

Quantifying River Bank Erosion with Scanning Laser Altimetry

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KEY WORDS: Bank erosion, bank collapse, scanning laser altimetry, non-point source pollution.

ABSTRACT

Detailed topographic data collected with an airborne laser scanner can help determine the extent of bank erosion and identify banks that are more vulnerable to bank collapse and thus require stabilization efforts. The Minnesota River which flows through a 95% agricultural watershed has been ranked among the top 20 most polluted rivers in the U.S. Greater than 50% of the sediment load carried by the river at Mankato, MN is delivered by a single tributary, the Blue Earth River. A 56km length of the main stem of the Blue Earth River corridor was scanned April 2001 with an helicopter mounted TopEye laser system. The database includes X, Y, Z coordinates of laser returns from the river valley plus return intensity. Other data collection included ground elevation measurements for two banks using a total station, and vegetation density at eight locations along the river. A bare earth model was constructed by removing returns from vegetation and is currently being tested against the ground elevation measurements. Plans are to make another scan in a year or more to calculate volumetric change in the river valley due to bank erosion / bank collapse. This volume change along with soil bulk density along the river corridor will be used to assess the extent of bank erosion. The mass wasting rates will then be converted to total suspended sediments assuming fine silt and clay fractions are most likely to be transported.

can dislodge and transport it, whereas drainage provides a conduit for transport of sediment and soluble nutrients to surface waters.

1 INTRODUCTION

Nutrients, pesticides and sediment from agricultural activities are the leading surface water pollutants in the U.S. At the root of the water quality issue are agricultural practices that allow sediment and nutrient transport to surface water bodies. Soil cultivation and drainage are such practices that are often necessitated by the climate and soils in the region. Cultivation exposes soil to forces that

Many of the same agricultural activities are linked to declines in water quality in the eight corn belt states that account for 80% of U.S. agricultural production (Fausey et al. 1995). The interaction between cultivation of 55.7 million hectares and drainage on 20.6 million hectares has affected the hydrologic regimes and water quality of several rivers in the mid-west United States.

One such river is the Minnesota River that flows through a relatively flat agricultural landscape, but is fed by tributaries that are incised with steep and unstable stream banks. According to one estimate, the Minnesota River carries between 0.2 and 2 million tons of suspended sediment per year at Mankato, MN. Approximately 55% of that sediment is contributed by a single tributary, the Blue Earth River (Payne, 1994).

The Minnesota Pollution Control Agency (MPCA) has stated that a 40% reduction in sediment load is required to meet federal water quality standards in the Minnesota River. But it is not known what proportion of the load is from surface runoff versus stream bank collapse. Gupta and Singh (1996) estimated the bank erosion contributions at 48-55% of the total sediment load in the Minnesota River at Mankato. Bauer (1998) estimated that 36 to 84% of the sediment in the Blue Earth River was from bank erosion. Based on ground surveys of a few banks, Sekely (2001) estimated that bank erosion varied between 31 to 44% of the total suspended sediment load from the Blue Earth River. However, most of the above estimates are based on assumptions that have not been tested.

To achieve the sediment reduction goal MPCA recommends conservation tillage adoption in as much of the Basin as possible. An assumption implicit in this recommendation is that most of the sediment in the river has its source in the uplands. This logic has been applied to soil erosion from agricultural landscapes for many years at considerable expense but with little improvement in water quality (Wilkin and Hebel, 1982).

In order to implement effective management practices to address pollution sources there must be a clear understanding of which mechanisms are the largest contributors. If monitoring showed for instance that large quantities of sediment were being contributed from stream bank collapse some effort could be re-directed to focus more attention on hydrologic processes both in-stream and via drainage networks that influence channel morphology. However, quantification of bank erosion is difficult due to the remote location of river banks. The process is also time consuming if done manually. Airborne scanning lasers provide a convenient, efficient, and cost effective means to monitor bank erosion / bank collapse.

The objective of this research is to determine the potential of laser scanning altimetry to provide comprehensive stream reach mass wasting estimates. Airborne laser altimetry measurement for stream bank mass failure rates has not been attempted to our knowledge, yet it has great potential for government agency and commercial application in erosion and water quality management. Advancements in techniques for measuring river bank erosion and channel migration have been slow to evolve (Lawler, 1993). The successful outcome of this research will demonstrate this technology is a viable method for estimating bank erosion and channel migration at an unprecedented level of detail and geographic extent.

2 THEORY

The premise behind airborne laser scanning for calculating mass wasting

rates is to construct a bare earth digital elevation model (DEM) at two times bounding an interval during which erosion occurs. The difference in surface elevations between the two models then reflects the volume change due to bank erosion / bank collapse.

