FINAL REPORT

PROJECT TITLE: Identification of Erosion Mechanisms and Volume Loss for River Banks and Ravines

PROJECT NUMBER: 00029943

PRINCIPAL INVESTIGATOR AND CO-INVESTIGATOR(S): Satish Gupta and Andrew Kessler

ABSTRACT

Provide a project summary describing an overview of the project including principle findings. Include a statement on how the project was of benefit to corn farmers.

Seepage is an important mechanism of river bank failure in the Minnesota River basin. Yet, methods to quantify seepage induced river bank erosion across large scales are lacking. The objective of this study was to assess if laser return intensities from terrestrial and airborne light detection and ranging (Lidar) could be used to detect seepage locations on river banks and if these seepage locations relate to the extent of bank erosion calculated from multi-temporal Lidar change detection. We tested the above concept (1) on a river bank along the Blue Earth River with terrestrial Lidar acquired in 2012 and 2013, (2) on a developing ravine along Carver Creek with terrestrial Lidar acquired in 2014 and 2015, and (3) on a second bank along the Blue Earth River with airborne Lidar collected in 2009 and 2012. The results indicate that both terrestrial and airborne Lidar return intensities provide a means to identify seep locations on river banks and this in combination with Lidar measured elevation change provides a means to evaluate seepage induced bank erosion. Since a majority of the sediments in the Minnesota River and Lake Pepin are from bank sloughing, the technique developed in this project helps to quantify bank erosion from seepage; an important bank sloughing mechanism. Information in this project helps corn farmers in making the case that sediments in the Minnesota River and its tributaries are to a large extent a result of natural processes.

INTRODUCTION

Provide background information related to the project including such item as the problem statement, knowledge gaps, and relevant previous work completed on this issue.

Seepage is an important mechanism of river bank erosion in the Minnesota River Basin. The basic mechanism involved in seepage induced bank erosion is that the shallow interflow exiting the face of river bank (i.e. seepage) reduces soil strength at the leading edge thus destabilizing the bank above which either detaches or slides down over time. In spite of the recognition that seepage is an important process controlling bank erosion, there is a lack of research on techniques that can remotely identify seepage areas on river banks at a broader scale as well as quantify the extent of bank sloughing from seepage induced bank instability. To date, ground based thermal imaging is the only technique that has been used to locate seeps along the face of river banks. However, ambient air temperature at different times of the day and year can mask the thermal detection of seepage on the face of river banks. Numerous remote sensing technologies have also been utilized to examine the relationship between reflectance and soil moisture. However, many of these technologies are based on the use of radar from satellites such as synthetic aperture radar. Furthermore, watershed scale measurements of soil moisture using radar are unable to isolate seep locations on the face of river banks. Also, the spatial resolution of many satellite platforms are too coarse (i.e. $\geq$ 30 m) for detecting seepage on river banks or hillslopes. Recently, studies have begun testing the relationship between soil moisture and return intensity from light detection and ranging (Lidar) at much finer (i.e. $\leq$ 1 m) spatial scale. The underlying principle of these studies is that near infra-red light is adsorbed by water thus decreasing the return intensity, an indication of increasing soil moisture content. With increased availability and use of terrestrial and airborne Lidar to quantify bank erosion, the goal of this study was to test the suitability of terrestrial and airborne Lidar to detect river bank seepage as well as quantify bank erosion from seepage induced bank sloughing.

OBJECTIVE AND GOAL STATEMENTS

1. To test the use of terrestrial and airborne Lidar to detect river bank seepage and quantify bank erosion as a result of seepage.

2. To compare Lidar technology with thermal infrared cameras technology for identifying seepage areas on river banks.

3. To quantify seepage induced bank erosion in Blue Earth County using airborne Lidar scans from 2009 and 2012.

MATERIALS AND METHODS

As appropriate, describe the site(s), experimental design, and other relevant methodology used in completing the project.

The study areas included two banks along the Blue Earth River in Blue Earth County, Minnesota and a newly developed ravine along Carver Creek, in Carver County, Minnesota. At the first site along the Blue Earth River, we tested terrestrial Lidar vs. thermal imagery to delineate seeps and quantify bank erosion. At the second site along Carver Creek, we quantified the effects of soil moisture and soil color on Lidar intensity and bank erosion. At the third site along Blue Earth River, we quantified seepage induced bank erosion using airborne Lidar. We used the return intensity values from Lidar to characterize seepage area.

