WATERSHED ANALYSIS AND URBAN STORMWATER SOLUTIONS FOR THE CROSSROADS DISTRICT OF KANSAS CITY, MISSOURI

A THESIS IN CIVIL ENGINEERING

Presented to the Faculty of the University
of Missouri – Kansas City in partial fulfillment of
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MASTER OF SCIENCE

By

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WATERSHED ANALYSIS AND URBAN STORMWATER SOLUTIONS FOR THE CROSSROADS DISTRICT OF KANSAS CITY, MISSOURI

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University of Missouri – Kansas City, 2018

ABSTRACT

The Crossroads District of Kansas City, Missouri is an urban area that receives runoff from many other parts of the city. More than 1,800 acres of drainage area supply runoff to this district and have many different land use types including urban, residential, commercial, and parkland. This area has challenges draining the rainwater it receives.

To alleviate the runoff concerns of the Crossroads District, this watershed analysis looks to contain water higher in the watershed and prevent the volume of water from reaching the quantities currently being captured by the city's current drainage infrastructure. The study will look to reduce the runoff volumes in the most economical manner possible while addressing the concerns of property owners, residents, interested government agencies, and city leaders.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the School of Computing and Engineering have examined the thesis entitled "Watershed Analysis and Urban Stormwater Solutions for the Crossroads District of Kansas City, Missouri," presented by Eric James Knight, candidate for the Master of Science degree and certify that in their opinion is worthy of acceptance.

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CHAPTER 1 – INTRODUCTION

1.1 Project Overview

In Kansas City, there are seven wastewater treatment plants that serve a basin of 260 square miles. Of that, the combined sewage and stormwater system serves 58 square miles [1]. When the wastewater overwhelms the system, the untreated waters are diverted into the Missouri River. This violates Section 402 of the Clean Water Act which is tasked with regulating pollutants from point source discharges such as wastewater treatment plants [2].

In 2002, the Environmental Protection Agency (EPA) filed a suit that tasked the city with eliminating the overflow from the wastewater treatment plants, including separating the combined system into a municipal separate storm sewer system (MS4) in various parts of the city. The language of the consent decree states:

"The City shall implement the remedial and Control Measures in accordance with the Performance Criteria and implementation schedule incorporated into this Consent Decree … The City shall complete construction and full implementation of all remedial and Control Measures... as expeditiously as possible but in no event later than December 31, 2035 [3]."

Though this was a thirty-three year time horizon, it put the city in a tough position. The cost of the project was a daunting expenditure. In order to pay for the improvements, Kansas City decided to issue capital improvement bonds.

In 2004, a referendum was held to determine if the voters were willing to authorize the issuance of the bonds. With almost 31,000 votes cast, the electorate passed the bond question with 73.39% voting "yes" [4].

In the original Overflow Control Plan that was issued by Kansas City Water Services (KCWS) in 2009, it was estimated that the project would cost approximately 2.5 billion dollars. This was up approximately twenty five percent from the original price tag of two billion dollars that the voters approved in 2004 [5]. If this cost inflation were to continue over the lifespan of the project, the final cost would be closer to six billion dollars. This figure is astronomically high for a city of a population of 450,000 people. At a twenty five year time horizon, it means the share for each citizen (not taxpayer, but citizen) is five hundred and thirty dollars per year for just this project.

KCWS is the agency responsible for the implementation of the overflow control and combined sewer separation, as they are the umbrella organization for clean water distribution, wastewater management, and stormwater runoff management [1].

1.2 Project Organization

Chapter 2 will focus on available literature and documentation of the problem and proposed solutions from civic and government entities, as well as resources in hydrology and hydraulics. Chapter 3 will analyze the watershed's current characteristics and determine baseline conditions. This will establish smaller sub-basins within the larger model and show the current flow volumes in each. Chapter 4 will propose a method to reduce flow volumes in each separate basin based on land usage and topography. Chapter 5 will show the results of the proposed changes to each sub-basin and the resulting water volumes. A sensitivity analysis, included in this chapter, will show the effect of adding or removing certain water control devices. Chapter 6 will summarize conclusions.

1.3 Project Purpose

The aim of this report is to find methods to reduce the amount of water runoff by utilizing green infrastructure and general stormwater detention methods. This report will analyze a single watershed within the Crossroads District of Kansas City and model proposed solutions to reduce and detain runoff. Detaining water at higher elevations within the watershed has the potential to provide significant cost savings as the size of the stormwater infrastructure can be reduced closer to the watershed outlet.

The Crossroads watershed is a large and diverse watershed that is almost three square miles in area. The land use is described in detail in Chapter 3. The Kansas City Overflow Control Plan identifies this watershed as Turkey Creek/Gooseneck Creek. The watershed generally drains east to west and outlets into the Kansas River. The watershed is generally quite steep and runoff can accumulate in the lower areas quickly. The higher elevations tend to be mostly residential and commercial, while the lower elevations are industrial, including railroads.

Currently, the water from the Crossroads watershed is collected at the Turkey Creek Pumping Station and delivered by a force main to the Westside Waste Water Treatment Facility, in the West Bottoms, near the Missouri River. Overflows from the Turkey Creek Pumping Station are diverted to the Kansas River [5].

Sites will be identified within the higher elevations to detain water to reduce the amount of water in the collection system. Detention ponds are an important component of water storage in these areas. If this can be achieved, the infrastructure needs can be reduced in the lower elevations that encounter larger flow quantities.

This project aims to provide the KCWS a template for stormwater solutions. The goal is to find methods that can eliminate as much as one-third of the runoff from the system, while reducing the peak flow of the water that does enter the system to levels that are manageable for a smaller storm sewer system. This template will address site specific conditions such as topography, land use, and available space. The template will be easily understood by KCWS personnel and will allow for block-by-block solutions without a detailed hydraulic analysis that was required for the UMKC Marlborough neighborhood study.

CHAPTER 2 – LITERATURE REVIEW

2.1 History

Kansas City, Missouri was originally founded as “the Town of Kansas” in the 1830’s. The location proved to be crucial for supply lines as it was founded on the confluence of the Missouri and Kansas Rivers. The Town of Kansas was the last depot that western settlers could secure supplies as they ventured out on the Oregon, Santa Fe and California Trails. This constant supply of travelers and merchants led to the growth of the city, officially incorporated in Missouri as “the City of Kansas” in 1853 [6].

This period was tumultuous for the region as the Kansas-Nebraska Act of 1854 split the Nebraska Territory into two states, pitting the residents of the city into the national debate over slavery, economics, and the size and scope of the federal government. The Kansas-Nebraska Act was seen as directly undermining the intent of the 1820 “Missouri Compromise,” a law that outlawed slavery above the 36th parallel except in Missouri. War broke out along the border of Kansas and Missouri between factions of abolitionists and anti-abolitionists, who mostly immigrated to the region from other parts of the country. The period was known as “Bleeding Kansas” of which culminated in the city of Lawrence, Kansas being completely destroyed by fires set by a Missouri militia known as the Bushwhackers. This conflict largely fueled the start of the American Civil War as it was decided that Kansas would be a “free state.” This tipped the balance of power in the United States Senate towards the side of the abolitionists [7].

The largest battle west of the Mississippi River was fought in the City of Kansas. To a degree not seen in any other location in the American Civil War, civilians were especially brutalized along the Kansas-Missouri border. The City of Kansas saw the majority of the Civil War fighting end when Confederate troops were defeated in the Battle of Westport [8].

Upon the end of the war, the city was renamed Kansas City and was rebuilt. The damage was not to the extent of the leveled cities in the South and East, but the peace proved an appropriate time to build up the fledgling city. The main catalyst for the growth in Kansas City was the construction of the first rail bridge across the Missouri River. This caused the population to swell in a rapid period. Infrastructure had to be built quickly to accommodate the new residents. This included roads, housing, railroads, and sewers [9].

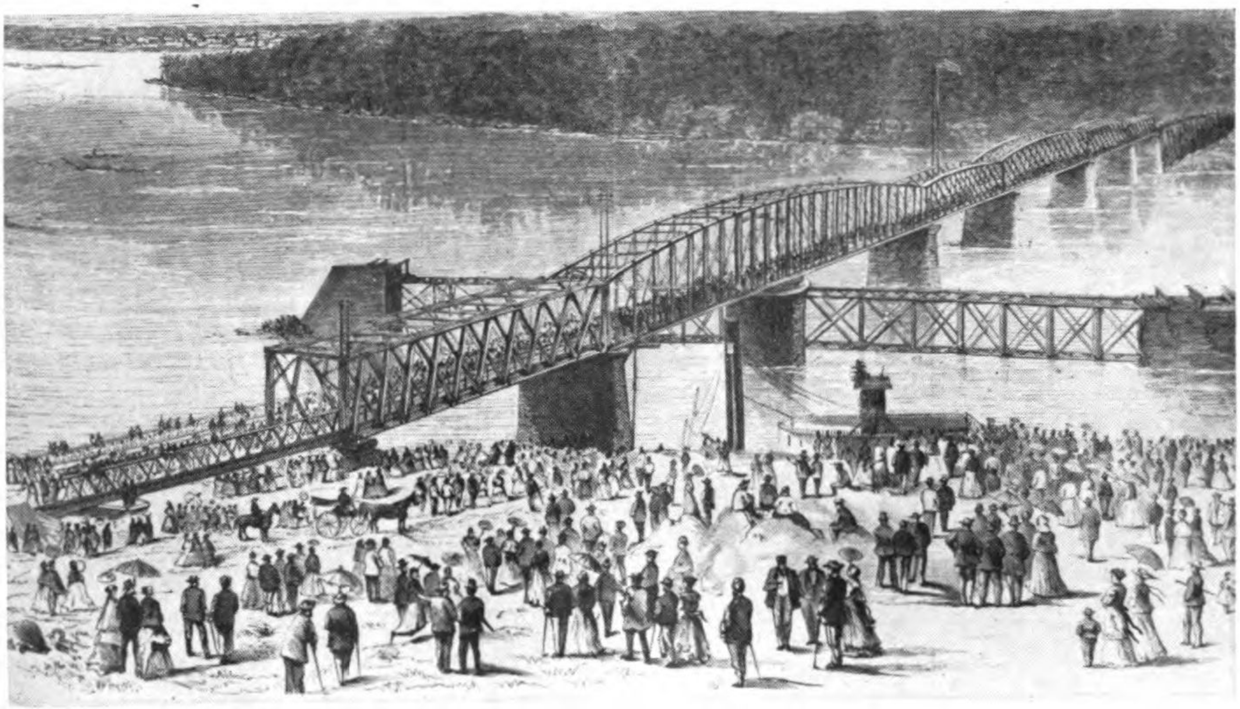


Figure 2.1: Early Missouri River Rail Bridge in Kansas City (Source: kcmeesa.com)

The city grew to be one of the largest rail hubs in the country. The Kansas City stockyards moved thousands of head of cattle per day to the slaughterhouses in Chicago. The horse and buggy was upgraded to the streetcar which was later supplanted by the automobile in the early 1900's. The infrastructure to accommodate the automobile sprang up quickly as the main corridors were paved to accommodate the new form of transportation. The incorporation of rolled steel beams into building design allowed for skyscrapers to be built in the central business district. Residential development stretched southward as the Town of Westport was incorporated into Kansas City and development sprawled towards Brush Creek [9].

As this development occurred, infrastructure investments included electrification of the city, clean water distribution, and the creation of roadways and rail yards. A facet of the city's infrastructure that was neglected in the process was the sewage system. Serving storm water runoff and wastewater collection, the network is known as a combined sewage and storm water system [10].

A combined sewage and stormwater system is problematic for a large city in two ways; first, the system relies on gravity and a decades old pumping system to move the wastewater to the treatment facility. Stagnation in the system can allow raw sewage to linger near the open air stormwater inlets and cause the sewage odors to escape. Second, and most importantly, during high intensity rain events, the treatment facility cannot treat all of the intake flow it is receiving. When the wastewater facility reaches its intake capacity, a portion of the effluent has to be diverted out of the system to the Missouri River and left untreated [11].

The Clean Water Act was signed into law in 1972. It gave the EPA the powers of enforcement for violations to the law. The EPA published a Combined Sewer Overflow Policy in 1994. The policy was devised to force municipalities to be in compliance with the law while simultaneously allowing flexibility for each jurisdiction to conform in the most cost effective manner possible. Over 750 municipalities were subject to the policy. The mandate was challenged up to the level of the United States Supreme Court, which upheld the constitutionality of the policy. The law of the land was now such that combined storm water and sewage overflows were no longer permissible to be discharged into waters of the United States [12].

2.2 EPA Consent Decree

A consent decree is a legally binding document that settles a legal disagreement without any fault admitted by the defendant for the infraction that was committed [13]. The consent decree between the EPA and Kansas City was settled in the United States District Court for the Western District of Missouri in 2010. The consent decree orders the city to find a solution to the combined sewage and wastewater overflow problem. Though the city operates seven wastewater treatment plants, two of these plants serve the combined sewage and wastewater areas; the Westside Wastewater Treatment Plant and the Blue River Wastewater Treatment Plant [3].

The decree alleges that the city violated Section 301 of the Clean Water Act as well as the terms and conditions of the National Pollutant Discharge Elimination System (NPDES) permits for discharges into the Missouri River and its tributaries, including the Blue River, Brush Creek, and Wilkerson Creek. The EPA recorded over 1,300 violations of the NPDES permit for illegal overflows in the span of 2002-2010 [3].

The purpose of the decree is to address four concerns:

(a) To achieve full compliance with the Clean Water Act

(b) To achieve full compliance with the NPDES permits as they relate to the wastewater treatment plants and collection systems

(c) To eliminate sanitary sewage overflows

(d) To eliminate prohibited collection bypasses

The decree institutes a compliance plan for the city that is to be completed "as expeditiously as possible but in no event later than December 31, 2035." The plan for the Crossroads watershed is to separate the sewage and stormwater collection system for approximately 66 acres of coverage area, beginning in 2020. Beginning in 2031, a gate will be built in the existing Gooseneck Arch sewer, which is on the corridor from the pumping station to the wastewater treatment plant.

The separation of the sewage system will allow for rainfall that is collected to free-flow into the Kansas River instead of being treated. The gate at Gooseneck Arch will allow for water to be detained, accommodating other sections of the collection system that are serviced by the Westside Wastewater Treatment Plant.

There are performance criteria outlined in the form of Nine Minimum Controls (NMC) which are to be reported to the EPA on an annual basis. These controls are as follows:

I. Proper operation and regular maintenance program
II. Maximization of storage in the collection system
III. Review and modification of pretreatment requirements
IV. Minimization of flow to the Publically Owned Treatment Works for treatment
V. Elimination of combined sewage overflows (CSOs) during dry weather
VI. Control of solids and floatable material in CSOs
VII. Pollution Prevention Programs to reduce Contaminants in CSOs
VIII. Public notification
IX. Monitoring to characterize CSO impacts and the efficacy of CSO controls

A water quality monitoring plan (WQMP) is required to be developed with specific water quality goals for impairments such as E. coli and other bacteria, low dissolved oxygen, algal blooms, and floating debris.

In 2009, the City of Kansas City submitted their proposal to known as the Overflow Control Plan (OCP) to be adopted within this consent decree [5].

2.3 Overflow Control Plan

KCWS has developed an OCP by order of the consent decree, which seeks to improve the overall the water collection system by using a combination of infrastructure improvements and watershed improvements to reduce and better control stormwater runoff.

Figure 2.3: Blue River Flooding at Red Bridge, August 2017 (Source: weather.gov)

The stated goals of the OCP are as follows:

- Minimize loss of life & injury
- Reduce property damage due to flooding
- Improve water quality while maximizing economic, social, and environmental benefits

The OCP defines the 8 design storms that define a typical year for Kansas City. The storms are classified by their peak hourly intensity, duration and frequency. The storms are defined in Table 2.2.1.

Table 2.2.1 – Table 5-1 from the Overflow Control Plan

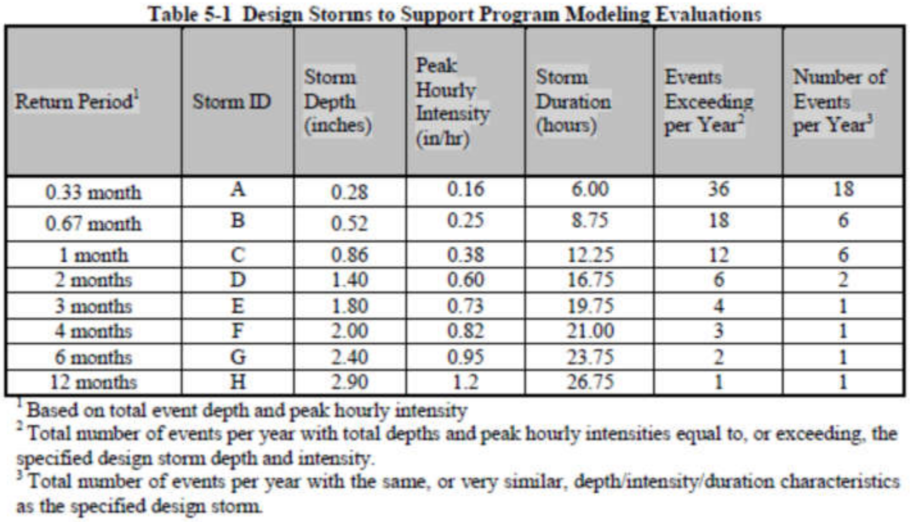


Table 5-1 Design Storms to Support Program Modeling Evaluations

Return Period[1]	Storm ID	Storm Depth (inches)	Peak Hourly Intensity (in/hr)	Storm Duration (hours)	Events Exceeding per Year[2]	Number of Events per Year[3]
0.33 month	A	0.28	0.16	6.00	36	18
0.67 month	B	0.52	0.25	8.75	18	6
1 month	C	0.86	0.38	12.25	12	6
2 months	D	1.40	0.60	16.75	6	2
3 months	E	1.80	0.73	19.75	4	1
4 months	F	2.00	0.82	21.00	3	1
6 months	G	2.40	0.95	23.75	2	1
12 months	H	2.90	1.2	26.75	1	1

[1] Based on total event depth and peak hourly intensity

[2] Total number of events per year with total depths and peak hourly intensities equal to, or exceeding, the specified design storm depth and intensity.

[3] Total number of events per year with the same, or very similar, depth/intensity/duration characteristics as the specified design storm.

Green solutions are mentioned in the OCP as a method to help reduce runoff from entering the system. KCWS has a basic framework to begin the process of implementing green solutions for the Kansas City metro. The following items are listed in the OCP:

- Dedicated funding for public education and outreach.
- An enhanced rain gardens and downspout disconnection program.
- Funding for job creation and work force development initiatives related to specific program objectives, including "green collar" jobs.

- Enhanced technical models, complemented by a “triple bottom line” evaluation framework, including specified social, economic, and environmental metrics.
- Green infrastructure pilot projects in the combined sewage and stormwater basins. Large scale pilot projects will be used to gather the information required to effectively implement green infrastructure on a broad scale while simultaneously constructing a portion of the basin-specific solution. Green infrastructure pilot projects will be also constructed to achieve a significantly higher level of control downstream of the project area.

The plan outlines the need for $28,000,000 in green solutions pilot projects. The first project was within a 100 acre area bounded roughly by Troost Avenue, Paseo Boulevard, 73rd Street, and 76th Street, known as the Marlborough neighborhood. This project was implemented by UMKC faculty and students, and proved that a series of well-placed stormwater runoff control measures could dramatically reduce the runoff within an entire sub-basin [14].

2.4 Kansas City Middle Blue River Pilot Study

The Kansas City Middle Blue River Pilot Study was conducted in southeast Kansas City, in the Marlborough Neighborhood. The study divided a watershed into two sections; an area treated with Best Management Practices (BMPs) and an area not treated with BMPs. BMP is an industry-wide term that is used to describe stormwater retention and reduction practices [15]. The treated area was approximately 55 acres and the area not treated was approximately 45 acres. The drainage basin flows into the Blue River from the city collection system. According to information from the EPA Region 7, the system overflows at 0.6 inches of rainfall [16].

The goal of the study was to find solutions to the city initiative 10,000 Rain Gardens. The city initiative is to reduce the total overflow volume from 6.4 billion gallons to 1.4 billion gallons. This is anticipated to reduce the CSO frequency by 65% [17].

The two watersheds from the neighborhood were monitored at four points in the collection system. Three points are all on East 77th Street from The Paseo to Lydia Avenue and the sum of these add up to the control volume. The test volume was measured on 76th Terrace near The Paseo [14].

Figure 2.4: Rain Gage Installed at 77th and Paseo (Source: Ma)

In the test watershed, the city installed a large quantity of BMPs; bioretention cells, bioswales, pervious pavement, and rain gardens. The bioretention swales included curb-cuts, curb extensions, and shallow retention areas. The pervious pavement was in the form of sidewalks, with and without an underdrain. The rain gardens also were installed with and without curb extensions. There were a total of 135 BMPs installed, or roughly 2.5 BMPs per acre of land. This study found that roughly 40 percent of the total runoff was captured before entering the system in the eight significant storms measured from November of 2012 to June of 2013 [14].

One of the pipes in the control area did not receive flow during the test period, so the control area was modified to a smaller region. This could have provided somewhat skewed numbers, but the results do show that there is a significant runoff reduction in the test area by using exclusively “green” measures.

2.5 Mid-America Regional Council BMP Manual

The Mid-America Regional Council (MARC) is a non-profit organization that seeks to promote cooperation of governmental agencies and facilitate regional planning in the Kansas City metropolitan area [18]. The MARC BMP Manual was developed as a companion document to the American Public Works Association (APWA) Section 5600 to help municipalities comply with water quality regulations found in NPDES [19].

MARC advocates for stormwater BMPs as providing the following benefits:

Reduced flooding – capture and storage of stormwater mimics the natural processes that would detain and infiltrate water.

Reduced infrastructure costs – modern BMPs are less expensive to build and maintain than traditional infrastructure and can be modified to adapt to changing environments
Improved water quality – water can be treated for pollutants including debris, sediment, and oils by natural filtration processes from soils and plants.

Natural resource conservation – preserving existing vegetation and planting native vegetation prevents waterways from degrading unnaturally.

Economic development – natural areas improve property values of adjacent properties and can attract development.

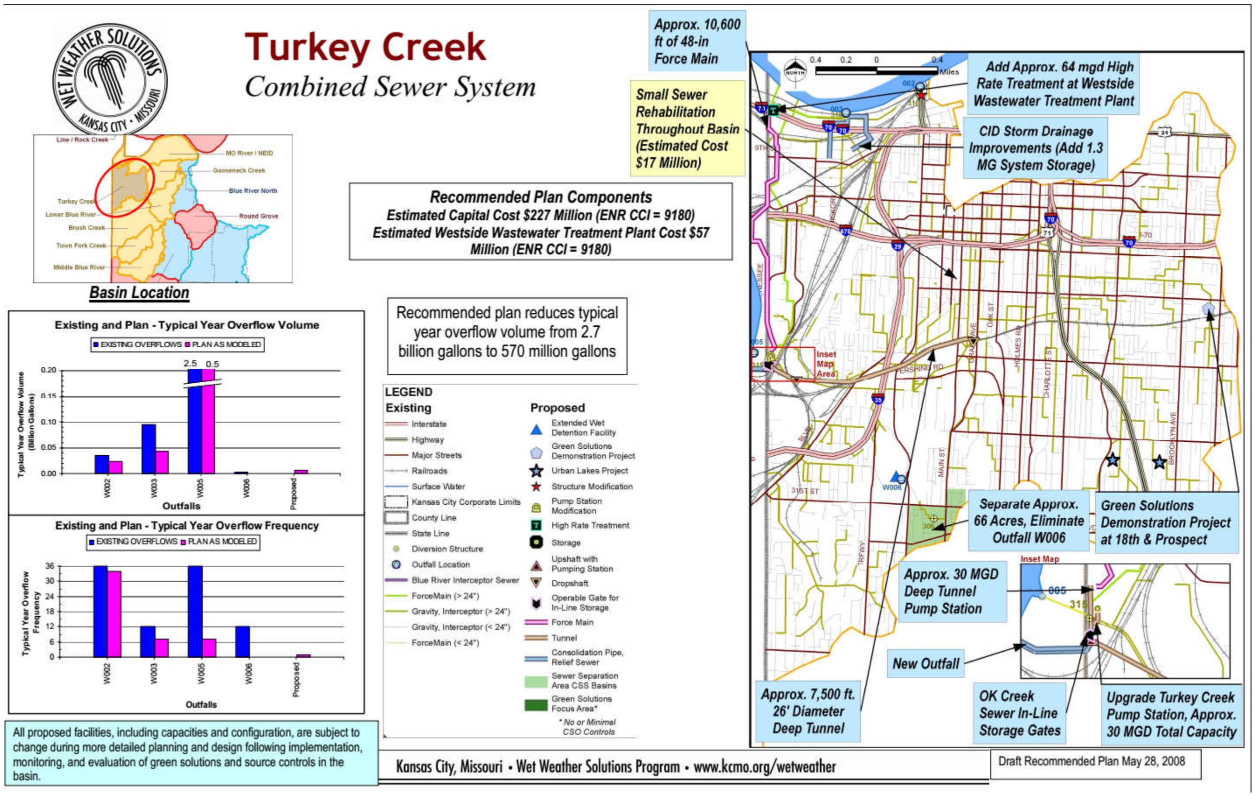
Conservation of recreational areas – preservation of stream buffers and natural landscaping can promote recreation such as running and hiking trails, fishing, boating, etc.

The BMP Manual shows how to estimate impacts from new developments on discharge and water quality and what measures are most appropriate to deal with the scenario [18].

2.6 Wet Weather Community Panel

The Wet Weather Community Panel was established in 2003 by Mayor Kay Barnes [20]. The panel included fifty members and was tasked with three goals; to minimize loss of life, to improve water quality, and to maximize the economic, social and environmental benefits of Kansas City's waterways. The panel found that the residents of Kansas City overwhelmingly preferred green solutions to solve the problem of stormwater runoff. A green solutions subcommittee was appointed to provide manageable solutions that could be meaningfully implemented throughout the city.

The recommendations from the committee are referred to as Green Solution Strategies. Action items presented include policy goals and efforts to educate and aid the community in the implementation of Green Solution Strategies. The most well-known recommendation is known as the "10,000 rain gardens" initiative. This is an effort to have the community take ownership of the problem and install rain gardens on their property. This initiative was marketed to the public with an advertising campaign and public relations outreach. The results of the campaign are inconclusive, as no official statistic is kept on how many rain gardens were installed though the website for the Sustainable Cities Institute declares it to be a successful campaign. The panel was disbanded when the city submitted the Overflow Control Plan to the EPA prior to the issue of the consent decree. The panel was disbanded in 2009 [20].


