Summer 2019

Analysis of Flood Patterns in Adams County, Pennsylvania Utilizing Drone Technology and Computer Simulations

Alyssa J. Kaewwilai
Gettysburg College

Kaewwilai, A.J. (2019). Analysis of flood patterns in Adams County, Pennsylvania utilizing drone technology and computer simulations. Pennsylvania Geographer 57(1), 1-20.

Analysis of Flood Patterns in Adams County, Pennsylvania Utilizing Drone Technology and Computer Simulations

Abstract

Drone imagery and photogrammetry models of the Gettysburg College campus and the terrain at Boyer Nurseries and Orchards were utilized to study flood patterns in Adams County, Pennsylvania. Gettysburg College has lower-sloped land and moderately built infrastructure while Boyer Orchards has drastically sloped land with many patches of abundant vegetation. The two locations were selected due to the fact that they have starkly different surface features, while the bedrock geology of the areas are very similar. The terrain of the models was isolated before a 3D carver and 3D printer were used to construct physical models to further analyze potential water flow and speed through virtual, modeled flood simulations. The models were used to compare real world rainfall data and flood events in the investigated areas from the months of June to August in 2018. I hypothesized that the Gettysburg College campus would experience more severe flooding that would take longer to subside in comparison to Boyer Orchards due to the steeper slope of the orchards' terrain. The research revealed that Boyer Orchards experienced more extreme flooding and rainfall than Gettysburg College but was able to neutralize the effects due to plentiful vegetation and physio-graphic differences. Modeled flood simulations demonstrated less rainfall in comparison to actual rainfall values: there were differences of 0.78 cm and 1.32 cm between the actual and simulated rainfall amounts for Gettysburg and the Boyer Orchards area, respectively.

Keywords

flooding, Adams Country, drones, photogrammetry, rain fall, Gettysburg College

Disciplines

Environmental Indicators and Impact Assessment | Environmental Monitoring | Environmental Sciences

Comments

This paper was the winner of the Pennsylvania Geographical Society undergraduate paper competition 2018.

Volume 57, No. 1 - Spring/Summer 2019

WINNER OF THE PGS UNDERGRADUATE PAPER COMPETITION 2018

ANALYSIS OF FLOOD PATTERNS IN ADAMS COUNTY, PENNSYLVANIA UTILIZING DRONE TECHNOLOGY AND COMPUTER SIMULATIONS

Alyssa J. Kaewwilai
Department of Environmental Science
Gettysburg College

Abstract

Drone imagery and photogrammetry models of the Gettysburg College campus and the terrain at Boyer Nurseries and Orchards were utilized to study flood patterns in Adams County, Pennsylvania. Gettysburg College has lower-sloped land and moderately built infrastructure while Boyer Orchards has drastically sloped land with many patches of abundant vegetation. The two locations were selected due to the fact that they have starkly different surface features, while the bedrock geology of the areas are very similar. The terrain of the models was isolated before a 3D carver and 3D printer were used to construct physical models to further analyze potential water flow and speed through virtual, modelled flood simulations. The models were used to compare real world rainfall data and flood events in the investigated areas from the months of June to August in 2018. I hypothesized that the Gettysburg College campus would experience more severe flooding that would take longer to subside in comparison to Boyer Orchards due to the steeper slope of the orchards' terrain. The research revealed that Boyer Orchards experienced more extreme flooding and rainfall than Gettysburg College but was able to neutralize the effects due to plentiful vegetation and physiographic differences. Modelled flood simulations demonstrated less rainfall in comparison to actual rainfall values: there were differences of 0.78 cm and 1.32 cm between the actual and simulated rainfall amounts for Gettysburg and the Boyer Orchards area, respectively.

Introduction

Adams County, Pennsylvania, located in the northeastern Appalachian region is particularly prone to excessive flooding and has a history of floodwater damage in locations such as Gettysburg, both on agricultural and residential land (McGillis 1997). Flash floods are fairly common in Adams County, such as the Gettysburg Flood in 1996, which caused damage to the town's infrastructure in excess of $16 million (McGillis 1997). Due to Gettysburg's location—built upon shale, quartz, and potassium feldspar bedrock—run-off rainwater is fairly common which thus promotes flooding. In contrast, Boyer Orchards in Biglerville, Pennsylvania is built upon diabase rock. Both Gettysburg and Biglerville are south of the Conewago Creek that connects to the Chesapeake Bay drainage basin through the Susquehanna River. Although this location can help prevent excessive flooding by allowing rainwater to drain, it can also promote flooding during certain storm events if the normal direction of rainwater is reversed (McGillis 1997).

The objective of the research was to utilize drone imagery, photogrammetry models, and computer flood simulations to study the effects of terrain features on flood patterns. The study of two starkly different locations was conducted to compare land features that contribute to flood patterns in each area. The research was conducted at the Gettysburg College campus in Gettysburg, Pennsylvania and Boyer Nurseries and Orchards in Biglerville, Pennsylvania. I hypothesize that the model will show that the Gettysburg College campus will experience more severe flooding that will take longer to subside in comparison to Boyer Nurseries and Orchards due to the flatter slope of the campus terrain.

First it is important to investigate the geology and the terrain of the areas of study in order to fully understand how they impact flood waters and to make in-depth cause and effect comparisons of storm events through means such as virtual flood simulations. Gettysburg has a combination of flat and sloped terrain, as well as sediment composition that primarily contains shale, along with smaller amounts of siltstone and sandstone (Blake et al. 2017; Faill 2003). Shale is common in large spans of flat, low-lying Pennsylvanian land such as deltas within proximity to the Gettysburg Basin, one of the many Triassic rift basins existing along the eastern coast of North America (Gates and Valentino 1991). This is where a bedrock consisting primarily of interbedded gray shales, sandstones, and conglomerates called the Gettysburg Formation were deposited (Faill 2002; Gates and Valentino 1991; Root 1988). The Gettysburg Basin formed due to extensional and diverging plate tectonic movement that led to the formation of alluvial fans and deltas which help drain water downstream into the Potomac and Susquehanna rivers and eventually to the Chesapeake Bay (Barnes et al. 2002; Boyer Nurseries and Orchards Incorporated 2018; Faill 2003; Root 1988).

These geologic structures connect to permanent overflow floodway channels and ridges composed of intrusive diabase sheets that help redirect water flow to nearby streams and ponds to prevent flooding (Faill 2003; Long et al. 2016; Root 1988). The rate by which rainwater flows downward is affected by the terrain slope and strength of water flow, meaning that extremely angled or sloped terrain with heavy water flow has the fastest rate of movement (Woltemade 1994). Vegetation also intercepts precipitation in accordance to vegetated tract size. Moreover, the position of cropland also impacts runoff and flooding. An increase in vegetation, especially when in grouped patches, can significantly increase root uptake of water and decrease flooding or the speed of water flow (Long et al. 2016). This is why the effects at Boyer Orchard, which experiences higher velocities of storm water flow than the Gettysburg College campus, are neutralized quicker as demonstrated in later research results. Contour farming is also utilized as a tactic to combat flooding at Boyer Orchard, which is a sustainable agricultural practice. Crops are planted across and perpendicular to the orchard's terrain slopes and follows the contours of a field to break up water flow and prevent erosion (Long et al. 2016).

