Sustainable Redevelopment of Fashion Square Mall

Technical Report
Presented to the Faculty of the School of Engineering and Applied Science, Department of Engineering Systems and Environment, University of Virginia

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On our honor as University students, we have neither given nor received unauthorized aid on this assignment.

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Abstract

This report discusses the Meadow Creek capstone group's goals and accomplishments in the 2021-2022 school year. The main purpose of this capstone is to redesign the Fashion Square Mall parcel to make a multi-use community space that results in less stormwater runoff. One major aspect of the design is the incorporation of green infrastructure, for it has the ability to improve water quality, reduce peak flows, and reduce the urban heat island effect. Green infrastructure also encourages the human-nature connection known as biophilia and engages residents with the natural environment. The team chose to focus on redesigning the Fashion Square Mall parcel because of its current lack of stormwater management, abundance of impervious surface and economic underutilization. PCSWMM, i-Tree, and Virginia Runoff Reduction models were developed for the site to perform hydraulic, hydrologic, and environmental analyses. Lastly, a cost estimation and a climate change resiliency analysis were conducted. The collective changes to the site's land cover achieved significant reductions in stormwater pollution, energy surrogate, and runoff volumes. These results demonstrate that stormwater management success can be achieved through land use changes that don't necessarily require costly infrastructure improvements. In addition, the site's transformation of underutilized commercial space creates opportunities for housing, recreation, energy production, transit, and community interaction.

Introduction

Charlottesville, Virginia is home to extensive residential and commercial development. Recent construction, such as the Stonefield shopping center in 2012 and UVA's Bond residential building in 2019, has improved the city's appeal as a place to both live in and visit. However, some portions of the area are outdated, poorly maintained, and are not significantly contributing to the Charlottesville community (Ingles, 2012; UVA Housing and Residence Life, n.d.). One such example is the Fashion Square Mall located directly off of Route 29 and approximately 5 miles from the University of Virginia (Figure 1). The mall first opened in 1980 but is now suffering from multiple stores closing and a limited visitor population (The Daily Progress, 2017). In June 2021, The Washington Prime Group, the owner of the mall, filed for bankruptcy. A month later, it was auctioned off to Charlottesville JP and is now expected to be redeveloped through this new ownership (Hirschheimer, 2021; Hammel, 2021).

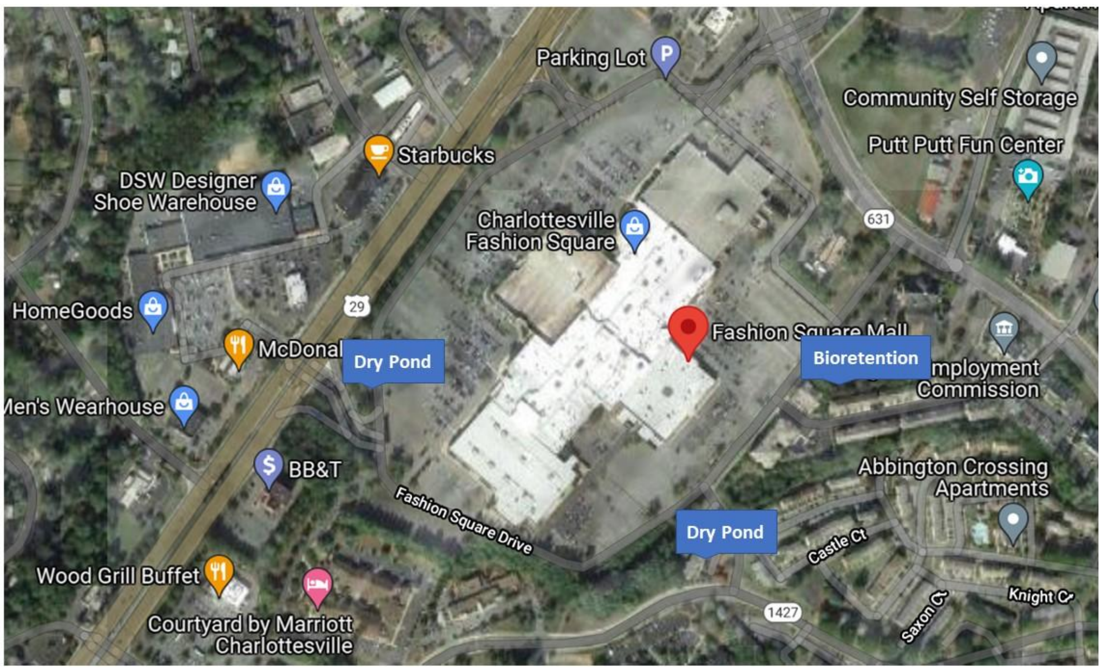


Figure 1. Aerial view of Fashion Square Mall from Google Earth with BMPs.

Moreover, the current design of Fashion Square is contributing to significant environmental issues in Charlottesville. The mall and its surrounding area consist of high amounts of impervious surface. These conditions create fast-moving stormwater runoff that picks up pollutants, deposited through either atmospheric deposition or anthropogenic means. As a result, excess nutrients such as nitrogen, phosphate and sediment enter the creek and harm the aquatic ecosystem. Additionally, the high runoff rates result in increased peak volumes and flooding that causes scour and deterioration of stream banks. The Meadow Creek watershed, which the Fashion Square Mall is located in, is now considered ecologically imparied and is being monitored per its listing on Virginia's 303(d) List (Virginia Department of Environmental

Quality, 2020). With the Charlottesville community continuing to grow and develop, additional strain will be placed on the stream to accept greater volumes of stormwater runoff. Furthermore, climate change will increase stormwater runoff volumes and velocities, as seasonal temperature patterns change and intense storms become more frequent (Morrison, 2021). This concern led our team to focus our civil engineering capstone project on redesigning the Fashion Square Mall to achieve better stormwater management and improve the social and environmental sustainability of the Charlottesville-Albemarle area.

Project Scope

The objective of this capstone project is to redesign the Fashion Square Mall to improve the ecological health of the area and create a more socially sustainable built environment. The team's year-long project schedule is given in Appendix A. The redesign aims to enhance community integration and improve accessibility by providing amenities ranging from athletic fields to commercial real estate. Additionally, it implements green infrastructure (GI), low-impact development (LID), and other environmental solutions. GI is a method of integrating nature into the built environment through the placement of vegetated land. It conserves natural environmental systems and provides a variety of ecosystem services including water quality improvement, air temperature reduction, and habitat provisioning. It is particularly beneficial for stormwater management since GI can naturally store and infiltrate stormwater runoff before it is discharged into downstream water bodies (Gagne & Tayouga, 2016).

The team designed the site layout and the proposed Best Management Practices (BMPs) on AutoCAD Civil 3D. Then, they modeled the existing and proposed conditions using PCSWMM, i-Tree, and Virginia Runoff Reduction Model (VRRM) in order to determine if the redesign improves stormwater management conditions. The use of three different modeling softwares gives the project several points of assessment that can be used for evaluating how well the redesign improves the site's environmental health. The team also used surface temperature modeling to complete an urban heat island analysis. This is based on the fact that GI and other vegetative elements can provide microclimate cooling to combat the urban heat island effect. This report also includes a cost analysis to understand the financial feasibility of the redesign.

Fashion Square Mall Site

The team made a field visit to the Fashion Square Mall to understand the current layout of the site. The mall has a large amount of unused parking lots. Almost the entire property consists of impervious surface area. The facade of the building is gray in color with very little greenery in the parking lot. Many of the potted plants near the building have dried out, and few green islands in the parking lots exist, and if they do, they are small in size. The team found existing stormwater facilities, a dry pond on the west and southeast side and a bioretention system, next to the parcel, on the east side. The locations of these facilities are shown in Figure 1. These facilities are filled with trash and have overgrown vegetation, as seen in Figure 2.

Figure 2. Existing dry pond on Fashion Square Mall property.

The site also faces challenges in its pedestrian accessibility, since it is located off a busy highway with limited sidewalk access, and its current entrance is on a steep incline (Figure 3). The inside of the mall is dull in style and receives little natural light (Figure 4). After recognizing the many areas for improvement at Fashion Square Mall, the team decided to focus on redesigning the site so that it serves as a center or hub for all members of the community with different uses and needs, while also ensuring it provides adequate GI and stormwater management practices.

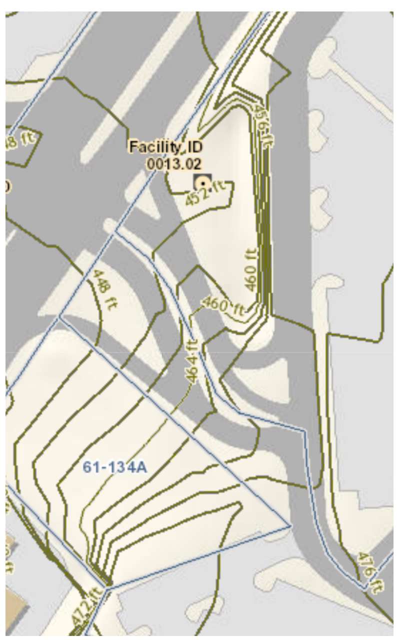


Figure 3. Elevation data showing steep incline at mall entrance.

Figure 4. Fashion Square Mall indoor area.

Design Plan

Using the previously mentioned objectives, the team developed a design plan for their proposed sustainable redevelopment of Fashion Square Mall (Figure 5). An important change made was the transformation into an outdoor shopping area, similar to Charlottesville's Downtown Mall. This requires the tearing down of the inner walking area between stores in order to create an entirely outdoor pedestrian area. Additionally, the redesign includes a transportation hub, parking garage, community garden, central plaza, mixed-use buildings, and athletic fields.