Please see additional details about our methodology in Chapter 4 of Andrew Kessler’s Ph.D. dissertation.

RESULTS AND DISCUSSION

Site 1:

At the first site on the Blue Earth River (Fig. 1), both terrestrial Lidar returns and thermal imagery taken in 2012 and 2013 data collection campaigns were able to delineate seepage locations on the river bank (Fig. 2). Seepage locations identified in thermal imagery aligned very well with seepage locations identified by RIMs (Return Intensity Models) on both 5 December 2012 and 26 September 2013. A regression analysis indicated a statistically significant ($F = 32.09$, p value < 0.01, $r^2 = 0.39$) direct relationship between Lidar return intensity and temperature in 2012. Uneven heating from partial shading by vegetation on 26 September 2013 created some false positives (i.e. vegetation was the same temperature as seepage water) for seepage locations, thus negatively affecting the ability of thermal imagery to detect correct seepage areas. However, RIM identified seepage areas match perfectly with the visual observations. These results indicate that under certain conditions RIMs provide a better alternative than thermal imaging for detecting seepage locations on river banks. The composite image of the threshold DOD (Difference in Digital Elevation Models between two dates) and the 5 December 2012 RIM image showed that most of the observed volume loss was directly related to the large seep areas (Fig. 3).

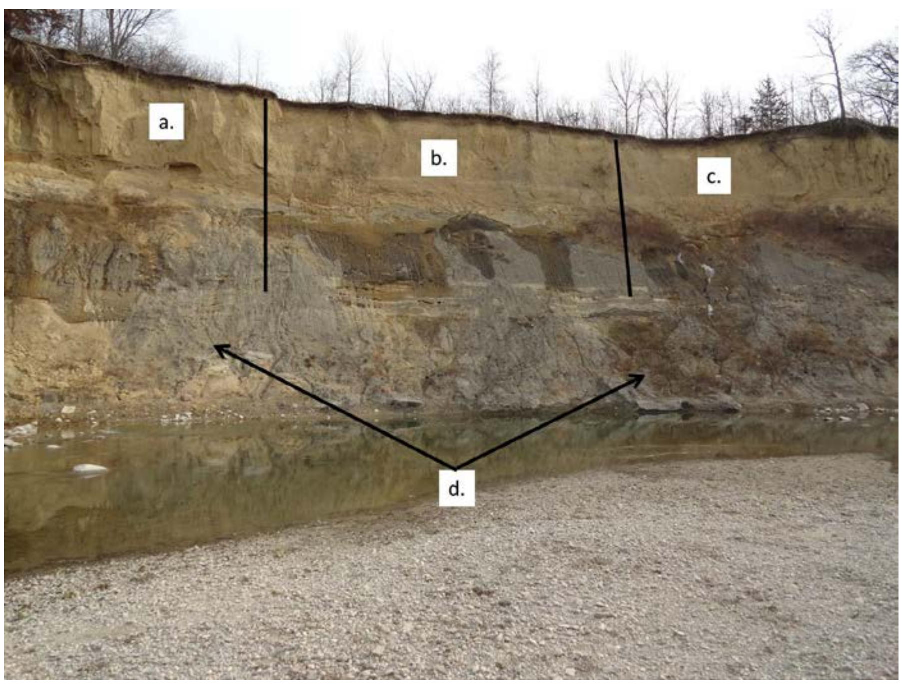

Figure 11. Picture of the Blue Earth River terrestrial Lidar study site # 1 taken on 5 December 2012 showing zone “a” with freeze-thaw caused fissure, zone “b” where seepage caused mass wasting occurred, zone “c” where seepage area is covered by failed bank material and some vegetation and zone “d” where failed bank material from the top has been deposited.