One method of combating and preventing future flood damage is by assessing flood patterns and risks prior to heavy rain storms through model simulations and corroborated by real time data. The use of virtual and physical models is a modern practice of risk analysis for prediction of future damage, multi-criteria decision-making, and estimates of the viability of large investments (Aronica et al. 2019). Future damage pertains to large campus development investments, such as at Gettysburg College, while multi-criteria decision-making involve consideration of factors such as durability of material and the prediction of future storm occurrences. Photogrammetry, the use of photography in surveying and mapping to measure distances between objects, is commonly used in these practices. Point-source flood areas can be located by investigating the geology and topography of studied areas. This task can be completed utilizing LiDAR, DEM (digital elevation model), DTM (digital terrain model), and DSM (digital surface model) data acquired by drone technology (Chen et al. 2018). Model simulations and drone technology are also commonly used to investigate how the geomorphic framework of areas, including features like patches of vegetation and deltas, affect flood patterns in various locations (Mercier et al. 2017).

The purpose of the research was to use LiDAR, DEM, DSM, and model simulations to evaluate how the variation of terrain slope, in conjunction with other variables, affects potential flood patterns at two distinctly different locations in Adams County, Pennsylvania: the Gettysburg College campus in Gettysburg, Pennsylvania and agricultural land at Boyer Nurseries and Orchards in Biglerville, Pennsylvania.

Gettysburg College is built on slightly sloped terrain and contains moderate infrastructure development and less spacious land in comparison to Boyer Orchards. Much of the college campus rests on a high point of land between two valleys with streams that flow into Rock Creek. Steven's Run Rock Creek Tributary runs through the southern tip of the campus, which is an area of high flood concern because half the Gettysburg College campus lies within the area. Debris blocks the Steven's Run and the surrounding areas during heavy storms, making the quality and volume of water entering Steven's Run upstream uncontrollable (Gettysburg College 2007; Figure 1-2).

Boyer Orchards is absent of any infrastructure; instead, there is a large amount of open land with crops, trees, and shrubs. The vegetation rests on sloping land with a variety of different native Pennsylvanian plants, such as sedges and wildflowers (Keystone Wildflowers 2019; McGillis 1997). Boyer Orchards does not have any human-made infrastructure other than a single road that runs south-to-north.

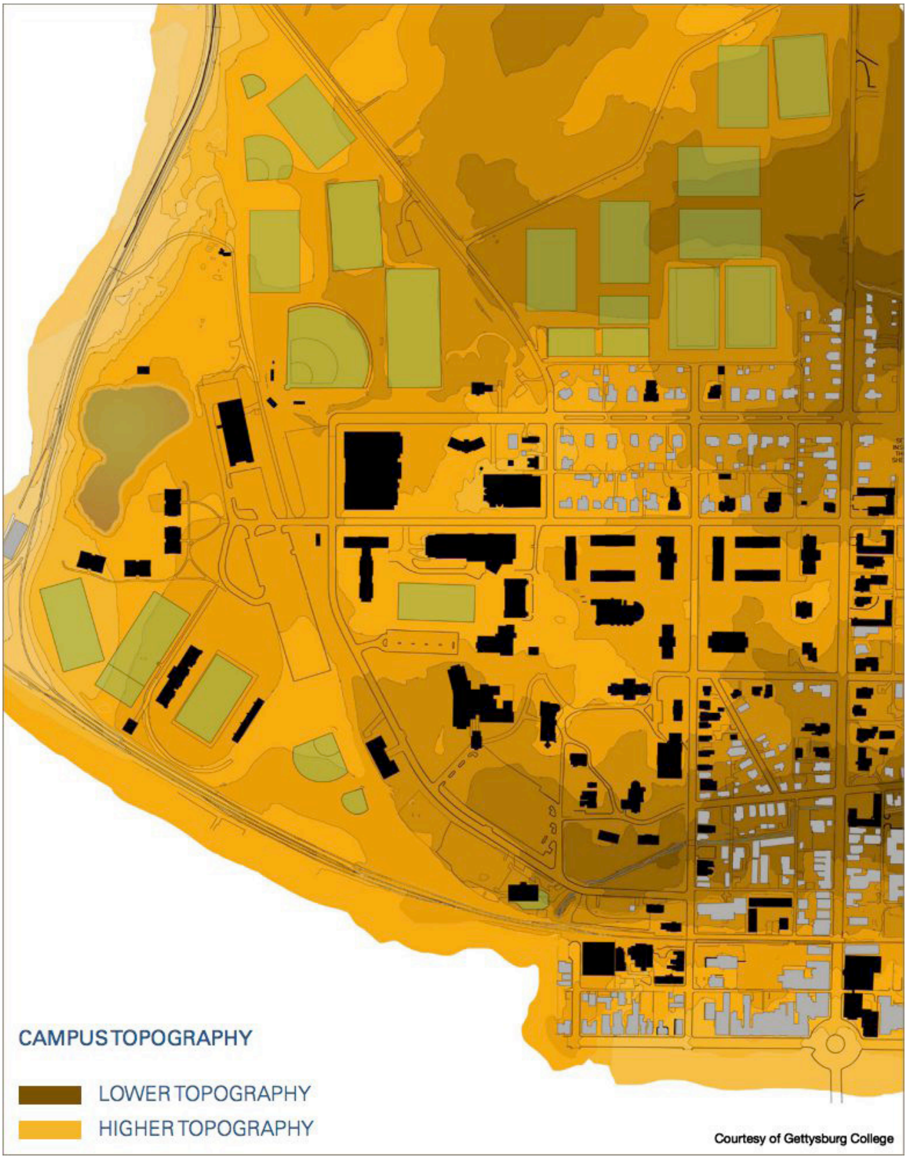

Figure 1. Topography of Gettysburg College campus including built infrastructure (Modified from Gettysburg College 2009; used by permission).

Methods

The Mavic Pro drone along with two phone-based applications, DJI Go 4 and Pix4Dmapper, were used to capture aerial, georeferenced images of the two areas of Adams County, Pennsylvania. DEM, DTM, and DSM models were created from this process: DEM are raster grids with built and natural structures filtered out of the terrain model. DTM consist of vector data set with regularly spaced points and natural features such

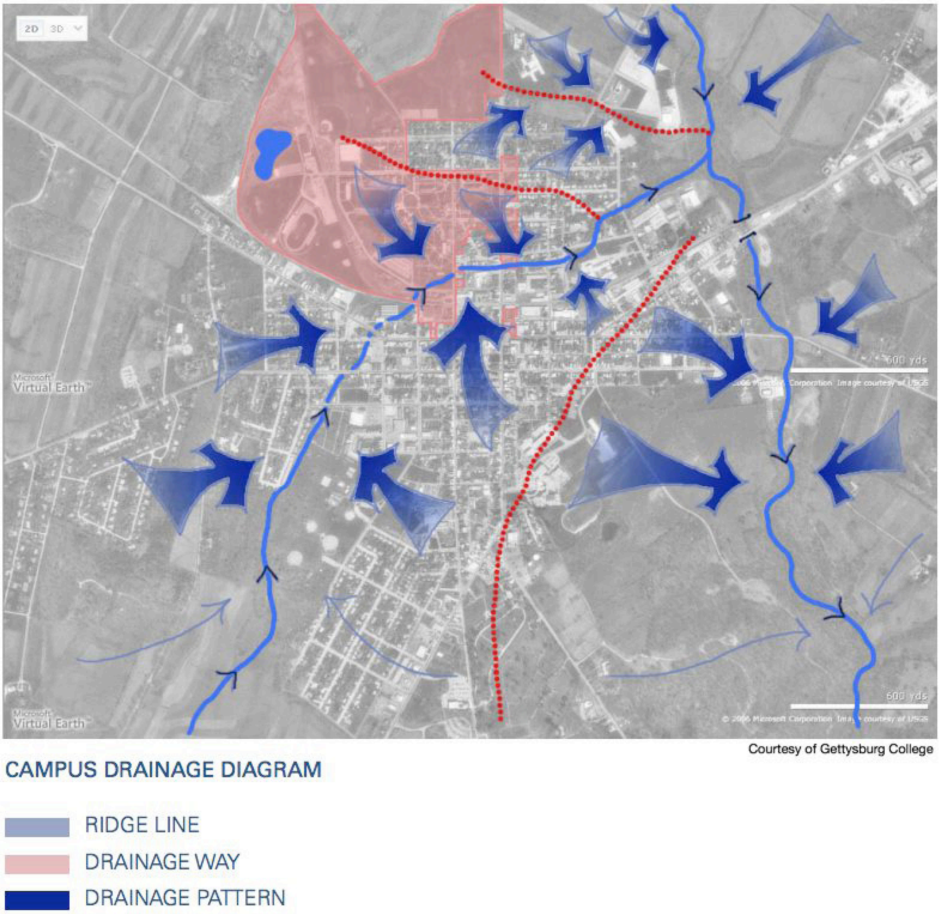

Figure 2. Gettysburg College drainage system (Modified from Gettysburg College 2009; used by permission).

