PC-SWMM MODELING OF POLICY CHANGES ON SUBURBAN WATERSHEDS IN JOHNSON COUNTY, KANSAS

by

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Abstract

Urban areas have traditionally been managed as separate entities from the natural environment. Recently, urban planners have been interested in reconnecting these areas back to the biosphere to capitalize on ecosystem services restoring damaged hydrologic processes. This study focuses on suburban Johnson County, KS (part of the Greater Kansas City area), which has 62 USEPA 303(d) listed "impaired" or "potentially impaired" waterbodies. Previous studies show that watersheds crisscrossed by multiple politically boundaries see increases in water quantity and decreases in water quality. Using a multi-watershed, multi-city spanning entity like a school district, it is investigated how stormwater best management practices (BMPs) employed over a large entity can help undo the negative effects of watershed political fragmentation.

BMP modeling includes simulating grassroots and planning policy change movements across three target watersheds using PC-SWMM watershed model. The grassroots simulation models rain barrels at single family homes and an extended dry detention basin (EDDB) at schools. Planning policy simulation models 10% and 20% reductions in impervious roads and parking lots in accordance to EPA Smart Growth practices. Resulting, it was seen that all three of these BMPs saw the greatest improvements from current conditions at low precipitation events. Ranking from least to most effective across the outlet's average flow, maximum flow, and total volume and supporting watershed infiltration, surface runoff, and surface storage are as follows: rain barrels + EDDB, 10% reduced, and 20% reduced impervious simulations. All three stormwater BMPs help demonstrate how grassroots movements and planning polices changes can positively impact regional waterbodies in this maturely suburbanized region.

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List of Acronyms

AIMS	Automated Information Mapping System
APWA	American Public Works Association
BMP	Best Management Practice
CSO	Combined Sewer Overflow
DEM	Digital Elevation Model
EDDB	Extended Dry Detention Basin
ET	Evapotranspiration
FISRWG	Federal Interagency Stream Restoration Working Group
JCSMP	Johnson County Stormwater Management Program
JOCO	Johnson County, Kansas
KC	Kansas City
KCMO	Kansas City Missouri
KDHE	Kansas Department of Health and Environment
LID	Low Impact Development
LIDAR	Laser Identification Detection and Ranging
MARC	Mid-America Regional Council
NRI	Natural Resources Inventory
SMSD	Shawnee Mission School District
SSURGO	Soil Survey Geographic Database
SWMM	Stormwater Management Model
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

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"Ad astra per aspera"	"Rule by obeying nature's laws"
State of Kansas' Motto	Kansas State University Motto

Preface

Interning in Johnson County's stormwater markets in the summer of 2014, I realized the growing role that stormwater managers have in urban planning. Not traditional in my engineering curriculum, I wanted to combine these while helping my hometown and public school district that shaped me for 13 years of my life become more environmentally sustainable.

Chapter 1 - Introduction

The planet has entered a human dominated era called the "Anthropocene" where over half of humanity resides in urban environments. From 2010 to 2030, urban populations are expected to increase from 50 to 60%, adding 1.5 billion people to cities worldwide (Elmqvist, 2013). This population increase poses many critical environmental issues in addition to existing ones. Traditionally, the built environment has been managed as a separate entity from the natural environment. However, as of recent urban planners are realizing the need to reconnect to the biosphere to capitalize on natural ecosystem services. These ecosystem services regulate and lessen negative urban environmental impacts and can help cities become more resilient towards climate change (Vogel et. al., 2015).

Johnson County, Kansas' Environmental Need

Kansas City Metropolitan is quickly growing and its governing structure is very complex causing many challenges for environmental management. Located on the edge of two states incorporating nine counties and one hundred and nineteen cities, these political boundaries fragment naturally occurring environmental boundaries like watersheds (MARC, 2015). Kim et al. (2014), correlates that watersheds across the U.S. with more political fragmentation (or multiple authorities/decision making structures cross managing the same natural resources) overtime see increases in water quantity and decreases in water quality. This can be attributed to natural systems and humans competing to manage watershed complexities resulting which can result in "non-reducible, spontaneous, and sometimes chaotic" outcomes (Kim et. al., 2014). Additionally, because watersheds are intersected and managed by multiple authorities/decision making structures, there can be issues of uncoordinated and competing relationships hindering watershed health goals.

In 2014, the KDHE listed 62 USEPA 303(d) listed, federally impaired or potentially impaired waterbodies within Johnson County (KDHE, 2014). These impairments are indicative of greater watershed impairments. In North America, fresh waterbodies (including rivers, streams, and lakes) have fauna extinction rates five times greater than terrestrial systems due to society having less values for freshwater systems (Thorp et. al., 2010). These 303(d) listings in Johnson County are primarily cited as affecting aquatic life. Ongoing studies by the USGS in Johnson County has found that as the percentage of impervious surface (e.g. parking lots, streets, and rooftops) increases in a watershed, the KDHE 10-metric aquatic insect score (based on richness and evenness) decreases (Figure 1.1; USGS, 2013).

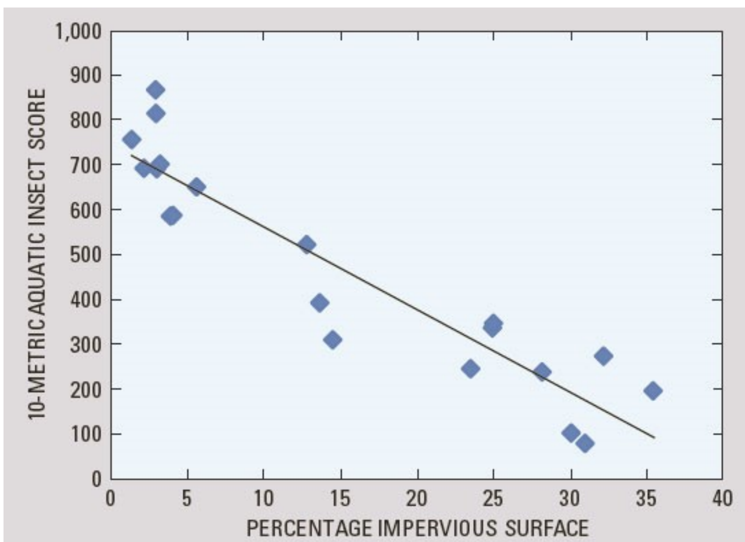


Figure 1.1: USGS generated graph of negative relationship between watershed impervious surface percentage vs. KDHE 10-metric aquatic insect score in Johnson County, KS (reproduced from USGS, 2013).

Further analyzing how aquatic communities are affected by watershed land coverings, the USGS in Johnson County analyzed watersheds that were mostly rural and mostly urban. Throughout 2003, 2004, and 2007 rural watersheds were able to better support aquatic insects with a majority of watersheds “partially supporting” while urban watersheds were mostly “non-supporting” (Figure1.2). Ecologically, watershed urbanization is transitioning Johnson County’s streams from supporting biologically diverse communities with pollutant intolerant aquatic insects (mayflies, stoneflies, and caddisflies) to less diverse communities composed of pollution tolerant insects (midges, leeches, and worms) (Rasmussen & Schmidt, 2009). Again, these findings are indicative of unhealthy watersheds.

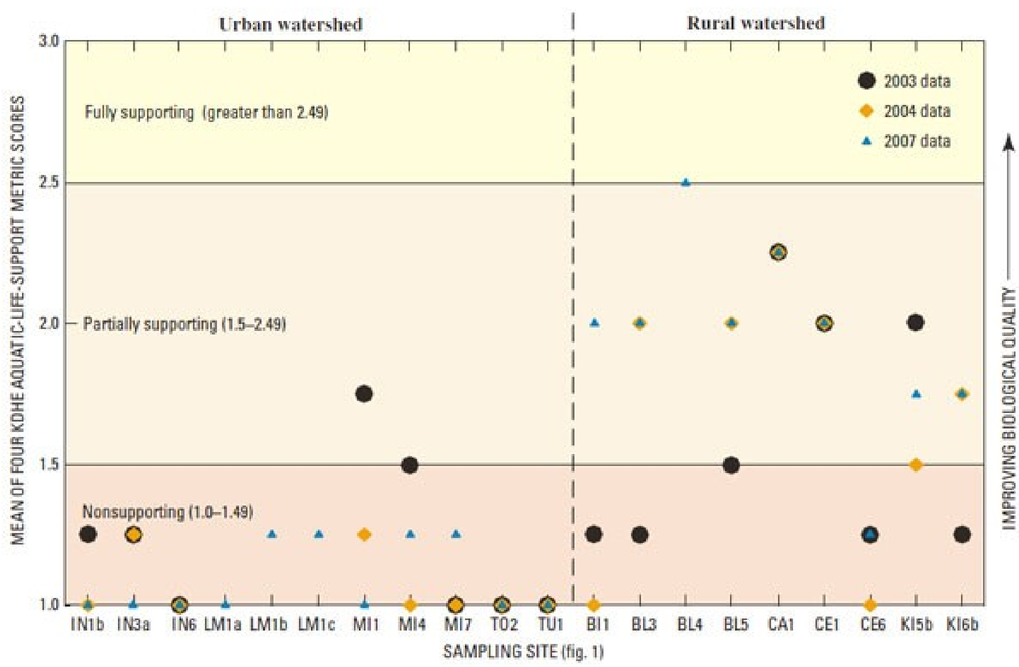


Figure 1.2: Plot of mean of four KDHE aquatic life support metric scores in Johnson County, KS (reproduced from USGS, 2013).