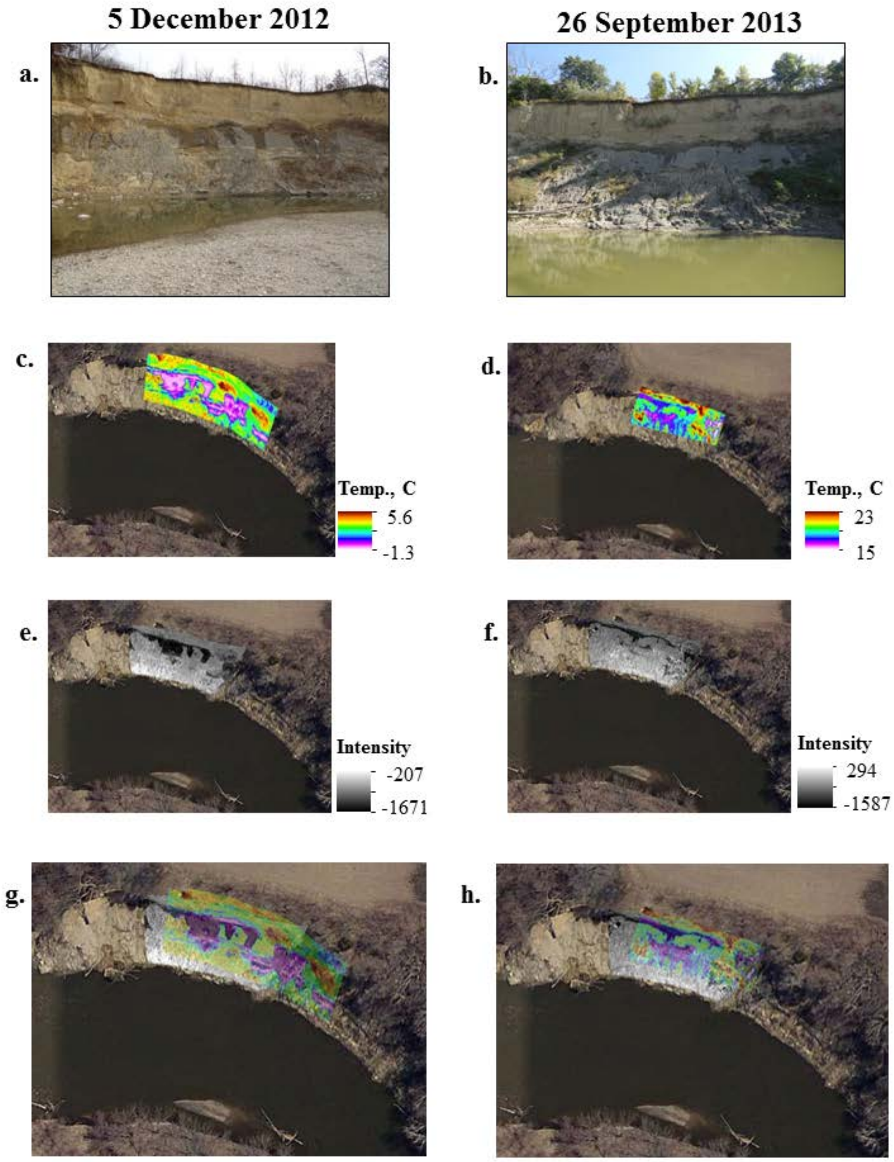

Figure 2. Digital images of a river bank (site #1) along the Blue Earth River in 2012 (a) and 2013 (b), the corresponding thermal imagery in 2012 (c) and in 2013 (d), and terrestrial Lidar return intensities in 2012 (e) and in 2013 (f). A composite image from all three techniques (2012 (g) and 2013 (h)) showed good correspondence between the thermal and the Lidar return intensity data for seep locations.