as break lines and ridges. Meanwhile, DSM show continuous elevation over a topographic surface that includes vegetation and man-made features (McGillis 1997). DEM, DSM, and DTM models were all used in the project in order to create models of the study sites and to isolate the terrain from built infrastructure in order to focus on the effects of terrain elevation. This not only simplifies the model but it also makes it easier to study the specific terrain features that lead to specific water flow patterns.

The DJI Go 4 and Pix4Dmapper drone applications are ideal for using drone data in conjunction with LiDAR-derived DEM data with image processing to create photogrammetry models of the study sites that could be located using satellite geolocation. These data can associate real-time storm events with photogrammetry models for the purpose of flood simulations. The two study sites were divided into a total of seven smaller, more specific areas to scrutinize: Quarry Pond, East Quad, West Quad, and Stine Lake at Gettysburg College as well as three large areas with vegetation at Boyer Orchards (Figures 3-4).

On the DJI Go 4 application, Multiple Flight Mode was enabled (in the Mavic Pro User Manual) to allow the drone to fly double-grid missions, a project setting used to generate 3D models at the lowest altitude possible of 30.18 m set in the Pix4Dmapper app. The double-grid mission took aerial photographs at evenly set intervals in a square formation to generate comprehensive computer models of the terrain, including landscape features. By flying the drone at lower altitudes, more accurate and clear images were produced by the drone.

The Multiple Flight Mode gathers an abundance of photos of a given area in order to produce the best photogrammetry model. Through this method, the clearest and most accurate photos pos-

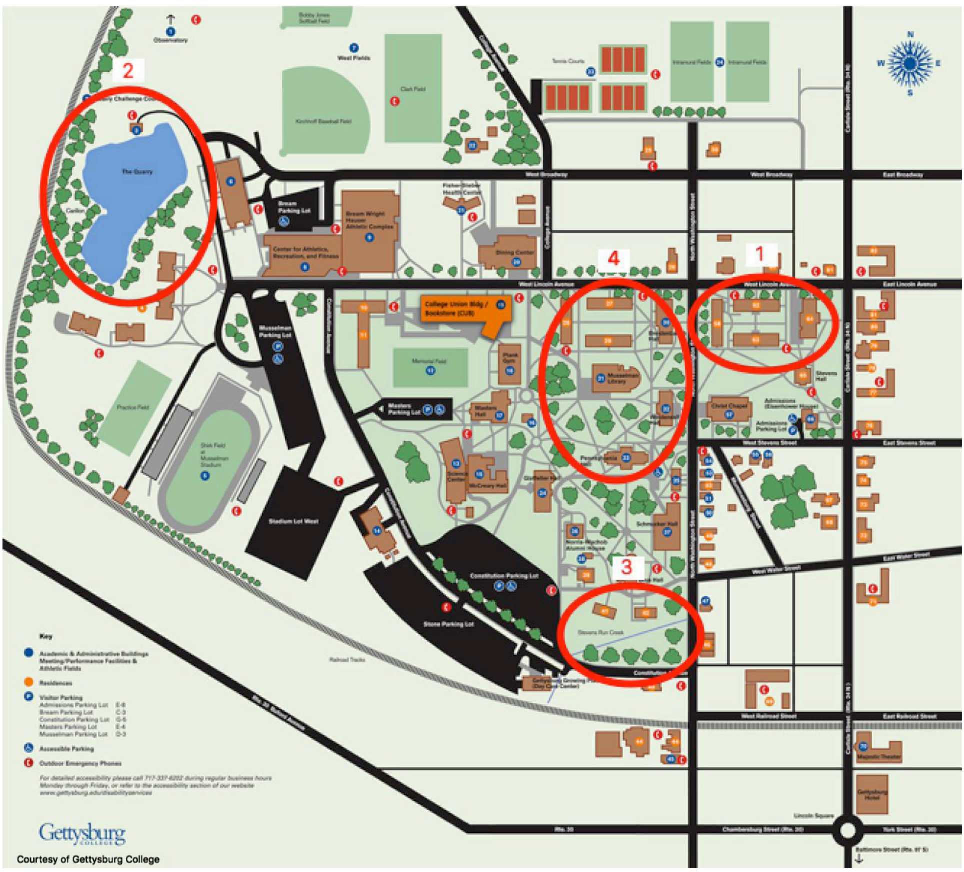

Figure 3. Four areas researched on the Gettysburg College Campus in Gettysburg, Pennsylvania: 1.East Quad, 2.Quarry Pond, 3.Creek on North Washington Street, 4.West Quad and Stine Lake (Modified from Gettysburg College 2019; used by permission).

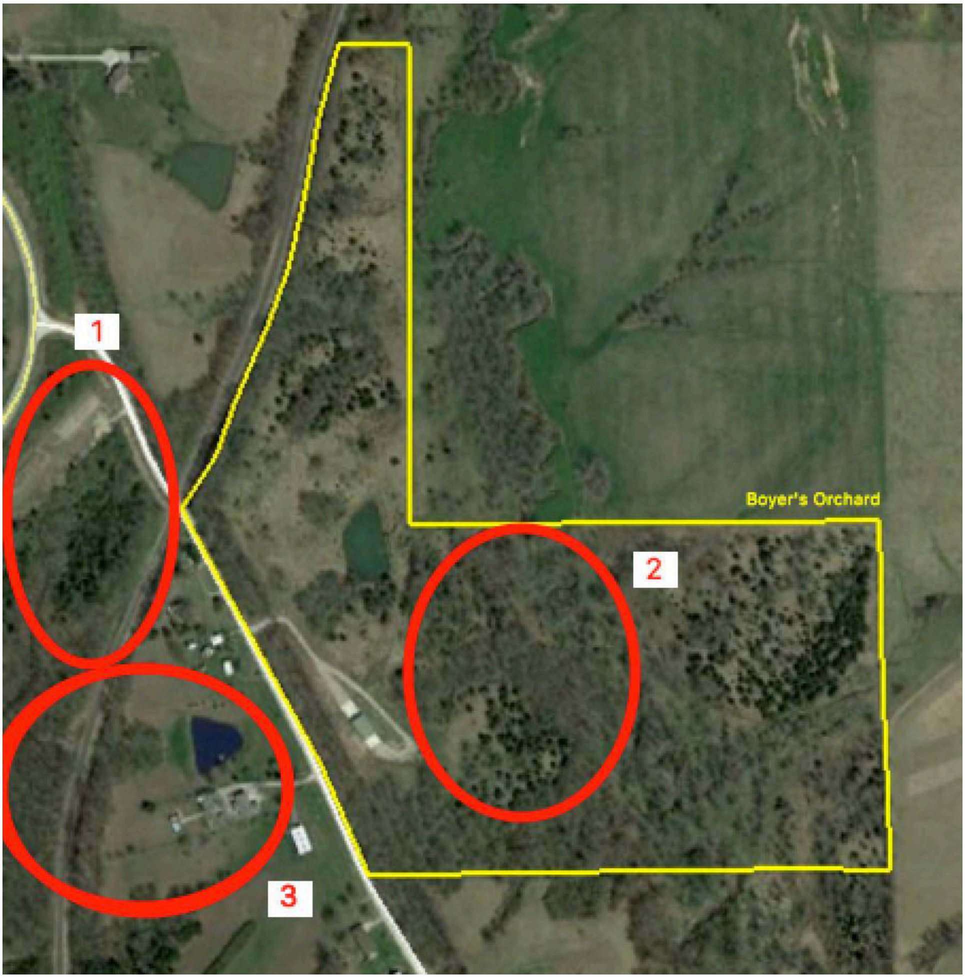

Figure 4. Three analyzed areas of Boyer Nurseries and Orchards Incorporated in Biglerville, Pennsylvania (Modified from Realtors Land Institute 2018; used by permission).

