

## **Finding the Relationship Between Elevation and Isotopic Compositions of Stream Waters in the Peruvian Andes**

### **Abstract**

The Peruvian Andes is a prime example of highly-elevated topography generated by oceanic plate subduction. As a result, several studies have been made to further understand the formation of the Andean Mountain Range, but as indicated by previous studies (Schildgen et al, 2007), researchers are still unable to ascertain the of the magnitude of the uplift solely based on structural history due to conflicting uplift histories and tectonic drivers. Several (conflicting) geodynamic theories and models were suggested for explaining the Andean orogeny— one of which was a continuous late Cenozoic event that caused the delamination of the lithosphere on the South American plate, which in turn generated plate uplift and canyon incisions in the late Miocene. Another theory was that during the late Cenozoic, the crust continuously thickened and shortened, which resulted in slow surface uplift and also caused canyon incision. As a result, we believe that best way to confirm or dis-prove the currently proposed models would be to apply several different proxy approaches that deviate from structural history research while extending the research areas in question.

To accomplish this, Dr. Breecker and his research group will combine proxy approaches, which involve retrieving volcanic glasses and soil carbonates to analyze and perform stable isotope analyses for  $\delta D$  values, while analyzing ignimbrites using the  $^{40}\text{Ar}/^{39}\text{Ar}$  geochronometer (these studies are to be done by another professor off campus in the research group). This is to be performed in conjunction with the analysis of a general circulation climate model (Poulsen et al 2007) that approximates the scale of the surface elevation changes and their effects on climate (Poulsen et al 2010)— to further verify the general circulation climate models, modern waters in the region can be analyzed using soil collection techniques (that undergo water extraction) along with precipitation gauge and rain bucket data. Field collection is a necessary process because there are no published data on the soil, precipitation, or

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stream water values on the study region, (there are few precipitation stations in Peru, but not enough to accurately model precipitation isotopic values).

IEGCMs, or isotope-enabled atmospheric general circulation models, are used to quantify regional (Fig. 3) and global climate change, allowing the distortion of isotope values ( $\delta^{18}\text{O}$ ,  $\delta\text{D}$ ) to be recognized (Poulsen 2010). As a result, the usage of IEGCMs is vital in our volcanic glass and soil carbonate analyses, as we want to minimize the external effects on the  $\delta^{18}\text{O}$  or  $\delta\text{D}$  values. The  $\delta\text{D}$  value is especially important to determine because through  $\delta\text{D}$  records, one can determine the elevation at which a measurement was taken, as higher elevations correlate with lower  $\delta\text{D}$  values. This inverse relationship occurs because of the rain out effect; when rain occurs in a region of increasing elevations, water that is  $\delta\text{D}$  enriched is deposited first at lower elevations, whereas  $\delta^{18}\text{O}$  enriched precipitation is deposited more towards the peaks in elevation, and the leeward side of the peak usually receives less water overall (unless multi-directional winds are experienced due to a phenomenon like El Niño, in which that complicates analysis).

One large assumption is made when using these two coupled IEGCMs, the assumption that the IEGCMs perform correctly under the scenario of this project. To further evaluate these models on their ability to quantify all extraneous factors affecting the  $\delta^{18}\text{O}$  or  $\delta\text{D}$  values, our research group plans to sample and analyze river waters (or waters extracted from soils) from Peru—the physical results can be compared to the IEGCMs' modeled results, possibly revealing insight about the limitations of these models (if there are any). This is a necessary process because there is currently no publication data on the soil, precipitation, or stream water values on the study region, (there are few precipitation stations in Peru, but not enough to accurately model precipitation isotopic values).

## **Purpose**

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As a result, making a map of the analyzed river waters can be an essential step to the formation of this research paper—maps of the sampled river waters not only provide a visual for the sampling locations, but it also brings the ability to spatially analyze the collected stream waters, bringing important relationships to light such as the correspondence between elevation and isotopic compositions of sampled waters. By calculating the area of upstream drainage basins for each sample point, one can split the basin areas of each sample into elevation ranges (~200m, 500m, etc.). After partitioning all of the drainage basin areas into groups, the weighted mean elevation for stream water can be calculated, and using the isotopic composition data provided by the research group in Peru, one can finally determine the relationship between isotopic composition and elevation, and see whether or not the coupled IECGMs also follow this relationship in its modeling process.

Due to the huge data load from ASTER DEMs and the instability of arcMap when handling large amounts of raster data, a “Proof of Concept” was established for the purposes of this class—instead of using all 26 of the sampling locations, which span over 15 ASTER DEMs (provided by NASA Reverb), only one sample location will be used (labeled R120) due to its easy-to-spot general basin drainage area and its lack of nearby sample points (to reduce clutter). This “Proof of Concept” will also help the user learn the skills necessary to operate ArcHydro tools in ArcMap (which were never explicitly used in class), while combining preexisting skills learned from GEO327G. Because the “Proof of Concept” only has one point, the weighted mean elevation of all stream water samples is not necessary because there is only one stream sample focused on in this (the POC).

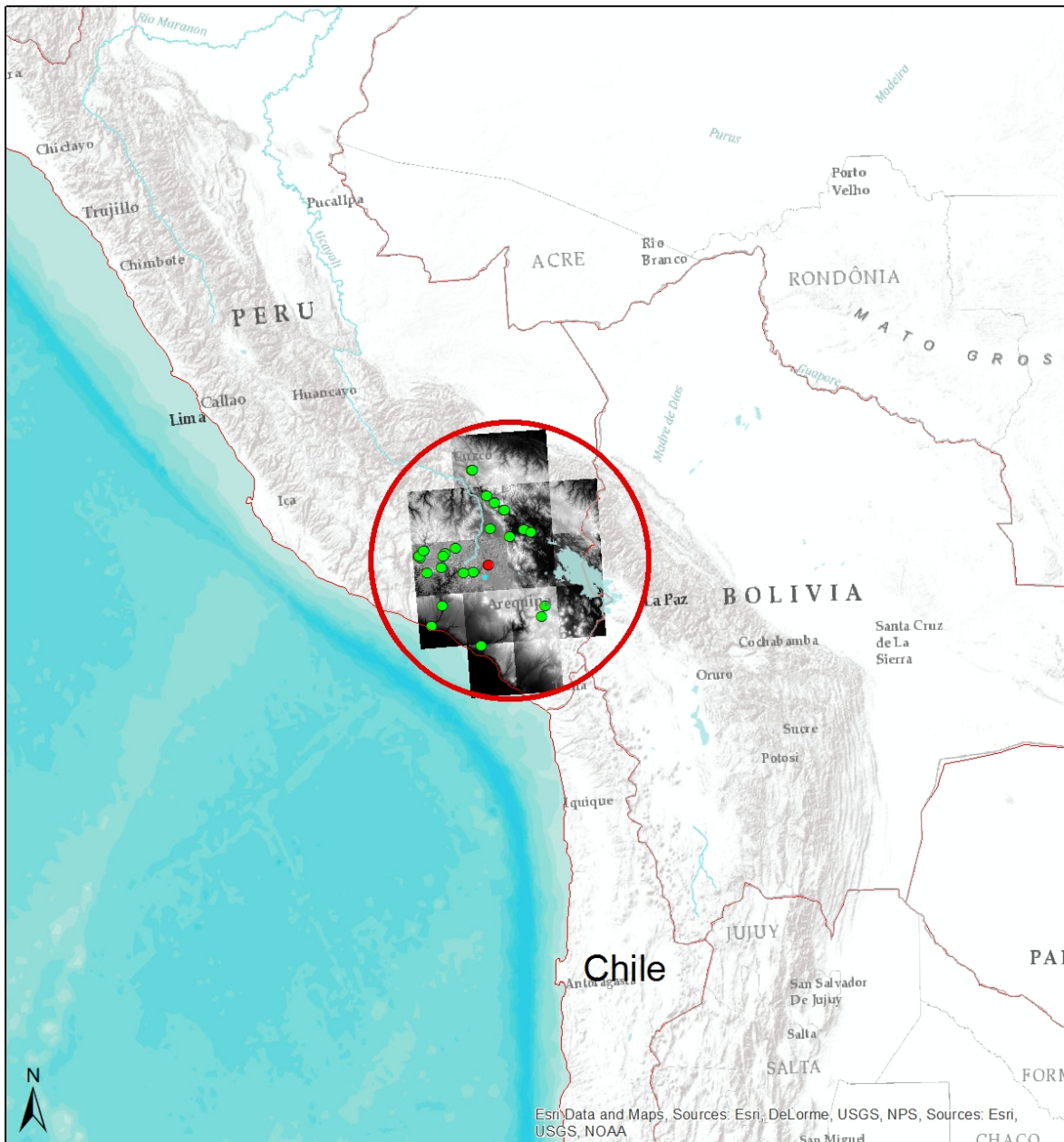
### **Data gathering and Pre-Processing**

