Remote Sensing and GIS Analysis of the Madison Area

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Abstract:

This paper focuses on the remote sensing and GIS food analysis of the Madison area. Our team was curious about how much damage occurred after the August 21st, 2018 flood in our study sites in Madison (Picnic Point, Brittingham Park, Lake Wingra, and Elver Park). In addition, we want to know why flooding occurred in those sites. Various remote sensing and GIS tools such as hydrology analysis, historical research, and the use of drones were utilized to answer our research questions. We discover that the increase of urbanization over time, low elevation, and a few numbers of watersheds are one of many factors that caused flooding in our study areas.

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Introduction:

Madison experienced significant flooding in the summer of 2018, which according to a Gov. Scott Walker Tweet has, "caused at least $208.7 million in damage" (The Associated Press 2018). This recent flooding shows how Madison, as a city, is extremely susceptible to flood damage and how certain parts of the city are more susceptible than other portions. Flooding closed city streets, other city facilities such as city parks, and caused extensive private property damage for numerous residents. With this devastation, our research had been conducted upon 4 sites. These sites will include Picnic Point, Elver Park, Brittingham Park, and Lake Wingra.

The recent flooding in Madison created pressing research questions. GIS and geospatial analysis methods will be utilized to attempt to answer the following questions. How have local flood regimes changed through time? In addition, can GIS and remote sensing techniques detect and measure the recent floods in August 2018 of the Madison area? In order to address these questions, our team will initially begin with an evaluation of historic imagery dating back to 1936 to evaluate landscape change in the Madison area. Next we will conduct GIS analysis based digital terrain models (DTM)/LiDAR data. Remote sensing techniques such as ISO unsupervised classification will be used based on Planet imagery to detect land-cover changes of flood-affected areas. Lastly, unmanned aerial vehicle (UAV) "drones" surveys, courtesy of UW Madison Drone Lab, will be conducted to produce elevation maps of Elver Park, a site that experienced flooding. Based on this analysis, our team will answer questions such as where and why did the recent floods occurred in certain areas. In addition, where will future flooding occur? More importantly, should there be any policy recommendations or changes submitted to the City of Madison?

Site Setting:

The location of the geographical and historical analysis of flooding events is the Madison, Wisconsin area. Madison is located within Dane County, which is in the central region of southern Wisconsin. It is located near four large lakes and one small lake that vary greatly in size and degree of human impacts. While each lake is carefully monitored, lake levels can become volatile with the increased precipitation which is coming due to the changing climate. Lake Mendota is the largest of the five and is located directly north of Madison and covers an area of 9,781 acres (Wisconsin DNR, 2018). The second largest is Lake Monona that covers an area of 3,359 acres and is located to the southeast of Madison (Wisconsin DNR, 2018). Lake Kegonsa covers an area of 3,300 acres, while Lake Waubesa covers an area of 2074 acres.1 Lakes Kegonsa and Waubesa are both located further southeast of Lake Monona. The smallest lake is Lake Wingra, located in south-central Madison, and a coverage of only 336 acres it is by far the smallest of the lakes. (Wisconsin DNR, 2018). All five lakes are glacial lakes that are believed to have formed from the last retreat of the glaciers that covered Wisconsin.

In analyzing and understanding flood conditions, it is vital to understand water coverage and the history of hydrology in the area. This is so as it can provide great understanding to how the features which are currently affecting the flooding came to be. Before the last glaciation the Yahara flood basin would have existed at a much lower elevation, roughly five hundred feet below the current level of Madison (which sits at roughly eight-hundred and forty feet above sea level) (Mickelson 2017). As the glaciers scraped the surface and carried debris south, it began to deposit large quantities of the debris into the valley and began filling it up creating large moraines (earthen barriers formed from dirt pushed in front of glaciers) in the southern edge of the area. However, as the glaciers began to retreat the rest of the valley was filled with meltwater and formed a massive glacial lake, Lake Yahara (Mickelson 2017). As the Yahara river cut through the moraines, it began to slowly drain the lake and eventually became the five lakes that are within the focus site of this geographic analysis.

The Yahara watershed covers much of the area and extends further north and further south with the five lakes making up the middle.

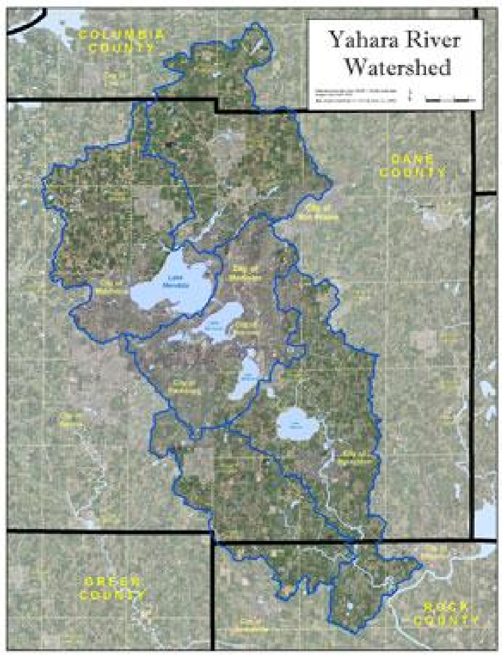


Figure 1: Yahara Watershed, Wisconsin via yaharapridefarms.org

It is responsible for the drainage of all precipitation in its one thousand, three hundred and forty-five square kilometer area and pushes the water through the Yahara River which drains into the Mississippi River (Carpenter 2015). It experiences an average of eighty-seven point six centimeters of annual rainfall on average (1981-2010 climate normals) (Carpenter 2015). The watershed suffers impacts from agriculture, changes in precipitation, as well as from human construction and continued interaction with the land. The negative impacts are the primary driving forces behind rapid change fluctuation in the watershed's stability. While a great deal of flood water comes from overland flow in a watershed, another concern in the Madison flooding has very little to do with the watershed and more to do with human intervention in the watershed in the form of underground sewer systems.

As with any urban development in the modern world, wastewater is one of the largest challenges that must be faced. How we remedy the situation of wastewater (human sewage and storm water) is a series of sewer systems that channel the water to the necessary locations. As rainwater and human sewage collects in these systems, they are channeled from one part of the city to another and eventually end up exiting through mass discharge into lakes (only storm water) or sent to a treatment facility to be processed and cleaned. "The rainfall that fell inside the 281 square mile watershed works out to about 4.5 inches, equivalent to 33,272 Olympic swimming pools of water. This is a lot of water to be sure, but if the storm had occurred 15 miles to the northeast...it would have dropped 8 inches of rainfall across the watershed, almost double what actually occurred" (Wright 2018). Generally, this is handled by changing channels of where wastewater is flowing and making room for the new runoff. However, with record rainfall as Madison experienced in late August, all channels can be full and with the increase in lake levels, (Wright 2018) the system was overburdened and lead to being backed up and flooding. It should also be mentioned that rain, lake level, and sewer systems aren't responsible for all the blame, much of it has to do with the fact that the rain fell in urban areas constructed on wetlands, so the ground is saturated. If the rain had fallen north in the farmland, it would have most likely have been harmless due to the ability of cropland to absorb large amounts of water (Wright 2018). Assessing localized flood vulnerabilities and associated mitigation options (including storm water infrastructure investments and better management of lake levels) is challenging but necessary to increase Madison's resilience to future rainfall and flood disasters (Wright 2018).

Literature Review:

In Governor Walker's letter to President Trump regarding the flooding of Madison, he had a thorough analysis of the devastation seen in Dane County. According to Walker's letter "over 1,800 property owners in Dane County reported damages totaling more than $70 million in losses. Businesses in Dane County reported over $50 million in damages and profit losses. Public-sector damage exceeded $28 million" (Walker, 2018). As seen in Walker's report to the President, an incredible amount of monetary damage was reported. Not only was there an excess of monetary issues arising from the flood, there were also health related issues. These issues were related with bacterial contamination to city wells. According to Walker's report there were 130 wells which were found to have a bacterial contamination (Walker, 2018). Along with the monetary and health related issues, many roads and bridges were also washed out or deemed impassable due to the flood. As stated in Walker's letter, "four bridges along HWY 14, which transits 10,000 vehicles per day, were rendered impassable due to washouts" (Walker, 2018). Governor Walker's letter shows how vulnerable to flooding the four lakes region is and how expensive the flooding can be in this area. This is a reason for why studying these areas and running flooding analyses are of the utmost importance. From Governor Walker's letter to the president, it can be concluded that further research into the flooding events of the four lakes region needs to be conducted. For this reason, we decided to research areas which had experienced intense flooding.

