A Thesis

Entitled

The Implementation of Green Stormwater Infrastructure in the Historic Vistula Neighborhood of Toledo

by

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Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Master of Science Degree in Civil Engineering.

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An Abstract of

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Since the industrial revolution and the mass migration of the population into urban centers, the need for impervious surfaces, roads, parking lots, and houses, has risen exponentially. While this construction is necessary, the environmental reproductions are a detriment to the human quality of life. One of the most pronounced deleterious effects of this urbanization is the man-made stormwater collection and conveyance systems. The method for handling stormwater runoff has been to capture, redirect, and release all water that enters the network. While this technique is effective in controlling flooding in areas directly adjacent to the collection points it deteriorates water quality as a whole; inhibits aquifer recharge; increases flooding downstream; and is extremely costly to construct and maintain. Implementation of green stormwater infrastructure (GSI) has become an attractive option to help mitigate these negative side effects. This project demonstrates that GSI, specifically rain gardens, can be accepted by the residents and implemented at multifamily housing units to reduce runoff. As well as providing a step by step process of how to successfully gather community input, find local champions, generate support for the project, and how to install GSI at low income multifamily housing units.

For Mom and Dad. I am the person I am because of you two, and I owe everything I have to you. I love you both!

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List of Abbreviations

EPA . . . . Environmental Protection Agency
GSI . . . . Green Stormwater Infrastructure
HSG . . . . Hydrological Soil Groupings
LID . . . . Low Impact Development
PVC . . . . Polymerizing Vinyl Chloride
SWMM . . . . .Stormwater Management Model
USDA . . . . United States Department of Agriculture
VMC . . . . .Vistula Management Company

CHAPTER ONE

LITERATURE REVIEW

1.1-Introduction

For most of complex human societal existence, standing water has been considered a direct threat to prosperous developments, both to human health and for the risk of damage to existing infrastructure. It is for this reason that the traditional approach for handling all runoff has been to quickly direct it away from settlements into sewers and then into waterways. It has been shown that this drainage strategy, while working in the short term, only exacerbates flooding in urban areas downstream from drainage sites, depletes ground water causing drought, and contributes to increases in the deterioration of surface water quality (White, 2004). While the alleged negative reproductions of long term standing water do have some validity especially within the context of an urban setting, the focus of stormwater management needs to be replicating as closely as possible the drainage conditions present in the area before the development of land, not immediate redirection as previously described. Unfortunately, while improvements to the system are desperately needed, large-scale changes on existing infrastructure can be costly, complicated, and inconvenient for both residents of the area as well as the city or organization charged with implementing the chances. For this reason, green stormwater infrastructure has emerged as an appealing alternative to remedy stormwater runoff problems.

1.2-Background

Runoff falls into two categories: diffuse, or non-point source, and point source runoff. Diffuse runoff collects over a wide area of sub catchment that cannot be traced or attributed to one specific source (White, 2004). While The Clean Water Act of 1972 significantly regulated point source runoff, its diffuse counterpart was left virtually untouched. Currently, the most common method of addressing diffuse runoff within urban areas is a collection system, either a separate sewer system or a combined sewer system (White, 2004). A combined sewer system collects runoff during a rain even, then funnels the water into the sanitary sewer system (Figure 1). Once in the system, the runoff flows to the waste water treatment facility where it is all treated and released to nearby waterways. While this system is effective when the amount of runoff is small, it does have some distinct problems in that it has the potential to add an overwhelming volume of water into the system with almost no warning, overloading the system. As the system becomes full the combined flows can no longer be treated effectively. It can be stored and treated or released, untreated, into the environment (White, 2004). This untreated sewage has the potential to harm humans and ecosystems. In addition, the contaminants found in storm runoff are significantly different and require different treatment processes to remove them as compared to the ones found in separate sanitary sewers. This means that the system in place incurs larger costs in order to bring the combined runoff to the same treatment standards as the rest of the treated waste water.

The separated sewer includes sanitary sewer and the stormwater system that are completely independent of each other (Figure 1). Typically, a separate sewer directs all stormwater runoff into nearby waterways untreated. While this solves the problem of overflows of raw sewage, it still introduces large quantities of untreated runoff into the environment. This problem can be exacerbated after long dry periods when pollutant concentrations increase exponentially. This system is also used in primarily rural areas, the only difference being that in many cases no formal collection system exists, just a series of drainage ditches leading to the nearest source of water.

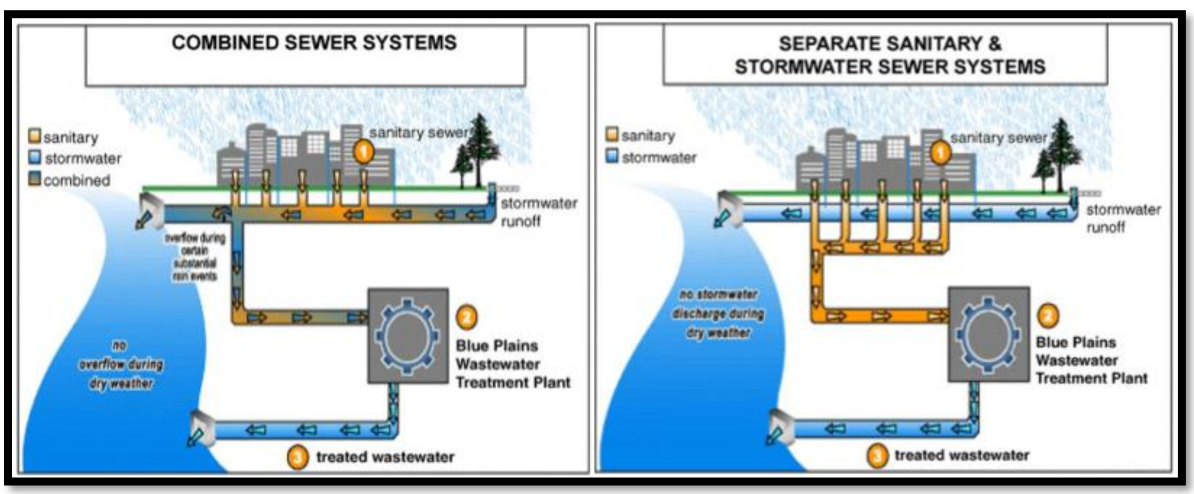

Figure 1: Combined and Separate Sewer Typical Flow Patterns (White, 2004)

Due primarily to The Clean Water Act of 1972, many of the point sources from manufacturing in urban areas are no longer the principle cause of water quality deterioration. This can now be attributed to the pollutants carried by diffuse runoff during large rain events (Glass, 2005). Runoff originates primarily from the large quantity of impervious areas (20 to 100%) found within cities (Sanders, 1986). Whether a combined sewer overflow of which the EPA estimates happens at least 40,000 times a year in the United States (Tchobanoglous, 1991) or an untreated separated storm sewer flow, it has become clear that something needs to be done to collect and treat runoff before release. It is with this goal in mind that the focus currently in storm water management is to construct new collection infrastructure, green or grey, that can capture, treat, and/or reduce runoff before it reaches the collection system (Tchobanoglous, 1991). This project was focused on the implementation of green stormwater infrastructure in Toledo.

The quantity of stormwater runoff generated at any site depends on the properties of the native soil species in the surrounding area (Table 1). Soil infiltration rate is driven by a number of factors including the soil's composition, porosity, pressure head of water above the soil, soil water content, intensity of the precipitation event, land cover, slope of soil, and by the depth of the water table in relation to the surface of the Earth (Miyazaki, 2006). For the purposes of this project the concern will fall most with the soil composition factor driving infiltration. In general, soils with good infiltration are composed of primarily sand or other similar coarse granular media with smaller percentages of either clay or loam, whereas soils with poor infiltration will be just the opposite, primarily composed of clay and or loam with the smaller percentages being attributed to sand and other coarse media. The difference between the soils' infiltration rates can be in part attributed to the particle size and the void ratio, the ratio of empty space to solid materials within the soil species, that accompanies the change in particle size of the material making up the majority of the soil. Please see (Table 2) below for typical grain sizes (Miyazaki, 2006). Clay, for instance, is a very fine-grained material, and therefore has far less physical space between particles. This inhibits the passage of water through the soil media. Sand has significantly larger particles in comparison and allows for freer movement of water between the particles. The location of the water table also affects the soil's ability to be used in GSI applications. Regardless of how well the soil takes in water if only a small vertical distance exists between the surface of the Earth and the water table, the soil will quickly saturate and lose the ability to take in more water, again making a site infeasible for the placement of GSI. The United States Department of Agriculture's rating system places soils in one of four hydrological soil groupings (HSG), A, B, C, or D, corresponding to the amount of water the soil has the ability to infiltrate in inches per hour (Table 1), (Werner, 2007). It is important to note that it is possible to have a dual soil classification, for example A/D indicating that the shallow depth of the water table acts as a restriction for the soil's infiltration ability (Werner, 2007).

