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The Gray & Green Stitch: Blending Green Infrastructure into Urban Transportation Right-Of- Ways

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The Gray & Green Stitch:
Blending Green Infrastructure into Urban Transportation Right-Of- Ways

by

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Report

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Dedication

To Architects, Urban Designers and City Planners,

who are genuinely striving to make the cities beautiful for its people.

Acknowledgements

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I am grateful to my parents for their constant encouragement and reminding me that education and knowledge are valuable gems of life that can never be stolen and will always guide me to choose the wisest paths. Lastly, I would like to thank my partner, Chico, for his continuous help and support.

Abstract

The Gray & Green Stitch: Blending Green Infrastructure into Urban Transportation Right-Of- Ways

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The University of Texas at Austin, 2019

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Rapid growth and climate change are two main challenges that the majority of the cities of the United States currently face. For this reason, it is time for cities to use smart and multidisciplinary techniques to address these challenges. To present an example, this study proposes ideas and strategies on how to manage stormwater runoff to reduce some of the impacts of floods. The consequences of stormwater are often hardly noticed until it is too late. In Texas, the cities have become hotter than before and are predicted to become more intolerable in the future. Hotter temperatures increase the frequency of storms annually, and with an increase in the number of storms comes heavy rainfall. In turn, heavy rainfall and an increase in impervious cover due to population growth can be the worst nightmare for the cities of Texas.

One of the sustainable techniques that few cities in the USA are implementing to overcome the issues of managing stormwater runoff is Green Streets. Green Streets allow the public right of way (ROW) to manage stormwater runoff with comparatively very affordable solutions than other longtime expensive grey infrastructures. As the concept of Green Street is new, not many cities have this program implemented. However, the cities that have implemented them agree that it has not only helped to reduce the impact of floods, but it has also greatly improved the quality of the surrounding neighborhoods.

The objective of this report is to investigate the challenges regarding stormwater management at three levels—Macro (Colorado River Watershed-the city of Austin), Meso (the Shoal Creek Watershed), and Micro (Clay Street), and help the city of Austin implement a Green Street program. This study can act as an information guide, providing steps to be taken to implement green streets for the City of Austin where no such program yet exists. It will provide recommended strategies to the city to tackle some of the climate issues highlighted in the "Atlas 14" Report and reduce the risks of flooding and polluted waters due to the increase in impervious cover.

Keywords

Watershed, Impervious Cover, Green infrastructure, Resilience Practice, Streets Network, Green Infrastructure System, Resilience Practice, Economic Cost, Flood Risk, Water Resource Management, Public Stormwater.

"Cities have the capability of providing something for everybody, only because, and only when, they are created by everybody."

— Jane Jacobs,

The Death and Life of Great American Cities

The Gray & Green Stitch

Blending Green Infrastructure into the Right-Of-Way

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List of Abbreviation

BMP	Best Management Practice
COA	City of Austin
DOT	Department of Transportations
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute
FHWA	Federal Highway Administration
GI	Green Infrastructure
GIS	Geographic Information Systems
GS	Green Street
GSI	Green Stormwater infrastructure
IC	Impervious Cover
IPCC	Intergovernmental Panel on Climate Change
LID	Low Impact Development
NFP	National Floods Program
NFIP	National Flood Insurance Program
NWS	National Weather Service
ROW	Right of Way
SCC	Shoal Creek Conservancy
SCM	Stormwater Control Measures
WPD	Watershed Protection Department
WPDRD	Watershed Protection and Development Review Department

Part One

| The Project Introduction

Chapter 1: Introduction

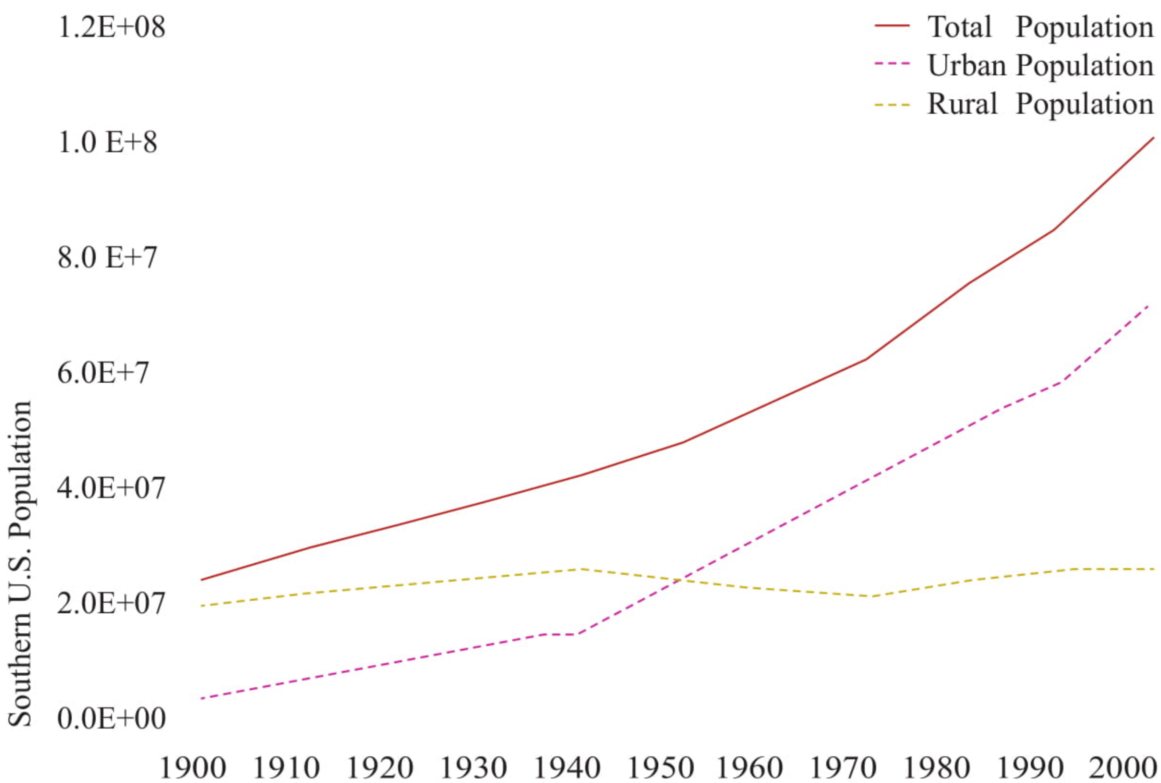


Figure 1Population change for the period 1900–2000 in the southern U.S. (O'Driscoll, Clinton, Jefferson, Manda, & McMillan, 2010)

The process of rapid urbanization and population growth brings many opportunities for existing and upcoming developments across cities in the United States. This process has also come with deficiencies as population increases; there is great pressure in balancing the redevelopment of the downtown and protecting its ecology. At least since the mid-20th century, the City of Austin has been facing issues with rapid urbanization and population growth. (Leffingwell, Member, Chris, & Hatfield, 2018) Urban areas of the city still struggle to cope with population growth and its impacts. One of the major challenging issues is that with an increase in population comes a demand for services. Such demands for services put a heavy strain on infrastructure. Older infrastructure needs to be replaced or rehabilitated, and missing ones constructed and built. But, beyond rapid urbanization, the second major challenging issue of the 21st century is undoubtedly climate change. Rising energy prices and alterations in the natural cycle by mankind, in turn, necessitate the need to completely reconsider the (re)design of cities. Although the Austin City Council passed a groundbreaking climate resolution ten years ago, climate change impacts have manifested as ongoing and repeated severe weather events are already evident in Austin. (City Council, 2017)

To reduce some of the challenges above, I intend to propose the 'The Gray & Green Stitch Project' within the City of Austin for my academic Masters of Science City & Regional Planning Professional Report (CRP PR) + Masters of Science Urban Design (UDP) Project Fall '19. It is a well-known fact that cities are made of two primary man-made elements: The 'Roads' and the 'Buildings.' In this study, the focused elements will be 'Public Roads' to sustainably mitigate some of the burden cities face. The reasons are two-fold:

-Twenty to thirty percent of cities of the United States is made up of streets.

-It is comparatively less complicated to implement and retrofit public streets.

The growth of cities always necessitates a greater demand for the construction of new streets and retrofitting of old ones for easy accessibility. The main idea in this research is to use one of the existing neighborhood roads to incorporate green infrastructure and present data that enables the city to manage stormwater runoff during the floods. The point here is to provide an example for retrofitting old streets and propose design ideas for new development.

1.1 Purpose of the study

Minimizing the problem

a. Reducing the impervious cover

   Covering concrete or asphalt by abortive soil or permeable material helps reduce runoff gathering in large pools that amplify flooding.

b. Lower the impact of flooding

   According to the Atlas 14 study, there are a total of 7200 structures now in Austin that are a substantial flood risk. By managing part of a load of stormwater runoff, this number could reduce. In the end, it is not just these structures within the floodplain that are affected; floods also cause destruction in many ways. The aftermath of the storms is costly and sometimes irreparable. (Wagner, 2012)

Maximizing the opportunity

a. Streets are significant infrastructure design to achieve many community goals. For example, redesigning some neighborhood streets by implementing green infrastructure helps improve roadway drainage and manage stormwater runoff. Streets increase the Walk Score of the community, which benefits people's health while reducing pollution. They also help to make a neighborhood more vibrant and enhances the "sense of place."

b. As streets are one of the most used infrastructures of cities, redeveloping them for the people to balance the ecology has the potential to foster social interaction and connect people across generations, benefit local businesses, and boost the economy of the neighborhood.

c. As green streets help to improve multiple problems like health, traffic safety, drainage, and floods, the government must increase the attention towards achieving walkable communities, especially when there is an elevated concern throughout the US concerning climate change.

d. The blend of the green in the grey infrastructure helps cities to save public funds. It further enables the city to hit multiple bottom lines in one investment, including, for example:

   -Transportation/ traffic calming measures: Improve the street network to facilitate better economic opportunity

   -Climate change: innovative ideas to deal with stormwater issues

   -Equity bottom line: improving neighborhoods that have been facing severe flooding

   -Environmental bottom line: Helping balance the hydraulic cycle and protect aquatic species

1.2. Research Questions

1. With the predicted dramatic change in climate leading to an increase in the storm events, will the surface water increase in the future compare to now?

2. Can public streets help mitigate some of our stormwater problems and provide a reduction in the surface runoff?

3. How should we design the public right of way (ROW) to reduce some of the stress of climate issues addressed in the "Atlas 14" (by the National Weather Service for the State of Texas region) and "IPCC" (by Intergovernmental Panel on Climate Change) report?

1.3 Methods & Limitation

The present study uses multiple methods to find answers to the above research questions. Rigorous web research at the initial stage helped build an understanding of the research topic and frame the literature review. It also helped in narrowing down a city to study, which is successful with various green infrastructures and green street programs. Next, a bike tour was organized to carry out an observational study of green infrastructure and green streets at the City of Portland. To understand the efforts, regulation, policy, and planning at the heart of the Green Street project, meetings with the Portland city officials was set up.

Once the topic was thoroughly researched and narrowed down, question one was answered by comparing the historical data of the City of Austin with the current climate change data given in the Atlas14 (Texas region), & IPCC reports.

Question two was answered through environmental engineering and sustainable site initiative data. ESRI Geographic Information Systems (GIS) and Microsoft Suite software were used to create most of the graphical data and maps for the study. Shapefiles and census data were 1) pulled from the online City of Austin website- “GIS data on open data portal and” 2) collected on request from City of Austin Watershed Protection Department, and Shoal Creek Conservancy. “The City of Austin Rating for the Green Street” was partly supported by research carried out by the student from the University of Tennessee.

Readings from the Environmental Land Use Planning and Management by John Randolph helped to create understanding for the calculation of stormwater runoff. Numbers and formulas for the calculation for the impervious cover and intensity of rain for a 24-hour flood were abstracted from the official website of the City of Austin, U.S. Geological Survey, and the National Oceanic and Atmospheric Administration. Software like Google Earth, AutoCAD, and Adobe Creative Suite helped develop the design for Clay Street.

The Grey- Green Stitch project was primarily to encourage the City of Austin to implement the Green Street program into the public right of way to reduce some of the burdens of upcoming storm events. However, the data are given in this research should not be considered as a base for any real scale implementation. The accuracy of the data and analysis of the design that was developed in this study is limited to the source it was obtained from. High emphasis should be given to the idea that this project is a guideline to all interested public and private groups to make a sustainable future for people living within the city. As the proposed project was created based primarily on limited data, the future study for a pilot project can be conducted with the involvement of experts. A team from an interdisciplinary field can provide in-depth analysis and diverse perspectives to propose a successful implementation of the green street.

Part Two

| Addressing the Current Issues

Chapter 2: Challenges

2.1 Urban Growth

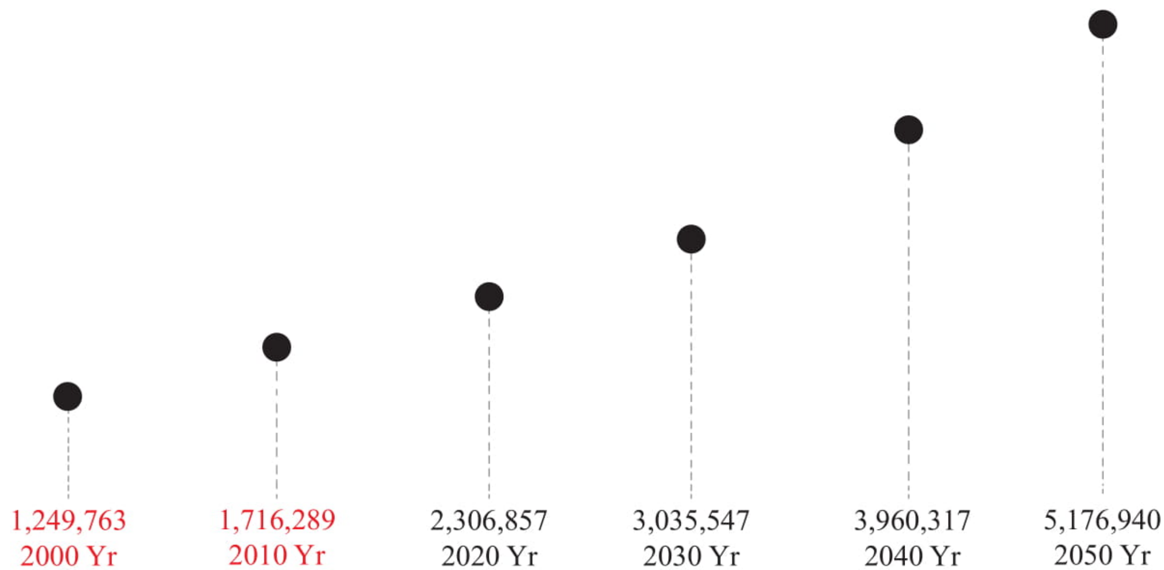


Figure 2Austin-Round Rock, TX Metro Area Population by Year (Business analyst ArcGIS)

We have entered the "first urban century." *(Steiner, 2017)* The word urbanization is not new; it has roots in ancient times and has been taking place since time immemorial. After WWII, the speed of urbanization rose in the United States and some of its cities at a record pace. The population of the United States in the last 30 years has increased from 58.6 million people to 311.6 million. By this figure, the US is currently the third most populous country in the world and is expected to increase its population to 392 million by the year 2050. In the 1950s, 60% of the population lived in urban areas. Today, however, the percentage has increased to 80%. (Wagner, 2012)

The City of Austin's MSA data shows that 1,249,763 people were living in 2000. This number rose to 2,115,827 people in 2017, and by 2050, it is predicted that the city will be home to 5,176,940 people. Explosive growth in the cities, especially in the downtown and commercial areas, will have a dramatic effect on the increased demand for transportation infrastructure development and the enormous pressure of retrofitting old ones. Eventually, this massive increase in infrastructure development is expected to potentially disturb the natural landscape of the city and in the process, contribute in significant ways to magnifying the impact of global warming. (McCaw-Binns & Hussein, 2012) The increase in the construction of new buildings and street networks dramatically affects the natural water system. When the development takes over, the process of using natural land to absorb stormwater run, storing it as groundwater, and eventually discharging it into waterways is cut short as significant stormwater runoff directly gushes into waterways.

2.2 Increase in Impervious Cover

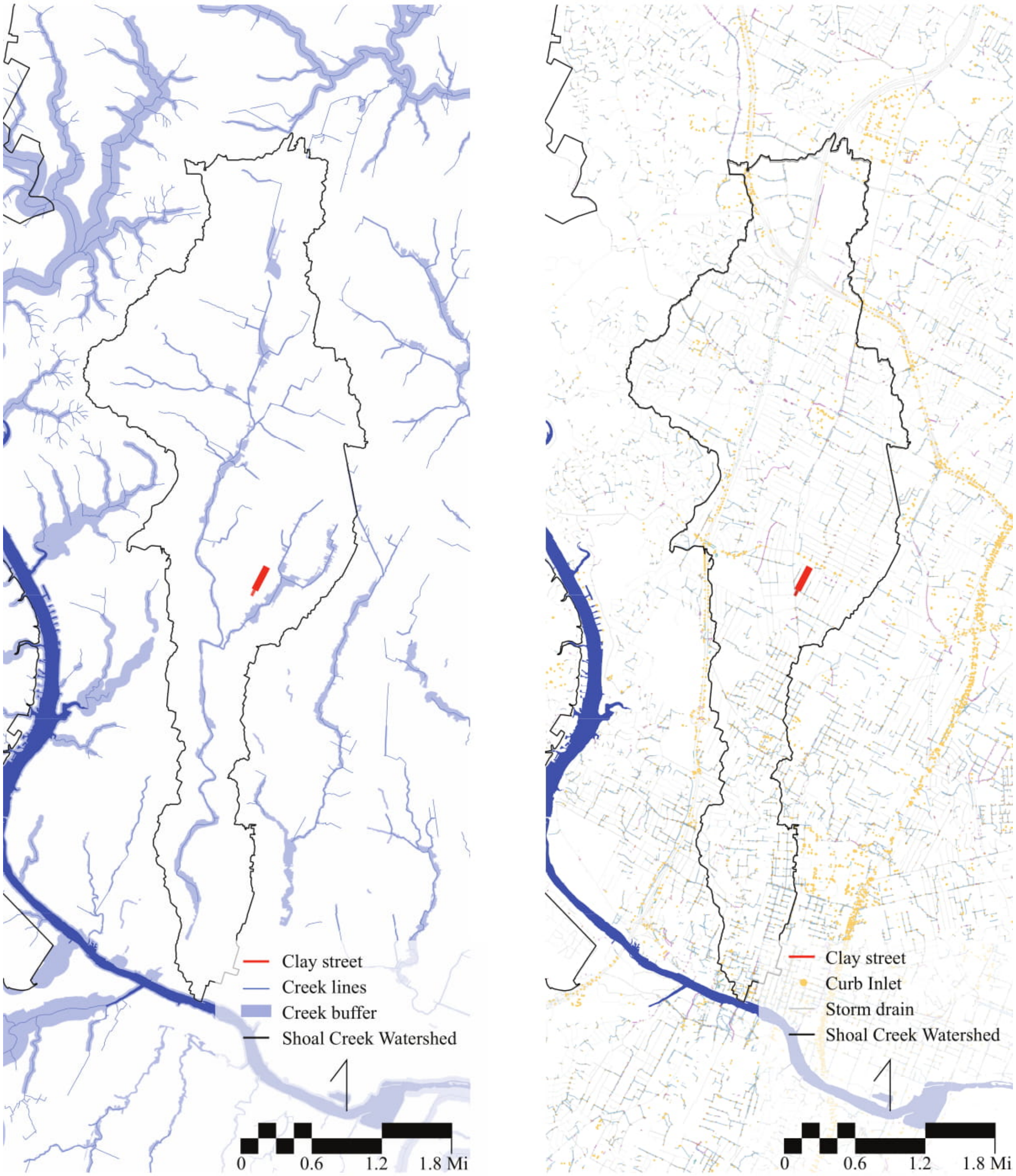


Figure 3 Shoal Creek Watershed- Natural stormwater system Vs. Man-made stormwater system.

Impervious covers have a drastic impact on both the quality and quantity of stormwater runoff as they do not allow water to penetrate. Impervious covers lead to an increase in exfiltration, decrease water quality, and streamflow. An increase in the development of the city results in an increase in the amount of impervious cover. The natural landscapes which were once intact and absorbed rainfall into the soil and vegetation are disturbed and no longer in place to intercept the runoff. Where the previous cover helps to slow down, to spread out, and soak the stormwater runoff, the impervious cover act as a vessel to collect pollutants like pesticides, oil, litter, and fertilizers. Pollutants in the runoff degrade the natural water bodies. Hydrologically, the stormwater runoff, which does not get absorbed due to impervious cover, eventually accelerates the peak flow, resulting in the flash flood and washing pollutants into streams, rivers, and lakes. (Implications & Cover, n.d.)

2.3 Climate Change and Atlas 14

Since the pre-industrial era, the earth's climate system has dramatically changed on both global and regional scales. According to the National Climate Assessment, Texas is going to be hotter. It is predicted that if the state does not do anything to reduce greenhouse gas emissions, by the end of the century, it will "experience an additional 30 to 60 days per year above 100 degrees" (Buchele, 2018). Austin currently experiences an average of 12 days per year above 100 degrees, so by the end of the century, it will have an average of 33 days per year above 100 degrees. There would also be an increase in drought conditions and an additional 1300 deaths per year. Drier future conditions will lead to stronger storms like Hurricane Harvey, increasing flood risk in non-coastal Texas. (Price, 2018)

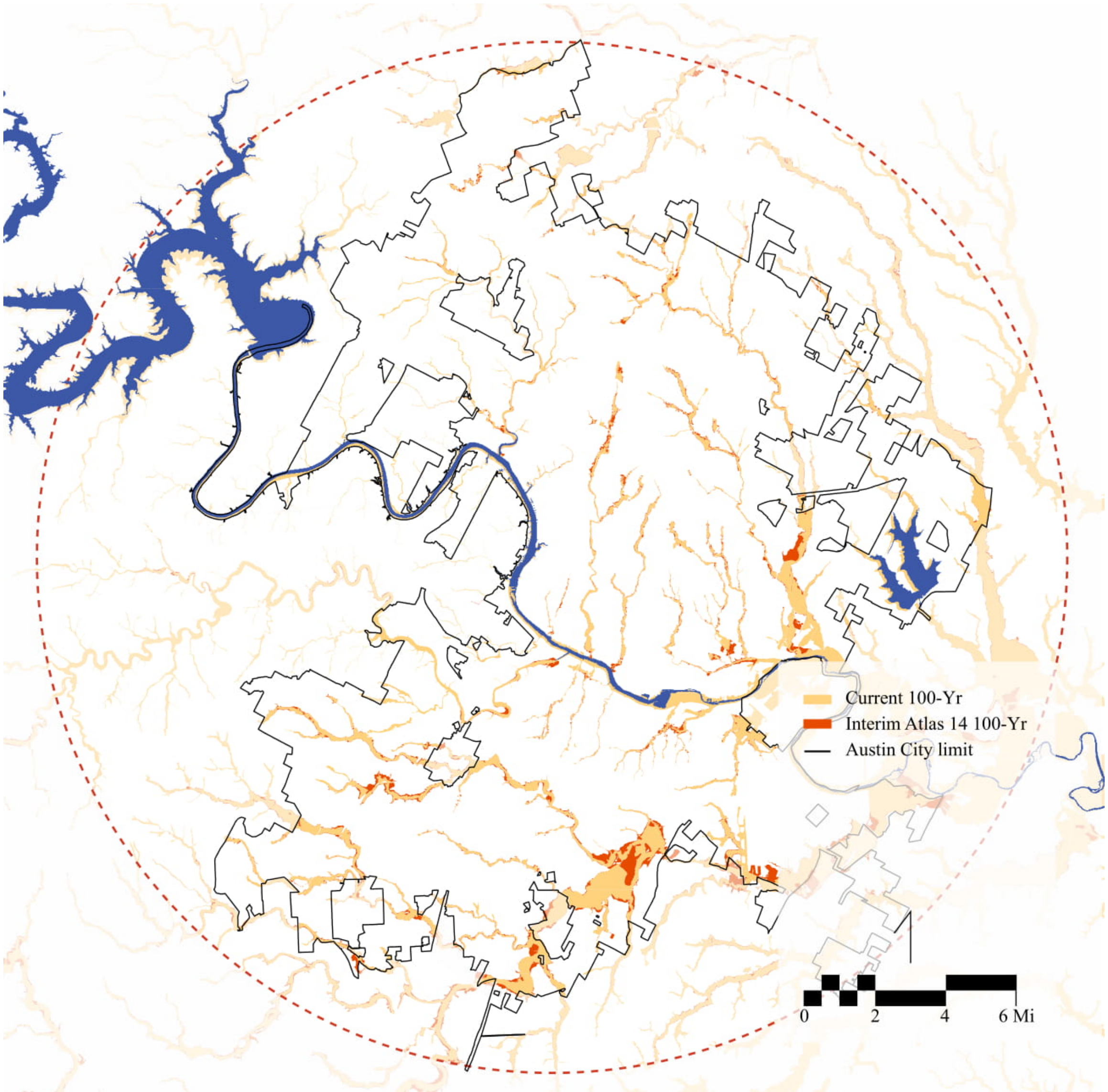


Figure 4 City of Austin- Current 100-year floodplain and Interim Atlas-14 100-year floodplain

In 2018, the National Weather Service came out with flooding (Storm & Work, n.d.) study called "Atlas 14," similar to the one that was released in 1961. "Atlas 14" explains the increase of extreme storms over time. According to this study, the greater the storm, the greater the flood risk. Approximately 3600 more properties will be in the high-risk floodplain. The rapidly urbanizing regions of Texas will be exacerbated due to these climate change impacts, and there will be increasing pressure for cities like Austin and Houston to design infrastructure to minimize the threat of flooding. (Neely & Holtgrieve, 2019)

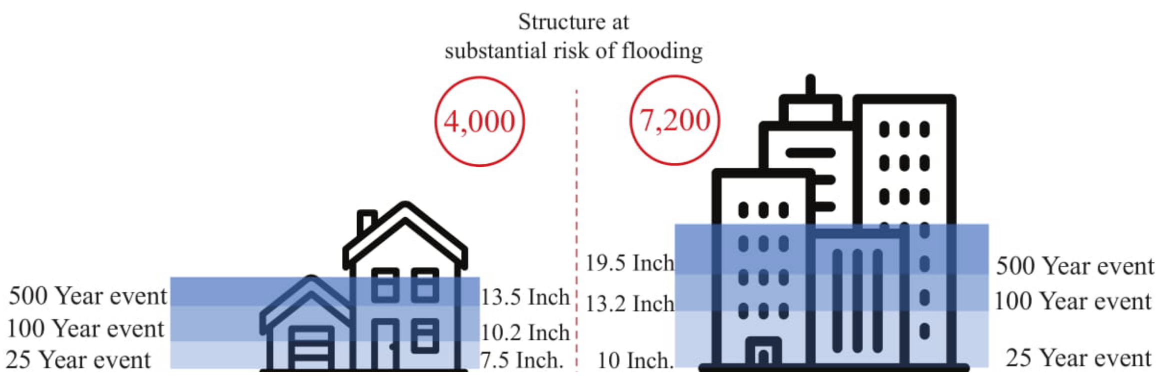


Figure 5 Structures at substantial flood risk in Austin before and after Atlas-14 Study

2.4 Current stormwater management system's ability in question?

The city of Austin's floodplain regulations and stormwater management are based on a 100- year floodplain. For years, much of the city's regulation and policies have been based on the one percent chance of flooding that could bring 10-inch rain in 24 hours. As mentioned above, the latest study completed by the National Weather Service called

“Atlas 14” states that central Texas will have to deal with more massive storms in the future than what had been predicted before. Atlas 14’s data invite us to consider whether our current stormwater system and regulation are ready to deal with upcoming challenges and predicted floods. (Smith, 2016)

2.5 Deteriorating condition of flora and fauna of water channels

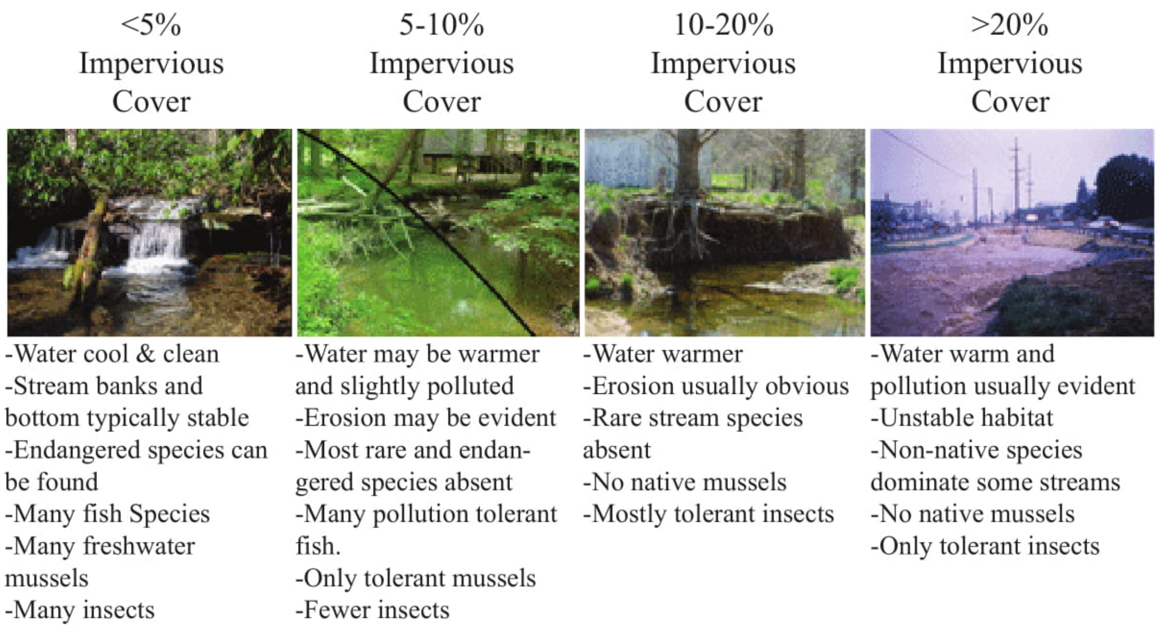


Figure 6 How Impervious Surface Impacts Stream Health. (Department of Natural Resource, n.d.)

