A NEW METHOD FOR EXTRACTING RIVER PROFILES AND NORMALIZED STEEPNESS VALUES WITH OPEN-SOURCE R SCRIPT

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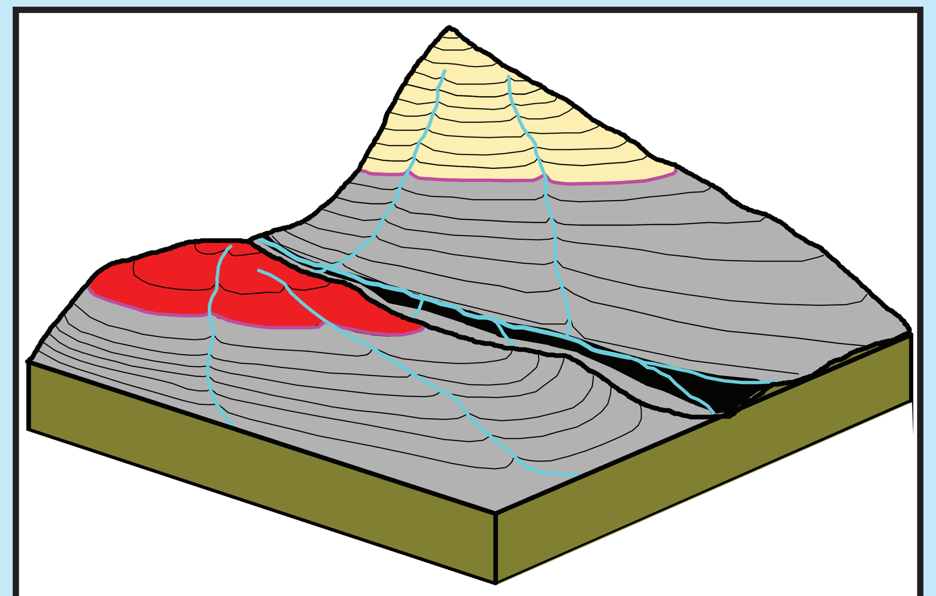
Abstract

Streams in the Cullasaja River basin were the focus of a recent study in which plots were produced using the StreamProfiler tool (http://www.geomorphtools.org) and Matlab, and were interpreted to have experienced a base-level change in the Miocene (Gallen et. al, 2013). The extraction of longitudinal profiles using R, an open-source computing language, instead of Matlab offers an alternative method to investigate uplift history. ArcMap v.10 hydrology tools were used to find the steepest path from the headwaters of each stream and the results were imported into R to draw stream profiles and calculate normalized steepness values (ksn) along multiple stream networks in the Blue Ridge of western North Carolina. A detailed description of the normalized steepness analysis of stream profiles can be found in many recent geomorphology papers (e.g. Kirby and Whipple, 2001; 2012, Duvall et al., 2004, Gallen et al., 2013).

With high-resolution LIDAR data (horizontal resolution of ~6 m and a vertical resolution of ~1/3 m) obtained from the NC Floodmaps program (http://www.ncfloodmaps.com/) a discretized slope map was produced using three topographic parameters. The first parameter was defined as areas with both elevations less than 1000 m and slopes less than 3 degrees. These areas correspond to possible lineaments. The second topographic style was defined as areas with elevations greater than 1000 m and slopes less than 10 degrees, and was used to find possible relict landscapes in the upper reaches of drainage basins. The third topographic style was defined as areas higher than 1000 m with slopes greater than 10 degrees. These areas correspond to high topography that is steep.

To establish a relative sequence of local uplift, a geomorphological study of knickpoint migration may be utilized (Gallen et al., 2011, Gallen et al., 2013, Miller et al., 2013). The addition of the discretized slope maps offers a new way to find relict landscapes and compare these with knickpoint locations.