Because of the Peruvian government did not provide a free DEM for the country, individual files from the ASTER GDEM had to be ordered and downloaded. The streams and inland waters were displayed from files by DIVA-GIS—while the files are not from a governmental organization, the data

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matches up relatively well with the DEMs, and DIVA-GIS was created by Robert J. Jijmans, a professor at UC Davis. A lot of preprocessing was required for any of the data was to be used—the sampled river data obtained by the research team in Peru was listed in UTM Eastings and Northings. The ASTER DEM data used GCS\_WGS\_1984, along with the inland water data. The preferred coordinate system for this project was South America Albers Equal Area Conic (which uses the South American 1969 datum). As a result, the sample location data points had to be imported as UTM coordinates to arcMap using the “Excel to Table” tool. Then, the points had to be projected (and saved as layer file) to the South America Albers Equal Area Conic, along with adding all the other files downloaded. ESRI Basemaps were then added to fill the blankness of the map region. After this somewhat tenuous process, the method could then be conducted.

## Peruvian Andes: River Sample Locations

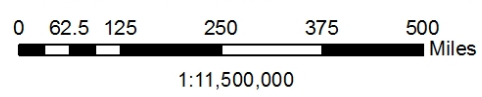


**Legend**

- Country Borders
- River Samples R109-R135
- R120 (Proof of Concept)
- Study Area of Peruvian Andes

**Study Area DEMs (Aster) Elevations**

High : 6414 (m)  
Low : 0 (m)



Coordinate System: South America Albers Equal Area Conic  
Datum: South American 1969  
Units: Meter

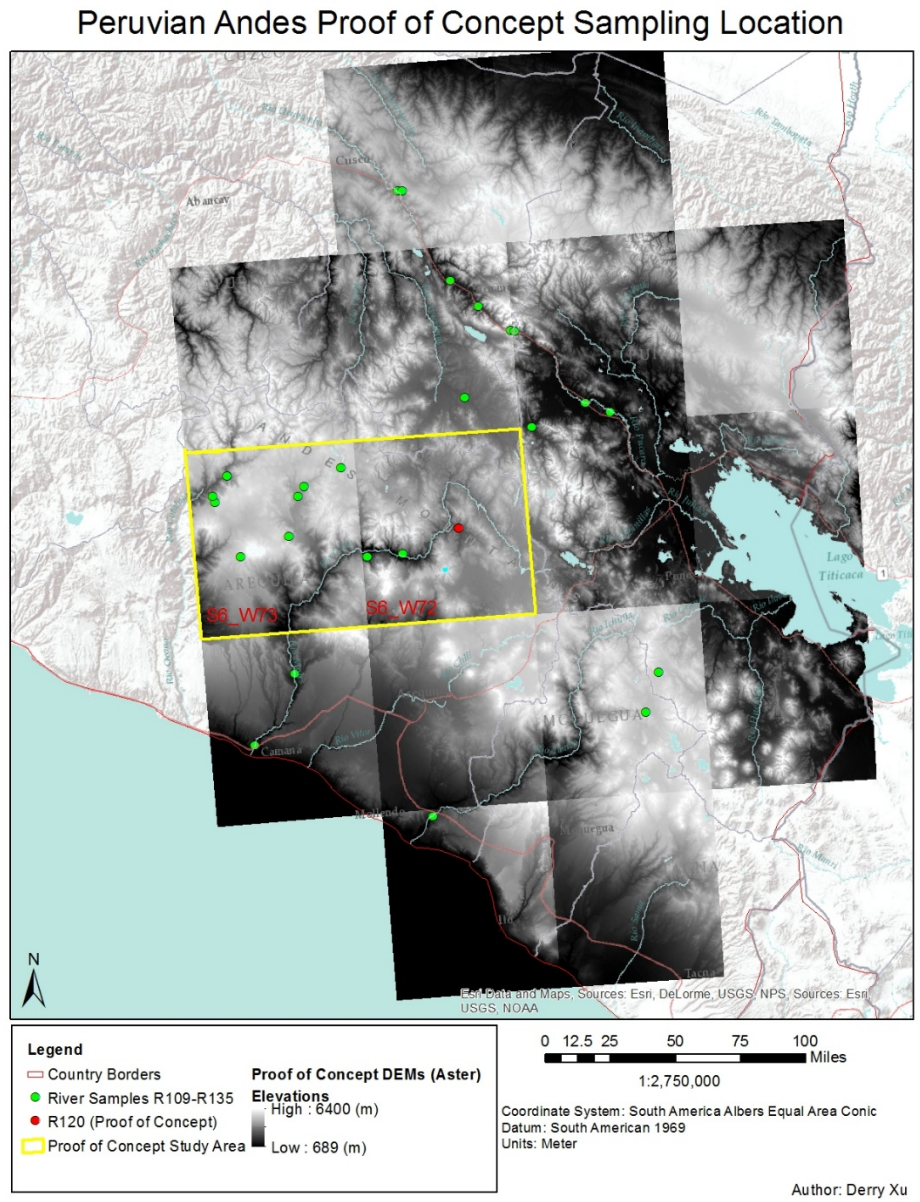
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Map 1- Post Preprocessing Map with a general view of the study area.

**Method\***

\*tools or processes already performed in labs will not have supplementary photos. Spatial Analyst and 3D Analyst were turned on beforehand.

