Rethinking Green Infrastructure on the University of Minnesota Campus

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Brandon J Thompson

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Abstract

As water events become more extreme and more common, we are having to find innovative ways to deal with this increase. In urban areas, current water systems that were designed to last around 100 years are failing well before originally planned due to erosion from runoff sediment. With all this water being put into the sewer system, it is also causing the water quality to drop significantly. The goal of this project is to slow the water down, spread the water out, and soak the water up so that smaller rainfall events can be handled through natural systems, and runoff from large rainfall events can be mitigated and take away our current reliance on inefficient and failing systems. The University of Minnesota campus is the 6th largest campus by population in the United States, located near downtown Minneapolis where impervious pavement is the norm. Founded in 1851, the current campus design was built for function, not sustainability and water quality, and we are trying to change the thinking and integrate the two. The campus is also split by the Mississippi River, one of the longest and most powerful rivers in the world. It is also one of the most polluted due to runoff contamination starting in Minnesota. This thesis looks to implement strategies to the current campus design to mitigate runoff and reduce the amount of runoff being sent to the Mississippi, but to do so in an educational way that sets a precedent for how water should be managed.

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List of Abbreviations

ADEQ: Arizona Department of Environmental Quality

ASCE: American Society of Civil Engineers

AWWA: American Water Works Association

CNT: Center for Neighborhood Technology

DNR: Department of Natural Resources

ECS: Ecological Classification System

GI: Green Infrastructure

GIS: Geographic Information Systems

IonE: Institute on Technology

SNA: Scientific and Natural Areas

CHAPTER I: INTRODUCTION

The University of Minnesota campus has seen an increase in large rain events that have increased flooding in the local area, but have also caused a decrease in water quality, forcing a large investment in water mitigation plans. As a public university, the campus is open and used by many and boasts one of the largest alumni associations in the country. With this comes a tradition and history that needs to be maintained, while also solving the issue at hand. As a heavy research institution, the solution to the water problem needs to be one that shows respect to the history of the school, but is also dynamic and visible to become teachable and repeatable. While the entire campus is just over 2,700 acres, the focus is on a 28-acre section at the core of the campus to educate people on the power of natural systems and water mitigation.

Green infrastructure will be a main focus and how designers and can implement strategies that adds value to the projects beyond monetary value. With value typically only being seen in dollars and cents, the way these systems are viewed as “valuable” needs to change. Looking at ways green infrastructure and rainwater design can be beautiful, educational, and functional is a major key. The focus is on three major points: creating diversity in stormwater management and water usage, connecting and using natural systems, and changing the behavior and thinking behind the need for green infrastructure.

As the climate continues to change, climate variability will continue to increase and result in larger flood events at a more frequent rate. A redesign of the Church Street Corridor looks to implement green infrastructure as an educational resource for students, while also serving as a base case that can be applied to the rest of the campus. As an extremely urban site, runoff is a major problem that is degrading the current stormwater system. Instead of band-aid fixes or a costly replacement of the whole system, a redesign will solve the current problems by making the area more self-reliant and diverse so that there is flexibility in a system that has been rigid for too long.

CHAPTER II: LITERATURE REVIEW

The first step in this investigation was to look at literature focusing on green infrastructure and why it has not gained popularity, and to understand the pieces that make up the whole. The literature that is evaluated is made up of experts from different backgrounds, such as biologists, engineers, architects, policy makers, and educators. A range of viewpoints is necessary to completely understand and recognize the pros and cons of the urban stormwater system and what needs to be done to fix the current issues.

The first section looks at the ecology of the earth and looks to point out that a mindset shift is needed before change can occur. There needs to be an understanding that to keep the earth in balance, the parts need to be understood before the whole can be understood, and that an ecological worldview is required, which is a drastic change in mindset. The second and third sections focus on understanding the problem of urban runoff and how cities are dealing with the changes in precipitation and global warming. This, paired with an increase in urbanization, has led to more impervious pavement and higher runoff rates. The general consensus looks towards creating a decentralized system. The next section looks at green infrastructure and how it can provide value beyond monetary value. While it does bring monetary value, money is not the important factor when looking at green infrastructure and how people can relate and use it. Finally, a review of current polices was done to look at how the current system is set up to keep green infrastructure from being implemented. A focus on institutional innovation working congruently with technological innovation will be key in pushing green infrastructure into cities.

a. The Ecology of Earth

Before diving into large systems and designs, it is important to understand the ecology of the earth and how it functions as a whole. In “The Future of Life” by biologist E.O. Wilson, he describes the biosphere, or the totality of life, “as a membrane of organisms wrapped around earth so thin that it cannot be seen edgewise from a space shuttle, yet so internally complex that most species composing it remain undiscovered” (2001, p.3). While humans have been on this planet for thousands of years, the complexity of earth and the totality of life has yet to be totally understood. To understand the whole, the parts that make up the whole need to first be understood, and to understand that these parts are ever changing.

For example, Wilson points out how organisms can adapt to their surrounds in order to survive. He states,

> "The outer reach of physiological resilience of any kind may have been attained by *Deinococcus radiodurans,* a bacterium that can live through radiation so intense the glass of a Pyrex beaker holding them is cooked to a discolored or fragile state. A human being exposed to 1,000 rads of radiation energy, a dose delivered in the atomic explosions of Hiroshima and Nagasaki, dies within one or two weeks. At 1,000 times this amount, 1 million rads, the growth of the *Deinococcus* is slowed, but all the bacterial still survive" (2001, p.6).

These "superbugs" were not developed for this, but over time they adapted in order to survive and to keep planetary diversity. Speaking of which, it has been proven that the greatest diversity of life is found in areas with "the most varied terrain and the greatest climactic stability across long stretches of time" (2001, p.10). As climactic stability begins to become less common, planetary diversity begins to decrease. It is not to say that this is permanent, but rapid change needs to occur to stabilize the climate and keep the planetary diversity. As it stands, life on earth has only just begun to be explored. Wilson states,

> "Even the most familiar small organisms are less studied than might be guessed. About ten thousand species of ants are know and named, but that number may double when tropical regions are more fully explored. Even deeper rounds of zoological exploration, driven by a sense of urgency over vanishing environments, have revealed surprising numbers of new vertebrates, many of which are placed on the endangered list as soon as they are discovered" (2001, p. 16-17).

We cannot fully understand the biosphere if we do not understand what makes up the biosphere, and climactic instability is occurring so rapidly that humans may not get the chance.

While the biosphere is complex, it can be broken down into two versions. Wilson defines these as the strong and the weak version.

> "The strong version holds that the biosphere is a true superorganism, with each of the species in it optimized to stabilize the environment and benefit from balance in the entire system, like cells of the body or workers of an ant colony. The strong version, however, is generally rejected by biologist as a working principle. The weak version, on the other hand, which holds that some species exercise widespread and even global influence, is well substantiated" (2001. p.12).

The weak version is named as it is because it makes the biosphere more vulnerable. The way it stands, the biosphere is at the mercy of these influential species, namely humans, and its existence and health depend on these species wanting it to exist and be healthy. Even if these species want a healthy biosphere, they have to understand how to make and keep it healthy. In this case, humans exercise widespread influence and the rest of the biosphere depends on balance from the top. Currently, there is no balance and the relationship is more like that of a parasite in that the humans are receiving all the benefit at the expense of the other species. Whether this is purposeful of not does not matter. According to C.S. Holling, "a measure of resilience is the magnitude of disturbance that can be experienced without the system flipping into another state or stability domain" (2002, p.50). While the biosphere is resilient, we are starting to see that human disturbance is starting to flip the system into another domain.

Looking at Hes and Du Plessis, the idea of an ecological worldview only works if you understand the whole. They state, "the world is a complex, adaptive and dynamic system governed by non-linear dynamics" (2015, p.31). The idea is that when things change, a feedback loop occurs that presents both positive and negative results. It is important to factor in both in order to completely understand the cycle. The current viewpoint within the world is a mechanistic worldview, which only tries to understand the parts (2015, p 29). To move towards sustainability and to understand the biosphere, there needs to be a switch towards an ecological worldview. While it is important to understand the parts, it is also required to understand how the parts fit within the whole, just as it is important to understand how each species has an impact on the biosphere.

b. Flows and Urbanization

For this thesis, the term stream will reference water flow as it moves across the land and not necessarily the typical view of a small river or tributary. As urbanization becomes more and more popular, more streams will occur over impervious surfaces as opposed to rock or sediment beds. The classification of storm runoff or direct runoff also needs to be defined as runoff is sometimes viewed as anything that flows. In their book, Derek Booth and Brian Bledsoe state, "if hillslope runoff reaches a stream channel during or within a day or so of rainfall, commonly following a flow path over or close to the ground surface, it causes high rates of discharge in the channel and is usually classified as storm runoff or direct runoff" (2009, p.96). As runoff increases, erosion also increases and creates more sediment to be moved and brought downstream. Inhabitants and city planners often neglect the fact that sediment is a large contributor to the chemical, physical, and ecological conditions of a stream.

> “Just as the flow and sediment load of a stream integrates the contributions from the upstream watershed, so the chemical composition of the water reflects the contributions of both natural constituents and human-generated compounds throughout the watershed. Urbanization invariably results in a net increase in surface runoff because of soil compaction and new impervious surfaces, and so a great proportion of the water delivered to streams bypasses the cleansing influence of soil and plants” (Booth & Bledsoe, 2009, p.99).

As erosion and the carrying of sediment increases along with the bypassing of the cleaning influence of soil and plants, less water can infiltrate and the result is a dump of sediment and uncleansed water downstream. On a larger scale, as urban runoff starts to run into the Mississippi River, it brings sediment and water chemicals into the river. If this happens during the whole journey of the river, from Minnesota all the way down to the Gulf of Mexico, the result is a discharge of chemically imbalanced water and large sediment releases. Not to mention that it can overtax the river and its tributaries and lead to flooding. Booth and Bledsoe state,

> “The increase of storm runoff has many costly consequences in urban areas. Frequent overbank flooding damages houses and gardens, or disrupts traffic. The capacities of culverts and bridges may be overtaxed. Channels become enlarged in response to the larger floods, and building lots suffer erosion and reduction of their value. Biological communities are disrupted by both these physical changes and the altered flow regime itself” (2009, p.103).

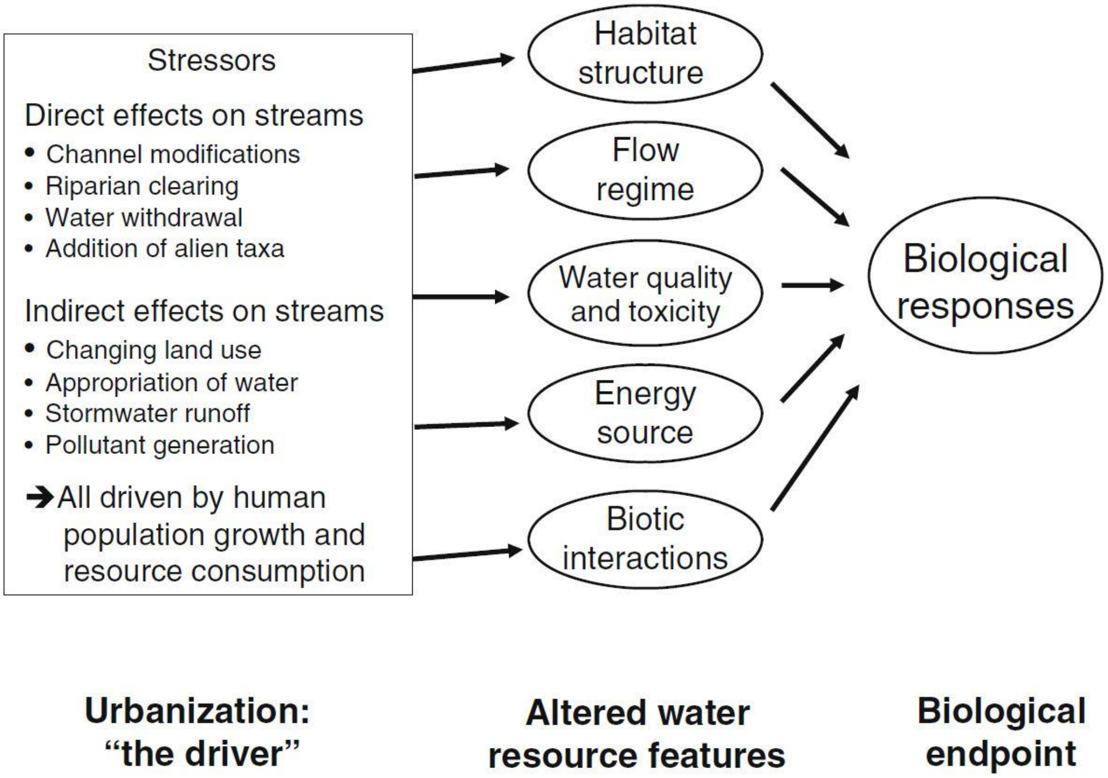


Figure 1: Features that Affect Urban Development and Biological Conditions

As these systems begin to become overtaxed as the flow is altered, many cities have implemented stormwater systems to mitigate the runoff and stop the flooding that is occurring.

> “The most common historic approach has been to convey stormwater runoff as rapidly and efficiently as possible away from developed areas to minimize the consequences of standing water. As this conveyance becomes more effective, however, the receiving downstream channels become subject to increasing peak discharges and consequent flooding of their own” (Booth & Bledsoe, 2009, p. 110).

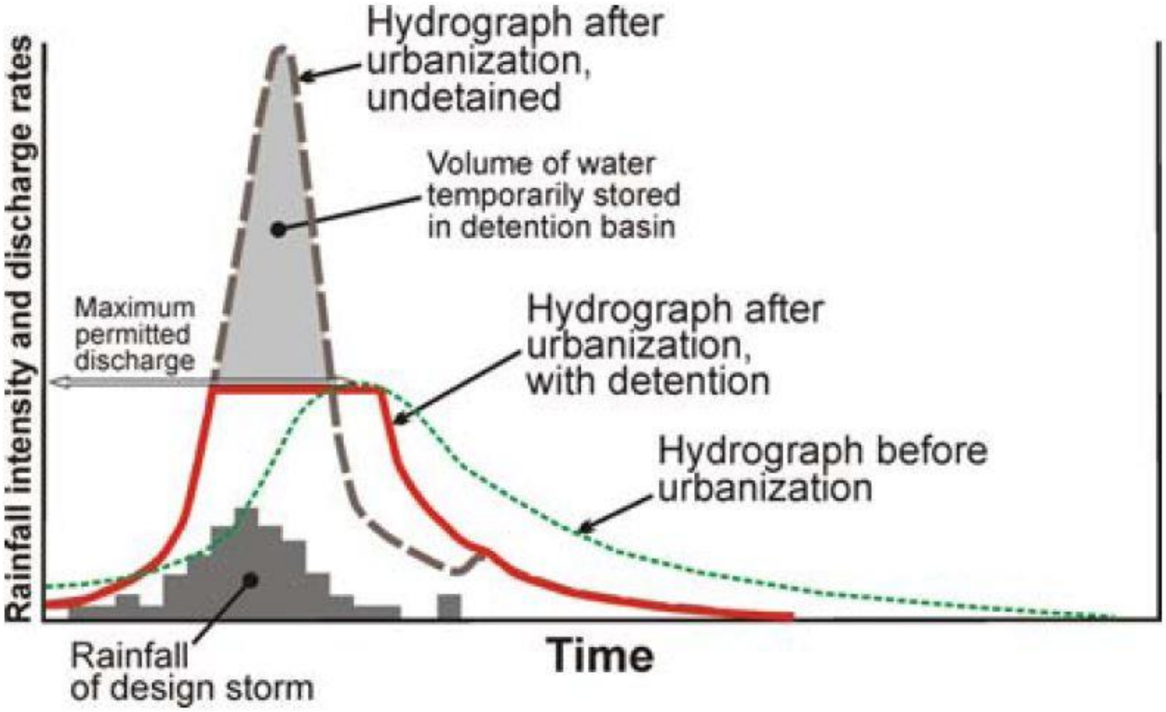


Figure 2: Hydrograph of Detention Pond Showing Presumed Rainfall

The above image shows the stream erosion that occurs with overtaxed systems and is a classic example of a mechanistic worldview in only looking at the parts instead of an ecological worldview and looking at the part's influence on the whole. The attempt to solve runoff in one place creates a larger issue in another and essentially causes more damage to the habitat than just letting the current system be.