The predicted increase in the flood risk will also have a significant impact on the aquatic ecosystem and cause a significant disturbance in its natural cycle. During extreme flood conditions, loss of life and destruction of infrastructure are elaborately reported in the media and well documented. However, other effects of freshwater aquatic ecosystem services on our life are left unnoticed. What affects and disturbs this ecosystem the most are the different types of pollution collected due to impervious covers. Currently, most urban pollution sources of the city are the streets and other travel surfaces. However, on the other hand, these street and travel surfaces could be seen as opportunities to help mitigate the flood risk by incorporating green infrastructure into their design. (Talbot et al., 2018)

POLLUTANT	SOURCE	EFFECTS
Trash		Physical damage to aquatic animals and fish, release of poisonous substances
Sediment/solids	Construction, unpaved Areas	Increased turbidity, increased transport of soil bound pollutants, negative effects on aquatic organisms reproduction & function
Metals • Copper • Zinc • Lead • Arsenic	 • Vehicle brake pads • Vehicle tires, motor oil • Vehicle emissions and engines • Vehicle emissions, brake linings, automotive fluids	Toxic to aquatic organisms and can accumulate in sediments and fish tissues
Organics associated with petroleum (e.g., PAHs)	Vehicle emissions, automotive fluids, gas stations	Toxic to aquatic organisms
Nutrients	Vehicle emissions, atmospheric deposition	Promotes sophistication and depleted dissolved oxygen concentrations

Figure 7 Pollutants Commonly Found in Stormwater Runoff. (Kloss & Lukes, 2008)

Figure 8 Processes linking small and extreme floods to changes in aquatic ecosystem services. (Talbot et al., 2018)

2.6 Political & public department challenges

Most current stormwater management practices are not sustainable and are focused only on controlling the quality and quality of runoff. Public departments and private agencies mostly prioritize flood control measures, but effects on aquatic life, the balance of water cycle, aesthetic, environment quality, and other such effects remain unattended to or passed from one department to another without much attention. When cities work on stormwater projects, they have the opportunities to improve a lot more than the given focused task. For example, billions of dollars are invested in street construction projects. So many aspects other than just traffic-calming measures can be addressed and improved alongside. It is well accepted that hitting all the bottom lines together by a single department of a city is nearly an impossible task, but cities can have a multi-disciplinary technical expert team that takes an integrated approach to hit all the bottom lines. That integrated approach will involve a team that addresses traffic claiming, climate change, environment measures all at one time. Such an approach would also help save a portion of public funds. Today, only a few cities practice sustainable stormwater management measures and create their manuals. Given enough multi-disciplinary technical expert teams practicing sustainable stormwater management master plans, we can soon have nation-wide design standards manual to reduce the impact of climate change.

Part Three |

The Need to Reduce Impervious Cover

Chapter 3: Hydrology

3.1 Why is the water cycle important?

To fully understand the root cause of the flooding issue, it is helpful to take a step back and understand the basic cycle of water. The water cycle, also known as the hydrological cycle, is an essential process for life on Earth. In this cycle, the fundamental ingredient is water, and this ingredient continuously rotates between land, water bodies, and the atmosphere in different forms like solid (snow), liquid (rain), and gas (moisture). When we see the earth from far, we see it reveal an endless amount of water available for use. In reality, however, there is only a tiny portion of it accessible for us to use. We need to ensure that this tiny portion of freshwater is stored in the right place and used meaningfully. The water cycle makes water accessibility for all living organisms and also regulates weather patterns. If the natural water cycle of the planet is disturbed, then there will be a shortage of clean water. During the precipitation, when enough water is condensed that the droplets become heavy enough to fall to the ground, it gets distributed in various forms. Some of it gets absorbed by the heat that is present in the air, some penetrate inside the ground, and the rest become surface water. This surface waters flow throughs creeks and river channels and eventually gather into larger water bodies. When impervious covers replace the natural soil that penetrates water through it, it alters the natural water cycle. As a result, there is an increase in the volume of surface water, which also makes the quality of the water-poor. These hydrological changes have a significant impact on the freshwater, and which eventually affects the lives of all living organisms on the earth**.** (Guamán & Yumisaca, 2015)

3.2 Affects of impervious cover on the water cycle

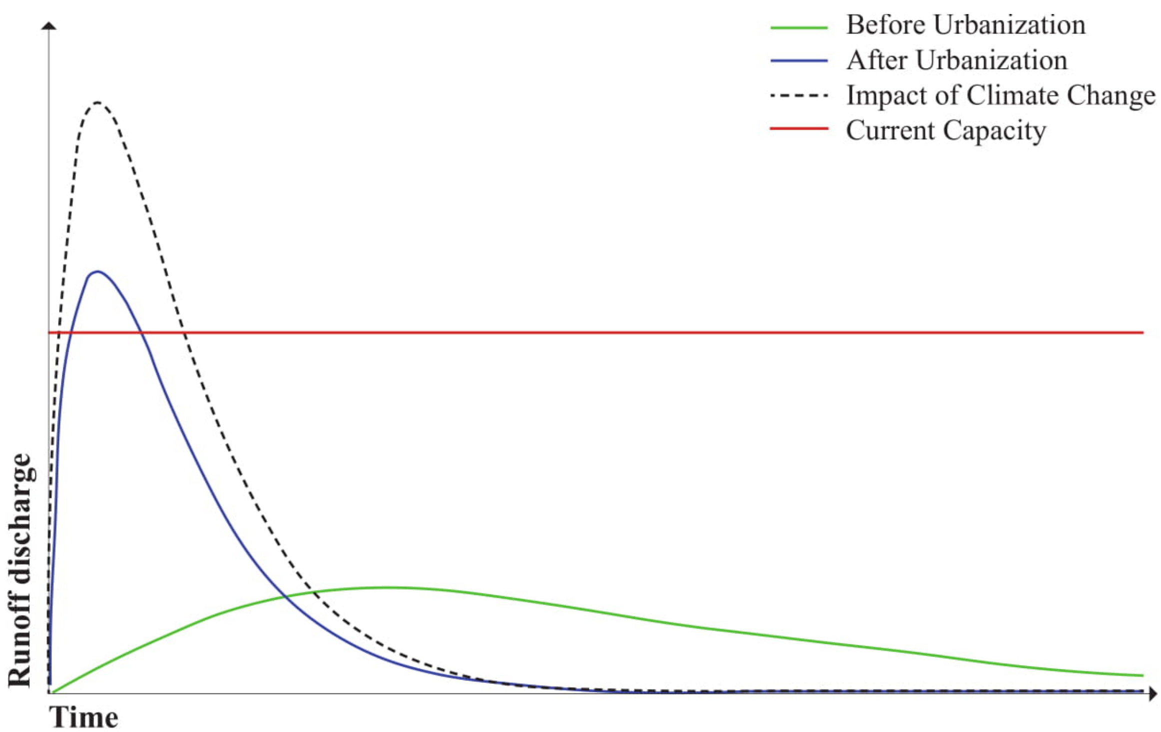


Figure 9 Effects of urbanization and expected outcomes of climate change on the runoff hydrographs. (Jaramillo, 2018)

Any surface that does not allow water to pass or penetrate through it is referred to as an impervious cover. Examples of such impervious surfaces are rooftops of buildings, streets, parking lots, etc. An increase in urbanization increases the disruption of the process of the water cycle. Once the runoff hits the ground, it pours the urban pollution and contamination into our rivers and creeks, which results in the degradation of freshwater and the ecosystem. Also, impervious cover leads to flooding. As there is less natural land to absorb the water and filter the pollution, when stormwater hits the impervious, instead of water getting absorbed, it runs quickly, getting collected in a larger volume and more intensely running towards downstream. Below is a figure showing how the natural stormwater behaves on the natural surface and developed lands.

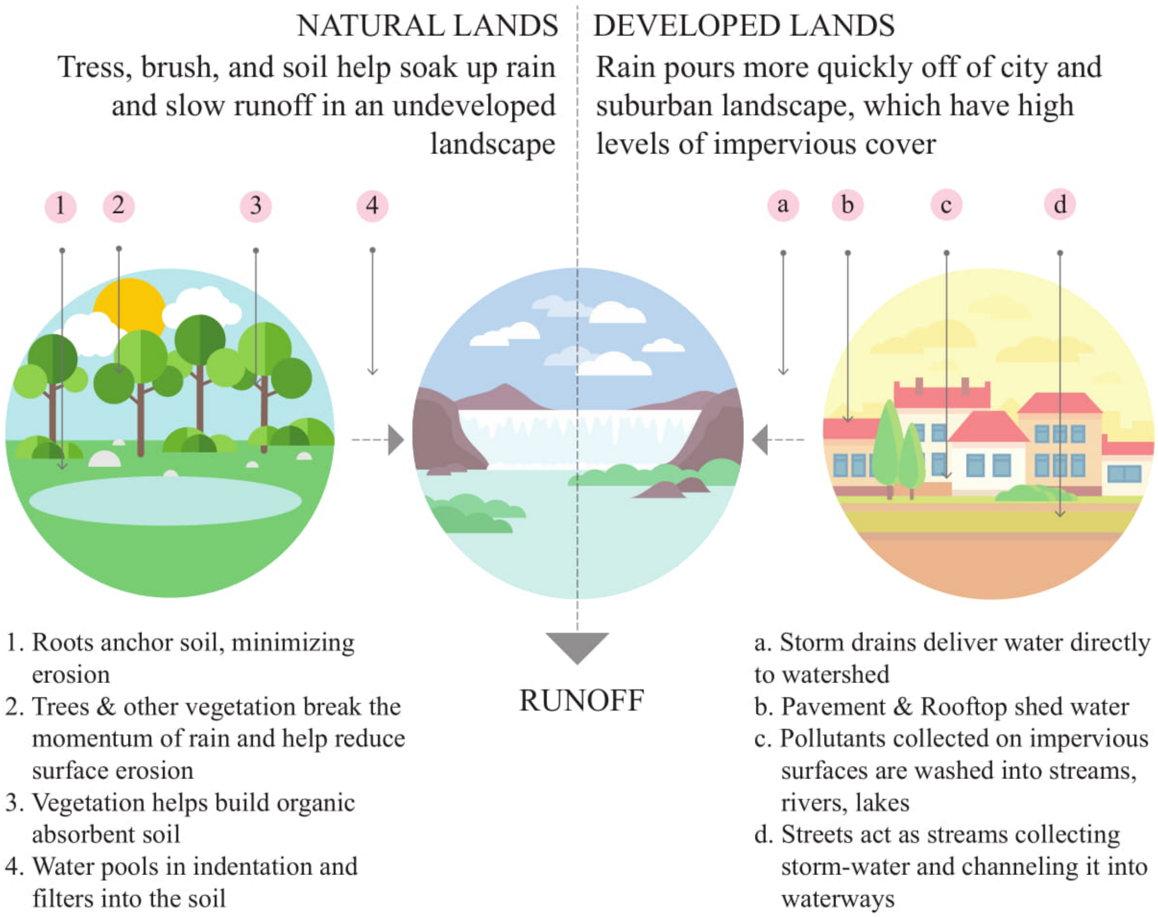


Figure 10 Impervious cover and urban drainage systems increase runoff to creeks and rivers. (Ruby, n.d.)

On the right side of the figure, we can see how natural land helps to balance the natural water cycle by accommodating significant peak stormwater runoff to creeks and rivers. Smaller volumes and slower velocity of water help to reduce the impact of flooding. It further helps to slow down the process of erosion and stops clogging of stream channels. On the left side of the image, we can see how urbanization can reduce the natural land leading to an increase of impervious cover and alteration of the water cycle. Due to this, there is a dramatic increase in the volume of stormwater runoff to creeks and rivers.

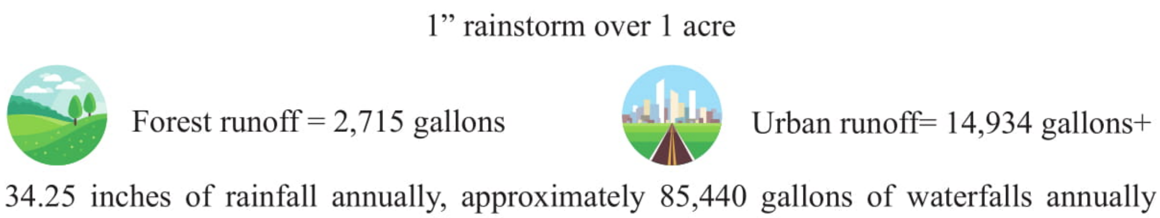


Figure 11 The impervious cover calculation for the City of Austin (Archer & Tharp, n.d.)

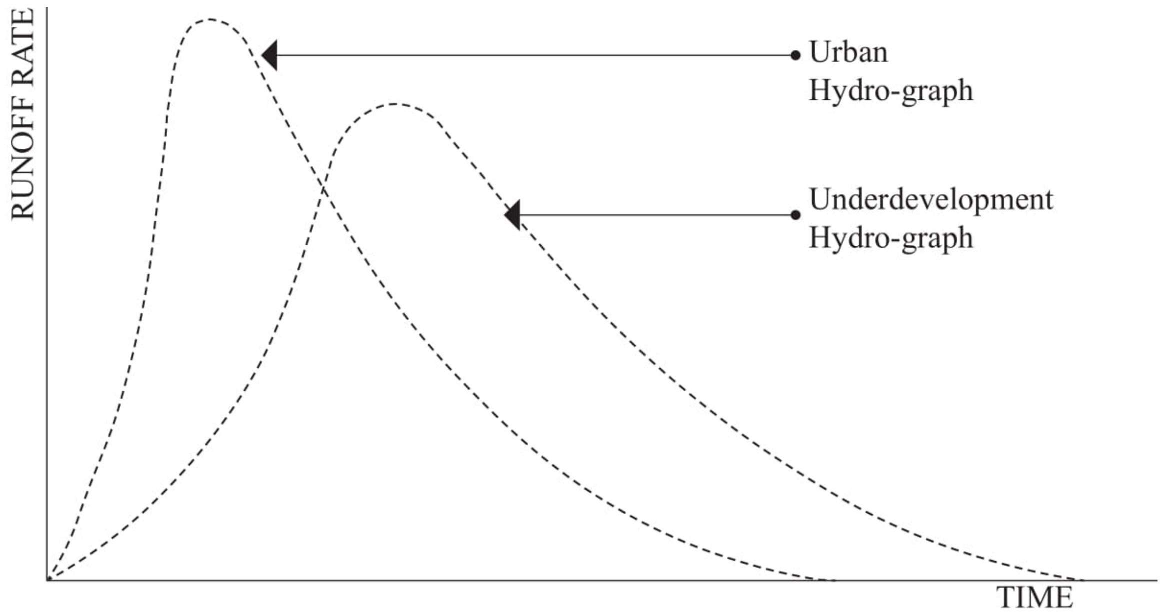


Figure 12 City of Austin- Hydrograph of urban development vs. rural development. (City of Austin, 2016)

The above graph by the watershed management of the City of Austin illustrates the effects of urbanization on the flood. Both the lines “urban hydrograph” and “undeveloped hydrograph” show how stormwater peak discharges in an urban watershed. It is clear that impervious cover in an urban watershed of a city has a larger volume and faster rate of discharge than the undeveloped watershed. Larger volume and faster rate of discharge often result in flooding and severe damage to the water ecosystem.

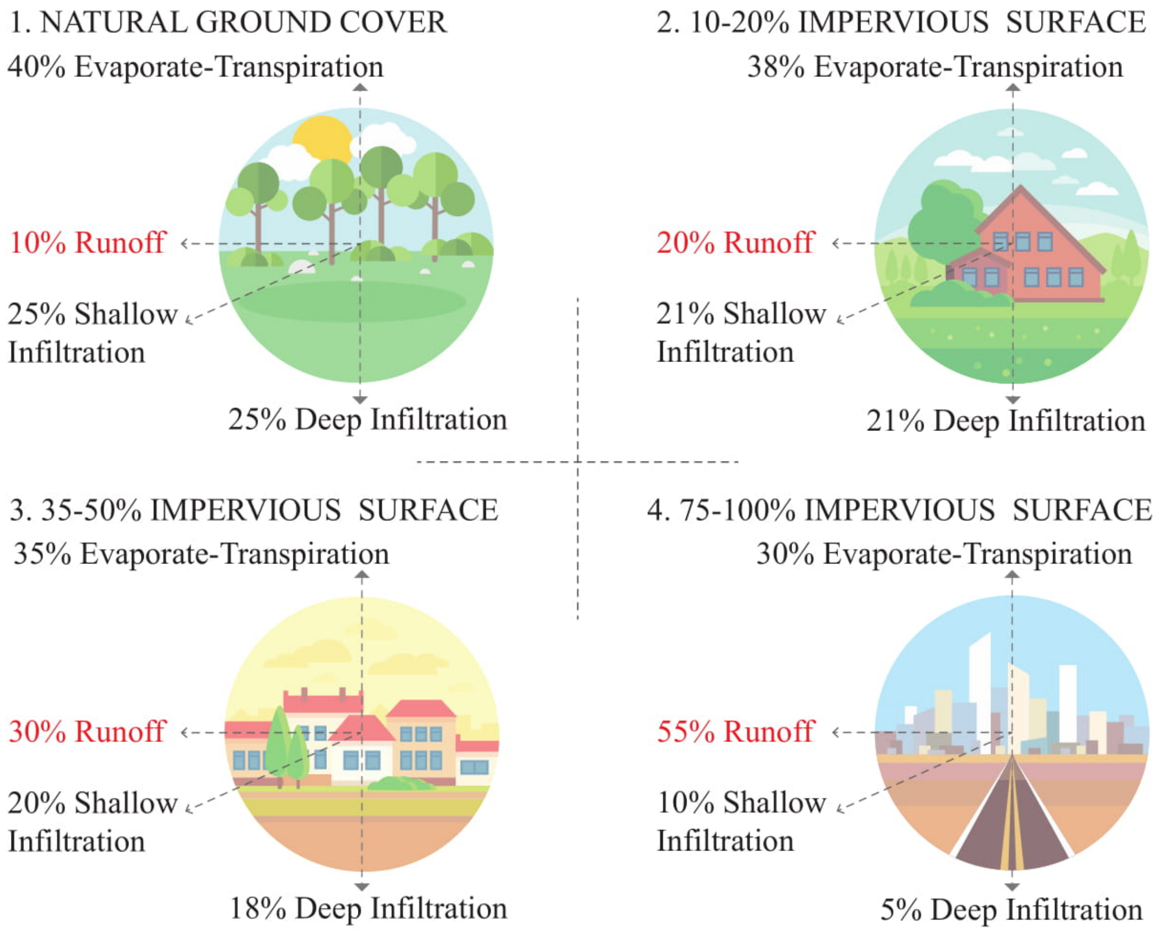


Figure 13Relationship between the impervious cover and surface runoff. ((EPA), n.d.)

1. Scene one illustrates how rain/snow behaves with natural ground cover: When the rain/snow hits a natural ground cover, a large volume of water infiltrates into the aquifer, and overall only very little quality is left as runoff.
2. Scene two illustrates how rain/snow behaves with 80-90 percent natural ground cover: When the rain/snow hits a surface that is 80-90 percent natural

ground and a portion of the surface is the impervious cover, then there will be an increase in the amount of runoff to 20 percent.

3. Scene three illustrates how rain/snow behaves with 50-65 percent natural ground cover: When the rain/snow hits a surface, which is half-natural ground and another half impervious cover, then that area will experience some level of flooding as the runoff will increase to 30 percent.
4. Scene four illustrates how rain/snow behaves with 0-25 percent natural ground cover: When the rain/snow hits a surface, which is entirely opposite to scenario one, then there is a large volume and faster rate of discharge, which leads to flooding and property damages.

3.3 What are the impacts of impervious cover?

Figure 14 Growth of the City of Austin with time. The increase in impervious cover and decrease in natural land.

Impervious cover, flooding, and the change in water quality all are interconnected. When the agricultural land or a forest is taken over by impervious cover, many changes come along with it. Our watershed's health and wellbeing are heavily impacted. The impacts of impervious cover can be further categorized into four subcategories for our understanding: hydrological, biological, chemical, and physical.

a. Hydrological impact of impervious cover

Once the rainwater reaches a watershed with impervious cover, it increases its runoff volume, peak flow rates, and bank full flows. Furthermore, it also decreases the base flow of the stream. When there is an increase in urban development and impervious cover in the urban watershed, the runoff increases. One acre of urban developed land has a higher chance of severe flooding than one acre of undeveloped land. Urban developed land creates more surfaces that do not allow the water to penetrate through them due to which infiltration declines dramatically. This also results in the reduction of groundwater as there is not enough water soaked into the natural soil. An increase in the volume of runoff without recharging the ground directly impacts our water channels.

b. Biological impact of the impervious cover

Even when there is a small amount of urbanization, there is a negative impact on the ecology of water, aquatic life. This small negative impact turns into an extremely degraded aquatic diversity when a more massive amount of urbanization takes place. As mentioned before, the negative change in water quality stresses the aquatic community and slowly creates an environment that declines in biological diversity and gives birth to pollution tolerant species. A high percentage increase in impervious cover affects the riparian area the most as it is habitat to many aquatic insects, fish, amphibians, and wetland plants. With the increase in pollution, there is a gradual replacement of these species to other species, which adapts to the pollution and flooding environment easily.

c. The physical impact of impervious cover

As mentioned in the above paragraph, urbanization in a watershed changes affects and reduces the water ecology. This will also change and disturb the natural water channels. In an undeveloped watershed, before the runoff reaches the streams and other water channels, its speed and volume of the runoff are reduced by the vegetation that grows in and around the riparian area. With an increase in impervious cover, there is less vegetation, and the organic matter eventually accelerates the speed and volume of runoff reaching the stream immediately after a storm. Also, it takes thousands of years for natural water channels to create their shape and adjust themselves with the surrounding physical context. Urbanization develops quickly and cuts short the natural meandering process, which leads to extensive erosion, channel enlargement, and loss of riparian cover.

d. Water quality/Chemical impact of impervious cover

Creek, streams, and their sub-branches are the first aquatic systems where the stormwater runoff drains into. The quality of this stormwater runoff is poor as it also collects the pollutants sitting on the impervious cover. Building the layer of pollution on the streets, parking lots, rooftops, and other impervious covers takes time, but when it rains or snows, it gushes all the dirt effectively to these water channels. Polluted water collected from the creeks and small water streams pours into downstream, creating water quality problems for larger water bodies of the watershed like lakes.

Thus, we can notice that as impervious surfaces increase, there is a direct impact on our water ecology, physically, hydrologically, biologically, and chemically. (Flinker, 2010)

Chapter 4: Current practices that deal with urban drainage issues

4.1 Introduction

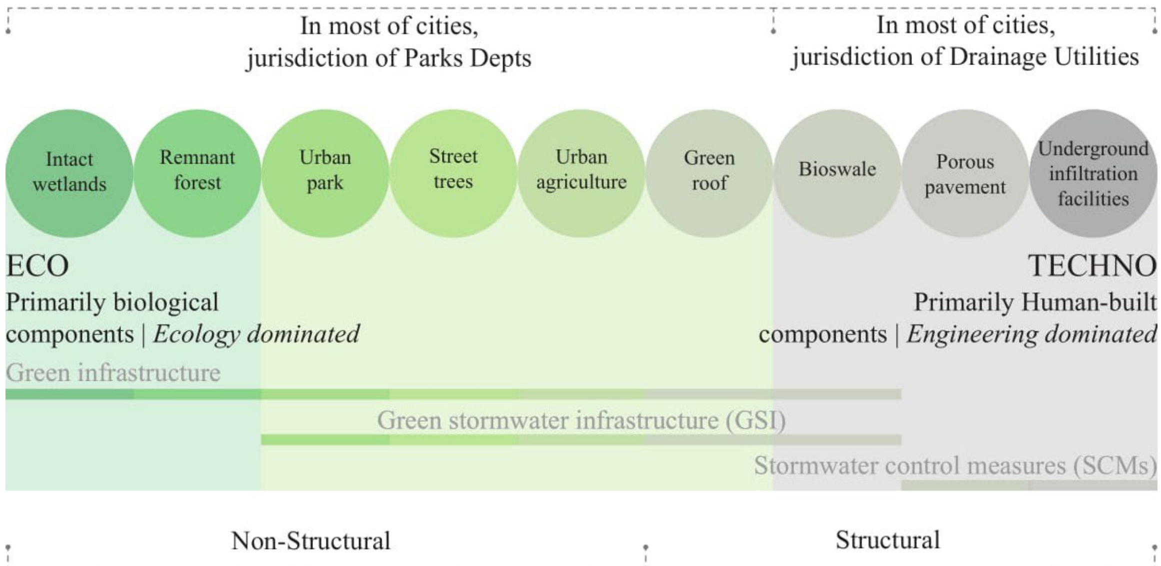


Figure 15 Eco-techno spectrum. Diagram adapted from (McPhillips & Matsler, 2018)

The Best Management Practice came into the picture due to the Clean Water Act. The goals of the BMP mainly revolve around controlling the floods, removal of pollutants, and helping to reduce the pollutant source. (Dias, Wilson, & Henn, 2017) They are categorized into two parts--Structural and Non-Structural BMPs. Some examples of structural BMPs are detention systems, retention systems, constructed wetland systems, filtration systems, and vegetated systems. Their role is to help control the quality and quantity of stormwater runoff. Non-structural BMPs, on the other hand, are natural ways to reduce the volume of runoff and pollutants level during the storm. They utilize existing natural systems like wetlands to balance our natural water cycle.

In most cases, the systems are implemented as close to the source as possible. Some of the non-structural BMPS include cleaning the streets, storm drains, and educating people and training employees. (Matsler, 2017)

4.2 Evolution of treatment of stormwater runoff

Stormwater management practices are not new concepts. Historically, people discover and design runoff stormwater management techniques that helped them to live, protect properties, farm, and irrigate. They found ways to store rainwater during drought as well as divert the runoff flow during extreme rainfall.

