Identifying Erosional Hotspots in North Shore Streams Using Airborne LiDAR

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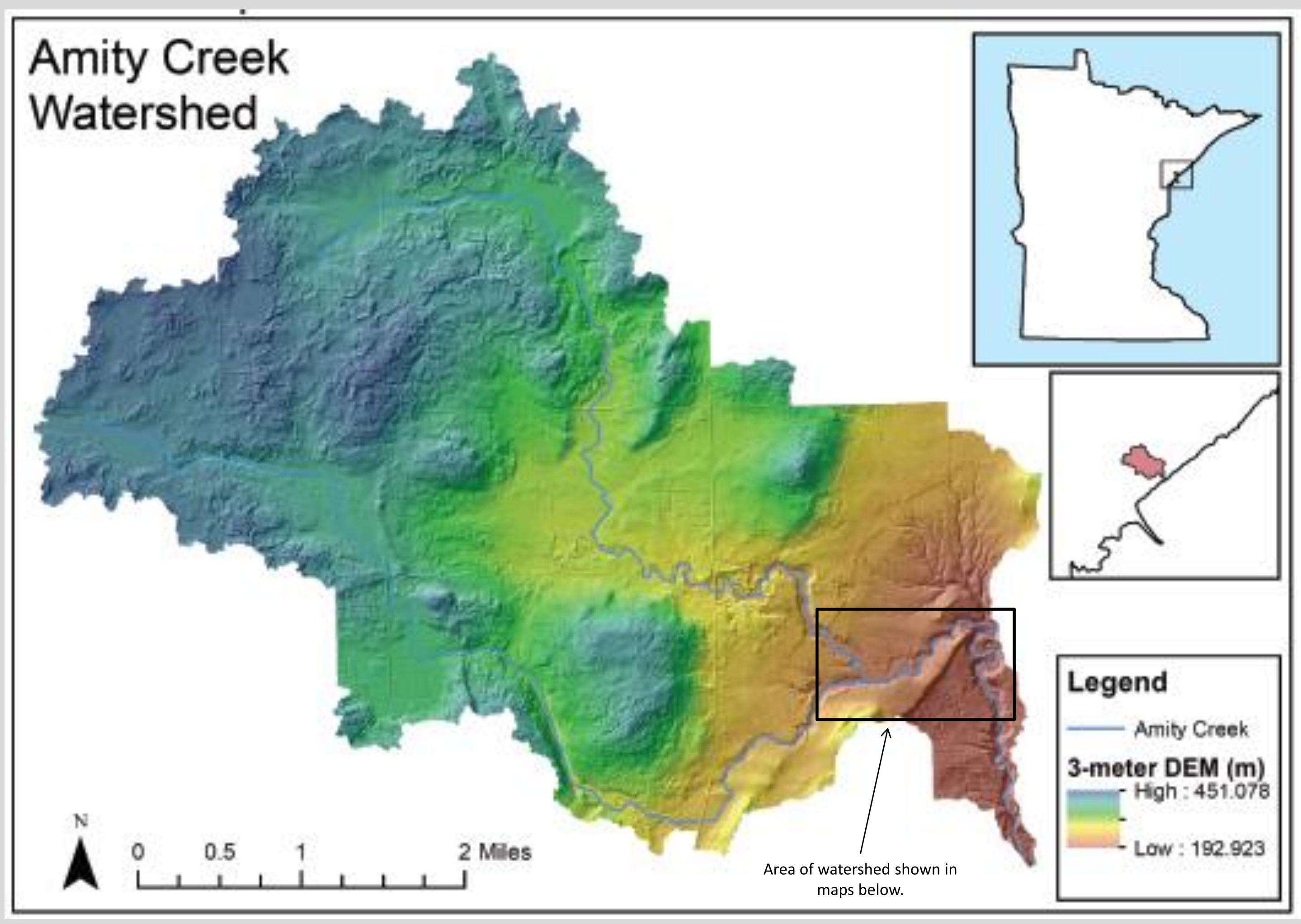
New high-resolution airborne LiDAR data may make it possible to develop a predictive model for stream erosion using only remote data. These data could be invaluable to help identify sediment sources in turbidity-impaired streams, simplifying the development of management plans to reduce sediment loading. The recent release of LiDAR-derived 3m DEMs (digital elevation models) for northeastern Minnesota, USA, offers a unique opportunity to test this possibility. Here, we develop a GIS-based predictive model for erosion potential along Amity Creek in Duluth, Minnesota, and compare the results to a field erosion index dataset collected after a large flood in June 2012.