> "Careful analysis, culminating in a synthesis of many separate studies showed how two factors, watershed percent imperviousness and watershed percentage with storm sewers, increased the peak discharges of floods. Large, infrequent floods were increased less than smaller, more common events" (Leopold 1968, Hollis 1975).

Most cities do not spend the money to keep up with their stormwater systems and make small, band-aid repairs. It creates a cycle where when problems arise, these small repairs are made and it is completely void of any strategic planning or desire for change. This creates an issue for the entire watershed. It is also susceptible to changes in water flow and increased water events. Booth and Bledsoe state,

> "Changes in precipitation will alter streamflow, with the most commonly anticipated change being an increase in extreme events and a corresponding increase in channel-scouring flows and flooding. The urban infrastructure is generally not tolerant of

> increased magnitudes or frequency of flooding, and the most common responses to increased flood risk are costly and further damaging the aquatic ecosystems" (2009, p.112).

From an economic standpoint, it makes more sense to invest in solutions that can tolerate the increased magnitude and frequency of flooding to avoid damage and costly repairs. From an ecological standpoint, these solutions clean the water, help the environment, and avoid putting stress on areas downstream.

c. Water Sensitive Cities and the Hydro-Social Contract

As discussed above, it has become obvious and well accepted that the current urban water management approach is not working and does not address the issues that will continue in the future. The idea of sustainability is supposed to be aimed at ways to protect and conserve natural resources and their infrastructure so that they can continue indefinitely without depleting or degrading the biosphere. Tony Wong and Rebekah Brown state that the three pillars for a water sensitive city are (2008, p.3.):

1. Access to a diversity of water sources underpinned by a diversity of centralized and decentralized infrastructure.
2. Provision of ecosystem services for the built and natural environment.
3. Socio-political capital for sustainability and water sensitive behaviors.

In this case, the socio-political context refers to the contemporary ideologies, regulations, policies, conditions, laws, practices, traditions, and events that define America's education. It also affects society as it has a connection with democracy.

The next question to answer is why communities seek resilience. Wong and Brown say that there are five reasons; global warming, climate variability, population growth, climate change, and the current rate of change is too slow (2008, p.4). In order to make cities resilient, a major overhaul of the current system must occur. For this case, resilience is defined as the amount of disturbance the system can absorb while remaining the same, the degree to which the system can self-organize, and the degree to which it can increase its capacity to learn and adapt. A resilient system should not only be able to withstand disturbance, but should also create opportunities. It has been shown that a socio-technical system, which is the interaction between society's complex infrastructure and human behavior is the best model for success. Wong and Brown state, "adopting a socio-technical perspective has been identified as the most promising for addressing the need for resiliency and advancing sustainable development, but is yet to be systematically applied to the urban water environment” (2008, p,6).

Figure 3: Urban Water Management Transition Framework

The image above shows the different states cities go through when trying to make change towards sustainable futures.

To achieve a water sensitive city, the city must have three characteristics to make it successful. According to Wong and Brown, these characteristics are (2008, p, 7):

1. Cities as Catchments: access to a diversity of water sources underpinned by a diversity of centralized and decentralized infrastructure.
2. Cities Providing Ecosystem Services: provision of ecosystem services for the built and natural environment.
3. Cities Comprising Water Sensitive Communities: socio-political capital for sustainability and water sensitive decision making and behaviors.

These alternative water sources for cities include groundwater, urban stormwater, runoff, recycled wastewater, and desalinated water. Having a portfolio with diverse water sources allows for the city to be flexible and to adapt to climate variability. While this is an adequate solution, the issue is that it does not address the immediate short-term solutions that cities need as time starts to run out. The key is to protect the environment from stormwater pollution and not to solve the problems upstream by creating more downstream.

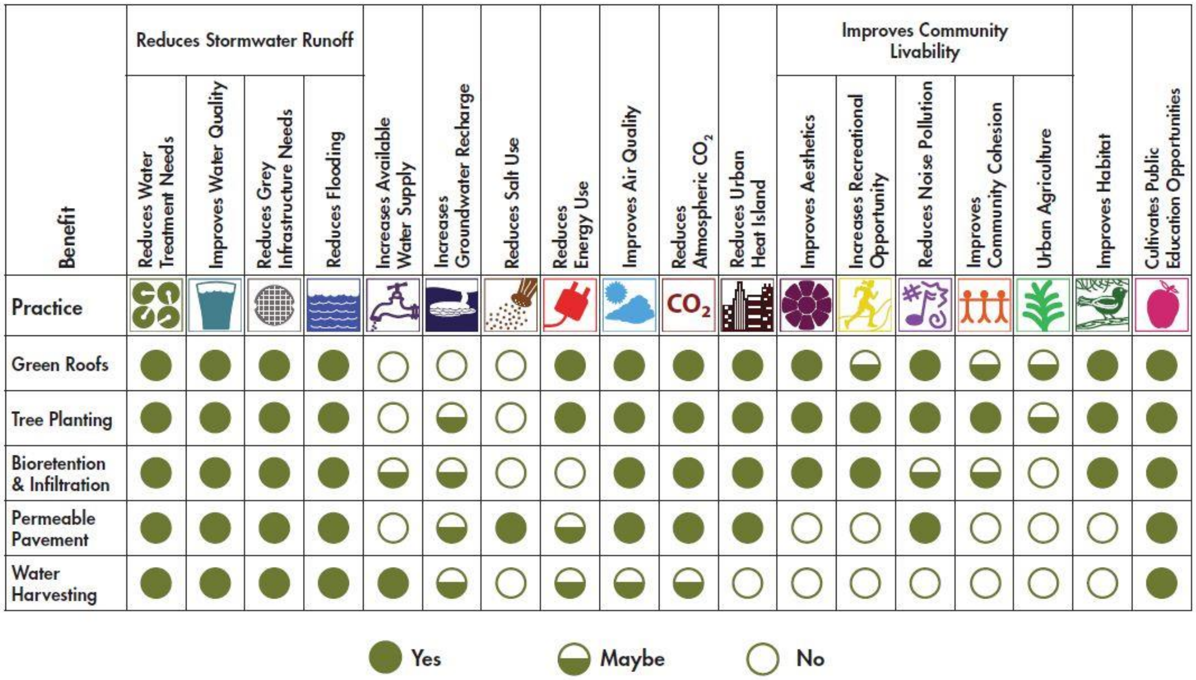
> “As we begin to realise the significance of global warming and climate change, new urban communities will need to strive for carbon neutrality and also have in-built resilience to face future uncertainties in urban water supplies and climatic extremes, and provide ecosystem services to protect/buffer downstream aquatic environments and other ecological habitats from these impacts. The pursuit of sustainability is aimed at initiatives to protect and conserve natural resources and to promote lifestyles, and their supporting infrastructure, that can endure indefinitely because they neither deplete resources nor degrade environmental quality. While such ambitions may seem unattainable, they set a challenge that lead to environmental, social and economic benefits as we edge towards the ultimate goal of sustainability. They represent a paradigm shift in urban design” (Wong & Brown, 2008, p,19).

d. The Value of Green Infrastructure

Often times green infrastructure is passed over during projects because people do not see the value and do not want to spend money on something they do not think will give them a return. Green infrastructure (GI), is defined by the Center of Neighborhood Technology as,

> “a network of decentralized stormwater management practices, such as green roofs, trees, rain gardens and permeable pavement, that can capture and infiltrate rain where it falls, thus reducing stormwater runoff and improving the health of surrounding waterways. While there are different scales of green infrastructure, such as large swaths of land set aside for preservation, this guide focuses on GI's benefits within the urban context” (2010, p.1).

This brings back the premise of a decentralized system and flexibility for cities instead of relying on an overtaxed stormwater system. The simple truth is that there are gaps in information that keeps policy and decision makers from seeing the monetary benefits of green infrastructure. Below is an image showing the benefits of green infrastructure that people typically have a hard time seeing a monetary benefit from.



Benefit	Reduces Stormwater Runoff				Increases Available Water Supply	Increases Groundwater Recharge	Reduces Salt Use	Reduces Energy Use	Improves Air Quality	Reduces Atmospheric CO_2	Reduces Urban Heat Island	Improves Community Livability					Improves Habitat	Cultivates Public Education Opportunities
Practice	Reduces Water Treatment Needs	Improves Water Quality	Reduces Grey Infrastructure Needs	Reduces Flooding								Improves Aesthetics	Increases Recreational Opportunity	Reduces Noise Pollution	Improves Community Cohesion	Urban Agriculture		
Green Roofs	●	●	●	●	○	○	○	●	●	●	●	●	◒	●	◒	◒	●	●
Tree Planting	●	●	●	●	○	◒	○	●	●	●	●	●	●	●	●	◒	●	●
Bioretention & Infiltration	●	●	●	●	◒	◒	○	○	●	●	●	●	●	◒	◒	○	●	●
Permeable Pavement	●	●	●	●	○	◒	●	◒	●	●	●	○	○	●	○	○	○	●
Water Harvesting	●	●	●	●	●	◒	○	◒	◒	◒	○	○	○	○	○	○	○	●

● Yes ◒ Maybe ○ No

Figure 4: Benefits of Green Infrastructure

While this does not cover all of the green infrastructure practices, it highlights the five that are most common and can produce the most benefits.

Green roofs, while they require a larger initial investment, have a lot of positives. These include reduction in stormwater runoff, reduction in energy use, improvements in air quality, reduction in atmospheric CO2, reduction in urban heat island, improvement in community livability, and they create public education opportunities (CNT, 2008, p.4-5). Green vegetation also helps support biodiversity and is a natural air and water filter. However, green roofs are not an the only adequate solution and not the answer for large urban projects. They fit best when they are paired with other strategies.

Bioretention and infiltration practices, as discussed earlier, are also viable options. These strategies help reduction in stormwater runoff, reduction in energy use, improvements in air quality, reduction in atmospheric CO2, reduction in urban heat island, improvement in community livability, and they create public education opportunities (CNT, 2008, p.8-9). Bioretention and infiltration can be done at various scales and include swales, wetlands, and rain gardens. In urban locations, they are often placed next to pavement in order to catch, filter, and infiltrate runoff. This helps slow the runoff speed and sends more water into the ground for aquifer recharge.

Permeable pavers have started to gain traction in urban environments for a variety of reasons. They create reduction in stormwater runoff, reduction in energy use, promote less salt usage, improvements in air quality, reduction in atmospheric CO2, reduction in urban heat island, improvement in community livability, and they create public education opportunities (CNT, 2008, p.10-11).   Also known as porous pavement, it allows for higher infiltration of stormwater. There has been pushback in colder states with a worry that the pavers will be damaged by snowplows, but a recent attachment to the underside of the plow has eliminated that worry.

Water harvesting is not new and has been used for thousands of years, but not on an urban scale. It can help with reduction in stormwater runoff, reduction in energy use, improvements in air quality, reduction in atmospheric CO2, reduction in urban heat island, improvement in community livability, and they create public education opportunities (CNT, 2008, p.12-13). Systems are already in place for water harvesting but most of the transport systems, such as gutters, send the water straight into the stormwater system and overtax it. There are also a lot of regulations about what stormwater can be used for and many people see it as a burden instead of a solution.

The big reason why green infrastructure has not been implemented more is the misunderstanding in value, and that value is always linked to money. Monetary value is not something that can always be assigned, and it is not the most important value. The monetary value comes in the stopping of flooding, leading to less flood damage, and better air quality so less people are getting sick. The figure below shows the process for valuing the climate change benefit of green infrastructure (CNT, 2008, p.16).

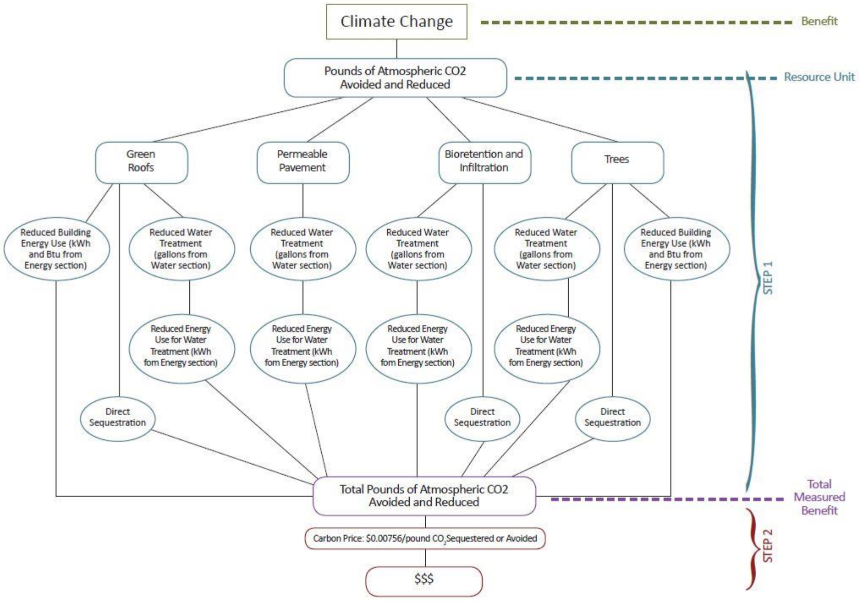


Figure 5: Process of the Climate Change Valuation

It has been shown that, "78 percent of the American public does not understand that runoff from agricultural land, roads, and lawns, is now the most common source of water pollution; and nearly half of Americans (47 percent) believes industry still accounts for most water pollution (NEEFT 2005)." The people are looking at industry to solve the problem when the issues are right in front of them. Green infrastructure has been proven to increase recreational opportunities, and cities such as Chicago, Milwaukee, New York, Philadelphia, Portland, and Seattle have already begun implementing green infrastructure and have started to see the value, beyond money, of the implementation. Booth and Bledsoe also state, "urban stream corridors should be much more than engineered conduits for fast conveyance of runoff and other discharges. Indeed, many communities are now focusing on stream and river corridors as high-value amenities not only for recreation, but as focal points for providing social, aesthetic, and educational benefits" (2009, p.117).

e. Green Infrastructure as an Artful Urban Landscape.

In looking at green infrastructure, the view has always been that these systems are ugly and should be out of view to the public. To be able to engage the community, they need to understand how these systems work and how they can be a valuable asset. "The treatment of stormwater runoff in conventional urban development has been driven by an attitude of "out of sight out of mind." This attitude reflected the view that stormwater runoff has no value as a useful resource and adds little to the amenity (aesthetic, recreation, education, etc.) of an urban environment" (Wong & Eadie, 2000). The idea of artful rainwater design has started to gain traction as communities start to recognize the value. Water designs such as fountains, waterfall features, etc. have been around and used, but not necessarily to support the stormwater system. Landscape architect Stuart Echols states,

> "Some communities are now recognizing that artful rainwater design can add value far beyond the required hydrological function may be difficult to pinpoint; however, communities have recognized that artful rainwater design can add value far beyond the required hydrological function and that rainwater systems can reflect the objectives and values of prospective users and not be viewed simply as a stormwater disposal systems" (2007, p.4).

The reason artful rainwater design has not been more popular is because there are two gaps that keep it from gaining traction. The first gap is the public concern about appearance, and the second is not understanding where value is added from the project. It is important to remember that these designs have multiple functions and stormwater management is only one of the objectives. Artful rainwater design has the potential to (Echols, 2007, p. 3-4):

> 1. raise property values through attributes that could encourage developers to create stormwater management facilities that surpass minimum requirements;
> 2. help policy planners and design review boards better understand the added value impact of stormwater management, potentially offering guidance for revisions to existing regulations;
> 3. provide greater public exposure to, engagement in, and education about ecological stormwater issues for the protection of aquatic systems and clean water;
> 4. provide design strategies for integrating stormwater management throughout a site rather than the pursuing an "out of sight out of mind" approach; and
> 5. enhance the likelihood of regular maintenance by making stormwater management facilities a clear and visible added value.

The figure below shows the value that artful rainwater design can bring.

