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Low Impact Development Mitigation for Base Flood Elevation Disparity between Adjacent Properties

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Low Impact Development Mitigation for Base Flood Elevation Disparity between Adjacent Properties

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ABSTRACT

Disputes between adjacent property owners in which new development at higher elevation requirements has caused adverse effects in stormwater drainage towards lower, older developments has recently grown in concern. The difference of elevations between properties causes a faster sheet flow effect that bypasses existing drainage paths in the servitude. The goal of this research is to design a low impact development methodology that encourages detention and redirection back toward the shared drainage boundary. Detention is encouraged through subsurface infiltration, storage and re-direction of the flow path. Infiltration trench simulations using EPA's SWMM software were used to mirror the new LID design and obtain hydrological outcomes of the study site to confirm initial applicability. The trenches sufficiently reduced peak flows for the site based on various parameters. The next step in completing this research is constructing the new LID system on campus to calibrate and verify the system design.

Keywords: Low Impact Development; Infiltration Trenches; Stormwater Mitigation; Property Elevation Differences; Base Flood Elevations

1.0 INTRODUCTION

1.1 Overview

The city of New Orleans is known for its beautiful culture, extravagant festivals, and, of course, the annual Mardi Gras season. The city is located in the southeastern area of Louisiana. What makes this city unique is the fact that it is encompassed by water. The Mississippi River runs directly along the southern lines of the city, Lake Pontchartrain sits right above it, and the Gulf of Mexico claims the rest of the surrounding water. The city of New Orleans also claims the title of the only city in the south to have an elevation below sea level. The only other cities in the United States to have elevations below sea level are in the state of California. The average elevation of New Orleans is around 2 feet below sea level. The combination of being surrounded by water and having an elevation below sea level causes New Orleans to have a geographical make that resembles something similar to a "bowl". This "bowl" causes New Orleans to be home to some of the worst flooding events. Figure 1.1 gives a cross sectional image through New Orleans.

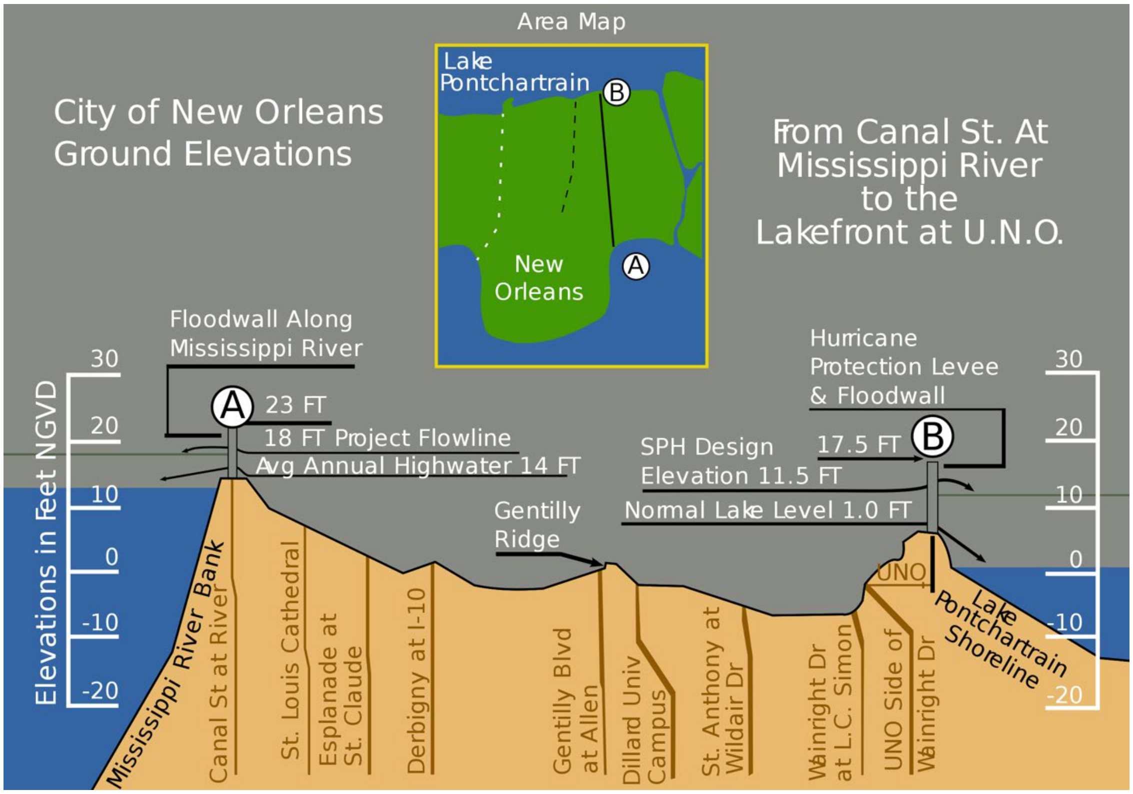

Figure 1.1 Cross section of the topography of the New Orleans area (Courtesy of Sewerage and Water Board of New Orleans/US Army Corps of Engineers New Orleans District).

In order to try and accommodate for New Orleans's vulnerability to flooding and significant risk to hurricane hazard and storm surges, there has been an implementation of various regulations regarding new developments. These new regulations have had positive outcomes for each home with flood protection. However, unknowingly, these regulations have caused disputes between older, lower elevated homes and its new counterparts. With the newer homes sitting at higher elevations, when the homes are adjacent to lower developed homes, it causes stormwater to flow from those higher elevations onto the lower homes.

This flow is causing backlash due to the fact that there is a presence of more flooding for the lower developments. For example, when a row of homes is at an elevation of -6 feet, while the next row of homes that share a back yard fence with those homes are at -5 feet, sheet flow from storm water will begin to flow onto the homes with an elevation of -6 feet.

Homes developed prior to the adoption of the new elevation regulations, will continue to face this problem until the houses are either elevated or demolished and reconstructed to the same height. Since New Orleans tied for second in highest poverty rate in the United States at a whopping 19.7%, these two solutions are costly and seen as unrealistic to the majority of residents (W. 2018). The dire need for an alternative solution provided motivation to develop a model that applied infiltration trenches between lots to analyze the outcomes. Pending successful outcomes, this implementation could provide solutions all around the city and extend to other cities facing the same elevation differences between adjacent homes.

1.2 Importance of Study

After speaking with one landowner in this situation, he provided detailed information on his current experiences that reflect the study problems addressed. His house is listed under FEMA Repetitive Loss which means the

National Flood Insurance Program paid at least two claims of more than $1,000 in any 10-year period since 1978. The problems that he experiences in his back yard are exactly what is being investigated here. The problem with his yard flooding started initially in 1993. This is when the street behind his home was developed and the lots had to be built at higher elevations due to the newest FEMA regulations. Prior to the development of the newer homes, he did not experience this constant flooding that occurs now.

As mentioned before, this study provides an alternative to reduce peak flow values and reduce flooding of landowner's property. Infiltration trenches that provide storage and transport of stormwater could be developed between homes of differing elevation to direct stormwater into the trench and off of people's property. This alternative could be a resolution to the issues that many landowners are experiencing consistently with their homes.

The methodology used to create the simulations can be replicated in similar areas experiencing the same issues. With the output generated by PCSWMM®, the ability to obtain and analyze results of the benefits of infiltration trench implementation is quite simple. In areas where elevations, pipe diameters, and manhole/inlet location data can be retrieved, the procedure could be repeated to interpret outcomes. PCSWMM® is a state-of-the-art water management

modeling tool that allows for detailed data and real-time models (SWMM5, 2021).

1.3 Objectives

- Select a study site that experiences flooding due to houses at higher elevations being adjacent to houses at lower elevations.
- Develop a stormwater model for the study site using the EPA SWMM5 Software.
- Select placements for the low-impact development of infiltration trenches that encourage flood water collection.
- Simulate scenarios of the designed infiltration trench by varying the hydraulic design parameters one at a time to produce an optimized design alternative for a 60-minute 10-year storm event.
- Provide analysis of results and determine if infiltration trench implementation is effective within the site.

2.0 LITERATURE REVIEW AND BACKGROUND INFORMATION

2.1 Introduction

Stormwater management has been the epitome of New Orleans's history. From the constant change in house construction to the adoption of new regulations, there has always been one goal for New Orleans; alleviate as much flooding as possible. Using the new and improved base flood elevation applications, there has been a number of residents that suffer from the negative impact. The Federal Emergency Management Agency (FEMA) is the regulatory agency that implements the programs to reduce flood disasters. FEMA provides the standards to reduce flood risk, but this can cause unintentional effects in specific situations. History has continued to steer the water management of New Orleans in a direction contrary to the processes of nature. Based on knowledge gained from this history, a resilient approach to stormwater management and modelling programs such as in Storm Water Management Model (SWMM), development of alternative solutions that will work simultaneously with the new elevation requirements can be developed.

2.2 History

Flooding in New Orleans dates all the way back to the 1800's. According to URS's "The History of Building Elevation in New Orleans", the initial establishment of the faubourg, a French word for suburbs, were on the higher grounds behind the natural levees to help mitigate flooding. However, major floods that occurred in 1816, 1841, 1849 caused significant damages. Since this area was so prominent to flooding, the incorporation of raised basement homes was soon adopted. Throughout early development, the government had no codes for addressing flooding. It was the responsibility of the landowner to address property flooding on his or her own. New Orleans was not an amateur when it came to flooding: However, the flood of 1849, also known as the Crevasse of 1849, was one of the most devastating floods to the area. To put into terms, when the Mississippi River flowed into the city in 1849, the water level was higher than that of Lake Pontchartrain when it flowed into the city during hurricane Katrina. The damage extended deeper into the Uptown parts of the city that did not flood during Katrina. An image of canal street during this storm is shown below (Ari Kelman, 2006).

Figure 2.1 Elizabeth Lamoisse, watercolor of Canal Street during the Mississippi River flood of 1849, New Orleans (Courtesy of Louisiana State Museum).

Throughout the Late 19th century, settlement was still restricted to higher grounds. The majority of the area outside of the French Quarter and immediate downtown remained swamps and scarcely inhabited. In order for the community to be able to extend past these inadequate amounts of land developments, it was mandatory to develop some kind of drainage system or systems to assist with water management within these areas. Towards the end of the 19th century, private companies began constructing canals along the pumps to carry the water from the already developed areas to Lake Pontchartrain. In 1899, voters finally approved a drainage, sewage and waterwork system. Within the next decade, the system would increase from 5 miles of piping to 350 miles of piping (Magill, 2003, p. 304).

Although improvements to the drainage systems and advancements in technology allowed for more land to be inhabited, it left many residents more vulnerable to flooding than before. These newer neighborhoods were so much closer to sea level because they were no longer built on the elevations of the natural levees or ridges. Thus, the requirement for houses to be raised or elevated increased substantially. Late 19th century codes required a lot to be raised higher than the adjacent sidewalk before a structure could be built. After the incorporation of concrete slabs, the city codes were modified in that the top of the slabs could be no less than 18 inches above the neighboring curb (City of New Orleans Building Code, 1949).

A popular house build used in this time period was known as basement homes. The term basement had many different definitions. In regard to basements in other parts of the country, they are known to be completely below ground level. The city then redefined the common use of basement as "cellar" and to their terms of basement which was a part of a home (roughly 40% of the first floor's elevation) was dedicated to mitigating residential flooding (City of New Orleans Laws Regulating, 1906).

Even with the implementation of the codes and the advancements, there was still drastic flooding for the city. The devastation of hurricanes- including those

of 1901, 1909, 1915, 1922, 1926, 1947, 1948, 1956, 1965, and 1998- continued to do damage to the city. Throughout the upcoming decades, the city would continuously add improvements, such as pumps, to facilitate water management. The remainder of the 20th century was dedicated to modifying and reconstructing the levees to be a more solid barrier (Roth, 2010).

On August 29, 2005, hurricane Katrina devastated the entire New Orleans area. Katrina grasped the title of being the most horrific natural disaster of the United States, claiming many lives with it. Engineer James S. Janssen, in a collection of his writings on the construction of New Orleans spoke on the flaws of the construction of homes by pouring the concrete slabs for home bases directly on native soil. He stated “It took a long time for designers, builders, and homeowners in New Orleans to realize the futility of basing buildings on spread footings. Such an approach was feasible when buildings were confined to the high, more solid land along the riverfront or on the sturdy alluvial deposits of Metairie Ridge or Gentilly Terrace. But, when development spread into the low, humus-laden soils of Lakeview, Broadmoor, etc., load distribution was to no avail if the subsoil below the footings consolidated, dried out and shrank as drainage improved. Many a building—even those of light construction—had to be jacked up, leveled, repaired, and even demolished. It was a costly lesson in building design. The repair work cost more than piling or some form of deep

support would have cost at time of construction" (Janssen, 1983). Immediately following Katrina, the requirements for the urbanism of New Orleans were altered. All residential developments must be raised on pilings or pillars. This practice was used in New Orleans for nearly 200 years before World War II but was relinquished by concrete slabs at grade level due to cheaper costs. Using piling or piers puts less dependence on the success of the flood protection developments and more on the individual's desire to protect his or her own property.

The Federal Emergency Management Agency (FEMA) partnered with state and local officials to implement the Hazard Mitigation Grant Program (HMGP), which was put into place to help alleviate damage outcomes from future storms. This program has funded nearly 1.4 billion to elevating houses above FEMA's Advisory Base Flood Elevation or demolishing and reconstructing elevations above future flood levels. The elevation program integrates all the lessons learned throughout the preceding centuries to ultimately prevent residential flooding. FEMA even went as far as replacing windows, elevating exterior heaters and air conditioning units, and roof tie-downs (FEMA, 2002).

Historically, elevating houses has been common within the New Orleans area. The only difference is, recently, the fiscal responsibility of elevating a

home is not solely on the homeowner anymore. With the incorporation of several programs that give grants towards flood mitigations, homeowners that are not wealthy are able to protect their homes.

Although the rules and regulations for the elevations of houses in the New Orleans area has changed various of times, the goal remained the same; protect houses from flooding. With the implementations of new requirements for new development, the older, lower developed houses that were at ground level, began having issues of flooding between properties. New construction requirements call for the grade of the site to start at a higher elevation than before. The source of these changes is the New Orleans City Ordinances Base Flood Elevation (Order of City Council 1955). The succeeding chapter will address changes in Base Flood Elevation application and the use of FEMA's Flood Insurance Rate Maps.

2.3 Base Flood Elevations

Base flood elevation is the elevation of surface water resulting from a flood that has a one percent change of equaling or exceeding that level in any given year. The BFE is shown on the Flood Insurance Rate Maps (FIRM) for zones

labeled AE (1% annual chance of flooding) and VE (1% chance of flooding with additional hazard) (FEMA flood maps).

2.3.1 Base Flood Elevation Past Requirements

The codes below were archived from the December 21, 2015 New Orleans, LA Code of ordinances. The newest and most current codes went into effect shorty after this date in June of 2016 (Order of the City Council, 2015). Below notes the codes that the majority of the houses currently in New Orleans were constructed by:

Sec. 78-81. - Minimum elevation.