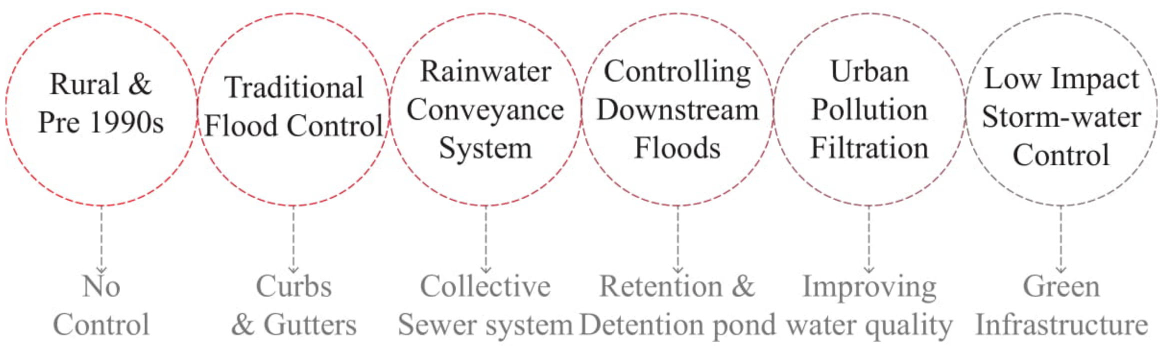


Figure 16Change in treatment of stormwater runoff with time

a. Rural and Pre 1900s

We can say that Historically, cities did not seriously address stormwater management. Before curb and gutter were thought off, roads were used as passive techniques to tackle surface water. Roads blended into side roads, and these side roads fused into the surrounding natural land. Back then, roads acted as a channel for the surface water to meander around the city. This often led to localized flooding, but some currently a lot of low impact stormwater controls reflects to the return to the older way of dealing with water.

b. Flood control by drainage pipes

Traditional stormwater practice exclusively focused on flood control. The excess runoff was diverted from the urban development to protect it from flood damages by incorporating catch curbs and gutters, basins, and drainage pipes. Attention was hardly paid to what happened to the downstream area during the peak flow. Designs did not address balancing the natural water cycle, securing aquatic ecology, or improving water quality. Overall, this method protected human lives and their properties. (Ambrose, n.d.)

c. Rainwater conveyance system.

Slowly when development increased and more land use was converted from agriculture to buildings, there was a need for a highly efficient rainwater conveyance system. When cities started to plan this system, each building was forced to be designed in a way that helped the runoff to meet at a common point or source that would drain the runoff of rapid fashion. The primary goal of this system was to develop a stormwater runoff sewer system. The goal was to collect runoff from rooftops, parking lots, streets, and other impervious covers and direct it through a drainage system (which could be combined or separate system). The problem with this system was that it forces the runoff directly from upstream toward the downstream while getting absorbed into natural soil. With an increase in development, this stormwater management strategy failed and brought more problems instead of solutions as downstream water bodies are profoundly affected by it. (Holman-Dodds, 2007)

d. Detention and retention ponds

By the 1960s, it was clear that when a larger volume of water rushed downstream directly, it led to flooding and impacted the ecology of downstream. There was an urgent need to implement new techniques that would spread and slow the flow of runoff before reaching the end. Thus, the next system that evolved from the past stormwater management practices was the installation of stormwater detention and retention. It helped to balance the upstream by storing runoff temporarily and as well as downstream from flooding. This also helped to reduce soil erosion and lower the impact of flooding on the environment. However, there was a problem with this system as well. Cities thought that this would solve the flooding problems, but it did not as nobody was keeping the tract of the ponds within the watershed. So, this fixed the localized flooding problem but would make it worse later as the discharge rates were not coordinated between the ponds.

e. Control floods as well as filter urban pollution

In the 1980s, people realized that flooding was not the only issue. The stormwater engineers started realizing that runoff also collects urban pollutants along its path and dumped into larger water bodies downstream. With water quantity, water quality also became a question. In the mid- and late 20th centuries, city planners and stormwater management agencies helped to pass the following legislation/policies/regulation nationwide to manage stormwater and assure the planning of quality and quantity of stormwater. (NRC, 2008)

f. Low impact stormwater control

In the late 1990s and early 2000s, a few cities like Portland and Seattle had implemented stormwater green infrastructure. It helped these cities to mitigate stormwater runoff by using innovative filtration methods. The basic concepts of these filtration systems were derived from and inspired by the natural system. Green-blue infrastructure replaced the grey infrastructure in these cases. Experts observed across the globe that this method removed pollutants, slowed the runoff, recharged the groundwater, reduced heating, and helped to develop beautiful public amenities. (Holman-Dodds, 2007)

We may conclude that in the past, stormwater systems were often located far away from the development, with a focus only on flood control. Over the years, the focus has changed from flood control to solving both the quantity and quality issues of runoff. Moreover, today, one of the essential components of stormwater management is sustainability. Even after knowing this, the majority of our stormwater management systems are not sustainable. Diverting the flow of runoff and disturbing other cycles of watershed do not qualify as sustainable. With these methods, we increase the protection of our properties, but there are severe damages to our natural ecosystems and balance of the water cycle. Beyond managing the quality and volume of runoff, we urgently need to manage the effects of runoff on the water cycle and aquatic life and protect the ecology of sensitive areas like the riparian areas. An integrated design national standard guide that controls floods protects our lives and properties, and the ecosystem needs to propose. (Echols & Pennypacker, 2015)

Chapter 5: The Role of Green Street in Climate Resilience and Urban Drainage

This research focuses on the Low Impact Development (LID) and Green Infrastructure (GI) incorporated with the street network. Thirty percent of our cities are built with streets, and the vast majority of the street networks are owned by the municipal right of way. Suppose some of the portions of the impervious cover of that 30 percent are turned into green sustainable infrastructure. When implemented in the Right of Ways (ROWs), GI has been proven easy to maintain and manage hence proved to be a smart and practical decision for cities. Another reason is that street networks are artificial drainage systems that are directly connected to natural sewer systems. New York City, Philadelphia, Portland, Seattle, Los Angeles, Washington DC, and Milwaukee are amongst some of the cities that have already adopted Green Street programs.

5.1 What are Green Streets?

The primary role of green streets is to collect stormwater runoff of the surrounding impervious cover through rain gardens and vegetated curb extensions. They also reduce the flow runoff, filter and remove urban pollution, and help to reduce soil erosion. In an urban watershed, they help to reduce the impact of impervious cover during the storm and help regain the balance of the water cycle, which has been disturbed due to development. Technically, there are many definitions of what exactly “Green Street” means. Different public organizations and watershed groups have their own definition, which more or less revolves around the idea of “sustainable stormwater treatment practice that is mainly implemented in the right of way and includes the utilization of plants for this purpose.” (Choi, 2016)

The table below has a different “Green Street” definition. Cities that have adopted or plan to adopt green streets have a slightly different definition of green streets from one another. These definitions focus on the purpose of improvement and function. For some cities, green streets act as open spaces, while for others, it is about stormwater treatment practice that reduces the flow of runoff and helps to recharge the groundwater.

1. WATER ENVIRONMENT RESEARCH FOUNDATION

Source: http://www.werf.org/liveablecommunities/toolbox/gst_design.htm

Definition:

"Green streets are an example of how individual storm-water BMPs are used as elements of a broader program aimed at mitigating a significant source of stormwater pollution."

Goals/ Purpose/ Approaches

Mimic local hydrology prior to the development
Provide multiple benefits including
-Stormwater management and volume reductions
-Providing a key link in the green infrastructure network
-Enhancing aesthetics
-Improving local air quality by intercepting airborne particulates and providing shade
-Enhancing economic development
-Improving the pedestrian experience

2. SEATTLE

Source: http://www.seattle.gov/transportation/rowmanual/manual/6_2.asp

Definition:

"Green Street is a street right-of-way that, through a variety of design and operational treatments, gives priority to pedestrian circulation and open space over other transportation uses. The treatments may include sidewalk widening, landscaping, traffic calming, and other pedestrian-oriented features"

Goals/ Purpose/ Approaches

-Enhance pedestrian circulation and create open space opportunities in the medium to high-density residential areas lacking adequate public open space.
-Create a vibrant pedestrian environment in the street right-of-way that attracts pedestrians.
-Strengthen connections between residential enclaves and other Downtown amenities by improving the streets-cape for pedestrians, bicycles and transit patrons.
-Support economic activity in Downtown neighborhoods by creating an attractive and welcoming "front door" for pedestrians.
-Maximize opportunities for trees and other landscaping to create a high-quality open space.

3. PORTLAND

Source: https://www.portlandoregon.gov/bes/45386

Definition:

"A street that uses vegetated facilities to manage stormwater runoff at its source is referred to as a Green Street. Green Street is a sustainable

Goals/ Purpose/ Approaches

-Reduce polluted stormwater entering Portland's rivers and streams;
-Improve pedestrian and bicycle safety;
-Divert stormwater from the sewer system and reduce basement flooding, sewer backups and combined sewer

Figure 17 Definition of Green Street

stormwater strategy that meets regulatory compliance and resource protection goals by using a natural systems approach to manage stormwater, reduce flows, improve water quality and enhance watershed health."

Overflows (CSOs) to the Willamette River;
Belmont and SE 42nd green street photo
-Reduce impervious surface so stormwater can infiltrate to recharge groundwater and surface water;
-Increase urban green space;
-Improve air quality and reduce air temperatures;
-Reduce demand on the city's sewer collection system and the cost of constructing expensive pipe systems;
-Address requirements of federal and state regulations to protect public health and restore and protect watershed health; and
-Increase opportunities for industry professionals.
Source: https://www.portlandoregon.gov/bes/45386

4. U.S. ENVIRONMENTAL PROTECTION AGENCY

Source:*http://water.epa.gov/infrastructure/greeninfrastruCture/upload/gi_munichand book_green_streets.pdf*

Definition:

"Green streets and alleys are created by integrating green infrastructure eleme-nts into their design to store, infiltrate, and evapotranspi-ration stormwater. Perme-able pavement, bios-wales, planter boxes, and trees are among the elements that can be woven into street or alley design."

Goals/ Purpose/ Approaches

-Enhance neighborhood livability and connectivity
-Increase community and property values
-Enhance pedestrian and bicycle access and safety
-Protect valuable surface and groundwater resources
-Add urban green space and wildlife habitat
Source: https://www.epa.gov/G3/green-streets-and-com-munity-open-space

5. PHILADELPHIA

Source: http://www.phillywatersheds.org/what_were_doing/green_infrastructure/programs/green_streets

Definition:

"Green Street uses green stormwater infrastructure to capture and manage rain or melting snow (runoff) direct-ly from the street. Green Streets allow runoff to soak

Goals/ Purpose/ Approaches

Water filters through the planting soil, improving water quality.
-It provides a physical buffer between pedestrians and the street.
-Creates aesthetic improvements to streetscape.
-It can be sized and placed to fit between existing

Figure 18 Definition of Green Street

into soil, filtering out pollutants like oil, and reduce the amount of stormwater making its way into Philadelphia's combined sewer pipes, which reduces the combined sewer overflows that degrade our waterways."

surface features such as driveways, signs, street furnishings, and street trees.
-It provides an area within the right-of-way for smaller plantings in addition to street trees.
(City of Philadelphia, 2014, p. 24)

6. FHWA/TEXAS TRANSPORTATION INSTITUTE

Source:*http://www.texasmpos.org/tempo/documents/Green%20Streets%20Workshop_Flyer_February%202013.pdf*

Definition:
"Integrate a system of stormwater management within its right of way"

Goals/ Purpose/ Approaches
--Reduce the amount of water that is piped directly to streams and rivers
-Be a visible component of a system of "green infrastructure" that is incorporated into the aesthetics of the community
-Make the best use of the street tree canopy for a stormwater interception as well as temperature mitigation and air quality improvement
-Ensure the street has the least impact on its surroundings, particularly at locations where it crosses a stream or other sensitive area

7. MANAGING WET WEATHER WITH GI: MUNICIPAL HANDBOOK: GREEN ST.

Source: Lukes, Kloss & the Low Impact Development Center, 2008, p. 2

Definition:
"Urban transportation right-of-ways integrated with green techniques are often called "green streets"

Goals/ Purpose/ Approaches
-Source control for the main contributor to stormwater runoff and pollutant load.
-Are beneficial for new road construction and retrofit.
-Provide source control of stormwater
-Limit its transport and pollutant conveyance to the collection system
-Restore predevelopment hydrology to the extent possible, and provide environmentally enhanced roads.
-Encourage soil and vegetation contact and infiltration and retention of stormwater.

Figure 19 Different definitions of Green Street

5.2 Why Green Street?

It is recommended that cities that are predicted to get dramatically affected by future storms due to climate change in the future and are willing to address their stormwater challenges are highly recommended to use sustainable stormwater treatment practices to reduce the flood risk. As the public right of way comes under the city's control, it is easy to implement a green infrastructure on the streets. This will help to solve many water quality issues in the city. Green streets are considered as the best solution when dense cities have a crisis of natural land within them.

Converting regular streets to green streets has been popularized recently in the USA. Portland, Seattle, and Philadelphia are amongst few cities in the USA that adopted green street in early 2000. A typical green street design will have trees lined on the side with bioswales in between or beside them. In some cases, more trees or green infrastructure are added by reducing or narrowing the driving lane. Many cities have adopted green street projects, but these current green streets projects still have room for improvement. More adoption of and experimentation with experiments with different green street designs will help cities to reduce flood risk effectively. (Choi, 2016)

There are many benefits of adding green infrastructure elements in a grey infrastructure project. In the context of green street projects, when impervious pavements are replaced by vegetation and planters, other than all the health and sustainable benefits, they also help to reduce the overall cost of the project. As the majority of urban streets are founded as per the view of either city Department of Transportations (DOT), public works or planning departments, blending the green to the grey infrastructure strategies will help save a portion of public funds. When public entities own projects, they are also easy to access and maintain in the future.

Green streets are easy to implement in a new street construction project as well as projects that include retrofitting the old streets of the city. While billions of dollars are spent every year to maintain and rehabilitate old streets in urban areas and retrofit and redesigns our streets, we have a great opportunity to construct stormwater improvement projects at the same time. A combination of stormwater management and transportation retrofit, and redesign can help cities hit multiple bottling lines at the same time. Examples are examined below:

1. Transportation--cities can create economic opportunities and traffic calming measures.

2. Climate change--Smart and innovative ideas to deal with stormwater challenges like reducing the flood risk and controlling the damage of our lives and properties.

3. Equity--helps to improve neighborhoods that are facing serious flooding issues

4. Environment--managing our water systems and greening streetscapes help to balance the natural water cycle. (Kloss & Lukes, 2008)

5.3 Successful Green Streets Case Study: City of Portland, Oregon

More than eight major cities in the US have regulated green street programs, and I had the privilege to carry out research on one—Portland, Oregon. Portland is one of the leading cities in stormwater management, with one of the most mature and well-planned city-wide GI programs in the country. In 2001, the city's three sustainable infrastructure committees studied GI practices over the world and proposed suitable solutions for local pilot projects. Portland was also amongst the first to use streets right of way to treat stormwater runoff and incorporate pedestrian safety elements in the design at the same time. To deal with the flood control challenges, the city has invested a total of $1.4 billion in building tunnels for combined sewer overflows and along with it, a $9 million for the green infrastructure programs. One of the reasons for investing in the GI program is to reduce some of the cost burdens that grey infrastructure construction places in the city. By investing $9 million in GI programs, the city predicts that it will save $224 million of combined sewer overflow expense. That will also save the burden of maintenance and retrofitting the underground tunnels. The city believes heavy annual precipitation makes it is easy to implement green streets projects and to beautify the streets than to manage the city's combined sewer overflow (Choi, 2016).

Before 2005, a private agency formed an interdisciplinary team called "Green Street Team" to research and identify the challenges and issues related to stormwater challenging in the city. The agency concluded that right of way and streets collect more than 60 percent of the city's stormwater runoff. The agency and city both saw this as an opportunity instead of a problem. They saw the streets and right of way of the city to improve many issues, including (a) claiming the traffic issues to making the city greener, (b) reducing gray infrastructure to balancing the natural water cycle, (c) reducing the flood risk, and many more. From 2005 to 2007, the team presented a list of comprehensive green street policies and agendas. The list also included several standards and regulations by the city of Portland that would act as a barrier to their ideas and proposals. Soon, they came up with a draft policy for the green street program citywide based on their early research of challenges and issues. In March 2007, the city adopted this resolution. After policies were approved and adopted, the team developed a program that would act as a platform for different agencies or city departments to communicate.

As the streets are part of many private and public agencies, to work with them would require all to communicate and plan together in order to distribute cost load and achieve many benefits at one go (Kloss & Lukes, 2008). In 2008, the mayor of Portland, Sam Adams, proposed a five-year grey-to-green infrastructure initiative. The initiative would include a budget of $5 million for various green elements to deal with the stormwater challenges. A part of the initiative was to incorporate 920 green streets in the City of Portland. Today, the city has 1400 individual green street facilities (Wise, 2008). I had the opportunity to do a 13-mile stormwater cycling tour this summer in the city of Portland.

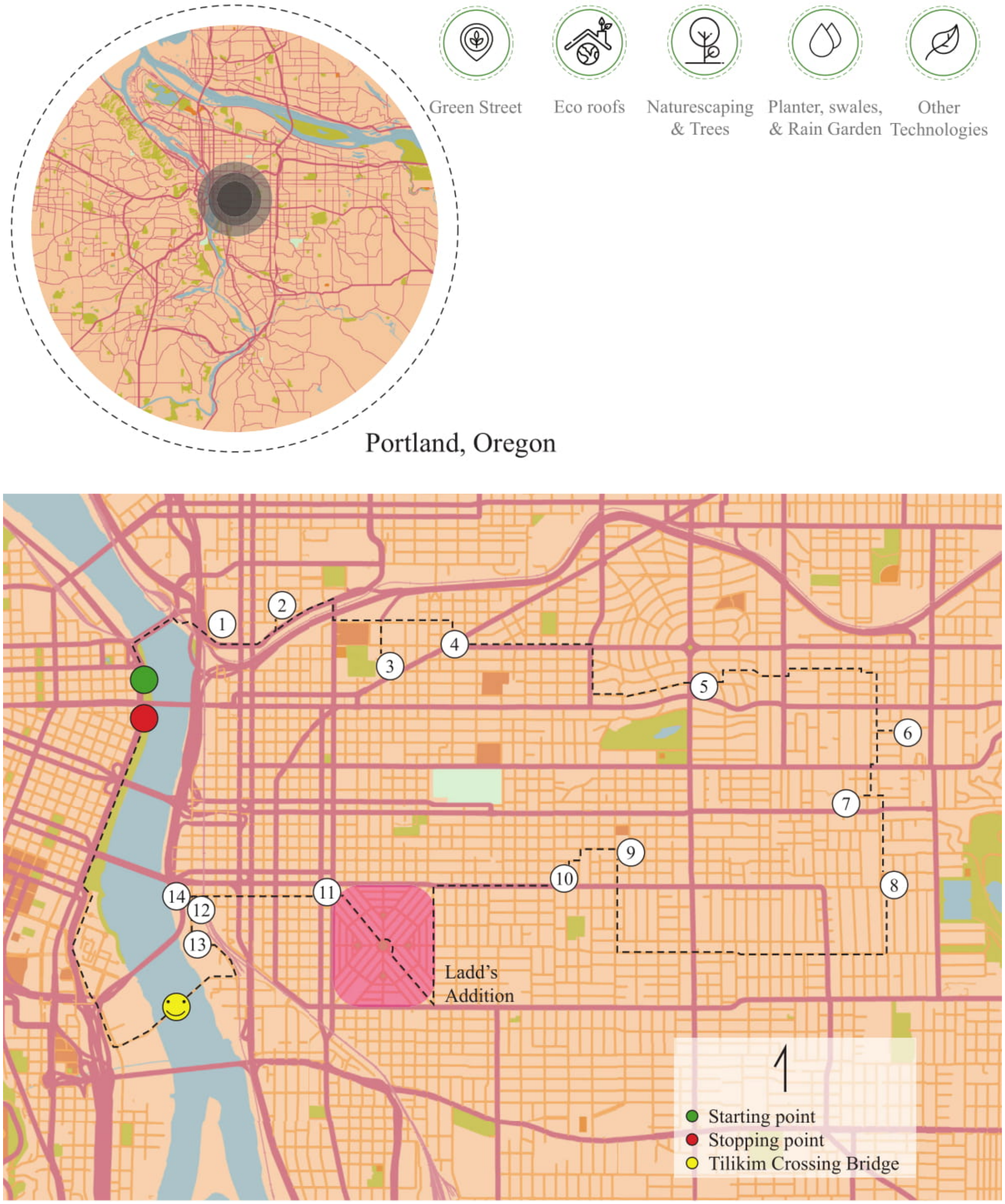


Figure 20, City of Portland- Stormwater cycle tour.

1. Convention Center
430 NE Lloyd Blvd

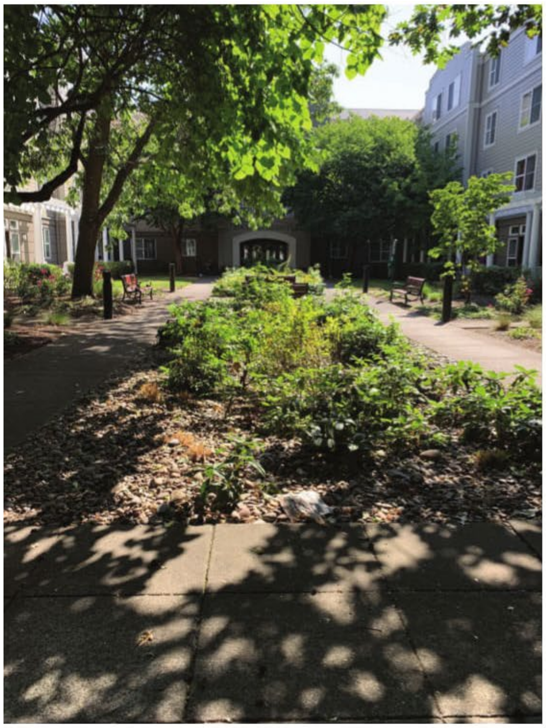
Naturescaping & Trees | Planter, swales, & Rain Garden | Other Technologies

The runoff of 5.5 acres of the roof gets treated by the rain garden located in the front of the building. Once the tank gets filled in the rain garden, it transfers water from it to the Willamette River.

2. Liberty Garage
629 NE Oregon St

Naturescaping & Trees | Planter, swales, & Rain Garden | Other Technologies

Stormwater planters collect and filter runoff from the top level of the garage.



3. Buckman Heights
430 NE 16th Ave

Planter, swales, & Rain Garden

Other Technologies

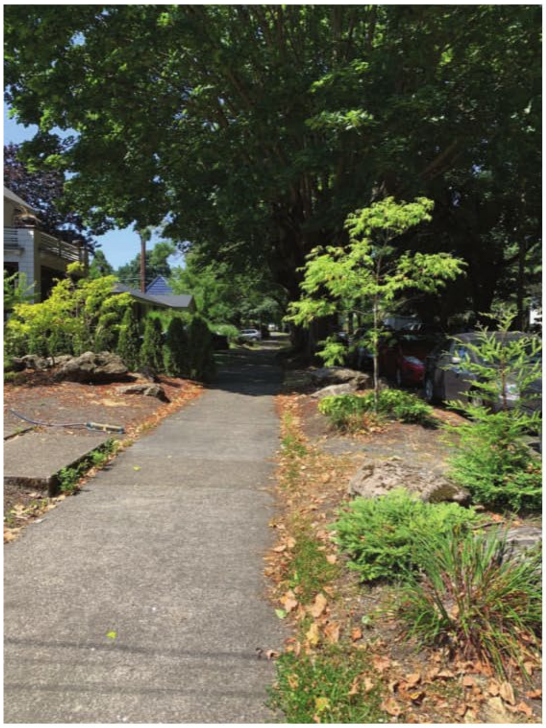
The rain garden designed in the center of the courtyard helps to infiltrate runoff from the downspouts.

4. Sandy Blvd
2240 NE Sandy Blvd

Green Street

Planter, swales, & Rain Garden

Rain gardens at one of the intersections between Sandy Blvd to NE 42nd. It helps to collect and treat street runoff.



5. Couch Street
3936 NE Couch St

Naturescaping & Trees

Swales on the in-between, the sidewalk and road manage surface runoff.

6. Mt. Tabor School
5800 SE Ash St

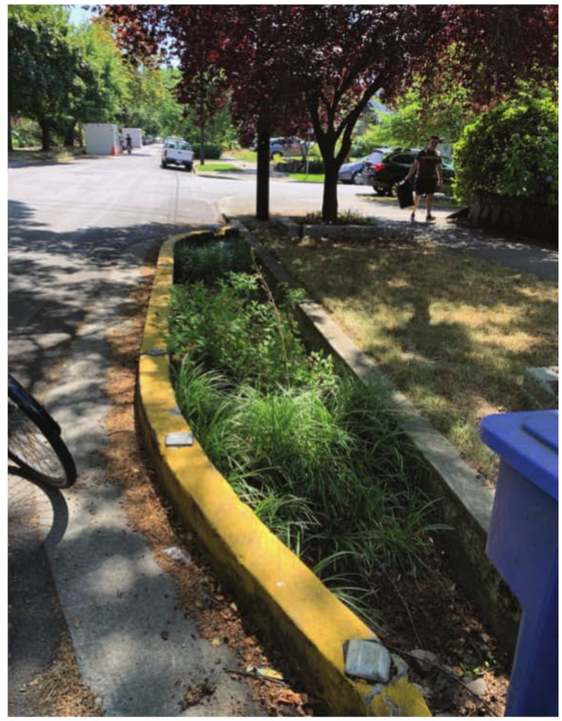
Naturescaping & Trees | Planter, swales, & Rain Garden | Other Technologies

Runoff from the roof and impervious play area get collects into the rain garden.

7. Glencoe School
5126 SE Morrison St

Naturescaping & Trees   Planter, swales, & Rain Garden

Parking lot swales and rain garden helps to manage the surface runoff from surrounding and any overflow.



8. Glencoe School St.
1535 SE 44th Ave

Eco roofs   Naturescaping & Trees   Planter, swales, & Rain Garden   Other Technologies

Narrowing the road width, the swales on the edge of sidewalks help clam the traffic and help treat stormwater runoff.

9. Sunnyside School
3421 SE Salmon St

Eco roofs | Naturescaping & Trees | Other Technologies

Eco-roof for naturescaping

10. Hawthorne Hostel
3031 SE Hawthrone Blvd

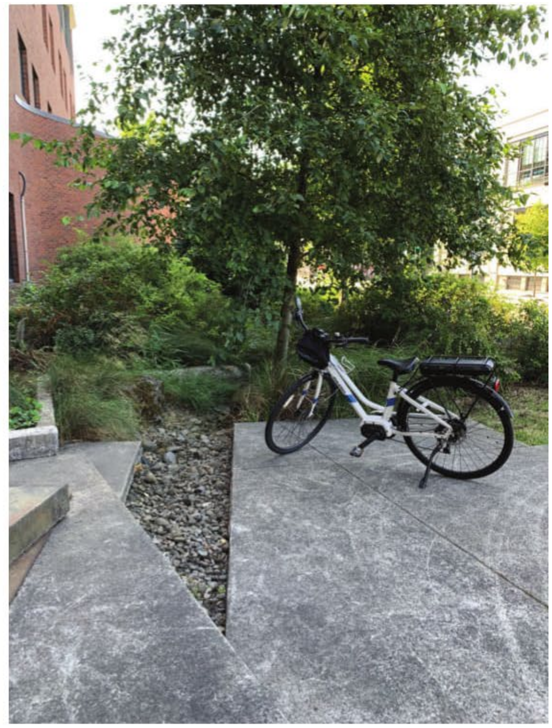
Eco roofs | Naturescaping & Trees | Planter, swales, & Rain Garden | Other Technologies

Entire porch cover with eco-roof. Runoff from the roof gets collected into cisterns and reused for toilet flush. Bioswales on the side of the building treat the cisterns overflows.