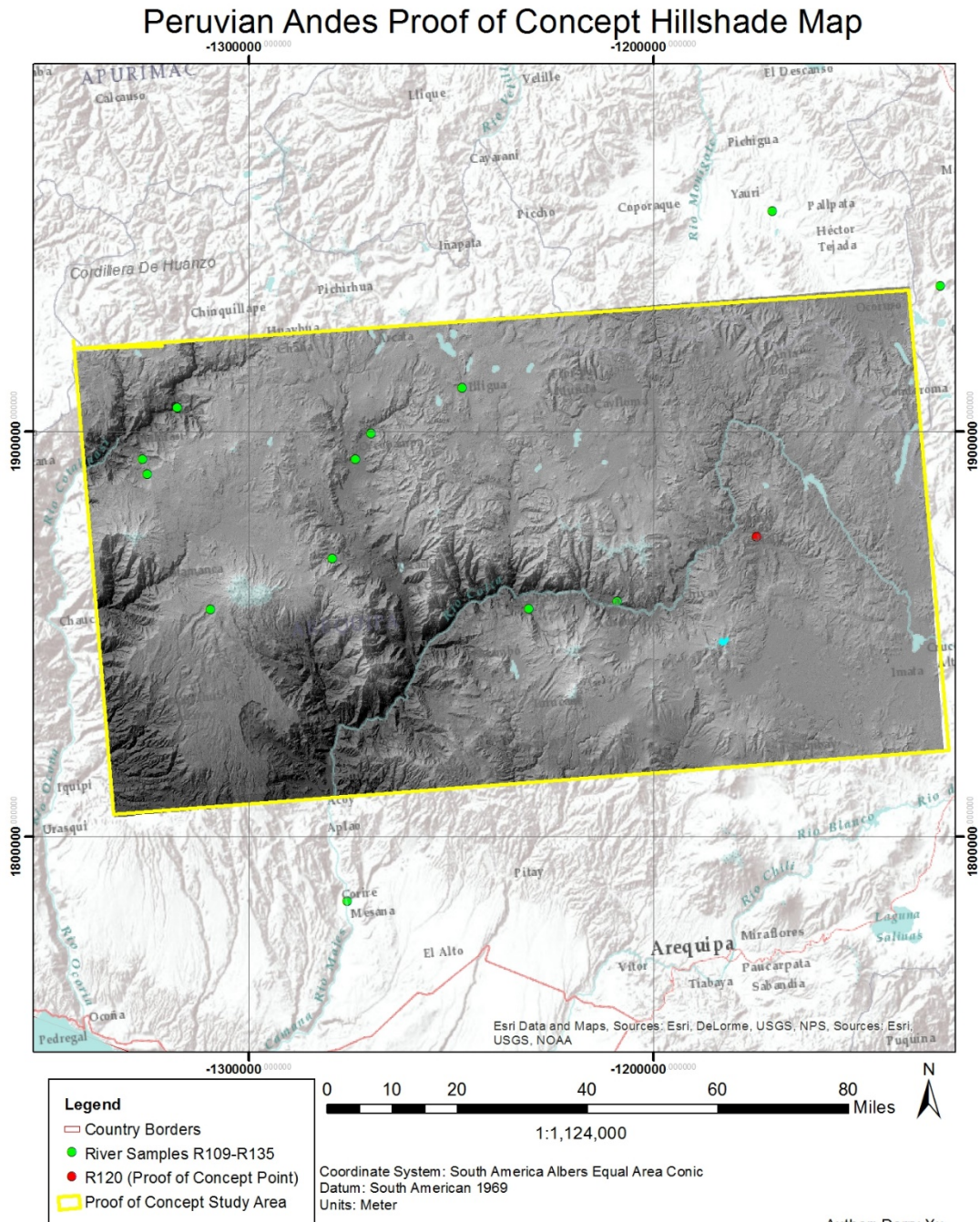
After all data processing was conducted, the first step was to create a mosaic for the area of interest (using the “Create a Mosaic Dataset” tool). This can be seen with Map 2. A “Fill” was also conducted to the mosaic to fix any errors due to the resolution of the data or rounding of elevations to the nearest integer value.



Map 2—Outlining the study areas for the POC. Two DEMs were used to test and review the mosaic process, even though DEM S6\_W73 is not necessary.

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Afterwards, a hillshade can be made (using the Hillshade tool) to show the elevations of the Peruvian Andes and provide insight on the drainage basins of the sample point. The DEM on top of the hillshade (by layer order) is made 50% transparent to show the “3D” features created by the hillshade while still retaining the study area mosaic. See Map 3.



Map 3—The unnecessary DEM layers were removed, and the combined DEM S6\_W73 and DEM S6\_W72 layers are both displayed on the map. The effects of the hillshade can be seen clearly.

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Afterwards, arcHydro tools are used. The first tool to be used before any other arcHydro tools is the “Flow Direction” tool (ignore the highlight). The input surface raster is the DEM for the study area, and the menu was used as shown below. The sink tool was also used after this to identify any sinks (no flow direction for an area), but no sinks were found.

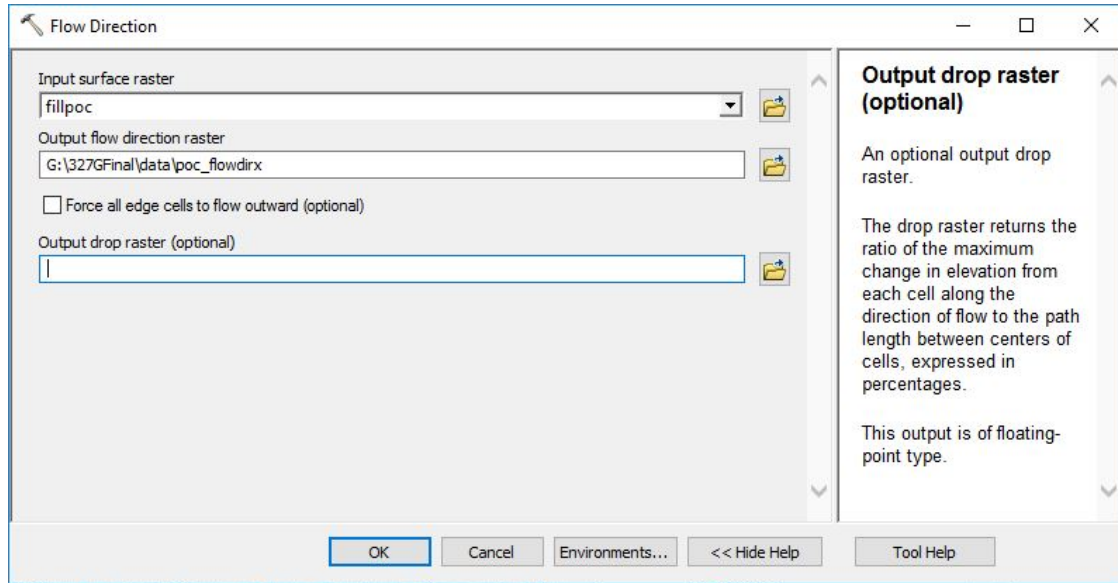


Fig. 1—The Flow Direction tool.

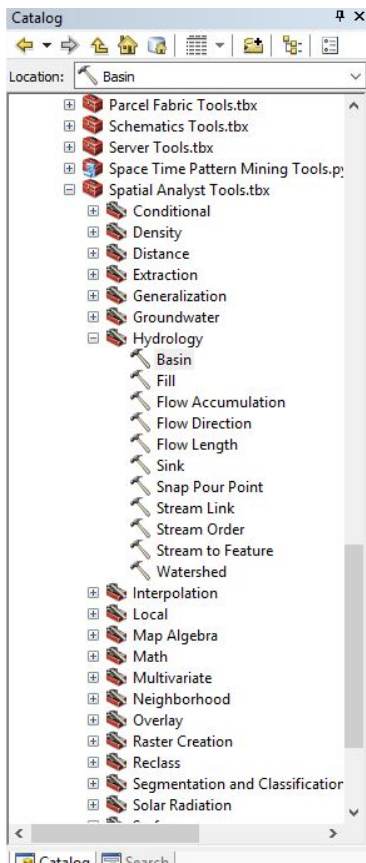


Fig. 2-- The arcHydro toolbox.