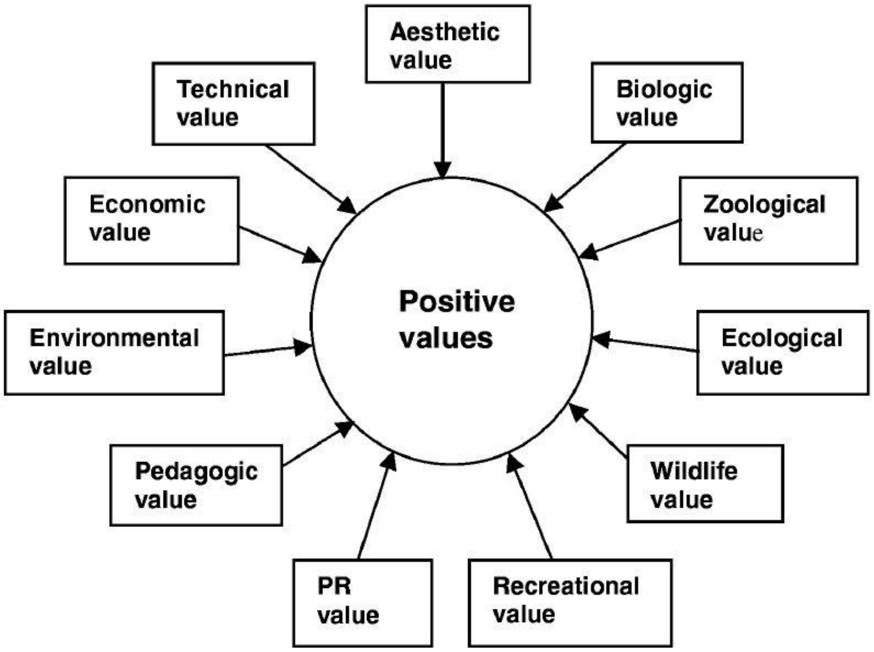


Figure 6: Values of Open Stormwater Drainage

The value comes from the projects being multifunctional. Designs should not only manage stormwater effectively, but also create opportunities for public engagement. Successful projects show off the hydrology, are maintained, provide awareness, encourage people to use them, are visually appealing, and create perceived value. The figure below compares traditional urban drainage to sustainable urban drainage as artful rainwater design.

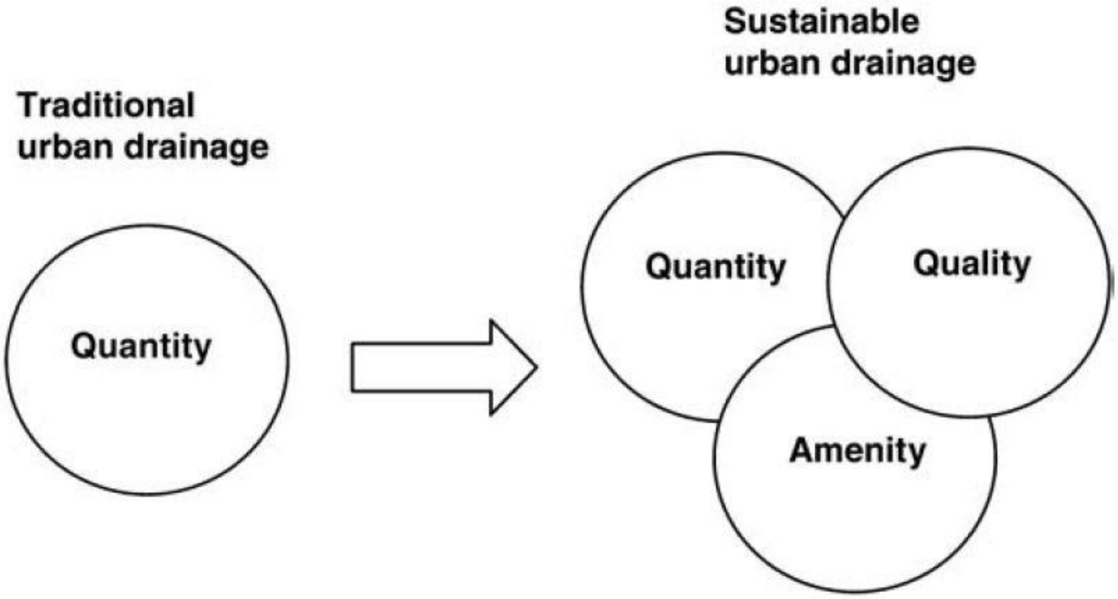


Figure 7: Urban Drainage Triangle

This shows the need to diversify and that urban drainage can be a benefit. Water should be a resource and not a burden. Herbert Dreiseitl said, “the value comes from the projects being multifunctional. Designs should not only manage stormwater effectively, but also create opportunities for public engagement. Successful projects show off the hydrology, are maintained, provide awareness, encourage people to use them, are visually appealing, and create perceived value” (2001, p.12).

f. Green Infrastructure and Policy Regulation

One of the biggest barriers for green infrastructure is governmental interference and policy. The path to implement green infrastructure is long and confusing and typically deters designers from trying to add it to projects. Steven Moore and Barbara Wilson state, “it is not that the body of knowledge of technoscience failed to keep up . . . but that . . . the sum of governmental and civil institutions collectively failed to exercise the sound judgment to serve human purpose through it”

(2014). Regulation should not be a deterrent, but instead a motivator and be giving incentives to implement green infrastructure. The image below shows an example pathway for a project in Arizona and highlights key areas where innovation is needed.

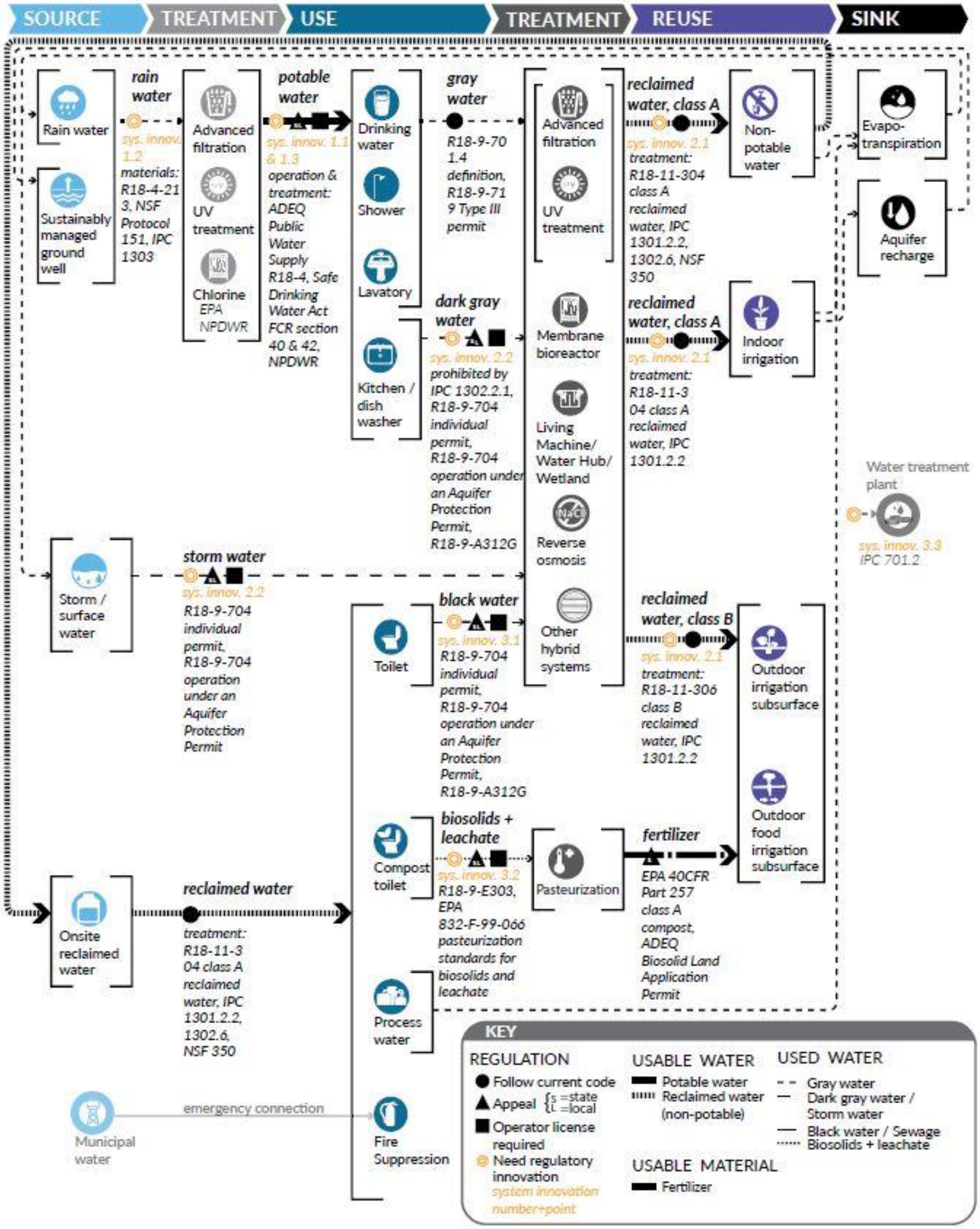


Figure 8: Arizona Regulation Pathway

The focus needs to be on making rainwater potable, reusing the water on site, and creating a decentralized water system. It is largely accepted that institutional innovation is just as important as technological innovation because the technology cannot be used if institutional regulation does not change. As mentioned earlier, the band-aid method of quick fixes will not work and current policy supports quick, temporary fixes that save the government money to spend elsewhere. Courtney Crosson says, “over the next 25 years, the American Water Works Association (AWWA) and the American Society of Civil Engineers (ASCE) estimate a required investment of $1 trillion for drinking water and $271 billion for wastewater infrastructure to meet current and future water demands” (2018, p.71). These are large numbers and would be much better used on green infrastructure that can support and take the reliance off of the current stormwater system.

For green infrastructure to be implemented, there needs to be a clear path that is easily understood by designers. Crosson says, “ADEQ and IPC offer no clear guidance on materials and products acceptable for the catchment component of rainwater to potable systems. There is no clear method of proving that performance criteria are met by custom-designed treatment systems for potable water provision” (2018, p.77). With no clear guidance, it is difficult to undertake these systems in a project. It has been proven that these systems work, and in places such as Arizona where there is a shortage of water, water usage and storage is a must. The figure below shows a comparison in the water budget for a project that does not have green infrastructure and what the budget would be with it.

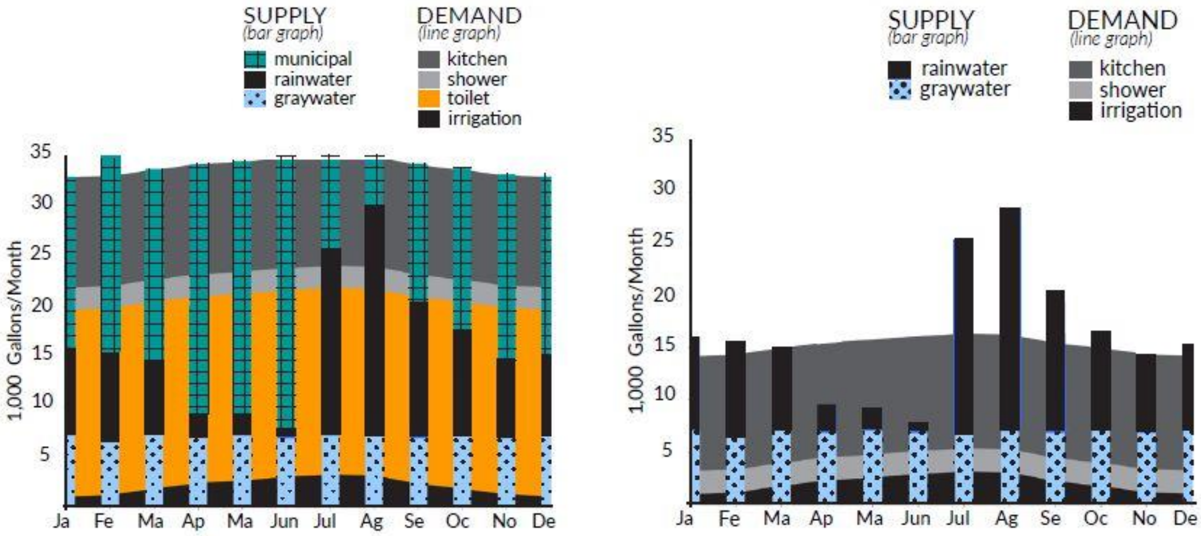


Figure 9: Water Budget Case Study for a Commercial Building

There is noticeably less demand and in some months an abundance of supply that can be collected and used in months where supply is short. With climate change becoming a big issue, this is only going to become more important. Crosson also states,

> "climate change and deteriorating, aged infrastructure portend an urban water crisis in the coming decades. The future of water resources will become increasingly dependent on architects and engineers to add resiliency to urban water infrastructure systems through buildings and community plans that integrate water-system technological advancements" (2018, p.80).

These problems are not going to fix themselves and policy makers and designers need to work together to promote green infrastructure.

CHAPTER III: DISCUSSION

The literature review has made it clear that there are issues with the current stormwater system that need to be fixed before it is too late. Right now, green infrastructure is just a discussion and it needs to start becoming a reality. The current worldviews and policies have made it hard to implement green infrastructure and a focus on an ecological worldview is needed in order to progress.

From the literature, there are four topics that bring this investigation to the light. These topics are 1) the ecology of the earth and flows of urbanization, 2) understanding flows in an urban setting, 3) how cities are dealing with water and how green infrastructure brings value to the city, and 4) how government and policy play a role in the success of green infrastructure.

First, the focus is on worldviews and how people perceive the earth and its parts. E.O Wilson (2001) points out that people currently look at the biosphere as a whole without trying to understand the parts that make up the whole. He points out that the complexity of earth is misunderstood and that while ideally all species of the earth would have an equal influence, only a select few have the influence to affect everything. Humans have the power to influence and so far their influence has created a burden to the biosphere and other species. Hes and Du Plessis (2015) state that humans currently have a mechanistic worldview and to understand the complexities of the earth there needs to be a switch to an ecological worldview. With climate variability becoming an issue and knowing how complex and adaptive the biosphere is, an ecological worldview is the change that is needed to make a push towards sustainability and regeneration.

Secondly, as impervious surface and urbanization continue to increase, there becomes an issue with water runoff and its effect on the stormwater system and locations downstream. Booth and Bledsoe (2009) point out that with increased runoff comes increased erosion, putting sediment and chemicals into the water. This erosion is causing degradation to the stormwater system, which is already been overtaxed. The sediment and chemicals have also caused issues downstream as cities look for solutions in a localized area without regard for what is happening downstream. They also state that as cities have tried to control runoff, flooding has actually become more frequent. From an economic standpoint, it makes sense to invest in solutions that will reduce the standing water and mitigate flooding, and from an ecological standpoint it makes sense to integrate systems that integrates solutions to clean the water and help the environment. Green infrastructure is something that can do both.

Third, to implement green infrastructure there needs to be a plan that makes cities resilient.

Wong and Brown (2008) point out that for cities to be successful, they need to create a decentralized water system, have services for the built and natural environment, and create an agenda for sustainability. Having a decentralized system allows for cities to be more flexible as the climate becomes more unpredictable, the population grows, and global warming continues. The current paradigm has set up a centralized system that is vulnerable and not flexible to change. There needs to be a paradigm shift in urban design for cities to successfully manage water in an effective and ethical way.

Creating a decentralized system starts with green infrastructure. Practices include green roofs, rain gardens, permeable pavers, and water storage systems. While there are currently gaps in information that keep policy makers from seeing the value in green infrastructure, it is clear that there is value. The Center of Neighborhood Technology (2010) says the value comes from reduction in stormwater runoff, reduction in energy use, improvements in air quality, reduction in atmospheric CO2, reduction in urban heat island, improvement in community livability, and they create public education opportunities. The key factor is that monetary value should not be the only factor considered when looking at implementing green infrastructure. This is not to say that there is no monetary value in green infrastructure because there certainly is, but that should not be the main and only consideration.

Not only should green infrastructure be operable, but should also promote community engagement. It should be beautiful, engaging, and educational. Stuart Echols (2007) says that green infrastructure that achieves these three things will raise property values, create public exposure, help policy makers see the monetary value, revamp the idea that stormwater is "out of site out of mind," and it enhances the likelihood of regular maintenance. Stormwater systems can be beautiful as well as function and this collaboration is what will engage the community to participate in stormwater mitigation. The only way to understand is to learn, and artful rainwater design is the best way to be hands on and learn.

Fourthly, policy and government play a huge role in how green infrastructure gets implemented and as it stands, green infrastructure has a hard time getting past legislation. While existing regulations were put into place for safety, current regulations are now hindering the progress of sustainability. Courtney Crosson (2018) states that current regulation is in favor of quick fix, band-aid solutions that do not keep up with the degradation of the stormwater system. With money being taken from the funds to upkeep the system and cheap, temporary fixes being the norm, the stormwater systems in cities are destined to fail. Policy needs to shift and focus on promoting green infrastructure in projects to move towards sustainability.

