Using Drainage Area Power-Law Relationships as a Method to Test for Points of River Capture

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GEOLOGICAL SURVEY OF NORWAY - NGU -

Can the hydraulic relationship between drainage area and channel length be used to pinpoint the location of a river capture event within a region?

I. Background

Many studies examining river evolution rely on the hydraulic relationships first put forth by Leopold and Maddock (1953) and Hack et al. (1957). The first of these relationships identified by Leopold and Maddock found that the hydraulic geometry of a stream channel as expressed by width, depth, velocity, and suspended load are simple power law functions of discharge at a given river cross section. These power law functions reveal similar trending graphs for river systems in varying physiographic settings (Leopold and Maddock, 1953). Further studies of this concept investigated the relationship between the morphologic features of a drainage basin and the topography of the surrounding landscape by examining the physical characteristics of the basin along with its longitudinal profiles. By analyzing a variety of different streams in varying environments, Hack et al. (1957) established a uniform relationship between stream length and drainage area such that stream length increases directly as the 0.6 power of the drainage area. The relationships established by both Leopold and Maddock (1953) and Hack et al. (1957) form some of the fundamental principles of geomorphology and have proven to be valuable tools in determining deviations from steady-state within a river network.
One such process that disrupts steady-state within a system is river capture. In an area like southwestern Norway where the landscape is heavily glaciated with little fluvial imprint remaining, determining points of river capture is extremely difficult. We propose a method in which we combine the previously observed geomorphic evidence in the region with a quantitative analysis of the hydraulic relationship between stream length and drainage area in order to accurately pinpoint where a capture event may have taken place.

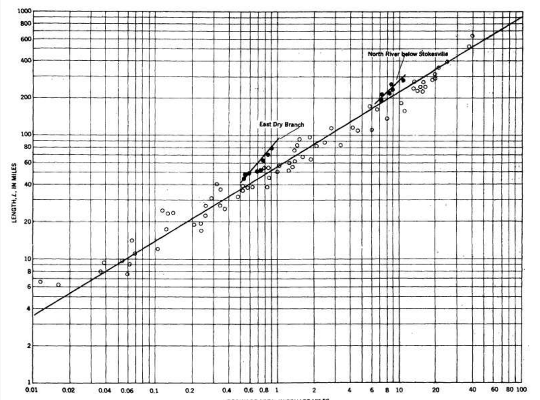


Figure 1: The relationship between drainage area and channel length (from the divide) from Hack et al. (1957). Reveals the power law relationship between the two variables as defined by the equation:

$$L=1.4A^{0.6}$$

Where L is length and A is area.

II. River Capture

River capture can take place as a result of a base level change or a tilt in the landscape. This causes one river, termed the "pirate", to capture another river, termed the "victim". Geomorphic indicators such as knickpoints, bedrock terraces, underfit river channels, low relief divides, barbed tributaries, and other drainage anomalies can all be indicative of river capture (Clark et al, 2004).

The process of river capture is difficult to detect in glaciated landscapes because a lot of the fluvial imprint has been either altered or erased entirely by the last glacial maximum, making it difficult to draw conclu-sions about river capture based solely on geomorphic evidence. With this in mind, it became necessary to develop a quantitative method for identifying points of river capture.

Figure 2

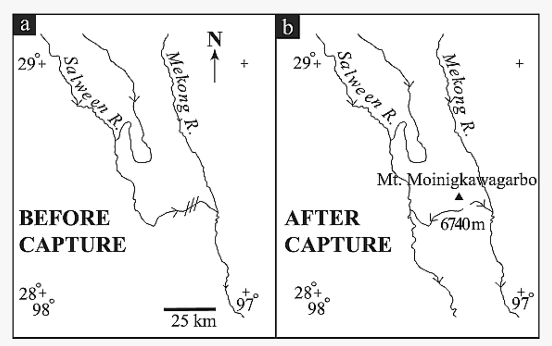


Figure 2: Reconstruction of channel patterns before and after a capture event (from Clark et al., 2004).

Figure 3

Figure 3: Example of a strath terrace found on the Rinna River.