Amity Creek Post-Flood
Examples of impacts observed after the 500-year flood event. While many of these bluffs existed prior to the flood, many experienced new slumps and failures and additional scouring. Large amounts of woody debris were transported in the flood (a, c) However, wetland channels in the upper reaches of Amity and the bedrock valleys in the lower reaches were not heavily impacted by the flood (e).

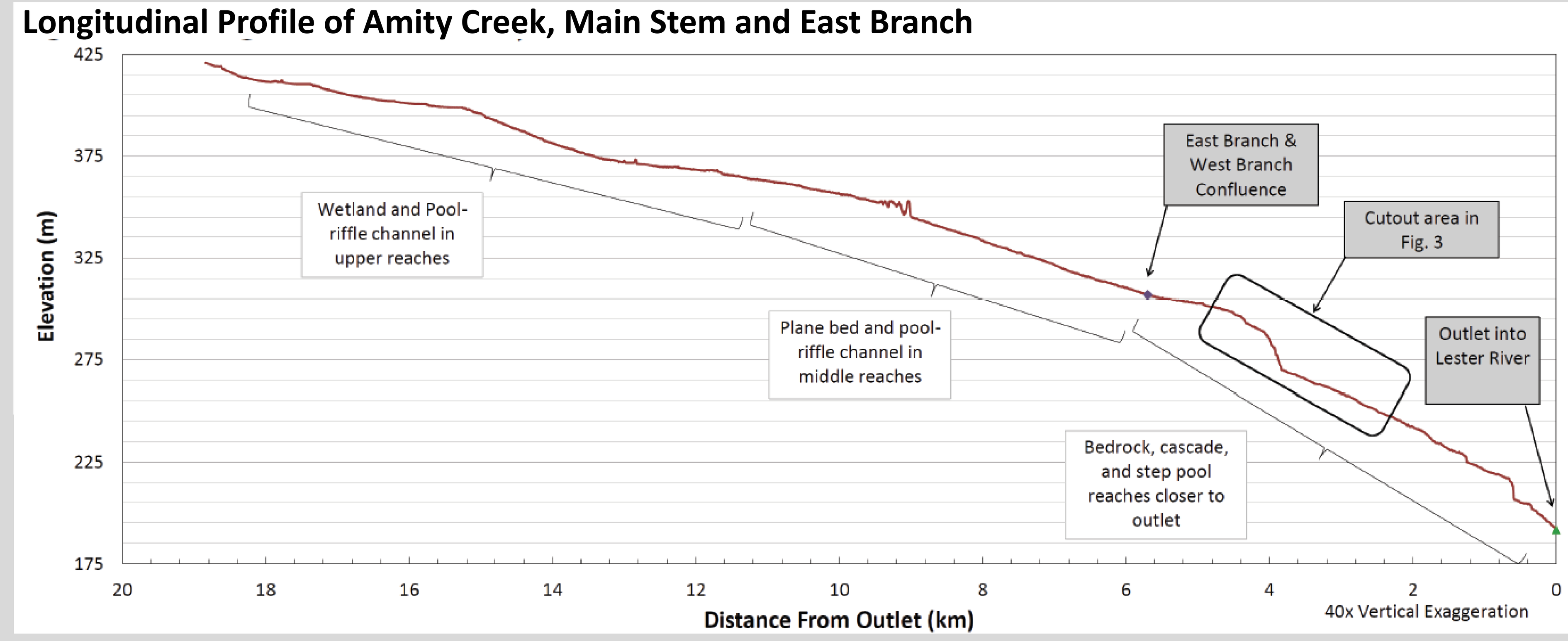
The Approach

We investigated geomorphic factors that can be taken from LiDAR-derived DEMs to identify erosion hotspots remotely. Previous studies have hypothesized that land use is the central driver in water quality impairments in Lake Superior streams (Detenbeck et al., 2003, Detenbeck et al., 2004, Crouse, 2013). However, correlations between land use variables and turbidity and TSS measurements are poor (Crouse, 2013). Thus we hypothesize that natural drivers like topography, soils, and hydrology are the main variables that control erosion potential and sediment loads in rivers. The 500-year flood that occurred on June 19 - 20th, 2012 gives us a unique opportunity to identify where erosion occurred along Amity Creek. The images at right illustrate the range of impacts the creek experienced during this flood. The most significant impacts observed were bluff erosion, clay slumps and slides, deposition of large cobble bars, and movement of large woody debris.