GIS:

Geographic Information Systems have played a huge part in flood analysis for over 20 years. GIS is a great system for performing flood analysis because of its ability to manage and analyze so many different types of data. In terms of flood analysis GIS can take constant data such as elevations of an area, discreet features such as river and stream networks, as well as data that can give further insight into socio-economic conditions such as where different populations live. By taking these different forms of data GIS is used to figure out where the flooding is most likely to happen, what features will affect it, and who will be affected by the flooding. The ability to use GIS in this way is gone over in detail in an article titled “Floodplain Management in Urban Developing Areas. Part II. GIS-Based Flood Analysis and Urban Growth Modeling.” While part one of this article talked about the need for floodplain management and modeling urban growth and development, part 2 addresses the possibility of using GIS to integrate all these data types to analyze flooding. The conceptual model the presented (Figure 1) shows GIS as a way of integrating urban development, social and economic analysis, floodplain, mapping, and environmental impacts, as well as how it could be furthered to inform both the public, and the policy makers. (Coreia, 1999) Our project is focused on the urban development and floodplain mapping but could easily be modified to incorporate the other data later. While this article is relatively old, the conceptual framework still applies. It did a great job of explaining the need for flood analysis, as well as the benefits and uses of using GIS to inform and solve problems related to flooding.

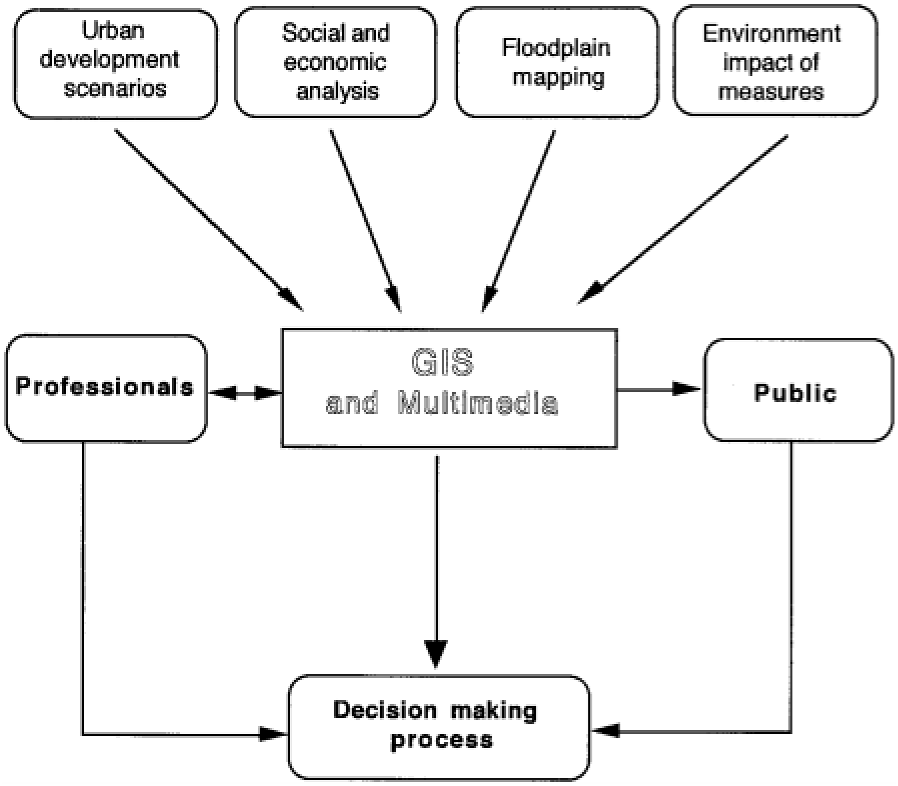


Figure 2. GIS as an integration tool to assist with the decision-making process. (From Correia, 1999)

(1) imperviously paved areas	(2) previously paved areas	(3) unpaved areas
1.1 streets and other traffic areas	2.1 streets and other traffic areas	3.1 green roofs
1.2 span-roofs (> 10 % grade)	2.2 yards, private parking lots, etc.	3.2 lawns, garden area
1.3 flat roofs (except green roofs)		3.3 garden area
1.4 yards, private parking lots etc.		

Figure 3. Classification of urban areas for drainage modeling. (From Schmitt, 2009)

Satellites:

Satellites are the most common remote sensing tool which imagery analysts use. In the 1970's the first civilian satellite was launched, named Landsat (Capolongo et al. 2018). Since then, thousands of satellites orbit around the globe. In this project, medium resolution satellite imagery, Landsat and Planet, will be used to detect water level changes and to make an unsupervised land cover map. Satellites are classified into classes; high, medium, low based on their spatial, spectral, temporal, and radiometric resolution. Spatial resolution is how detailed the image is. The higher the resolution the sharper it is. Spectral resolution is the number of bands. The more bands that a satellite has the higher the spectral resolution. Temporal resolution is the amount of time it takes for a satellite to revisit a site. Lastly, the radiometric resolution is the amount of sensitivity in the sensor (Capolongo et al 2018). In this project, medium resolution satellite imagery, Landsat and Planet, will be used to detect water level changes and to make an unsupervised land cover map. Medium resolution satellites usually produce a moderate spatial resolution, seven bands (spectral resolution), 12-bit (radiometric resolution), and can take an image of the same site every sixteen days (temporal resolution).

Temporal Analysis:

Temporal analysis is comparing two images of the same site but on different dates. One of the main ways to monitor flood change is using a technique called change/no change. There are numerous case studies that use change/no change technique to analyze floods. Several studies that utilized medium and high spatial resolution satellite imagery from Landsat, Quickbird, and Digital Globe. One researcher used high spatial resolution imagery to analyze floods near the Gulf of Mexico (Klemas, 2015). Another analysis technique is the multitemporal image analysis. Multitemporal image analysis compares the spectral differences between the two images and highlights them (Congalton, et al 2017, p. 240). Multitemporal image analysis is effective in identifying areas of change. Potential scenarios may include detecting when a wetland is drained or if a forested area just got converted into a residential area. On study conducted temporal remote sensing of Seyfe Lake which is in central Turkey (Reis and Yilmaz 2008). They utilized

Landsat imagery from different time periods 1975, 1987, and 2001 Then, an unsupervised classification method was used to classify 20 land-use classes. This was their primary method to measure lake level change by comparing the hectares of the lake class.

Unmanned Aircraft Systems:

The use of UAS or drones has been proliferated in the civilian world in the last decade. Originally used in the military, drones have almost unlimited applications in the civilian world. Due to the widespread use of drones in the United States, the FAA established part 107 drone regulations in 2016. Part 107 governs the use of drones commercially and to conduct research in that is compliant with UW-Madison regulations. Our team has a license part 107 drone pilot that will conduct the flight.

Most civilian drones are quadcopters and our team will be using a DJI Phantom 4 which is a quadcopter. Quadcopters are excellent because of its' stability and versatility. In addition, the customization of different cameras and affordability has enabled people to use drones for applications ranging from aerial photography to mail delivery. Remote sensing is also another immense application for drones (Casagrande, Sik, and Szabo 2018). The International Journal of Remote Sensing, a leading academic journal in remote sensing, has recently devoted an issue for drones. Specifically, there is a considerable amount of literature of researchers using drones to conduct flood analysis. In Hungary, a team from the General Directorate of Water Management has conducted drone surveys to create terrain maps to determine flood risk (Casagrande, Sik, and Szabo 2018).