Turkey Creek
Combined Sewer System

Recommended Plan Components
Estimated Capital Cost $227 Million (ENR CCI = 9180)
Estimated Westside Wastewater Treatment Plant Cost $57 Million (ENR CCI = 9180)

Recommended plan reduces typical year overflow volume from 2.7 billion gallons to 570 million gallons

Approx. 10,600 ft of 48-in Force Main

Small Sewer Rehabilitation Throughout Basin (Estimated Cost $17 Million)

Add Approx. 64 mgd High Rate Treatment at Westside Wastewater Treatment Plant

CID Storm Drainage Improvements (Add 1.3 MG System Storage)

Separate Approx. 66 Acres, Eliminate Outfall W006

Green Solutions Demonstration Project at 18th & Prospect

Approx. 30 MGD Deep Tunnel Pump Station

New Outfall

Approx. 7,500 ft. 26' Diameter Deep Tunnel

OK Creek Sewer In-Line Storage Gates

Upgrade Turkey Creek Pump Station, Approx. 30 MGD Total Capacity

All proposed facilities, including capacities and configuration, are subject to change during more detailed planning and design following implementation, monitoring, and evaluation of green solutions and source controls in the basin.

Kansas City, Missouri • Wet Weather Solutions Program • www.kcmo.org/wetweather

Draft Recommended Plan May 28, 2008

Figure 2.6: Wet Weather Solutions Turkey Creek Analysis

2.7 BMP Analysis

The primary method for reducing runoff from the collection system is infiltration. Infiltration is when water is returned to the groundwater table by penetrating the surface of the ground. When water infiltrates, the benefits include available water for vegetation and adequate soil moisture content, which prevents wind erosion of topsoil.

The soils in Kansas City are assumed to all be in Hydrologic Soil Group D, which has the poorest infiltration rates [21]. Due to the development involved with urban areas, it is assumed that all soil has been compacted at some point, therefore losing most of the void space between soil particles.

2.7.1 Infiltration Basins

One of the most common infiltration methods is to build an infiltration basin. These basins are areas that serve a relatively large area, proportional to their size and capture, store and infiltrate water. An infiltration basin is a concave area that is designed to capture overland flow. The surface is typically vegetated with a topsoil layer, followed by a permeable media, such as sand, and then a layer of gravel surrounding a drain tile. A filter fabric is recommended between the gravel and sand to avoid the sand filling the voids in the gravel. The side slopes of the infiltration basin should be at 3:1 (length: height) for maintenance and safety purposes. Figure 4.1 shows a basic diagram of a typical infiltration basin [22].

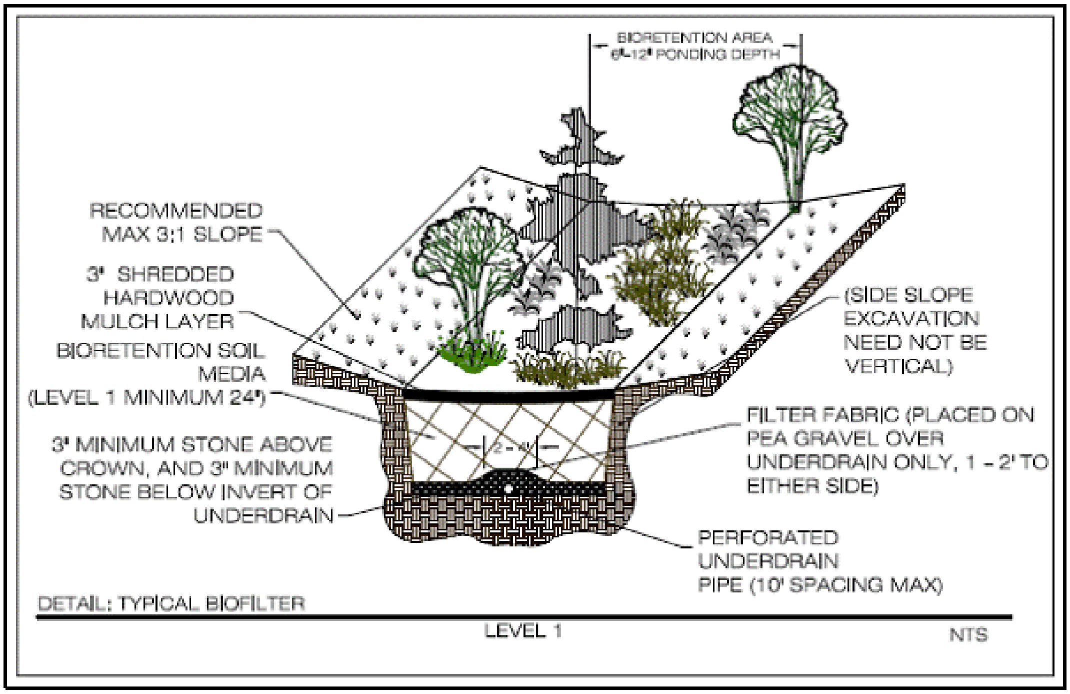


Figure 2.7.1: Bioretention Basin Schematic (Source: Virginia Water Resources)

The drain tile (also called perforated pipe) can be excluded if the natural soils have an infiltration rate of 1 inch per hour. In downtown Kansas City, it will be assumed that no soils meet this criterion.

The vegetation is selected for infiltration basins based on its facultative rating adopted by the United States Army Corps of Engineers. This system rates plants based on their ability to survive with or without wet conditions. Obligate plants need a constant supply of water. Upland plants will perish with too much water. Facultative plants can withstand both periods of dry and wet conditions. Facultative plants are typically the only plants that will endure the conditions of an infiltration basin [23].

Maintenance of infiltration basins is important to ensure optimum functionality. Stormwater carries clay and silt sediment that can clog the topsoil of its infiltration capacity. The soils are aerated as necessary and accumulated trash and debris removed. Care is to be taken that lawn crews do not mow or remove the installed vegetation in the infiltration areas, while removing invasive vegetation. Infiltration basins require a knowledgeable grounds crew to ensure proper long term functioning [22].

2.7.2 Rain Gardens

Rain gardens are a solution for smaller properties such as single family homes. Rain gardens operate similarly to a bioretention swale, without the bottom layer of gravel and drain tiles. A rain garden is typically situated in the topographically lowest point on a property, or near a drainage inlet. Plant selection is intended to be native, infiltrate water, and be aesthetically pleasing [24]. Figure 4.1.2 is a basic diagram of a rain garden.

Figure 2.7.2: Rain Garden Schematic (Source: University of Nebraska)

Rain Gardens utilize native plants because the root systems are typically well suited for the localized climate. These roots typically grow deeper than non-native plants and create small channels that water can follow underground. This makes the rain garden more efficient the longer it is in place.

2.7.3 Curb Cuts

Curb cuts are an infiltration method designed to capture street runoff and infiltrate instead of letting that water enter the storm collection system. They are designed by removing a section of curb, leaving water free to flow into a small infiltration basin.

The construction of the curb cuts is similar to the infiltration basin but on a much smaller scale. There is native facultative vegetation in a layer of permeable topsoil. There is a layer of permeable media, such as sand, under the topsoil that drains to either the natural ground or a drain tile system [25].

These are ideal for urban areas as the space between the curb and sidewalk is typically under the jurisdiction of municipal easements. Curb cuts were successfully deployed as one of the primary water infiltration methods in the Marlborough Neighborhood Study [14]. These BMPs are easy for municipal crews to access and maintain.

Figure 2.7.3: Curb Cut at KCMO Water Services Building

Curb cuts are also very visible to the community and can add unquantifiable benefits to the areas in which they are placed. Not only are they aesthetically pleasing, but they can add community buy-in to the water reduction systems by showing municipal investment and forward thinking in their neighborhood.

2.7.4 Pervious Pavement

Pervious Pavement is a method of constructing pavement so that water does not runoff from the site on which it is constructed. Gaps are intentionally constructed in the pavement either through concrete pavers with permeable joint material or through concrete that designed with large void spaces between the gravel materials [26].

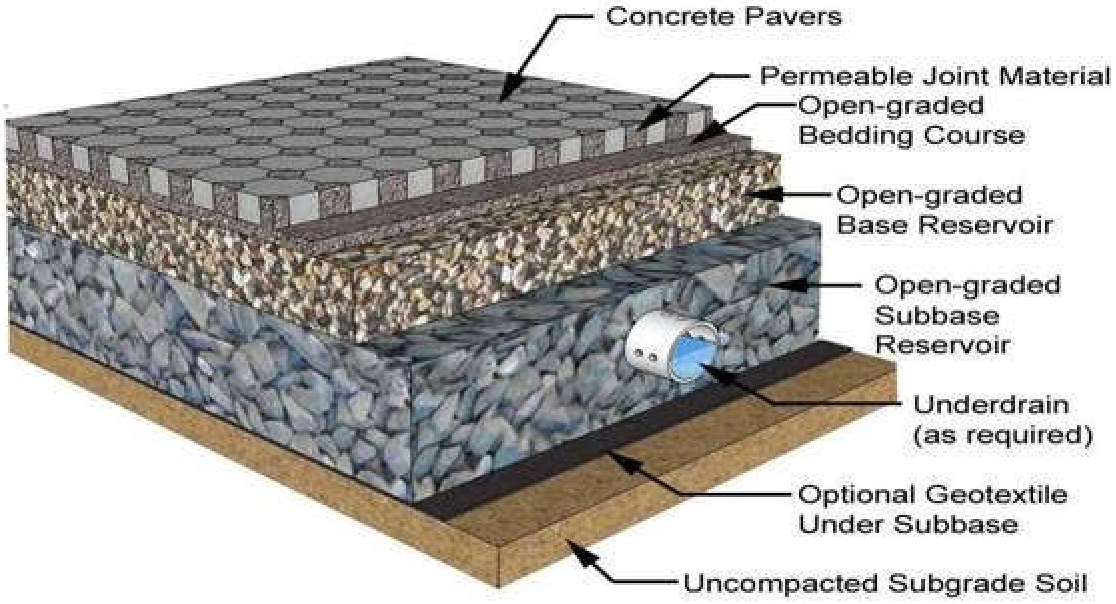


Figure 2.7.4: Diagram of a Typical Concrete Paver Permeable Pavement Setup (Source: Caltrans – State of California)

The basic design of permeable pavement is the same with the exception of the surface material. There is a gradient of gravel under the surface pavement designed to store and infiltrate water, eventually leading to an outlet such as an underdrain or drain tiles. Pervious pavement is not recommended for high speed roadways. Parking lots and low speed neighborhood roads are the best candidates for pervious pavement conversion.

Pervious pavement infiltrates water at a rate better or equal to typical city open space. The design engineer always determines the exact storage capacity based on site conditions, but it is typical to hold as much as 12 inches of water before the drain tiles are reached. Pervious pavement requires an educated maintenance and snowplow staff, and can be more expensive to install than typical pavement, but the extra cost can eventually be offset by the savings in earthwork and pipe construction lower in the watershed [27].

2.7.5 Detention and Retention Ponds

Detention and retention hold large volumes of water at locations within a watershed. Commonly referred to as “wet ponds” and “dry ponds,” these features are typically utilized within large scale developments such as office complexes or housing developments, where water capture methods would be infeasible for each individual structure. While both methods are similar in their capture methods, there are operational differences.

Detention ponds or “dry ponds” are designed to be entirely empty during periods between rain events. They typically fill up quickly and slowly release the water they have stored back into the watershed. This attenuation process is controlled by a ground level outlet to allow for all of the water to drain out [28].

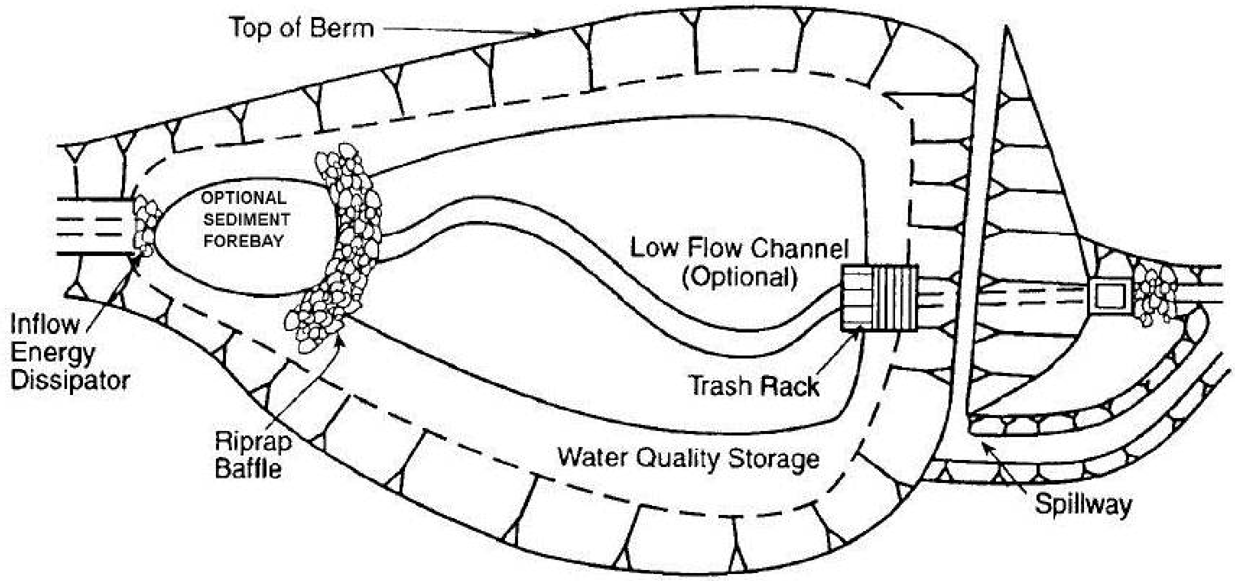


Figure 2.7.5: Typical Detention Pond Design (Source: US EPA)

Retention ponds or “wet ponds” operate similarly to detention ponds, but are designed to have a permanent pool of water. A riser pipe at the outlet couples with a low-flow orifice to provide two water levels. A key feature of the retention pond that is not typically added to detention ponds is the sediment forebay. This smaller pond reduces inlet velocities, allowing sediment to fall out of the water before moving on to the permanent pool. This allows for easier access for maintenance crews who are cleaning out the sediment and typical garbage that collects in the storm water runoff [29].

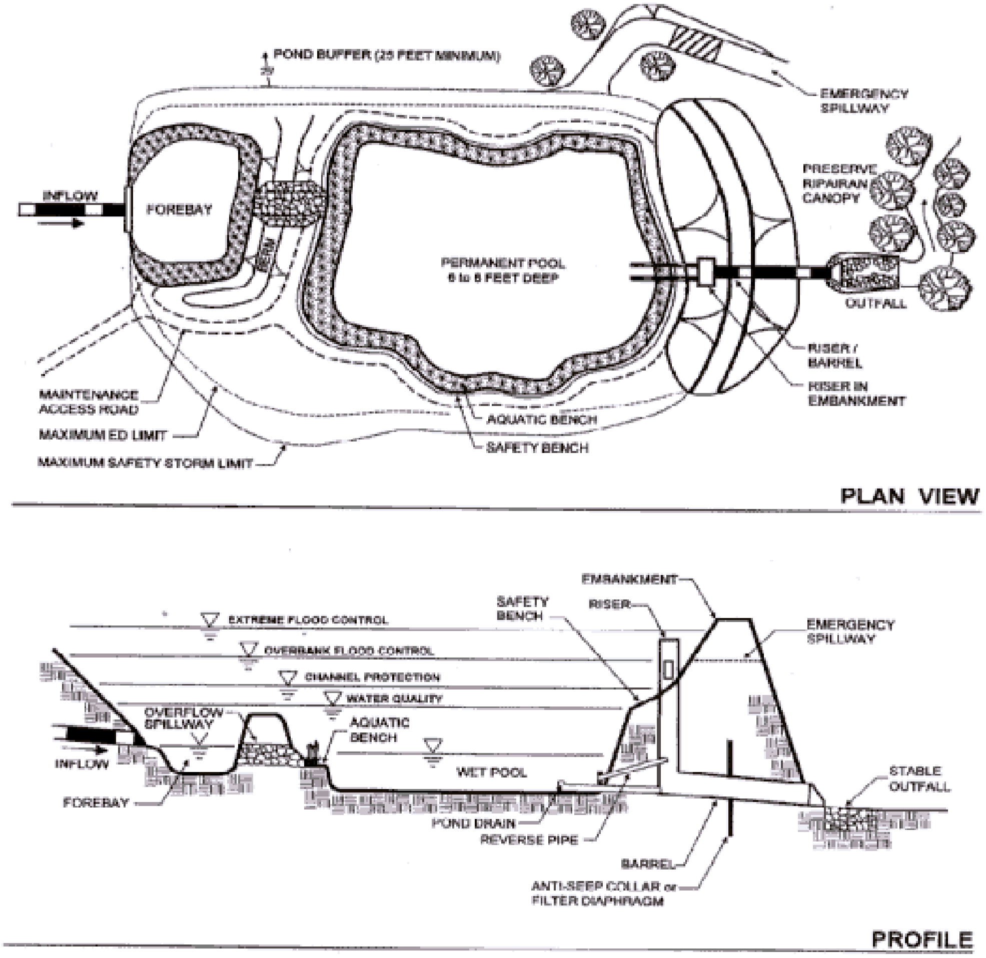


Figure 2.7.6: Typical Retention Pond Design (Source: Minnesota Pollution Control Agency)

2.7.6 Rain Barrels

Rain barrels are large containers that are attached to downspouts of gutters to collect rainwater from the rooves of buildings. This is a simple solution to collect water from residential properties that can later be used to water lawns and landscaping. The barrels are typically 55 - 90 gallons and can be constructed for as little as $30 [30]. According to the APWA 5600, the water quality storm is 1.37 inches of rain over 24 hours. For a residential rooftop of 1,200 square feet, that would be 137 gallons.

Figure 2.7.7: Typical Rain Barrel (Source: City of Barberton, Ohio)

Problems can develop with rain barrel due to homeowner's interactions with them. If the homeowner doesn't empty the barrel before the next rainstorm, there is no storage offered for the incoming rainfall. Also, the rainwater does not tend to be used immediately following a rain event because the landscape has been recently watered by the rainfall. Thus, looking at this water as a reservoir to be stored for much later can lead to inefficient capture.

2.8 Rain Garden Study in Kansas City, Missouri

Jason Nall's UMKC Master's thesis is a study of the effectiveness of rain gardens within the watershed. Rain gardens can help to infiltrate water in micro-basins that not only serve to reduce the amount of runoff in the higher elevations of the watershed, but also serve to recharge the groundwater in these areas [31].

Nall monitored the infiltration rates of rain gardens with infiltrometers. Full-inundation testing showed a sustained infiltration rate of 7.4 in/hr. This is a rate of 0.62 cfs/ft^2. Tests were performed in the city limits of Kansas City, Missouri, soil that is described as silty clay loam, and is assumed to be NRCS hydrologic soil group D.

Rain garden locations were chosen by local topography and subsequent percolation tests. Favorable sites were found by digging a six inch hole, filling it with five inches of water and timing the infiltration of the water into the soil. Though this does not address the permeability of the subsoils, it can be a good indicator of favorable rain garden locations. Clay soils are not considered a suitable for rain garden locations.

Figure 2.8: Rain Garden Studied in 2010 (Source: Nall)

The results of the rain garden analysis were shown to reduce runoff from residential properties by 25-30% [31].

2.9 Kansas City Middle Blue River Study

The Kansas City Middle Blue River Study is a long term study of watershed management performance that examines the performance of the BMPs installed in the Marlborough neighborhood over a period from 2012 – 2014. This investigation was documented through Yanan Ma’s UMKC Doctoral Dissertation under the guidance of Dr. Deborah O’Bannon. Due to a drought in the Kansas City area in 2012-2013, the monitoring period was extended from 2014 – 2015, which allowed the UMKC team to collect an expansive data set of the performance of the rain gardens and bioretention swales that were installed in the Marlborough Neighborhood. This data enables accurate predictions of the runoff reductions impacting not only the collection system, but the Blue River, which is the ultimate receiving water [32].

From this data set, Ma seeks to derive a regression model for rain garden performance. This is done by analyzing the infiltration of the previously installed rain gardens compared to the intensity and duration of rain events. This will help to provide predictable, repeatable results for installing rain gardens in Kansas City’s urban core.

The rain gardens that were monitored had underdrain pipes installed with v-notch weirs as outlet structures. This allowed the measuring of runoff capture simply from the difference of inflow and outflow. The primary factor discovered for effective runoff capture was the amount of time between rainfall events and the corresponding moisture content of the soil. The more time between rainfall events, the more effective the rain garden performed.

The study suggests that the infiltration rates of rain gardens improve over time. This is due to the maturation of the plants within the garden developing mature root structures, and possibly an increase in the plants uptake of the water.

Recommendations for future site selection of rain gardens include finding places with the appropriate drainage area size, watershed slope, street slope, and inlet conditions [32].

CHAPTER 3 – SUBBASIN ANALYSIS

The Crossroads District watershed comprises approximately 1,836 acres of a highly urbanized portion of Kansas City. The land use includes residential, industrial, and commercial properties as well as park land and wooded hills. The elevation in the watershed is from approximately 1,005 to 770 feet above sea level. The area is shown in its entirety in Figure 3.1.

The northern border is bounded by Interstate 670. It is assumed that any rainfall that could possibly drain across the bridges that pass over the highway is negligible. Troost Avenue is the boundary for the southeastern portion of the area. Though the topographic maps do not indicate it, the road acts as a localized high point and does not allow drainage to cross. If a building was located on a watershed boundary, it was assumed that the roof drainage mirrored the topographic boundaries on the ground.

To analyze the Crossroads watershed more effectively, the watershed was analyzed as seven separate basins, each with their own unique characteristics. Basins were delineated based on local topography, with analysis of U.S.G.S. topographic maps and an in-depth site investigation. The names given to these watersheds describe the neighborhood or the defining feature of the watershed. They are not delineated based on USGS HUC boundaries.

A site investigation was used to determine the finer points of the drainage areas, such as the direction of drainage inlet flow and local micro-topography. A topographic map sourced from the U.S.G.S. is shown in Figure 3.2 with 10 foot intervals.

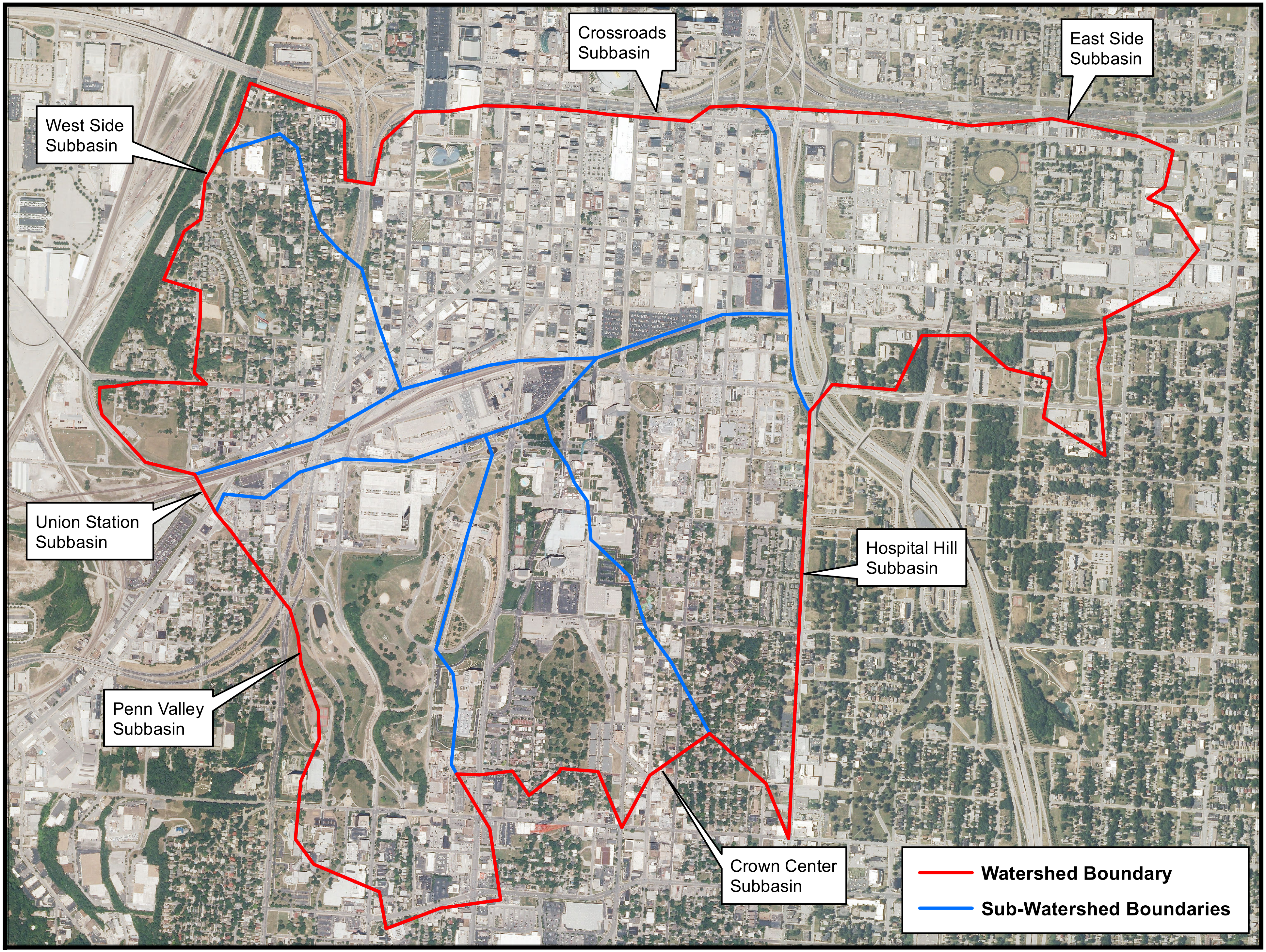


Figure 3.1: Aerial Imagery of the Crossroads Watershed

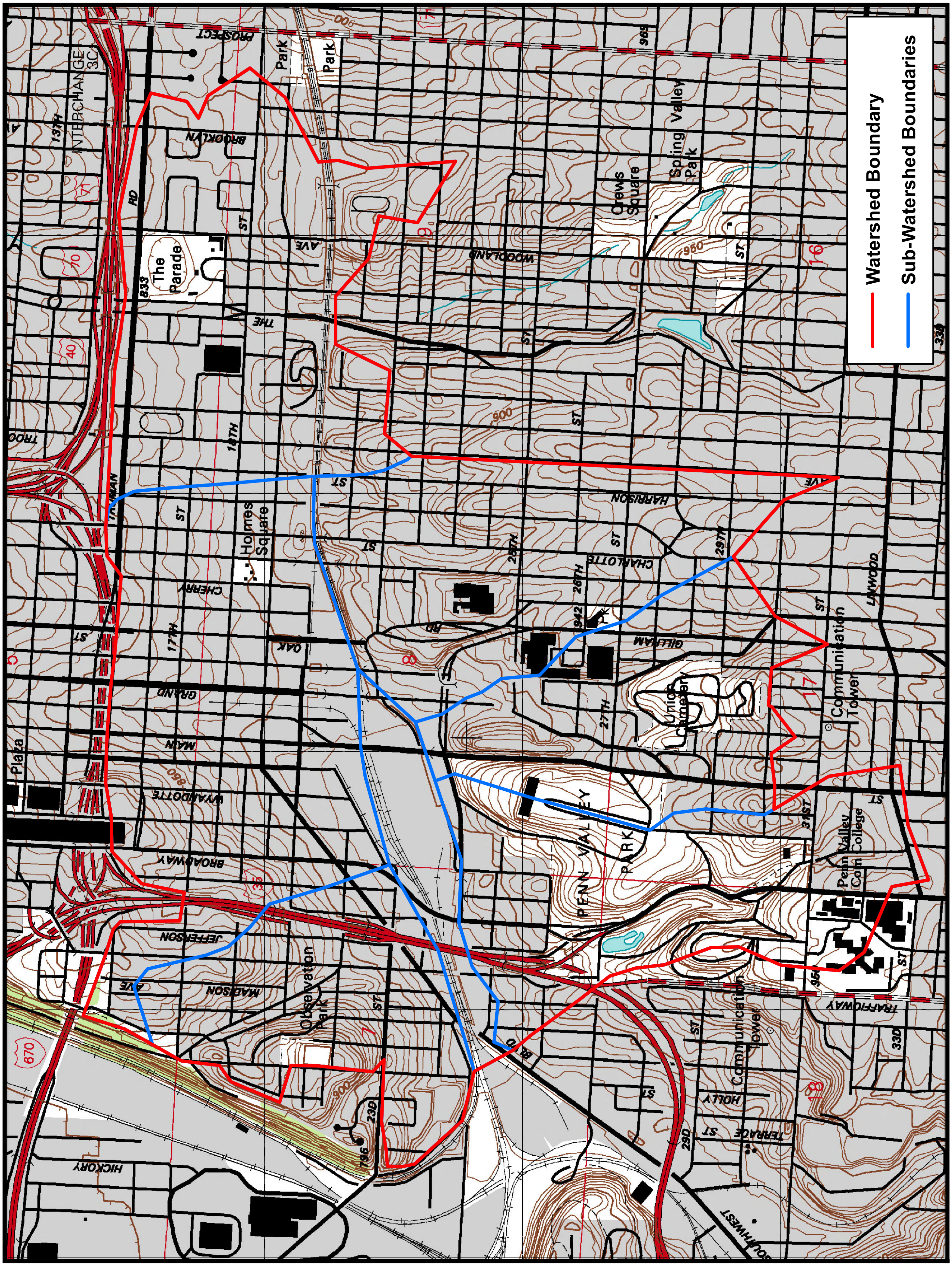


Figure 3.2: Topographic Data of the Crossroads Watershed

3.1 Methodology

The hydrologic modeling for this analysis was performed using TR-55, a program made available by the Natural Resources Conservation Service (NRCS) which is a division of the United States Department of Agriculture (USDA). TR-55 utilized the Soil Conservation Service (SCS) Hydrograph Method to compute discharge totals.

