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Determining the Feasibility of a Sponge City Design on Montclair State University Campus

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ABSTRACT

In this project I examine the sponge city concept as a Low Impact Development (LID) approach to mitigating the adverse impact of stormwater runoff. LID techniques incorporate Green Infrastructure (GI) practices, which minimize the adverse impact of contemporary urban areas. Specifically, I am examining LID on the Montclair State University (MSU) campus within the context of stormwater runoff

The Quad and the Quarry, two areas on the MSU campus, were selected for both their topographic depressions for containing runoff and for their built environment with large buildings and parking lots, an urban design feature that increase runoff. A 1/9 arc-second Digital Elevation Model (DEM) was downloaded and analyzed in ArcGIS Pro to determine surface flow characteristics at these two sites. The buildings and parking lots were extracted and digitized to evaluate the feasibility of the following GI design solutions: extensive green roofs, rain gardens, porous asphalt, and bioswales.

Based on the slope of the ground surface, stormwater drains towards the Quad and Quarry. During large weather events, the stormwater runoff from the buildings and parking lots at these two locations could be directed there. The amount of runoff each study area can collect and store is 3,761 m^3 for the Quad and 94,579 m^3 for the Quarry. Designing a LID approach with GI can provide flood resiliency and alleviate storm damages. This sponge city concept can minimize the negative effects of flooding by reducing runoff, improving water quality, and enhancing ecosystems.

The Soil Conservation Service Curve Number (SCS-CN) was used to quantify runoff. Extensive green roofs at the two sites would reduce stormwater runoff by approximately 30% compared to metal roofs. The Rational Method was used to calculate the peak discharge to prevent overwhelming and overflowing stormwater systems on campus.

A Cost-Benefit Analysis (CBA) was calculated using a Life Cycle Cost Analysis (LCCA) and Benefit Analysis (BA). Published costs derived from these methods were used to determine the cost effectiveness of the GI design practices. The LCCA analyzed total project cost. Using CBA I found extensive green roofs to provide a saving of about $34 million in life cycle costs over its projected 40-to 50-year lifespan. Savings were generated through mitigation of projected environmental costs. Rain gardens over a 20-year life expectancy provided a saving of approximately $760,000. Similarly, bioswales had a saving of around $600,000 over 20-year lifespan. Porous asphalt costs exceeded saving by $2 million.

Keywords:
Sponge City
Low Impact Development (LID)
Green Infrastructure (GI)
Digital Elevation Model (DEM)
Geographic Information System (GIS)
Montclair State University (MSU)

MONTCLAIR STATE UNIVERSITY

DETERMINING THE FEASIBILITY OF A SPONGE CITY DESIGN ON MONTCLAIR STATE UNIVERSITY CAMPUS

By
Megan Barron
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1. Introduction

A sponge city is a concept that is incorporated in urban areas to provide flood control by encouraging infiltration and minimizing stormwater runoff. To do this, sponge cities integrate features such as green roofs, permeable pavement, and contiguous open green spaces. In sponge cities the surface water ideally infiltrates into the local groundwater, where it can be treated and utilized for city water supply (World Future Council, 2016). Some advantages of designing sponge cities include improved water quality for drinking and groundwater, reduction in flood risks/hazards, and ecosystem services (Jenkins, 2020). Sponge cities also provide a sense of biophilia–or a connection with nature–repair the damaged natural habitats caused by urban development, and minimize the effect of urbanization.

One country that has embraced the idea of sponge cities is China. China faces many water related issues such as flooding, waterlogging, and water quality that were addressed by incorporating a sponge city design (Dai et al., 2017). Professor Kongjian Yu conceived the term “sponge city” in 2013 for urban stormwater management (Griffiths et al., 2020). There is a similar concept known as Low Impact Development (LID) in the United States or Sustainable Drainage Systems (SuDS) in the United Kingdom (Gill, 2021). A sponge city design is a relatively new approach to flood mitigation and improvement of water quality and quantity. Several case studies implemented sponge cities and documented the benefits it provides.

The government in Wuhan, China introduced a sponge city program to improve impaired water quality and reduce flooding issues affected by runoff. In Wuhan, sponge cities circumvented waterlogging from excess stormwater runoff and potentially reuse the filtered and treated water (Dai et al., 2017). The sponge city design also minimized the damages associated with waterlogging and increased infiltration (Dai et al., 2017).

Water quality and quantity issues were also investigated during a case study for sponge cities in Changzhou, China (Li et al., 2017). Li et al. analyzed how sponge cities could treat the contaminated water supply and reduce urban flooding problems. The sponge city design integrated a LID approach to remediate different types of water issues to create a sustainable environment. After the sponge city application in Changzhou, the water problems were reduced and increased green spaces (Li et al., 2017).

Another sponge city design was introduced in Zhengzhou, China to manage the issues linked from water shortages and waterlogging (Dong et al., 2019). Once the sponge city was applied the stormwater was reused and repurposed to regulate water quantity concerns. Sponge cities addressed the water challenges in three different cities in China stemming from expanded urban systems.

1.1. Urban Systems

Cities have expanded urban systems such as residential houses, commercial and industrial buildings, roads, etc. and ultimately reduced green space. Roads, roofs, and other impermeable paved surfaces allow runoff to directly impact local waterways (Müller et al., 2020). Land consumption through urban development has adverse effects leading to stormwater runoff linked to erosion, flooding, degraded habitat, and water quality (Ferreira et al., 2018). Impervious surfaces transport and convey pollutants from urban stormwater runoff that deteriorate the water quality. Soil erosion has been linked to excess runoff that breaks down the organic matter and nutrients found in topsoil (Du et al., 2021). Intense rainfall leads to higher runoff rates that cause transportation of suspended sediment load (Mohamadi and Kavian, 2015). Stormwater runoff causes soil loss that damages nearby waterways and land mass. Urban development reduces natural lands where rainwater minimizes infiltration or evapotranspiration and quickly turns into runoff (Qin, 2020). Impermeable surfaces cause runoff to result in flooding due to the minimized green areas and overflowed drainage systems. Climate change escalates the runoff volumes in areas with increased storms.

1.2. Impact on Climate Change

Flooding is a major hazard to urban areas, and is made worse due to the impacts of climate change. Climate change has fueled more intense and frequent storms with record temperatures (NJDEP, 2020). These record temperatures influence large weather systems such as hurricanes, tropical storms, and weather fronts that are fueled by warm moist air (NASA, 2019). As temperatures increase and more evaporation occurs, it contributes to more water vapor concentrations in the atmosphere (NASA, 2019). Water vapor becomes trapped and retained due to the excess heat fueling extreme storms.

The latest storm that affected northern New Jersey was Hurricane Ida. On September 1, 2021, Hurricane Ida, previously a category 4 storm, quickly flooded large overdeveloped areas of northeastern New Jersey. In some parts of New Jersey, Hurricane Ida released around 30 centimeters of rainfall (Torres, 2022). The cause for concern was flash flooding from the previous tropical storm, Henri, which saturated the ground

August 22-23, 2021 (Torres, 2022). The waterlogged ground produced stormwater runoff at higher rates. Even a tornado made landfall during Hurricane Ida.

Previous large storms to impact the area include Hurricanes Floyd and Irene. During September 15 to 16, 1999, Hurricane Floyd dropped approximately 30 centimeters of rainfall inland that flooded several river systems (Robinson, 2000). Northern and central New Jersey were impacted with record rainfall amounts, especially Bergen, Essex, and Passaic counties (Robinson, 2000). On August 27 to 28, 2011, Hurricane Irene, a category 3 storm, released between 20 to 40 centimeters of rainfall on New Jersey (USGS, 2011). The volume of rain overflowed several rivers that flooded multiple homes and buildings. Torrential rainstorms similar to Hurricanes Floyd, Irene, and Ida are prime examples of how stormwaters can quickly flood urban areas with increased impervious surfaces.

1.3. Low Impact Development

Low Impact Development or (LID) is a land usage design and approach that mimics the natural environment by mitigating stormwater runoff produced from urbanization (Martin-Mikle et al., 2015). Green Infrastructure (GI) is a type of LID that incorporates natural practices to manage stormwater runoff through the preserving, recycling, reducing, and reusing of natural areas. Common GIs include green roofs, rain gardens, bioswales, porous pavement, etc. that together constitute a sponge city concept. GI retains floodwaters through natural storage by evaporation and infiltration (Bai and Guo, 2021). In the U.S., a LID might only incorporate a single GI while sponge cities integrates multiple GIs (Li, 2018). Designing a LID using GI across regions susceptible to flooding can alleviate the negative impacts of heavy rainstorms. Hurricane Ida affected Montclair State University's (MSU) campus even with its implementation of some aspects of LID. Integrating a sponge city design will allow for an alternative to traditional flood control methods by encompassing LID with GIs.

Green roofs are an alternative to traditional roofs that integrate vegetation to decrease stormwater runoff. There are two main types of green roofs: extensive and intensive. Extensive roofs are cheaper to install and have a thinner substrate layer while intensive roofs are expensive to install and maintain, since they incorporate small trees and shrubs with a thicker substrate layer (GSA, 2011). Extensive roofs are ideal for commercial and public buildings since it is envisioned for garden amenity space and requires low maintenance. An extensive green roofs comprises 6 different layers starting from the base: waterproof membrane, root resistant barrier, drainage layer, filter plate, growing medium or substrate layer, and vegetation layer (Marafa and Alibaba, 2019) (Figure 1, Townshend and Duggle, 2007). Extensive green roofs would not be an unknown concept because Montclair State currently has an extensive green roof integrated on the Center for Environmental and Life Sciences (CELS) building. (Figure 2, MSU, 2017).

Rain gardens or bioretention systems are depressions in the ground that collect the stormwater runoff from various outlets such as conventional roofs, impermeable pavement, or other impervious surfaces. The structure of a rain garden has three main parts: ponding area, inflow structure, and overflow structure (Basdeki et al., 2016). At the top is the ponding area that is either naturally or artificially constructed in the ground with several layers lined on the bottom. Beginning at the base, the first layer consists of gravel that is used for capturing the excess water from the second layer. The bulk contains mulch and topsoil (Malaviya, et al., 2019) (Figure 3, MassDEP). Surface areas with a large slope are not ideal for rain gardens, because an earth berm would need to be constructed to account for unevenness (Malaviya, et al., 2019). Stormwater runoff would be directed towards the ponding area using an inflow structure. As the water overflows in the ponding area, it is directed towards an outlet such as a sewer. Typically, the depths of rain gardens are 0.8 to 0.9 meters with backfill that is composed of sand, topsoil, and organic matter (Malaviya, et al., 2019). The collected stormwater runoff infiltrates into the ground to replenish the vegetation (Malaviya, et al., 2019). Rain gardens can be ecodesigned with native plant species that are planted to enhance biophilia, biodiversity, and reduction of peak runoff rates. Native plant species provide higher absorption rates due to the elongated root systems. As stormwater is infiltrating into the rain gardens, there are reduced the amounts of pollution being outputted into nearby bodies of water. It contributes to an adequate stream flow when there are dry seasons because it increases recharge and infiltration. Rain gardens were constructed on MSU campus in front of the CELS building as parts of storm management practice (Figure 4).

Porous asphalt is a type of porous pavement that serves as an alternative to impermeable pavement and acts as a stormwater management to minimize surface runoff. The structural design consists of an aggregate base, or subbase, reservoir layer, a choker-stone layer or treated base layer, and a porous asphalt layer on top (Bruinsma et al., 2017, Figure 5). Stormwater can pass through the interconnected void spaces of the porous asphalt layer since it has a finer grained subgrade mixture (Bruinsma et al., 2017). Porous asphalt increases infiltration through the void spaces to minimize runoff. The stormwater runoff would filter contaminants to reduce conveyance through waterways and storm sewers.

Bioswales are type of stormwater runoff system, which are engineered and constructed, into or extended off from, impermeable surfaces (Everett et al., 2015). Bioswales increase storage capacity through transpiration that reduces soil moisture (Everett et al., 2015). There are several layers to create a bioswale that consists of gravel at the base with a perforated pipe. In the middle is the bioretention soil and mulch layer. On top is the bioretention swale with multi layer vegetation. These layers help filter and slow down stormwater runoff from entering the groundwater (Figure 6; Brankovic et al., 2019). Native vegetation has better filtration of contaminants carried by runoff compared to non-native vegetation (NRCS 2005). Integrating native plant or grass species will increase the infiltration and absorption rates of stormwater. Bioswales were applied on MSU campus in front of the CELS building that was connected through sidewalks (Figure 7).

1.4. Study Area

The first study area is the Quadrangle or “Quad” that is located in the center of campus. The surrounding buildings are Student Center and Annex, the School of Nursing/ the Graduate School, Calcia Hall, Finley Hall, Conrad J. Schmitt Hall, and Center for Computing and Information Science. The second study location is the Quarry at the North End of Campus and Route 46, 1968 (MSU, 2020) or “Quarry” is situated at the north end of campus. The Quarry buildings are the Overlook Corporate Center, Overlook Corporate Center Parking Lot, MSU Train Station, Dioguardi Field–including two parking lots–and Yogi Berra Stadium. Both study areas are illustrated in Figure 8.

1.5. Social, Economic, and Environmental Impact

A sponge city concept includes LID techniques that provide many social, environmental, and economical benefits when integrating a GI design. Sponge cities are a comprehensive collection of GI, with each of its own individual advantages. Evaluating every aspect of a sponge city approach with GI will allow a community to mitigate stormwater runoff issues stemming from climate change.

Sponge cities improve a community aesthetically, through public health and human welfare, and sustainably (Liu et al., 2022). The aesthetics of sponge cities will improve and encourage faculty and students to go towards the Quad and Quarry. However the Quarry is in an isolated location on campus that makes it an uncommon area for the students and faculty to visit. In contrast, the Quad is positioned in the center of campus and is currently used for recreational or school activities. The newly added greenery will enhance the Quad to become a more popular attraction, although for a different use than it currently is. MSU could be a showcase for other campuses to adopt a sponge city design while integrating various GIs.

A sponge city uses various GIs to increase exposure to the natural environment and biophilia by adding biodiversity and habitats with native plant species. Native vegetation and grass increases infiltration through the extended root systems and higher retention of rainwater. Each GI offers multiple benefits that were examined through a Benefit Analysis or (BA). Rain gardens, bioswales, and porous asphalt reduce water pollution through filtration by incorporating several gravel layers, mulch layers, and using native plants. Green roofs reduce heat island effect through evapotranspiration and improve air quality through carbon storage. The carbon sequestration of rain gardens, bioswales, and green roofs are higher due to the vegetation and bioretention soil layers (Kavehei et al., 2018). The various GI for the sponge city technique will improve hydrological performances such as flood mitigation, groundwater recharge, and increased ecological benefits (Liu et al., 2022). Further investigation of each benefit was evaluated in a BA (Tables 6A, 7A, 8A, and 9A).

Extensive green roofs and rain gardens on and around the buildings surrounding the two study areas will increase the amenity value and reduce stormwater and energy costs. Initially, the rate to construct sponge cities with GI is more expensive than traditional urban systems. A cost-benefit analysis (CBA) would be used to determine if the overall benefits would outweigh the costs since MSU would be saving in longevity. The CBA would analyze the life cycle cost analysis of initial construction costs, operations and maintenance, and disposal (Tables 6B, 7B, 8B, and 9B). Routine maintenance and operations are essential for a cost-effective and successful GI approach. Stakeholders might implement the sponge city concept on commercial and office buildings.

1.6. Project Significance

The importance of this project is to promote and incorporate greener methods that traditional grey infrastructures lack. Grey infrastructure increases stormwater runoff through various urban systems with impervious areas. Future storms will generate more rainfall amounts and GIs are needed to produce a sponge city to mitigate stormwater runoff. The purpose of this project is to determine the effectiveness of a sponge city design incorporating green infrastructure in order to reduce issues linked from runoff. Implementing a sponge city design to susceptible areas will understand its overall effectiveness and performance as a flood prevention method.

MSU has integrated several different types of GI across campus such as green roofs, bioswales, and rain gardens. Multiple buildings on campus are part of the Leadership in Energy and Environmental Design or (LEED) certificates. LEED is a worldwide recognized rating system for implementing green buildings. The project is intended for MSU administration in the offices of the Vice President and Campus Health and Safety since they are in charge of making important decisions and following proper health and safety protocols. MSU recognizes the stormwater benefits GIs provide, which highlights the feasibility of a sponge city design on campus.

MSU campus is approximately 2,000,000 m^2 but the two study areas, Quad and Quarry and surrounding buildings, were analyzed using DEMs in a Geographic Information System (GIS). A digital elevation model (DEM) is a 3D representation of the topological surfaces produced from elevation data that excludes surface objects (DEP, 2013). DEMs are a raster grid of the Earth’s terrain formulated from the GIS layer. DEMs are referenced to the elevation data based on the vertical datum. The bare ground was mapped with spatial resolutions that vary in size (DEP, 2013). DEMs are collected from ArcGIS Pro Version 2.6 (ArcGIS Pro) by a variety of source satellite, aerial, or plane data. The images were displayed as a raster grid that is mainly seen as a cube or 3x3x3. I chose the highest-resolution DEM available (i.e., the DEM with the smallest grid cell size) that was a 1/9 arc-second or 3-meter DEM. Each cell value corresponds to the ground elevation above sea level that was measured in a cubic foot.

Digitization is a process that converts geographical data from downloaded aerials or photographs into vector data through tracing features (Buhur, 2009). The traced geographical features are stored as coordinates that capture and create a point, line, or polygon. The digital aerial maps were utilized to extract roofs and parking lots from campus to determine if green roofs, rain gardens, porous asphalt, and bioswales would be applicable.

Watersheds on campus were located to find the surface water drainage. Watersheds are land areas that drain all of the surface water from rainfall and streams towards a shared outflow point. An outflow point is the land areas that drain the surface water towards the outflow location (Water Science School, 2019). With heavy rainfall events the stormwater can convey and collect pollutants that will affect the watersheds. A majority of the precipitation falls and pools within a watershed but it can infiltrate, evaporate, transpire or evaporate, and store (NOAA, 2021).

1.7. Topography and Geology

New Jersey is comprised of different types of terrains that range from low-lying coastal plains to hilly, rocky regions. MSU is situated on a gently sloping to relatively steep topography. In the Essex County Soil Survey Data, MSU is part of the Boonton substratum-Boonton complex urban land (NRCS, 2007). The landscape is categorized as the Till Plain, where MSU is on the Rahway Till Formation. Based off of the USGS Bedrock Geology Map of the Orange Quadrangle, the Passaic Formation of the Lower

Jurassic and Upper Triassic is an interbedded sequence of reddish-brown sandstone and a mix of pebbly sandstone and shaly siltstone. According to USGS Surficial Geology of the Orange Quadrangle, the Rahway Till is reddish-brown to light-reddish-brown silty sand to sandy clayey with various ranges of pebbles to boulders.