Remote Sensing:

One large part of remotely sensed images that we will be looking at for our project involves comparing old images to new. Specifically, how the urban land cover has changed in the area. A large part of flooding is impervious surfaces and urbanization contributes greatly to the number of impervious surfaces in an area. One journal article that goes into depth about this topic is “Remote Sensing-Based Urban Land Use/Land Cover Change Detection and Monitoring.” This article says that the urban center is “snowballing” and that remote sensing can help city planners make decisions about the city itself. It then goes on to explain conceptually how to analyze images to detect change. (Erasu, 2017) From this article we will be focusing on how they correct remotely sensed images, how they classify what is visible in the images, how to assess the accuracy of the classification, and finally, the most in depth and specific part, the change detection. This article did a great job of going through the theoretical process of analyzing satellite images captured at different times to detect changes in land cover types. The article could have benefited from more real-world relationships, but a case study would fill the gap. Between our images we hope to be able to see where urbanization has occurred, and how that could affect a current flood, as well as predict where urbanization could spread to in the future for future flood analysis.

To fill in the gap of modeling around a real-world example, we looked at a case study titled “Coastal Flood Risk Analysis Using Landsat-7 ETM+ Imagery and SRTM DEM: A Case Study of Izmir, Turkey. This study looked at coastal areas, relatively like Madison’s lakes, and used a conglomeration of many data types to map flood risk. (Figure 3) This figure shows the general model for how they did their analysis. (Demirkesen, 2006) One thing from the study that would be useful for our project that was not previously brought in is geology and soil information which they overlay in the final analysis. This would be helpful to bring into our project because different soil types hold water differently. Plenty of Madison was built on wetland, which generally means that the water could be held in that soil type for longer, therefore making large amounts of rain a problem, as the land there would already be saturated.

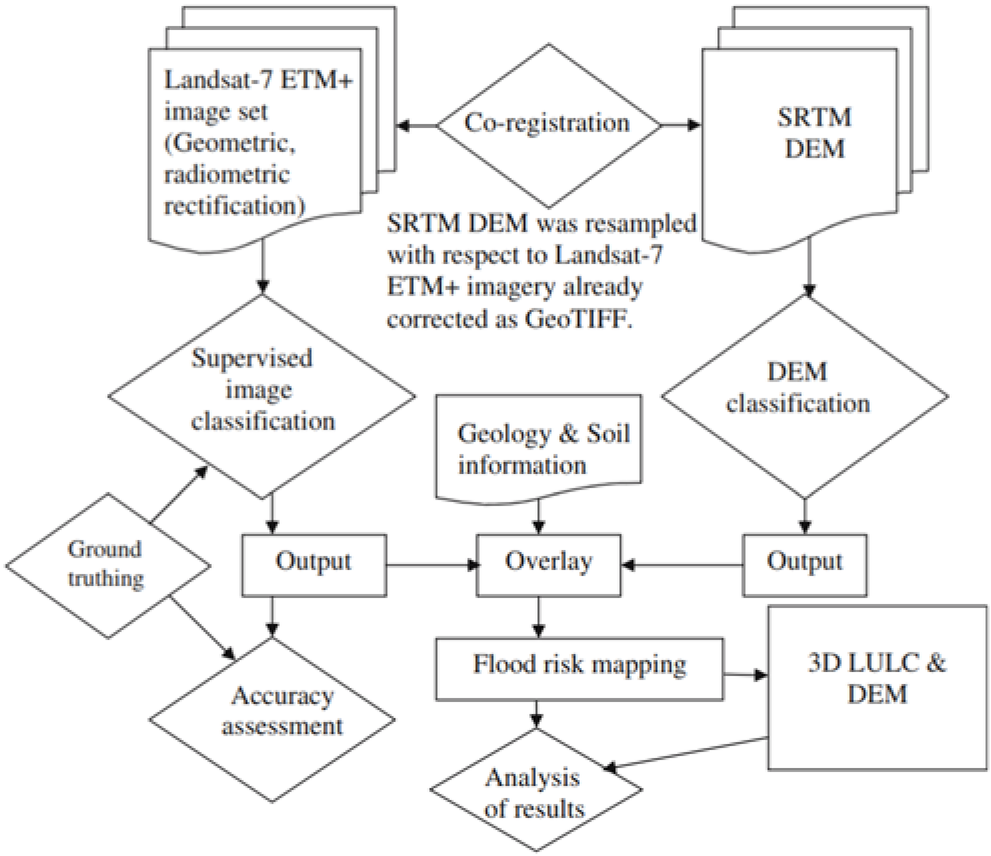


Figure 4. Flood risk mapping model for Izmir, Turkey. (From Demirkesen, 2006)

Methods:

Georeferencing:

With the understanding of the theoretical framework of precision, accuracy, and bias, georeferencing can be accomplished using GIS software with relative ease. After importing the a scanned file of your historical map and importing a modern map of the area that is projected in the PCS (Projected Coordinate System) that provides minimal distortion to your data site, one can to begin to georeferenced. Creating control points on the historic map on familiar features or points on the map, such as a road intersection that still exists or an old building that's still standing, will allow you to match those control points to ones then created on the modern map. As the software registers these control points, it begins "stretch" the historical map to line up with the modern projected plane created by importing the modern map. Given this logic, the more control points you have, the more accurate and precise the historical map will be stretched. Once the desired accuracy is obtained, the historical map is now ready for analysis.

Hydrological Analysis:

ArcGIS will provide us with the base for our analysis of the flooding in Madison, Wisconsin. The initial step in order to perform any kind of analysis through GIS applications is to acquire the proper data. To perform a flood analysis, it was necessary to attain a digital elevation model (DEM) of Dane County. This was found through the Wisconsin State Cartographer's website. The purpose of the DEM of Dane County is to assign elevation values (Z-scores) to a map with the goal of displaying topographic features (Hutchinson & Gallant, 2000). The DEM we found through the State Cartographer's Office is set at a 1-meter resolution. The spatial resolution of 1 meter is a reference to how each pixel on the image represents an area of 1 meter. Along with the indication of what each pixel is representing in terms of size, the spatial resolution also gives the user an idea of how detailed the image is going to be. (Horning, N. 2004). A 1-meter resolution gave us an accurate representation of the topographic features of Dane County. At the same time the data is not too detailed restricting our analyses with computational limitations as the complexity of the data obstructs our available computers to run analyses. While searching for the DEM data of Wisconsin, we found two DEM's which seemed potentially fitting for our flood analysis. These two DEM's had the spatial resolution of 2 feet, and 1 meter. Our decision to use the 1-meter resolution was also based upon time restrictions. If we had used a DEM with 2-foot spatial resolution, any sort of analysis using this data would have taken hours if not days. With a larger scale resolution of 1 meter the analyses which will be used on the data will take a shorter amount of time. While we our sacrificing some detail, a 1-meter resolution will still give us enough detail to run an accurate flood analysis.

Once we had chosen our DEM, it was necessary to clip the DEM into the four regions which we were studying. The four areas which our DEM was clipped into are; Picnic Point, Elver Park, Brittingham Park, and Lake Wingra. This was conducted through the Clip Raster Tool in the ArcMap tool box. We were able to clip the data by entering two x and y coordinates which set the Latitude and Longitude of the clipped data. Clipping the data allowed us to run a more accurate hydrology analysis on the regions which experienced significant flooding during the August of 2018 flooding in the Madison area.

With the focus of our research being on the flooding of the Madison area during August and September, it is necessary to use multiple ArcGIS hydrology tools to run a proper analysis. After acquiring a DEM of Madison, it was necessary to find the sinks which are located on the DEM's of Elver Park, Brittingham Park, Lake Wingra, and Picnic Point. A sink is when a multi-cell area is assigned lower Z-score values than their surroundings. If this occurs the flow of the water will become stuck in this sink and not flow in a natural manner. A solution to this problem is the fill tool. The fill tool searches the DEM for any sinks which are inaccurately recorded. For invalid sinks, the tool fills in the divots allowing the flow to continue over them. When a sink is considered to be valid, a pour point is assigned. This pour point is the point at which water will flow out of the sink allowing the flow to continue on. Once this analysis runs, a depressionless DEM is considered to be created. A depressionless DEM is a necessity for the rest of our analyses. This is so as with a depressionless DEM there will not be any restrictions which limit any kind of analyses looking at the flow of water.

