Final Report

Project Title: Applied use of unmanned aerial vehicles in surface water quality protection
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Project Overview

The objective of this research is to evaluate the accuracy of erosion calculations derived from Structure from Motion (SfM) captured with unmanned aerial vehicles (UAV) and determine the best practices for use of this technology for this purpose. The research project combines results from SfM digital surface models (DSM) with ground-truth measurements of erosion to determine the accuracy of this approach. Derived values were incorporated into existing models (e.g., BSTEM) to determine if SfM data were a valid model input. The result of this research is a scientific validation of the erosion calculations derived from DSM. The research serves as a proof-of-concept project to develop a method by which UAVs could be employed to identify, quantify, and monitor erosion in drainage channels and other eroded areas. This would enable federal, state, and local agencies to utilize this technology to more efficiently monitor, remediate, and regulate degradation of surface waters. Outputs from this research project include transfer of information on the appropriate data collection strategies for UAV-based erosion assessment, as well as best practices, along with methods, estimates of accuracy, and any necessary cautions. This data will be communicated to stakeholders through scientific exchange and interaction, in addition to the established University Extension network.

Accomplishments

We conducted regular UAV missions to collect image data for the purposes of creating SfM-generated DSM. At the same time, field survey was conducted to provide ground-truth data. We used two different UAV to conduct flights. These included the DJI Phantom4 and Inspire2. The relative advantage of the Phantom4 is the price point (~$1300), while the Inspire2 (~$4000) offers the ability to obtain unobstructed 360° view with the camera, as well as independent camera and flight controls.

Over the course of the study, we made several key changes to research methods to overcome issues experienced in the first half of the study. In the beginning, we worked in a southern area of South Farm on a 750-m reach of the main channel of Catalpa Creek. Flights were conducted to generate DSM of the reach (http://bit.ly/2RgcJh4). However, we changed our focus to a tributary in the second phase of the project, moving into a shallower area with less vegetation. We selected a tributary that flows from the 21 Apartments area of Starkville into Catalpa Creek near the bridge to the Aquaculture facility. At first, we were relying solely on survey grade GPS data to provide ground truth data. However, when our field data were compared to our DSM, we noted that problems with the approach existed (Fig. 1). Following this finding, we supplemented our GPS survey with more traditional forms of landscape survey utilizing total stations and traditional survey poles (Fig. 2).

Finally, we also continued to evolve in our choice of calibration materials. We started with soccer cones (Fig. 3), but found these were not durable enough for the environment. We upgraded to rebar with caps which could be permanently placed on-site. The attrition rate for

Figure 1. Comparison of elevation sampled from digital-surface-model and GPS-reported elevation. Color shift from blue to yellow shows increasing disparity between modeled and measured elevation. Increased size of dots coincides with decreased precision of GPS instrument (as reported by the instrument under vertical dilution of precision). Small dots with blue, pink, or red are considered acceptable.

It was also noted that there is a compounding effect on disagreement between modeled and measured values when the horizontal precision of the GPS instrument is low because measurements are taken on sloped streambanks (thus, being in the wrong place on the slope inherently results in the wrong elevation being reported).

Figure 2. Students who participated in this project had previous classroom experience with use of survey equipment. Following a brief refresher course from an instructor in the Civil and Environmental Engineering Department, we utilized a total station and reflector survey poles to gather cross sectional elevations from our monitored tributary to Catalpa Creek.