Table 1: Hydrological Soil Groups and Specifications (Werner, 2007)

Soil Grouping	Runoff Potential	Sand%	Clay%	Texture	Conductivity
A	Low	>90%	<10%	Sand	>= 5.67in/hr
B	Moderately Low	50%-90%	10%-20%	Sandy Loam or Loamy Sand	1.42in/hr-5.67in/hr
C	Moderately High	<50%	20%-40%	wider Variety of Loamy Soils	0.14in/hr-1.42in/hr
D	High	<50%	>40%	Clay	<0.14in/hr

Table 2: Soil Particle Size (Miyazaki, 2006)

Grain Type	Size in mm
Gravel	> 2
Coarse Sand	2-0.2
Fine Sand	0.2-0.02
Silt	0.02-0.002
Clay	<0.002

Along with the native soil, it is important to consider the runoff potential of all other surfaces located within a sub catchment. For example, sidewalks, roadways, rooftops, and parking lots all represent areas of imperviousness, completely halting all infiltration. This higher percentage of impervious surfaces contributes directly to the deterioration of surface water sources surrounding urban centers as large volumes of surface runoff flow over dirty urban surfaces and outfall to either an overwhelmed combined sewer system or run untreated directly into a body of water in the case of a separated sewer. This is in sharp contrast to more undeveloped rural areas where a huge volume of pervious land exists and run off has an opportunity to make its way back into the Earth. This is described with the use of a runoff coefficient, a unitless value that expresses the percentage of precipitation that falls on a surface that will be converted into runoff (Riley, 2011).

1.3-Green Stormwater Infrastructure

Green stormwater infrastructure (GSI) is defined as, “an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations” (Benedict, 2002). GSI is a series of constructed apparatuses working in conjunction with each other and with already existing infrastructure to help developed urban areas preserve their natural runoff, drainage, and infiltration properties. Although GSI can take a plethora of different forms within a system, rain gardens, pervious pavement, green roofs, etc., all work towards the same general goal. This goal is to slow, capture, and infiltrate runoff leaving adjacent impervious areas, so that the total amount of water entering the traditional collection and treatment system can be lessened by a quantifiable amount (Benedict, 2002). In addition to controlling the amount of runoff leaving sites during rain events, GSI can treat pollutants found in stormwater runoff through a number of different natural processes including adsorption, filtration, and plant uptake (Katsifarakis, 2015). This work included the implementation of rain gardens, which are a specific type of GSI.

Rain gardens (also referred to as bio-retention cells) are systems with highly permeable surfaces placed within a shallow depression, usually containing plant life, designed to collect, infiltrate, and treat all or a large portion of the runoff leaving the surface of a highly impermeable area, such as a parking lot or roof, before it has the chance to enter the stormwater system (Dietz, 2005). These systems are best suited for contributing drainage areas smaller than 2 acres (Mathews, 2006). While it is possible to implement rain gardens at a wide variety of different locations it is most advantageous to place them in an area with soil of a high hydraulic conductivity (0.5 in/hr or higher) to encourage aquifer recharge through infiltration into the surrounding soils (Dietz, 2005). While the layers within a rain garden are the primary contributors to it effectiveness, numerous other design elements also play an important role including the size of the GSI. Rain gardens are suggested to be sized at a minimum of 5% the square footage of contributing areas composed of > 25% impervious surface (Mathew, 2006).

Rain gardens can be extremely effective at lowering the amount of runoff leaving a site (Dietz, 2005). Another benefit to the rain garden/bio-retention cell is their ability to remove heavy metals including lead, arsenic, and copper (Glass, 2005). However, rain gardens do become fouled the longer they are in service and will require periodic replacement (Mangangka, 2015).

Figure 2: Constructed Rain Garden in Vistula

Green stormwater infrastructure (GSI) has been increasingly employed as a method of both raising the infiltration rate in highly impervious areas, as well as a natural water treatment method so as to lesson the load on already undersized municipal wastewater treatment facilities. GSI intercepts stormwater flowing on impervious surfaces before it can reach the traditional stormwater collection system so that it can be infiltrated and returned to the environment with no further human intervention. It is for these reasons that the goal of this project was to design and implement GSI in an historic yet underserved neighborhood in Toledo comprised primarily of multifamily housing sites. This project also aimed to incorporate the direct input of local citizens in the GSI selection and implementation process.

1.4-Vistula Neighborhood Background

This project was focused on the Vistula Neighborhood founded in 1833 by Benjamin F. Stickney and bounded by the Maumee River to its south and the modern streets of Bush to its east, Cherry to its West, and the Greenbelt Parkway to the north (Floyd, 2004). The Vistula Neighborhood is the oldest portion of the City of Toledo and a direct product of both the English surrender in the war of 1812, as well as the short conflict between the State of Ohio and the then territory of Michigan (Floyd, 2004). The Vistula neighborhood was chosen for this study because of the aging infrastructure and the need for community revitalization. The entire neighborhood is serviced by a combined sewer system, meaning both the sanitary sewer and the storm sewer system flow into the same collection system. During heavy snowmelts and large rain events, the runoff generated can overload the combined system, requiring the flows to be pumped into large holding tanks placed around the city or to be discharged untreated to nearby waterways.

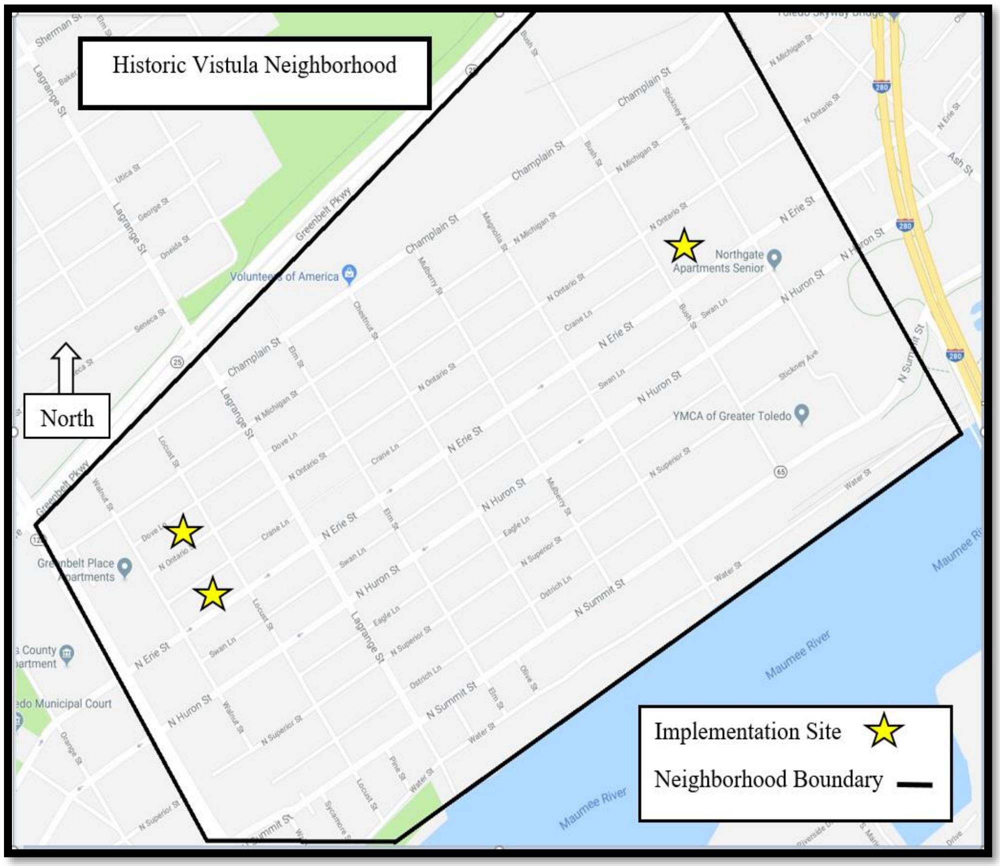

Figure 3: Map of Historic Vistula Neighborhood Boundaries

This area, plagued with vacant properties, presents an opportunity for GSI installation in the traditionally ignored sector of low income, multifamily housing sites, in which residents themselves can play an integral role in the design process. The Vistula neighborhood is an underserved community with high levels of underemployed, underrepresented residents as well as a significant population of senior citizens and young children, (Figure 4). This figure shows the percentage of each of the demographic markers at the states, regional, and nationwide level. This project provided an unique opportunity to a traditionally very transient, disadvantaged population to have an impact within their neighborhood, even without property ownership themselves. Also, the full cooperation of a local property owner, a Mr. John Kiely of the Vistula Management Company, was granted to both design and install GSI structures on his multifamily housing units. In addition, the physical properties of this portion of the city lend itself very strongly to the construction of GSI. For example, when examining the USDA soils maps, they show native soil species with a hydraulic conductivity greater than 0.5 in/hr. making the installation of green infrastructure both cost effective, as underdrains need not be implemented, and useful as a infiltration increasing tool. Lastly, the site's proximity to the central downtown portion of the city, as well as its listing on the National Registry of Historic Places, make it a high visibility area that is useful as a showcase to exactly what GSI implemented at low income multifamily house units are capable of doing. Additionally, combined sewer regions benefit more from stormwater mitigation than on with a separated sewer system.