sible were captured at 40 meter intervals using the Mavic Pro drone's 4K photo resolution and 3-axis gimbal. Higher image quality, spatial resolution, and range of image perception led to more precise georeferenced points for the photogrammetry. These images were then used to generate 3D models of the selected terrain areas. Photographs were taken using the Mavic Pro drone during late mornings and afternoons, which had sufficient sunlight to produce high resolution photos.

The Pix4Dmapper Pro photogrammetry software processed the captured images and mission paths of the drone to create photogrammetry models (Figure 5). All DSM processing options were enabled in order to generate layered triangle meshes that created the dimensions of the DSM and DTM terrain photogrammetry models. Photo-

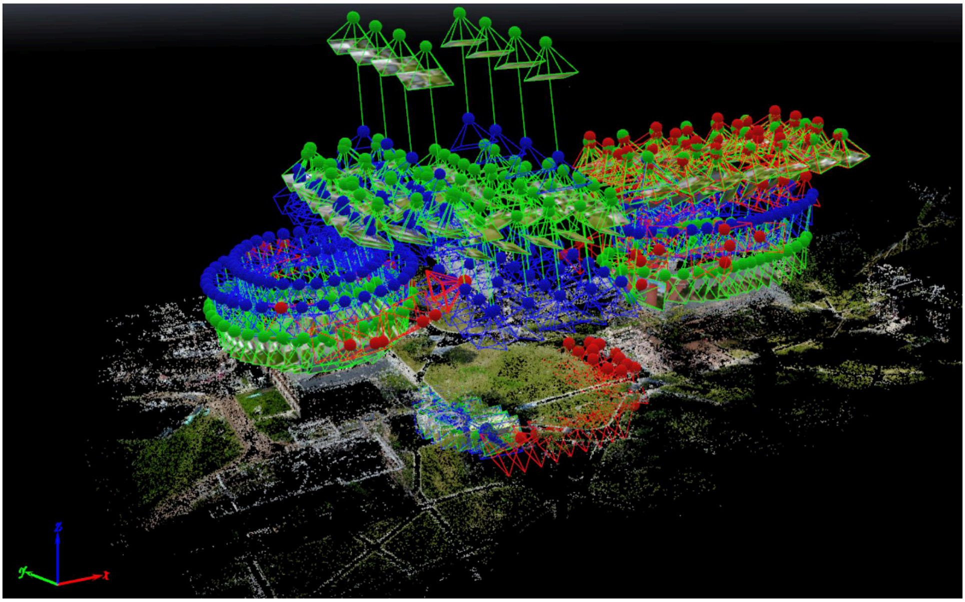

Figure 5. Pix4Dmapper Pro point cloud view of images captured during Mavic Pro drone flight missions around Stine Lake and West Quad on the Gettysburg College campus.

grammetry is used in conjunction with DEMs derived from LiDAR to evaluate floods because it not only utilizes accurate, updated information but it also creates interactable 3D models that users can view from all angles to obtain a full understanding of waterflow patterns. A point cloud mesh tool—a computer software feature that can edit the 3D features of the photogrammetry model—removed human created infrastructure, such as street lights and buildings, alongside tall trees. It was done in order to isolate the effect of the terrain on waterflows. Surfaces within Pix4D were then created using a dimensional tool to fill voids and join any disconnected elements of the 3D mesh to ensure that no spatial data would be missing.

The final models were then generated before Pix4D virtual flood simulations were processed, utilizing terrain data of each location (Figures 6-10). The same type of virtual flood simulation was used for each of the study sites. The modelled Pix4D flood simulation is a function of the photogrammetry software that uses the orthomosaic DTM of 0.5 m intervals and DSM data to create a colored heat map. The heat map showed flood depth and slope direction to demonstrate expected patterns of movement due to gravitational force. An animation keyframe feature that accounted for the terrain's hydrological features was then used on the source object of the model generated by DTM and DSM. The elevation data based on the DTM and DSM of the terrain were incorporated into account the model. The lowest point of elevation indicated by an indigo color and the highest point of elevation indicated in red on the heat map were used as part of the terrain elevation parameter for

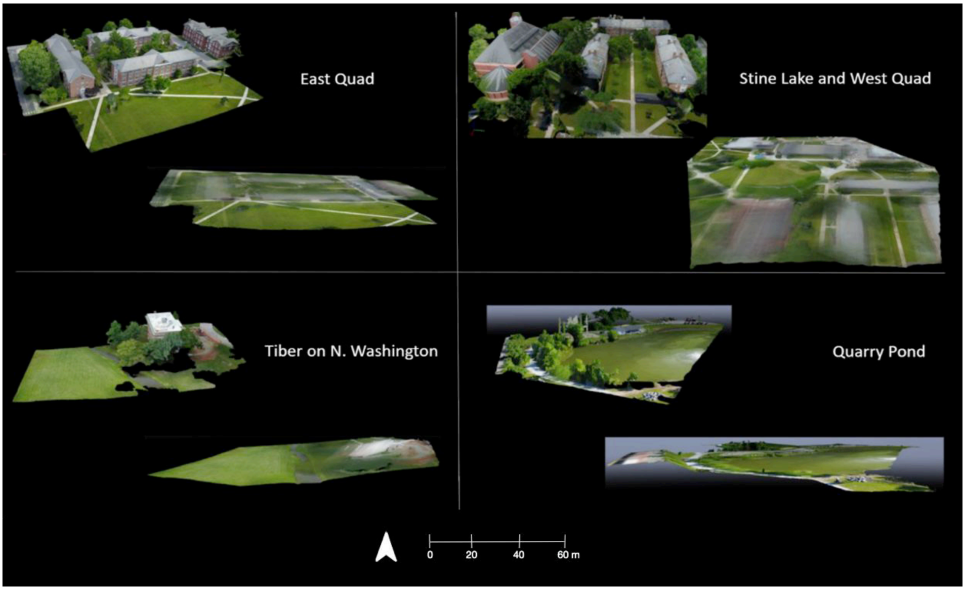

Figure 6. Photogrammetry models of four analyzed areas of the Gettysburg College campus created with the Mavic Pro drone and Pix4D software.

