WHERE IS THE FERTILIZER GOING?

Using GPS and LIDAR derived Digital Elevation Models to Determine Flow Path of Fertilizer Runoff

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Abstract:

Nutrient pollution is a growing problem. With fertilizer use rising for the past 50 years, monitoring fertilizer runoff has never been more important. Excess nutrients from fertilizer runoff end up in local water bodies where they stimulate plant growth causing eutrophication. Villanova University uses fertilizers to keep their athletic fields and highly visible areas looking presentable. It is crucial for Villanova to understand where this fertilizer run off is going.

In this project, the potential paths of fertilizer runoff were determined by constructing multiple digital elevation models (DEM's) of Villanova's Campus. Campus was broken up into 3 separate areas, Main, West and South. Roughly a 100,000 point elevation and positon dataset was constructed using a GPS. Data was logged in 1s intervals as campus was covered on foot. Using ArcGIS, the dataset was used to create 3 DEM's which were then used to determine flow path. A second set of DEM's were created using a LIDAR dataset in an attempt to compare the accuracy of the two methods.

Both models found the highest single point elevation value of all 3 study areas to be on Main campus (520.3/469.83 ft.). The lowest single point elevation value was found on South (387.23/394.92 ft.) and the highest average was found on West (451.08/445.76 ft.). Both models predicted water on Main campus to flow from Mendel field to Lancaster Ave. towards Pike Lot, West campus to flow away from the center in both directions and South campus from Lancaster Ave. towards Good Counsel.

Introduction:

With the use of nitrogen-based fertilizers rising steadily since the 1950's (USDA 2013), it has become increasingly important to be able to identify where fertilizers tend to runoff during storm events. Fertilizer runoff ending up in local bodies of water in high enough concentrations can lead to eutrophication, creating an environment where hypoxic conditions can thrive. (Bortman et al.,2003). It is well known that eutrophication can be detrimental to aquatic ecosystems. Excess nitrates and phosphates from fertilizer runoff stimulate plant growth, deplete oxygen levels and eventually lead to hypoxic conditions. If a body of water reaches hypoxic levels, fish and other organisms will begin to die and the effects can have damaging long term consequences to the aquatic ecosystem (ESA, n.d.).

Water pollution in general can derive from a number of sources but usually they are divided into two categories, point and non-point sources. Point sources of pollution are easier to identify, regulate and stop because they come from a particular, traceable point, like a pipe from a factory leading into a river. Non-point pollution is much harder to identify simply because there is no single traceable point to identify and cut off to solve the problem. A common example of non-point pollution is nutrient pollution from fertilizer runoff, which is the focus of this study.

In order to better understand the origins of non-point pollution it becomes necessary to develop a model to help understand water flow. Since water travels from the highest elevation to the lowest, this can be accomplished by knowing the change in elevation of a particular study area. By understanding the change in elevation, the path of runoff can be predicted. Many techniques for analyzing flow path exist but one of the most modern methods of determining flow path derives from the use of Digital Elevation Models (Pourali, S. et al., 2014). A Digital Elevation Model is a “continuous representation of elevation values over a topographic surface by a regular array of z-values, referenced to a common datum” (Nigeria, 2011). For this study, two different types of spatial data were used to create two different sets of digital elevation models, manually obtained GPS data and publicly available LIDAR data. By using DEM’s as a means of flow path analysis, it becomes straightforward to predict where runoff might go. By having an idea of the runoff flow path, non-point source pollution mitigation efforts can begin.

Villanova’s grounds division is well aware of the potential damage that can be caused by careless fertilizer use. Villanova uses a minimal amount of mostly organic fertilizer on athletic fields and certain high visibility, high traffic areas like Mendel field. During the fall, Holly Tone fertilizer is used on many evergreens and shrubs that are under stress. While these fertilizers may be organic, that does not mean they don’t contain nitrates and phosphates. It is still crucial to understand where these runoff nutrients are headed.

This experiment broke Villanova’s campus up into 3 logical study areas, Main, West and South/Athletic. Two sets of DEM’s were developed for each study area in an attempt to determine the possible flow paths from each location. With the flow path defined, other factors such as the presence of impermeable or permeable surfaces along flow path and digital elevation model accuracy can begin to take place. The presence of impermeable surfaces along the predicted flow path could result in more fertilizer runoff than the model predicted and less if the flow path is dominated by permeable surfaces. (Doran, 2012). Determining the level of digital elevation model accuracy is largely dependent on the application of the project (Erdogan, 2009).

This was kept in mind when designing the project and deciding to use two different models. The hypothesis for Main campus was that the center of Villanova's Main campus is the highest in elevation, runoff will originate in the center of campus and flow down to areas of lower elevation. West was thought to have highest elevation points towards the back and South was predicted to have lowest points near Good Counsel. GPS elevation values were hypothesized to be much less accurate than LIDAR elevation values.