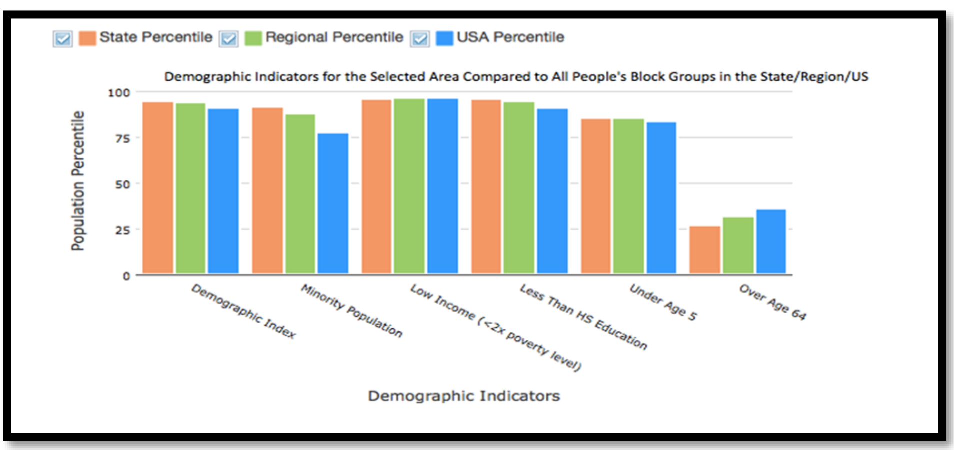

Figure 4: Environmental Justice Data

CHAPTER TWO

METHODOLOGY

2.1-Community Education and Engagement

Another important aspect of this project was educational opportunities for the citizens. The goals of the educational activities were to collect general feedback about their perceptions of the community, to inform them about GSI options, and to collect their input on GSI implementation in the neighborhood. This education primarily took the form of voluntary community meetings at which presentations were given that explained both storm water practices and other more general community improvement projects (Figure 5). Additionally, researchers were given the opportunity to be part of a community block party where the citizens were able to take part in hands on educational experiences and provide their feedback on potential improvements in their neighborhood.

Figure 5: Community Meeting

The community meetings took place in Vistula over the course of 2017 and followed the same general format for each meeting, the exception being the block party (Table 3). This format consisted of a short educational presentation in the form of a Power Point presentation covering the topic of green stormwater infrastructure, specifically rain gardens, permeable pavement, green roofs and walls, and trees. This was immediately followed by an opportunity for those attending to pose questions and concerns. The Final event that took place in Vistula as part of the community outreach portion of the project was researcher involvement in the Vistula Neighborhood block party on July 29^{th}, 2017. Pastor Mike Hanek of Salem Lutheran Church invited the researchers to attend, and give the residents an opportunity for some hands-on learning experiences about GSI. The first and largest opportunity for residents at this event was the rain barrel painting, while neighborhood children were invited to decorate rain barrels, some of which were to be given away at the conclusion of the party. Two rain barrels made their way home with residents of Vistula following the party, while the remaining 4 found their way into the hands of other local establishments, such as Salem Lutheran Church and a local women's shelter. Another display set up at this event was a GSI education table. At this table residents again could find literature on the subject, as well as a number of planter boxes designed to be attached to down spouts. This was done in an effort to show residents some things they can do in their own homes without modifying the structure to help with lower runoff amounts. Demonstrations of the planter boxes were given throughout the day showing how they work. Following the resident responses to the presentation a number of different voluntary information collection techniques were utilized in an effort to gather data that could be utilized in the GSI selection, siting, and design process. Techniques employed to gather data consisted of a resident survey, informal feedback, and preferences selected by dot voting.

Figure 6: The Author Interacting with Vistula Residents

Figure 7: Home GSI Demonstration

Figure 8: Children Taking Part in the Rain Barrel Paint

Table 3: Vistula Community Meeting Information

Meeting Name	Location	Address	Date	Description	Attendenced
Meeting 1	The Friendly Center	1324 N Superior St, Toledo	1/17/2017	Education	18 People
Meeting 2	Salem Lutheran Church	1127 N. Huron St, Toledo	2/14/2017	Education/Information Collection	40 People
Meeting 3	Salem Lutheran Church	1127 N. Huron St, Toledo	4/5/2017	Education/Dot Voting	40 People
Vistula Block Party	Salem Lutheran Church	1137 N. Huron St, Toledo	7/29/2017	Hands on Learning	Not Collected

2.2-Implementation Sites

The sites chosen for this project were four separate properties: 730 Bush Street, 819/827 Ontario Street, 823 Erie Street, and 918 Michigan Street (Figure 3). Of these four, implementation has been completed at all but the Michigan Street site, which is slated to be finished as soon as winter passes. All properties in question represent large multifamily living facilities, and are owned by Mr. John Kiely of the Vistula Management Company, who partnered on this project. The Erie Street site represents an area of just over a third of an acre (Figure 9). Of this site, 0.113 acres are impervious roof surface (approx. 34%).

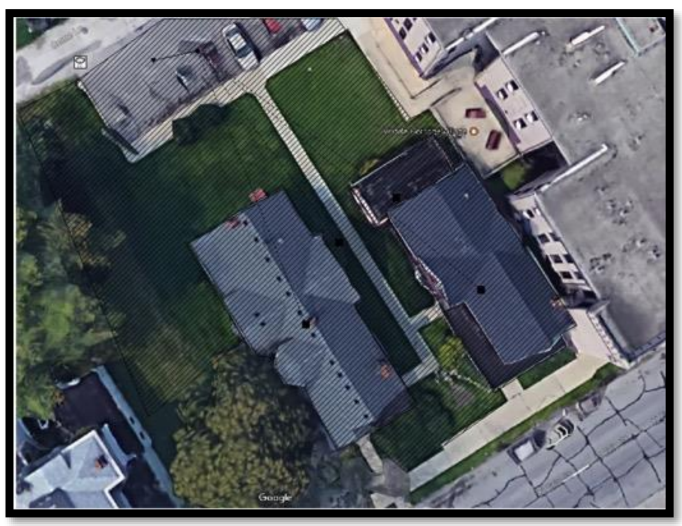

Figure 9: 823 Erie St. SWMM Model

The Ontario Street site covers an area of approximately 0.25 acres, with 50% impervious roof area (Figure 10). This site consists of 3 separate sub-catchments, 2 separate impervious roof areas, and the remaining consists of the undeveloped lot and parking area.

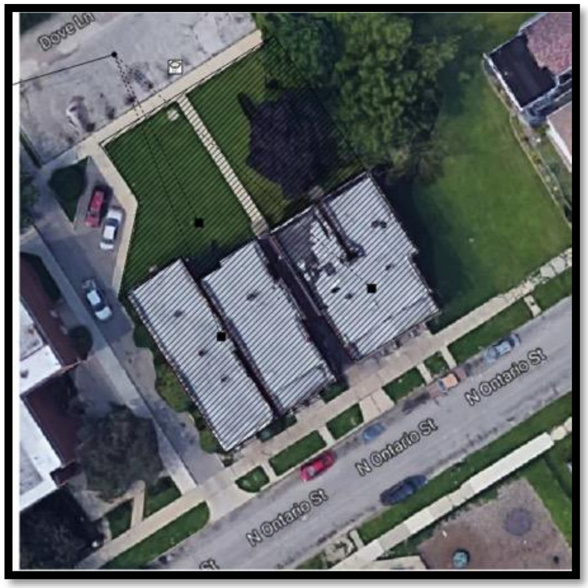

Figure 10: 819/827 Ontario St. SWMM Model

Finally, the most complicated of all the construction sites is the Bush Street location. This site, is with 50% impervious roof area (Figure 11). This site has 10 separate sub-catchments, 9 of which represent different roof areas and the 10th representing the remainder of the lot.

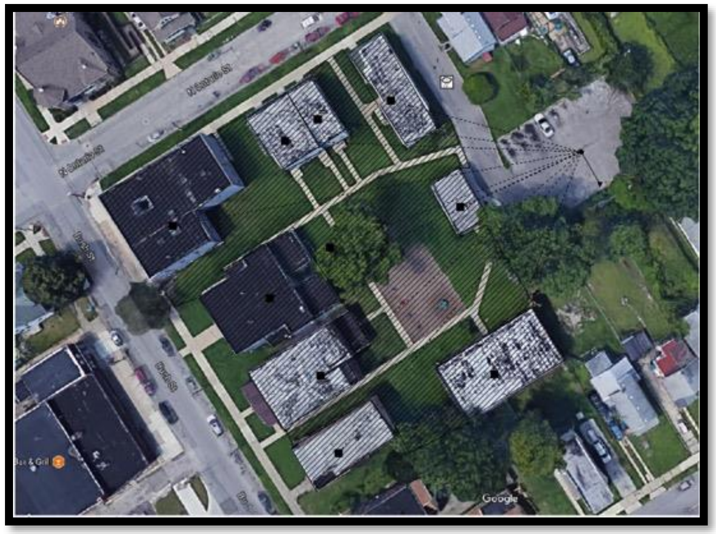

Figure 11: 730 Bush St. SWMM Model

2.3-GSI Selection and Design

The residents of the Greater Toledo area are accustomed to and generally comfortable with implementation of rain gardens as they are an increasingly common installation within Toledo. Rain gardens were chosen for this project as they allowed for the best compromise between mitigation needs of the Vistula Neighborhood, and resident wishes. Rain gardens consist of a few different principal layers (Figure 12). Starting at the Surface the first is a mulch layer of no less than 3 inches. The mulch layer serves as both control for undesirable plant life that may take advantage of the prepared soil layer and choke out the intended growth. It also serves to control the erosion of the surface of the rain garden as well as providing a biological layer that promotes filtering, capturing, and degrading pollutants that may be within the runoff (Mathews, 2006). The second layer consists of the planting soil media. This layer is to be no less than 24 inches and no greater than 48 inches, depending primarily on the species of plant one wishes to contain within the rain garden. The soil is an engineered mixture, designed to allow for maximum water infiltration while still maintaining plants rooted within it. The soil classification is loamy sand and consists of at least 80% sand and no more than 10% clay, with a pH of between 5.2-8.0 (Mathews, 2006). The third layer is referred to as the filter layer and is designed to keep the fines from the planting soil layer from migrating into the lower gravel storage layer and any lower infrastructure. This layer typically consists of 3 inches of pea gravel. The final typical layer found within a rain garden is the water storage layer consisting of 10 to 12 inches of ¾-inch gravel. This layer allows water to be stored as it seeps into the surrounding natural soil (Mathews, 2006). In the event the native soils located below the rain garden have a poor hydraulic conductivity (less than 0.5 in/hr.) an underdrain may also be utilized within the storage layer. It is important to note that the raingardens being implemented are designed to hold a 1 year 24 hour storm without overflowing this constitutes 2 inches of rain over a 24 hour period in Toledo Ohio. Anything greater than this presents the possibility for an overflow based on a number of external factors such as antecedent wet days or soil conductivity (Mathews, 2006).