11. Clay Street
600-698 SE Clay St

Naturescaping & Trees | Planter, swales, & Rain Garden | Other Technologies | Green Street

Bioswales at every intersection to calm the traffic, manage the surface runoff, and reduce the amount of flow towards the river.



12. PCC Plaza
1626 SE Water Ave

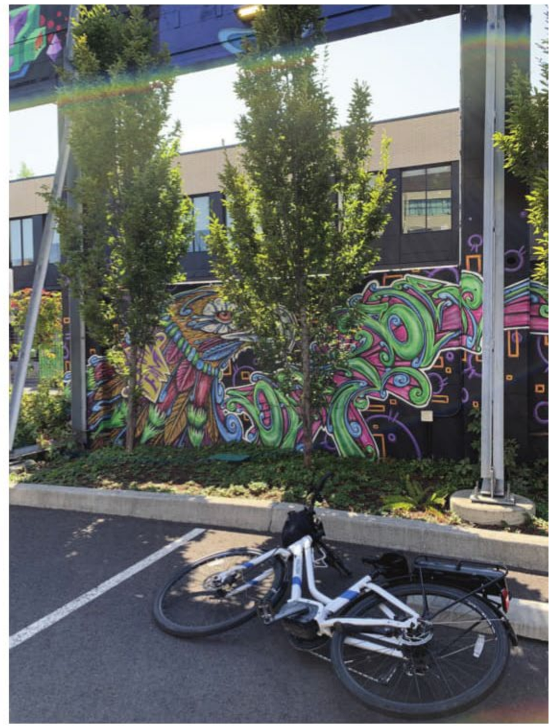
Eco roofs | Naturescaping & Trees | Planter, swales, & Rain Garden | Other Technologies

A beautiful plaza on Clay street that exhibits the history of the place, types of green infrastructures install.

13. OMSI
1945 SE Water Ave

Naturescaping & Trees
Planter, swales, & Rain Garden

Curb cuts allow the runoff to flow into the bioswales installed on the side of the parking lot



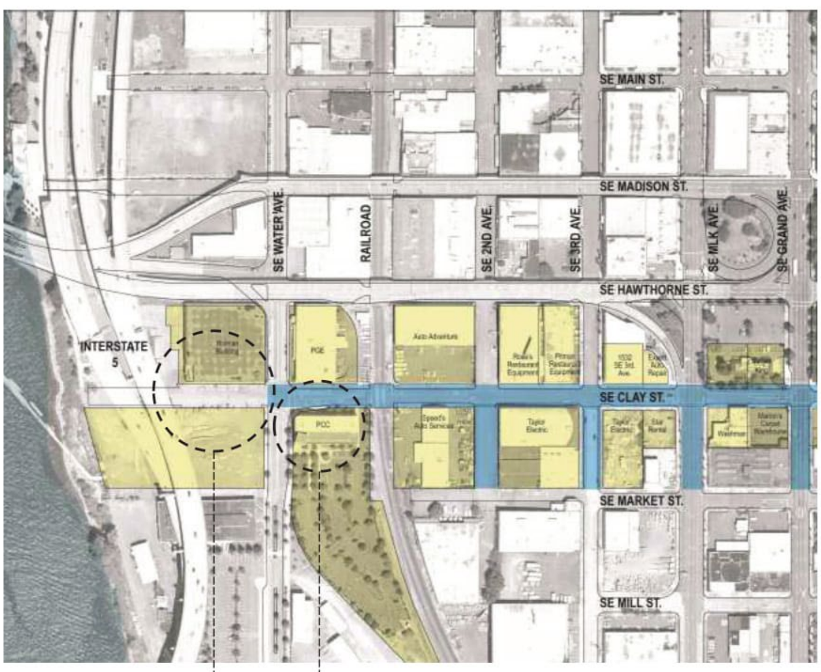
14. River East
5126 SE Morrison St

Naturescaping & Trees
Planter, swales, & Rain Garden
Other Technologies
Green Street

A combination of impervious and previous helps to recharge the ground of this parking lot. Swales on the end of the parking lot collects and treats the surface runoff.

SE Clay Street Green Street Project (Images 11,12,13,14)

This $3.4 million EPA funded project is a combination of an exhibit and installation of multiple green stormwater management systems. The exhibit kiosk has an Eco roof on its top, which displays educational information for people regarding low impact stormwater movement. All the green infrastructure elements like rain gardens, swales, permeable pavement help to manage more than 525,0000 gallons of storm runoff every year. (The City of Portland Oregon, 2015)



RiverEast

RiverEast Center
Completed 2006

PCC CLIMB Plaza
Completed 2012

PCC CLIMB

Figure 21 Clay street Green Street Project, Portland, Oregon. (Coker & Wethington, 2012)

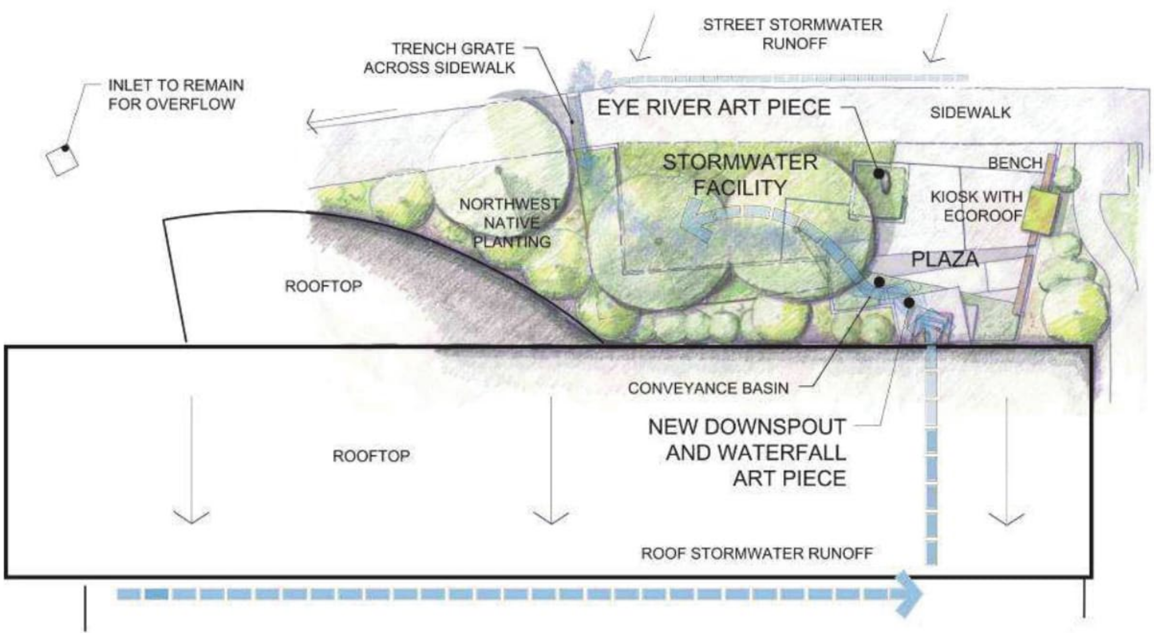


Figure 22 PCC Climb Plaza, Clay Street. (Coker & Wethington, 2012)

Part Four |

Why Blend Green Infrastructure into the Right-Of-Way

Chapter 6: The Three Scale

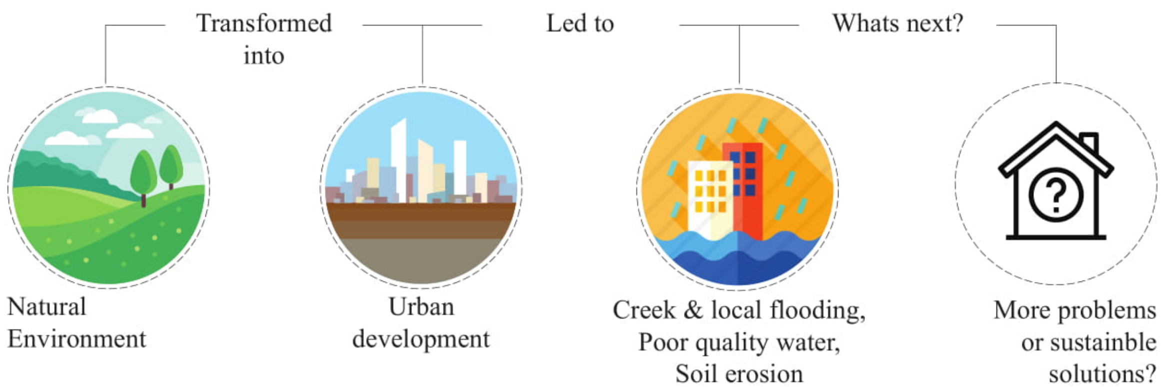


Figure 23 Transformation of the natural environment into urban development/city

Looking at the above figure, at present, we as a designer and a planner, we have two levels of designing and planning to work with. First, stormwater master plan and drainage requirements in the city, which is dealing with 25 and 50 years of storm events. Second is the National Flood Programs through the National Flood Insurance Program, which most of all cities of the United States have floodplain part of them (100-year storm event). Part of the design challenge in this proposal is that we are dealing with multiple storm events which have different volumes, different purposes, and different regulatory system for both the type of storm events. Green Streets can help deal with water quality improvements, peak flow reduction, and volume management of the different levels of storm events.

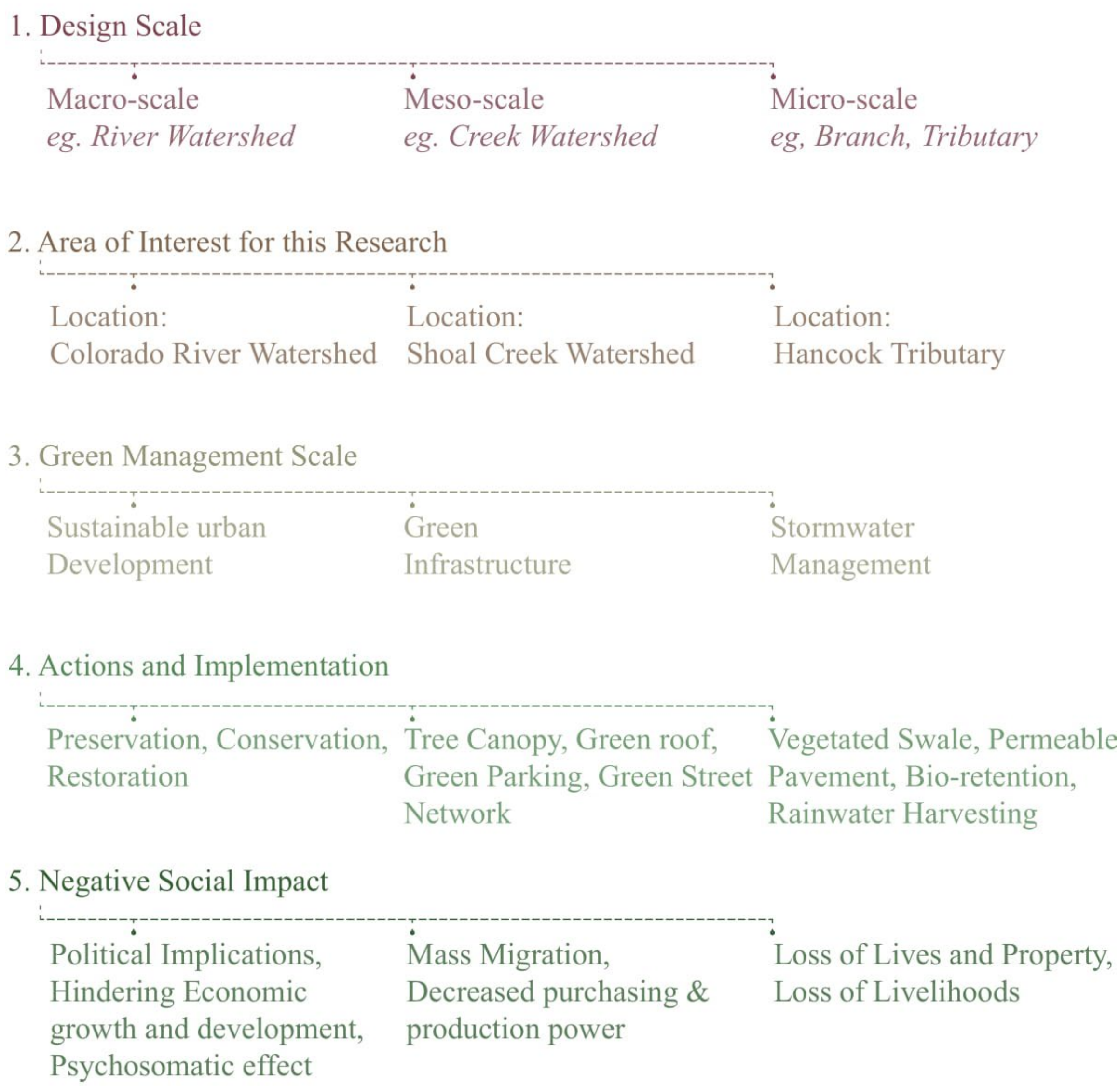


Figure 24 Intervention of project at different scales

Chapter 7: Analysis at macroscale: Colorado River Watershed (The City of Austin)

7.1 Introduction

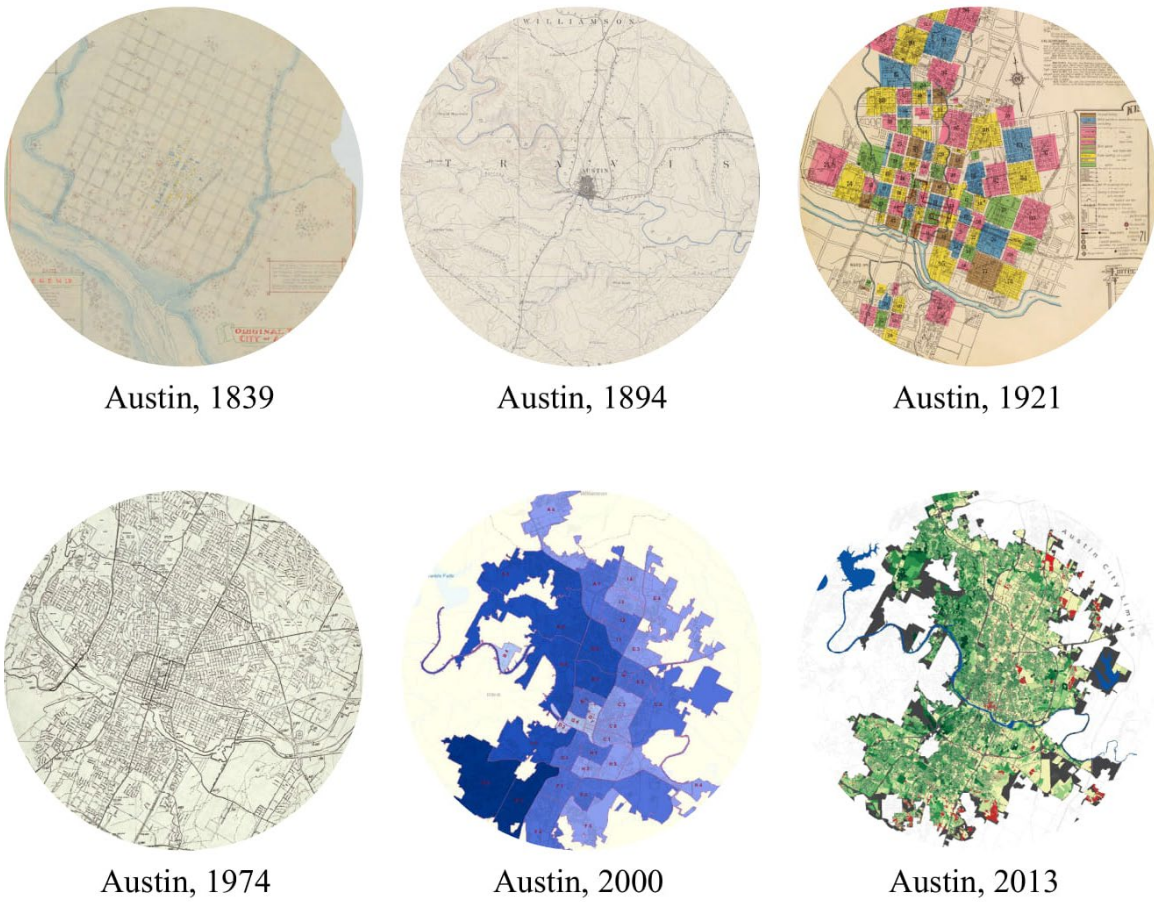


Figure 25 Change of Austin's city limit with time.

The City of Austin is located in central Texas. The city's land expands majorly over four different physical geographical regions: 1) the Edwards Plateau, 2) the Texas Blackland

Prairie, 3) the Colorado River Floodplains, and 4) the Low Terraces and the East Central Texas Plains. Most of the urban development of the city is over the Texas Blackland Prairie region. For more than at least 11,000 years, the land of Austin remains inhabited, and it was only until 1730 that few Spanish colonists started traveling through its area. In the 1830s, pioneers first settled, and construction of the seventh most significant building of the world, the State Capitol building, took place by the 1880s. Soon afterward, the city's population began to increase. Currently, Austin is one of the fastest-growing cities in the US. Austin's population mostly comprises college students, recently graduated, and retired baby boomers. It is predicted that by 2030, Austin will have 3.2 million people staying in its metropolitan area.

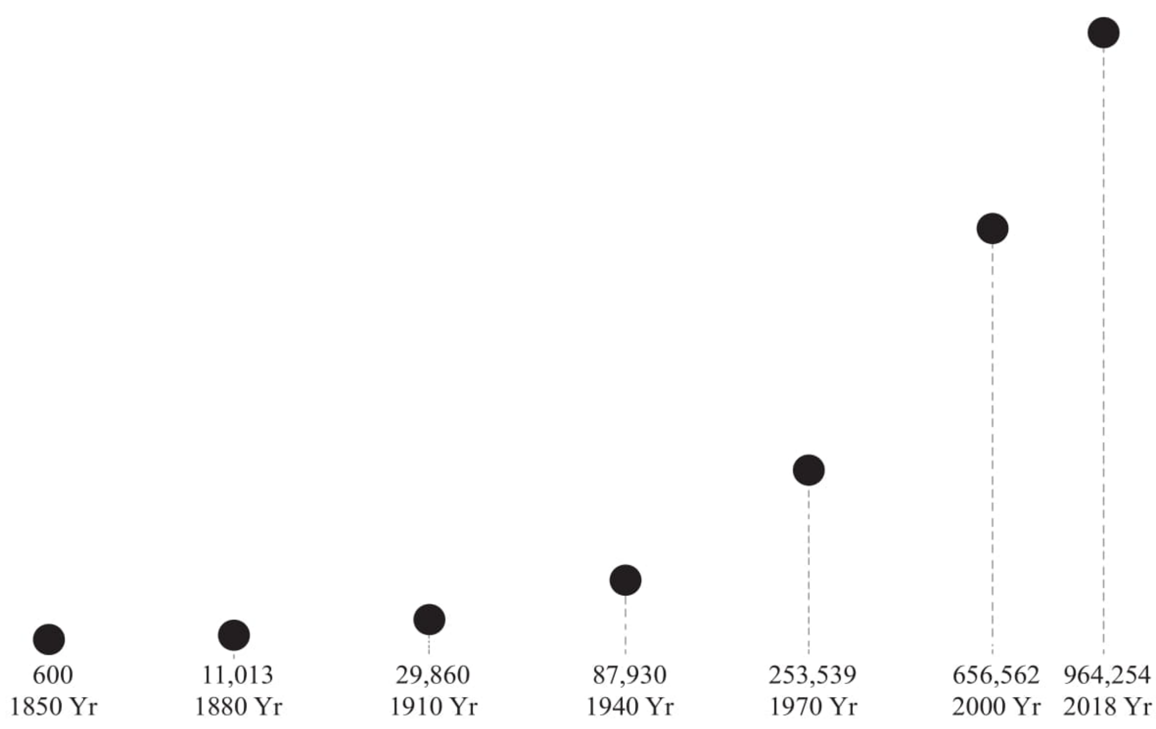


Figure 26Austin population with year. (US Census City/Town Population estimates, n.d.)

Looking at the numbers and other studies, population predictions and other studies indicated that the city would continue to grow, but with time, its pace will eventually slow down. The reason is that the city has so many sources for entertainment, food, restaurants, and affordable housing, but providing new services is hard to cope up with the rate of population growth. Currently, Austin is ranked third-worst traffic congestion in the urban area of the country.

7.2 Physical Characteristics:

a. Soil

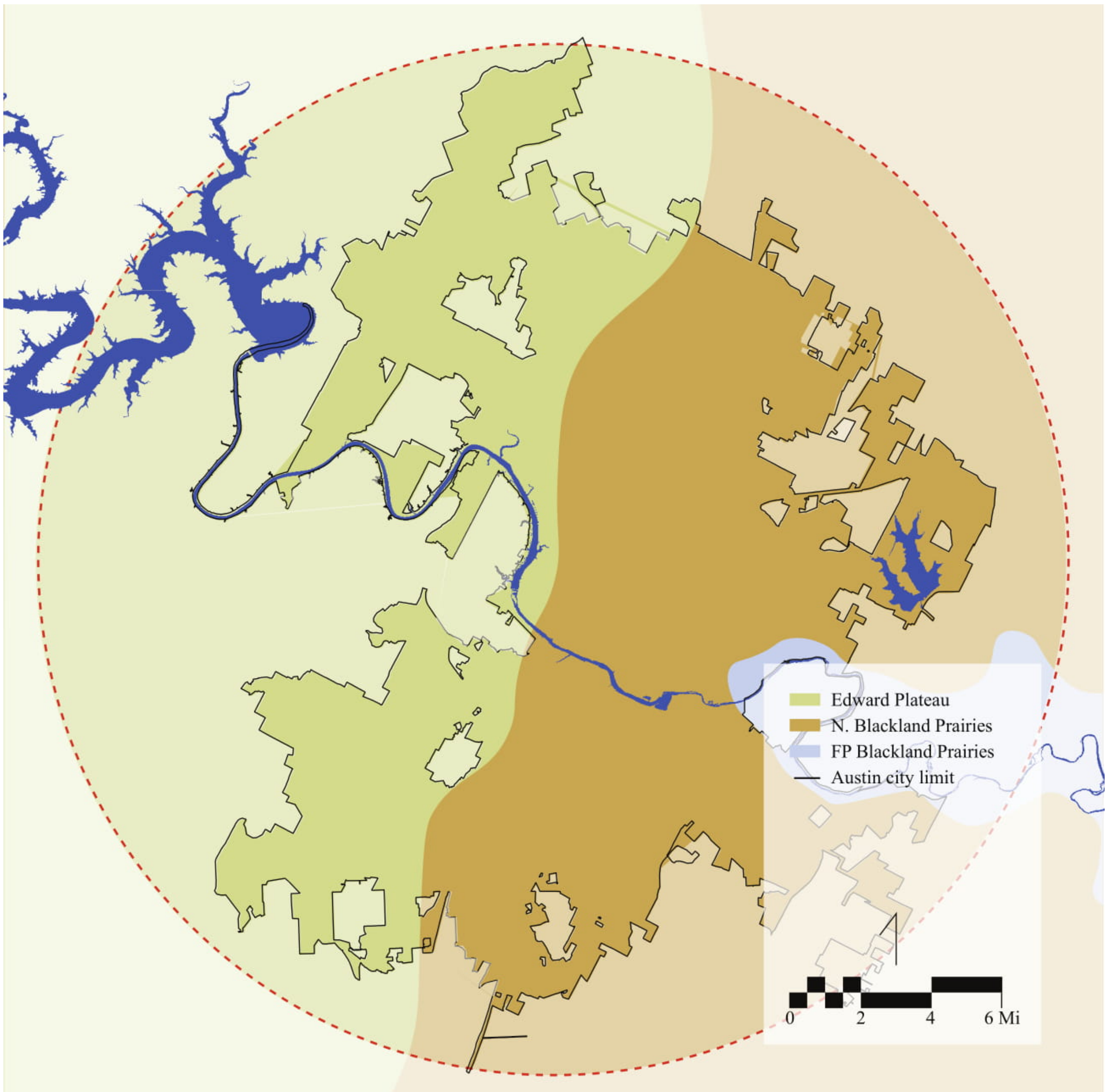


Figure 27 City of Austin-Geographic Regions

In general, soil types are majorly based on the rockbed underlying beneath them. They are categorized into four hydrological parts: Group A, B, C, and D. The map above shows that a vast portion of Austin is covered with Group C and D. C and D are soil types with very low inflation rates. Group D especially has the highest runoff potential. The water bodies, their surrounding water branches, and floodplains have a different soil deposit. From 12 to 20 inches deep of Colorado River has "red-brown, calcareous and non-calcareous sandy loams, silty clay loams, and gravelly." Until 24 inches of depth, the water tributes of Colorado Rivers like creeks have "gray-brown to dark brown, calcareous, gravelly clay and silt loams." Surrounding floodplain areas of these water bodies, 12 to 38 inches deep, have dark gray to brown, calcareous silt loams, clay loams, and sandy loams. Overall, the soils in and around water that have been deposited are fine-grain and highly erodible. (Austin, 2011)

