Towards Urban Sustainability: Stormwater Management & Solar Power Potential of Auburn University Campus, AL.

by

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Abstract

'Sustainability' is a big concern these days, since it seeks environmental protection, social development, and at the same time ensuring economic development. Now people are more aware of long-term viability of earth, their own survival as well as better future for next generation. Social media is a great source to get sense of people's thinking in any aspect of life nowadays. Exploring tweets with '#sustainability' reveal that people from all over the world are well concerned about sustainability, talking about other relevant topics like climate change, solar power etc. Among various sustainability measures to improve urban areas, Auburn University (AU) has focused mainly on s focused mainly on stormwater management and solar power potential on campus. on campus ("Auburn Climate Action Plan v 1.1," 2019). Keeping this in mind, this study targets on these two sustainability measures for AU. The study does a thorough stormwater management assessment for AU using Environmental Protection Agency's SWMM model. Stormwater management needs attention although major flooding is not an issue on campus on campus, but it causes pollution of nearby waterbodies, especially 'Parkerson Mill Creek' through polluted runoff. A risk map has identified areas where water likely flows at higher speed. Among sustainable stormwater management initiatives, bio-retention cell has great potentiality in terms of reducing amount as well as volume of stormwater runoff. Suitability analysis for bio-retention cell identifies potential areas on AU campus where bio-retention cell can be installed for most effective outputs. Auburn has 214 days of sunny weather, so solar power potential maps are created for AU to give an estimation of how much energy savings can be done. For this purpose, LiDAR data was used to extract building rooftop area of AU to calculate solar power potentiality, one of the great sources of renewable and sustainable energy.

Acknowledgments

I did it! Finally, I am going to be graduated. This thesis is the ultimate outcome of my persistency, dedication to learn new things, and working from morning to till 10 PM of most of the nights. First, I would like to thanks to Almighty God for His tremendous blessings in our life. Because He wanted me to be here, that’s why I am here!

Here I would like to take the opportunity to express my heartful gratitude to my major advisor Dr. Chandana Mitra. She has always been kind, caring, and supportive starting from the very first day of my life here at Auburn University and till today and I believe it will continue even I move out from Auburn. She motivated me to explore new and most sophisticated research tools and techniques. I also want to thanks to Dr. Jose Vasconcelos for his supports when needed and most importantly for the joint-venture idea from his and Dr. Mitra to work on stormwater management of Auburn University campus which is the major part of my research. I am very much grateful to Dr. Christopher Burton for his insightful guidelines in accomplishing my research. He helped me a lot as a member of my thesis committee as well as course instructor of two courses as I acquired very effective knowledge and skills to apply in my research work.

Lastly, I want to express my love, respect, deep feelings to my mother who is continuously praying for me sitting back home (Bangladesh). I am also very much glad to have an elder brother like Molla Ibrahim Hossen, who is not only a brother for me but more than that. After my father died back in 2011, he is taking care of mine, my family.

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List of Abbreviations

CUM – Circular Urban Metabolism

ASU - Arizona State University

MIT – Massachusetts Institute of Technology

SWMM – Stormwater Management Model

PCSWMM – Personal Computer Stormwater Management Model

LID – Low Impact Development

LiDAR – Light Detection and Ranging

DEM – Digital Elevation Model

DSM – Digital Surface Model

ADEM – Alabama Department of Environment

MS4 – Municipal Separate Storm Sewer System

Chapter 1: Introduction

Contents

1.1 Sustainability

'Sustainability' has its origin in biology and ecology. Ecologists and biologists primarily used 'sustainability' to refer to the rates at which without jeopardizing ecosystem structure and function, renewable resources can be utilized (Romero-Lankao et al., 2016). The most popular definition of sustainability has been given in Brundtland report of 1987 where sustainable development has been defined as, '…development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (MRCGP, 1988). Over the years, sustainability has been using in different context such as 'sustainable development', sustainable society', 'sustainable growth', 'ecological sustainability' etc. (Vos, 2007). 'Sustainability' issues are gaining topmost significance not only from researchers but also from general people due to increased concern about the healthy existence of our planet Earth. According to United States Environmental Protection Agency (US EPA), "Sustainability is based on a simple principle: Everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. To pursue sustainability is to create and maintain the conditions under which humans and nature can exist in productive harmony to support present and future generations" (US EPA, 2014).

Not only in textbooks or journals, do we see the popularity of the word 'sustainability' but also in social media, the word is very popular concept. Social media is presently a very effective way of expression of thoughts & ideas, raising awareness. Among the social networking sites, twitter is the most popular platform for doing academic research since it provides the opportunity to access huge amount to data through 'Application Programming Interfaces (API) (Ahmed, 2019). All of us might have seen people using hashtags when we are scrolling twitter feed. To understand how people perceives sustainability on twitter, a data driven approach has been taken to explore the usage of the word 'sustainability'. Some 20 random tweets were considered to get an idea who, what and from where people are talking about sustainability. The whole process has been done with Python coding (figure 1.1) using 'PyChram'- one of the most popular Python coding platform.

```
import os

import tweepy as tw
import pandas as pd
consumer_key = [redacted]

consumer_secret = [redacted]

access_token = [redacted]

access_token_secret = [redacted]

auth = tw.OAuthHandler(consumer_key, consumer_secret)

auth.set_access_token(access_token, access_token_secret)

api = tw.API(auth, wait_on_rate_limit = True)


# define the search term and the date_since  date as variables

search_words = "#sustainability"

date_since = "2019-08-01"



# Removing retweets

new_search = search_words + " -filter:retweets"
new_search

tweets = tw.Cursor(api.search,
                   q=new_search,
                   lang="en",
                   since = date_since).items(20)


# Finding users and locations

users_locs = [[tweet.user.screen_name, tweet.user.location] for tweet in tweets]
users_locs

# Creating pandas DataFrame with user and location

tweet_text = pd.DataFrame(data=users_locs,
                          columns=['User',"Location"])
print(tweet_text)
```

Figure 1.1: Codes for exploring tweets with '#sustainability' (Source: "Get and Work With Twitter Data in Python Using Tweepy," 2018)

The major steps of this approach are generating user specific keys, tokens; import necessary packages into 'Python'; define keys, tokens in Python; specifying search time and term; removing retweets and limit number of output tweets; and get users' names and locations.

From the last stage of analysis , all users name and locations are as follows:

	User	Locations
0	cdjcoulter	
1	SaltLakePotash	Perth, Western Australia
2	PieventsJapan	Tokyo, Japan
3	AlcottGlobalSG	Singapore
4	CryptoWeb9	United States
5	SinarSuryaTekno	Menara Global, Jakarta Selatan
6	StephTweetChat	St Louis, MO
7	Vikezmedia	San Jose, CA
8	staciibazaar	The Internet
9	FNGhadaki	Closer than you think
10	paulbeddie	Shanghai
11	CR_office	Cambridgeshire
12	TechTweet24h	Vijayawada, India
13	Vikezmedia	San Jose, CA
14	HafsaHanif_	San Francisco , California
15	Vikezmedia	San Jose, CA
16	Vikezmedia	San Jose, CA
17	RationalAus	Canberra
18	Vikezmedia	San Jose, CA
19	CaelusGreenRoom	

Figure 1.2: Users' name and location

If we check contents of some of the tweets, we can get an overview what people are saying when they are using '#sustainability'.

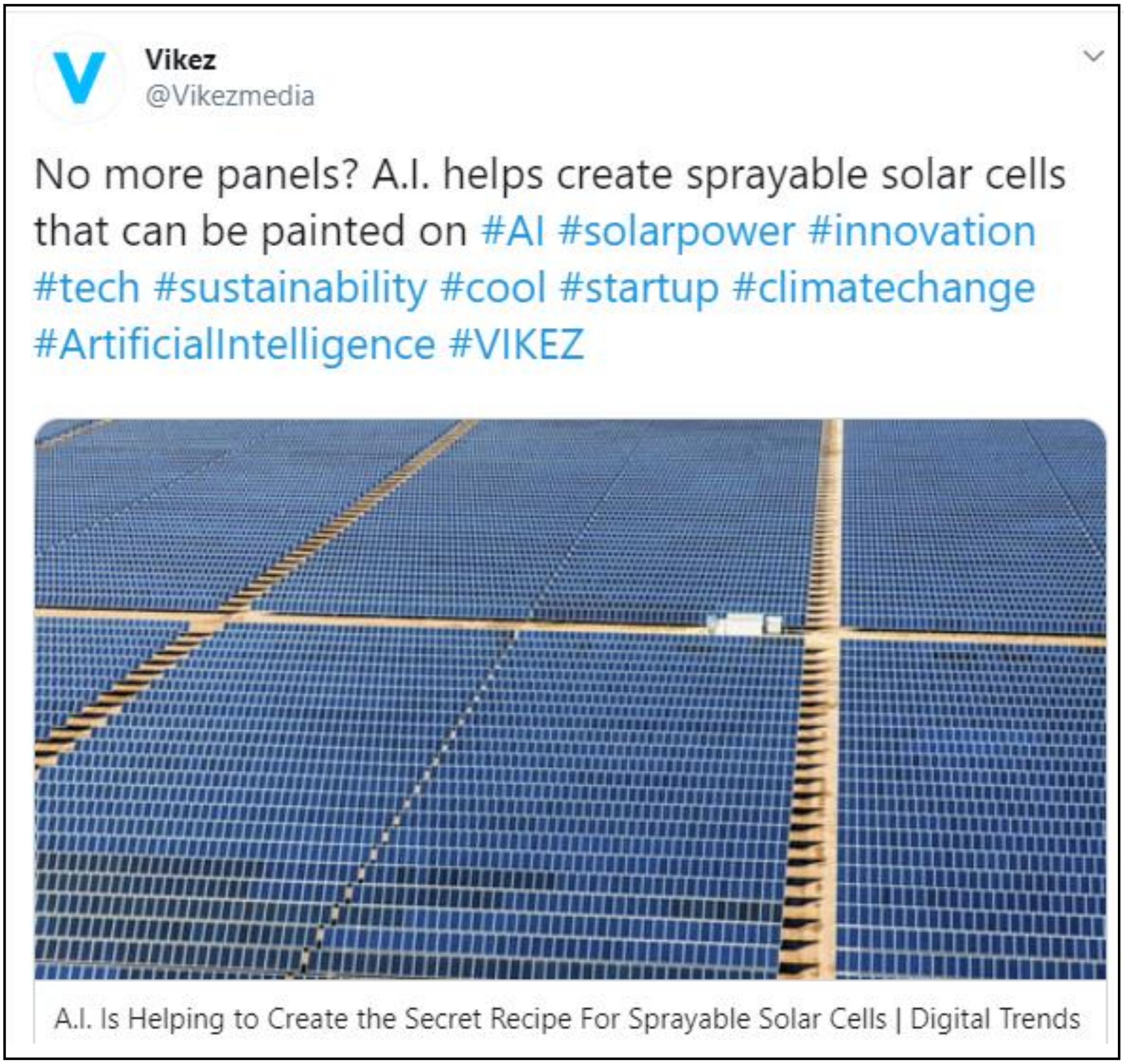


Figure 1.3: Example tweet 1

From the example tweet 1 (figure 1.3), we can see that this user is talking about couple of relevant things (solar power, innovation, tech, sustainability, climate change, artificial intelligence, etc.)

Figure 1.4: Example tweet 2

From example tweet 2 (figure 1.4), we see that same user in same day (but in different time) is talking about giant solar park near the Southern Egyptian City of Aswan and which is a great renewable push for Egypt.

Figure 1.5: Example tweet 3

And in example tweet 3 (figure 1.5), the user is talking about a community change initiative for Ohio. Here we can see that user has also used other hashtags (#equity, #Wagegap, #racism) along with '#sustainability'.

Now it could be a general query about who and from where they are talking about sustainability. From figure 1.2, we have seen people from different places (such as, san Jose, CA; Tokyo, Japan; Singapore, Shanghai; Canberra etc.) around the world are talking about sustainability. Although this output is not directly related to my research objectives but can gives us an idea that people from developed countries are more concern about sustainability.

1.2: Urban Sustainability

'Urban Sustainability' refers to a condition when resource use and waste production remain at levels below the carrying capacity of supporting ecosystems of concerned urban area (city, town) while ensuring a quality life standard for present and future generations (Romero-Lankao et al., 2016). Urban Sustainability is an integrated system and it encompasses all aspects of urban life such as economy, technology, environment, space, society, processes etc. and often it is termed as 'Circular Urban Metabolism' (CUM) (van Broekhoven and Vernay, 2018).

1.3: Characteristics of Urban Sustainability

Over time, relevant documents, literatures have mentioned some key characteristics of urban sustainability. Some of them are: "intergenerational equity, intragenerational equity, minimal use of nonrenewable resources, protection of the natural environment, economic vitality and diversity, individual well-being, and satisfaction of basic human needs" (Maclaren, 1996). There might be debate over which aspect should be in top in terms of importance, because it will solely depend on existing condition (social, economic, environmental, community values) of the area.

1.4: Properties of Urban Sustainability Indicator

In order to do research on urban area and how to improve them, it is required to assess the condition and status of the concerned urban area (Verma and Raghubanshi, 2018). Urban sustainability indicators are ways to do these tasks against variety of factors (Phillips R. (2014) in Michalos A.C.). Urban sustainability indicators designed to measure progress towards sustainability for an area or community may not be applicable for another area/community

(Maclaren, 1996) due to contextual differences. Despite the fact, there are some fundamental properties which all communities aspire to follow. These have been shortly described below (Maclaren, 1996):

- **Integrating:** Sustainability indicators are integrative. There exists interconnection among environmental, social and economic dimensions of urban sustainability through sustainability indicators.
- **Forward-Looking:** Sustainability indicators are forward-looking in the sense that they describe past trends and indirectly provide information about future sustainability. There should be two reference points (targets and thresholds) to make indicators more forward-looking. Targets are level which should be met in order to ensure sustainability in future and thresholds refer to limit which should not be exceeded.
- **Distributional:** It refers that indicators should be able to describe environmental, economic, and social conditions of all people, across all over the regions.
- **Multi-Stakeholder Input:** The last and most important property is that a broad range of stakeholders are involved in the development of urban sustainability indicators which ensures stakeholders engagement, participation and overall their hopes and aspirations are given duly attention.

1.5: Themes/Pillars of Urban Sustainability

Sustainability/Urban Sustainability stands on three pillars/themes (figure 1.6,) where each of them is vitally important and well connected. Three of the pillars works in an integrated system to ensure sustainability.

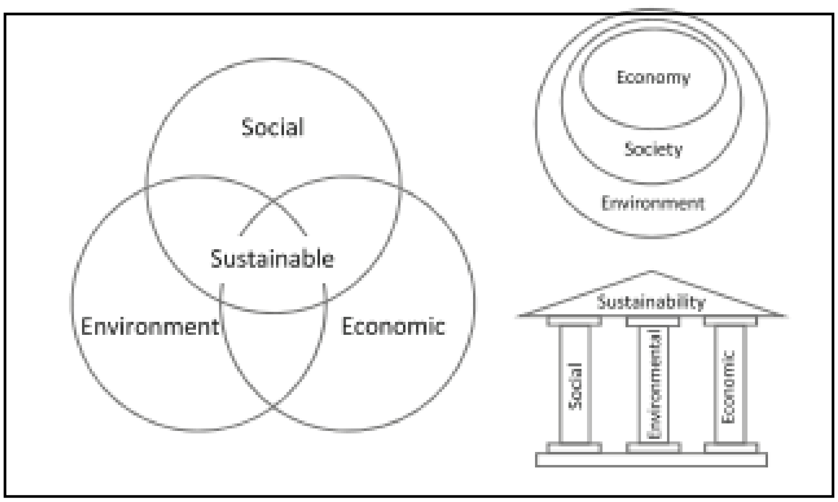


Figure 1.6: left, sustainability as three intersecting circles. Right, alternative 'pillars' and 'concentric circles' approach (Source: Purvis et al., 2019)

Table 1.1: Themes/Pillars of Urban Sustainability

Theme	Urban Sustainability
Economic	➢ Focusing on man-made, natural, human and social capital ➢ Not affecting future income while utilizing resources ➢ Ensuring equity of resources for all generations ➢ Taking into consideration of ecological basis when performing economic activities
Social	➢ Proper concern for perpetuity of social values, relationships and institutions ➢ Ensuring health, education, food, water, housing for everybody ➢ Big role on maintenance and creation of skills, capabilities of future generations
Environmental	➢ Taking consideration of environmental issues when performing economic, social initiatives ➢ Giving highest priority on natural resource management ➢ Proper understanding and communication of sudden changes, thresholds (air, water pollution levels)

(Source: Adapted from Verma and Raghubanshi, 2018)

1.6: Sustainability Research and Practice

Amongst the topmost entities which are conducting cutting edge research on sustainability, universities across the world are in leading position. In fact, universities are becoming 'Living laboratory' for sustainability innovation and practices ("ASU Sustainable Campus," n.d.).

Universities are not only incorporating sustainability issues but also designing programs solely dedicated for sustainability studies. For an example, Arizona State University (ASU) aims to develop problem solving skills and successful collaboration with experts through it's sustainability programs in School of Sustainability and which could be achieved through new teaching and learning strategies (Brundiers et al., 2010). A comparison between 2000 and 2017 (Elgqvist, 2017) for universities all over U.S. (focusing on solar Photo-voltaic (PV) cell adoption) can give us a concrete idea that sustainability practices are increasing day by day, people are becoming more aware.