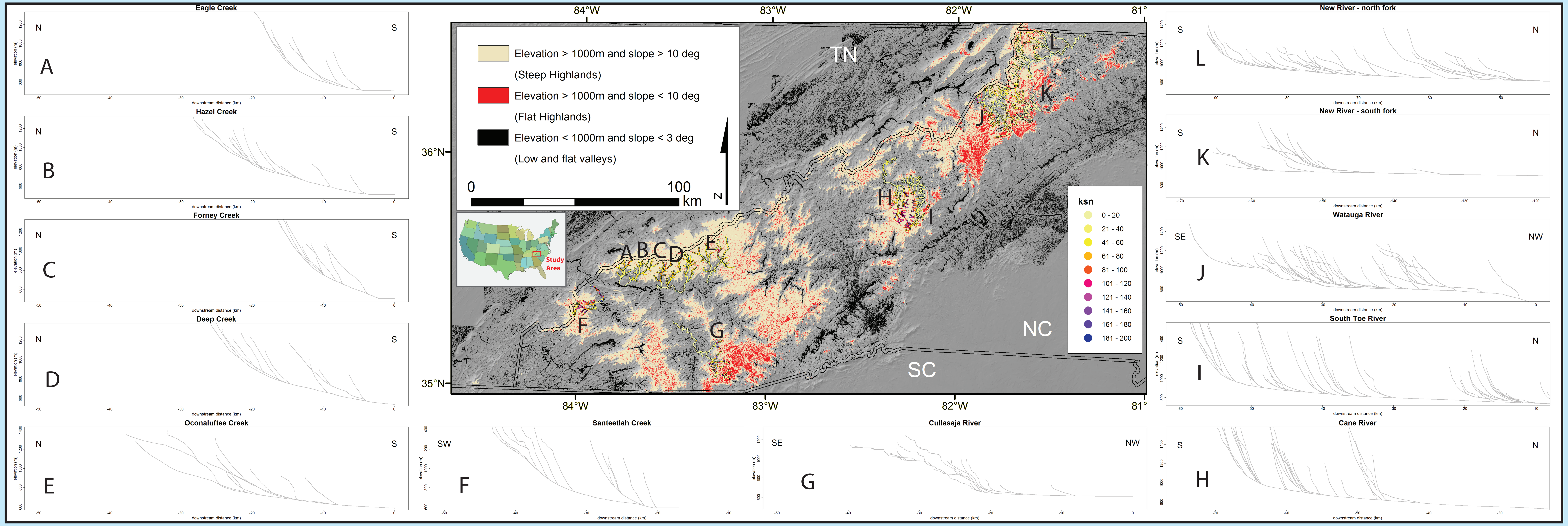
How to read this map:

This map is divided into 3 topographic styles:
- High and steep - beige
- Hign and flat - red
- Low and flat - black

The streams are colored according to normalized steepness, or ksn. It is calculated like this:

$$ksn = (S) x (A^\theta)$$

- ksn = normalized steepness
- S = slope
- A = drainage area
- θ = reference concavity



Step 1: Execute the following steps in ArcMap to find the downstream path and export it as a *.dbf file.

Add your DEM. I added hillshade and colors. Make sure your data frame and the DEM are in the same projection. Use (Data management → projections and transformations → raster → project raster) if needed.

Now you need to fill the DEM to remove any pits, etc. Use (spatial analyst → hydrology → fill)

Now use (spatial analyst → hydrology → flow direction). Input the filled DEM and the name you want for the flow direction raster. This name can not exceed 13 characters.

Now use (spatial analyst → hydrology → flow accumulation). Input the flow direction and the name you want for the flow accumulation raster. Set type to "integer."

Now use (spatial analyst → hydrology → flow length). Input the flow direction raster and the name you want for the flow length raster.

Add a new shapefile. Make it a point. Name the file and assign the same projection as the DEM.

Now you assign the top of the streams with the editor tool. You can find this by right-clicking an item and choosing (edit features → start editing)

Click on the locations of all the headwaters (beginning of streams). I have turned on a water layer to help find streams. Click all the points you want included as profiles for each basin.

Use (spatial analysis → distance → cost path)
Input raster = shapefile of selected points
Cost distance = flow accumulation raster
Backlink raster = flow direction raster
Output raster = name of the cost path raster file

Use (spatial analysis → extraction → sample) to extract the x,y,z, length, and accumulation into a *.dbf file. This file will be read directly into R.