Methods:

GPS Derived Digital Elevation Model -

During the summer of 2014, 3 separate elevation and position datasets were constructed using a Trimble GeoExplorer 6000 GPS; a 45,037 point dataset of Villanova's Main Campus (see fig. 1), a 23,289 point dataset of West Campus (see fig. 2) and a 14,095 point dataset of South/Athletic Campus (see fig. 3). Data was logged in 1s intervals as campus was covered on foot in passes of approximately 5 feet. A buffer of approximately 10 feet was used around all buildings due to accessibility and GPS signal interference.

After data was collected, the datasets were post-processed using Trimble GPS Pathfinder Office and then exported from .SFF files to .SHP in order to be compatible with ArcGIS. The datasets were put into Esri's ArcGIS where they were projected in the NAD 1983 Pennsylvania State Plane South coordinate system and overlaid with an aerial image of Villanova's campus. Outliers in the dataset were removed manually and the datasets were converted from point based vector data to a continuous raster form. After the data was rasterized, the "DEM" tool was used to create raster surface representations of the study areas. The raster digital elevation models were used to model water flow using the "flow direction" and "basin" tools in ArcGIS.

Triangulated Irregular Network's (TIN's) digital elevation models were also derived from point based vector data (see figs. 4, 5, 6).

LIDAR Derived Digital Elevation Model -

During the fall of 2014, PAMAP Program LAS files, a publicly available LIDAR dataset of Pennsylvania was downloaded from the Pennsylvania Spatial Data Access Clearinghouse (PASDA) and used to create a second digital elevation model for all three study areas. 3 separate elevation and position datasets were constructed using the LIDAR data; a 186,934 point dataset of Villanova's Main campus (see fig. 7), a 89,793 point dataset of West Campus (see fig. 8) and a 101,187 point dataset of South/Athletic Campus (see fig. 9). The LAS files came already projected in NAD 1983 Pennsylvania State Plane South coordinate system. Using the LAS Dataset to TIN tool, the LAS files were turned into a TIN DEM (see figs. 10, 11, 12).

Results:

GPS -

The highest single point elevation value of all 3 study areas was found on Main campus at 520.3 feet (158.59m) above sea level. The lowest single point elevation value was found on South campus at 387.23 feet (118.03m). The highest average value was found on West campus at 451.08 feet (137.49m). The lowest average value was found on South campus at 427.85 feet (130.41m).

The water flow model for Main campus predicts water to flow from the center of campus down towards Lancaster Ave towards Pike Lot (see fig 13.) The water flow model for West campus predicts water to flow away from the center (see fig 14.) The water flow model for South campus predicts water to accumulate near Good Counsel (see fig 15).

LIDAR -

The LIDAR model also had the highest single point elevation value of all 3 study areas on Main campus at 469.83 feet (143.2m). The lowest single point elevation value was found on Main campus at 392.84 feet (119.73m). The highest average value was also found on West campus at 445.76 feet (135.86m). The lowest average value was also found on South at 418.31 feet (127.5m).

Discussion:

Comparison of methods (GPS vs LIDAR) -

Elevation values of GPS and LIDAR models were surprisingly similar with a difference of less than 10 feet between mean values produced by both models (See Table 1). It was hypothesized that GPS elevation values would be much less accurate due to a number of factors including inconsistent GPS signal, lack of accuracy of handheld GPS unit and much smaller dataset compared to the LIDAR dataset. The only slight discrepancy between the two models was that the lowest single point elevation value was on south according to the GPS and on Main according to the LIDAR, however these values were only 2.08 feet apart.

Knowing that the accuracy of GPS derived elevation models varies only slightly from more advanced and harder to obtain LIDAR datasets allows for the use of manually obtained GPS derived DEM’s as relatively accurate alternative to LIDAR produced DEM’s. This can be useful in areas that lack LIDAR datasets. GPS derived DEM’s could also be used in the classroom as an interesting exercise in GPS and GIS methodology.

Water Flow Models -

Water flow models for all 3 study areas were created under the assumption that water always flows from highest elevation point to lowest. However, other factors such as impermeable/permeable surfaces were not taken into account. A significant portion of campus is covered in brick and concrete, in order to truly understand what is going on a more sophisticated model needs to be developed.

Both GPS and LIDAR models for Main campus agree that the majority of water would flow from Mendel Field to Lancaster Ave. towards Pike Lot. This was somewhat of a surprise considering the amount of water that accumulates in the Villanova Wetland's, however the tool used in ArcGIS was based off of a rasterized version of vector data. Elevation values of all cells were taken into account and determined that the majority of water would actually end up accumulating near Lancaster Ave. The model had water on West campus flowing away from the center in both directions and South campus from Lancaster Ave. towards Good Counsel. These results were hypothesized.