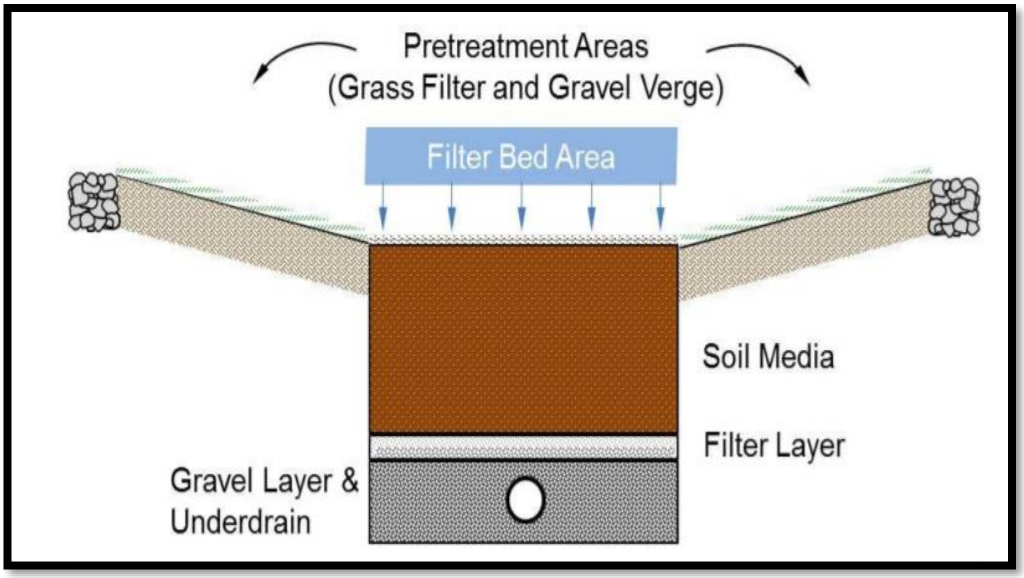

Figure 12: Rain Garden Cross Section (Mathews, 2006)

2.4-Hydrologic Modeling

A multitude of relevant factors in runoff generation (e.g., impervious percentages), a large diversity of surface types, severely altered native soil species, and a general lack of open undeveloped land all contribute to the ever-increasing complexity in accurately calculating runoff. It is for this reason that for the past few decades the popularity of different modeling software has been skyrocketing within the stormwater control industry. Although complexity of use and cost have been traditional barriers to entry for those wishing to become acquainted and competent with electronic modeling, the EPA's open source Stormwater Management Model (SWMM) has, at least in part, resolved these problems and helped to bring an increased ease of use and a degree of accuracy into modern stormwater management.

Storm water management model, or SWMM, is a dynamic rainfall-runoff simulation model capable of modeling single event simulations and long term simulations for primarily urban areas (Rossman, 2015). This program was first developed in the early1970's as a way to plan, analyze, and design drainage strategies, although since then it has gone through a number of important iterations. SWMM presents an opportunity to use large quantities of site information generated within other useful software, including GIS, to more accurately match real world conditions (Waikar et al., 2015). Another important feature within the SWMM software is the ability to model different GSI installations. SWMM allows the user to place into any model a number of different GSI installations such as rain gardens, bio-retention cells, green roofs, infiltration trenches, permeable pavement, rain barrels, rooftop disconnections, and vegetative swales (Rossman, 2015; Tao et al., 2016).

SWMM operates much as the flow chart pictured in figure 13 demonstrates. Precipitation falls within the SWMM model on to subcatchments drawn within the model. The model can incorporate real or theoretical rain data based on the project needs. From there the water is either infiltrated into the earth or converted into runoff. The model calculates this runoff quantity based on other user-entered data such as impervious percentage within the subcatchment, storage capacity of the different surfaces, slopes, and GSI installations within the subcatchment, please see table 4 below for user entered data vs. computer based assumptions. Uninfiltrated precipitation, runoff, then flows into collection nodes. A collection node is any structure that serves to collect runoff and channel it into a thoroughfare that eventually terminates in the outfall. Examples of real world structures that serve as collection nodes with in SWMM are catch basins, storm drains, or even runoff infiltration ponds. Following collection, runoff then enters the links within from the program, links are anything that transports runoff one point to the outfall, such as a pipe network, drainage ditch, or even surface flow. Lastly, the runoff makes it to the outfall, or the point in which it exits the model (Rossman, 2015).

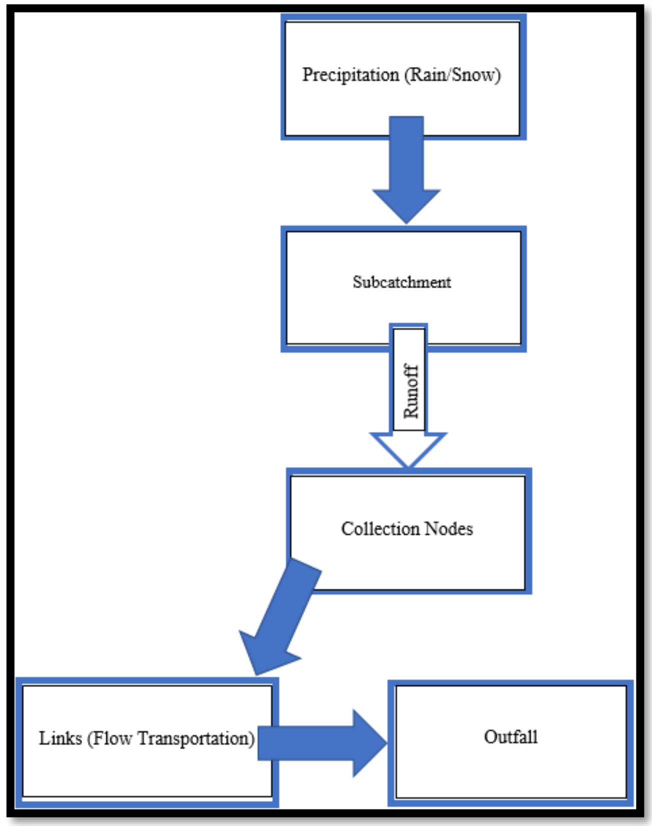

Figure 13: SWMM Operational Flow Chart

Table 4: Computer Based Assumptions vs. Measured Data

Measured	Assumptions
All Areas	Infiltration Rate
Rain Garden Construction Specifications	Infiltration Model
Pipe Properties	Rain Garden Soil Values
Rain Data	Slopes
Imperviousness	
Surface Storage Capacity	

2.5-Precipitation

A collection of real rain data for the spring of 2015 spanning from April through June was chosen to demonstrate performance of the rain gardens. This event was chosen as it is real world data and therefore it is the most accurate simulation of actual conditions. Additionally, the spring of 2015 was an especially wet period of time, so it acts effectively as a worst-case stress test of the systems.

2.6-Soils

At all of the implementation sites, the native soil species consist of different forms of urban fill, either 100% urban land or Dixboro-urban land complex. When examining the typical profiles of these soils provided by the United States Department of Agriculture (USDA) soils map it is possible to see that they consist mainly of sandy loam. This soil type typically has a relatively low runoff potential (hydraulic conductivity of approximately 0.85 inches/hour). This soil is considered hydrological soil group B, which represents soil with a moderately low runoff potential. Also provided by the USDA are the typical slope values for the areas in question. When examining the grade of the Vistula neighborhood, it can be observed that the typical grade falls somewhere between 0% and 2%. For the purposes of stormwater management, this indicates that any runoff generated within the area has a tendency to pool where it falls. The majority of flow generated in this neighborhood can be attributed to the crests of the roadways directing water to the curb and subsequently down the street. The last piece of hydrological data used for the model was the percent imperviousness. A percent imperviousness of approximately 65% was calculated using Google earth images, and this was used as a standard value for all sub catchments within the model. The roofs and the large parking lots were considered 100% impervious. The sub-catchments representing the installed Low Impact Developments, LIDs, had their imperviousness adjusted to 0% to better replicate the hydrological characteristics of the rain gardens they represent. LIDs are defines as any installations designed to help mitigate stormwater runoff without modifying the current infrastructure in place. By taking these areas together, we were able to estimate an average imperviousness for the neighborhood.