It shall be the responsibility of the department of safety and permits to act as a repository for lowest-floor elevation records and to assign required lowest-floor elevations. The notation shall be made on the face of the building permit. The lowest-floor elevation of new residential construction and substantial improvements must, at a minimum, be *elevated to the 100-year base flood level (BFE)* as determined by the FEMA flood insurance rate maps dated March 1, 1984, as amended, inclusive of the FEMA letter of map revision dated July 11, 1986, relative to the South Shore Harbor Project. In cases where floodproofing is utilized for nonresidential new construction and substantial improvements, proper certificates from a registered professional engineer or licensed architect shall be obtained and maintained.

(Code 1956, § 32-20; M.C.S., Ord. No. 23242, § 1, 9-18-08)

Sec. 78-82. - Review of permits for construction.

It shall be the responsibility of the director of the department of safety and permits to assure that:

1) The lowest-floor elevation of new residential structures or substantial improvements be *at or above the base flood level of a 100-year storm.*

2) The lowest-floor elevation of new nonresidential structures or substantial improvements be either *at or above the base flood level* of a 100-year storm, or if below the base flood elevation, that together with its attendant utility and sanitary facilities be floodproofed up to the level of the base flood elevation of a 100-year storm.

3) New construction or substantial improvements within special flood hazard areas be protected against flood damage, be anchored in accordance with the Building Code of the City of New Orleans to prevent flotation, collapse, or lateral movement of the structure, utilize construction materials and utility equipment that is resistant to flood damage, and utilize construction methods and practices to minimize flood damage.

(Code 1956, § 32-2; M.C.S., Ord. No. 23242, § 1, 9-18-081)

The codes above state that construction for the first-floor elevation only must be **at** or **above** the base flood elevation of a 100-year storm. Therefore, If the BFE for a certain area was -6 feet in elevation, the house could be constructed with the first floor at 6 feet below sea level.

2.3.2 Base Flood Elevation Current Requirements

The current base flood elevation requirement noted below went into effect on June 1, 2016 (Order of the City Council, 2020). These are presently the most current codes for the New Orleans area. Notations below indicate the difference

from the prior codes. The codes were archived on January 1, 2021 and as of that date, the most recent version was November 30, 2020.

Sec. 78-81. - Minimum elevation required.

a) The lowest floor elevation of new residential and non-residential construction and substantial improvements must, at a minimum, *be elevated to one foot above the BFE* as determined by the FIRM adopted by this article, or three feet above the highest adjacent curb (in the absence of curbing, three feet above the crown of the highest adjacent roadway), whichever is higher.
b) In cases where flood-proofing is utilized for non-residential new construction or substantial improvements, proper certificates from a registered professional engineer or licensed architect shall be obtained and maintained by the director. Such structures utilizing flood-proofing measures must be flood-proofed to a minimum of one foot above the requirement established above.
c) Historic structures within the jurisdiction of the Historic District Landmarks Commission, Central Business District Historic District Landmarks Commission, Vieux Carré Commission, or which are certified as contributing elements of a National Register district, or property that is included in the definition of "historic structure" under the NFIP, shall be permitted to build to either the base flood elevation as determined by the FIRM adopted by this article, or 18 inches above highest adjacent grade, whichever is higher.

(M.C.S., Ord. No. 26906, § 1, 5-5-16, eff. 6-1-16)

Sec. 78-82. - Review of permits for construction.

a) It shall be the responsibility of the director of the department of safety and permits to ensure that:
   1. The lowest-floor elevation of new or substantially improved residential structures be *placed at or above the required minimum elevation* as established by this article.
   2. The lowest-floor elevation of new or substantially improved non-residential structures be placed either at or above the required

minimum elevation as established by this article; or, if below the required minimum elevation, that together with its attendant utility and sanitary facilities, be flood-proofed in accordance with the minimum requirements provided by this article.

3. New construction or substantial improvements within special flood hazard areas be protected against flood damage, be anchored in accordance with the building code of the City of New Orleans to prevent flotation, collapse, or lateral movement of the structure, utilize construction materials and utility equipment that is resistant to flood damage, and utilize construction methods and practices to minimize flood damage.

(M.C.S., Ord. No. 26906, § 1, 5-5-16, eff. 6-1-16)

New construction or substantial renovation of homes must be at an elevation of one foot or above the BFE. The previous regulations only called for an elevation at or above the BFE. This update in the codes causes new construction to sit 12 inches above its previous counter partners.

2.3.3 Flood Insurance Rate Maps

In addition to the implementing of the new base flood elevation requirements, the new flood insurance rate maps went into effects just 4 months after. The FIRM maps provide the BFE and the Advisory Base Flood Elevations (ABFE) for the entire New Orleans area. The following images show New Orleans flooding hazards and base flood elevation requirements through different maps (Figures 2.3-2.5).

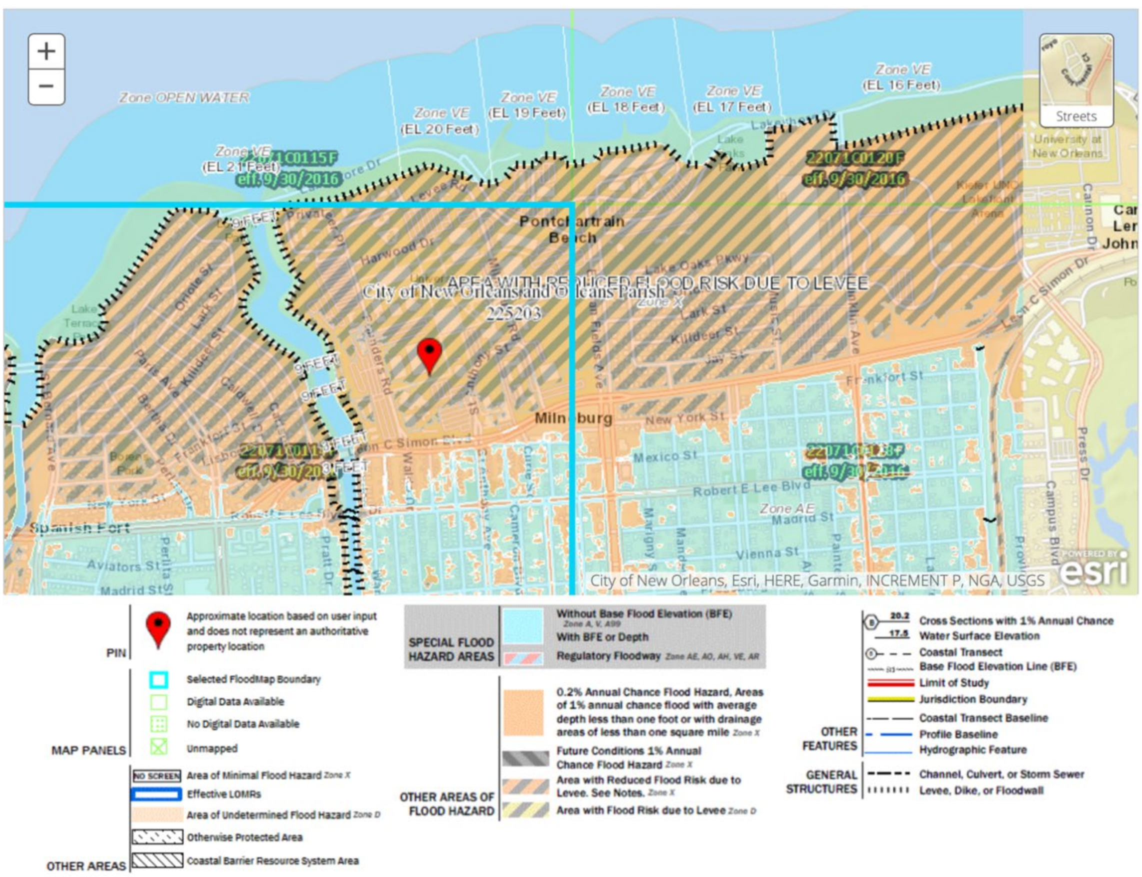

Figure 2.2 Map near The University of New Orleans. Depicts the different areas of flood hazard that correspond with the legend. (Image taken from FEMA FIRM website)

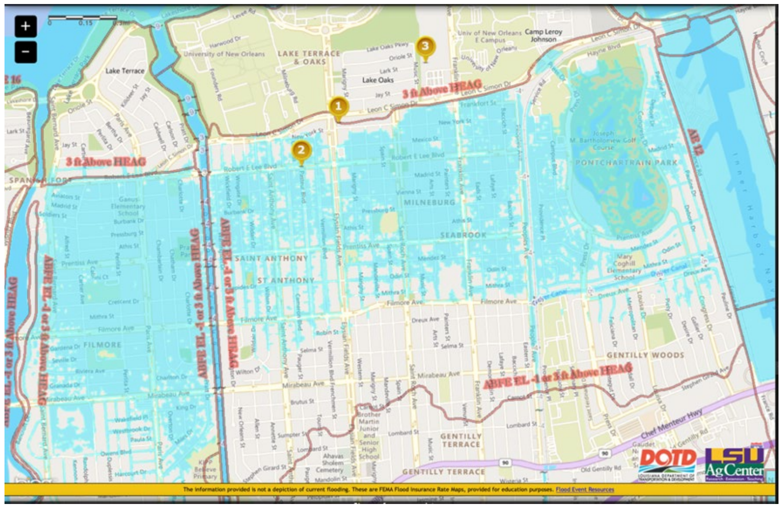

Figure 2.3 Map above shows Advisory Base Flood Elevation (ABFE) and recommended elevation in comparison to the highest existing adjacent grade (HEAG) (Obtained from http://maps.lsuagcenter.com/floodmaps/).

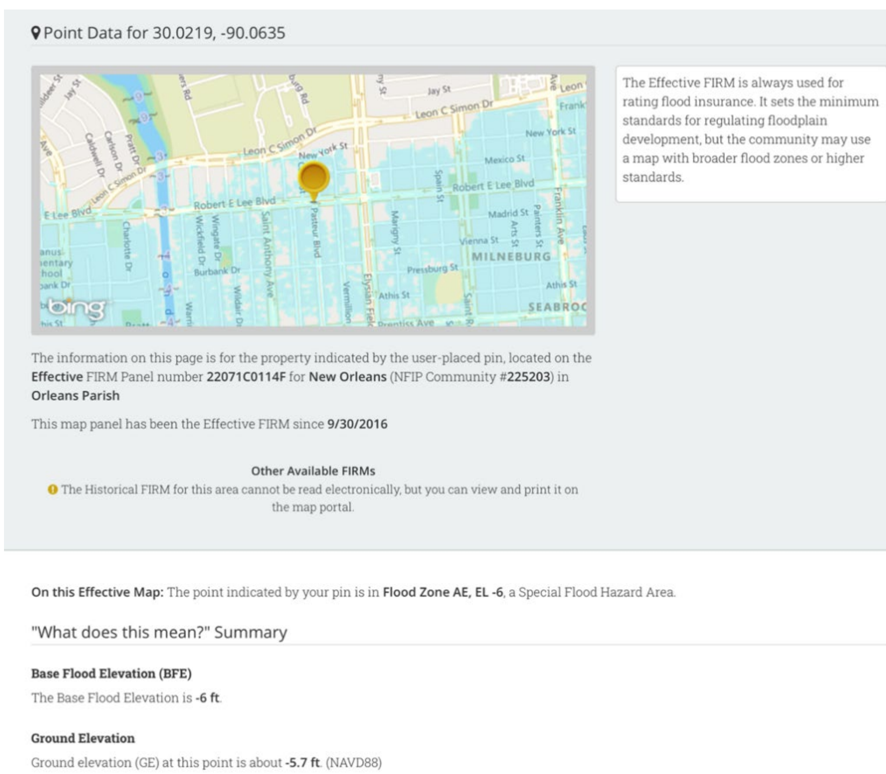

Figure 2.4 The map below gives a summary of exact point (Obtained from http://maps.lsuagcenter.com/floodmaps/).

Using the FIRM maps published on Louisiana State University AG Center website, one can find the recommended BFE and the ground elevations for a known location. The point selected above shows the base flood elevation is -6 feet and the ground elevation at -5.7 ft. The new ordinances state that new construction in the area must be 1 foot above the base elevation. Therefore, new construction in this area will be at a minimum ground elevation of -5.0 feet. This will cause new construction in this area to be at a higher elevation which, in return, will result in sheet flow produced from stormwater to flow from the higher elevation to lower elevations. This directly ties into this study because these new BFE regulations cause the lower developments to be more susceptible to elevation disparity flooding.

2.4 Disputes Between Adjacent Homeowners

There are many arising disputes regarding land being developed at higher elevations than previous developments. The negative impact on stormwater management from the elevation differences is causing trouble for the residents of the lower grade homes. Damage to one's house due to water can cause various of problems for the homeowner. The damages such as mold, the collapsing of ceilings and floors, and the altered structure of the house are all damages that carry an expensive price tag to repair. Typically, the neighbor will

not be responsible for damages caused by naturally occurring rainfall resulting in surface runoff. However, if a neighbor changes his or her landscape or altered his or her property and those changes are the primary source of the increase of surface runoff, he or she could be held responsible (Water Damage and Neighbor Disputes, 2019). An example of such change could be a homeowner changing all of his or her back yard into pavement. This impermeable surface would lead to an increase in surface runoff. This idea is like that of the newer developments that must be at higher elevations in the New Orleans area. While the older, lower developments did not have previous flooding issues from smaller storm events, adding a new home at a higher elevation reduces the amount of runoff able to infiltrate the soil by increasing the amount of impermeable surface. This change directly effects the quantity of runoff and causes a sheet flow of water to move from the higher development to the lower development.

2.4.1 Can I Hold My Neighbor Responsible?

According to HG Legal Resources', "What Can I Do about Water Drainage on My Property Caused by the Adjourning Property", there are three diverse types of laws that may allow one to hold his or her neighbor responsible for his or her actions: Reasonable Use Rule, Common Enemy Rule, and Civil Law

Rule. These laws differentiate based on the landowner's ability to prove that his or her neighbor has committed these issues knowingly. For the Reasonable Use Law, one must be able to prove to the courts that his or her neighbor did an altering to his or her property that was unreasonable and caused a drastic change to the natural flow of the surface runoff. Some key facts that help the courts come to a decision are the importance of the modifications, the ability to foresee the outcomes to his or her neighbor's property, and, lastly, the comparison of damage caused to the landowner's house to the increased value of the neighbor's property (HG Legal Resources). When discussing Common Enemy Rule, this option is typically the less favorable. This rule calls for each homeowner to protect his or her own land from rainwater and other natural sources of water. The landowner is expected to build walls or ditches or any other solutions they can find to protect his or her land from the water (HG Legal Resources). The final rule discussed is Civil Law Rule. This rule enforces a liability on any landowner that changes his or her land that alters the natural flow of surface runoff across the land. Similarly, to the reasonable use law, the civil law allows modifications of land as long as the modifications are reasonable and do not cause drastic changes. The civil rule also considers the common enemy rules in the regards to the landowner taking an initiative to protect his or her land first (HG Legal Resources).