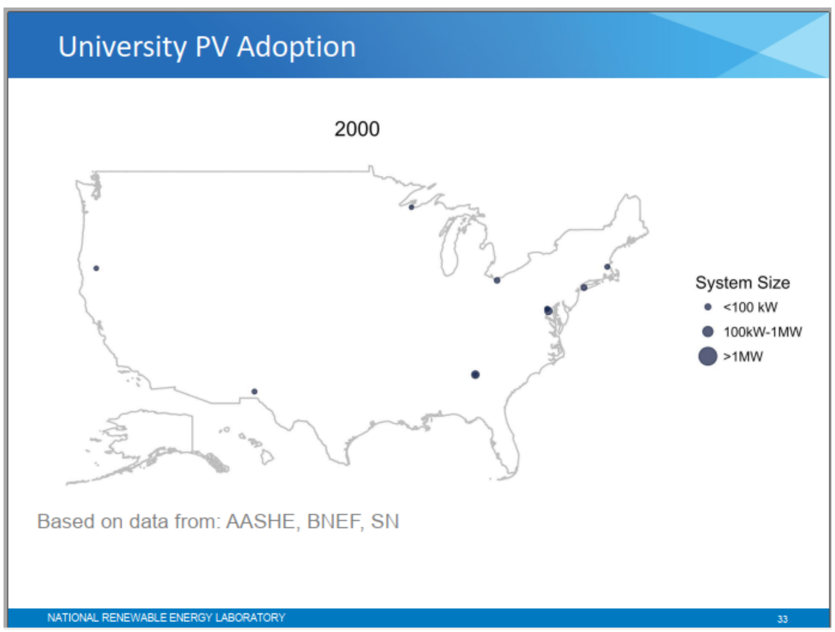


Figure 1.7: U.S. universities PV adoption in 2000 (Elgqvist, 2017)

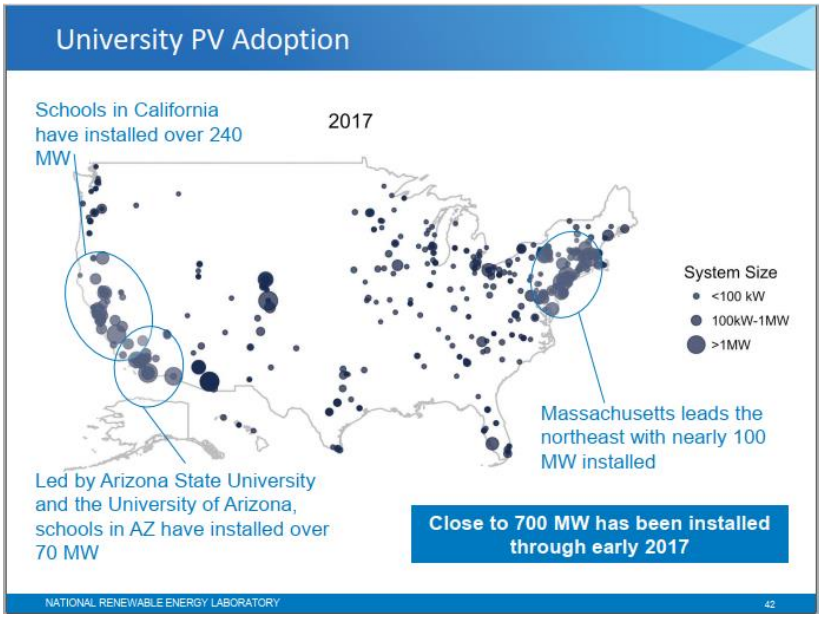


Figure 1.8: U.S. universities PV adoption in 2017 (Elgqvist, 2017)

It can be easily seen that Schools in California, Arizona and Massachusetts have been driving force for solar power initiatives. ASU is on top for solar power initiative if we compare at individual university level. It has 24.1 MW on site and 28.8 MW off site solar PV cell installed (Elgqvist, 2017).

ASU is one of the leading universities for implementing and promoting sustainability practices. The university situated in desert-like settings and trying to make use of the environment, making significant progresses in sustainability practices. There are four pillars behind its sustainability efforts as follows (“ASU Sustainable Campus,” n.d.):

Figure 1.9: "Climate Neutrality"

Figure 1.10: "Zero Solid and Water Waste"

Figure 1.11: "Active Engagement"

Figure 1.12: "Principled Practice"

Climate Neutrality: Eliminating 100 percent of its greenhouse gas emissions from building energy and waste-related sources by 2025, and 100 percent of its carbon emissions from transportation by 2035.

Zero Solid and Water Waste**:** ASU is reducing water waste through using efficient fixtures, better water management and distribution systems. Also, they are diverting solid waste from landfill through recycling, reusing etc. ways.

Active Engagement: ASU is engaging its community through education, participation, collaboration, and recognition.

Principled Practice: It addresses how ASU community contributes into first two principles within offices, labs, housing, classrooms.

The 'Massachusetts Institute of Technology' (MIT) is another exemplary institution practicing sustainability. It's also using the campus as a 'Urban Living laboratory and Test Bed' for sustainability practices (MIT Office Of Sustainability, 2019). MIT working on several sustainability working areas (figure 1.12) such as: Clean Energy, Water Conservation, Sustainable Consumption, High Performance Buildings etc. and bringing faculty, staff, student to address current sustainability challenges and enabling development of innovative, scalable solutions for on campus applications as well as in the world. Innovative financial support "Campus Sustainability Incubator Fund" supports these research activities and they have already gained success in exploring carbon neutral cooling, building life cycle assessment, new methods for battery storage, and more. (MIT Office Of Sustainability, 2019).

Figure 1.13: MIT Sustainability Initiatives (Source: (MIT Office Of Sustainability, 2019)

A design tool from MIT's sustainability design lab has been proved very much effective to calculate energy use and emissions for entire collection of buildings within a design and determine comfort index at indoor as well as outdoor level ("Urban sustainability," n.d.).

Auburn University (our study area) is also doing well in implementing sustainability practices. In 2013, 2016 and 2019, it got silver 'Sustainability Tracking, Assessment, and Rating System (STARS)' rating ("Reports | Auburn University Office of Sustainability," 2017 and "Auburn University | Institutions | STARS Reports," 2019). STARS is a framework for colleges and universities to facilitate their sustainability measurement by self-reporting. Till now 990 institutions have registered for STARS and among them 665 are members of the 'Association for the Advancement of Sustainability in Higher Education' (AASHE). Auburn University is also registered for STARS and member of AASHE ("Auburn University | Institutions | STARS Reports," 2019). 'Office of Sustainability' of Auburn University is the main body to take care, incorporate sustainability issues in different activities ("Auburn University Office of Sustainability," 2020). Auburn University aspire to be a national leader in sustainability teaching, research, outreach, and practice. To achieve this goal Auburn University has set some policies such as incorporating more ways of sustainability in design, construct, operate, and maintain campus facilities; helping to expand sustainability practices in the region; following the strategies outlined in 'Climate Action Plan' (("Auburn Climate Action Plan v 1.1," 2019).

Sustainability according to 'Auburn University Office of Sustainability':

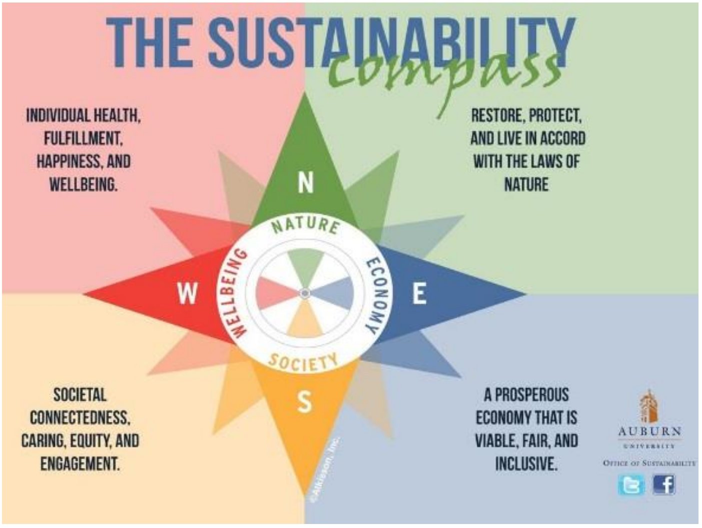


Figure 1.14: "The Sustainability Compass" of Auburn University

1.7: Sustainability Performance Indicators (of Auburn University):

As part of sustainable initiatives, Auburn University assess sustainability performances based on following major areas ("Operations | Auburn University Office of Sustainability," 2017):

- Buildings
- Climate
- Dining Services
- Energy
- Grounds
- Purchasing
- Transportation
- Waste
- Water

This research is mainly focused on two important components of urban sustainability: Stormwater Management (which is under 'Water' performance area) and Solar Power Potential (which is under 'Energy' performance area). Addressing issues with these two components will a big step to achieve goal set in Auburn University 'Climate Action Plan'.

Expressing solidarity with 'United Nations Framework Convention on Climate Change' (UNFCCC) which aims to limit temperature increase to 1.5 degrees Celsius, Auburn University targets to reduce core campus greenhouse gas emissions 100% from 2008 levels by 2050 ("Auburn Climate Action Plan v 1.1," 2019). Auburn University has put due emphasize on all major areas of action and have a plan to install one pilot project among three renewable areas at least (solar thermal pre-heat, solar thermal photovoltaic, biomass gasification) as well as developing a stormwater management plan that will put emphasize on rain gardens, creek daylighting, drains, bioswales, constructed wetlands, and other best management practices ("Auburn Climate Action Plan v 1.1," 2019).

1.8: Significance of the Study

Sustainability is a global concern. We need to ensure sustainability for our own betterment, for our survival, for being just to our future generation. Universities are on of the main research entities, innovation hub all over the world. Universities are playing vital in dealing existing problems, making most accurate prediction about future problems, complexities through cutting edge research.

As just discussed in previous section, this research is focused on two important sustainability concerns – stormwater management and solar power potential due to specific significance. Stormwater management is one of the prime concerns for developed areas – more urbanized.

Auburn University is heavily urbanized (detailed in chapter 2), which ultimately resulted in greater proportion of imperviousness within campus area. Imperviousness directly related with surface water quality and quantity. More impervious area generates more runoff during storm events, sometimes it could be the sole reason for flooding. Stormwater runoff has very negative consequences of water quality, since it washes off pollutants, chemicals, heavy metals and other poisonous substances into nearby waterbodies and dangerous disrupt existing ecosystem balance. Flooding is not a big issue for our study area, but water quality is. In fact, Parkerson Mill Creek (where runoff from study area find final place) has been determined as 'Impaired Water" and placed Alabama Department of Environment (ADEM) 303(d) list of impaired and threatened waters ("POLICY ON STORMWATER MANAGEMENT COMPLIANCE," 2016). This research is a great initiative to work on improving water quality by taking initiatives of sustainable stormwater management through implementation of Low Impact Development (LID). LIDs are proven effective measures for improving stormwater quality. Auburn University's Stormwater Management Program Plan (SWMP) has put main emphasize on initiatives to improve water quality (Stormwater Management Committee, 2019).

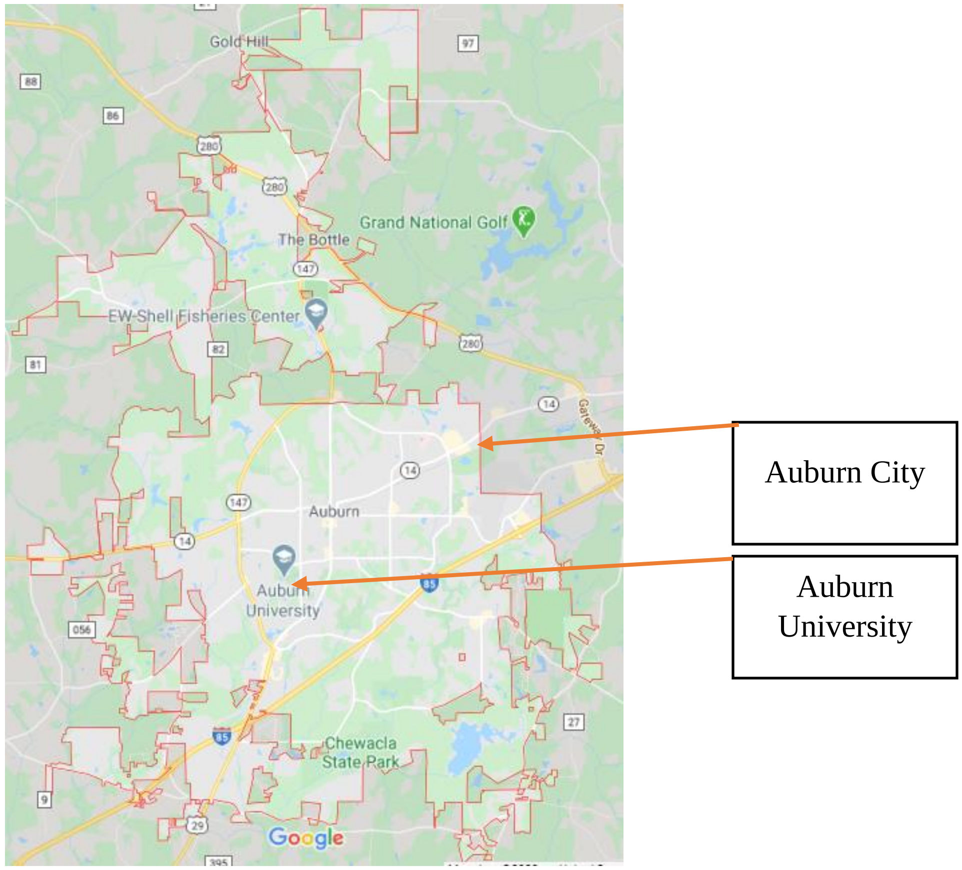
Due to geographical position, Auburn has high potential (detailed in chapter 3) to use solar power since it experiences on an average 214 sunny days per year. Utilizing solar power will help to reduce power supply cost, which is a huge amount, Auburn University currently paying to Alabama Power. In addition, adopting renewable energy initiatives will help to reduce green house gas emission, which one of the prime concerns of Auburn University sustainability initiatives.

The first solar power initiative in Auburn university was taken back in 2012 through installation of 24 solar panels on top of the northeast and southeast stairwells of the stadium parking deck, funded by facilities management in partnership with Office of Sustainability. A student from Biosystem Engineering came up with this great idea. It was capable to produce 6.6 kilowatts of power per day, which could be used charging of 10 electric vehicles (“Featured Story - Auburn University generating solar power to charge electric vehicles,” 2012). But unfortunately, that initiative stopped in near past. This study is aiming to resume solar power initiatives within campus in larger scale.

1.9: Study Area

Auburn University is a public research university in ‘Auburn’ city of Southeastern U.S. state of ‘Alabama’ on interstate 85 (“Maps & Directions,” n.d.). It’s a land, sea and space grant university and was chartered in 1856 (“How Does Auburn University Rank Among America’s Best Colleges?,” 2020) . Currently there are more than 21,000 students, 1200 faculty members, and more than 8,000 staff, student workers and administrators (“Auburn University General Information,” n.d.).

The ‘City of Auburn’ has about 61,462 population (“Best Places to Live in Auburn, Alabama,” n.d.). Auburn is one of the best places to live, scores 7.5/10 in climate comfort index, with on an average 217 sunny days, 54 inches of rainfall per year (“Auburn, Alabama Climate,” n.d.)



(Source: Google Maps)

Figure 1.15: Auburn University within Auburn City map

A simplified "Object-based Image Analysis" (OBIA) classification of NAIP Image (taken at 19th October of 2017) for AU campus (figure 1.15) can give us more information about study area. Here, only four classes (impervious, shadow, vegetation, waterbody) have been considered. This classification has been done using 'eCognition' software. From visual interpretation, most of the areas are impervious (more noticeable at the core of campus) which has strong connection with stormwater runoff

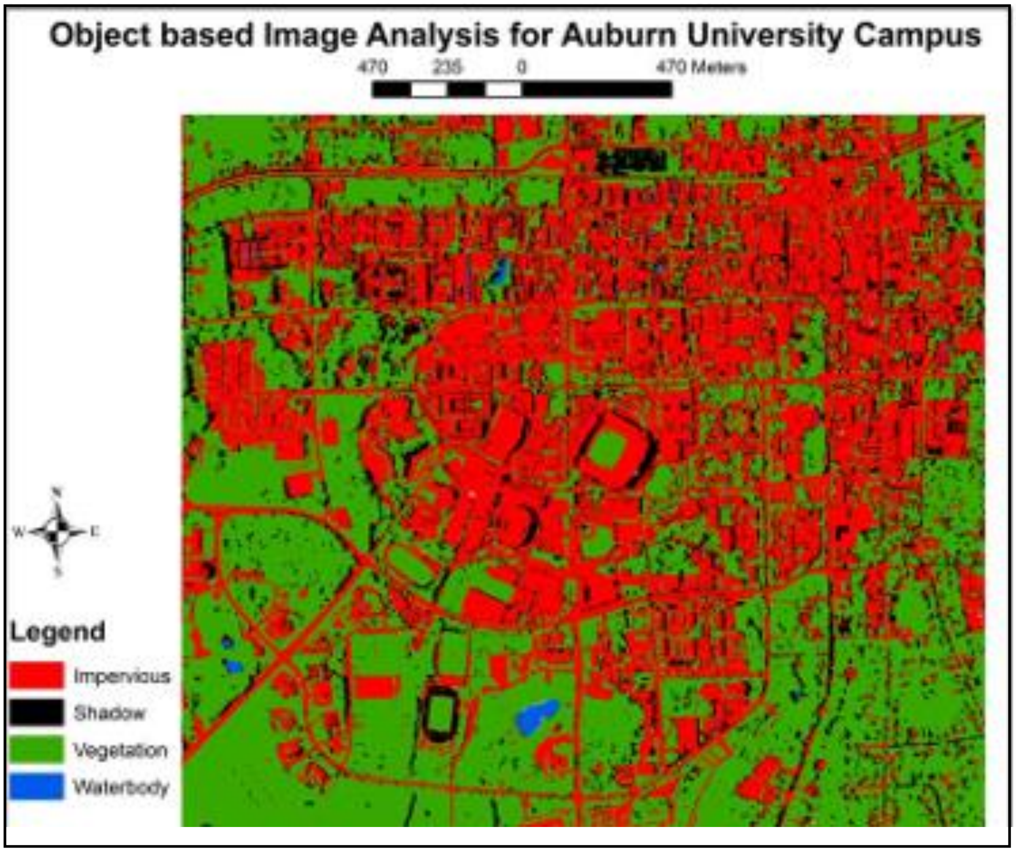


Figure 1.16: OBIA classification of Auburn University campus

1.10: Conclusion

‘Sustainability’ issues are big concern not only for experts but also for general people. Social media data like twitter data can provide us useful information about what, how and who are thinking and talking about sustainability all over the world. Over the years, people are raising awareness about sustainability, bringing technological innovations for sustainability practices and making positive changes in lifestyle. More and more research, practices have been conducting on sustainability by researchers, urban thinkers, experts, different institution and organization. Among the research entity, ‘Universities’ are main innovation hub and have been conducting cutting edge research to progress our society, to make our life more comfortable, shape our planet to be more viable and environment friendly. In fact, university campuses have been using as living laboratory and testing bed for sustainability practices. So, researching on the two sustainability components - ‘stormwater management’ and ‘solar power potential’ for AU campus is more important for the growth of the university in the realm of a sustainable future.

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Chapter 2: Stormwater Management in Auburn University campus

Contents

2.1 What and Why Stormwater Management

According to United States Environmental Protection Agency, “Stormwater management is the effort to reduce runoff of rainwater or melted snow into streets, lawns and other sites and the improvement of water quality” (Environmental, 2018).

In usual cases, stormwater soaks into ground soils and then filtered and finally replenishes ground water storage. But when ground surface is impervious, then instead of soaking, water creates runoff form and flows downward areas.

Rapid urbanization is not only a problem on its own, but also the reason for many problems (Larson et al., 2016). The most noticeable outcome of urbanization is increased proportion of imperious surface area. Once vegetated, porous land is turning into hard, impervious area so rapidly. This phenomenon is the main concerns behind stormwater management, because more the impervious surface area, more it creates runoff during storm event. In some cases, it takes such a mighty form that huge amount of runoff causing flooding in downward areas.