The Geographic Information System (GIS) that was utilized to compute areas of land use is Arc-GIS. National Agriculture Imagery Program (NAIP) aerials were traced in conjunction with Google Earth, to create accurate shapefiles of the land use. Land use was divided into six separate types: grass/vegetation, asphalt, concrete, houses, flat roofed buildings, and railroad property. Surfaces that are impermeable but do not fit any of the above categories (gravel roads, parking lots of undeterminable material, etc.) was considered concrete. Flat roof buildings were considered separately from houses as the roof angle of a typical house would allow for water to repel off of the roof more quickly, increasing the peak of a hydrograph of the study area.

Areas were then entered into TR-55 to calculate drainage quantities using the SCS Hydrograph method. This method relies on finding a “curve number” in a given area. This accounts for common factors that affect runoff, including soil type, impervious surface area, and the density of vegetated areas. Rainfall is programmed into the system using the American Public Works Association (APWA) 5600 rainfall amounts for storms of various return periods.

Available GIS data from the NRCS identified six soil groups in the drainage area: Knox Urban Land Complex, 5-9 percent slopes, Knox Urban Land Complex, 9-14 percent slopes, Snead Urban Land Complex, 9-30 percent slopes, Urban Land – Harvester Complex, 2-9 percent slopes, Urban Land – Upland, 2-9 percent slopes, and Urban Land – Bottomland, 0-3 percent slopes, rarely flooded. All of these soils are in Hydrologic Soil Group D, which defines poorly drained soils, with high curve numbers.

Assumptions were made in order to calculate the water volumes. For the time of concentration calculations, the furthest point was approximated from the areal imagery. The sheet flow length was measured from the approximated point. The shallow concentrated length was always assumed to be thirty feet or less, a typical distance from a house to a curb in Kansas City. The channelized lengths are assumed to have multiple parts, including driveway, curb, and sewer pipe sections.

Each sub-basin is assumed to drain into the Union Station watershed in a single discharge point in the underground sewage system. The exception is the East Side watershed which is assumed to drain into the Crossroads watershed at a single discharge point. The entire system is assumed to outflow at a single point that flows into the wastewater treatment center located near the Kansas River.

Differences exist in each sub-basin due to the different topography and land use. These differences will be addressed in each following section.

3.2 Union Station

The Kansas City Terminal (KCT) Railway is the organization responsible for the operation of all railroads within the Kansas City metropolitan area. Originally created to coordinate flood efforts between various railroads, the organization now oversees eighty-five miles of track. KCT was the founder and proprietor of Union Station before it was sold into a public/private partnership in 1996.

This watershed is characterized as mostly flat with industrial buildings and parking lots comprising the majority of the land use. This watershed is the catchment for all of the other sub-basins and drains into the Kansas River. Most of the flooding problems that happen within the entirety of the study area happen within this sub-basin causing backups to propagate in the water collection system from here.

The Union Station sub-basin has an area of 142.6 acres. The land use areas are given in Table 3.2.1.

Table 3.2.1: Union Station Land Use

Feature	Area (Acres)
Grass	2.1
Roads	25.0
Buildings	15.7
Houses	0.0
Railroad	11.9
Concrete	16.7
Watershed	71.3

The general slope of this watershed is calculated as 0.0043 feet per foot, as characterized by a 20 foot drop in elevation over a distance of 4641 feet. Table 3.2.1 illustrates the mostly impervious nature of this watershed, with only 2.1 acres of pervious surface over 71.3 acres. Figure 3.2.1 shows the boundaries and land use of the watershed.

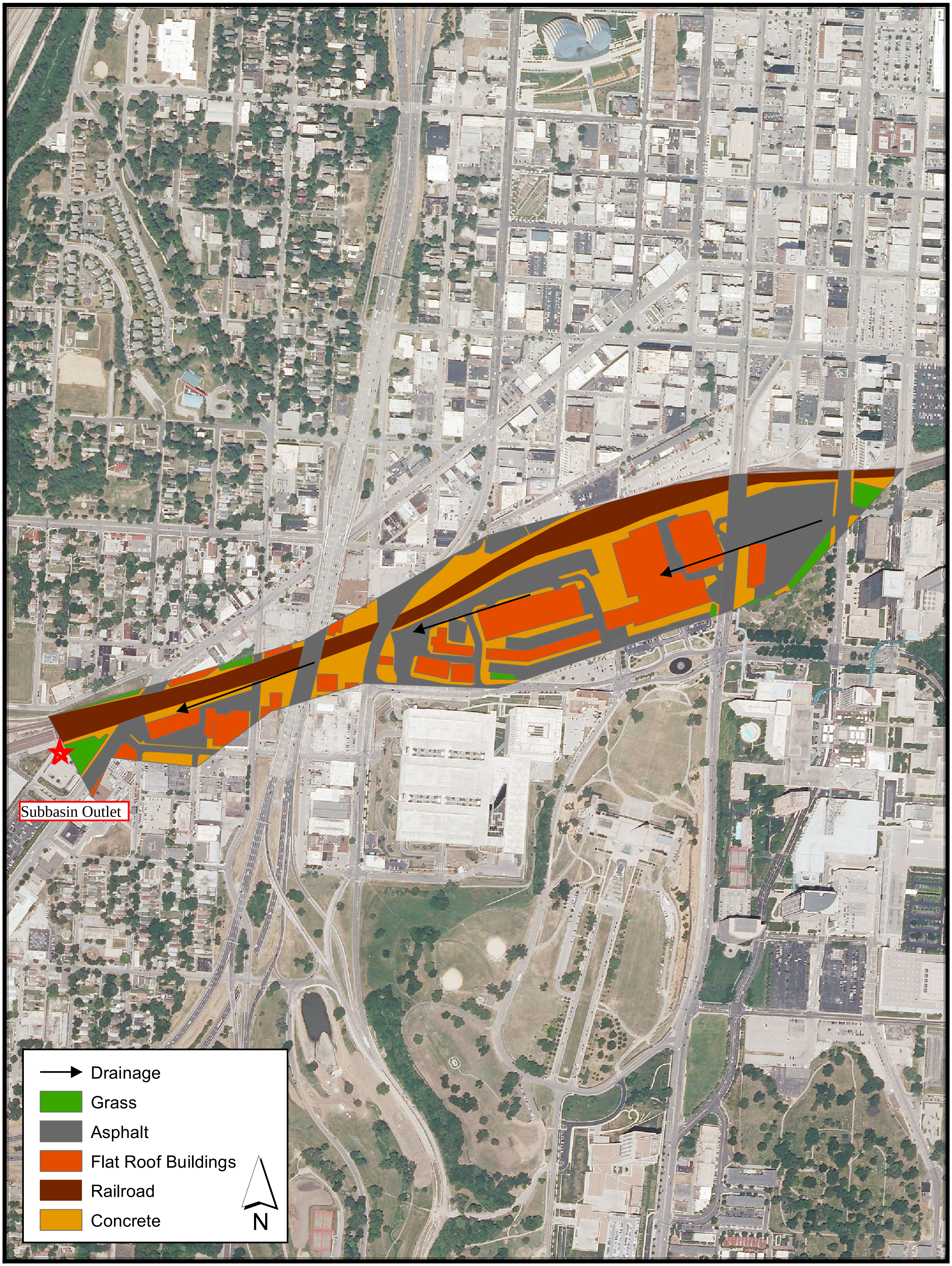


Figure 3.2.1: Union Station Watershed Boundary

The time of concentration for the watershed is 0.71 hours and the discharge for this site is as follows:

Table 3.2.2: Calculated Discharges Using TR-55

Return Period	2 year	5 year	25 year	50 year	100 year
Discharge (cfs)	146	195	267	298	334

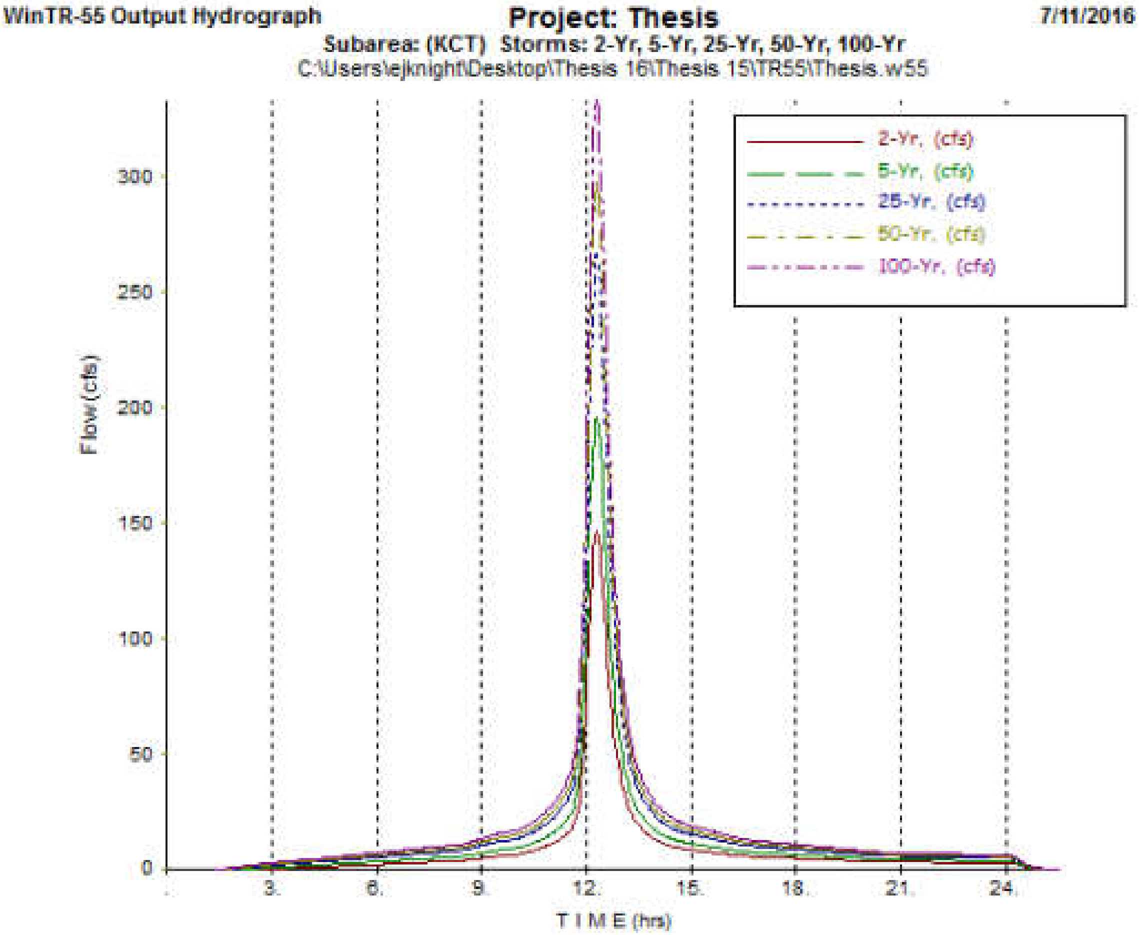


Figure 3.2.2: Existing Union Station Basin Hydrograph

3.3 West Side

The West Side sub-basin is a diverse section of the city, with residential and commercial land use interwoven over large areas of impervious areas such as fields, parks, and undeveloped hill-slopes. This is one of the older residential sections in Kansas City, with some houses pre-dating the civil war. The majority of the residential properties were constructed around the turn of the 20th Century.

This watershed is characterized as very steep. This watershed contributes a large amount of runoff to the Union Station sub-basin very quickly due to the steep slopes.

The West Side sub-basin has an area of 202.2 acres. The land use areas are given in Table 3.3.1.

Table 3.3.1: West Side Land Use

Feature	Area (Acres)
Grass	73.7
Roads	49.1
Buildings	17.8
Houses	15.2
Railroad	0.0
Concrete	46.5
Watershed	202.2

The general slope of this watershed is calculated as 0.0444 feet per foot, as characterized by a 186 foot drop in elevation over a distance of 4188 feet. Figure 3.3.1 shows the boundaries and land use of the watershed.

There is an area in the southwest portion of this drainage area where the flow direction is ambiguous as to the direction it flows. If it was to flow to the west, it would be blocked and pool against the rail embankment structure that creates the southwestern border. It is assumed that this water will follow the typical drainage path and outlet to the Union Station sub-basin.

The time of concentration for the watershed is 0.24 hours and the discharge for this site is as follows:

Table 3.3.2: Calculated Discharges Using TR-55

Return Period	2 year	5 year	25 year	50 year	100 year
Discharge (cfs)	670	923	1271	1420	1594

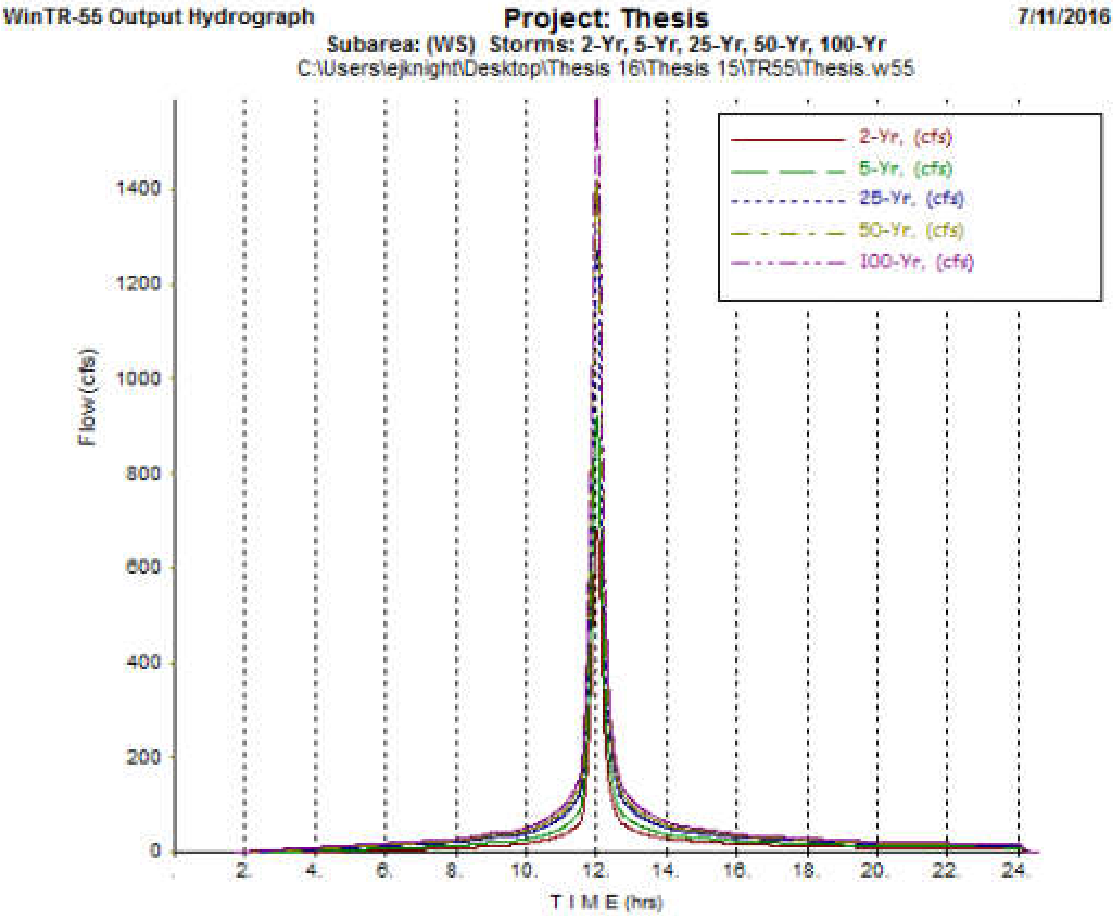


Figure 3.3.1: Existing West Side Basin Hydrograph

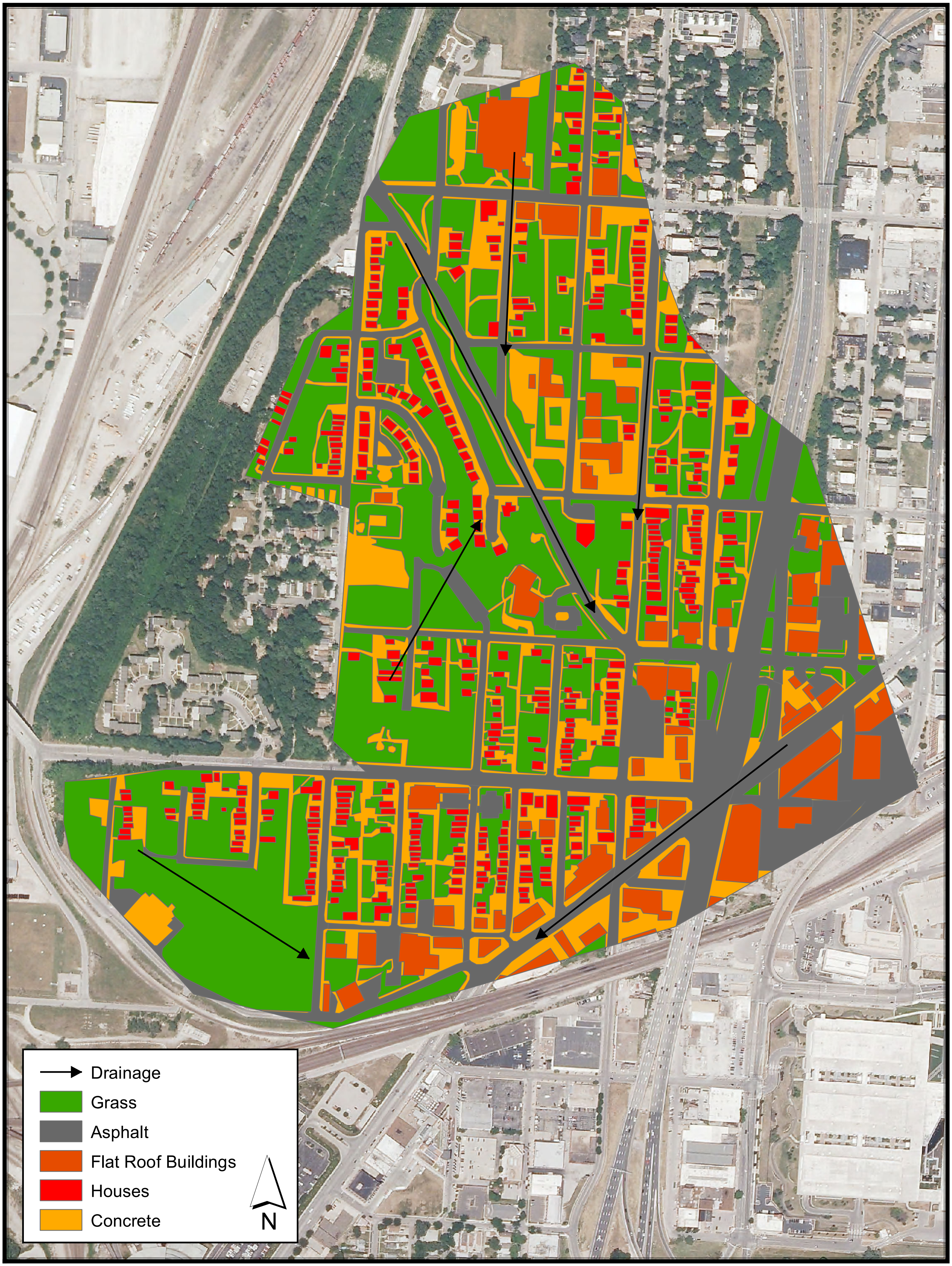


Figure 3.3.2: West Side Watershed Boundary

3.4 Penn Valley

The Penn Valley sub-basin is the most vegetated of all the sub-basins analyzed. The land use is wooded parkland, residential, some commercial and a college. The parkland is mostly on the hillslopes that separate Midtown from Downtown Kansas City. The residential portions of this sub-basin are in the higher elevations to the south.

As with the West Side sub-basin, this watershed is characterized as very steep, but the vegetation acts as a limiting factor for the runoff velocities. This lowers the peak discharges from this sub-basin slightly from the other watersheds with similar slopes.

The Penn Valley sub-basin has an area of 290.8 acres. The land use areas are given in Table 3.4.1.

Table 3.4.1: Penn Valley Land Use

Feature	Area (Acres)
Grass	124.4
Roads	69.1
Buildings	47.3
Houses	2.1
Railroad	0.0
Concrete	48.0
Watershed	290.8

The general slope of this watershed is calculated as 0.0379 feet per foot, as characterized by a 216 foot drop in elevation over a distance of 5707 feet. Figure 3.4.1 shows the boundaries and land use of the watershed.

The time of concentration for the watershed is 0.45 hours and the discharge for this site is as follows:

Table 3.4.2: Calculated Discharges Using TR-55

Return Period	2 year	5 year	25 year	50 year	100 year
Discharge (cfs)	682	952	1339	1507	1706

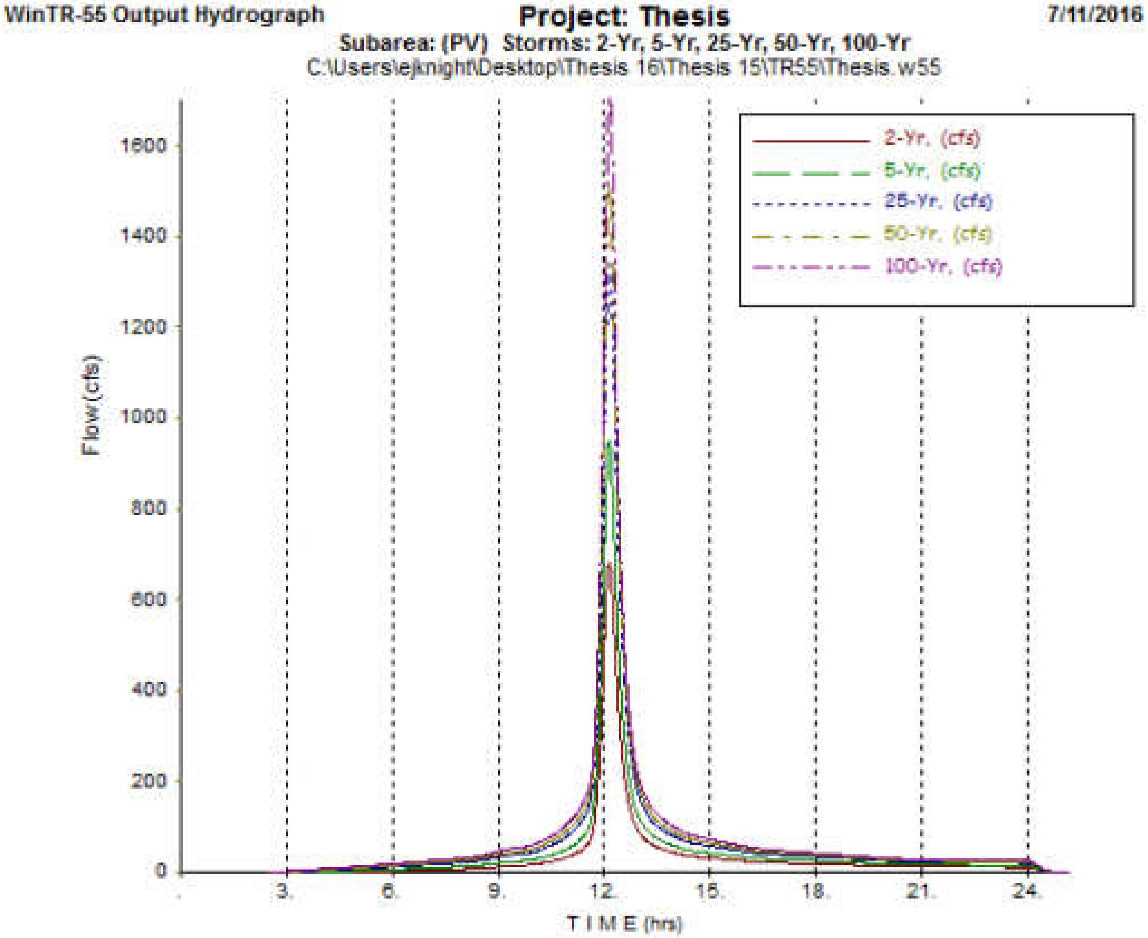


Figure 3.4.1: Existing Penn Valley Basin Hydrograph

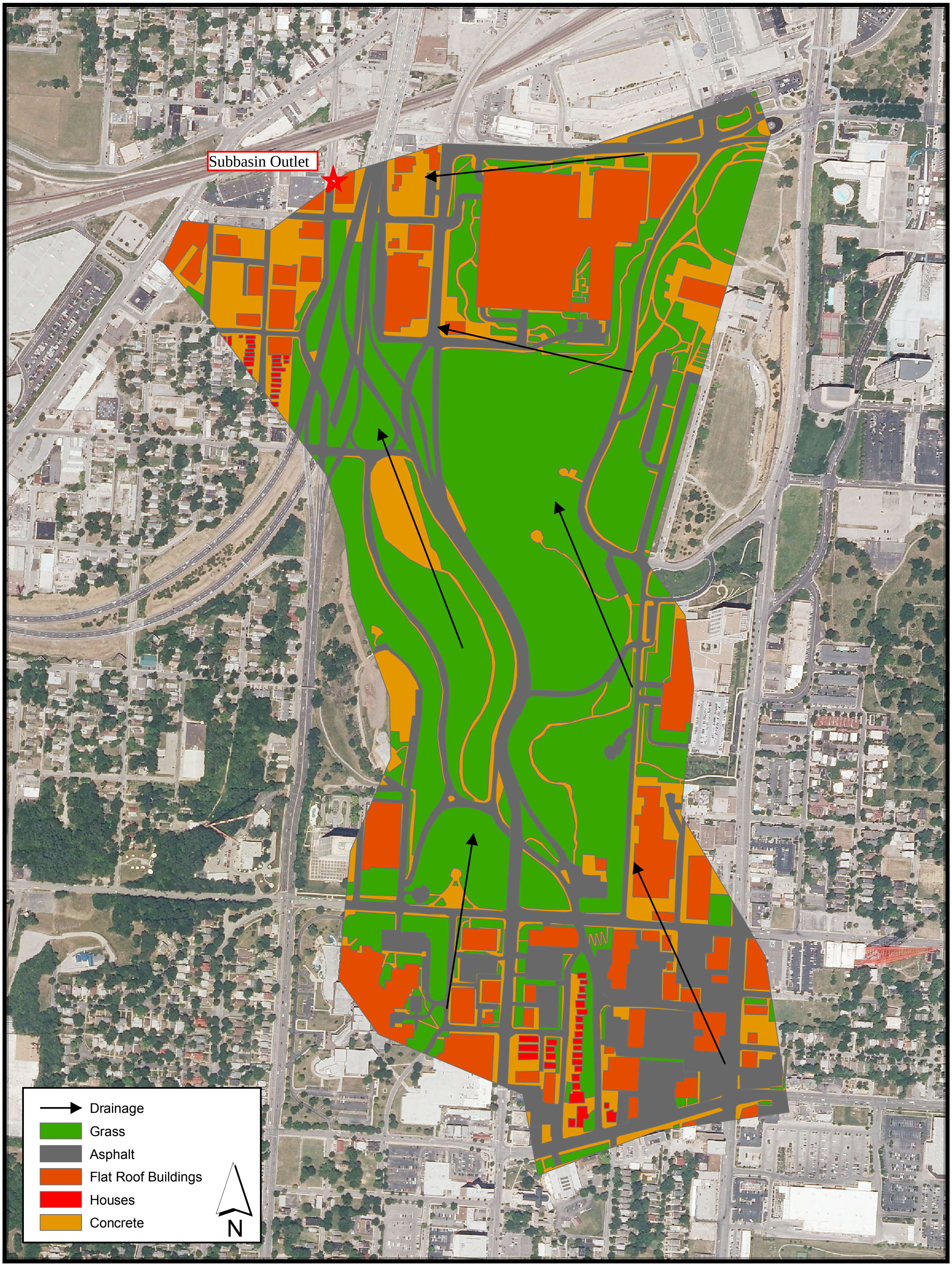


Figure 3.4.2: Penn Valley Watershed Boundary

3.5 Hospital Hill

The Hospital Hill sub-basin begins at the highest elevation in the Crossroads watershed. The land use is industrial, residential, some commercial and two large hospitals. The hospital campuses dominate the higher elevations of this sub-basin, with residential to the south and west. The industrial district of this sub-basin is in the lower elevations to the north.