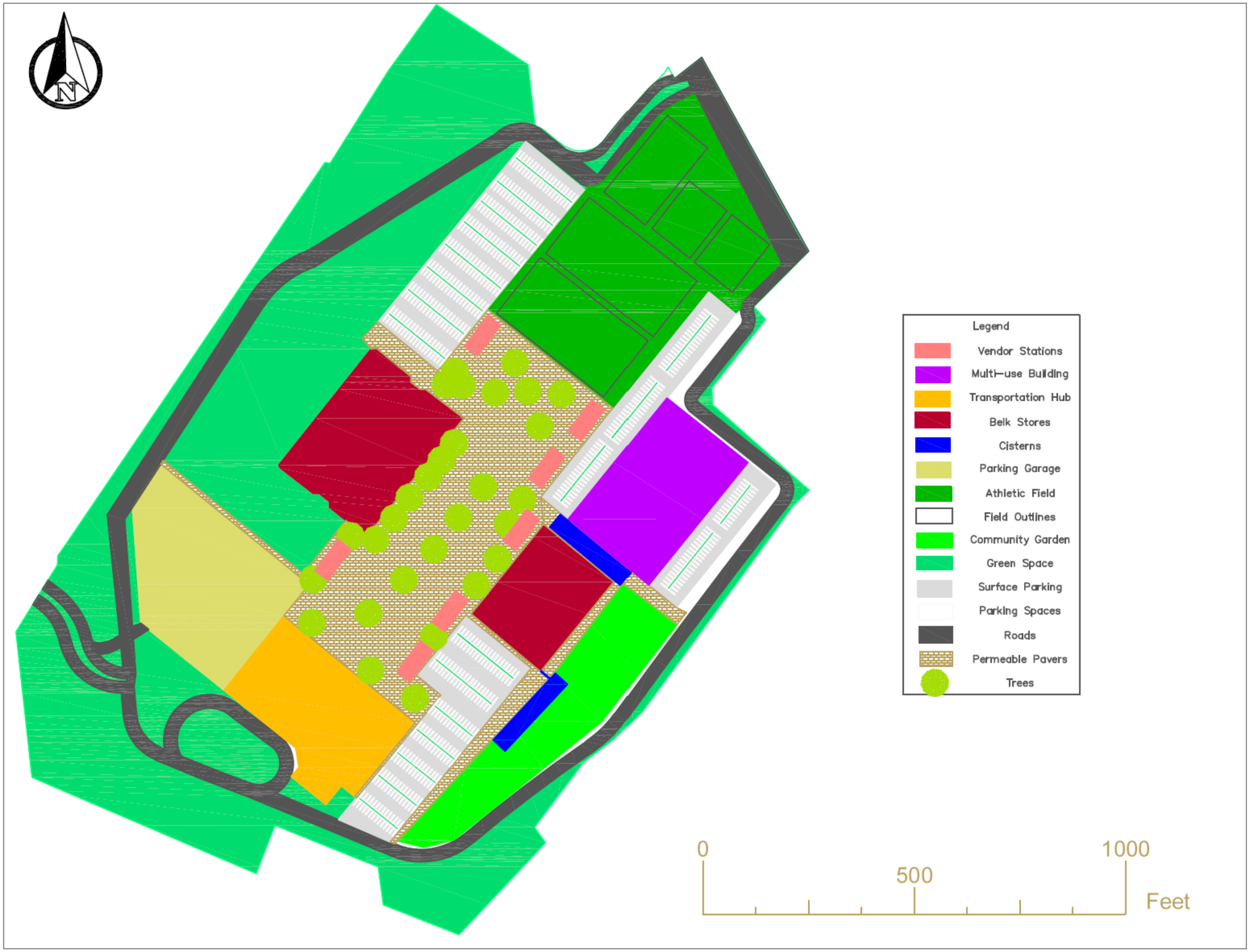


Figure 5. AutoCAD Redesign Plan.

Transportation Hub

The transportation hub will be located on the western entrance of the mall parcel, as a renovation of the old JC Penney department store (Figure 6). It will provide intercity transportation to other regional cities and provide community residents with a central hub for long-distance bus transit. Additionally, the hub will serve as a transfer station that connects the Charlottesville airport, UVA, and downtown Charlottesville. It will connect to existing bus routes such as the Charlottesville Area Transit (CAT) system and encourage the expansion of bus transit in the surrounding area. The hub features electric vehicle charging stations, a loading and unloading loop, and a solar roof. Additionally, the transportation hub has the space to accommodate micro-mobility, such as bikes and electric scooters, and ride sharing modes like Uber and Lyft.

Figure 6. Example of Transportation Hub (Krajewski, 2016).

Parking Garage

The redesign includes a three-level parking garage, akin to Figure 7, that is accessible directly off of Route 29. In order to accommodate the redesign's significant replacement of surface parking, the parking garage has an expected capacity of 1200 spaces. Some surface parking will still be available, and the combination of both will satisfy minimum parking requirements.

Figure 7. Example of Parking Garage.

Community Gardens

The community gardens will replace 120,000 square feet of pavement with agricultural space modeled in Figure 8. This area is intended to be a public growing space where community members can contribute to the gardening process. The garden will consist of native vegetation, and rainwater will be irrigated to the gardens via rainwater harvesting from buildings on-site.

Figure 8. Example of Community Garden (Ngoc X Doan, 2021).

Central Plaza

The parcel features a central plaza for gathering and provides access to all of the site features. The plaza area is designed with permeable pavers, with a similar brick look to the Charlottesville Downtown Mall. These pavers absorb water instead of the water running off the surface like normal pavement. Additionally, the access paths throughout the plaza and site would be made of permeable concrete. Permeable concrete serves the same stormwater drainage purpose as the permeable pavers, but provides easier access for visitors. Pavers tend to be bumpy and uneven to walk on or wheel over. Providing permeable pavers and permeable concrete options creates more accessibility throughout the site while modeling the classic Charlottesville brick aesthetic. The plaza is a large open space, but it is designed to have landscaping and vegetation throughout. Trees in the plaza produce shade to the area and create a cooling effect. Additionally, the plaza features benches and tables for visitors to gather. The plaza also provides the opportunity for small vendors to table and sell products. Figure 9 shows an example of a plaza similar to the design.

Figure 9. Example of Permeable Pavement Plaza (*Permeable Pavement Plaza*, n.d.).

Mixed-Use

The mixed-use building features a commercial level on the bottom floor. The commercial level is expected to give residents and site visitors access to small stores and restaurants. Ideally, these stores and restaurants would be local businesses. The upper levels of the building feature apartments, with the opportunity to be affordable units. The mixed-use building is in an ideal location due to its close proximity to stores. Aldi lies across Rio Road, north of the parcel, and Lidl lies across Route 29, west of the parcel. Additionally, there are restaurants and other stores nearby. The mixed-use building features a solar roof and a rainwater harvesting system. The solar roof supplies a large portion of the building's energy. The rainwater harvesting system collects water to be distributed to the community garden, athletic fields, and the various greenery throughout the parcel. The residents of the building have access to the nearby community garden. There is specific parking that is designated to residents, but the building is also near the proposed transportation hub. Figure 10 shows an example of a mixed-use building with a lower comercial level and higher residential levels.

Figure 10. Example of Mixed-Use Building (*Mixed Use Building,* n.d.).

Athletic Fields

The old, unused Sears parking lot, in the north end of the parcel will be converted into various sports fields. These fields include: two soccer fields, three tennis courts, two basketball courts, and two beach volleyball courts. The sports fields are a gathering space that can be utilized for community team practices and games. The soccer fields would be considered managed landscape and would provide stormwater benefits in allowing water infiltration. Additionally, the field irrigation is provided by the rainwater harvested on site. Figure 11 shows an example of a sports field complex.

Figure 11. Example of Sports Field (*Sports Field,* n.d.).

Overall Site Conversion

One of the largest changes to the site is the reduction of the impervious parking lots that are currently unused. Much of this is done through the expansion of green space and the addition of permeable pavement. This land cover change results in a large reduction in stormwater runoff and pollutants as much of the space that did not allow water to infiltrate is being converted into space that does allow infiltration. The commercial space on the site will also be greatly reduced, since much of it is vacant and not currently being used. This vacant space will be converted into a plaza area and transportation hub that will provide benefits to the community. The layout of the site with the proposed additions is seen in Figure 12.

Figure 12. Layout of Proposed Features.

Best Management Practices

The two Best Management Practices (BMPs) included in the redevelopment plan are rainwater harvesting and permeable pavement. Two separately functioning rainwater harvesting systems will be installed to capture roof runoff on the easternmost Belk anchor store and the proposed mixed-use building. As shown in Table 1, these systems will capture and store stormwater runoff that can now be slowly released into the watershed through irrigation practices.

Table 1. Rainwater Harvesting Design Specifications.

Building	Roof Area (ft^2)	Storage Capacity (gallons)	Overflow Events (days)	Runoff Reduction Volume Credit	Irrigation and Drawdown (gal/day)	Irrigation Usage
Belk Store	64,311	50,000	3	96%	8905	100,000ft^2 of community gardens
Mixed-Use	77,491	50,000	2	98%	17811	200,000ft^2 of athletic fields

These rainwater harvesting systems are designed to align with the Virginia Department of Environmental Quality's design specifications related to this best management practice (Virginia Department of Environmental Quality, 2013). The systems are designed with the intention of irrigation being used at a rate of 1 inch per week between the months of April and October. During other months, a secondary drawdown will be required to discharge at the same daily rate as the seasonal irrigation.

For the Belk harvesting system, rainwater will be captured from the roof and conveyed to an underground storage tank, as shown in Figure 14. Figure 13 displays how the mixed-use building will capture rainwater and store it in another underground cistern. These cisterns will be made of fiberglass and will require pressure proofing. The Belk system's associated cistern will be buried under the community garden and require pumping to allow for usage within the garden space. Likewise, the cistern for the mixed-use building will be buried under permeable pavement and additional pumping and distribution will be required to irrigate the athletic spaces. The mixed-use cistern's proximity to the central plaza could also facilitate irrigation for the trees and other vegetation within that space.

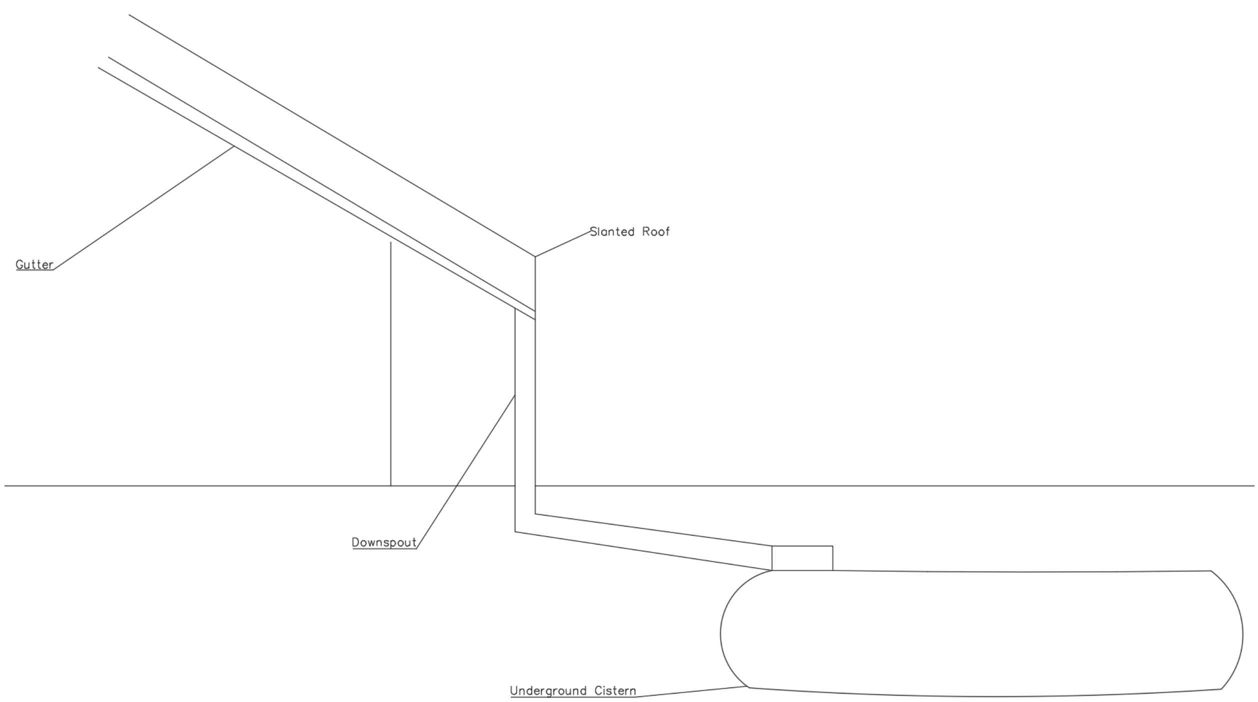


Figure 13. Rainwater harvesting off of mixed-use building.