2.7-Existing Stormwater Infrastructure

In terms of stormwater infrastructure already in place within the Vistula neighborhood, the area is serviced by a combined sewer that leads directly to the Toledo Wastewater Treatment Plant located just north of the neighborhood on the Maumee

River, at the mouth of Lake Erie. As previously stated, the area's relatively flat slope guides runoff primarily along the streets being guided by the crest of the roadway to the catch basins that allow the water to enter the stormwater system, and subsequently the waste water system as a whole. It is important to note that the model does not seek to represent an exact copy of the stormwater infrastructure in place, but rather it models a simplified version in which an entire subcatchment drains to one collection point. This was done in an effort to more clearly show the difference in the runoff amounts after the implementation of raingardens.

2.8-Sites

At the Bush Street site, it was proposed that three different rain gardens be built (Figure 14). The first, North Garden, is directly adjacent to the office building at 730 Bush Street, and has flow directed into it from the roofs of the three building surrounding it. The second, East Garden, is adjacent to the easternmost corner building within a courtyard, and will be sized to handle the flow of water leaving the roofs of the roofs of the three buildings located in the northeast corner of the property. The last rain garden, South Garden is located directly between the southernmost two buildings within the courtyard. It again handles the three buildings closest to it. It is important to note with this model one of the roofs was divided into two separate drainage areas as its flow would be split when the rain garden was implemented. This site was remediated by three separate rain gardens. The first, North Garden, is 350 square ft., the second, East Garden, is 240 square ft., and the final, South Garden, is 360 square ft. again, all roofs were modeled at 100% imperviousness with no capacity for storage.

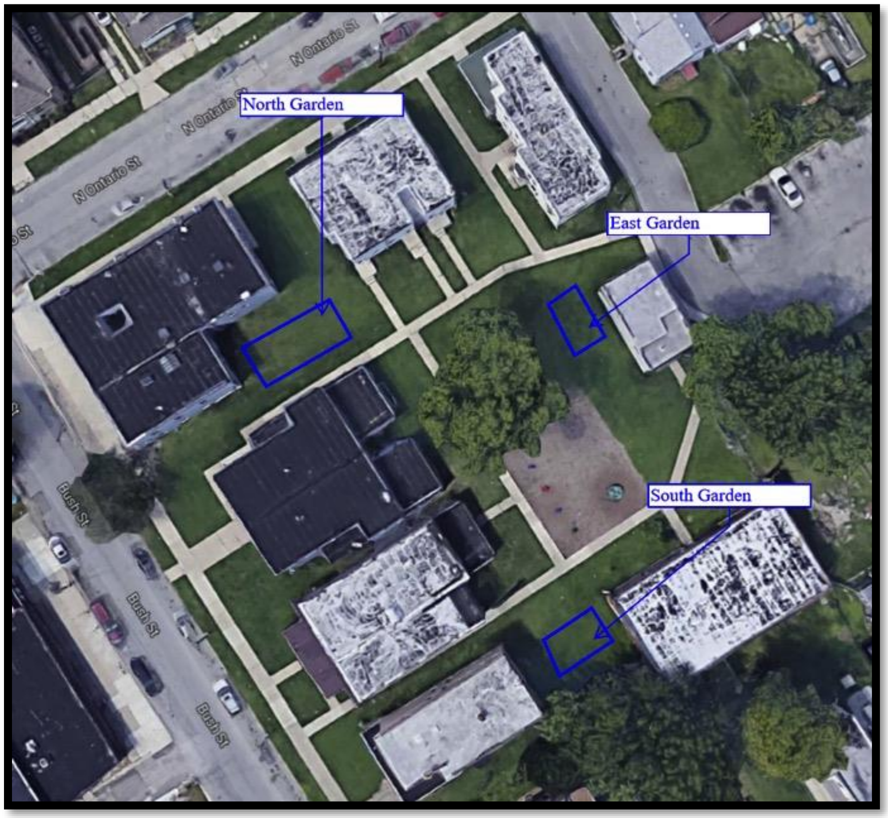

Figure 14: Bush Street GSI Siting

The Ontario Street site was remediated with two separate rain gardens, one treating the two building on the West with an area of approximately 215 square ft., and a second with an area of 175 square ft. treating the buildings on the East. All sub-catchments drain to a single collection node and subsequently to an outfall. Again, the roof areas are modeled at 100% imperviousness with no storage available. At the Ontario Street location two rain gardens were built, Left Garden and Right Garden, to handle flow leaving the roofs of the three building that make up the multi-family housing unit (Figure 15). These rain gardens were constructed north of the buildings in the adjacent yard, and will be connected to the roof via downspout and subterranean pipe. Left Garden handles the two buildings on the left of the property and Right Garden handles the larger building on the right.

Figure 15: Ontario Street GSI Siting

The final construction site on Erie Street has only one rain garden, Rain Garden 1, which can be observed in (Figure 16). This garden is located north of the building in the adjacent yard and is designed to take in the flow leaving the building roof it is directly adjacent to, as well as the flow from the roof of the back porch of the building directly east of it. Much the same as all other gardens built in this project, the rain garden is tied to its runoff producers via downspouts that feed into subterranean drainage pipes.

Figure 16: Erie Street GSI Siting

Table 5: Rain Garden Size

LID	**Dimensions**	**Area in Square feet**
Erie Garden	22ft X 11ft	242
Ontario Garden Left	18ft X 12ft	216
Ontario Garden Right	16ft X 11ft	176
Bush Garden North	29ft X 12ft	348
Bush Garden East	17ft X 14ft	238
Bust Garden South	30ft X 12ft	360

2.9-The SWMM Model

For the model of the constructed sites it was decided to look at each address as an individual entity rather than part of a larger neighborhood system. This was in an effort to show specifically the effect of rain garden implementation at each address. For each of the three sites where rain gardens had been installed two model versions were constructed, the only difference being the addition of the constructed rain gardens. In all constructed models, all subcatchments flowed to one collection node then immediately to an outfall. These models do not seek to exactly replicate the existing infrastructure within the Vistula Neighborhood, but rather provide a simplified version in order to more clearly show any changes associated with LID implementation. As previously stated, apart from the specific sub-catchments highlighted associated with roof areas, the percent imperviousness of all sites was calculated to be 65%. In addition, a hydraulic conductivity of 0.85 inches/hour was found and implemented throughout the model, again with the exception of the sub-catchments representative of the entirely impervious roof surfaces. This value was found using the USDA soil maps, and further supported by the EPA stormwater calculator. Additionally, the Green and Ampt model of infiltration was used for all rain events.

For model parameters, refer to (Table 6). The berm had a height of 1.5 ft., a soil media depth of 3 ft., a 0.5 ft. depth of filter material composed of equal parts sand and gravel, and a storage media, gravel, layer depth of 1 ft. (Mathews). The native soil species were be used as the planting media, therefore both the hydraulic conductivity of the planting media, and the seepage rate of the soil beneath the structure were be 0.85

in/hr. Additionally, the design parameters included within the model that can be found in the SWMM user manual are as follows; vegetated volume, or ratio of plants within the garden, the Manning's coefficient, the surface slope, the porosity of the soil media based on the sandy loam composition of the native soil species, the field capacity of the soil, the wilting point, or moisture content necessary to keep plants alive, the conductivity slope , the suction head, and lastly the void ratio of the storage media (Rossman) (Table 6). It is important to note also that although this was designed as a rain garden it is modeled as a bio-retention cell because of the ability to include a gravel storage layer. For cross sectional schematics please see Appendix I, Section A entitled Drawings.

Table 6: Rain Garden Properties

LID Properties	Value
Manning's Coefficient	0
Surface Slope	1%
Soil Porosity	0.43
Field Capacity	0.321
Vegetated Volume	0.1
Wilting Point	0.221
Conductivity Slope	59.1
Suction Head	9.45 in
Void Ratio	0.625

A total of four sub-catchments make up the site 3 roof areas and the surrounding lot, and it is remediated by 1 rain garden approximately 250 square ft. in area. The roof areas are modeled at 100% imperviousness with no storage capacity. All sub-catchments flow directly into the single collection node, and subsequently into the outfall.

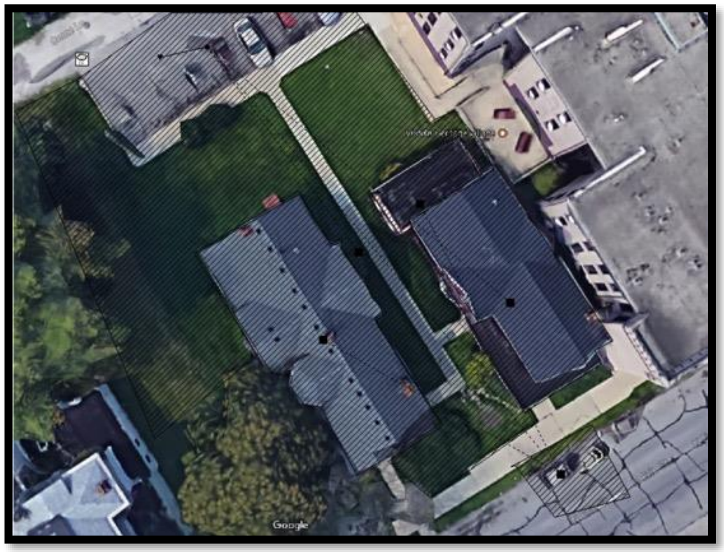

Figure 17: Erie St. Site with Rain Garden Implemented

The technique used to model the implementation of low impact developments, LIDs, into the Vistula Neighborhood was to redirect the flow of the completely impervious areas into an entirely new sub-catchment of the same size as the proposed rain garden associated with that impervious area, (Table 6). For instance, at the Erie Street site, (Figure 17), we see one new sub-catchment located to the south of the model, and the subcatchment will be sized to 5% of the roof surface it's linked to. The same flow redirection and sub-catchment creation technique applies to the Bush Street site and the Ontario Street site. These new sub-catchments were made to reflect a completely pervious surface, that is to say 0% imperviousness, and were also designed to reflect an LID that takes up the entire area of the sub-catchment. This is done as an effort to demonstrate a situation where all flow leaving these impervious surfaces is directed to these specific LIDs, and not a situation where a given percentage of the entire subcatchment is the LID. Flow is then directed from the new LID subcatchment back into the subcatchment where the rain garden would be placed during actual construction. This demonstrates the real world scenario where once the rain garden becomes saturated and overflows it then flows across another permeable surface before leaving the site entirely and entering the collection node. This node collects total flow generated from the rain garden and surrounding site. Given this it should provide an opportunity to have a convenient place to look for the changes the implemented garden is responsible for.