This watershed is also characterized as very steep. Site reconnaissance indicated that Troost Avenue is the eastern boundary for the sub-basin through local micro-topography that is not indicated on the USGS maps.

The Hospital Hill sub-basin has an area of 294.0 acres. The land use areas are given in Table 3.5.1.

Table 3.5.1: Hospital Hill Land Use

Feature	Area (Acres)
Grass	77.5
Roads	76.5
Buildings	51.4
Houses	14.1
Railroad	2.8
Concrete	71.7
Watershed	294.0

The general slope of this watershed is calculated as 0.0285 feet per foot, as characterized by a 185 foot drop in elevation over a distance of 6489 feet. Figure 3.5.1 shows the boundaries and land use of the watershed.

The time of concentration for the watershed is 0.43 hours and the discharge for this site is as follows:

Table 3.5.2: Calculated Discharges Using TR-55

Return Period	2 year	5 year	25 year	50 year	100 year
Discharge (cfs)	757	1034	1435	1613	1812

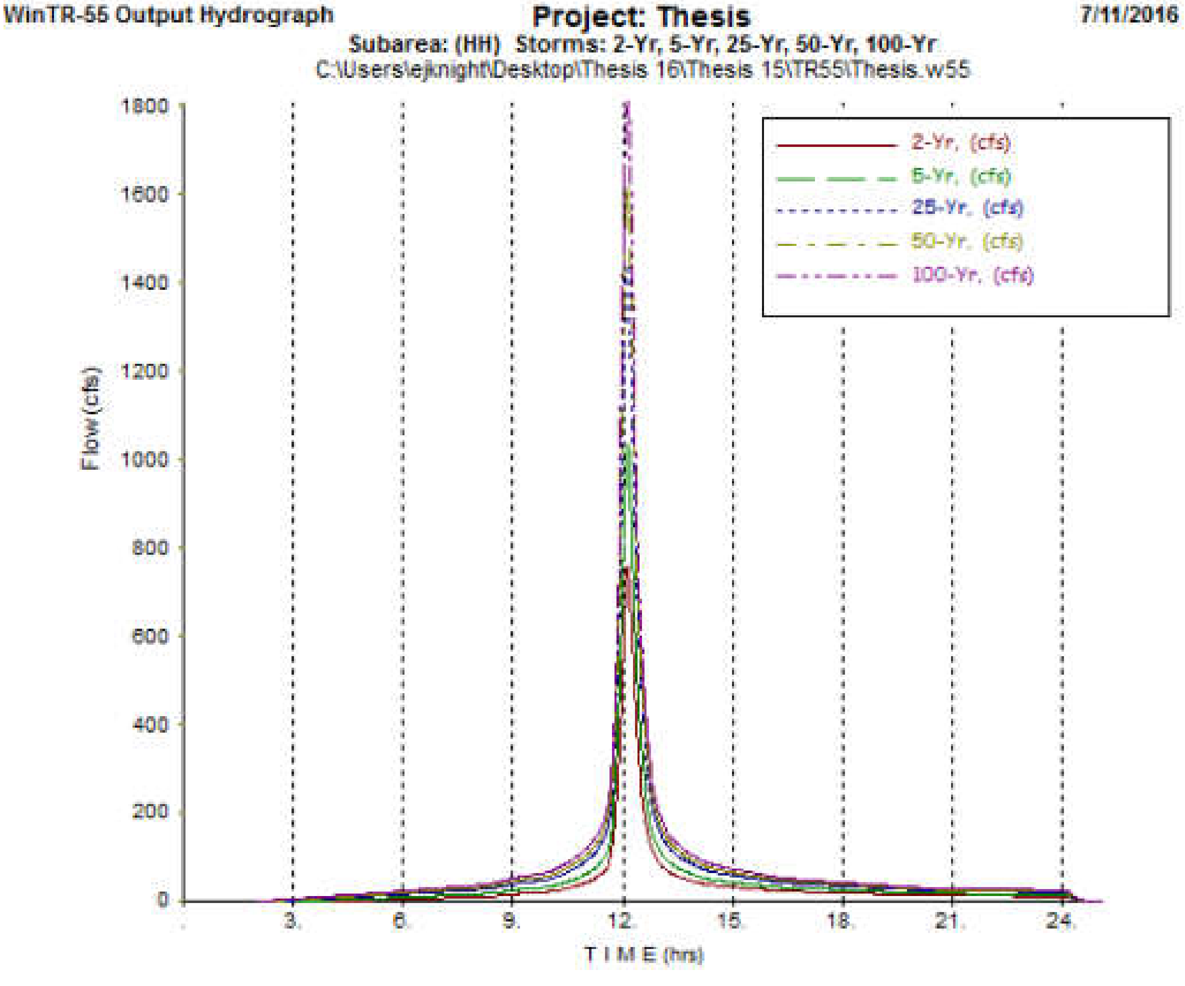


Figure 3.5.1: Existing Hospital Hill Basin Hydrograph

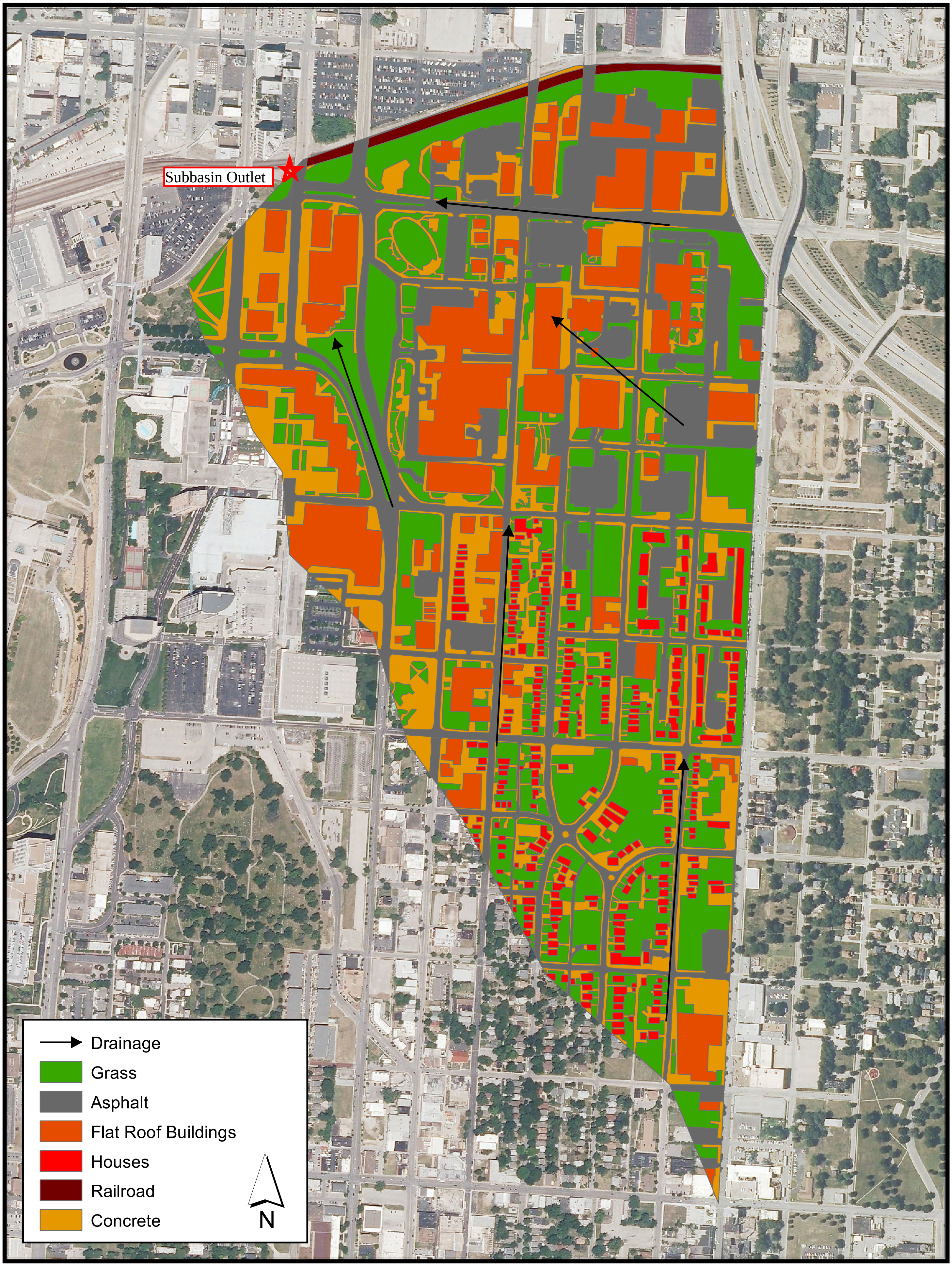


Figure 3.5.2: Hospital Hill Watershed Boundary

3.6 East Side

The East Side sub-basin is a mix of residential, commercial and industrial land use with schools and parks dotting the landscape. The area is historically an economically disadvantaged area with working class residents at the turn of the 20th century, gradually digressing until the 1950s, when redlining and blockbusting practices segregated the African American community to this section of the city.

Most of the water in this watershed is channeled to a low area where 19th Street passes under US Highway 71.

The East Side sub-basin has an area of 355.7 acres. The land use areas are given in Table 3.6.1.

Table 3.6.1: East Side Land Use

Feature	Area (Acres)
Grass	93.2
Roads	147.8
Buildings	64.4
Houses	10.1
Railroad	5.2
Concrete	35.0
Watershed	355.7

The general slope of this watershed is calculated as 0.0444 feet per foot, as characterized by a 186 foot drop in elevation over a distance of 4188 feet. Figure 3.6.1 shows the boundaries and land use of the watershed.

The time of concentration for the watershed is 0.38 hours and the discharge for this site is as follows:

Table 3.6.2: Calculated Discharges Using TR-55

Return Period	2 year	5 year	25 year	50 year	100 year
Discharge (cfs)	1019	1372	1878	2101	2351

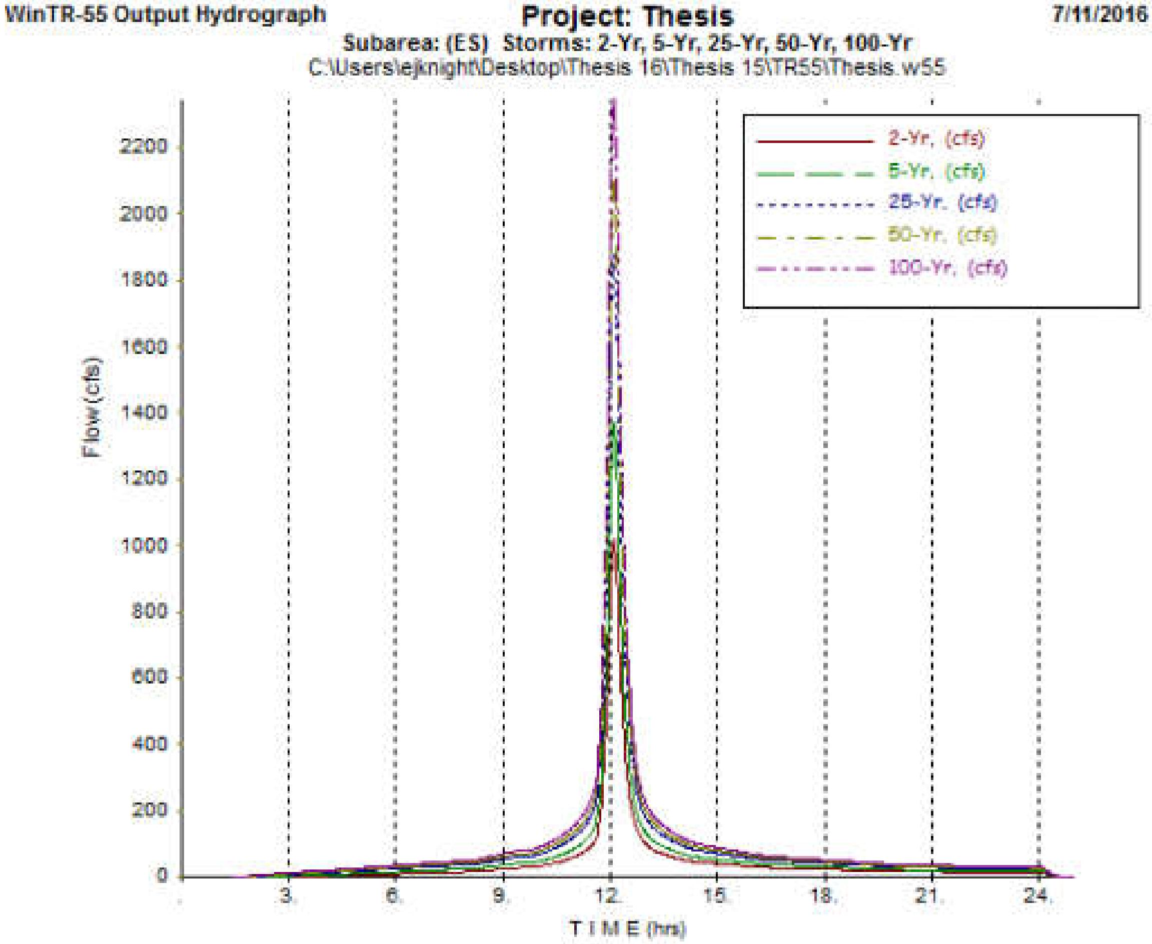


Figure 3.6.1: Existing East Side Basin Hydrograph

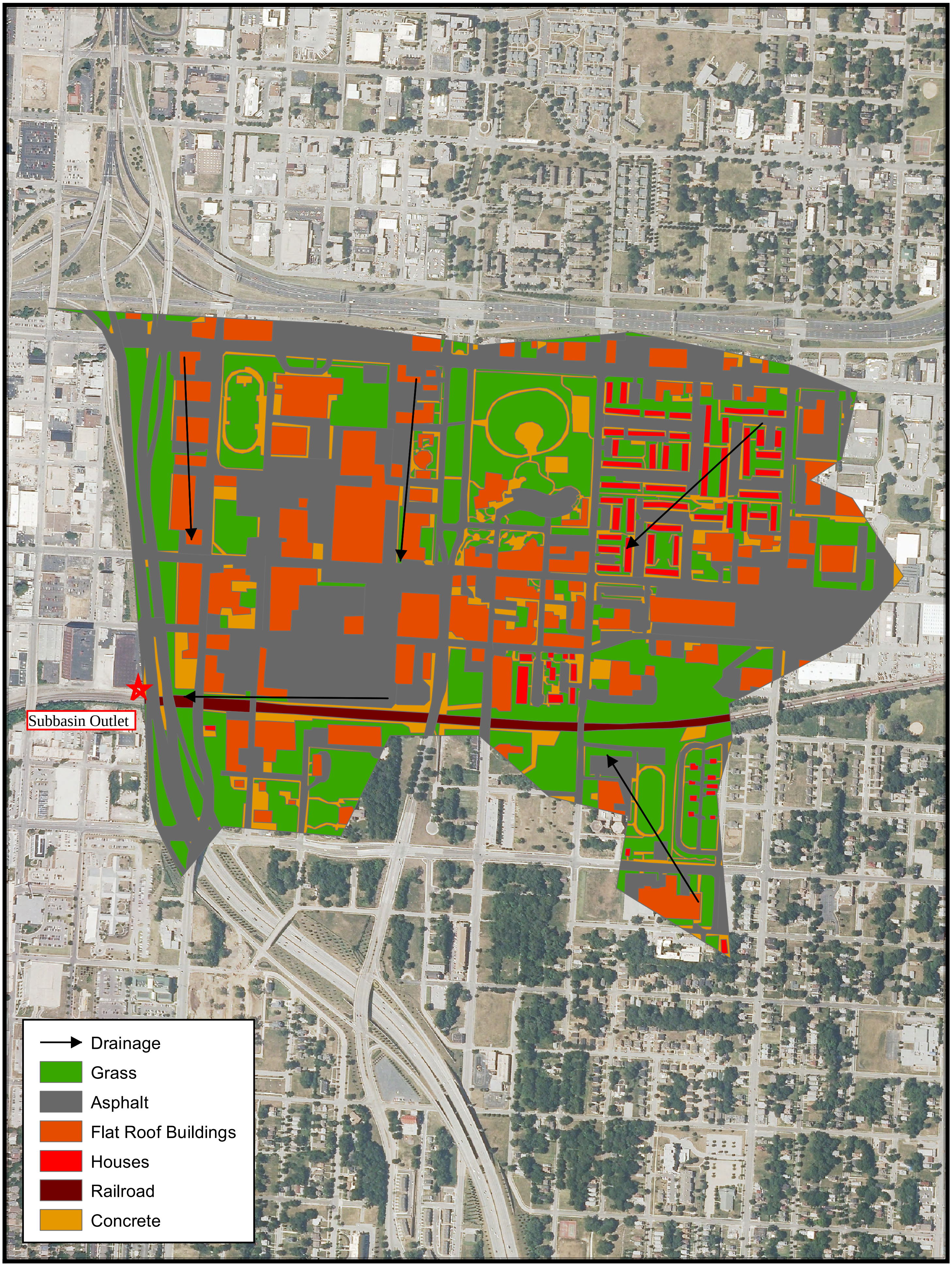


Figure 3.6.2: East Side Watershed Boundary

3.7 Crossroads

The Crossroads sub-basin is the most urbanized of all the watersheds analyzed. The land use is industrial, residential, and commercial, and possesses one of the city's most popular entertainment areas: the Crossroads Arts District. The arts district is located in the lower elevations of this district and is subject to flooding, which is of special importance to city leaders as the area is beginning to become an economic engine of the city, drawing residents, businesses and tourism.

The Crossroads sub-basin has an area of 396.4 acres. The land use areas are given in Table 3.7.1.

Table 3.7.1: Crossroads Land Use

Feature	Area (Acres)
Grass	37.5
Roads	165.6
Buildings	127.0
Houses	5.82
Railroad	0.9
Concrete	59.5
Watershed	396.4

The general slope of this watershed is calculated as 0.0144 feet per foot, as characterized by an 81 foot drop in elevation over a distance of 5625 feet. Figure 3.7.1 shows the boundaries and land use of the watershed.

The time of concentration for the watershed is 0.46 hours and the discharge for this site is as follows:

Table 3.7.2: Calculated Discharges Using TR-55

Return Period	2 year	5 year	25 year	50 year	100 year
Discharge (cfs)	1060	1422	1939	2164	2423

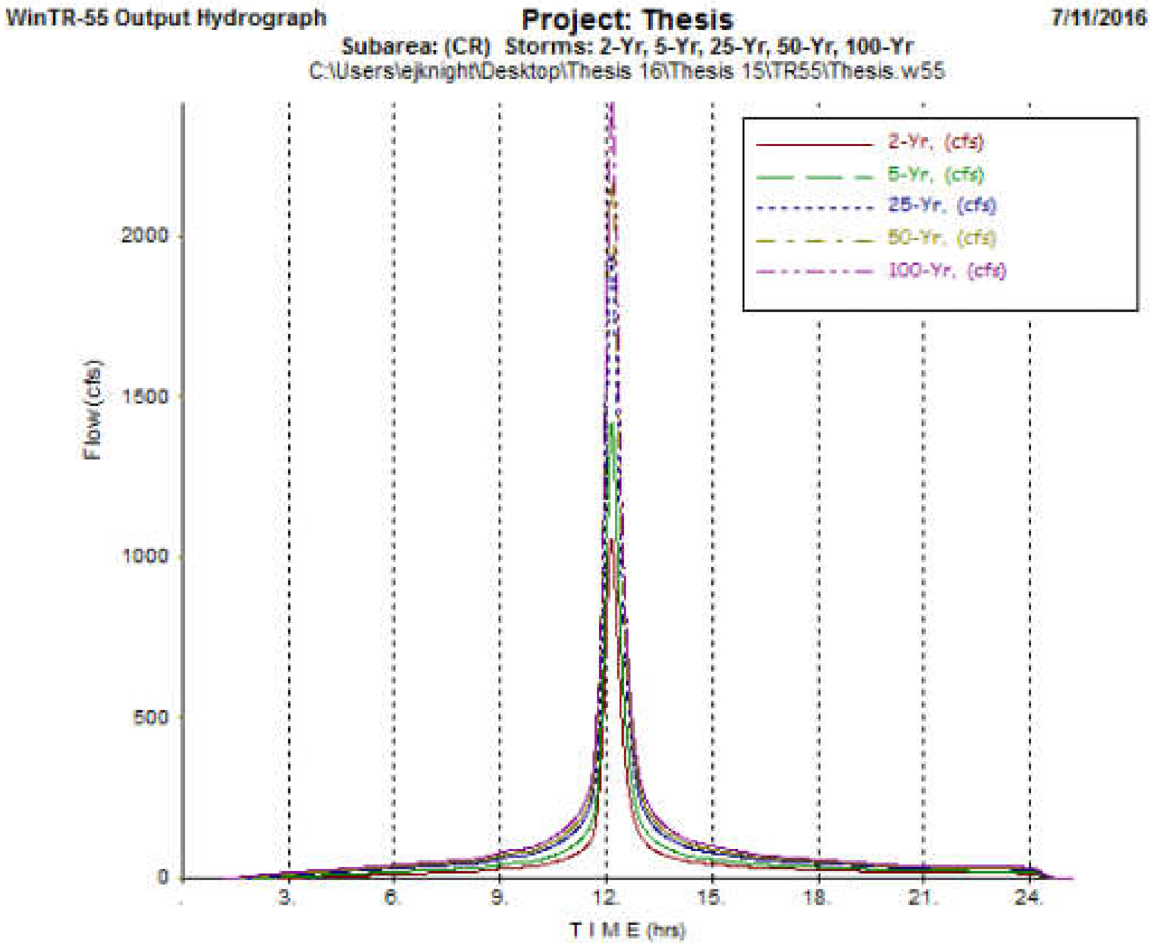


Figure 3.7.1: Existing Crossroads Basin Hydrograph

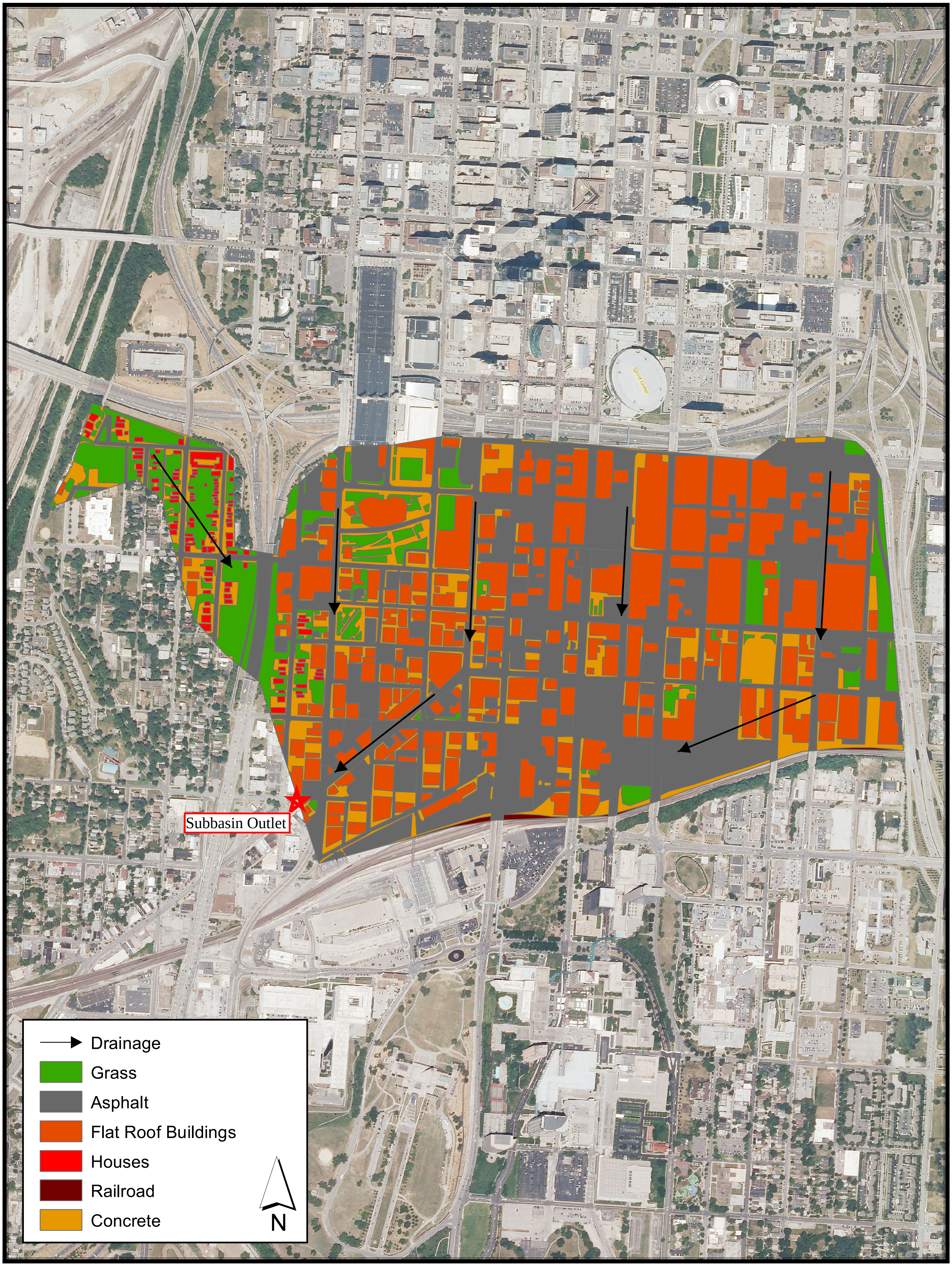


Figure 3.7.2: Crossroads Watershed Boundary

3.8 Crown Center

The Crown Center sub-basin has a similar makeup as the Hospital Hill watershed. The land use is residential and commercial with large city landmarks such as Liberty Memorial and the Crown Center complex. The residential areas are located in the higher elevations of this sub-basin, with the commercial areas to the north.