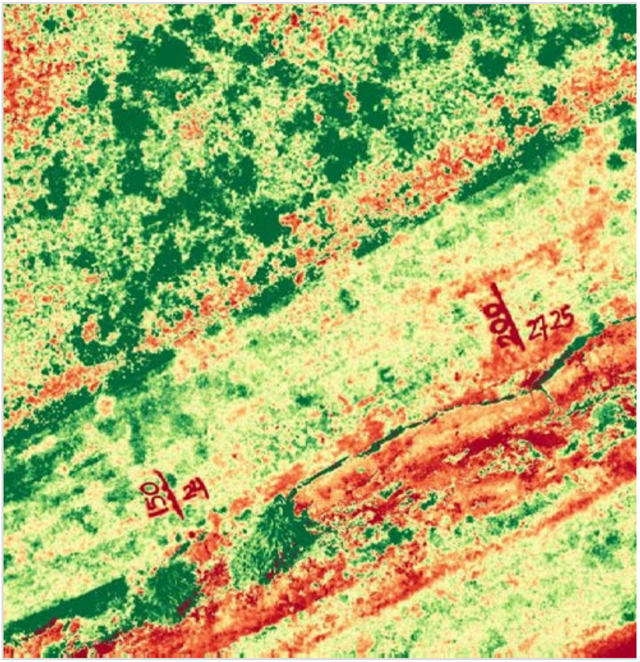
CEE Graduate Student, James Grafe, led the efforts to conduct total station survey of the tributary. Mr. Grafe is a student under Dr. Ramirez-Avila.

rebar in highly erodible areas was quite high, and the introduction of rebar likely increased erosion on-site. Thus we augmented our rebar caps with landscape paint (Fig. 4). After reviewing work at other universities, we introduced calibration boxes which could be used for georectification, as well as height and volume calibration. These boxes were built from salvaged materials and painted for maximum visibility (Fig. 5). Boxes can be measured within the DSM to verify height and volume are reported correctly by the model.

Figure 3. Soccer cones were placed at varying heights throughout the study area to serve as ground control points for vertical and horizontal accuracy of Structure from Motion digital surface models. The soccer cones were highly visible, inexpensive, and easy to deploy, but they were not durable enough for the environment.

Figure 4. Landscape paint was used to supplement rebar caps as a ground control element. The paint was highly visible in vegetation indices. The advantage of the paint was that it could be used to document other information which could be used to further verify the accuracy of Structure from Motion digital surface models.

Figure 5. Calibration boxes were built from scrap materials and painted for high levels of visibility. While these large boxes were not suited for ground control points, they were useful in assessing the accuracy of volume estimates from the Structure from Motion digital surface models.



Using our collected data, we conducted research to evaluate our how data collection and processing choices affected the DSM outputs from SfM. We evaluated several options for processing available to end users including proprietary desktop software AgiSoft Photoscan, paid subscription cloud-based DroneDeploy, and hybrid desktop/cloud paid subscription Pix4DModel. We also incorporated our DSM into the Bank Stability and Toe Erosion Model (BSTEM), developed by the National Sedimentation Laboratory in Oxford, MS to determine how useful these surfaces would be for model users. More specific comments on these activities is presented under the Results and Conclusions sections.

Student Training

Over the course of the project, the following students have assisted with data collection and processing, with and without direct support from project funds.

Name	*Level*	*Department*
James Grafe	Graduate	Civil and Environmental Engineering
Taylor Noble	Undergraduate	Civil and Environmental Engineering
James Steele	Undergraduate	Civil and Environmental Engineering
Katelyn Polk	Undergraduate	Civil and Environmental Engineering
Andre Remedios	Undergraduate	Civil and Environmental Engineering
Ryan Horton	Undergraduate	Civil and Environmental Engineering
Shanika Musser	Undergraduate	Civil and Environmental Engineering
Lucas Whittenton	Undergraduate	Agricultural Economics
Gage Creel	Undergraduate	Agricultural and Biological Engineering
Adam Goldman	Undergraduate	Agricultural and Biological Engineering
Shelby Adair	Undergraduate	Agricultural and Biological Engineering
Dillion Drake	Undergraduate	Agricultural and Biological Engineering
William Jarrell	Undergraduate	Agricultural and Biological Engineering
Garrett Prater	Undergraduate	Agricultural and Biological Engineering
Jesse Mitchell	Undergraduate	Landscape Architecture

As the Catalpa Creek watershed has become an experimental laboratory used by different instructors in their academic exercise, students enrolled in the course Stream Reconnaissance (Fall 2017) advanced the hydrologic characterization of different reaches and the main stream within the watershed while gaining experience in these techniques. In addition, several students have been trained to collect stream information related to temporal and spatial variability of flow and sediment loads along the studied reaches. This dataset was used as a reference for modeling purposes. Figure 6 showcases some of the diversity in student activities associated with this project.