Building off of these previous studies, I have applied the concepts of sponge city techniques to calculate the runoff volumes from areas in MSU campus, and how much of that volume could be stored in the Quarry and Quad. I have digitized buildings and parking lots bordering the two study areas. I created a Benefit Analysis (BA) and Life Cycle Cost Analysis (LCCA) that was used to determine a Cost-Benefit Analysis (CBA). I then calculated the CBA of green installations. After I produced a Cost-Benefit Analysis, a benefit cost ratio was generated to evaluate if a project was economically feasible.

2. Methodology

2.1. GIS Methods

In ArcGIS Pro, fill, flow direction, and flow accumulation are tools that determine the direction of surface water flow. These methods were helpful since it helped determine the surface water flow of the watersheds in and around the campus of MSU. Additional surface hydrology tools were applied to find the total volume and maximum depth of the Quarry and Quad. This would assist in estimating how much stormwater runoff can fill both of the study areas.

2.1.1. Surface Hydrology Tools

I used DEMs to determine the surface water flow direction by determining the direction of greatest slope. I downloaded a 1/9 arc-second (3-meter) DEM from the United States Geological Survey (USGS) National Elevation Map (NED), which was added to the ArcGIS map. I utilized ArcGIS Pro to analyze the surface flow direction, accumulation, and watershed on campus to determine the feasibility of a sponge city design.

I utilized the clip tool to crop areas that were within two kilometers of MSU to focus on a smaller section on and near campus. I combined the clipped DEM with the 3-meter DEM in New Jersey to show the location (Figure 9).

If there is a sink or unevenness in the surface that creates an internally-drained basin, the Fill command tool will automatically fill in the DEM for the surface to be hydrologic-connected. With the Fill command tool any depressions, such as sinks, were removed or smoothed out to eliminate discontinuities in the drainage network (Ozdemir and Bird, 2009) (Figure 10, ArcGIS Pro).

The Flow Direction for each pixel was created utilizing the filled DEM, where the direction of surface water would flow out of the cell to one of the eight surrounding pixels (Ozdemir and Bird, 2009). Flow direction is represented with a single arrow in each cell that points to where the surface water follows the steepest slope. I inputted the filled DEM into the flow direction tool to demonstrate the eight different ways a particle could flow towards the steepest descent. The various colors corresponded to the direction of where the ridges' faced using the 8D pour point model (Fairfield and Leymarie, 1991). (Ozdemir and Bird, 2009). Each output number correlates with a compass direction where 1 is East, 2 is Southeast, 4 is South, 8 is Southwest, 16 is West, 32 is Northwest, 64 is North, and 128 is Northeast. The clipped filled DEM was entered into the flow direction tool (Figure 11).

The cells were assigned a value equal to the number of cells drained through a given cell in the flow accumulation (Ozdemir and Bird, 2009). Flow accumulation tool calculated the weight accumulation of all the cells determined from the flow direction. Each arrow is allotted a weight that is dependent on how many arrows are flowing into each cell. If an arrow is not pointing into another cell, then the weight is a value of 1. Flow accumulation is the accumulated weight of all the cells flowing into the steepest cell of the output raster. Cells with a high flow accumulation or in white color signified the concentrated flow areas, which could potentially be used to identify stream channels. The cells with values of 0 or in black color were used to identify ridges. Flow accumulation was created from the clipped flow direction DEM that shows the tributaries of the different watersheds the surface water drained to see Figure 12A.

The maximum stretch type was increased to 95 to display the streams that were too small and not visible. Once the streams were more visible I identified several streams closer to campus. A pour point shapefile was created that had to be positioned on the exact grid cell displayed on the stream. The pour point shapefile was placed along the Quarry. The pour point was produced using the flow accumulation map that was named Quarry. Two additional pour point shapefiles were created West of Quarry and along Normal Avenue. The locations of the three pour points are shown in Figure 13A. I created a topographic map showing the five pour point locations (Figure 14).

The watershed tool was utilized by inputting the flow direction map with the Quarry pour point shapefile created. If the pour points were not accurately placed on the exact grid cell then the watershed tool would not run properly. The primary symbology was changed to Unique Values to have one solid color to display the watershed. The Normal Avenue watershed was produced to see if any surface water drained towards the Quad. Based on the watershed, the Normal Avenue watershed does drain the Quad but covers a larger portion Southwest of campus. All three watersheds were produced (Figure 15A).

I could not locate any tributaries for the Quad on the filled 3-meter DEM. I did not use the Fill tool since the tributaries for the Quad were smoothed out. I applied the Flow Direction and Flow Accumulation tools using the clipped 3-meter DEM. The unfilled flow accumulation DEM had smaller, interconnected tributaries that were more visible (Figure 12B. Two pour points were placed on the Quad watershed tributary boundaries (Figure 13B). The watershed tool was used to illustrate where the pour points were placed (Figure 15B).

I used the Cut/Fill tool to find the volume difference from the unfilled 3-meter DEM and filled DEM. The Cut/Fill tool subtracts the unfilled DEM by the filled 3-meter DEM, which outputs a new raster that displays the DEM showing the net gain in red, unchanged in grey, and net loss in blue. I found the Quarry and Quad polygons from the cut/fill DEM (Figure 16). I clipped each area to separate and then calculated the area. I utilized the raster calculator by subtracting the clipped filled Quarry and Quad layer from the clipped unfilled Quarry and Quad layer. I selected the polygons and exported each area into its own layer. I applied the extract by mask tool by inputting the clipped DEM and the exported polygons of the Quarry and Quad. After I used the extract by mask tool, the output raster depicted a range of cell values for both study areas (Figure 17).

I calculated the depth of cells by multiplying the depth in meters by count values. The count values are how many values of depths in meters are repeated. I computed the volume in cubic meters by multiplying the depth of cells by 9. I summed all the volumes to get the total volume. I divided the total volume by the total area for the Quarry and Quad (Tables 1A and B).

2.2. Digitization

In ArcGIS Pro, I digitized the buildings' rooftops and parking lots around the two study areas. I digitized the watersheds and two focus areas. I used the polygon format and traced the downloaded aerial photographs for the mentioned above locations.

I digitized the Quad and Quarry buildings and parking lots. The digitized buildings for the Quad were Student Center and Annex (North), the School of Nursing/ the Graduate School (West), Calcia Hall (West), Finley Hall (South), Conrad J. Schmitt Hall (East), and Center for Computing and Information Science (East) (Figures 18A and B). The Quarry digitized buildings and parking lots were the Overlook Corporate Center (North), Overlook Corporate Center Parking Lot (North), MSU Train Station (Southwest), Dioguardi Field plus two parking lots (South), and Yogi Berra Stadium (South) (Figures 19A and B). I digitized the Quarry, Quarry West, Normal Avenue, Quad, and Quad South watersheds and two study areas, the Quad and Quarry.

2.3. Calculations

I converted each raster into a polygon in order to calculate the area in square meters. The area calculations of each digitized buildings and parking lots around the Quad and Quarry, watersheds, and two study areas (Table 2A through D).

2.3.1. Total Precipitation

After I calculated the area, the volume was computed from the average point rainfall amounts listed by the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Volume 2 (2020). The table illustrated NOAA County-Specific, New Jersey 24-hour Rainfall Frequency Data measured in inches and displayed the counties of New Jersey, years, and rainfall amounts. MSU is located on the border of Essex and Passaic Counties with a large portion of campus in Passaic County. I chose the Passaic County's rainfall amounts for all of the calculations (Appendix 1).

The rainfall amounts were converted to meters in order to find the total volume of rainfall in Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms. I calculated the total volumes by multiplying the area in square meters by the rainfall amount in meters for the digitized watersheds, the two study locations, buildings and parking lots surrounding the Quad and Quarry (Appendices 2A through 2D).

2.3.2. Soil Conservation Service-Curve Number Method

I applied the NOAA rainfall events to calculate the total precipitation runoff volume from the watersheds utilizing the Soil Conservation Service Curve Number (SCS-CN) method. The SCS-CN method was able to calculate direct runoff volumes for a rainfall event (Soulis, 2021). SCS-CN is an empirical method to determine the relationship between ground conditions (i.e., soil, management, and ground conditions) and rainfall (P) (Alves et al., 2019). The Curve Number was dependent on the soil moisture conditions by using the Hydrologic Soil Group and Land Use Description. The Curve Number for parking and paved spaces was 98 for Hydrologic Soil Group C and D and the average was 98. I calculated the Curve Number for parking and paved spaces for Hydrologic Soil Group C at 79 and D was 84 and the average was 81.5. The Curve Number for parking and paved spaces was 98 for Hydrologic Soil Group C and D and the computed average was 98.

Hydrologic Soil Groups are classified by the Natural Resource Conservation Service and estimated from runoff potential and appointed to one of the four groups where A has the smallest and D has the greatest runoff potential (NRCS, 2009). The Hydrologic Soil Group for campus is C or D. Hydrologic Soil Group C has a slow infiltration rate when saturated and composed of sandy clay loam (Purdue, 2022). Hydrologic Group D has a very slow infiltration rate, or high runoff potential when saturated and composed of predominantly clay layers.

The Hydrologic Soil Group for the study area lies on Boonton that is categorized as Hydrologic Group C or D (NRCS, 2009). The land use descriptions utilized for traditional roofs and green roofs would use parking, and paved spaces, and open spaces (Purdue, 2022). I calculated the curve number by taking the average between Hydrologic Soil Group C and D for lawns, parking lots, and roofs. I computed S and then Q by using the storm frequencies and then converted the results into meters. I calculated the total volume runoff by multiplying the Q by the total area (SWAMP, 2021). I subtracted the buildings and parking lots within the Normal Avenue, Quarry, and Quarry West watersheds because those watersheds covered most of those buildings around the Quad and Quarry. I did not subtract the buildings for the Quad and Quad South watersheds with only portions of the buildings being covered by the two watersheds.

$$S = \left(\frac{1000}{CN}\right) - 10 \qquad Q = \frac{[(P - 0.2\,S)^2]}{(P + 0.8\,S)}$$

(NCRS, 2009 and Purdue, 2022)

S – potential maximum retention after runoff begins
CN – Curve Number from TR-55
Q – direct runoff in inches
P – rainfall depth in inches

$$Calculate\ Volume = Q \times Total\ Area$$

2.3.3. Rational Method

The average rainfall intensity data collection was used from the NOAA storm frequencies rainfall amounts that were converted into mm/hr (Appendix 1). The runoff coefficient was determined based on Runoff Coefficients for Urban Watersheds (Thomason, 2019). The runoff coefficient for roofs ranged from 0.75 to 0.95, asphaltic was 0.85 to 0.95, and the track and field that used sandy soil was 0.10 to 0.15. I converted the area for the digitized locations into hectares. I calculated the maximum peak runoff rate from a watershed using the runoff coefficient, average rainfall intensity, and drainage area divided by 360 to convert into meters.

$$Q = \frac{CIA}{Z}$$

Q – Maximum rate of runoff (m^3/second)
C – Runoff Coefficient
I – Average Rainfall Intensity (mm/hr)
A – Drainage area (ha)
Z – Conversion factor (360 for metric) (Thomason, 2019)

2.4. Green Infrastructure Benefit Analysis

I researched each GI benefit that was appointed a value to determine the annual avoided cost for each benefit. Extensive green roofs, rain gardens, porous asphalt, and bioswales were examined to help assess the benefit savings of this project. The main benefits that were analyzed are in (Tables 6A, 7A, 8A, and 9A).

I produced a BA for an extensive green roof to analyze the various benefits this GI offers. I multiplied each benefit with avoided costs with the total area for the buildings and parking lots around the Quad and Quarry (Table 6A). The reduced stormwater runoff has benefits savings of \$22 per m^2 (Feng and Hewage, 2018). Extensive green roofs provide increased amenity value with all the greenery of benefit savings of \$5 per m^2 (Feng and Hewage, 2018). The lifespan of extensive green roofs is about 40-to 50-years with benefits of \$160 per m^2 (Bianchini & Hewage, 2012). No costs were appointed for improvement of air quality and reduction in urban heat island effect. I then computed the total benefit savings from the BA in Table 6A.

I generated a BA for rain gardens that have many benefits that decrease costs over time. The total area was multiplied by each benefit for the Quad and Quarry buildings and parking lots (Table 7A). The runoff is decreased through natural infiltration with avoided costs of \$12 per m^2 (Nordman et al., 2017). Amenity value of added greenery has benefits of \$5 per m^2 (Nordman et al., 2017). Benefit savings for filtering pollutants was

\$1 per m^2 (Nordman et al., 2017). The water quality is improved from the pollutants being removed with benefits of \$28 m^2 (Autocase, 2018). Improving air quality had benefits of \$12 per m^2 (Autocase, 2018).

I created a BA for porous asphalt by examining the benefits this GI provides. I multiplied each benefit by the total area for the parking lots around the Quarry (Table 8A). Reducing stormwater runoff rates has benefits to be \$5 per m^2 (Autocase, 2018). Filtering pollutants has benefits worth \$1 per m^2 (Nordman et al., 2017). The water quality is improved that helps save about \$29 per m^2 (Autocase, 2018). Minimized heat island effect helps avoid costs of \$4 per m^2 (Autocase, 2018).

I conducted a BA for bioswales to investigate the benefit savings for this project. The total area was multiplied by each benefit for the Quarry parking lots (Table 9A). Bioswales reduce stormwater runoff with avoided costs of \$15 per m^2 (Nordman et al., 2017). Amenity value has benefits of \$3 per m^2 (Nordman et al., 2017). The benefits for bioswales improving water quality are \$29 per m^2 (Autocase, 2018). Air quality has improved with benefits of \$11 per m^2 (Autocase, 2018). Bioswales help cool the temperature that reduces the urban heat island effect with benefits of \$89 per m^2 (Autocase, 2018).

2.5. Green Infrastructure Life Cycle Cost Analysis

I applied a Life Cycle Cost Analysis (LCCA) to assess the total cost for a LID approach using GI on campus. LCCA determines maximized savings by focusing on every financial aspect related to obtaining, owning, and disposing of project materials. LCCA estimates the overall cost for a project’s alternatives to find the lowest amount and place it with a monetary value. A LCCA to examine the initial construction, operations and maintenance, and disposal processes for the different GI is needed.

When researching the cost of the different green infrastructures most were measured in per square foot. A simple conversion was applied to each GI following the use of this formula to calculate cost per square meter.

$$\textit{Conversion of Green Infrastructure Cost per } m^2 =$$

$$\left(\frac{\textit{Cost of Green Infrastructure}}{\textit{Area}}\right) \times 10.764$$

I created a LCCA to determine extensive green roof total costs for the buildings and parking lots surrounding the Quarry and Quad as seen in Table 6B. I used the measured building footprints to determine the feasibility of an extensive green roof application. The initial construction unit costs for an extensive green roof were about 323 per m^2 (First American Roofing, 2021) Monthly operations and maintenance costs was around \$7 per m^2 (Feng and Hewage, 2018). No costs were appointed for disposal methods. I calculated the total costs for a LCCA of an extensive green roof (Table 6B).

I generated a cost analysis to compare installation of an extensive green roof against a metal roof replacement on the campus buildings adjacent to the Quad and Quarry. The unit cost to replace a metal roof was \$117 per m^2 (Attics, 2021). I computed the estimated total by multiplying the area of the digitized buildings and parking lots adjacent to the Quad and Quarry by the unit cost for an extensive green roof per square meter (Appendices 5A and B).

A LCCA was produced for rain gardens to decide the cost effectiveness of its design (Table 7B). The installation unit costs for rain gardens costs was \$32 per m^2 (CostHelper, 2022). I calculated the estimated total by multiplying the area of the digitized building and parking lots surrounding the two study locations by the unit cost for a rain garden per square meter demonstrated in Appendix 6. The cost of operations and maintenance was \$8 per m^2 (Boguniewicz-Zablocka and Capodaglio, 2020). There was no cost for disposal of a rain garden.

I generated a porous asphalt LCCA to evaluate the total unit costs (Table 8B). Initial construction unit cost for porous asphalt was \$107 per m^2 (Grupa, 2021). I computed the estimated total unit cost by multiplying the area of the digitized Quad and Quarry buildings and parking lots by the unit cost for porous asphalt shown in Appendix 7. Operations and maintenance was \$7 per m^2 (CTC & Associates LLC, 2012). The cost to dispose of porous asphalt was \$22 per m^2 (Hometown Demolition, 2021).

I made a LCCA for bioswales to examine the economic feasibility of this project (Table 9B). Bioswale installation unit cost was \$113 per m^2 (CostHelper, 2022). The total estimate was calculated by multiplying the area of the digitized Quad and Quarry by the total unit costs for bioswales as exhibited in Appendix 8. Low maintenance and operation fees were required to be \$1 per m^2 (Zablocka and Capodagio, 2020). There were no disposal fees for bioswales.

3. Results

I determined the surface water flow directions and identified watersheds that drained to the Quarry (Figure 15A). I found the Quad surface flow drainage after not applying to the Fill tool (Figure 15B).

I established the maximum depth for the Quad to be 1.76 meters and Quarry was 7.29 meters after the tools utilized (Figure 17). I found the total volume for the Quad to be 3,761 m^3 and for the Quarry was 94,579 m^3. The average depth for the Quad was 0.83 in meters and the Quarry was 4.86 meters. See Tables 1A and B for the calculations for total volume and average depth.

I computed each area for the digitized buildings and parking lots adjacent to the Quad and Quarry and watersheds in Tables 2A through C. I located the Quad and Quarry polygons after the Cut/Fill tool was applied (Figure 16). I digitized the two study areas: the Quad area was 4,547 m^2 and the Quarry was 19,461 m^2 (Table 2D).

After I calculated the areas for these locations, I calculated total runoff volumes using the SCS-CN method. The total runoff generated from the combined 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms for a metal roof is in Appendices 3A through D. For an extensive green roof the total volume runoff amounts using the frequency storms is in Appendices 4A through D. For an extensive green roof, the total runoff for the digitized buildings bordering the Quad was 9,135 m^3, the Quarry buildings and parking lots were 33,227 m^3, watersheds were 478,265 m^3, Quarry was 12,234 m^3, and Quad was 2,858 m^3 (Tables 3A through D). The extensive green roof the total runoff was 535,720 m^3 (Table 3E). The total runoff when replacing with a metal roof for the digitized buildings adjacent to the Quad were 13,602 m^3, the buildings and parking lots surrounding the Quarry were 49,472 m^3, watersheds were 670,882 m^3, Quarry was 18,215 m^3, and Quad was 4,256 m^3 (Tables 4A through D). For the metal roof the total runoff was 756,436 m^3 (Table 4E).