Following the creation of a depressionless DEM, we then ran a Flow Direction analysis over each of the four regions. This analysis is performed by an algorithm which assigns different numbers to 8 neighboring cells. This algorithm of assigning cells numbers corresponding to their z-value is named the D8 flow direction type. The D8 is performed throughout the entire DEM. Once the images z-values are assigned with values, the flow direction of the water is assigned. This is done by determining which cell has the lowest assigned number in a block of 8 cells. The cell which has the lowest assigned value is the way the flow of water is going to be directed (ArcGIS Desktop).

Following the sink and fill assignments, the next step is to create snap pour points. A snap pour point will assess pour points (previously defined) and find the cells with the highest amount of water accumulation. This tool will then move the pour points to these cells with the highest concentrations of water. This will allow for an accurate representation of the water flow direction (ArcGIS Desktop).

The following process is to create watersheds for the DEM using the watershed tool. According to ArcGIS.com “A watershed is the upslope area that contributes flow—generally water—to a common outlet as concentrated drainage" (ArcGIS Desktop). The watershed is created by an analysis of the flow direction in the watershed tool. This tool alienates an area for different sections of the water flow where water can be traced back to an origin thus creating a watershed (ArcGIS Desktop).

With watersheds being assigned to the DEM, a stream network must be created to show where water will flow with different amounts of rainfall. A stream network is created through the use of the flow accumulation tool. A flow accumulation tool uses data from the flow direction tool showing where the water is flowing and assigns different numbers depending on the amount of water which will accumulate at certain points. These areas designated to be of high accumulation can then be used to identify stream channels. The stream channels are created through assigning a threshold value of 200. What this value means is that when a cell has at least 200 cells flowing into it, the cell can then be determined a stream network. To find these cell blocks, the con tool can be used. In the con tool, a segment of code is written to set the standard of a cell with 200 cells flowing into it can be deemed to be a steam channel. An example of what this code looks like is; newraster = con(accum > 200 1) (ArcGIS Pro). The next step to create a stream network is to use the stream order tool with the desire of differentiating each stream channel. This tool looks at all of the stream channels created and assigns a number to each channel. The purpose of using the stream order tool is for being able to look at which tributaries run into one another while analyzing a flood.

The final step in performing a flood analysis is to use the flow length tool. The flow length tool is used to determine the time of concentration in a watershed. The time of concentration is "is the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet" (Kent et al., 15-3). This information can be used to determine the length of the flow path depending on the given time of concentration. Mapping the length of the flow path will show the areas which are most impacted by the flooding.

Once we had an understanding of our analyses, we were able to create a model builder with ArcMap. Having this model builder allowed us to easily process all of these analyses mentioned. Our model builder began with the clipped DEM's being run through the fill tool. Once this analysis is complete, the depressionless DEM's will be ran through the flow direction. The flow direction allows us to then run the watershed, flow length, and flow accumulation tools. The flow accumulation is able to designate stream networks. The stream networks are created based upon the con analysis. We had a con threshold of 200, meaning at least 200 pixels need to be flowing together in order to be designated. With the stream networks created, we were then able to run a stream order analysis on them.

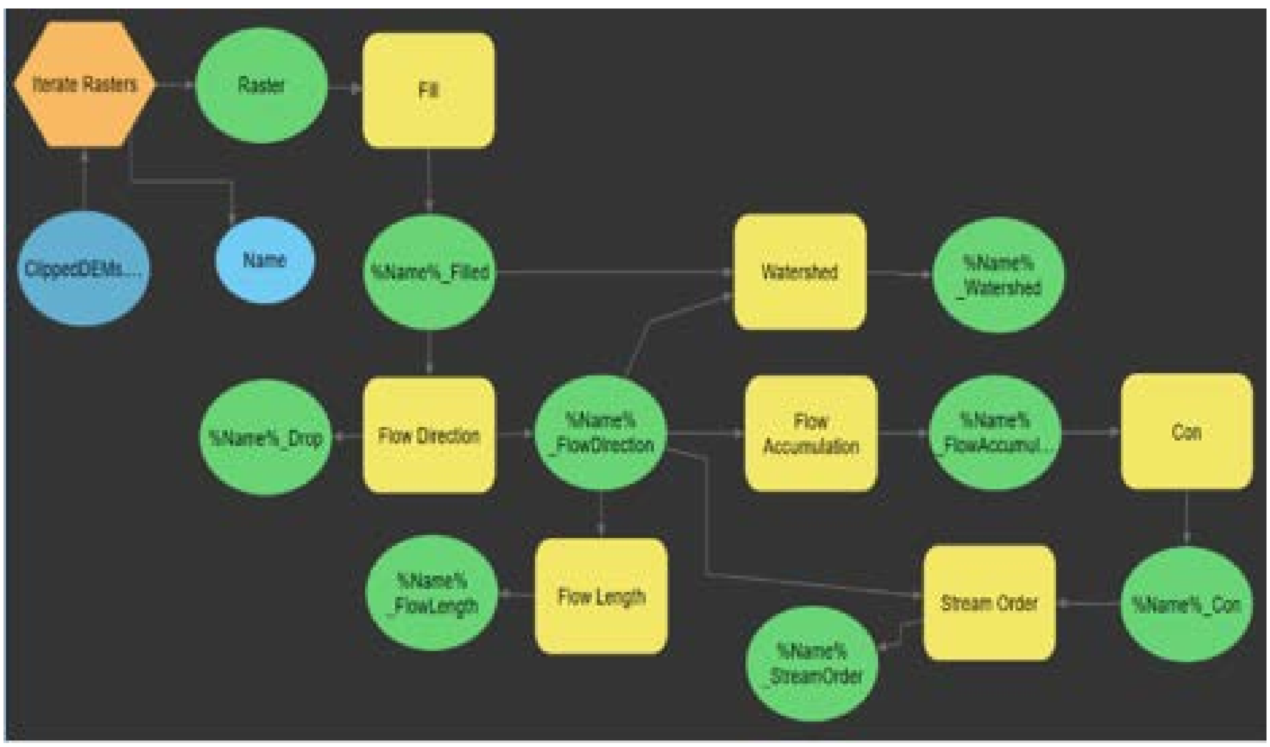


Figure 5. Model Builder for Flood Analysis (Trevor Grayson, David Lombardo)

Unsupervised/Supervised Classification:

Unsupervised Classification is one of two methods to classify land cover and land cover change by analyzing spectral clusters and patterns (Congalton et al. 2017,). There are many advantages to do unsupervised classification. Unsupervised saves time for the analyst since the computer will conduct the work of classifying land cover. Additionally, the analyst does not need prior knowledge of the area to conduct unsupervised classification. Currently, unsupervised classification algorithms rely on per pixel classifiers. There are two per pixel classifiers, K-means and ISODATA. K-means utilizes the nearest neighbor classifier which searches away from a pixel and compares other pixels in the vicinity. In addition, K-means allows the analyst to specify the minimum and a maximum number of iterations he/she desires in the cluster. ISODATA is somewhat like K-Means. However, there are key differences. ISODATA allows the analyst to specify the minimum and maximum of cluster variance. During the classification process if two clusters go below the specified minimum then the classes will be merged. If the two clusters go above the maximum, then the two clusters will be split into two (Green et al. 2017).

Supervised Classification is the other method to classify land cover. It relies on the user and rules to decide how to classify a pixel. These rules are called training samples. The more training samples that the user gives to the computer the better the classification. Overall, supervised is more accurate than unsupervised but relies on the user and can be more time intensive.

To conduct a satellite remote sensing analysis, we need to obtain the data. Our team will use images from two satellite companies, Landsat and Planet. The satellite imagery should be taken around the time of the flood, before the flood, and after the flood. Then an unsupervised and supervised classification will take place on the imagery. For this project, we will be utilizing the ISO unsupervised classification because that's the main unsupervised classification method that ArcGIS Pro uses. To conduct an ISO unsupervised classification analysis, Landsat and Planet images will be imported into ArcGIS Pro. In the ISO toolbar, we had specified between 10 and 20 classes for the computer identify which is more than enough to produce an accurate assessment map. Generally, if the accuracy of the classification is below than 83 percent then the process of supervised classification will be initiated.