Figure 6. Students working on the Catalpa Creek project gain experience in a range of scientific skills. These include everything from operating unmanned aerial vehicles to collecting soil cores.

Results

The UAV is a low-cost, rapid turnaround solution for characterizing landscapes. When paired with the cloud-based processing environment, users could be generating interactive 3D models of their landscapes in less than a day, with little to no skill, and no pre- or post-flight effort. The tool could easily find its place with stakeholders such as NRCS personnel as a means to characterize and visualize eroded landscapes, and to discuss options for conservation implementation with their landowners. However, this action does not assume a need for high accuracy of the output DSM data, only realistic looking images and models. Obtaining the accuracy necessary for any type of measurement or modeling requires a more stringent attention to ground control and ground truth.

Ground control points (GCP) are a necessity. The GCP should be placed beyond the extent of the study site to avoid distortion within the DSM. They should be uniformly placed, but not in a linear pattern. When we used linear placement of GCP, our surfaces were warped due to trending in interpolation. We also noticed that our ability to accurately fit DSM at the edges was harder due to the lack of coverage of GCP in these areas. The unwritten guideline is that 20 GCP are sufficient for accuracy. However, this ignores variation in elevation for areas with large changes in topography. Using our calibration boxes we were able to discern that without the variation in elevation of GCP, the DSM did a poor job of accurately representing the z-axis (i.e., elevation). Material and appearance of GCP is also important, as our early attempts at using soccer cones and rebar caps each produced unique challenges. Significant maintenance was associated with the rebar caps in the form of weed eating around rebar. When we put the rebar caps flush with the ground, we still needed to ensure grass was not covering the cap at the time of imaging.

Figure 7. The growth of trees and other vegetation with the survey areas prevented survey crews from returning to the same survey points. This effected the results because we could not reproduce results along the same line to monitor for small changes in cross section geometry.

Vegetation was a constant problem for the study. The error between the collected data and the DSM was generally attributed primarily to vegetation. However, vegetation also effected the ability of survey crew to maintain the cross-section line over the course of the study (Fig. 7). This is also a consideration for time series studies as vegetation will be changing with each collection. Even the growth of grass on flat surfaces can produce different elevation results between two time periods. From a conservation standpoint, we'd most likely want to encourage the presence of vegetation to reduce the erosivity of the system. This creates something of a paradox for how we are to monitor critical systems that we hope to recover. Vegetation challenges are, however, not unique to SfM, also affecting currently-standard technologies such as terrain laser scanning.

Generally UAV missions are conducted with some sort of flight app for a mobile device. The UAV controller is generally reserved for use for takeoff, landing, and emergencies. These apps offer functionality to conduct SfM missions, which typically consist of a flight plan with both north-south and east-west flight lines, forming a hash sign. This is necessary to obtain the multiple view angles necessary to re-create 3D structure. In our review of the necessity of this flight plan, we conclude that it is in fact the best practice (Fig. 8) to use both sets of flight lines rather than a single set. The addition of oblique images has been recommended by other researchers, which we also introduced into our later collections. The issue with oblique imagery is understanding the critical angle of deviation. If the angle is too great, the software can no longer create tie points in the imagery. This is the problem confronting the software when oblique images are introduced, particularly in areas of steep banks and tall vegetation (e.g., trees). Thus we are hesitant to recommend oblique imagery without adding a multitude of caveats for collection.