I found the peak discharge for the Quarry and Quad digitized buildings by applying the Rational Method. I computed the total peak discharge for the Quad and Quarry buildings and parking lots (Table 5A and B).

I computed the total savings from the BA for an extensive green roof as seen in Table 6A. The total savings in reduction of stormwater runoff was $1,886,835 (Feng and Hewage, 2018). All the new greenery increases the amenity value for a total savings of $559,312 (Feng and Hewage, 2018). Over time green roofs have a longer life expectancy that has total savings in longevity to be $52,922,853 (Bianchini & Hewage, 2012). I calculated the total saving for all the benefits for the two study area buildings and parking lots to be $55,369,000.

I calculated the total savings rain garden from the BA for the Quad and Quarry buildings and parking lots (Table 7A). The total benefit savings of stormwater runoff reduction was $808,644 (Nordman et al., 2017). The amenity value for rain gardens has total savings about $67,387 (Nordman et al., 2017). Rain gardens improve air quality with total benefits of $808,644 (Autocase, 2018). The total benefit savings filtering of pollutants were reduced by about $18,142 (Autocase, 2018). Water quality enhances within a rain garden with total benefit savings of $1,866,835 (Autocase, 2018). I computed all the total savings from the BA for the buildings and parking lots adjacent to the Quad and Quarry of $3,638,896.

The total porous asphalt benefit savings were calculated from the individual benefit avoided costs illustrated in Table 8A. Porous asphalt decreases stormwater runoff of total benefits around $90,712 (Autocase, 2018). Filtering pollutants of total benefit savings about $18,142 (Nordman et al., 2017). The improvement of water quality has total saving benefits of $526,132 (Autocase, 2018). Minimizing urban heat island effect with total savings around $72,570 (Autocase, 2018). I then summed all total benefit savings for the Quarry parking lots was about $707,557.

I computed the total bioswale benefit results for the adjoining parking lots to the Quarry shown in Table 9A. Bioswales reduce stormwater runoff with total benefits of $277,580 (Nordman et al., 2017). The enhancement of water quality has total benefit savings of $523,773 (Autocase, 2018). Improving air quality total benefits of $201,744 (Autocase, 2018). The evapotranspiration reduces carbon emissions with a total savings of $14,877 (Autocase, 2018). Bioswales minimize the urban heat island effect with total savings for the parking lots of $1,607,787 (Autocase, 2018). The extra greenery increases the amenity value with total benefits approximately to be $60,233 (Autocase, 2018). I calculated all the total benefit savings for the Quarry parking lots to be $2,685,994.

I calculated the total costs for the LCCA processes for an extensive green roof around the Quarry and Quad buildings (Table 7B). The total unit initial construction for a green roof was $20,920,169 (First American Roofing, 2021). Extensive green roofs need low maintenance and operations with total costs about $478,447 (Feng and Hewage, 2018). I summed the initial construction, operations and maintenance, and disposal expenses to be $21,391,878.

I examined a metal roof replacement cost analysis and the total estimates were computed for the buildings and parking lots surrounding the Quad and Quarry. Reroofing the metal roof total estimate was $7,060,566. A detailed analysis of the total sum estimates for an extensive green roof and metal roof replacement as seen in Appendices 5A and B.

I examined the LCCA for rain gardens (Table 7B). The installation total unit cost of a rain garden was $2,342,223 (CostHelper, 2022). I computed each total sum for a rain garden estimate as shown in Appendix 6. Rain gardens require minimal operations and maintenance with total costs around $544,587 (Boguniewicz-Zablocka and Capodaglio, 2020). I calculated the total sum from the LCCA expenses to be $2,894,796.

I computed each of the total costs from the lifecycle analysis for porous asphalt (Table 8B). The total unit cost for initial construction was $2,082,577 (Grupa, 2021). A detailed analysis was demonstrated for the total estimate of porous asphalt (Appendix 7). Porous asphalt needs regular operations and maintenance with total benefits about $126,997 (CTC & Associates LLC, 2012). The disposal method for porous asphalt has benefits of $585,821 (Hometown Demolition, 2021). The total expense from the LCCA was $2,795,395 for the parking lots around the Quarry.

I calculated the total costs from the LCCA for bioswales (Table 9B). The installation total cost of a bioswale was $2,050,100 (CostHelper, 2022). I totaled the sum of the bioswale estimate (Appendix 8). Bioswales need minimal operations and maintenance with total costs at about $24,129 (Zablocka and Capodagio, 2020). I totaled the sum from the LCCA costs to be $2,074,229.

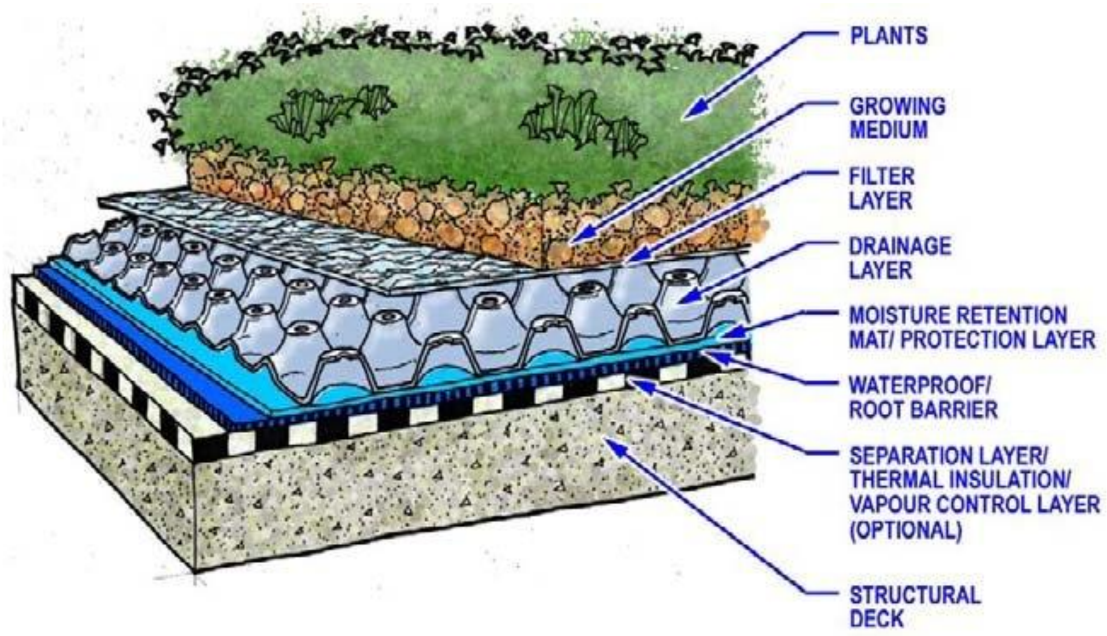


Figure 1. An extensive green roof structure with a structural deck at the base that is common for most roofs. Next are a thermal layer (optional), a waterproof membrane, root resistant barrier, drainage layer, filter plate, growing medium, and native plant layers. Source: Townshend, D. & Duggie, A. (2007). Study on green roof application in Hong Kong.

Figure 2. The extensive green roof has been incorporated on the CELS building on MSU campus. This is located on the third floor with two green roofs. Source: https://www.montclair.edu/facilities/sustainability/green-building-on-campus/

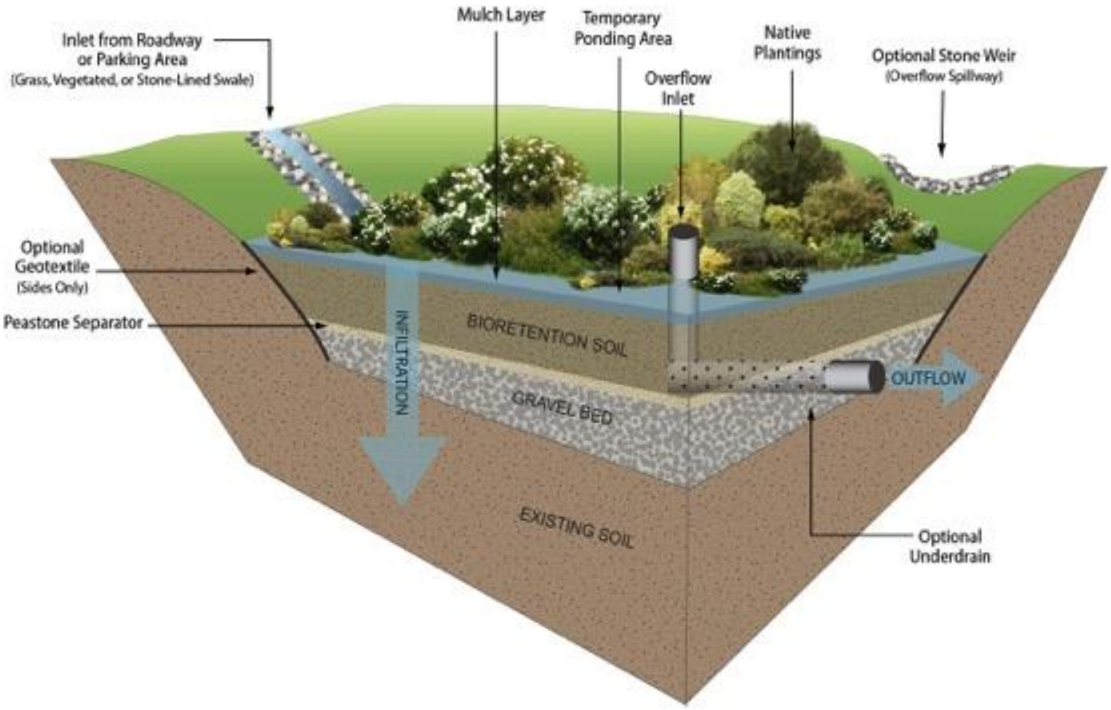


Figure 3. A rain garden illustrates the construction layers. At the base is the gravel layer, then top soil and mulch layer, and ponding area on top with native plants. An inflow structure that guides the stormwater towards the ponding area and an outflow structure drain the water to a waterway or sewer. Source: https://megamanual.geosyntec.com/npsmanual/bioretentionareasandraingardens.aspx

Figure 4. A rain garden design integrated in front of the CELS building. The stormwater runoff would be mitigated off the metal roofs and directed into the rain garden. Source: https://www.montclair.edu/facilities/sustainability/stormwater-on-campus/

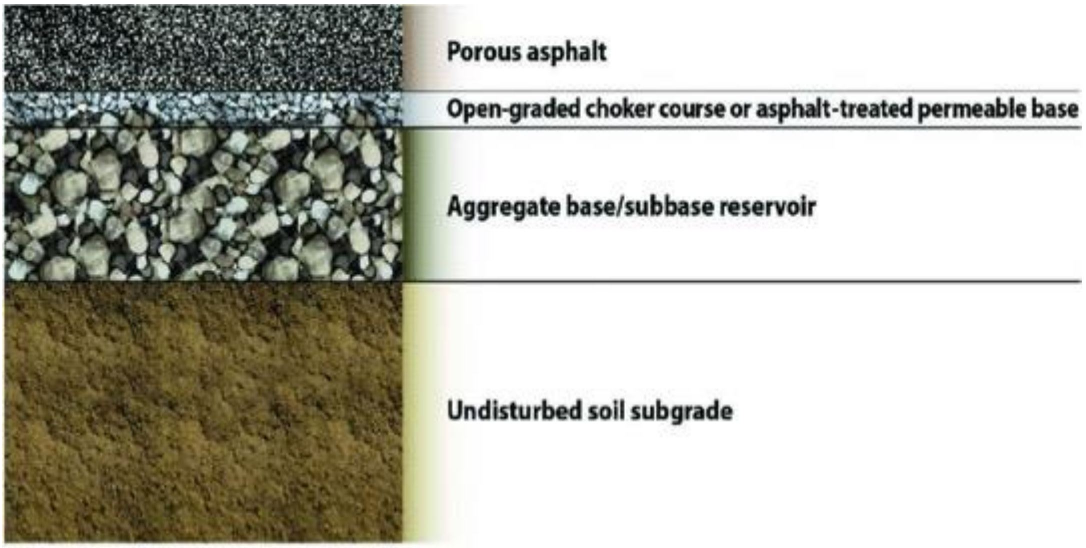


Figure 5. The cross section illustrates a porous asphalt structural design. At the base is soil subgrade, then an aggregate base or subbase reservoir layer, a choker-stone layer or treated base layer, and porous asphalt layer on top. Source: Bruinsma, J. & Smith, K. & Peshkin, D. & Ballou, L. & Eisenberg, B. & Lurie, C. & Costa, M. & Ung, C. & Nassiri, S. & Shi, X. & Haselbach, L. (2017). Guidance for usage of permeable pavement at airports.

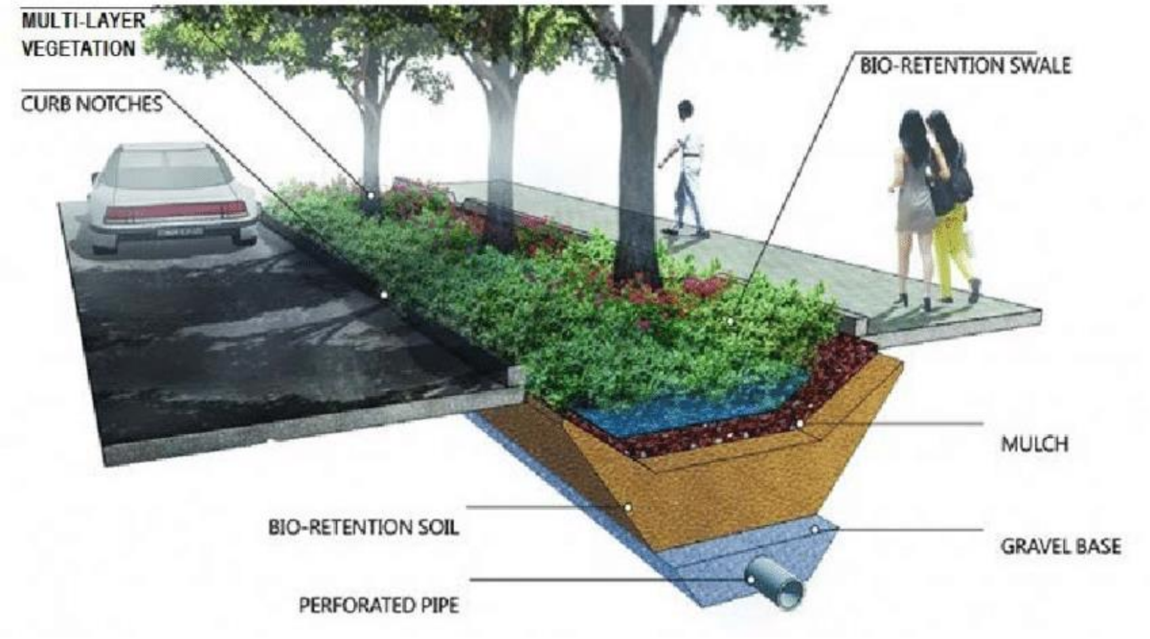


Figure 6. The bioswale composition with a gravel base integrated with a perforated pipe. In the middle are a bioretention soil layer and mulch layer. On the top is the bioretention swale and native vegetation. Bioswales are designed extended into or off of an impervious surface. Source: Brankovic, M., Mitkovic, P., Protic, I., Igic, M., & Dekic, J. (2018, November). *(PDF) Bioswales as elements of green infrastructure.*

Figure 7. The bioswale application in front of the CELS building. The bioswale is connecting off from the sidewalks to reduce runoff. Source: https://www.usgbc.org/projects/cels

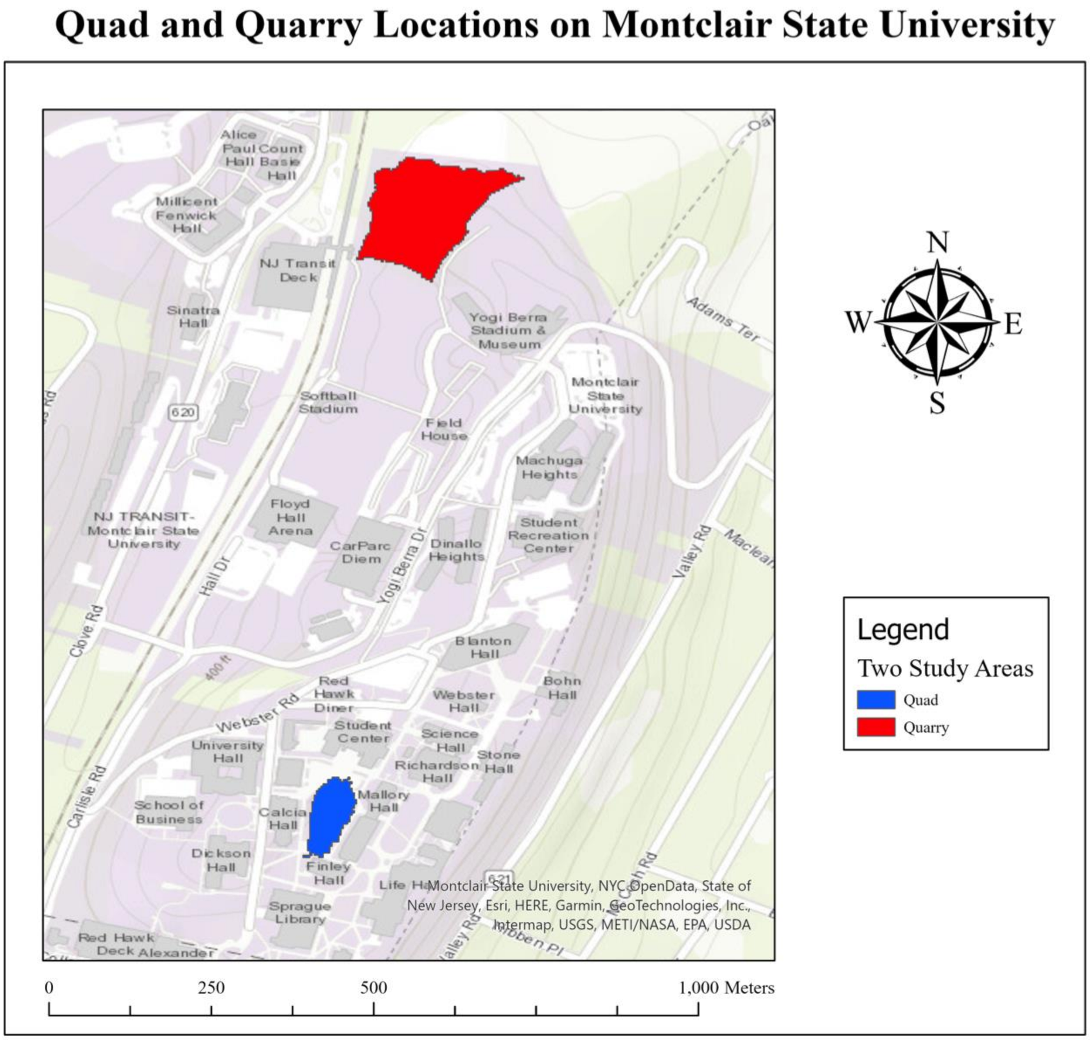


Figure 8. The two study locations on Montclair State University campus. The Quad is in blue and the Quarry is depicted in red.