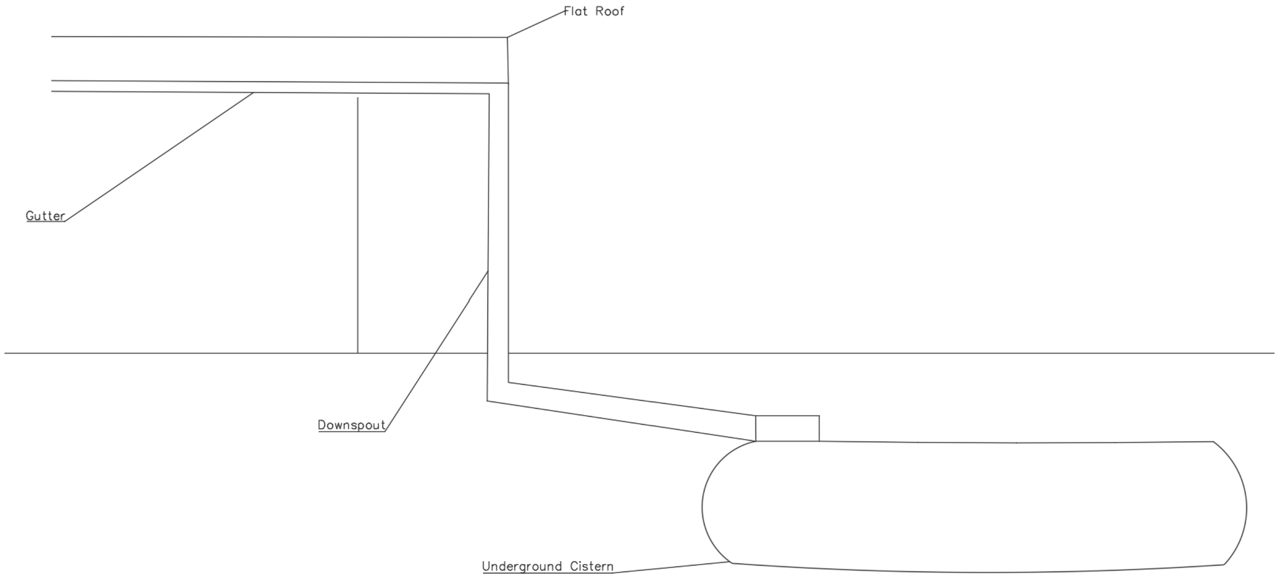


Figure 14. Rainwater harvesting off of Belk roof.

Permeable pavers make up the surface of the inner plaza and connecting paths throughout the site. In order to maintain accessibility, permeable concrete pedestrian paths will provide the primary walking space that connects the site facilities. Permeable concrete was chosen for the pedestrian paths throughout the plaza and surrounding shops due to accessibility issues with permeable pavers. Permeable concrete is smoother to walk and ride on making it more accessible. The design of the site's permeable pavement aligns with the BMP specifications set forth by Virginia Department of Environmental Quality. As depicted in Figure 15, they are as follows, 3" of permeable pavement, 2" of bedding layer, 6" of stone reservoir, and 2" of stone layer.

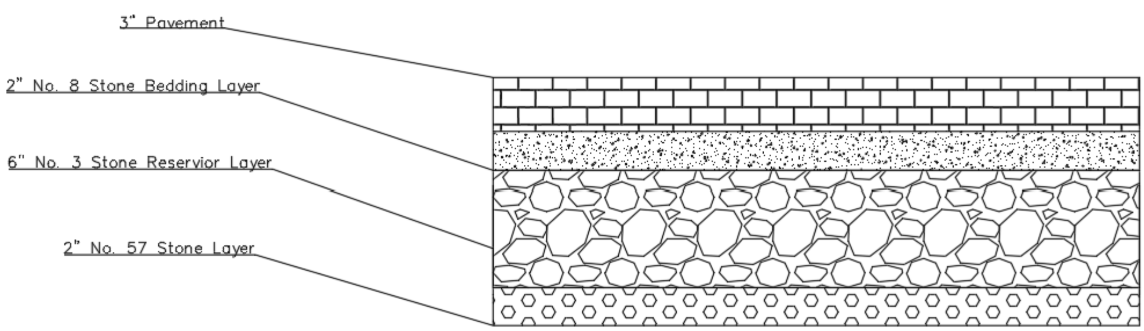


Figure 15. Permeable Pavement cross section design.

Modeling and Analysis

Solar Roof Potential

The National Renewable Energy Laboratory's photovoltaic performance predictor tool, PVWatts, was used to provide estimates for energy production and energy value based on various solar parameters. The solar potential of 4 rooftops in the design (West Belk, East Belk, residential and commercial building, and transportation hub) was estimated. A tilt angle of 38 degrees was selected as the optimal tilt angle is the latitude degree of Charlottesville. The azimuth parameter was 180 degrees, or south facing, to receive the optimal amount of sunlight. Designs of a solar panel, drawn in Civil 3D, can be seen in Figure 16 and Figure 17 below.

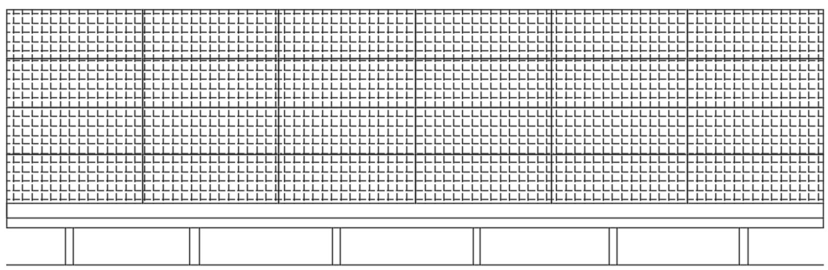


Figure 16. Solar panel design model.

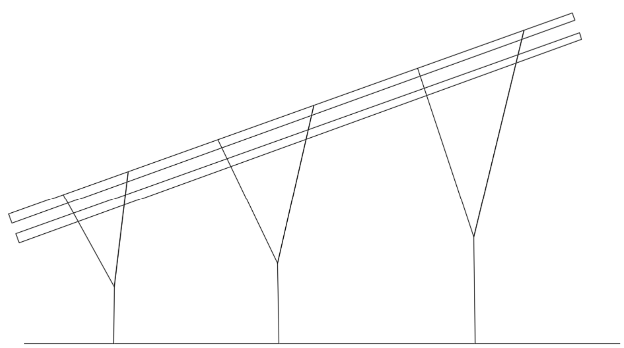


Figure 17. Solar panel side view model.

The results of the photovoltaic performance predictor tool as well as cost estimations are shown in Table 2 below.

Table 2. Solar Potential for Fashion Square Mall Rooftops.

Building Name	Annual Energy Production	Annual Value	DC System Size	Installation Cost	ITC Credit	Federal Depreciation Savings	State Savings	Total Savings (5 years)	Payback Period	Energy Usage
	(kWh/Year)	($)	(kW)	($)	($)	($)	($)	($)	(Years)	(kWh/ Year)
West Belk	6.75E+05	52,600	500	1,095,000	284,700	228,636	76,212	304,848	**9.6**	1.74E+06
East Belk	4.72E+05	36,800	350	766,500	199,290	160,045	53,348	213,394	**9.6**	1.19E+06
Transportation Hub	6.75E+05	52,600	500	1,095,000	284,700	228,636	76,212	304,848	**9.6**	1.65E+06
Mixed Use	5.40E+05	59,600	400	876,000	227,760	182,909	60,970	243,878	**6.8**	1.37E+06
Totals	2.36E+06	201,600	1750	3,832,500	996,450	800,226	266,742	1,066,968	-	5.95E+06

All of the solar systems use standard size commercial grade solar panels that are 78” by 39” (*4 differences*, 2022). The west Belk and the transportation hub can handle a 500 kW system based on the roof area. Both of these would accrue an annual value of $52,600 each. The mixed-use building solar array is a 400 kW system that accrues $59,600 annually. The east Belk has a 350 kW system and accrues $36,800 annually. The average energy usage per building was estimated using 18.3 kWh per square foot (*Retail Buildings*, n.d.). Though the four solar roof systems generate a large amount of energy, based on the estimation it is not enough to self sustain them. The roofs provide a large open space for solar arrays, but they cannot take up the entire roof space. The system size was estimated by comparing the system size and roof size of other solar roofs, for example the UVA Bookstore roof. The solar panels have a high upfront cost, but there are credits to offset it. The Investment Tax Credit (ITC) provides a 26% tax credit to those who pay the full upfront cost of the solar panels. Additionally, states have savings plans and the panels generate depreciation savings (Schell, n.d.).

Overall, the estimated price for the solar panels is about $3.8 million, but the total ITC credit is about $1 million. Table 2 shows the estimated payback period for each solar roof. The west Belk, east Belk, and Transportation Hub have a payback period of 9.6 years. The mixed-use building has a payback period of 6.8 years. Many benefits come from adding solar panels to the site. After the payback period, much of the energy needed to power the buildings will come from solar power. This will save the owners money in energy as they will only have to cover the small portion that is not powered by the panels. Additionally, solar panels are a sustainable, clean energy source.

VRRM

The project team created a VRRM file as one of our stormwater analysis methods (Appendix B). We input the land cover of the existing area of Fashion Square, which was characterized in ArcGIS Pro. Then, post-development land cover was calculated using the areas of our anticipated BMPs and land cover changes. The entire site was considered as a single drainage area, and all land cover qualified as B soils. As shown in Tables 3 and 4, almost 50 percent of the existing impervious cover is turned into managed turf in the redesign. Next, permeable pavement and rainwater harvesting and their corresponding acreages were added onto VRRM as BMPs. The model calculated that the land cover changes and BMP additions led to a total phosphorus (TP) load reduction of 7.77 lb/year, which exceeds the target TP load reduction by 18.74 lb/year (Figure 18). Therefore, the team concluded that the design changes were more than adequate for stormwater quality improvement purposes. One of the major benefits of a high phosphorus removal is that it can earn financial credit. In the James River watershed, 1 lb of phosphorus credit is equivalent to $10,430 (Fitch et al., 2014). Therefore, the phosphorus removal from this analysis would be worth $81,000 (Appendix D).