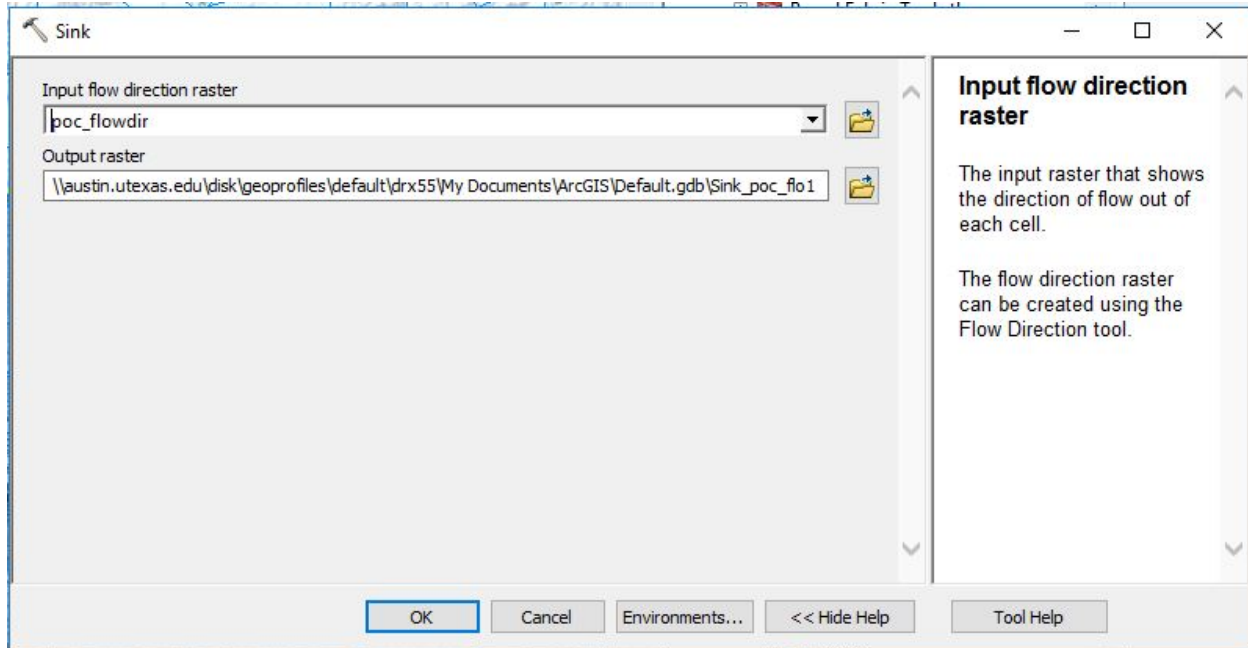


Fig 3—The Sink tool. It had no effect for this map because no sinks were made, and thus could not be corrected.

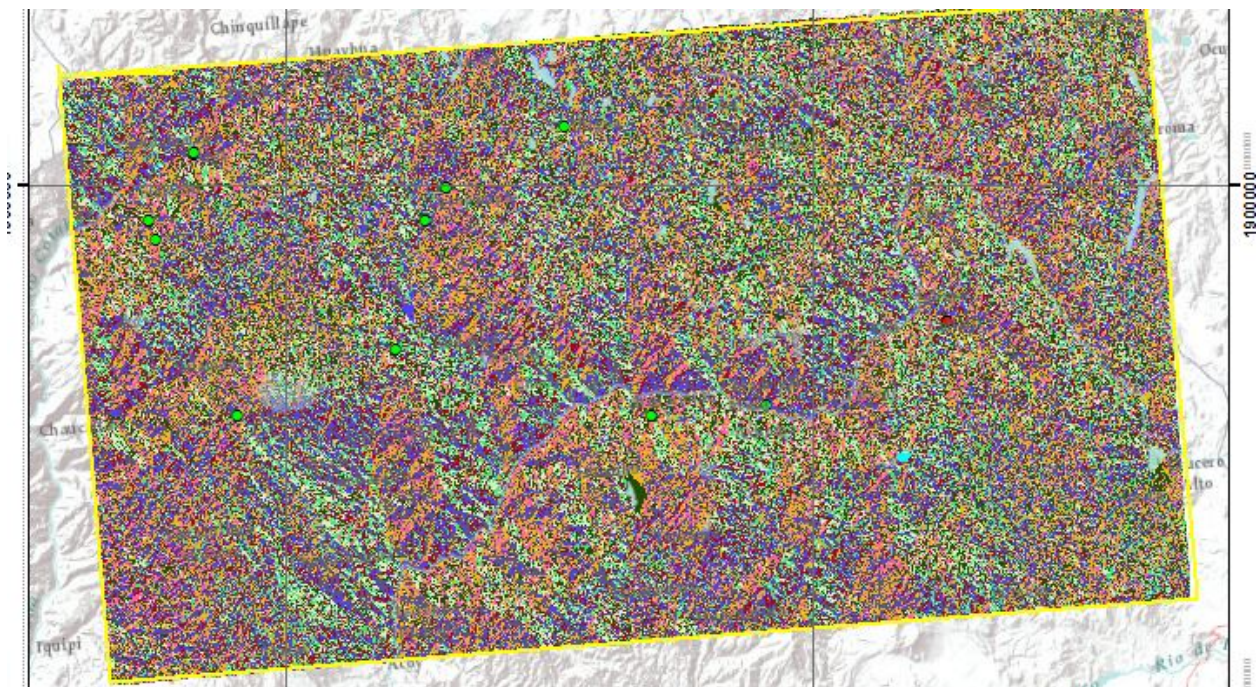


Fig. 4—The result of the flow direction raster. Every cell is assigned a direction for water flow due to the changes in elevation from cell to cell.

Afterwards, the watershed tool could be used. The input raster was the flow direction raster, the point of the interest was the POC, and the watershed was to be determined by the “Elevation” field of the point.