III. Field Site

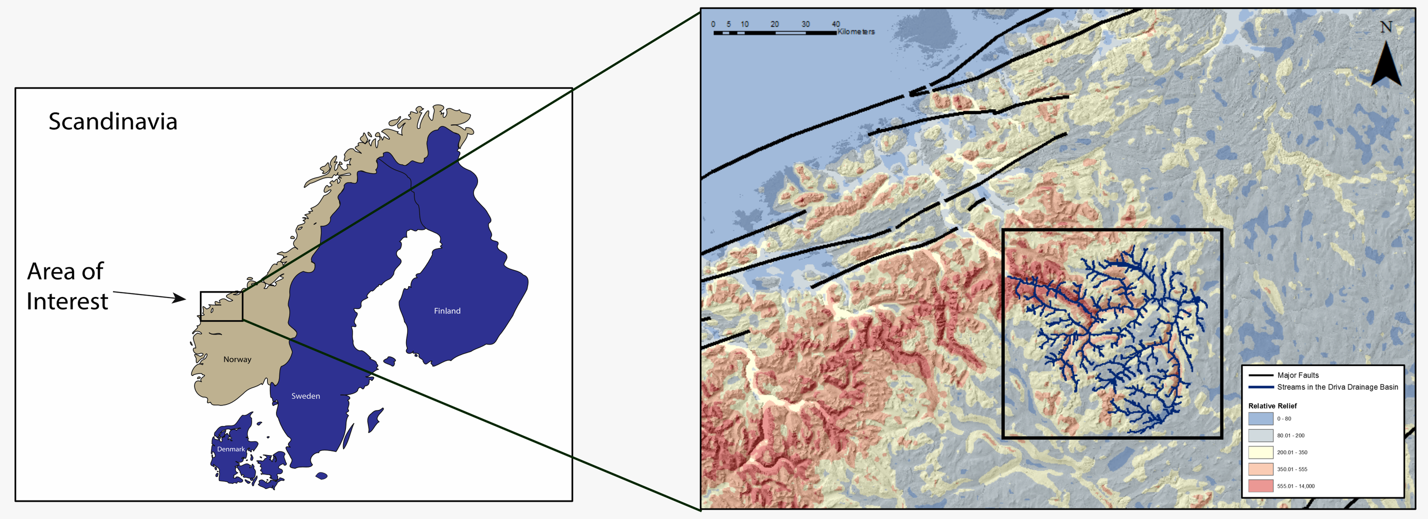


Figure 4: Area of study in relation to the rest of Scandinavia. The map on the right shows relative relief overlaying a hillshade with high relief in red and low relief in blue. Streams from the Driva drainage basin are highlighted in dark blue while major faults are identified in black.

IV. Methods

In order to quantitatively test for river capture in the region of southwestern Norway, we extracted profile parameters of drainage area and channel length through methods developed by Snyder et al. (2000) and Kirby et al. (2003). This method starts with a digital elevation model (DEM) and utilizes built-in functions in ArcGIS to create flow accumulation arrays and delineate drainage basins. This data is then ran through a series of MATLAB codes to extract and plot stream profile data using the information from the accumulation arrays and drainage basins generated by ArcGIS (Wobus et al., 2006). We specifically extracted data for drainage area and length of the channel from the divide and plotted these parameters as a power law relationship. If a capture event had taken place, the addition of a captured river and its associated drainage basin would result in an abrupt jump in drainage area at the point of capture; thus, disrupting the linear trend of data. These resulting jumps in data were then correlated to geomorphic evidence of capture on the landscape in order to emphasize these locations as likely points of river capture.