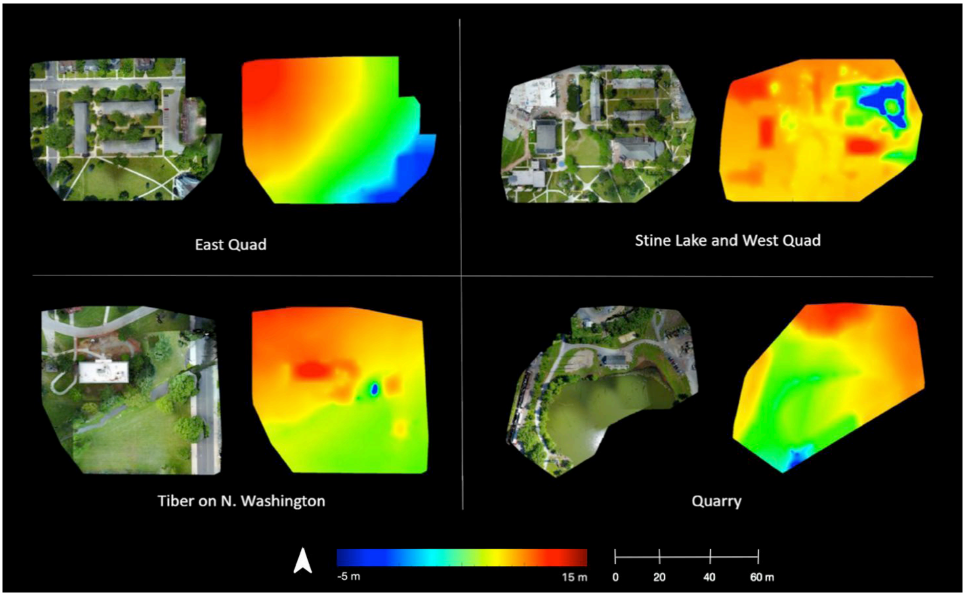

Figure 7. Digital terrain models showing change of elevation of selected areas on Gettysburg College campus.

the simulation. Other parameters of the study included the amount of vegetation as well as the underlying geology of a given area. Factors such as amount of vegetation were incorporated in the data analysis after flood simulations

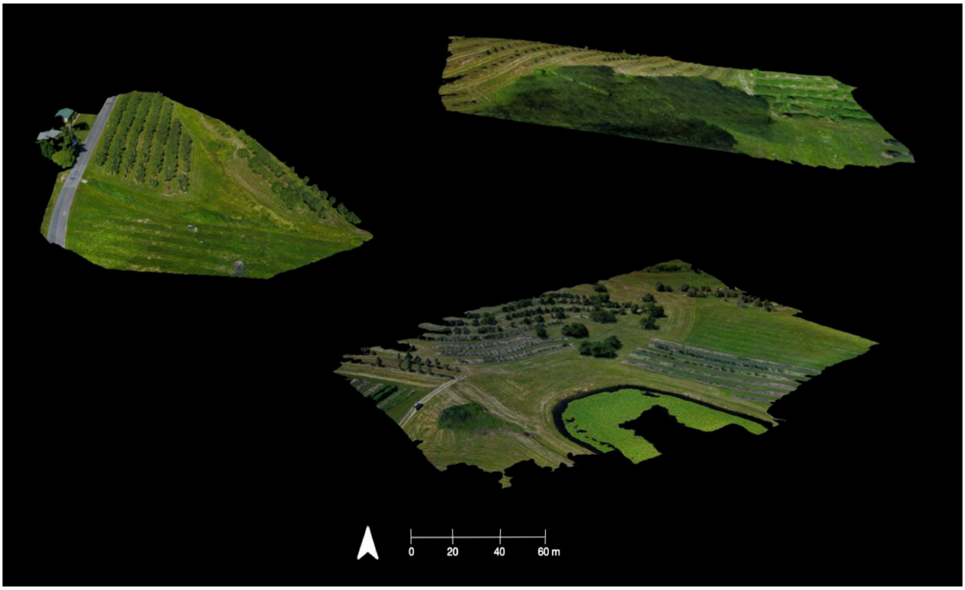

Figure 8. Three photogrammetry models of analyzed agricultural areas of Boyer Orchard created with the Mavic Pro drone and Pix4Dmapper Pro software.

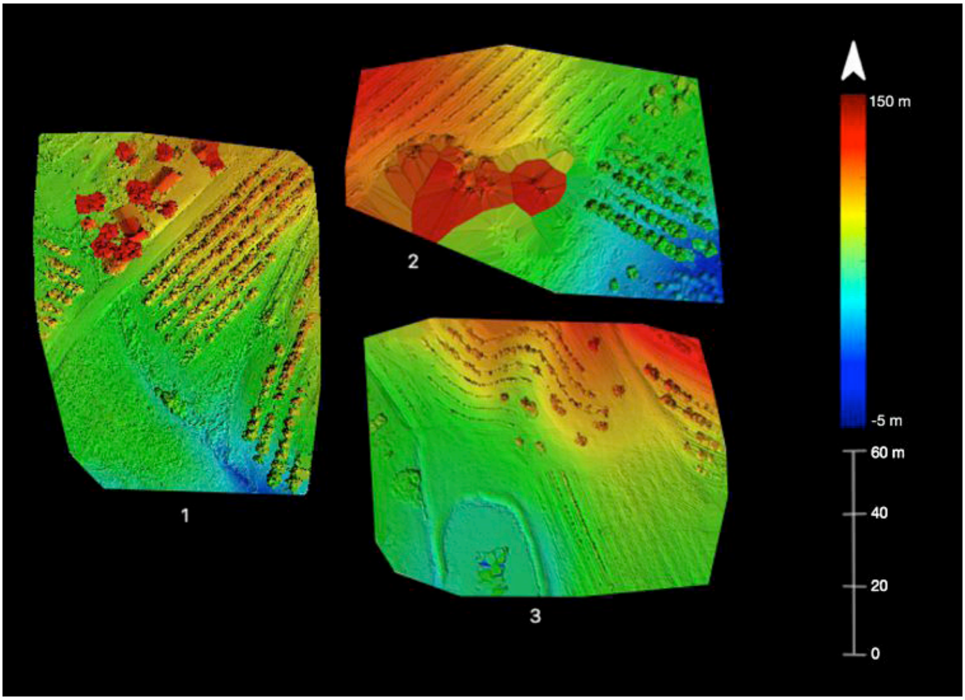

Figure 9. Digital surface models of analyzed agricultural areas of Boyer Orchard created with the Mavic Pro drone and Pix4Dmapper Pro software.

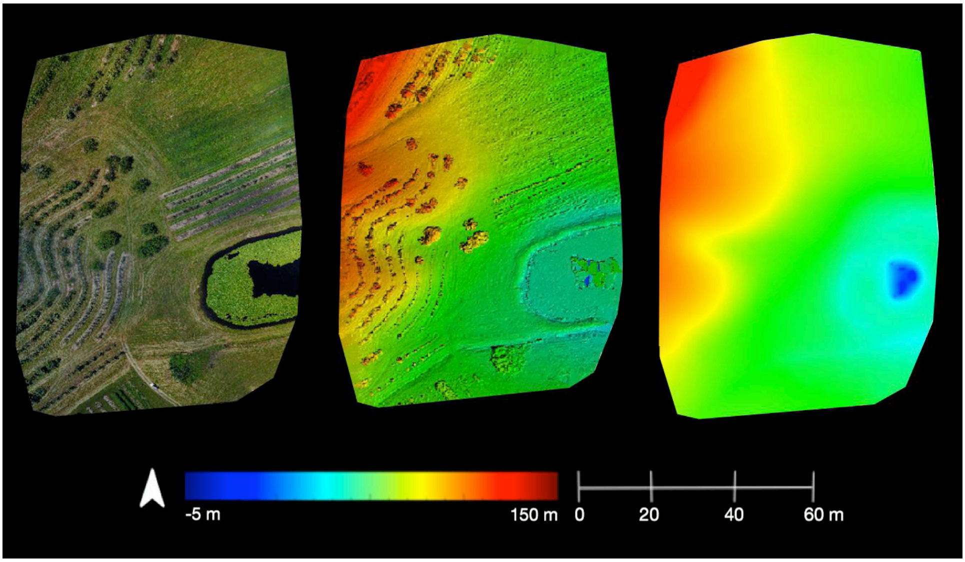

Figure 10. (Left to right) Drone photograph, digital elevation model, and digital terrain model progression of Area 3 of Boyer Orchard.

were conducted in order to contextualize results of the digital test.