The Crown Center sub-basin has an area of 225.6 acres and is characterized as very steep. The land use areas are given in Table 3.8.1.

Table 3.8.1: Crown Center Land Use

Feature	Area (Acres)
Grass	75.1
Roads	57.8
Buildings	29.1
Houses	11.4
Railroad	0.0
Concrete	52.2
Watershed	225.6

The general slope of this watershed is calculated as 0.0336 feet per foot, as characterized by a 178 foot drop in elevation over a distance of 5300 feet. Figure 3.8.1 shows the boundaries and land use of the watershed.

The time of concentration for the watershed is 0.33 hours and the discharge for this site is as follows:

Table 3.8.2: Calculated Discharges Using TR-55

Return Period	2 year	5 year	25 year	50 year	100 year
Discharge (cfs)	655	896	1243	1394	1566

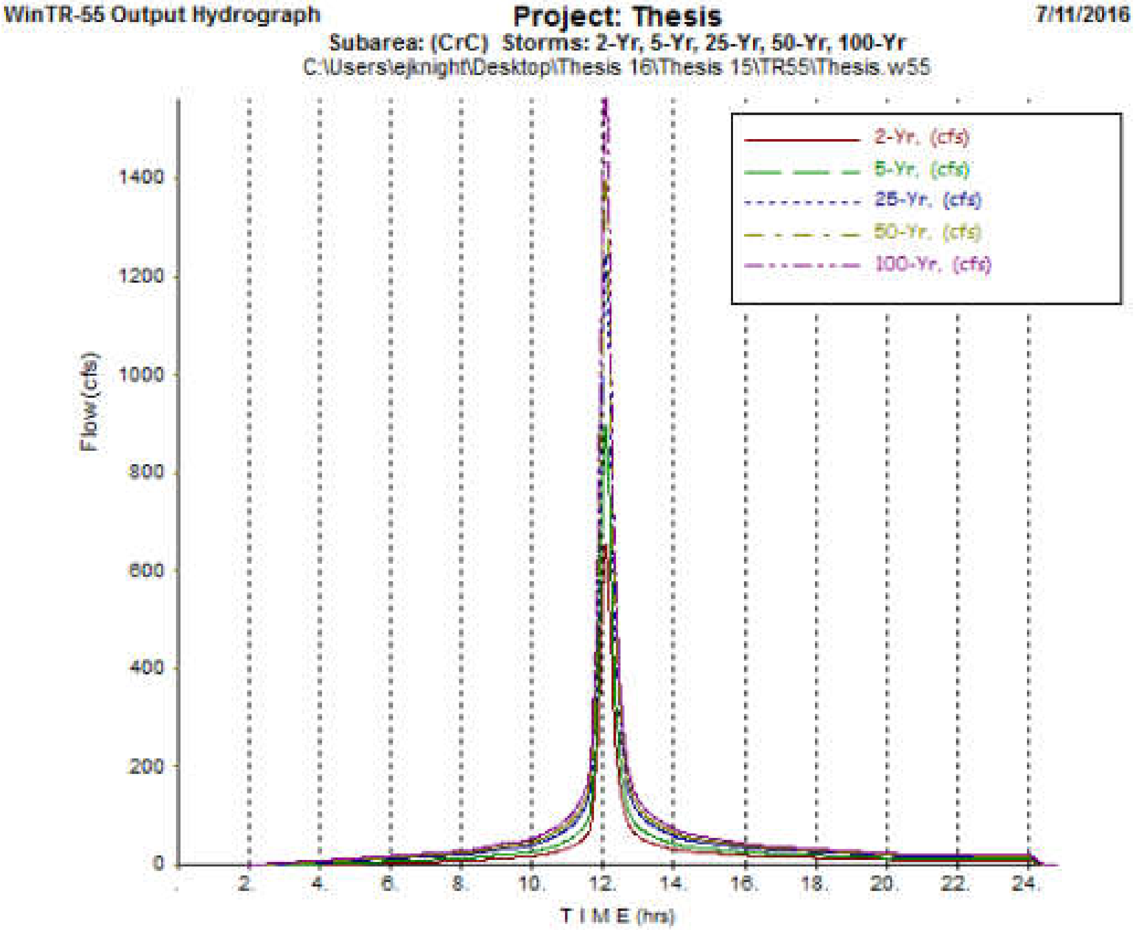


Figure 3.8.1: Existing Crown Center Basin Hydrograph

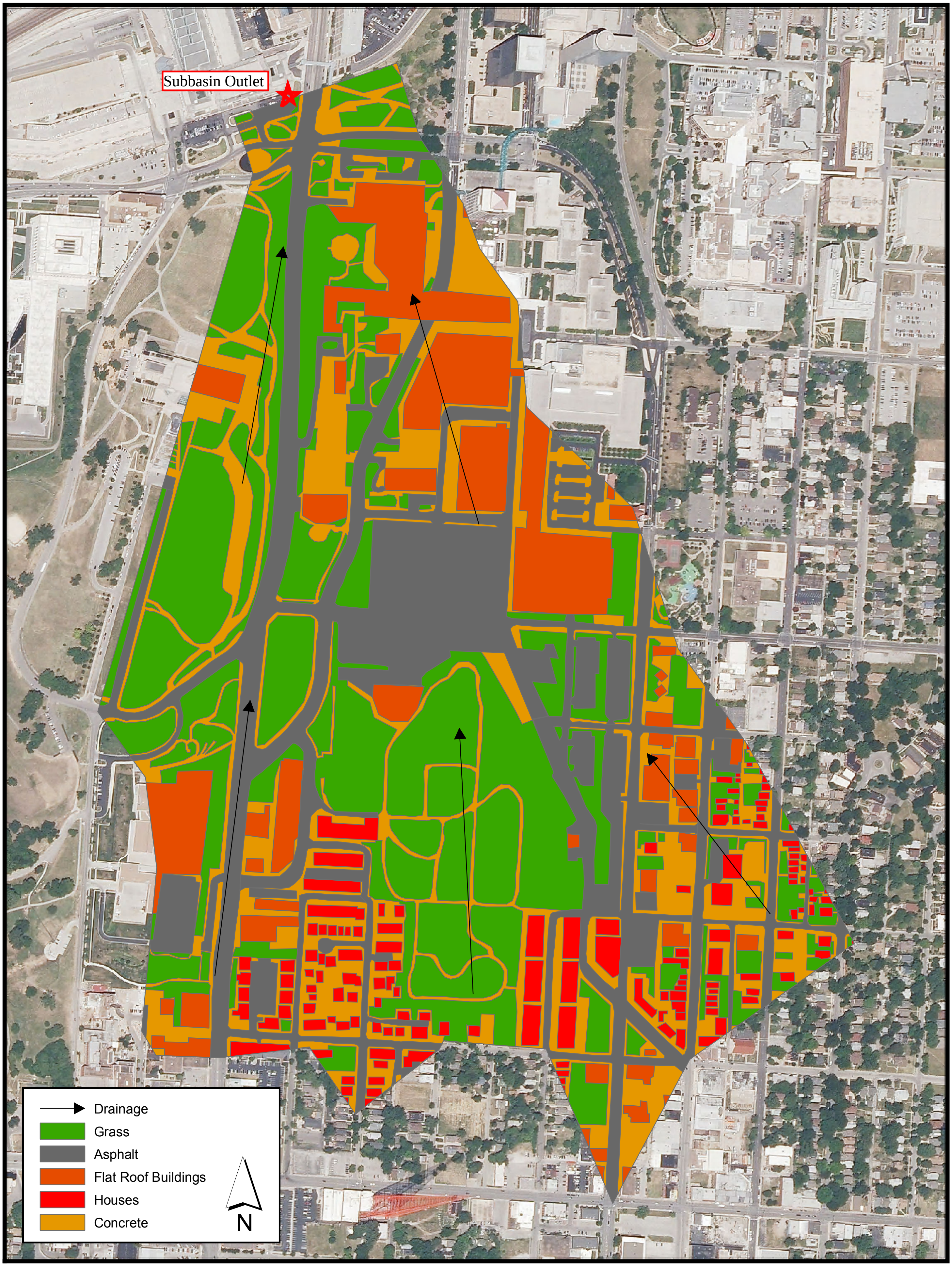


Figure 3.8.2: Crown Center Watershed Boundary

CHAPTER 4 – APPLICATION

In order to maximize the effectiveness of this study, a system must be developed that can be easily understood by city workers and grounds crews. It is not feasible from a budgetary perspective to have a team of engineers design every specific BMP and BMP location. There are certain guidelines that can be established in order to streamline the decision making process and maximize the BMP effectiveness and the associated cost of designing and installing the BMPs. This is an effort to establish conditions that crews can make basic assessments of site conditions and select an effective BMP from a matrix and gives them the autonomy for site selection.

The assumed infiltration rates and loading capacities have been determined by the studies of Nall and Ma. These studies were conducted within the Kansas City limits and provide detailed localized soil profiles that can be easily integrated into this plan.

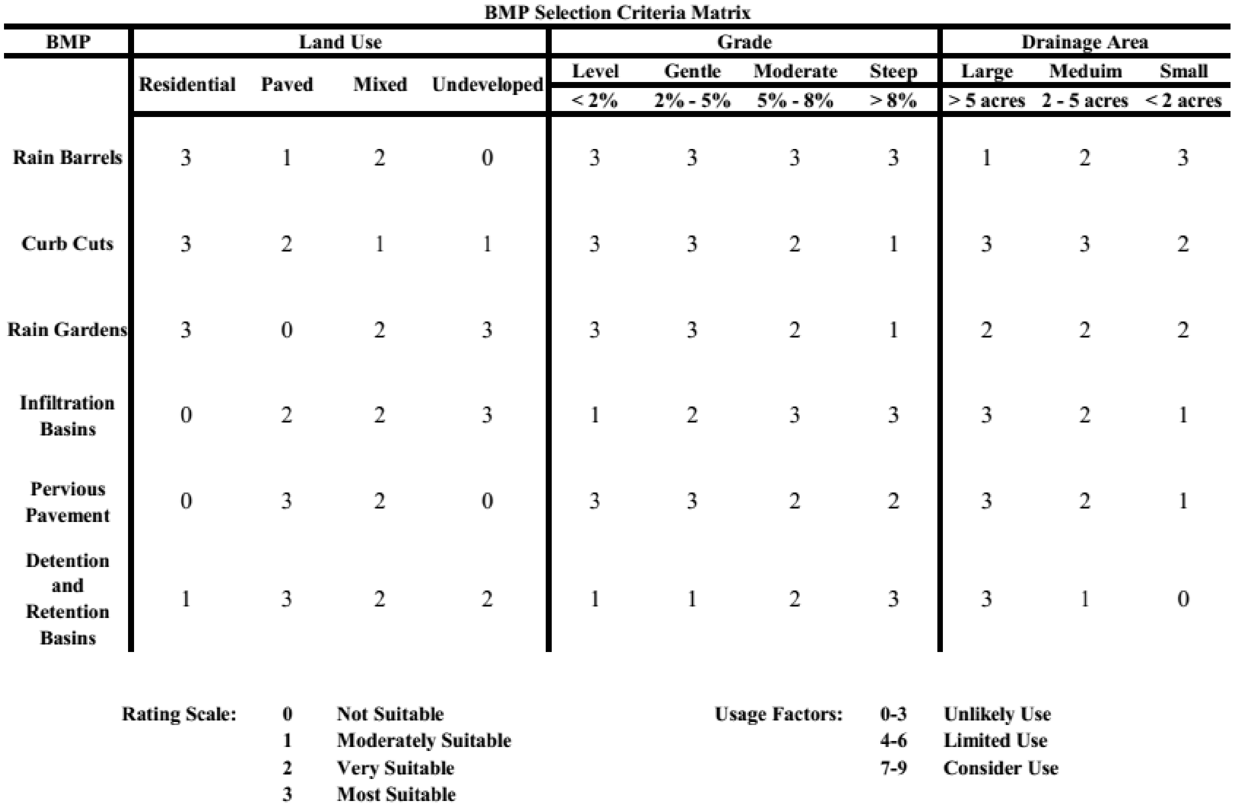
4.1 Decision Matrix

The following decision matrix can be used by city personnel to make quick decisions on the appropriateness of BMPs in certain situations.

This decision matrix is a quick reference that personnel can use to deploy BMPs in most situations. The scale is from zero to three for suitability, zero meaning the BMP is not suitable and three being the most suitable.

The three categories are added together from the land use, grade and drainage area. That usage is factored together on a scale from 0-9 to determine the overall effectiveness of the BMP in the given situation. Seven or above is considered very suitable, zero to three is considered not suitable, and 4-6 is considered not well suited.

Table 4.1.1: BMP Decision Matrix



BMP Selection Criteria Matrix

BMP	Land Use				Grade				Drainage Area		
	Residential	Paved	Mixed	Undeveloped	Level	Gentle	Moderate	Steep	Large	Meduim	Small
					< 2%	2% - 5%	5% - 8%	> 8%	> 5 acres	2 - 5 acres	< 2 acres
Rain Barrels	3	1	2	0	3	3	3	3	1	2	3
Curb Cuts	3	2	1	1	3	3	2	1	3	3	2
Rain Gardens	3	0	2	3	3	3	2	1	2	2	2
Infiltration Basins	0	2	2	3	1	2	3	3	3	2	1
Pervious Pavement	0	3	2	0	3	3	2	2	3	2	1
Detention and Retention Basins	1	3	2	2	1	1	2	3	3	1	0

Rating Scale:

0	Not Suitable
1	Moderately Suitable
2	Very Suitable
3	Most Suitable

Usage Factors:

0-3	Unlikely Use
4-6	Limited Use
7-9	Consider Use

4.2 Drainage Area Characterization

To understand what types of BMPs will be required for a specific situation, the area must be classified into one of four main groups: residential, paved (commercial/industrial), mixed use, and undeveloped. The crew must determine what the size of the drainage area is and where the runoff is being captured by the collection system. This can be as simple as calling the area small, medium, or large. They must ascertain the general slope of the drainage area; level, gentle, moderate, or steep.

For example, a crew is trying to determine the best solution for Madison Avenue from 17th to 18th Street. The street slopes gradually from north to south. The street has undeveloped land, commercial buildings, and residential properties. This would be classified as mixed use. The street drains an estimated area of 3.5 acres as determined from a Google Earth measurement. The elevation drops 31 feet over a length of 658 feet, or 5%. This would be considered a moderate slope. There is a collection drain at the corner of Madison and 17th Street, so it can be assumed that the runoff from 17th Street is captured.

The street is then classified by the city crew as a 3.5 acre, mixed-use, moderately sloped area with no collection system. Figure 4.

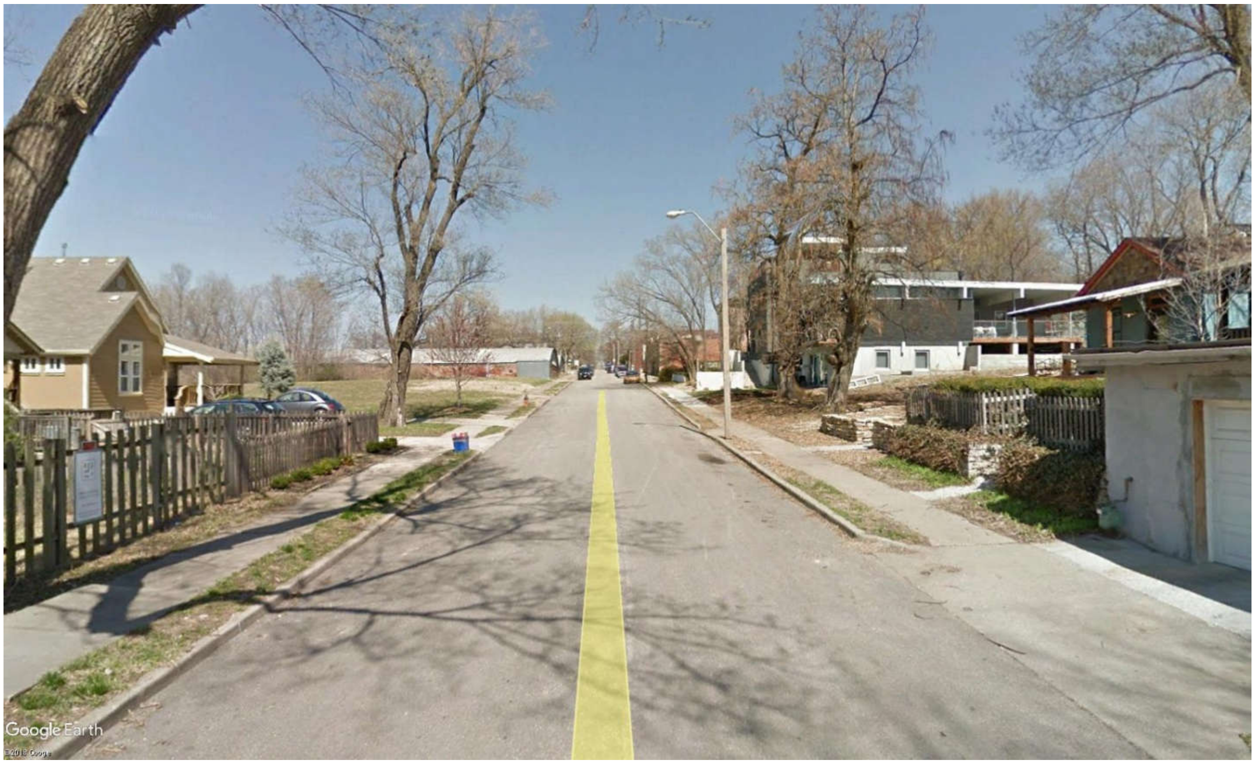


Figure 4.2.1: Google Earth Street View of 1700 Block Madison Ave (Facing North)

The BMP selection matrix can then be used as the example in Figure 4.2.2 in order to determine the suitability for this location.

BMP Selection Criteria Matrix

BMP	Land Use				Grade				Drainage Area		
	Residential	Paved	Mixed	Undeveloped	Level	Gentle	Moderate	Steep	Large	Meduim	Small
					< 2%	2% - 5%	5% - 8%	> 8%	> 5 acres	2 - 5 acres	< 2 acres
Rain Barrels	3	1	[✓ 2]	0	3	3	[✓ 3]	3	1	[✓ 2]	3
Curb Cuts	3	2	[✓ 1]	1	3	3	[✓ 2]	1	3	[✓ 3]	2
Rain Gardens	3	0	[✓ 2]	3	3	3	[✓ 2]	1	2	[✓ 2]	2
Infiltration Basins	0	2	[✓ 2]	3	1	2	[✓ 3]	3	3	[✓ 2]	1
Pervious Pavement	0	3	[✓ 2]	0	3	3	[✓ 2]	2	3	[✓ 2]	1
Detention and Retention Basins	1	3	[✓ 2]	2	1	1	[✓ 2]	3	3	[✓ 1]	0

Rating Scale:		
	0	**Not Suitable**
	1	**Moderately Suitable**
	2	**Very Suitable**
	3	**Most Suitable**

Usage Factors:		
	0-3	**Unlikely Use**
	4-6	**Limited Use**
	7-9	**Consider Use**

Figure 4.2.2: BMP Selection Matrix for Madison Avenue

The Usage Factors indicate that rain barrels, curb cuts, rain gardens, infiltration basins and pervious pavement all will be acceptable BMPs for this street.

4.3 BMP Selection

BMP selection is based on the volume of water and where the water would flow if there were no stormwater measures in place. Rain gardens are typically used in areas with micro topography that would allow ponding. Curb cuts are useful on streets that have collection systems that can be easily overwhelmed or have no collection system at all. Retention and detention basins are useful for large storage capacity but only in places that have large areas of space to spare. Pervious pavement can be used on streets and parking lots, but the initial costs can be high.

For this section of Madison Avenue, the road has a curb running the entire length from 17th Street to 18th Street. There is no collection system, and there is an easement between the sidewalk and street. This would be an ideal location for curb cuts to drain into a small infiltration basin. There are 16 residential properties on this block and it can be assumed that roughly 15% (2 on this block) property owners will install rain gardens.

Rain barrels would also be appropriate to distribute to the residential properties. It can be assumed that half of the residential properties would use the rain barrels.

4.4 Water Volume

For the Type D rainfall storm of 1.37 inches over 24 hours, the volume of rain that can be expected to fall over this block is roughly 17,400 cubic feet of water. The overall reduction goal of 1/3 would mean 5,800 cubic feet of water would need to be removed from the system.

It is assumed that half of the homeowners would be willing to participate in installing rain barrels on their property. Four 55-gallon rain barrels distributed to eight of the sixteen properties would retain 1,760 gallons or 235 cubic feet of rainwater. This is water that is instantly removed from the system.

Two rain gardens are going to be installed on residential properties. These gardens can be assumed to be roughly ten feet by ten feet. Using the infiltration rates established by Nall in the residential rain garden study, the rain gardens will infiltrate 7.4 inches of rainwater per hour. For a 10’ x 10’ garden, that is the equivalent of infiltrating 61.7 cubic feet per hour, or 1480 cubic feet per 24 hours.

Curb cuts to infiltration basins will use the same engineered soil that rain gardens use, so the same infiltration rate can be inferred. The easement between the street and sidewalk is 3 feet. Placing four 15-foot curb cuts can capture 111 cubic feet of runoff per hour, which is the equivalent of 2,664 cubic feet per 24 hours.

The resulting combination of these BMPs is that 235 ft^3 from the rain barrels, 2,960 ft^3 from the rain gardens and 2664 ft^3 from the curb cuts has been removed from the collection system. This total of 5,859 ft^3 is above the target volume of 1/3 the overall runoff.

Figure 4.4: BMP Locations for 1700 Block of Madison Avenue

4.5 Drainage Area Characterization

Another example of how the BMP matrix can be used is Locust Street from 17th to 18th Street. This is a highly urbanized area within the Crossroads subbasin. The street has commercial and industrial buildings as well as large parking lots. Parking is at a premium as cars line the curbs and fill the lots during business hours and into the evening. This would be classified as a paved area.

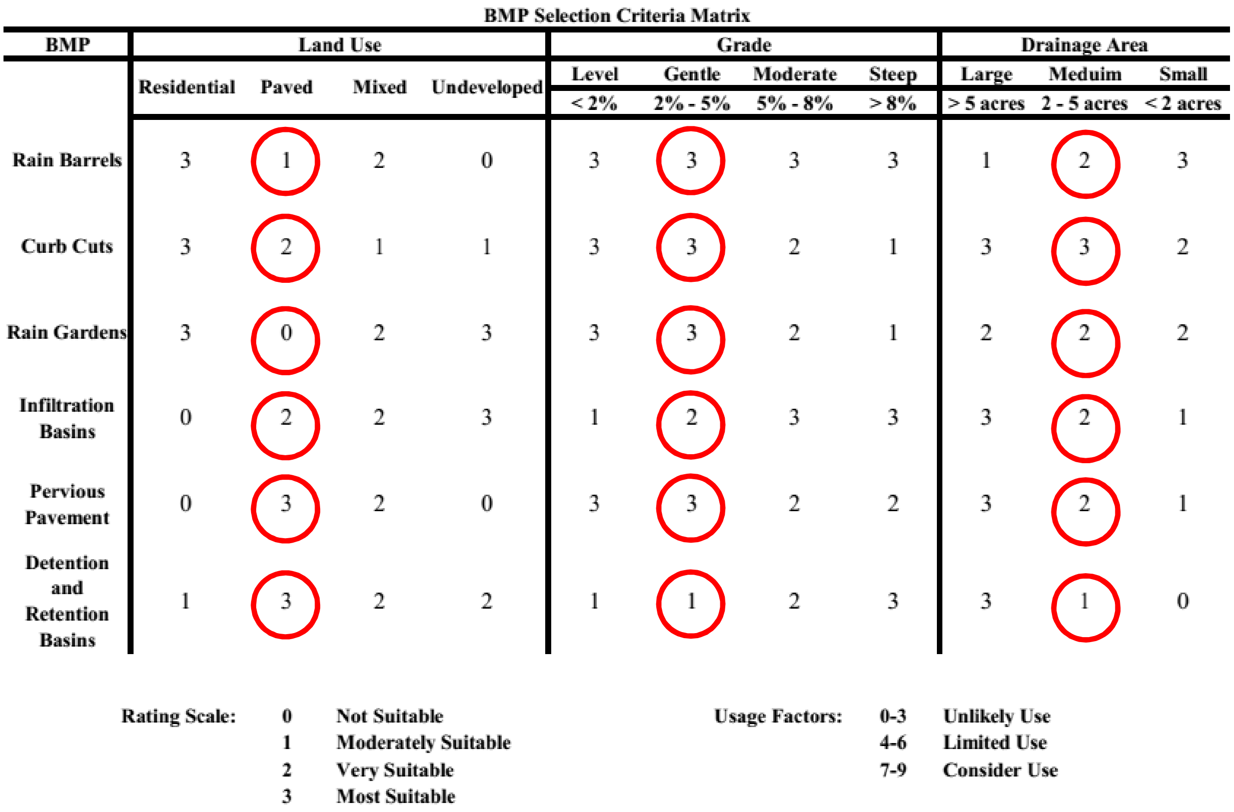
Figure 4.5: Google Earth Street View of 1700 Block Locust Street (Facing North)

The flow direction on this street is from north to south. The street drains an estimated area of 3.25 acres as determined from a Google Earth measurement. The elevation drops 21 feet over a length of 603 feet, or 3.5%. This would be considered a gentle slope.

