through sediment aggradation and/or erosion. Combining these maps with geomorphic fieldwork will also help to create a more targeted sampling plan for the next round of sampling, focusing on areas with excellent, long-term flood records.

References

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Smith, A. Sampson, C., Bates, P. 2014. “Regional Flood Frequency Analysis at the Global Scale.” Water Resources Research 51: 539-553.