The lowest area of the model was selected as the "destination track" where animated flood waters moved in the direction towards in order to run the flood simulation while the highest point of elevation was the origin of the animation. However, these predicted models did not include the Gettysburg College drainage system due to a lack of access to information, which may affect the accuracy of the flood simulations compared to a real flood event. The generated models were created in order to partially represent real flood events in the investigated areas of Boyer Orchards and Gettysburg College as some man-made objects were removed from the model.

The contour line of each of the orthomosaic DTM models were then remade as duplicate file copies with varied shaded regions based on the contours and changing elevations of the land. This allowed for different layers of each location to be created as a wooden, physical models to create concrete simulations in which actual water was physically poured upon the wood carvings. The physical test was conducted to compare the results to the digital photogrammetry models made earlier in the research process. The data files for each of the investigated sites were uploaded beginning with the highest elevation shading to the Inventables Carvey 3D Carver Easel software (Inventable Products 2018). Physical models were created for Stine Lake from Gettysburg College in addition to Area 1 and 2 of Boyer Orchards. Contour lines were then carved at 0.05 inch increments into wood by the 3D carving machine (Figure 11).

Figure 11. (Top left to right) Wooden models of Area 3 of Boyer Orchard, Quarry Pond, and Stine Lake/West Quad created using computer numerical controls of the Carvey Inventables 3D Carver.

Site Analysis and Results

The computer flood simulation generated predicted, calculated rainfall patterns that led to the flood patterns created in the computer simulations. Data from the flood simulation exhibited that monthly rainfall in Gettysburg during the months of June, July, and August were 10.8 cm, 7.9 cm, and 8.13 cm, respectively (Figure 12). It was exhibited that monthly rainfall in Biglerville during the months of June, July, and August were 8.6 cm, 7.6 cm, and 7.6 cm, respectively (Figure 13). The results from the flood simulation exhibited monthly rainfall that was less than the actual values of 10.9 cm, 8.6 cm, and 9.7 cm during the months of June, July, and August in both Gettysburg and Biglerville (United States Climate Data 2019). On average, the simulated Gettysburg rainfall was 0.78 cm less than the actual rainfall values for the area. Meanwhile, the simulated Biglerville rainfall was 1.32 cm less than the actual rainfall values.

Most of the changes of terrain elevation are relatively slight on the Get-

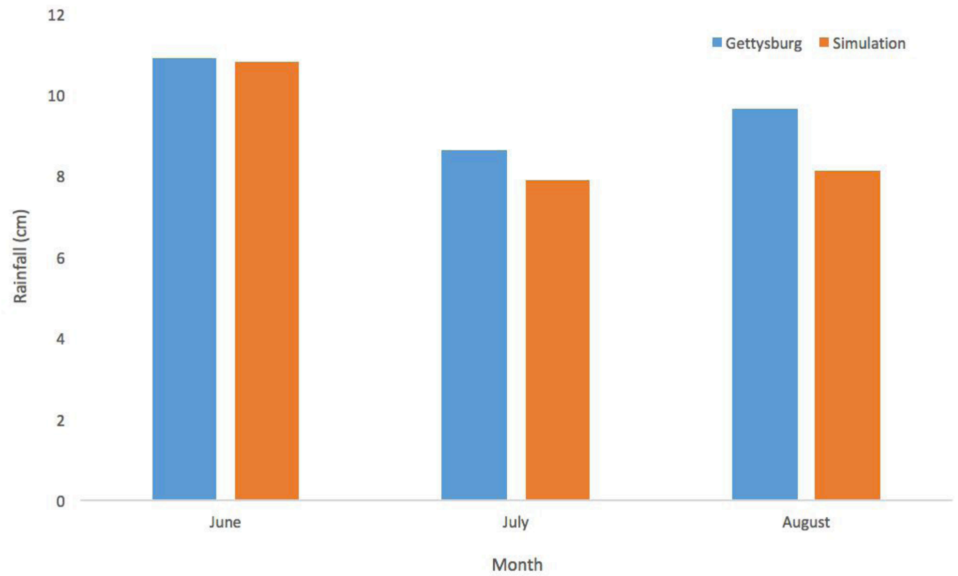

Figure 12. Average rainfall in Gettysburg, Pennsylvania in 2019 in comparison to Pix4D flood simulation.

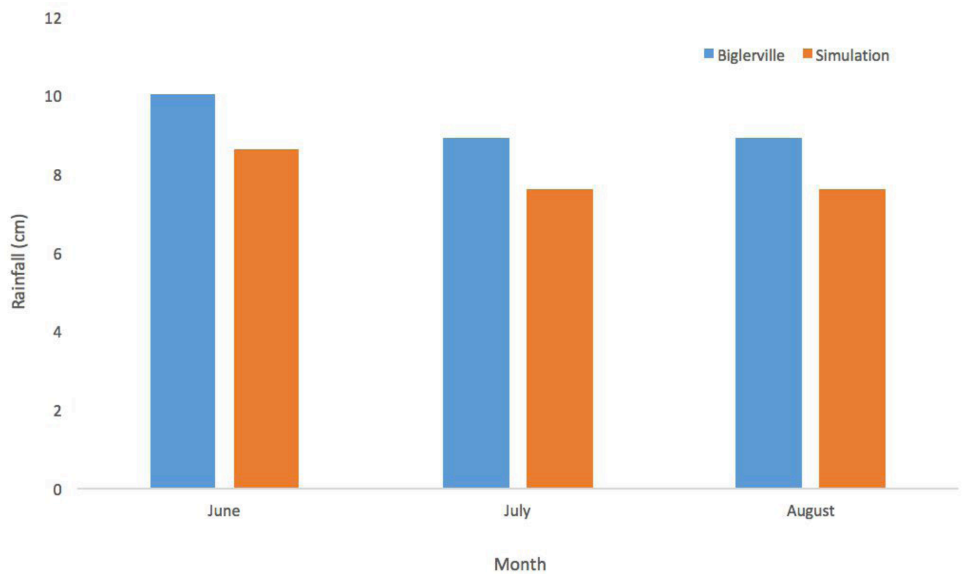

Figure 13. Average rainfall in Biglerville, Pennsylvania in 2019 in comparison to Pix4D flood simulation.

tysburg College campus at all four investigated areas of East Quad, the creek on North Washington Street, Quarry Pond, along with Stine Lake and West Quad within a 0-60 m elevation difference (Figure 6). The East Quad region of the campus has a natural change of elevation that gradually decrease from northwest from 12 m to -5 m for a total of 17 m change of elevation (Figure 7). The creek on North Washington Street is much more drastic in its rapid changes of high to low elevation from 15 m to -5 m, a total of 20 m change of elevation (Figure 7). There is a sudden increase in elevation near the creek where an academic building is located, while the lowest point of terrain is found in a small section of land towards the mid-eastern region (Figure 7).

The West Quad and Stine Lake areas of the campus show similar patterns of sudden rises in elevation while the lowest point of -5 m is located in the northwest region near an academic building (Figure 7 and 11). Terrain elevation at Quarry Pond decrease near the middle of the site where the pond, surrounded by trees, is located around sections of open land with a 15 m change of elevation (Figure 7 and 11). Open land at Gettysburg College and Boyer Orchards was defined as any given area that contain less than 15% of built infrastructure and tall vegetation, such as trees. Flood waters primarily flow in accordance to terrain slope from northwest to southwest at East Quad, north to southeast at the creek near North. Washington Street, north to south inward to Quarry Pond, and southwest to northeast at Stine Lake and West Quad (Figure 7).