Figure 5

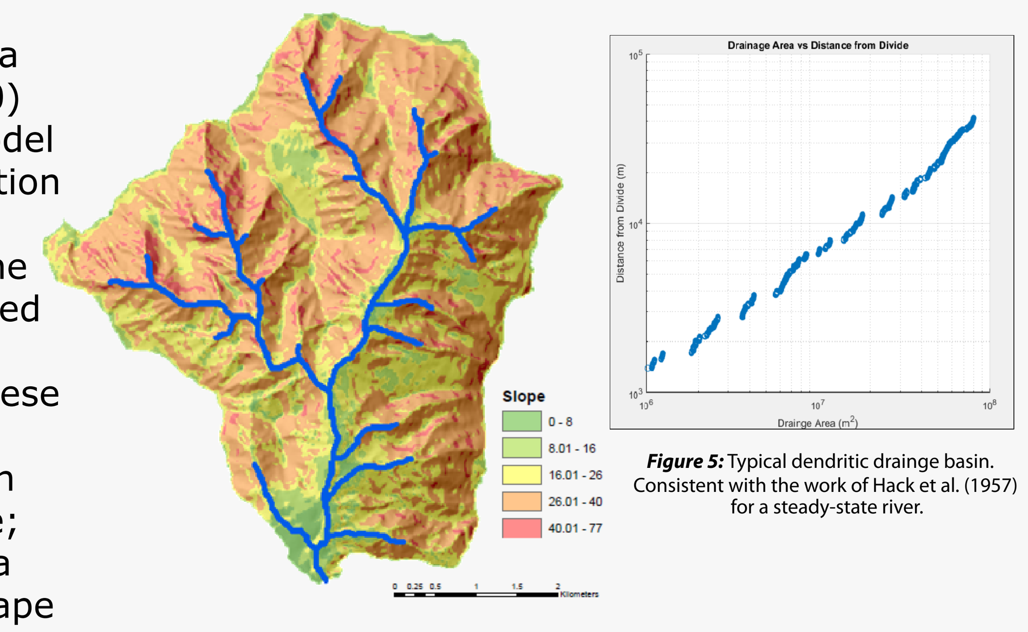
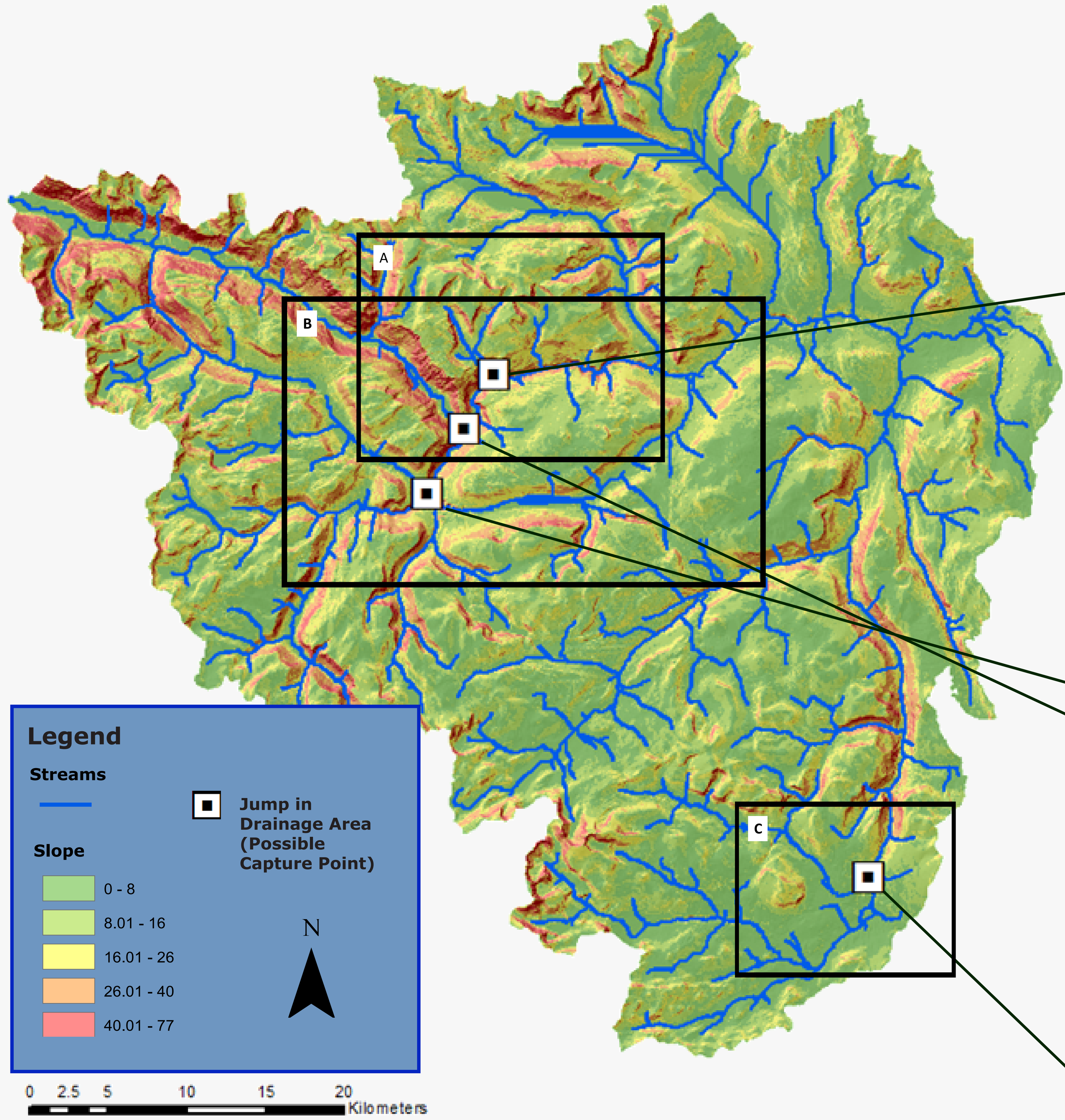
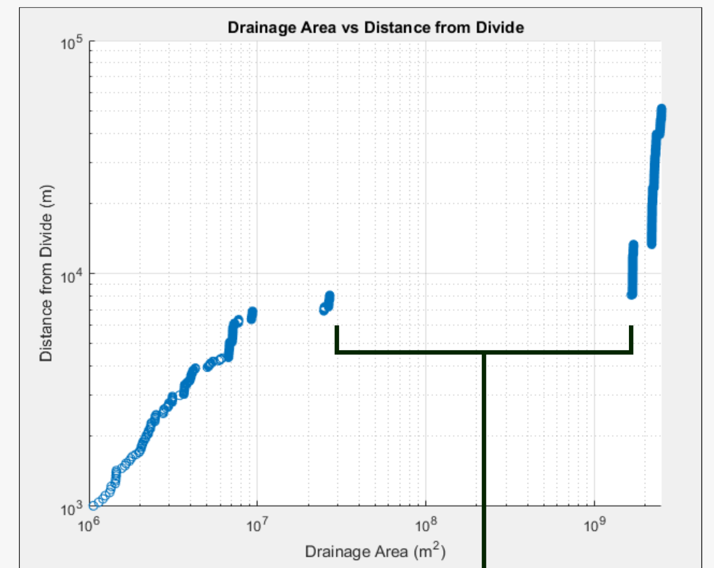