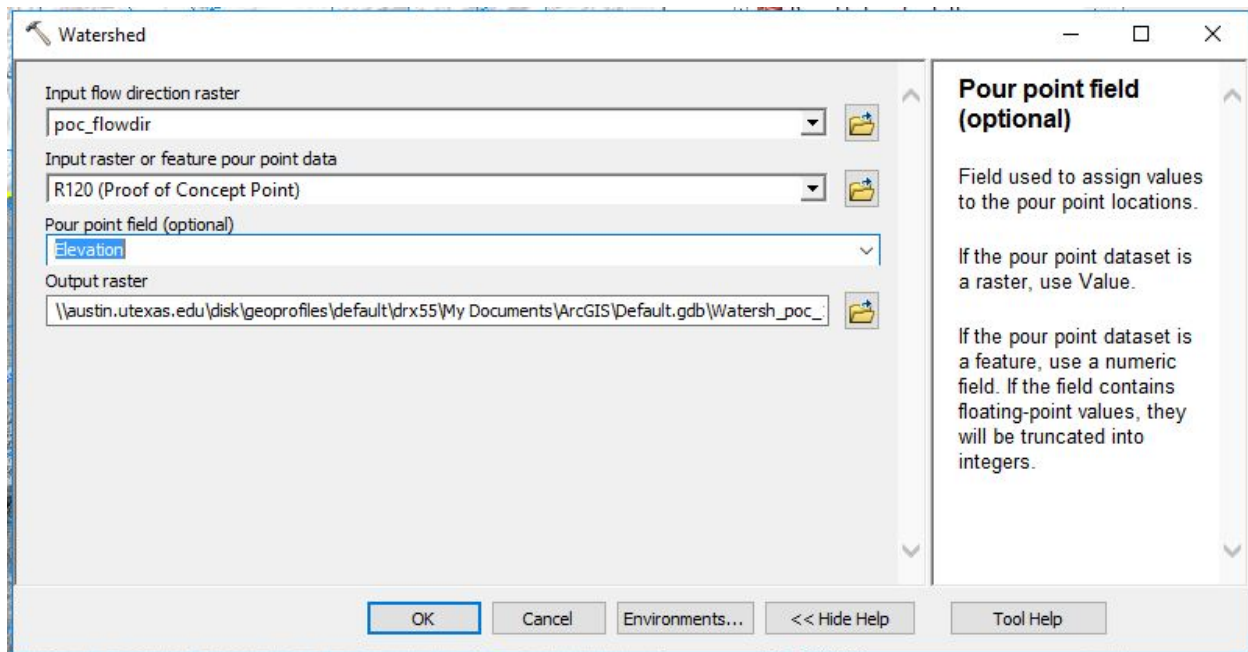
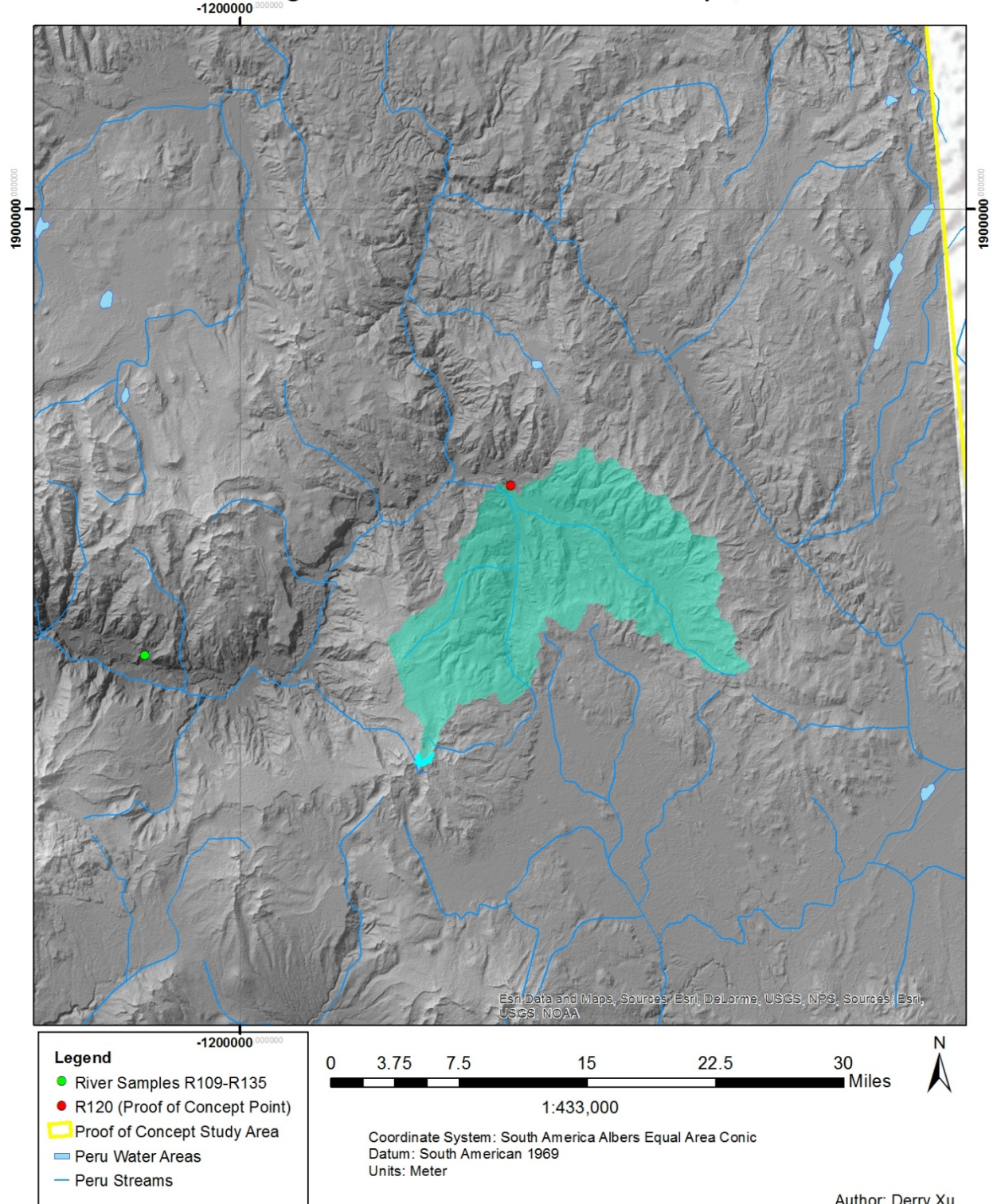


Fig 5 – Watershed tool. Output raster is not actually in that place.

# Drainage Basin for Proof of Concept, R120



Map 4—Drainage Basin. The Peruvian inland water sources and rivers are added to this map. (The label for the drainage basin is missing on this map, note.).

Afterwards, the “Contour” tool was used with these parameters, which resulted in the figure below the tool.

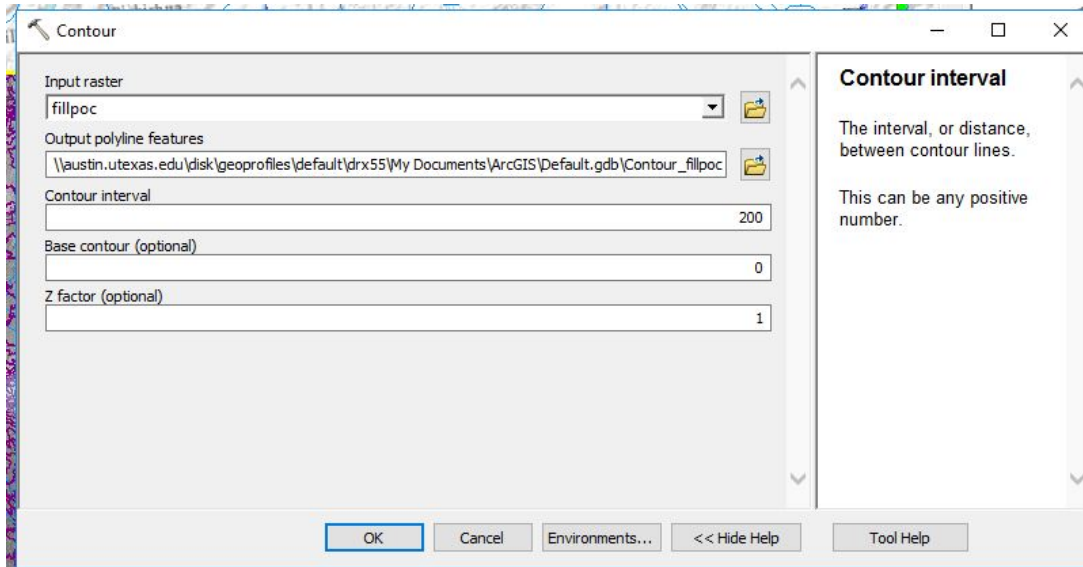


Fig 6—Contour tool.