In regard to the development of new homes at higher elevations, this construction falls under the exceptions of both the reasonable use rule and the common enemy rule. With the reasonable use rule, there is a clause that specifically addresses the increase use or value of the neighbor's property. In this case, the neighbor's property is being used to house a family, and the value of the property will increase with the addition of the new construction. The common enemy rule where each landowner is supposed to protect his or her land individually, this is where the application of the stormwater management alternative of properly designing an infiltration trench will be helpful. It gives landowners an efficient, cost-effective solution to address flooding due to elevation differences between adjacent homes.

2.5 Infiltration Trench Design and Applicability

There are many stormwater best management practices that are currently in use in the United States. For the scope of this project, it was determined that infiltration trenches would be a perfect fit due to low installation costs and the ability to use the space for landscaping. Infiltration trenches are linear excavations, lined with filters and filled with gravel or stone, that create a temporary storage for surface runoff. The trench intercepts overland flow and allows for the water to slowly percolate into the native soil over several hours

as well as redirect the excess stormwater to the subsurface drainage system. To receive optimum output from the trench, residential or commercial use with flow entering laterally from surrounding impervious surfaces works best. Figures 2.6 and 2.7 give the advantages and disadvantages of a trench along with the typical design of a trench respectively (susdrain.org).

Advantages	**Disadvantages**
Can reduce runoff rates and volumes significantly	Need pre-treatment to prevent clogging
Can reduce pollutant loads entering surrounding bodies of water such as total suspended soils, phosphorus, and nitrogen	Not suitable for sites with low permeability soils
Design flexibility allows for easy incorporations into sites. Can fit next to roads	Maintenance is mandatory for trench upkeep
Promotes natural percolation of water into native soils	Fit for relatively small watersheds

Figure 2.5 The advantages and disadvantages of infiltration trenches. (www.susdrain.org)

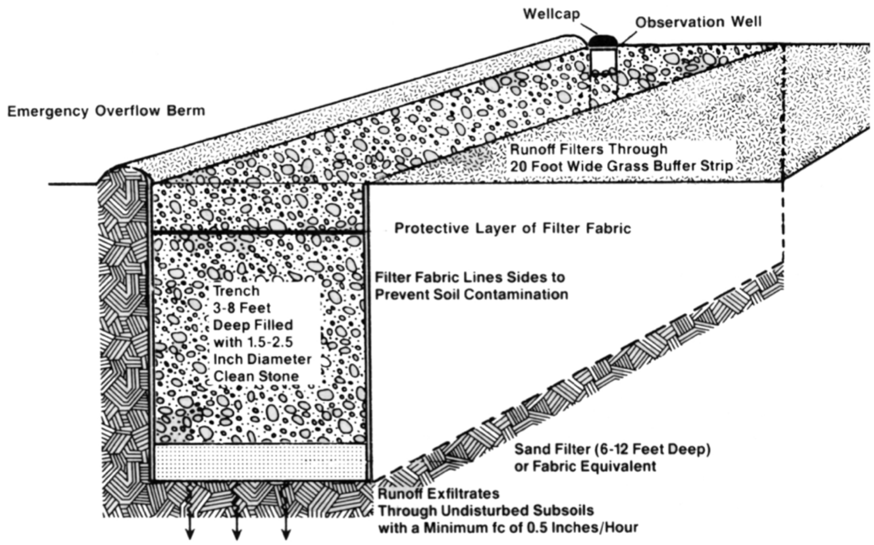

Figure 2.6 Typical infiltration trench design (Source: Schueler, 1987).

When analyzing the design and applicability of an infiltration trench on a site, there are two components that must be taken into consideration: Pre-construction concerns and trench design breakdown.

2.5.1 Pre-Construction Concerns

Factors to consider before Application:

1. Site Selection
2. Runoff Water Quality
3. Groundwater and Bedrock
4. Frost Line
5. Native Soil

Site Selection: The selection of the site is a vital factor in the success of an infiltration trench. There are numerous aspects that contribute to this success including soils, slope, groundwater depth, depth to impermeable soil layer, area of contributing watershed, land use, and others. Infiltration trenches typically favor a site that has gentle slopes, deep impermeable soil layers and water table, permeable upper-layer soils, and a contributing watershed of 2 acres or less (Infiltration trenches, 2015). A site evaluation is highly recommended to assess the conditions of the site. A total of three soil (3) borings should be placed in the proposed area of the infiltration trench. The use of the borings will help determine many important factors, such as soil type and infiltration rates. According to Metropolitan Council / Barr Engineering Co, the site evaluation should consider these factors:

Runoff water quality: Runoff water should not contain certain pollutants due to the possibility of contaminating the groundwater. The existing material that will be the source of stormwater runoff will be the main factor in water quality. Sites with water that stems from an industrial or commercial site with high levels of pollutants should not use infiltration trenches. However, if the use of an infiltration trench is approved, adequate pre-treatment of the water must be arranged.

Groundwater/Drinking Water Wells and Bedrock: A minimum of 3 feet should be between the bottom of the infiltration trench and the annual peak water table. The same 3 feet minimum requirement applies for the top of the first impermeable soil layer and the bottom of the trench. In regard to water wells, the trenches should be located at least 150 feet away from the nearest one. This will reduce the possibility of contamination.

Frost Line: Although New Orleans rarely reaches a temperature to allow frosting, it is important to mention this guideline. The frost line is known as the depth below the surface in which the moisture present in the soil will freeze. Assuming the design depth has been reached, the water within the trench should be below the frost line of the soil to allow percolation throughout the winter season.

Hydraulic Conductivity and Infiltration Capacity of the Soil: The measure of the soil permeability is another vital factor in deciding the applicability of an infiltration trench. The soil must be able to drain the design volume of the trench in 48 hours or less (can be up to 72 hours in different areas). The ideal soil infiltration should be greater than 0.53 inches/hour to maintain proper operations. The value 0.53 inches per hour should be after multiplying the actual soil infiltration by a safety factor to account for a deficit

in trench efficiency due to accumulation of sediment or soil compaction between scheduled maintenance. Sites with clayey soils are not suitable for infiltration trenches. Soils that are tightly packed have a low infiltration capacity. Capacity and permeability work hand and hand. An ideal soil will have an average percolation rate which will also allow for a sufficient water capacity.

2.5.2 Current Practice in Trench Design

The following current practice guidelines are recommended by Metropolitan Council / Barr Engineering Co.:

Pretreatment: There should be some form of pretreatment practice that is installed for use prior to the runoff entering the infiltration trench. There are multiple pretreatment practices that are available, such as a grass channels or filter strips. The pre-treatment should be able to treat at least 25 percent of the volume of water entering the trench. If the infiltration rates of the soils increase, a larger percentage of total water volume entering the trench must be pre-treated. For infiltration rates between 2 and 5 inches per hour, a minimum of 50 percent of the total water entering should be able to receive pretreatment. For infiltration rates exceeding 5 inches per hour, a pre-treatment practice must be

installed that could treat 100 percent of the entering water (Operation, 2021).

Figure 2.8 below shows a grass filter option for pretreatment.

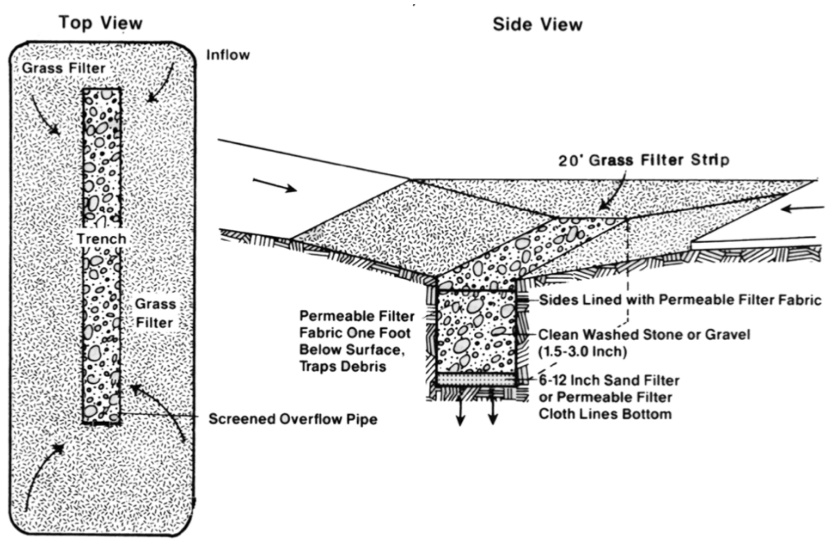

Figure 2.7 Grass filter strip surrounding trench for pre-treatment (Source: Schueler, 1987).

Trench Volume:

Area of the bottom level is stated below:

$$A = \frac{12 * V}{P * n * t}$$

A= bottom area of the trench (ft^2, m^2)

V= runoff volume to be infiltrated (ft^3, m^3)

P= infiltration rate of underlying soil (in/hr, m/hr)

n= void space fraction in the storage media (0.4 for clear stones)

t= retention time (between 6 and 72 hours)

Depth of the trench (typically between 3 and 12 feet):

$$D = \frac{P * t}{n * 12}$$

D= depth of the trench (ft, m)

P= Infiltration rate (inches/hr, m/hr)

T= retention time (between 6 and 72 hours)

Filter Fabric: A filter fabric, also known as a geotextile fabric, must be installed on all the sides of the trench as well six to twelve inches below the trench surface. The filters on each side of the trench acts as a protective layer to limit soil contamination. The fabric that is placed 6 to 12 inches below the surface is used to collect suspended solids and prevent them from clogging the storage media. At the bottom of the trench, there is the option of using a filter or a six-to-twelve-inch layer of clean sand. This alternative is strictly for the bottom of the trench only.

Storage Media: A infiltration trench uses aggregate stone as a filling to provide storage. The trench should be filled with clean stone that ranges from 1.5 to 3 inches in diameter. This size range provides around 40 percent of storage which was mentioned earlier in the area equation. (SEWRPC, 1991, Harrington, 1989, Schueler, 1987)

Observation Well: An observation well, shown below, should consist of a 4-to-6-inch diameter pipe with perforations installed in the center of the trench to monitor performance and retention.

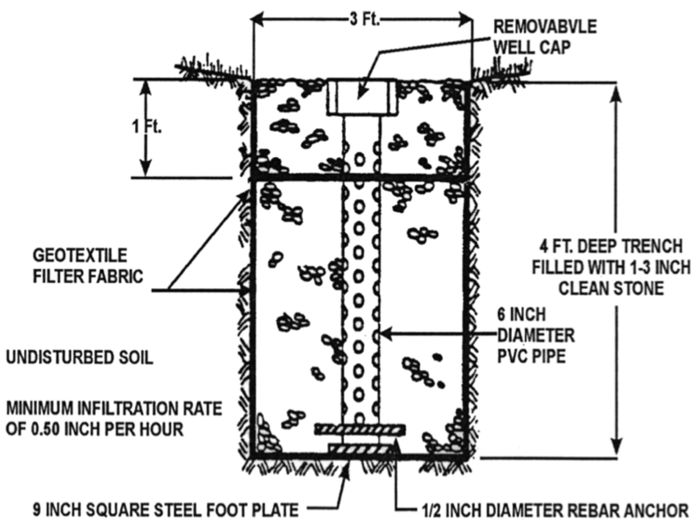

Figure 2.8 Observation well details (Source: SWRPC, 1991).

Overflow Protection: Each infiltration trench should have an emergency overflow berm. This is vital to maintain water in the trench when runoff quantities exceed design capabilities. In addition to the berm, there should be a

presence of an overflow pipe or an underdrain to regulate flows that exceed design capabilities. This pipe should allow for water to flow out of the trench after reaching a certain height and safely move it to the nearest storm drain. In order to allow for a safe transition into the nearest grey infrastructure, a device such as an oil/grit separator must be installed to remove solids and oils from the water.

Groundwater Mounding: Groundwater mounding is a complication that can occur beneath stormwater management practices that are designed to use infiltration. The mounding is caused by water moving vertically up through the trench at a rate faster than it can move horizontally away from the trench. The image below shows a detailed visual of this process.

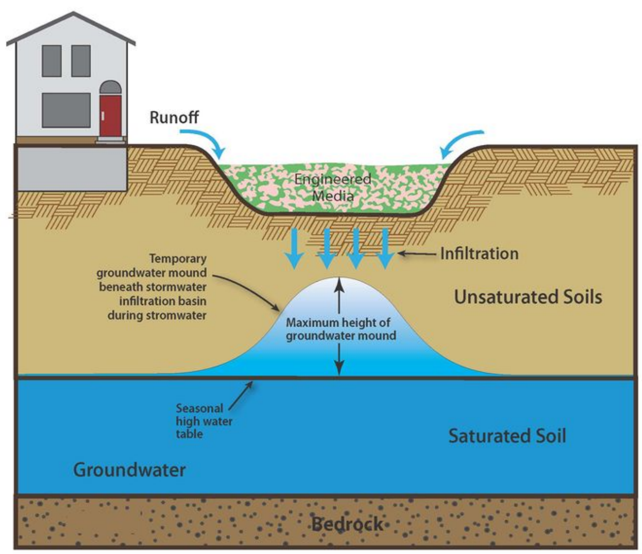

Figure 2.9 Groundwater mounding detailed (Source: Operation, 2021).

2.5.3 Sequencing/Construction & Maintenance

According to Metropolitan Council/Barr Engineering Co., the longevity of the infiltration trench is based on the precautions taken during construction and the upkeep post-construction. The construction sequence and methods for each installation of infiltration trenches should be strictly followed. A maintenance schedule should be produced prior to the trench going online to ensure the trench will last for its design period.

These key standards are to be followed during construction:

1. Construction should only start after the site has been completely stabilized.
2. A fence or rope should be placed around the perimeter of the trench during the construction period.
3. Sediment and erosion control should be a heavy focus to preserve the infiltration trench.
4. Heavy equipment should not be used in the construction process.
5. Compaction of soil and storage media should be minimized to maintain percolation capacity.
6. Smearing of soil should be limited; If it happens, it could be corrected by raking.

7. After excavation, all material should be moved downstream to reduce the risks of reentering the trench.
8. The trench floor should be as flat as possible to insure even infiltration.

Maintenance: A maintenance plan with clear guidelines should be in effect for the trench. Proper maintenance expands the life expectancy and performance of the infiltration trench. Maintenance includes all aspects of the trench, including pre-treatment, filters, storage, observation wells, and underdrain if applicable. Proper methods include:

1. Inspections of the trench after the first couple of major storms is vital to insure proper function. Water levels in the observation wells should also be checked up to 72 hours after the storm to monitor drainage.
2. Maintenance after the first few months should be reduced to no less than twice a year. The main items an inspector should be looking for is ponded water in or around the trench, sediment build-up, debris in the pretreatment practice, and clogging of pipes.
3. If clogging or water ponding occurs, maintenance must occur immediately to correct the problem.
4. If there is ponding water inside the trench 24 hours after a storm, which can be viewed from the observation well, it indicates an infiltration

failure from the bottom of the trench. In a case like this, all storage media, filter, and soil must be removed and maintenance to the soil to reinduce infiltration must occur. Fresh fabric and stone should be refilled into the trench. Figure 2.11 is an image of a trench failing due to clogging and inadequate maintenance.

Figure 2.10 Trench failure due to clogging (Source: Operation, 2021).