Background *Watershed Characteristics and Natural History*

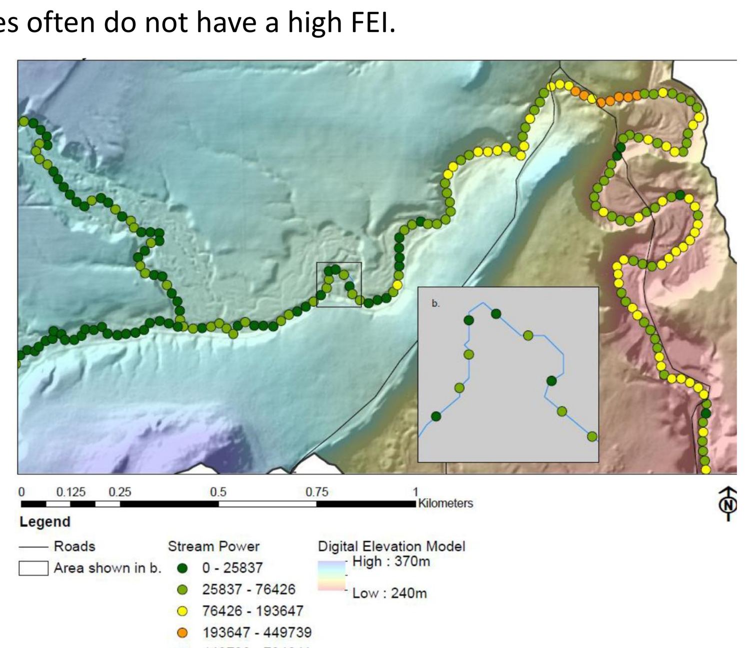
The Laurentide ice sheet receded from this area 12,000 years ago, leaving the clay-rich glacial till through which Amity Creek drains. Isostatic rebound after the glacier retreated has resulted in uplift along the north shore of Lake Superior relative to the south shore. This has created a steep change in elevation parallel to the shore of Lake Superior, across which Amity flows. Because of this, the long profile of Amity Creek and other North Shore rivers are opposite of typical mountain streams: they steepen closer to the outlet (Fitzpatrick et al., 2006). We can see this in the long profile of Amity's east branch and main stem at the right. Amity's valley is typically confined in the lower reaches, entrenched in middle reaches, and unconfined in the upper reaches. Glacial scour of the Lake Superior basin and the drop in base level after the draining of Glacial Lake Duluth, which formed as the Superior Lobe of the Laurentide Ice Sheet receded, has resulted in subsequent incision of Amity Creek that continues today. The highest potential for erosion typically occurs in the middle reaches where steep slopes meet the glacial sediments in entrenched channels in narrow valleys (Fitzpatrick et al., 2006).