Macroinvertebrates are an easy indicator to sample for in stream and watershed health. Unlike instantaneous water chemistry tests, macroinvertebrate sampling looks at long term habitat support. Affected by both water quantity and quality, these macroinvertebrates are susceptible to slugs of pollutants or flashy pulses of flood water instantaneous water chemistry tests can miss (Braebrek et. al., 2002). Literature suggests that there is a threshold of 10-25%

imperviousness that watersheds can endure before macroinvertebrate richness and stream quality is degraded (Brabec et. al., 2002; Wang et al. 2011; Jacob & Lopez 2009; Bledsoe & Watson, 2001). Impervious surfaces reduce infiltration and increase surface runoff (Figure 1.3). This increase in surface runoff hits streams faster and with more energy causing erosion and down cutting in these urban environments (Bledsoe & Watson, 2001; FISRWG, 1998). These increases in impervious areas modifying natural hydrologic processes contribute to the 62 USEPA 303(d) listed waterbodies. It is not fully understood how policy changes with respect to grassroots movements and urban planning employed over a multi-watershed, multi-city spanning entity can help undo the negative impacts of political fragmentation (specifically increased water quantity), restoring natural hydrologic processes that urbanization impair.

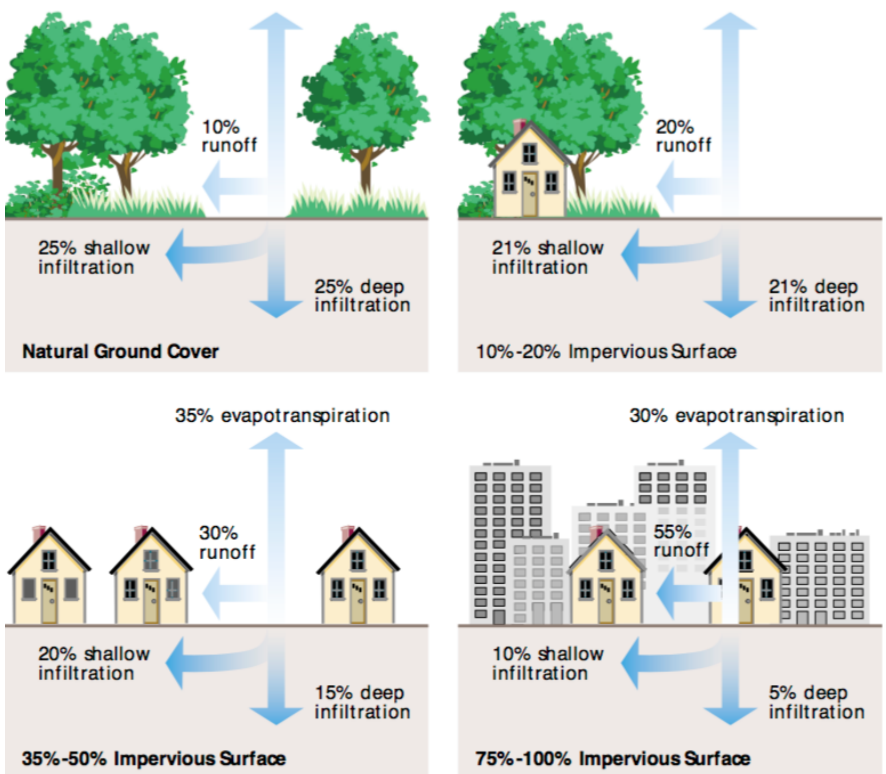


Figure 1.3: Graphic demonstrating how increases in urban density increases surface runoff and decreases infiltration (reproduced from FISRWG, 1998).

Overview of Stormwater Managing Political Entities in Johnson County

Highly politically fragmented watersheds are seeing increases in water quantity and decreases in water quality due to "destructive competition and/or a lack of systematic cooperation" amongst neighboring and overlapping political entities (Kim et al., 2014). Here, responsibilities and authority are not always clear and there can be differing levels and lengths of interest/investment in common overlapping goals. The three major types of political entities with a hand in Johnson County's stormwater management are outlined below.

First, MARC is a nonprofit planning organization unifying the two states, nine counties, and one hundred and nineteen cities spanning the Greater Kansas City Area (Figure 1.4; MARC, 2015). With respect to water resources, MARC provides technical expertise with studies, designs, and master plans, applies/manages national grants, and educates the public about water resources issues (MARC, 2015). Their extent spans from regional to the local governance levels, but it can be argued that this political entity's extent is too large and spread too thin to focus on localized watershed improvements.

Next, JCSMP was specifically created to unify Johnson County's stormwater management. Here, JCSMP completes most of the tasks as MARC, but they are solely focused on their twenty independent cities (Figure 1.4). These tasks include helping fund studies, designs, and construction of stormwater projects, updating floodplain maps, providing cities stormwater technical expertise, applying/managing national grants, and educating the public about water resources issues (JCSMP, 2015). Progressive for the Midwest, JCSMP has overseen the creation and monitoring of 11 pieces of green infrastructure throughout Johnson County. These are located within the International Stormwater BMP Database. Again, it can be argued that this nested entity is too large and spread too thin across the highly diverse Johnson County to see significant localized watershed improvements.

Finally, independent cities govern their own stormwater management. With these cities greatly varying in size, so do their resources to address stormwater issues. The larger city of Lenexa for example, runs a nationally award winning “Rain to Recreation” stormwater management program which writes progressive urban watershed management policies into its government (Figure 1.4; City of Lenexa, 2015). Notably, Lenexa was the first city in the Greater Kansas City Area to create a stream setback ordinance in 2002 (City of Lenexa, 2015). Additionally, the city completes biology and geomorphic inventories of their streams, designs and maintains stormwater BMPs throughout the city, and educates/funds public educational programs including rain barrel and rain garden cost sharing opportunities. This successful program is financially supported by a stormwater tax that 78% of residents passed (City of Lenexa, 2015). While the city of Lenexa is progressively managing stormwater issues, they are only doing so within their political boundary that covers four partial watersheds in the county. Thus, even one of the largest of Johnson County cities needs help from a larger authoritative/decision making entity to make entire watershed scale improvements.