In airborne laser scanning, thousands of pulses per second are fired at the ground. The sensor receives multiple echoes from each returning laser pulse. Typically the first returned pulse is the top of vegetation canopy while the last is usually the ground. In situations where the last echo return is not from the ground, filtering must be employed to remove these elevation data if interest is purely in the bare earth elevations (Ritchie, 1994). The elevation of the earth surface is determined as the difference between platform elevation above a reference ellipsoid and platform height above the earth surface. Platform height is a function of the time it takes a laser pulse to be transmitted to the land surface and then reflect back to the sensor. Lateral positions of laser pulses are georeferenced using a global positioning system (GPS) and an inertial navigation system (INS) (Krabill and Martin, 1987; Wehr and Lohr, 1999).

3 METHODS

This study was conducted on the main stem of the Blue Earth River, a tributary of the Minnesota River. Bauer (1998) identified 136 eroding stream bank sites along 157 km of the Blue Earth River between Mankato and Blue Earth, MN. This stretch of the Blue Earth River has steep (up to 90°) and unstable banks as high as 30m (Figure 1). The eroding

stream banks range in area of 102 to 18364 m². Bauer classified banks into minor, moderate and severely eroding. We focused on river reaches between the confluence of the Blue Earth and Wantonwan rivers and Amboy (~56km river length) which contain 10 minor, 30 moderate, and 15 severely eroded sites greater than 3m high.



Figure 1. Eroding river bank on the frozen Blue Earth River with farm buildings for scale.

Field Work

In February 2001, 56km of the river between Rapidan Dam and Vernon Center were mapped with a March III GPS to 5m accuracy and stream banks on either side of the river were photographed and categorized qualitatively by size, erosion activity, and vegetation coverage. The start and end points of all large banks were recorded. This data is being used to aid interpretation of the laser scan and to independently compute bank lengths.

Two stream banks were surveyed with a total station during February 2001. These surveys are being used as reference standards to determine absolute accuracy of the airborne

scanning laser system. On April 28 and 29, 2001, eight locations representing various vegetation cover types were also surveyed for vegetation canopy density using a Geographic Resource Systems densitometer.

Laser Scanning

On April 24 and 25, 2001 Aerotec Inc. completed a 56 km scan of the river corridor using the Saab TopEye laser range finding system.

The scan specifications were:

flight platform – Eurocopter Astar 350 series helicopter
flight altitude - 375 m
flight speed - < 25 m/s
distance between foot prints - 0.305 m
laser foot print diameter - 0.116 m
laser pulse rate – 7000 Hz
returned echoes - 5
scan width - 273 m
scan angle - 20 degrees
mirror frequency 12.5 Hz
ground reference station - Trimble 4000 SSI dual frequency receiver

4 RESULTS

The data was filtered by Aerotec to remove reflections from vegetation resulting in a bare earth model which was then gridded and contoured to derive topographic maps. Figure 2 shows an example of a scanned river bank along the Blue Earth River. Usually, water bodies absorb infrared laser pulses, but some reflections occurred from the Blue Earth River due to high sediment loads in the water. We are in the process of comparing the elevation measurements from the laser

scan against the total station derived elevations and are currently building DEM's (Figure 3) that will be used for volume change estimates when a second scan is completed. The DEM constructed from the April 2001 scan is also being used to create a 3-D fly-through animation of the river valley. The animation will be used as a tool to demonstrate the significance of bank erosion problems in the Minnesota River Basin.

A second scan of the same 56km length of the river will be made in about a year. The difference in DEM's will provide a measure of sediment volume change in the river valley. Sediment bulk density will be determined to convert volume change into mass wasting. The contribution of suspended sediment from bank erosion will be estimated as a portion of fine silt plus clay in the mass wasted materials. These estimates will then be compared against the suspended sediment load from river monitoring to estimate the proportion of sediment from upland versus stream bank erosion.

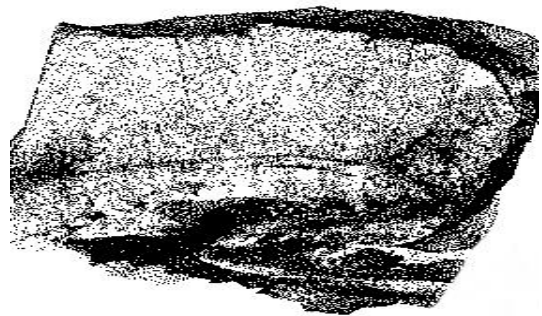


Figure 2. Raw laser data 'image' of an eroding river bank. The X, Y, Z point data is used to construct gridded elevation model and topographic map products. This view has a perspective similar to Figure 1.