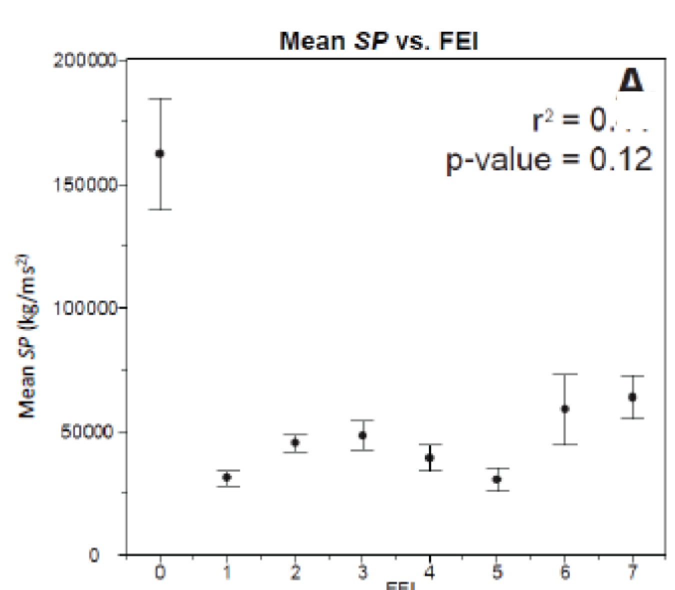
Longitudinal Profile of Amity Creek, Main Stem and East Branch



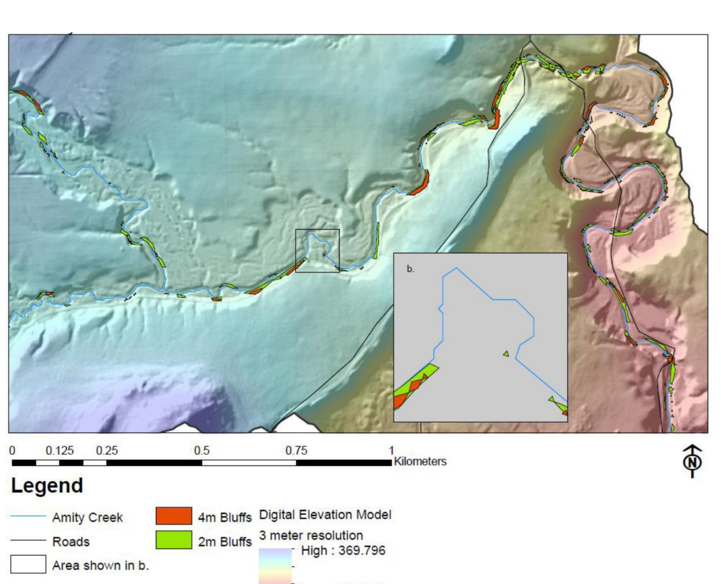
Successful Predictors

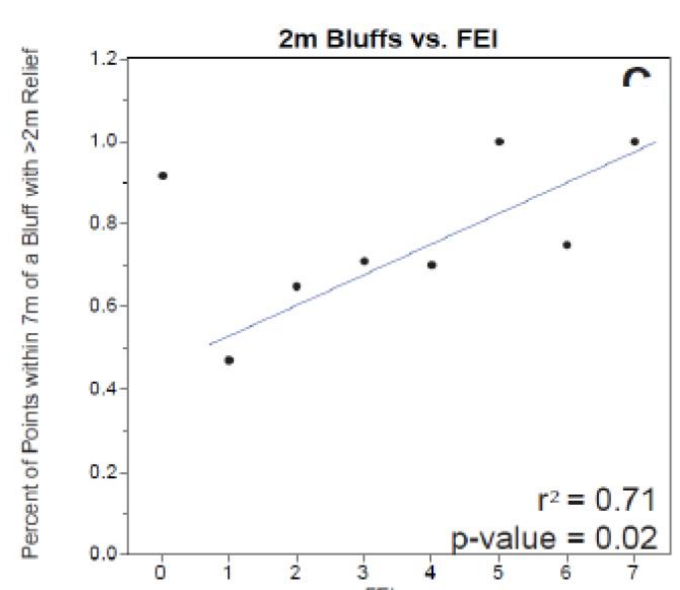
Stream Power-based Erosion Index (*SP*)
- Calculated from long profile slope and upstream area, which both increase erosion potential.
- Points are shown every 25m in figure.
- North Shore streams often have bedrock channels close to the outlets where slopes are high. Thus, areas with high EI values often do not have a high FEI.