By understanding where potential runoff may accumulate, the University can alter fertilizer application techniques to avoid high potential runoff areas or if absolutely necessary, use sparingly in those areas. The models can also be consulted in the future if new drainage systems are implemented.

Figures and Tables

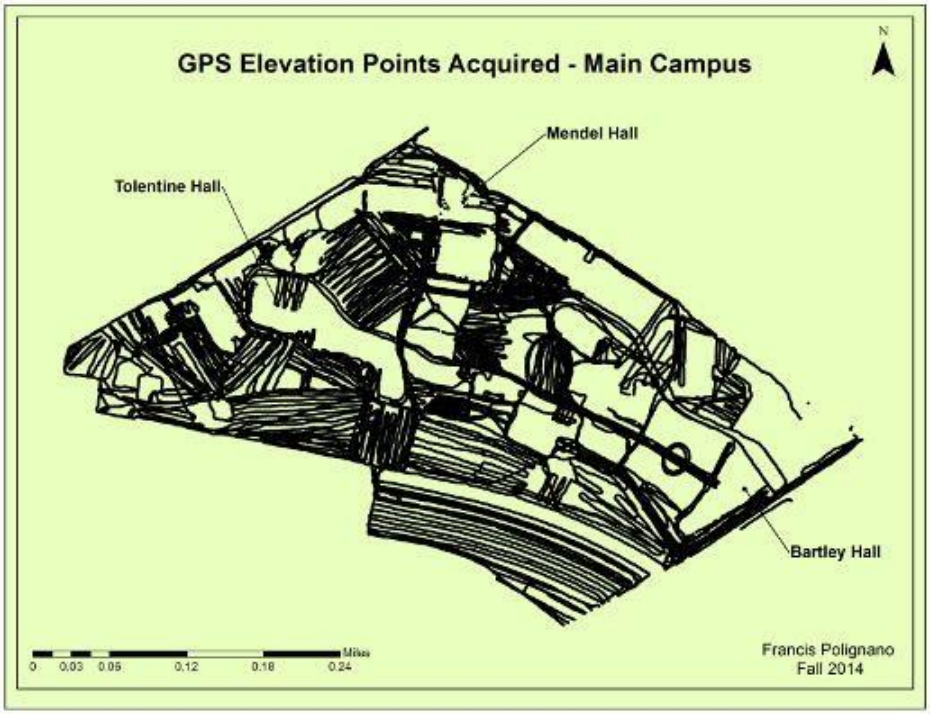

Figure 1. GPS Elevation Points Acquired – Main

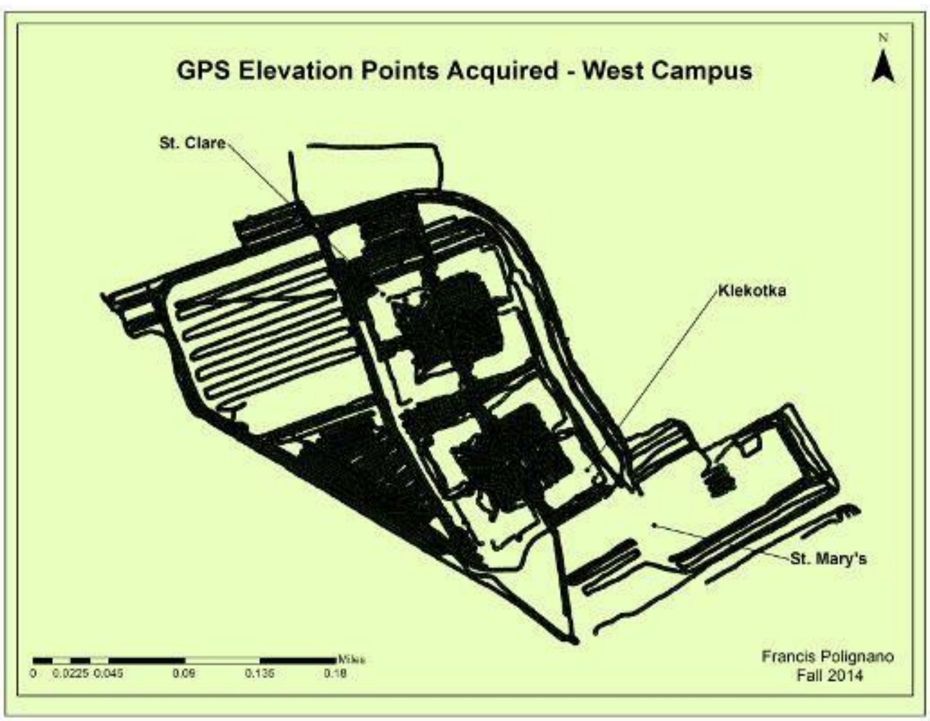

Figure 2. GPS Elevation Points Acquired – West

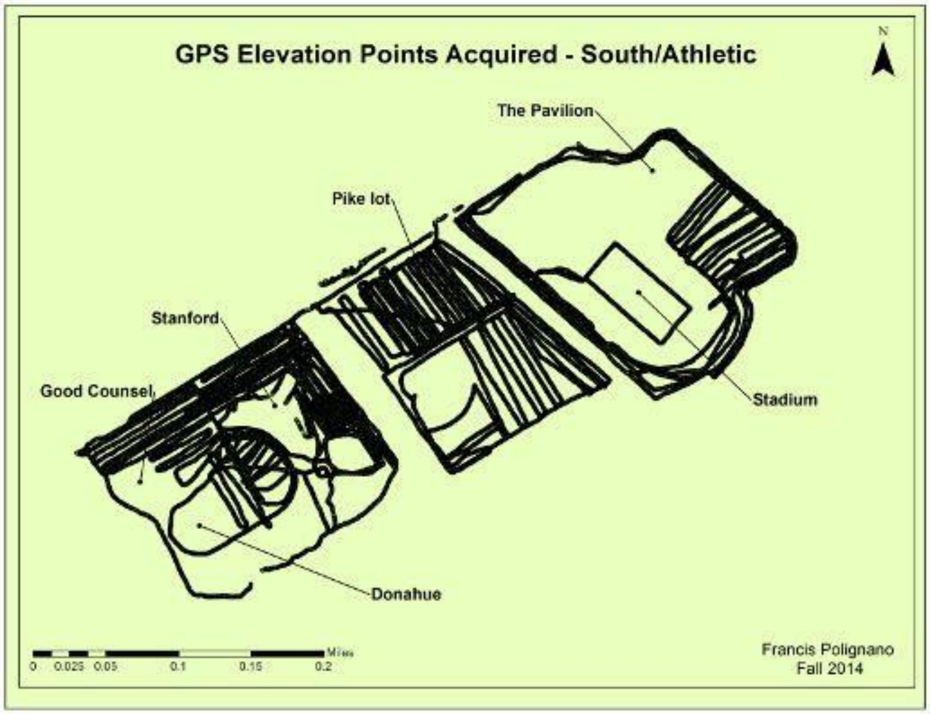