We also investigated how processing affects the accuracy. With the cloud-based services, the user has no options regarding processing. These services are thus easy to use because beyond uploading the images, there is little else to do. However, from a research standpoint, this is less than ideal operation. Using our proprietary software, we are able to control many aspects of the generation of DSM. The two primary choices are cloud density and filtering. From a filtering standpoint, surface characteristics will dictate the choice. We determined mild filtering was best for our study site because it provided the best balance between noise and smoothing. When we experimented with cloud density settings, we found differences in elevation values were most frequent in areas of tree cover (Fig. 9).

Between the proprietary and cloud choices, the cloud services provided a better platform for sharing results. Both DroneDeploy and Pix4DModel cloud services offer sharable weblink functionality; only Pix4DModel allows recipients to utilize measurement tools. However, both services offer measurement capabilities to the licensed user. DroneDeploy offers the ability to plot cross section lines and view profiles, a feature not available in Pix4DModel. Pix4DModel, however, had a unique inspection feature that allows the user to select portions of the 3D model and view the actual UAV images which generated that section of the model. In order to share results with Photoscan, the recipient would also need a license for the software.

Between the DroneDeploy cloud and the Pix4DModel cloud, the 3D models from DroneDeploy were far superior in appearance. The desktop version of Pix4DModels were comparable to DroneDeploy. At a cost of \$130/month for DroneDeploy versus \$50/month for Pix4D cloud and desktop together, we would still promote DroneDeploy over the alternative. Both options require elevated licenses (re: more money) to export DSM (or any type of useable structure file), thus neither is a complete solution. In this case, the profile tool and better appearance make a case for DroneDeploy. While the subscription license for Pix4DModel comes with a desktop installation that has improved functionality, for advanced users, nothing replaces the control of Photoscan. Despite the learning curve, computational intensity, and storage requirements for raw and processed data, for research purposes, we could not recommend other options.

It is worth noting that Pix4D offers a desktop program (Pix4DMapper) that has full functionality comparable to Agisoft Photoscan. In our other work, we have found that we prefer Photoscan, if