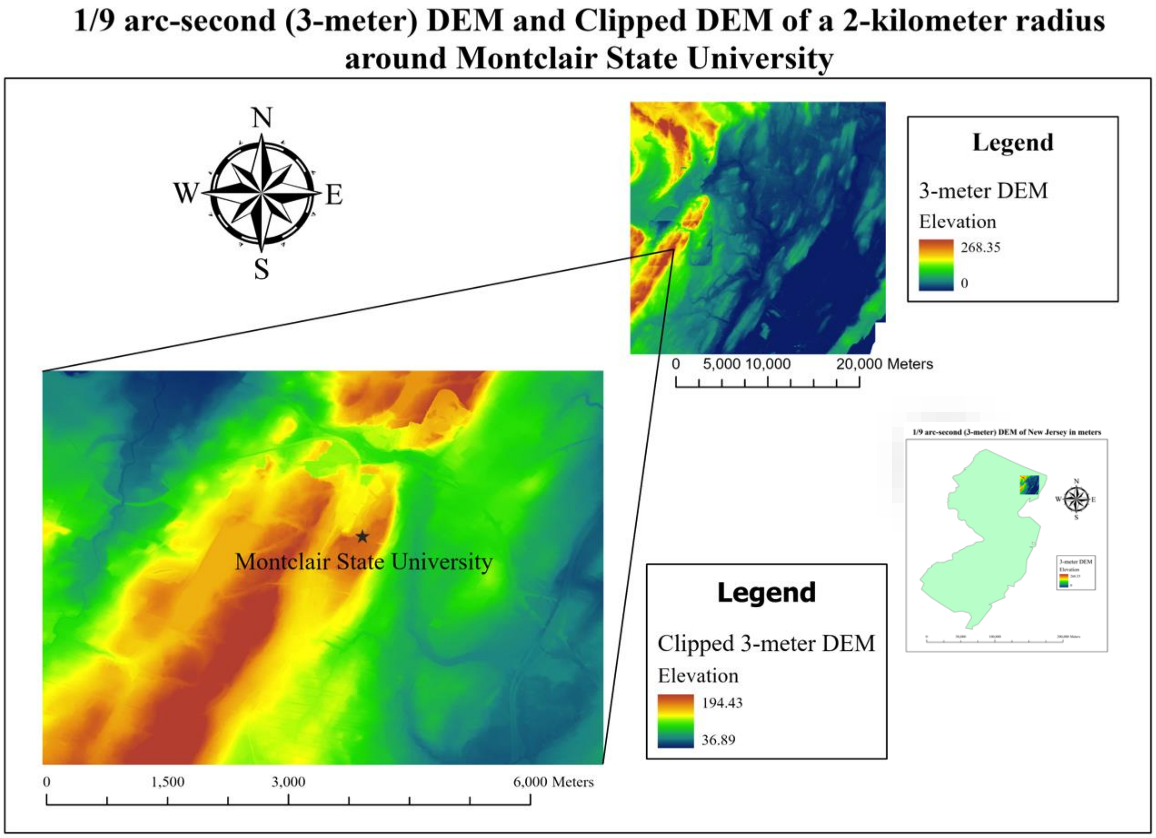


Figure 9. The 1/9 arc-second (3-meter) DEM from the USGS National Elevation Dataset (NED) of New Jersey. The clipped DEM is zoomed out from the 3-meter DEM showing a two-kilometer radius around Montclair State University campus. A smaller map illustrates New Jersey where the 3-meter DEM is located. The DEM shows low elevations in blue and high elevations in red.

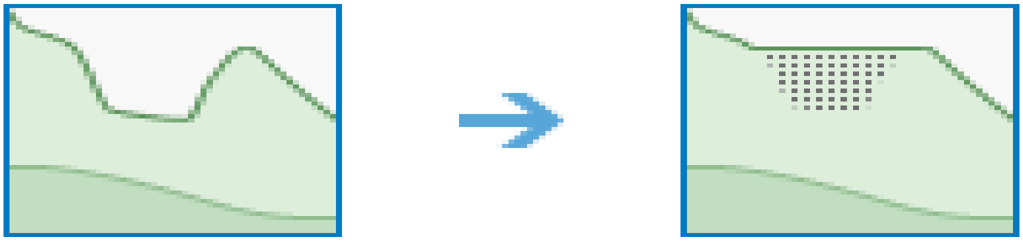
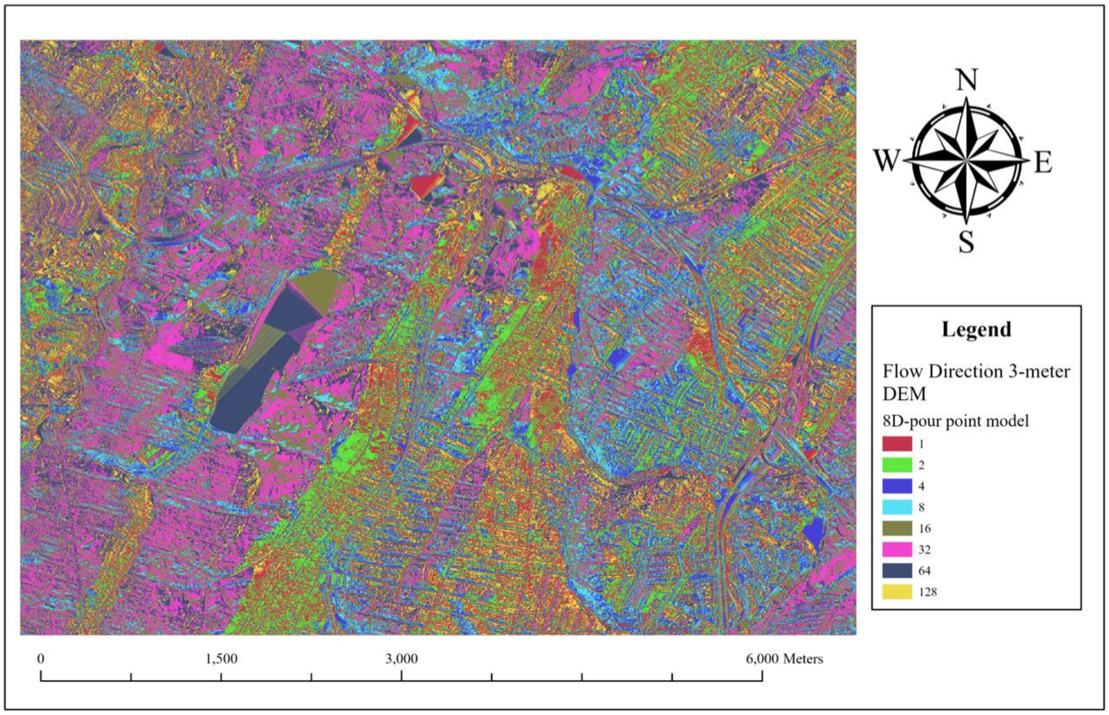
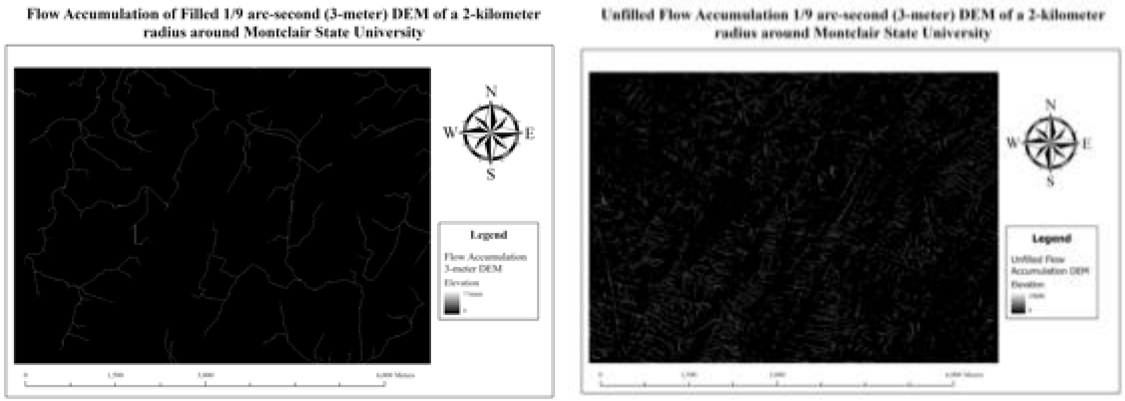


Figure 10. The illustration shows how the fill command tool was applied to the 3-meter DEM by filling in any sinks or depressions in the ground. The fill command removed discontinuities by smoothing out the surface. Source: https://pro.arcgis.com/en/pro-app/2.8/tool-reference/spatial-analyst/fill.htm



Flow Direction of 1/9 arc-second (3-meter) DEM of a 2-kilometer radius around Montclair State University

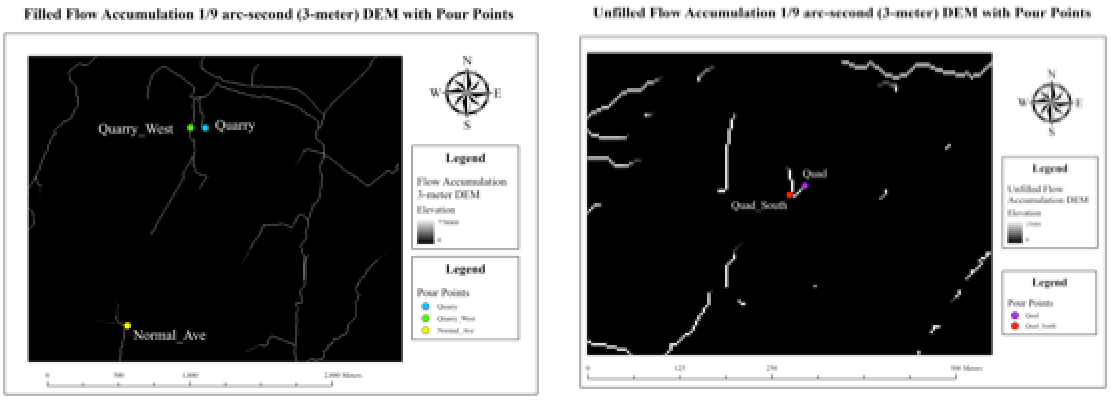
Figure 11. Flow Direction tool applied on Filled clipped 3-meter DEM that identified the ridges’ direction shown through the multiple colors. The numbers associated with the 8D pour model demonstrates the compass direction. 1 is East, 2 is Southeast, 4 is South, 8 is Southwest, 16 is West, 32 is Northwest, 64 is North, and 128 is Northeast.



Flow Accumulation of Filled 1/9 arc-second (3-meter) DEM of a 2-kilometer radius around Montclair State University

Unfilled Flow Accumulation 1/9 arc-second (3-meter) DEM of a 2-kilometer radius around Montclair State University

Figures 12A and B. Flow accumulation was produced from the clipped flow direction DEM that shows the tributaries of the different watersheds the surface water drained to, elevation in meters. The cells with values of 0 or in black color were used to identify ridges. Cells in white color are the stream channels. The Flow Accumulation DEM on Figure 12A has longer interconnected white. In Figure 12B the Flow Accumulation DEM has shorter interconnected white lines.



Figures 13A and B. Pour points were placed on the tributaries to determine where the stream channels drained towards the two study locations. In Figure 13A two pour points were placed on the Quarry in green and west of the Quarry depicted in blue. A third pour point was created along Normal Avenue to identify where the Quad tributary would be in yellow on Figure 13A. In Figure 13B two pour points were located on the Quad in purple and Quad South shown in red.

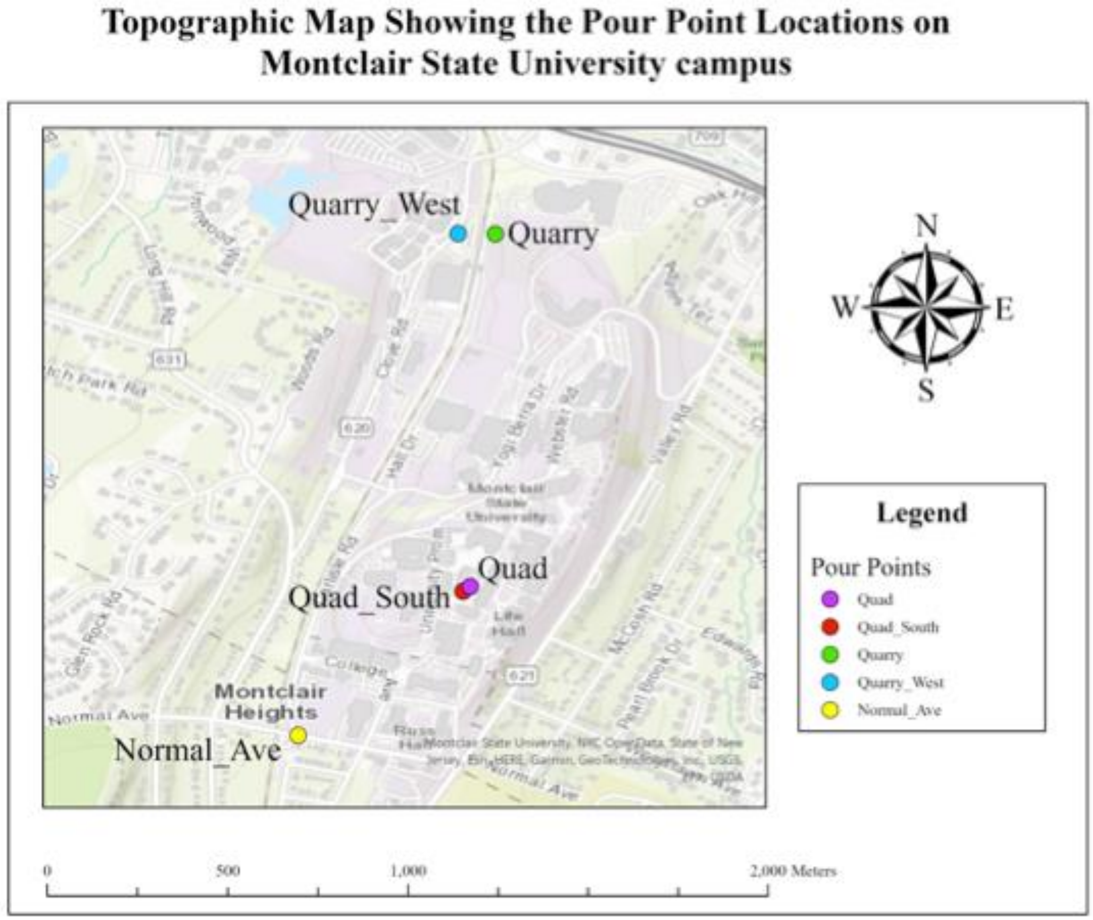
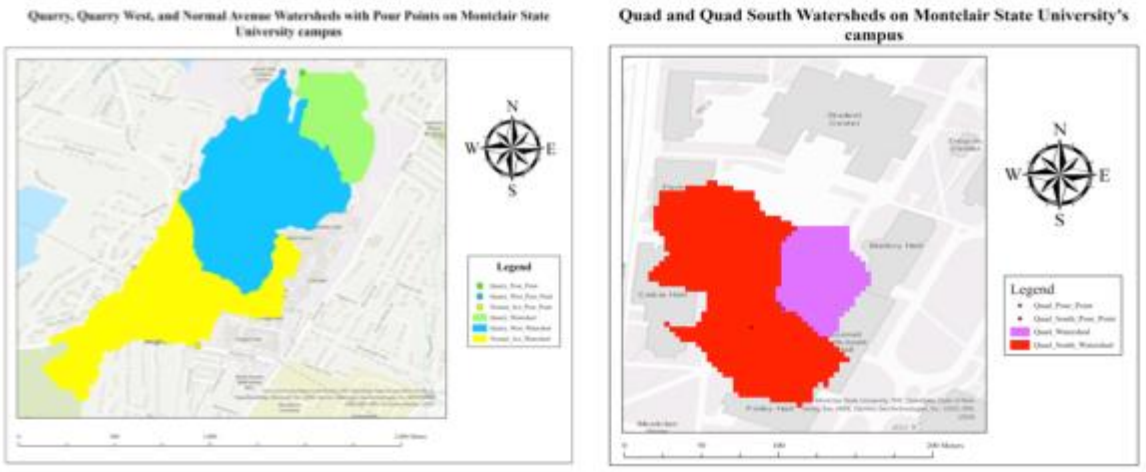


Figure 14. A topographic map shows where the five pour point locations on MSU campus. The Quad is in purple, Quad South in red, Quarry in green, Quarry West in blue, and Normal Avenue in yellow.



Figures 15A and B. In Figure 15A the Quarry, Quarry_West, and Normal_Ave Watersheds were produced from the three pour points. The Quarry watershed in blue and Quarry_West watershed in green drained towards the Quarry. The Normal_Ave in yellow watershed was created to see if it drained towards the Quad. In Figure 15B the Quad and Quad_South watersheds were generated from the two pour points. The Quad watershed in purple and Quad_South watershed in red drained towards the Quad.