A combination of these four ideas is the solution to fixing a system that is on the verge of collapsing. Not only would a collapse cause huge financial losses, but it would endanger the quality of the water that tens of millions of people rely upon. The solution comes in fixing the parts to collectively improve the whole. Humans are responsible for creating this problem and it is humanity's duty to fix the problem, not just for themselves, but for all the species that are influenced by the decisions of humanity.

CHAPTER IV: SITE SPECIFIC DATA

Solutions to water issues are largely dependent on site specific date. While there are various strategies to mitigate water runoff and increase ground infiltration, the strategy or strategies that are used must take into account the geographical location of the site and all that encompasses its characteristic. Factors such as soils, geographical classifications, infiltration rates, runoff rates, natural growth and animal patterns, etc. must be taken into account when implementing strategies on site. Strategies that work in one location will not necessarily work in another location. Having an understanding of the site and its history is key in understanding what will be successful. The University of Minnesota, an institution since 1851, has changed and redeveloped the landscape to include pervious area such as lawns, impervious areas such as streets and sidewalks, catch basins, and waterflow systems that line up with the university's standard for sustainability and water management.

a. Site Data

Local Context

Located in a humid subtropical climate, the summer months have average temperatures in the mid-70s, while the winter months average temperatures in the low 20s. Minneapolis annually receives about 32 inches of rainfall and 52 inches of snowfall. Expecting rain to become more prominent in the region, the design considers a 40-inch annual rainfall with a 7.5-inch rain event in a 24-hour span. The current site does not have any permeable pavers and one building incorporates a green roof. 100% of the hardscape is impermeable and water runoff is all sent to the sewer system before being sent into the Mississippi River. With only 29% of the site comprising of green or planted areas, infiltration is a huge issue. With a site slope of around 1%, ponding and flooding occurs even though the U4A soil has a high infiltration rate because of the amount of impervious pavement over the top of the soil. Sloping increases as the water gets closer to the Mississippi River as a result of river erosion over thousands of years.

Land Cover

The selected site is located on the University of Minnesota campus in Minneapolis, Minnesota and includes a 27.3-acre plot starting on Washington Avenue to the south and extending to University Avenue to the north. The site is what will be referred to as the Church

Street Corridor, named because the main connection road through the middle of the site is Church Street Southeast.

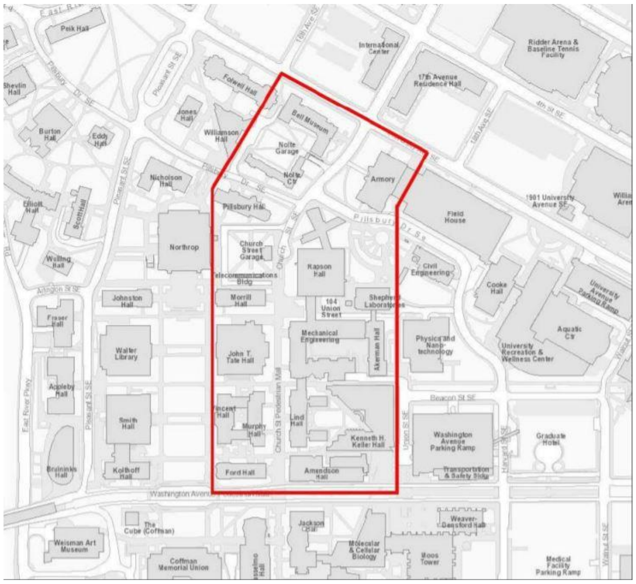


Figure 10: Site Location on University of Minnesota Campus (GIS)

The site includes pervious cover, vegetation, impervious cover, building footprints, and a lower topography seeing that the site is near the bottom of the watershed that flows into the Mississippi River. The figures below show the pervious ground cover, vegetation, impervious ground cover, building footprints, and topography.

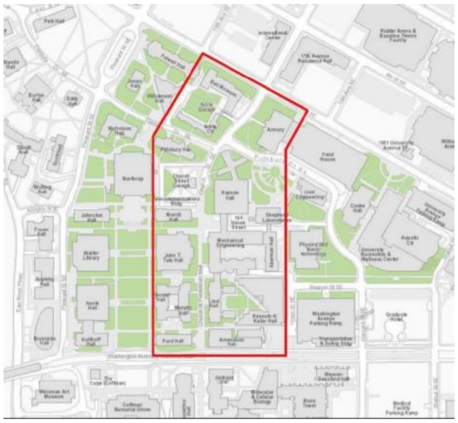


Figure 11: Pervious Ground Cover (GIS)

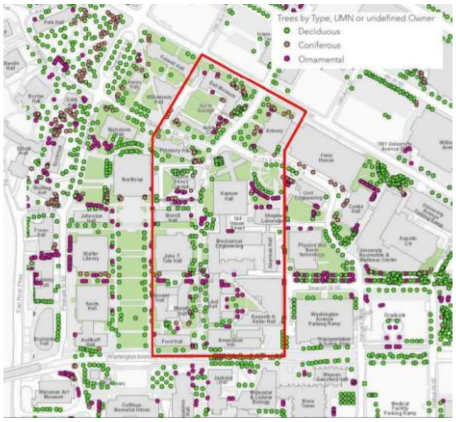


Figure 12: Vegetation Cover (GIS)

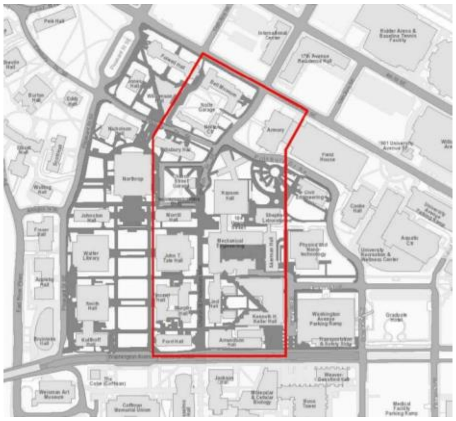


Figure 13: Impervious Ground Cover (GIS)

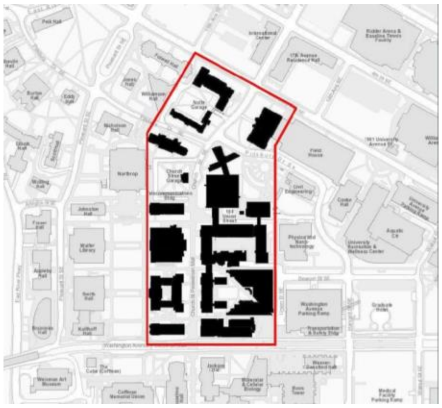


Figure 14: Building Footprints (GIS)

Figure 15: Topography (GIS)

It can be seen that while there is some pervious land cover, largely coming from the lawns surrounding the buildings, and there is some vegetation, most of the site is made up of impervious cover, such as sidewalks, roads, driveways, and building footprints

Human Connections

Being in a large city, there are various human connections that also add to the site. With the university having a total enrollment of nearly 50,000, transportation connections are abundant. Within a one-mile radius of the site, there is access to multiple bike trails and walking trails, 25 university sponsored bus stops, on-street parking meters, and multiple pay lots for cars. These connections give access to the site not only to University of Minnesota students, but access to the public to be on site.

Scientific and Natural Areas (SNA)

SNAs are areas where native plants and animals are abundant and flourish because they are protected and provide an opportunity to learn about native plant communities, populations of rare species, and the geological features of the area. Surrounding the site, there are four SNAs nearby, with two of them being less than 10 miles away. The Scientific and Natural Areas are Pig's Eye Island: Heron Rooker, Wood Rill, the Blaine Preserve, and St. Croix Savannah. Figure 16 shows the locations of these SNAs in relation to Minneapolis.

Figure 16: SNA locations (GIS)

Ecological Classification System (ECS)

The ECS is a nationwide system that was developed to help manage natural resources in sustainable ways. It creates a framework and identifies relationships and connections between ecological components like soil, vegetation, topography, climate, animals, and other things. The Minnesota Ecological Classification System is broken up into six nested classification units. The ecological units are province, section, subsection, land type association, land type, and land type phases (DNR). In Minnesota, there are four provinces, which are the Prairie Parkland Province, Tallgrass Aspen Parklands Province, Eastern Broadleaf Forest Province and the Laurentian Mixed Forest Province. The Eastern Broadleaf Forest Province makes up the entirety of the site and covers around 12 million acres in Minnesota (DNR). It is the transitional zone between the prairie in the west and the hardwood forests of the northeast. The landforms include lake plains, outwash plains, moraines, and drumlin fields and shows a variation in topography from lake plains to very steep slopes in the southeast section.

Figure 17: Ecological Provinces of Minnesota (Minnesota DNR)

Minnesota has ten ecological sections. These sections are defined by the origins of glacial deposits, regional climate, distribution of plants, and regional elevation. The site is located in the Anoka Sand Plain, which covers parts of central and eastern Minnesota (DNR).

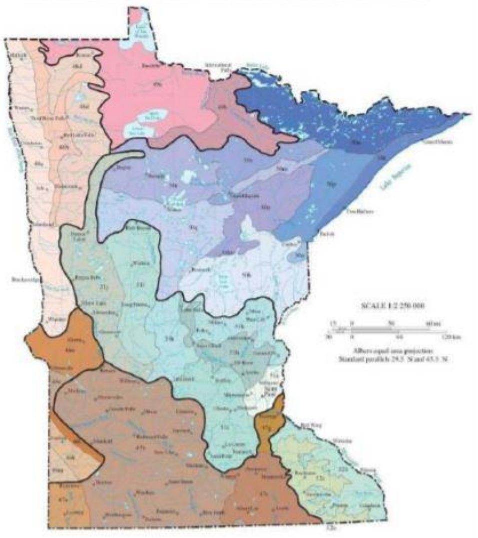


Figure 18: Ecological Sections of Minnesota (Minnesota DNR)

These sections are then divided further into subsections, which are county sized areas defined by local climate, bedrock formations, glacial landforms, topography, and distribution of plants. The site is located within the St. Paul Baldwin Plains and Moraines. The primary plant communities are Oak and Aspen Savannah, but Tallgrass Prairie and Maple Basswood Forests are also common.

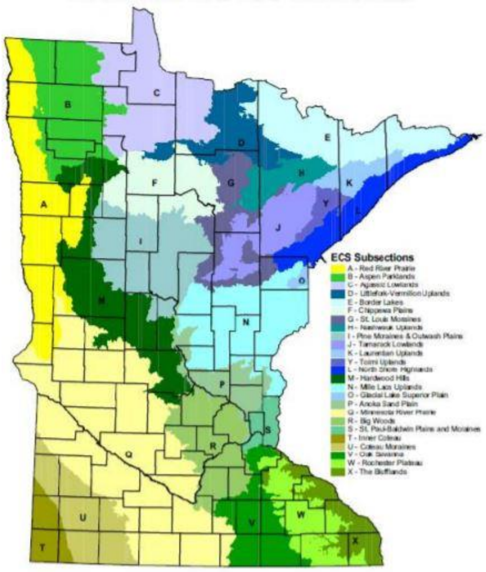


Figure 19: Ecological Subsections of Minnesota (Minnesota DNR)

The Church Street Corridor is part of the natural community and rare species of the Hardwood Swamp Forest. This includes the Mixed Hardwood Swamp and Black Ash Swamp subtypes. These areas are dominated by shallow organic soil from the outwash plains.

Animal Movements and Species

Air and land animals are both abundant in Minnesota and on the site. The United States has four major flyways; the Pacific Flyway, the Central Flyway, the Mississippi Flyway, and the Atlantic Flyway. Minnesota is located in the Mississippi Flyway and includes birds such as ducks, eagles, hawks, loons, and many others. While the Mississippi Flyway extends as far east as Ohio, most of the density is along the Mississippi River, right next to the Church Street Corridor.

While most of the land animal movement occurs in the northern parts of Minnesota, there is also a lot of activity near large bodies of water, and an increase in the Prairie Corridor. With the

Mississippi being a major body of water, it attracts land animals near the site even though it is an urban setting. This urban setting is an important area in making sure that endangered animals don't go extinct due to overdevelopment.

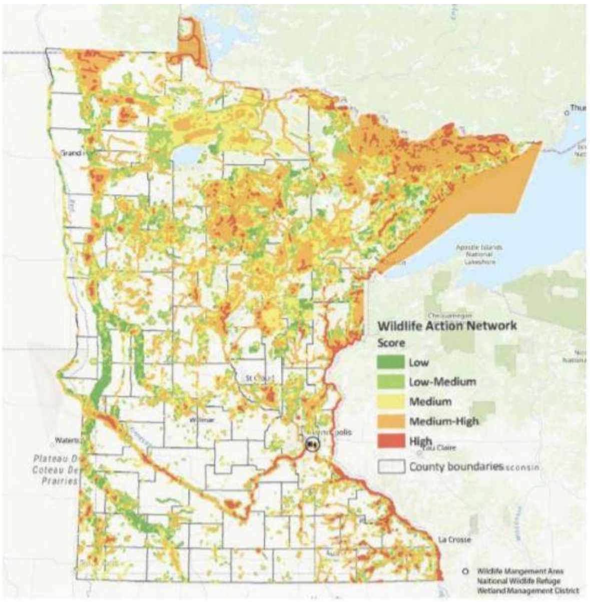


Figure 20: Minnesota Wildlife Network (Minnesota DNR)

b. Soils

The area surrounding the site is made up of various different soils, but 50% of the soils within a one-mile radius are U4A soils (Urban Land-Udipsamments). On site, the entire 27.3 acres is made up of U4A soil. The characteristics of U4A soils are below:

- Slope: 0 - 2 percent
- Depth to restrictive feature: 80+ inches
- Natural drainage class: Somewhat excessively drained
- Depth to water table: 80+ inches
- Frequency of flooding and ponding: None
- Farmland Classification: Not prime farmland

Description of Udipsamments: Cut and Fill Land Setting (DNR)

- Landform: Stream terraces, outwash plains
- Down-slope shape: Linear

- Across-slope shape: linear
- Parent Material: Variable sandy material

The importance of the soil on site can be taken for granted because in an urban area, soil that drains well and avoids ponding is good for infiltration and runoff mitigation. The fact that it is found in a location with little to no slope also means that runoff moves slowly, allowing time for it to infiltrate into the ground. The is a very sharp contrast to the existing condition where impervious surfaces increase the runoff rate and limit infiltration, often times overbearing small sections that are relied upon for the infiltration of large areas.

Figure 21: Surrounding Soil Map (GIS)

Greenfields and Brownfields

Greenfields and brownfields can have a tremendous effect on the water on site, which is especially important for drinking water. A greenfield is a project that lacks restraints imposed by prior work and there is no need to work within the constraints of the existing infrastructure (DNR). A brownfield is previously developed land that is no longer in use. It is also described as a location that was previously used for commercial or industrial purposes that have been known to have soil contamination or pollution. On site, there are two brownfield locations. In 1995 there was groundwater contamination on the site of the Mechanical Engineering building, and in 2004 there was contamination on the site of the Civil Engineering building. Both were gas leaks that have since been treated and the incidents have been closed.

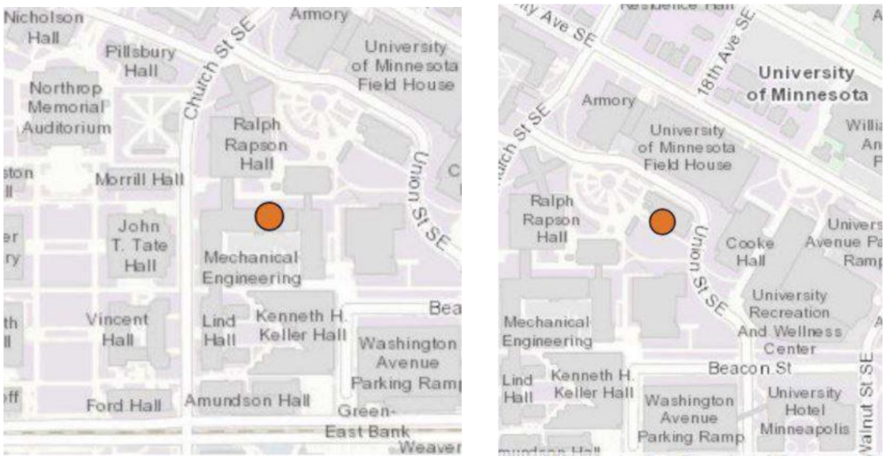


Figure 22: Brownfields on Site (City of Minneapolis)

University of Minnesota Soil Strategies

Construction on site looks to limit soil disturbance and erosion. Soil disturbance must be limited to 40-feet beyond the building parameter, 15-feet beyond primary roadway curbs, main utility trenches, and stormwater management features, 5-feet beyond walkways, and no closer than 5-feet from tree driplines. The top 12-inches of topsoil must also be returned to the site to promote growth of pervious surfaces, such as lawns and other vegetation.