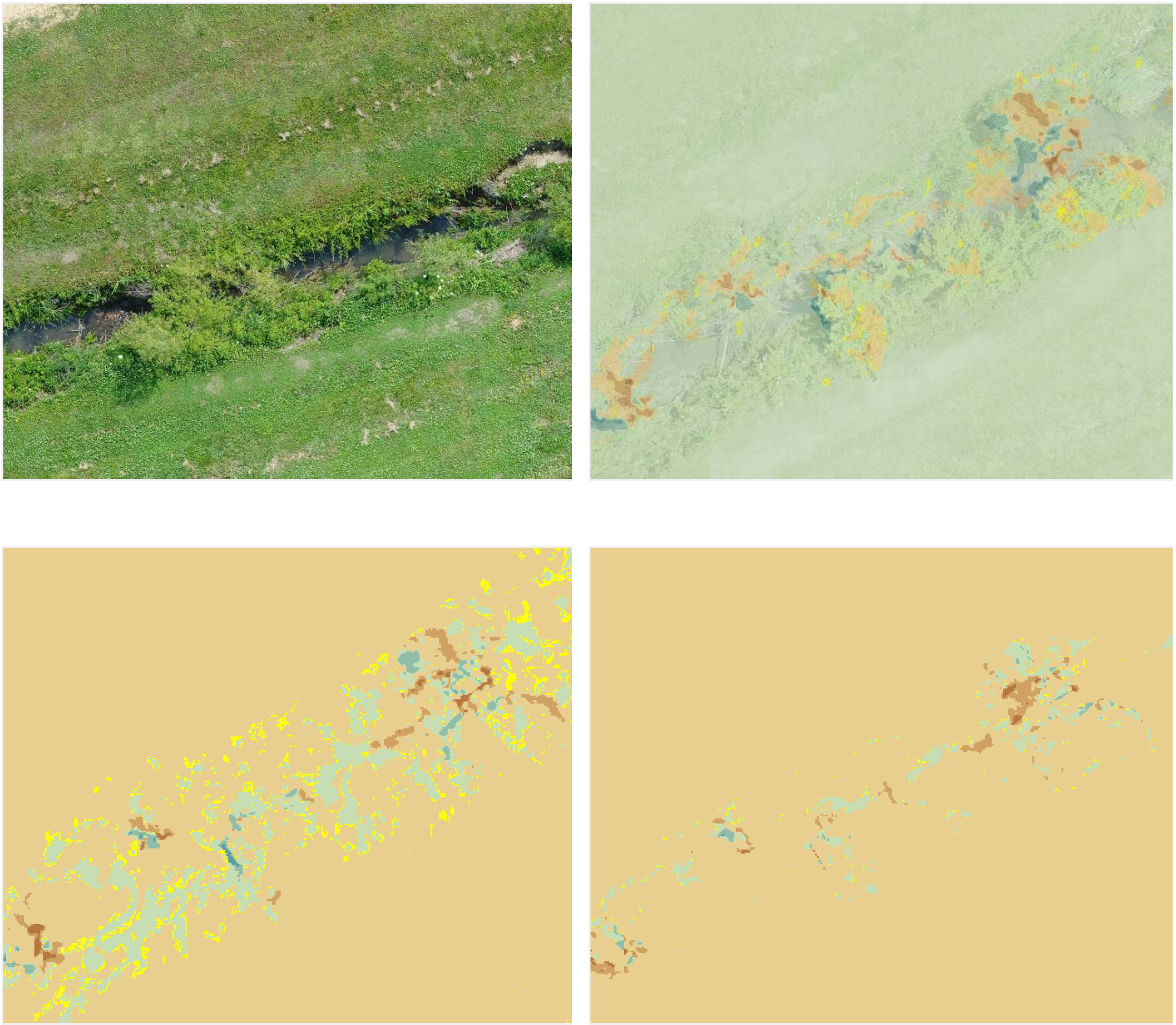


Figure 8. Using a sub-section of the tributary (shown upper left), we processed our image data using north-short flight lines only, and east-west flight lines only. The other three images in the panel represent comparisons between output digital surface models. In all images, areas of yellow are what we desire to see. Yellow areas are areas of neglible difference between output surfaces. As colors grow darker brown or blue, disagreement between outputs increases by 1m, up to 3m of difference. Elevation values from the two surfaces (NS vs. EW) were compared to determine the agreement between surfaces (shown upper right). Few areas of yellow indicate these outputs are not comparable, and thus NS and EW flight lines only do not produce comparable results to each other. The mostly bluish tones indicate that the longer NS flight lines estimate higher elevations than the EW lines, expect in the areas with significant tree coverage, where we see dark browns, indicating higher elevations from EW flight lines. We further compared each surface against a digital surface model generated using both sets of flight lines, to determine how much each differed from the best practice. We saw more areas of agreement (yellow) in the comparison of EW flight lines (shown lower left) than the NW flight lines (shown lower right). Generally, both single direction flights produced elevations that were 1m higher than the output using both sets (indicated by the large amount of light brown color).