Figure 3. GPS Elevation Points Acquired - South

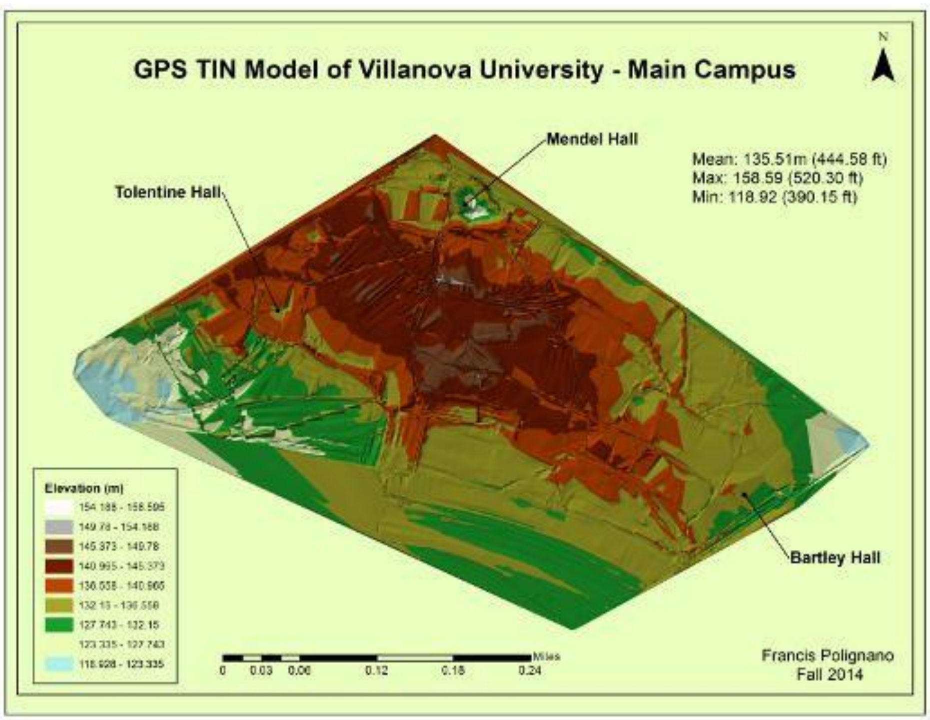

Figure 4. GPS Tin Model – Main

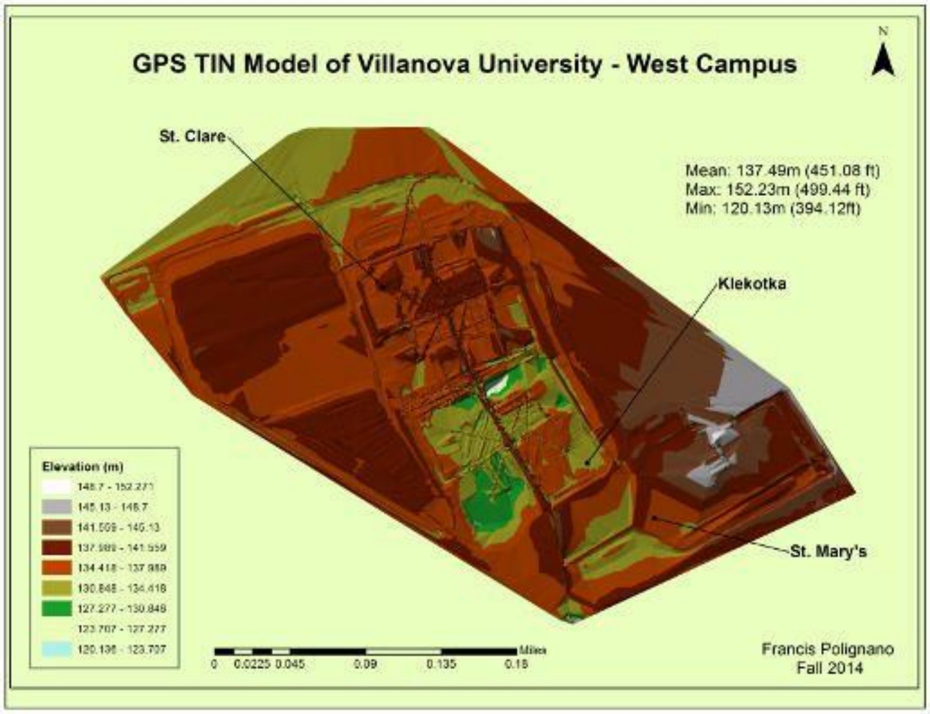

Figure 5. GPS TIN Model – West

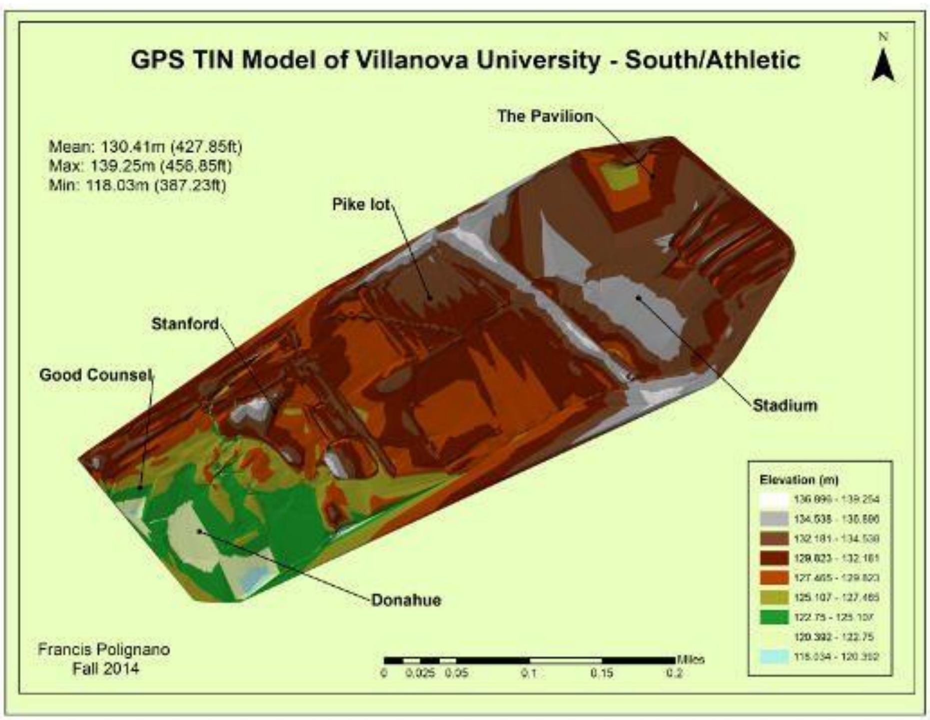

Figure 6. GPS Tin Model – South