Table 3. Pre-Redevelopment Land Cover Information Extracted from VRRM Site Tab.

	A Soils	B Soils	C Soils	D Soils	Totals
Forest/Open Space (acres): undisturbed forest/open space	0.00	7.96	0.00	0.00	**7.96**
Managed Turf (acres): disturbed, graded for yards or other turf to be mowed/managed	0.00	0.78	0.00	0.00	**0.78**
Impervious Cover (acres)	0.00	47.90	0.00	0.00	**47.90**
					56.63

Table 4. Post-Redevelopment Land Cover Information Extracted from VRRM Site Tab.

	A Soils	B Soils	C Soils	D Soils	Totals
Forest/Open Space (acres): undisturbed, protected forest/open space or reforested land	0.00	7.96	0.00	0.00	**7.96**
Managed Turf (acres): disturbed, graded for yards or other turf to be mowed/managed	0.00	26.55	0.00	0.00	**26.55**
Impervious Cover (acres)	0.00	22.13	0.00	0.00	**22.13**
					56.63

Total Phosphorus

FINAL POST-DEVELOPMENT TP LOAD (lb/yr)	72.77
TP LOAD REDUCTION REQUIRED (lb/yr)	-10.97
TP LOAD REDUCTION ACHIEVED (lb/yr)	7.77
TP LOAD REMAINING (lb/yr):	65.00

REMAINING TP LOAD REDUCTION REQUIRED (lb/yr): 0.00 **

** TARGET TP REDUCTION EXCEEDED BY 18.74 LB/YEAR **

Figure 18. VRRM Total Phosphorus Reduction Results.

EPA SWMM

In order to determine the effectiveness of GI on the site, first the existing conditions must be modeled, and then the effect of proposed changes can be seen from an additional model. To create these representations of the existing and proposed systems, the Environmental Protection Agency's Storm Water Management Model was used (SWMM).

Originally, the team had hoped to use the Personal Computer Storm Water Management Model (PCSWMM), an adaptation of SWMM. However, this model requires knowledge of detailed pipe information such as pipe sizes, inverts, and slopes, which the county of Albemarle did not have on record.The existing pipe infrastructure (conduits and junctions) are shown in Figure 19, but this dataset merely gives their location and only a few pipe sizes. In order to make a PCSWMM model, the extensive network around the mall parcel would need more information, so instead the system was simplified, such as areas with multiple inlets being reduced to a single inlet. The simplified pipe network is shown in Figure 20.

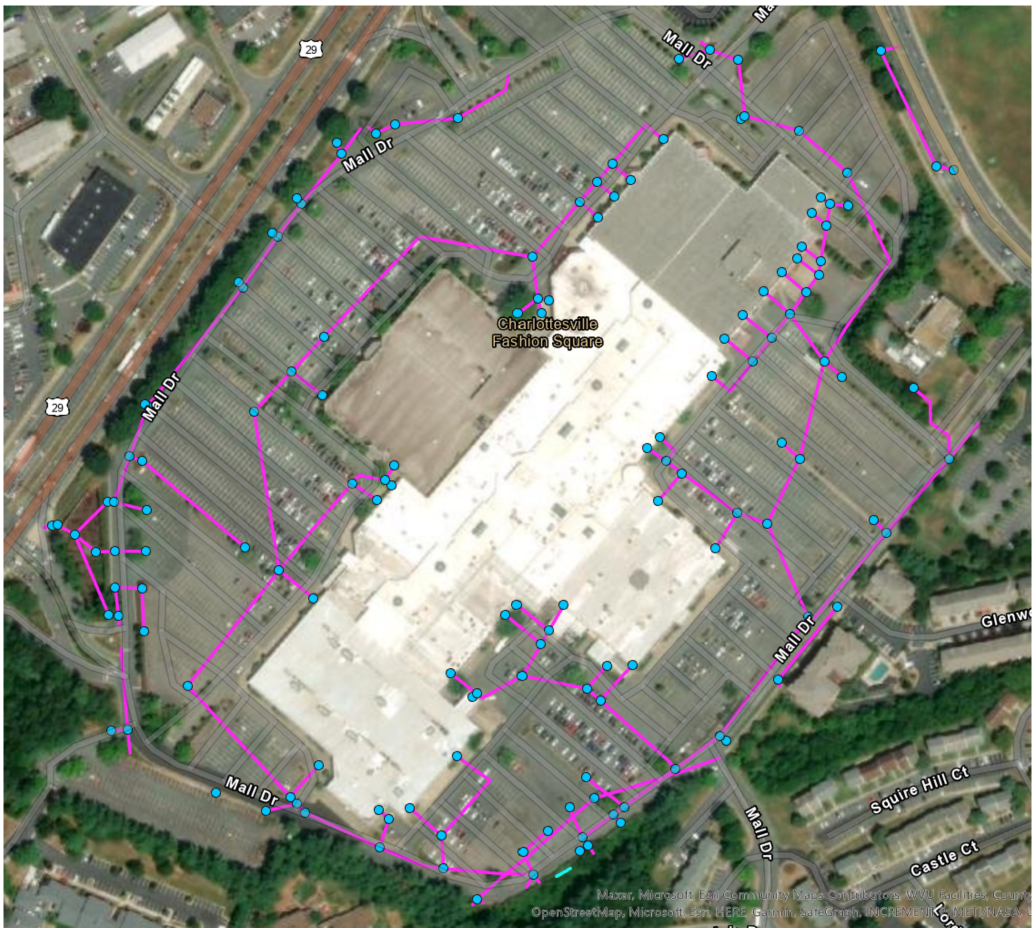


Figure 19. Existing Pipes on Project Site.

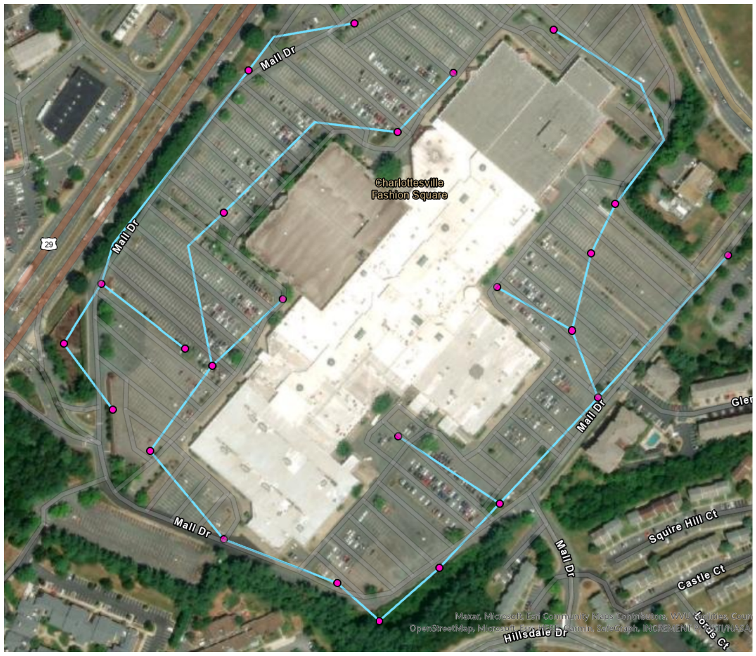


Figure 20. Simplified Pipe Network.

This simplified layout was used to determine drainage areas and outlet locations for the SWMM model. A map of the two subwatersheds is shown in Figure 21. The entire mall parcel drains to two outlets, Identified by Albemarle county as 0013.01 and 0013.02. Facility 0013.01 is at the southern corner of the site, and is a grassy retention area and channel. Discharge flows through the grassy area and into conduits which flow further south to Hillsdale Drive, to stormwater facility 0080.01, and ultimately to Meadow Creek.

Figure 21. Drainage Areas to Site Outfalls.

The two subwatersheds were modeled in SWMM for the 1-year and 10-year 24 hour storms. The results from these simulations are shown in Tables 5 and 6. The peak runoff for the 1 and 10 year storms from the whole site were 215 and 412 cfs respectively, with the majority of runoff being directed to the Branchlands Drive stormwater facility.

Table 5. Existing Condition SWMM results: 1 year storm.

1-year 24-hour							
Subcatchment	total precip (in)	Imperv Runoff (in)	Perv Runoff (in)	total runoff (in)	total runoff (10^6 gal)	total runoff (ft^3)	Peak runoff (cfs)
West	3.03	2.46	0.39	4.47	1.19	159460	56
East	3.03	2.65	0.3	4.63	3.3	442200	159
total					**4.49**	**601660**	**215**

Table 6. Existing Condition SWMM results: 10 year storm.

10-year 24-hour							
Subcatchment	total precip (in)	Imperv Runoff (in)	Perv Runoff (in)	total runoff (in)	total runoff (10^6 gal)	total runoff (ft^3)	Peak runoff (cfs)
West	5.52	4.51	0.81	5.32	2.22	297480	110
East	5.52	4.84	0.6	5.44	6.1	817400	303
total					**8.32**	**1114880**	**412**

Another model was created in SWMM to determine the reduction in runoff simply from land use change. The proposed condition was modeled as one watershed, with the percent impervious much lower, from the implementation of open green space, a garden, and athletic fields. The proposed condition will not follow the existing drainage pattern, so the two subcatchments were consolidated into one subcatchment. Results from the model run with new land cover conditions are shown in appendix E, as well as project files for each model created. These changes in land use reduced the impervious area percentage from 86 to 39 percent. The resulting reduction of peak runoff from the site was 31% and 22% for the 1-year and 10-year storms respectively.

After the land use was changed, BMPs were implemented using the LID (Low Impact Development) feature in SWMM. Permeable pavement was added, as well as an array of rain barrels to represent the two cisterns on site. Results from model runs from the 1-year and 10-year storms are shown in Tables 7 and 8. The peak runoff was reduced by 48% for the 1-year storm and by 38% for the 10-year storm. This reduction far exceeds the Virginia requirement that stormwater runoff from a redeveloped site is either the same as pre-development or less (Virginia Code, 2022).

Table 7. BMP SWMM results: 1 year storm.

1-year 24-hour							
Subcatchment	total precip (in)	Imperv Runoff (in)	Perv Runoff (in)	total runoff (in)	total runoff (10^6 gal)	total runoff (ft^3)	Peak runoff (cfs)
Site	3.03	0.98	0.83	1.82	2.8	375200	111

Table 8. BMP SWMM results: 10 year storm.