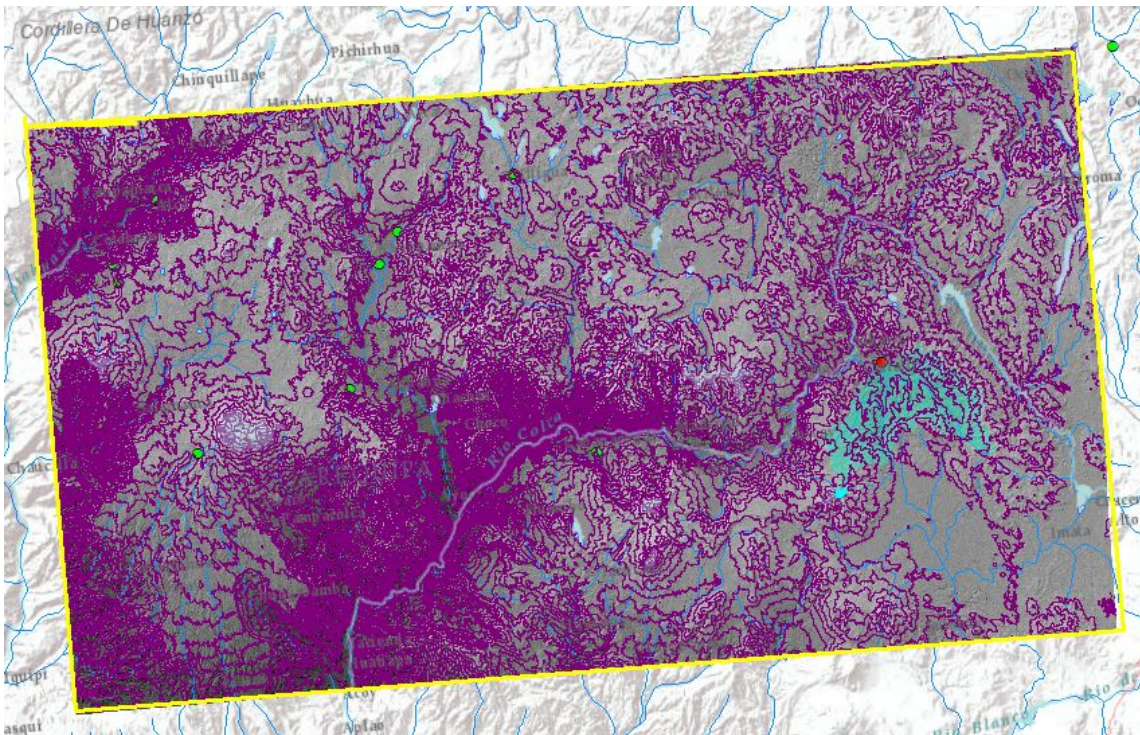


Fig 7—Effects of the contour tool on the whole mosaic.

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After using the “Contour” tool, the “Clip” tool was used to restrict the contours to the drainage basin area. There were some complications yet to be understood with regards to labeling the contour. Finally, the “Split polygons” tool is used to split the drainage basin into smaller pieces using the contour lines made earlier. The purpose of this is to split the entire area into small fragments of known elevations (at least, between the contours).

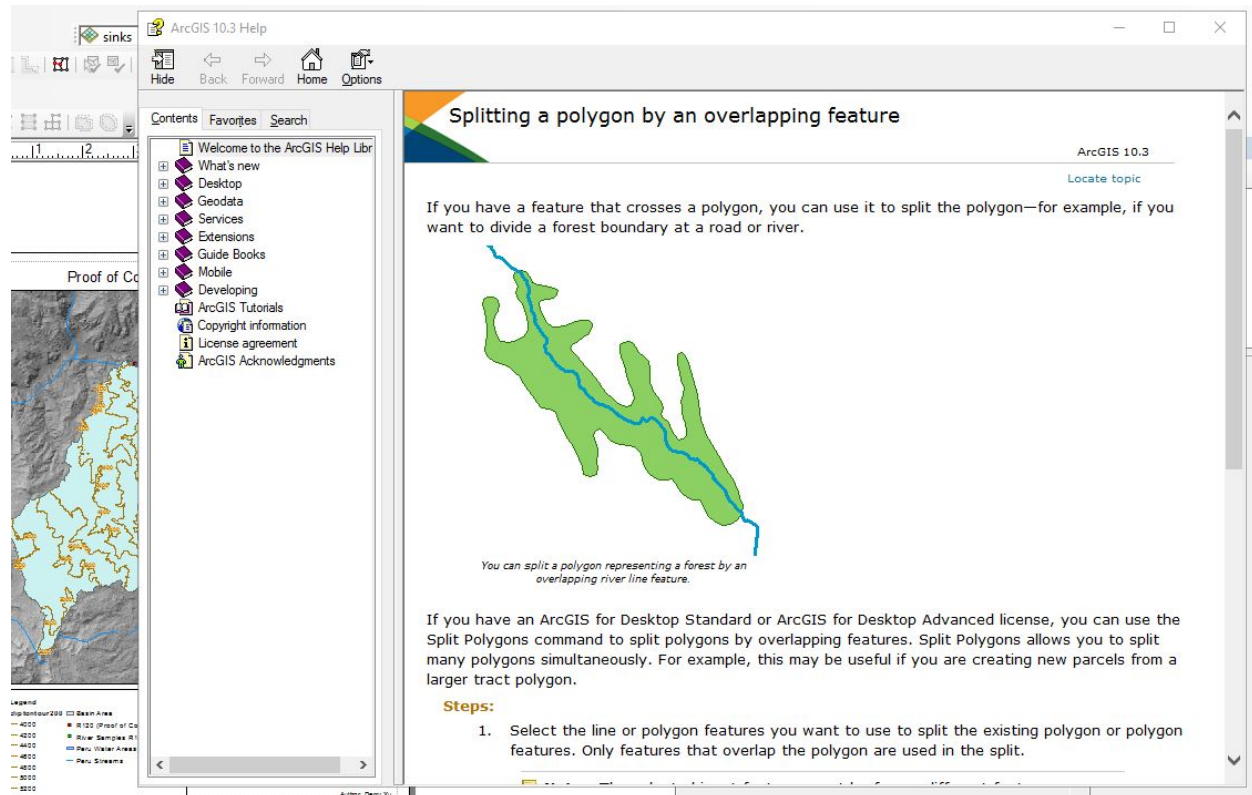
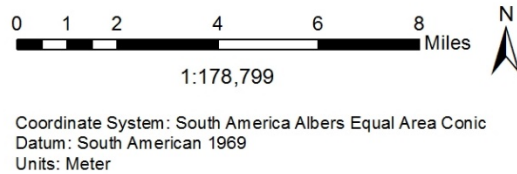
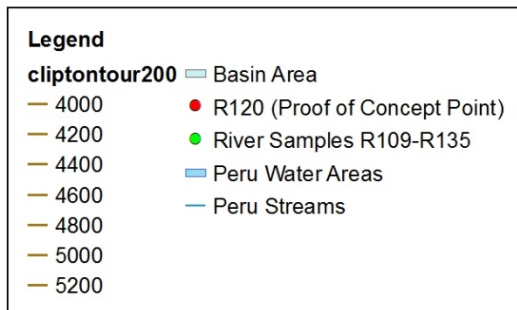
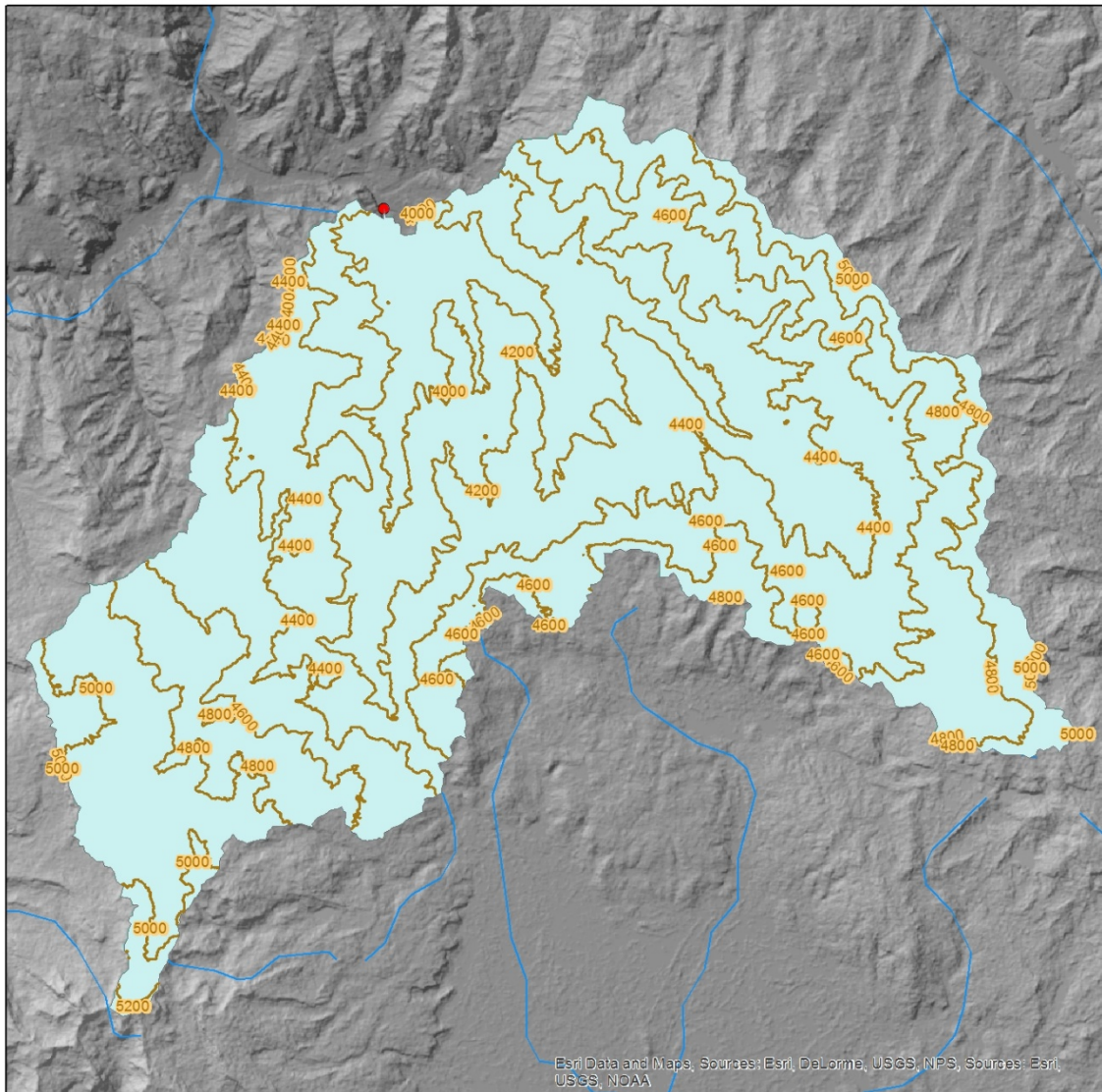