The street is then classified by the city crew as a medium sized, paved, gently sloped area with no collection system.

4.6 BMP Selection

For this section of Locust, the road has a curb running the entire length from 17th Street to 18th Street except for the driveways to the businesses and parking lots. There is no collection system, and there is no unpaved easement between the sidewalk and street.



BMP Selection Criteria Matrix

BMP	Land Use				Grade				Drainage Area		
	Residential	Paved	Mixed	Undeveloped	Level	Gentle	Moderate	Steep	Large	Meduim	Small
					< 2%	2% - 5%	5% - 8%	> 8%	> 5 acres	2 - 5 acres	< 2 acres
Rain Barrels	3	1	2	0	3	3	3	3	1	2	3
Curb Cuts	3	2	1	1	3	3	2	1	3	3	2
Rain Gardens	3	0	2	3	3	3	2	1	2	2	2
Infiltration Basins	0	2	2	3	1	2	3	3	3	2	1
Pervious Pavement	0	3	2	0	3	3	2	2	3	2	1
Detention and Retention Basins	1	3	2	2	1	1	2	3	3	1	0

Rating Scale:			Usage Factors:		
	0	Not Suitable		0-3	Unlikely Use
	1	Moderately Suitable		4-6	Limited Use
	2	Very Suitable		7-9	Consider Use
	3	Most Suitable			

Figure 4.6: BMP Selection Matrix for Locust Street

From the usage factors, it is determined that curb cuts and pervious pavement will be the most effective in this scenario. With no unpaved easement available, curb cuts would prove ineffective, so pervious pavement is determined to be the most effective solution.

The parking lot on the southwest corner of Locust Street would be an ideal location for a pervious pavement BMP, not only for the amount of pavement that is removed from the system, but the drainage could also be diverted to the lot as it flows down the street.

4.7 Water Volume

For the water quality storm of 1.37 inches over 24 hours, the volume of rain that can be expected to fall over this block is roughly 16,160 cubic feet of water. The overall reduction goal of 1/3 would mean roughly 5,400 cubic feet of water would need to be removed from the system.

Figure 4.7: BMP Location for 1700 Block of Locust Street

The 0.5 acre parking lot will have detention storage built in to hold the water until it infiltrates into the groundwater. The engineered gravel and soil mixture can be designed to be poorly graded and have a 20% void ratio. With a three foot detention depth, this would hold approximately 13,000 ft^3 of water, well above the target of 5,400 ft^3, and nearly the entire runoff volume of 16,160 ft^3 that falls on this drainage area.

CHAPTER 5 – RESULTS

5.1 Infiltration Basins

A solution for the stormwater volume includes infiltration basins placed in strategic areas throughout the watersheds. Sites for the infiltration basins were chosen based on current land use and topography. Five of the seven sub-basins have an area available for infiltration basin placement. The infiltration basins will be designed using guidance of the Wisconsin Department of Natural Resources Conservation Practice Standard 1003.

Kansas City has poor soil quality (NRCS Category D), so the soil will need to be removed and an engineered soil mix will need to replace the existing soil. Native plants would then be added to provide extra absorption through transpiration. Soils need to be tested for proper porosity and infiltration capacity.

5.1.1 West Side

The infiltration basin for the west side watershed was chosen on an area of land that is both undeveloped and a parking lot for an abandoned building. The plot of land is advantageous due to its location as a bottleneck within the drainage area and its ability to capture water from a point of sharp relief. These attributes allow the basin to capture water that would quickly flow off of the site. This allows the hydrograph peak to be reduced for the overall West Side drainage area.

The original hydrograph for the two year (50% chance) storm peaked at 680.0 cfs and 1593.8 cfs for the 100 year (1% chance) storm, both peaks occurring at 12.0 hours. The resulting hydrograph from the 2 year storm has a peak of 141.5 cfs and 352.1 cfs for the 100 year storm, at 12.08 hours. Overall, 22.1% of the runoff has been removed from the hydrologic system.

Table 5.1.1: West Side Land Use

Feature	Area (Acres)
Grass	20.8
Roads	9.9
Buildings	3.2
Houses	4.6
Railroad	0.0
Concrete	13.5
Watershed	52.0

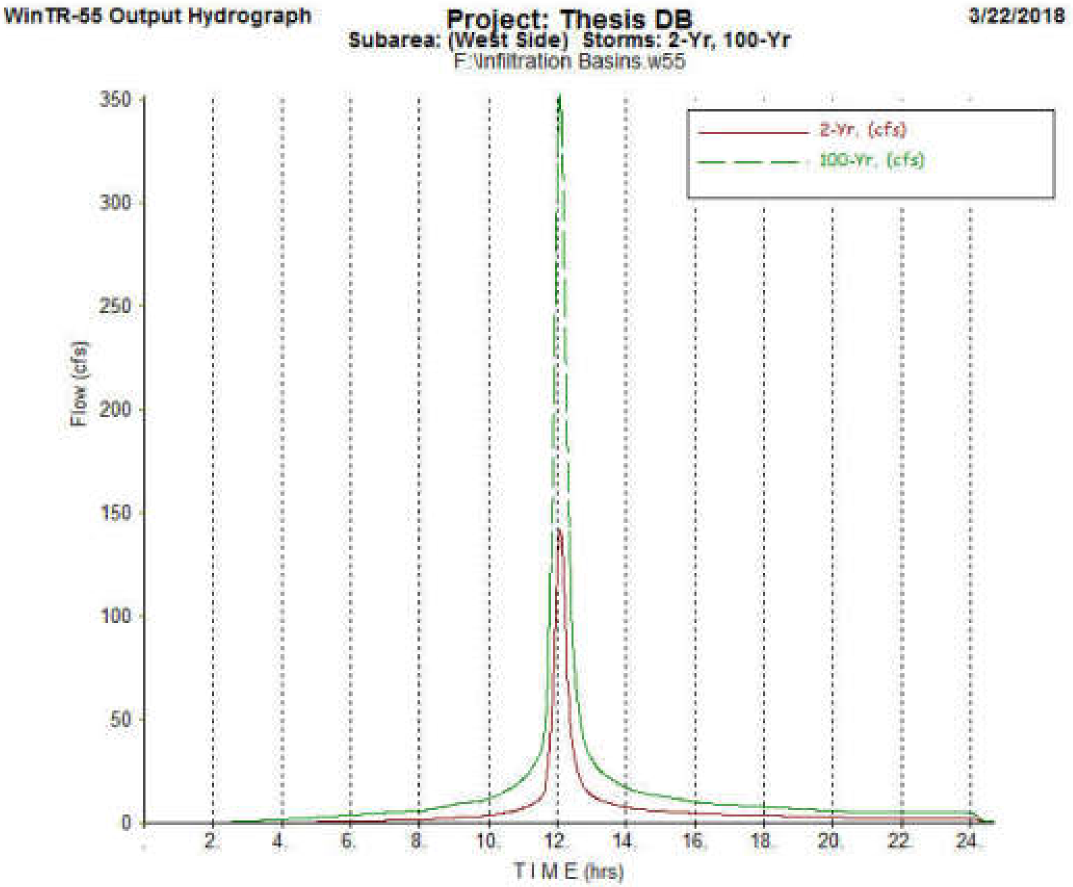


Figure 5.1.1: West Side Infiltration Basin Hydrograph

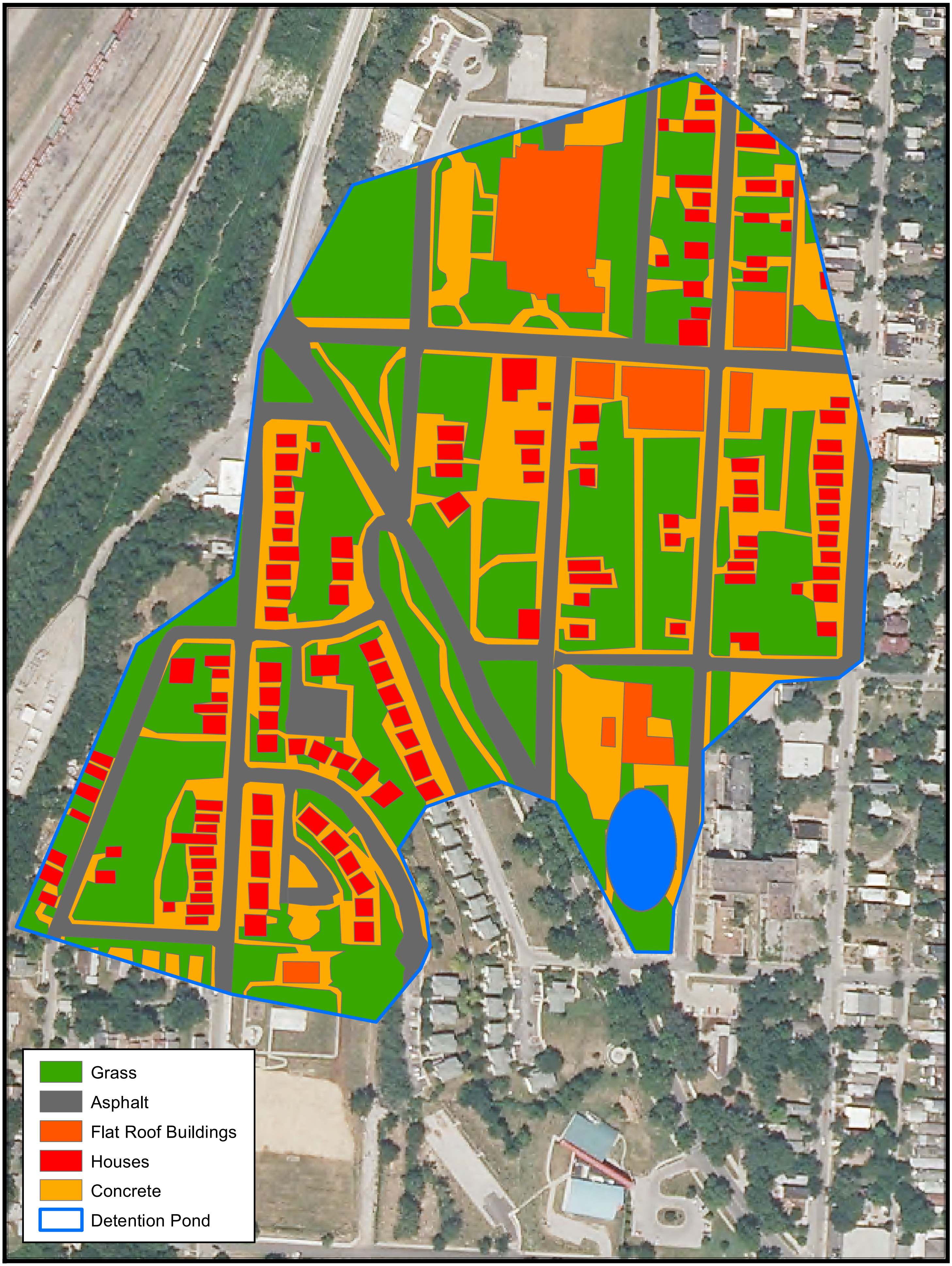


Figure 5.1.2: West Side Infiltration Basin

5.1.2 Penn Valley

The Penn Valley drainage area has the most complicated solution to its drainage problems due to its sudden relief north of 31st Street. However, the watershed can significantly reduce most of its urban drainage by strategically placing a pond with a forebay in the area of 31st and Broadway. The flow would drain to the forebay to slow the water before entering the infiltration basin. Reliving the overall sub-basin of this flow will relieve pressure from the downstream infrastructure to better serve the flow from the other sub-basins. This allows the hydrograph peak to be reduced for the larger Penn Valley sub-basin.

The original hydrograph for the two year storm peaked at 682.4 cfs and 1706.0 cfs for the 100 year storm, both peaks occurring at 12.3 hours. The resulting hydrograph from the 2 year storm has a peak of 182.6 cfs and 429.2 cfs for the 100 year storm, at 12.1 hours. Overall, 28.9% of the runoff has been removed from the hydrologic system.

Table 5.1.2: Penn Valley Land Use

Feature	Area (Acres)
Grass	12.8
Roads	28.9
Buildings	14.1
Houses	21.5
Railroad	0.0
Concrete	9.8
Watershed	67.1

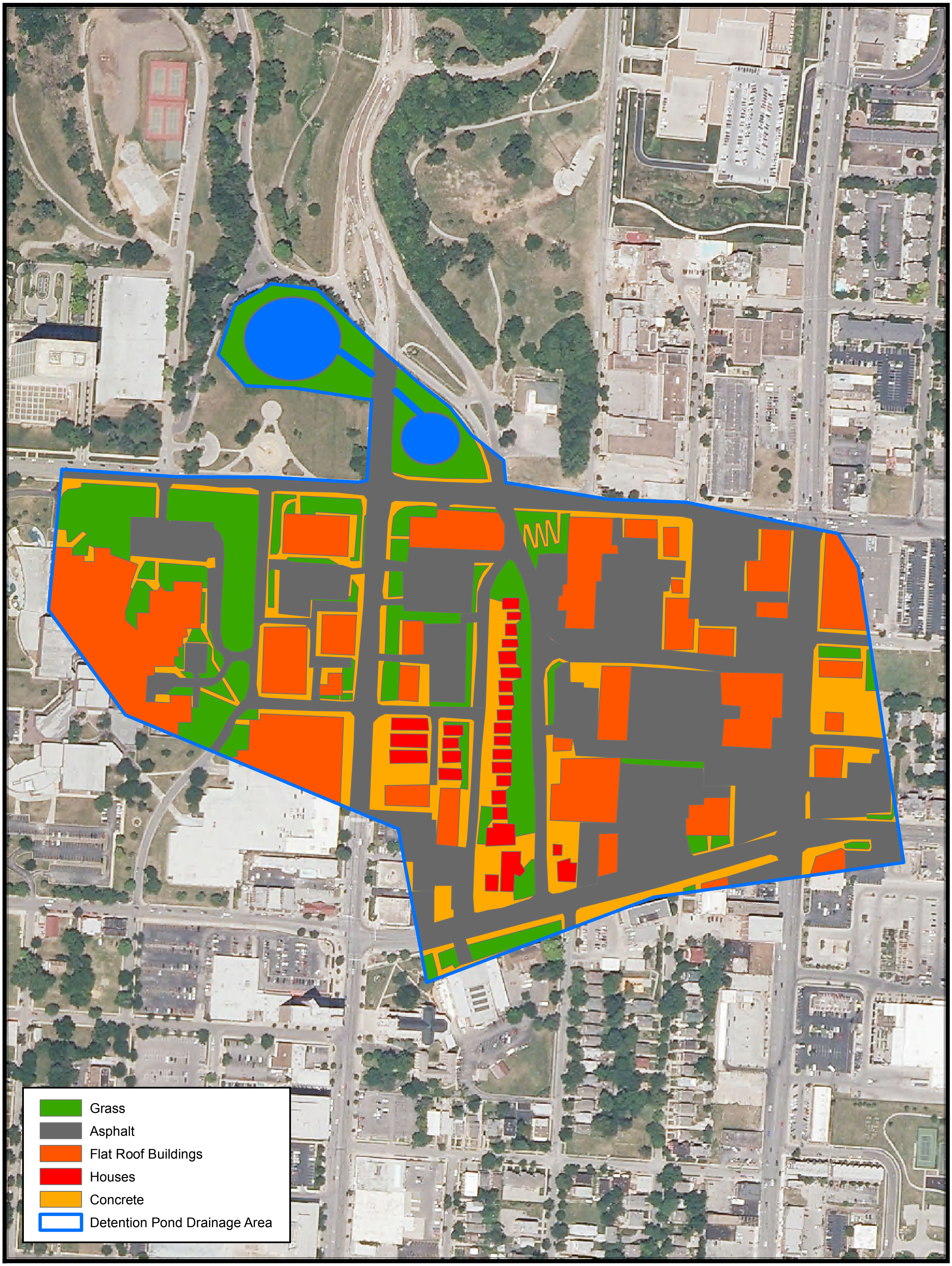


Figure 5.1.3: Penn Valley Infiltration Basin

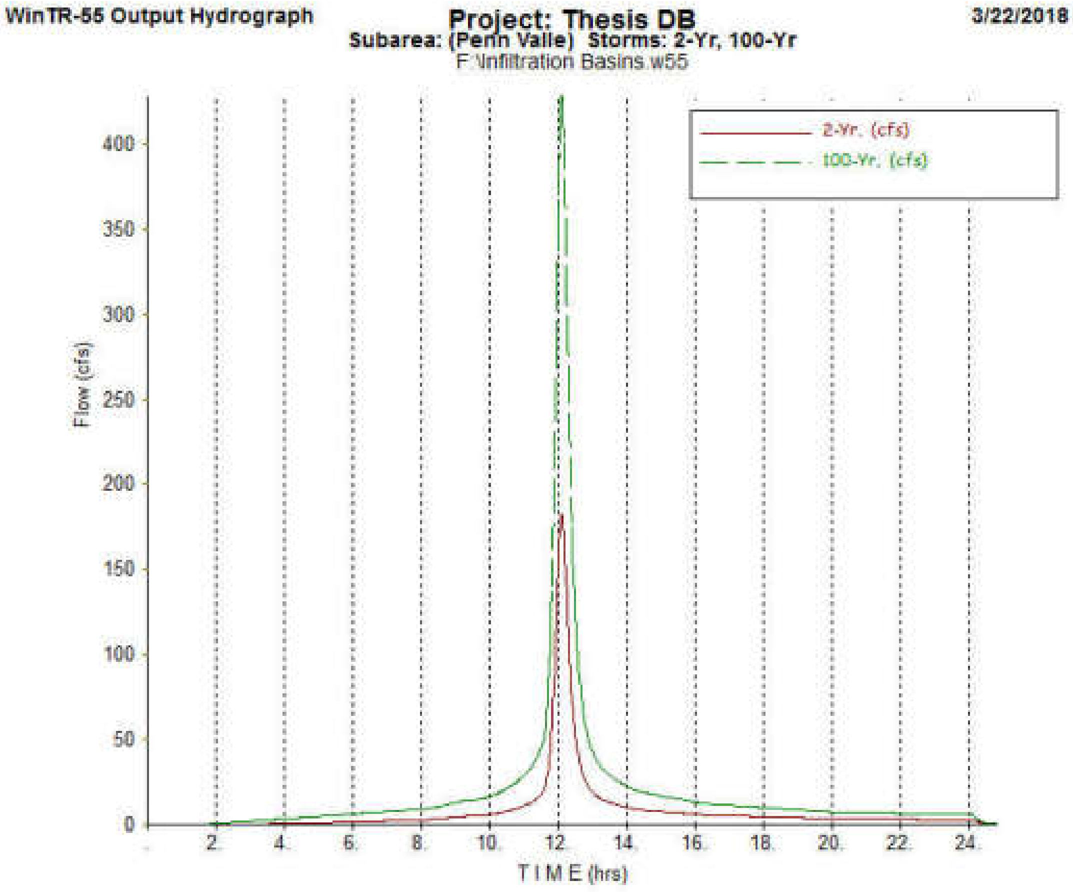


Figure 5.1.4: Penn Valley Detention Basin Hydrograph

5.1.3 Hospital Hill

The property selected to establish an infiltration basin in the Hospital Hill sub-basin is located on the corner of 25th Street and Charlotte. The property is currently an open field and a parking lot. A large portion of the watershed drains to this location, of mostly residential land use. Drainage to this point is undeterminable through the storm sewage system, but the topography of the area allows for a reasonable assumption that all runoff will flow to the detention basin.

This configuration allows the hydrograph peak to be reduced for the larger Hospital Hill sub-basin. The original hydrograph for the two year storm peaked at 757.1 cfs and 1811.9 cfs for the 100 year storm at 12.1 hours. The resulting hydrograph from the 2 year storm has a peak of 193.5 cfs and 483.6 cfs for the 100 year storm, at 12.1 hours. Overall, 26.7% of the runoff has been removed from the hydrologic system.

Table 5.1.3: Hospital Hill Land Use

Feature	Area (Acres)
Grass	31.8
Roads	15.2
Buildings	6.1
Houses	10.8
Railroad	0.0
Concrete	19.4
Watershed	83.3

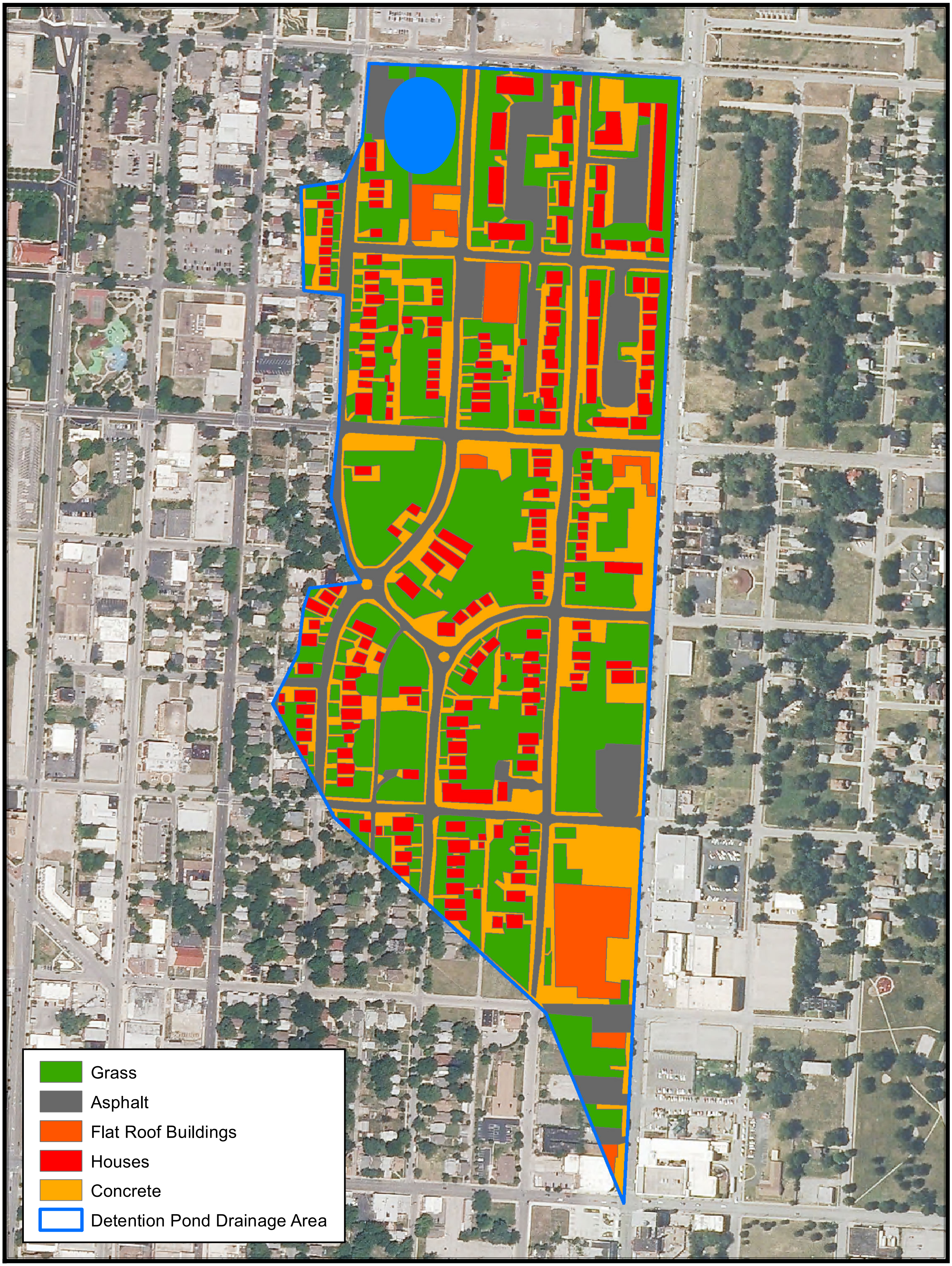


Figure 5.1.5: Hospital Hill Infiltration Basin

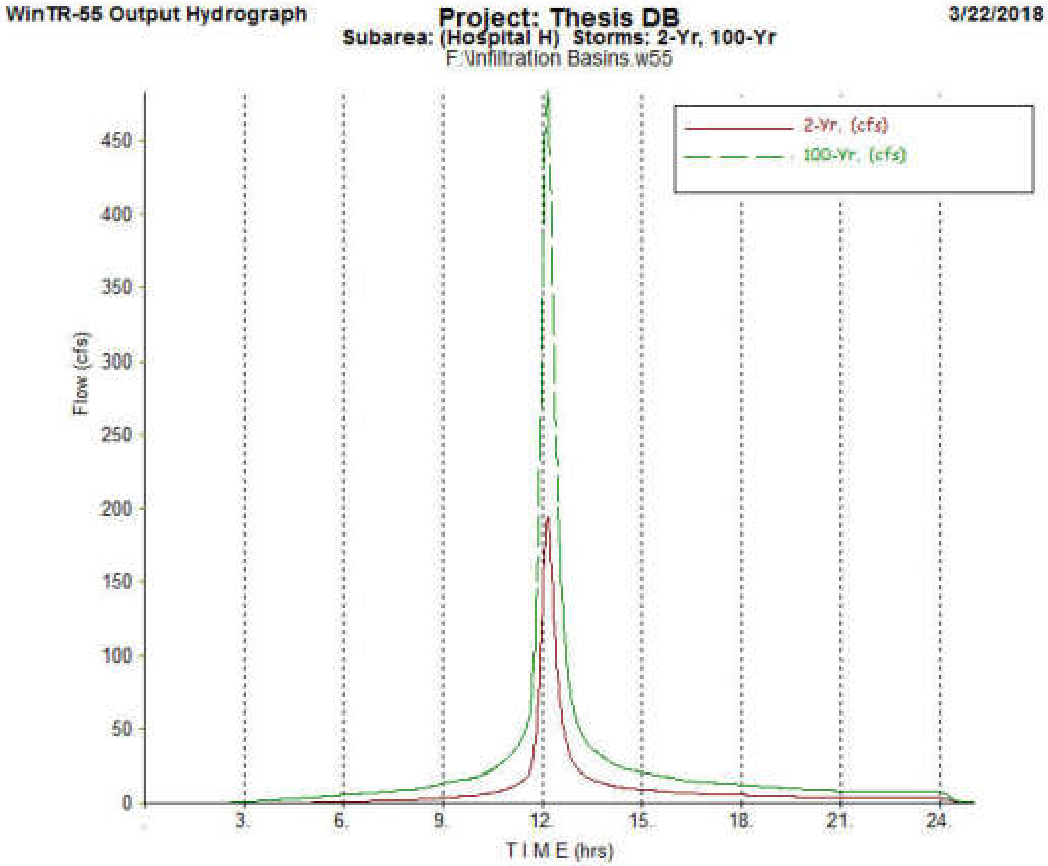


Figure 5.1.6: Hospital Hill Infiltration Basin Hydrograph

5.1.4 East Side

The East Side detention basin was selected due to its topography and current land use. The site is currently a storage yard for industrial materials or possibly industrial trash. The site is on the corner of 18th Street and Lydia Road. The configuration of the storm drains are not known, so it is assumed that the drainage from the area will flow based on the topography. It is also assumed that the drainage area located north of the railroad tracks will flow across the bridges into the watershed. During storm events this has been monitored at various times and confirmed that this occurs, though there is some capture by storm sewers.