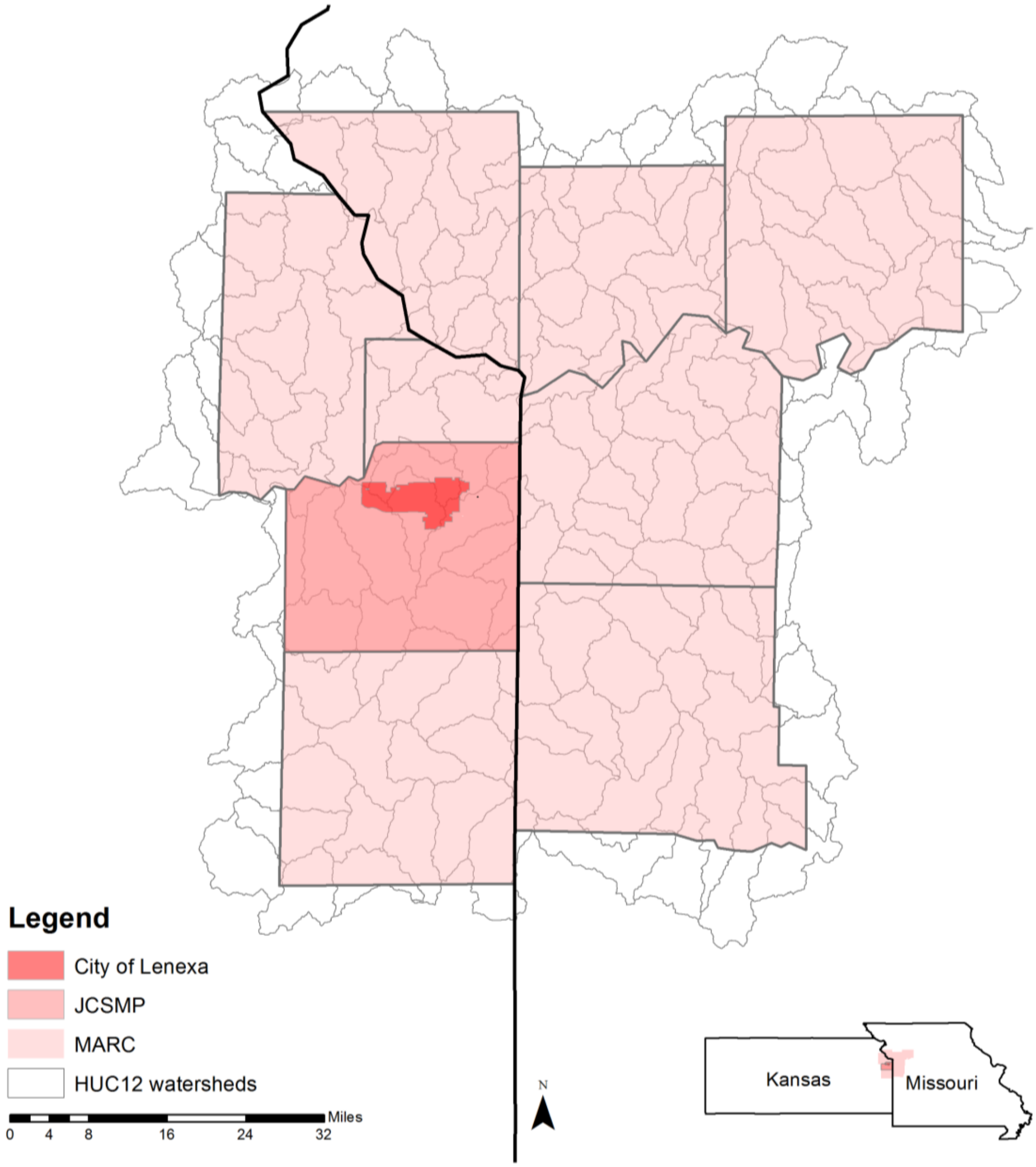


Figure 1.4: Map of political fragmentation in Great Kansas City Metropolitan who shares boundary with MARC. Map shows three different levels of watershed managers in the area with underlying HUC 12 watersheds delineated.

Why add another authoritative/decision making entity? With MARC and individual cities focused on multiple areas other than stormwater management, they are economically in favor of pro-growth and development. This urban development can conflict with water resource goals, laws, and ordinances. While MARC, JCSMP, and individual cities are all collectively working on maintaining and improving watershed health at various spatial scales, there is an opportunity for a different governing body to improve watershed management. For instance, an independent entity like the SMSD within Johnson County would be able to focus all three levels of stormwater management as it lies within the jurisdiction of watersheds and multiple cities. Furthermore, this entity has significant influence within Johnson County's oldest and most developed suburban core - an area of environmental need. The school district would also have larger success improving watershed health because of its ability to better target, educate, and motivate individual residents to help with the cause.

Educational Need in Johnson County

In July of 2009, JCSMP issued a stormwater survey to area residents measuring changing public views from the same survey issued three years earlier in 2006. The primary purpose of this survey was to understand what residents knew about water resources so that JCSMP could tailor public outreach programs. In 2009, 731 residents participated via mail or phone and the results are accurate to +/-3.6% at the 95% confidence level (ETC Institute, 2009). When asked about the term "watershed," 55% of residents did not know if they lived in a watershed, around a watershed, or were not familiar with the term. Only 32% of residents knew stormwater directly enters streams from stormwater drains without treatment. Around half (48%) did not know where stormwater went, 16% thought it went to a wastewater treatment plant, and 4% thought it went to water bodies after some treatment (ETC Institute, 2009). This survey demonstrates a significant area of water resources educational need in order for residents to understand why water resources matter, what their individual and communal impacts are to them, and how they can step in to make a difference. This education is needed to fuel a grassroots movement in water resources improvements.

Residents were also asked if they could personally help improve water quality in lakes, streams, and waterbodies, and 66% of residents responded that they could, 22% did not know, and 12% did not think they could. 82% of residents stated they have never participated in stream cleanup events and watershed festivals. Of this non-participating group, 44% indicated they would participate, 31% were unsure, and 25% would not participate if these stream cleanup events and watershed festivals were made public to them (ETC Institute, 2009). This indicates that there are a large untapped percentage of Johnson County residents (54%) that have participated or would participate in stream clean up events and watershed festivals if these events were made more public to them. There is great community potential to support and maintain a grassroots movement in water resources improvements.

Intergenerational Environmental Education

Intergenerational environmental education is the idea that sustainable practices taught to children at school can be shared from child to parent influencing entire households. These educational programs are found to be most effective at transferring knowledge from classroom to household when local issues are addressed and where households can positively take action (Georgios, 2013). Additionally, it is believed that ditching books and learning about these local issues in nontraditional settings (e.g. field trips, visits from professionals, extra-curricular activities, and hands on experiments) will foster more discussion at home as opposed to stationary learning from textbooks. One study of a Great Britain school district's new sweeping environmental education curriculum, taught across all grade levels, found that a majority of parents surveyed between two study classes at two separate schools believed that the district's sustainability initiatives had influenced their at-home adoption of sustainability practices. This is because sustainability was central in the district's curriculum, not just a mission statement

(Georgios, 2013). This school district was successful because teachers were on board, taught the curriculum to students, students shared this knowledge at home through homework activities, and the initiatives were again reinforced through newsletters to the parents.

Georgios' study, (2013) centered on municipal waste and recycling, domestic water use reductions, public transportation, and energy use reductions hypothesized that working class families might be more financially motivated to uptake sustainability practices while middle class families are more altruistic and ethically motivated. These motivations may be true, however, it was found that all families were interested in adopting more sustainable habits that saved money. This is great news because while Johnson County appears to be financially well-off, the SMSD of interest has 37% of its K-12 students qualifying for free or reduced lunch assistance (SMSD, 2013). Although, the Great Britain study focused more on multiple sustainability initiatives, it is believed this idea of intergenerational learning can be applied to watershed science facilitated through green infrastructure on public school properties.

By installing highly functioning, multifaceted green infrastructure at the SMSD schools, these areas can be used as outdoor classrooms to engage students in watershed science. These multi functioning educational landscapes can help reduce environmental impact on water resources (quality and quantity) at the localized school level as well as offer educational opportunities on sustainability, hydrology, green infrastructure, low impact development, biodiversity, native plantings, and pollinators, etc. to create more environmentally conscious students. These students would then be the drivers of sustainability information and diffuse it throughout their family's practices.

Green Infrastructure & Grassroots

The Midwest is behind the coasts in adopting sustainable stormwater management practices. This is evident in the scarce amount of green infrastructure and low impact development present in this region. For example, the International Stormwater BMP Database (2015) only has 11 documented pieces of green infrastructure in the Greater Kansas City area, all of which are within suburban Johnson County. One of interest is the EDDB located on at a SMSD area high school (Figure 1.5). This structure is primarily an infiltrating and water detaining pond that does not keep a permanent pool of water beyond its two day water holding design (MARC & APWA, 2012).

Figure 1.5: Photograph of EDDB at SMSD area high school with native vegetation. Photograph by Grant Brady.

Green infrastructure adoption issues in the Midwest are thought to stem from societal perceptions/awareness/education, government policies and regulations, and economics (Vogel et. al., 2015). Green infrastructure aims to restore natural hydrologic processes including infiltration, evaporation, and storage to treat stormwater quantity and quality at its source. These natural system approaches to stormwater management can help reduce air pollution, noise pollution, increase biodiversity, and increase cultural amenities in addition to improving stormwater runoff quantity and quality (Vogel et. al., 2015). Additionally, they can help buffer against negative climate change effects. Beddington et. al., (2011) states that the Midwest is likely to see more intense storms with longer durations between these storms because of climate change. Even if these ecosystem services are only functioning at fractions of their true natural state, the ecosystem service gains with green infrastructure far exceed grey infrastructure (or pipes and concrete channels traditional in stormwater networks).