B. Water

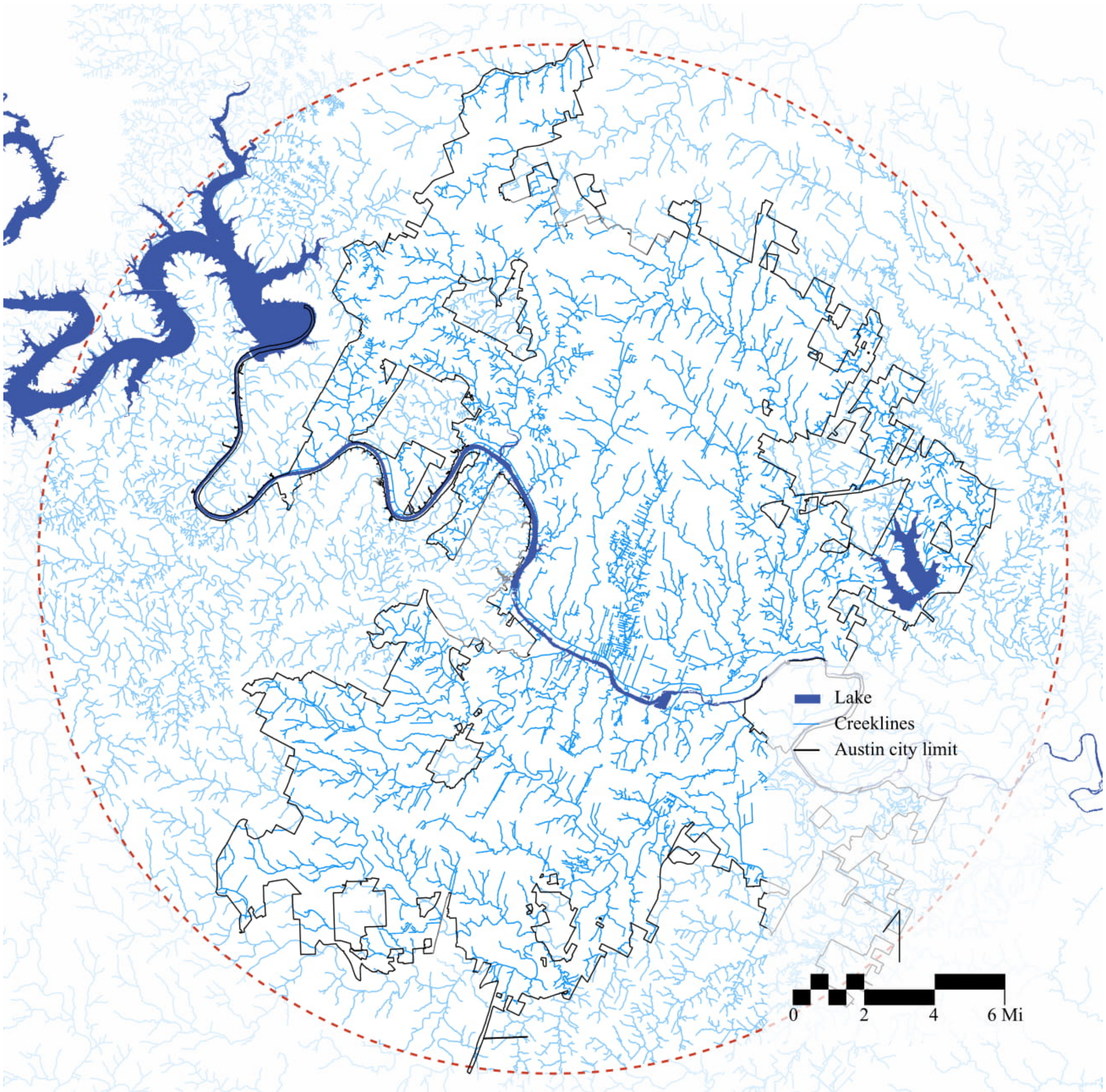


Figure 28 City of Austin- Creek lines

Austin is blessed with several water bodies in forms of lakes, creeks, and springs. Some of the common ones are Lady Bird Lake, Lake Travis, Barton Spring, Shoal Creek, and Waller Creek. The spread of many creeks and their tributaries supports a wide range of different plants and animals and helps keep Austin's land as a beautiful landscape. This land is divided into watersheds based on the location of the creeks and lakes. After the Memorial Day flood of 1981, the city implemented drainage fees, which help to collect funds for stormwater management programs. The Watershed Protection and Development Review Department (WPDRD) helps by controlling and reviewing the quality and quantity of the hydraulic cycle of the city. (Austin, 2011)

c. Tree canopy

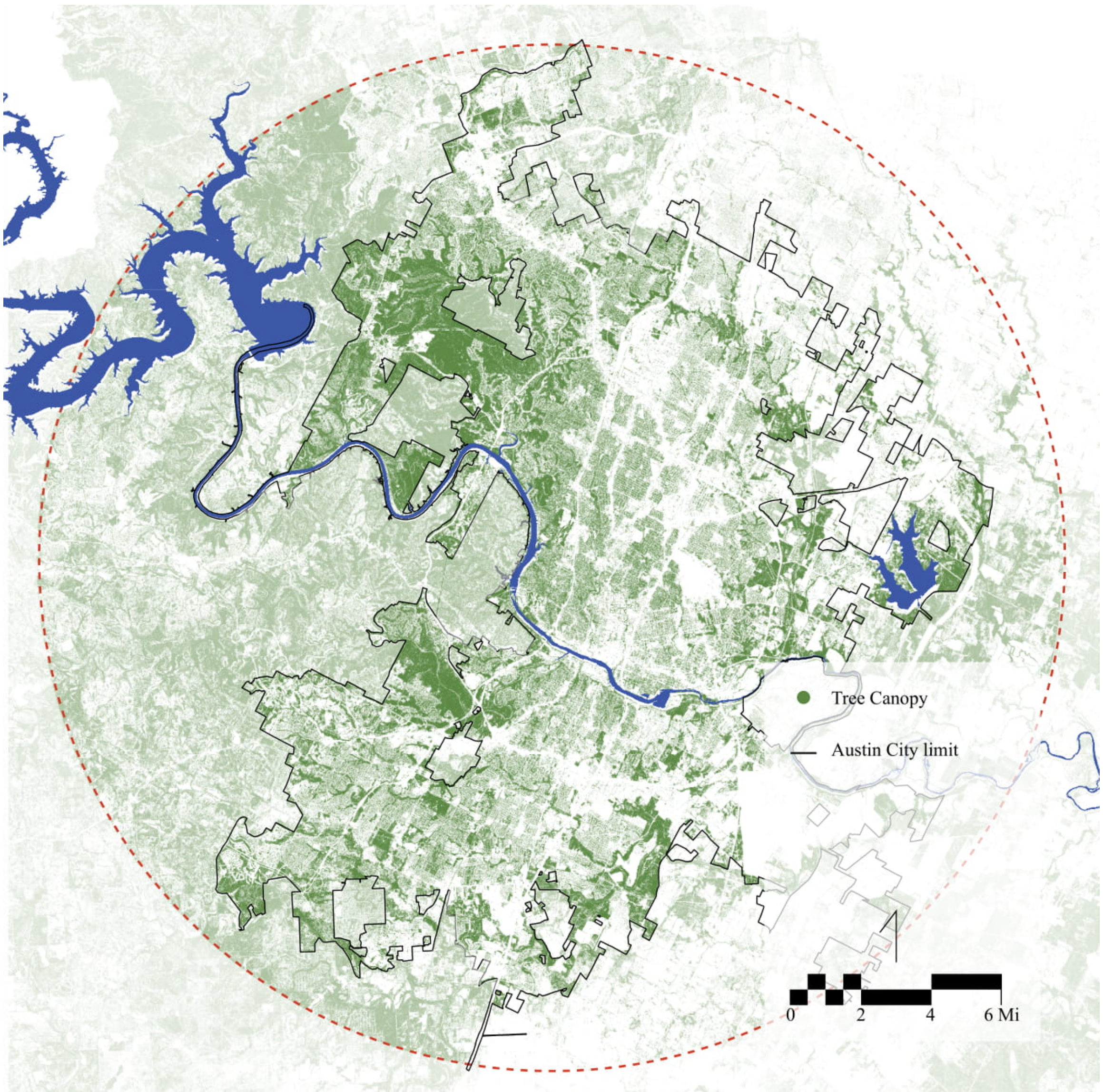


Figure 29City of Austin- Tree canopy

Today, Austin's tree cover is 30.8 percent, and most common trees found in the city are "Ashe juniper, cedar elm, live oak, sugarberry." The Edwards Plateau, the Blackland Prairie, and the Post Oak Savannah are three bioregions of Austin. Each of these bioregions has a distinct species and types of green vegetation. As the majority of development happened and is still happening in the Prairie region, the region has lost much of its tree coverage, which currently makes Edward Plateau denser and forest-like. According to a study carried out by Urban Forest Features in 2014, Austin has 173 trees per acre. Austin lost a lot of its tree density in the past couple of decades to agriculture, mining. Non capitalized and urban development. This loss has severely affected the city's hydraulic cycle, surface temperature, and stormwater runoff, and alters the natural and physical characteristics of the city in many ways. (Austin Utilities, 2009)

D. Climate

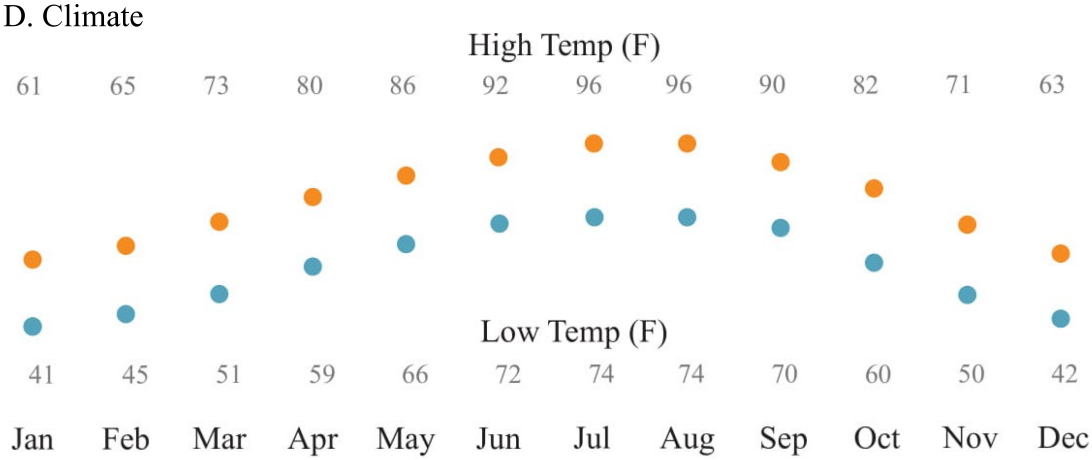


Figure 30Austin average monthly temperature in Fahrenheit. (Weather Spark, n.d.)

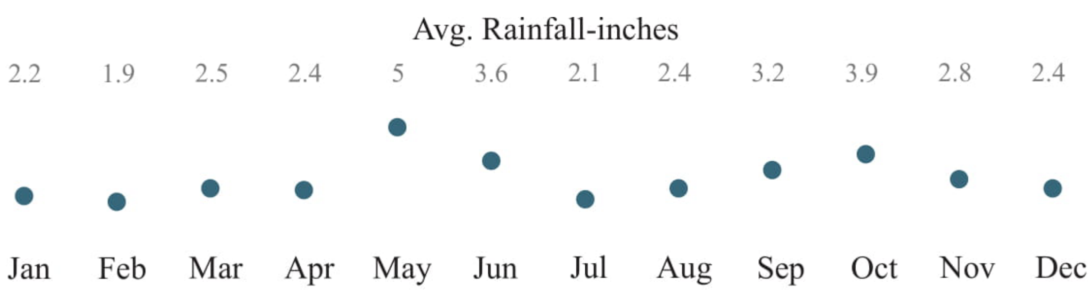


Figure 31 Austin average precipitation in inches. (Weather Spark, n.d.)

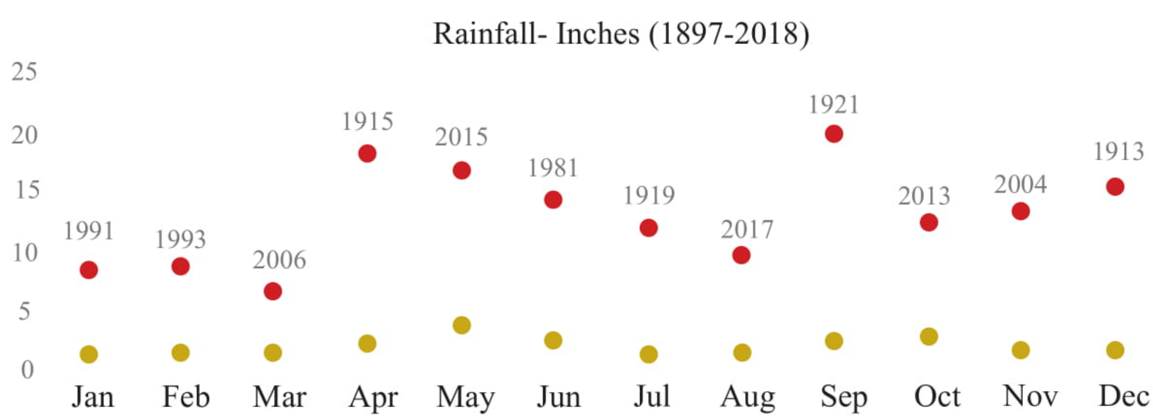


Figure 32 Highest and lowest monthly rainfall in Austin from 1897-2018 (Shoal Creek Conservancy, 2019)

Austin falls under a humid subtropical climate due to hot summers, mildly cold winters, and warm springs. It rains throughout the year but heaviest in spring and fall, but nothing is fixed as heavy rains may occur at any time in the year. The average annual rainfall is 34 inches. On a very rare occasion in winter, it may snow, or sleet. In the past couple of decades, due to urbanization, which has increased carbon emissions, the climate has altered a lot of its natural cycle. Austin and other cities of Texas Are predicted to become increasingly hotter. That is, more heat results in more storms, and more storms lead to flash floods.

7.3 Man-Made development

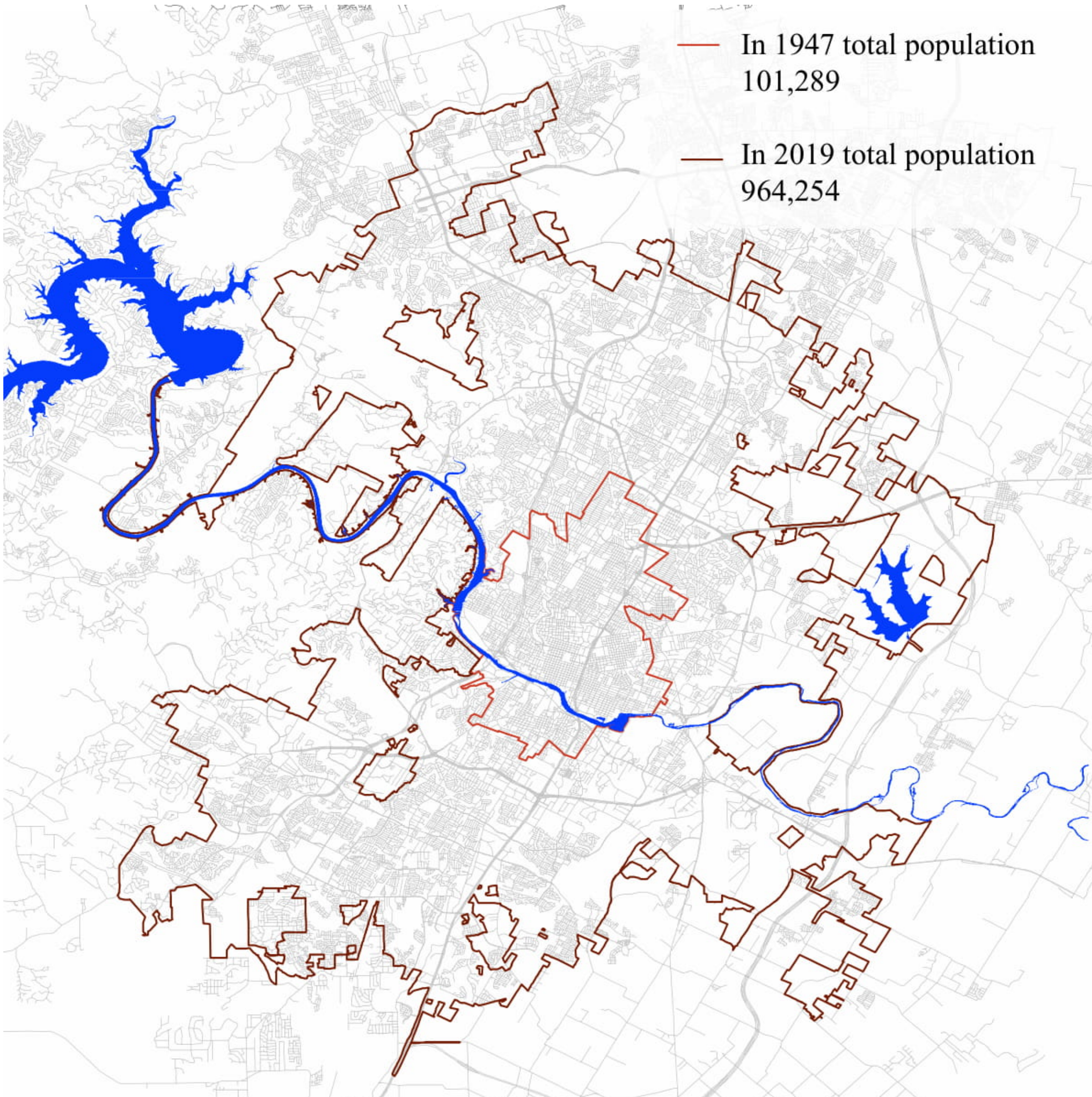


Figure 33Increase in population and city limit of Austin from 1947 to 2019

Urbanization and development, directly and indirectly, affect all the above natural and physical characteristics of the city. As mentioned earlier, Austin is predicted to have 3.2 million people in its metropolitan area by 2030. There is no doubt that without sustainable measures, the city would be heavily impacted by climate change. (Anderson, 2015)

Figure 34 Increase in the impervious cover of City of Austin from 1997 to 2015

7.4 The problems the city is facing today and will face in the future

a. Flooding

The city's data shows that from 1999 to 2009, over 8600 localized flooding complaints have been registered. A recent study called Atlas 14 predicts more rainfall in Austin than thought, so there is no doubt that in the future, the scenario will be worse if no action is taken. (Austin, 2011) Before the publication of Atlas 14, 7400 structures were calculated to be at risk of creek flooding. Currently, roughly 2750 more Austin properties are added that will be within the high-risk floodplains. The new floodplain boundaries mapped by the National Weather Service study will set new parameters and impact everything for these properties like construction type and insurance rate for the development. Not only the properties but floods also affect other infrastructure of the cities like bridges, public parks, and roads. There is an urgent need to incorporate sustainable means to solve inadequate storm drain systems issues and reduce city-wide risk to public safety and property. (Perica et al., 2018)

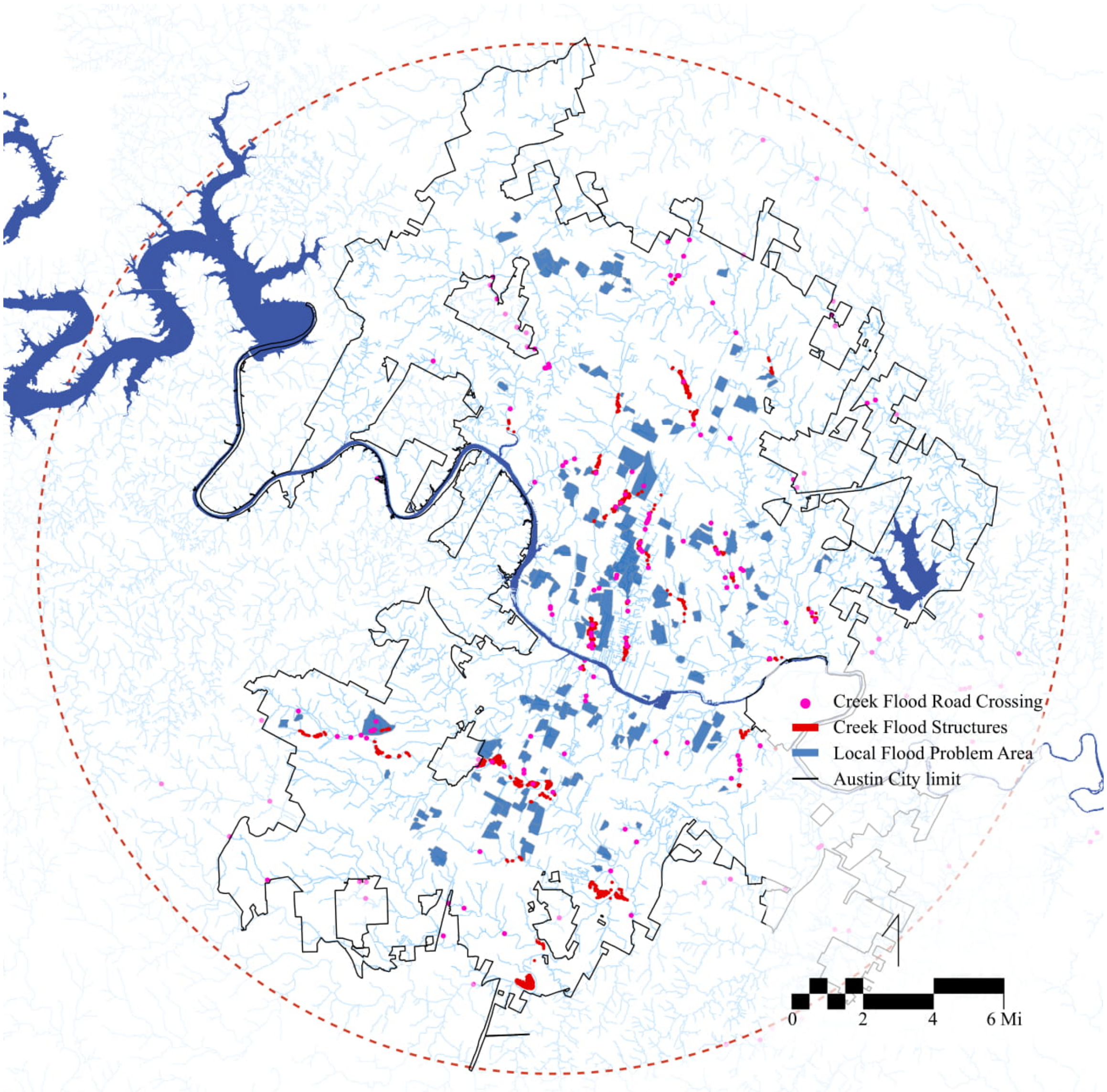


Figure 35 City of Austin- Infrastructure at risk during the local flood and creek flood

b. Soil erosion

The increase in development precipitates increases in impervious coverage. The more impervious cover, the more higher water flows through the creeks. Thus, even with a small rainfall event, there is a significant increase in the rate, magnitude, and duration of erosion. The New erosion data identifies that at present, over 1000 sites are threatened. All of these threats are primarily connected to the modification of watershed hydrology due to changes in land-use conditions and encroachment of human activities into natural water boundaries.

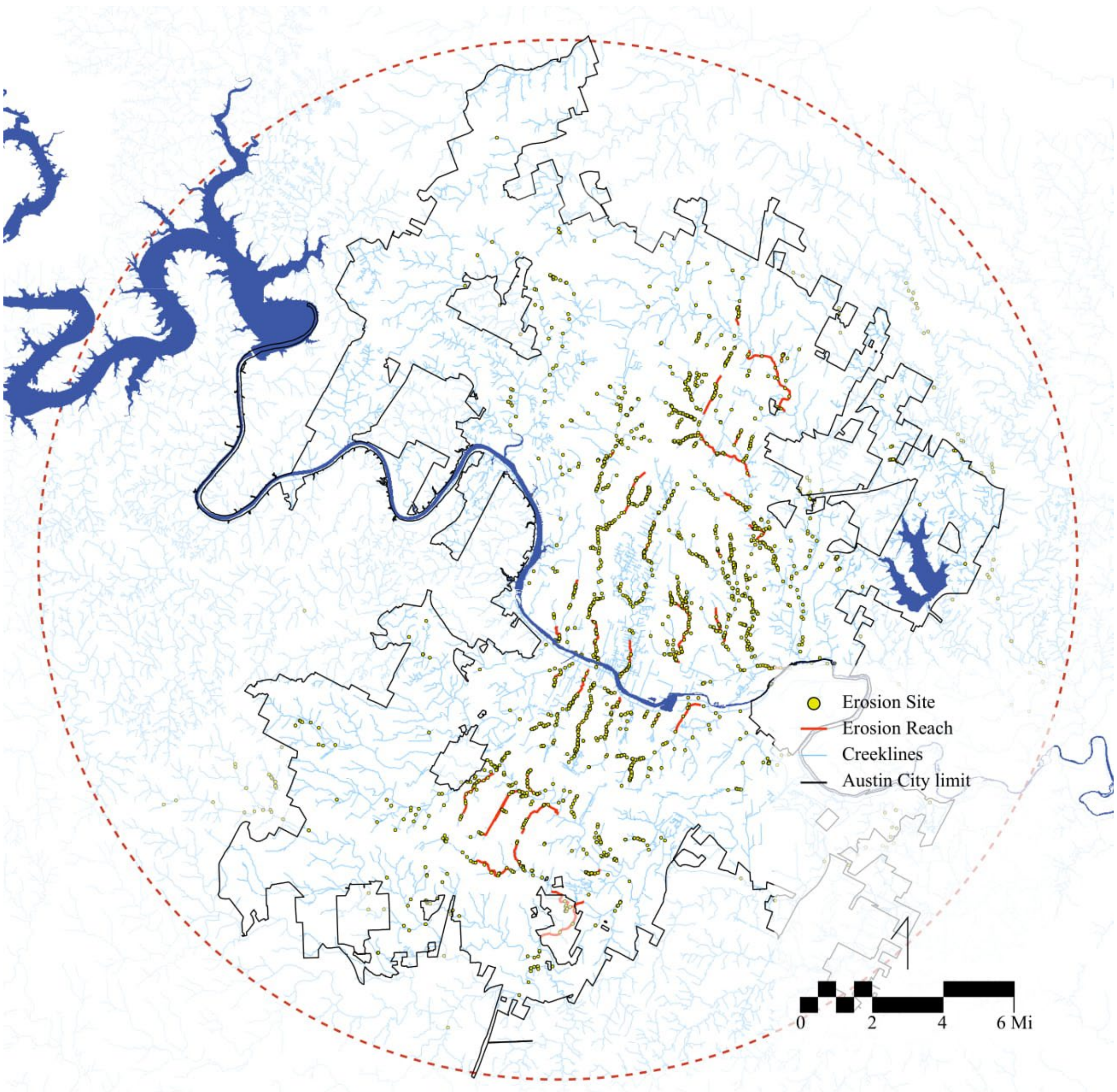


Figure 36 City of Austin- Erosion sites and creek segments

7.5 Timeline of flooding events and actions taken. (City of Austin)

Figure 37 Flooding events in the City of Austin

1869	Austin's Worst flood (Colorado River Flood)
1890	Voted for dam
1892	Constructed
1900	Dam failure
1912	Rebuild dam
1915	Dam damage
1938	Floods in the 1930s bifurcated Austin along Congress
1940	Tom miller Dam completed
1957	Citywide flood
1970	Adoption of watershed ordinances
1974	Waterway Ordinance passed
1974	First structural flood detention ponds built
1977	Drainage Criteria manual adopted
1979	Austin Tomorrow Comprehensive Plan
1981	Memorial day flood
1982	Created comprehensive drainage fee (a user-fee revenue system
1982	$18.4 M was approved for streets and drainage.
1982	$48.5 M for drainage and flood control projects.
1986	The 1986 Comprehensive Watersheds Ordinance
1991	Declared its drainage system to be a public utility
1991	Citywide flooding (December)
1992	Passed the landmark Save Our Springs (SOS) Ordinance
1996	Watershed protection department created
1998	$10.75 M for erosion and flood control projects.
1998	Williamson creek, onion creek flooding
2001	Williamson creek, onion creek flooding
2001	Approved the Watershed Protection Master Plan,
2004	City-wide flooding (November)
2006	$95 M for erosion, flood, & water quality projects.
2012	Imagine Austin comprehensive Plan
2013	Williamson creek, barton creek/ grains tributary flooding
2015	Memorial day flood (shoal, Barton, Waller
2015	The Flood Mitigation Task Force was created
2018	Colorado river and lake Travis flooding
2018	Atlas 14- NOAA release new flood plain maps
2018	City of Austin creates a 100-year water resiliency plan

Figure 38 City of Austin actions taken to mitigate some of the impacts of flooding

7.6 Austin Green Streets Rating

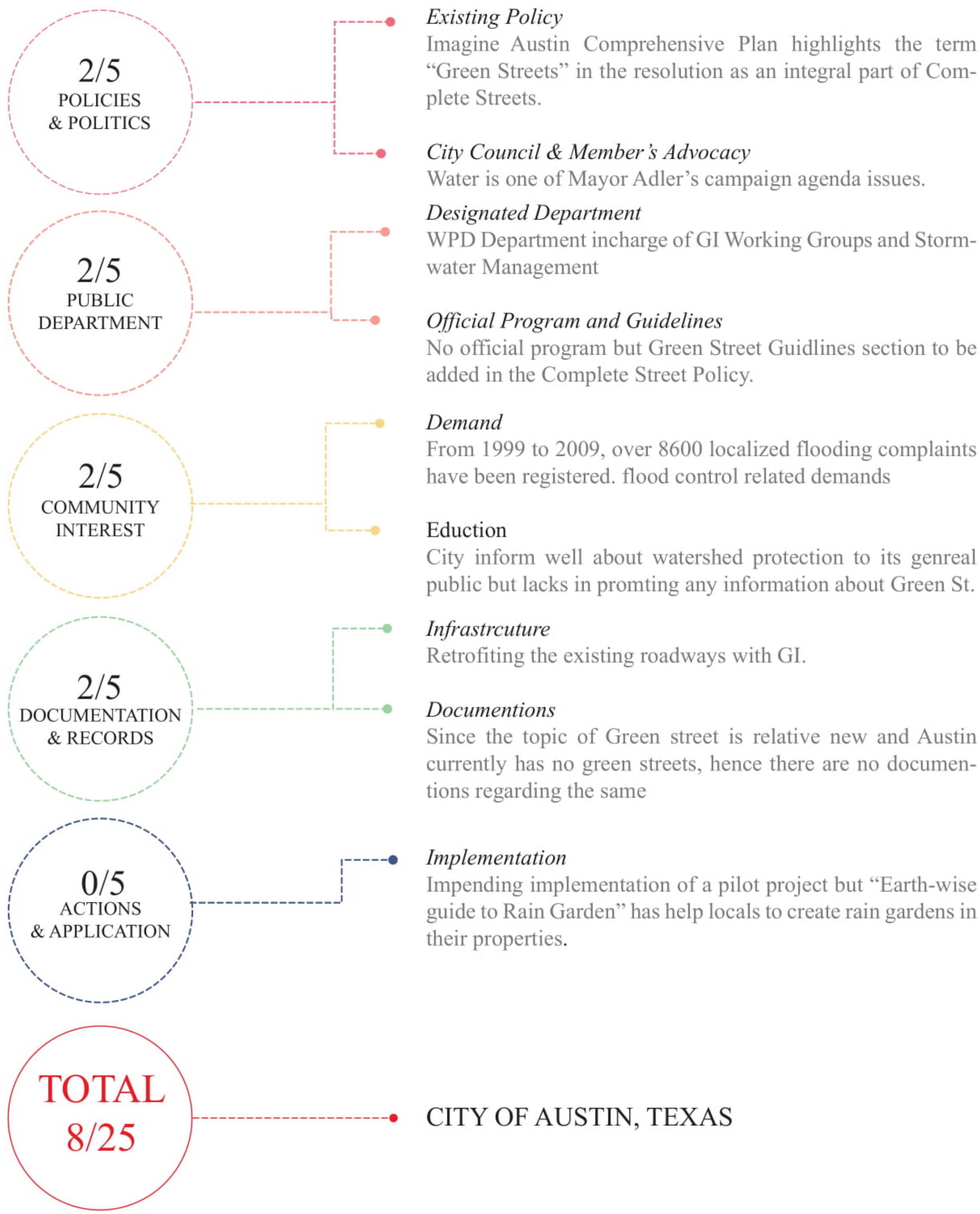


Figure 39 Green Street Rating for Austin. Adapted from Source: (Chio, 2016)