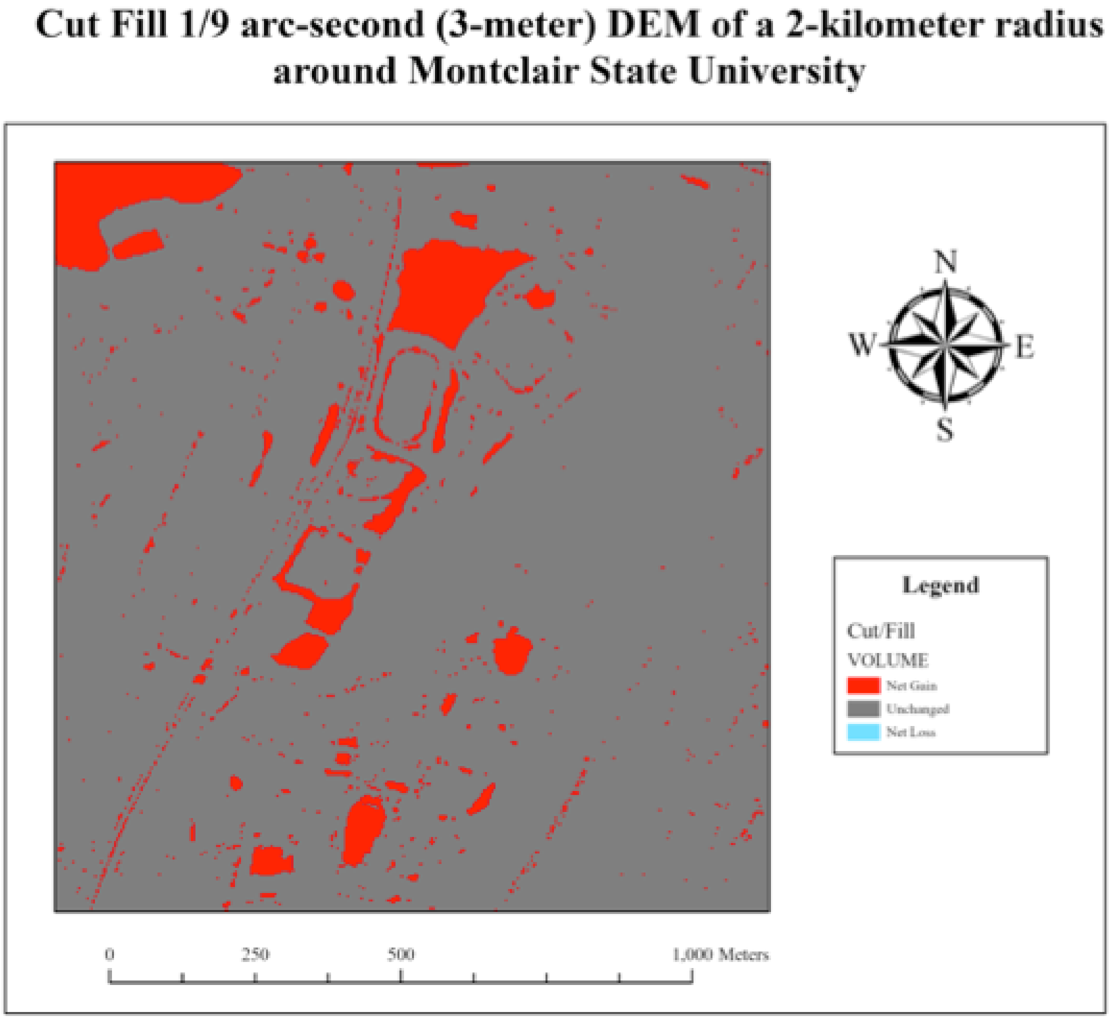
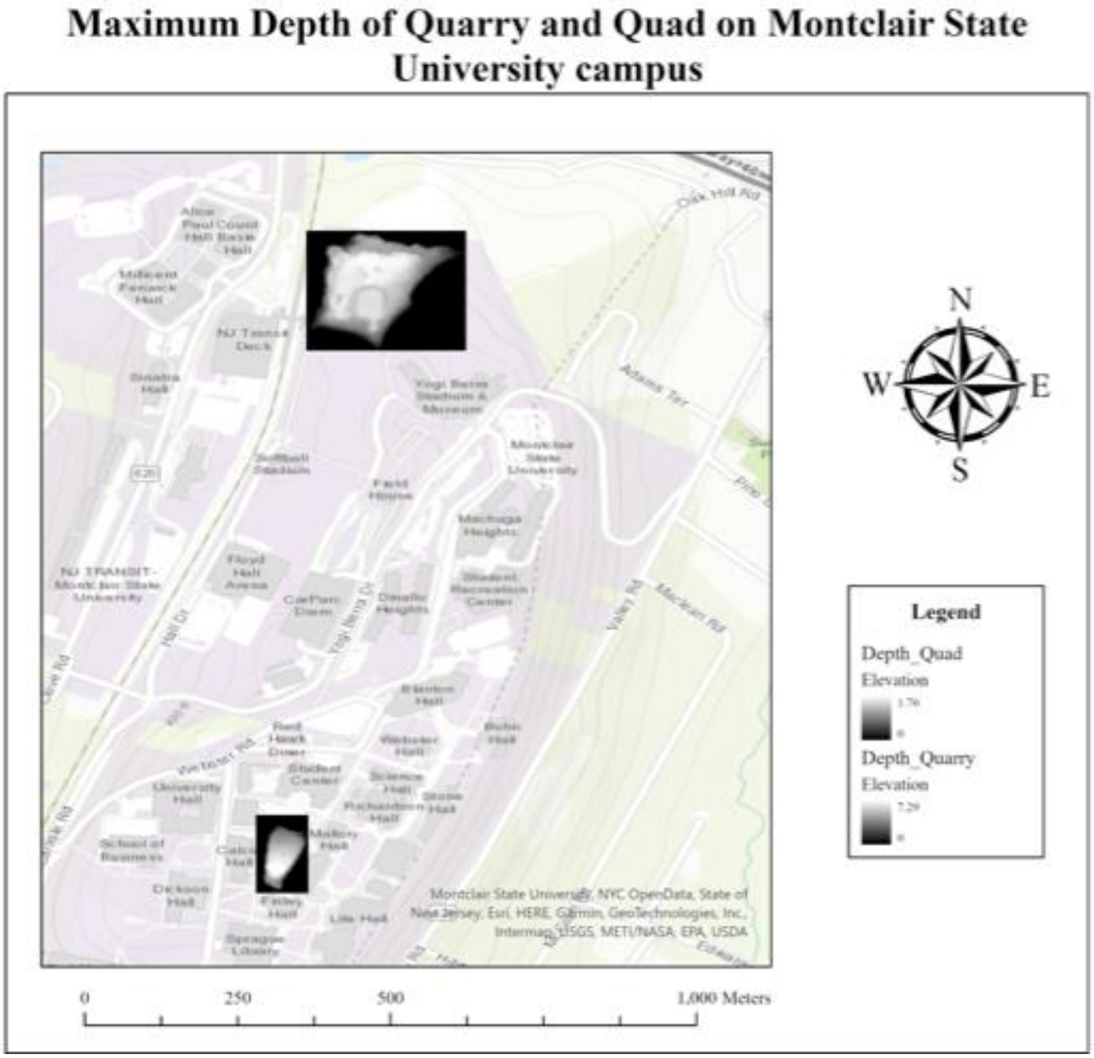


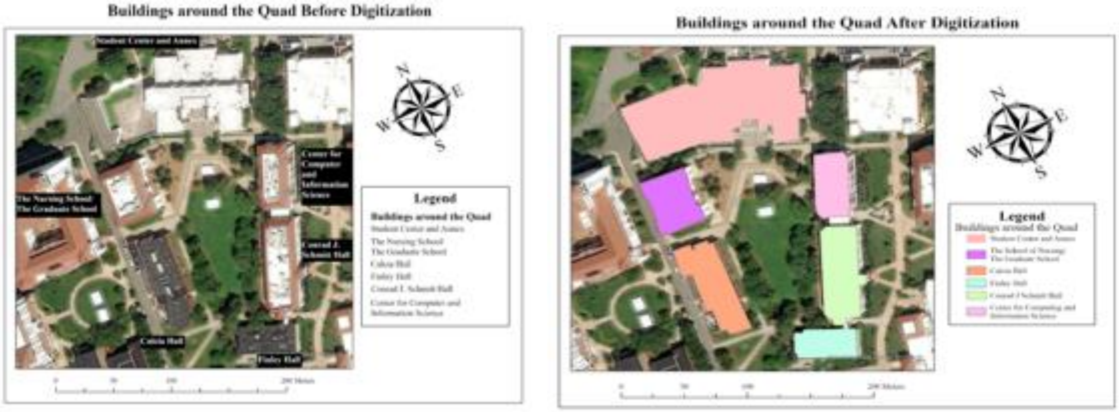
Figure 16. The Cut/Fill map displays the net gain in red and unchanged in grey. The net gain demonstrates the filled in sinks or depressions from the unfilled DEM subtracting by the filled DEM. Both Quarry and Quad are displayed on the Cut/Fill DEM.



Maximum Depth of Quarry and Quad on Montclair State University campus

Montclair State University, NYC OpenData, State of New Jersey, Esri, HERE, Garmin, GeoTechnologies, Inc., Intermap, USGS, METI/NASA, EPA, USDA

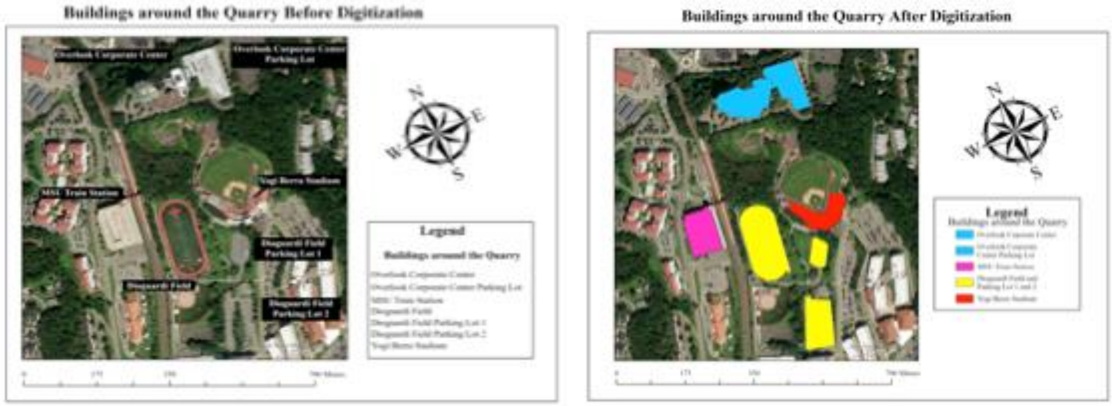
Figure 17. The Quarry and Quad demonstrates the maximum depth on Montclair State University. Maximum depth for the Quad is 1.76 meters and for the Quarry is 7.29 meters. The maximum depth shows low elevations in black and high elevations in white.



Buildings around the Quad Before Digitization

Buildings around the Quad After Digitization

Figures 18A and B. The satellite image on Figure 18A used to digitize the buildings surrounding the Quad. In Figure 18B the buildings digitized were the Student Center and Annex (North), the School of Nursing/ the Graduate School (West), Calcia Hall (West), Finley Hall (South), Conrad J. Schmitt Hall (East), and Center for Computing and Information Science (East).



Figures 19A and B. The satellite image on Figure 19A utilized to digitize the buildings surrounding the Quarry. In Figure 19B the buildings digitized were the Overlook Corporate Center (North), Overlook Corporate Center Parking Lot (North), MSU Train Station (Southwest), Dioguardi Field plus two parking lots (South), and Yogi Berra Stadium (South).

Total Volume in m^3 and Average Depth in m for the Quad	
Total Volume (m^3)	3,761
Total Average (m)	0.83

Table 1B. The total volume in m^3 and average depth in m was calculated for the Quad.

Total Volume in m^3 and Average Depth in m for the Quarry	
Total Volume (m^3)	94,579
Total Average (m)	4.86

Table 1B. The total volume in m^3 and average depth in m was calculated for the Quarry.

Area of Quad Digitized Buildings m^2	
Digitized Buildings around the Quad	**Area in m^2**
Student Center and Annex	6,815
The School of Nursing/ The Graduate School	1,413
Calcia Hall	1,945
Finley Hall	992
Conrad J. Schmitt Hall	2,021
Center for Computing Information Science	1,345
Total Digitized Quad Area	14,531

Table 2A. The table shows the area for the digitized buildings adjacent to the Quad. The area was calculated in m^2.

Area of Digitized Quarry Buildings and Parking Lots in m^2	
Digitized Buildings and Parking Lots around the Quarry	**Area in m^2**
Overlook Corporate Center	7,427
Overlook Corporate Center Parking Lot	7,702
MSU Train Station	7,630
Dioguardi Field	13,841
Dioguardi Field Parking Lot 1	2,467
Dioguardi Field Parking Lot 2	8,473
Yogi Berra Stadium	5,815
Total Digitized Quarry Area	53,355

Table 2B. The area was computed in m^2 for the digitized parking lots and buildings surrounding the Quarry.

Area of Digitized Watersheds in m^2	
Digitized Watersheds	**Area in m^2**
Normal Avenue	334,552
Quarry	12,076
Quarry West	396,046
Quad	2,453
Quad South	10,460
Total Digitized Watersheds Area	755,587

Table 2C. The table illustrates the area for the digitized watersheds. The area was calculated in m^2.

Area of Digitized Study Areas in m^2	
Digitized Study Areas	**Area in m^2**
Quarry	19,461
Quad	4,547

Table 2D. The table demonstrates the area for the digitized two study areas in m^2.

Total Runoff in m^3 with an Extensive Green Roof using the combined 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms	
Buildings around the Quad	**Total Runoff in m^3 with the combined frequency storms**
Student Center and Annex	4,284
The School of Nursing/ The Graduate School	889
Calcia Hall	1,223
Finley Hall	623
Conrad J. Schmitt Hall	1,270
Center for Computing Information Science	846
Total Runoff for the Digitized Buildings around the Quad	9,135

Table 3A. The Soil Conservation Service Curve Number method was used to compute the total direct runoff for an extensive green roof. The total runoff for an extensive green roof in m^3 using Passaic County rainfall amounts from the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms. The digitized Quad buildings were utilized to find the total runoff.

Total Runoff for Digitized Buildings and Parking Lots around the Quarry in m^3 with an Extensive Green Roof using the combined 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms	
Digitized Buildings and Parking Lots around the Quarry	**Total Runoff in m^3 with the combined frequency storms**
Overlook Corporate Center	4,528
Overlook Corporate Center Parking Lot	4,669
MSU Train Station	4,797
Dioguardi Field	8,701
Dioguardi Field Parking Lot 1	1,551
Dioguardi Field Parking Lot 2	5,327
Yogi Berra Stadium	3,656
Total Runoff for the Digitized Buildings and Parking Lots around the Quarry	33,227

Table 3B. The Soil Conservation Service Curve Number method was used to calculate the total direct runoff for an extensive green roof. The total runoff for an extensive green roof in m^3 using Passaic County rainfall amounts from the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms. The digitized Quarry parking lots and buildings were applied to compute the total runoff.

Total Runoff for Digitized Watersheds in m^3 with an Extensive Green Roof using the combined 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms	
Digitized Watersheds	**Total Runoff in m^3 with the combined frequency storms**
Normal Avenue	218,685
Quarry	4,177
Quarry West	246,786
Quad	1,637
Quad South	6,980
Total Runoff for the Digitized Watersheds	478,265

Table 3C. The Soil Conservation Service Curve Number method was used to compute the total direct runoff for an extensive green roof. The total runoff for an extensive green roof in m^3 using Passaic County rainfall amounts from the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms. The digitized watersheds were utilized to calculate the total runoff.

Total Runoff for Digitized Study Areas in m^3 with an Extensive Green Roof using the combined 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms	
Digitized Study Areas	**Total Runoff in m^3 with the combined frequency storms**
Quarry	12,234
Quad	2,858
Total Runoff for the Digitized Watersheds	15,092

Table 3D. The Soil Conservation Service Curve Number method was used to compute the total direct runoff for an extensive green roof. The total runoff for an extensive green roof in m^3 using Passaic County rainfall amounts from the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms. The digitized Quad and Quarry buildings and parking lots were used to find the total runoff.

Total Runoff for All the Digitized Locations in m^3 with an Extensive Green Roof using the combined 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms	
Total Runoff for an Extensive Green Roof in m^3	535,720

Table 3E. The Soil Conservation Service Curve Number method was used to compute the total direct runoff for an extensive green roof. The total runoff for an extensive green roof in m^3 using Passaic County rainfall amounts from the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms. All the digitized locations were utilized to calculate the total runoff.

Total Runoff for the Digitized Buildings around the Quad in m^3 with Metal Roof using the combined 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms	
Digitized Buildings around the Quad	**Total Runoff in m^3 with the combined frequency storms**
Student Center and Annex	6,379
The School of Nursing/ The Graduate School	1,323
Calcia Hall	1,821
Finley Hall	928
Conrad J. Schmitt Hall	1,891
Center for Computing Information Science	1,259
Total Runoff for the Digitized Buildings around the Quad	13,602

Table 4A. The Soil Conservation Service Curve Number method was used to compute the total direct runoff on a metal roof. The total runoff for metal roof in m^3 using Passaic County rainfall amounts from the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms. The digitized Quad buildings were utilized to find the total runoff.

Total Runoff for the Digitized Buildings and Parking Lots around the Quarry in m^3 with Metal Roof using the combined 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms	
Digitized Buildings and Parking Lots around the Quarry	**Total Runoff in m^3 with the combined frequency storms**
Overlook Corporate Center	6,741
Overlook Corporate Center Parking Lot	6,952
MSU Train Station	7,142
Dioguardi Field	12,955
Dioguardi Field Parking Lot 1	2,309
Dioguardi Field Parking Lot 2	7,931
Yogi Berra Stadium	5,443
Total Runoff for the Digitized Buildings and Parking Lots around the Quarry	49,472

Table 4B. The Soil Conservation Service Curve Number method was used to calculate the total direct runoff on a metal roof. The total runoff for metal roof in m^3 using Passaic County rainfall amounts from the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms. The digitized Quarry parking lots and buildings were applied to compute the total runoff.

Total Runoff for the Digitized Watersheds in m^3 with Metal Roof using the combined 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms	
Digitized Watersheds	**Total Runoff in m^3 with the combined frequency storms**
Normal Avenue	306,758
Quarry	5,860
Quarry West	346,177
Quad	2,296
Quad South	9,790
Total Runoff for the Digitized Watersheds	670,882

Table 4C. The Soil Conservation Service Curve Number method was used to compute the total direct runoff for a metal roof. The total runoff for metal roof in m^3 using Passaic County rainfall amounts from the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms. The digitized watersheds were utilized to calculate the total runoff.

Total Runoff for the Digitized Study Areas in m^3 with Metal Roof using the combined 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms	
Digitized Study Areas	**Total Runoff in m^3 with the combined frequency storms**
Quarry	18,215
Quad	4,256
Total Runoff for the Digitized Study Areas	22,471

Table 4D. The Soil Conservation Service Curve Number method was used to calculate the total direct runoff on a metal roof. The total runoff for metal roof in m^3 using Passaic County rainfall amounts from the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms. The digitized Quad and Quarry buildings and parking lots were used to find the total runoff.

Total Runoff for All the Digitized Locations in m^3 with Metal Roof using the combined 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms	
Total Runoff for Metal Roof	756,426

Table 4E. The Soil Conservation Service Curve Number method was used to compute the total direct runoff on a metal roof. The total runoff for metal roof in m^3 using Passaic County rainfall amounts from the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms. All the digitized locations were utilized to calculate the total runoff.