Stormwater runoff has another negative consequence. It causes pollution of streams, lakes, other waterbodies. Runoff washes away pollutants, heavy metals from upward developed areas to downward nearby waterbodies. As a result, making water unsuitable for most of the usual purposes, jeopardize living organisms within water environment.

So, managing stormwater could significantly helpful in order to reduce flooding (some cases) of downward areas and maintain water quality of nearby waterbodies. This can ultimately results into a balanced ecosystem.

2.2 Why Sustainable Stormwater Management

Previously, most of the work related to stormwater management mainly focused on increasing capacity of stormwater drainage network, which have been proved not effective in the long. That's why concerned people are moving towards sustainable ways to manage stormwater. Some of the ways of sustainable stormwater management initiatives are permeable pavement, rainwater harvesting, rain garden, and bio-retention cell (Marlow et al., 2013).

Figure 2.1: Rain Garden

Figure 2.2: Porous Pavement

Figure 2.3: Rainwater Harvesting Tank

Figure 2.4: Vegetated Roof

(Source: “Examples of Low-Impact Development Practices | Thurston Regional Planning Council, WA,” n.d.)

These sustainable ways of stormwater management have additional ecological and economic benefits (Berland and Hopton, 2014). When there will be less stormwater runoff and screening of runoff, then the chances of polluting nearby waterbodies are less. This will also reduce clean-up costs. Natural beauty, air quality will also be improved through different trees used in bio-retention cell, rain garden approaches of sustainable stormwater management initiatives. Groundwater table will also be recharged through infiltration. Researchers have found that bio-retention cell is more effective in reducing amount of stormwater runoff, screening pollutants from runoff. (Davis et al., 2009).

2.3 Bio-retention Cell

Basically, bio-retention cell is small vegetated depression in ground, and which can treat stormwater runoff from upslope developed areas. Treatment of stormwater runoff is vitally important since it can pollute nearby waterbodies by carrying pesticide nutrients, herbicides, heavy metals from developed areas and depositing them in nearby waterbodies (Hall, 2015). Various layers of grass filter strip, soil, sand is placed on top of another in an engineered design for bio-retention design. Among the several benefits of bio-retention cell are its capacity of removing up to 75% nitrogen from contaminated water, relatively cheap installation cost, minimal maintenance cost, easy to install in small areas etc. (Hall, 2015).

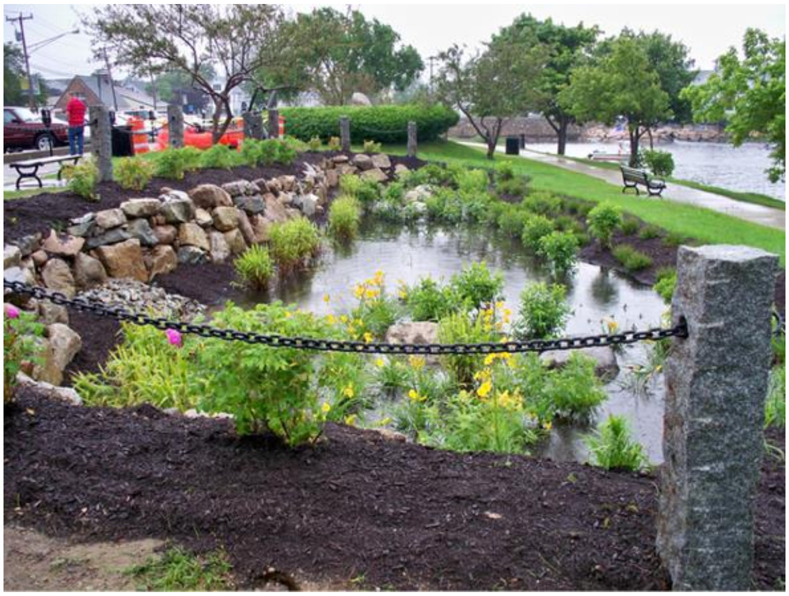

Figure 2.5: Bioretention at Water Street in Plymouth Center, Massachusetts (Source: Hall, 2015).

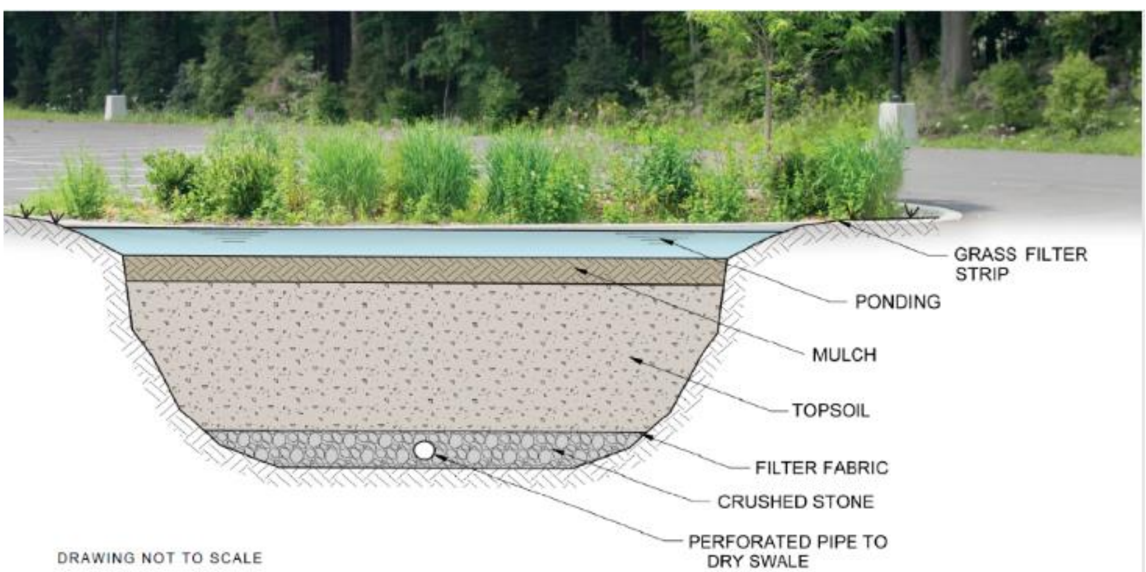

Figure 2.6: Schematic of 'Bio-retention Cell' (Source: "Bioretention Cells Design and Materials | Lyngso Garden Materials | South San Francisco, Bay Area," n.d.)

2.4 Why Stormwater Management at Auburn University

As already mentioned, developed areas produce more stormwater runoff and has negative effects on nearby waterbodies ("Why is Stormwater a Problem? | ddoe," n.d.). From our personal experiences, we can easily visualize impervious areas all over Auburn University campus

In order to assess imperviousness at Auburn University, following 'Normalized Difference vegetation Index' (NDVI) could be a great help. Although, NDVI is normally used to assess vegetation, but it is also very much helpful to get imperviousness (Kaspersen et al., 2015).

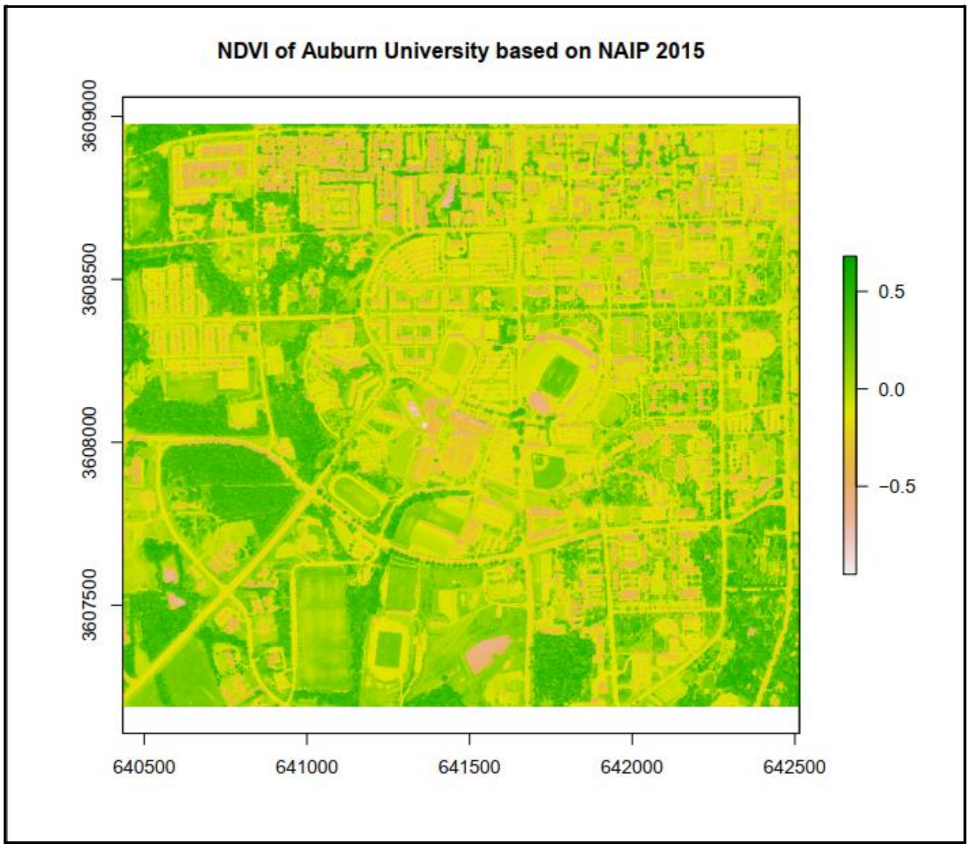

Figure 2.7: NDVI map of Auburn University

NDVI value range is -1 to +1, where higher the value, more the vegetation. Negative value indicates no vegetation. Values closer to zero (either from positive or negative way) (here areas with yellow color) refer impervious areas. Larger negative values refer to waterbody. Thus, we can see that Auburn University campus has most areas covered with impervious surfaces. This indicates that there will be more runoff during storm event. The above calculation of NDVI has been performed with the following codes in 'R' programming language using 'National Agricultural Imagery program' (NAIP) image of Auburn during from 18th September 2015.

```
install.packages("raster")
install.packages("leaflet")
library(raster)
library(rgdal)
library(rgeos)
library(RColorBrewer)
library(leaflet)
# Turn off factors
options(stringsAsFactors = FALSE)

# open NAIP image
NAIP_15 <- raster("m_3208529_nw_16_1_20150918.tif")

# plot NAIP image
plot(NAIP_15)



# stacking image

NAIP_stack <- stack("m_3208529_nw_16_1_20150918.tif")

# import campus boundary
crop_extent <- readOGR("CampusBoundary.shp")


# plot cropping extent
plot(crop_extent,
     main = "Auburn Universiy Boundary",
     axes = TRUE,
     border = "blue")

# calculate NDVI with red (band 1) and nir (band 4)
NAIP_NDVI <- (NAIP_stack[[4]] - NAIP_stack[[1]]) / (NAIP_stack[[4]] + NAIP_stack[[1]])

```

```r
# plot NDVI data
plot(NAIP_NDVI,
     main = "NDVI of Auburn University based on NAIP 2015",
     axes = FALSE, box = FALSE)

# save NDVI as .tif file
writeRaster(NAIP_NDVI, filename = "NDVI_AU_2015.tif", overwrite = TRUE)

# open raster NDVI
Raster_NDVI <- raster("NDVI_AU_2015.tif")


# Crop NDVI
CROP_NDVI <- crop(Raster_NDVI, crop_extent)


# plot crop NDVI
plot(CROP_NDVI, main = "NDVI of Auburn University based on NAIP 2015")

# save cropped NDVI
writeRaster(CROP_NDVI, filename = "NDVI_Auburn2015.tif", overwrite = TRUE)
```

Figure 2.8: ‘R’ codes for NDVI Calculation for Auburn campus.

Another very important information needs to be mentioned here which will demystify why it’s really urgent to manage stormwater in Auburn University municipal separate storm sewer system (MS4). Parkerson Mill Creek has been determined as “Impaired Water” has been placed on the Alabama Department of Environmental Management (ADEM) 303(d) list of impaired and threatened waters. Pathogens are water quality concern for Parkerson Mill Creek and urban runoff and sewer cross connections are identified as probable reasons for water quality concern(“POLICY ON STORMWATER MANAGEMENT COMPLIANCE,” 2016).

2.5: Stormwater Management at Auburn University

Auburn University has been designated as an owner/operator of a phase II municipal separate storm sewer system (MS4) by United States. EPA's Clean Water Act Phase II Stormwater Regulations (implemented March 2003) require operators of regulated Phase II MS4s to obtain a National Pollutant Discharge Elimination System (NPDES) permit and develop own stormwater management program plan (SWMPP) to reduce stormwater runoff and maintain water quality ("POLICY ON STORMWATER MANAGEMENT COMPLIANCE," 2016).

According to Auburn University's 'POLICY ON STORMWATER MANAGEMENT COMPLIANCE', "it shall manage stormwater in compliance with NPDES General Permit ALR040030 ("The Permit"), or subsequent permits, and the University's Stormwater Management Plan ("POLICY ON STORMWATER MANAGEMENT COMPLIANCE," 2016).

Auburn University has prepared its own SWMPP. It has followed the guidelines provided in Title 40 Code of Federal Regulations (CFR), Part 122.26(d), which has been incorporated in the Alabama Administrative Code 335-6 as administered by the ADEM and NPDES ALR040030 Phase II General Permit effective October 1, 2016 (Stormwater Management Committee, 2019).

2.6: Objectives

1a) The first objective is to assess the existing stormwater network efficiency in Auburn campus. It will help us to build strong knowledge base for all of the works afterwards in regard to stormwater management for Auburn campus.

1b) 'Maximum Water Velocity Mapping' of study area will provide clear view about potential areas where runoff will flow very rapidly during storm event.

2) 'Low Impact development' (LID) practice in sustainable stormwater management is one of the most popular method. People now adays are more interested in using LID component/s. Thus, the second objective will be to simulate storm event with 'Personal Computer Stormwater Management Model (PCSWMM), where one modeling scenario will have LID components and

another one without LID components and then comparing the two scenario results side by side within PCSWMM.

3) Among the LID methods, bio-retention cell has greatest potentiality to reduce amount of stormwater runoff and reduce peak runoff rate. Thus, the third objective of this chapter is to conduct a suitability analysis for bio-retention cell to find best places within AU campus for it's installation.

2.7: Literature Review

2.7.1 Stormwater Modeling & Management with 'Stormwater Management Model' / Personal Computer Stormwater Management Model

EPA's SWMM has been widely used all over the world for planning, analysis and design related to stormwater runoff, evaluating gray infrastructure stormwater control strategies, and creating green/gray hybrid stormwater control solutions (US EPA, 2014). SWMM is a widely used and most preferred model to deal with watershed hydrology and water quality when it comes to working within urban area (Obropta and Kardos 2007). SWMM is a dynamic hydrology-hydraulic water quality simulation model. It is primarily used for runoff quality and quantity simulation for single event or long-term simulation for urban areas ("Storm Water Management Model | U.S. Climate Resilience Toolkit," 2019). Hydrological flow, characteristics within urban area is completely different than rural, river catchment area due to high complexity of landform, rate of imperviousness etc.in an urban area. SWMM was first developed (SWMM I) back in 1971 by United States Environmental Protection Agency (U.S. EPA) for rainfall runoff quality and quantity simulations (Metcalf and Eddy 1971). It was written in FORTRAN. But due to several limitations (such as the model was only applicable for watersheds with area from 10 to 5, 000 acres), SWMM II was released in 1975. SWMM II was applicable for larger watersheds. It also had some pollutants modeling capabilities (Huber et al. 1975). With the release of SWMM 3 in 1891, it was possible to use for planning and design purposes. SWMM 4 (released in 1988) came with more additional capabilities such as computational improvements were made to the hydraulic routines to eliminate convergence problem. Finally, in 2005, SWMM 5 was released which is has been written completely in C, and has come with high computational capabilities, with no limitation on number of elements could be added into model (Niazi et al., 2017). Over the years, academicians, researchers, policy makers, urban planners, and urban thinkers are successfully using this model in diverse application areas and contributing on stormwater management initiatives. The unique aspect of SWMM is, it emphasizes on engineered water conveyance systems for stormwater runoff and wastewater management, which set it apart from other urban watershed models (Niazi et al., 2017).

Before discussing about relevant research works, having a clear understanding of SWMM will help us to understand things better in later. A schematic (figure 2.9) will serve our best interest in this regard.

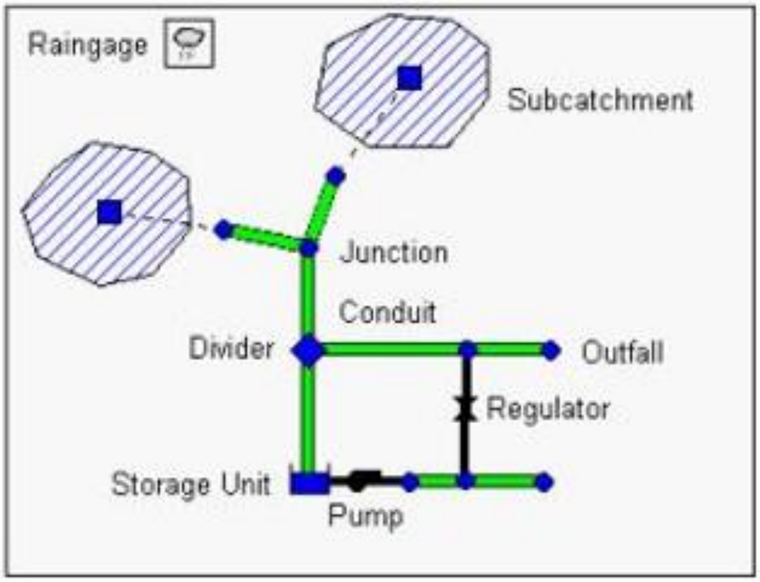

Figure 2.9: Components of SWMM Model (Source: Rossman, 2015)

In SWMM Model, there are two types of components:

1) Hydrology: Rain Gage, Subcatchment, Snowpacks etc.

2) Hydraulics: Node (Junction, Outfall, Divider), Link (Conduit, Pump, Orifice, Weir, Outlet etc.) etc.

Another important aspect associated with SWMM modeling is 'Continuity Error', which determine validity of concerned 'Model'. There are two kinds of continuity errors: runoff and routing, a short description and interpretation has been given below for both of them.

Runoff Continuity Error: it is the 'uncertainty' within 'hydrology' components. If the error is > 5 %, it will be indicated in 'red' color; when the error is < 5% but > 1%, it will be indicated as ‘yellow’; and when the error is < 1%, it will be indicated as ‘green’. Simulation could produce meaningful results when error is < 1%. It is calculated as: 100* (1- total outflow / total inflow)

Where,

Total inflow = Rainfall + Initial Storage + Initial snow cover

Total outflow = evaporation + infiltration +runoff+ snow removed + final storage + final snow cover (“SWMM Interpreting continuity error,” n.d.).