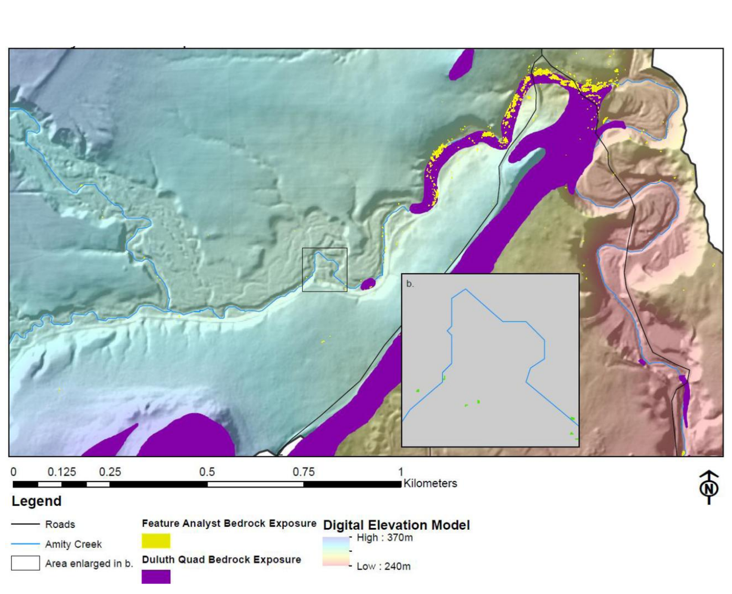
Bluff Proximity
- Erosion potential elevated where the stream interacts with high till valley walls.
- Map shows bluff taller than 2m and 4 m located within 14 meters of stream centerline.
- Delineated bluffs with greater than 2m relief and greater than 4m relief within a 12m x 12m window, located within a 14-meter buffer of the channel centerline. This method does not differentiate between bedrock and till bluffs.
- The correlation between 2m bluffs and FEI was stronger (shown, $R^2 = 0.71$) than 4m bluffs and FEI ($R^2 = 0.44$).