Supervised classification process takes more time and intensive ArcGIS Pro. After identifying the training samples, the computer will make a map. If the map is not insufficient, then training samples must be redrawn until the final map is sufficient enough for analysis.

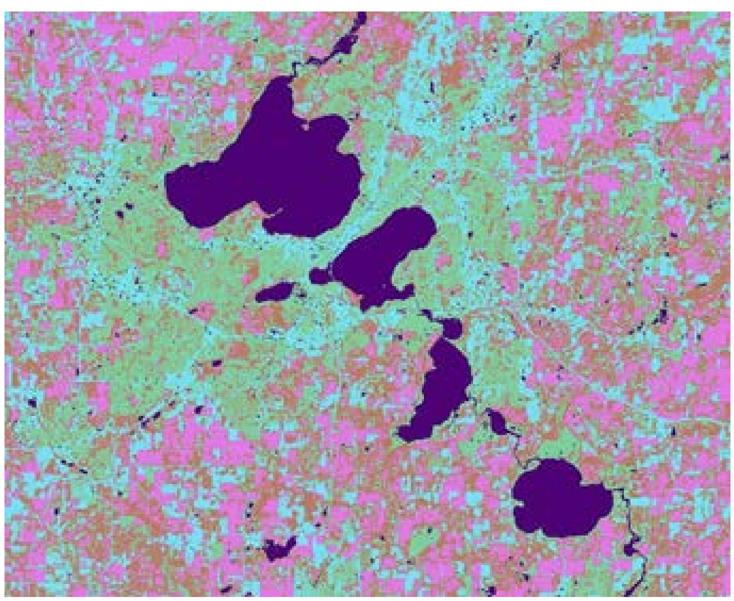


Figure 6. An unsupervised classification of Madison (Source: Daniel Yun)

Drone Analysis:

The drone analysis will be conducted with UW-Madison Drone Lab. Dr. Chris Johnson, the faculty member at Engineering and Mechanics Astronautics, oversees the lab. Elver Park is the chosen site to conduct the drone analysis. Elver Park is the largest park in the Madison Public Park System boasting 250 acres (The City of Madison Parks Division 2018) The park is located southwest of UW-Madison campus on 2100 McKenna Boulevard and consists of two large fields, sports facilities, and picnic areas.

There are several reasons why Elver Park is an excellent site to conduct the drone analysis. First, is safety. Elver Park is located more than five miles from the nearest airport which eliminates the necessity of sending a waiver to the FAA to get a flight approved. In addition, the park has a wide-open space which is very safe to operate a drone. Second, the heavy rain from August 21st, 2018 caused the lake in Elver Park to overflood into residential areas. By conducting a drone analysis of the lake, we can possibly find a cause to the flooding such as low terrain elevation.

Figure 7. Elver Park (Source: Google Earth)

To create a map of terrain elevation, photogrammetry procedures will be required. Photogrammetry is the art and science of taking a measurement of photos and converting the photos into a three-dimensional model (Casagrande et al. 2018). Usually, this process is done by overlapping photos onto each other to create an accurate point cloud map. Since photogrammetry requires precise precision, an automated flight plan is recommended since the pilot input is not as precise. There is plenty of different flight planning software that makes the process easy for drone pilots. Grid, polygon, road or circular flight patterns are the most common plans that drone pilots will use Once the flight plan is completed, a 3D map can be created. The quality of the 3D map will be determined by image sharpness, blue, type of surface, and other external factors. Before a drone flight, a safety assessment must be conducted. First, we will check on the airspace surrounding the site. Elver Park is outside the five-mile radius of the nearest airport therefore dense air traffic will not be a concern. Next, we will look at a TAF (Terminal Aerodrome Forecast) and a METAR (Meteorological Aerodrome Forecast) to make sure that the weather will be safe for flying. Finally, we will make sure that the site will be clear of humans, animals, or other obstructions.

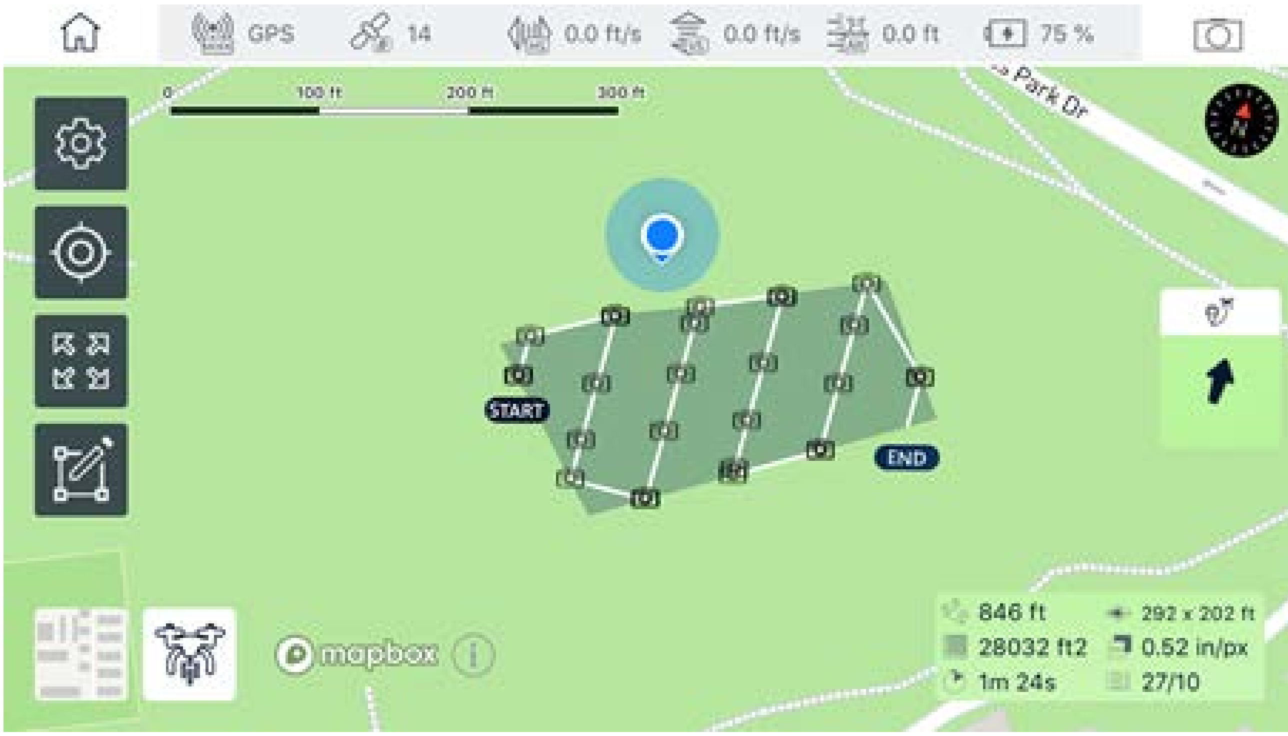


Figure 8. Example of a flight plan (Source: Daniel Yun)

After conducting a safety assessment, the drone flight can commence. An automated flight plan will be uploaded on the drone (DJI Phantom Pro 4 or Mavic Pro) so that we can produce high-quality data for the 3d map. We set the drone flight path to take photos at a 75 percent overlap and at a 150 feet vertical resolution. When the drone flight is underway, the operator will follow drone to ensure safety and accuracy. Once the flight plan is finished the data will be uploaded on the 3D survey, a photogrammetry software. The images will be imported and be converted to a sparse point cloud. Then, the process of converting the sparse point into a full point cloud will start. Finally, a height map and contour map will be produced to analyze the elevation of the lake and the surrounding area.