10-year 24-hour							
Subcatchment	total precip (in)	Imperv Runoff (in)	Perv Runoff (in)	total runoff (in)	total runoff (10^6 gal)	total runoff (ft^3)	Peak runoff (cfs)
Site	5.52	1.95	1.98	3.93	6.05	810700	254

In addition to modeling the design storms of 1 and 10 years, a specific storm event was modeled. On May 31, 2018 an unprecedented storm hit Ivy, VA near Charlottesville and deposited 6.7 inches of rain in 9 hours. A graph of the cumulative rainfall for this event is shown in Figure 22. Comparing this storm's precipitation intensity to historical data from the hydrometeorological design studies center, this storm has an estimated return period of 100 years (NOAA, 2022). Data for this storm was taken from Weather Underground, and inputted into SWMM as an additional time series. Results from the existing and proposed conditions for this storm are shown in Tables 9 and 10. This storm is more intense than the design storms, but the proposed site design is still able to reduce outflow, just not as effectively as storms with a lower intensity.

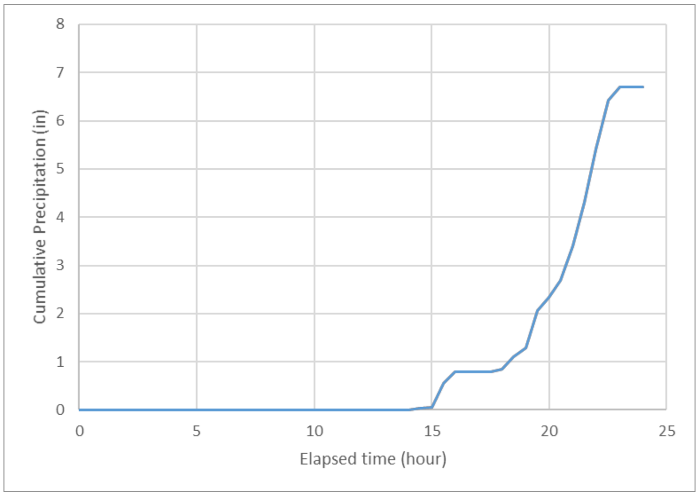


Figure 22. Ivy Storm Cumulative Precipitation.

Table 9. Existing Condition SWMM results: Ivy storm.

Ivy Storm							
Subcatchment	total precip (in)	Imperv Runoff (in)	Perv Runoff (in)	total runoff (in)	total runoff (10^6 gal)	total runoff (ft^3)	Peak runoff (cfs)
West	6.7	5.47	1.02	6.49	2.7	361800	34
East	6.7	5.88	0.74	6.62	7.42	994280	93
total					**10.12**	**1356080**	**128**

Table 10. Proposed BMP SWMM results: Ivy storm.

Ivy Storm							
Subcatch ment	total precip (in)	Imperv Runoff (in)	Perv Runoff (in)	total runoff (in)	total runoff (10^6 gal)	total runoff (ft^3)	Peak runoff (cfs)
Site	6.7	2.19	2.52	5.04	7.75	1038500	110

Additionally, an energy surrogate was calculated for each model, and the existing and proposed conditions (with BMPs) are compared in Table 11 below. The reduction in energy is far beyond the requirement for redevelopment of such a site.

Table 11. Energy Surrogate Calculations.

Storm	Condition	Energy Surrogate (ft^6 / s)	% reduction
1-year 24-hour	Existing	129489265	68%
	Proposed	41564656	
10-year 24-hour	Existing	459453197	55%
	Proposed	205593520	
Ivy Storm	Existing	173049369	34%
	Proposed	114380390	

Overall, these results show that the redevelopment was effective in reducing both peak flows and total flows from the site. Land use change was the biggest contributor to this reduction, and the BMPs further decreased both values. The implemented GI was also effective when modeled with more intense storms, such as the Ivy storm. These results are promising as climate change will impact storm intensity. The proposed infrastructure was still shown to decrease runoff and peak flow in these storms, increasing the resilience of the system.

i-Tree Hydro

In addition to the modeling done in EPA SWMM, i-Tree Hydro and i-Tree Hydro+ were used to assemble a hydrological model of the Fashion Square Mall site. This model provided the team with an alternative approach to simulate the effects that various land cover, tree canopy and green infrastructure changes to the site will have on the quantity and quality of runoff. By modeling both at the site-scale and subwatershed-scale, these models help the team determine not only how the design choices will improve the site, but also how they will improve the greater Meadow Creek Watershed. Models in i-Tree were run using precipitation data for the entire year of 2020, allowing the team to see the effects of design choices on the runoff from the site over the course of a typical year.

To assemble the model, a 10-meter digital elevation model (DEM) obtained from the United States Geological Survey (USGS) was modified in ArcGIS Pro so that its extents matched that of the site parcel and its projection matched that required for i-Tree inputs - Universal Transverse Mercator (UTM). Once processed, this was inputted into i-Tree to define the topography of the site. National Climate Data Center (NCDC) weather data for the year 2020 was also properly formatted and inputted for model creation. Next, to manually parameterize the current land cover of the subcatchment in i-Tree, a 10-meter land-use raster file was obtained from the Chesapeake Bay Conservancy (CBC) (Figure 23) and the portion within the site parcel was extracted. A number of assumptions were made in order to use the CBC data - which defines 17 different land classes - to populate the 7 different land class fields in i-Tree. Table 12 indicates what each of the CBC land classes that appeared in the subwatershed were classified as in the i-Tree Models. Finally, BMPs were implemented using the GI feature of i-Tree Hydro+. BMP dimensions and some hydrological parameters associated with the BMPs were parameterized based on the team's design and the overall hydrological parameters of the site, respectively. However, due to a lack of documentation regarding many of the adjustable parameters in i-Tree Hydro+, many of the BMP parameters were left as default values.

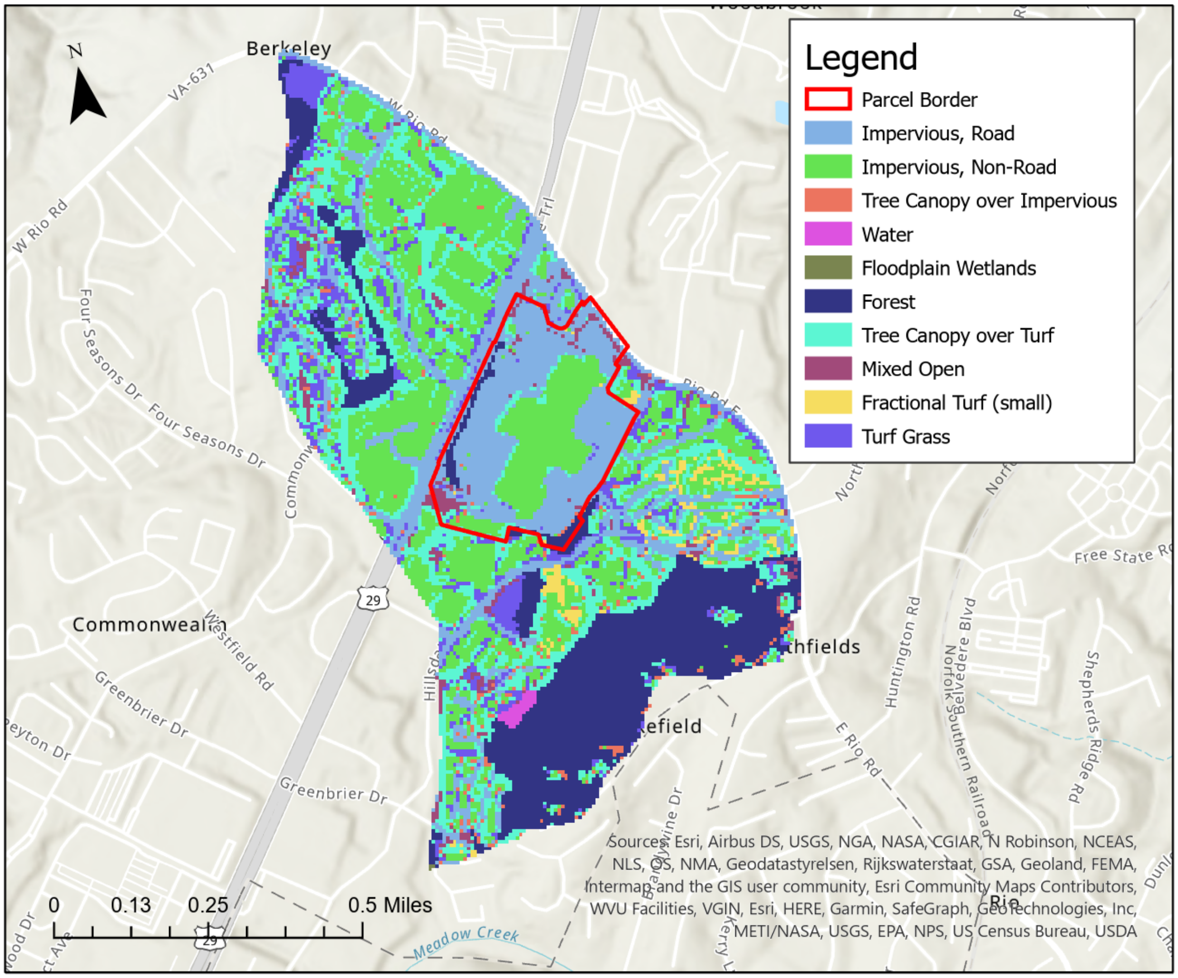


Figure 23. Chesapeake Bay Foundation Land Use Raster Layer Clipped to the Subwatershed.

Table 12. i-Tree Land Class used in Model based CBC Land Class.

i-Tree Land Class	CBC Land Class
Pervious under Tree Canopy	Tree Canopy Over Turf Forest Floodplain Wetlands
Impervious under Tree Canopy	Tree Canopy Over Impervious
Shrub Canopy	-
Herbaceous	Mixed Open Fractional Turf (small) Turf Grass
Water	Water
Impervious	Impervious, Road Impervious, Non-Road
Bare Soil	-

i-Tree was used to look at three different design scenarios with varying amounts of tree canopy. Tree canopy scenarios - low, medium, and high - were defined based on what the project team felt were appropriate goals for how much tree canopy coverage could be achieved within the green space, permeable pavement, and surface parking areas of the design (Table 13). The “low” tree canopy scenario represents the team’s absolute minimum goal for tree canopy coverage whereas “medium” and “high” represent the target coverage and the feasible upper limit, respectively. Table 13 summarizes the percent area of each feature of the design that is shaded by tree canopy in each of the scenarios. The model was run twice for each of the three tree canopy scenarios, once without the stormwater BMPs and once with the BMPs. This was done in order to see what improvements could be achieved solely from the imperviousness reductions associated with the design and what additional improvements could be achieved by the extra investment in permeable pavers and the rainwater harvesting system. For the existing conditions and these six scenarios, the model was run using the 2020 precipitation data. Results from these scenarios are shown in Table 14.