Erosion control strategies must all be put in place to minimize the time bare soil is exposed to the elements. These strategies are most necessary on steep slope sites, which is not the case on in the Church Street Corridor, but it is good practice to protect the soil and to keep concentrated flows in stabilized ditches and pipe systems.

Urban Soil Management

The function of soil is to regulate stormwater runoff, filter urban pollutants, prevent erosion, and support trees, shrubs, lawns, and gardens. Urban soils are classified as anthropic soils, meaning they are non-agricultural and are influenced by human activities and developments. These soils are typically found in urban watersheds, parks, recreation areas, green belts, community gardens, and lawns, but can also be found in more densely populated suburban areas. Urban soils are classified as having:

- High solid bulk density

- Less organic matter
- High PH levels
- Poor structure
- Low water holding capacity
- Decreased aggregate stability
- Less soil depth

While urban soils do have issues, they can be enhanced or restored by protecting the soil and vegetation whenever possible, reducing soil compaction, reducing the use of pesticides and fertilizers, and by adding compost. This is important on site because in an area that has a small portion of green space, these spaces must be kept and managed to prevent the soil from becoming too compact to the point where it cannot support vegetation growth.

c. Stormwater Management

Overview

The Mississippi River is the major water source near the site and is a part of the Mississippi River Watershed. This watershed is the fourth largest in the world and covers about 40% of the landmass of the United States. It touches or covers the entirety of 32 states and two Canadian provinces and drains down into the Gulf of Mexico. This is a major watershed that holds a lot of the clean water in the United States. Within Minnesota, the Church Street Corridor is located within the Mississippi River Basin, which drains into the Mississippi River, and is part of the Mississippi Watershed Management District.

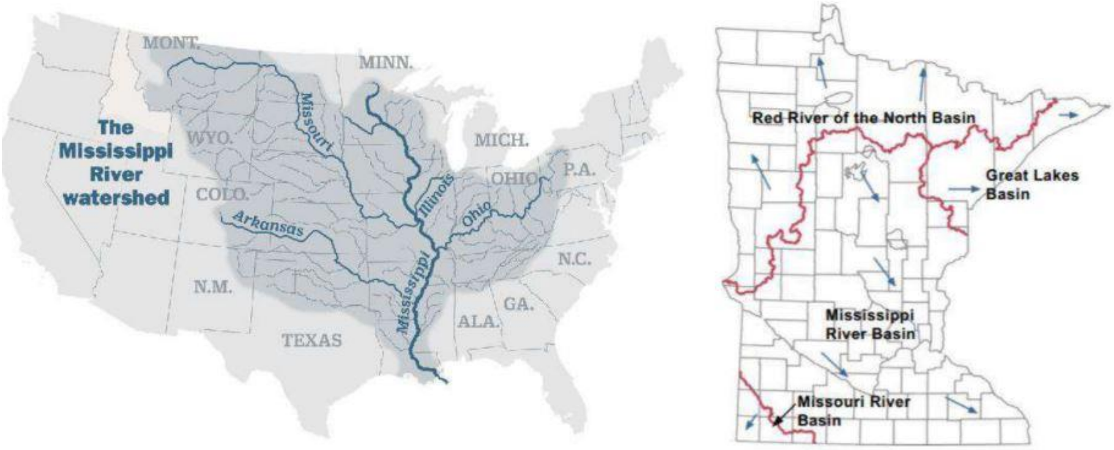


Figure 23: Watershed of the United States and Minnesota (DNR)

Water Conditions

With the exception of the Mississippi River and an abundance of lakes, most of the freshwater in Minnesota is stored in underground aquifers. These aquifers are fed by infiltration from water above ground that seeps through the soil and rock and is stored on a bedrock shelf. The aquifer sources in Minnesota are glacial drift sources, glacial outwash sources, and the third is bedrock sources. The Church Street Corridor is supplied by bedrock aquifers and artificial cleaning systems connected to the Mississippi River. The bedrock aquifers are porous and release water into surrounding wells.

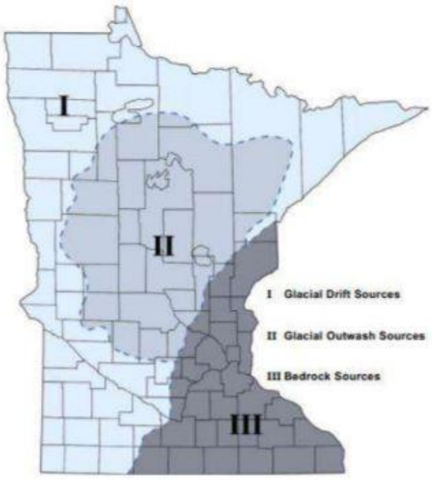


Figure 24: Minnesota Ground Water Sources (DNR)

Recharge rates of these aquifers depend on the amount of precipitation, evapotranspiration, runoff, and water uses on site. On average, Hennepin County gets about 32 inches of rainfall per year, and about 52 inches of snow per year. This may fluctuate, and in recent years there has been an increase in rainfall, but this is what is typically expected. Figure 18 shows the average precipitation in Minnesota and the average precipitation minus evapotranspiration.

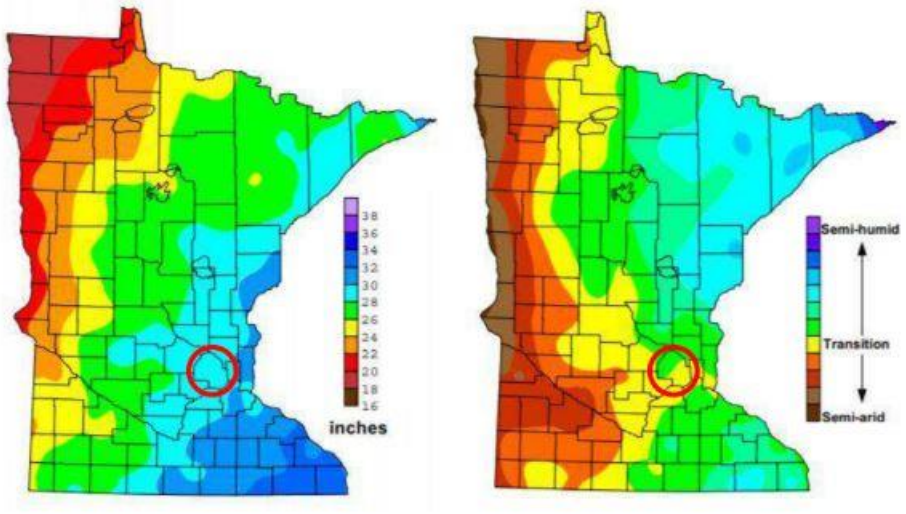


Figure 25: Precipitation in Minnesota (DNR)

The issue on site is that the runoff rate is extremely high. Pre-urbanized areas of Minnesota have a runoff rate of less than 20%, while the site has a runoff rate above 60%, which is significantly higher than other areas and creates a problem when trying to slow water down. The Church Street Corridor is 75-90% impervious pavement, so water has nowhere to go. The Department of Natural Resources considers the runoff on site to be "severe" with a significant challenge in slowing the water down and putting it into the ground. The natural sources of water on site are precipitation, while the water usage on site includes irrigation, drinking, flushing, industrial and washing. Not only is the water that runs through the site an issue, but the water being used and sent to the Mississippi River is also an issue.

Direction of water flow is important and the placement of catch basins coincides with the direction of flow. The figures below show the water movement on site and whether it is coming from the street, roof, or landscape and where the water empties into a catch basin.

Figure 26: Water flow on site

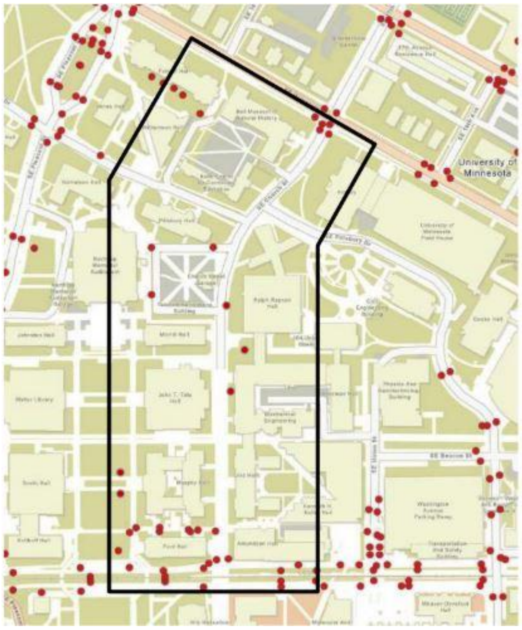
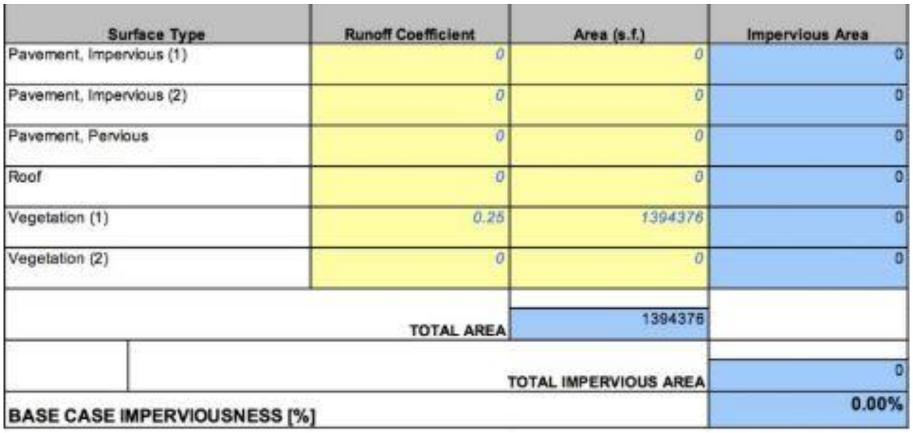


Figure 27: Catch basins on site (GIS)

Typically, the rainwater that falls from the roof is directed towards the landscaping along the sides of the buildings, allowing water to absorb into the ground. The landscaping is generally sloped towards main vehicle streets or driveways as runoff, and the driveways and streets are always sloped towards the catch basins. These catch basins collect the water and send it directly to the Mississippi River. The original design for this system was to be for large rain events, however, with the amount of runoff on site, they are used for nearly every rain event. The increased runoff and increased water speed means more erosion to the system. A system that was designed to last for 100 years or more will not last nearly that long, especially in the case of more large rainfall events.

d. Pre-settlement Conditions

Prior to urbanization, the Church Street Corridor had a very different look and a very different water cycle. The pre-settlement landscape was mostly prairies and grasslands and the dominate vegetation was grasses and herbs as opposed to trees. The prairies flourish in areas that are too wet to be desert but too dry to be forests. The soil makeup was mostly Mollisols, which are very dark soils that are very fertile, mostly derived from organic materials like plant roots. They fit within hydrological soil group C, which are sandy/clay soils with good infiltration and low runoff coefficients. The pre-settlement infiltration rate was 0.20 inches/hour and a runoff coefficient between 0.26-0.44. Given that the site is around 1,394,376 square feet, this can be broken down into pervious and impervious surfaces to help understand where the water goes. Below is a breakdown of the pre-settlement conditions.



Surface Type	Runoff Coefficient	Area (s.f.)	Impervious Area
Pavement, Impervious (1)	0	0	0
Pavement, Impervious (2)	0	0	0
Pavement, Pervious	0	0	0
Roof	0	0	0
Vegetation (1)	0.25	1394376	0
Vegetation (2)	0	0	0
	TOTAL AREA	1394376	
		TOTAL IMPERVIOUS AREA	0
BASE CASE IMPERVIOUSNESS [%]			0.00%

Figure 28: Pre-settlement Imperviousness Calculation

The base case shows that there is no impervious pavement and no existing buildings to increase runoff. With 0% imperviousness, calculations can be made to show how much water is being taken from evapotranspiration, how much is being infiltrated, and how much runoff occurs.

During the summer months, Minneapolis sees about 6.54 inches of evapotranspiration. While only about six months of the year sees weather warm enough for rain and evapotranspiration, the 6.54 inches can be multiplied by 6 to get the average evapotranspiration per year, which is 39.24 inches/year or 3.27 feet/year. Using the 1,394,376 square feet of the Church Street Corridor, this means that 4,459,609 gallons of water are removed each year from evapotranspiration.

Infiltration rate is also important seeing as there was a lot of grass in during pre-settlement. In the mid-1800's, the average rainfall was about 28.90 inches/year. The recharge rate on site, pre-settlement, was 20-25% of precipitation. With an average rainfall of 28.90 inches, the recharge rate was between 5.78 inches and 7.22 inches. This allowed the water to infiltrate the ground and recharge the aquifers below.

The normal runoff rate can be calculated and shows how much water is runoff after evapotranspiration and infiltration. It is calculated using Q=ciA where Q is peak discharge, c is the rational runoff coeficcent, i is rainfall, and A is the drainage area. As shown previously, the runoff rate for the pre-settlement soil between 0.26-0.44, so c will be the average at 0.35. The average rainfall, i, is 28.90, and the drainage area is the size of the site, 1,394,376. Following the formula, the pre-settlement runoff rate is 16.8 gallons/minute or 24,150 gallons/day.

The pre-settlement water cycle is broken up into water sources, water uses, and water that moves out of the site. It is exactly as described, a cycle, that continues to cycle the water from the sky, to the ground, through the ground, and back into the air to start all over again.

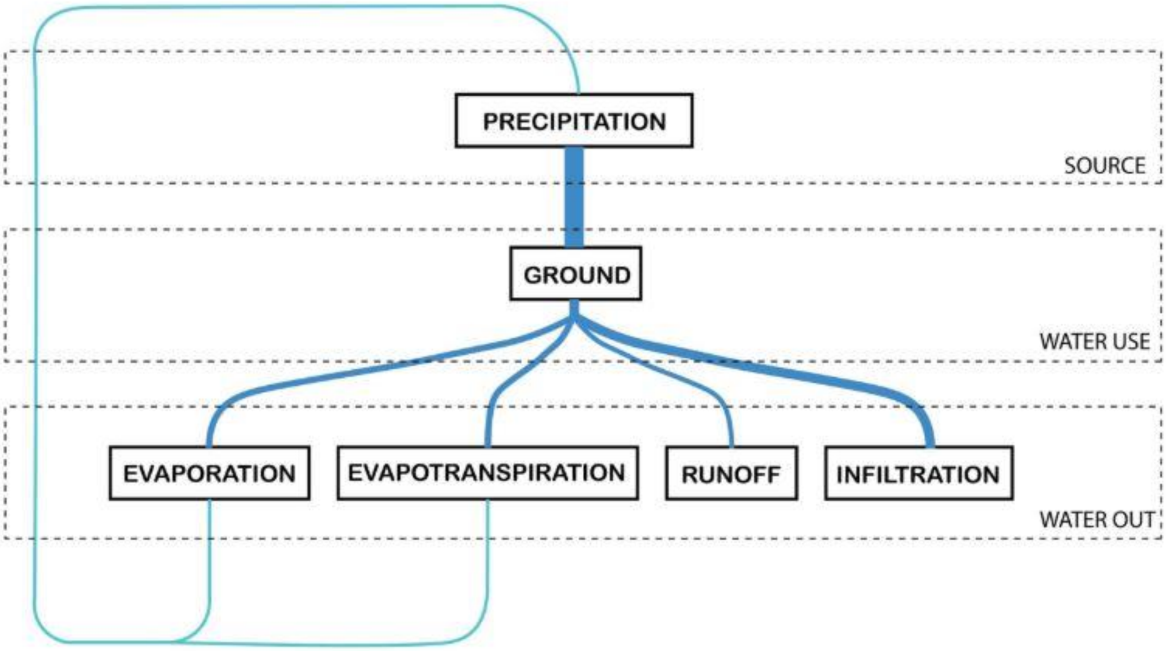
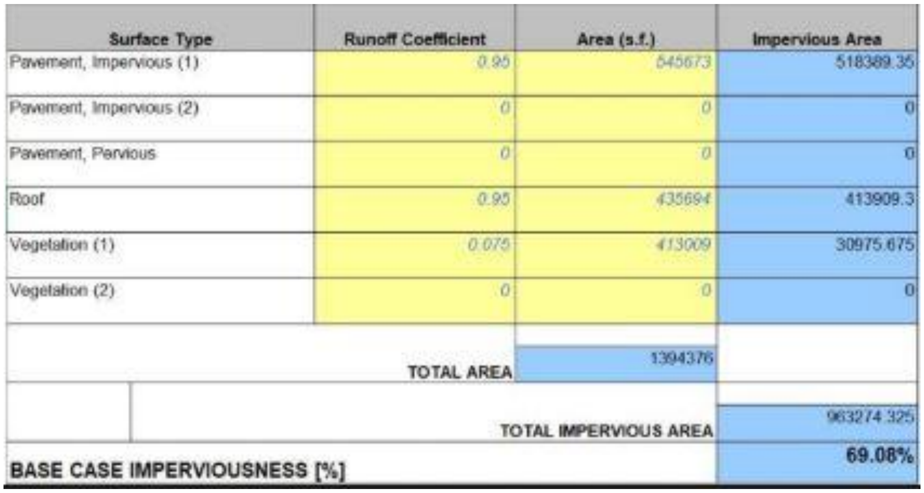


Figure 29: Pre-settlement Water Cycle

e. Current conditions

Once the University of Minnesota began to expand, the amount of impervious pavement began to increase. As more people and more building started, the soils began to diminish into the U4A soils seen today, green space started to shrink, and water systems were put into place. The udipsamments soil on site comes from urban uses, however, since the parent soil was sandy, it limits ponding. With the construction on site the 1,394,376 is divided into pervious pavement and impervious pavement. There is 413,009 square feet of soil or grass cover, which is 29.62% of the site and carries a runoff coefficient of 0.05-0.10. The impervious pavement is broken into sidewalks, pathways, and driveways, and roof area. There is 545,673 square feet of sidewalk and street pavers, or 39.13%, that carries a runoff coefficient on average of 0.85, and 435,694 (31.25%) square feet of roof space with an average runoff coefficient of 0.85. These are drastically higher than the runoff coefficient of 0.35 that was in place during pre-settlement.