Peak Discharge for Digitized Buildings around the Quad in m^3/s utilizing the rainfall amounts in Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms								
Digitized Buildings around the Quad	**Peak Discharge in m^3/s**							
Year(s)	**1**	**2**	**5**	**10**	**25**	**50**	**100**	**Total Frequency Storms**
Student Center and Annex	0.13	0.16	0.20	0.24	0.29	0.34	0.39	1.76
The School of Nursing / The Graduate School	0.03	0.03	0.04	0.05	0.06	0.07	0.08	0.36
Calcia Hall	0.04	0.05	0.06	0.07	0.08	0.10	0.11	0.50
Finley Hall	0.02	0.02	0.03	0.03	0.04	0.05	0.06	0.26
Conrad J. Schmitt Hall	0.04	0.05	0.06	0.07	0.09	0.10	0.12	0.52
Center for Computing and Information Science	0.03	0.03	0.04	0.05	0.06	0.07	0.08	0.35

Table 5A. The peak discharge for the digitized buildings surrounding the Quad in m^3/s utilizing the rainfall amounts in Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms. Each frequency storm was totaled for the Quad buildings.

Peak Discharge for Digitized Buildings and Parking Lots around the Quarry in m^3/s utilizing the rainfall amounts in Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms								
Digitized Buildings and Parking Lots around the Quarry	**Peak Discharge in m^3/s**							
Year(s)	**1**	**2**	**5**	**10**	**25**	**50**	**100**	**Total Frequency Storms**
Overlook Corporate Center (Parking Lot)	0.14	0.17	0.21	0.25	0.31	0.36	0.42	1.86
Overlook Corporate Center	0.14	0.17	0.22	0.26	0.32	0.37	0.43	1.92
MSU Train Station	0.15	0.18	0.23	0.27	0.33	0.38	0.44	1.97
Dioguardi Field	0.04	0.05	0.06	0.08	0.09	0.11	0.13	0.56
Dioguardi Field (Parking Lot 1)	0.05	0.06	0.07	0.09	0.11	0.12	0.14	0.64
Dioguardi Field (Parking Lot 2)	0.16	0.20	0.25	0.30	0.37	0.42	0.49	2.19
Yogi Berra Stadium	0.11	0.14	0.17	0.20	0.25	0.29	0.34	1.50

Table 5B. The peak discharge for digitized buildings and parking lots around the Quarry in m^3/s utilized the rainfall amounts in Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms. The total frequency storm was computed for each building and parking lot surrounding the Quarry.

A Benefit Analysis for an Extensive Green Roof in Savings		
Benefits	**Avoided Costs, per m^2**	**Total Savings**
Reduce Stormwater Runoff	$22	$1,886,835
Amenity Value	$5	$559,312
Minimize Urban Heat Island Effect	$0	$0
Improve Air Quality	$0	$0
Longevity	$160	$52,922,853
Total Benefit Savings		$55,369,000

Table 6A. A BA was created for an extensive green roof in savings for the Quad and Quarry building area. The benefits were calculated from previous studies by producing the avoided costs and its associated benefits. Reduction in stormwater was \$22 per m^2 (Feng and Hewage, 2018). Amenity Value was \$5 per m^2 (Feng and Hewage, 2018). Longevity was \$160 per m^2 (Bianchini & Hewage, 2012).

A LCCA for an Extensive Green Roof in Costs		
Benefits	**Costs per m^2**	**Total Costs**
Initial Construction	$323	$20,920,169
Operations and Maintenance	$7	$471,709
Disposal	$0	$0
Total Life Cycle Costs		$21,391,878

Table 6B. The LCCA results for an extensive green roof applied on the Quarry and Quad buildings and parking lots in costs. The total cost for an extensive green roof using the initial construction, operations and maintenance, and disposal. Initial Construction was \$323 per m^2 (Feng and Hewage, 2018). Operations and Maintenance was \$7 per m^2 (Feng and Hewage, 2018).

A CBA and BCR for an Extensive Green Roof on the buildings and parking lots surrounding the Quad and Quarry	
Total Benefit Savings	$55,369,000
Total Life Cycle Costs	$21,391,878
Total BCR	2.6

Table 6C. A total CBA was created for an extensive green roof. BCR was applied for the Quad and Quarry buildings and parking lots.

A Benefit Analysis for a Rain Garden in Savings		
Benefits	**Avoided Costs, per m^2**	**Total Savings**
Reduce Stormwater Runoff	$12	$808,644
Amenity Value	$5	$67,387
Filter Pollutants	$1	$18,142
Enhance Water Quality	$28	$1,886,835
Improve Air Quality	$12	$808,644
Reduce Carbon Emissions	$0	$0
Total Benefit Savings	$3,638,896	

Table 7A. A BA was created for an extensive green roof in savings for the Quad and Quarry building area. The benefits were calculated from previous studies by producing the avoided costs and its associated benefits. Reduction in stormwater was \$12 per m^2 (Nordman et al., 2017). Amenity Value was \$1 per m^2 (Nordman et al., 2017). Filtering pollutants was \$1 per m^2 (Nordman et al., 2017). Enhance Water Quality was \$28 per m^2 (Autocase, 2018). Improve Air Quality was \$12 per m^2 (Autocase, 2018).

A LCCA for a Rain Garden in Costs		
Benefits	**Costs per m^2**	**Total Costs**
Initial Construction	$32	$2,342,223
Operations and Maintenance	$8	$539,096
Disposal	$0	$0
Total Life Cycle Costs	$2,881,318	

Table 7B. The LCCA results for an extensive green roof applied on the Quarry and Quad buildings and parking lots in costs. The total cost for an extensive green roof using the initial construction, operations and maintenance, and disposal. Initial Construction was \$32 per m^2 (CostHelper, 2022). Operations and Maintenance was \$8 per m^2 (Zablocka and Capodagio, 2020).

A CBA and BCR for a Rain Garden on the buildings and parking lots surrounding the Quad and Quarry	
Total Benefit Savings	$3,638,896
Total Life Cycle Cost	$2,881,318
Total BCR	1.3

Table 7C. A total CBA was created for a rain garden. BCR was pertained for the Quad and Quarry parking lots and buildings.

A Benefit Analysis for Porous Asphalt in Savings		
Benefits	**Avoided Costs, per m^2**	**Total Savings**
Reduce Stormwater Runoff	$5	$90,712
Filter Pollutants	$1	$18,142
Minimize Urban Heat Island Effect	$4	$72,570
Enhance Water Quality	$29	$526,132
Total Benefit Savings	$707,557	

Table 8A. A BA was established for porous asphalt in savings. The benefits were calculated from pervious studies by creating the avoided costs and its associated benefits. Reduction in stormwater was $5 per m^2 (Autocase, 2018). Filter Pollutants was $1 per m^2 (Nordman et al., 2017). Minimize Urban Heat Island Effect was $4 per m^2 (Autocase, 2018). Enhance Water Quality was $29 per m^2 (Autocase, 2018).

A LCCA for Porous Asphalt in costs		
Benefits	**Costs per m^2**	**Total Costs**
Initial Construction	$107	$2,082,577
Operations and Maintenance	$7	$126,997
Disposal	$32	$585,821
Total Life Cycle Costs	$2,795,395	

Table 8B. The LCCA results for an extensive green roof applied on the Quarry and Quad buildings and parking lots in costs. The total cost for an extensive green roof using the initial construction, operations and maintenance, and disposal. Initial Construction was $107 per m^2 (Grupa, 2021). Operations and Maintenance was $7 per m^2 (CTC & Associates LLC, 2012). Disposal was $22 per m^2 (Hometown Demolition, 2021).

A CBA and BCR for Porous Asphalt on the parking lots surrounding the Quarry	
Total Benefit Savings	$707,557
Total Life Cycle Costs	$2,695,395
Total BCR	0.3

Table 8C. A total CBA was created for porous asphalt. BCR was pertained for the buildings surrounding the Quarry.

A Benefit Analysis for a Bioswale in Savings		
Benefits	**Avoided Costs, per m^2**	**Total Savings**
Reduce Stormwater Runoff	$15	$277,580
Amenity Value	$3	$60,233
Enhance Water Quality	$29	$523,773
Improve Air Quality	$11	$201,744
Reduce Carbon Emissions	$1	$14,877
Minimize Urban Heat Island Effect	$89	$1,607,787
Total Benefit Savings		$2,685,994

Table 9A. A BA was illustrated for a bioswale in total savings. The benefits were calculated from previous studies by creating the avoided costs and its associated benefits. Reduction in stormwater was $15 per m^2 (Nordman et al., 2017). Amenity Value was $3 per m^2 (Nordman et al., 2017). Enhance Water Quality was $29 per m^2 (Autocase, 2018). Improve Water Quality was $11 per m^2 (Autocase, 2018). Reduce Carbon Emissions was $12 per m^2 (Autocase, 2018). Minimize Urban Heat Island Effect was $89 per m^2 (Autocase, 2018).

A LCCA for a Bioswale in Costs		
Benefits	**Costs per m^2**	**Total Costs**
Initial Construction	$113	$2,050,100
Operations and Maintenance	$1	$24,129
Disposal	$0	$0
Total Life Cycle Costs		$2,074,230

Table 9B. A LCCA was produced for a bioswale in costs. The total cost for porous asphalt using the initial construction, operations and maintenance, and disposal. Initial Construction was $113 per m^2 (CostHelper, 2022). Operations and Maintenance was $1 per m^2 (Zablocka and Capodagio, 2020).

A CBA and BCR for a Bioswale on the parking lots around the Quarry	
Total Benefit Savings	$2,685,994
Total Life Cycle Costs	$2,074,230
Total BCR	1.3

Table 9C. A total CBA was created for a bioswale. BCR was pertained for the parking lots surrounding the Quarry.

4. Discussion

ArcGIS Pro was utilized to analyze the watershed surface flow on MSU campus around the Quad and Quarry. Once the watersheds were mapped, the buildings and parking lots were digitized surrounding the two study locations. Rainfall amounts were selected from the NOAA for Passaic County to calculate the total precipitation from 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency storms. These frequency storms were applied to compute the total direct runoff using SCS-CN and Rational Method. The total runoff was produced from the Quad and Quarry buildings and parking lots. The Rational Method was used to find the peak discharge to prevent overwhelming and overflowing the stormwater systems on campus. Then a BA and LCCA were produced to assess each benefit and costs associated with the GIs. Through this a CBA was generated to determine the economic feasibility of a sponge city concept. The BCR was used to measure if this project was deemed economically feasible.

A different approach to analyze the topography is using Light Detection and Ranging (LiDAR) drone to examine the Quad and Quarry, plus the adjacent buildings and parking lots on MSU campus. A LiDAR drone gathers detailed data to produce 3D models (Dogru and Marques, 2022). This would collect more accurate and high-resolution data in comparison from the downloaded 3-meter DEM. The LiDAR drone data collected can be applied to calculate more accurate results for GI feasibility, direct stormwater runoff, and peak discharge. If another student were to replicate this study, then utilizing a LiDAR drone would be more effective in gathering higher resolution 3D topographical surface data.

Using GIS to locate the watersheds helped determine the direction of the surface water drainage in the two study areas. Five watersheds were mapped: three for the Quarry on campus and two for the Quad (Figure 7). GIS was also used to digitize the watersheds, two study locations, and buildings and parking lots surrounding the Quarry and Quad and then also calculated the area (Table 2A through D).

Selecting the Passaic County rainfall amounts for the frequency storms, simulated if a heavy rainstorm occurred. By computing the area for each digitized building and parking lot, it helped measure stormwater runoff and GI application using the SCS-CN and Rational Method. Climate change would shift the frequency storm patterns with increased rainfall amounts by about four to eleven percent by 2050 (NJDEP, 2020). Instead of a projected 25-year storm occurring in a given year, it could happen every 5-to 10-years with larger precipitation volumes (NJDEP, 2020). According to the NDJEP, warmer oceans and atmosphere would potentially increase the intensity of tropical storms due to climate change.

These increased rainfall amounts have caused climate change vulnerability to urban areas. Storms are occurring more frequently and intensifying as climate change progresses. According to the US EPA, the application of LID and GI can reduce flood liability and insurance (2015). As part of the Federal Emergency Management Agency, they developed a Community Rating System that earns points for a community through flood insurance discounts (US EPA, 2015). The Community Rating System encourages natural resource protection to manage stormwater. There would be less purchasing of flood insurance and offsets because the flooding damages would be reduced.

The four GIs can provide mitigation, adaptation, and resiliency against the climate crisis. Mitigation can help reduce flooding issues when a frequency storm occurs. Through adaptation it helps prepare a community for the flood hazards and risks of those storms. Then resiliency allows the community to recover quicker from these storms.

The SCS-CN method was applied to calculate the total runoff generated from the frequency storms off of the two study locations. After finding the SCS-CN method results, green roofs were compared with metal roofs to calculate the stormwater runoff volumes produced off of each building and parking lot around the two study areas (Tables 3A through E and 4A through E). The total runoff for an extensive green roof was 535,720 m^3 and a metal roof was 756,426 m^3. When incorporating an extensive green roof in comparison to metal roof there was about a 30% decrease of stormwater runoff. Green roofs are designed to increase infiltration by reducing runoff (GSA, 2011).

Once I found the total stormwater runoff volumes, the total volume depth and total depth were calculated to examine how much rainwater would fit into the Quad and Quarry on campus (Table 1A and B). When potential rainstorms occur, the runoff produced from the buildings and parking lots was directed to the Quad and Quarry. These two locations would serve as basins where water could be collected and stored during rainfall events. The Quad could store up to 3,761 m^3 and the Quarry on campus could collect about 94,579 m^3 of stormwater runoff.

The Rational Method is useful when calculating the peak discharge for a stormwater outlet design (Table 5A and B). This is important in order to not overflow and overwhelm a stormwater system. MSU has roof drain pipes on the corner of each building to guide the water towards outflow outlets nearby. In this case calculating the peak runoff would be key to minimize damages to the pipes and ensure that their capacity is efficient to handle large flows.

I also utilized different GIs, extensive green roof, rain garden, porous asphalt, and bioswale to evaluate the cost efficiency for a sponge city design. A BA was produced to visualize the individual benefits a GI provides (Table 6A, 7A, 8A, and 9A). These are avoided costs for a GI construction that help a community through environmental and social benefits.

I constructed a BA for an extensive green roof to evaluate the total estimates savings for this GI around the Quad and Quarry buildings and parking lots (Table 6A). An extensive green roof is a type of green roof that allows for reduction in stormwater runoff through increased infiltration by native vegetation with total savings about $1,900,000 (Feng and Hewage, 2018). Stormwater is absorbed through the drainage, root resistant barrier, and waterproof membrane layers that act like a sponge (Figure 1).

Extensive green roofs minimize urban heat island effect through evapotranspiration of the vegetation and plants (US EPA). The improvement of air quality occurs through evapotranspiration processes of the planted vegetation (Feng and Hewage, 2018). However, there are no avoided costs for reduced urban heat island and improved air quality (Bianchini & Hewage, 2012) (Feng and Hewage, 2018).

The additional greenery for the extensive green roof increases amenity value since it is aesthetically pleasing with a total savings of $559,312 (Feng and Hewage, 2018). The lifespan of green roofs is around 40-to 50-years because of the thick waterproofing membrane layers reducing direct sunlight from UV rays (Ulubeyli et al., 2017). Extensive green roofs have a life expectancy that minimizes having to replace it often, leading to benefits of around $53,000,000 (Bianchini & Hewage, 2012). The total benefit savings for the two study area buildings and parking lots was $55,000,000 (Table 6A).

I produced a BA for a rain garden to investigate the total benefits (Table 7A). Rain gardens increase infiltration by collecting and storing rainwater to seep into the ground naturally (Johnston et al., 2020). The runoff is decreased through natural infiltration through increased infiltration of native vegetation with total benefit savings about $809,000 (Nordman et al., 2017).

Incorporating multiple plant species will be aesthetically-pleasing and increase amenity value with benefits around $67,000 (Nordman et al., 2017). Rain gardens serves as a filtration system with the plants taking up pollutants and the bioretention soil/ mulch layer and gravel bed filters out the pollutants with benefits of $18,000 (Nordman et al., 2017) (Malaviya, et al., 2019). Water quality enhances through the filtration layers within a rain garden with total benefit savings approximately $1,900,000 (Autocase, 2018). Rain gardens improve air quality through carbon storage by evapotranspiration from the vegetation with total savings about $809,000 (Autocase, 2018). I computed all the total benefit savings from the benefits for the Quad and Quarry buildings to be approximately $3,700,000.

The total porous asphalt benefit savings were calculated from the individual benefits illustrated in Table 8A. Porous asphalt increases infiltration by allowing stormwater runoff to seep through the interconnected void spaces of total benefit savings around $90,000 (Autocase, 2018). The interconnected void spaces filter the pollutants from entering the ground with benefits about $18,000 (Nordman et al., 2017). The filtration layer of porous asphalt improves the water quality of total saving expenses $520,000

(Autocase, 2018). Regular asphalt raises surface temperatures on parking lots during summer months, while porous asphalt reduces the urban heat island effect with total benefits approximately 73,000 (Autocase, 2018). I then summed all total benefit savings for the Quarry parking lots to approximately $700,000.

The total benefit savings of a bioswale for the Quad and Quarry were estimated at $280,000 (Table 9A). Bioswales reduce stormwater runoff similarly to rain gardens where the mulch and bioretention soil layer absorbs the rainwater (Nordman et al., 2017). They also enhance water quality through filtration of pollutants through the mulch and bioretention soil layer with total benefits savings at $520,000 (Brankovic et al., 2019).

Carbon emissions are reduced through planting native vegetation that naturally absorb and store more water with total benefit savings about $14,000 (Autocase, 2018). Through these processes it enriches air quality by carbon sequestration with benefit savings approximately $200,000 (Autocase, 2018). Since bioswales are usually built into or off of impermeable surfaces, the temperatures are increased (Everett et al., 2015). Bioswales help cool the temperature that reduces the urban heat island effect total benefit savings about $1,600,000 (Autocase, 2018). The amenity value is increased through social factors of biophilia from total savings at approximately $60,000 (Autocase, 2018). I calculated all the total benefit savings for the Quarry parking lots to be $2,600,000.

Costs were computed to determine how much each GI would cost to integrate on campus through LCCA (Tables 6B, 7B, 8B, and 9B). Life Cycle Cost Analysis or LCCA assesses the total cost of a future project or owning a building. In order to conduct a successful LCCA, it would be in the initial design development then further adjustments can be made. Most of the waste generated can be recycled and reused for other projects since it incorporates the natural environment.

