EFFECTS OF DRONE LIDAR DIGITAL ELEVATION MODELS (DEMS) RESOLUTION AND FLOW AREA RESOLUTION ON HYDRODYNAMIC MODELING RESULTS

Elizabeth M. Prior[1], Jonathan A. Czuba[1], Thomas J. Pingel[2], Valerie A. Thomas[3], Randolph H. Wynne[3], W. Cully Hession[1]

1. Department of Biological Systems Engineering, Virginia Tech
2. Department of Geography, Virginia Tech
3. Department of Forest Resources and Environmental Conservation, Virginia Tech

Abstract

As drones become cheaper, and sensors become lighter, light detection and ranging (lidar) acquisition is more accessible to researchers and industry. This increase in accessibility requires decisions to be made about resolution of subsequent data products. Our study focuses on analyzing how lidar digital elevation model (DEM) and flow area resolutions affect hydrodynamic model results. Lidar data were collected for about 5 ha along 1.5 km of Stroubles Creek at the Virginia Tech StREAM Lab in Blacksburg, VA. Ground points were identified using the simple morphological filter, DEMs were created at several resolutions (0.1 m, 0.25 m, 0.5 m, 1 m, 2 m), and were inputted into a two-dimensional (2D) hydrodynamic model with two flow area resolutions (1 m, 2 m). Model results of depth and velocity were assessed for spatial differences between each model simulation. Greater differences between simulations were found at shallower water depths near the flood extent boundary and along the channel-floodplain interface. We found that simulations from larger resolutions had lower velocity maximum values. The results of this study can be utilized to inform selections of DEM and flow area resolutions for 2D hydrodynamic modeling.

1. Introduction

1.1 Motivation

For most hydrodynamic modeling purposes, topographic information (digital elevation models or DEMs), in the form of rasters, are utilized at fixed spatial resolutions due to being made by state or federal agencies. Now with the advent of drone lidar (light detection and ranging) affordability, DEMs can be created by stakeholders at their desired resolution. While this creates flexibility and independence from coarse DEMs, the user now must decide what resolution they need for their model. Very high resolution DEMs (centimeters in scale) are pedantic and will result in artificial roughness (noise) due to the excessive undulations that probably do not represent reality. This is probably due to the failure of conventional ground interpolators that were designed for coarser lidar data collected from planes, not from drones. Conversely, coarse resolution DEMs can overly smooth the terrain. Ultimately, the decision of DEM resolution will affect hydrodynamic model results of depth and velocity.

1.2 Research objective

We aim to investigate how DEM resolution affects modeled results of water depth and velocity. We will also investigate how 2D flow area resolution within the hydrodynamic model affects modeled results as well. This will be done by utilizing several tools to study these interactions including 2D hydrodynamic modeling with inputs from drone lidar.

1.3 Background

By utilizing lidar and the drone platform, we can collect high density data, resulting in over 450 points/m^2. This can be utilized to create DEMs at various resolutions. Lidar uses near infrared light that is emitted from the sensor and then is reflected off objects. The sensor records how long it takes the reflected light to return, and then calculates elevation by using the speed of light. This then creates a 3D point cloud, that penetrates the canopy and detect the ground.

2. Methods

2.1 Field site

All data has been collected at the Virginia Tech (VT) Stream Research, Education, and Management (StREAM) Lab (Figure 1). This outdoor laboratory is a 2.1 km restored section of Stroubles Creek used for interdisciplinary research. This site offers the desired riverscape and long-term stage data, thus allowing for model validation and calibration.

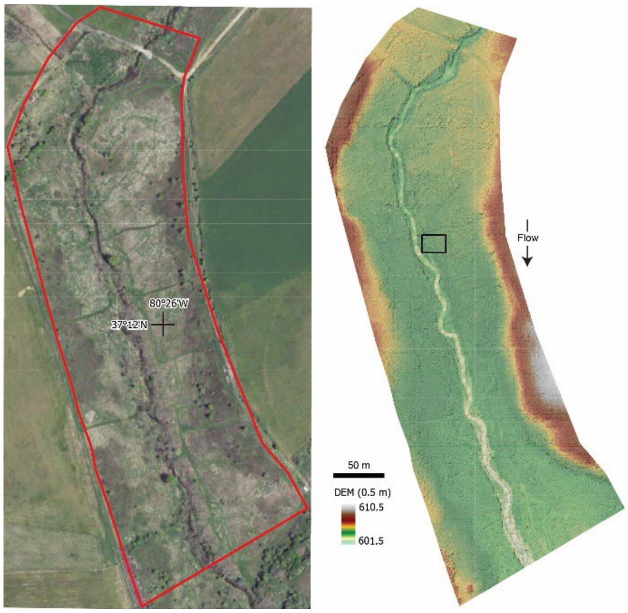

Figure 1. Map of the VT StREAM Lab. Outline of 2D flow area is in red on the left, and an example of a digital elevation model (DEM) at 0.5 m spatial resolution for the study site is on the right.