Sustainable stormwater management practices also include moving away from centralized stormwater management (e.g. regional detention ponds) to mixed centralized and decentralized stormwater BMPs. This diversifies water quality and quality benefits (Vogel et. al., 2015). Stormwater practices not only include structures but they also include watershed management. This includes education, land use policy like maximum impervious area limits, and good yard-keeping limiting point sources pollution (Jacob & Lopez, 2009).

One major widespread stormwater BMP campaign that received national attention in the Greater Kansas City region is the "10,000 rain garden" initiative. Here, the city of KCMO started a grassroots effort to promote rain barrels and rain garden adaption by area residents to help intercept, detain, and infiltrate stormwater runoff before it headed to the city's CSO system under heavy regulation by the USEPA. The city of KCMO is still exploring a mix of grey and green infrastructure options to meet environmental compliance but this "10,000 rain garden" initiative has brought great public engagement into this issue. Additionally, the city of KCMO has created green street pilot projects where bioretention cells, porous sidewalks, rain gardens, and bioswales are strategically placed throughout the pilot Middle Blue River Basin (KC Water Services, 2013). Together, these grassroots and city demonstrations are fueling the success and awareness of each other.

Furthering this idea of using green infrastructure to meet environmental compliance throughout KCMO's combined sewer overflow system, Cohen et. al., (2012) completed a cost comparison for grey and green infrastructure in Kansas City, Missouri's Turkey Creek Basin (8.7 square miles). This study demonstrates how green infrastructure can show significant cost savings. Two scenarios were compared –grey infrastructure only and mixed grey and green infrastructure. For scenarios, base construction costs, traffic adjustment, land, engineering, administration, inspection, present worth operation & maintenance, salvage value, and project contingency were calculated. Grey infrastructure alone required upsizing pipes and underground storage areas. Pipes ranged from 12 to an astounding 26 feet in diameter. Grey infrastructure alone would cost $1.95 billion just within this 8.7 square mile basin for its 50 year lifespan. Grey and Green infrastructure showed cost savings between $22 and $35 million dollars based on whether 24,500 large rain gardens holding 214 ft^3 (1,600 gallons) each were modeled or 51,800 small rain gardens holding 100 ft^3 (750 gallons) each were modeled at individual properties. These cost savings were made from not having to upgrade grey infrastructure as much or as drastically. A spatial analysis was completed and it concluded that these rain gardens would fit within KCMO's current infrastructure and developments. These demonstrated and modeled simulations show how green infrastructure in the region is economically feasible and gaining popularity.

Public Policy & Planning

The Greater Kansas Metropolitan, like the Midwest, is also behind the coasts in sustainable planning policies. "With sustainability-oriented planning and design have yet to become prominent on either public works or in planning agendas" (ETC Institute, 2009). Planning issues in Kansas City have largely focused on managing aging infrastructure and traffic flow, not toward strategic planning for improving watershed health in the area even though there are obvious costs and impacts. Cities within the Greater Kansas City area are waiting for more progressive cities to employ Smart Growth practices and tie in green infrastructure before adopting it themselves (ETC Institute, 2015). The area is paying close attention to cities like Lenexa, Overland Park, and Olathe (all within Johnson County) to see how their more deviations from the planning status quo play out socially, environmentally, and financially. However, each of these three cities are maturely suburbanized for the most part. Current drivers of sustainability in the less progressive areas of the Greater Kansas City area include a grassroots organization of citizens respectfully campaigning for bike lanes. City planners in the region have been somewhat compliant trying to include extra bike lanes in new or redeveloped areas.

Although there is a tradeoff between water quality interested in decreasing impervious surfaces, and public health objects interested in increasing impervious surfaces for walking and biking initiatives, it can be argued that sprawl has largely defeated future walking and biking initiatives because areas of interest are far and disconnected from each other. Additionally, reducing impervious surfaces might be counter with bicycle safety, although it can be argued that the low adoption of bicycling is also in part due to existing safety with no bike lanes or alternative paths for bicyclists to use in these suburban watersheds. However, this can again be addressed through policy changes. Limiting parking to only one side of the street can still allow for thinner roads while still allowing for emergency vehicles to pass through. When the lifespan of these grey infrastructure networks end, instead of direct replacement of pipes and conduits, green infrastructure elements should be considered.

While green infrastructure structures can improve water quantity, it is also interesting to chip away at impervious surfaces bit-by-bit to throughout an entire watershed to see their improvements on water quantity. Communities that adopt Smart Growth strategies are better prepared to mitigate current and future environmental issues (USEPA, 2005). Smart growth principles of interest include shared parking lots, increased allowance of street parking, and reduction mandated parking lot and residential roads, and retrofitting existing parking lots with green infrastructure. The USEPA suggests that streets, which compose 40-50% of the impervious areas in residential developments, be narrowed 5-20%, resulting in lower amounts of stormwater runoff (USEPA, 2005). This has other benefits including water quality and reduction of the urban heat island effect (solar thermal absorption of paved structures) (APA, 2009) Commercial parking lots are designed with respect to old planning regulations created by parking demand surveys. Parking lots are considered "full" when 85-90% of their spaces are occupied (APA, 2009). This ensures that parking areas seldom or never fill and creates excessive impervious areas and stormwater runoff. Periods of high parking demand include the holiday shopping season, most notably Black Friday. However, peak shopping is now being distributed across stores with staggered day and hour Black Friday Sales. Additionally, the increase of online shopping is thought to have reduced Black Friday parking demand. Business parking areas are also overdesigned with some studies seeing 16-63% empty spaces in Midwestern areas (APA, 2009). This thesis is interested in reducing impervious areas through USEPA Smart Growth principles in maturely suburbanized watersheds.

Objectives

This study investigates how a large multi-city multi-watershed encompassing entity (specifically the SMSD) can undo the negatively correlated effects of political fragmentation and restore hydrologic processes in maturely urbanized watersheds. Explicitly, water quantity reductions from current conditions will be modeled using PC-SWMM (a popular watershed model for urban areas) by employing policy changes with respect to grassroots movements and urban planning changes throughout the SMSD.

With respect to a watershed grassroots movement, this simulation seeks to model the reduction in runoff if the school district employs educational green infrastructure at their locations that foster rain barrel adoptions at home. These educational green infrastructure pieces will be used as outdoor classrooms teaching hands on lessons about localized watershed issues. It is believed that this knowledge will successfully transfer from students to parents and encourage rain barrel use at home. Specifically, this simulation decided to model rain barrels at every single family residentially zoned lot as a best case scenario. Overall, this grassroots effort is only modeling easy to quantify stormwater structures and not more qualitative stormwater managing practices.

Second, policy driven modeling seeks to model reductions in runoff if the governing area creates policy reducing the amount of impervious surfaces in their area when roads and parking lots are redeveloped following Smart Growth principles. Specifically, a 10% reduction in impervious surfaces and a 20% reduction in impervious surfaces as hypothetically attainable by USEPA Smart Growth principles will be modeled.

The results of this study while specific to the watersheds modeled are thought to be somewhat transferrable throughout the Kansas City Area. The general ideas and theories as to “why” and “how” are transferrable to suburban watersheds throughout the Midwest. The remainder of this thesis is organized into chapters that address watershed selection and PC-SWMM model set up, a watershed analysis and comparisons, results and discussions, and final conclusions.

Chapter 2 - Site Selection & Model Set Up

The SMSD was chosen as a large multi-city, multi-watershed spanning entity to try and undo the negatively correlated effects of political fragmentation in the area. Figure 2.1 and 2.2 shows the SMSD which encompasses 76 mi^2, seven major watersheds and fourteen cities. SMSD covers approximately fifteen percent of Northwest Johnson County, Kansas' suburban core located all within Kansas City's I-435 loop. This district oversees forty five elementary, middle, high, and alternative schools with an enrolment of nearly 27,500 students. It is the third largest district in the state of Kansas (SMSD, 2013).