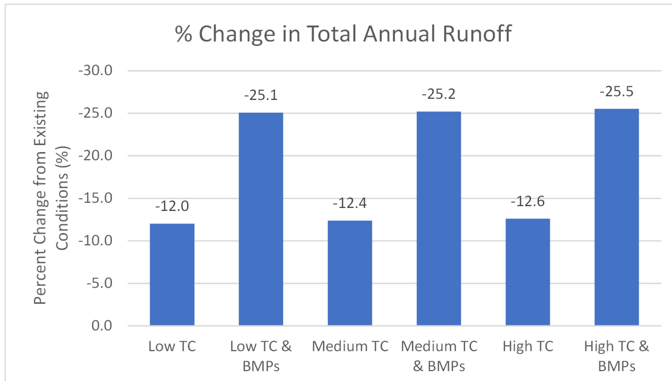
Table 13. Percent Tree Canopy Coverage by Design Feature for each Tree Canopy Scenario.

Tree Canopy Coverage (%)			
	Low	Medium	High
Parking Lot	15	30	45
Plaza (Permeable Pavers)	30	40	50
Green Space	40	50	60

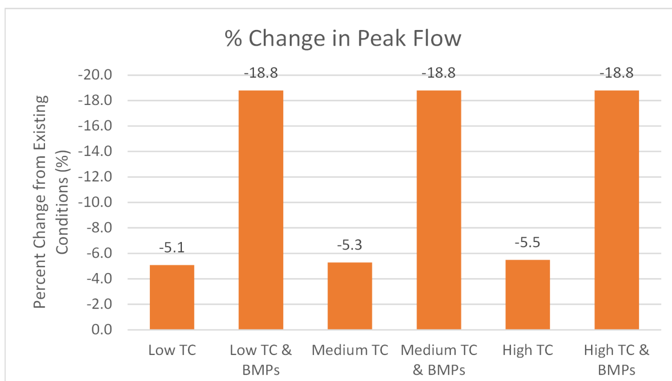
Table 14. i-Tree Results - Existing Conditions vs. Proposed Conditions with Varying Tree Canopy Coverage.

2020 Precipitation			
Scenario	**Total Annual Runoff (10^6 ft^3)**	**Peak Flow (cfs)**	**Total Annual Base Flow (10^3 ft^3)**
Existing Conditions	8.73	9.84	13.85
Proposed Conditions Scenarios			
Low TC	7.68	9.34	60.41
Low TC & BMPs	6.54	7.99	41.15
Medium TC	7.65	9.32	60.41
Medium TC & BMPs	6.53	7.99	41.16
High TC	7.63	9.30	60.40
High TC & BMPs	6.50	7.99	41.16

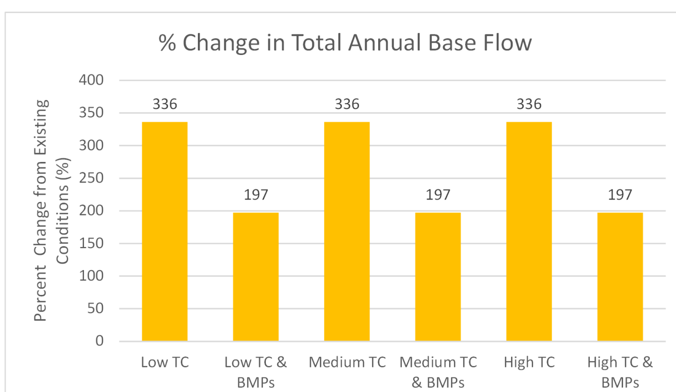
Figure 24 summarizes the percent changes in total annual runoff, peak flow and total annual base flow from the existing conditions to each of the 6 model scenarios. According to the i-Tree model, the proposed land cover scenarios would achieve a 12-25.5% reduction in total annual runoff (Figure 24-a) and 5.1-18.8% reduction in peak flow (Figure 24-b) from the site. The total annual base flow (Figure 24-c) increased 197-336%, suggesting that significantly more water will infiltrate into the subsurface if the proposed conditions are adopted. General trends in Figure 24 show that the percent changes only varied by a few tenths of percent between all three tree canopy scenarios, suggesting that the effect of achieving medium or high tree canopy values will have a negligible effect on the quantity and intensity of runoff from the site. Another trend seen in the figures is that the addition of BMPs significantly reduces all three of the flow parameters.



(a)



(b)



(c)

Figure 24. Plots of percentage change in Total Annual Runoff (a), Peak Flow (b) and Total Annual Base Flow (c) from existing to proposed scenario.

In addition to the 2020 weather data, i-Tree was also used to model the storm that hit Ivy, Virginia on May 31, 2018 that was modeled in EPA SWMM. Since it was determined that tree canopy had a negligible effect on runoff quantity and this is likely to be even more true for intense storms where the leaves of trees are quickly saturated, the model was only run for this storm for the medium tree canopy scenario. It was also run both with and without BMPs. Results from these scenarios are shown in Table 15.

Table 15. i-Tree Results - Existing Conditions vs. Proposed Conditions.

Ivy Storm		
Scenario	**Total Runoff (10^6 ft^3)**	**Peak Flow (cfs)**
Existing Conditions	1.70	33.61
Proposed Conditions Scenarios		
Medium TC	1.62	32.44
Medium TC & BMPs	1.39	27.37

For the proposed conditions with medium tree canopy and no BMPs there was a 4.9% and 3.5% reduction in total runoff and peak flow, respectively. With BMPs, there was an 18.4% and 18.6% reduction in total runoff and peak flow, respectively. While these are less than percent reductions seen over the 2020 precipitation scenario, these results confirm that the design, especially with BMPs, is capable of significantly reducing the quantity of runoff from the site in the event of an intense storm.

The results of the modeling done in i-Tree Hydro and i-Tree Hydro+ support the efficacy of the team's design plan and raise a variety of considerations for its implementation. As shown in Figure 24, both the land cover changes and the addition of BMPs have significant impacts on runoff volume and intensity. The significant differences between pre- and post-BMP results - especially for the Ivy storm - suggests that if BMP addition is financially feasible, they are worthwhile additions. In addition, by increasing base flow, the proposed design will help surface waterways that are fed by groundwater from this area to remain flowing and healthy even in dry spells during the summer. Lastly, based on the negligible impact that variations in tree canopy had on runoff, tree canopy should not be heavily considered as a means for runoff reduction in design implementation.

Urban Heat Island Analysis

The team used land cover data and surface temperature data to analyze how the area is affected by the urban heat island effect. Four zones, seen in Figure 25, near the Fashion Square Mall parcel were analyzed. Zone 1 was set as a larger area encompassing the other zone. Zone 2 encompassed the Fashion Square Mall Parcel, which is mostly covered in impervious surfaces as seen in Figure 25. Zone 3 was set as an area that contains a mixture of impervious surfaces, but also vegetation. Zone 4 consisted of few impervious surfaces and mostly green space. The areas were analyzed by type of land cover and the surface temperature that accompanied that land cover. A map of the surface temperature is visible in Figure 26.

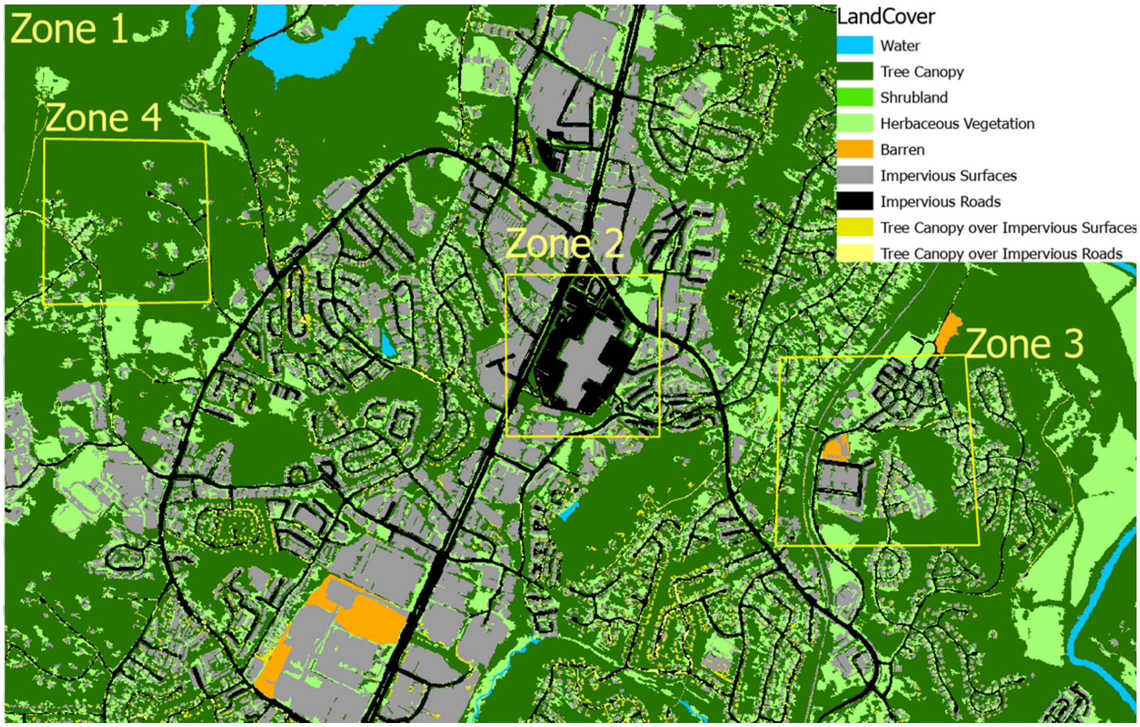


Figure 25. Land Cover Map of Charlottesville.