To address the problems of public stormwater, the city needs to use green infrastructure methods and utilize the public right of ways to transform into green streets. Austin currently lacks green street projects as the concept is very new. This is compounded by the absence of community demand as the general public lacks enough knowledge of its benefits. However, the city council is pushing for the implementation of green street projects. In 2014, the complete street guideline was developed. Soon after, in 2015, an interdisciplinary team from several departments like Transportation, Parks, and Recreation, Watershed Protection, Public Works, and others of the city, presented a document called “Green Street: An Introduction.” The city plans, in the future, to create “Green Streets Technical Guidelines,” which will help to mainly focus on infiltration, storage, and evapotranspiration of stormwater

Chapter 8: Analysis at the mesoscale: Shoal Creek Watershed

8.1 Introduction

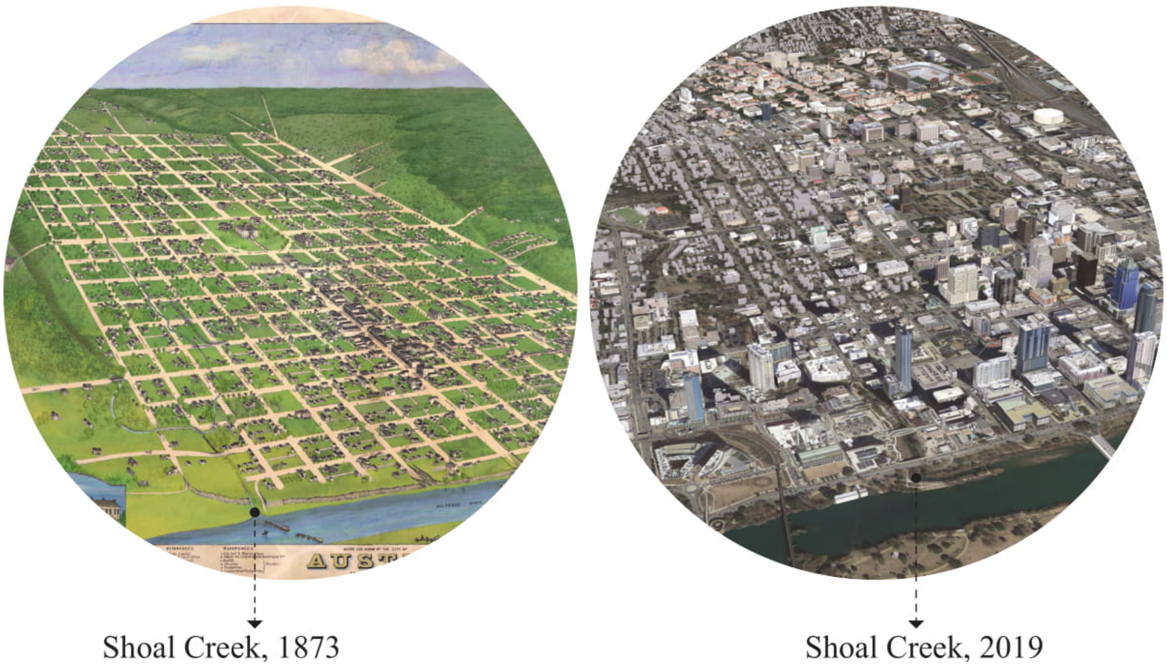


Figure 40Shoal Creek Watershed now and then

Shoal Creek is a 16-mile long stream and 8300-acre urban watershed of the city of Austin. At present, it is considered the city's hidden jewel that branches out 30 miles of streams smoothly into the most developed part of the city. The tip of the creeks starts from the center of the city and runs downwards north of the Lady Bird River.

Since the early 1800s, the time when the settlers invaded the land between Shoal Creek and Waller Creek, Shoal Creek was under attack with various human activities. Its initially use mostly for recreational purposes as the entire west side of the creek was undeveloped. Due to the hot climate, people in those days enjoyed swimming, diving, and fishing in Shoal Creek. In early 1960, nature lovers built the first trail of the city along with it. Today, the creek suffers from suffocation due to the intense and dense development around it. (Watershed Protection, 2016)

8.2 Physical Characteristics

SHL1, SHL2, SHL3, and SHL4 are four divisions of the Shoal Creek watershed defined by The City of Austin Watershed Protection Department. SHL1 is the end of the watershed that drains the stream into the Lady Bird Lake, and SHL4 is the origin located at the intersection of Loop 360 and Mopac. The main water stream splits into two major tributaries— Spicewood Springs and Hancock Branch. Spicewood Spring, from 1871 to 1986, functioned as a popular resort and bathhouse.

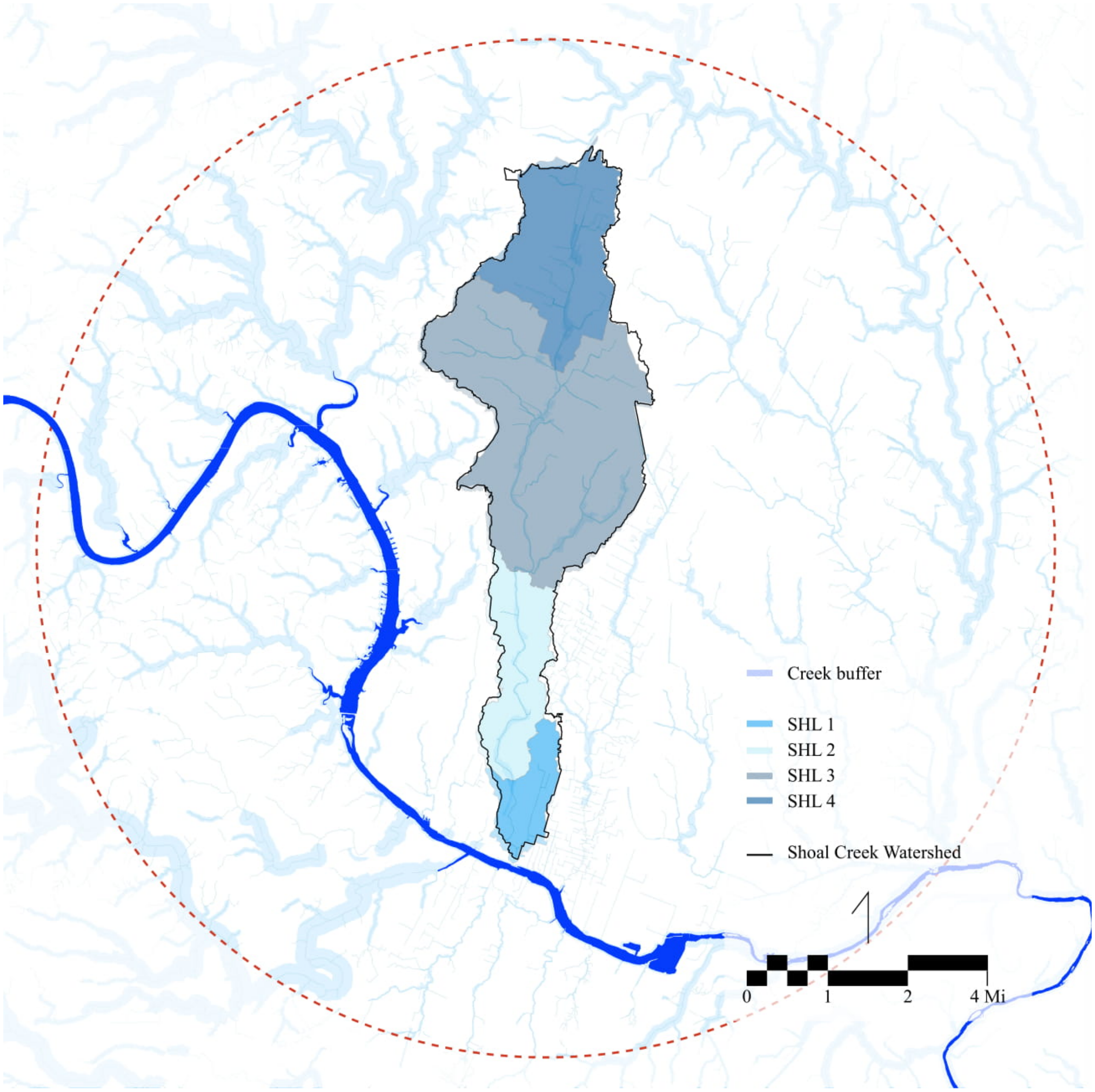


Figure 41 Shoal Creek Watershed boundary and its Reaches

8.3 Man-made development patterns

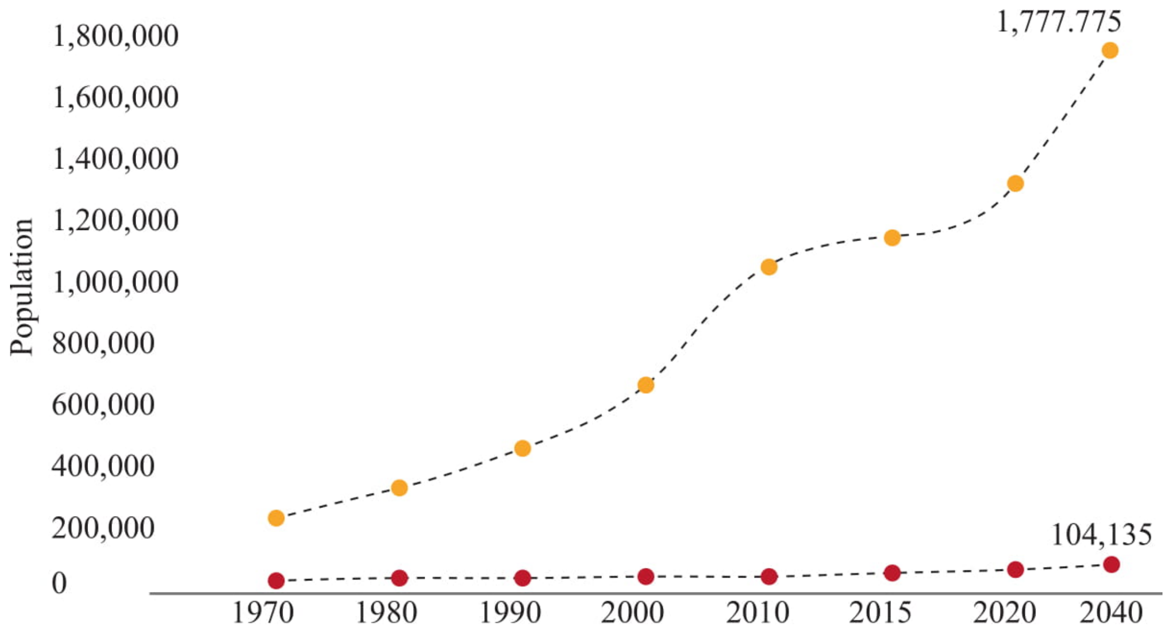


Figure 42 Population growth of Austin (yellow dots) vs. Shoal Creek Watershed (Red dots)

Approximately 72,000 people live within Shoal Creek Watershed, and by 2040, it is predicted that the population of this creek will rise to 104,000 people. The density of the number of people per acre will increase from 7.5 to 12.5. With an increase in density, there will be more development, and with that, more impervious cover added to this urban watershed. (Shoal Creek Conservancy, 2019)

A. Land Use

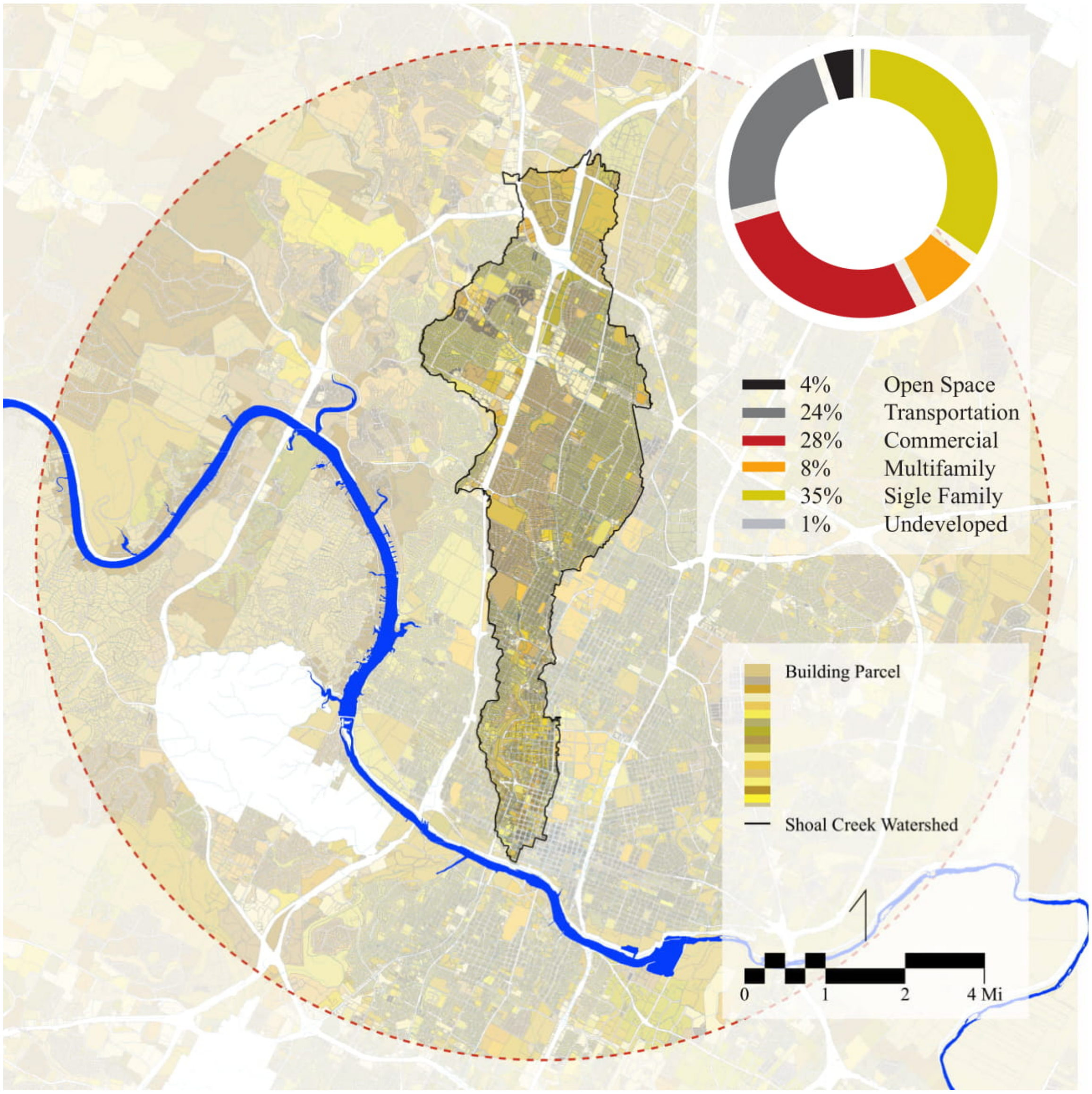


Figure 43 Shoal Creek Watershed dense density and land use percentage

Ninety-five percent of the Shoal Creek watershed is currently developed, with only 5 percent of land left undeveloped. Due to its location downtown, zone SHL1 has 36 percent of its area dedicated to commercial use and 39 percent to transportation. In SHL2, 40 percent of the area is occupied by single-family units, and SHL3 by 46 percent. About

40 percent of a large area of SHL4 is occupied for commercial uses. Overall, 35 percent of the watershed is occupied by single-family, and 28 percent by commercial. A quarter of the total area is taken up by transportation. (Shoal Creek Conservancy, 2019)

B. Open vs. Built

At present, Shoal Creek is counted among the top five most impervious watersheds of the city of Austin. In the future, if all the sites present within the boundary of the watershed are developed to their maximum impervious cover limit, there will be 5,312 acres of impervious land (65 percent). Thus, for an inch of a rainstorm, there will be a minimum of 79,329,408 gallons of urban runoff. As of today, more than half of the watershed is already impervious, and 27 percent of that impervious cover is only because of transportation, as transportation is primarily the paving of the streets and roads. When there is a 1-inch rainstorm, the streets (1210 acres) alone produce 18,070,140 gallons of runoff. With the drainage system and other infrastructure incorporated into the site, only 19 percent of the total impervious cover is treated for water quality. Essentially there is not much runoff that most of it go into Lady Bird Lake untreated. The Colorado River (which forms Lady Bird Lake because of the Longhorn Dam) is the source of drinking water, agricultural irrigation, and wildlife habitats downstream.

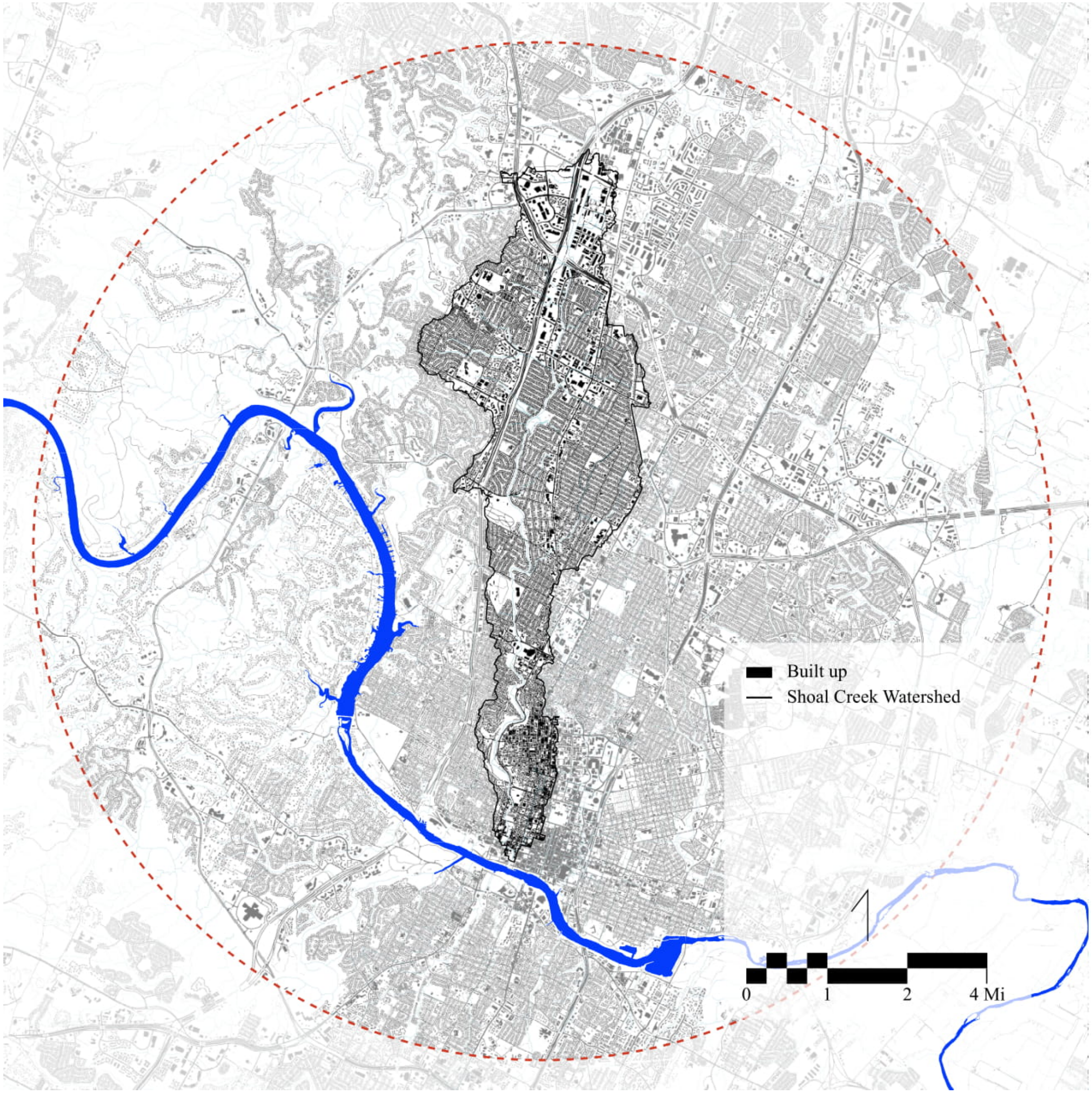


Figure 44 Shoal Creek Watershed Built vs. Open Map

8.4 Current Problems

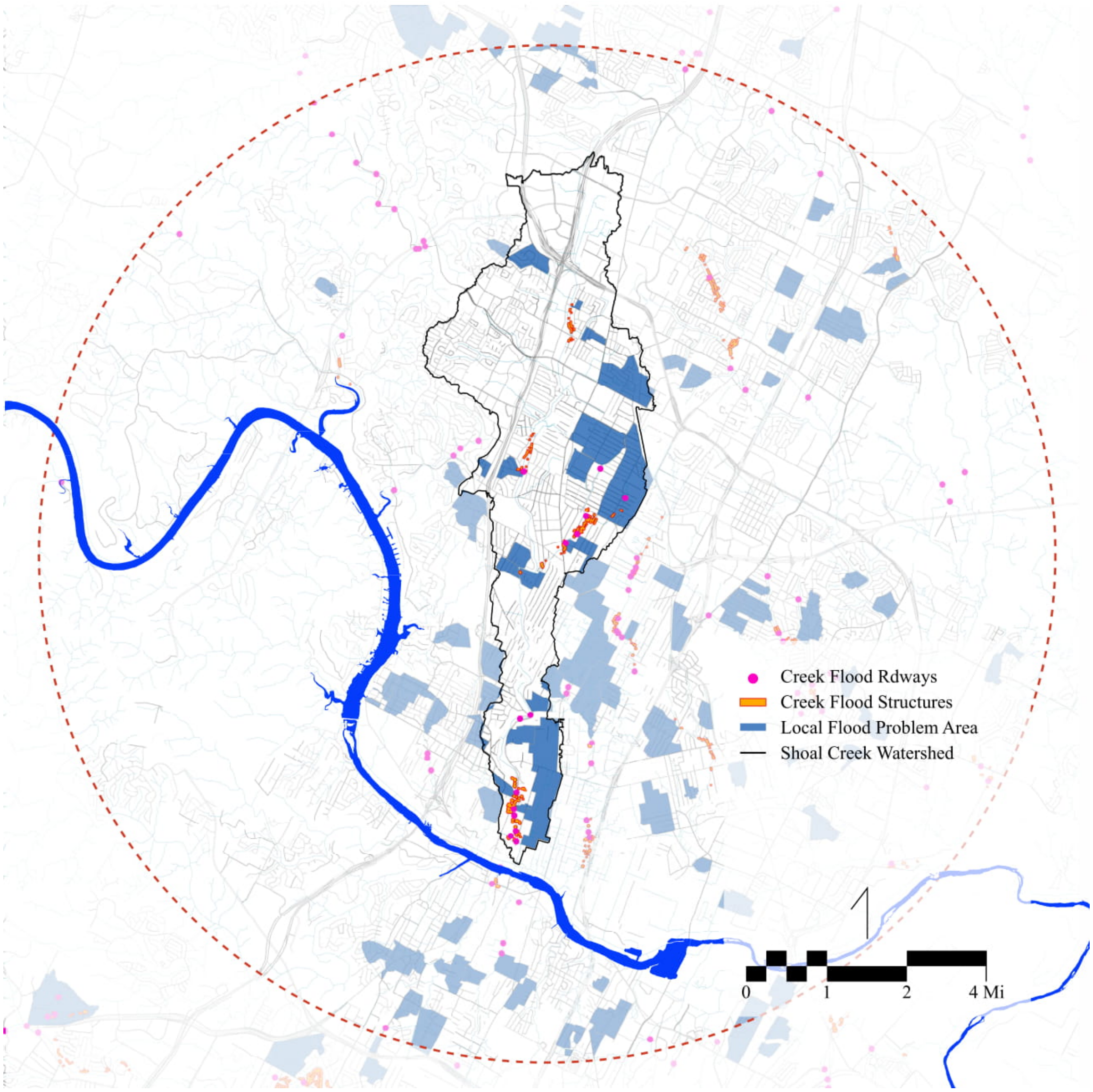


Figure 45 Shoal Creek Watershed Infrastructure at risk during the local flood and creek flood

At present, 40 streets/roadway and 275 structures within the Shoal Creek Watershed are at risk of the 100-year floodplain. One of the reasons is that the east of Shoal Creek in the downtown area was literally the place where the City of Austin was first developed. Due to the early development, 60 percent of this watershed area was occupied and built prior to the modern drainage regulation. By the time water quality regulations were adopted, the area was 71 percent developed. Second, the creek is seriously suffering from suffocation. Seven thousand two-hundred people live within the creek, and dense development of 1400 residences and commercial buildings directly built along the Creekside leads to uncontrolled polluted storm runoff. Third, one of the serious problems Shoal Creek faces is flooding. In the past, the creek has been a victim of the temporary overflow of water on its land with very high intensity that has killed many innocent lives, destroyed many properties, and disturbed the surrounding ecology. Currently, the population within the creek is 72000, and the total impervious cover is 54 percent. The city demographic study predicts that by 2040, there will be 104,000 people, and impervious cover will increase to 64 percent with the watershed boundary. There are higher chances that the aforementioned problems will increase if not addressed with a sustainable management plan.

Figure 46 Shoal Creek Watershed- Erosion sites and creek segments

8.5 Timeline of flooding event and actions taken for the Shoal Creek Watershed

1915

1981

2015

2018

Figure 47Images of Shoal Creek flooding

1869	The highest, and probably the most disastrous flood that ever came down the Colorado
1915	Night storm of 10 inches in less than 2 hours
1960	7”-10” of rain fell, 2.5 million dollars in damages
1974	Waterways Ordinance restricts development in the 25-year floodplain and reduces post-development peak flows.
1974	The MoPac Expressway undergoing construction in 1974,
1977	Adoption of Austin’s first Drainage Criteria Manual.
1981	The original Memorial Day Flood.
1983	100-year floodplain established.
1991	Over 66% of the land area of the north urban watersheds (Shoal) was developed prior to the Urban Watersheds Ordinance of 1991
1991	Urban Waterways Ordinance establishes setbacks for streams and critical environmental features; mandates the use of water quality controls.
2013	WPO expands stream setbacks to eastern watersheds, restricts development in the Erosion Hazard Zone, & strengthens floodplain modification criteria.
2013	The original Halloween Flood.
2015	Memorial Day Flood 2.