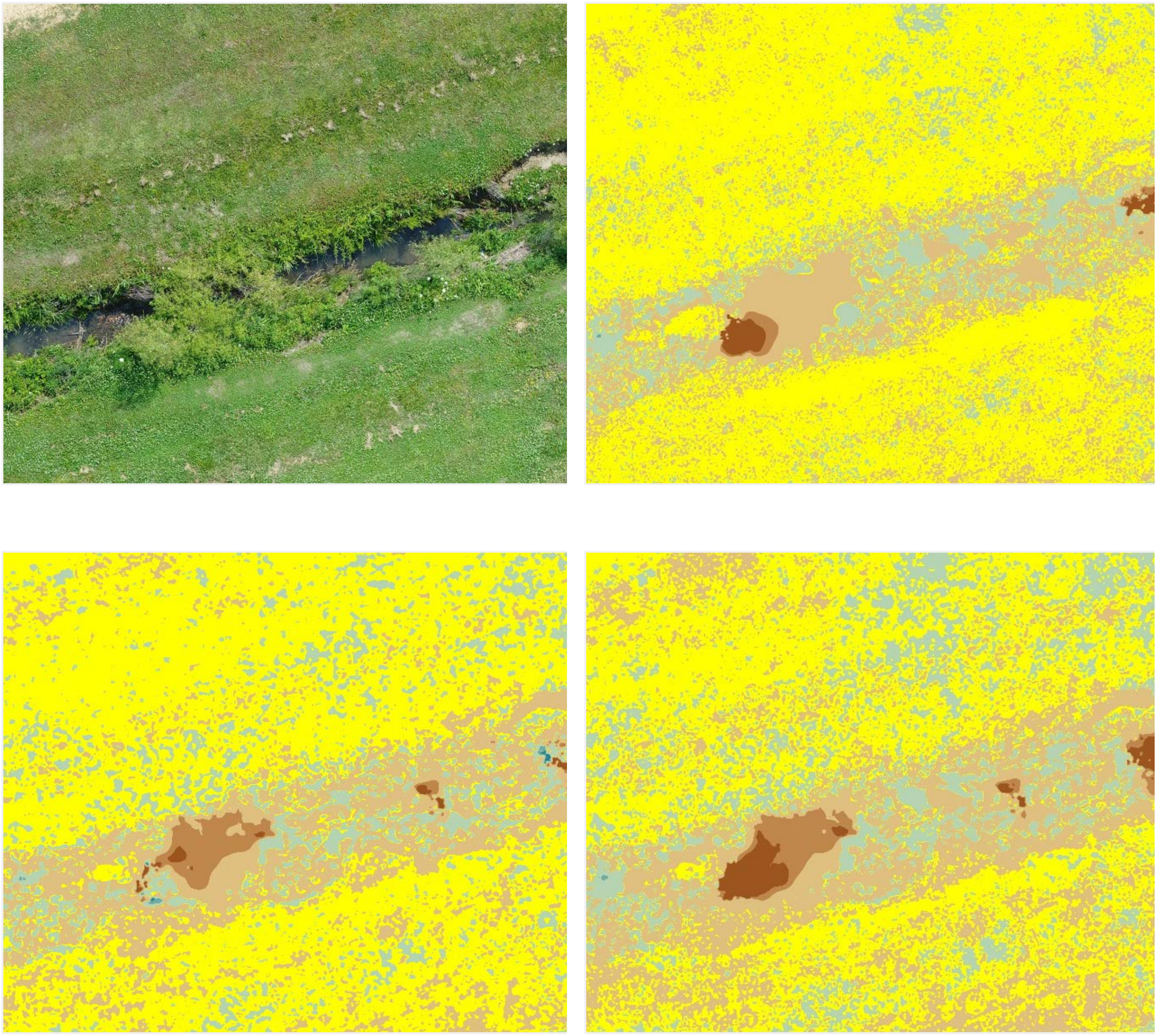


Figure 9. Using a sub-section of the tributary (shown upper left), we processed our image data with ultra-high, high, and medium density point clouds. The other three images in the panel represent comparisons between output digital surface models. In all images, areas of yellow are what we desire to see. Yellow areas are areas of neglible difference between output surfaces. As colors grow darker brown or blue, disagreement between outputs increases by 1m, up to 3m of difference. The comparisons included ultra-high vs. high (shown upper right), high vs. medium (shown lower left), and ultra-high vs. medium (shown lower right). Large areas of yellow indicate that there is much agreement between surfaces, especially in the upslope regions. Areas with trees, and other vegetation lead to differing elevations, generally favoring higher elevations on the part of the lower cloud density DSM.

only for the price point. The educational license for Photoscan is ~$550, with the professional license at ~$3500. The Pix4D educational license is ~$2000 (for 2 devices), with the professional license at ~$5000 (for 2 devices).