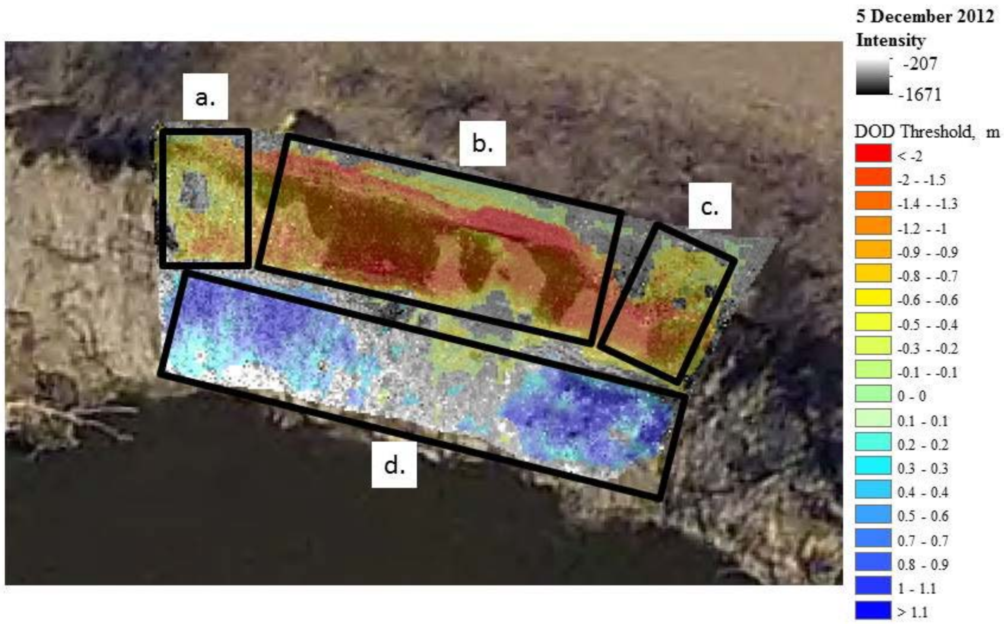

Figure 3. Composite image of the elevation difference grid and return intensity derived from terrestrial Lidar data showing zones with areas impacted by non-seepage erosion mechanisms (zone a), seepage caused mass wasting (zone b), seepage covered by failed bank material (zone c), river bank material deposition (zone d).

<u>Site 2:</u>

Figure 3 shows a portion of failed Carver Creek ravine. The Lidar return intensities in both 2014 and 2015 data collection campaigns at Carver Creek varied inversely with soil water. However, the relationships differed between the two dates. An analysis of variance using the multiple regression approach showed that the intercepts between the two relationships were significantly different ($t = -18.85$, p value < 0.01) but the slopes of the relationships were statistically similar ($t = -0.17$, p value $= 0.86$). This indicated that the relative change in Lidar return intensity between the two collection periods was similar and this shift in the intercept is likely due to the use of a different Lidar system. In 2014 scan, there was also more variability in return intensities at a given water content. We envisioned this variability as result of varying colors of different layers at the site. Preliminary analysis using soil colors from Munsell color charts showed some merits to this hypothesis. Since we had not collected our soil water content data by soil layer in 2014 campaign, we were unable to fully parse color effects in 2014 return intensities. To address the effect of soil color on return intensity, in 2015 campaign we collected data by soil layer as well as devised a controlled experiment to simultaneously test soil color and wetness effects on terrestrial Lidar return intensities.

Figure 3. Sampling locations at Carver Creek Ravine where nails with 5 cm diameter plastic heads were inserted for soil moisture measurements and later for reading return intensities from terrestrial Lidar scans.

The 2015 data showed a general decreasing trend in return intensity as a function of soil water content. However, there were some differences in the relationship among various soil layers. For example, layers 1, 2, and 5 all showed similar relationship between return intensity and soil water content but layers 3, 4, and 6 all indicated different relationships (Fig. 4). These results supported our hypothesis that return intensity is also a function of other soil properties such as soil color. To address this issue, we further conducted a controlled experiment with natural and painted cores at two water contents and evaluated the effects of soil color on return intensity values (Fig. 5). The results showed that Lidar return intensities are influenced more by soil color than by soil water content. For example, return intensities from black, red, and brown (dark colors) painted soils showed little variation as a function of water content. Comparatively, yellow (light color) painted soil cores followed by natural colored (light color) soil cores (i.e. no paint applied) showed a decrease in return intensity with an increase in soil water content. These results suggest that while there is a relationship between Lidar return intensity and soil moisture in relatively light colored soils, other factors such as soil type and/or color may be dominating or at least need to be considered. Although the core experiment covered a range of colors from highly adsorbent (black) to moderately reflective (yellow), in many soil profiles or river banks, it is unlikely that there will be such a wide variation in color at any given location.

The DEM results (Fig. 6) showed that over 1,178 m^3 of net soil erosion occurred at this site between 11 June 2014 and 23 April 2015. Considering that the bulk density values at the site ranged from 1.3 Mg m^{-3} to 1.6 Mg m^{-3}, the mass wasting estimates ranged from 1,531 Mg to 1,885 Mg of soil loss from the site in less than one year.