Routing Continuity Error: It refers to the ‘uncertainty’ within ‘hydraulics’ components. It is calculated in the same way just like runoff continuity error, except there are more ways for water to enter and exit (inflow and outflow) (“SWMM Interpreting continuity error,” n.d.).

Since hydrological flow is a spatial phenomenon, it requires taking supporting data from other spatial data handling software such as ArcGIS. In order to overcome this problem, ‘Computational Hydraulics Inc. Canada Water.com’ (CHI Water.com) has devised a new model called ‘Personal Computer Stormwater Management Model’ (PCSWMM), which is a combination of SWMM engine and GIS engine and because of this unique characteristics, PCSWMM is most effective and efficient model for stormwater modeling (“SWMM 5 modeling with PCSWMM,” n.d.). In the following section, a well-articulated approach has been taken to examine how researchers all over the world are using EPA- SWMM, PCSWMM for stormwater management and modeling purposes.

As just discussed, spatial characteristics play vital role in hydrology, so GIS can contribute in stormwater modeling due to innate capacity in spatial data processing (Zhu, 2010). The very first step in stormwater modeling for an area is catchment delineation. Previously, most of the cases it was done manually as hand-drawing on watershed map (Dongquan et al., 2009), but in recent decades, things have changed a lot and this time consuming task can be done using different methods, tools, or software (Tikkanen, 2013) Although it is always best to have the customized model (for an area) validated through calibration, but non-calibrated model could also provide significant results in some analyses such as measuring effects of climate change on urban water balance (Tikkanen, 2013). Before introducing PCSWMM, because of lacking spatial analysis engine in SWMM, approaches were mostly coupling ArcGIS with SWMM (Wang et al., 2018). This coupling approach could significantly improve urban flood modeling which will eventually results in less damages during flood (Wang et al., 2018) and it is more applicable for larger watersheds (Barco et al., 2008). Coupling of one-dimensional (1D) SWMM with two-dimensional (2D) model could also help to reasonably predict flood damage in urban areas (Seyoum et al., 2012). Sometimes, coupling can happen of 1D sewer/1D surface network and 1D sewer/2D surface flow model and former one is susceptible to more errors than later case (Leonardo et al., 2009 and Abbasizadeh et al., 2017). SWMM itself is promising for urban flood modeling and combination of 'ignore' and 'both' is better than any other options of 'Dynamic Wave' routing, 'ignore' is best for inertial terms and Nash-Sutcliffe for assessing modeling performance (Liu et. al., 2013) although SWMM can't forecast precisely as it doesn't have surface runoff routing (Jiang et al., 2015) and performance could vary based on application. PCSWMM has improved simulation of urban flood modeling which can help identifying flood-prone areas (Abdelrahman et al., 2018) and predicts the influence of imperviousness on the hydrological characteristics of the catchment (Liwang et al., 2017). While simulating urban flood modeling, spatial resolution of Digital Elevation Model (DEM) and temporal resolution of hyetograph could affect model output (Abedin and Stephen, 2015). The way in which urban catchment is define during modeling also can affect model results and when urban catchment is modeled as single watershed, model can produce significant results even in un-calibrated condition (Swathi et al., 2018 and Laouacheria et al., 2017). Stream network modeling and quantification are also highly dependent on DEM resolution since morphometric parameters of stream network are dependent on DEM resolution (Paul et al., 2017). All stormwater models can be classified as semi distributed (SD) and fully distributed (FD). FD models are more realistic as they avoid simplicity and spatial data aggregation applied in SD models on subcatchment level (Pina et al., 2015).

Catchment discretization level are two types: macro-scale (contain minimum required number of subcatchments to retain original sewer network properties) and micro-scale (every subcatchment defined for unique soil and land-use combination). These discretization levels also have an impact on modeling. Modeling output uncertainties are far less for micro-delineation and calibrated parameters could be used in other ungauged sites, but the same task might not be good for macro-delineation because of reduced confidence (Sun et al., 2014). An innovative SWMM discretization where diameter of each conduit is ten times as discretization length is preferred when modeling highly dynamic flows in SWMM because of less computational effort in improving model results (Pachaly et al., 2019).

Till now most of the modeling were based on traditional catchment discretization but in recent time, researchers have started modeling with ‘mesh’ techniques and the significance of this technique is that meshes can be adapted at optimum level in time and space when required – in response to flow characters as well as it has the capability to represent complex topography while reducing computational cost (20 – 84 %) (Hu et al., 2018).

2.7.2 Stormwater Management and Low Impact Development

According to the 'United States Environmental Protection Agency' (US EPA) - "The term 'Low LID refers to systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration or use of stormwater in order to protect water quality and associated aquatic habitat" (US EPA, 2015) . LIDs such as vegetative swales, bioretention cell, rainwater harvesting tank, permeable pavement etc. are gaining popularity in recent time due to effectiveness in sustainable stormwater management - onsite management with additional benefits. LID approaches are sometimes used in different names such as 'Low Impact Urban Design and Development' (LIUDD), 'Best Management Practices' (BMPs), 'Sustainable Urban Drainage Systems' (SUDS/SuDS), 'Green Infrastructure' (GI), 'Water Sensitive Urban Design'(WSUD) etc. in different parts of the world (Fletcher et al., 2015).

However, LID approach is comparatively new, more research is needed to determine suitable LID approach specific to areas. One study has found that 'infiltration trench' and a combination of 'infiltration trench' with 'green roof' can reduce significant volume of stormwater runoff (Joksimovic and Alam, 2014). In another study, permeable pavement and bioretention cell both did work good in terms of reducing runoff volume (Ping Lu and Tao Yuan, 2011). In addition to using individual LID components, sometimes a combination of several types could be more effective. Both cases, either individual or combination, could be effective for small and medium scale rainfall event, but they are not that much effective for heavy rainfall event (Li Na et al., 2016). Rainfall intensity is more considerable than rainfall depth in evaluating LIDs performances. Future more studies will be greatest things on evaluating LIDs performances in heavy storm scenarios represented with 'Intensity-Duration-Frequency' (IDF) curve. "IDF curve is a graphical representation of the probability that a given average rainfall intensity will occur" ("IDF Curve | The Climate Workspace," n.d.). SWMM has been proved very efficient simulating impacts of LIDs on changing climate scenarios where precipitation data was used from 'Coupled Model Inter-Comparison Project Phase 5' (CMIP5) and modified according to a new proposed methodology, which led to not only reduction in runoff volume but also noticeable reduction in peak flow rate as final output.(Zahmatkesh Zahra et al., 2015). Proportion of total impervious area that is hydrologically connected to storm sewer system also known as 'Effective Impervious Area' (EIA) is an important determining factor in stormwater runoff (Ebrahimian et al., 2016). Effectiveness of LIDS in different design storm events (2, 5, and 10 years) increase proportionally with decrease in % of EIA (Palla and Gnecco, 2015). LIDs could also have positive impacts on reduction of flood inundation hazards and this effect is more noticeable in areas within high flood risk zone (60 to 80 %) (Eckart et al., 2017).

2.7.3 Suitable site selection for 'Low Impact Development'

Suitability analysis is one of the most common methods and effective analysis in GIS ("Suitability Analysis—ArcGIS Pro | Documentation," n.d.). In a GIS platform, it is possible to include several types of data as separate layers, assign importance in output through % of weight. Both biophysical and programmatic criteria can be considered into a customized GIS model (Bhandaram, n.d.). Installation of LIDs could potentially involve different uncertainties in terms of location, size, costs, benefits and these can significantly influence decision making process from one stakeholder to another. Simulating decision making process could certainly provide better understanding of decision-making process of one or more stakeholder such as local government, state government, household or developer etc. Sometimes, actual budgeted funding might not be reliable, and policymakers prefer to base on installation cost when planning for expenditures (Castonguay et al., 2018). Another approach of practicing sustainability in stormwater management would be focusing on all appropriate LID types at a time. While considering different types of suitability indicators, including social indicators could benefit in terms of implementation in real scenarios. (Christman et al., 2018). In addition to preparing own customized GIS model, there are other some standard methods available such as EPA's Green Long-Term Control EZ template (Environmental Protection Agency, 2011), EPA national Stormwater Calculator (US EPA, 2014), RECARGA model ("RECARGA Model - Storm water runoff - Wisconsin DNR," n.d.), L-THIA (Purdue University, 2015), WMOST (US EPA, 2013) , MUSIC (eWater, 2012), SUSTAIN (US EPA, 2014), etc. which could be used to model stormwater runoff. In general case, suitability analysis is conducted usually based on pre-defined criteria. And for suitability for green stormwater infrastructures such as bio-retention cell, considering hydrologic principles could significantly improve output results. 'Green stormwater infrastructure' practices might have been using with different names, but the concept remains the same. For an example, this approach is known as 'Water Sensitive Urban Design' (WSUD) in Australia, 'Nature Based Solutions' (NBS) in Europe, Sponge City Systems in China, etc. (Kuller et al., 2019). Sometimes, efforts for sustainable stormwater management can result into a 'Decision Support System'. 'Spatial Suitability Analysis Tool' (SSANTO) - a GIS-based multi-criteria decision analysis tool, is a recent addition in decision support system and works great in sustainable stormwater management initiatives. One unique feature of SSANTO – considering suitability from two perspectives (Needs and Opportunities) has given this tool extra edges over others (Kuller et al, 2019). SSANTO combines different criteria like biophysical, socio-economic, planning and governance (‘Opportunities’) with criteria relating to ecosystem services (‘Needs’). SSANTO has facilitated understanding of the relationship between multi-faceted and highly complex urban contexts and urban planning outcomes for green stormwater infrastructure practices. As already mentioned earlier, increased proportion of impervious surface due to rapid urbanization process has been crucial to think more about green stormwater infrastructure. Detailed consideration of all factors related urban context such as urban form, biophysical or socio-economic are strongly recommended to get optimum benefits in WSUD. A thorough study of current practices can reveal which type of factors are top one the priority list. One study has found that in most of the cases, biophysical and urban form factors are given highest priority whereas socio-economic factors remain overlooked which means only engineering practices have been the governing factors of current WSUD planning practices and which could lead less attainment of potential benefits from green stormwater infrastructures (Kuller et al., 2018). Freely available data can be used to identify priority sites for LID and the identification task could be highly accurate (94 ± 5.7%) (Martin-Mikle et al., 2015).

All the studies related to green stormwater infrastructure; location is one of the widely used criteria. Because of efficiency of spatial analysis in GIS software, ‘Multi-Criteria Decision Analysis’ has been common suitability analysis technique in any aspect. Newly developed ‘spatial multi-criteria decision analysis’ (SMCDA) has the potentiality of using GIS tools (from toolbox) when it is being integrated with ArcGIS and also the newly developed tool can be used in any site selection study because of non-site specific, adaptive and comprehensive nature (Rahman et al., 2012). Just like bio-retention cell, raingarden is another green stormwater management measure. Interestingly, in some places like in the U.S., these two terms are used often interchangeably where there are little bit differences in their design criteria, place of installation and maintenance (Webb, n.d.). Consideration of different layers – soil properties, slope, land use, land ownership, and ground water level have been proven effective to produce suitability map as raster layer based on predefined score of the considered input layers (Vaculová and Fuska, 2017).

From above discussion, it is a clear indication that managing stormwater through sustainable measures – LIDs are gaining popularity day by day. And among the measures, bio-retention cell and raingarden are the most effective. In this study due to contextual preference, an initiative has been taken to identify suitable locations (through suitability analysis with ArcGIS ModelBuilder) for bio-retention cell in Auburn University campus.

2.8: Data and Methods

2.8.1 Data Requirements

Data requirements have been described in a similar way we have described this study objectives.

1a) Objective **1a** of this study is to assess capacity of the existing stormwater network. This task will require DEM of study area, existing stormwater network and rainfall data. DEM has been produced with 'Light Detection and Ranging' (LiDAR) data which has been collected from the 'City of Auburn'. Existing stormwater network data has been collected from 'District Energy Plant' of Auburn. Sources of rainfall data are two – design storm-event data has been used from 'Natural Resources Conservation Service' (NRCS) 'Technical Release -55' of the 'United States Department of Agriculture' (USDA) and onsite rainfall data has been collected through installed rain gauge (figure 2.10) on top of Haley Center at Auburn University.

1b) Objective **1b** will require only DEM of the study area**.**

2) Data requirements for objective 1a will be enough to conduct analysis for objective 2.
3) Objective three will require existing roads, waterbodies, soil types, parking lot locations, slope, structures data as GIS layer. These have been collected from Auburn University Library GIS data portal.

Figure 2.10: Rain Gauge Installed on Top of Haley Center

2.8.2: Methodology

a) Analysis for objective one and two are based on same input data and because of that, methodology for these two have been presented together (figure 2.11).

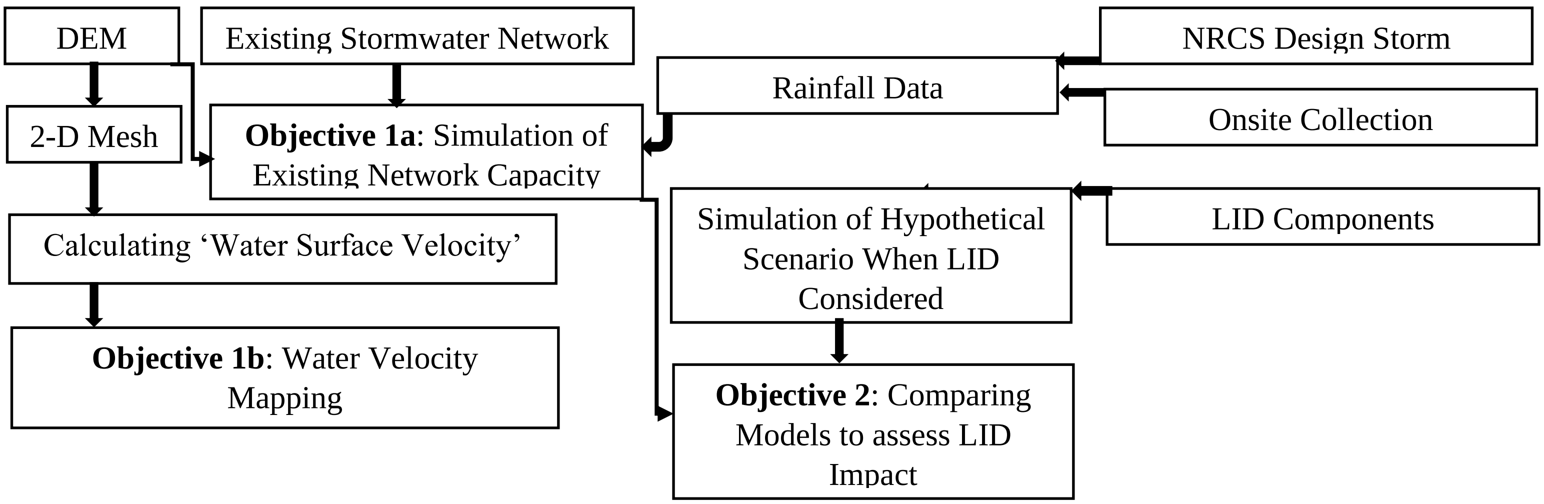

Figure 2.11: Methodological Framework (for objective 1a, 1b, & 2)

With the LiDAR Data collected, DEM has been generated in ArcGIS. DEM, existing storm sewer network map and field visit are the basis for sub-catchment delineation. Although, it was possible to automatically delineate sub-catchment based on solely DEM in PCSWMM, but doing this work using ArcGIS for this study gave the advantages of having stormwater network map, DEM, google street map as background layers and most importantly presenting the ground information more authentically. The DEM, sub-catchment shape file has been imported in PCSWMM. Slope % for each sub-catchment has been calculated in PCSWMM with "Set DEM Slope" tool. % of Slope has also been calculated in ArcGIS to cross validate the computation process. Conduits and Nodes 'Computer Aided Design' (CAD) files have been converted into shape file and then imported in PCSWMM. Making Conduits, Nodes layers as background and locking them, new Conduits, Nodes layer has been generated by referencing locked layers in PCSWMM. Areas for subcatchment have been automatically calculated in PCSWMM and depth for nodes have been defined as per collected stormwater network map. Finally, conduits types and dimensions have been correctly defined. When all preliminary works have been done, then a SWMM 5 Model has been generated in PCSWMM for our study area. Using NRCS Technical Release 55 from USDA, customize NRCS Type III and 2,5- and 10-year return period with 24 Hours storm have been designed in PCSWMM. Then the SWMM 5 Model has been run (with only 10 Year return period rainfall data) and observed the results. In addition, in order to describe study are context, a map max. water velocity has been calculated to identify areas where runoff water will flow most rapidly, medium rapidly and so on.

In next stage, some LID components (rainwater harvesting tanks and permeable pavements, and one bio-retention cell) have been incorporated into SWMM 5 Model. With the LID components considered, the model has been run again and compared with previous results to see any differences between them.

b) Taking into consideration of relevant literatures, contextual preferences, working on bio-retention cell installation would be more appropriate for this study. The methodological approach for objective three is basically developing a GIS model to locate suitable sites for bio-retention cell and that is very popular and common spatial analysis approach. Using all the required data layers (described in data requirements section), a GIS Model has been developed in ArcGIS Model Builder to find suitable places for bio-retention cell installation. The whole process can be represented as a flowchart (table 2.12):

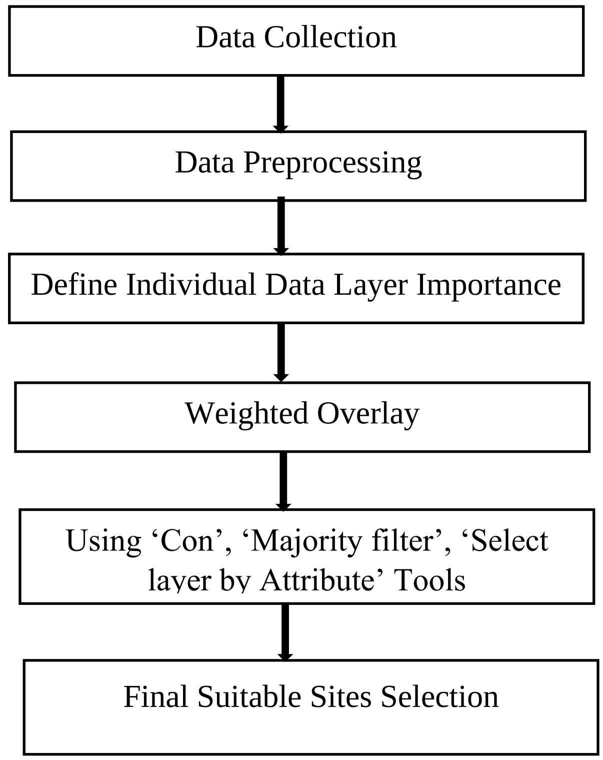

Figure 2.12: Simplified methodological Framework for Bio-retention Suitability (objective 3)

During model building in ArcGIS, several important parameters with specific considerations were followed to have best output results possible.