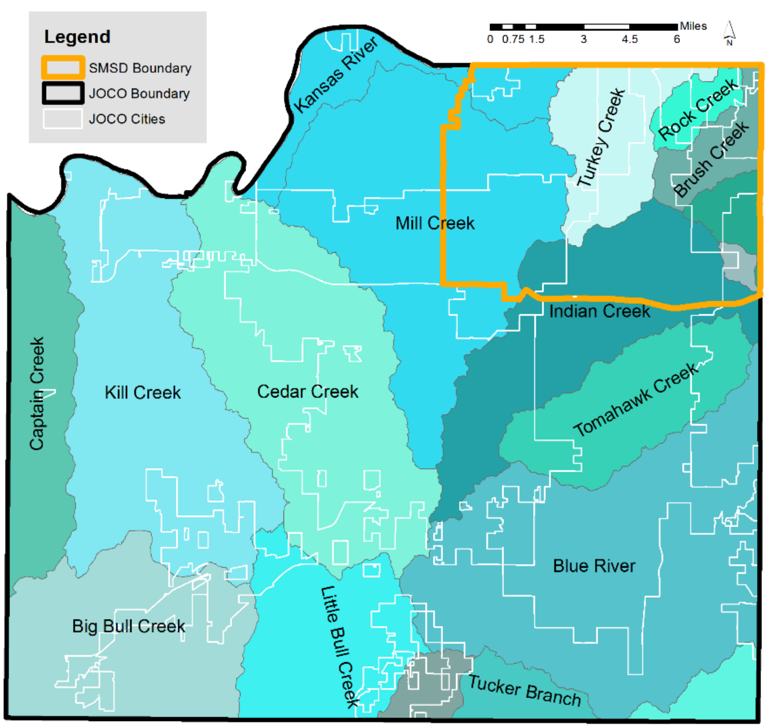


Figure 2.1: Map of Johnson County and its major watersheds and cities. SMSD, the focus area for this study is seen in the northwest corner.

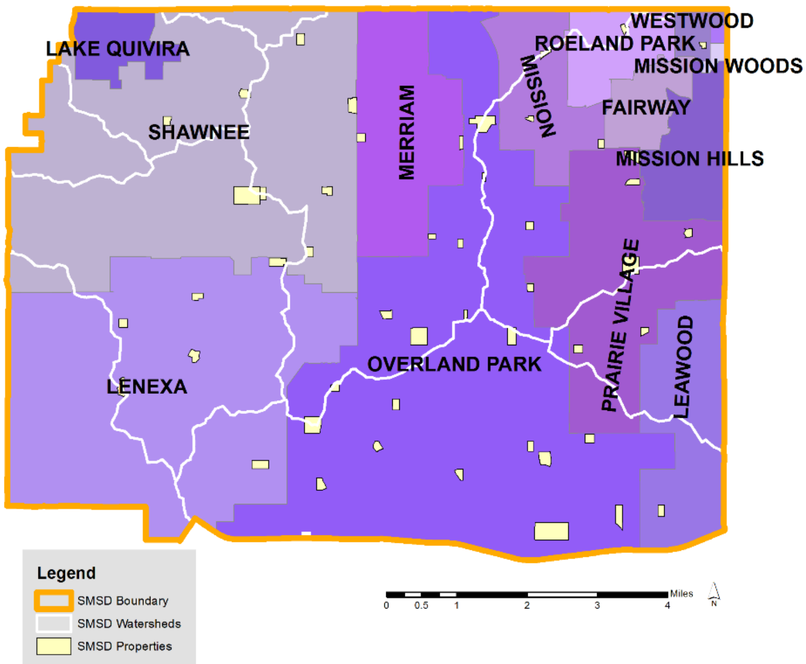


Figure 2.2: Map of the SMSD's major watersheds underlain with its 14 encompassing city boundaries. School properties are also shown in yellow rectangles.

Within this district, watersheds of approximately one square mile were selected with differing proportions of property zoning (primarily residential, mixed residential/business, and primarily business) to model different watershed scale BMPs. To do this, the LIDAR DEM with 3.2 x 3.2 ft raster size was used to delineate watersheds of about one square mile completely contained within the SMSD boundary were present (JoCo AIMS, 2013). Ultimately, only three watersheds met this criterion that also had at least one SMSD school located within its boundary and were composed of differing proportions of business/residential zoning. These watersheds (Figure 2.3) are named after the SMSD schools that they contain including Overland Park, Pawnee, and Westridge. All three watersheds are in completely mature suburbanized areas.

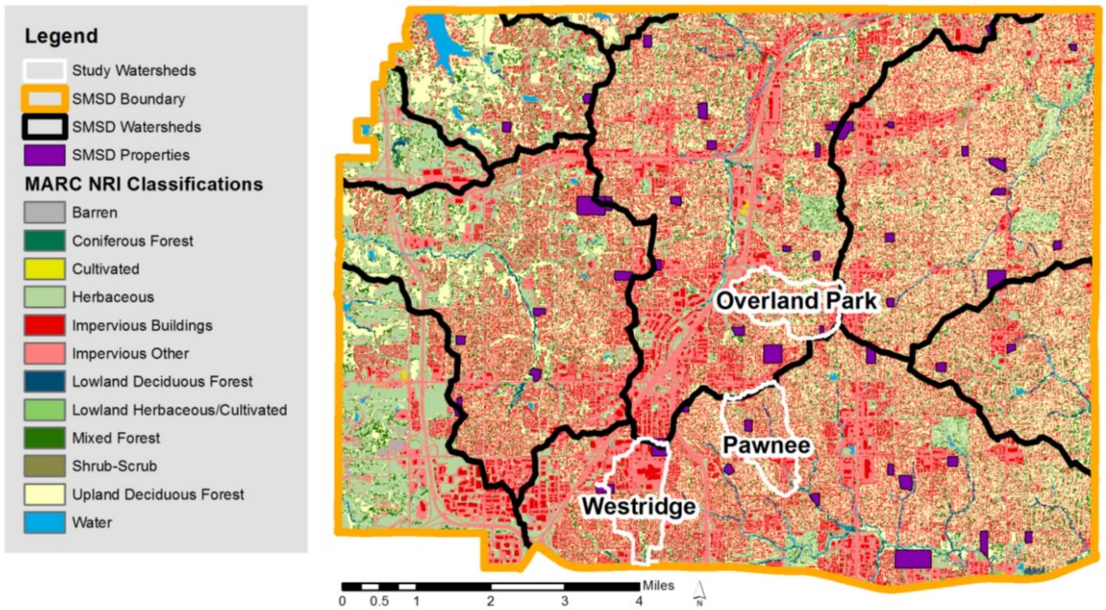


Figure 2.3: Land-use map of the SMSD's major watersheds and three square mile selected watersheds. MARC's NRI (MARC, 2013) data shows the land use land cover of the suburban district with red/pink showing impervious surfaces.

All three watersheds, with differing business/residential zoning proportions are used to understand the effectiveness of three watershed scale BMPs. PC-SWMM outputs of interest (including watershed infiltration, surface runoff, and surface storage; outlet average flow, maximum flow, and total volume) were compared amongst all three BMPs to current conditions. Additionally these outputs were compared across the watersheds to understand which zonings were more effective for each BMP. The first BMP is the grassroots inspired "RB+EDDB" scenario (Table 2.1). Here, adoption of rain barrels were modeled at every single family property, symbolizing maximum rain barrel adoption rates, in the watershed coupled with a 125,000 ft^3 EDDB located at each watershed's SMSD school site. This EDDB is modeled after an existing EDDB existing at one of the SMSD high schools and whose functionality is reported in the International Stormwater BMP Database (2015). The next two BMPs seek to understand the effect of planning policy changes in the area including a "10pctR" simulation and a "20pctR" simulation (Table 2.1). Here, NRI "impervious other" classified land use/land cover is reduced by 10% and 20% across the watersheds respectively. This represents the area adopting various levels of impervious reduction as the USEPA Sustainable Smart Growth principles have seen and believe are attainable (USEPA, 2005).

Table 2.1: List of PC-SWMM modeling simulations

Simulation	Details
RB+EDDB	55 gal. rain barrels modeled at every single family residential property, 125,000ft3 EDDB modeled at one SMSD property in each watershed
10pctR	10 % reduction in NRI's "impervious other" classification replaced by "herbaceous" area
20pctR	20 % reduction in NRI's "impervious other" classification replaced by "herbaceous" area

PC-SWMM Inputs

The following sections describe the major data inputs into the PC-SWMM model. Major model sections include subcatchments, subareas, infiltration, LID Controls, LID usage, junctions, outfalls, conduits, cross sections, timeseries, and coordinates.