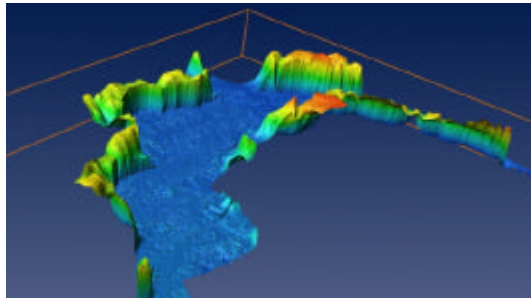


Figure 3. Rendered 3-D image of the Blue Earth River valley used in an animated fly-through movie. Color is used to represent elevation. Height is not to the scale.

5 CONCLUSIONS

Improved understanding of sediment sources and delivery mechanisms is important to efficiently allocate resources for mitigation of sediment pollution in rivers and lakes. This project is examining the potential of scanning laser altimetry to measure comprehensive mass wasting rates from actively eroding river banks, an heretofore improbable task using traditional surveying means. Once successful, this tool will provide not only a means to measure bank erosion but also a means to determine allocation of resources to projects that have the greatest potential for non-point source pollution abatement. Additionally, quantifying upland contributions by subtracting stream bank inputs from total sediment load will help determine effectiveness of current upland soil erosion control practices.

6 ACKNOWLEDGEMENTS

The research was in part supported by funds from the Water Resources Center and the Graduate School of the University of Minnesota, the Minnesota Corn Council, the Minnesota Soybean Council, and the University of Minnesota Supercomputing Institute. The authors gratefully acknowledge the computer rendering of the laser scanning data by Cal Kirchof of the Supercomputing Institute.

7 REFERENCES

- Abdalati, W. and W.B. Krabill 1999. Calculation of ice velocities in the Jakobshavn Isbrae area using airborne laser altimetry. *Remote Sensing of Environment*, (67) pp. 194-204.
- Bauer, D.W. 1998. Stream bank erosion and slumping along the Blue Earth River. M.S. thesis Dept. Soil, Water and Climate. University of Minnesota, pp. 2-72.
- Fausey, N.R., L.C. Brown, H.W. Belcher, and R.S. Kanwar 1995. Drainage and water quality in great lakes and cornbelt states. *Journal of Irrigation and Drainage Engineering* July/August, pp. 283-288.

Gupta, S.C., and U.B. Singh 1996. A review of non-point source pollution models: Implications for the Minnesota River Basin. Department of Soil, Water, and Climate, College of Agricultural, Food, & Environmental Sciences, University of Minnesota, St. Paul, MN.

Krabill, W.B., R.H. Thomas, C.F. Martin, R.N. Swift, and E.B. Frederick 1995. Accuracy of airborne laser altimetry over the Greenland ice sheet. *International Journal of Remote Sensing*, (16)7, pp. 1211-1222.

Krabill, W.B., and C.F. Martin, 1987. Aircraft positioning using global positioning system carrier phase data. *Navigation: Journal of the Institute of Navigation*, (34)1, pp 1-21.

Lawler, D.M., 1993. The measurement of river bank erosion and lateral channel change: A review. *Earth Surface Processes and Landforms*, (18) pp. 777-821.

Minnesota Pollution Control Agency (MPCA) 1994. Minnesota River Assessment Project Report: Volume II, Physical and Chemical Assessment. Report to the Legislative Commission on Minnesota Resources, pp 12-38.

Payne, G.A. 1994. Sources and transport of sediment, nutrients, and oxygen-demanding substances in the Minnesota River Basin, 1989-1992. In Minnesota River Assessment Project Report, Vol II: Physical and Chemical Assessment. MPCA.

Ritchie, J.C., E.H. Grissinger, J.B. Murphey, and J.D. Garbrecht, 1994. Measuring channel and gully cross-

sections with an airborne laser altimeter. *Hydrological Processes* (8) pp. 237-243.

Sekely, A. 2001. Stream bank slumping and its contribution to the phosphorus and suspended sediment loads of the Blue Earth River. M.S. Thesis, University of Minnesota, St. Paul.

Vaughn, C.R., J.L. Bufton, W.B. Krabill, D. Rabine, 1996. Georeferencing of airborne laser altimeter measurements. *International Journal of Remote Sensing* (17)11 pp. 2185-2200.

Wehr, A., and U. Lohr, 1999. Airborne laser scanning-an introduction and overview. *ISPRS Journal of Photogrammetry & Remote Sensing* (54) pp. 68-82.

Wilkin, D.C., and S.J. Hebel, 1982. Erosion, redeposition and delivery of sediment to Midwestern streams. *Water Resources Research*, (18)4 pp. 1278-1282.