Table 2.1: Specific Considerations for Data Layers Used for Model Building of Bio-retention Suitability

Parameter	Restriction	Weight	Score (1 to 5)
Slope	NA	10	<14 - Score 5 0-14 – Score 3 0 - Score 1
Road	0 – 15 feet	30	‘Euclidean Distance’ reclassified into five classes, assigning higher score to the closet class category and lower score to a further class and so on…
Structure	0 – 20 feet	10	Closer areas are more suitable than further areas
Waterbody	0 – 15 feet	10	Closer areas are more suitable than further areas
Parking Lot	NA	30	Closer areas are more suitable than further areas
Soil	NA	10	Marvyn loamy sand – 5 Pacolet sandy loam – 4 Marvyn-urban land complex – 3 Pacolet- urban land complex – 2 Urban land - 1

Here, restriction column (from table 2.1) refers to the areas excluded from analysis. Although, it is good to have bio-retention cell closer to road because roads surfaces add pollutants with water, but up to 15 feet from road has been excluded from analysis. The reason being the necessity for spaces on both sides of road in future to expand, as well as there should be provision for utility installations. Similarly, up to 20 feet from existing structures has been excluded since water accumulated in bio-retention cell very close to structures could be a potential threat for foundational damage. Up to 15 feet from waterbodies has been excluded so that there is less potential of water pollution. Parking lot and road layers have been assigned highest weight (30) as they are the main sources of runoff generation as well as pollutants. Plain areas (slope – 0) have been considered least suitable for bio-retention cell as water likely to be clogged down in that areas permanently. Areas with slope 0 – 14 % have been considered best (Score 5) for our purpose. For road, structure, waterbody and parking lot, more closer areas have been considered best and it decreases with increase of distances. Loamy soil has more permeability, that's why it has been assigned score 5. Consequently, other soil types have been assigned less score due to less permeability. 'Weighted Overlay' enabled us to assign pre-determined weight for each individual layer. With all information provided, finally the model was run to get initial suitability map (scaled 1 to 5) for whole study area. Because of relative higher importance, areas with score 5 have been extracted with 'Con' tool within the model environment. In order to get most desired place and making the raster based analysis more accurate, 'Majority Filter' tool has been added in the model and it used value 8, which means the kernel of the filter is 8 nearest neighbors (3 by 3 window) to present cell. 'Replacement Threshold' is 'Majority' (5 out of 8 connected cells must have the same value) in 'Majority Filter' tool. The output raster then converted into polygon using 'Raster to polygon' tool. And finally, in order to optimize area selection (selection larger chunk of areas), 'Select layer by Attribute' too has been added to the model with 'Selection Type' as 'SUBSET_SELECTION' and 'Expression' as 'Area >= 50, 000 square foot'.

2.9: Analysis and Discussion

Although in order to get presentational advantages, methods for objective one and two have been combined and presented together in 'Data and Methods' section, but here all analysis and discussion associated with three objectives have been presented individually.

a) Analysis and Discussion for Objective 1a

DEM of an area is one of the main vital information in order to do stormwater modeling for that area. Because of that reason, a high-resolution DEM has been prepared for our study area instead of using freely available low-resolution DEM. Although our study area is Auburn University campus, but existing main stormwater network doesn't cover whole campus area; in addition, in northern side some outside areas drained out water within campus. The area north of campus drains its water into demarcated university area, thus increasing the chances of water logging. These facts have been taken into consideration when preparing DEM (figure 2.12) and SWMM 5 Model (figure 2.14).

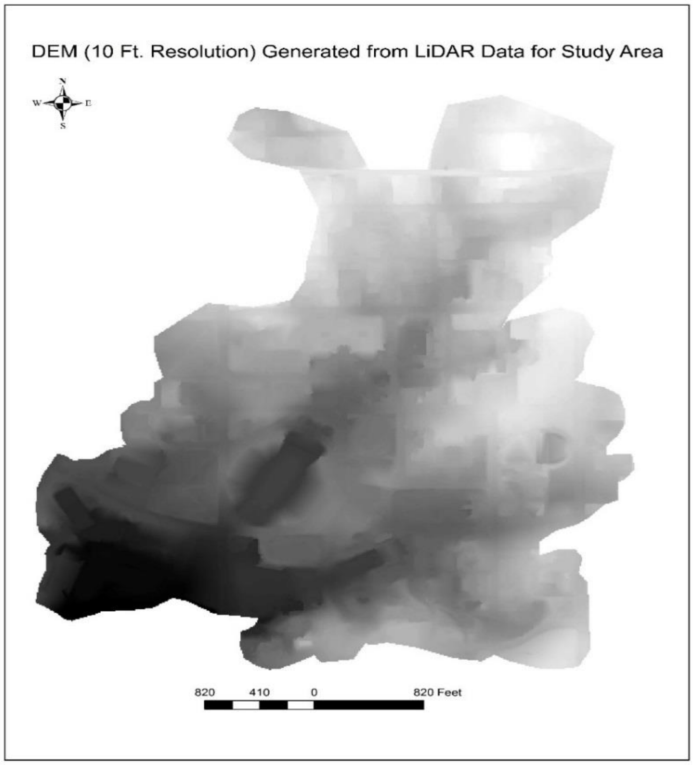

Figure 2.13: DEM for the area covered by existing stormwater network in study area

One of the main advantages for using PCSWMM is that it has some pre-designed storm event rainfall data and even it has the option to customize rainfall for an area where it's not already been provided. Using NRCS 'Technical Release -55', Type III, 10 -Years storm event rainfall data (figure 2.13) has been customized for Auburn area.

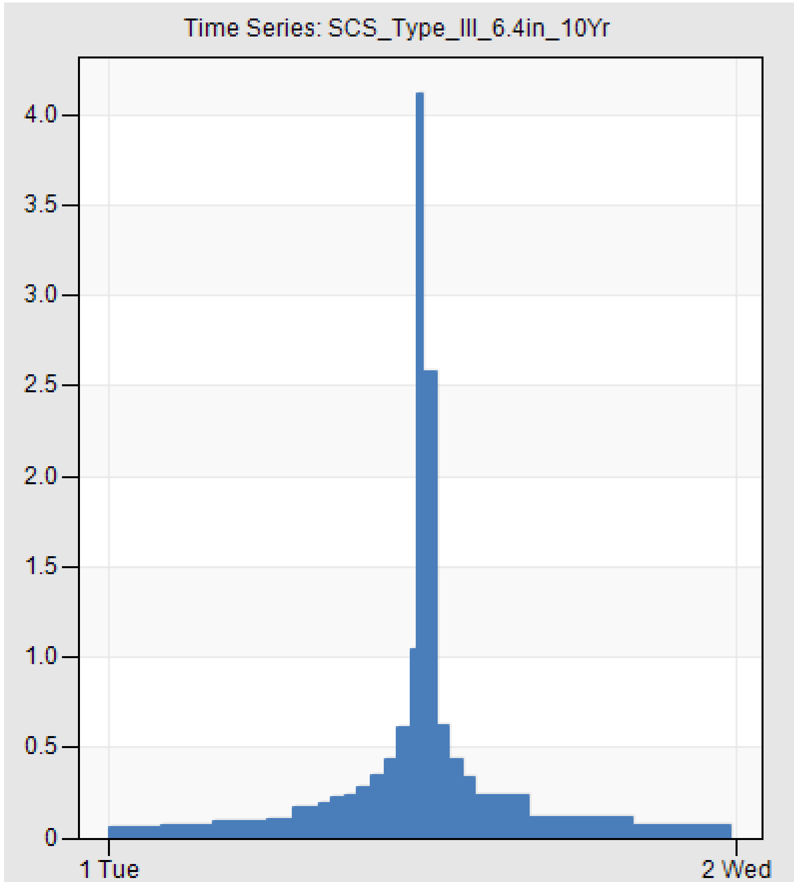

Figure 2.14: NRCS (previously 'Soil Conservation Service' -SCS) Type III, 10 Years Return Period Storm Event Rainfall Time Series

With necessary inputs (discussed in 'Data and Methods' section), a SWMM 5 Model (figure 2.14) has been exported from PCSWMM for our study area. There are 26 sub-catchments, 41 junctions and 41 conduits.

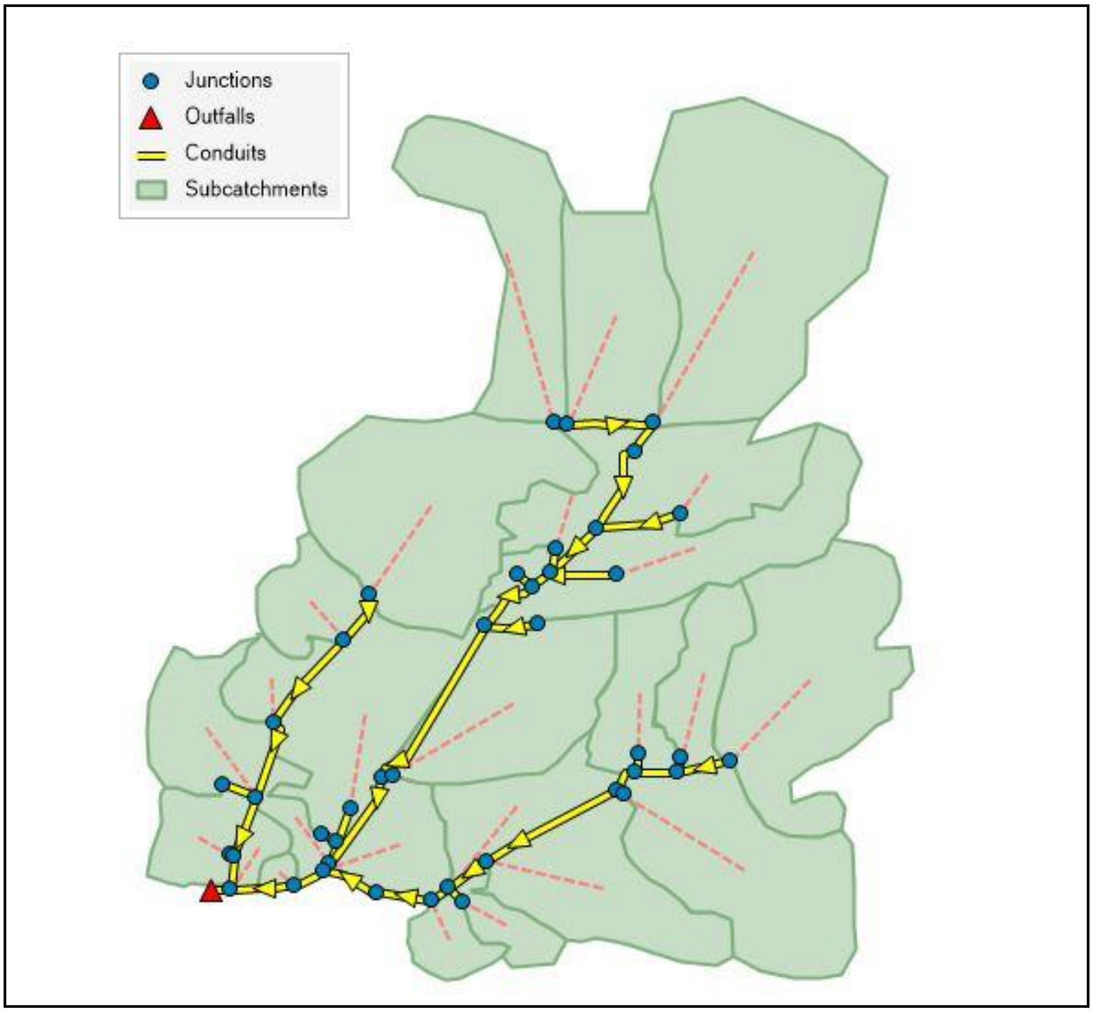

Figure 2.15: SWMM 5 Model for study area

In order to get more clear idea about extent of the whole model, it's sub-catchments and locations of 'Junction', whole model has been showed in 'Google Earth' (figure 2.15) from PCSWMM with levels for subcatchment (as 's') and junction (as 'j').

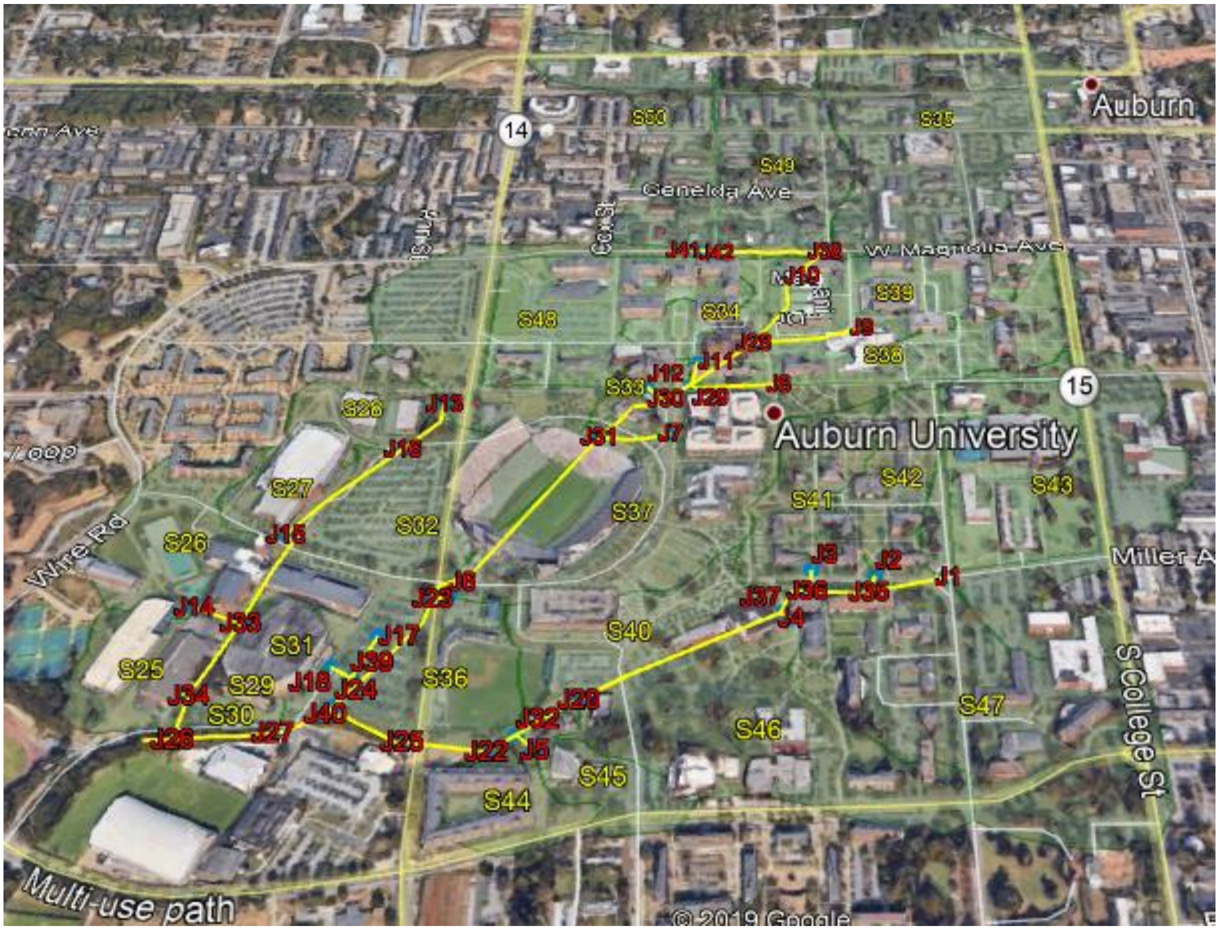

Figure 2.16: SWMM 5 Model showed in 'Google Earth'

Simulating '10- Years Return Period' storm primarily indicates potential nodal flooding (indicated red in figure 2.16).

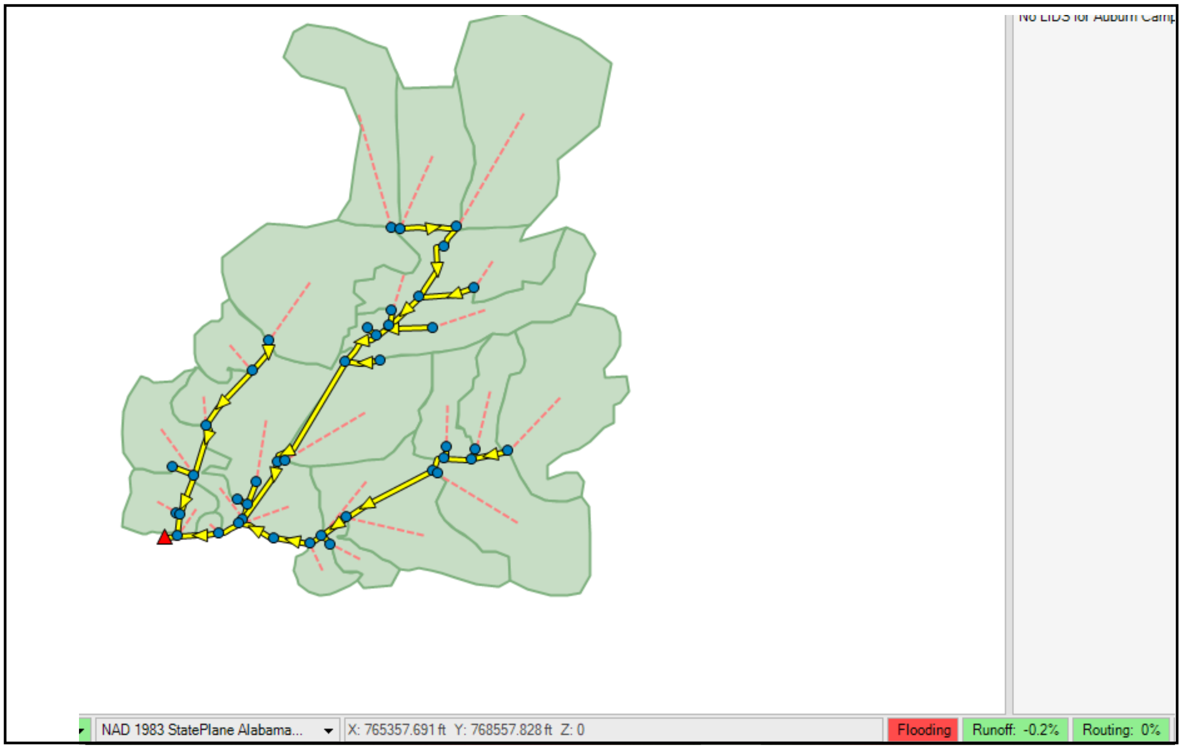

Figure 2.17: Output of simulation '10- Years Return Period' Storm Event

By close observation of simulation summary report, we get only 6 nodes are flooded (in table 2.2) and among them two (J31, J38) are relatively significant than others. It means currently we don't have too much to worry about flooding within Auburn University campus.