Results/Analysis:

Historical:

To obtain significant comparison between historical Madison area infrastructure and modern infrastructure in relation to intensity and coverage, aerial photos were stitched together and georeferenced to obtain a visual overlay to see where expansion had occurred and what to do degree. The four areas of focus: Brittingham Park, Elver Park, Picnic Point, and the Lake Wingra area; have all seen significant increase in infrastructure from the historical timeframe of 1937. Infrastructure has been highly expanded, human intervention in waterways and land cover and use have also drastically changed, making a strong case for increased erosion and a higher vulnerability to flooding. Elver Park has undergone the most extreme change, and it also has been recipient of the heaviest increase of flooding over time. Elver Park was cropland until the 1960’s and has suffered far more natural soil erosion from farming and land expansion that any of the other focus sites.

Figure 9: Picnic Point 1937, Wisconsin Historical Society, Aerial Imagery

Figure 10: Picnic Point Modern Day, Google Earth, Satellite Imagery

While picnic point has had an increase in human intervention and infrastructure, it is the lease affected of the four sites chosen for this study.

Figure 11: Brittingham Park 1937, Wisconsin Historical Society, Aerial Imagery

Figure 12: Brittingham Park Modern Day, Google Earth, Satellite Imagery

Brittingham Park has undergone massive urban renewal since 1937 and has been increasingly affected by human change and intervention making it vulnerable to flooding from human induced erosion.

Figure 13: Lake Wingra 1937, Wisconsin Historical Society, Aerial Imagery

Figure 14: Lake Wingra Modern Day, Google Earth, Satellite Imagery

Lake Wingra has had minor increase in infrastructure leading to minor erosion, but the lake itself has been altered and affected by human change. However, most of the increased flooding in the area is caused by the low elevation and high discharge levels into the lake from the old wastewater systems.

Figure 15: Elver Park 1937, Wisconsin Historical Society, Aerial Imagery

Figure 16: Elver Park Modern Day, Google Earth, Satellite Imagery

Elver Park has undergone the most change in the time span of the analysis. Consisting of only cropland until the 1960's, massive infrastructure and human erosion, topped with the soil erosion from farming for decades has led to a substantial increase in flooding in the area and was the most active of the four sites during the flooding events of August 2018.

GIS:

The areas we chose to take a closer look at were chosen due to their proximity to bodies of water. Figures 17-19 show local watersheds and stream flow order in the areas. The local watersheds are designated by different colored polygons. The stream flow order are designated by lines of varying thicknesses and colors. The darker and thicker the stream, the higher order flow it will have, indicating the possibility of extra erosion taking place here or flooding during or after an extreme rainfall event.

The analysis of Brittingham park showed that the area of largest flow was on the eastern edge of the park. This area is along the road, Brittingham Place. This is due to the part of the road with the highest predicted flow being lower than the other sections of it in the neighborhood. Towards the center of the park are streamlines indicative of a low-lying area around the thinner horizontal lines. This area would be prone to flooding because it is low lying, and so close to the lake. This could possibly put the Brittingham Community Garden and the Butterfly Garden located there at risk. Figure 17.

Picnic Point provided an interesting analysis. The long horizontal flow lines show that water would collect and stay in one area. The central part of the peninsula is lower than the rest, with a thin wall-like edge around the side closest to the lake. This thin wall is enough to be able to keep a pool of water until it flows through a single outlet on the north side. This area, as designated by a thick red line, would be at high risk of erosion, and possibly loss of land to the lake in an extreme rainfall event. The local watersheds of Picnic Point also point towards the central area of the peninsula being at risk of flooding. The central purple watershed would collect the most water. Figure 18.

The analysis that we did on Lake Wingra showed that the area surrounding the water would all flow into the lake or stay within that area. There was really only one major watershed for the area which means that this space would hold a lot of water and stay saturated. This area also showed that rain would flow easily through neighborhood streets, as the stream network resembles the layout of the streets. Figure 19

Figure 17. Watershed and Stream order analysis of Brittingham Park

Figure 18. Watershed and Stream order analysis of Picnic Point

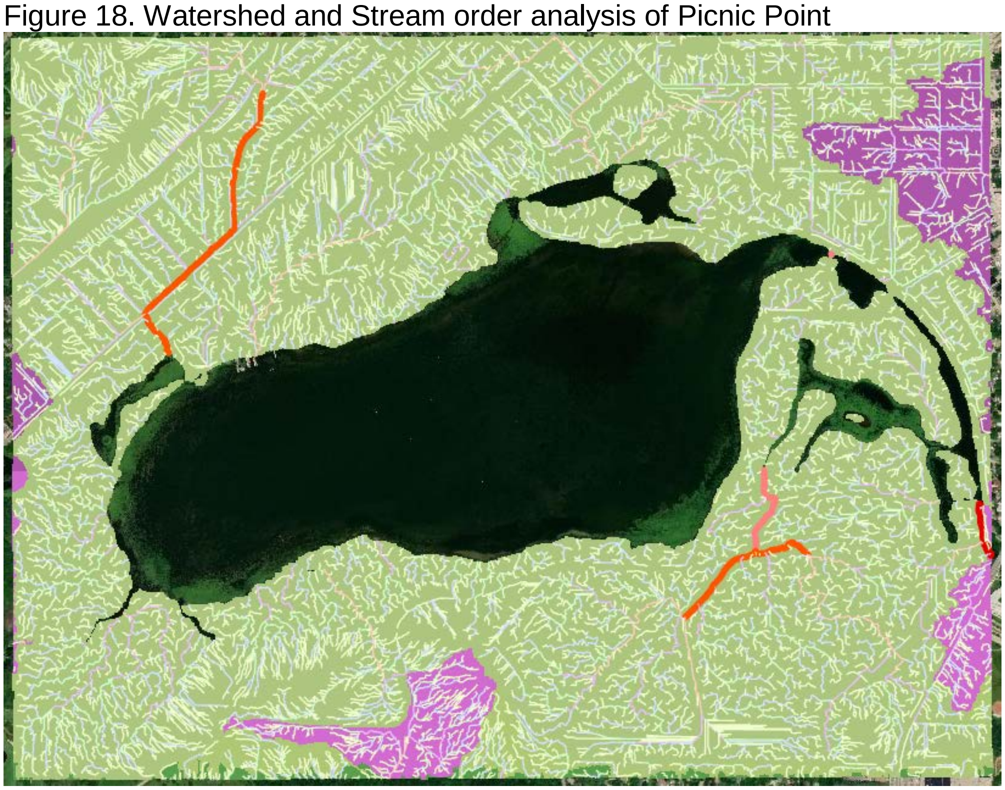
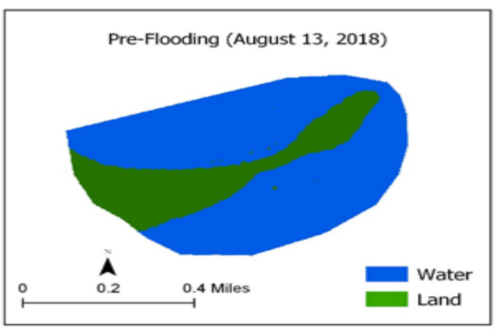


Figure 19. Watershed and Stream order analysis of Lake Wingra

Change Detection Results:

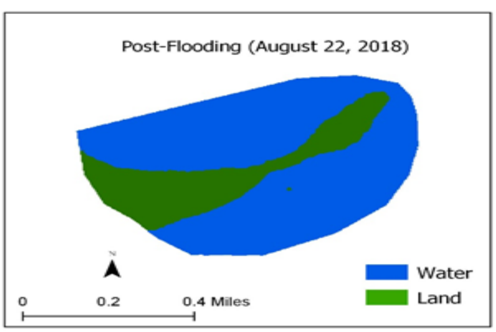
The change detection was somewhat challenging in the beginning due to trying to find quality images to have a successful classification. The dates varied for each area but images that were selected were before and after the August 21st flood. Unfortunately, we could not conduct a change detection analysis on Elver Park due to time and poor quality of the images. However, the ISO unsupervised change detection was successful detecting the land cover change. In the spatial extent of Picnic Point there was 1.2 percent increase in water cover and a 1.2 percent decrease in land cover.