The placement of the detention basin in this location allows the hydrograph peak to be reduced for the larger East Side sub-basin. The original hydrograph for the two year storm peaked at 1018.7 cfs and 2351.0 cfs for the 100 year storm at 12.1 hours. The resulting hydrograph from the 2 year storm has a peak of 262.6 cfs and 631.8 cfs for the 100 year storm, at 12.2 hours. Overall, 26.9% of the runoff has been removed from the hydrologic system.

Table 5.1.4: East Side Land Use

Feature	Area (Acres)
Grass	31.9
Roads	44.8
Buildings	21.5
Houses	1.7
Railroad	2.4
Concrete	10.5
Watershed	112.8

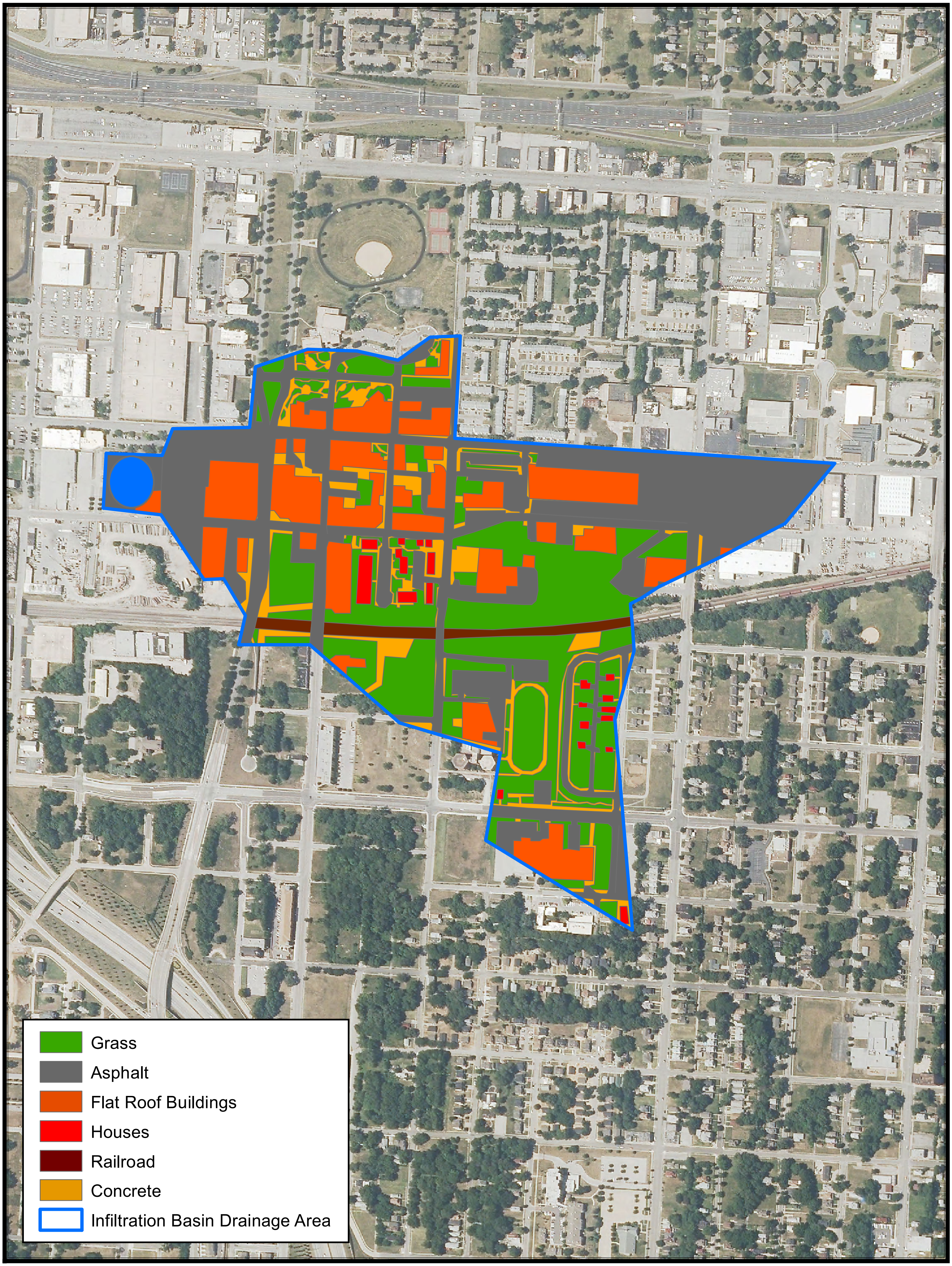


Figure 5.1.7: Hospital Hill Infiltration Basin

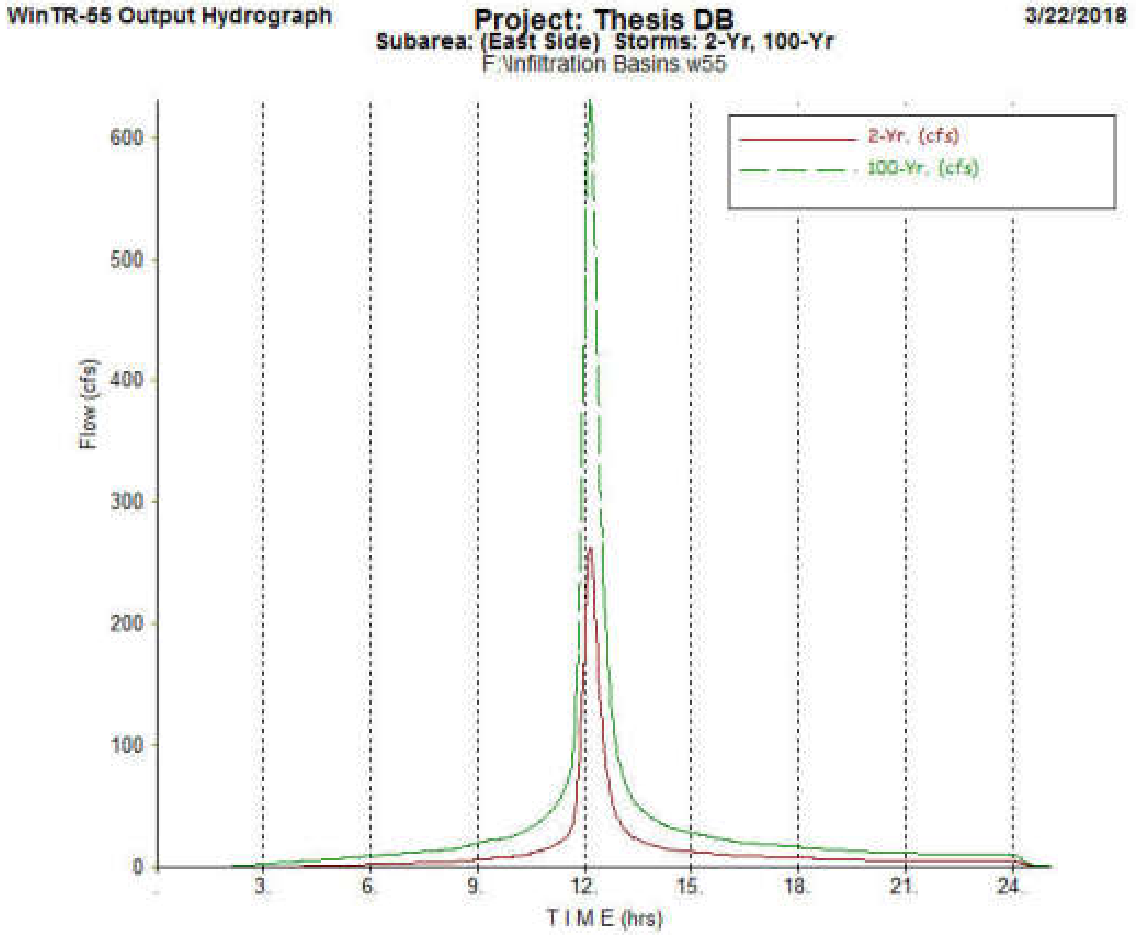


Figure 5.1.8: East Side Infiltration Basin Hydrograph

5.1.5 Crown Center

The detention basin for the Crown Center subbasin is located in the open space where Main Street and Grand Boulevard meet near 27th Street. The land is currently undeveloped and used as a public art space. This design would still allow this space to function in that capacity, while also serving as an infiltration basin.

This infiltration basin placement allows the hydrograph peak to be reduced for the larger Crown Center sub-basin. The original hydrograph for the two year storm peaked at 654.8 cfs and 1566.3 cfs for the 100 year storm at XXX hours. The resulting hydrograph from the 2 year storm has a peak of 121.7 cfs and 285.3 cfs for the 100 year storm, at 12.0 hours. Overall, 18.2% of the runoff has been removed from the hydrologic system.

Table 5.1.5: Crown Center Land Use

Feature	Area (Acres)
Grass	7.2
Roads	10.4
Buildings	6.1
Houses	1.7
Railroad	0.0
Concrete	13.5
Watershed	38.9

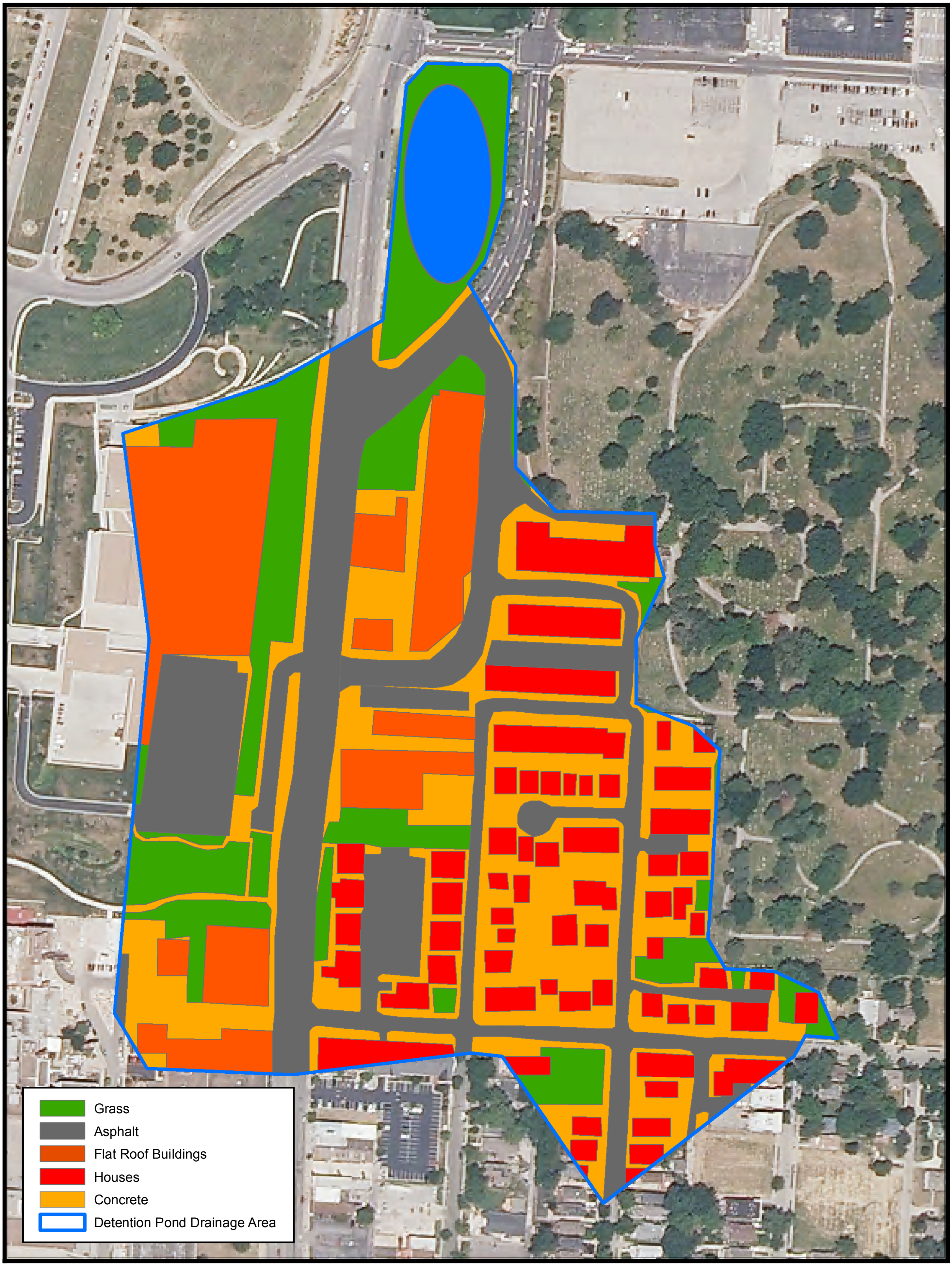


Figure 5.1.9: Crown Center Infiltration Basin

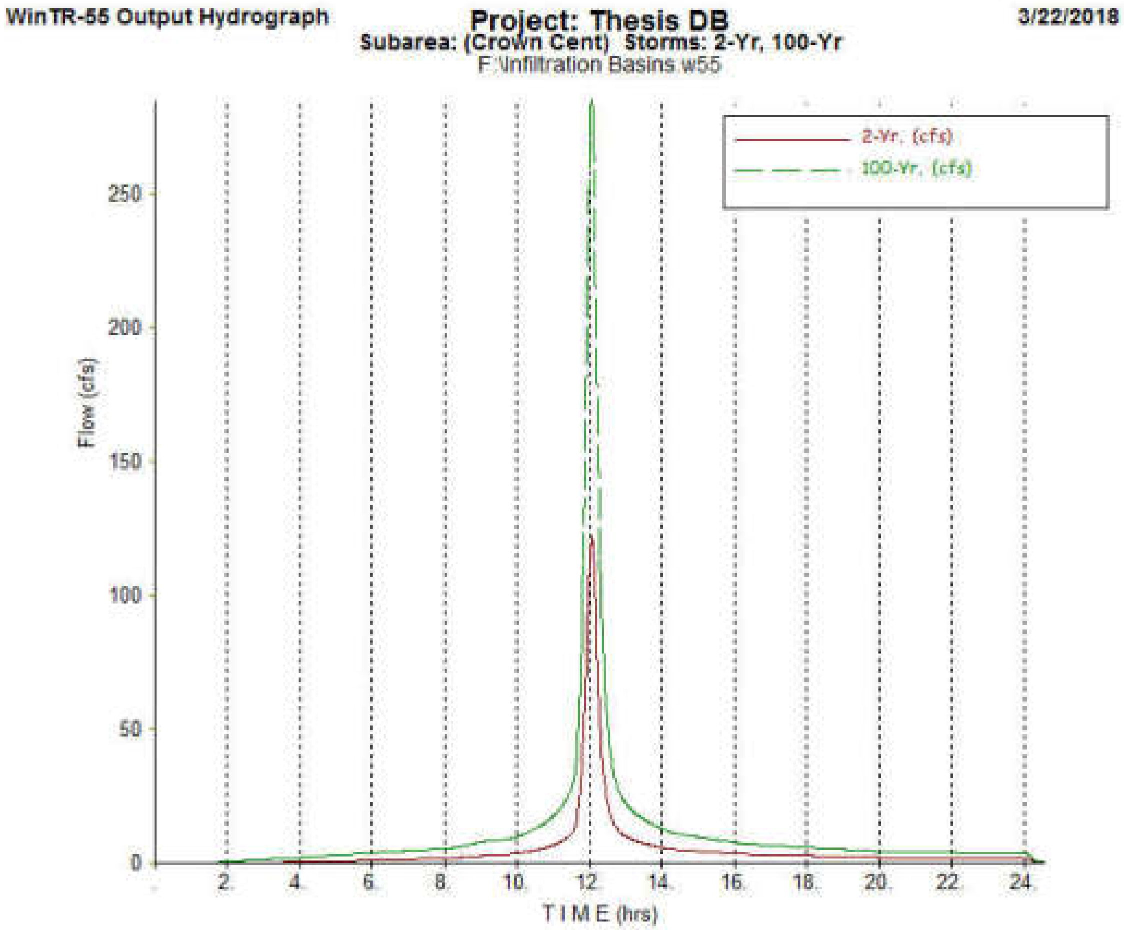


Figure 5.1.10: Crown Center Infiltration Basin Hydrograph

5.2 Small Area BMPs

From 2008 to 2013, UMKC performed a study on the Marlborough Neighborhood in the southeast section of the city. The purpose of the study was to monitor runoff volumes in a small watershed before and after the installation of 135 rain gardens and curb cuts over a 54.4 acre area. The results indicate that as much as 80% of the runoff could be captured with well-placed BMPs.

These findings have the ability to revolutionize the way urban planners and engineers think about stormwater design. For example, extrapolating from the UMKC study, 76th Terrace between Troost Avenue and Lydia Avenue is a quarter mile long and receives drainage from approximately 30 homes on 1/8 acre lots. The street has a 3% grade from west to east. Two rain gardens were placed in the right-of-way at the downslope intersection. Each rain garden is approximately 200 square feet and has a curb cut to capture the runoff. Simple solutions such as this can be implemented on almost every street.

Rain gardens are a solution for communities with high levels of citizen involvement. If property owners are committed to the maintenance of rain gardens, they can operate at a high level. In areas without that support, they are not a viable option, as city crews would not be able to maintain the gardens, as they are mostly on private property [32]. Some of the property owners in Kansas City would meet this criterion, others would not. It is a case by case basis.

5.3 Resulting Hydrographs

When accounting for the loss of surface area that the infiltration basins will absorb, the following hydrographs are the result. These values represent the reductions from the infiltration only and do not include the small area BMPs.

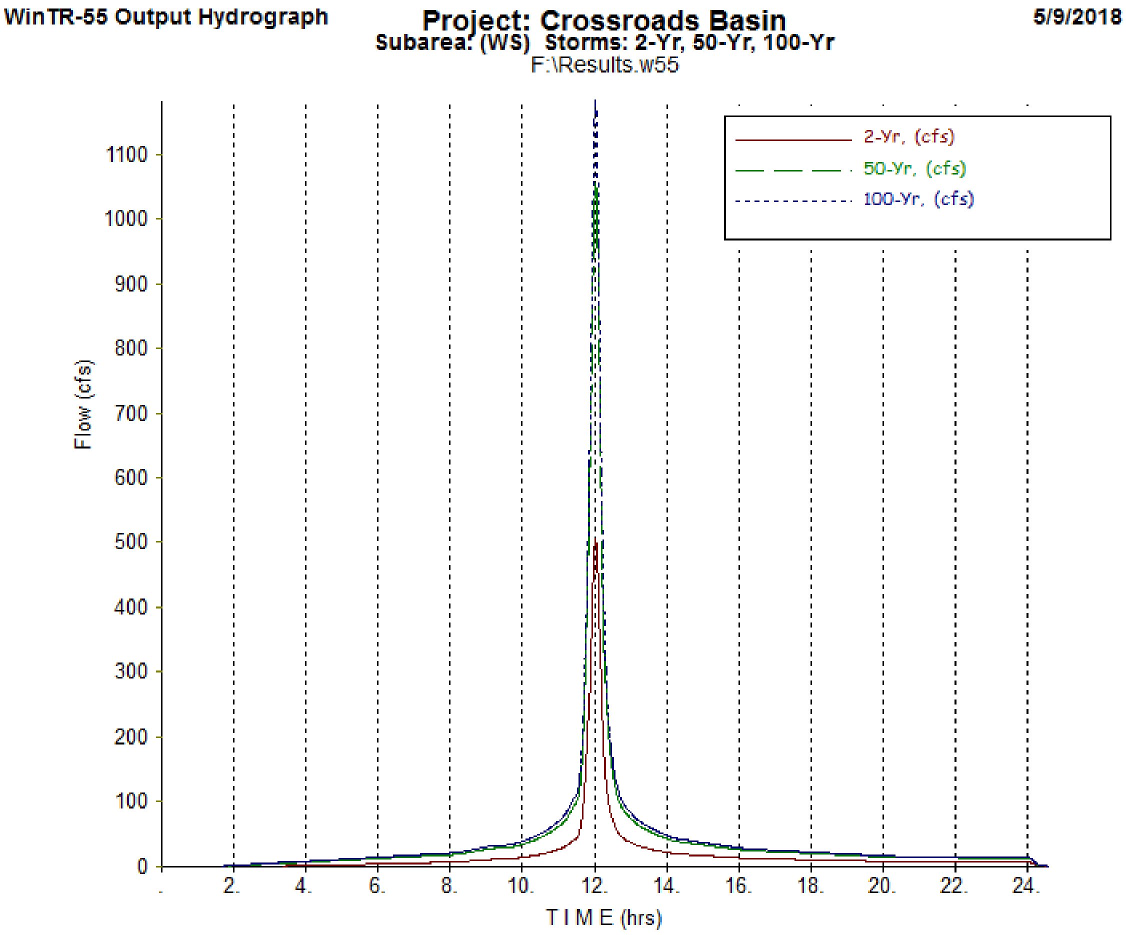


Figure 5.3.1: Resulting West Side Basin Hydrograph

Figure 5.3.1 shows the hydrograph for the Westside subbasin. The hydrograph peaks at approximately 12 hours, and has a peak reduction from 679.9 cfs to 505.3 cfs for the 2-year event, from 1,420.3 cfs to 1055.5 cfs for the 50-year event and from 1593.8 cfs to 1184.4 cfs for the 100-year event. All of these values represent roughly 26% of the runoff removed from the system.

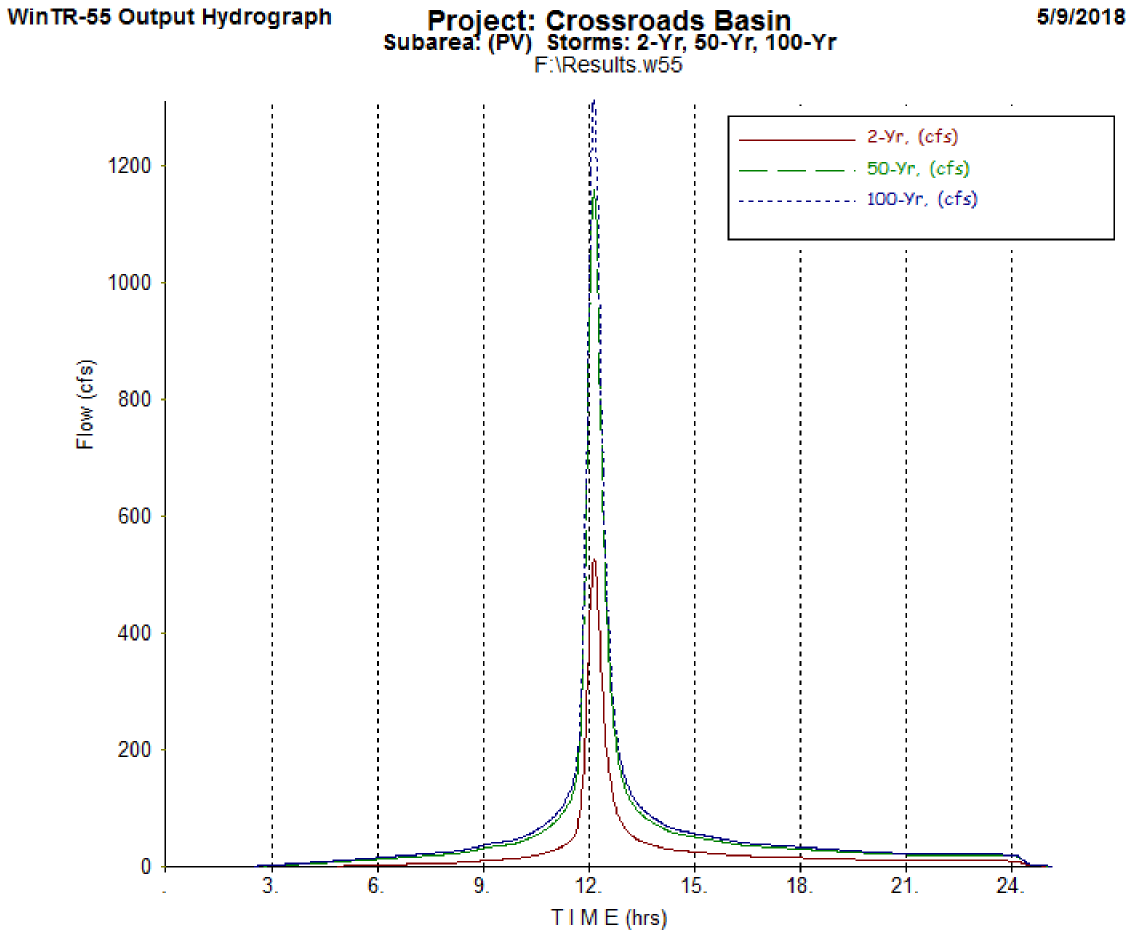


Figure 5.3.2: Resulting Penn Valley Basin Hydrograph

Figure 5.3.2 shows the hydrograph for the Penn Valley subbasin. The hydrograph peaks at approximately 12 hours, and has a peak reduction from 682.4 cfs to 524.9 cfs for the 2-year event, from 1507.5 cfs to 1159.8 cfs for the 50-year event and from 1706.1 cfs to 1312.5 cfs for the 100-year event. All of these values represent roughly 23% of the runoff removed from the system.