3. Theoretical/Experimental Setup and Methods

3.1 EPA Storm Water Management Model (SWMM)

The Storm Water Management Model (SWMM) is a rainfall-runoff-routing model used to model simulations of runoff quantity and quality. This study is performed using the proprietary version PCSWMM by Computational Hydraulics Inc. (CHI) through an educational grant. The simulation will be a relative study based on an uncalibrated model for the demonstration of infiltration trench effects on the selected location. This simulation will show runoff peak flow and timing and volume for a design rainfall event as infiltration trench design parameters are adjusted.

This study will focus on the simulation of an infiltration trench using PCSWMM, in which there are two main components, LID Control Editor and LID Usage Editor, that are adjusted in order to effectively incorporate the infiltration trench design into a simulation (Rossman, 2015).

3.1.1 LID Control Editor

The LID Control Editor is the first step in customizing the development. First, give the LID a name, then select the LID type (bio-retention cell, rain garden, green roof, infiltration trench, permeable pavement, rain barrel, or

vegetative swale). After that, use the tabs labeled surface, storage, underdrain, and pollutant removals to enter specific data for the LID. For infiltration trenches, only the surface, storage, and underdrain tabs are available.

Surface Layer Tab Properties

Berm height (in): This is the depth of storage. This value is considered the maximum depth in which water can pond before overflow occurs above the surface of the infiltration trench.

Vegetative Volume (fraction): This is the fraction of vegetation within the storage depth. This is the fraction occupied merely by stems and leaves. Normally this value can be ignored but could be up to 0.2 for dense vegetation. For infiltration trenches, this value is zero.

Surface roughness* (Manning's n): This value is used to measure the resistance of overland flow from various surfaces. According to the SWMM manual, this value should be 0 for infiltration trenches due to the fact that the trench will not carry water along the surface of the trench but, if needed, water will be carried through an underdrain.

Surface slope* (percent): For infiltration trenches, this value will be 0 due to the fact that the surface will be flat, and water will be carried through an

underdrain if needed. It is noted that if either surface slope or roughness is equal to zero, it is assumed that the water will completely overflow once berm height is reached.

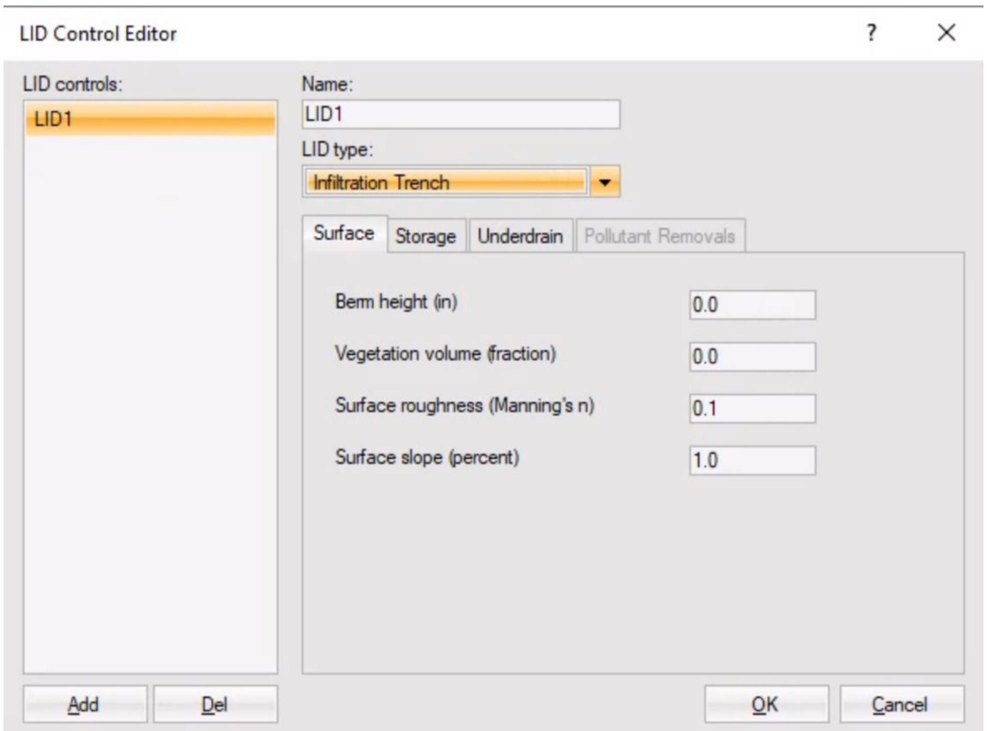

Figure 3.1 Surface tab on LID Control Editor window in PCSWMM.

<u>Storage Layer Tab Properties:</u>

Thickness (in): This value is known as the depth of the storge media or gravel layer that is chosen to fill the infiltration trench. As stated before, the usual design for an infiltration trench calls for no more than 75% storage media.

Void Ratio (Voids/Solids): The is the volume of voids in relation to the volume of solids. With the recommended clean stone stated in chapter 2.5.2, a void ratio around 40 percent (0.4) will correspond.

Seepage Rate (in/hr): The rate at which the water will infiltrate the native soil is known as the seepage rate. As previously stated in chapter 2.5.2, the ideal infiltration rate should be greater than 0.53 in/hr.

Clogging Factor: The clogging factor is the total volume of treated runoff it takes to completely clog the bottom layer divided by the void volume of the layer. Clogging progressively reduces the infiltration rate. With the use of this data option, one can see how the infiltration rate will decrease proportionally to the cumulative runoff. This is typically a concern for infiltration trenches that do not have an under drain. Use a value of 0 to ignore clogging.

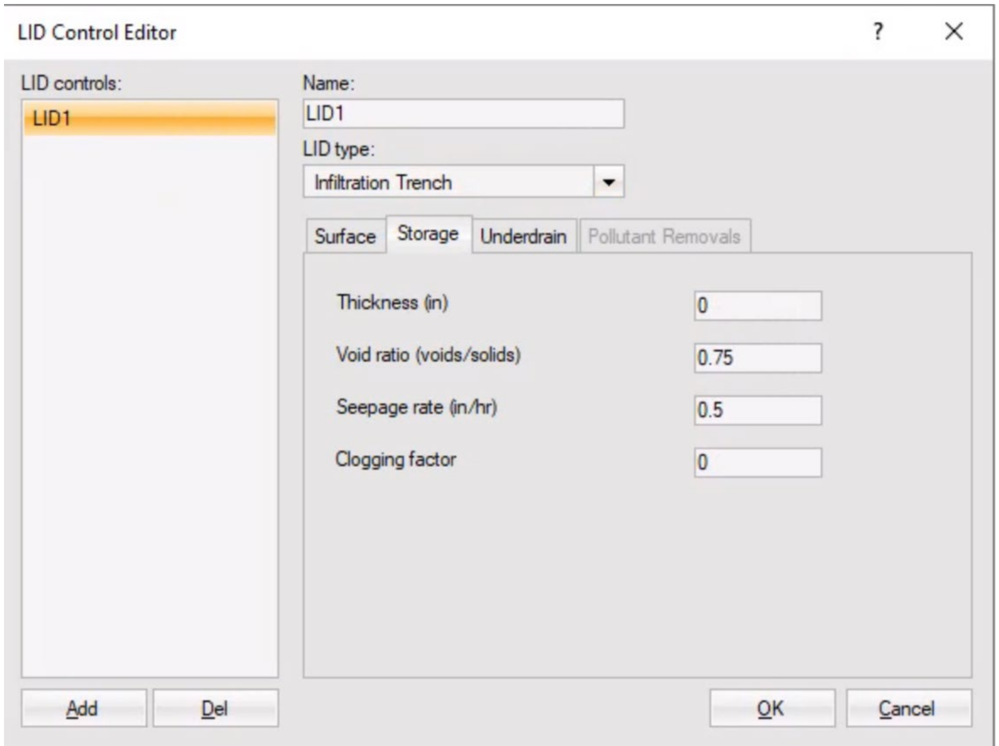

Figure 3.2 Storage tab on LID Control Editor window in PCSWMM.

Underdrain Tab Properties:

If the infiltration trench does not have an underdrain, use a value of 0 for the drain coefficient and the rest of the information below can be disregarded. Infiltration trenches that do contain an underdrain can have a portion of the collected runoff transferred to a storm water drain or nearby grey infrastructure system. The drain can be offset from the bottom of the storage layer to allow for some runoff to store and infiltrate the native soil before being collected and removed from the LID. Typical design criteria for an underdrain consists of a

perforated PVC pipe with a minimum diameter of 4 inches, a slope of at least 0.5, two cleanout wells for maintenance, and two or more inches of choking stone to prevent blockage. The perforations typically should be 3/8 inches every 6 inches along the pipe.

Drain Coefficient (in/hr): Using the equation:

$$q = Ch^n$$

Where:

q = outflow (in/hr),

h = height of saturated media above the drain (in),

C = drain coefficient,

n = drain exponent, and

t= drain time (hr)

Assuming that the drain exponent is 0.5, it can be derived that:

$$C = \frac{2h^{0.5}}{t}$$

Drain Exponent: A typical value for a drain exponent would be 0.5 which will make the drain act as an orifice.

Drain Offset Height (in): This is known as the height above the bottom of the storage layer up to the drain line.

Open Level (in): For the scope of this project, this value should remain at default.

Closed Level (in): For the scope of this project, this value should remain at default.

Control Curve: For the scope of this project, this value should remain at default.

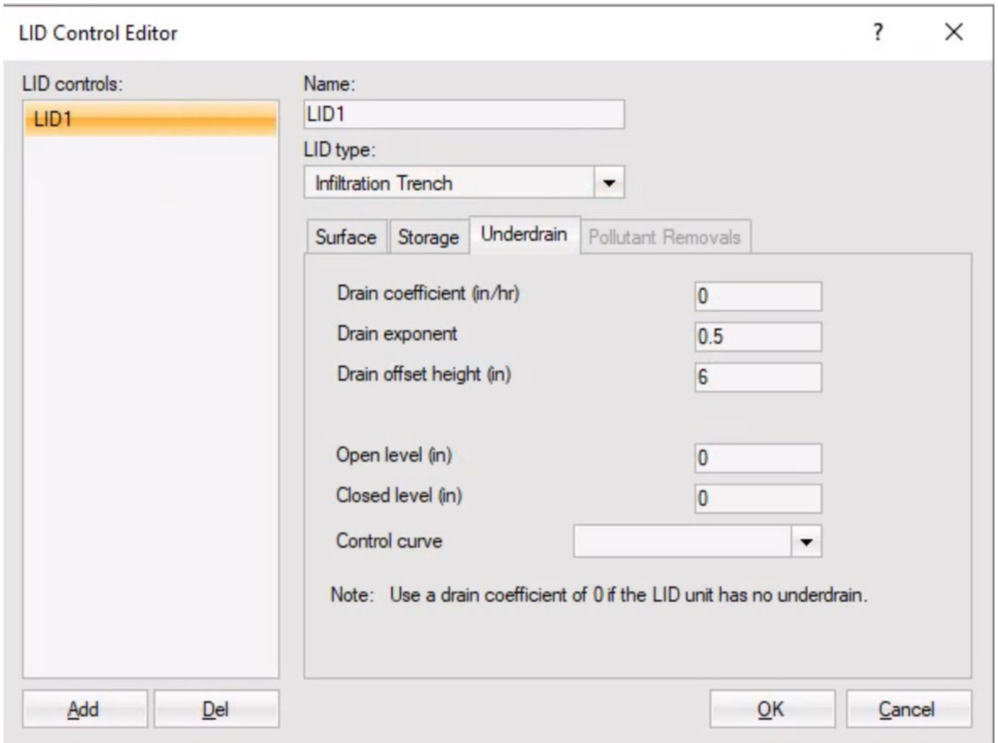

Figure 3.3 Underdrain tab on LID Control Editor window in PCSWMM.

3.1.2 LID Usage Editor

The first step in using the LID usage editor is selecting the LID control name that was created previously in the LID Control Editor to apply that exact design to a subcatchment. An image of the editor screen is shown below.

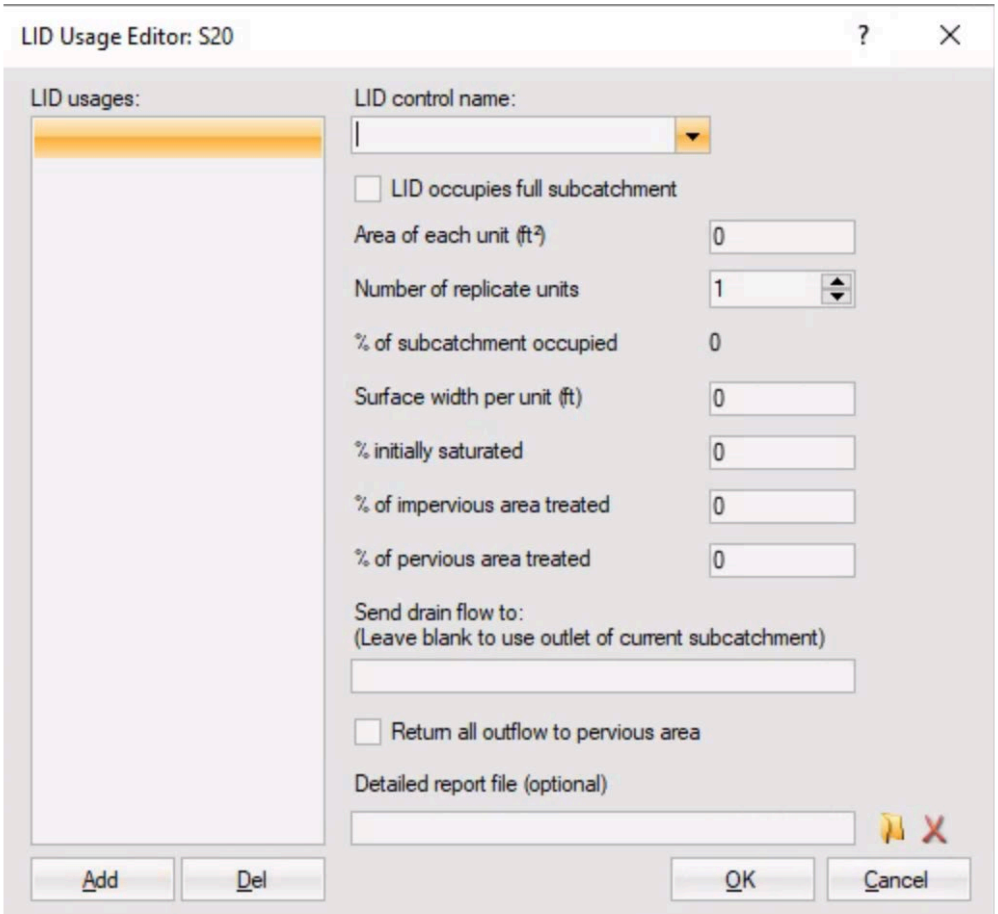

Figure 3.4 LID Usage Editor window in PCSWMM.

Control Name: The name of the LID that was created previously in the LID control editor.

Area of each unit (square foot): The surface area for which each replicated unit occupies.

Number of Replicate Units: The number of units that will have the same surface area provided above.

% of Subcatchment Occupied: This number will populate automatically based on the information provided in the two previous data entries and the area of the subcatchment.

Surface Width Per Unit: The width of the surface of the infiltration trench for each identical unit.