Picnic Point



	Count	Hectares
Water	38735	3486.15
Land	12890	1160.1

Pixel Size: 3 x 3

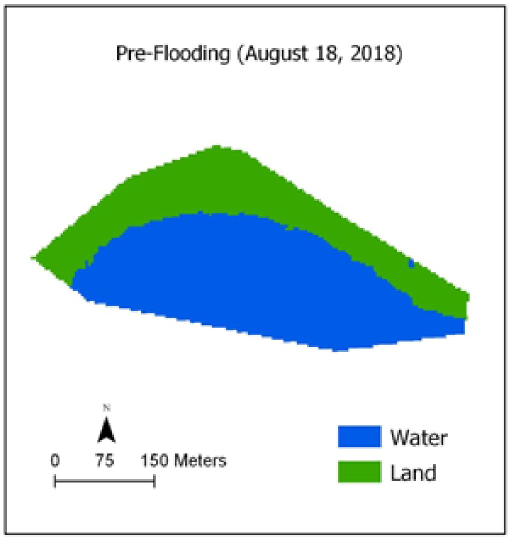


	Count	Hectares
Water	39395	3545.55
Land	12230	1110.7

Pixel Size: 3 x 3

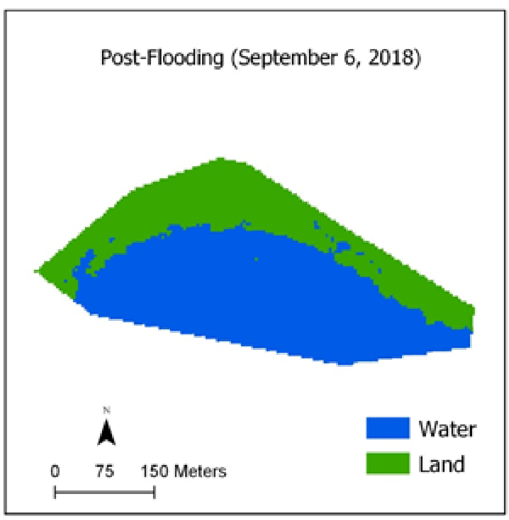
Figure 20. In the spatial extent of Picnic Point there was 1.2 percent increase in water cover and a 1.2 percent decrease in land cover.

Brittingham Park



Classification	Pixel Count	Hectares
Water	4378	394.02
Land	2692	242.28

Pixel Size: 3 x 3



Classification	Pixel Count	Hectares
Water	4417	397.53
Land	2653	238.77

Pixel Size: 3 x 3

Figure 21. At Brittingham Park, the area experienced a .4 increase in water cover area and .5 percent decrease in land cover area.

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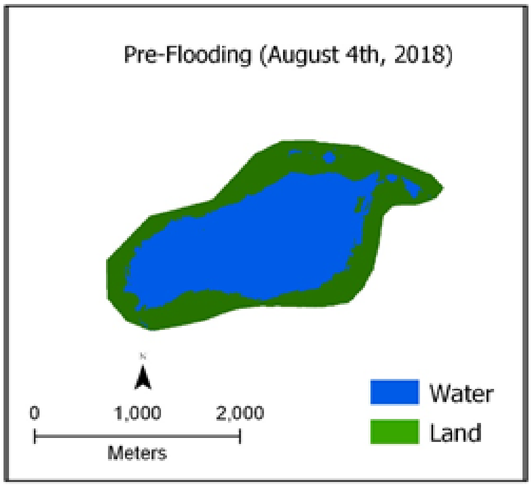
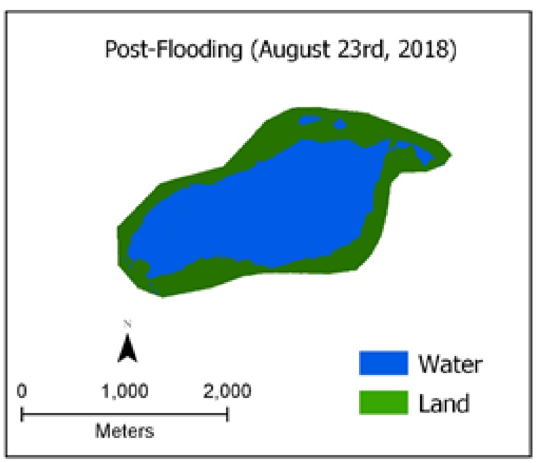
Lake Wingra



Classification	Pixel Count	Hectares
Water	122992	11069.28
Land	89604	8064.36

Pixel Size: 3 x 3



Classification	Pixel Count	Hectares
Water	127752	11497.68
Land	84844	7635.96

Pixel Size: 3 x 3

Figure 22. At Lake Wingra, water cover gained three percent in area while land cover lost two percent in area

Overall, the change detection shows the results we expected. Flooding affected the land cover change. Some were heavier than others but nonetheless it impacted the areas across Madison.

UAV:

The drone analysis was somewhat smooth. One challenge is the long processing time to import photos and covert into a 3-D model and point cloud for further analysis. After we made a 3D model that shows the flight path of the drone, where the images were taken, and ortho-mosaic of the area.

Figure 23. 3-D Flight Map of Elver Park

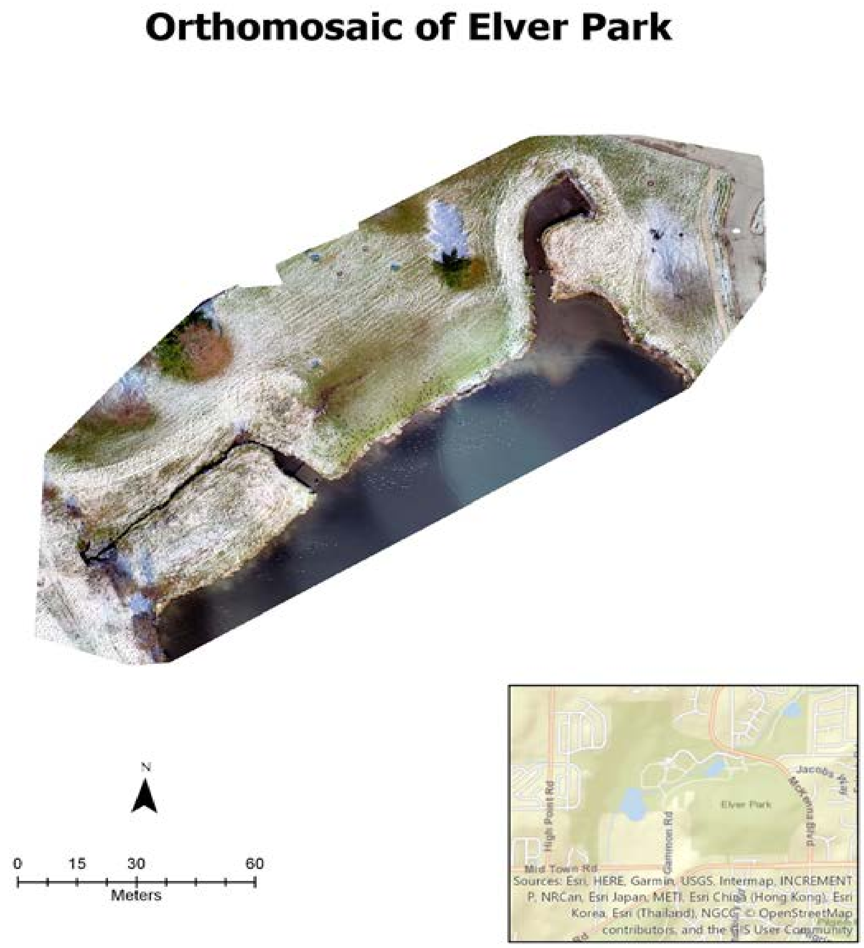


Figure 24. Orthomosaic Map of Elver Park

After creating the point cloud data, I transferred it to ArcGIS Pro where we made a digital terrain model of Elver Park. By analyzing the model, we can make a couple of "conclusions." First, the lake rose to around six feet. Furthermore, the model showed a low depression next to the lake which may indicate why heavy flooding occurred.