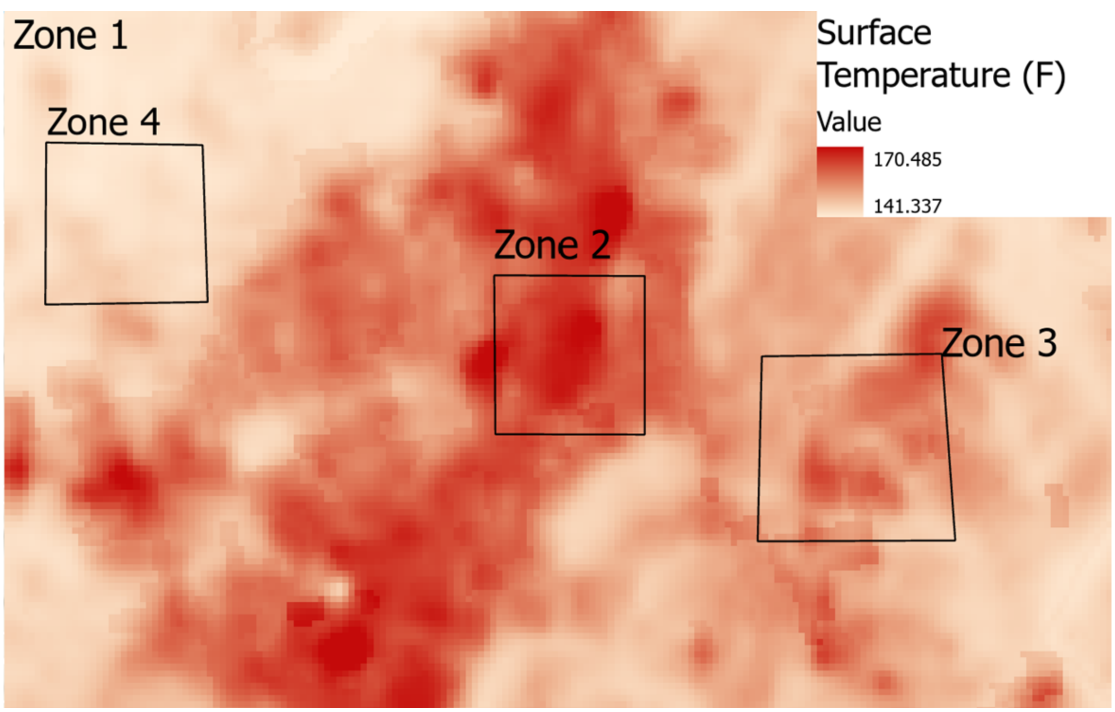


Figure 26. Surface Temperature Map of Charlottesville.

The surface temperature data was collected in the afternoon on August 24, 2021. Figure 26 shows that there are certain areas throughout the zones that are hotter, darker red, than others. Zone 2 consists of mostly dark red spaces versus Zone 4 which is mostly light. When compared to Figure 25, there is a connection between the land cover and temperature. Zone 2 is mostly impervious and has the highest temperature. Zone 4 is mostly green space and has the lowest temperature. The land cover and surface temperature data were further analyzed through a statistical analysis. The results are seen in Table 16 and Figure 27.

Table 16. Land Cover and Surface Temperature Data By Zone.

Zone 1 Data							
Land Cover Zone 1	**Count**	**Minimum (°F)**	**Maximum (°F)**	**Range (°F)**	**Mean (°F)**	**St. Dev**	**Median (°F)**
Water	271.0	143.9	156.7	12.8	145.8	1.9	145.6
Tree Canopy	11324.0	142.0	163.7	21.7	149.2	3.6	148.3
Shrubland	3.0	146.5	149.1	2.7	147.4	1.2	146.5
Herbaceous Vegetation	3228.0	145.1	167.8	22.7	151.7	3.7	151.3
Barren	117.0	152.4	164.1	11.8	158.6	2.7	158.9
Impervious Surfaces	3303.0	145.3	170.5	25.2	156.2	4.2	156.4
Impervious Roads	1736.0	145.5	167.8	22.2	155.0	4.0	155.1
Tree Canopy over Impervious Surfaces	281.0	145.6	162.6	16.9	151.7	3.5	150.8
Tree Canopy over Impervious Roads	143.0	145.6	159.3	13.8	150.4	2.7	150.0
Zone 2 Data							
Land Cover Zone 2	**Count**	**Minimum (°F)**	**Maximum (°F)**	**Range (°F)**	**Mean (°F)**	**St. Dev**	**Median (°F)**
Water	-	-	-	-	-	-	-
Tree Canopy	107.0	152.0	163.7	11.7	157.5	2.3	157.2
Shrubland	-	-	-	-	-	-	-
Herbaceous Vegetation	71.0	152.0	160.8	8.8	156.3	2.2	156.7
Barren	-	-	-	-	-	-	-
Impervious Surfaces	197.0	153.2	165.3	12.1	159.6	2.7	159.0
Impervious Roads	244.0	154.2	165.6	11.4	159.4	2.0	159.8
Tree Canopy over Impervious Surfaces	5.0	156.2	157.7	1.5	157.0	0.5	157.1
Tree Canopy over Impervious Roads	-	-	-	-	-	-	-
Zone 3 Data							
Land Cover Zone 3	**Count**	**Minimum (°F)**	**Maximum (°F)**	**Range (°F)**	**Mean (°F)**	**St. Dev**	**Median (°F)**
Water	-	-	-	-	-	-	-
Tree Canopy	454.0	147.2	159.7	12.5	151.7	2.7	151.2
Shrubland	-	-	-	-	-	-	-
Herbaceous Vegetation	203.0	148.5	157.7	9.2	152.7	2.0	152.4
Barren	10.0	153.3	157.3	4.0	155.5	1.1	155.5
Impervious Surfaces	144.0	148.7	159.1	10.4	154.1	2.5	154.1
Impervious Roads	96.0	149.5	158.7	9.2	154.1	2.2	154.4
Tree Canopy over Impervious Surfaces	7.0	150.2	157.6	7.4	152.9	2.2	152.2
Tree Canopy over Impervious Roads	2.0	151.7	152.8	1.1	152.3	0.6	152.3
Zone 4 Data							
Land Cover Zone 4	**Count**	**Minimum (°F)**	**Maximum (°F)**	**Range (°F)**	**Mean (°F)**	**St. Dev**	**Median (°F)**
Water	-	-	-	-	-	-	-
Tree Canopy	578.0	144.5	148.9	4.3	145.8	0.8	145.7
Shrubland	-	-	-	-	-	-	-
Herbaceous Vegetation	54.0	145.6	149.2	3.6	146.9	0.9	147.0
Barren	-	-	-	-	-	-	-
Impervious Surfaces	19.0	145.3	147.3	2.0	146.4	0.6	146.3
Impervious Roads	15.0	145.6	147.7	2.1	146.3	0.6	146.1
Tree Canopy over Impervious Surfaces	1.0	145.6	145.6	0.0	145.6	0.0	145.6
Tree Canopy over Impervious Roads	1.0	146.8	146.8	0.0	146.8	0.0	146.8

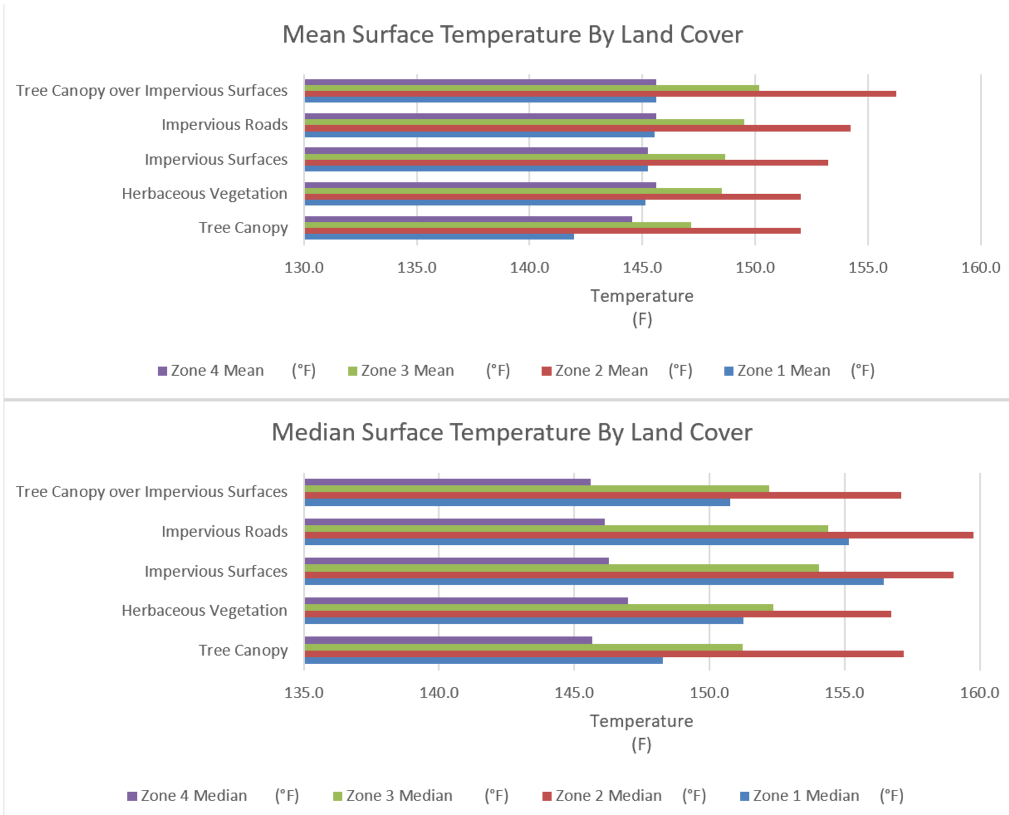


Figure 27. Graphs of Surface Temperature By Land Cover.

This analysis assessed the temperature maximum, minimum, mean, median, range, and standard deviation for each land cover in each zone. As expected, Zone 2 had the highest temperatures, Zone 3 had the middle values, and Zone 4 had the lowest. Another important factor to consider is the standard deviations in each zone. Zone 1 had the highest standard deviations overall, whereas Zone 4 had significantly lower stand deviations than the rest. There is a wide variety in the temperature difference of various land covers in Zone 1-3. The ranges in temperature of the land covers vary while some have a seven degree difference others have twelve or more. While looking specifically at Zone 2 and 3, this difference is due to changes in land cover. The areas that are farther away from the impervious spots have lower temperatures than those near the imperviousness. This is further explained by looking at the analysis of Zone 4. Since the area is mostly green space there is little variation in temperature and the overall averages and medians are lower than that near impervious areas. The graphs in Figure 27 visually show the temperature differences due to land cover for each zone. The most drastic difference is that of Zone 2 and Zone 4 in both the mean and median graphs. The mean and median temperature for each land cover in Zone 2 is significantly higher than that of Zone 4.

This analysis shows that there is a relationship between land cover and surface temperature. If the proposed land cover changes occurred on the Fashion Square Mall parcel, then the temperature would decrease to some extent. A weighted average of the temperature based on land cover was calculated for Zone 1 and Zone 2. Zone 1 was found to be approximately 152.2 °F, whereas Zone 2 was found to be 158.4 °F. With the proposed land cover changes, the temperature of the parcel could be reduced by around 6 °F. This potential temperature change would lead to a more resilient area in terms of climate change. Climate change will lead to more extreme heat events and having a lower temperature would lessen the negative impacts of extreme heat events.

Cost Analysis

The team also performed a cost analysis of major components of the redesign in order to understand the feasibility of this project. According to Virginia DEQ BMP specifications, interlocking permeable pavers cost between $5 and $10 per square foot to construct. Assuming average pricing conditions, the total cost for the permeable pavement will cost approximately $2 million. Initially, the team considered including a constructed wetland in the redesign. However, the cost of installing a constructed wetland is typically $22,000. This was a factor that led to the decision of installing rainwater harvesting through a rooftop disconnection, which would only cost about $2,500 (Home Advisor, 2022). Additionally, a major expense may include the removal of the existing asphalt throughout the site other than the two buildings being kept for commercial or residential use. This would cost $1 to $3 per square foot, which would be approximately $4.5 million (Appendix C). Other important cost considerations include grading of land and the previously mentioned solar panel installation. Despite the high cost of the construction of this redesign, it is compensated financially, such as through phosphorus removal credits, as well as through its environmental and social benefits. The environmental benefits of this project include solar energy conversion, surface temperature reduction, and water quality improvement. The social benefits are community engagement, residential and commercial space, and outdoor recreation.