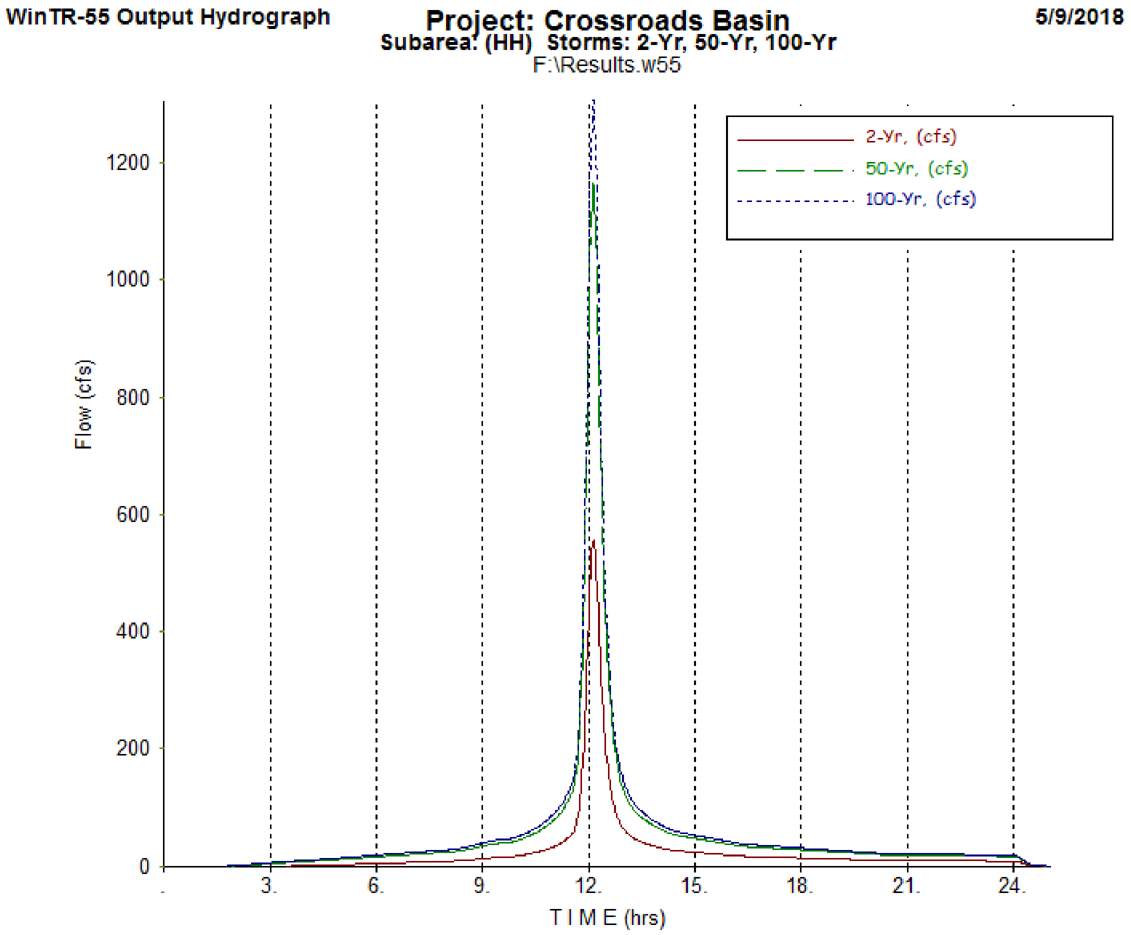


Figure 5.3.3: Resulting Hospital Hill Basin Hydrograph

Figure 5.3.3 shows the hydrograph for the Hospital Hill subbasin. The hydrograph peaks at approximately 12 hours, and has a peak reduction from 757.1 cfs to 557.0 cfs for the 2-year event, from 1613.1 cfs to 1164.9 cfs for the 50-year event and from 1811.9 cfs to 1307.1 cfs for the 100-year event. All of these values represent roughly 28% of the runoff removed from the system.

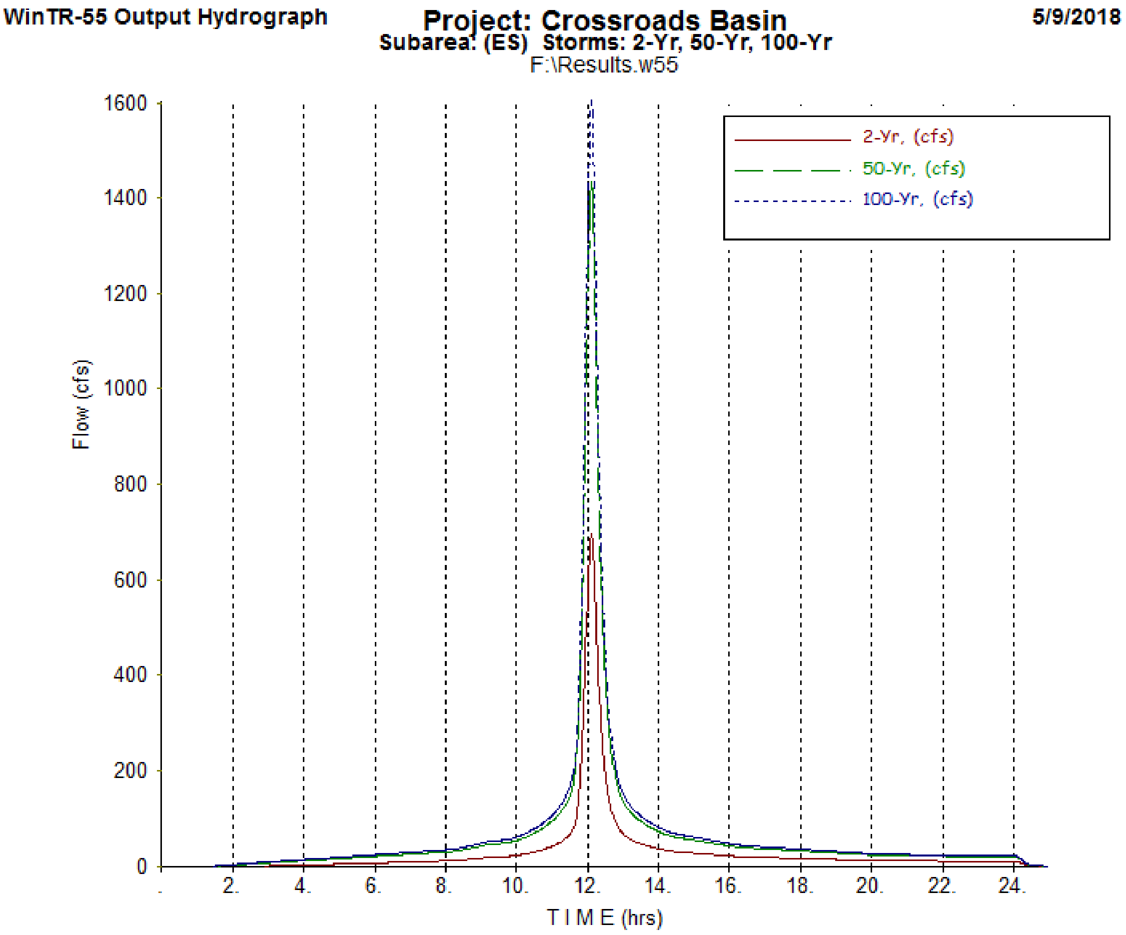


Figure 5.3.4: Resulting East Side Basin Hydrograph

Figure 5.3.4 shows the hydrograph for the East Side subbasin. The hydrograph peaks at approximately 12 hours, and has a peak reduction from 1018.7 cfs to 695.7 cfs for the 2-year event, from 2101.2 cfs to 1435.1 cfs for the 50-year event and from 2351.0 cfs to 1605.6 cfs for the 100-year event. All of these values represent roughly 32% of the runoff removed from the system.

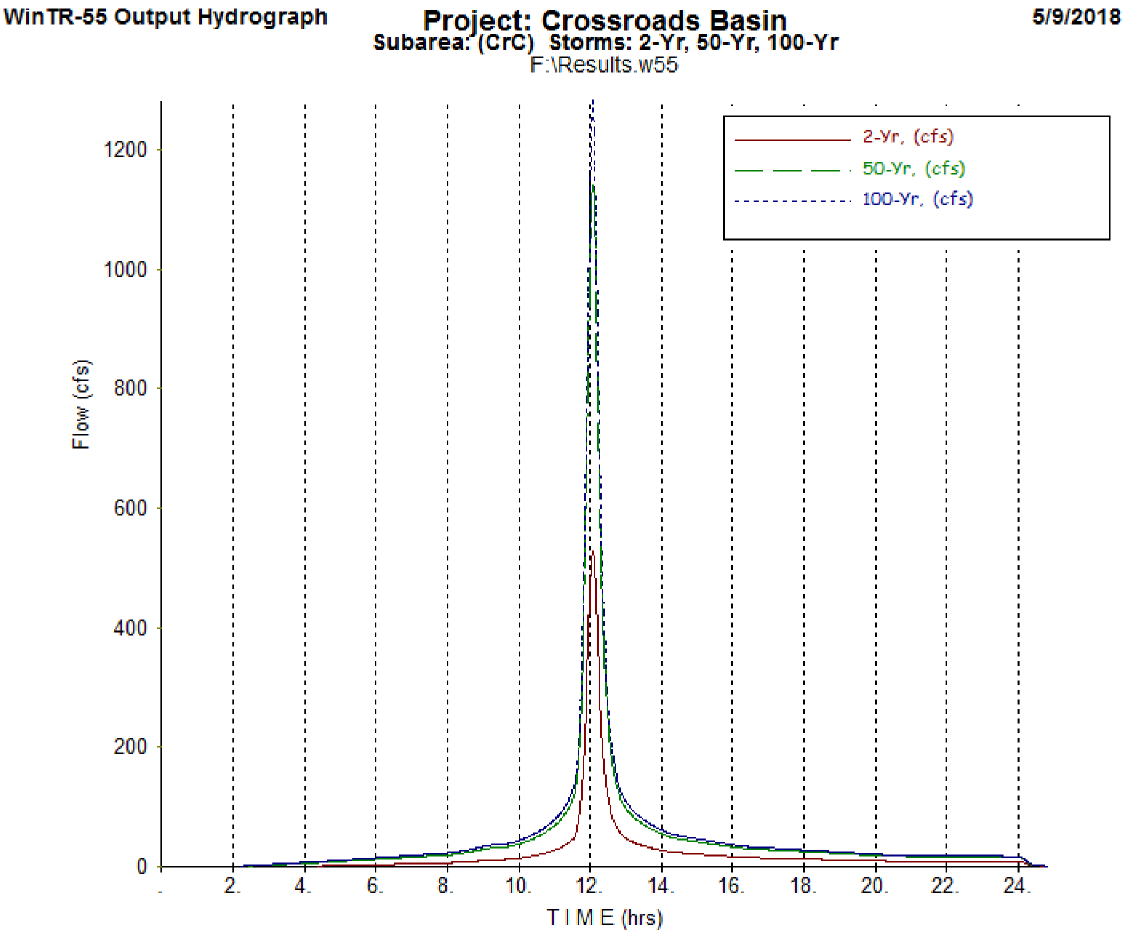
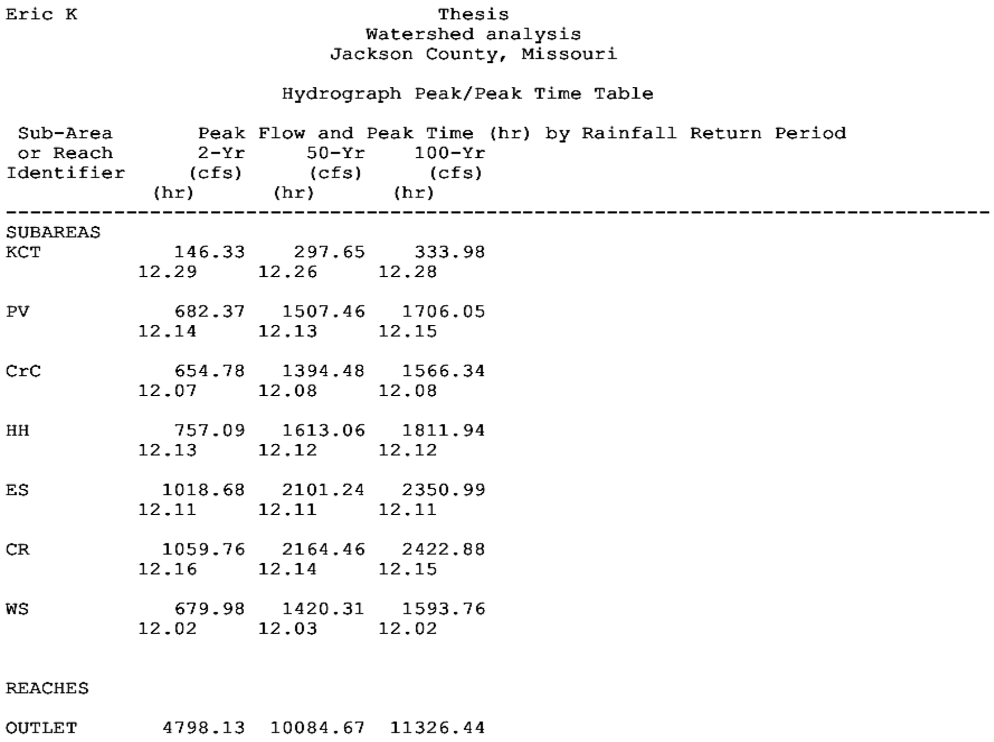


Figure 5.3.5: Resulting Crown Center Basin Hydrograph

Figure 5.3.5 shows the hydrograph for the Crown Center subbasin. The hydrograph peaks at approximately 12 hours, and has a peak reduction from 654.8 cfs to 526.5 cfs for the 2-year event, from 1394.5 cfs to 1140.9 cfs for the 50-year event and from 1566.3 cfs to 1284.7 cfs for the 100-year event. All of these values represent roughly 18% of the runoff removed from the system.



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Eric K                                  Thesis
                                 Watershed analysis
                              Jackson County, Missouri

                          Hydrograph Peak/Peak Time Table

 Sub-Area       Peak Flow and Peak Time (hr) by Rainfall Return Period
 or Reach       2-Yr      50-Yr    100-Yr
Identifier     (cfs)     (cfs)     (cfs)
            (hr)      (hr)      (hr)
----------------------------------------------------------------------------------
SUBAREAS
KCT            146.33    297.65    333.98
            12.29     12.26     12.28

PV             682.37   1507.46   1706.05
            12.14     12.13     12.15

CrC            654.78   1394.48   1566.34
            12.07     12.08     12.08

HH             757.09   1613.06   1811.94
            12.13     12.12     12.12

ES            1018.68   2101.24   2350.99
            12.11     12.11     12.11

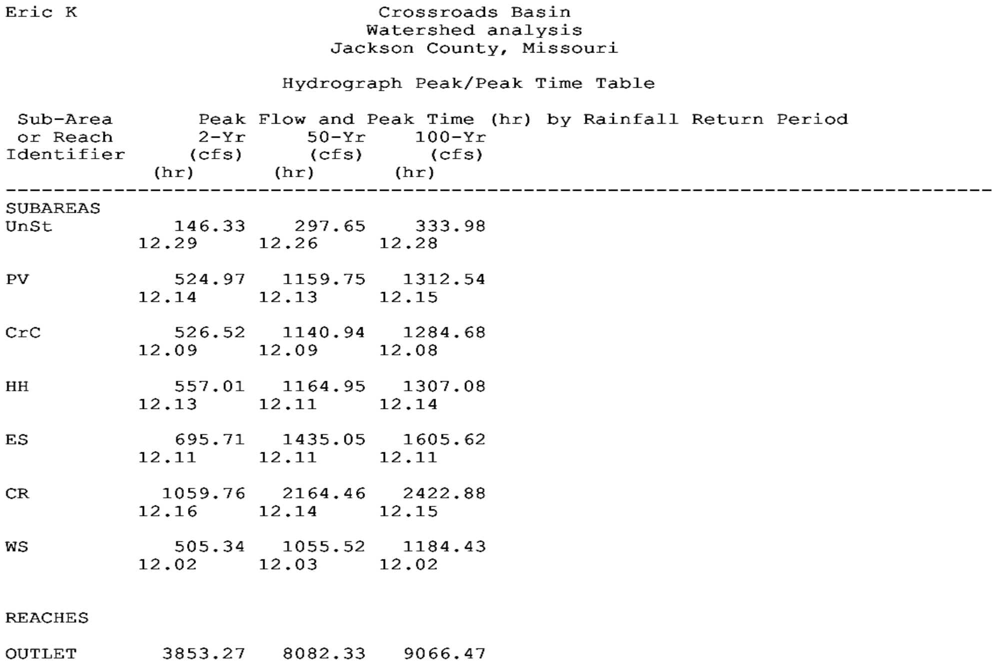
CR            1059.76   2164.46   2422.88
            12.16     12.14     12.15

WS             679.98   1420.31   1593.76
            12.02     12.03     12.02


REACHES

OUTLET        4798.13  10084.67  11326.44
```

Figure 5.3.6: Outlet Current TR-55 Peak Discharge



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Eric K                              Crossroads Basin
                                 Watershed analysis
                              Jackson County, Missouri

                          Hydrograph Peak/Peak Time Table

 Sub-Area       Peak Flow and Peak Time (hr) by Rainfall Return Period
 or Reach       2-Yr      50-Yr    100-Yr
Identifier     (cfs)     (cfs)     (cfs)
            (hr)      (hr)      (hr)
----------------------------------------------------------------------------------
SUBAREAS
UnSt           146.33    297.65    333.98
            12.29     12.26     12.28

PV             524.97   1159.75   1312.54
            12.14     12.13     12.15

CrC            526.52   1140.94   1284.68
            12.09     12.09     12.08

HH             557.01   1164.95   1307.08
            12.13     12.11     12.14

ES             695.71   1435.05   1605.62
            12.11     12.11     12.11

CR            1059.76   2164.46   2422.88
            12.16     12.14     12.15

WS             505.34   1055.52   1184.43
            12.02     12.03     12.02


REACHES

OUTLET        3853.27   8082.33   9066.47
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Figure 5.3.6: Outlet Proposed TR-55 Peak Discharge

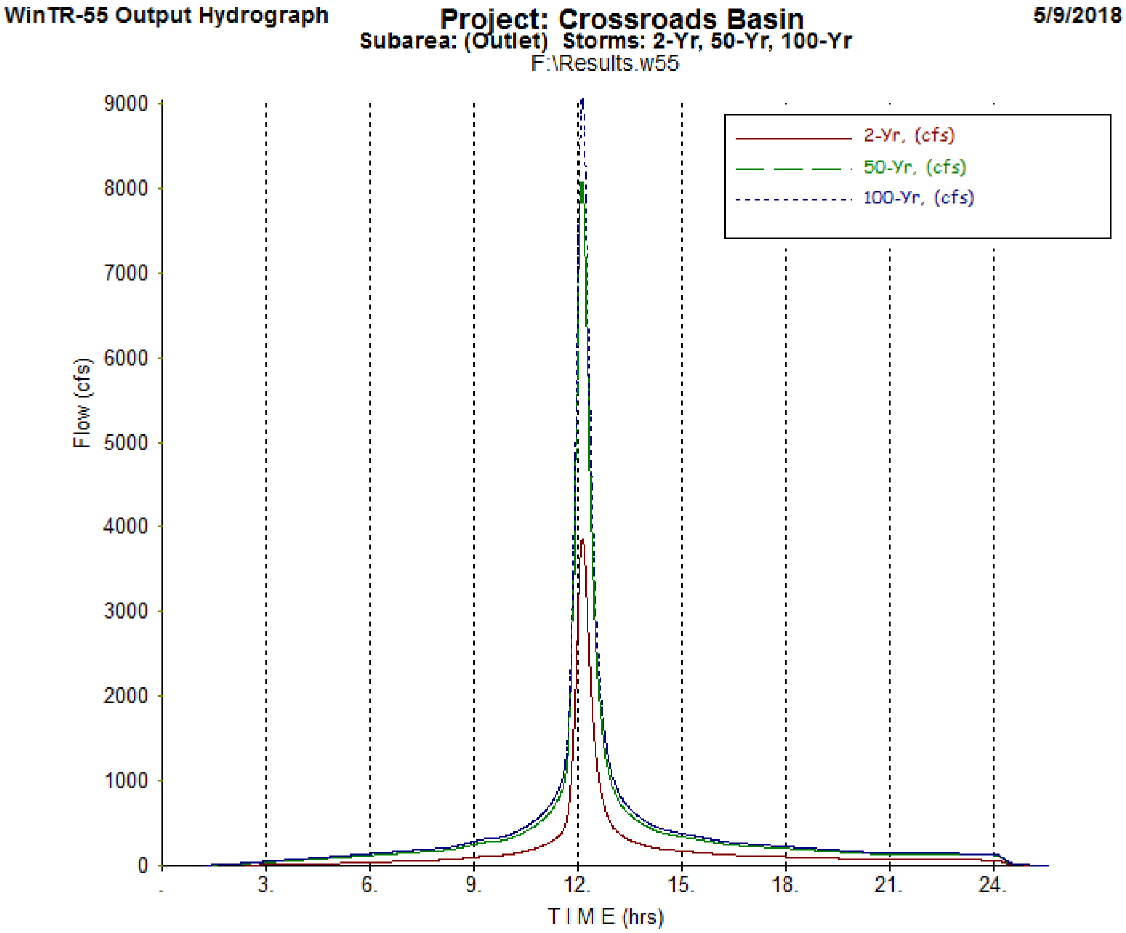

Figure 5.3.8: Current Outlet Hydrograph

Figure 5.3.6 and Figure 5.3.7 show the calculated discharges from TR-55 for the 2-year, 50-year, and 100-year rain events for the entire watershed. The discharges are for the current condition and the proposed condition with the infiltration basins included. The proposed conditions do not include the street-by-street small area BMP calculations as too many variables are involved to make blanket assumptions about the entire watershed.

Figure 5.3.8 and Figure 5.3.9 are the hydrographs associated with the watershed outlet for the current and proposed conditions. The peak discharge for the 2-year storm has decreased from 4,798 cfs to 3,853 cfs. The peak discharge for the 50-year storm has decreased from 10,085 cfs to 8,082 cfs. The peak discharge for the 100-year storm has decreased from 11,326 cfs to 9,096 cfs, an overall reduction of approximately 20% of the runoff.

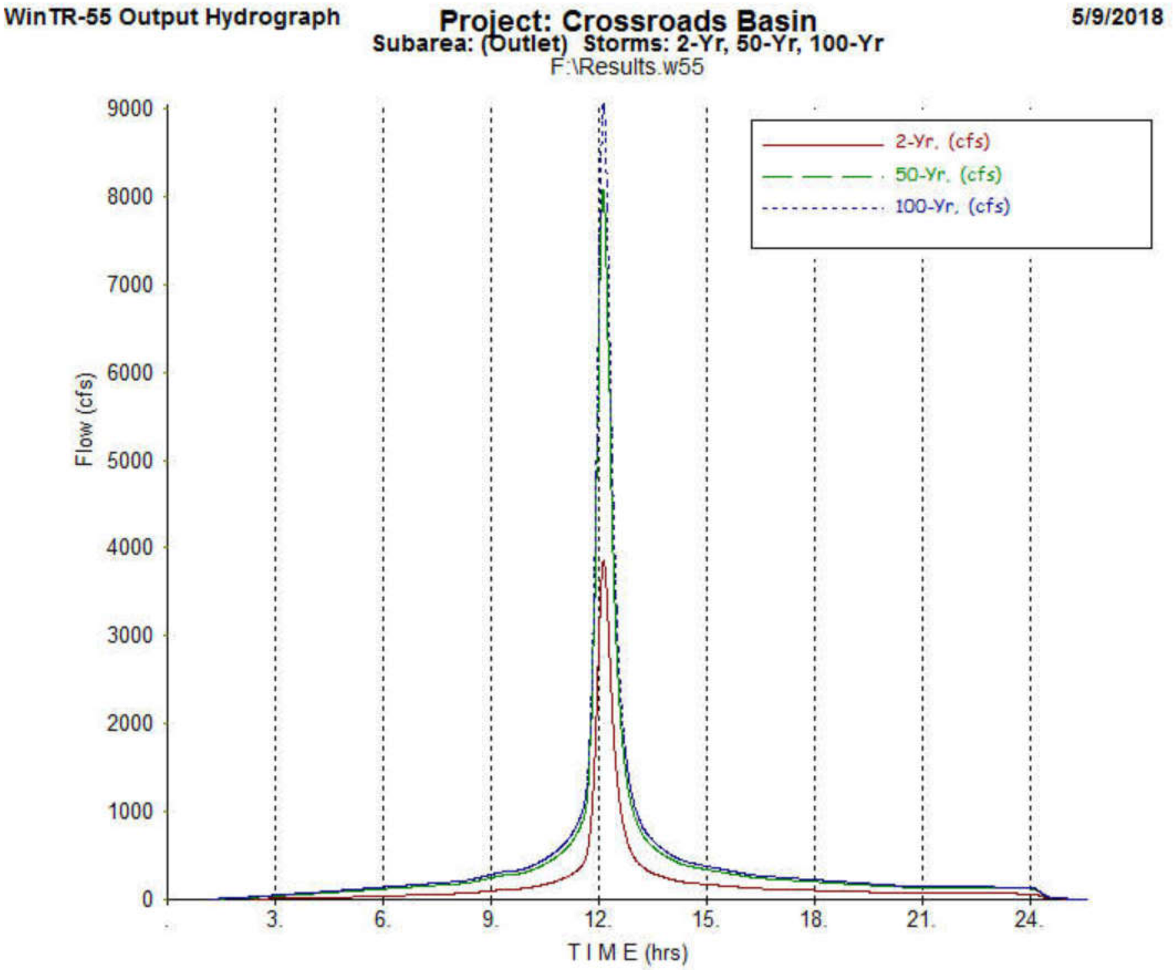

Figure 5.3.9: Current Outlet Hydrograph

CHAPTER 6 – CONCLUSIONS

Though this thesis has been theoretical in nature, if the solutions prescribed within this document were to be enacted, much of the City's stormwater problems could be alleviated [34].

The solutions found to be most effective in this study are infiltration basins and rain gardens. When water is captured from the roadways and diverted to infiltration BMPs, it can drastically reduce the runoff that is received by the city collection system.

Some considerations on these solutions include initial cost, maintenance, staffing, and community engagement. Though the upfront investment could save the city millions in the future, it can be difficult to persuade the public to make that commitment to unfamiliar practices. Maintenance will need to be performed on all BMP sites including trash removal, weeding, soil replenishing, and general upkeep. This will require the city to hire and train more staff. This can also be difficult to convince the public that this is a priority worthy of tax dollars. This is why community engagement and education is such a vital component of the urban BMPs success. People need to understand the significance of urban BMPs in order for the other components to work. Public education can also be an asset for preventing vandalism and having eyes on the ground when problems occur.

In order to do a full and thorough analysis, the storm sewer system would need to be entirely mapped, the pipe sizes would need to be known, and the hydraulics analyzed to determine flow direction, speed, etc. [34]. It was assumed that in all cases the stormwater system matched the topography of the ground above it, but it could be discovered that this is far from the reality. It is also assumed that the system flowed to a single point at certain locations and could be severed at certain points to divert flow to infiltration basins.

An alternative to reducing the overall amount of water in the wastewater system is to separate the combined sewage system. This would be a monumental task involving digging up nearly every street in Kansas City, relocating many utilities, large scale earthwork and purchasing two pipes for every road, one of concrete, the other PVC or similar material. The financial burden would be untenable.

Another alternative is to build larger wastewater treatment plants that can handle the flow from the system during 100 year events. The city currently operates seven wastewater treatment plants, making the upgrades extremely expensive. Upgrading the wastewater treatment plants would also do little to alleviate localized flooding in the roadways from stormwater systems that back up and flood when inundated. A good example of this is on Southwest Trafficway between 43rd Street and 31st Street. During large rain events, only the middle lane is passable of the three lanes in either direction. Similar problems exist on Volker Boulevard, Wornall Road, etc. Some roads and businesses located near the major creeks and rivers can sustain damage or have to temporarily close when the water gets too high. This problem will still persist with an upgrade only at the end of the hydraulic system.

Though this report details only one possible solution, due to the Consent Decree agreed to by the City of Kansas City and the EPA, doing nothing is no longer an option. Solutions must be found to address the CSO problem.

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