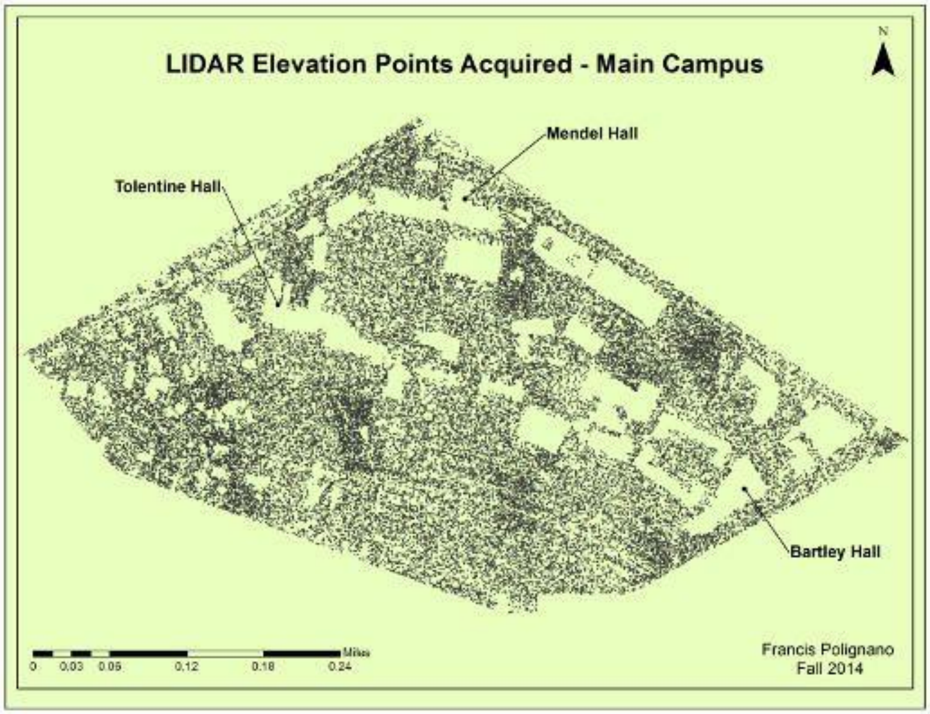

Figure 7. LIDAR Elevation Points Acquired – Main

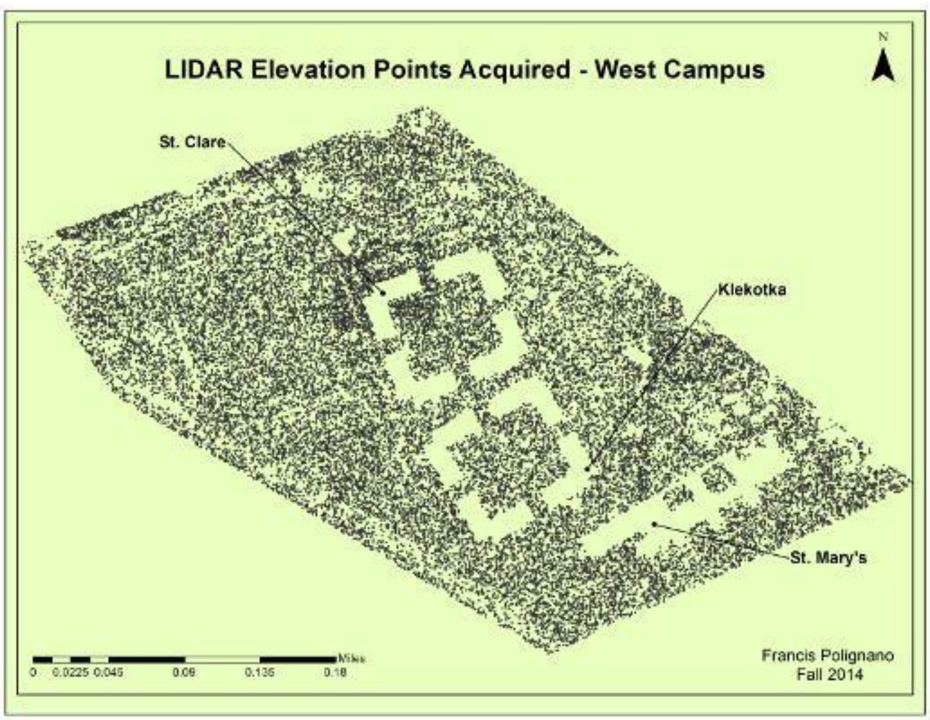

Figure 8. LIDAR Elevation Points Acquired – West

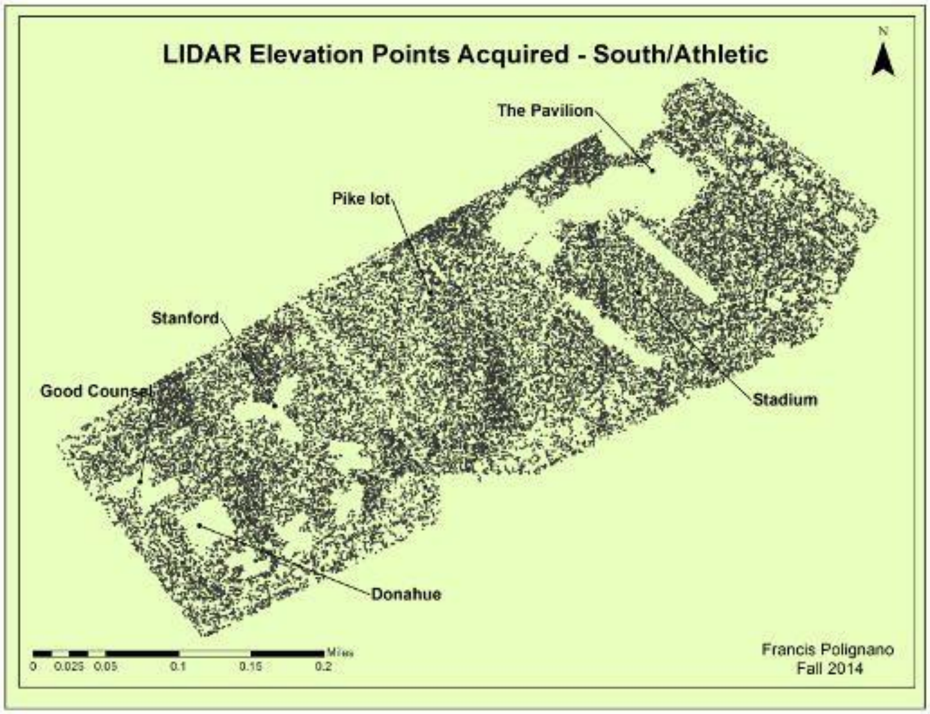

Figure 9. LIDAR Elevation Points Acquired – South