Subcatchments

Inputs to the PC-SWMM model's subcatchment section included subcatchment size, percent impervious, flow width, percent slope, curb length, and snowpack. First, stormwater network GIS data was obtained from Johnson County AIMS including inlet, junction boxes, outfalls, conduits, natural channels (JoCo AIMS, 2015). Next, stormwater pipes over 24 inches in diameter were selected to further simplify the complex networks for modeling. Inlets along 24 inch or greater pipes were used as pour points to delineate and create subcatchments. Specifically, the pour points were snapped to the flow accumulation raster (an intermediate step within ArcMap watershed delineations) created by the LIDAR DEM using a snapping distance of 13 feet, which is half a residential road width. Delineated subcatchments under 0.50 acres were manually combined with larger downstream watersheds. On the other hand, subcatchments unrealistically too large were manually cut into smaller polygons using contour lines from the DEM as deemed necessary. This entire process resulted in a final set of subcatchments where subcatchment size in acres was able to be determined. Summary of watershed size, number of subcatchments, number of inlets and junction boxes, and lengths of conduits and channels for each study watershed can be seen in Table 2.2.

Table 2.2: Summary statistics of study watershed properties.

	Overland Park	Pawnee	West
Watershed Size (mi^2)	0.94	0.96	1.02
Number of Subcatchments	148	127	137
Number of Inlets and Junction Boxes	203	244	277
Lengths of Conduit and Channels (mi)	5.3	5.4	8.7

Percent impervious area was calculated using the MARC NRI (MARC, 2013). This 8.2 x 8.2 ft land use/land cover raster classifies barren, coniferous forest, cultivated, herbaceous, impervious building, impervious other, lowland deciduous forest, lowland herbaceous/cultivated, mixed forest, not classified, shrub-scrub, upland deciduous forest, upland herbaceous/cultivated, and open water areas. Subcatchment percent impervious was created by combining impervious building and impervious other (e.g. streets and parking lots) classifications to determine the percent area they occupied within each subcatchment. These calculations were again repeated with a 10% and 20% reduction in "impervious other" area simulations.

Flow width, or the width of overland flow within the subcatchment, was assumed at 5 ft. wide because a high majority of all overland flow within these subcatchments exits through a street cub to a stormwater inlet. Percent slope was averaged across the entire watershed. Overland Park resulted in a 6% slope while Pawnee and Westridge were slightly steeper 7% slopes. Curb length was ignored and set to 0 because it is only used in pollutant build-up analyses standardized to the length of curb. Additionally, snow pack was ignored and left blank.

Subareas

Subareas is another category that contains subcatchment properties including N-Imperv, S-Imperv, PctZero, RouteTo, and Pct Routed. USEPA SWMM 5 User's Manual (Rossman, 2010), suggests the Manning's *n* for impervious surface overland flow, or N-Imperv, is 0.013 describing "ordinary concrete lining." Likewise, the Manning's *n* for pervious surface overland flow, or N-Perv, is 0.24 describing "dense" grasses. S-Imperv and S-Perv are the depressional storage for impervious and pervious surfaces within the subcatchment. The USEPA SWMM 5 User's Manual suggests values of 0.05 inches and 0.2 inches for impervious surfaces and lawns, respectfully (Rossman, 2010). PctZero, or the percentage of impervious surface without any depressional storage, was placed at a 25% assumption. RouteTo field tells the PC-SWMM model which surface, either impervious or pervious, routes to the stormwater inlet. Using the impervious GIS polygons created during the percent impervious calculations, stormwater inlets were identified as being contained on impervious surfaces or non-impervious surface using ArcMap's select by location tool. This created impervious or pervious categories with PctRouted, or percent routed, left at 100%.

Infiltration

The SCS Curve Number Method was chosen over the Green-Ampt method because of its ability to account for both above surface interception and below surface infiltration. SCS Weighted curve numbers were created by intersecting MARC NRI land use/land cover data

(MARC, 2013) with SSURGO soil hydrologic group GIS layers (Soil Survey Staff, 2015), assigning individual curve numbers (Table 2.3), and then calculating the weighted average curve number for each individual subcatchment. USEPA SWMM 5 User's Manual (Rossman, 2010), suggests the dry time, or time it takes a fully saturated soil to completely dry out, ranges from 2-14 days with our model selecting an intermediate 7 days; however, this is not factored into this study because our continuous models do not allow for dry days between storms. Problems using the SCS Curve Number method could include when vegetative surfaces cover impervious surfaces picked up by the MAR NRI (e.g. when trees shade streets, parking lots, and buildings). Here the SCS Curve Number method will account for interception by the vegetated surface, but not the impervious surface below that prevents infiltration. Thus, it is likely that there are some impervious surfaces unaccounted for in the 8.2 x 8.2 ft. raster cells of the MARC NRI.

Table 2.3: Curve numbers chosen for MARC NRI classifications and accompanying hydrologic group from (Huffman et al., 2011). "-" indicate this combination of NRI and hydrologic soil group were not present.

MARC NRI Classifications	Hydrologic Group		
	B	C	D
Barren	82	87	89
Herbaceous	61	74	80
Impervious Buildings	98	98	98
Impervious Other	98	98	98
Lowland Deciduous Forest	55	70	-
Lowland Herbaceous/Cultivated	69	79	-
Mixed Forest	55	70	77
Shrub-Scrub	48	65	73
Upland Deciduous Forest	55	70	77
Water	98	98	-

Weighted curve numbers were recalculated for the 10pctR and 20pctR simulations with herbaceous areas and their appropriate underlying soil hydrologic group replacing 10% or 20% impervious other surfaces in each subcatchment.

LID Controls

These LID Controls and LID Usage sections only pertain to the RB+EDDB simulations. Here in LID Controls, design properties of the two LID controls used – rain barrels and EDDB are listed. Rain barrels are modeled as 7.4 ft^3 (55 gal) containers with no underdrain. Properties include a barrel height of 35 inches, a drain coefficient of zero to simulate the lack of underdrain, and a surface area of 2.76 ft^2 of surface area. These barrels were modeled to overflow onto pervious areas.

EDDBs were modeled as a bioretention cell with a tall berm and no underdrain. Using the SMSD EDDB's published data on the International Stormwater BMP Database (2015); the EDDB was designed to retain a flood volume of 125,000 ft^3 with an 11 acre watershed flowing into it. This was accomplished by creating a 25,000 ft^2 bioretention cell with a 5 foot tall berm with no underdrain. All other properties within the EDDB usage were model defaults. Notable attributes include a soil thickness of 12 inches, porosity of 50%, suction head of 3.5 inches, and a seepage rate of 0.5 in/hr. Not modeled, but interesting from a functionality standpoint, the SMSD EDDB first detains and treats 1.15 acre feet of water for water quality polishing. However, the entire system is built on a staggered 5, 10, 25, and 100 year outlet system and can detain up to 2.86 acre feet of water for flood detention for a maximum 48 hours (International Stormwater BMP Database, 2015).

LID Usage

LID Usage lists how many rain barrels and EDDBs are in each subcatchment. For the rain barrels, property zoning data by Johnson County AIMS (JoCo AIMS, 2015) was used to identify how many 'single family residential' properties were within each watershed. This total number of residential properties was used as the total number of rain barrels each watershed. Because subcatchments intersect this single family residential zoning layer and fragment properties into two or more subcatchments, rain barrels were accounted for at only the largest intersected properties up to the total watershed number. For example, there are 832 single family residences in the Overland Park watershed. After intersecting subcatchments with single family residential properties, there were 1,647 single family residence polygons. Only the largest 832 polygons were selected and were summed within each subcatchment. This means that there are exactly the same numbers of rain barrels as single family residential properties, but some subcatchments might be slightly overestimating while others slightly underestimating the number of rain barrels within them.

EDDBs were placed in school property subcatchments. If these subcatchments did not have a full 11 acres to drain into the EDDB, then this square footage was proportionally divided into two adjacent subcatchments.

Junctions

Junction properties include invert elevation, max depth, and surcharge depth for stormwater inlets receiving subcatchment surface runoff as well as junction boxes that only connect two conduits together. Invert elevation was acquired from the Johnson County AIMS stormwater network data (JoCo AIMS, 2015). From here, max depth was calculated by subtracting the surface LIDAR DEM elevation from the invert elevation in feet. When pipe invert information was missing, or when surface elevations were erroneously below pipe invert elevations, a simple correction was made. This included taking either the more trusted ground or invert pipe elevation and either adding or subtracting the pipe diameter plus 18 inches which is a standard height needed for stormwater inlet/manhole covers (APWA, 2013).

Surcharge depth or depth of water able to flow above the maximum depth that is allowed before the inlet/junction boxes flood was set to 5 feet. This modification helped the models run more smoothly without getting hung up on minor inaccuracies in invert or max depth data.

Outfalls

Outlets of all three watershed stormwater networks were modeled as "free" outfalls. Here, only invert elevation was needed. No other outlets were found within the stormwater network data on pipes 24 inches and larger.