The DSM were incorporated into HEC-RAS for 1D hydraulic modeling analysis, and into the BSTEM in both excel and HEC-RAS installations. This was done by generating cross-section profiles with the 3D Analyst tools in ArcGIS. The cross-sections were used as inputs for bank geometry in the model. The images themselves were also found to be useful in making adjustments to Manning's coefficient, used for 1D hydraulic modeling, based on vegetation present. The excel version of BSTEM is easier to setup and simpler to use than the HEC-RAS version, but it was limited in its ability to use very detailed cross-sectional data, and we recommend users consider the HEC-RAS installation for use with DSM. Compared to current methods, the DSM-based bank geometry had more detail in the cross sections and reach profiles, and thalwegs were more easily identified. This is due to the high-resolution nature of the DSM, which contrasts with the limited resolution of topographic surveys (by GPS or total station). The frequency and number of points taken by a surveyor to include more survey details is driven by time restrictions, site accessibility, and even understanding how relevant having detailed topography could be for a specific purpose or analysis. The excel version of BSTEM required downgrading of the resolution to function, rendering the effort to collect higher resolution of low utility. If we assume that the accuracy provided by the input DSM is adequate, the potential is phenomenal for incorporation of UAV-enabled SfM for the HEC-RAS installation of BSTEM. Initial assessment of streambank erosion rates resulted in significant differences in the generation of channel geometry caused by the mentioned effect of vegetation. However, an initial application of the BSTEM model properly represented occurrence of bank failure for the evaluated geometries (Fig. 10).

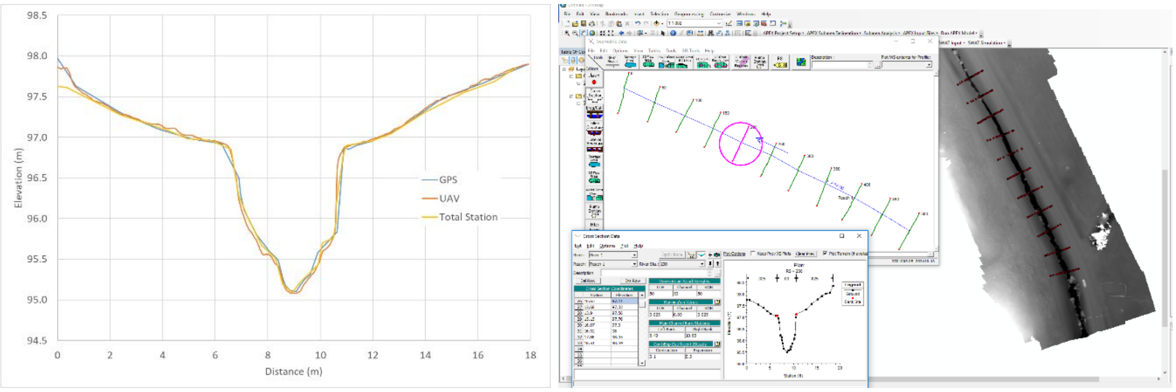


Figure 10. (Left) Comparison of bank geometry generated by three different survey methods. (Right) Geometry generated from DSM for a stream segment in the Catalpa Creek and setup in HEC-RAS for 1D Hydraulic modeling and bank erosion.

One drawback for using geometry extracted from DSM is the flow depth at the moment of UAV survey. Since our experimental reaches were flashy systems running almost all the time under baseflow conditions, water depth appears not to be a factor affecting the bathymetric assessment of the channel. However, in other systems, this could represent a major limitation that should be noted. There are some examples of use of this technology for shallow-water bathymetry, but that field is still developing. Competing solutions, such as LiDAR, are also challenged by overlying water, and this is not a problem unique to SfM.

Presentations

Prince Czarnecki, J. M., Hathcock, L. A., Ramirez-Avila, J. J., Linhoss, A. C., & Schauwecker, T. J. 2017. Unmanned Aerial Vehicles and Structure from Motion Techniques and their Use in Protecting Surface Water Quality. 2017 American Water Resources Association Annual Conference, Nov. 5-9, 2017, Portland, OR. Oral presentation. Online at: http://bit.ly/2NuPm1D

Ramirez-Avila, J. J., Langendoen, E. J., Ortega-Achury, S. L., McAnally, W. H., Martin, James L., Schauwecker, T., & Prince Czarnecki, J. M. 2017. Estimación y Predicción de Descargas de Sedimentos y Tasas de Erosión de Bancos Fluviales. 1st International Congress and 2nd National Congress of Rivers and Wetlands. Neiva, Colombia.