Area 1 of Boyer Orchards feature agricultural bush vegetation aligned in rows and has its highest point of elevation at 90 m, while Area 2 located further east exhibit a more drastic slope of elevation from -5 m to 140 m for a total of 145 m change of elevation (Figure 8-9). Area 2 had crops planted in straight, even rows and along curved contours of the land, while a patch of tall trees was also present (Figure 8- 9). Meanwhile, Area 3 has a great amount of open, flatter land (Figure 8-9) with 155 m of elevation change (Figure 9 and 11). The majority of terrain within this site was either flat or gradually sloped upward before sloping downward into the small pond at -5 m in elevation (Figure 9; Figure 11). Flood waters flow from east to west for both Area 1 and Area 2 due to the drastic change of slope of Boyer Orchards while the slope of the terrain of Area 3 caused water to flow at a high velocity east to west before ultimately collecting in the pond downhill (Figure 9-10). This is due to the natural contours and slope of the terrain, the geologic structure, and vegetation.

<u>Discussion</u>

The results from the flood simulation exhibited flood levels that were less than the actual values for both Gettysburg and Biglerville, most likely due to the fact that the photogrammetry models used to generate flood simulations did not account for natural, unpredictable factors such as increased erosion and landslides (Figure 12-13). For example, erosion fills water channels which leads to less available water storage that causes flood heights to increase (Woltemade 1994). Natural factors can create positive feedback loops in which rain patterns and distribution change, thus causing differences in rainfall simulation and actual rainfall data. Flood simulations derived from drone technology were useful in the application of the project as digital parameters could be compared with real world flood events and data.

Sloping terrain adjacent to flat land creates a positive feedback loop in which sediment quickly erodes, such as during frequent flash floods like the Gettysburg Flood in 1996. That year, the lower Susquehanna River Valley in south-central Pennsylvania experienced drastic flooding with nearly 27.9 cm of rainfall in just over three hours and 1.22 m of floodwaters that inundated the streets of Gettysburg on June 19th. Since the event, it has been a goal to prevent future severe flood damages in order to avoid yet another disaster (McGillis 1997).

Gettysburg College is built upon slightly sloped land that is flatter than Boyer Orchards, meaning that the rate of flood flow is noticeably less and that the difference of flow speeds increases with heavier precipitation (Figure 1, 6, and 8; see also Woltemade 1994). Gettysburg is also built on a foundation of shale which acts as an aquitard, a zone within the Earth that restricts the flow of groundwater from one aquifer to another. This is due to its compacted clay composition, which promotes flooding particularly in flat locations that experience extreme inundation—shale beneath slopes lead to valley flooding due to reduced infiltration (Blake et al. 2017). This results in more severe flooding that requires a longer amount of time to subside (Woltemade 1994). Although much of the campus terrain is comprised of shale, approximately 40% of the site contains impermeable surfaces that can lead to increased flooding (Blake et al. 2017; Faill 2003).

Several factors that lead to Gettysburg College's high exposure to flooding include its combination of flat and sloping terrain, as portrayed by the drone imagery models (Figure 1). The terrain is built mainly upon shale, which due to its fine-grained and non-porous texture does not absorb large amounts of water; this leads to increased flooding within the area (Blake et al. 2017; Faill 2003). In contrast, Boyer Orchards is built upon diabase rock which has a coarse grain size that is better suited to absorb excess water which reduces the amount of flooding the orchard experiences (Blake et al. 2017).

The flat terrain of Quarry Pond and the creek on North Washington Street can combat flooding if they connect to floodways and ridges that redirect water flow or retain the water until a full capacity is reached. Model results indicate that constructing floodways in low slope areas of the campus would drastically reduce flooding (Figure 1, 7, and 10; see also McGillis 1997). This is due to the fact that lower terrain slopes lead to lower velocities of drainage and redirection of excessive storm waters to larger bodies of water (McGillis 1997). As noted earlier, the Gettysburg drainage system was not incorporated into the project due to a lack of access to information. However, if the drainage patterns were included in the flood simulations, water patterns would diverge at quicker rates in various directions where drainage relief was present.

Aside from that, the shale-dominated terrain at the Gettysburg College campus has extremely poor water absorption properties, thus leading to flooding on flatter terrain downhill (Blake et al. 2017; Faill 2003) and continuously increasing erosion over time. Although the campus does have spacious, open terrain with some trees and shrubbery (Figure 6-7), the amount of planted surfaces are not sufficient enough, nor is it dispersed in the necessary grouped patches, needed to sufficiently absorb excess storm waters to help prevent extreme flood events (Mercier et al. 2017). A potential land use design that can help mitigate flood risk includes planting additional woody trees near areas of low elevation. Rain gardens with native plants such as ferns, wildflowers, and shrubs can also be constructed along the southeastern lawns of East Quad as well as northeastern lawns of Stine Lake alongside West Quad. Specific grass and sedge species native to Pennsylvania such as *Carex pennsylvanica* and *Bouteloua curtipendula* can also be planted around the outer perimeter of Quarry Pond to help retain flood waters within a close proximity to the body of water (Keystone Wildflowers 2019).

A reason for the lack of plants is the institutional land use need for buildings, concrete and asphalt surfaces, alongside grass and park areas. This increases the overall number of impermeable surfaces and lead to more flooding in comparison to Boyer Orchards (Figure 7). Storm models of this study for the selected sites incorporated parameters such as terrain elevation vegetation and underlying geology. The models demonstrated that flooding frequently occurs in most locations at Gettysburg College regardless of the amount of infrastructure due to the flat terrain that lacks vegetation. The locations of Quarry Pond, Stine Lake, East/West Quad, and the creek area are the most flood prone areas of the campus.

Boyer Orchards has a greater change in elevation between the highest and lowest points, leading to fast water flow during storms (Figures 9 and 11). The diabase foundation of the area contains materials that do not promote rainwater runoff as much as shale in Gettysburg; this contributes to less water runoff in Biglerville at the orchard. As expected, the orchard contains many linear arrangements and grouped patches of vegetation, both from farming and natural forest, which heavily contribute to flood prevention due to the rapid uptake of flood waters by plant roots (McGillis 1997). The result is less severe flooding that quickly subsides (Nature Conservancy 2002; McGillis 1997).

Only one road is present in the three researched areas of the orchard, meaning that there is hardly a presence of an impermeable surface at Boyer Orchards, other than shale that makes precipitation absorption more difficult on flatter, lower levels (Figure 8). The limited infrastructure at Boyer Orchards includes a single driveway and a small house. While these features decrease the overall permeability of the orchard, their overall significance is extremely low. Boyer Orchards also utilizes contour farming in the placement of various crops in order to reduce erosion that would otherwise drain downstream into both the Potomac and Susquehanna rivers and eventually to the Chesapeake Bay (Figure 8-10; see also Boyer Nurseries and Orchards Incorporated 2018).

Although more frequent and sudden modelled precipitation patterns in conjunction with the sloped land of the orchard would normally lead to increased erosion, the orchard's contour farming techniques and location of the orchard and nursery prevents this from occurring. Low areas where water accumulates, as indicated in flood simulations, are targets for combatting flooding while greater terrain slopes help transport the excessive water to these areas (Long et al. 2016; Woltemade 1994). The same model simulations that were performed on the Gettysburg College campus areas were also performed on the study sites at the orchards. Knowledge of contouring allows the Boyer Orchards management to utilize the contours of the terrain to regulate and redirect water flow. The water dissolves over expanded terrain downhill before it collects in the pond at the lowest level of the terrain in order to combat excessive flooding (Figure 9-11; see also Chen et al. 2018). Modelled flooding of this study site demonstrated that the land of Boyer Orchards hardly experiences dire flooding issues due to the open space and plentiful vegetation.