Figure 48 Action taken to mitigation some of the flood impacts of Shoal Creek Watershed

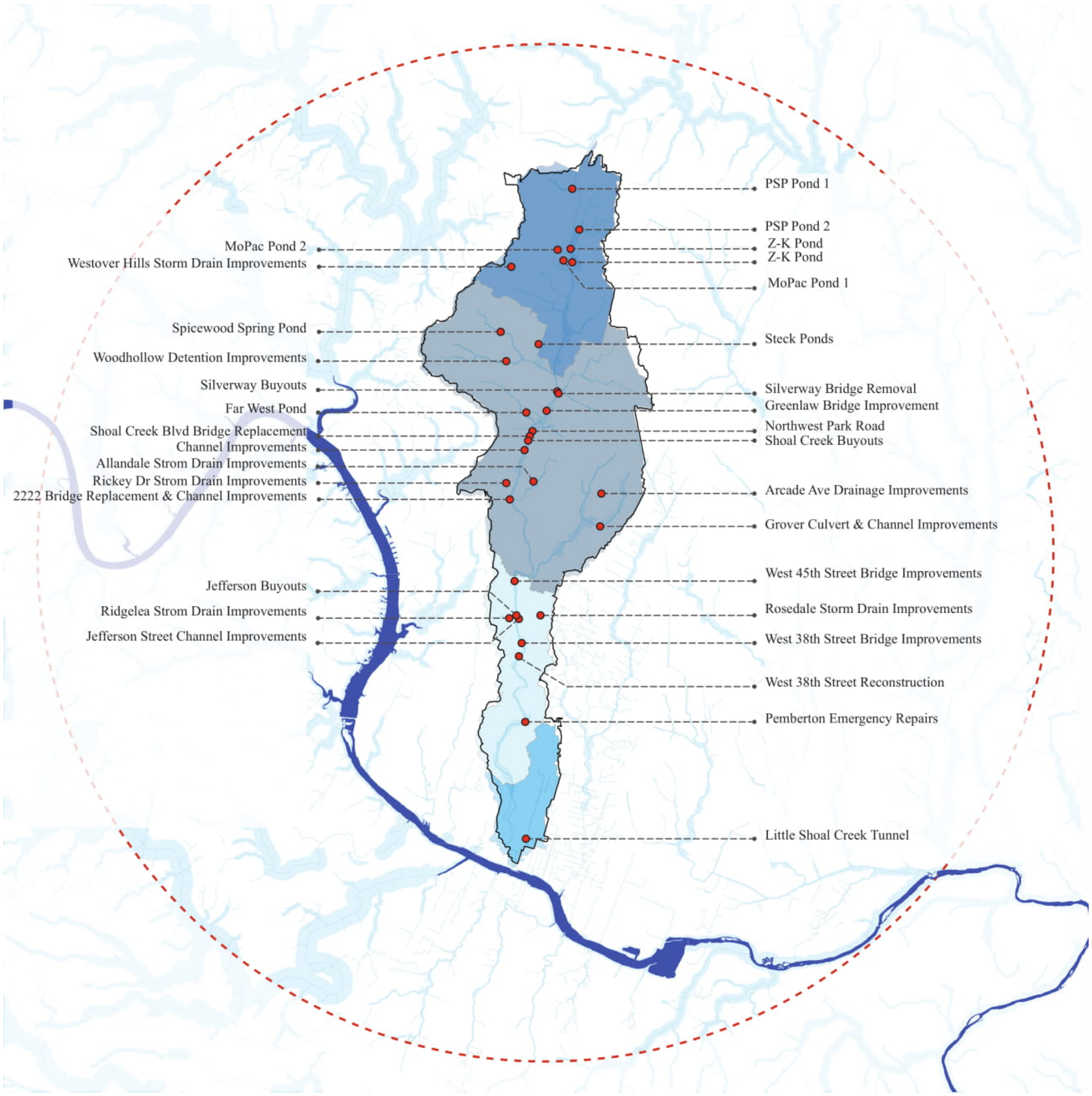


Figure 49 Shoal Creek Flood Mitigation History

Chapter 9 Analysis at the microscale: Clay Street, Austin

9.1 Project Location

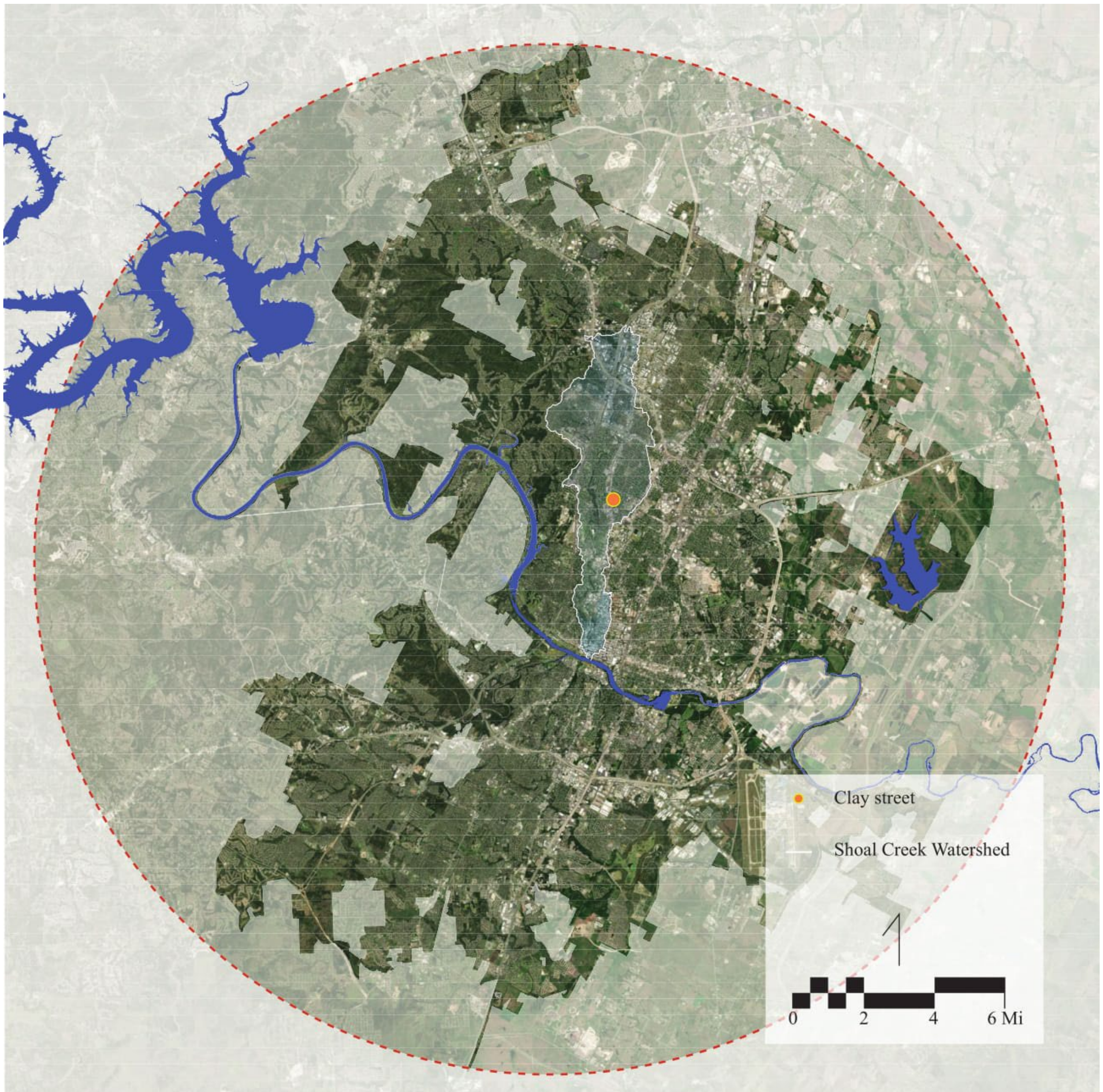


Figure 50 Location of Clay Street in the City of Austin

Clay Street is a 0.3-mile-long city-owned local roadway in the heart of Brentwood neighborhood in Austin. The Brentwood neighborhood is located in the north-central of the region of Austin. As one of the best places to live in the city, it is very densely populated. The vicinity of Clay Street is very vibrant and has many recreational activities like bars, restaurants, cafes, and parks. Due to this lively character, more than 46% of the population living adjacent to the street are millennials. Until 1954, there was hardly any development around Clay Street, and it was primarily used for cotton farming. Today, there are 196 households and 355 people living adjacent to it. The apparent difference in the open versus to built land in 1954 and the present day is evident in the figure below.

Figure 51 Clay Street in 1954 & 2019

In order to address the problem discussed in this report, a specific site within the Brentwood Neighborhood will be zoomed into and focused on. When the natural land of the neighborhood transformed into a densely populated area, it gave birth to many flood-related challenges. The location of Clay Street is 0.2 miles from the Hancock Branch of Shoal Creek. Because of its proximity to the creek, it has the great opportunity to set itself as a case in point to mitigate some of the flooding issues on its densely populated surroundings.

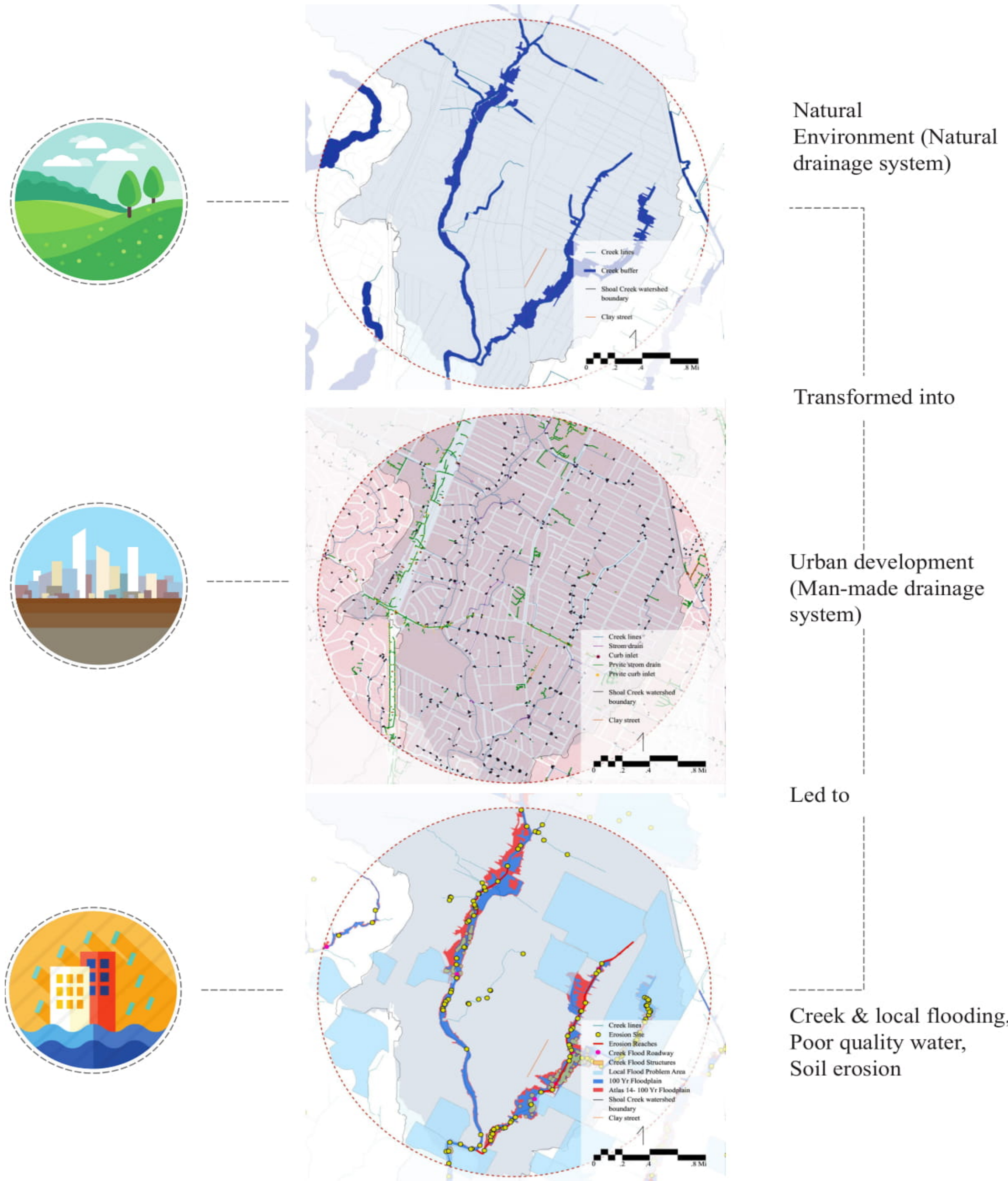


Figure 52 Transformation of the natural environment of Hancock Brach of Shoal Creek into urban development/city and its current flooding Problems.

9.2 Site Context, Characteristic & Constrains

Clay Street is a two-way local road that plays a vital road in connecting residents with the surrounding area and neighborhood. The right of way is 30 feet wide. The entire roadway is one travel lane with on-street parking on both sides. This local street of Brentwood neighborhood very interestingly interacts with the junction of the arterial road (Burnet Road) and collector road (Houston Road). There are three intersections along the entire street. The first is a major intersection of Clay Street with Burnet road at the starting of the road. A couple of blocks later, there is a minor intersection at Houston street, directly. The third one is where the street ends while cutting Ullrich Street. The surrounding buildings are mainly a mix of Commercial, Vertical Mixed-Use, and Single-Family Residence.

The topography within the selected site area is generally flat, with a gradual slope to the southeast in the direction of the Hancock Branch of Shoal Creek. The total impervious cover of the Clay Street within its right of way is approximately 1 Acre. Since the curb inlets are situated only near the Houston intersection and Vertical Mixed-Use buildings, in case of storm events, the majority of the surface runoff gets collected along with urban pollution and poured into the creek directly. Eighty percent of the sidewalks are missing on both sides of the street. The trees are scarce in the southern part of the street, but as we go up towards Ullrich Street, it gets lush tree canopy.

Figure 53 Clay Street site analysis

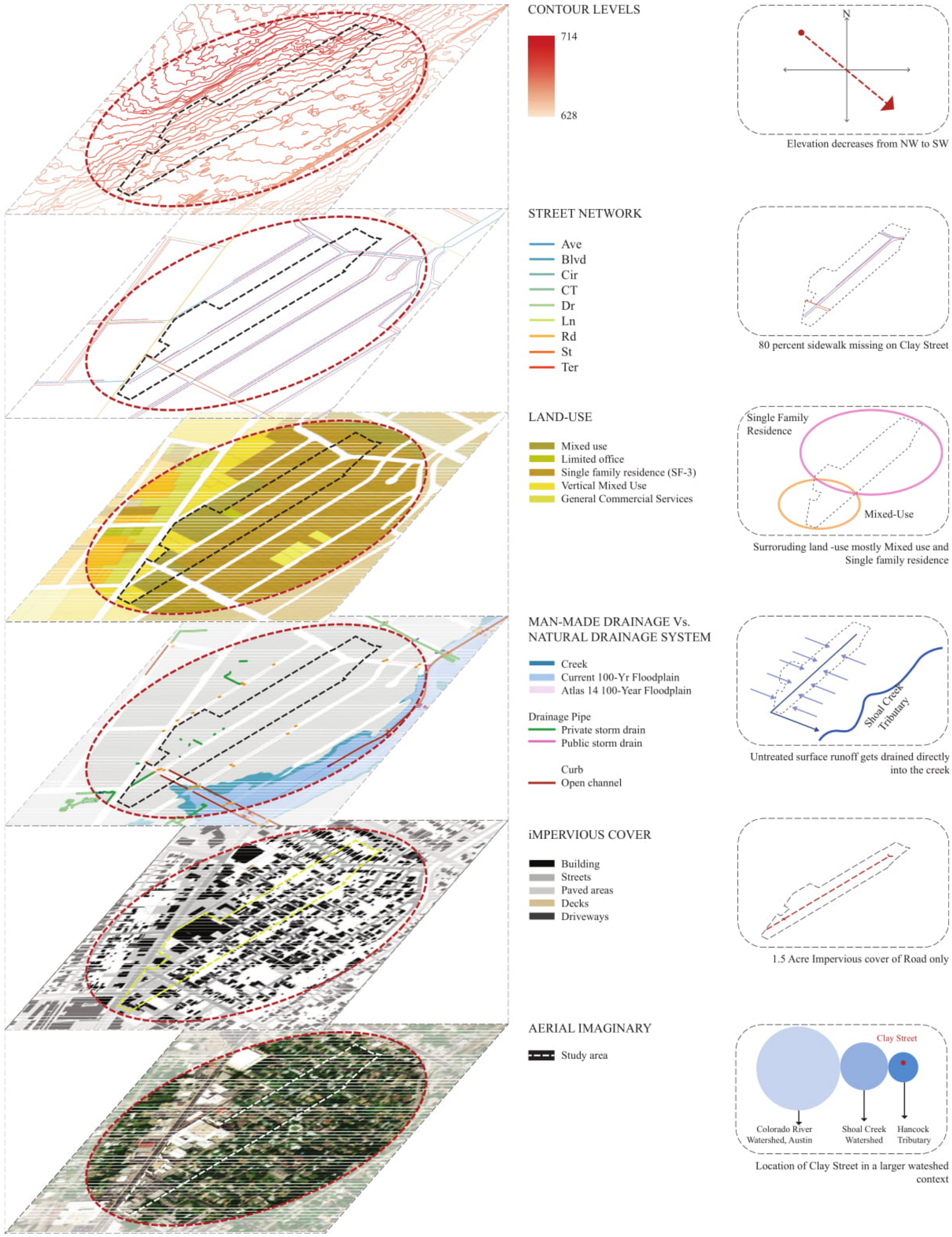


Figure 54 Axonometric Site characteristic of Clay street

Figure 55 Contributing area for Clay Street

9.3 Goal and Concept

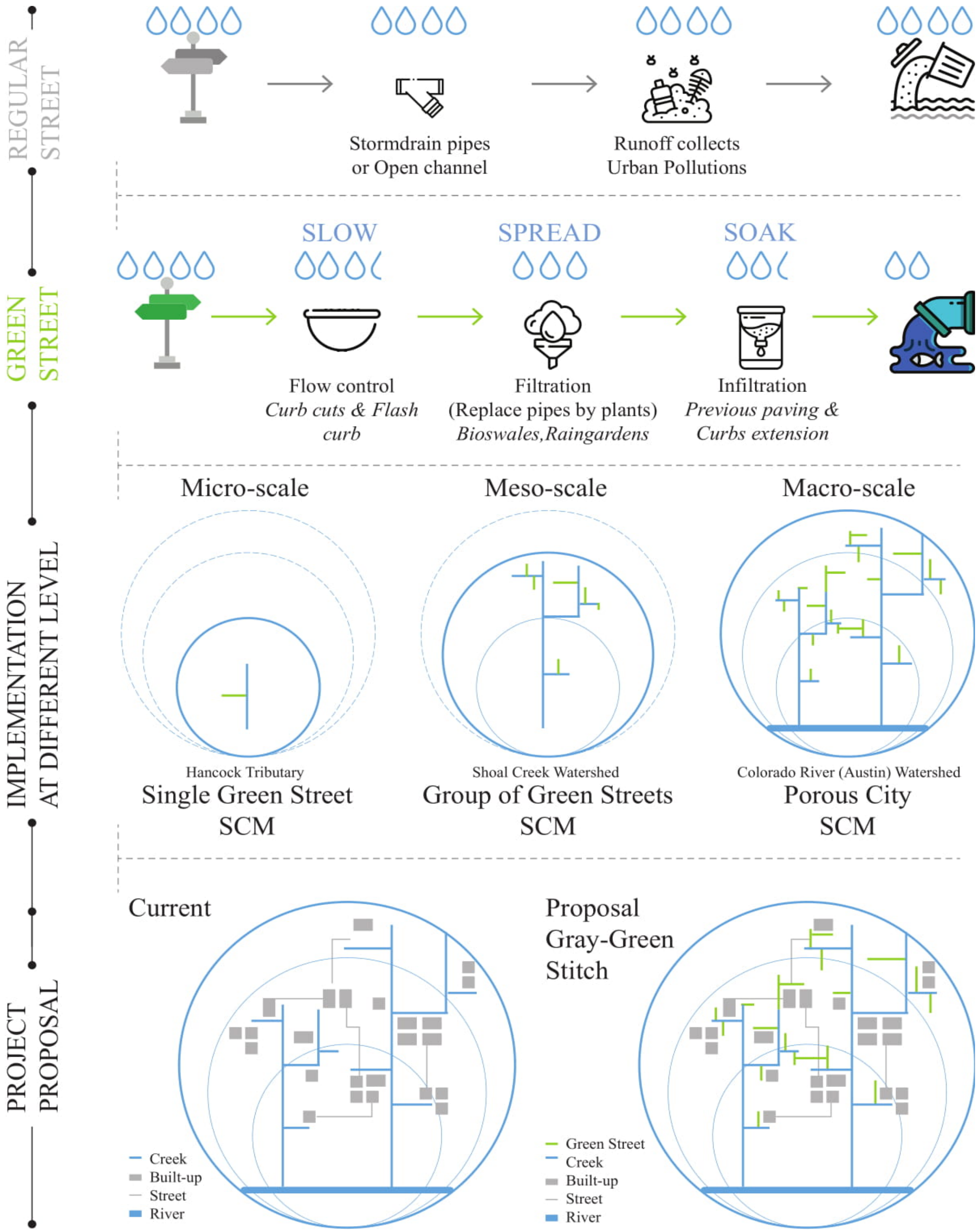


Figure 56 Conceptual analysis for the Clay Street project

The City of Austin is blessed with water bodies that meander all around the city's built-up. Unfortunately, current approaches of urban design in the city fail to ignore the fact that with increase in impervious cover and predicted storm events frequency, not only do our cities, according to Peñalosa (Wright & Wheelwright, 2017), "need green in Sizes of S, M, L, and XL-otherwise the human ecosystem is incomplete", but we also need smart techniques that use public grey infrastructure like streets to mitigate some of the flood challenges by incorporating green in them.

General Overview

The main objective of the project centers around the idea that, in the most densely populated area of the city, urban streets can be converted into green streets. Doing so will help not only manage surface runoff fully but also benefits the city to do the following: improving air quality; adding amenity value; promoting wellbeing; ensuring cooling effects; reducing energy consumption; providing habitat; developing social cohesion; and increasing property process and land values.

Goal

Begin with a design of a single street that incorporates green infrastructure into its public right-of-way to deal with local flooding issues. Next, create and implement the same to neighboring or connecting streets to mitigate watershed issues. Finally, create a network of green streets at a regional level to preserve, converter restore the ecology of the city, and achieve multiple objectives.

Clay Street Green Street Overview

The proposed design on Clay Street, Austin, will incorporate various ecological-based stormwater management approaches on the street. This will favor soft engineering to treat the storm runoff on the site itself. The goal here is to manage stormwater runoff close to its source or on the site itself through a network of distributed treatment landscape. Unlike the traditional method of using curbs and gutters to channel the runoff and its pollutants elsewhere, here, the rainfall is managed through the vegetated treatment network and techniques that include infiltration, filter, store, and evaporation. This method will help to reduce and improve the quality of runoff discharging into the Hancock Branch of Shoal Creek and recharge the grounds which was initially covered by the impervious cover.

Goal

Change the typical design criteria of the street from maximization of vehicle flow per hour and drainage to a design that accommodates multimodal transit, ensures ped-bike safety, and minimizes the impact on the natural ecology by incorporating stormwater management techniques.

9.4 Proposed design elements for the Clay Street

The proposed design elements discussed and recommended below are intended to fit within the existing right-of-way of Clay Street.

A. Roadway Design Criteria

*Functional Classification-*The design does not propose any functional classification of Clay Street. Clay Street is designated as a local road and will remain the same after the implantation of green infrastructure proposed in this project. Also, the two lanes (with one lane each direction) will remain the same.

*Traffic and Circulation-*As, most of the land-use in surrounding Clay Street, is residential, the proposal recommends slowing down the excessive speeding during the off-peak hours. An example will include implementing GI elements as traffic-calming devices along both sides of the road and all three intersections.

*Lane Width-*The current average lanes width of Clay Street varies from 7 to 8 ft. The proposed green street design considers 8ft lane widths.

B. Ped & Bike Design Criteria

Sidewalk- 80% of the sidewalks are missing on both sides of Clay Street. One of the main recommendations for the design will be to propose sidewalks on both sides of the street, which comply with ADA regulations for pedestrian safety.

Pedestrian Crossing- The intersection of Clay Street with Burnet Road is 71ft wide. For easy pedestrian crossing, curb bump-outs will be suggested in the design. This will also serve as a traffic-calming measure at the junction.

Bicycle Design Criteria- There are no designated bike lanes on Clay Street. Green-colored paint symbol of Shared Lane Markings (SLMs), or "Sharrows," would help the bikers to bike safely on the shared lanes and increase visibility.

C. Other Design Criteria

On-Street Parking- There is an entire strip of on-street parking on both sides of Clay Street. The proposal will replace the on-street parking space with strips of vegetation landscape that will help mitigate stormwater issues.

Pedestrian Scale Light- The current streetlights are designed mainly for keeping automobile safety at the height of 20-30 feet high and approximately at 150-300 ft of the distance between them. For pedestrian and bikers' safety, it is recommended to add human scale light fixtures between the street poles. This will also improve the aesthetics and make the street livelier during the dark hours.

D. Stormwater Infrastructure

While traditional stormwater works by directing the on-site surface runoff by pipes and discharging it into the nearby water channel right way, the Clay Street design proposes the installation of design elements to treat the runoff differently. The process will include slowing, spreading, and soaking the runoff before discharging it into the nearby water bodies.

1.Slow-Flood Control

Curb Alternatives: Low-impact development curb alternatives are absent on Clay Street. This issue can be addressed by preparing a few curb alternatives (for example, flush curb, curb cuts) to help distribute runoff to adjacent treatment facilities evenly. It will certainly help to retain as much stormwater on-site as possible on Clay Street.

2.Spread-Filtration

Bioswales & Rain Garden: Once the surface runoff is distributed evenly, the next step is to incorporate design elements that will reduce the flow rate of runoff on the site. Installing continuous bioswale or vegetated landscape strip along the right-of-way of Clay Street to filter the urban pollution and recharge the grounds will be practical.

3.Soak-Infiltration

Pervious Paving & Curb Extension: Finally, install curb extension at the intersections and in the parking area of Clay Street to reduce the risk of accidents at the junctions and manage the storm runoff at the same time. As 80% of sidewalks are missing on Clay Street, adding pervious paving in the sidewalks will help reduce impervious cover and encourage infiltration during small storm events.