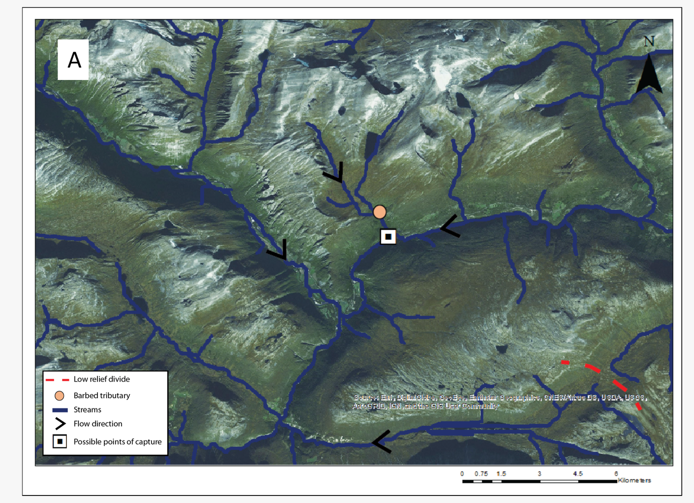
Figure 5: Typical dendritic drainge basin. Consistent with the work of Hack et al. (1957) for a steady-state river.

V. Results

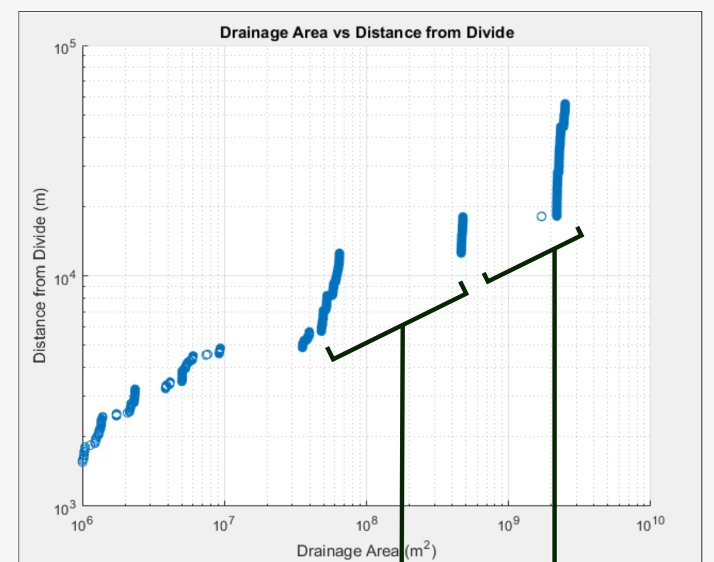
Figure 7: Slope overlaying a hillshade with areas of analysis highlight and correlated to both jumps in drainage area and physical evidence on the landscape.