I analyzed the total costs from a LCCA to determine the extensive green roof cost effectiveness on the buildings and parking lots adjacent to the Quarry and Quad (Table 6B). Extensive green roofs typically last 40- to 50-years approximately the same lifespan as the metal roofs that are currently on campus. Initial construction depends on the cost of labor and quality of materials for a green roof (Ulubeyli et al., 2017). The total initial construction for an extensive green roof was approximately $21,000,000 (First American Roofing, 2021). Extensive green roofs require low maintenance and monitoring with total costs about $471,709 (Feng and Hewage, 2018). The cleanup includes removing weeds, fertilizing the plants, and inspecting the roof for any damages. End-of-life disposal of green roof materials can be recycled and reused for other purposes with no appointed cost. The initial construction, operations and maintenance, and disposal expenses were approximately $22,000,000.

A LCCA was produced for rain gardens to investigate the total costs of this project (Table 7B). The initial construction costs for rain gardens vary from the construction materials and labor costs about $2,300,000 (CostHelper, 2022). Rain gardens need minimal upkeep, similar to that of green roofs with mechanical weed control and fertilization (Siwiec et al., 2018). The cost of low operations and maintenance was about $540,000 (Boguniewicz-Zablocka and Capodaglio, 2020). The average lifespan of rain gardens is about 20-years and materials can be recycled. No costs were calculated for disposal methods of a rain garden. The total cost from the LCCA for rain gardens was approximately $2,900,000.

I examined the total costs from the lifecycle analysis for porous asphalt to examine the practicality of this project (Table 8B). The initial construction total of porous asphalt was approximately $2,000,000 (Grupa, 2021). Porous asphalt needs regular operations and maintenance to avoid water clogging with total costs about $120,000 (CTC & Associates LLC, 2012). The lifespan of porous asphalt under proper maintenance is about 20-years. The disposal methods for porous asphalt includes being recycled with costs about $580,000 (Hometown Demolition, 2021). The total cost for porous asphalt from a LCCA was approximately $2,800,000.

Based from the LCCA, the total costs for bioswales is illustrated in Table 9B. The installation total cost of a bioswale was about $2,000,000 (CostHelper, 2022). Bioswales need minimal operations and maintenance with total costs around $24,000 (Zablocka and Capodagio, 2020). 20-years is the typical life expectancy for bioswales and then disposal methods must be properly administered. No disposal costs were generated for bioswales. I totaled the sum from the LCCA costs to be $2,000,000.

A CBA was produced to analyze the various benefits and LCCA expenses that demonstrate this project's overall productivity. The four GIs were used to construct a CBA in Table 6C, 7C, 8C, and 9C.

A CBA is a method to create economic and business evaluations to determine if a project is feasible. CBA measures a project's social values by quantifying the costs and benefits in monetary value (e.g., University of Connecticut and Rutgers, The University of Michigan). CBA compares one or more options of overall costs and estimated benefits. At the University of Connecticut, a CBA analyzed a LID that was integrated at various locations of their campus to reduce environmental degradation and encourage green infrastructure (Kambli, 2018). Kambli found through the CBA that green roofs and rain gardens were most cost effective. University of Michigan assessed various green roofs on campus in a CBA that evaluated the cost effectiveness of its design (Gerrity et al., 2012). The results were extensive green roofs being economically feasible on campus (Gerrity et al., 2012).

A benefit-cost ratio or (BCR) was another method to determine if the overall benefits would outweigh the costs for this project. CBA and BCR were applied for the extensive green roof, rain garden, and porous asphalt. If a project has a BCR value greater than 1, the project is deemed economically feasible. BCR was applied by the following calculation.

$$BCR = \frac{Benefits\ Expected\ from\ the\ Project}{Costs\ of\ the\ Project}$$

This CBA is a simplified version where I was able to analyze only the costs and benefits. Further steps can be calculated to guarantee a more precise economic based valuation of the project. Some studies have taken the next step by calculating the net present value, discount rates, and rate of return. Net Present Value or NPV determines the future profits of a project. NPV uses the expected value of the potential costs and benefits towards a project. A positive NPV produces a greater return over time while a negative NPV creates a loss in return over time. A discount rate is used to determine the discounted value of future benefits at present time.

Return on Investment or ROI is a tool that measures the total profit generated from an investment. ROI investigates if a project will produce the overall best profit and benefit for a company or personal investments. ROI can be calculated by using the cost and gain of an investment then multiplying by 100 percent. If the ROI is positive then a profit is returned, but if the ROI is negative then the costs outweigh the gains.

A simplified CBA was then completed for an extensive green roof after calculating the benefit savings and life cycle costs. All the total benefit savings added to around $55,000,000 and LCCA totaled cost was $21,000,000 (Tables 6A and B). The extensive green roof bar graph displays how the effectiveness of green roofs overcomes the costs (Figure 20). Future benefits of green roofs will only increase as the climate crisis increases flood damages. Carter and Keeler (2008) found that green roofs are becoming more economically feasible in highly urbanized areas as energy and stormwater costs are increasing. Our results are consistent with this study about extensive green roofs being beneficial towards the environmental, social, and economical aspects.

I then completed a BCR to evaluate if the benefits generated from the extensive green roof would be greater than the life cycle costs. The calculated total BCR was 2.6, suggesting that the overall benefits outweigh the costs for green roofs by 2.6 to 1 (Table 6C). Since the benefits outweighed the costs, extensive green roofs would be economically feasible to incorporate into a sponge city design.

The CBA was conducted to evaluate the likelihood of installing rain gardens on campus. The total benefits savings was $3,600,000 and the life cycle costs was $2,900,000 (Table 7C). The bar graph portrays the benefits outweighing the costs for rain gardens (Figure 21). Potential benefits of rain gardens reduce the flood risks and hazards implicated by climate change with urban systems. Rain gardens are a cost-effective way to provide resiliency for susceptible cities (Boguniewicz-Zablocka and Capodaglio, 2020). Our findings are compatible with Boguniewicz-Zablocka and Capodaglio (2020) in that rain gardens would be feasible on campus. Heidari et al., (2022) that rain gardens have benefits exceeding the costs.

A BCR was generated to determine if a rain garden would be feasible. The total BCR was calculated to be 1.3 that illustrates the overall benefits were greater than the costs for rain gardens (Table 7C). Incorporating rain gardens into a sponge city across MSU campus would be economically efficient.

Additionally I computed a CBA for porous asphalt with adding the total savings from the BA and LCCA. The total benefit savings totaled to $700,000 and the LCCA total cost was $2,700,000 (Table 8C, Figure 22). The LCCA costs exceed the benefit savings for porous asphalt. Regulated maintenance of the porous asphalt would be essential and beneficial in maintaining the cost-effectiveness (Zhang and Kevern, 2021). Our results are consistent with Zhang and Kevern (2021) on porous asphalt being cost effective on campus through the many benefits it provides. Even though there are benefits to porous asphalt, the overall costs are too expensive to justify integrating it into a sponge city.

The overall effectiveness and efficiency of porous asphalt can be portrayed from the CBA. I calculated the total BCR to be 0.3 signifying that the costs were greater than the benefits for porous asphalt as emphasized in Table 8C. Porous asphalt would not be economically productive for a sponge city design because the costs surpassed the benefit savings. Perhaps, instead of covering the entire parking lots with porous asphalt, targeting certain areas would be more effective. Building next to curbs and drainage systems to reduce ponding to increase benefits and minimize the costs.

I then calculated the BA and LCCA to produce a CBA for a bioswale. The bioswale total benefit savings was about $2,700,000 and LCCA was around $2,000,000 as demonstrated in Table 9C. Figure 23 depicts the benefits outweighing the costs for bioswales. Future benefits of bioswales are cost-effective to help mitigate stormwater runoff during heavy rainfall events (Ekka et al., 2021). Our outcomes are consistent with bioswales offering many benefits that surpass the costs (Ekka et al., 2021).

Finally, I computed the BCR to establish the economic performance of a bioswale. The total BCR calculated was 1.3 that explains the benefits outweighing the costs as underlined in Table 9C. Bioswales would be an effective GI to integrate for a sponge city with its flood mitigation characteristics.

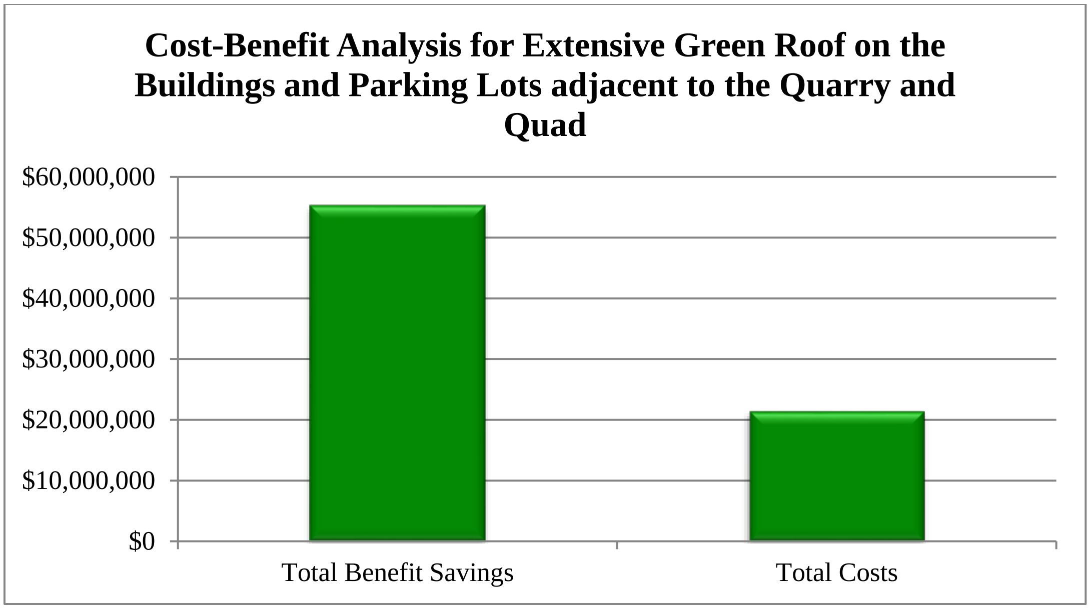


Figure 20. The CBA was for an extensive green roof around the Quarry and Quad buildings and parking lots. The total benefit savings is approximately $55 million dollars for green roofs. The total costs for extensive green roofs are a little over $21.3 million dollars. The benefit savings exceeded the costs by about $34 million dollars over its project 40-to 50-year lifespan.

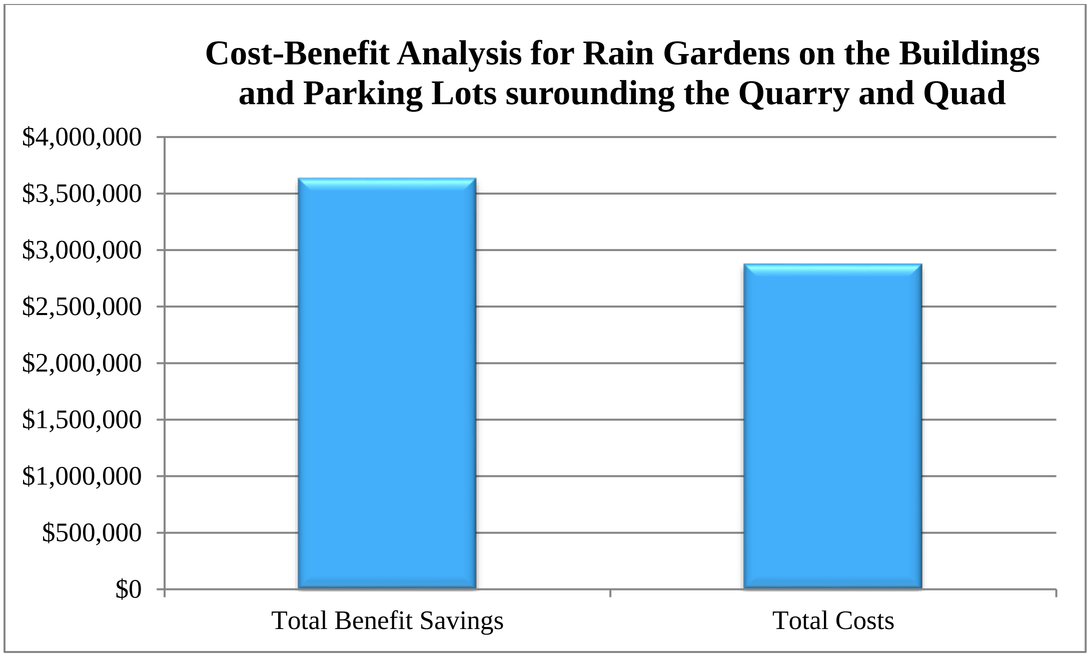


Figure 21. The CBA was for rain gardens surrounding the Quarry and Quad buildings. The total benefit savings is about $3.7 million dollars for rain gardens. The total costs for rain gardens are almost $2.9 million dollars. Rain gardens have benefit savings that outweigh the costs by approximately $760,000 dollars over 20-years.

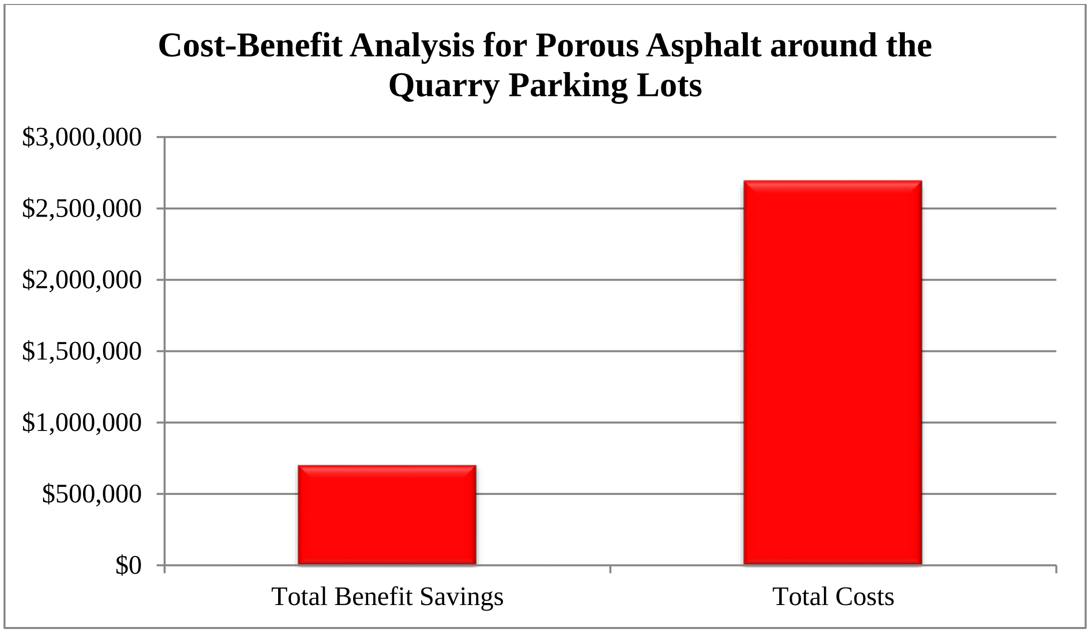


Figure 22. The CBA was for porous asphalt on the parking lots around the Quarry. The total benefit savings is approximately $700,000 dollars for porous asphalt. The total costs for porous asphalt is almost $2.7 million dollars. The costs exceed the benefits by about $2 million dollars over a 20-year life expectancy.

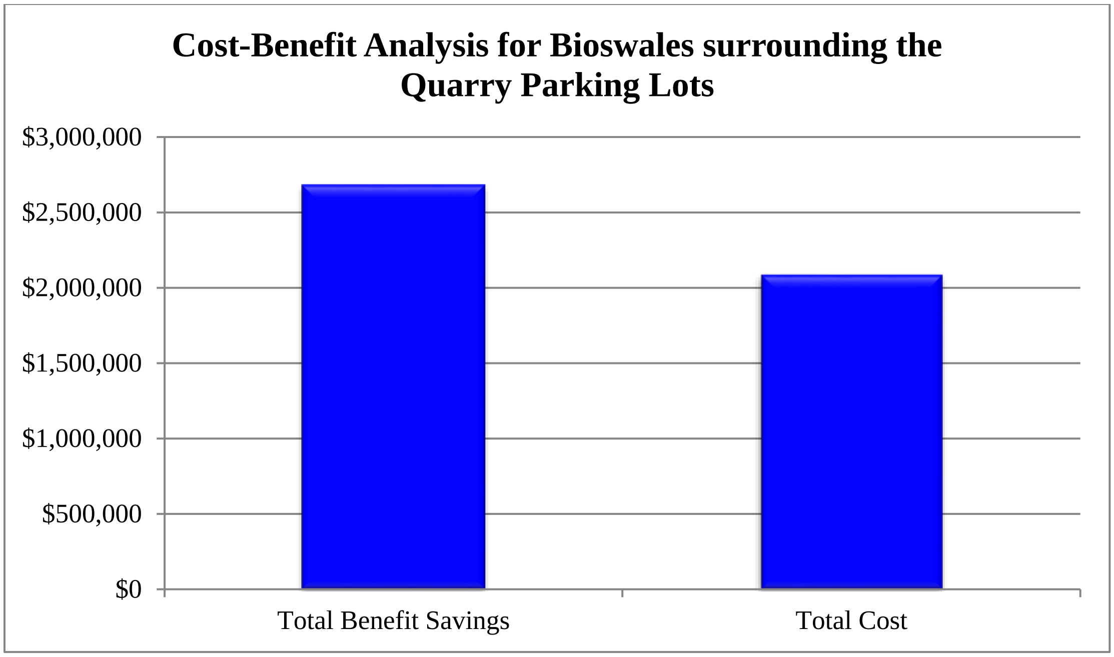


Figure 23. The CBA was for bioswales on and near the parking lots around the Quarry. The total benefit savings is approximately $2.7 million dollars for bioswales. The total costs for bioswales is a little over $2 million dollars. The benefit savings outweigh the costs by about $600,000 dollars over a 20-year lifespan.

5. Conclusion

As climate change becomes more detrimental towards the environment and society, the need for flood mitigation increases. Sponge cities when combined with GIs, will aid in stormwater management for the campus due to the imminent effects of flooding. This will help the local environment since integrating GIs for a sponge city would provide many benefits such as improving water quality, enriching biodiversity, and reducing stormwater runoff.

The data analysis of a sponge city design for the two study areas on MSU campus determined the feasibility of this project. GIS mapping of the five watersheds revealed the surface flow drainages towards the Quad and Quarry on campus. When incorporating an extensive green roof the stormwater runoff generated off the digitized buildings was reduced by 30% in comparison to metal roofs.