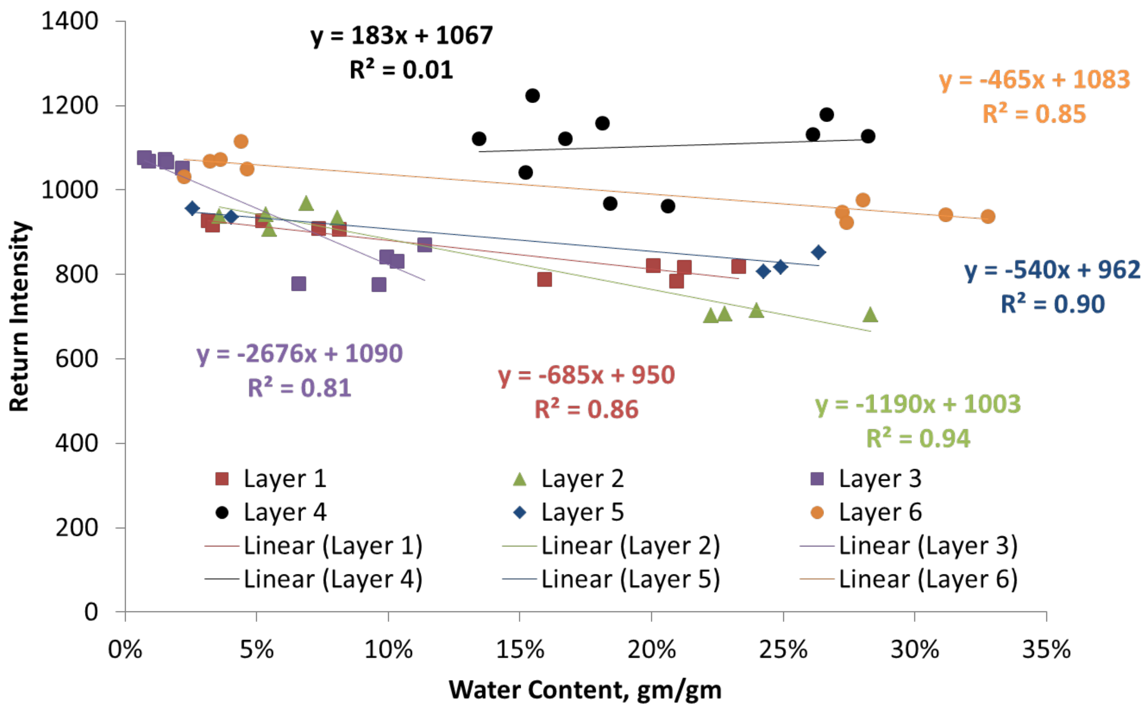

Figure 4. Regression relationships between Lidar return intensity and soil water content for various soil layers in the Carver Creek ravine.

Figure 5. A set-up of painted and natural soil cores used to characterize color and moisture effects on Lidar return intensity.

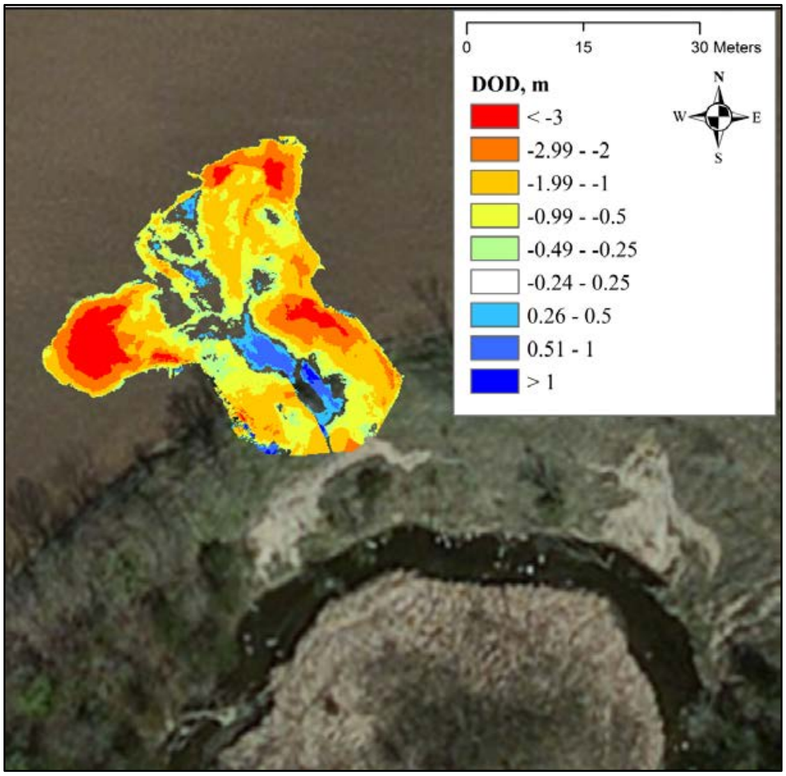

Figure 6. Geomorphic change detection (GCD) analysis of the Carver Creek ravine showing erosion (red) and deposition (blue) between 11 June 2014 and 23 April 2015. Areas with no color corresponds to areas with 0.25 m of erosion or deposition.