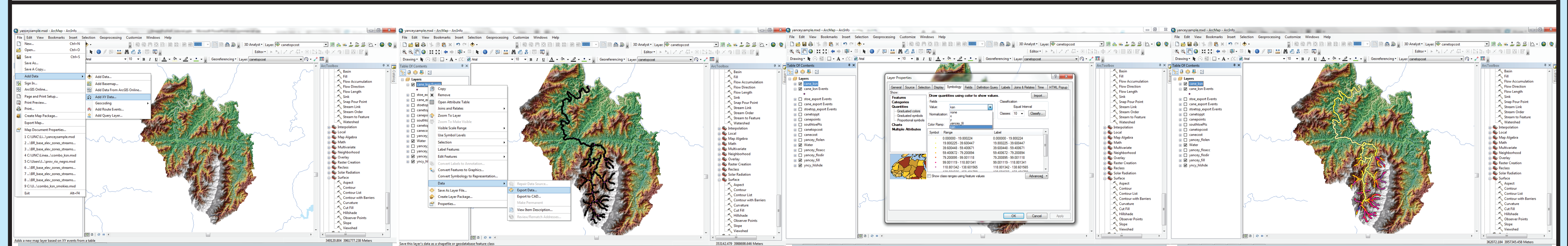
Step 2 : Execute the following R codes to plot the profiles and to calculate the ksn values of each stream.

```
#### Here's a function that makes png images of stream profiles in R
#### from dbf files with columns containing: x,y,z,length,accumulation
#### The units of elevation are converted from ft to m in this example.
dbfprofileR =function (combofile,title,header,upstream,downstream,Xlim,Ylim )
{
mcombo = as.matrix(combofile)
cc=mcombo
cc = cc[order(cc[,5],decreasing=TRUE),] ## put in order of down stream distance
X = cc[,2]
Y = cc[,3]
Z = cc[,4]
L = cc[,5]
A = cc[,6]
Z = Z*0.3048 ### ft to m. remove this if units are already metric

dev.new() ## this opens the plotting window in R
out1=paste(title,".png",sep="") ## adds ".png" to the title and defines file name
png(file=out1,width=2400,height=600) ## defines dimensions of .png file in pixels
par(mai=c(1,1.5,.7,1)) ### this defines the margins

### plot the downstream distance vs. elevation
plot (-(L/1000),Z,main = header,
xlab= 'downstream distance (km)', ylab = 'elevation (m)',cex=.2,pch=.02,col='gray',
xlim= Xlim,ylim = Ylim ,cex.main=3.5,cex.axis=1.8,cex.lab=2)

### this plots text for upstream and downstream directions
text (Xlim[1],.9*Ylim[2],upstream,cex=4)
text (Xlim[2],.9*Ylim[2],downstream,cex=4)
graphics.off() ## close the plotting window
}
```

```
## try it out! First call the package "foreign" to read in the *.dbf file
library(foreign)

# The dbf file has six columns: index(useless) ,x,y,z,flowlength, and flow accum.
# The flow accumulation is not used in this code but I keep it in the dbf
# export process anyway for simplicity

## this is an example of how to execute the code

## south new river
## this assigns the name of the working directory
setwd('C:/UNC/Lineaments/R/profile_figs/test')

## this reads in the dbf file. Call it what ever you want without spaces
caneriver =
read.dbf("C:/UNC/Lineaments/streams/cane/export/cane_exportcombo.dbf")

## Run the function
dbfprofileR(caneriver,"Cane_River","Cane River","S","N",
Xlim = c(-170,-120),Ylim = c(700,1500))

## You should see a plotting window pop up then disappear. You can find your plot
## in the working directory
```

```
# Here's a function that will caluculate Ksn values
# ksn = slope / (drainage area ^ ( concavity index) )

ksn2dbf=function(stream)
{
Xdbf = read.dbf(stream)
mtop = as.matrix(Xdbf)
mtop[,4]=mtop[,4]*0.3048 # ft to meters
mtop = mtop[order(mtop[,5],decreasing=TRUE),] ## downstream order

## define the internal functions slope and smooth
slope = function (x,y)
{
n = length(x)
dxdy=matrix(ncol=1, nrow=n)
for(i in 1:n-1)
{
dxdy[i,1] = ((y[i]-y[i+1]))/(x[i] - x[i+1])
}
dxdy[1]=dxdy[2]
return(cbind(x,dxdy))
}

smooth=function(x,y,w)
{
windo=w
dmax = max(x)
dmin = min(x)
nn = length (x)
### this scales the sampling window so that it is in realworld distance
### instead of rows or indices. The number is rounded to a whole number.
winrow = windo*(nn/(dmax-dmin))
winro = round(winrow,digits=0)
w= winro
n= length (x)
hw=(w/2) #half-window
smth= matrix(ncol=2,nrow=n-w)
smth[,1] =rbind(x[hw:(n-(hw)-1)])
{
k=1
for (i in ((hw):(n-w)))
{
smth[k,2] = (sum(y[(i-hw):(i+hw)])) / w
k=k+1
}
}
smth[1,2]=smth[2,2] #### this makes the second row equal the first to remove spike
return(smth)
}

S = slope(mtop[,5],mtop[,4])
nn = length (S[,1])
winrow = 1000*(nn/(max(S[,1])-min(S[,1])))
winro = round(winrow,digits=0)
hw=winro/2
Sm =smooth(S[,1],S[,2],1000)

## Drainage Area
Ar = mtop[hw+1:(nn),6]*( (20*0.3048)^2)

#XYlm = lm(log10(Sm) ~ log10(Ar))
#theta= XYlm$coefficients[1]

ksn = Sm[,2]*(Ar ^.45) ## concavity = 0.45

newxyz=cbind(mtop[,2:4])
newxyz = newxyz[hw+1:(nn),]

headsup=c("x","y","z","ksn")
ksn_output=(cbind(newxyz,ksn))
return(ksn_output)

}
```