CHAPTER THREE

RESULTS AND DISCUSSION

3.1-General Purpose

This project was focused on the implementation of green stormwater infrastructure at multi-family housing sites in the historic Vistula neighborhood to reduce stormwater runoff. Community education and engagement combined with the collection of individual feedback led to identifying the type of green infrastructure that was desired by the neighborhood residents. Three properties were identified for implementation of rain gardens through coordination with a project partner and building manager, Vistula Management Corporation (VMC). Additionally, throughout the course of the project the steps taken toward effect project completion were recorded and prioritized, so projects in similar areas could be completed in a similar manner. The steps are as follows:

1. Identify and collaborate with community partners
2. Engage, educate, and collect feedback from residents
3. Consider GSI alternatives based on physical constraints and resident feedback

4. Identify and acquire funding source(s)
5. Identify potential locations for GSI
6. Design and implement GSI
7. Ensure construction quality of GSI
8. Estimate GSI performance

3.2-Community Education and Engagement

In this section, the data collected from community engagement activities and the projected performance of the implemented green stormwater infrastructure are provided. Throughout the entirety of the Vistula Neighborhood GSI installation project there existed a goal of keeping citizens of the neighborhood involved in the process from start to finish. Primarily, it was necessary to educate residents about GSI so that their wishes for their own neighborhood were understood. As engineers, it is not only a duty to provide the best solution to an existing problem, but to also consider the opinions, feeling, and concerns of those who live with the designs every day. Particularly in the case of GSI, in the long run, the installations will require care and attention from area residents to continue to thrive and operate correctly. Also, by involving the community it was possible to begin to build trust within the neighborhood, and open the door for further projects.

This area represents a historically low-income neighborhood within the city of Toledo that has been traditionally underserved by the city government as a whole.

Therefore, making this neighborhood makes an excellent choice for the project, both on the grounds of needed repair and rebuilding relationships with the residents. This neglect is evident when examining the advanced state of blight that the majority of the neighborhood finds itself in. This tradition of neglect on both the part of the city and the land owners has bred an attitude of distrust for city officials and generally those positions of power among the residents, not totally without cause.

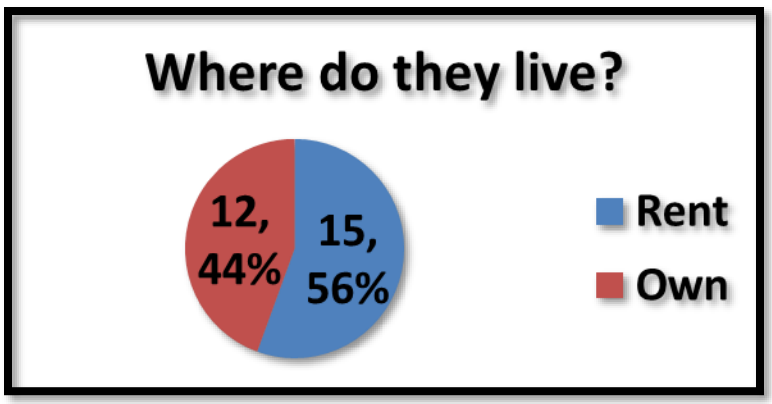

Figure 18: Demographics of Meeting Attendees

Meeting attendees were stakeholders for the Vistula neighborhood. Many of them are residents or land owners (Figure 18). Regarding the resident attitude toward GSI implementation, it would be accurate to describe it as general apprehension. This is best expressed in the verbal communication with residents directly following the meeting presentations, as well as in the surveys they took part in. The most common theme addressed at these meetings was the general state of disrepair of the neighborhood and the lack of safety. Stakeholders voiced worries about time and money needed in the future for upkeep of the installed GSI system. Additionally, concerns were expressed about potential vandalism of the site. The number of responses can be observed below in (Figure 19). This data is important because it articulated the residents' primary concern of rebuilding and safety before the voting data was ever collected and allowed for the first stages of design to take place.

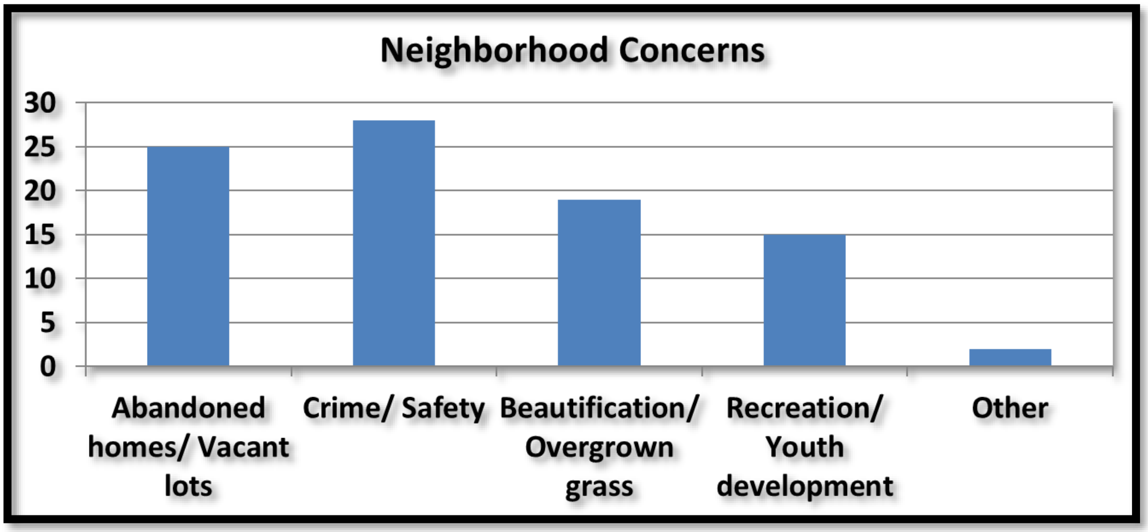

Figure 19: Resident Concerns

Dot voting was carried out at the second community meeting held at Salem Lutheran Church. Residents were introduced to various images of neighborhood improvements including GSI. Again, the residents showed the most interest in rebuilding the community around them, 14 votes (Table 7) of 40 present. The third and fourth most popular results, green along streets and permeable pavement, follow along this same general theme. The second most popular voting option was community green spaces with 11 votes. A green space for the purpose of this project represents any open undeveloped area where residents have an opportunity to come together and commune. The general area preference for rain gardens was combined with the resident preference of a community green space for this project. Since residents were very concerned about upkeep of gardens or other natural habitat and maintaining abundant available green space, rain gardens covered with low mow grass as the plant species instead of the more traditional native plant species. This decision reduced both maintenance and cost, while providing little to no opportunity for vandalism.

Table 7: Vistula Resident Dot Voting Results

Green Infrustructure Type	Vote Count
Re-Building	14
Community Green Space	11
Green Along Streets	8
Permeable Pavements	7
Rain Garden	4
Restore Nature	4
Green Roofs and Walls	3
Plant Trees	3

3.3-Installing Green Infrastructure

Perhaps the most exciting component of this project was the ability to design and install GSI at a number of multifamily housing units. After a number of years of discussion about this possibility, it came to fruition through the implementation of community feedback, the provision of a design that met community needs, and the availability of funding from other development and expansion projects occurring at these properties. The properties selected are located on Bush St., Ontario St., and Erie St. Beginning in June of 2017 and continuing through early October of the same year, these installations were designed and implemented in accordance with the specifications outlined in the methods section. Excavations were made at each site for rain garden installation (Figure 20). The rain gardens were filled with layers of materials in accordance with the standard design specifications. The down spouts of the structures on each of the sites were then tied into entrenched 6 in polymerizing vinyl chloride, PVC, connections, that flowed at a 0.5% grade into the nearest rain garden. These pipes are the primary filling mechanism of the rain gardens, see (figure 20). Finally, low mow grass was planted over the top of the rain gardens to accommodate the interests of the residents of the community (Figure 2). These installations have been visually inspected and have performed well since their installation.

Figure 20: Pipe Trench.

3.4-Estimating Green Infrastructure Performance

The properties selected for implementation are at Vistula Management Company multi-family housing sites located on Bush St., Ontario St., and Erie St. Rain Gardens planted with grass were designed and installed at these sites in 2017 by VMC. Before the effectiveness of the entire installation site as a whole could adequately be analyzed, the individual site characteristics were compared to better understand the final results (Table

8). The treatment area percentage indicates the ratio between the rain garden area and the contributing impervious surface (Table 9). These vary between 4 and 7% at the project sites.