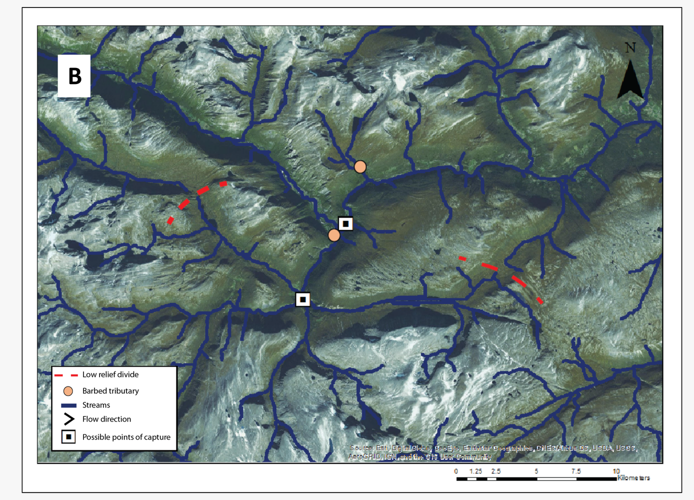




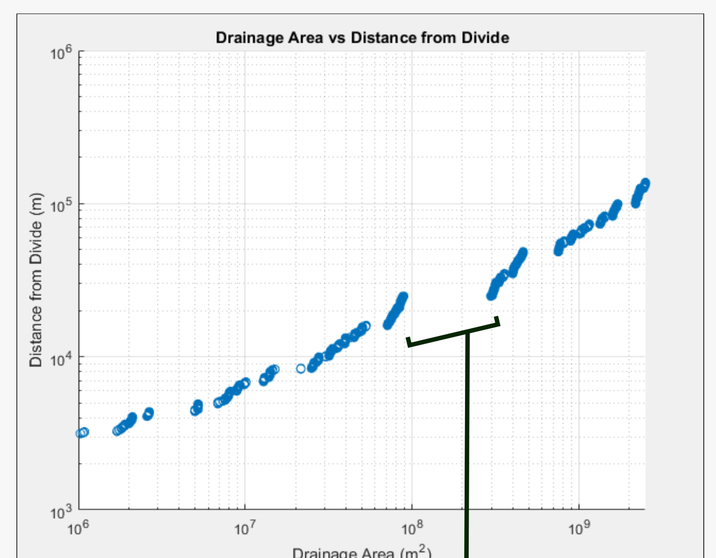


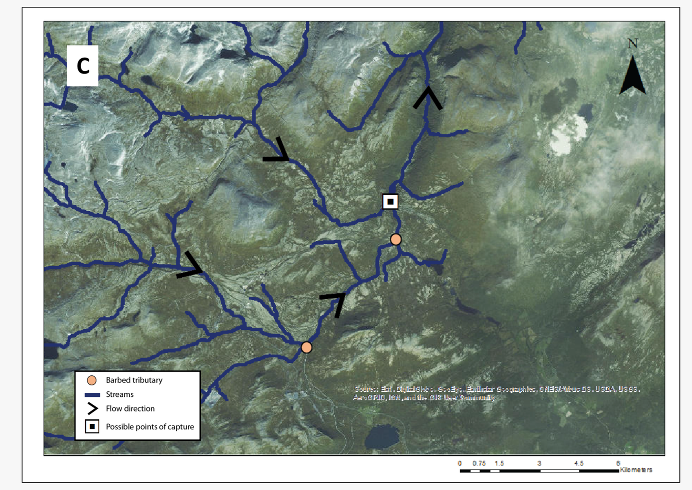
The location where this jump in drainage area occurs has a barbed tributary present and is located near a low relief divide. This point also marks a zone of deep incision.





The location where this jump in drainage area occurs forms a star shaped drainage and is located near two barbed tributaries and two low relief divides.





The location where this jump in drainage area occurs has a barbed tributary present as well as various small tributaries that curve away from the main channel.

VI. Conclusions

-The correlation of jumps in drainage area to geomorphic evidence proves our method to be succesful in identifying areas of river capture. This suggests that river capture is able to be assessed in a region even in the absence of fluvial indicators.

-Future work will involve reconstructing paleo-drainage networks throughout southwestern Norway by continued identification of capture points.

-The successful completion of reconstructed drainage networks will allow us to further constrain the timing of past and present geological processes within the region.

Acknowledgments & References

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