% Initially Saturated: This is the percentage of the storage layer that is initially filled with water. For the purpose of our simulation, we will use a value of 0 for dry conditions before the storm event.

% of Impervious Area Treated: This is the percent of the subcatchment area, not including the area of the infiltration trench, that will be treated by the infiltration trench. If the trench is only collecting water directly from rainfall, then this value will be zero (0). If it desired for only half of the runoff from impervious sources in the subcatchment to go through the trench, then a value of 100 % would be used. If the infiltration trench consumes the entire subcatchment, then this value will be ignored.

% of Pervious Area Treated: This value is like that of the previous data entry. It should be assumed that the rainfall that did not infiltrate the pervious area initially to be routed to the trench for each specific subcatchment. If this is

the case, this number should be 100 %. Conversely, if one does not want the infiltration trench to treat any excess runoff from pervious materials, the value will be zero (0).

With all of the various data entries available within the LID Control and the LID Usage Editors, there is a plethora of design combinations to simulate infiltration trenches. Some of the values are more standardized than others. For example, the stone diameter for the storage media is unlikely to change due to the fact that a certain percentage of voids should be available for proper treatment and storage and the fact that standard sizes are commercially available. Nonetheless, there are still many parameters that can be adjusted to create various storage and infiltration outcomes. Following the successful inputting of all data points, the customized infiltration trench/trenches created will be shown within the subcatchment and accounted for during simulations.

3.2 Study Area

The site selected to simulate the implementation of the infiltration trenches is a span of about four (4) blocks located less than 1/2 mile southwest of the University of New Orleans main campus in the Milneburg neighborhood. This area has desired elements such as the presence of new developments that sit at a higher elevation than the existing homes. The following images give depictions of this site.

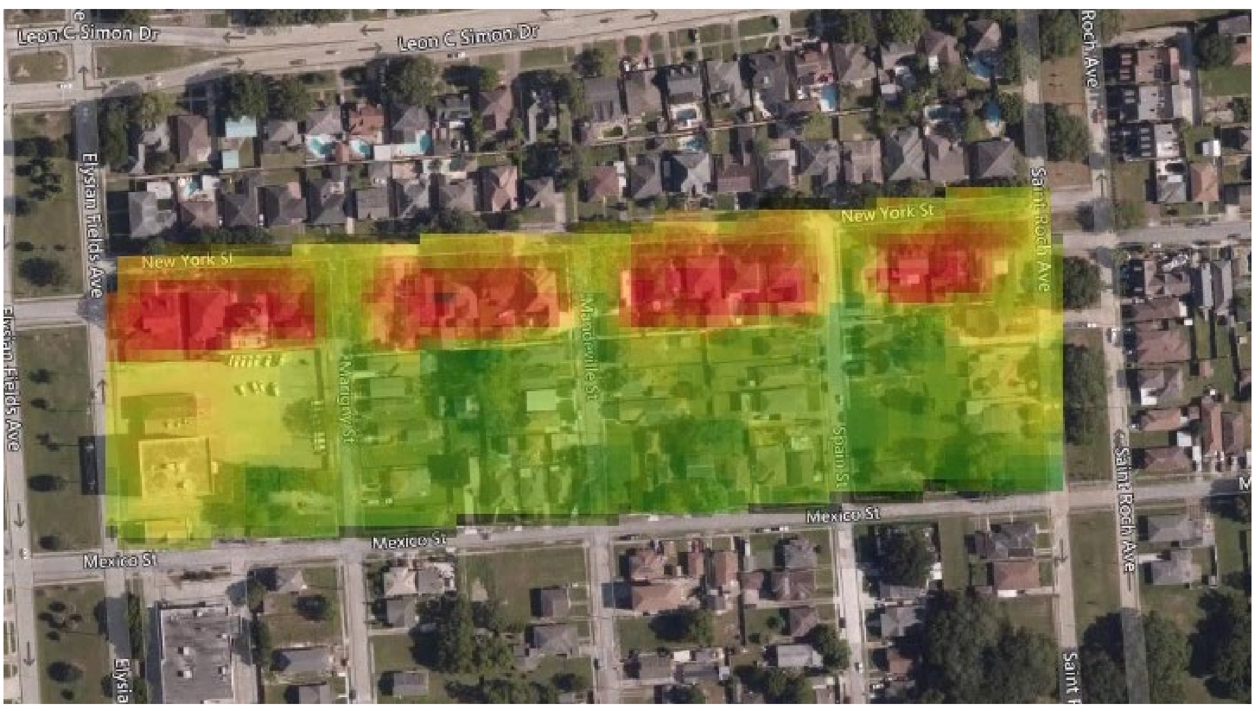

Figure 3.5 Topography of Study area.

Figure 3.6 Street View of Study Area.

Figure 3.5 gives the arial view of the study area which shows the top row of houses sitting at a much higher elevation than the houses directly below them. Figure 3.6 gives a street view visual of the higher elevation development in front of the older homes behind this property.

The Flood Insurance Rate Map (FIRM) of the study site shows that there is flooding hazard for the older establishments while its neighboring, new establishments show little to no flood hazard risks (Figure 3.7). The higher elevations toward the North show no hazard while there is a presence of flood hazard directly south. This situation is can be used to simulate the effects of the

application of infiltration trenches. Figure 3.7a provides the legend for the given FIRM.

Figure 3.7 FIRM of study location (Obtained from http://maps.lsuagcenter.com/floodmaps/).

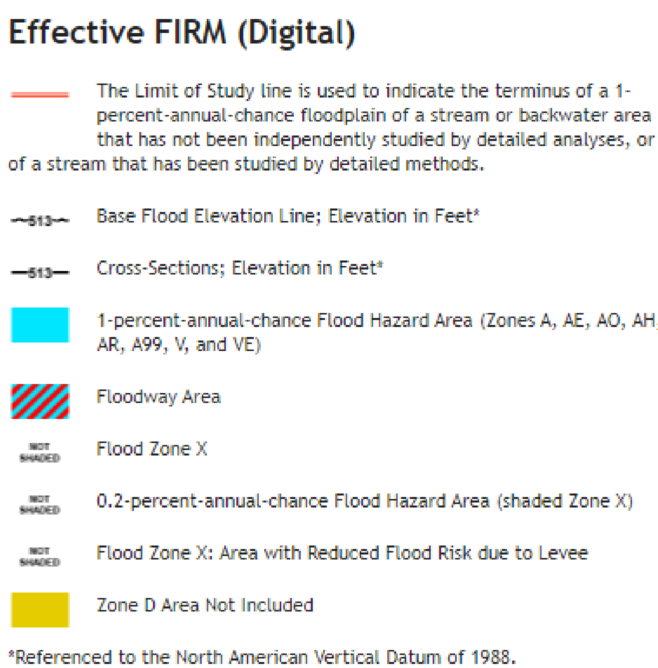

Figure 3.7a FIRM legend (Obtained from http://maps.lsuagcenter.com/floodmaps/).

3.2.1 Residential Changes Over Time

There are two main time frames discussed for this study site. The time periods are from 2006 to 2013 and 2013 to present. The image that is available for 2006 was in June, which is just a little under a year after the devastating natural disaster: Hurricane Katrina (Figure 3.8a). Between June 2006 and the next image date, March 2013, there was a total of eight demolished houses and one reconstructed house within the four blocks being studied (Figure 3.8b). One of the homes had a blue FEMA tarp on the roof. The tarp is used to protect homes from further damage. By 2013, only one new house had been built on a previous vacant lot. These numbers are astounding considering that only about ten percent of the area that was previously destroyed was rebuilt. From 2013 to 2020 (Figure 3.8c), five of the lots that were previously vacant are currently occupied with new construction. This is positive because it is showing improvement in the area. However, there are still elevation differences that run risks for all low-grade development in the area.

Figure 3.8 Images of study site from (a) June 2006 (top), (b) March 2013 (middle), and (c) currently (bottom)

3.3 Data Collection

3.3.1 Maps

Maps were collected from multiple sources in order to obtain enough data to recreate the drainage system in SWMM for the study area. One of the maps obtained was the drainage map from the Sewerage and Water Board of New Orleans (SWBNO). This map, Figures 3.9 and 3.10, included information about manhole locations, manhole types, inlet locations, pipelines, canal lines, pipe diameters, and direction of flow. With the use of this map, the ability to locate and incorporate pipe diameters along with manhole and inlet locations into the model was straight forward. The images also allowed the flow direction of stormwater throughout the subsurface drainage system to be verified.

In addition to the drainage maps, profile elevations were obtained from the United States Geological Survey (USGS) National Map as well as through the use of a DEM file of the study site (https://apps.nationalmap.gov/viewer/). The DEM file allowed for the proper placement of manhole rim elevations on SWMM while the profile elevations were used as a verification.

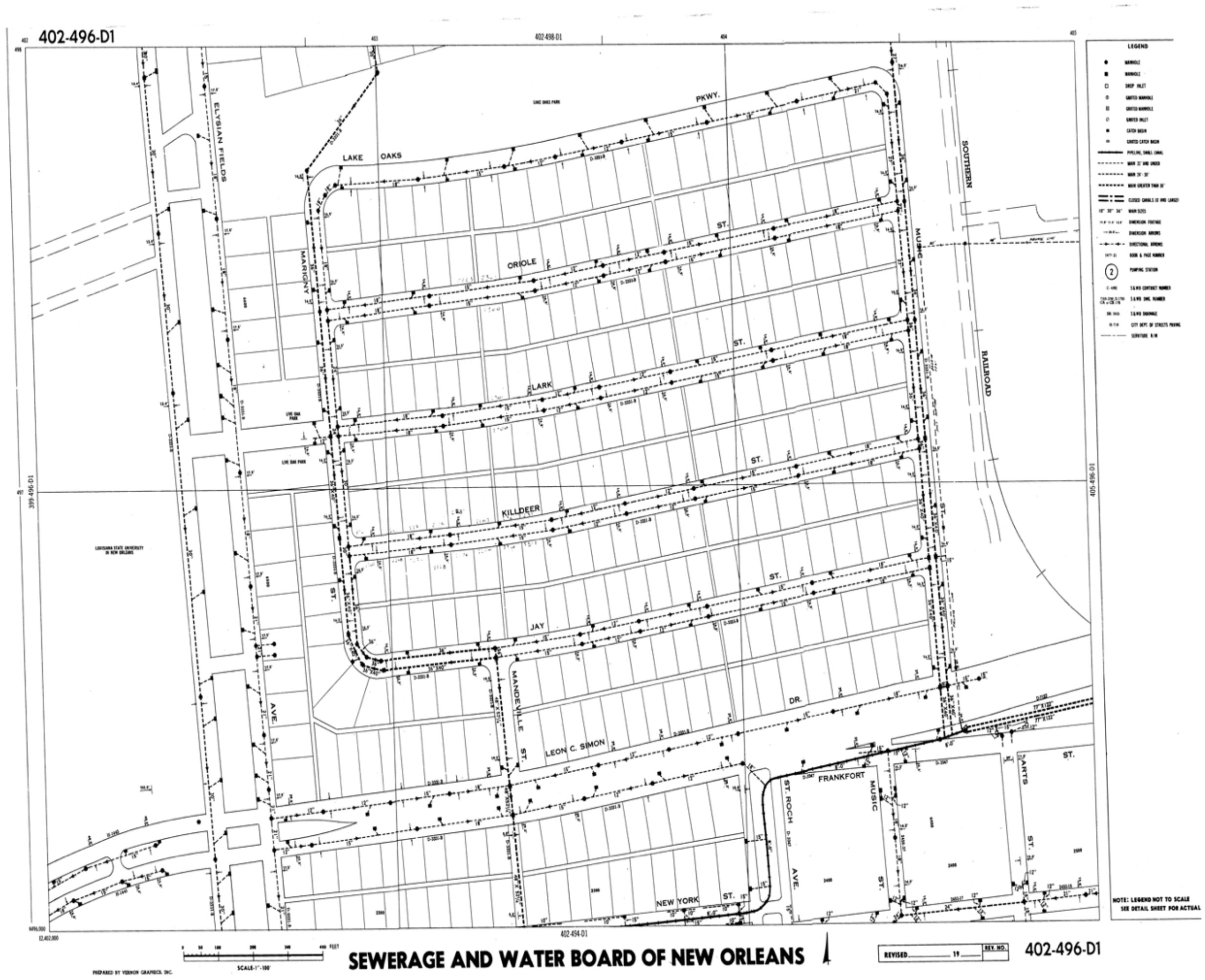

Figure 3.9 Drainage map of northern region of study site. (Courtesy of Sewerage and Water Board)

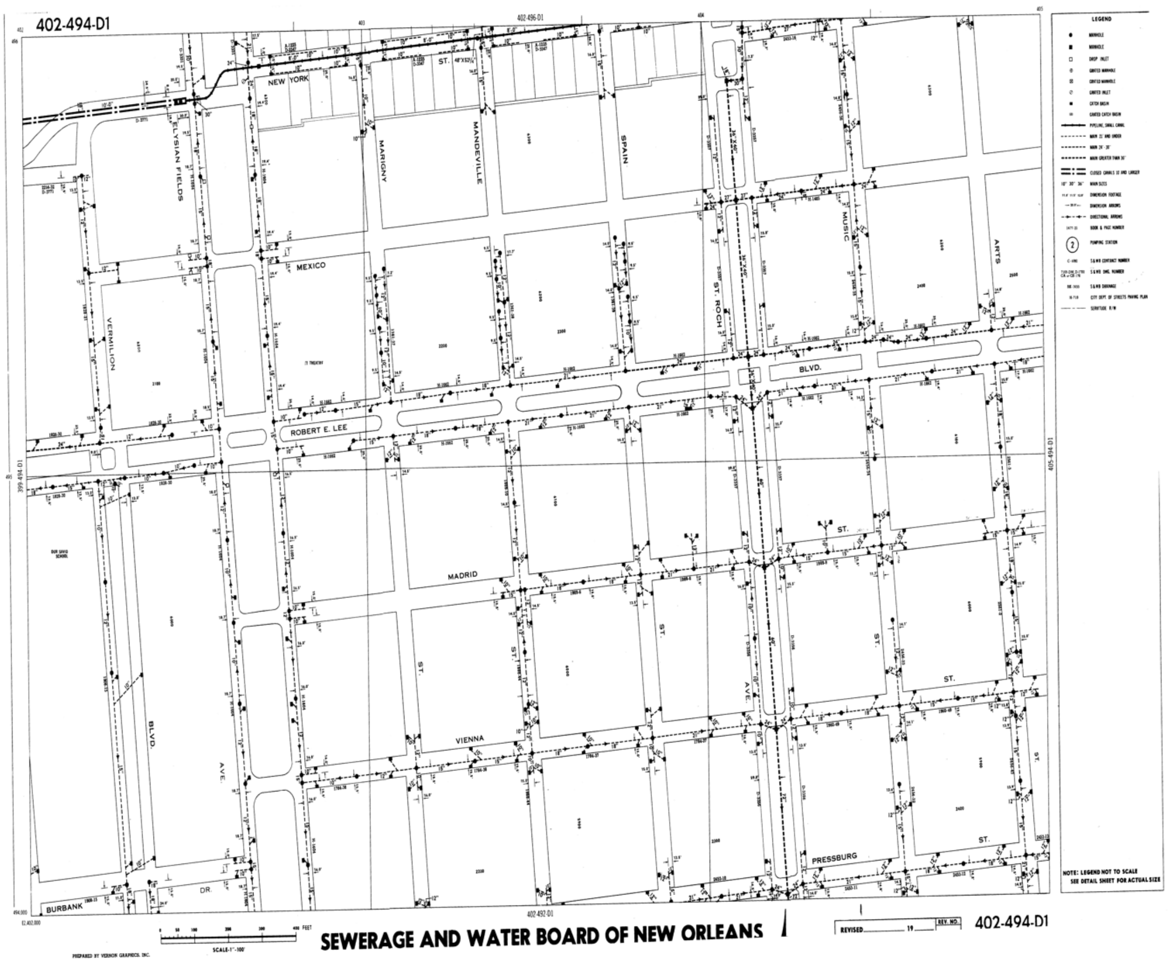

Figure 3.10 Drainage map of southern region of study site. (Courtesy of sewerage and water board).