2.2 Lidar data and model creation

The drone used for lidar surveys was a Vapor35 (AeroVironment, Simi Valley, CA, USA) with a YellowScan Surveyor Core lidar unit (Monfeerier-sur-Lez, France). The lidar unit consists of a Velodyne VLP-16 laser scanner (Velodyne, San Jose, CA, USA) and a GNSS-inertial Trimble APPLANIX APX-15 (Trimble, Richmond Hill, ON, Canada). To plan and conduct Vapor35 flights, we used the wePilot1000 flight control system and the weGCS ground control system software (weControl SA, Courtelary, Switzerland). The lidar flights were flown at a 30 m altitude, with 20 m flight-line spacing, which was recommended by YellowScan staff for optimum point spacing and density.

The YellowScan system is ultralight (2.1 kg) which is the allowable payload limit for the Vapor35. The lidar system can record two returns per pulse and uses a wavelength of 905 nm. The Velodyne VLP-16 and the APPLANIX unit allow for one button data acquisition. After the flight, data was corrected using a local CORS base station, and was exported into a LAS file format in UTM zone 17N.

The lidar point clouds were corrected following procedures outlined in (Prior et al., 2022). Next, the point cloud was then passed through a Python code that utilized the Simple Morphological Filter (SMRF) to classify ground points (Pingel et al., 2013). The point cloud file was then imported into ArcGIS Pro (version 2.9.2). It was filtered to just include the points classified as ground. The ground points were then used to create a DEM raster by using the "LAS Dataset to Raster" tool, where the interpolation type was set to binning, cell assignment was set to nearest, and void fill method was set to natural neighbor. Raster size was set to 0.1 m, 0.25 m, 0.5 m, 1 m, and 2 m.

Next, bathymetric cross-sections surveyed all along the stream were then used to create a raster of stream bathymetry using the “Topo to Raster.” The bathymetry raster and the DEM rasters were then combined using the “Mosaic to New Raster” tool.

Next, a hydrodynamic model was created in Hydrologic Engineering Center's River Analysis System (HEC-RAS). All of the DEMs were imported as terrains, and roughness was set to the floodplain and channel roughness coefficients outlined in (Prior et al., 2021). Eleven flows were used in the model which represented flow scenarios that commonly occur at StREAM Lab. See Figure 2 for an overview of methods.

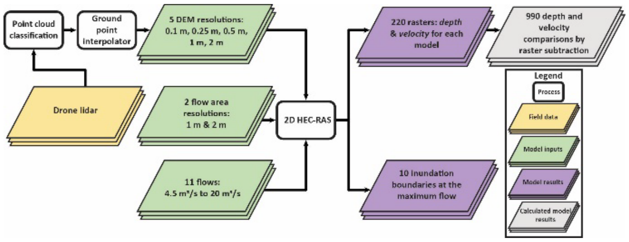

Figure 2. Workflow showing methods and model outputs.

3. Preliminary results

From the depth raster comparisons, we found that the depths vary longitudinally from upstream to downstream (top to bottom). This variation seems to become more evident as flow increases. This can be seen in Figure 3, when comparing the different flow scenarios to each other (comparing rows to each other). The differences also seem to be more spatially uniform when comparing models that utilized DEMs of similar spatial resolution (left column of Figure 3). The longitudinally stratified differences may be occurring due to the static downstream boundary condition that was used in the model. This type of downstream boundary condition is typically used in this type of model.