Fig 8- Details of the split polygons tool.

## Proof of Concept (R120) Drainage Basin



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Map 5- The final POC Map of the drainage Basin. The "jigsaw" Basin Area layer cannot be seen, but it can be viewed via the attribute table. The area of each portion is also calculated. (See Fig 9).

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| OBJECTID * | Shape * | Id | gridcode | Shape_Length | Shape_Area     |
|------------|---------|----|----------|--------------|----------------|
| 1          | Polygon | 1  | 3382     | 186.465843   | 1482.535222    |
| 2          | Polygon | 2  | 3394     | 124.324342   | 743.439782     |
| 3          | Polygon | 3  | 3884     | 5565.5131    | 480568.83949   |
| 4          | Polygon | 3  | 3884     | 72.884625    | 309.109856     |
| 5          | Polygon | 3  | 3884     | 182.906749   | 1384.790355    |
| 6          | Polygon | 3  | 3884     | 14243.361083 | 3657224.498056 |
| 7          | Polygon | 3  | 3884     | 9130.435954  | 1311980.306551 |
| 8          | Polygon | 3  | 3884     | 190.489232   | 1776.022301    |
| 9          | Polygon | 3  | 3884     | 145.242727   | 1442.879731    |
| 10         | Polygon | 3  | 3884     | 86.951411    | 347.262304     |
| 11         | Polygon | 3  | 3884     | 318.546416   | 5862.051047    |
| 12         | Polygon | 3  | 3884     | 128.0985     | 1000.12805     |
| 13         | Polygon | 3  | 3884     | 74.210733    | 286.320439     |
| 14         | Polygon | 3  | 3884     | 682.389568   | 18858.137627   |
| 15         | Polygon | 3  | 3884     | 560.841774   | 10730.578586   |
| 16         | Polygon | 3  | 3884     | 931.98241    | 24000.826263   |
| 17         | Polygon | 3  | 3884     | 835.64047    | 18161.229977   |
| 18         | Polygon | 3  | 3884     | 97.93278     | 485.868208     |
| 19         | Polygon | 3  | 3884     | 1372.143938  | 91259.746945   |
| 20         | Polygon | 3  | 3884     | 99.273173    | 496.853697     |
| 21         | Polygon | 3  | 3884     | 223.717527   | 2990.387625    |
| 22         | Polygon | 3  | 3884     | 449.508095   | 10980.436343   |
| 23         | Polygon | 3  | 3884     | 359.248409   | 5291.028109    |

*Fig 9- Proof that the basin is now split into smaller pieces, each labeled with areas.*

## **Conclusion**

As a result of all the data collection, a spreadsheet (Fig 10) of all the areas of each “piece” of the basin bounded by elevation contours of 200m is formed (“Table to Spreadsheet” was used to export the data). Using this data, one can find the area of each portion, match it to the corresponding contours it is bound by, and eventually obtain the weight of each 200m section detailed by the data. Of course, this requires a lot of tedious, rote Excel processing, and for the sake of this assignment, the concept is more important. Once the Excel operations are performed, the data for the POC can be correlated to a spreadsheet of all the isotopic compositions for the samples (measured vs. SMOW), (Fig 11). As said referenced earlier, this entire process is to be repeated 25 more times so that each point can calculate the area of its drainage basin with respect to its elevation. Even though this entire process is extremely tedious, the end process can be worthwhile, for only using arcMap, physically sampled river samples, and an assortment of data collected from the internet, one can essentially “peer-review” (or at the least cast doubt) on some frequently used climate models.