3.3.2 Precipitation Records

Precipitation records, Figure 3.11, were obtained from National Oceanic and Atmospheric Administration's (NOAA) National Weather Service and used to create the hyetograph for the 60- minute 10-year design storm. The same precipitation records were used to create the 10-year intensity-duration-frequency curve for the storm, figure 3.12. The design storm designed to drive the model was selected as a 10-year event because it is likely the return period that was used for the design of the existing subsurface drainage. The hyetograph was created using the Alternating Block Method. This method specifies the depths of precipitation by the selected time intervals for the design storm duration. The hyetograph had a time step of 15 minutes to be consistent with the time of concentration of the site. The table below gives the time input series of the storm.

Duration	PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]									
	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.553** (0.442-0.691)	**0.627** (0.501-0.785)	**0.754** (0.600-0.947)	**0.865** (0.684-1.09)	**1.02** (0.784-1.34)	**1.16** (0.860-1.54)	**1.29** (0.924-1.76)	**1.43** (0.980-2.01)	**1.63** (1.07-2.35)	**1.79** (1.13-2.61)
10-min	**0.809** (0.648-1.01)	**0.918** (0.734-1.15)	**1.10** (0.879-1.39)	**1.27** (1.00-1.60)	**1.50** (1.15-1.97)	**1.69** (1.26-2.25)	**1.89** (1.35-2.58)	**2.10** (1.43-2.94)	**2.39** (1.56-3.45)	**2.62** (1.66-3.83)
15-min	**0.987** (0.790-1.24)	**1.12** (0.895-1.40)	**1.35** (1.07-1.69)	**1.54** (1.22-1.95)	**1.83** (1.40-2.40)	**2.06** (1.54-2.74)	**2.30** (1.65-3.14)	**2.56** (1.75-3.59)	**2.91** (1.91-4.20)	**3.19** (2.02-4.67)
30-min	**1.49** (1.19-1.87)	**1.71** (1.36-2.14)	**2.07** (1.65-2.60)	**2.39** (1.89-3.01)	**2.85** (2.18-3.73)	**3.22** (2.39-4.27)	**3.60** (2.58-4.91)	**4.00** (2.74-5.61)	**4.56** (2.98-6.58)	**5.00** (3.17-7.31)
60-min	**2.01** (1.61-2.52)	**2.30** (1.84-2.88)	**2.82** (2.24-3.54)	**3.30** (2.61-4.16)	**4.04** (3.11-5.35)	**4.67** (3.49-6.25)	**5.35** (3.84-7.35)	**6.09** (4.18-8.60)	**7.15** (4.69-10.4)	**8.02** (5.09-11.7)
2-hr	**2.53** (2.04-3.14)	**2.89** (2.33-3.59)	**3.56** (2.86-4.43)	**4.21** (3.36-5.26)	**5.23** (4.08-6.92)	**6.12** (4.62-8.17)	**7.09** (5.15-9.71)	**8.17** (5.67-11.5)	**9.75** (6.47-14.1)	**11.0** (7.07-16.0)
3-hr	**2.86** (2.31-3.53)	**3.25** (2.63-4.02)	**4.03** (3.25-5.00)	**4.81** (3.85-5.99)	**6.07** (4.78-8.06)	**7.20** (5.48-9.62)	**8.45** (6.19-11.6)	**9.86** (6.89-13.9)	**11.9** (7.98-17.2)	**13.7** (8.80-19.8)
6-hr	**3.42** (2.79-4.19)	**3.91** (3.19-4.79)	**4.89** (3.97-6.01)	**5.89** (4.75-7.27)	**7.53** (5.99-9.95)	**9.00** (6.93-12.0)	**10.7** (7.89-14.5)	**12.5** (8.85-17.5)	**15.3** (10.3-21.9)	**17.6** (11.5-25.3)
12-hr	**4.01** (3.30-4.86)	**4.62** (3.80-5.61)	**5.83** (4.78-7.10)	**7.02** (5.71-8.59)	**8.94** (7.15-11.7)	**10.6** (8.24-14.0)	**12.5** (9.33-16.9)	**14.6** (10.4-20.3)	**17.7** (12.1-25.2)	**20.3** (13.4-29.0)
24-hr	**4.62** (3.83-5.55)	**5.40** (4.47-6.50)	**6.87** (5.67-8.29)	**8.25** (6.77-10.0)	**10.4** (8.36-13.4)	**12.3** (9.56-15.9)	**14.3** (10.7-19.0)	**16.5** (11.9-22.6)	**19.8** (13.6-27.8)	**22.4** (14.9-31.7)
2-day	**5.24** (4.38-6.25)	**6.20** (5.18-7.40)	**7.94** (6.60-9.50)	**9.54** (7.89-11.5)	**12.0** (9.66-15.2)	**14.0** (11.0-18.0)	**16.2** (12.3-21.4)	**18.7** (13.5-25.3)	**22.1** (15.3-30.8)	**24.9** (16.7-35.0)
3-day	**5.60** (4.71-6.64)	**6.63** (5.56-7.86)	**8.48** (7.09-10.1)	**10.2** (8.46-12.2)	**12.8** (10.4-16.1)	**15.0** (11.8-19.1)	**17.4** (13.2-22.8)	**20.0** (14.5-26.9)	**23.7** (16.5-32.9)	**26.7** (18.0-37.3)
4-day	**5.93** (5.00-7.00)	**6.97** (5.87-8.25)	**8.88** (7.45-10.5)	**10.6** (8.88-12.7)	**13.4** (10.9-16.8)	**15.7** (12.4-20.0)	**18.2** (13.9-23.8)	**20.9** (15.3-28.1)	**24.8** (17.4-34.4)	**28.0** (19.0-39.1)
7-day	**6.92** (5.86-8.11)	**7.99** (6.77-9.38)	**9.98** (8.42-11.7)	**11.8** (9.93-14.0)	**14.7** (12.1-18.4)	**17.2** (13.7-21.7)	**19.9** (15.3-25.8)	**22.8** (16.8-30.5)	**27.0** (19.1-37.2)	**30.5** (20.9-42.3)
10-day	**7.86** (6.70-9.18)	**8.99** (7.65-10.5)	**11.1** (9.38-13.0)	**13.0** (11.0-15.3)	**16.0** (13.2-19.8)	**18.5** (14.8-23.3)	**21.2** (16.4-27.5)	**24.3** (18.0-32.3)	**28.6** (20.3-39.2)	**32.1** (22.1-44.4)
20-day	**10.6** (9.12-12.3)	**12.0** (10.3-13.9)	**14.5** (12.4-16.8)	**16.7** (14.2-19.5)	**19.9** (16.4-24.3)	**22.5** (18.2-27.9)	**25.3** (19.7-32.2)	**28.3** (21.1-37.1)	**32.4** (23.2-43.9)	**35.7** (24.9-49.0)
30-day	**12.9** (11.1-14.8)	**14.6** (12.6-16.8)	**17.4** (15.0-20.1)	**19.8** (16.9-23.0)	**23.3** (19.3-28.1)	**26.0** (21.0-31.9)	**28.8** (22.5-36.3)	**31.7** (23.7-41.2)	**35.7** (25.7-47.9)	**38.7** (27.1-52.9)
45-day	**15.8** (13.7-18.1)	**17.8** (15.4-20.4)	**21.1** (18.2-24.2)	**23.8** (20.4-27.5)	**27.6** (22.9-32.9)	**30.5** (24.7-37.0)	**33.3** (26.1-41.6)	**36.2** (27.2-46.7)	**40.1** (29.0-53.4)	**42.9** (30.3-58.4)
60-day	**18.2** (15.8-20.8)	**20.5** (17.8-23.4)	**24.2** (20.9-27.7)	**27.2** (23.4-31.3)	**31.2** (26.0-37.0)	**34.3** (27.9-41.4)	**37.3** (29.3-46.3)	**40.2** (30.3-51.6)	**44.1** (32.0-58.4)	**46.9** (33.2-63.6)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

Figure 3.11 Site Precipitation Frequency (obtained from noaa.gov)

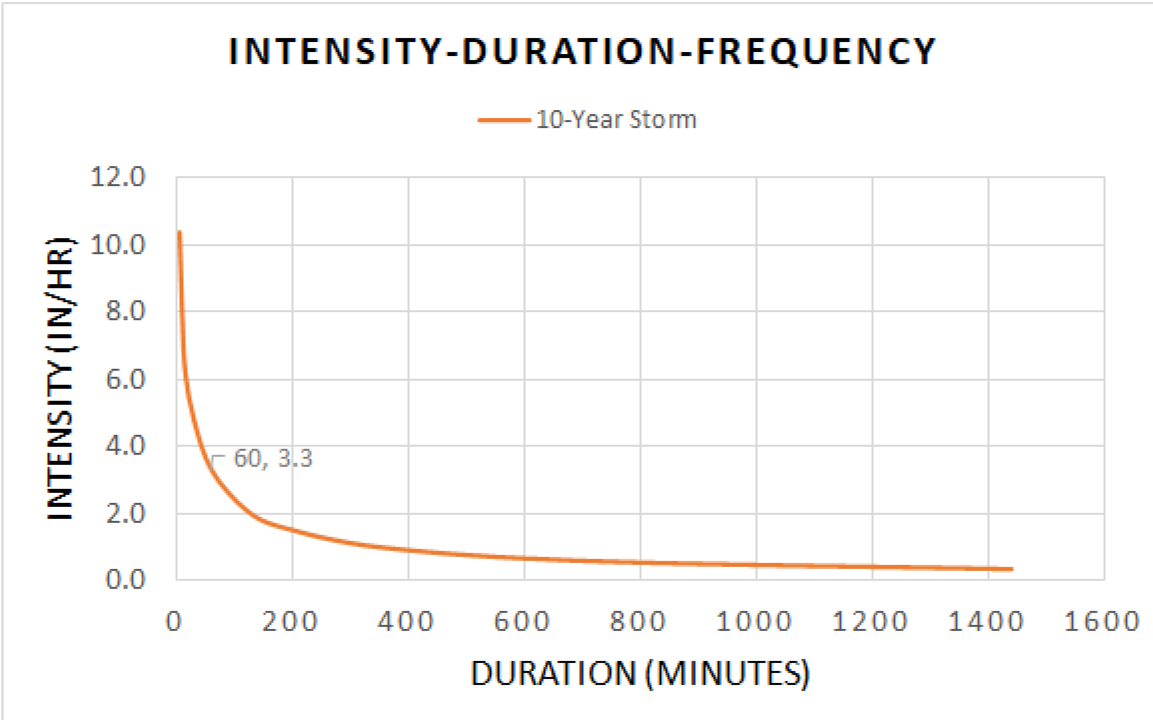

Figure 3.12 Intensity-Duration-Frequency (IDF) curve for a 10-year storm.

Time (minute)	Depth (inch)
0	-
15	0.445
30	1.54
45	0.85
60	0.445

Table 3.1 Time series input data.

3.4 SWMM Model

3.4.1 Set Up

The drainage system of the study site, Figure 3.13, has a total of 25 manholes/inlets, 26 conduits, 2 outfalls, and 19 subcatchments. The number of manholes and conduits were obtained directly from the obtained drainage map above. The junction elevations were merged from a DEM file of the area. An assumed slope of 0.18 % was used for each conduit to allow gravitational flow of storm water. The outfall was placed on the north-west corner of site because runoff from Elysian Fields, Marigny, Mandeville, part of Mexico, and Spain Streets all flowed into this main pipe away from the site. The South-Eastern corner of the site, runoff collected from St. Roch and part of Mexico Street flows to a separate main. Figure 3.13 gives a depiction of the SWMM model as well as the location of where the proposed infiltration trenches will be located.

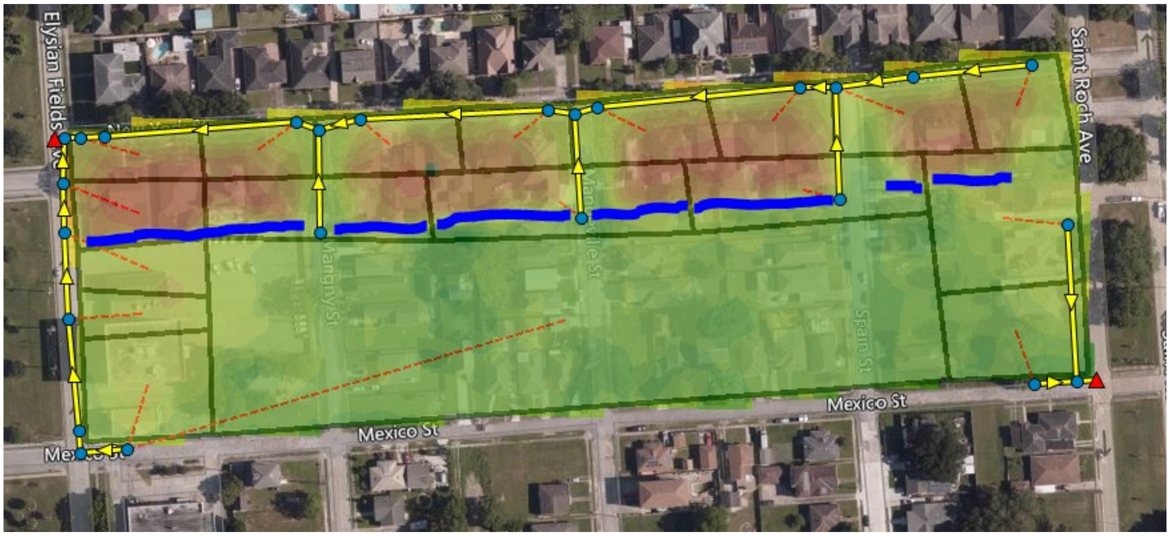

Figure 3.13 Drainage network of study site and proposed trench locations (blue).

For the 19 subcatchments, the following attributes were altered from default to account for each individual subcatchment: Outlet, Area, Slope, Impervious %, Width, and Curve Number. Each outlet and area were selected based on the subcatchment's location. Typically, these values are set to a default value and need to be updated with values representative of the site. In order to obtain the slopes of each subcatchment, an elevation profile was used. To find the impervious percentage, the area tool on SWMM was used by measuring the area of the streets, houses and other imperviousness in comparison to the respective subcatchment. This ruler tool was also utilized to determine the width of the subcatchments perpendicular to the furthest flow length. Lastly, the Curve Number Table of Urban Hydrology, Figure 3.14, assisted in the

determination of curve numbers for each subcatchment. The soil at this location is a part of the hydrologic soil group, C with a slow infiltration rate around 0.75 in/hr.