Site 3:

At this site, we characterize seepage induced bank erosion using 2009 and 2012 airborne Lidar. The 2009 RIM (Return Intensity Models) derived from airborne Lidar data readily identified the seep locations on a river bank in Blue Earth County, MN (Fig. 7). The threshold DOD indicated a net volume loss of 17,234 m^3 (18,316 m^3 of erosion and 1,082 m^3 of deposition) between 2009 and 2012. These results are similar to the DOD generated estimates using terrestrial Lidar at site#1 as well as consistent with the findings of Kessler et al. (2012) that the majority of volume change in river banks was driven by large (> 2 m) changes in elevation. These results further show that the seepage location causing bank erosion could also be delineated in RIM derived from airborne Lidar.

For additional discussion, please read Chapter 4 in Andrew Kessler's Ph.D. Thesis.

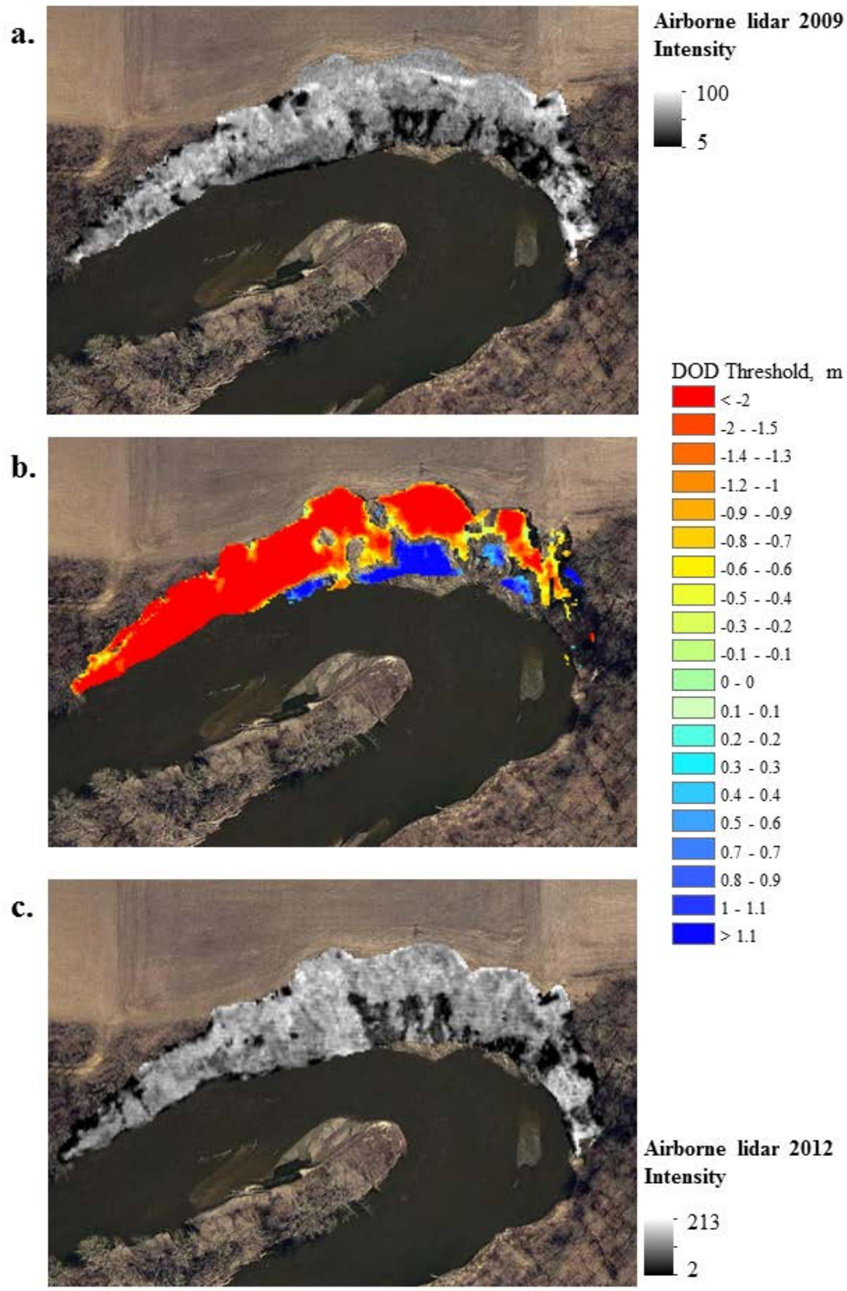

Figure 7. The 2009 Lidar return intensities (a), the difference in digital elevation models with a fuzzy inference system threshold (b), and the 2012 Lidar return intensities (c) for a 27 m tall river bank on the Blue Earth River.

CONCLUSIONS

Both terrestrial and airborne Lidar derived return intensities successfully delineated seepage locations on river banks at two different locations in Blue Earth County, MN. The results also established that Lidar derived RIMs are a suitable alternative to thermal imaging techniques for identifying seepage locations along river banks. Furthermore, all three different

Lidar systems (1 airborne, 2 terrestrial) with laser wavelengths in two different portions of the electromagnetic spectrum were able to delineate seepage locations, indicating the technique is robust across different platforms. The field experiments conducted at the Carver Creek ravine show a significant relationship between Lidar return intensity and soil moisture for various soil layers. However, a controlled experiment with painted soil cores at various soil water contents suggests that the Lidar return intensities are also affected by soil color. In general, darker color soil will overwhelm the differences in return intensity from differences in soil water contents. This suggests that Lidar based system may have limitations in delineating seep areas in darker colored soils. This is, particularly important if a Lidar system used to characterize bank erosion operates in the green portion (i.e. 532 nm) of the electromagnetic spectrum.