Table 8: Site Characteristics

Site Characteristics	Bush Street	Ontario Street	Erie Street
Total Impervious Area ft^2	19,689	6,242	4,922
Total Pervious Area ft^2	23,478	5227	10,018
Number of Rain Gardens	3	2	1
Total Rain Garden Area ft^2	950	390	250
Percent of Impervious area treated	4.90%	6.20%	5%
Total Site Area ft^2	43,167	11,469	14,940

Table 9: Ratio of Treated Impervious Surface to Rain Garden Area

Individual Rain Garden Treatment Area Percentage	Bush Street
North Garden	4.20%
East Garden	6.30%
South Garden	4.40%
Individual Rain Garden Treatment Area Percentage	Ontario Street
Left Garden	5.79%
Right garden	7.02%
Individual Rain Garden Treatment Area Percentage	Erie Street
Garden 1	5%

Bush Street is the largest in total area, comprising almost a full acre as compared to Ontario and Erie Street whose areas are 0.26 and 0.34 acres, respectively (Table 8). To begin with, the most important measure of the efficacy of the installed rain garden is the percentage of water that enters the rain garden that is subsequently converted into runoff or conversely the percentage of water that enters the rain garden that is subsequently infiltrated. The quantities of inflow, infiltration, and outflow are represented in SWMM as inches of depth per area of the rain garden (Table 10, 11, 12). These values are used to calculate the runoff percentage. The runoff percentage for the North, East, and South Gardens at the Bush Street site was estimated at 39.7%, 30.0%, and 38.5%, respectively (Table 10). Higher percentage indicates less treatment (or more flow being converted to runoff). This is in direct agreement with the findings that the smallest treatment percentage, the North Garden, generates the largest percentage of runoff (Table 9). Treatment percentage represents the ratio of impervious area to the rain garden surface area designed to remediate it. The standard convention used in the design of rain gardens is a 5% treatment percentage.

These results are measured directly at the rain garden itself and not at the outfall. This pattern continued at the Ontario Street site where the smaller rain garden (left garden) produces more runoff (36% with a treatment percentage of 5.8%) (Table 11). This is in comparison to the right garden at the site where only 31% of the total flow entering the site was converted into runoff, where the treatment percentage is higher (7.02%). This trend is the product of the higher capacity the proportionally larger rain gardens have when compared to the smaller percentages at similar sites. All three sites facilitated increased infiltration of more than 60% (Figure 21). Infiltration percentage was highest at the Erie St. Site (71%), indicating that the best mitigation of stormwater runoff through the rain garden occurred at this site.

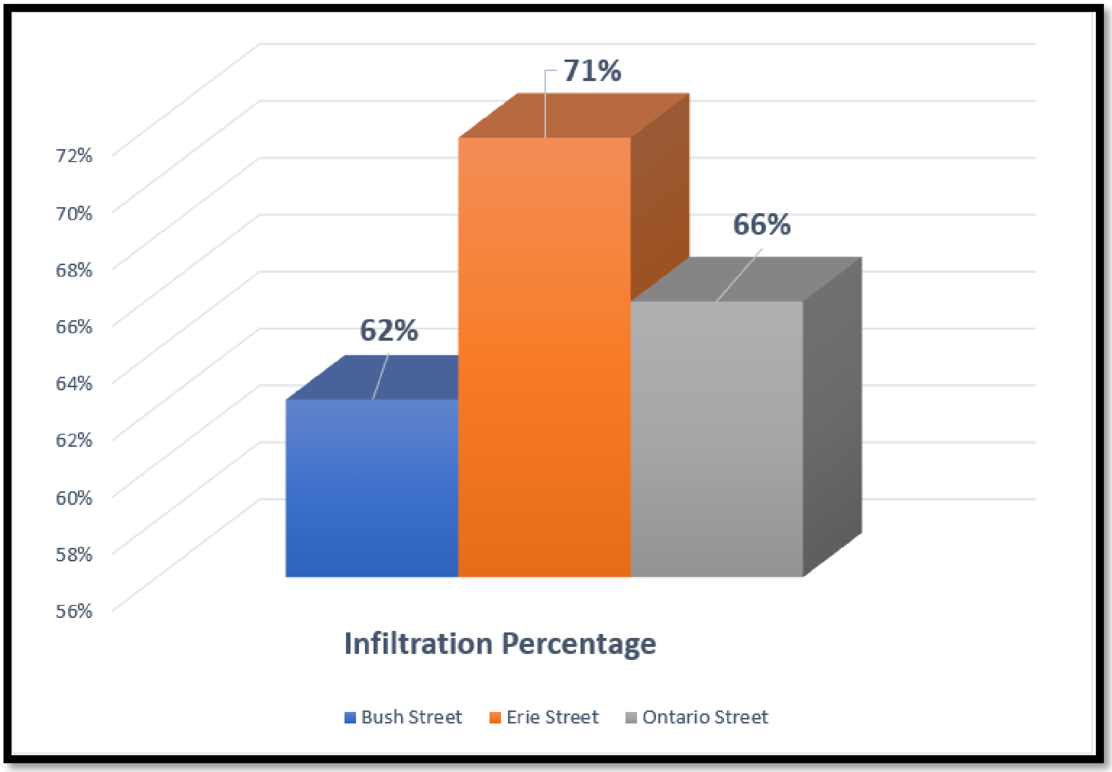

Figure 21: Percentage of Runoff Infiltrated After Entering Rain Garden

Table 10: Individual LID Performance Bush Street

LID Performance	Bush Street
North Garden Inflow	487.14 in.
East Garden Inflow	304.49 in.
South Garden Inflow	434.26 in.
North Garden Infiltration	277.77 in
East Garden Infiltration	206.8 in.
South Garden Infiltration	260.62 in.
North Garden Outflow	193.54 in.
East Garden Outflow	91.42 in.
South Garden Outfall	166.99 in.
Percentage of Inflow Converted to Runoff North Garden	39.73%
Percentage of Inflow Converted to Runoff East Garden	30.02%
Percentage of Inflow Converted to Runoff South Garden	38.45%
Average	36.07%

Table 11: Individual LID Performance Ontario Street

LID Performance	Ontario Street
Left Garden Inflow	349.2 in.
Right Garden Inflow	291.59 in.
Left Garden Infiltration	218.39 in.
Right Garden Infiltration	194.26 in.
Left Garden Outflow	124.42 in.
Right Garden Outflow	91.08 in.
Percentage of Inflow Converted to Runoff Left Garden	36%
Percentage of Inflow Converted to Runoff Right Garden	31%
Average	33%

Table 12: Individual LID Performance Erie Street

LID Performance	Erie Street
Garden 1 Inflow	255.56 in.
Garden 1 Infiltration	178.19 in.
Garden 1 Outflow	71.24 in.
Percentage of Inflow Converted to Runoff Garden 1	28%
Average	28%

This difference in area, in part, explains some of the performance differences between the 3 sites. For instance, when examining why the total outfall loading both pre (407,000 gal) and post (220,000 gal) installation is greater at the Bush Street site than either of the other sites (Figure 22). this is directly attributed to the greater collection area present at this site. While the Bush Street site has the greatest total area covered in rain gardens and the greatest number of rain gardens, they represent the smallest percentage of impervious surface treatment (treatment percentage) of any of the three sites. All of the area of the GSI installments combined at the Bush Street site represent only 4.9% of the total impervious roof area, while the Ontario Street and Erie Street sites have a slightly higher coverage percentages, 6.2% and 5.0% respectively. These differences in treatment areas can be attributed primarily to the difference in available space to build rain gardens present at each of the three sites. Differential treatment was observed between rain gardens at specific sites. For example, conversion to runoff ranged from approximately 30 to 39% at the Bush Street site, indicating that placement and sizing of the rain gardens can contribute to their performance even on the same site. Performance of each of the individual rain gardens was combined in the following results section to establish performance at each site.