Conduits

The conduits section primarily includes naming data to link junctions and pipes together. Additionally, length and Manning's n data was needed. Length (in feet) was directly obtained from Johnson County AIMs stormwater network data (JoCo AIMS, 2015) while Manning's n was changed depending on conduit/channel material. Here, values used were 0.013 for concrete pipes/channels, 0.025 for corrugated metal pipes, and 0.30 for natural channels and were determined by the USEPA SWMM User's Manual (Rossman, 2010).

Cross Sections

Another category for conduits, Cross Sections includes shape of pipe (e.g. rectangular closed, semielliptical, circular, arch, trapezoidal) and pipe geometry. Shape of pipe and pipe geometry (diameter in feet) were directly from Johnson County AIMS stormwater network data (JoCo AIMS, 2015). Natural channels on the other hand were manually determined. Here, natural channels were modeled as trapezoids with their geometry estimated by cutting sections in the LIDAR DEM using ArcMap's 3D analyst features. Cross section data inputs include, geometry 1 (base width in feet), geometry 2 (depth in feet), and geometry 3 and 4 (left and right side slopes ft. /ft.).

Timeseries

Timeseries is where precipitation events are created. Single storm events were of high interest to this study. Here, small one year SCS Type II, 6 hour and 24 hour events were created. The 6 hour event is centered around the 3 hour mark and composed of 5 minute intensities intervals totaling 2.23inches (Figure 2.4). The 24 hour event is centered on the 12 hour mark and was analyzed under 6 minute intensity intervals totaling 3.09 inches respectively (Figure 2.5).

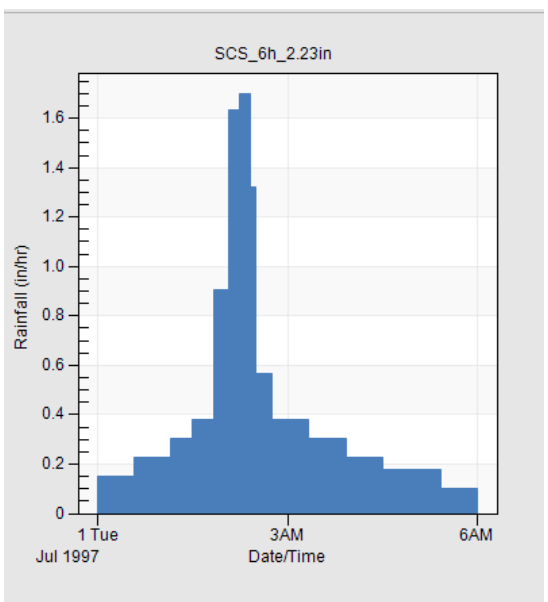


Figure 2.4: Graph of one year SCS Type II 6 hour rainfall intensity vs. time. Total rainfall volume is 2.23 inches

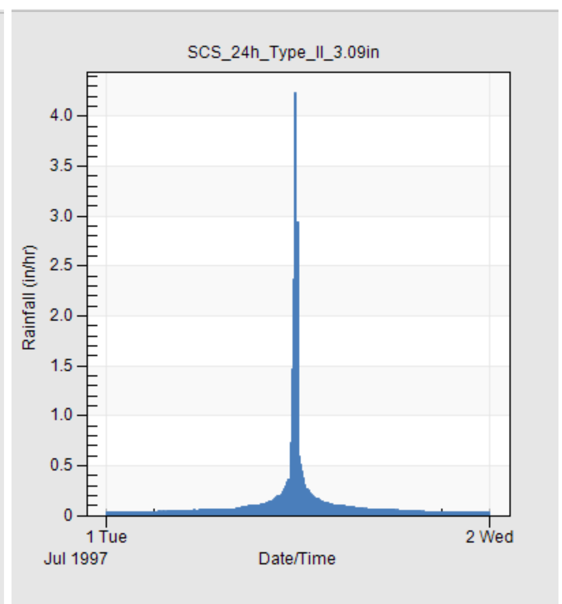


Figure 2.5: Graph of one year SCS Type II 24 hour rainfall intensity vs. time. Total rainfall volume is 3.09 inches.

Similarly, continuous storms under climate change constraints were of interest. Here, one year 48 hour and 7 day rainstorms were created using the upper 90 percentile of the NOAA Atlas 14 Point Precipitation Frequency Estimate for the Overland Park, Kansas area (Perica et al., 2013). For the one year, 2 day event, standard 48 hour SCS Type II intensity was used. Here, the storm is centered on the 24 hour mark and 15 minute rainfall intensity intervals were used with a total rainfall depth equaling 4.39 inches (Figure 2.6). The one year, 7 day event was uniquely modified. Here, the total rainfall depth equaled 6.00 inches but this was split up into 7 back-to-back SCS Type II one day events totaling 0.86 inches (Figure 2.7). These back-to-back 24 hour storms were centered on the 12 hour mark with 30 minute intensity intervals.

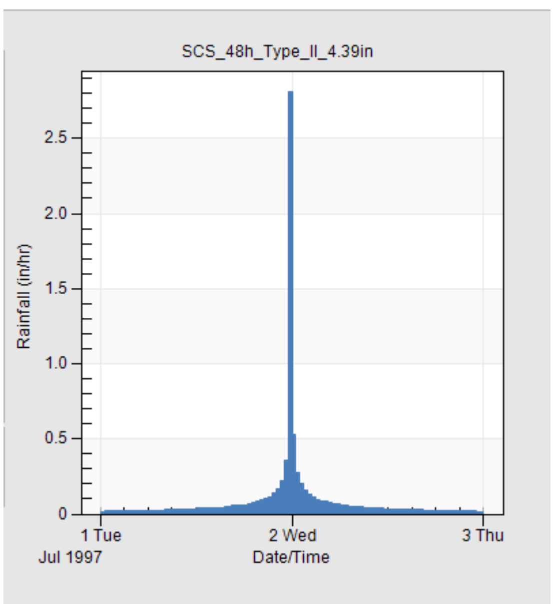


Figure 2.6: Graph of one year SCS Type II 48 hour rainfall intensity vs. time. Total rainfall volume is 4.39 inches.

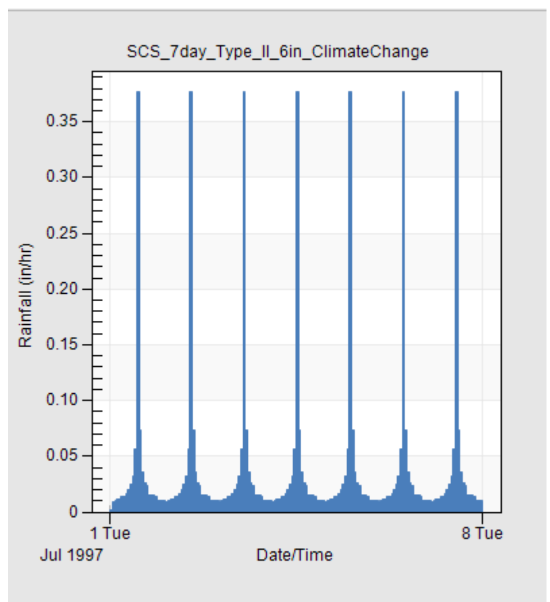


Figure 2.7: Graph of one year SCS Type II 7 day rainfall intensity vs. time. Total rainfall volume is 6.0 inches.

Coordinate

Longitude and latitude imported from Johnson County AIMS stormwater network data (JoCo AIMS, 2015) was used for visualization of the stormwater networks within PC-SWMM. This was only necessary for junction data points.

Calibration

Pipe networks were calibrated by running a 25 year, 24 hour SCS Type II storm (6.75 inches, the design standard for non-primary roads in Johnson county) within the PC-SWMM models and resolving node flooding issues at nodes with total flooding volumes greater than 0.5x10^6 cubic feet. This primarily included readjusting pipe inverts that were not properly aligned to allow smooth drainage. These kinked stormwater conditions could exist in real life, but it is assumed for these instances; Johnson County AIMS data was inaccurately reported.

Calibration was attempted recorded rainfall data and stream water height sensors at the outlet of Westridge's box culvert with known cross sectional dimensions. Here, the recorded rainstorms were run through the PC-SWMM model and peak discharges within the PC-SWMM model were compared to calculated discharges from the water sensor data. This calculation of peak discharge was accomplished using the Manning's equation and estimating a range of Manning's n values from the receiving natural channel and estimating a range of velocities running through outlet's box culvert. These minor changes in estimated Manning's n values and velocities produced comparable discharges from the real and modeled outlet discharges. Peak discharges were also compared across all three one square mile watersheds, and all discharges were closely related. Thus, Johnson County AIMS stormwater network data is accurate enough to investigate the objectives of this thesis without more stringent watershed.