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

Figure 3.14 Runoff curve numbers for urban areas.

3.4.2 Run Without Trenches

Using the design storm declared above, there was a presence of flooding in the simulation. The results produced runoff and routing continuity errors below 1% which means outflow at outfall will be slightly underestimated. The

simulation output of purely the storm generated a peak flow of 33.88 cubic feet per second and total volume of 83,320 cubic feet. The time to peak was 46 minutes. There was a presence of flooding in Junction 1 which is one of the only two junctions constructed for Mexico Street. The flooding summary, hyetograph, hydrograph, and data of the simulation is shown below.

```
*********************
Node Flooding Summary
*********************

Flooding refers to all water that overflows a node, whether it ponds or not.
--------------------------------------------------------------------------
                                                          Total   Maximum
                                 Maximum   Time of Max    Flood    Ponded
                        Hours       Rate    Occurrence   Volume     Depth
Node                  Flooded        CFS   days hr:min  10^6 gal     Feet
--------------------------------------------------------------------------
J1                       0.85      16.33      0  00:45     0.194    0.000
```

Figure 3.15 Node flooding summary.

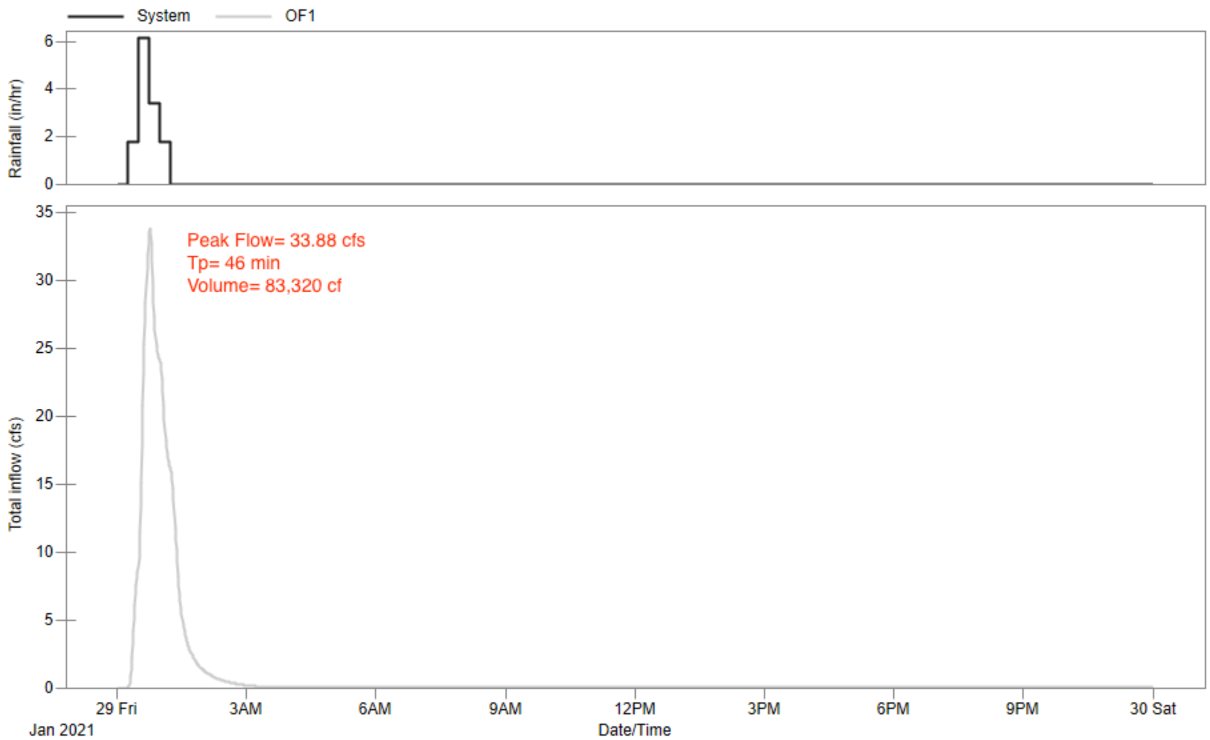

Figure 3.16 Hyetograph (top) and hydrograph (bottom) of the simulation without trench implementation.

	OF1
Maximum Total inflow (cfs)	33.88
Minimum Total inflow (cfs)	0
Mean Total inflow (cfs)	0.965
Duration of Exceedances (h)	23.98
Duration of Deficits (h)	0.2333
Number of Exceedances	1
Number of Deficits	1
Volume of Exceedances (ft^3)	83320
Volume of Deficits (ft^3)	0
Total Total inflow (ft^3)	83320

Table 3.2 The objective functions for the total inflow into outfall 1.

3.5 Trench Parameter Adjustments

For subcatchments 1, 2, 3, 4, and 5, infiltration trenches of various areas were implemented (Figure 3.17) These subcatchments were selected because they included the elevation drops between the adjacent home properties. The trenches were 5 feet wide and varied in length for each subcatchment. However, the total area of the trenches within the subcatchments was 5,430.6 square feet.

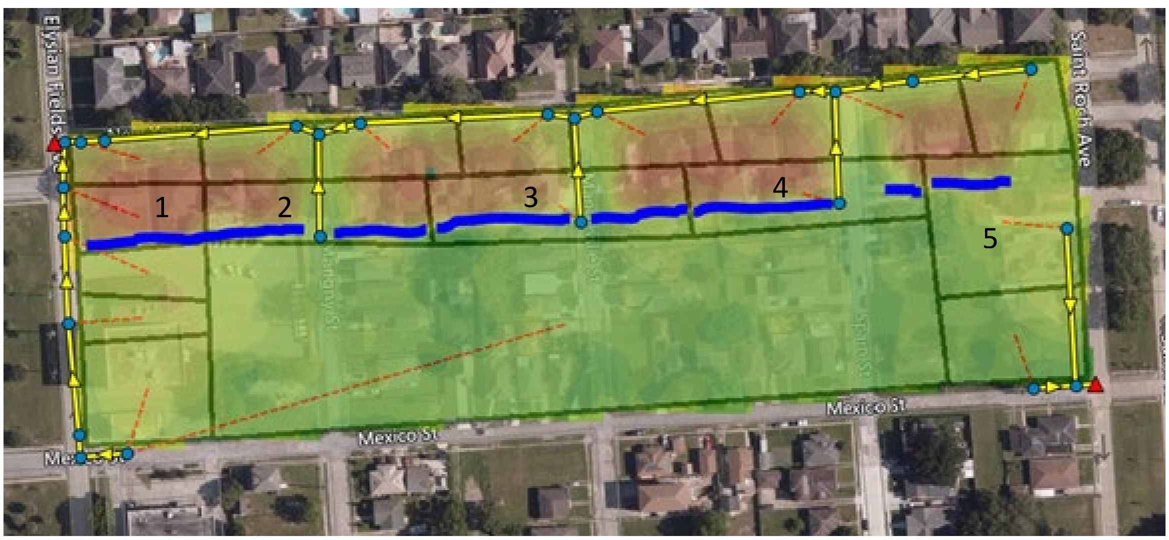

Figure 3.17 Subcatchment numbering and proposed trench locations (blue)

There were many different aspects that were used to assess peak flow reductions (trench depth, void ratio of storage media, side slope, and storage thickness/depth). A total of 9 runs were simulated. Only one parameter changed at a time from the base case scenario (run 3). The table below shows the parameters for each run and the factors changed in each respective run. The first

set of runs were adjustments to trench depths, the 9th run was merely a use of a different storage material, and the final run set was adjustment to surface slopes. Each item that is bolded and underlined represents the changed factor for each simulation.

	Surface Editor		Storage Editor	
	Depth (in)	Surface Slope (%)	Storage Thickness (in)	Void Ratio
Run 1	**18**	0	**13.5**	0.4
Run 2	**24**	0	**18**	0.4
Run 3	**36**	0	**27**	0.4
Run 4	36	0	**36**	0.4

Table 3.3 Increasing Trench Depth.

	Surface Editor		Storage Editor	
	Depth Height (in)	Surface Slope (%)	Storage Thickness (in)	Void Ratio
Run 3	**36**	0	**27**	0.4
Run 9	36	0	27	**0.3**

Table 3.4 Decreasing Void Ratio.

	Surface Editor		Storage Editor	
	Depth Height (in)	Surface Slope (%)	Storage Thickness (in)	Void Ratio
Run 3	**36**	0	**27**	0.4
Run 5	36	**30**	27	0.4
Run 6	36	**45**	27	0.4
Run 7	36	**60**	27	0.4
Run 8	36	**100**	27	0.4

Table 3.5 Increasing Side Slope.

4. RESULTS

The following chapter presents the results produced from the 9 simulations. The results were ultimately analyzed on their ability to reduce peak flow.

4.1 Results of Various Depths

The first set of runs consisted of depth modifications. The peak flow reductions are provided for each run on the table below, along with the volumes and time to peaks. The graph below shows the hydrographs of the first 4 simulations in comparison to the Initial run without the trenches. The Initial run is red while all of the other runs have highlighted peak flows that correspond to its respective hydrograph.

	Surface Editor		Storage Editor		Results			
	Depth (in)	Surface Slope (%)	Storage Thickness (in)	Void Ratio	Peak Flow Reduction (%)	Volume (Cubic Feet)	Time to peak (Min.)	Peak Flow (CFS)
Run 1	18	0	13.5	0.4	16.79%	74240	48	28.19
Run 2	24	0	18	0.4	29.87%	71240	60	23.76
Run 3	36	0	27	0.4	33.83%	65290	46	22.42
Run 4	36	0	36	0.4	33.83%	64,230	46	22.42

Table 4.1 Results for depth runs.

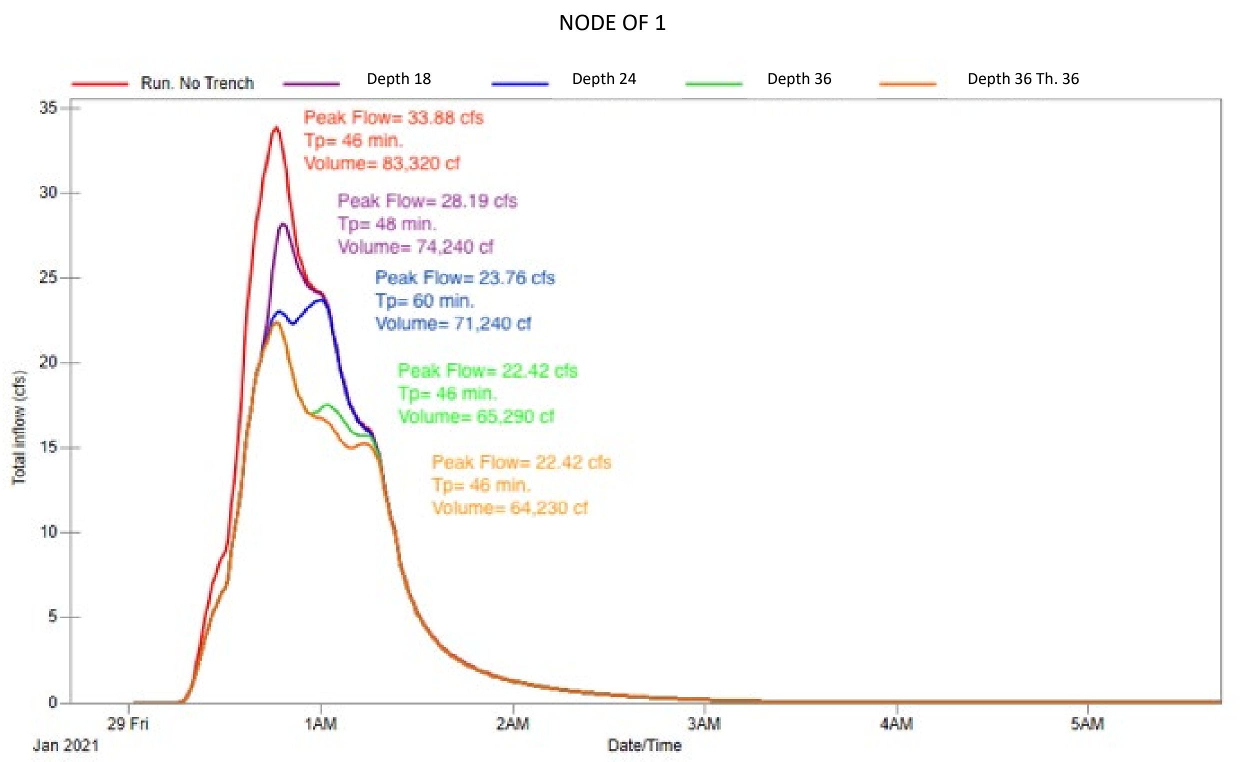

Figure 4.1 Hydrographs with depth runs.

4.2 Result of Varied Void Ratio

The results of the 9th run with only the void ratio show an increase in volume which is shown in table 4.2. The image below shows the hydrographs of the first simulation without trenches along with the 3rd run and 9th run. The 3rd run from the previous simulations was added to this hydrograph because the change in parameters was stemmed from these initial parameters. Run 3 is in green while run 9 is yellow.

	Surface Editor		Storage Editor		Results			
	Depth Height (in)	Surface Slope (%)	Storage Thickness (in)	Void Ratio	Peak Flow Reduction (%)	Volume (Cubic Feet)	Time to peak (Min.)	Peak Flow (CFS)
Run 3	36	0	27	0.4	33.83%	65290	46	22.42
Run 9	36	0	27	0.3	33.83%	65900	46	22.42

Table 4.2 Result for void ratio run.