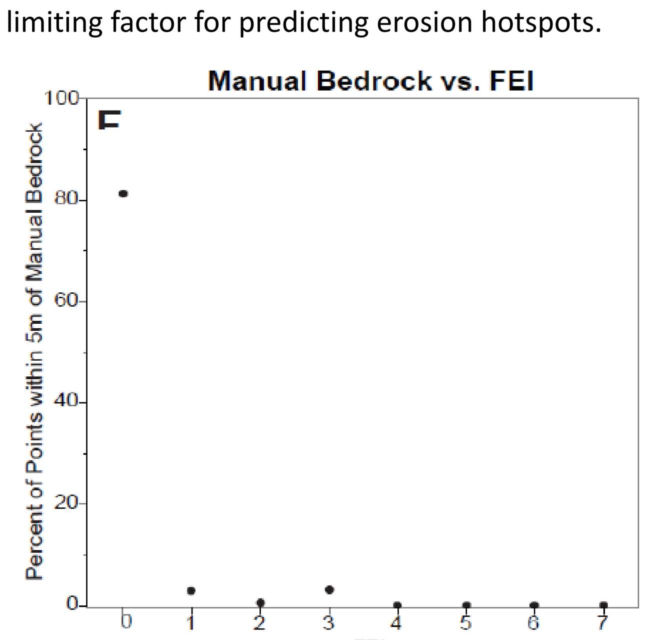




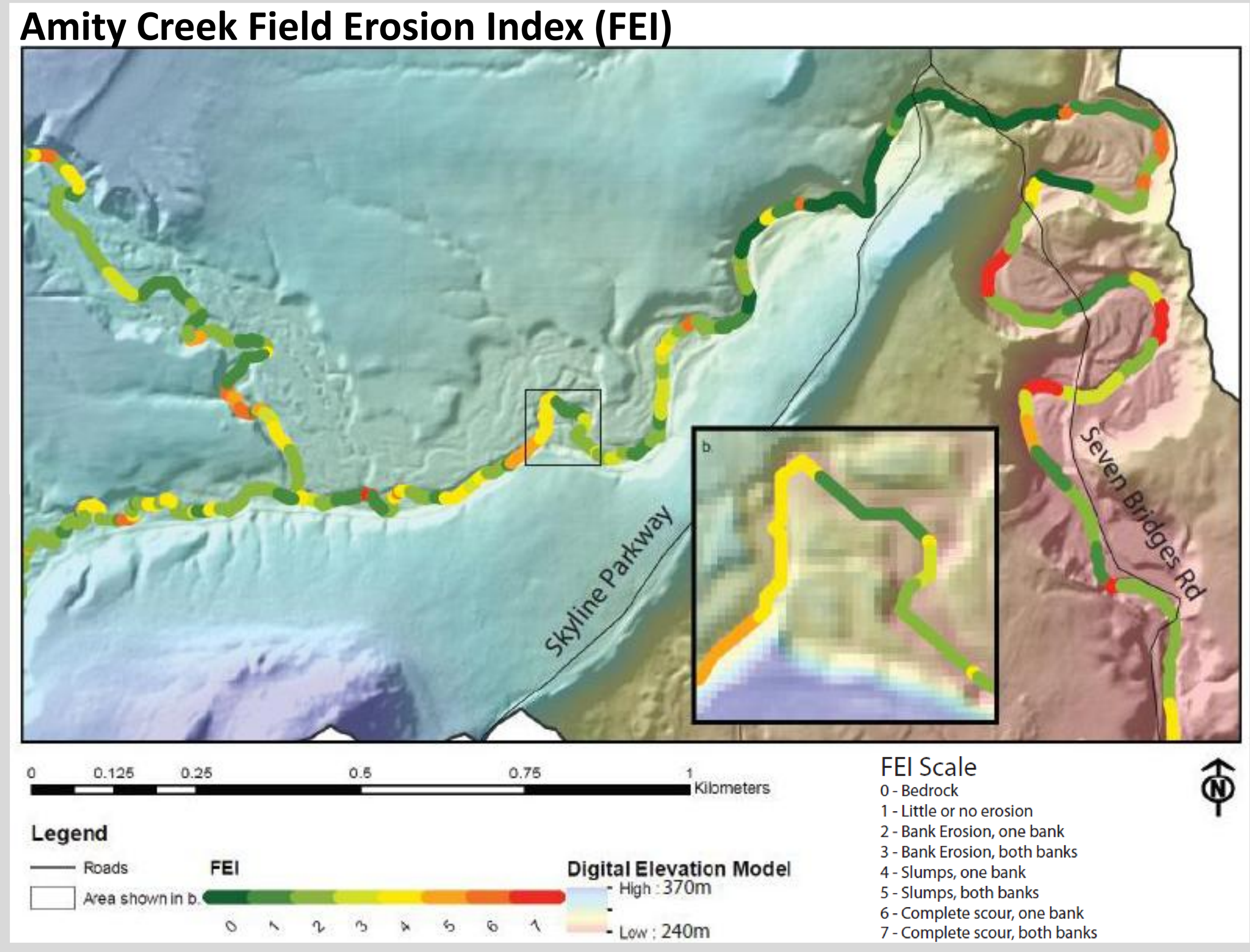
Bedrock Exposure Bedrock exposure was mapped using three methods:
- Extracting bedrock data from the Field Erosion Index (FEI) dataset and manually digitizing it (Manual Bedrock). This method requires collection of a field dataset.
- Feature Analyst, an ArcGIS extension (distributed by Visual Learning Systems Inc.) that delineated bedrock exposure based on pattern identification using training polygons and input datasets like LiDAR and high resolution air photos. In trialing this method, we used field data to define our training polygons, which would not typically be possible. Mapping bedrock exposure using Feature Analyst was promising, but widespread application of Feature Analyst for this purpose is limited by computing power and a lack of high-resolution air photos for the North Shore.
- Minnesota Geological Survey (MGS) surficial and hard rock geology maps that contained bedrock exposure data. These maps were generalized and did have good correlations with field data.