We also demonstrate that seepage locations from RIMs could be combined with DODs either from terrestrial or airborne Lidar to evaluate the impact of seepage on river bank mass failures. As multi-temporal airborne Lidar becomes more commonly available, it presents an opportunity to use the method developed in this study to quantify the extent of seepage driven river bank erosion across river networks especially in the Upper Midwestern United States where bank erosion is a major source of sediments to the rivers.

EDUCATION, OUTREACH, AND PUBLICATIONS

Identify conferences, workshops, field days etc. at which project results were presented. Include number of farmers estimated to be present. List articles and/or manuscripts in which project results were published.

Kessler, A.C., S.C. Gupta, M. Brown, A. Grundtner, and K. Wolf. 2015. Quantifying Seepage Induced River Bank Erosion in the Minnesota River Valley Using LiDAR. Drainage Research Forum, Owatonna, MN 23 November, 2015.

Kessler, A.C., S.C. Gupta, M.K. Brown, A.L. Grundtner. 2015. A Method to Quantify Seepage Impact on River Bank Erosion. Abstract and presentation at the Annual Meetings of the Soil Science Society of America, Minneapolis, MN. Abstract 199-8.

Kessler, A.C., S.C. Gupta, M. Brown and A.L. Grundtner. 2014. A Method to quantify the impact of seepage on river bank erosion. Minnesota Water Resources Conference, St. Paul. 14-15 October 2014.

Kessler, A.C. and S.C. Gupta. 2014. Historic surficial retention capacity of the Greater Blue Earth River Basin. Poster presented at Ag. Expo., Mankato, MN. 8-9 January 2014. Poster Presentation.

Kessler, A.C., and S.C. Gupta. 2013. River flows and mechanism of bank erosion in the Minnesota River Basin. Minnesota Soybean Growers Association meeting, St. Paul, MN. 15 February 2013.

Kessler, A.C. 2015. River bank erosion in the Minnesota River Valley. Ph.D. degree public defense. Water Resources Science.

REFERENCES

Kessler, A.C., S.C. Gupta, H.A.S. Dolliver, and D.P. Thoma. 2012. Lidar quantification of bank erosion in Blue Earth County, Minnesota. Journal of Environmental Quality. 41:197-207, DOI: 10.2134/jeq2011.0181.

Kessler, A.C. 2015. River bank erosion in the Minnesota River valley. Ph.D. Dissertation, University of Minnesota, pp 184.

For additional references, please see Chapter 4 in Andrew Kessler's Ph.D. Thesis.