Surface Type	Runoff Coefficient	Area (s.f.)	Impervious Area
Pavement, Impervious (1)	0.95	545673	518389.35
Pavement, Impervious (2)	0	0	0
Pavement, Pervious	0	0	0
Roof	0.95	435694	413909.3
Vegetation (1)	0.075	413009	30975.675
Vegetation (2)	0	0	0
	TOTAL AREA	1394376	
		TOTAL IMPERVIOUS AREA	963274.325
BASE CASE IMPERVIOUSNESS [%]			**69.08%**

Figure 30: Current Imperviousness Calculation

This comes with an increase in impervious pavement from 0 square feet to 981,367, or an increase from 0% to 69.08% of the site.

While the rate of evapotranspiration stays the same at a possible 4,459,609 gallons per year, that number is significantly less as that water is moved from the site to the Mississippi River through runoff and drainage systems. The water simply moves too fast and in the case of a large rain event, flooding would occur too quickly for it to make a difference. With less area for water to slow down and infiltrate, the less effective evapotranspiration will be on site.

The infiltration/groundwater recharge rate stays largely the same. While there is an increase in annual rainfall from 28.90 to 29.41, this is a very small increase in the recharge rates. The recharge rate is 20-25% of precipitation, making the recharge rates 5.90 inches and 7.35 inches, respectively. However, with less pervious ground, the water is not getting into the ground to recharge the groundwater sources.

The same calculation can be done for runoff rate and the increase in impervious pavement has a large effect on runoff. Using the same formula, Q=ciA with Q being the peak runoff, c being the runoff coefficient, i being the average rainfall, and A the total drainage area, the runoff on the Church Street Corridor can be calculated. With c increasing to 0.85, i increasing to 29.41, and A decreasing to 981,367, the runoff rate increases to 28.9 gallons per minute or 41,537 gallons per day. This is a substantial increase from 16.8 gallons per minute and 24,150 gallons per day that existed pre-settlement.

Figure 31: Current Water Cycle

f. Water Usage

Similar to the water cycle, the site has water sources, water users, and exit sources that makes up the water cycle. To simplify, this can be broken down into water inputs and water outputs. Water inputs include precipitation and potable water, and water outputs include stormwater, evapotranspiration, evaporation, greywater, blackwater, and infiltration. The main water source for the site is precipitation, which annually the site receives 29.41 inches of rain per year over 1,394,376 square feet of land. This gives the site a water input of 22,909,838 gallons of water per year. There are 11 buildings on site, all with documented water usage, that include water users such as sinks, flushing, washing, etc. Once the water is used, it is sent to a treatment facility and sent back into the Mississippi River. The figure below shows the cycle.

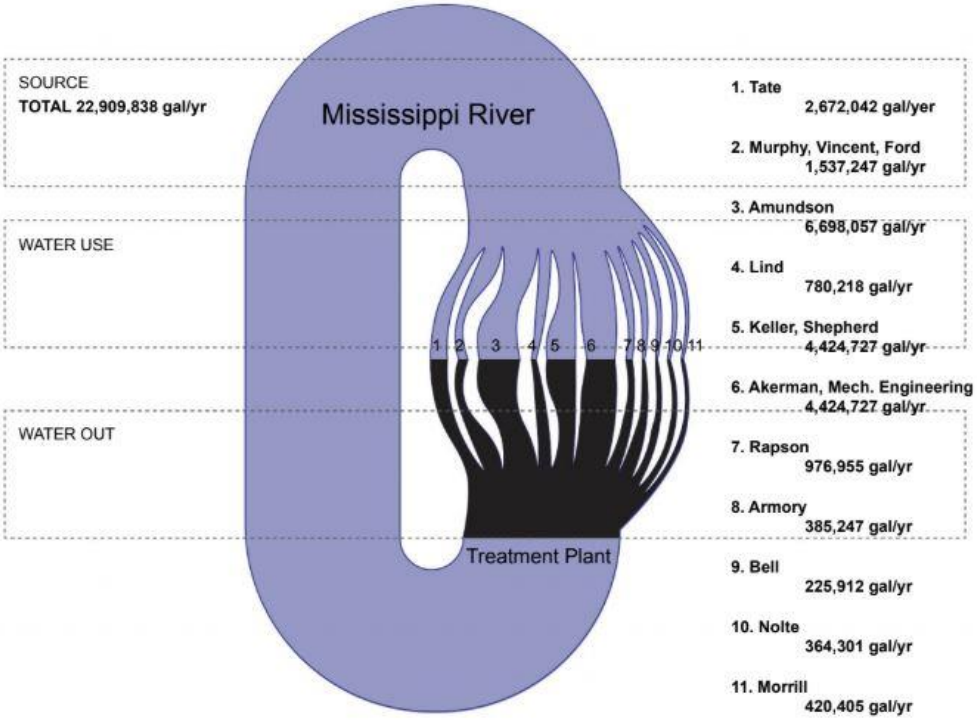


Figure 32: Site Water Cycle

With over 11 million gallons being used by buildings, it is important to understand what the uses are and where this water is going. Most of the water that is discharged after being used in the buildings is classified as greywater or blackwater. Greywater can be used on site for irrigation but blackwater is sent out for treatment before making its way to the Mississippi River. Blackwater comes from plumbing, which is a major water user on site. It can be seen that most of the building water usage is from plumbing, with the positive being that flow fixtures typically produce greywater, which could be reused for irrigation. The complete breakdown in below.

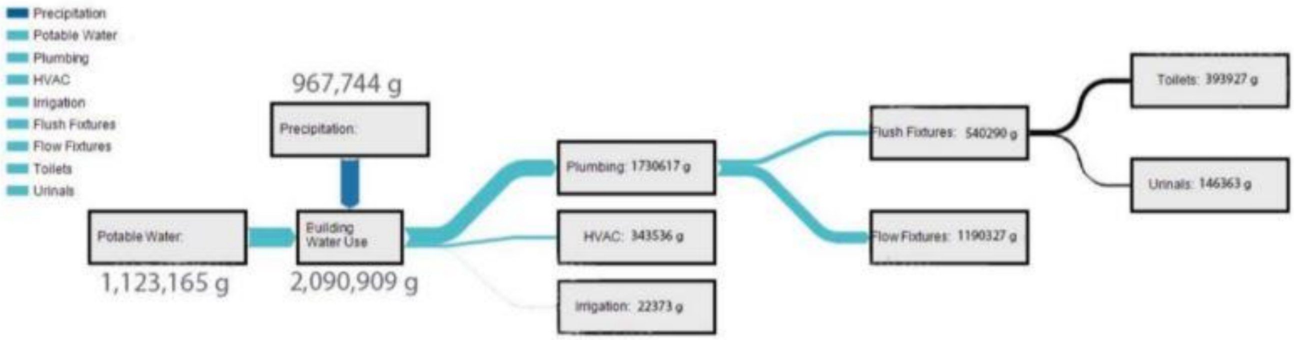


Figure 33: Building water usage for a typical building on site

Seeing that there is a lot of water moving across site from precipitation and building water usage, this presents a challenge as the runoff coefficient on site is nearly 0.9 and most of the water on site is not reused. This limits groundwater recharge and a drop in aquafer levels has been measured because of it. An intervention needs to be made that slows the water down, spreads the water out, and soaks the water up.

g. Summary

It has become clear that the Church Street Corridor has vastly changed from its pre-settlement conditions and that what is happening now needs change. The increase in impervious pavement has sped the water up and creates more runoff. With more buildings and more impervious pavement, green spaces have been reduced, which in turn means that less water is infiltrating into the ground. With the water moving so quickly and being put into the stormwater system, there is limited surface water for evaporation and evapotranspiration, which would be a big contributor to managing the water on site. This is putting reliance on a stormwater system that was designed to last a century because it was to be used for large rain events. With the water on site increasing in both quantity and speed, the stormwater system is being used for very small rain events, making it deteriorate even faster. The increased quantity and speed of the water is carrying sediment that it is picking up from the ground and eroding the concrete pipes at a much faster rate. A change in the design for water on the Church Street Corridor would not only mean better water usage and an opportunity to reuse water, but it could also have a large financial savings that the university could use elsewhere.

CHAPTER V: DESIGN OF THE CHURCH STREET CORRIDOR

Design of the Church Street Corridor requires alignment with the needs and standards of the University of Minnesota. The Institute on the Environment at the University of Minnesota has laid out a strategic plan for 2019-2022 that looks to engage the community and present positive change. A report from the IPCC on the impact of global warming released in 2018 stated that we have about 12 years to make changes to reduce environment change before it becomes permanent. The Institute on the Environment (IonE) has laid out its goals to include:

1. Build a scalable and replicable model, so that IonE leads the nation in developing testable, replicable models of sustainability in the relevant sandbox of Minnesota, and advances the application of those models globally through best-in-class storytelling.
2. Grow and galvanize the IonE community, so that IonE fully engages each member, so that each person – from the most senior researcher to a first-year student – can articulate and act out the institute's mission, individually and collectively. In other words, the institute seeks to build ownership among its key internal and external stakeholders.
3. Improve our recipe, so that IonE is top of mind among university centers and institutes, as well as external partners, as having a proven method for convening, connecting, and moving the needle on sustainability challenges.

These goals align with the goals of the redesign of the Church Street Corridor. The design looks to be a model that is tested and scalable and can be implemented across the university and beyond. It also looks to engage the students and the community in an educational way that would expand the knowledge of water and the need for sustainability. A successful design would be looked at and studied for use at other universities and larger scales and to connect people with a resource that is taken for granted.

a. Concept

The concept proposal looks to incorporate education and participation from the users of the site while also creating dynamic spaces that currently go to waste. The campus currently has dead space between buildings that create courtyards of unused gravel space that are rarely inhabited. There is also a 30-foot-wide walkway that extends through the center of the site. 14 feet is needed to allow for emergency vehicles to access the buildings along the walkway, and even though it is a heavily travelled area, this is an unnecessary impervious core that would provide a great platform to educate the users on water. Getting people to understand the importance of the water on site and that caring about what happens to stormwater is something everyone needs to do. This does not just stop at the site, but the concepts learned here extend to the top of the watershed where it all starts. Taking small steps to solve a big problem is a start, but we ultimately need to accelerate the learning process and begin implementing solutions on a larger scale before it is too late. The elimination of impervious surfaces, inclusion of a large bioswale, underground cisterns, and visible rainwater collection tanks are all viable solutions that maintain the integrity of the site while also improving its water performance. With the amount of precipitation increasing and large rain events becoming more common, the design is based around a 40-inch annual rainfall and to have the capacity to withstand a 7.5-inch rain event. The current system sees about 29.4-inches per year and a 7.5-inch rain event would cause the system to collapse.

b. Tactics

Building scale

Many of the building roofs on site are flat and unused, making them perfect for green roofs. There is over 435,000 square feet of roof space for green roofs (31% of the site). Green roofs, in combination with water catchment systems, would reduce 10,726,000 gallons of runoff on site. Runoff would be eliminated with the infiltration from the green roof, water storage, and infiltration by the green space the site currently has.

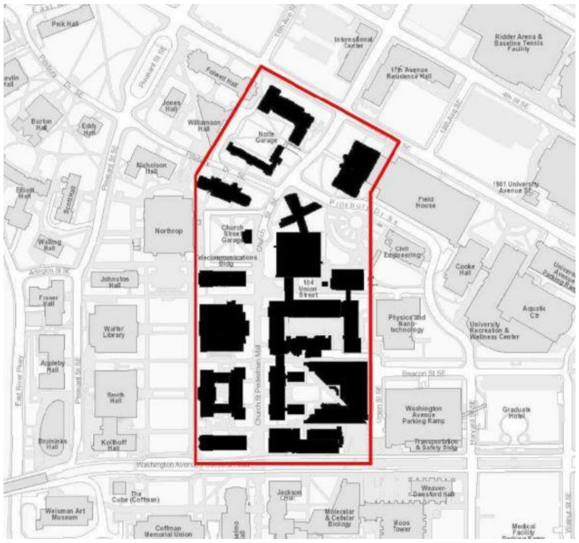


Figure 34: Potential Green Roof Locations

While green roofs would not be viable on every roof due to a diminishing return because of the expense to construct a green roof, buildings with little green area surrounding it would be good candidates as the water runoff from the roof would have nowhere to infiltrate once on the ground. Tate Hall is a good example as it is surrounded by impervious sidewalks on each side. Green roofs can retain between 70%-90% of precipitation that falls on them in the summer months, meaning increased evaporation and decreased runoff. Each green roof is different, but there are examples of successful green roofs in Minneapolis, such as the green roof at the Target Center. They are costly and typically costs between $10-$24 a square foot, creating a large initial investment.

Water storage using new and existing catchment systems is also a viable way to collect roof runoff for storage. Making these systems visible showcases the reduction and reuse of water and allows for human interaction and education. The newly renovated Tate Hall has a large open area in the center that has room for a 25,000-gallon storage tank. The water will drain from a roof system down a vertical living wall that can be attached structurally to the main staircase. Below is a section showing the system and water storage location.

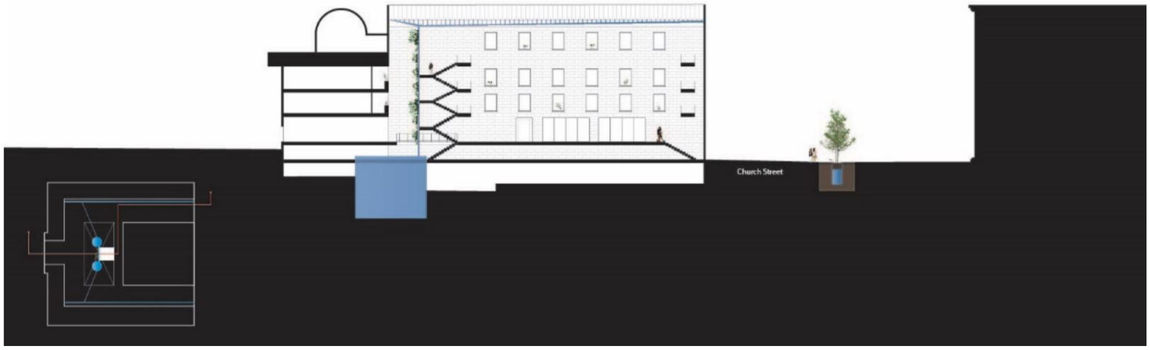


Figure 35: Section Through Tate Hall

The system takes advantage of the existing stormwater plan and openness of the plan to showcase water storage. As the water makes its way down the vertical living wall, it will be naturally filtered before being cleaned and stored in the tank. The cleaning of the water will take place before it is stored to keep contaminants from being stored in the tank. In case of a large rain event, excess water will be piped to exterior storage tanks. The living wall and clear glass storage tank will educate the occupants about natural filtration and highlight water storage as a viable option on campus.