Limited bedrock exposure datasets for the North Shore are a major limiting factor for predicting erosion hotspots.





Amity Creek Field Erosion Index (FEI)



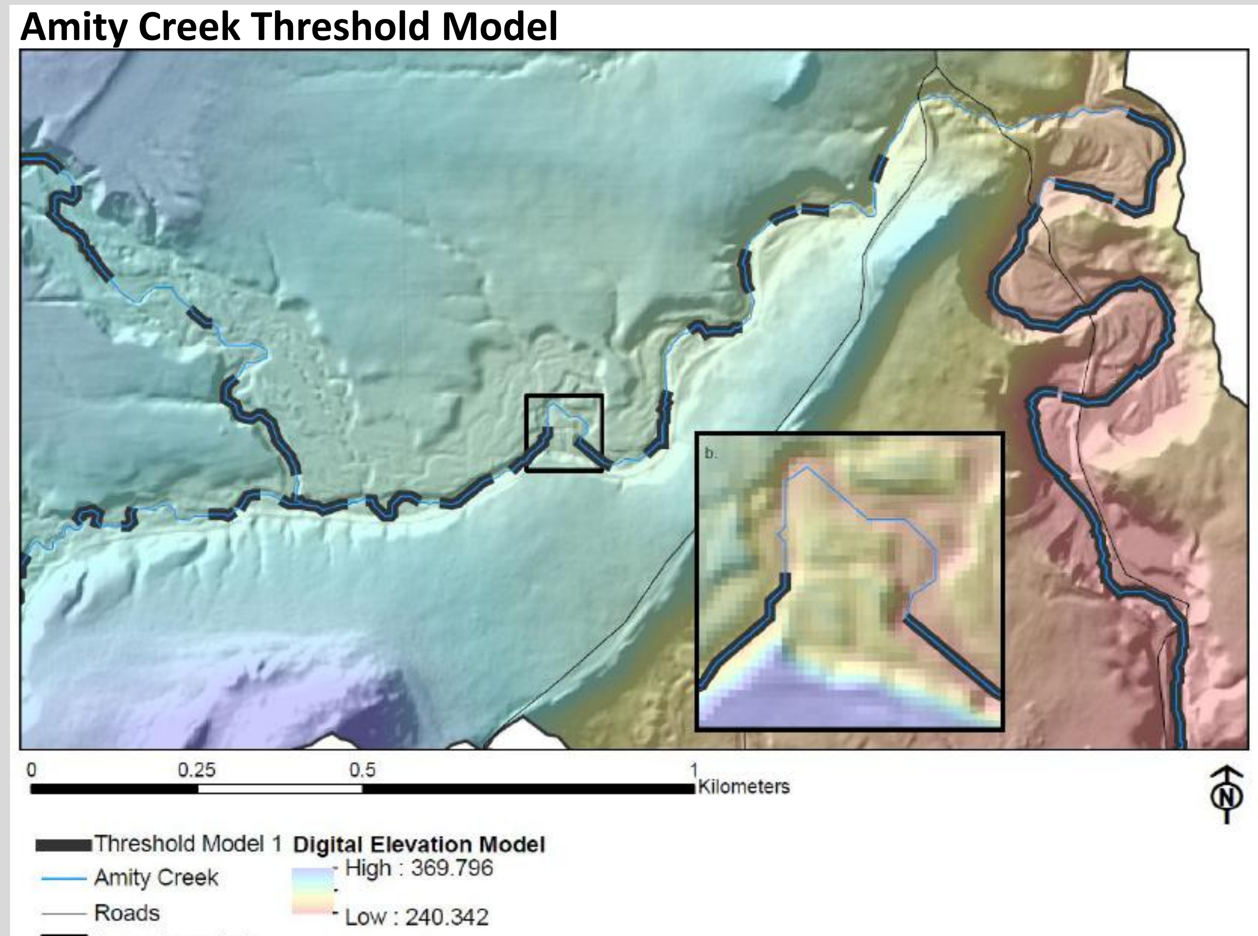
Field Erosion Index Surveys
- Conducted after the 500+ year flood on June 19 – 20, 2012.
- Collected 340 points, and a running assessment of fluvial erosion (see scale above)