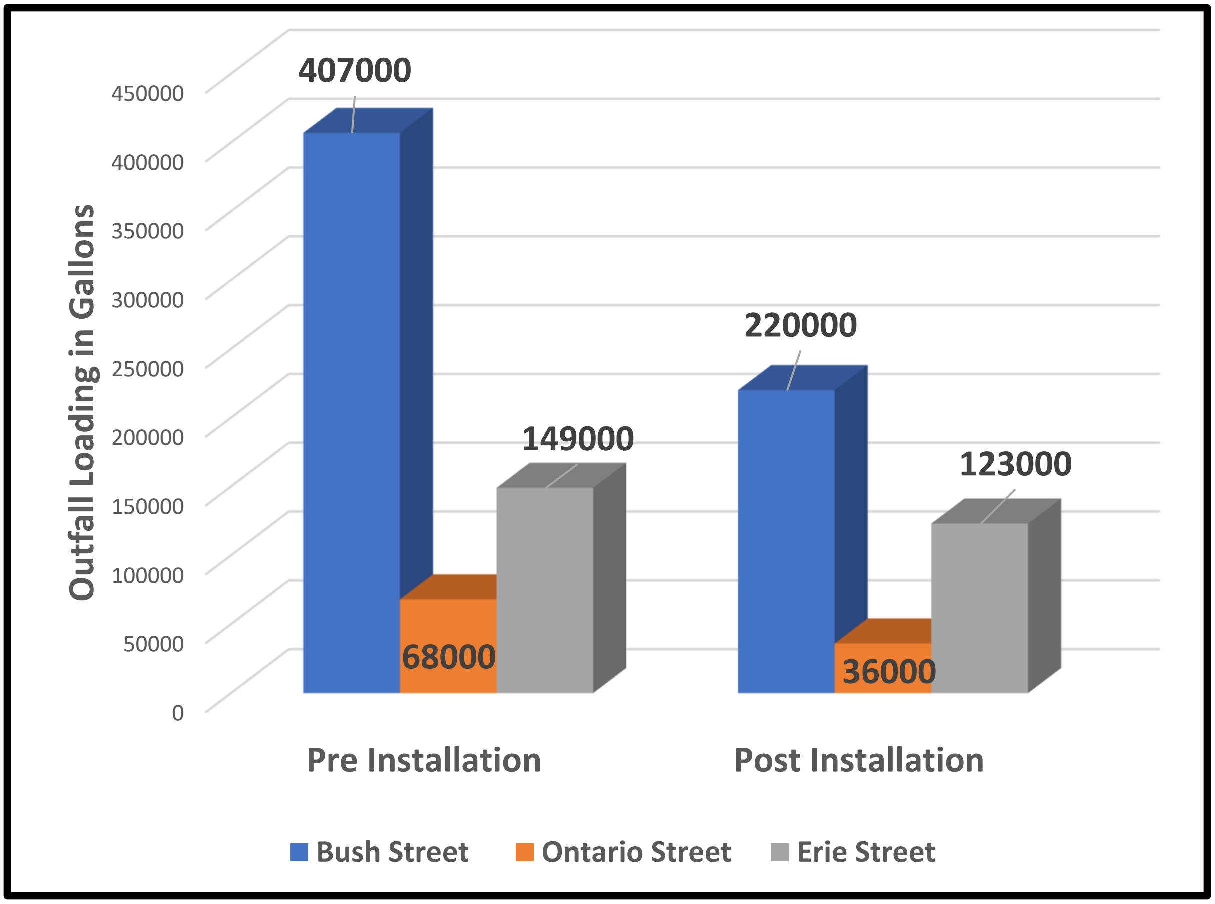

Figure 22: Outfall Loading Per and Post Rain Garden Installation

With the individual results established, it was possible to examine the results for the site as a whole by reviewing the Outfall Loading data for each site. A reduction in total volume of water leaving the site, referred to below as Outfall Loading has occurred at each site (Table 14). The greatest percent reduction occurred at the Ontario Street site (47% reduction). This is consistent with the data presented in (Table 9) since the Ontario Street site has the largest treatment percentage (area of rain garden to area of impervious surface). The Bush Street Site had the next highest total reduction percentage of flow (45%), which seems to contradict the previously presented data since that site has the smallest percentage of total rain garden area. This phenomenon can likely be attributed to the sheer volume of other pervious land surrounding the rain gardens, permitting infiltration during overland flow to the outfall where the results for this section were measured. This was supported by the fact that that the Bush Street rain gardens are the highest average distance away from an impervious surface (8.33ft). This is followed by the Ontario Street gardens with an average of 5.5ft and lastly the Erie Street installation at 3 ft. see (Table 13).

Table 13: Rain Garden Distance from Impervious Surface

Bush Street Rain Garden Distance to Impervious Surface	
North Garden	4 ft
East Garden	13 ft
South Garden	8 ft
Average	8.3 ft
Ontario Street Rain Garden Distance to Impervious Surface	
Left Garden	7 ft
Right Garden	4 ft
Average	5.5 ft
Erie Street Rain Garden Distance to Impervious Surface	
Garden 1	3 ft
Average	3 ft

Another important performance statistic to examine is the reduction in flow frequency through the outfall or the percentage of the total time modeled in which there was water flowing through the outfall. This is an indication of the GSI ability to both infiltrate precipitation for the duration of an event and to extend the time in which no runoff enters the collection system. All three sites experienced a reduction of flow frequency, the highest being both the Bush Street and Ontario Street sites at 25% each (Table 14). The Erie Street Site reduction was somewhat smaller at 7%. This is consistent with the other performance statistics since overall the Erie Street site had the worst performance of the three sites. This difference in flow frequency percentage can likely be attributed to the combination of a smaller treatment percentage and its proximity to an impervious surface.

The last site performance statistic to be examined is the maximum flow reduction percentage, which is an indicator of a reduction in the erosion potential of the runoff. Flow reduction is desired to reduce erosion at downstream locations and to increase the capacity of infrastructure to handle storm flows. GSI does not always do an effective job of reducing stormwater flows since GSI is often designed to attenuate flow. Also, the size of the storm event used in the simulation will impact flow reductions. GSI is designed to mitigate a typical or relatively small storm, not a large storm. Again, the best performance was at the Bush Street site at 15% flow reduction, followed by the Erie Street site at 2% flow reduction. The Ontario Street Site saw no reduction in flow. The substantial difference in performance across this category is likely the result of a substantial difference in flows to begin with, measured in the max flow rate at the outfall (Table 14). Sites with higher flow rates pre installation have more room for improvement, and sites where the value was already low had less room to improve. For example, the initial max flow at the Bush Street site is 7.31CFS whereas the initial flow at the Ontario street site is only, 0.03CFS. It stands to reason that one can expect to see less measurable reduction at the Ontario Street site. Additionally, the Ontario Street site is the smallest and generates the smallest volume of runoff.

Table 14: Outfall Loading Data

Outfall Loadings	Bush Street	Ontatio Street	Erie Street
Flow Frequence Percentage Pre Installation	13.20%	3.86%	4.26%
Flow Frequence Percentage Post Installation	9.93%	2.91%	3.97%
Percent Reduction of Flow Frequency	25%	25%	7%
Average Flow Pre Installation	0.05 CFS	0.03 CFS	0.06 CFS
Average Flow Post Installation	0.04 CFS	0.02 CFS	0.05 CFS
Max Flow Pre Installation	7.31 CFS	0.16 CFS	2.10 CFS
Max Flow Post Installation	6.12 CFS	0.16 CFS	2.06 CFS
Percent Reduction of Max Flow	15%	0%	2%
Total Outfall Loading Pre Installation	407,000 GAL	68,000 GAL	149,000 GAL
Total Outfall Loading Post Installation	222,000 GAL	36,000 GAL	123,000 GAL
Percent Reduction in Total Outfall Loading	45%	47%	17%

CHAPTER FOUR

CONCLUSION AND FUTURE RECOMMENDATIONS

Since the mass migration of people into urban settings at the onset of the industrial revolution, surface water quality has rapidly decreased due in part to the increased volume of impervious surface within cities and the subsequent rise in surface runoff. Standard approaches have failed to fully mitigate the problem. Recently, the option of green stormwater infrastructure has become a widespread viable option for the capture and subsequent treatment of runoff generated at impervious sites. These structures attempt to capture, divert, and treat runoff and have the potential to substantially reduce both pollutant loadings and runoff quantities. This project diverged from the traditional GSI implementation project because it involved an underserved demographic of the city, low income multi-family housing units. This choice presented several unique challenges including community willingness to be involved in the project, knowledge of the topic, limited resources, and a highly transient and apathetic population of residents. To address these challenges, the very first step was to cultivate a relationship with the residents to engage them in the GSI selection and design process. Therefore, it was necessary to have a number of face-to-face meetings with residents to educate the citizens and put to rest some of their larger concerns. This process was made incalculably easier with the help of well-established, trusted community leaders including Salem Lutheran Church and the Toledo Arts Commission. These organizations helped to plan and deliver community meetings to educate residents and select and design suitable GSI.

One of the greatest challenges that needed to be overcome in order for this project to succeed was the acquisition of a local champion that would help researchers to work effectively within the neighborhood, as well as input from the residents themselves. By partnering project educational opportunities with trusted pillars of the community, Salem Lutheran Church, The Toledo Arts Commission, and The Friendly Center, some of the residents identified as leaders, initial worries were quelled as these pillars have established themselves within the neighborhood prior to this project and have shown that they have the best interest of the residents in mind. This allowed for the education process to move forward unencumbered by unfounded resident concerns, and opened the door for productive discussion about the project with a basis of trust between researchers and residents. Once open discussion began flowing at community meetings researchers we able to giver presentations, address worries, conduct information gathering activities, and effectively take into consideration resident input.

Implementation of GSI at low income, multi-family housing sites is uncommon even though runoff generation and urban greening is needed. This project provided a model for future GSI projects in other urban neighborhoods. There were some existing advantages in this neighborhood including an EPA Urban Waters funded project team. In addition, the property management company (VMC) had already acquired funding for building improvements, which included funds for mitigation of stormwater runoff. Also, the sites had native soils with good infiltration and/or established stormwater infrastructure to tie into, which greatly reduced project cost and increased anticipated GSI performance. All sites (Bush St., Erie St., and Ontario St.) chosen for design and implementation suggest a quantifiable reduction in the total runoff leaving the site. Additionally, all three appear to be performing well in real world conditions with positive reviews coming in from the landowner (VMC). This project has laid the groundwork to build more GSI structures in the Vistula Neighborhood and similar neighborhoods across the region and perhaps the country. With the knowledge gained in how to effectively locate leaders and partners with the neighborhood, gather support, educate residents, properly design and install systems, and methodology in cost reduction it appears that GSI can effectively and affordable be installed in neighborhoods with substantial multi-family housing units.

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Appendix A

Drawings