Grafe, J., Ramirez-Avila, J. J., Schauwecker, T., Ortega-Achury, S. L., Prince Czarnecki, J. M., & Langendoen, E. 2018. Understanding Relations between Streamflow, Turbidity, and Suspended-Sediment Concentration in an Impaired Mississippian Stream. Mississippi Water Resources Research institute. Jackson, MS. Oral Presentation.

Ramirez-Avila, J. J., Grafe, J., Schauwecker, T., Prince Czarnecki, J. M., Ortega-Achury, S. L., Martin, James L. & Noble, T. 2018. Impacts of Riparian Buffer Zones on Stream Water Quality: A Quantitative Assessment in the Catalpa Creek Watershed. Mississippi Water Resources Conference. Jackson, MS. Oral Presentation.

Ramirez-Avila, J. J., Schauwecker, T., Martin, James L., Ortega-Achury, S. L. & Prince Czarnecki, J. M. 2018. A Project Based Learning Study Oriented to Develop a Natural Stream Restoration Design. Mississippi Water Resources Conference. Jackson, MS. Oral Presentation.

Ramirez-Avila, J.J., T. Schauwecker, J. Czarnecki, E. Langendoen, S. Ortega-Achury, J. Martin, 2018. Quantifying and Modeling in-Stream Processes: A first step to restore the Catalpa Creek. 2018 World Environmental & Water Resources Congress. Minneapolis, MN. Oral Presentation.

Ramirez-Avila, J; Schauwecker, T; Czarnecki, J; Ortega-Achury, S. L.; Langendoen, L. and Martin, J. 2018. Identification and assessment of stream processes within the Catalpa Creek in Mississippi. Ecostream Conference. Asheville, NC. Poster Presentation.

Czarnecki, J. Linhoss, A., Hathcock, L., Ramirez-Avila, J., & Schauwecker, T. 2018. Assessing Soil Erosion with Unmanned Aerial Vehicles for Precision Conservation. 73rd Soil and Water Conservation Society International Annual Conference. Albuquerque, NM. Oral Presentation.

Schauwecker, T.; Ramirez-Avila, J.J.'; Czarnecki, J; Baker, B. 2018. Hydraulic and vegetative modeling for the restoration design of the upper reach of catalpa creek, an impaired stream in northeast Mississippi. 2018 National Conference on Ecosystem Restoration. New Orleans, LA. Poster Presentation.

Czarnecki, J. 2018. Best Practices and Lessons Learned in creating 3D Structure from UAV Imagery. MAST Mississippi Geospatial Conference 6. Long Beach, MS. Oral Presentation.

Future Plans

Additional analyses are in progress to give a better approach on the comparison of erosion rates assessment and model performance using the different sources of geometry data. Results are expected to be included in a manuscript for submission to a peer reviewed journal during spring 2019. Proposed title: Comparing hydraulic and bank erosion modeling results from using topographic and UAV remote sensing survey to generate channel geometry.

We are also working to incorporate use of tracers with this technology. Preliminary tests have shown that we can detect tracers in sand medium in contained areas with a hyperspectral sensor mounted to a UAV (Fig. 11). Our next steps are to broaden the scale of this study and then move into other landscape types. If we could combine the DSM information with tracer ability, we could move one step closer to the UAV as a multi-use tool for monitoring and managing erosion.

Figure 11. Increasing percentages of metallic, florescent tracer mixed with sand medium were placed in containers for imaging. A hyperspectral sensor was mounted to an unmanned aerial vehicle and images were taken to assess if the technology could be used to detect the tracer and if so, at what concentration.