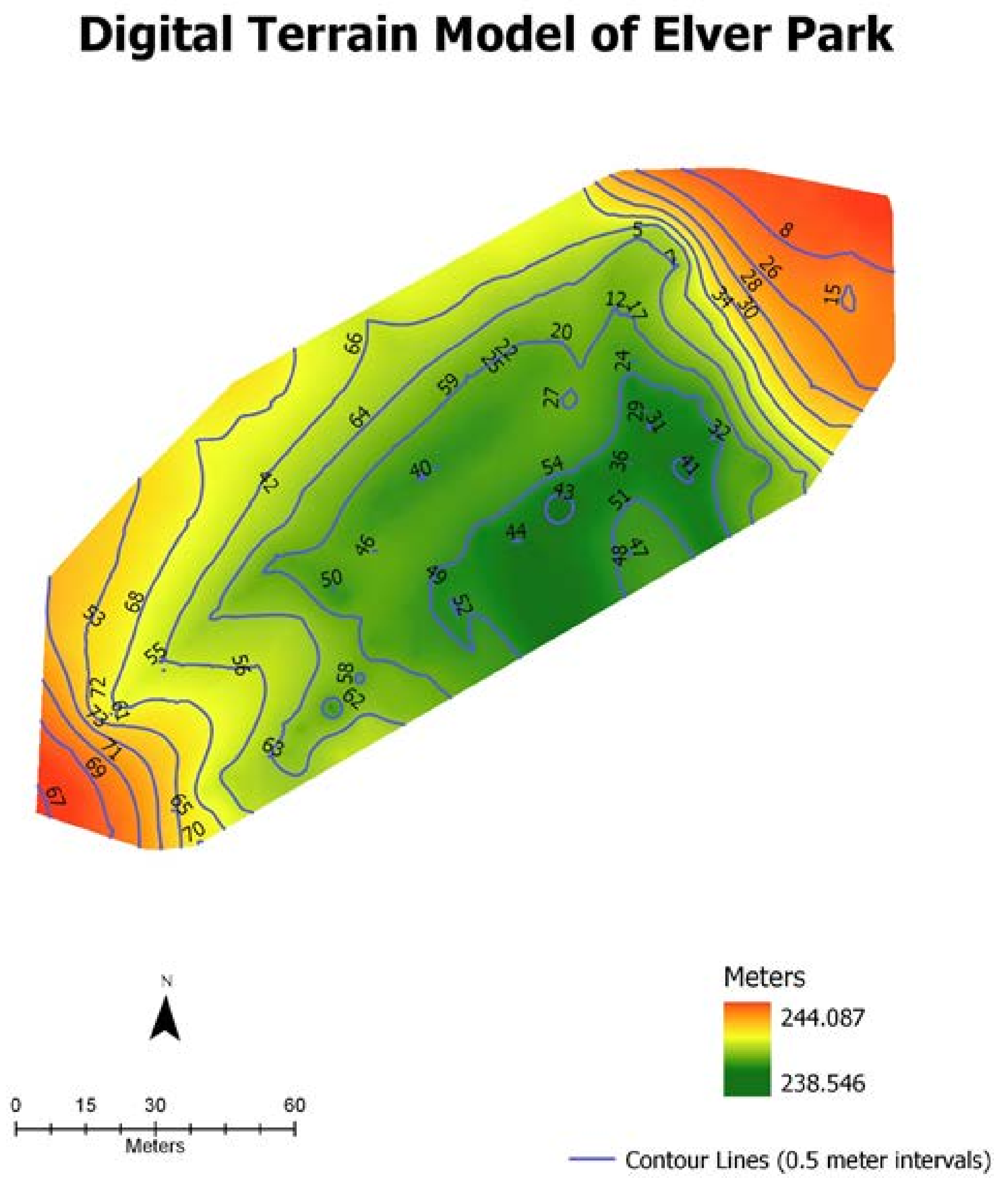


Figure 25. Digital Terrain Model of Elver Park

Discussion/Future Research:

Due to time limitations (along with other factors) there are numerous areas which we would have liked to research to further expand our analyses. The first part which we would expand our analyses on is to have a DEM of 2-foot resolution. A DEM with 2-foot resolution would allow the analyses to have much greater accuracy. With a DEM of this resolution, there will be a great amount of data. To run the hydrology analyses which were used for the project, there would be two components which would be necessary. The first component would be to have a computer with enough computational power. The immense amount of data in a DEM with 2-foot resolution is going to take a very powerful computer. If we were able to have a computer with enough computing to run the analyses, we would also need a significant amount of time. We would need this time to first have each of the analyses run, then second to analyze what the findings of the analyses mean. The analyses would create a significant amount of data which would need to be looked over and understand.

Another area where we would like to further expand our research is the size of the area in which we analyze. Currently, we have only analyzed four places of interest (Picnic Point, Elver Park, Brittingham Park and Lake Wingra). If we had the time to further expand our research, we would have analyzed the entirety of the four lakes region which experienced flooding the summer of 2018. Having an area this extensive would allow us to truly understand how a flood event effects the entirety of the four lakes region. To run an analysis over this entire region, we would need the same components as for our future 2-foot analysis. These, of course, are time and computing power. Computing power would be a challenge for this as not only would we be analyzing 2-foot DEM data, the area being studied is significantly larger. A solution to this, would be to run multiple analyses on different areas then mosaic them together.

We would also like to include the sewer systems located in the region which we are studying. An analysis including the sewer systems in the study of interest would provide us with a much more accurate analysis. This is so as instead of labeling pour points by their Z-score, there would be areas where the pour point is rather the drainage hole. This would change how our analyses run as a large portion of the water would run through the sewer system rather than on the ground.

With the rest of this further research, we would also like to be able to run an analysis predicting how different amounts of rainfall floods different areas of interest. With the data from this analysis we would create maps showing the impact of floods on different areas depending on the amount of rainfall expected. These maps would be extremely useful for the cities which lay within our area of interest. Our hope would be that cities would be able to properly warn citizens if a rain event might have a substantial impact on them. Along with this, the city engineers could also study our maps to see which locations are at high risk of flooding and create appropriate measures based upon the analysis.

From the lake levels group fantastic presentation, we would like to see how the different lake levels affect the flooding in the Madison area. This ‘collaboration’ could have a huge impact on both of our research. We would be able to research a flood analysis based upon the different lake levels. This would benefit our research as we could have a better understanding of how the different lake levels of Mendota impact flooding. It would also be beneficial for the lake group as they would be able to further improve their arguments on whether or not Lake Mendota’s water levels should be lowered.

Conclusion:

Through our historical, remote sensing/UAV, and GIS analyses, we have determined significant causes that could explain the increase in volume and severity of flooding in the south-central Madison area. We have also been able to gain confidence in predicting where future flooding may occur in the future as well as possible policy recommendations to the city of Madison to mitigate damage or future issues regarding flooding events.

Our historical analysis showed the large and invasive increase in infrastructure throughout the south-central Madison area. This increase in development has led to increased erosion and wear on the land and natural barriers to flood waters, and in turn allowed for an increased negative effect of flood waters. Another contribution to this phenomenon is the ever-increasing volume of precipitation and precipitation events due to a changing climate. The GIS/UAV analysis produced data that can confirm our belief that the flooding has increased as well as the effect of high precipitation has overloaded the local watersheds and stream systems. These factors combined with an old wastewater system has led to a continued deterioration in flood water prevention in the south-central Madison area.

In regard to Madison and policies that we would be able to suggest, slowing down urbanization and construction on an already eroded land would possible mitigate some of the severity of future events. Lowering lake levels could also prevent the lakes hydrological cycle from being overwhelmed and causing a lack of a sink for storm water. If possible, restore unused land back to wetlands to allow further dampening of the flood water and conditions. While all of these policies are extreme, we live in an age of extreme climate change, and drastic measures may have to be taken.

Based on this analysis, our team will answer questions such as where and why the recent floods occurred in certain areas. In addition, where will future flooding occur? More importantly, should there be any policy recommendations or changes submitted to the City of Madison

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