Limitations

The analyses provided in this report are meant to be preliminary for future sustainable redevelopment in the Fashion Square Mall area. Therefore, there are some limitations that could benefit from further study. The solar potential calculated in this project is a rough estimate based on roof area and other solar roofs in comparison. The roofs have not been observed for how much space is actually available for solar arrays. Additionally, the structural strength and ability to carry a roof full of solar panels has not been evaluated. Though energy usage was estimated in the cost payback calculations, the team does not know how much energy each building uses or would use with the proposed changes. Another uncertainty in the results stems from the inaccuracy of the land cover data. The land cover data was not completely up to date, and as Charlottesville continues to rapidly develop, accurate data is crucial for correct site analysis. Additionally, as stated in the SWMM section, the current stormwater system has not been surveyed for details such as pipe size, elevation, and slope. With these details the SWMM model would be more realistic and provide more details about the functionality of the system.

Another major limitation is the lack of full development of the BMP's and site. In a typical site plan, many different components are assessed and designed. The capstone team did not have the skills nor was it within the scope of this project to accurately redesign the site. Therefore, when undertaking a true re-design of the mall, many more factors need to be considered and assessed. Though climate change has been taken into consideration in the design of the site and stormwater management systems, it is impossible to predict what the future of climate change will look like. The designs take into account the fact that storms will become larger and heat waves will become more extreme, but the size and extent is unknown. The limitations that affected the i-Tree model are that the BMPs were not fully parameterized, it was hard to predict what amount of tree canopy coverage would actually be achieved (trees both grow and die), and climate change may affect when trees gain and lose their leaves. Lastly, the values given in the cost analysis are based on average construction costs and are highly likely to vary depending on Charlottesville's local economy as well as the individual contractors hired for construction.

Conclusions and Future Work

In this study, the capstone team redesigned Fashion Square Mall based on its imperviousness, lack of stormwater management, and current economic status. Designs were created in both ArcGIS and AutoCAD, then i-Tree, SWMM, and VRMM were used to model the proposed systems. In order to improve the stormwater performance and resilience of the site, land use was reverted back to open green space and two BMPs were implemented. The final design was modeled in SWMM and i-Tree to determine reductions in volume, energy, and pollutant loads. In addition to stormwater analysis, the urban heat island effect was explored to better understand the climate impact of the redevelopment. Future work can analyze other parts of the Meadow Creek watershed and lack of GI or explore the possibility of retrofitting other failing malls around the country. More detailed plans could also be created, which would provide more information on the extent of redevelopment. A more detailed plan would also lend itself to a more comprehensive cost analysis. Community engagement and feedback would also be a worthwhile addition to the project.

This capstone project allowed the team to apply their knowledge from their civil engineering undergraduate careers towards a design that impacts the Charlottesville community. It gave them the opportunity to create a design proposal from the ground up, which is well in preparation for their future careers in civil engineering. It also allowed them to explore their interests in design and environmental sustainability and strengthen their understanding of the natural and built environments. The project gave them both the professional guidance to receive expert insight as well as the autonomy to be creative in the design. The team plans on taking not only the technical skills but also the team-building, organizational, and professional skills with them as they transition into their future careers.

Appendices

Appendix A: Tentative Schedule

Original Schedule from Fall Semester:

GANTT CHART TEMPLATE

PROJECT TITLE	Meadow Creek Capstone	TEAM MEMBERS	Shreya Moharir, Burke Haywood, Neha Awasthi, Curtis Gore, Annalee Wisecarver, Rachel Yates
ADVISOR	Teresa Culver	DATE	10/6/2021

WBS NUMBER	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION (DAYS)	PCT OF TASK COMPLETE
1	Project Conception and Initiation					
1.1	Background Research	All	9/1/21	9/30/21	29	100%
1.2	SWMM Workshop w/ Seth	All	10/6/21	10/6/21	1	100%
1.3	ITree workshop w/ Seth	All	10/15/21	10/15/21	1	0%
2	Project Definition and Planning					
2.1	Scoping	All	9/15/21	9/29/21	14	100%
2.2	Complexity	All	9/22/21	9/29/21	7	100%
2.3	Scheduling	All	9/29/21	10/6/21	7	100%
2.4	Site Selection	All	10/6/21	10/31/21	25	0%
3	Project Launch & Execution					
3.1	Green Infrastructure Planning Site 1	S C B	11/1/21	11/15/21	14	0%
3.2	Green Infrastructure Design Site 1	C B S	11/15/21	11/30/21	15	0%
3.3	Green Infrastructure Planning Site 2	A N R	11/1/21	11/15/21	14	0%
3.4	Green Infrastructure Design Site 2	A N R	11/15/21	11/30/21	15	0%
3.6	iTree Model Creation	C B N	11/1/21	11/30/21	29	0%
4	Project Analysis					
4.1	Climate Impact Analysis	S C R	1/20/22	2/15/22	25	0%
4.2	Economic Analysis	A	1/20/22	2/15/22	25	0%
4.3	Comparison of Alternatives	All	2/16/22	3/14/22	28	0%
4.4	Benthic Analysis and Comparison	B	1/20/22	2/15/22	25	0%
5	Project Reports					
5.1	Midterm Progres Report	All	10/6/21	10/15/21	9	0%
5.2	Fall Semester Final Report	All	10/15/21	12/7/21	52	0%
5.3	Progress Report 1	All	1/19/22	2/15/22	26	0%
5.3	Progress Report 2	All	2/15/22	3/15/22	30	0%
5.5	Final Report	All	3/15/22	4/30/22	45	0%

Revised Schedule for Spring Semester:

GANTT CHART TEMPLATE

smartsheet

PROJECT TITLE	Meadow Creek Capstone	TEAM MEMBERS	Shreya Moharir, Burke Haywood, Neha Awasthi, Curtis Gore, Annalee Wisecarver, Rachel Yates
ADVISOR	Teresa Culver	DATE	1/26/2022

FALL SEMESTER: September, October, November, December — SPRING SEMESTER: January, February, March, April, May

WBS NUMBER	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION (DAYS)	PCT OF TASK COMPLETE
1	Project Conception and Initiation					
1.1	Background Research	All	9/1/21	9/30/21	29	100%
1.2	SWMM Workshop w/ Seth	All	10/6/21	10/6/21	1	100%
1.3	ITree workshop w/ Seth	All	10/15/21	10/15/21	1	100%
2	Project Definition and Planning					
2.1	Scoping	All	9/15/21	9/29/21	14	100%
2.2	Complexity	All	9/22/21	9/29/21	7	100%
2.3	Scheduling	All	9/29/21	10/6/21	7	100%
2.4	Site Selection	All	10/6/21	10/31/21	25	100%
3	Project Launch & Execution					
3.1	Green Infrastructure Planning Site 1	All	11/1/21	11/15/21	14	100%
3.2	Green Infrastructure Design Site 1	All	1/20/22	3/1/22	41	0%
3.3	VRRM Model	S	1/26/22	2/1/22	5	0%
3.4	iTree Model Creation I (Model Paramerization)	C B	11/1/21	11/31/21	31	100%
3.5	SWMM Model Creation Existing Conditions	A	11/1/21	11/31/21	31	100%
3.6	SWMM Model with BMPs	A	2/1/22	3/1/22	28	0%
3.7	iTree Model Creation II (Calibration, BMPs)	C B	1/19/21	2/14/22	26	0%
4	Project Analysis					
4.1	Climate Impact Analysis	S C R N	1/20/22	2/15/22	25	0%
4.2	Cost-Benefit Analysis	A	1/20/22	2/15/22	25	0%
4.3	Comparison of Modeling Results	All	2/16/22	3/14/22	28	0%
4.4	Benthic Analysis and Comparison	B	1/20/22	2/15/22	25	0%
5	Project Reports					
5.1	Midterm Progress Report	All	10/6/21	10/15/21	9	100%
5.2	Fall Semester Final Report	All	10/15/21	12/7/21	52	100%
5.3	Progress Report 1	All	1/19/22	2/15/22	26	0%
5.4	Progress Report 2	All	2/15/22	3/15/22	30	0%
5.5	Final Report	All	3/15/22	4/25/22	40	0%
5.6	Presentation	All	3/15/22	4/25/22	40	0%

Appendix B: VRRM
VRRM sheet: VRRM_Redev_PostBMP.xlsm
Entry calculations: VRRM entry calculations

Appendix C: Cost analysis calculations

- Permeable pavement (interlocking pavers):
  $5-10 per sq. ft.
  Area = 6.11 ac = 266151.6 sq. ft.
  Cost = $1,330,768 - $2,661,516
  Avg = $1,996,142 ≈ **$2 million**
  (Virginia Department of Environmental Quality, 2013)
- Constructed wetland:
  For surface-flow constructed wetland, cost = $4,000-40,000
  Avg cost ≈ **$22,000**
  (Phillips, 1997)
- Asphalt removal:
  $1-3 per square foot
  Avg = $2 per square foot
  Total site area = 56.63 acres
  2 buildings on existing site being kept = 2.32 ac + 1.69 ac = 4.01
  Area for asphalt removal = 52.62 acres = 2,292,127.2 sq. ft.
  Cost = 2 * 2,292,127.2 = 4,584,254.4 ≈ **$4.5 million**
  (Hometown Demolition Contractors, n.d.)

Appendix D: Phosphorus removal credit
1 lb phosphorus credit in James River watershed is $10,430
Total TP removal = 7.77 lb
Cost: $10,430 * 7.77 = $81,041.10 ≈ **$81,000**
(Fitch et al., 2014)

Appendix E: SWMM results

Land use change: 1-year 24-hour storm

1-year 24-hour							
Subcatchment	total precip (in)	Imperv Runoff (in)	Perv Runoff (in)	total runoff (in)	total runoff (10^6 gal)	total runoff (ft^3)	Peak runoff (cfs)
Site	3.03	1.29	1.05	2.34	3.59	481060	149

Land use change: 10-year 24-hour storm

10-year 24-hour							
Subcatchment	total precip (in)	Imperv Runoff (in)	Perv Runoff (in)	total runoff (in)	total runoff (10^6 gal)	total runoff (ft^3)	Peak runoff (cfs)
Site	5.52	2.36	2.38	4.74	7.29	976860	321

Appendix F: Project files

FSM.Existing.inp

FSM.Proposed.LandUseChange.inp

FSM.Proposed.BMP.inp

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