One limitation to this study is the exclusion of the Gettysburg College drainage system and the construction of various underground electrical wiring that may affect water flow. If the Gettysburg College drainage system was incorporated into flood models, the amount of water drainage and velocity of water flow would probably have increased significantly. The drainage way along the northwestern areas of the college campus lead flood waters into the drainage pattern that connects to Rock Creek, thus increasing the velocity of water flow. However, a new northwest parking lot built in 2008 stores 15,000 gallons of rainwater from campus roofs. The design slowly releases the rainwater into the ground to help prevent flooding of the nearby stream (Gettysburg College 2009). Incorporation of other built features would include impermeable surfaces that affect the direction of water flows, as well as where rainwaters collect over a period of time. It is important for future studies to acknowledge these features in order to accurately study flood patterns at Gettysburg College and Boyer Orchards, as well as to accurately portray storm events through flood simulations.

Sources of error in this study include the manner in which unclear drone photography inaccurately portrayed DTM and DSM elevations of areas like the creek, Quarry Pond, as well as Stine Lake and West Quad. Several buildings were perceived to be part of the terrain when they should have been excluded from the generated DTM models, which is expected to remove built features and tall trees (Figure 7).

This was due a limitation of the clipping tool in which the Pix4D computer software did not recognize the differences between built infrastructure and natural terrain slope.

Another limitation is the reflection of water in drone imagery that caused technical difficulties with depth perception of the Pix4Dmapper Pro program in constructing the models. Reflections from elements such as water cause depth perception errors that lead to inaccurate DTM and DSM models in which the elevation of the bank of water is perceived to be noticeably higher or lower than it actually is. Factors that could be changed during image-capturing drone missions include selecting days with cloudy weather in order to reduce the amount of water reflection (Figure 11).

Many of the errors mentioned may have also affected the accuracy of the wooden models (Figure 11). Such errors could have been avoided by taking drone imagery from a lower set elevation level as well as by taking drone pictures on cloudy days in order to avoid excessively reflected sunshine upon different water surfaces. Future studies could possibly examine how different forms of precipitation such as snow or hail may affect the erosion of various landscapes in Gettysburg.

Conclusion

Although Gettysburg College experienced a slight 0.45 cm more rainfall than Biglerville, Gettysburg experiences more frequent and severe flooding on a height-based level for road surfaces, buildings, sidewalks, and all other lawn space of the area. Gettysburg experiences flooding of a slower downhill flow pace that takes longer to subside in comparison to Boyer Nurseries and Orchards due to the flatter terrain and existing impermeable road surfaces. Results from this study indicate Gettysburg College can combat and control flooding by increasing the number of native vegetation around downward sloped areas. Virtual flood simulations predicted rainfall patterns that were consistently less than the actual monthly values in both Gettysburg and Biglerville due to a lack of incorporation of shifting natural factors during the analysis. Although the extreme slope difference at Boyer Orchards results in rapid rainwater flow, the agricultural area does not frequently experience problematic flooding due to the spacious and plant-rich land that quickly absorbs excess rainwater.

Acknowledgements

The funding of the research conducted—including all equipment, software, licenses, machines, and cost of the official Federal Aviation Administration Part 107 exam—was entirely sponsored by the Gettysburg Information Technology Department. A sincere thank you is addressed to Director Eric Remy for his guidance, knowledge, and endless support. Extreme gratitude is also addressed to Professor Andrew Wilson, Rutherford Platt, Charles Kann, and Sarah Principato for advising the publication and research process of the project, as well as for their boundless encouragement and help with the project planning process. Gratitude is also expressed to the Gettysburg College Department of Public Safety and Boyer Nurseries and Orchards Incorporated for allowing the collection of data and conduction of research on their private property.

Literature Cited

Aronica, G. T., Bouwer, L. M., Brujin, K. M., Castillo-Rodriguez, J. T., and Molinari, D. 2019. Validation of flood risk models: Current practice and possible improvements. *International Journal of Disaster Risk Reduction* 33: 441-448.

Barnes, J. H., and Sevon, W. D. 2002. The geological story of Pennsylvania. *Pennsylvania Geological Survey* 4: 4-22.

Blake, J. M., Stephen, S. C., and Johannesson, K. H. 2017. Application of REE geochemical signatures for Mesozoic sediment provenance to the Gettysburg Basin, Pennsylvania. *Sedimentary Geology* 349: 103-111.

Boyer Nurseries and Orchards Incorporated. 2018. "Conservation." About Us. http://www.boyernurseries.com/about/new-photos/.

Chen, S., Chen, Wenjun, Ding, K., He, B., Nover, D., Yang, J., and Yuan, H. 2018. Analyzing inundation extent in small reservoirs: A combined use of topography, bathymetry and a 3D dam model. *Measurement* 118: 202-213.

Faill, R. T. 2003. The early Mesozoic Birdsboro central Atlantic margin basin in the Mid-Atlantic region, eastern United States. *Geological Society of America Bulletin* 115(4): 406-421.

Gates, A. E., and Valentino, D. W. 1991. Late Proterozoic rift control on the shape of the Appalachians: The Pennsylvania Reentrant. *The Journal of Geology* 99: 863-872.

Hippensteel, S. P. 2016. Carbonate rocks and American Civil War infantry tactics. *GeoScienceWorld* 2: 354-365.

Gettysburg College. 2019. "Campus Map." *Gettysburg College Map*. https://www.gettysburg.edu/visiting_gettysburg/map/Campus%20Map%200817.pdf.

Gettysburg College. 2009. "Climate Action Plan." *Gettysburg College Facilities Services.* https://www.gettysburg.edu/offices/facilities-services/pdfs/2019/Climate%20Action%20Plan.pdf.

Gettysburg College. 2009. "Master Plan." *Gettysburg College Facilities Services.* https://www.gettysburg.edu/offices/facilities-services/pdfs/2019/GettysburgMP_FINAL5_highres2013.pdf.

Inventables Products. 2018. *Carvey Manual: Carving with Easel.* https://carvey-instructions.inventables.com/easel/.

Keystone Wildflowers. 2019. "Grasses and sedges." *Native Plants*. http://keystonewildflowers.com/plants/grasses-sedges/.

Long, D., Rauwendaal, F., Williams, J. D., and Wuest, S. B. 2016. Contour planting: a strategy to reduce soil erosion on steep slopes. *Research Gate* 1: 1-10.

DJI Products. 2016. "Mavic Pro User Manual." *Operations.*

McGillis, N. P. 1997. The Gettysburg Flood of 19 June 1996. *Meteo* 418W, 1: 1-27.

Mercier, D., Piegay, H., Rapple, B., and Stella, J.C. 2017. What drives riparian vegetation encroachment in braided river channels at patch to reach scales? Insights from annual airborne surveys. *Ecohydrology* 10: 1-26.

Nature Conservancy. 2002. A natural areas inventory of Adams County, Pennsylvania. *Adams County Planning and Development* 1: 1-179.

Realtors Land Institute. 2018. "Listings." Location Finder. https://rliiowachapter.com/

Root, S. 1988. Structure and hydrocarbon potential of the Gettysburg, Pennsylvania and Maryland. *Developments in Geotectonics* 22: 353-367.

United States Climate Data. 2019a. "Biglerville." *Climate Biglerville*. https://www.usclimatedata.com/climate/biglerville/pennsylvania/united-states/uspa0131.

United States Climate Data. 2019b. "Gettysburg." *Climate Gettysburg.* https://www.usclimatedata.com/climate/gettysburg/pennsylvania/united-states/uspa0131.

Woltemade, Christopher J. Form and process: Fluvial geomorphology and flood-flow interaction, Grant River, Wisconsin. *Annals of the Association of American Geographers* 84: 462.