Table 2.2: Summary of Nodal Flooding

Node Flooding Summary
****

Flooding refers to all water that overflows a node, whether it ponds or not.

Node	Hours Flooded	Maximum Rate CFS	Time of Max Occurrence days hr:min	Total Flood Volume 10^6 gal	Maximum Ponded Depth Feet
J11	0.01	8.21	0 11:48	0.000	0.000
J28	0.01	25.12	0 11:48	0.000	0.000
J31	0.75	109.54	0 12:00	1.453	0.000
J38	0.22	72.63	0 12:00	0.333	0.000
J42	0.01	18.14	0 11:50	0.001	0.000
J8	0.75	42.59	0 12:00	0.399	0.000

Times of flooding (in figure 2.2) are very negligible except junction 31 and 8 (both 45 minutes). Maximum rate of water flow for junction 31 (109. 54 Cubic Feet per Second) is considerably higher than others. Highest flood volume (10^6 Gallons) will occurs for junction 31. Node surcharging is another important consideration during stormwater modeling, and which occurs when water rises above the top of the highest conduit connected. Surcharging time for junction 18 (in table 2.3) could be as much as 47.02 hours, although height above crown is much lower (only 1.686 Feet). Even though surcharging hours for junction 28 is very low (0.71 hour), but maximum height above crown could be 11.050 Feet.

Table 2.3: Summary of Node Surcharge

```
**********************
Node Surcharge Summary
**********************

Surcharging occurs when water rises above the top of the highest conduit.
---------------------------------------------------------------------
                                               Max. Height   Min. Depth
                                   Hours       Above Crown    Below Rim
Node                 Type      Surcharged           Feet         Feet
---------------------------------------------------------------------
J10                  JUNCTION        0.10          4.066        2.234
J11                  JUNCTION        0.30          5.700        0.000
J12                  JUNCTION        0.29          6.005        3.995
J18                  JUNCTION       47.02          1.686        1.344
J28                  JUNCTION        0.71         11.050        0.000
J29                  JUNCTION        0.78          9.294        0.506
J30                  JUNCTION        0.28          5.581        4.719
J31                  JUNCTION        0.77          6.800        0.000
J38                  JUNCTION        0.78          4.100        0.000
J42                  JUNCTION        0.22          2.800        0.000
J5                   JUNCTION        0.74          2.320        6.680
J8                   JUNCTION        0.77          6.400        0.000
```

Surcharging could occurs for 17 conduits (table 2.4) and it occurs when :

- The conduit flows full along its entire length, or
- The conduit's flow is equal or above the normal full-depth manning flow ("SWMM What constitutes surcharged flow in a conduit," n.d.).

Surcharging could occurs for in variable extent for both ends as well as upstream and downstream individually but there is nothing to worry when we look into hours above normal flow (in table 2.4) for surchared conduits.

Table 2.4: Conduit Surcharge Summary

Conduit Surcharge Summary

Conduit	Hours Full Both Ends	Hours Full Upstream	Hours Full Dnstream	Hours Above Full Normal Flow	Hours Capacity Limited
C1	0.10	0.10	0.71	0.01	0.01
C13	0.01	0.01	0.30	0.01	0.01
C14	0.01	0.01	0.10	0.01	0.01
C19	0.01	0.01	47.02	0.01	0.01
C2	0.71	0.71	0.78	0.29	0.29
C3	0.28	0.28	0.78	0.80	0.01
C30	0.01	0.01	0.75	0.01	0.01
C35	0.74	0.74	1.21	0.01	0.01
C36	0.01	0.01	0.01	0.50	0.01
C38	0.10	0.10	0.78	0.72	0.01
C39	0.01	0.01	0.22	0.01	0.01
C4	0.28	0.28	0.77	0.01	0.01
C40	0.22	0.22	0.78	0.01	0.01
C5	0.77	0.77	16.32	0.48	0.47
C6	0.30	0.30	1.92	0.01	0.01
C7	0.28	0.28	0.29	0.01	0.01
C9	0.01	0.77	0.01	0.80	0.01

b) Analysis & Discussion for Objective 1b

During intense rain events, pedestrians and vehicles might be at risk of being swept by runoff flows, and one risk factor in this problem is the overland flow velocity. Mapping of high overland flow velocities, along with flow depths, can help in the guide decision-makers in developing safety plans in the watershed. PCSWMM 2-D modeling capabilities can be used to compute overland flow velocities, and this model was used in the present research.

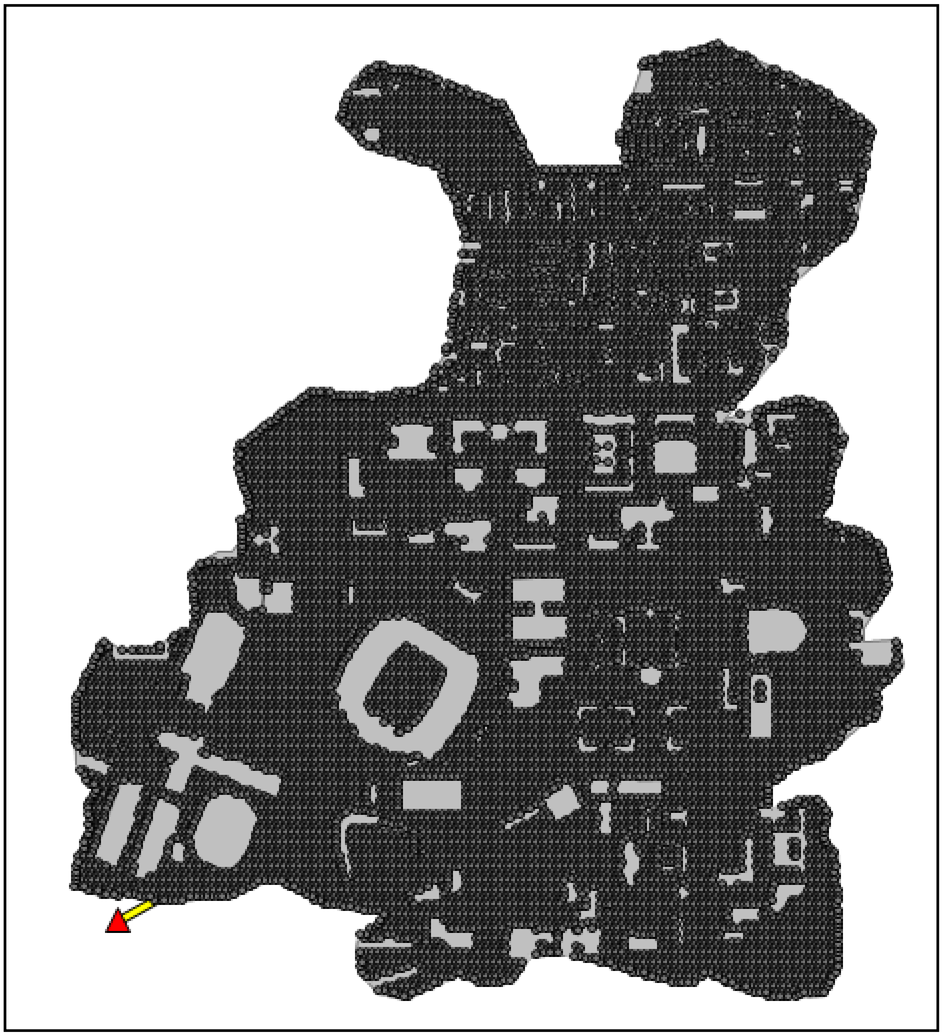

Figure 2.18: 2-D Mesh for Study Area

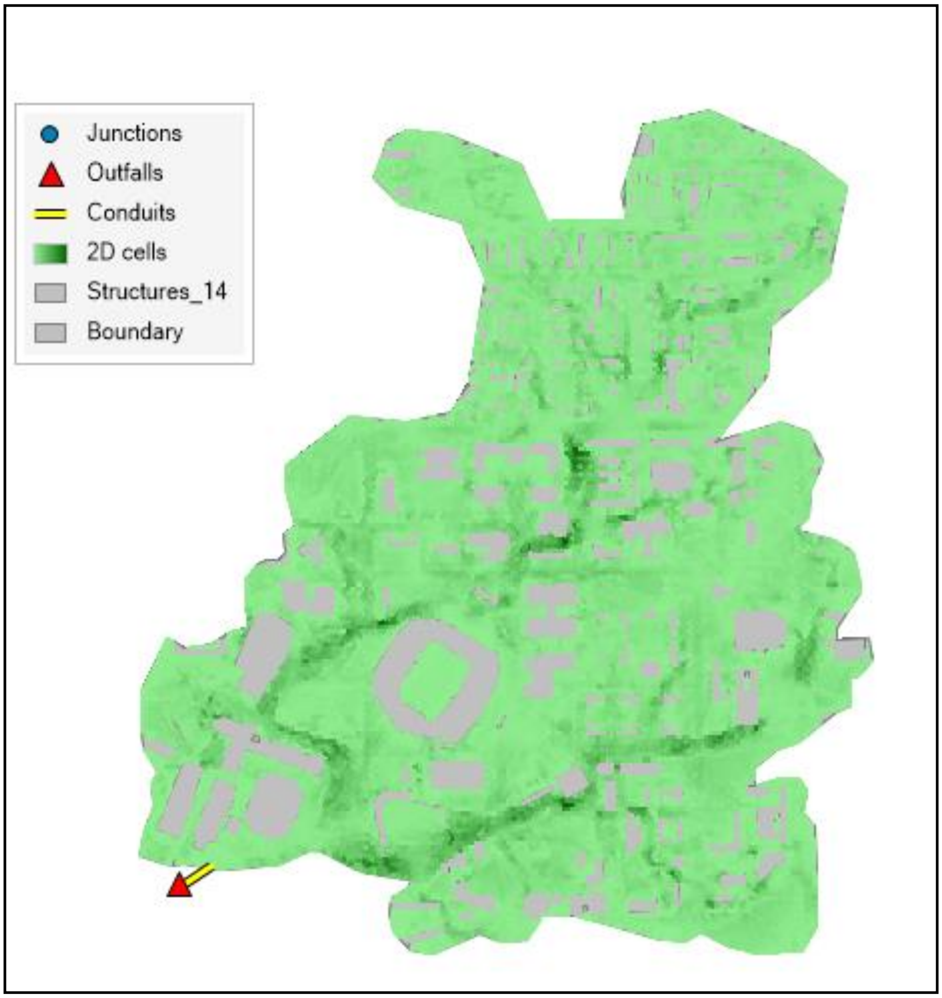

Figure 2.19: 'Maximum Water Velocity' Map for Study Area

Based on velocity of water surface, three categories (in table 2.5) have been defined.

Table 2.5: Max. Water Velocity Categories for Study Area

Categories	**Definition**
High Velocity	MWV > 8.01 ft/s
Medium Velocity	4 < MWV < 8.01
Low Velocity	MWV < 4

(Source: author's own interpretation)

‘High Velocity’ areas are where MWV > 8.01 Feet/Second, ‘Medium Velocity’ areas are with MWV between 4 and 8.01 Feet/Second, and ‘Low Velocity’ areas are with MWV < 4 Feet/Second. Final output is the ‘Maximum Water Velocity Mapping’ (figure 2.20) for Study Area.

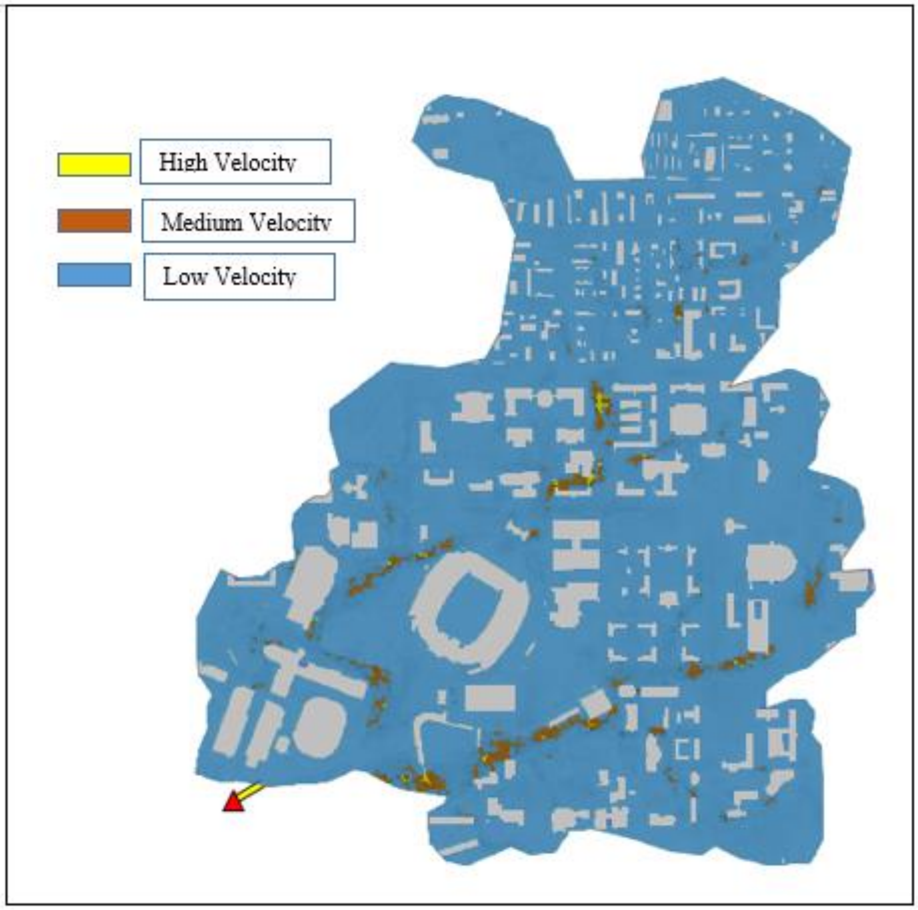

Figure 2.20: ‘Maximum Water Velocity Mapping’ of Study Area

Most of the areas are identified (in figure 2.10) as low velocity (blue color), and here it means water in those areas don’t flow so rapidly, less possibility for runoff generation during storm events. Only a small area is identified as high-velocity areas (red color), where we do expect water flowing comparatively rapidly.

c) Analysis and Discussion for Objective 2

So far from objective 1 results, we can say that there is nothing much to worry about flooding during storm event in Auburn University campus but still we have some issues with runoff even during light rainfall event. We have seen runoff flowing from more steeper surface areas to less steep surface areas, getting our shoes, pants wet and most importantly runoff finding its final place into nearby waterbodies. So, stormwater management should be taken into consideration. In more recent time, instead of thinking in line of traditional approach, people are more interested in managing stormwater in sustainable ways ("Why Sustainable Stormwater Management Matters," n.d.). By objective 2, we are going to examine how the effects would be if we include some sustainable stormwater management measures.

Table 2.6: Considered LID Types

Sub-catchment	LID Type	Number of Unit	Unit Area (Square Foot)
S31	Rainwater Harvesting	2	500
S32	Bio-retention	1	20, 000
S34	Permeable Pavement	3	5, 000
S35	Permeable Pavement	6	5, 000
S37	Permeable Pavement	5	5, 000
S38	Permeable pavement	5	5, 000
S49	Permeable pavement	4	5, 000
S50	Permeable Pavement	5	5, 000

Including all the LID components (table 2.6), a new model has been created and run with NRCS 10 Years Storm Event rainfall data, and which has given pretty much satisfactory results.

Table 2.7: Comparison Between Two Model's Results (for NRCS 10 Years Storm Event)

Name	MyAuburnStorm	NOLIDS_Auburn
Results statistics		
Max. subcatchment total runoff (MG)	5.64	5.71
Max. subcatchment peak runoff (cfs)	148.45	148.78
Max. subcatchment runoff coefficient	0.981	0.981
Max. subcatchment total precip (in)	5.5	5.5
Min. subcatchment total precip (in)	5.5	5.5
Max. node depth (ft)	15.05	15.05
Num. nodes surcharged	12	12
Max. node surcharge duration (hours)	47.04	47.02
Max. node height above crown (ft)	11.05	11.05
Min. node depth below rim (ft)	0	0
Num. nodes flooded	5	6
Max. node flooding duration (hours)	0.76	0.75
Max. node flood volume (MG)	1.447	1.453
Max. node ponded volume or depth (acre-in/1000 f...	0	0
Max. storage volume (1000 ft³)	n/a	n/a
Max. storage percent full (%)	n/a	n/a
Max. outfall flow frequency (%)	93.28	93.72
Max. outfall peak flow (cfs)	953.82	955.96
Max. outfall total volume (MG)	42.057	42.495
Total outfall volume (MG)	42.057	42.495
Max. link peak flow (cfs)	953.82	955.96
Max. link peak velocity (ft/s)	47.48	47.51
Min. link peak velocity (ft/s)	0	0
Num. conduits surcharged	18	17
Max. conduit surcharge duration (hours)	47.04	47.02
Max. conduit capacity limited duration (hours)	0.48	0.47

Middle column ('MyAuburnStorm' in table 2.7) refers to the results when LID components (table 2.6) have been considered, and last column ('NOLIDS_Auburn') represents results when no LID components were considered. When LIDs are considered, number of nodes flooded decreased (from 6 to 5). Total outfall volume also decreased from 42.495 to 42.057 Million Gallon (MG). Also, we have observed a decrease in maximum link peak flow from 955.96 to 953.82 Cubic feet per Second (cfs). Apparently, these number might look insignificant, but it makes sense as we have only considered LID components in some pre-selected subcatchments with limited capacity for preliminary analysis. There is always provision of exploring applicability of LIDs in other subcatchments and increasing their size/capacity. As a result, we can expect more effectiveness of LIDs for stormwater management.

At this time, an approach has been taken to explore efficiency of LIDs in case of light rainfall event (onsite collection). That same two models have been run again with onsite rainfall data collected on April 6, 2019.