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|    | A        | B  | C        | D            | E           | F | G | H | I | J |
|----|----------|----|----------|--------------|-------------|---|---|---|---|---|
| 1  | OBJECTID | Id | gridcode | Shape_Length | Shape_Area  |   |   |   |   |   |
| 2  | 1        | 1  | 3382     | 186.4858428  | 1482.535222 |   |   |   |   |   |
| 3  | 2        | 2  | 3394     | 124.3243418  | 743.4397517 |   |   |   |   |   |
| 4  | 3        | 3  | 3884     | 5965.5131    | 480588.8395 |   |   |   |   |   |
| 5  | 4        | 3  | 3884     | 72.88482507  | 309.1098582 |   |   |   |   |   |
| 6  | 5        | 3  | 3884     | 182.9067488  | 1384.790355 |   |   |   |   |   |
| 7  | 6        | 3  | 3884     | 14243.36108  | 3657224.498 |   |   |   |   |   |
| 8  | 7        | 3  | 3884     | 9130.438954  | 1311980.307 |   |   |   |   |   |
| 9  | 8        | 3  | 3884     | 190.4892319  | 1776.022301 |   |   |   |   |   |
| 10 | 9        | 3  | 3884     | 145.2427286  | 1442.879731 |   |   |   |   |   |
| 11 | 10       | 3  | 3884     | 86.95141131  | 347.2623044 |   |   |   |   |   |
| 12 | 11       | 3  | 3884     | 318.5464158  | 5862.051047 |   |   |   |   |   |
| 13 | 12       | 3  | 3884     | 128.0984999  | 1000.12905  |   |   |   |   |   |
| 14 | 13       | 3  | 3884     | 74.21073302  | 286.3204389 |   |   |   |   |   |
| 15 | 14       | 3  | 3884     | 882.389688   | 18858.13783 |   |   |   |   |   |
| 16 | 15       | 3  | 3884     | 690.841774   | 10730.57859 |   |   |   |   |   |
| 17 | 16       | 3  | 3884     | 931.9824097  | 24000.82626 |   |   |   |   |   |
| 18 | 17       | 3  | 3884     | 835.6404697  | 18161.22998 |   |   |   |   |   |
| 19 | 18       | 3  | 3884     | 97.93277954  | 485.8682078 |   |   |   |   |   |
| 20 | 19       | 3  | 3884     | 1372.143938  | 91259.74694 |   |   |   |   |   |
| 21 | 20       | 3  | 3884     | 99.27317299  | 496.853697  |   |   |   |   |   |
| 22 | 21       | 3  | 3884     | 223.7175272  | 2990.387825 |   |   |   |   |   |
| 23 | 22       | 3  | 3884     | 449.5080947  | 10980.43634 |   |   |   |   |   |
| 24 | 23       | 3  | 3884     | 359.2484092  | 5291.028109 |   |   |   |   |   |
| 25 | 24       | 3  | 3884     | 105.4825276  | 724.896938  |   |   |   |   |   |
| 26 | 25       | 3  | 3884     | 221.2830264  | 2316.617829 |   |   |   |   |   |
| 27 | 26       | 3  | 3884     | 159.827498   | 1719.015374 |   |   |   |   |   |
| 28 | 27       | 3  | 3884     | 210.155676   | 932.4350341 |   |   |   |   |   |
| 29 | 28       | 3  | 3884     | 87.87475406  | 539.6669792 |   |   |   |   |   |
| 30 | 29       | 3  | 3884     | 2667.244681  | 354698.3923 |   |   |   |   |   |
| 31 | 30       | 3  | 3884     | 72.61113231  | 170.6255737 |   |   |   |   |   |
| 32 | 31       | 3  | 3884     | 1156.321717  | 29413.88783 |   |   |   |   |   |
| 33 | 32       | 3  | 3884     | 2781.430836  | 289683.1023 |   |   |   |   |   |
| 34 | 33       | 3  | 3884     | 739.4270178  | 13457.94665 |   |   |   |   |   |
| 35 | 34       | 3  | 3884     | 5343.270476  | 727200.297  |   |   |   |   |   |
| 36 | 35       | 3  | 3884     | 15237.60696  | 4033910.698 |   |   |   |   |   |
| 37 | 36       | 3  | 3884     | 16.35665183  | 9.583787286 |   |   |   |   |   |
| 38 | 37       | 3  | 3884     | 611.846654   | 8811.580835 |   |   |   |   |   |
| 39 | 38       | 3  | 3884     | 88.08829985  | 537.5055766 |   |   |   |   |   |
| 40 | 39       | 3  | 3884     | 92.65416814  | 610.888859  |   |   |   |   |   |
| 41 | 40       | 3  | 3884     | 135.3423964  | 989.8037807 |   |   |   |   |   |
| 42 | 41       | 3  | 3884     | 127.7487444  | 871.9288099 |   |   |   |   |   |
| 43 | 42       | 3  | 3884     | 103.9352116  | 501.3305391 |   |   |   |   |   |
| 44 | 43       | 3  | 3884     | 356.3478259  | 8082.869183 |   |   |   |   |   |
| 45 | 44       | 3  | 3884     | 333.0200175  | 6771.739072 |   |   |   |   |   |
| 46 | 45       | 3  | 3884     | 224.855964   | 2779.173055 |   |   |   |   |   |
| 47 | 46       | 3  | 3884     | 2897.410419  | 130260.1509 |   |   |   |   |   |
| 48 | 47       | 3  | 3884     | 582.1958298  | 18401.03872 |   |   |   |   |   |
| 49 | 48       | 3  | 3884     | 198.5362395  | 1737.168856 |   |   |   |   |   |
| 50 | 49       | 3  | 3884     | 88.40108447  | 358.7394388 |   |   |   |   |   |
| 51 | 50       | 3  | 3884     | 3965.754668  | 602473.2298 |   |   |   |   |   |
| 52 | 51       | 3  | 3884     | 142.2840139  | 1289.54694  |   |   |   |   |   |
| 53 | 52       | 3  | 3884     | 396.9243421  | 9945.908872 |   |   |   |   |   |
| 54 | 53       | 3  | 3884     | 237.5118272  | 2967.367451 |   |   |   |   |   |
| 55 | 54       | 3  | 3884     | 60835.14832  | 36150209.39 |   |   |   |   |   |
| 56 | 55       | 3  | 3884     | 9107.358365  | 1355283.966 |   |   |   |   |   |
| 57 | 56       | 3  | 3884     | 585.7635526  | 14773.69622 |   |   |   |   |   |
| 58 | 57       | 3  | 3884     | 260.2118218  | 2532.445473 |   |   |   |   |   |
| 59 | 58       | 3  | 3884     | 55293.95395  | 23462895.17 |   |   |   |   |   |
| 60 | 59       | 3  | 3884     | 58.89191682  | 212.3401232 |   |   |   |   |   |
| 61 | 60       | 3  | 3884     | 1519.881328  | 119439.072  |   |   |   |   |   |
| 62 | 61       | 3  | 3884     | 447.5234612  | 14200.44289 |   |   |   |   |   |

Fig 10- Exported Areas of all the pieces of the drainage basin.

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The image shows a screenshot of an Excel spreadsheet titled "2016\_Peru\_river\_waters\_dD - Excel". The ribbon is set to "Home" with the "Font" and "Alignment" groups visible. The active cell is A1, containing the text "sample name". The spreadsheet data is as follows:

|    | A                 | B               | C                 | D | E | F  |
|----|-------------------|-----------------|-------------------|---|---|----|
| 1  | sample name       | dD (‰ vs. SMOW) | d18O (‰ vs. SMOW) |   |   | 26 |
| 2  | R109 201606231255 | -119.8          | -15.9             |   |   |    |
| 3  | R110 201606231740 | -119.8          | -16.1             |   |   |    |
| 4  | R111 201606241350 | -95.7           | -12.7             |   |   |    |
| 5  | R112 201606241539 | -115.2          | -15.6             |   |   |    |
| 6  | R113 201606251627 | -121.4          | -16.7             |   |   |    |
| 7  | R114 201606261039 | -132.4          | -17.8             |   |   |    |
| 8  | R116 201606271433 | -119.2          | -15.0             |   |   |    |
| 9  | R117 201606281211 | -134.7          | -17.5             |   |   |    |
| 10 | R118 201606281511 | -128.5          | -17.1             |   |   |    |
| 11 | R119 201606291308 | -128.6          | -17.1             |   |   |    |
| 12 | R120 201606301645 | -114.5          | -14.2             |   |   |    |
| 13 | R121 201607011204 | -115.0          | -15.6             |   |   |    |
| 14 | R122 201607011641 | -121.9          | -16.0             |   |   |    |
| 15 | R123 201607061642 | -118.0          | -14.3             |   |   |    |
| 16 | R124 201607071408 | -123.2          | -15.8             |   |   |    |
| 17 | R125 201607081030 | no data         | -15.3             |   |   |    |
| 18 | R126 201607081357 | -113.9          | -15.1             |   |   |    |
| 19 | R127 201607111211 | -118.4          | -15.7             |   |   |    |
| 20 | R128 201607111329 | -122.3          | -16.1             |   |   |    |
| 21 | R129 201607111613 | -121.3          | -16.5             |   |   |    |
| 22 | R130 201607111659 | -116.2          | -15.5             |   |   |    |
| 23 | R131 201607121230 | -126.3          | -17.5             |   |   |    |
| 24 | R132 201607121550 | -116.3          | -15.3             |   |   |    |
| 25 | R133 201607131324 | -122.6          | -16.4             |   |   |    |
| 26 | R134 201607131415 | -124.8          | -16.6             |   |   |    |
| 27 | R135 201607141536 | -97.0           | -12.6             |   |   |    |
| 28 |                   |                 |                   |   |   |    |
| 29 |                   |                 |                   |   |   |    |
| 30 |                   |                 |                   |   |   |    |
| 31 |                   |                 |                   |   |   |    |
| 32 |                   |                 |                   |   |   |    |

Fig 11- Isotopic Values, R120 is highlighted.

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Sources:

*(Tutorial for archHydro)*

<https://www.crrw.utexas.edu/gis/gishydro07/Introduction/Exercises/Ex4.html>

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Peru GDEM

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