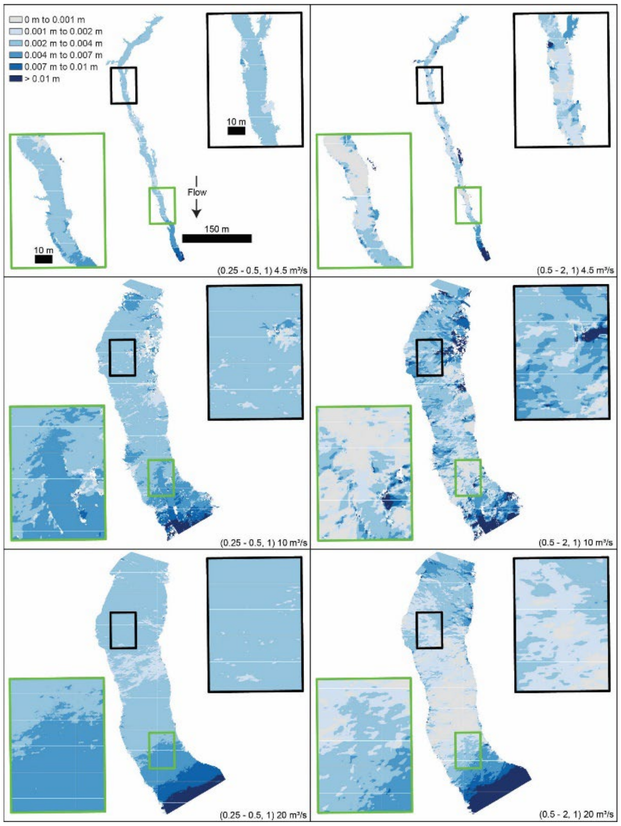

Figure 3. Depth difference maps. The right column shows the depth differences between models using 0.25 m DEM and 0.5 m DEM. The left column shows the depth differences between models using 0.5 m DEM and 2 m DEM. The first row shows results for 4.5 m^3/s, second row is for 10 m^3/s, and the third row is for 20 m^3/s.

After raster subtraction, this resulted in 20 pairwise model comparisons for each flow scenario, thus resulting in a total of 220 comparisons. When examining a single flow scenario (Figure 4, inset graph), we can see that the largest differences occur between models that have the highest DEM resolution difference, and eventually decrease to less than 5 mm of depth difference between models that have the least DEM resolution difference. When looking at all of the depth difference results (Figure 4), we can see that this basic trend holds true for each flow scenario. We can also tell that the largest depth difference occurs at the second flow scenario when the channel is overtopped and the flow spills into the floodplain. Depth differences decrease to somewhat of a steady value after this event.

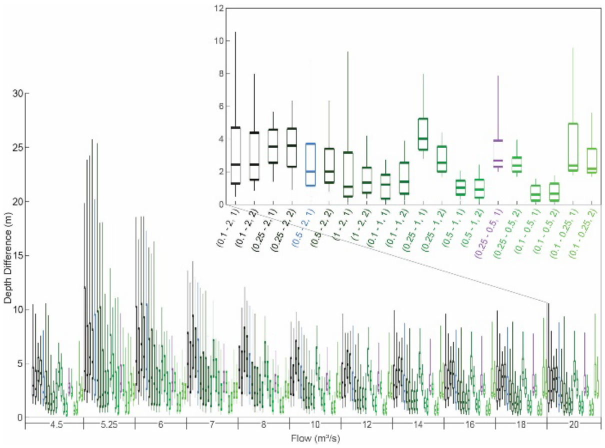

Figure 4. Boxplots for each model pairwise comparison at each flow scenario with a zoomed in perspective of the 20 m^3/s flow scenario. The blue and purple boxplots correspond to the model differences visualized in Figure 3.

5. Future steps

We plan to continue our analysis of these results by conducting similar comparisons for the velocity magnitude, as well as the inundation boundary at the maximum flow of 20 m^3/s. We also plan to see if there are any correlations between differences and ground lidar point density to better understand if errors are occurring where there is less available topographic data. From these results, we hope to be able to recommend best practices when deciding on DEM and 2D flow area resolutions for hydrodynamic modeling.

References

Fathi-Maghadam, M., Kouwen, N., 1997. Nonrigid, nonsubmerged, vegetative roughness on floodplains. Journal of Hydraulic Engineering 123, 51–57. https://doi.org/10.1061/(ASCE)0733-9429(1997)123:1(51)

Kouwen, N., 1988. Field estimation of the biomechanical properties of grass. Journal of Hydraulic Research 26, 559–568. https://doi.org/10.1080/00221688809499193

Kouwen, N.N., Li, R.-M., 1980. Biomechanics of vegetative channel linings. Journal of the Hydraulics Division 106.

Pingel, T.J., Clarke, K.C., McBride, W.A., 2013. An improved simple morphological filter for the terrain classification of airborne LIDAR data 77, 21–30. https://doi.org/10.1016/j.isprsjprs.2012.12.002

Prior, E.M., Aquilina, C.A., Czuba, J.A., Pingel, T.J., Hession, W.C., 2021. Estimating Floodplain Vegetative Roughness Using Drone-Based Laser Scanning and Structure from Motion Photogrammetry. Remote Sensing 13, 2616.

Prior, E.M., Czuba, J.A., Pingel, T.J., Thomas, V.A., Wynne, R.H., Hession, W.C., 2022. INVESTIGATING FLOOD-VEGETATION INTERACTIONS THROUGH REMOTE SENSING AND MODELING. Presented at the 2022 Virginia Space Grant Consortium Student Research Conference.