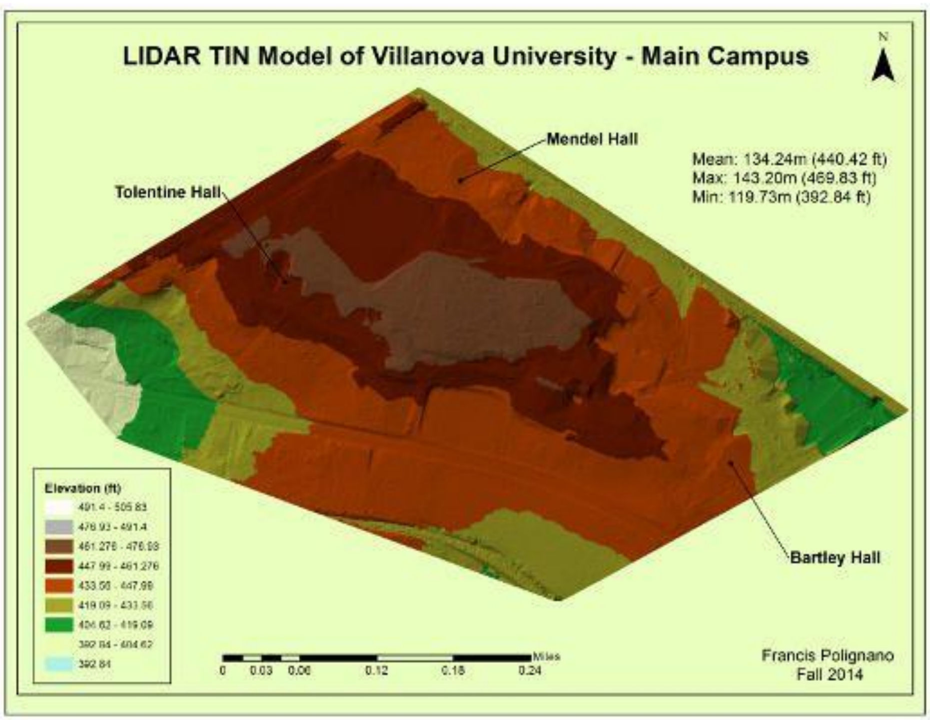

Figure 10. LIDAR TIN Model – Main

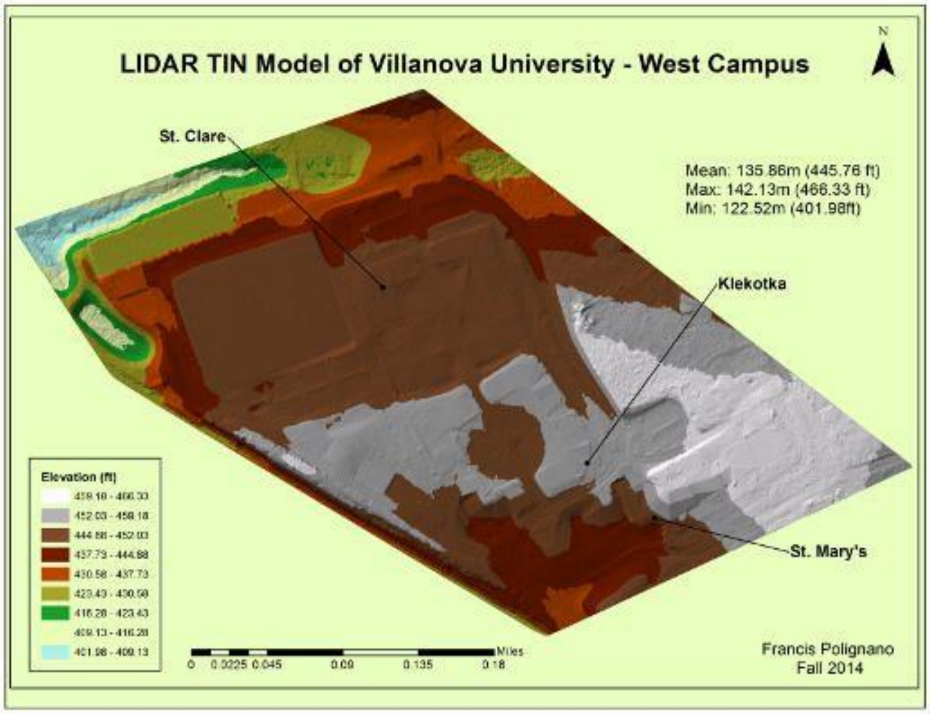

Figure 11. LIDAR TIN Model – West

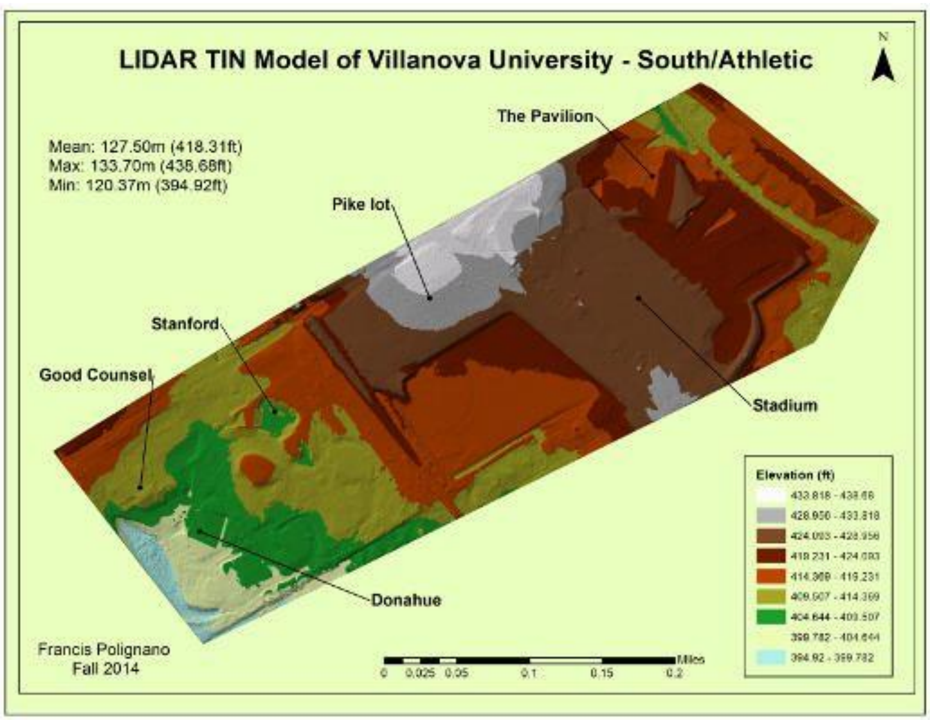

Figure 12. LIDAR TIN Model – South

Table 1. GPS and LIDAR Mean, Max and Min Elevation Values (feet)

		GPS	LIDAR
Main	Mean	444.58	440.42
	Max	520.3	469.83
	Min	390.15	392.84
West	Mean	451.08	445.76
	Max	499.44	466.33
	Min	394.12	401.98
South	Mean	427.85	418.31
	Max	456.85	438.68
	Min	387.23	394.92

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