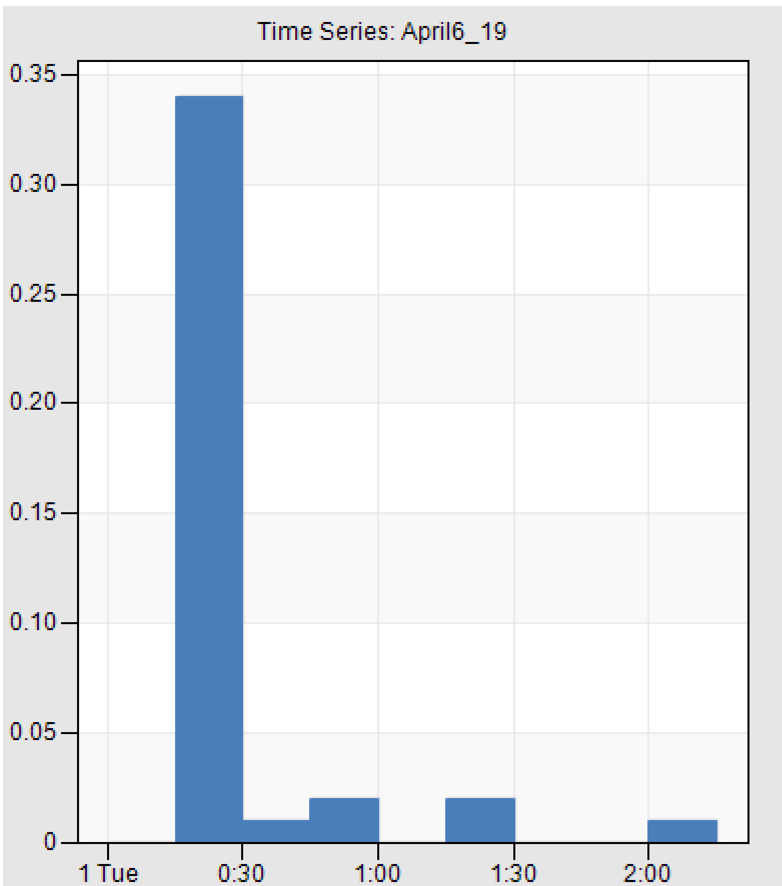

Figure 2.21: Time Series for Rainfall Data Collected on April 6, 2019

Table 2.8: Comparison Between Two Model's Results (for April 6, 2019 Rainfall)

Name	MyAuburnStorm	NOLIDS_Auburn
Results statistics		
Max. subcatchment total runoff (MG)	0.05	0.06
Max. subcatchment peak runoff (cfs)	5.46	7.1
Max. subcatchment runoff coefficient	0.628	0.628
Max. subcatchment total precip (in)	0.1	0.1
Min. subcatchment total precip (in)	0.1	0.1
Max. node depth (ft)	3.38	3.37
Num. nodes surcharged	1	1
Max. node surcharge duration (hours)	47.53	47.53
Max. node height above crown (ft)	0.88	0.871
Min. node depth below rim (ft)	0	0
Num. nodes flooded	0	0
Max. node flooding duration (hours)	0	0
Max. node flood volume (MG)	0	0
Max. node ponded volume or depth (acre-in/1000 f...	0	0
Max. storage volume (1000 ft³)	n/a	n/a
Max. storage percent full (%)	n/a	n/a
Max. outfall flow frequency (%)	41.99	46.78
Max. outfall peak flow (cfs)	26.24	40.35
Max. outfall total volume (MG)	0.369	0.475
Total outfall volume (MG)	0.369	0.475
Max. link peak flow (cfs)	26.24	40.35
Max. link peak velocity (ft/s)	16.27	16.27
Min. link peak velocity (ft/s)	0	0
Num. conduits surcharged	2	2
Max. conduit surcharge duration (hours)	47.53	47.53
Max. conduit capacity limited duration (hours)	0.01	0.01

Here we can see noticeable improvements when LIDs are considered. Maximum outfall peak flow, total output volume and maximum link peak flow has been reduced respectively 26.24 from 40. 35 (cfs), 0.369 from 0.475 (MG), 26.24 from 40.35 (cfs). These reduction in volume is additional benefits, since our LIDs consideration are primarily to improve surface water runoff quality. Long term flooding is not a issue for our study area.

Most important conclusion can be drawn based on above results and discussions. We can see, LIDs are more effective when rainfall is not heavy. From our previous experience we have noticed, flood, heavy storm is not much frequent for the area of Auburn University campus. And most importantly SWMPP has put great emphasize on improving quality of surface water runoff by reducing amount of pollutants contained in stormwater runoff through implementation of best management practices (BMPs)/LIDs (Stormwater Management Committee, 2019). These facts validate our proposition that consideration of LIDs would be more appropriate for stormwater management of Auburn University campus.

d) Analysis and Discussion for Objective 3

Our extensive literature review and study area context have suggested that, bio-retention cell would be more applicable for our study purpose – sustainable stormwater management. Locating in most suitable place/s is very important if we want to see expected outputs from bio-retention cell. Objective 3 is designed to find most suitable sites for bio-retention cell installation. With all the necessary inputs and executing sequential procedures (described in 'Data and Methods' section), a model was developed (figure 2.22). By running the model, we have got final suitability map (figure 2.23).

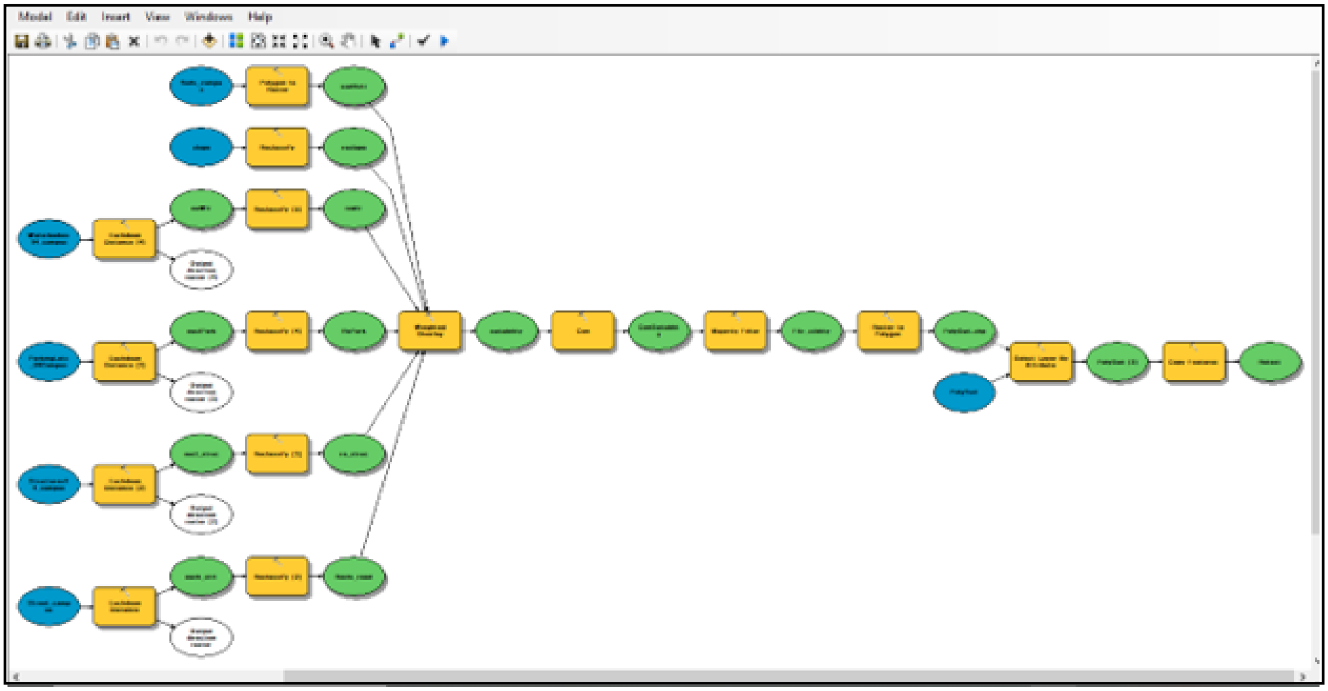

Figure 2.22: GIS Model for Bio-retention Suitability Analysis

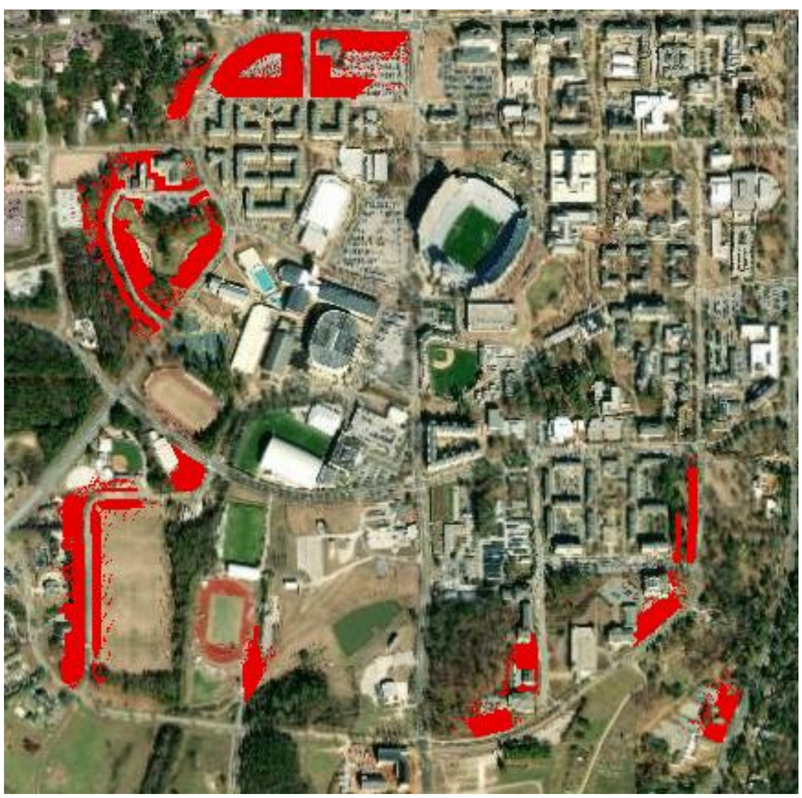

Figure 2.23: Most suitable areas (with score 5 - red color) for Bio-retention Cell

A number of areas have been identified (in figure 2.23) as suitable sites for bio-retention cell installation. Those areas are with score 5. The reason of choosing only areas with score 5 is, primarily we would like to work with only best suitable locations. And in future, if there is any requirement after dealing with these areas, we will then focus on comparatively less suitable (areas with score 4, 3) areas (which are out of focus for this study). In the northern part of campus, large parking areas have also been identified as suitable, but it is not likely that we will recommend converting all parking areas into bio-retention cell. Only small area conversions will be done in the parking lots.

2.10: Conclusion

Even though, big storm events are not likely to make flooding scenario at Auburn campus, but others important aspects of stormwater within campus suggested that managing stormwater would be beneficial for Auburn campus. Managing stormwater in sustainable ways would provide short term as well as long term benefits. Among the sustainable stormwater management measures, bio-retention cell would provide more benefits for this study purpose. Taking necessary steps based on this study would be a good start for 'sustainability' practices in the Auburn University campus.

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Chapter 3: Solar Power Potential in Auburn University campus

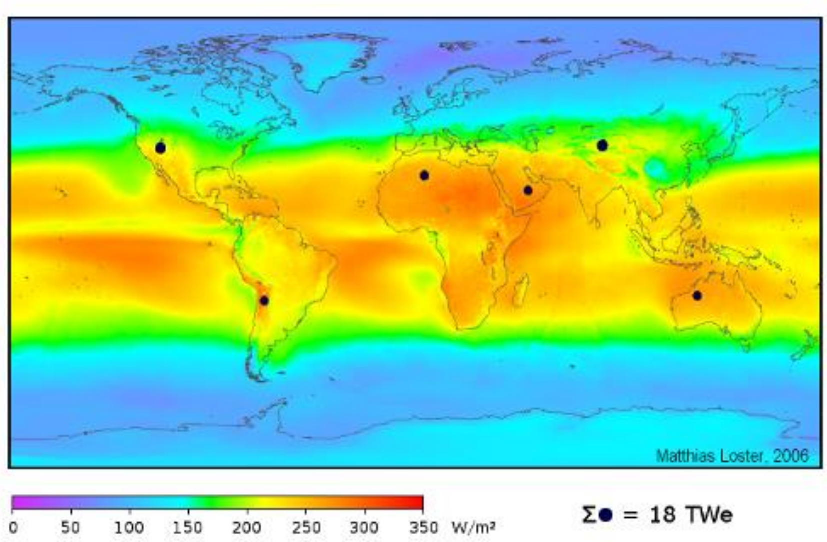
Contents

3.1: Solar Power

Solar energy is considered as the major source of renewable energy due to its limitless nature. In fact, solar energy possesses the potentiality of meeting total energy demands of the entire world if required technologies are available (Blaschke et al., 2013). Another important issue behind thinking of solar energy is growing concern over carbon emissions (Kabir et al., 2018), fossil fuels are the biggest sources of it. Adoption of solar technologies could significantly reduce carbon emissions, for an example, in California, U.S; about 696,544 metric tons of CO_2 emissions have been reduced or avoided through the installation of 113,533 household solar systems (Kabir et al., 2018).

3.2: Solar Power Potential

On an average, earth surface receives 342 W m^{-2} of solar energy, 30 % of which is scattered or reflected and remaining 70 % can be harvested or captured (Kabir et al., 2018).



(Source: "Total Primary Energy Supply," n.d.)

Figure 3.1: Global Solar Irradiance (annually).

Global solar irradiance varies from place to place, and interestingly only black dot areas (in figure 3.1, with radii of 100 km) can sufficiently supply world's total energy demand ("Solar Energy Potential and Utilization | EARTH 104: Earth and the Environment (Development)," n.d.).

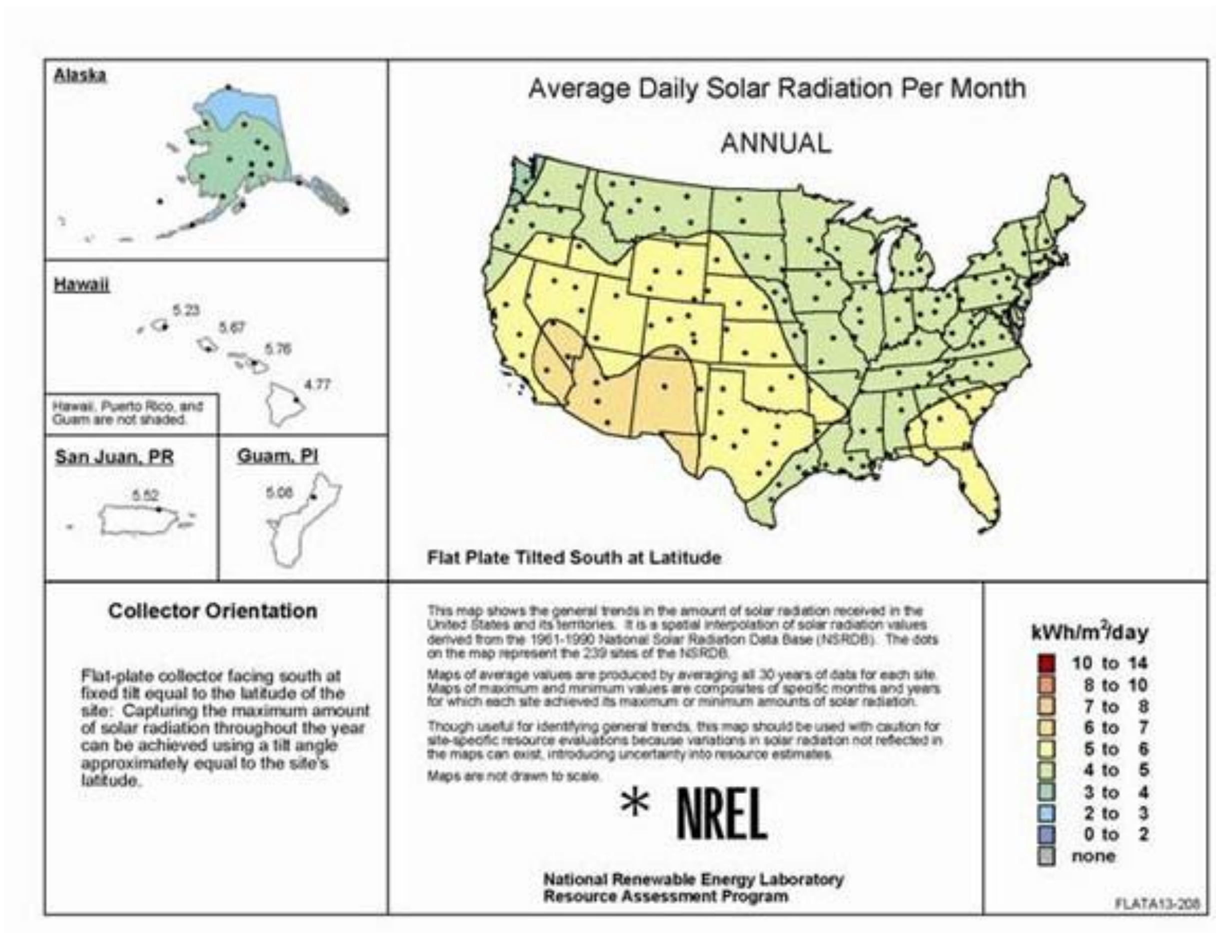


Figure 3.2: Solar Radiation for U.S.

According to the 'National Renewable Energy Laboratory' (NREL), solar energy potential within U.S. can provide as much as 400 zettawatt-hours annually ("National Renewable Energy Laboratory," 2012). Although a major chunk of areas in south-western U.S. (parts of Texas, New Mexico, Arizona, Nevada, and California) (in figure 3.2) has the highest solar power potentiality, but if we look in the south-eastern side where Auburn is located, we can get the sense that adopting solar power technology is reasonable for our study area. An estimate shows that 100, 000 square feet of solar panel surface area could generate enough electricity for about 1291 houses ("Solar Energy Potential," n.d.)