Stormwater Cisterns.

Six large stormwater systems, varying in depth and dimension have been placed on site in underused areas to showcase the water storage. Portions of the cisterns are below ground, while other parts are above ground to activate space and create usage for the students on site. Varying in size and capacity, locations were chosen in areas where runoff builds up and floods frequently. Some locations take advantage of areas that would be otherwise uninhabited, while other locations are near heavy traffic to bring attention to the cisterns. Below shows the areas on site where stormwater buildup is prevalent along with the locations of catch basins.

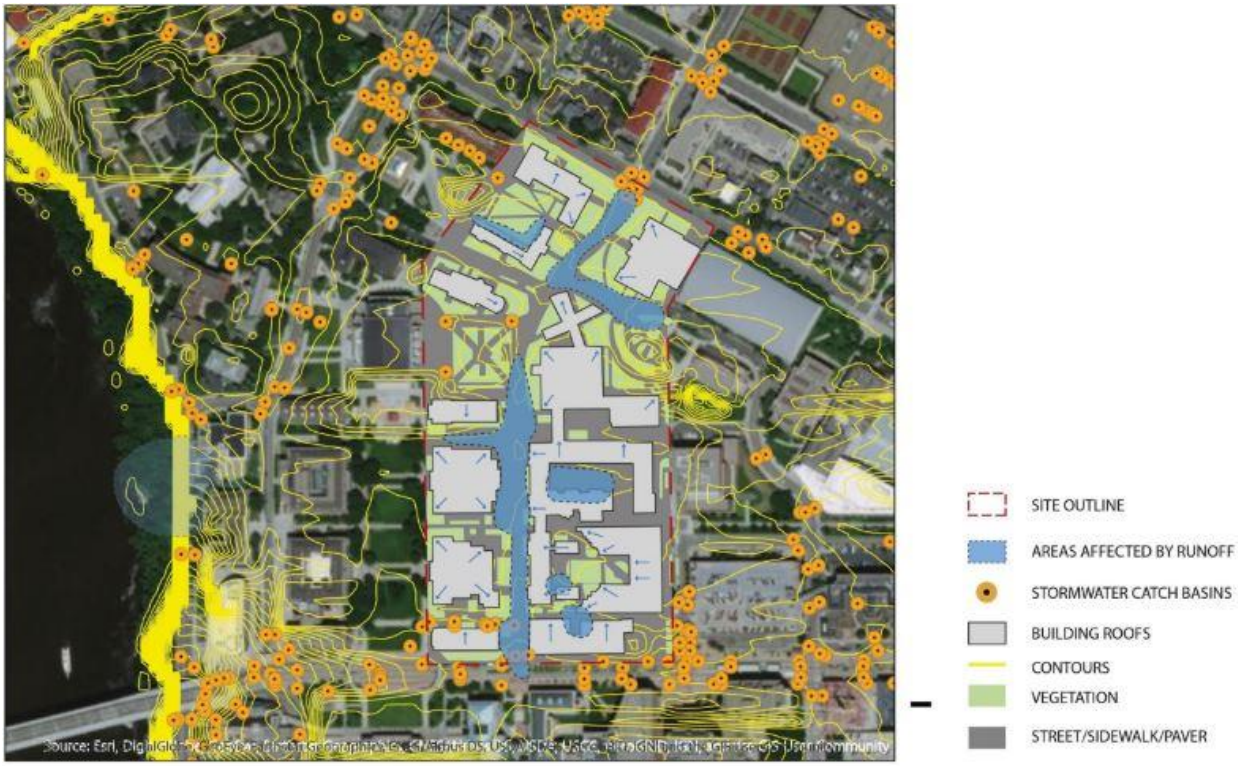


Figure 36: Stormwater Runoff on site

The most noticeable is a 335,000-gallon system of eight connected cisterns located below a bioswale, cutting an 8-foot section from the large, 30-foot walkway down the middle. The location of these cisterns are placed in open areas and not under buildings to allow for easy access for cleaning and maintenance. In total, there is enough storage for 2.2 million gallons of water, enough for 6 months of winter water usage at 360,000 gallons per month. Below are the locations of all the cistern locations.

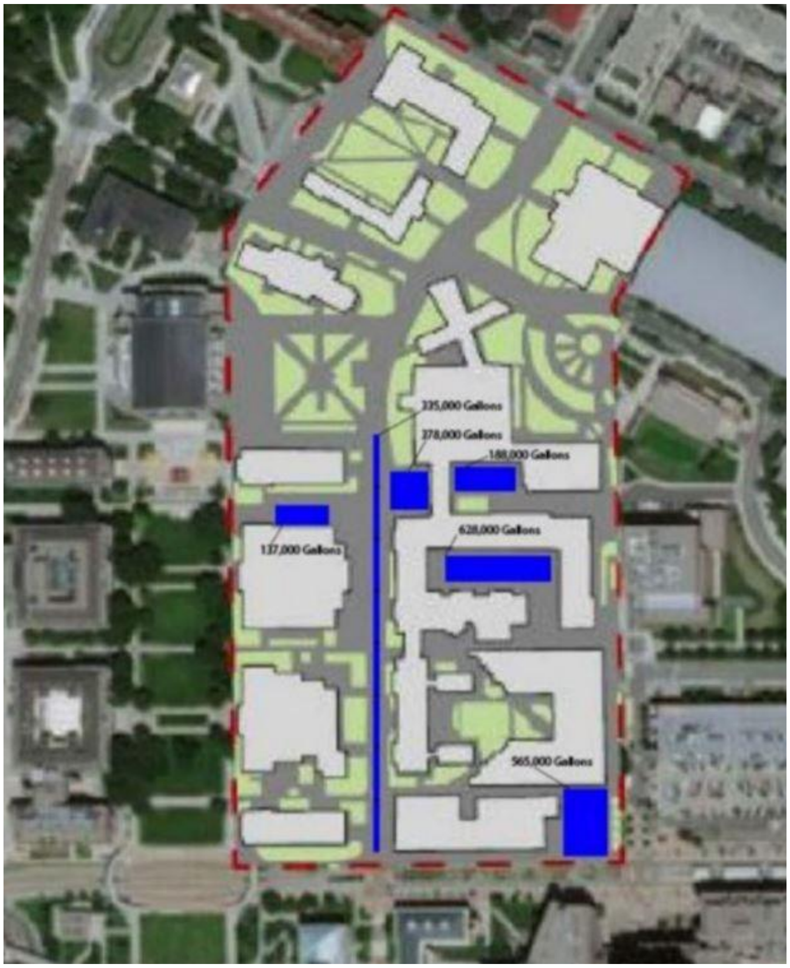


Figure 37: Stormwater Cistern Locations

The smallest of the cisterns is located above ground and acts as a secondary storage tank for Tate Hall, the building that uses the most water of the buildings on site. It is used to supplement the interior 25,000-gallon cistern during dry months to keep the most visible water attraction full when water is otherwise scarce. It is an above ground, 137,000-gallon tank that includes glass for viewing and seating for visible interaction. It makes use of the unused space between buildings and creates a shady study space for students.

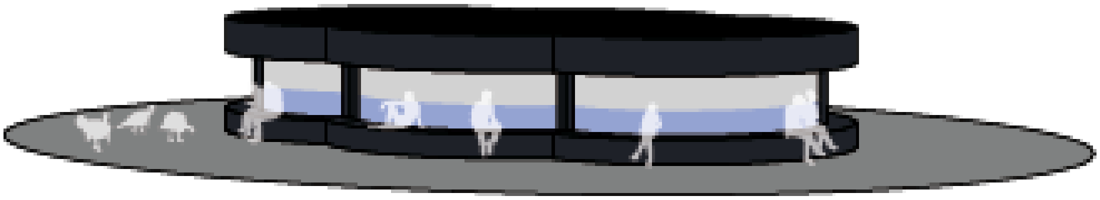


Figure 38: Cistern 1

Cistern 2 is the most complex. To limit the amount of impervious pavement on Church Street, six feet of concrete has been replaced with a bioswale, which contains a 335,000-gallon system of cisterns to store water in the most common flood area on campus. The system of eight cisterns connected by pipes eliminates excess surface water, provides more infiltration into the soil, and slows down any water that might eventually make its way to the Mississippi River. Water also infiltrates though permeable pavers that have replaced the concrete that currently sits there.

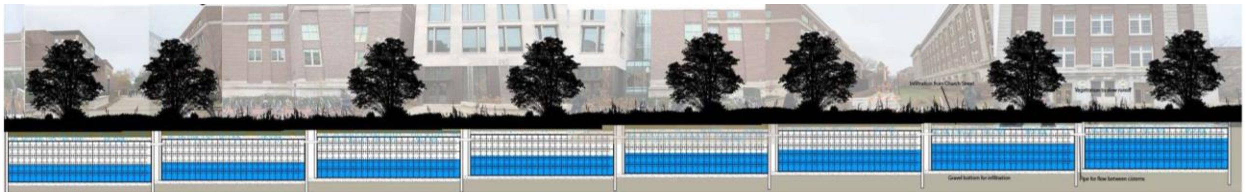


Figure 39: Section of Cistern 2 System

The bottom of the cisterns are lined with gravel to allow for slow infiltration into the ground. As water fills the tanks faster than the infiltration rate, the tanks begin to fill. When one fills, an overflow pipe brings the excess water to the next cistern, and so on. In the event of a very large rain event and all cisterns are filled, a release pipe brings the water down to the Mississippi River to take away the chance of flooding in that area. Above ground, the swale is planted with trees and other vegetation to make it an area for students to enjoy. Seating is provided and with an opening to the south it receives plenty of sunlight. Below is a section of the bioswale.

Figure 40: Section Through Bioswale

Cistern 3, located mostly below ground, adds usefulness to an otherwise underused section of the site. It is centered in a very open and populated area, so having a spiral seating section above ground allows students a place to sit, but also to show the systems that are being utilized below them on their campus. It holds 378,000 gallons and keeping the water storage below ground allows for the natural temperature of the ground to keep the water from freezing.

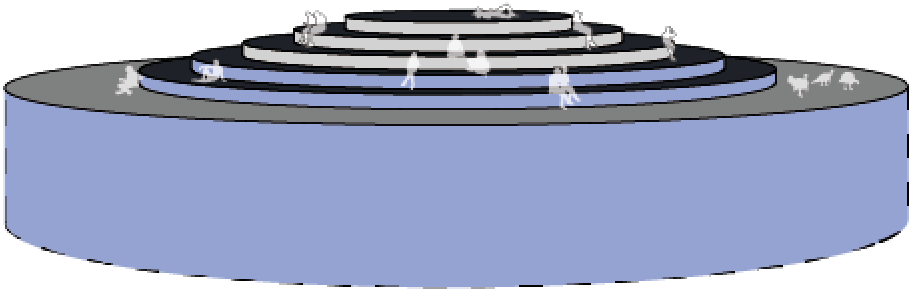


Figure 41: Cistern 3

Partially underground, partially above, cistern 4 creates a unique place to relax in the outside courtyard of the Architecture School. Currently used as construction parking and gravel pit, this cistern would make this space more enjoyable while at the same time helping to eliminate runoff to the sewer system. The above ground portion features charred wood to absorb heat and keep the water from freezing during the winter months. Although smaller, it maxes out at 188,000 gallons.

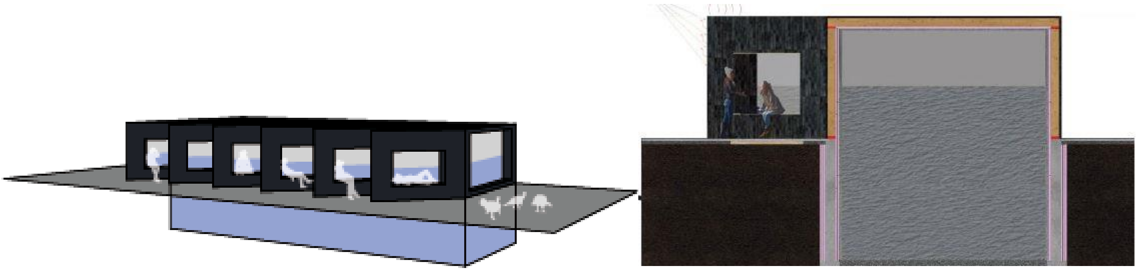


Figure 42: Cistern 4

Cistern 5 also looks to liven up an area of the site that is heavily underused and to create an outdoor space for students to relax. Designed as bleacher style seating, occupants can see the systems being used, which will help educate them as to their importance. It can also be used as seating for outdoor lectures and sports viewing on the weekends. Being the largest cistern, it holds 628,000 gallons.

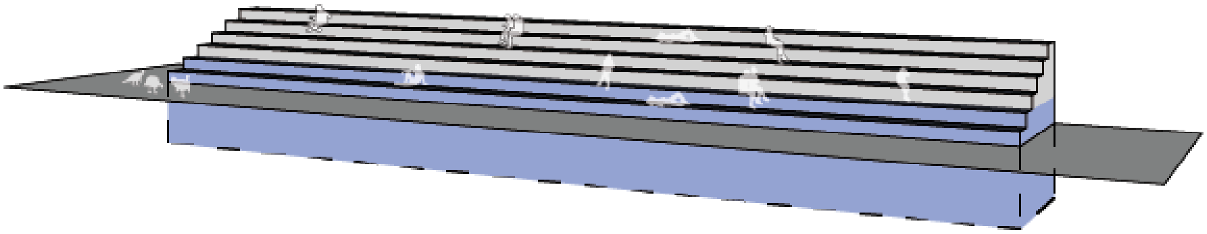


Figure 43: Cistern 5

Cistern 6 is located near a busy intersection on the site and will be a useful and functional art piece to show water storage and runoff mitigation. With the ability to hold 565,000 gallons, this tiered cistern could be a highlight in an already busy area along Washington Street in the corner of the Church Street Corridor. Located near student apartments, dorms, and businesses, this is sure to be an educational piece that reaches a lot of people.

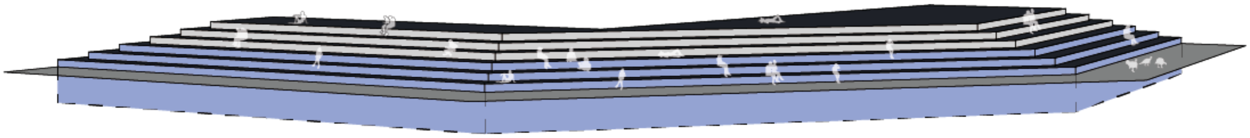


Figure 44: Cistern 6

Permeable Pavers

With nearly one million square feet of impermeable surfaces on the site, a change was needed to add permeable surfaces. Church Street provided a 30-foot impermeable walkway for conversion to permeable pavers without disruption to circulation and building access for emergency vehicles. It also keeps the campus history intact while increasing infiltration on site. With the switch to permeable pavers in this location, about 30% of the impermeable surfaces were replaced with permeable pavers, reducing over 4.5 million gallons of runoff and increasing infiltration. While there has been pushback on campus about permeable pavers due to snow plows having the potential to rip up the pavers, a rubber connector has been developed that attaches to the bottom of the plow to eliminate this fear. The figure below shows the location of the permeable pavers and the final site plan.