Conceptual Model Approach

Development of a predictive statistical model was difficult due to the inability to incorporate specific knowledge of stream processes, such as the fact that erosion is severely reduced in bedrock channels. An alternative approach is to develop a threshold-based conceptual model based on our understanding of physical processes and the effective predictors. We defined thresholds in our predictors above which a given reach is more prone to erode. For example, we know that above a certain threshold of *SP*, the critical shear stress is high enough to entrain and transport sediment. In the threshold-based model, we set a threshold for SP, included only reaches that interact with tall bluffs, and excluded all bedrock reaches from hotspot predictions. We determined thresholds for each of the predictors based on single-predictor models compared to the FEI data set for Amity Creek (Wick, 2013).

When compared to all points where FEI data were collected, the threshold model was 70.7% accurate for predicting erosion hotspots on Amity Creek. For actual hotspots (FEI ≥ 2) the model was 73.4% accurate. One might expect a model developed for Amity Creek using field data for the same creek to be highly accurate. After developing the threshold model based on Amity Creek field data as described above, we applied the model to the Talmadge River. On the Talmadge, the percent accuracy for all points ranges from 64.3 - 66.7%, but the percent accuracy for FEI ≥ 2 (locations that were actual hotspots) are much lower, ranging from 31.6 - 36.8%. This is likely because high resolution bedrock data were not available for the Talmadge River.

Amity Creek Threshold Model



Threshold Model
Hotspots are defined as reaches that met all of the following:
- Had *SP* > 15,000 kg/ms^2
- Were within 7 meters from bluffs > 2 meters tall
- Were not within 5m from bedrock exposure (Manual Bedrock)

Conclusions

- Statistical models were unsuccessful but development of a threshold-based model allowed us to incorporate knowledge of stream erosion processes.
- There may be differences in the locations of erosion hotspots in a single large-scale flood event vs. long-term erosion hotspots. This adds to error in model.
- An inability to predict site-specific characteristics like large woody debris or vegetation patterns makes predicting erosion hotspots in a specific event very difficult.
- Knowing where bedrock is exposed is vital to accurately predict erosion hotspots. This may be a major limiting factor in North Shore streams due to a lack of high-resolution bedrock exposure data for most North Shore Streams.

The threshold-based erosion hotspot model can be a useful tool for land-use planners during preliminary studies of studies on North Shore Streams, but additional field investigations will still be necessary.

References Crouse A. B. 2013. Land Use/Land Cover and Hydrologic Effects on North Shore Tributary Water Quality. (Masters Thesis) University of Minnesota Duluth. 118 p. Detenbeck N. E., Elonen C. M., Taylor D. L., Anderson L. E., Jicha T. M., and Batterman S. L. 2003. Effects of hydrogeomorphic region, catchment storage and mature forest on base flow and snowmelt stream water quality in second-order Lake Superior Basin tributaries. Freshwater Biology 48, 912 – 927. Detenbeck N. E., Elonen C. M., Taylor D. L., Anderson L. E., Jicha T M., and Batterman S. L. 2004. Region, landscape, and scale effects on Lake Superior tributary water quality. Journal of the American Water Resources Association June, 705 -720. Fitzpatrick F.A., Peppler M.C., DePhilip M.M. and Lee K.E. 2006, Geomorphic Characteristics and Classification of Duluth-Area Streams, Minnesota. USGS Scientfiic Investigations Report. Nanson G C. and Hickin, E J. A statistical analysis of bank erosion and channel migration in western Canada. Geological Society of America Bulletin 97, 497 – 504. Wick, M. J. 2013. Identifying Erosional Hotspots in Streams Along the North Shore of Lake Superior, Minnesota using High-Resolution Elevation and Soils Data. (Masters Thesis) University of Minnesota Duluth. 91 p.

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