Step 3 : Add the stream back into ArcMap and color it according to normalized steepness (ksn).



Use (File → Add Data → Add XY Data) to bring the streams back into Arcmap after the ksn values have been calculated.

Right-click on the new file in the layers menu, then use (Data→ Export Data) to save the layer as a shapefile.

Right-click on the new shape file in the layers menu, then click 'properties.' Under the 'symbology' tab select (Quantities → Graduated colors). Select 'ksn.' Choose a color ramp and make sure to change the classification to 'equal interval.'

All done! Now the stream is colored by normalized steepness. The colors and width of the stream can be manipulated to highlight knickpoints.

Works Cited:

Duvall, Alison (2004), Kirby,Eric, Burbank, Douglas, Tectonic and lithologic controls on bedrock channel profiles and processes in coastal California, Journal of Geophysical Research, v. 109,

Gallen, Sean F. (2011), Wegmann, Karl W., Frankel, Kurt L., Hughes, Stephen, Lewis, Robert Q., Lyons, Nathan, Paris, Paul, Ross, Kristen, Bauer, Jennifer B., Witt, Anne C., Hillslope response to knickpoint migration in the Southern Appalachians: implications for the evolution of post-orogenic landscapes; Earth Surface Processes and Landforms v. 36, no. 9

Gallen, Sean F. (2013), Wegmann, Karl W., and Bohnenstiehl, DelWayne R., Miocene rejuvenation of topographic relief in the southern Appalachians, GSA Today, v. 23, p. 4-10

Kirby, Eric (2001), Whipple, Kelin, Quantifying differential rock-uplift rates via stream profile analysis, Geology, v. 29, no. 5, p. 415-418

Kirby, Eric (2012), Whipple, Kelin, Expression of active tectonics in erosional landscapes, Journal of Structural Geology, v. 44, p. 54-75

Miller, Scott R. (2013), Sak, Peter B., Kirby, Eric, Bierman, Paul R., Neogene rejuvenation of central Appalachian topography: Evidence for differential rock uplift from stream profiles and erosion rates, Earth and Planetary Science Letters, 369- 370, p. 1-12

R is a free software that can be downloaded from: cran.us.r-project.org/