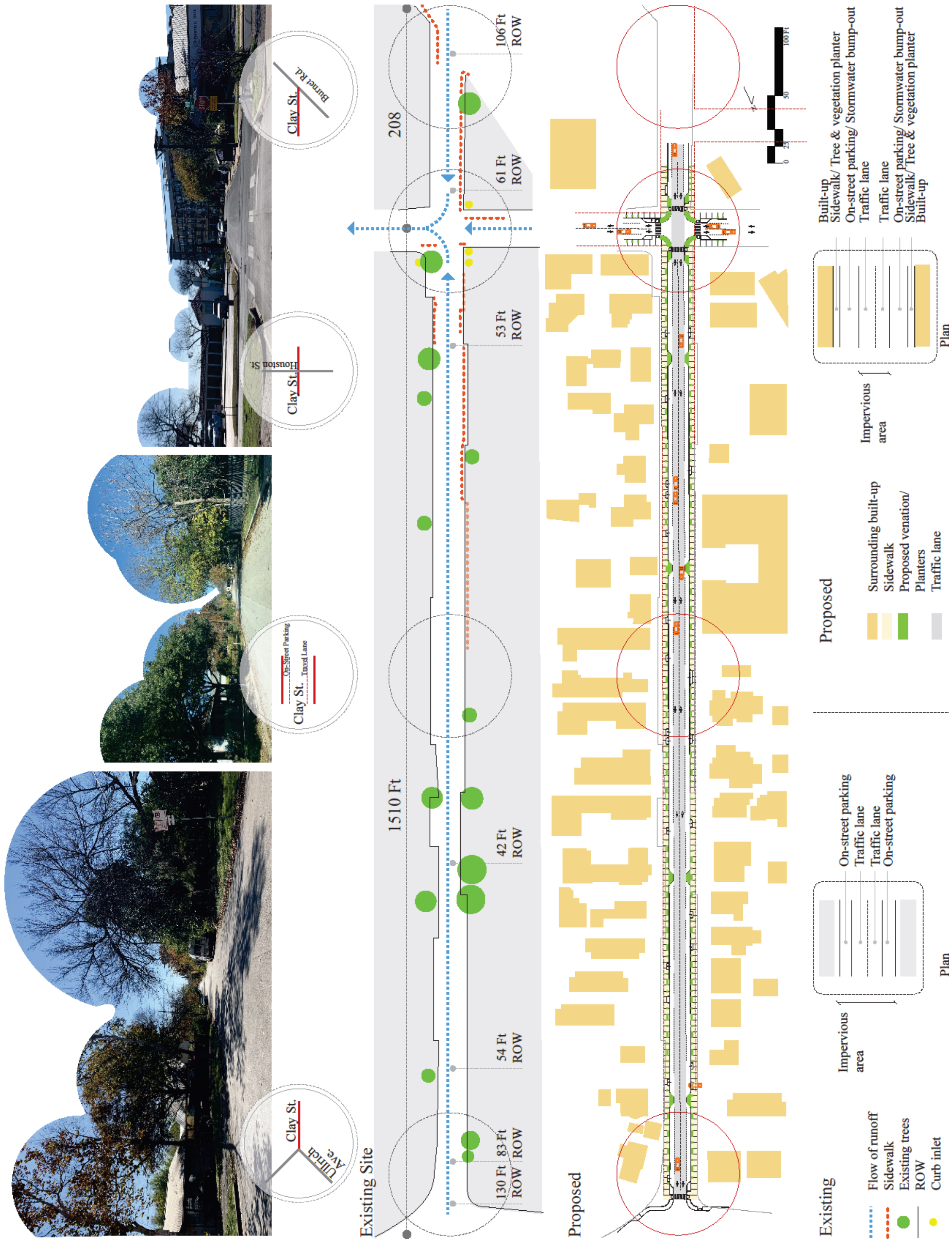


Figure 57 Conceptual design plan for Clay Street.

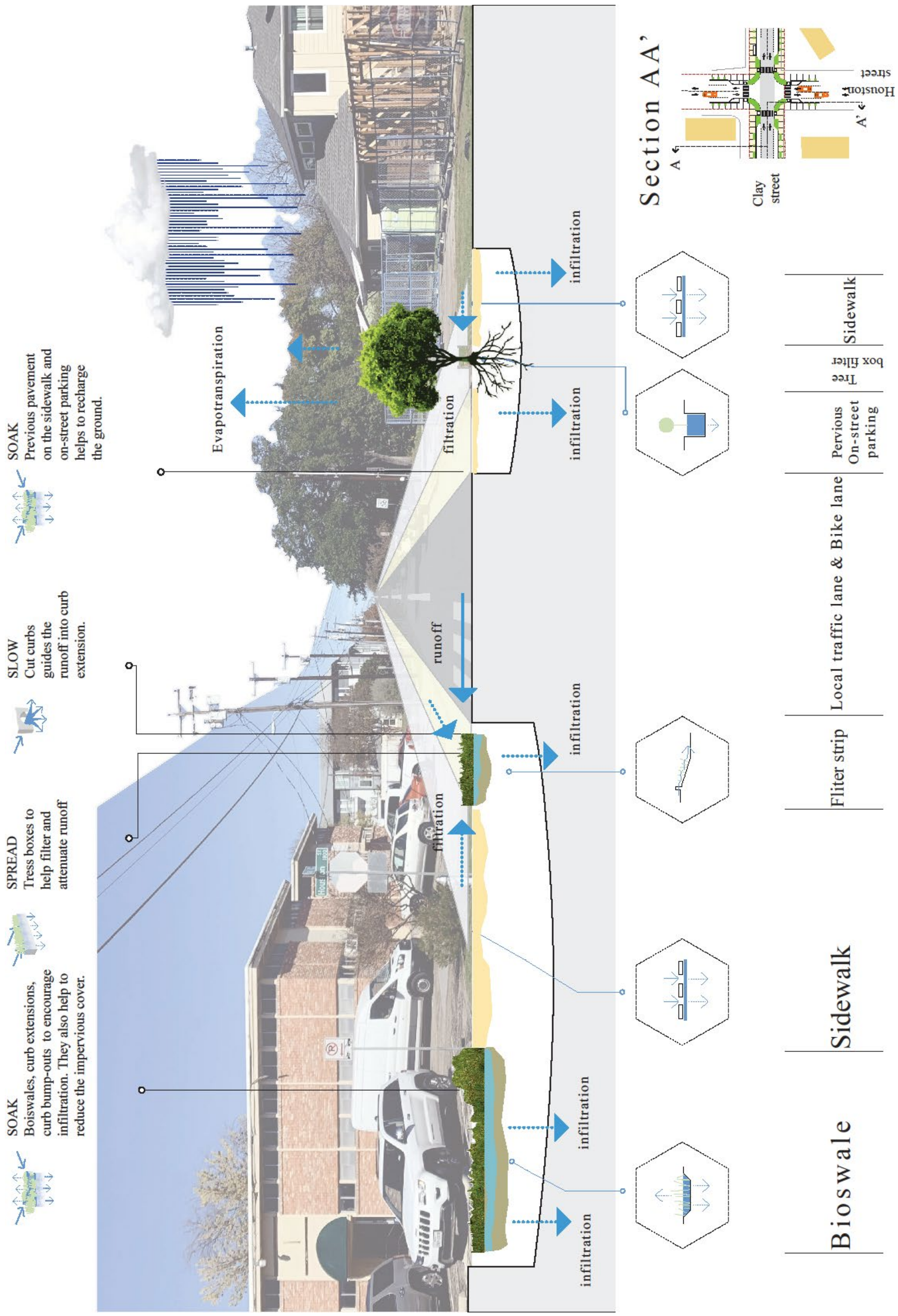


Figure 58 Design local streets as landscapes to achieve multiple goals

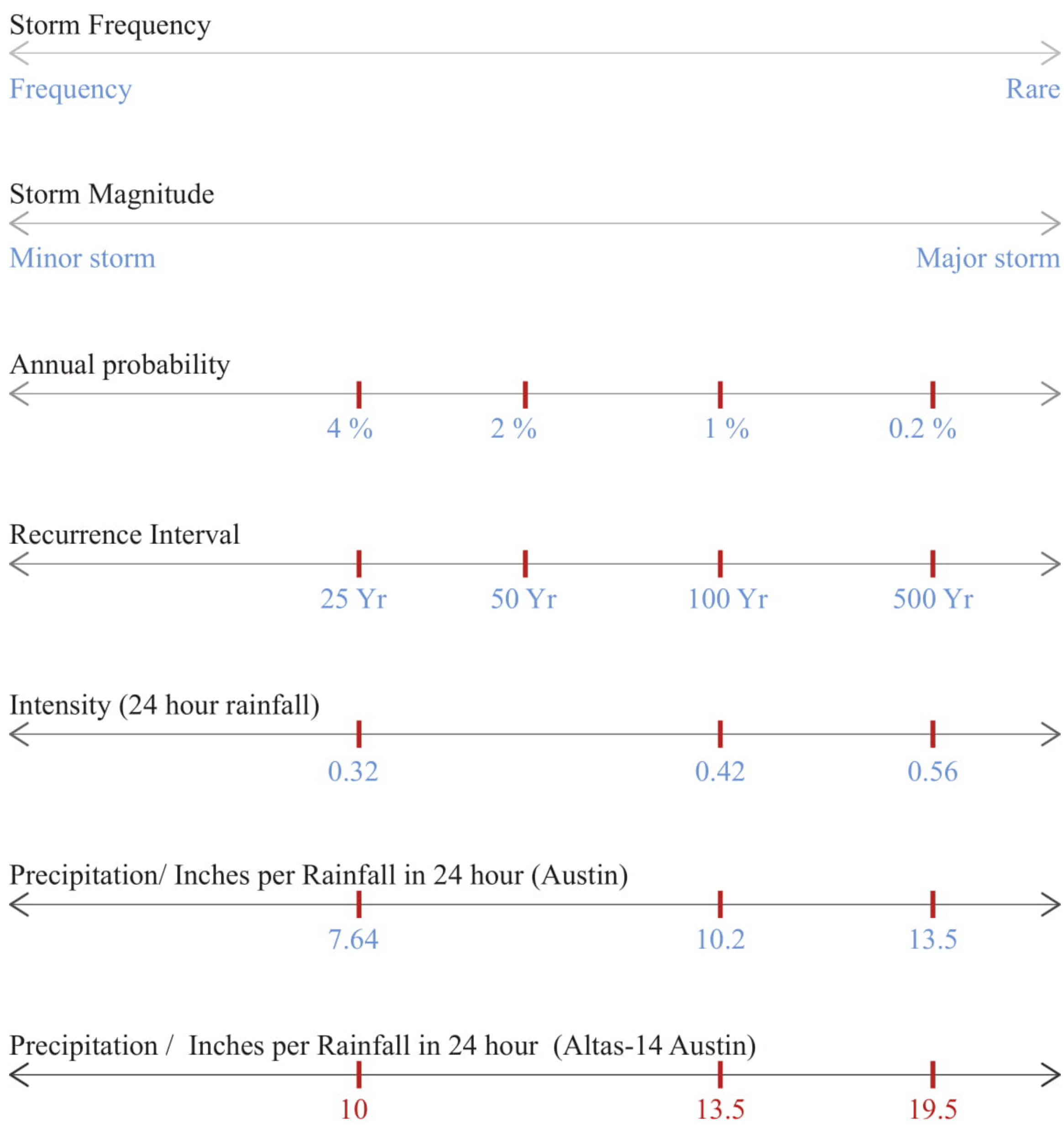


Figure 59 Strom event classification and predicted rainfall precipitation for the City of Austin.

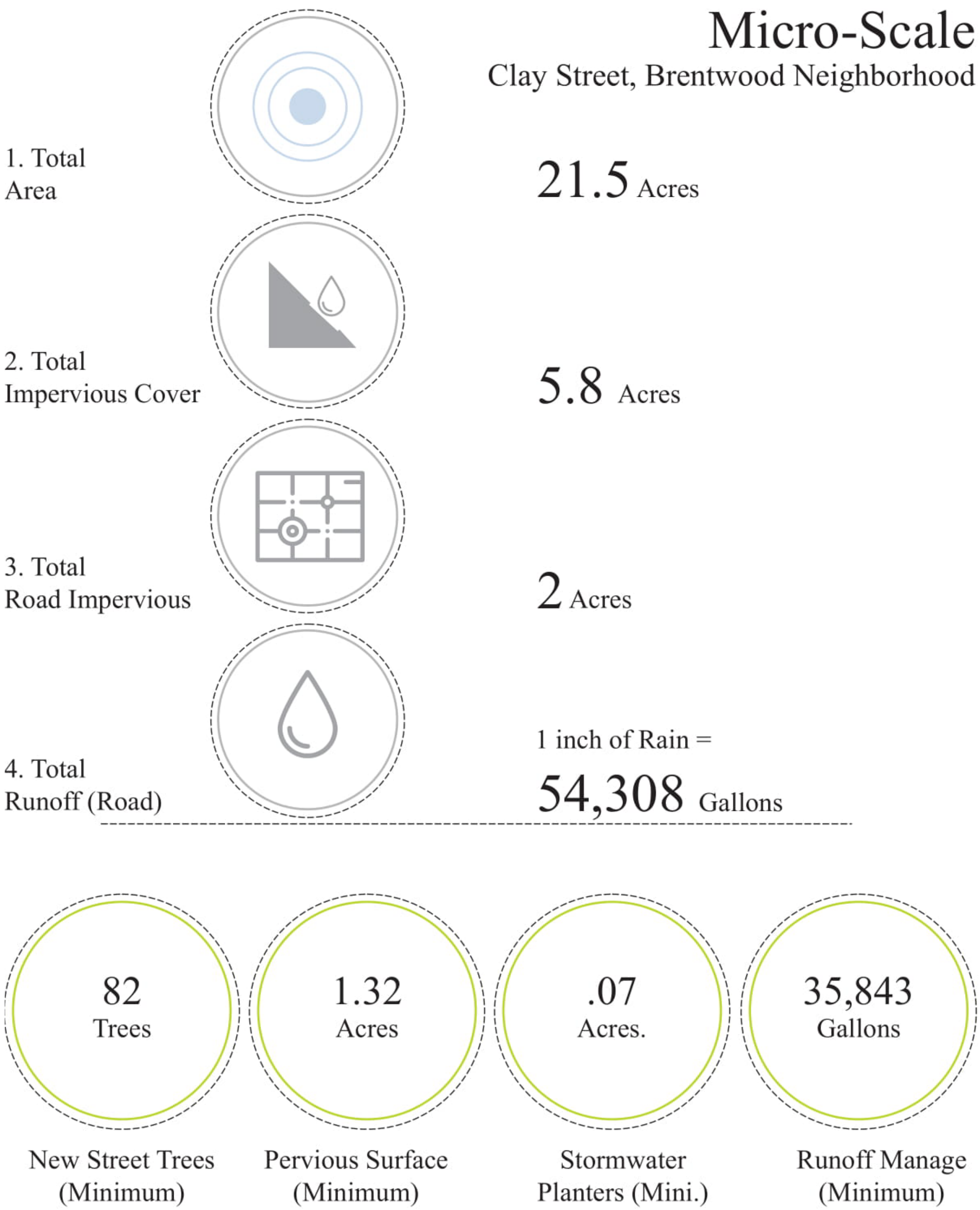


Figure 60 Calculation results for Clay Street

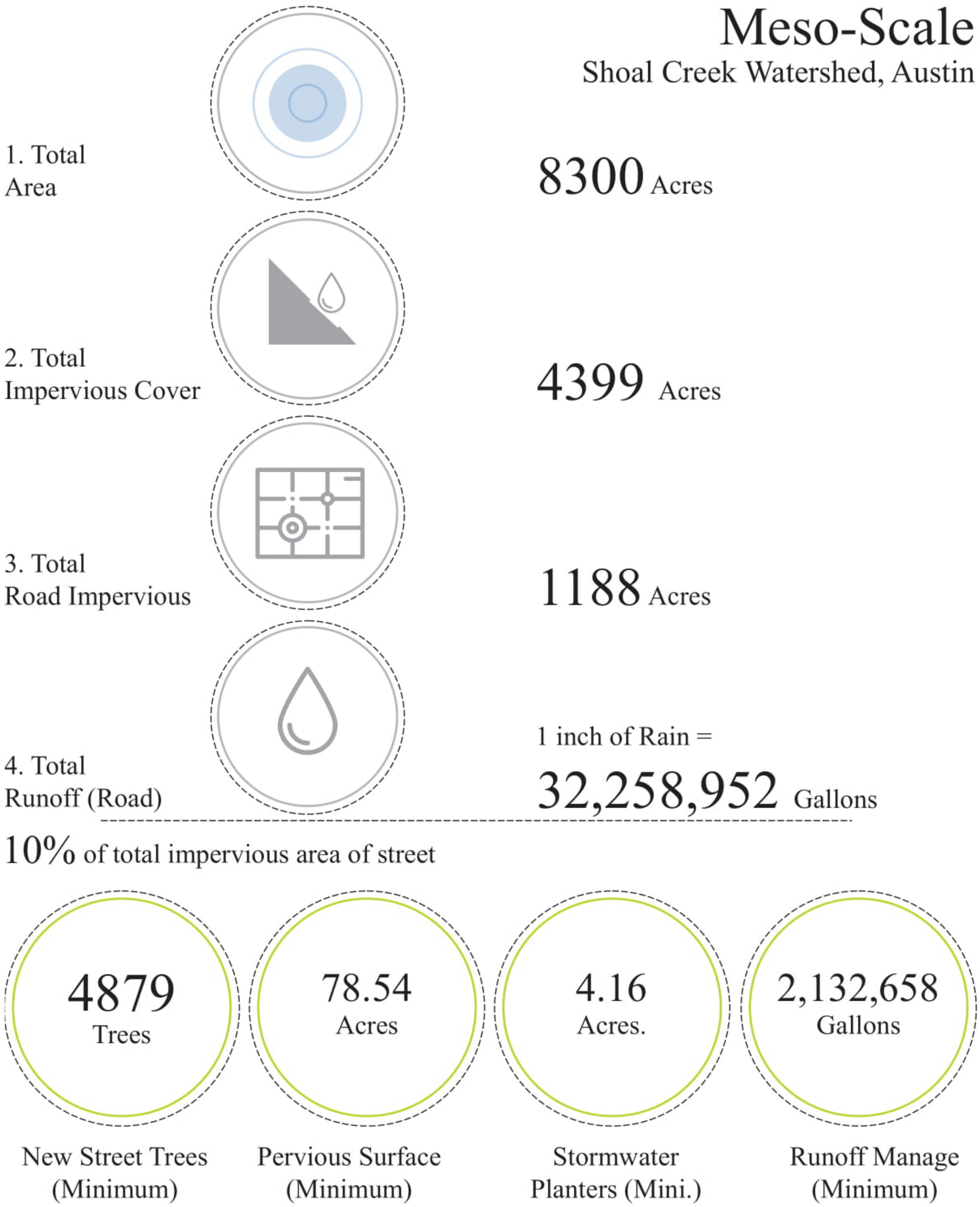


Figure 61 Calculation results for Shoal Creek Watershed. (10 percent of street area converted into Green Street)

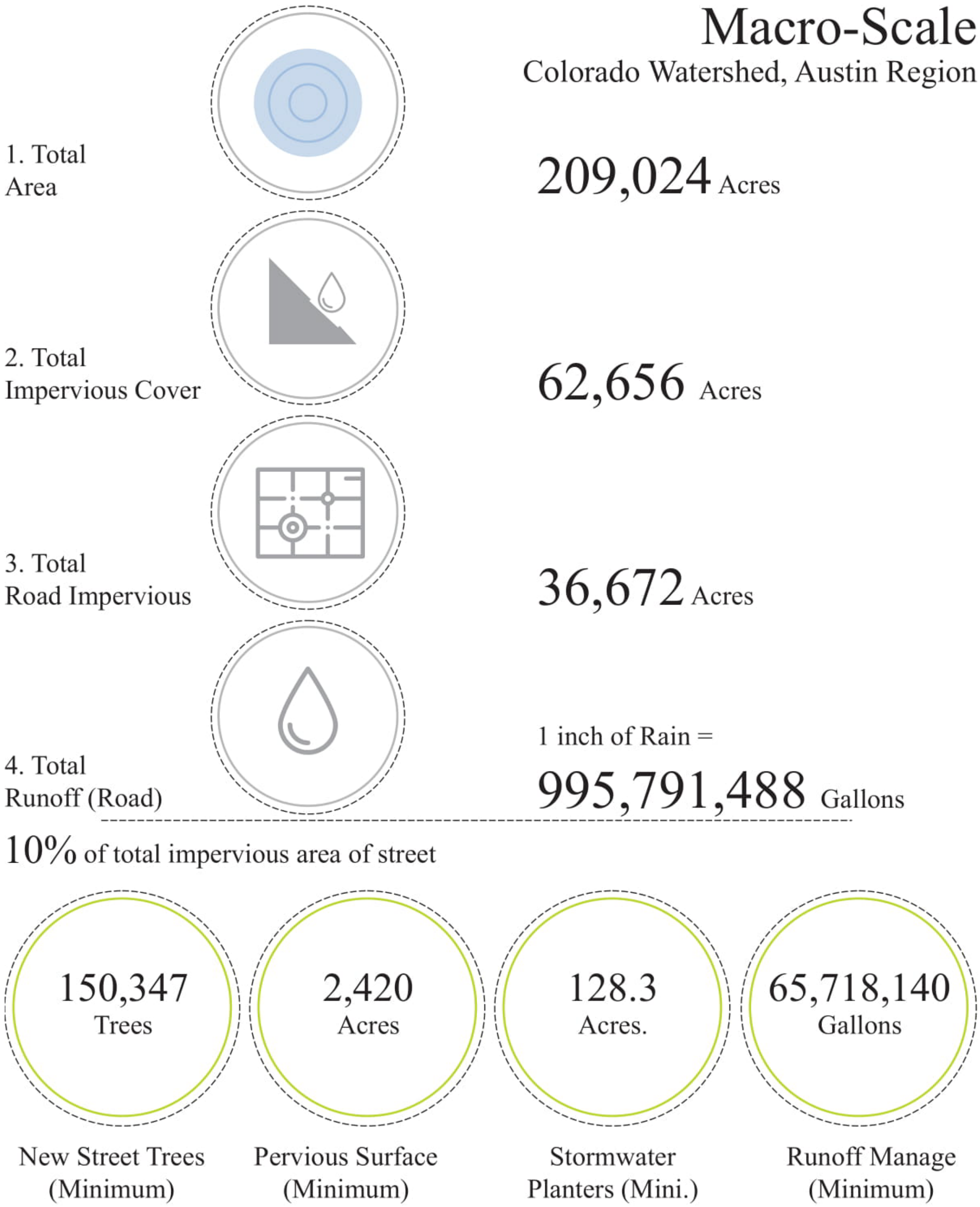


Figure 62 Calculation result for the City of Austin. (10 percent of street area converted into Green Street)

Chapter 10: Conclusion & Calculations

No doubt, climate change is predicted to increase the frequency of storm events and rainfall. If the current planning and urban design approaches of cities do not divert towards sustainability, then predicted climate change has the potential for mass destruction of the city's development and ecology. The impact of the first urban century discussion has been flowing in the United States for quite some time. Still, only in recent years have cities like Portland, Seattle, Philadelphia taken this discussion seriously. Currently, the negative impacts of urbanization are increasingly being discussed; more and more cities are curious to know about Low Impact Development (LID) and Stormwater Control Measures (SCM). There are many LID, and SCM cities can adopt and rely upon to better prepare themselves for the upcoming storm challenges. But this report primarily focuses on how streets' Right-of-Way can help the City of Austin mitigate some of the burdens of the predicted storm event.

After 1920, the streets were designed with the expertise of civil engineers. Very high importance was placed on the two design criteria back then: drainage and the smooth flow of vehicles in each lane per hour. Green streets are more efficient than traditional street design. They help to manage and treat the surface runoff. They also bring back the era that existed before 1920, where the street was also for urban activities like gathering, playing, relaxing, and greener less impervious. Not only that, unlike tradition streets' ROW design, a green street design incorporates the full spectrum of ecological services.

To understand the importance of Green Street, this report presents a detailed look at the conceptual Green Street design for Clay Street, located in Brentwood. The design explains the techniques of treating stormwater runoff by slowing, spreading, and soaking rather than directly discharging it with urban pollution and treating elsewhere.

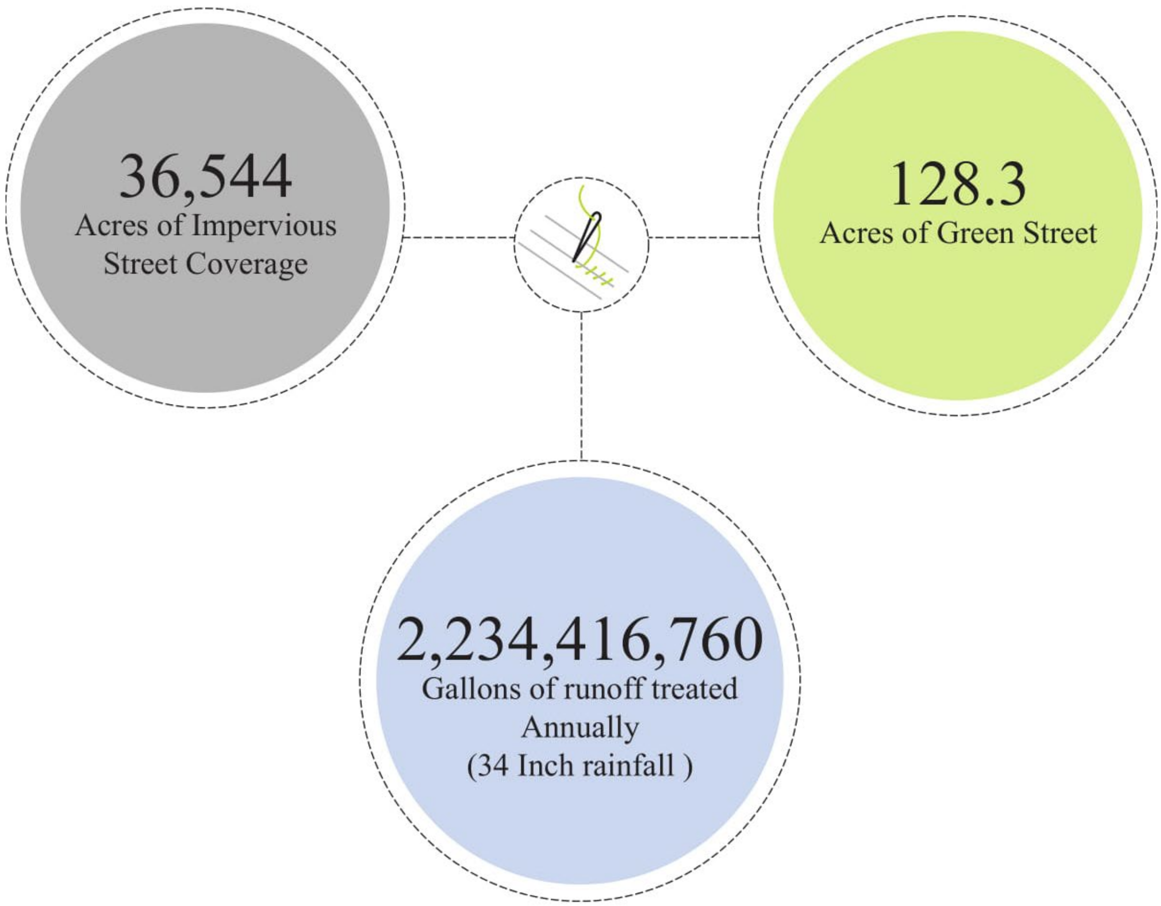


Figure 63 The gray & green stitch

Only 10 percent of street impervious coverage of Austin is considered and plugged in with the number derived from the Clay Street design then a total of 2420 acres of impervious cover is into the pervious surface. Preserving the existing trees, minimum of 150,347 additional street trees are added on the site to fill the gaps. 128.5 acres of stormwater planters are proposed. 2,234,416,760 gallons of storm runoff can be managed annually. Overall, the Green Street design elements help to control the volume of stormwater runoff, improve water quality, and reduce the peak flow rate. Additionally, they also help to balance the water cycle, promote health, calm traffic, reduce the effect of heat island, and lower the impact of the storm event.

Here, Clay Street Green Street Project demonstrates itself as a case in point concerning how Green Street helps achieve stormwater management, traffic, environment, and clean water goals. The same purposes can be reapplied to many other urban streets of the city. It would help create a network of connected Green Streets, which together could be more useful to solve even bigger regional-scale climate change and environmental issues. It is crucial to understand and keep in mind that each street is unique, and any alteration must be made to its design and planning after studying the particular context. To conclude, this report sums up with an idea of how streets can be designed to become the most significant asset, not a liability to manage some of the predicted storm events along with many other issues. When Green Street is planned and designed well, they can stitch the grey (impervious cover) and green infrastructure (green street) to help the blue (creeks, tributaries, and river) of the City of Austin.

The Grey and Green Stitch project was created primarily to motivate the City of Austin's planners and designers to implement green infrastructure into the Right-of-Way of the street. Both private and public entities can refer to this report. However, the project should not be considered a standard for any real-life project. In the future, with the help of an interdisciplinary expert team, and with proper planning and designing, a pilot project can be implemented

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