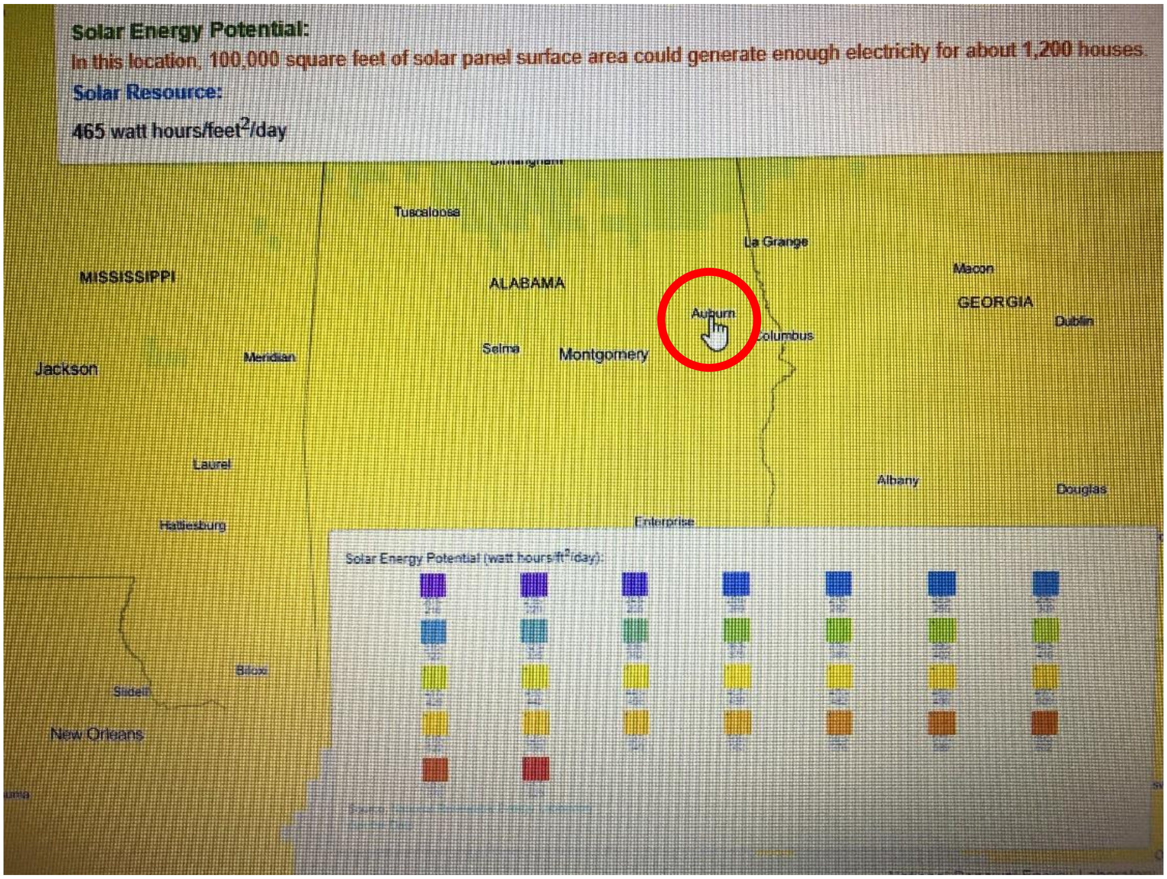


Figure 3.3: Solar Energy Potential for Auburn (red circled) (source: energy.gov)

3.3: Objectives of The Study

1) Auburn is a city in the south-eastern part of Untied States with many days of sunlight. This objective is intended to calculate solar power potential of building rooftops within Auburn campus using 'Light Detection and Ranging' (LiDAR) data. LiDAR technology has made it possible to do sophisticated research work, which previously

was beyond imagination. LiDAR has enabled us collect detailed, high resolution data from distant places, places where it is quite impossible to go physically.

3.4: Literature Review

Solar energy has been gaining popularity, due to its efficiency and environmental, social, and economic benefits (Kabir et al., 2018). Excessive use of fossil fuels in last decades have heightened the risk of climate change, greenhouse effects and its multi-tier effects. Due to these alarming facts, researchers are conducting cutting edge research on estimating solar power potential to accelerate the process of conversion to renewable energy.

GIS can provide best results when working on problems with spatial dimeshin. And among GIS analytical approaches, GIS modeling is preferable when the goal is to spatiotemporal modeling. Solar power potentiality is a spatial-temporal phenomenon, since it varies from space to space, from time to time due to sun's relative psotion. 3D GIS modeling could be highly effective in identifying the key areas on the facades and rooftops of buildings receiving maximum solar radiation (Chow et al., 2014). LiDAR data can be beneficial when we want to calculate solar potential in city scale, where LiDAR data are used to create altimetric data inputs ('Digital Surface Model' – DSM, 'normalized DSM' – nDSM) along with planimetric (represents building footprints) data (Santos et al., 2011). In more advanced research, suitable site can be identified using LiDAR technique and GIS (Latif et al., 2012). And more surprisingly individual structure level solar photovoltaic potential calculation can be performed when LiDAR data is used with additional GIS layers and DEM (Leitelt, 2010). Cloud coverage plays significant role in net solar power potential. Investigating cloud coverage could significantly improve solar power calculation output (Wong et al., 2016). Cell mathematical models have been proven effective to calculate solar per meter, per year with real photovoltaic cell conversion efficiency ((Morcillo-Herrera et al., 2014). In a similar kind of research, statistical models developed for small & medium buildings and large buildings have proven highly effective to simulate productivity of photovoltaic modules on the roof area to arrive at the whole U.S. nationwide technical potential for photovoltaic (Gagnon et al., 2016). Calculating solar potential within urban area most of the times a little bit complicated since shadow of nearby buildings could affect solar insolation rate. Building shadow analysis using 'hillshade' could be helpful to find suitable rooftop for photovoltaic (PV) cell installation (Hong et al., 2016). Sometimes, LiDAR data could be unavailable and very costly, so using open source data is still useful in mapping solar power potential (Korfiati et al., 2016). Building features calculation method can varies based on rooftop types such flat rooftops, shed rooftops, hipped rooftops, gable rooftops and mansard rooftops. A newly developed method can consider these differences and can calculate solar power potentials with satisfactory accuracy (Song et al., 2018). During photovoltaic potential values modeling, linear regression analysis for measuring influence of slope, elevation, rooftop area, and lot size could also significantly improve output results (Carl, 2014). During solar power calculation purposes, 3D visualization can improve presentation of outputs results and Unity 3D engine could a good option for 3D visualization ((Buyuksalih et al., 2017). In addition to solar power potentiality calculation using LiDAR, GIS data, considering present market value of photovoltaic panel can be helpful for economic potentiality analysis (Mansouri Kouhestani et al., 2019). In a more improved 5- steps methodology, merging GIS and object specific image recognition capabilities has also been effective to calculate solar power potentiality and it could be guiding line for future solar PV installation research and its geographical potentiality (Wiginton et al., 2010). Solar power potentiality not only depends on solar radiation but also other factors such as ambient temperature, wind velocity, weather topographic conditions etc. and considering all of these factors is really important to calculate solar power potentiality in realistic way (Harinarayana and Kashyap, 2014).

From the above discussion, it has been observed that LiDAR data, GIS technologies are commonly used in solar power potential calculation. So, dealing with LiDAR data within ArcGIS would be the best decision if we want to these kinds of analysis. Fortunately, 'LAS Dataset Toolbar' in newer ArcGIS version has made it handy to works with LiDAR data in ArcGIS ("The interactive LAS Dataset toolbar—Help | ArcGIS Desktop," n.d.). That's why this study has been designed to use ArcGIS las Dataset Toolbar to process LiDAR data and 'Area Solar Radiation' tool calculate solar power potentiality for Auburn campus.

3.5: Data and Methods

LiDAR point could data has been used for solar power potential calculation. Initially, LiDAR data for Auburn University campus has been extracted with ArcGIS 'LAS Dataset Toolbar' from large LiDAR dataset for whole Lee County. Then using extracted LiDAR data, a 'Digital Surface Model' (DSM) has been created. Using DSM as input file 'Area Solar Radiation' tool in ArcGIS, solar insolation for Auburn campus has been calculated for getting idea about gross solar insolation. Due to certain fact (described in 'Analysis and Discussions' section), only building rooftops within Auburn campus has been extracted and finally using building rooftops layer, solar insolation for typical year 2018 grossly as well as individual monthly have been calculated. The whole process has been presented graphically in figure 3.4.

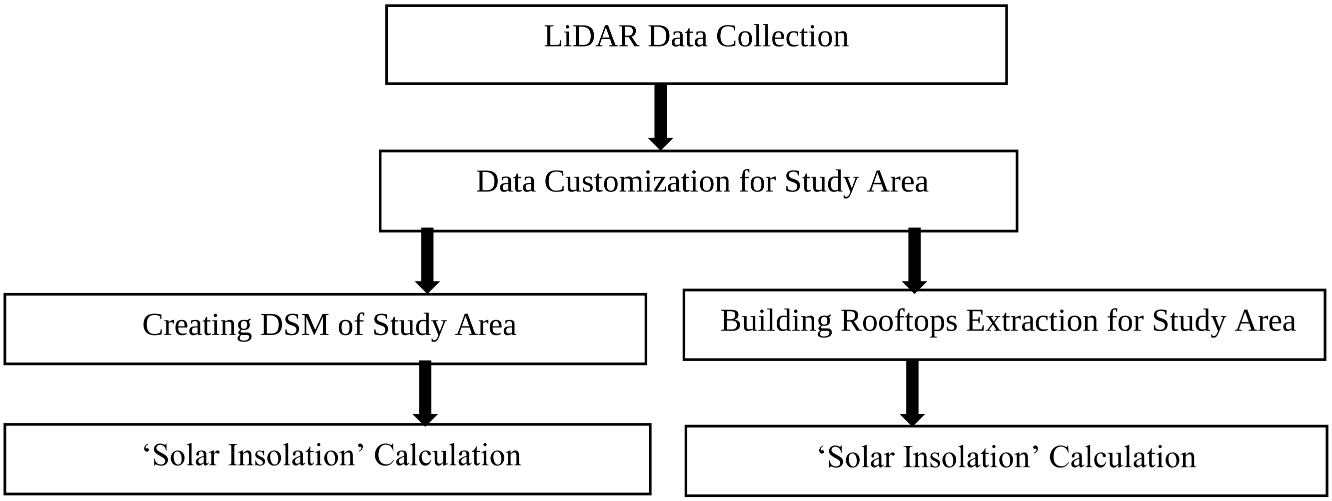


Figure 3.4: Simplified Methodological Framework

3.6: Analysis and Discussions

As discussed in 'Data and Methods' section, first requirement for solar power potential is creating a DSM with LiDAR data

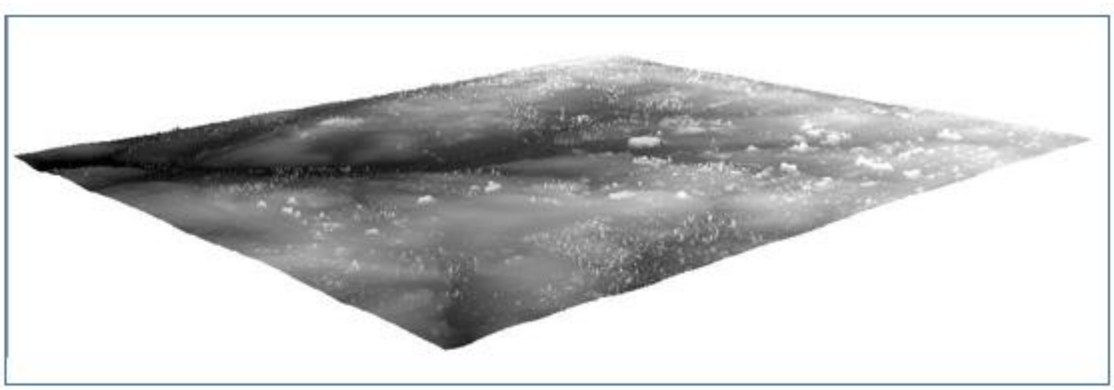


Figure 3.5: DSM of Study Area in ArcScene

DSM of study area has been used to calculate solar power potentiality (in figure 3.6).

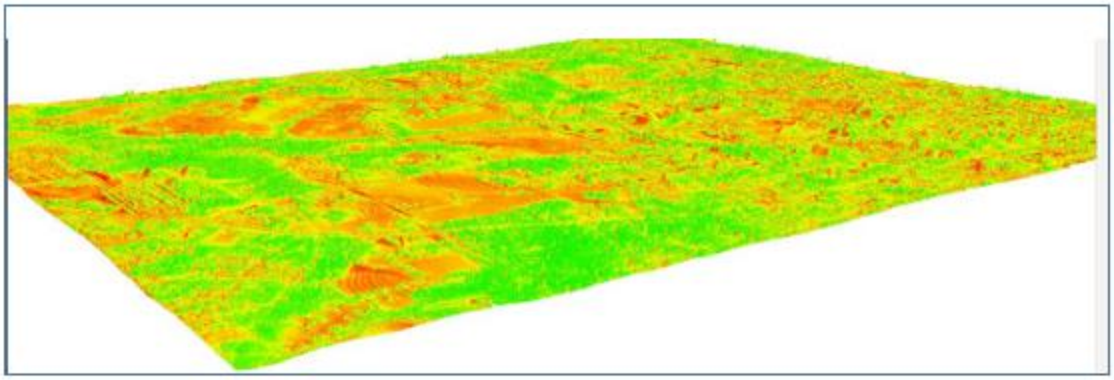


Figure 3.6: Solar Power Potential in ArcScene

By close observation of solar power potential for whole study area from above calculation, it has been observed except some parking lots, mostly building rooftops are areas with highest solar power potential. Because of this fact, in next stage, only building rooftops have been considered for solar power potential calculation.

From LiDAR data, only building rooftops (figure 3.7) have been extracted using ArcGIS ‘LAS Dataset Toolbar’.

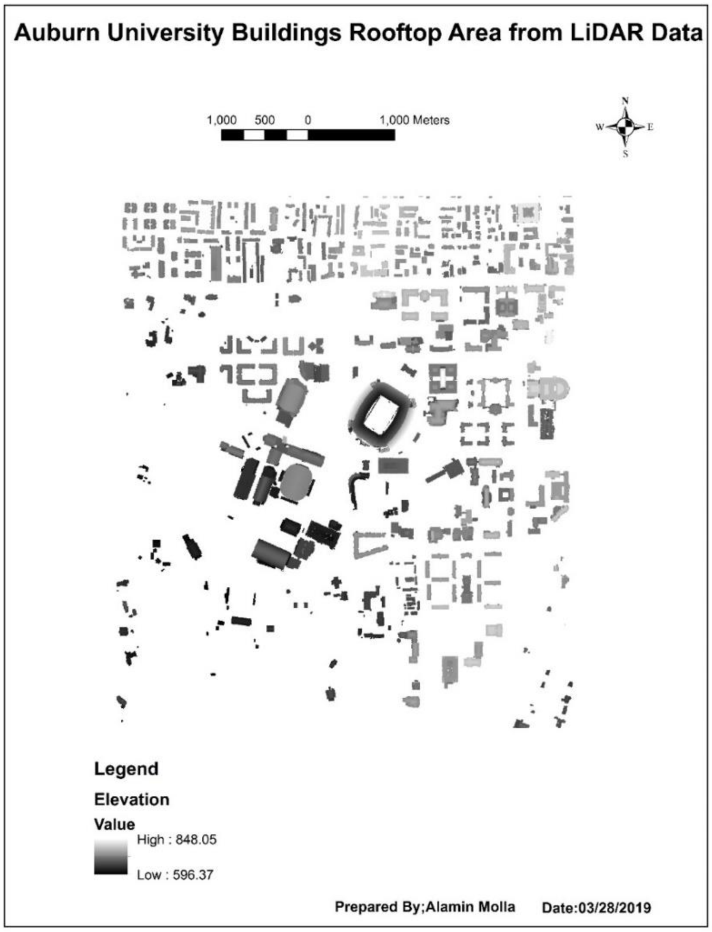


Figure 3.7: Buildings Rooftop of Study Area

In similar way as like previously done, using building rooftops as input layer in ArcGIS 'Area Solar Radiation' tool, solar power potential has been calculated for typical year 2018 grossly(figure 3.11) as well as for individual month basis (from figure 3.8 to figure 3.10). 'Area Solar Radiation' tool in ArcGIS is a great addition for people interested in solar power potential calculation ("Area Solar Radiation—Help | Documentation," n.d.). This tool has been proved very effective to estimate solar power potentiality in small scale area where there is no difference in latitude. It takes into consideration apparent sun position throughout day, surrounding buildings shadow effect, slope etc.

Figure 3.8: Solar Power Potential for January, February, march, and April months of 2018

Figure 3.9: Solar Power Potential for May, June, July, and August months of 2018

Figure 3.10: Solar Power Potential for September, October, November, and December months of 2018

Figure 3.11: Solar Power Potential for 2018

In above maps, more the red more solar insolation and more it takes blue, less the solar insolation. We can see that for whole 2018-year (figure 3.11), solar radiation could be as high as 1.93785 times ten to the power 006 and as low as 3061.11 Watt/Square Meter (W/Sq.M). When we compare individual month basis, then the lowest 'Low' amount could be 29.6394 W/Sq.M for February month and highest 'High' amount could be 179940 W/Sq.M. With consideration high and low amount, month of April is most efficient time in terms of getting higher solar insolation. Although individual month basis solar insolation calculation won't help much to decide about solar panel installation, but gross potential (in figure 3.11) will be much helpful to get idea about places with most solar power potential.

3.7: Conclusion

Solar power has the potentiality to meet energy demands instead of relying only fossil fuels. As part of sustainability efforts, Auburn University also interested in taking necessary steps for solar power utilization ("Auburn Climate Action Plan v 1.1," 2019). This study has some promising outputs since it has identified some potential areas where it would give optimum results if photovoltaic cells are installed. This research is a good start to think about potential location of solar photovoltaic cell installation. In next stage of this research, it would be most effective to find out exact locations of photovoltaic cell installation before taking final decision of installing it.

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Chapter 4: Conclusion

Contents

4.1: Conclusion

Although, sustainability concept is relatively a new idea, but the movement started very earlier along with social justice, conservationism, internationalism and other past movements ("McGill University, what is sustainability", n.d.). It is gaining more popularity in recent time as people are now more conscious about environment and the future of our Earth. Exploring social media data is a great way to get an overview about what, how people are thinking, shaping their ideas about sustainability. This study has explored some tweets with '#sustainability'. Within the retrieved tweets with '#sustainability', people from different places around the world are talking about many relevant concepts such as climate change, solar power, wage gap etc. Among sustainability issues, stormwater management and solar power potential for auburn University have been considered in this study. Although, simulations of storm event for existing stormwater network has showed that big flooding/storm events are not common for AU campus, but still there are some issues with stormwater runoff. Even for small scale rainfall event, we see runoff flowing towards less steeper places, making us wet when we are moving around. But most deleterious aspect of stormwater runoff is that it makes nearby waterbodies polluted, example, 'Parkerson Mill Creek' for Auburn campus. LIDs have been increasingly used for sustainable stormwater management. And more specifically, this research has shown that LIDs are more effective small-scale rainfall, which is mostly common on AU campus. Among the LID approaches, a bio-retention cell is greatly effective to reduce amount of stormwater runoff as well as velocity. A sustainability analysis for bio-retention cell has identified most suitable sites for bio-retention cell installation, which will greatly help to make decision about installing bio-retention cell within Auburn campus. Like, stormwater management, solar power potential is considerably important for AU due to locational advantage, making 241 sunlit days. Solar power potentiality has been calculated for building rooftops using LiDAR data generated rooftop area coverage. Initial assessment show that most of the building rooftops can produce significant solar energy over a typical year. With further analysis of exact suitable locations for photovoltaic cell installation, decisions can be made on which roofs can generate the maximum solar energy. Aspects of this study if implemented will benefit AU campus in taking steps forward towards attaining more visibility as a sustainable and environment friendly university.

4.2: References

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