A CBA was constructed to examine the GIs overall benefits and costs. By designing a sponge city with GI, a CBA evaluated if the benefits outweighed the costs. Extensive green roof total benefit savings of approximately $55,000,000 exceeded the total costs of about $21,000,000. A rain garden total benefit savings of roughly $3,600,000 outweighed the total cost of approximately $2,900,000. Porous asphalt total cost of roughly $2,700,000 surpassed the total benefit savings of almost $700,000. A bioswale total benefit savings of about $2,700,000 outweighed the total cost of approximately $2,000,000 A more thorough BA must be conducted for porous asphalt in order for the benefits to exceed the costs. Based on the BCR, green roofs, rain gardens, and bioswales are economically, environmentally, and socially feasible to adopt on campus.

Future research would use the LiDAR drone to map and collect the aerial data to distinguish between flat versus sloped rooftops for the Quad and Quarry. Ideally, green roofs would be constructed on flat roofs instead of sloped roofs, or less than a 30-degree angle. The building rooftops would either be retrofitted or reconstructed from scratch in order to apply an extensive green roof. During the initial construction phase of a buildings' rooftop, the costs would be more expensive than retrofitting for a flat roof (HorstConstruction, 2020). Not only is it more cost effective, but also the preexisting materials are already in place and its time efficient.

Perhaps incorporating an integrated dual approach on existing flat rooftops could coexist. A dual design can be applied for a sponge city by implementing an extensive green roof and solar panels. A hypothetical study conducted in Hong Kong analyzed if green roofs and solar photovoltaic systems would be able to coexist (Hui and Chan, 2011). Hui and Chan examine four different approaches on energy performance for building rooftops: bare roof, green roof, solar photovoltaic roof, and combined system. Energy performance was effectively and efficiently utilized with the combined system (Hui and Chan, 2011). Hui and Chan discovered an integrated design of both solar photovoltaic panels and green roofs can coexist. This would provide additional benefits such as minimized heat urban island effect.

The expected outcomes are for MSU to possibly implement sponge city features in the Quad and Quarry on campus as part of its ongoing sustainability initiatives. MSU is known for its sustainability facilities that are optimal to incorporate additional green infrastructures. Since MSU has obtained both Gold and Silver LEED certificates, it illustrates the campus' buildings of resource productivity and sustainable action plans that are imperative for our climate crisis. LEED is a worldwide recognized rating system for implementing green buildings. With the addition of GIs, there is the possibility of obtaining more LEED certifications. MSU would become a leader or an example to other universities on how to install sponge city characteristics.

The Association for the Advancement of Sustainability in Higher Education or (AASHE) is a leading association of universities and colleges, which work to produce a sustainable future. AASHE is a database for various colleges and universities to promote their sustainable innovations and initiatives. AASHE has its own Sustainable Tracking, Assessment, and Rating System (STARS) recognized to ensure participation has advantages. The STARS program was designed to gain acknowledgment of sustainable efforts and performance, generate new concepts, and engage the community. Currently, MSU has not participated in the STARS program, but with a sponge city concept it could gain recognition.

Further investigation should be conducted in order to implement a sponge city design on campus. A detailed version of the CBA including discount rate, NPV, and ROI should be calculated to consider the time value of money in present dollars. The Quad is used for other school and recreational purposes, which could potentially pose an issue with the runoff being directed into it. During heavy rainstorms, the Quad would not be utilized for recreational activities and serve as stormwater runoff collection and storage. Creating a survey to gauge the student’s attitudes towards a sponge city design would help to determine its popularity on campus. To attend other universities and present a sponge city concept to educate them about the several benefits GIs provides. Partnerships with stakeholders across campus that are knowledgeable in urban green infrastructure could improve a sponge city design (Nastran, 2022).

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APPENDIX

NOAA New Jersey 24-hour Rainfall Frequency Data for Passaic County							
Year(s)	1	2	5	10	25	50	100
Rainfall Amount (in/hr)	2.87	3.47	4.42	5.23	6.43	7.47	8.62
Rainfall Amount (m)	0.07	0.09	0.11	0.13	0.16	0.19	0.22
Rainfall Amount (mm/hr)	72.90	88.14	112.27	132.84	163.32	189.74	218.95

Appendix 1. The NOAA New Jersey 24-hour Rainfall Frequency Data illustrates the Passaic County for the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms. The rainfall amounts were in inches per hour and converted into meters for the SCS-CN method and millimeters per hour for Rational Method calculations.

Total Precipitation Volume for Digitized Quad Buildings in m^3							
Digitized Buildings around the Quad	**1 Year**	**2 Years**	**5 Years**	**10 Years**	**25 Years**	**50 Years**	**100 Years**
Student Center and Annex	477	613	750	886	1,090	1,295	1,499
The School of Nursing/ The Graduate School	99	127	155	184	226	267	311
Calcia Hall	136	175	214	253	311	370	428
Finley Hall	69	89	109	129	159	188	218
Conrad J. Schmitt Hall	141	182	222	263	323	384	445
Center for Computing Information Science	94	121	148	175	215	256	296

Appendix 2A. The total precipitation volume for the digitized Quad buildings, measured in m^3 using the NOAA County-Specific, New Jersey 24-hour Rainfall Frequency Data. The reoccurrence intervals for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms utilized the Passaic County rainfall amounts in meters.

Total Precipitation Volume for Digitized Quarry Parking Lots and Buildings in m^3							
Digitized Buildings and Parking Lots around the Quarry	**1 Year**	**2 Years**	**5 Years**	**10 Years**	**25 Years**	**50 Years**	**100 Years**
Overlook Corporate Center	504	648	792	936	1,152	1,368	1,585
Overlook Corporate Center Parking Lot	520	668	817	966	1,188	1,411	1,634
MSU Train Station	534	687	839	992	1,221	1,450	1,679
Dioguardi Field	969	1,246	1,522	1,799	2,214	2,630	3,045
Dioguardi Field Parking Lot 1	173	222	271	321	395	469	543
Dioguardi Field Parking Lot 2	593	763	932	1,102	1,356	1,610	1,864
Yogi Berra Stadium	407	523	640	756	930	1,105	1,279

Appendix 2B. The total precipitation volume for the digitized Quarry parking lots and buildings measured in m^3 using the NOAA County-Specific, New Jersey 24-hour Rainfall Frequency Data. The reoccurrence intervals for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms utilized the Passaic County rainfall amounts in meters.

Total Precipitation Volume for Digitized Watersheds in m^3							
Digitized Watersheds	**1 Year**	**2 Years**	**5 Years**	**10 Years**	**25 Years**	**50 Years**	**100 Years**
Normal Avenue	23,419	30,111	36,801	43,492	53,528	63,565	73,601
Quarry	845	1,087	1,387	1,570	1,932	2,294	2,657
Quarry West	27,723	35,644	43,565	51,486	63,367	75,249	87,130
Quad	172	221	270	319	392	466	540
Quad South	732	941	1,151	1,360	1,674	1,987	2,301

Appendix 2C. The total precipitation volume for the digitized watersheds measured in m^3 using the NOAA County-Specific, New Jersey 24-hour Rainfall Frequency Data. The reoccurrence intervals for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms utilized the Passaic County rainfall amounts in meters.

Total Precipitation Volume for Digitized Study Areas in m^3							
Digitized Study Areas	**1 Year**	**2 Years**	**5 Years**	**10 Years**	**25 Years**	**50 Years**	**100 Years**
Quarry	1,362	1,752	2,141	2,530	3,114	3,698	4,281
Quad	318	409	500	591	727	864	1,000

Appendix 2D. The total precipitation volume for the digitized study areas measured in m^3 using the NOAA County-Specific, New Jersey 24-hour Rainfall Frequency Data. The reoccurrence intervals for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms utilized the Passaic County rainfall amounts in meters.

Total Runoff for an Extensive Green Roof in m^3 using the NOAA total volume of rainfall in Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms							
Year(s)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
Digitized Buildings Around the Quad	**Total Volume Runoff in m^3**						
Student Center and Annex	216	298	436	561	750	917	1,106
The School of Nursing/ The Graduate School	45	62	90	116	155	190	229
Calcia Hall	62	85	125	160	214	262	316
Finley Hall	31	43	63	82	109	133	161
Conrad J. Schmitt Hall	64	88	129	166	222	272	328
Center for Computing Information Science	43	59	86	111	148	181	218

Appendix 3A. The Soil Conservation Service Curve Number method was used to calculate total runoff for an extensive green roof for digitized watersheds, buildings, parking lots, and study areas in m^3. The NOAA the Passaic County rainfall amounts for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms were utilized.

Total Runoff for an Extensive Green Roof in m^3 using the NOAA total volume of rainfall in Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms							
Year(s)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
Digitized Buildings Around the Quarry	**Total Volume Runoff in m^3**						
Overlook Corporate Center	229	315	461	593	792	970	1,169
Overlook Corporate Center Parking Lot	236	324	475	611	817	1,000	1,205
MSU Train Station	242	333	488	628	839	1,027	1,238
Dioguardi Field	439	605	886	1,139	1,522	1,863	2,246
Dioguardi Field Parking Lot 1	78	108	158	203	271	332	400
Dioguardi Field Parking Lot 2	269	370	542	697	932	1,141	1,375
Yogi Berra Stadium	185	254	372	479	640	783	944

Appendix 3B. The Soil Conservation Service Curve Number method was applied to calculate total runoff for an extensive green roof for digitized watersheds, buildings, parking lots, and study areas in m^3. Used the NOAA the Passaic County rainfall amounts for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms.

Total Runoff for an Extensive Green Roof in m^3 using the NOAA total volume of rainfall in Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms							
Year(s)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
Digitized Watersheds	**Total Volume Runoff in m^3**						
Normal Avenue	10,406	26,971	20,978	26,971	36,045	44,120	53,194
Quarry	199	515	401	515	689	843	1,016
Quarry West	11,743	30,437	23,673	30,437	40,677	49,789	60,029
Quad	78	202	157	202	270	330	398
Quad South	332	861	670	861	1,150	1,408	1,698

Appendix 3C. The Soil Conservation Service Curve Number method was utilized to calculate total runoff for an extensive green roof for digitized watersheds, buildings, parking lots, and study areas in m^3. The NOAA the Passaic County rainfall amounts for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms were applied.

Total Runoff for an Extensive Green Roof in m^3 using the NOAA total volume of rainfall in Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms							
Year(s)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
Digitized Study Areas	**Total Volume Runoff in m^3**						
Quarry	618	850	1,246	1,602	2,140	2,620	3,159
Quad	144	199	291	374	500	612	738

Appendix 3D. The Soil Conservation Service Curve Number method was used to calculate total runoff for an extensive green roof for digitized watersheds, buildings, parking lots, and study areas in m^3. Utilized the NOAA the Passaic County rainfall amounts for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms were utilized.

Total Runoff for Metal Roof in m^3 using the NOAA total volume of rainfall in Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms							
Year(s)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
Digitized Buildings Around the Quad	**Total Volume Runoff in m^3**						
Student Center and Annex	457	561	724	864	1,072	1,252	1,451
The School of Nursing/ The Graduate School	95	116	150	179	222	260	301
Calcia Hall	130	160	207	247	306	357	414
Finley Hall	66	82	105	126	156	182	211
Conrad J. Schmitt Hall	136	166	215	256	318	371	430
Center for Computing Information Science	90	111	143	171	212	247	286

Appendix 4A. The Soil Conservation Service Curve Number method was utilized to compute the total runoff for metal roof for the digitized Quad buildings in m^3. Used the NOAA total rainfall amounts using the Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms.

Total Runoff for Metal Roof in m^3 using the NOAA total volume of rainfall in Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms							
Year(s)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
Digitized Buildings and Parking Lots Around the Quarry	**Total Volume Runoff in m^3**						
Overlook Corporate Center	483	593	765	913	1,132	1,323	1,533
Overlook Corporate Center Parking Lot	498	611	789	941	1,168	1,364	1,581
MSU Train Station	512	628	810	967	1,200	1,401	1,624
Dioguardi Field	928	1,139	1,469	1,754	2,176	2,542	2,946
Dioguardi Field Parking Lot 1	165	203	262	313	388	453	525
Dioguardi Field Parking Lot 2	568	697	900	1,074	1,332	1,556	1,804
Yogi Berra Stadium	390	479	617	737	914	1,068	1,238

Appendix 4B. The Soil Conservation Service Curve Number method was utilized to compute the total runoff for metal roof for the digitized buildings and parking lots around the Quarry in m^3. Applied the NOAA total rainfall amounts using the Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms.

Total Runoff for Metal Roof in m^3 using the NOAA total volume of rainfall in Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms							
Year(s)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
Watersheds	**Total Volume Runoff in m^3**						
Normal Avenue	21,977	26,971	34,796	41,539	51,529	60,186	69,759
Quarry	420	515	665	794	984	1,150	1,333
Quarry West	24,801	30,437	39,268	46,877	58,150	67,920	78,724
Quad	164	202	260	311	386	450	522
Quad South	701	861	1,111	1,326	1,645	1,921	2,226

Appendix 4C. The Soil Conservation Service Curve Number method was used to compute the total runoff for metal roof for the digitized watersheds in m^3. Utilized the NOAA total rainfall amounts using the Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms.

Total Runoff for Metal Roof in m^3 using the NOAA total volume of rainfall in Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms							
Year(s)	**1**	**2**	**5**	**10**	**25**	**50**	**100**
Digitized Study Areas	**Total Volume Runoff in m^3**						
Quarry	1,305	1,602	2,066	2,467	3,060	3,574	4,142
Quad	305	374	483	576	715	835	968

Appendix 4D. The Soil Conservation Service Curve Number method was applied to compute the total runoff for metal roof for the digitized two study areas in m^3. Used the NOAA total rainfall amounts using the Passaic County for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms.

Total Extensive Green Roof Estimate Calculated the Area of Digitized Quad and Quarry Buildings and Parking Lots		
Type of Roof	**Extensive Green Roof**	
Digitized Areas	**Unit Cost per m^2**	**Total Estimate**
Quad Buildings		
Student Center and Annex	$323	$2,368,999
The School of Nursing/ The Graduate School	$323	$491,308
Calcia Hall	$323	$676,165
Finley Hall	$323	$344,694
Conrad J. Schmitt Hall	$323	$702,422
Center for Computing and Information Science	$323	$467,692
Quarry Buildings and Parking Lots	**Unit Cost per m^2**	**Total Estimate**
Overlook Corporate Center	$323	$2,503,509
Overlook Corporate Center Parking Lot	$323	$2,581,598
MSU Train Station	$323	$2,652,209
Dioguardi Field	$323	$4,810,983
Dioguardi Field Parking Lot 1	$323	$857,445
Dioguardi Field Parking Lot 2	$323	$2,945,364
Yogi Berra Stadium	$323	$2,021,291
Total Estimate for Extensive Green Roof		$20,920,169

Appendix 5A. The total estimate for an extensive green roof cost was calculated for the digitized buildings and parking lots around the Quarry and Quad. The unit cost to $323 per m^2 and multiplied by the area of the digitized two study locations.

Total Replacement Metal Estimate Calculated the Area of Digitized Quad and Quarry Buildings and Parking Lots		
Type of Roof	**Metal Roof**	
Digitized Areas	**Unit Cost per m^2**	**Total Estimate**
Quad Buildings		
Student Center and Annex	$117	$799,538
The School of Nursing/ The Graduate School	$117	$165,817
Calcia Hall	$117	$228,206
Finley Hall	$117	$116,334
Conrad J. Schmitt Hall	$117	$237,068
Center for Computing and Information Science	$117	$157,846
Quarry Buildings and Parking Lots	**Unit Cost per m^2**	**Total Estimate**
Overlook Corporate Center	$117	$844,935
Overlook Corporate Center Parking Lot	$117	$871,290
MSU Train Station	$117	$895,122
Dioguardi Field	$117	$1,623,709
Dioguardi Field Parking Lot 1	$117	$289,388
Dioguardi Field Parking Lot 2	$117	$994,062
Yogi Berra Stadium	$117	$682,187
Total Estimate for Replacement Metal Roof		$7,060,566

Appendix 5B. The total replacement metal roof estimate was for the digitized buildings around the Quarry and Quad. The unit cost to replace metal roof is $117 per m^2 and multiplied by the total area of the digitized buildings and parking lots.

Total Rain Garden Estimate Calculated the Area of Digitized Quad and Quarry Buildings and Parking Lots		
Quad Buildings	**Unit Cost per m^2**	**Total Estimate**
Student Center and Annex	\$32	\$236,885
The School of Nursing/ The Graduate School	\$32	\$49,128
Calcia Hall	\$32	\$67,612
Finley Hall	\$32	\$34,467
Conrad J. Schmitt Hall	\$32	\$70,238
Center for Computing and Information Science	\$32	\$46,766
Quarry Buildings and Parking Lots	**Unit Cost per m^2**	**Total Estimate**
Overlook Corporate Center	\$32	\$250,335
Overlook Corporate Center Parking Lot	\$32	\$258,144
MSU Train Station	\$32	\$265,204
Dioguardi Field	\$32	\$481,069
Dioguardi Field Parking Lot 1	\$32	\$85,739
Dioguardi Field Parking Lot 2	\$32	\$294,518
Yogi Berra Stadium	\$32	\$202,117
Total Estimate for Rain Gardens		\$2,342,222

Appendix 6. The total rain garden estimate was calculated for the digitized buildings around the Quarry and Quad. The unit cost was \$32 per m^2 and multiplied by the area of the digitized two areas.

Total Porous Asphalt Estimate Calculated the Area of Digitized Quarry Parking Lots		
Digitized Quarry Parking Lots	**Unit Cost per m^2**	**Total Estimate**
Dioguardi Field (Parking Lot 1)	$107	$283,160
Dioguardi Field (Parking Lot 2)	$107	$972,667
Overlook Corporate Center	$107	$826,750
Total Estimate for Porous Asphalt		$2,082,577

Appendix 7. The total porous asphalt estimate was computed for the digitized parking lots around the Quarry. The unit cost was $107 per m^2 and multiplied by the area of the digitized two study locations.

Total Bioswale Estimate Calculated the Area of Digitized Quarry Parking Lots		
Digitized Quarry Parking Lots	**Unit Cost per m^2**	**Total Estimate**
Dioguardi Field (Parking Lot 1)	\$113	\$278,744
Dioguardi Field (Parking Lot 2)	\$113	\$957,499
Overlook Corporate Center	\$113	\$813,858
Total Estimate for Bioswale		\$2,050,100

Appendix 8. The total bioswale estimate was for the digitized parking lots around the Quarry. The unit cost was \$113 per m^2 and multiplied by the area of the digitized two study areas.