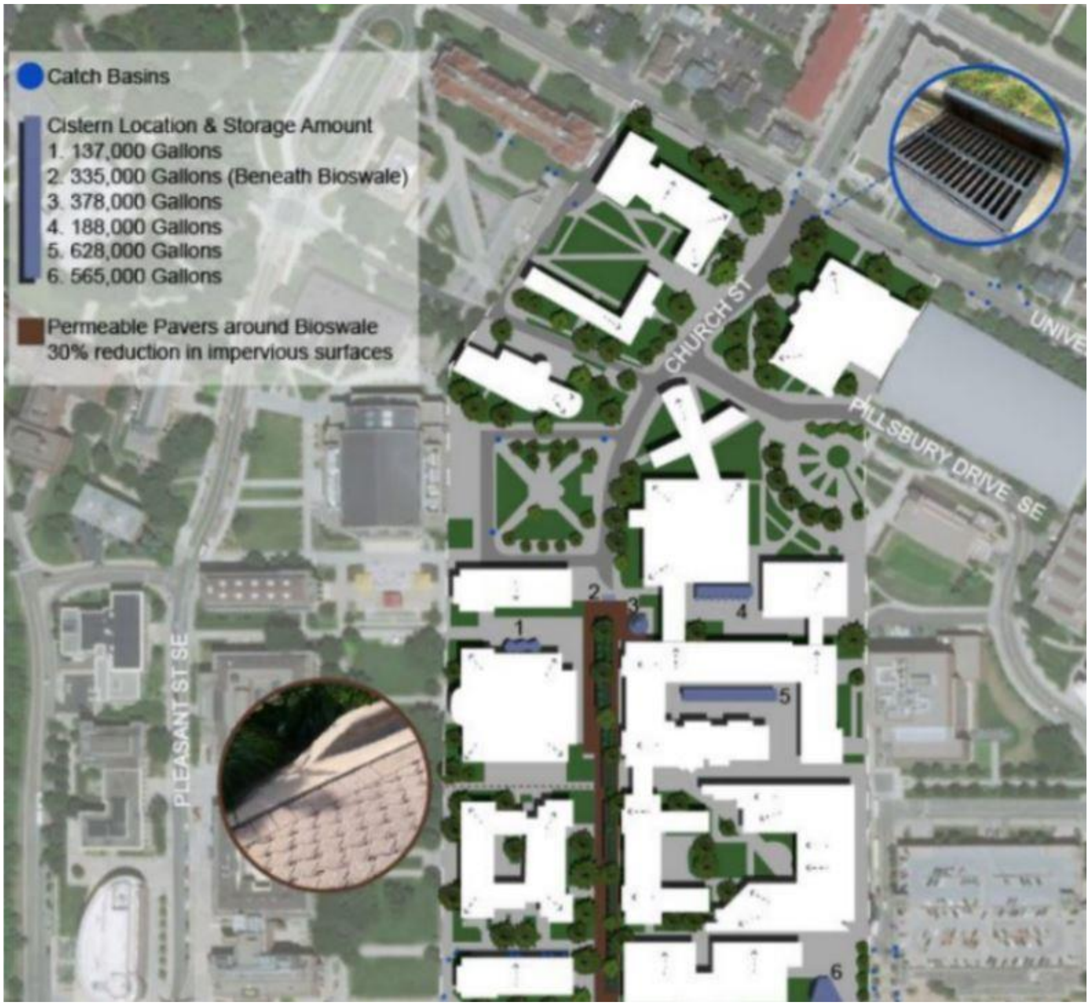


Figure 45: Final Site Plan

c. Design by the Numbers

Even though Minneapolis currently sees about 30 inches of rainfall a year, data shows that this number will only increase. In the design, final numbers and estimated water on site is based on a 40-inch annual rainfall with the expectation of a 7.5-inch rain event. The total water on site includes precipitation, evapotranspiration, potable water, runoff, flow fixtures, treated greywater, flush fixtures, shallow infiltration, and deep infiltration. The goal was to take all of the inputs and balance them with the outputs to take advantage of the resources on the site. Through a series of flows, a cycle was created that slows the water down, spreads the water out, and soaks the water up. The image below shows how the water moves through the site and what it is being used for in a combination of inputs and outputs, which is a drastic increase from the base case.

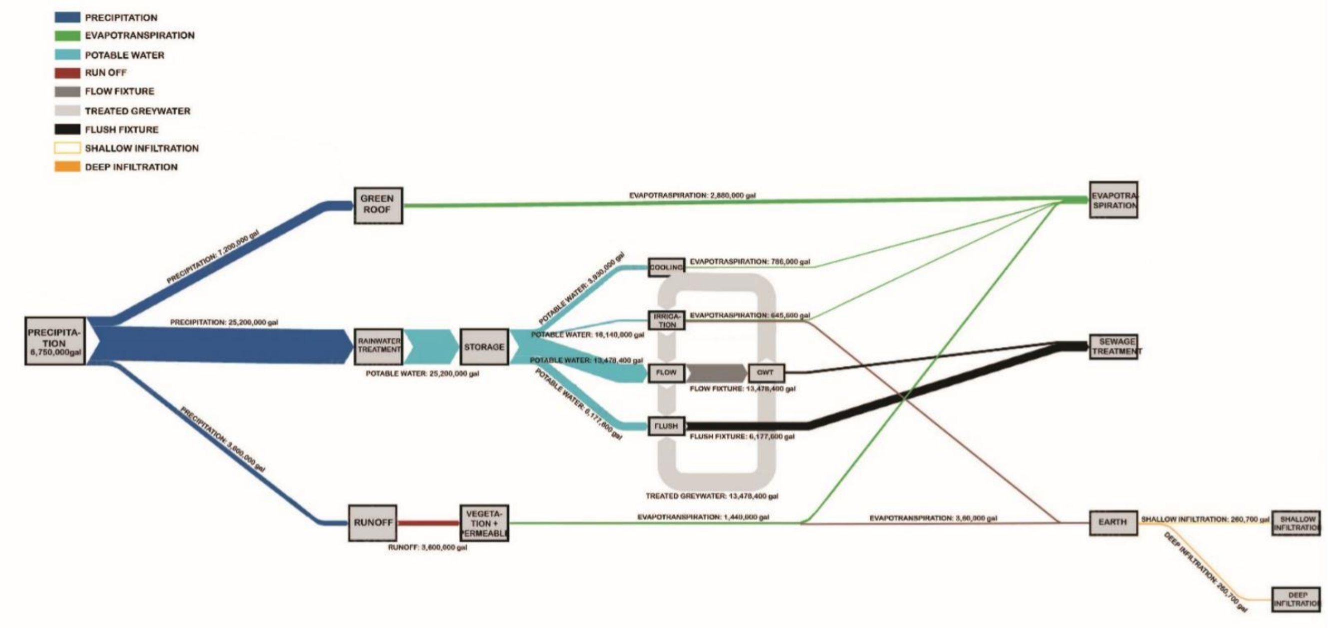


Figure 46: Total Water on Site

While a full list of calculations can be seen in Appendix A, the total water on site from a 7.5-inch rain event is about 6.7 million gallons. With nearly 7 million gallons of water on site within a 24-hour span, the design needs to be able to hold up without overtaxing the sewer system. With the addition of permeable pavers, there is an increased amount of deep and shallow infiltration. The addition of the green roof helps eliminate roof runoff while also storing water and sending it to indoor storage tanks. The large cisterns can hold up to 2.2 million gallons of water, or 33% of the total water and the overflow system is designed to slow down and filter any water that reaches the Mississippi River so that the quantity and quality of the water going into the river is improved.

d. Cost Analysis

While monetary cost is not the most important factor, it will definitely play a part in deciding whether to implement green infrastructure. Starting with the water storage tanks, to hold 2.2 million gallons of water would require 294,750 cubic feet of concrete. With concrete costing an average of $4.45 per cubic feet, the total cost to construct the concrete storage tanks would be $1,310,000 (Concrete Network). Adding in excavation costs and gravel for infiltration, the total cost is about $2 million for the water storage tanks. Planting and landscape can be added as preferred which will add additional cost, but also provide a more attractive scene.

The green roof on Tate Hall is also a good example of green infrastructure implemented into the design. The roof of Tate Hall is roughly 35,000 square feet, and the cost of a green roof, on average, is $17 per square feet (Green Roof Council). While there are many factors that go into the cost of a green roof, this is the average cost of an extensive green roof with water repellent membranes. This puts the cost of the green roof at $595,000 Adding in extra structural support that may be needed and additional water systems, a safe estimate for the green roof would be $800,000. The green roof also connects into the 25,000-gallon clear plastic storage tank and vertical wall. The cost of the storage tank is about $30,000 and the addition of the vertical wall and pipe connections to the tank adds an additional $100,000 (National Storage Tank). This completes the cost of the green roof and adjoining systems at a total cost of 930,000.

The switch from impervious concrete to pervious pavers is another big change on site to help with water management and infiltration. Replacing the Church Street section between Washington Street and Rapson Hall is over 30% of the impervious pavement on site. It is an 815-foot by 30-foot section totaling 24,450 square feet. Permeable pavers cost an average of $5.00 per square foot including, including installation for interlocking pavers (Rockville Cost Estimation). This puts the total for the installed pavers at $122,250. Removal of the existing concrete will add an additional $200,000 with labor and equipment (Rockville Cost Estimation). This puts the total for the pervious pavers at $322,250.

Altogether, the basics for this project looks to cost about $3.25 million. Factoring in permit costs, additional material, water cleaning systems, and taxes, it is reasonable for the total project to come to a final total of $5 million. While this is a fairly large price tag, it does include monetary savings. For example, water in Minneapolis costs $3.68 per unit of water, which is about 750 gallons (City of Minneapolis). The design has the ability to hold 2.2 million gallons, which was chosen to make sure enough water is stored for six months of winter at 360,000 gallons per month. With 2.2 million gallons of water being stored, this has a potential savings of $10,795 per year in water fees. The cost per water unit for sewer is $4.54 per water unit (City of Minneapolis). With the buildings on site using 15 million gallons of water per year for flush and flow fixtures, the savings of cleaning this water with natural systems and cutting the greywater in half would be over $34,000 per year. In the event of a 7.5-inch rain event, the storage tanks can absorb about 33% of the water, taking significant strain off of the stormwater system. At an average cost of $225 per foot to replace concrete storm pipes, the average repair cost on campus for the stormwater piping system is around $200,000 annually (City of Minneapolis). This cost is on the low end as if it not done each year, more damage such as sinkholes, flooding, and other things can happen. Without a redesign of the Church Street Corridor, the flood damage that would be done by a 7.5-inch rain event would cost millions of dollars. This shows that green infrastructure provides a much bigger monetary return than it currently recognized.

e. Findings and Recommendations

<u>Findings:</u>

Overall, there are three main findings about green infrastructure and its implementation in urban settings. These are the understanding of the ecological state, its value monetary and public value, and policy.

First, there needs to be an understanding that green infrastructure is a system of parts that makes up a whole. Just as it is important to understand the parts that make up the biosphere, it is important to understand that green infrastructure is made up of parts that make a whole. It is impossible to understand the whole without understanding the parts. While there are others, these parts include rain gardens, permeable pavers, green roofs, and bioretention. One of these on their own will not fix the problems cities currently face, but working together they can.

Second, as green infrastructure is typically passed over due to a failure to see the monetary and public value, it is important to understand that while green infrastructure brings monetary value, that is not the only benefit it brings. Green infrastructure reduces runoff, lowers the urban heat island, reduces CO2, creates educational opportunities, and creates public spaces, among other things. While monetary value can be assigned to the reduction of CO2 and the improved health that people can see from green infrastructure, the monetary value is not the most important factor. The most important factor is maintaining the water so that it does not degrade or deplete, which would create much bigger problems.

Third, policy needs to align with the goals of green infrastructure. As it stands, policy is working against the implementation of green infrastructure and a change in policy views is just as important as the development of green infrastructure. Policy has the ability to push green infrastructure and incentivize it for people to start implementing it. As this thesis has shown, there are plenty of reasons why green infrastructure is important to cities and for something like the fear of change to be holding it back would be a missed opportunity to correct mistakes that have been made in the past.

Recommendations:

As discussed, green infrastructure will play a vital role in flood mitigation, water quality issues, and stormwater degradation as global warming and climate variability continue. In areas such as Arizona where drought is common, green infrastructure helps manage and store water for uses when water is not abundant. For areas like Minnesota, where the annual rainfall continues to increase, stormwater mitigation is a huge concern. Not only is precipitation increasing, but large rainfall events that cities are not prepared for are becoming more and more common. With this in mind, this thesis recommends the following:

- Implement green infrastructure in parts to create a whole solution. While still helpful, individual practices can only do so much. When various, smaller solutions, work together, they have a large impact.
- While it is certainly not the only possible design, using the design shown in this thesis in the Church Street Corridor as an example and case study for other locations is recommended. The combination of water storage, pervious pavers, bioswales, and green roofs works together to significantly reduce runoff, take reliance off of the stormwater system, and provide enough water storage to be self-reliant.
- When looking to implement green infrastructure, do not make monetary value the only consideration. If money is the deciding factor, use the calculations in Appendix A to understand how green infrastructure can create a return on investment.
- Work with lawmakers to make the path to green infrastructure easier. The current system is failing and keeps designers from implementing green infrastructure into their designs

This thesis serves as a resource to help bridge the information gap that currently exists between green infrastructure, designers, and policy makers. The redesign of the Church Street Corridor is an example of what can be done with existing sites to help them become less reliant on the current stormwater system.

CHAPTER VI: CONCLUSION

Green infrastructure will be a main focus and how designers and can implement strategies that adds value to the projects, beyond monetary value. With value typically only being seen in dollars and cents, the way these systems are viewed as “valuable” needs to change. Looking at ways green infrastructure and rainwater design can be beautiful, educational, and functional is a major key. The focus is on three major points: creating diversity in stormwater management and water usage, connecting and using natural systems, and changing the behavior and thinking behind the need for green infrastructure.

As the climate continues to change, climate variability will continue to increase and result in larger flood events at a more frequent rate. The redesign of the Church Street Corridor looks to implement green infrastructure and an educational resource for students, while also serving as a base case that can be applied to the rest of the campus. As an extremely urban site, runoff is a major problem that is degrading the current stormwater system. Instead of band-aid fixes or a costly replacement of the whole system, a redesign will solve the current problems by making the area more self-reliant and diverse so that there is flexibility in a system that has been rigid for too long.

While the redesign is not the only solution, it is a prime example of how effective green infrastructure can be when the parts are working together to create a whole. The reliance on the current stormwater system has created a huge problem that needs to be fixed or the outcome will be disastrous. Green infrastructure gives the best opportunity to fix this issue before it is too late.

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APPENDIX A
Calculations

Calculations for a 40-inch Annual Rainfall:

Building Roof - 435,694 SF

- 10,726,000 gal/yr Precipitation
        - 10,726,000 gal/yr Runoff

Grass/ Planted Area - 413,009 SF

- 10,034,000 gal/yr Precipitation

Street/ Sidewalk/ Paver - 545,673 SF

- 13,494,000 gal/yr Precipitation
        - 8,034,000 gal/yr Runoff

Site Outline - 1,394,376 SF (435,694 + 313,009 + 545,673)

- 34,600,000 gal/yr Precipitation
    - 10,440,000 gal/yr Evapotranspiration
    - 720,000 gal/yr Deep Infiltration
    - 4,680,000 gal/yr Shallow Infiltration
        - 18,760,000 gal/yr Runoff (10,726,000 + 8,034,000)

Calculations for a 7.5-inch Rainfall Event (24-Hours)

- 6,750,000 gal Total Site Water Precipitation
    - 4,640,860 gal Stormwater on ground
    - 2,109,140 gal Stormwater on roof
        - 1,957,500 gal Evapotranspiration
        - 135,000 gal Deep Infiltration
        - 877,500 gal Shallow Infiltration
        - 1,957,500 gal Evaporation
            - 1,822,500 gal Runoff Currently

Calculations for Building Water Usage

- 23,000,000 gal/yr Building Water
    - 23,400,000 gal/yr Grey Water
    - 12,600,000 gal/yr Black Water
        - Flush Fixtures: 6,177,600 Gallons [toilet (4,492,800) + Urinal (1,684,800)]
        - Flow Fixtures: 13,478,400 Gallons (Faucets)

        - HVAC: 3,930,000 Gallons
        - Irrigation: 257,299 Gallons

Calculations for Water Collection

Storage:
Precipitation - Building Water Use + Green Roof (20%) + Runoff (10%)

36,000,000 - (23,000,000 + 7,200,000 + 3,600,000)

=2,200,000 Gallons of Storage

= about 360,000 gallons per month for 6 winter months

Calculations for Project Cost

Storage Tanks:

- 2.2 million gallons of water requires 294,750 cubic feet of water storage
    - 294,750 cubic ft x $4.45 per cubic ft = $1,311,637.50
- Dirt excavation costs = $690,000 (average for 15-foot depth_
    - = ~$2,000,000

Green Roof:

- 35,000 square ft x $17 per square ft = $595,000
    - Additional work and systems estimate: $205,000
    - =$595,000 + $205,000 = $800,000
- Average cost of plastic 25,000 gallon storage tank = $30,000
- Vertical wall and systems installation = $100,000

Total Cost = $800,000 + $100,000 + $30,000 = ~$930,000

Permeable Pavers:

- 24,450 square ft x $5.00 per square ft = $122,250 (installed)
- Removal of existing concrete = $200,000 (average estimate)

Total Cost = $122,250 + $200,000 = $322,250

Total Project Cost: $2,000,000 + $930,000 + $322,250 = $3,252,250