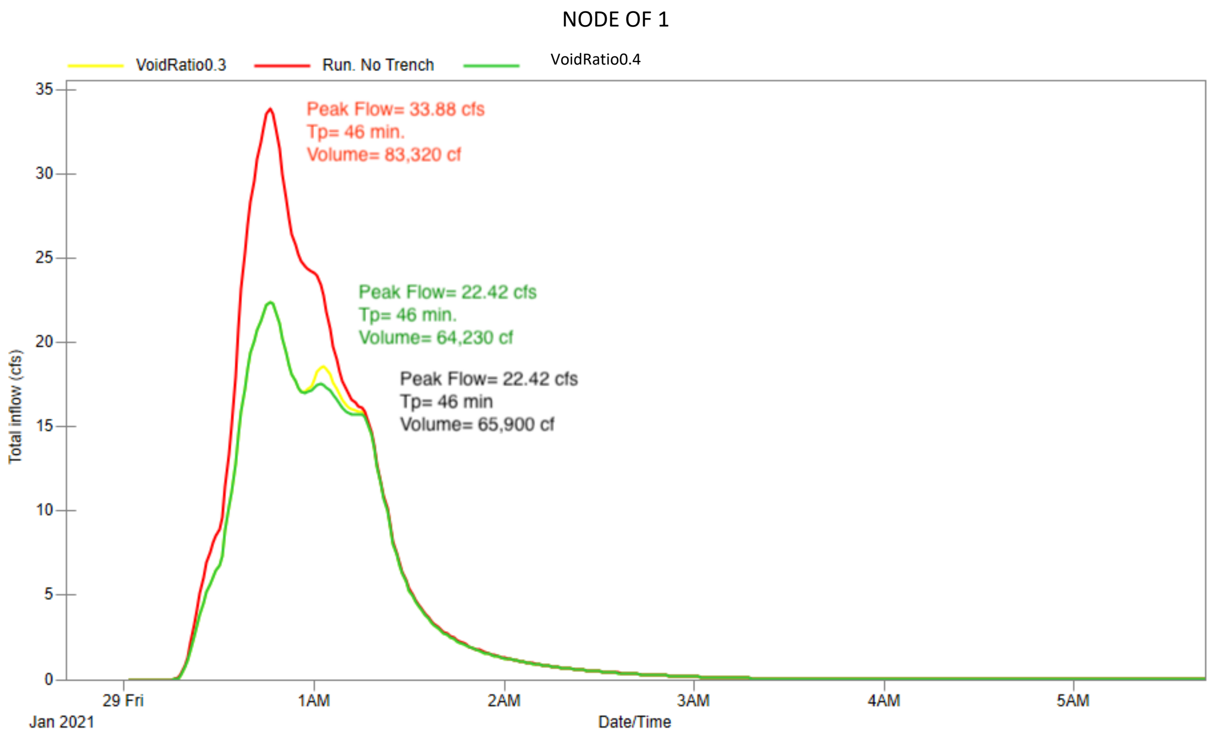

Figure 4.2 Hydrographs with void ratio run.

4.3 Results of Surface Slopes

The following results are given for the final set of runs where the surface slopes are altered. The image below shows the hydrographs of the first simulation without trenches along with the 3rd run and 5^{th}-8^{th} runs. The 3rd run was added again to this hydrograph because the change in parameters as the base case scenario with zero side slope applied from these initial parameters. Run 3 is in green while the other runs are in multiple colors that can't be seen because the peak flows are the same.

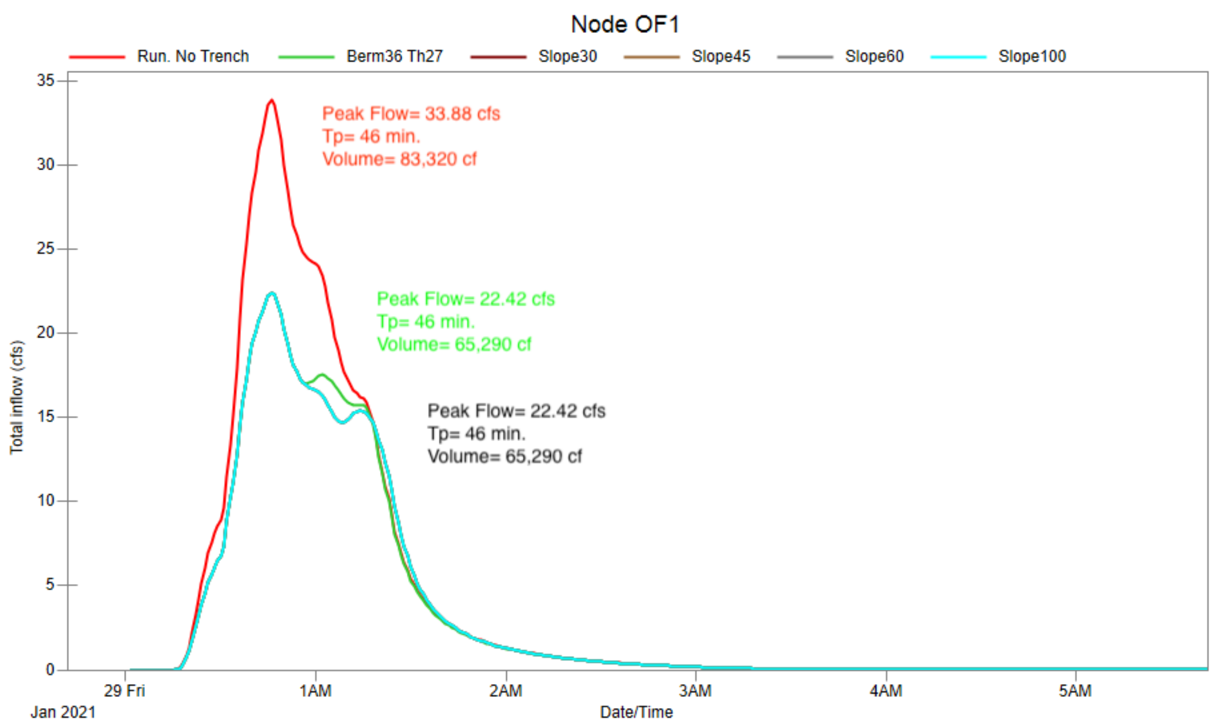

Figure 4.3 Hydrographs with surface slope runs.

5. DISCUSSION

5.1 Discussion of Depth and Void Ratio Results

The results discussed in this section include the simulated peak flow, time to peak and volume as a function of infiltration trench changes in depth and void ratio. As shown above, there were three different simulations that were ran with trench depths. The depths used increased from run 1 to run 3. The max depth of the trenches considered in this project was 3 feet. This depth allowed for the maximum peak flow reduction of 33.88%. The relationship between peak flow reductions and trench depth was direct. The graph below shows the trench depths vs. the peak flows with optimal design depths occurring from 1.5 to 3 ft.

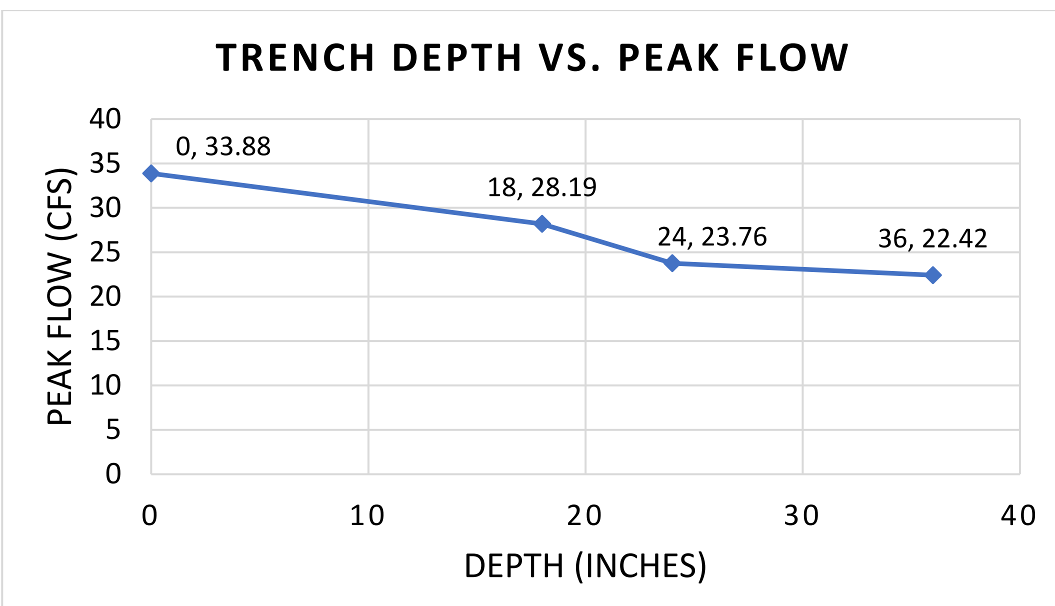

Figure 5.1 Graph of trench depth vs. peak flows

Additionally, as seen above, the time to peaks varied for each depth. With run 1 (depth 1.5 feet), the time to peak was 48 minutes. With run 2 and 3 (depth 2 feet and 3 feet), the time to peak was 60 minutes and 48 minutes respectfully. The time to peak increased with depth until the final run. This was due to the fact that the water was being slowed down with the depths of 1.5 feet and 2 feet. With these depths, the runoff was slowed down but it ultimately still overflowed the trenches and eventually made its way to the outfall. Thus, a future study should include design rainfall simulations that do not cause flooding. However, in regard to the three-foot depth trench in run 3, the trenches were able to sufficiently hold all of the excess runoff within the assigned subcatchments. This caused the peak flow shown to be sourced from the subcatchments in the watershed that did not have infiltration trenches. Due to this, the time to peak occurred at the same time as the simulation without any trenches because there was not a delayed release of water from trench overflow that causes the time to peak to increase.

Each of the simulated trench depths considered, had a storage media depth that was 75% of the total depth. For instance, run 3 with the 3-foot depth trench had a storage thickness of 2.25 feet. For run 4, the modification was an increase in storage depth to 100% of the trench depth. This parameter change produced the same time to peak and peak flow as the 3rd run with only 75% media. The

only factor that changed was volume of stormwater runoff which decreased by 1.6%. This is due to the fact that there was more storage available for the water.

The 9th run included a variation in storage media size. The 3rd run with the 3-foot depth trench had the clean aggregate stone which produced a void ratio of 40%. The modification to this included a change from the clean stone to pea size gravel. This reduced the void ratio size to from 40% to 30%. With this reduction, the time to peak and peak flow remained the same as well because the changes were not considered significant enough to cause changes to peak flow and time to peaks in relation to the 3rd run. However, the volume of storm runoff was altered. The volume actually increased by 2.6%. This was due to the fact that less runoff was able to be held in the trench because there was a smaller percentage of voids available for stormwater storage and infiltration.

5.2 Discussion of Surface Slope Results

As seen in the results section, there were four different runs with what were thought to be infiltration trench side slope adjustments. The side slopes considered were planned to range from a mild slope of 30% to 100% mirroring a vertical wall in the trench. However, results showed no change in time to peaks, peak flows, or volumes. After investigating this unexpected result, it turns out that SWMM does not have an option that allows infiltration trenches

to have the ability to vary side slope. In SWMM, the slope for the infiltration trench refers to the bottom slope when an underdrain is installed. The underdrain collects and transfers the excess water to the junction that it ties into. This slope thus refers to the pipe flow within the Manning equation. The only LID option offered by SWMM that allows modifications to side slope is the vegetative swale.

5.3 Flooding Related to Inadequate Inlets

As seen in the preceding chapter, only 2 inlets intake all of the flow from nearly 6.5 acres of development. This is likely a major contributing factor for flooding issues due to the inability of water to be stored, infiltrated, and moved from higher elevation properties into the drainage system rather than onto to adjacent lower elevation properties. The excess runoff from higher elevations in this situation by-passes the subsurface drainage inlets and flows onto the lower elevation properties. Flood water builds up on the lower elevation property due to the increased overland flow time to reach the nearest available subsurface drainage inlet. The decreased time to peak of the higher elevation runoff may also overload inlet capacity causing a buildup of flood water in the surrounding area. In this case study, 3 out of 5 of subcatchments considered above have only

2 inlets which are all located on northern region of the street. This leaves the remainder of the street length to flow to these available inlets.

The city of New Orleans was built on swamp lands which causes it to have a high-water table. Direct consequences form the water table cause the accumulation of potholes, bumps, ridges and irregularities for the streets and foundations of New Orleans. With this, many areas that may have initially been able to allow stormwater to travel to the existing inlets are now hindered by the natural formation of obstacles.

In addition to elevated inlets or flow blockage, there is also the issue of catch basin blockage. The image below is from Marigny street within the study site. This image gives a great depiction of storm drains being clogged and unable to capture as much stormwater as it was initially designed to. This exact inlet below is one of the two available inlets discussed in the previously. This could directly contribute to flooding and ponding in this area.

Figure 5.2 Street inlet elevated (right) and blocked inlet on Marigany Street (left). (Obtained from NOLA.com and google maps)

5.4 Uncertainties in Input Data

Any measurement or interpretation of data is susceptible to uncertainties. The uncertainty can be the result of human error, equipment error, limitations of data and may other aspects. Every experiment or research methodology should take in account the possibility of uncertainties.

5.4.1 Rainfall Data Uncertainty

In regard to rainfall data with SWMM, there are several different methods that can be used to predict precipitation volumes. For this research, the alternating block method was used to create a hyetograph. This hyetograph was then entered into SWMM and used to interpolate rainfall values. For the

alternating block method, it is assumed that rainfall intensity will be constant throughout the time step selected for the hyetograph. If a small enough time step is not selected, it can skew the results and give higher or lower precipitation values that are not accurate.

5.4.2 Ground/Invert Elevation Uncertainty

The data used to predict ground elevations was obtained from elevation profiles and DEM files. DEM files are raster images of elevation data created from a remote sensing device. This leaves a window of uncertainty due to limitations or assumptions produced in the programing of the devices. As discussed previously, the New Orleans high water table causes irregularities and changes to street elevations frequently. Consequently, elevations could not be as accurate as they once were.

Another very important attribute that could be liable to uncertainty is invert elevation at manholes, inlets, and catch basins. In order to get complete accurate data of invert elevations, it is necessary to obtain a survey of the accessible storm drainage system in the site for proper simulation. In this case study, pipe diameters and manhole information were obtained from drainage maps courtesy of the Sewage and Water board which could date back to 40 years old. If the

data does not reflect the current conditions of the elevations and conduit slopes, this could affect the output values of the simulation.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been derived from the study:

1. A SWMM model has been completed for the study site area that gives validation to the purpose of the study. The methodology for this model can be applied to other locations that are experiencing flooding due to elevation differences between adjacent properties. SWMM can be utilized to obtain hydrologic responses and observe the results of infiltration trench implementation.
2. It was observed that flooding within the single node of the simulation could be caused by the lack of inlet availability to the stormwater within the study area.
3. Runoff estimates can be altered due to the uncertainties produced by human error of data entry and/or limitations of selected design storm method.
4. The altering of the depth of the trench allowed for a peak flow reduction by 33.83%.

5. Using a trench that is completely filled with storage media as opposed to 75% filled will allow for a reduction to volume of stormwater runoff but no change in peak flow or time to peak.
6. Using a trench with a smaller storage media voids will cause a relatively small increase in stormwater runoff released to the outlet.
7. SWMM does not have an option to allow infiltration trenches to have side slopes.

6.1 Recommendations

1. Use smaller time steps to allow for precise estimates of runoff.
2. Run simulations of the model using smaller return periods under varying duration scenarios that are not expected to cause flooding to better monitor the capacity of the trench and its ability to produce peak flow reductions under various simulations.
3. Survey the site to obtain and verify manhole, inlet, and invert elevations to reduce uncertainty errors and allow for more accurate runoff estimates.
4. Monitor the study site for runoff flows and calibrate and verify the SWMM model.
5. Incorporate a side slope by manipulating a combined use of the infiltration trench and vegetative swale LID option provided by SWMM.

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VITA

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In the Fall of 2019, Shaelynn began her graduate studies at the University of New Orleans as a graduate assistant for the Civil and Environmental Engineering Department. While pursuing a Ph.D. in Engineering and Applied Sciences with a concentration in Civil Engineering, she decided to, simultaneously, obtain a Master of Science in Engineering with a concentration in Civil.

The author has completed her master's degree with a 4.0 GPA and plans to maintain her academic diligence throughout the rest of her graduate studies at the University of New Orleans.