Chapter 3 - Watershed Analyses & Comparisons

Although Overland Park, Pawnee, and Westridge watersheds are within two miles of each other, they have vastly different compositions. Overland Park, the northern most watershed, is a part of the larger Turkey Creek watershed. Pawnee and Westridge are both encompassed in the Indian Creek watershed, and all subject watersheds eventually make their way to the Missouri River. Pawnee is composed of primarily residential zoning districts (92%) while Westridge is composed of heavy business zoning districts (32%) that include the entire Oak Park Mall and some surrounding shopping districts. Overland Park is fairly mixed with distinct business (16%) and residential (84%) zoned areas. All three watersheds are primarily encompassed within the city of Overland Park, Kansas with the Overland Park watershed partially spreading into the city of Mission, and Westridge watershed partially spreading into the city of Lenexa.

These stormwater systems date back to before the 1972 USEPA Clean Water Act establishment of regulation of National Pollution Discharge Elimination System (NPDES) system its Phase II 1999 expansion requiring post-construction BMPs in new and redeveloping areas (Vogel, et. al., 2015). These systems were created with the sole goal of reducing flooding along suburban streets and were designed to drain water to streams as quickly as possible. Like most suburban areas, this caused flashy streams that down cut due to the increase stream power (both quantity of water and force of water) being sent at them (Bledsoe, 2001). These systems are continuously repaired and updated, however the layout of the maturely suburbanized watersheds greatly restrict new stormwater BMPs.

One way to think of excessive surface runoff problems is by the lack of infiltration. All three watersheds are within 7 points of each other with respect to weighted curve numbers.

Overland Park and Pawnee have 82 and 81 weighted curve numbers, respectively, which is comparable to the 83 and 81 curve numbers for 1/4 and 1/3 acre property sizes for residential areas in hydrologic group "C" soils. Westridge's curve number is notably higher at 88 influenced by Oak Park Mall's highly impervious area. With respect to infiltration, soil hydrologic group has a large effect on curve number infiltration. Table 3.1 shows accompanying hydrologic group percentages for each watershed. Here, it can be seen that a majority of each watershed is dominated by hydrologic group "C" soils which have relatively high runoff potential compared to better infiltrating "B" soils. With "C" soils dominating the area, these watersheds are still expected to see high amounts of runoff, but the employment of rain barrels + EDDB and reduction in 10% and 20% in impervious surfaces will be able to help.

Table 3.1: Percentage of hydrologic group in each study watershed obtained from SSURGO data (Soil Survey Staff, 2015).

Hydrologic Group	Overland Park	Pawnee	Westridge
B	8%	43%	37%
C	88%	51%	62%
D	0%	3%	1%

Each watershed is individually analyzed more in depth with respect to their location, hydrology, hydraulics, land cover/land use, curve numbers, weighted curve numbers, impervious areas, rain barrel + EDDB locations and property zoning.

Overland Park

Overland Park drains 0.94 square miles and runs primarily east to west. Here, 148 subcatchments drain into 203 inlets and junction boxes and travel through 4.3 miles of pipes/concrete channels and 1.7 miles of natural channels (Figure 3.1). Some stormwater infrastructure dates back to 1983. For rain barrel BMP treatment, Overland Park is mildly residential with 832 single family residential properties, all of which have one, 55 gallon rain barrel modeled for them. These rain barrels can detain up to 45,760 ft^3 per rainstorm event. Additionally, Overland Park Elementary, located high in the watershed, has a 125,000 ft^3 EDDB modeled at it (Figure 3.2).

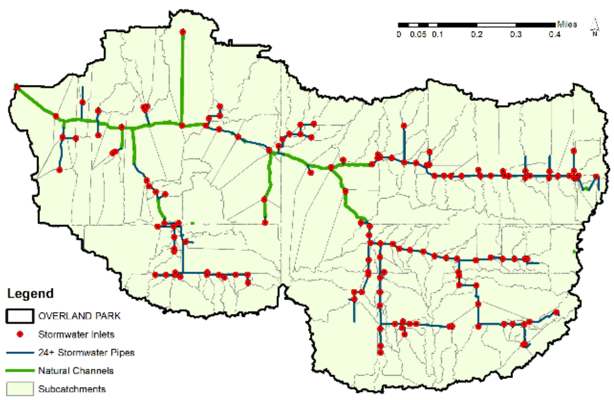


Figure 3.1: Map of Overland Park watershed hydrology (subcatchments) and hydraulics (24+ inch conduits, natural channels, and accompanying stormwater inlets).

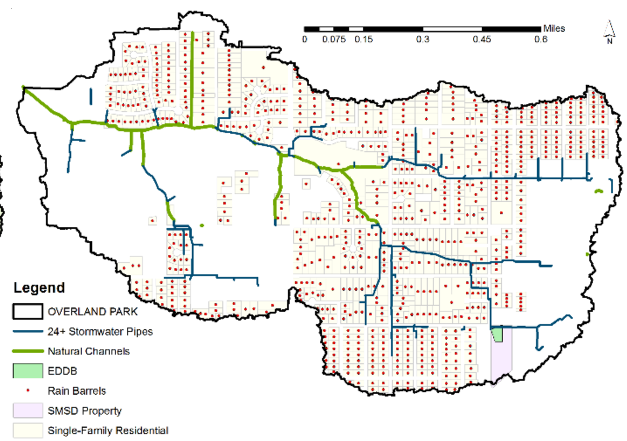


Figure 3.2: Map of modeled EDDB location at Overland Park elementary school and 832 rain barrels dispersed across the watershed at each single family residence.

Land cover in Overland Park is composed of 55% pervious surfaces with the largest land cover being "upland deciduous forest" at 34% (Figure 3.3). This large forested area, however, is highly fragmented throughout residential neighborhoods by individual yards and streets. The only contiguous swaths of upland deciduous forest are found along Pawnee's extensive riparian areas. Impervious areas are heaviest near the headwaters and the outlet of the watershed and are associated with the business zonings here (Figure 3.4). Business zone areas only compose 16% of the watershed while the midsection of the watershed is composed of the 83% residential areas (Table 3.2, Figure 3.5).

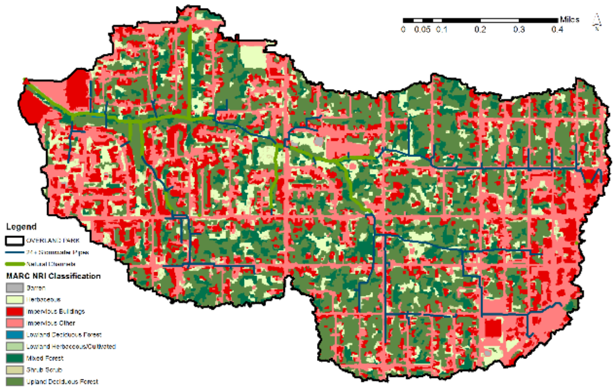


Figure 3.3: Map of Overland Park MARC NRI land use/land cover classifications for current conditions.

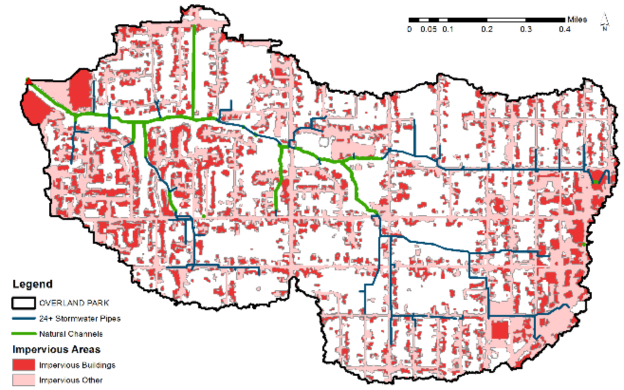


Figure 3.4: Map of isolated "impervious building" and "impervious other" under current conditions for visualization of impervious areas throughout Overland Park.

Zone Classification	Current
Single Family Residential	60%
Multi-Family Residential	22%
Subtotal Residential	83%
Business-Commercial	2%
Business-Office	1%
Multi-Use	13%
Industrial	0%
Subtotal Business	16%
Other	1%

Table 3.2: Property zoning percentage break down for Overland Park

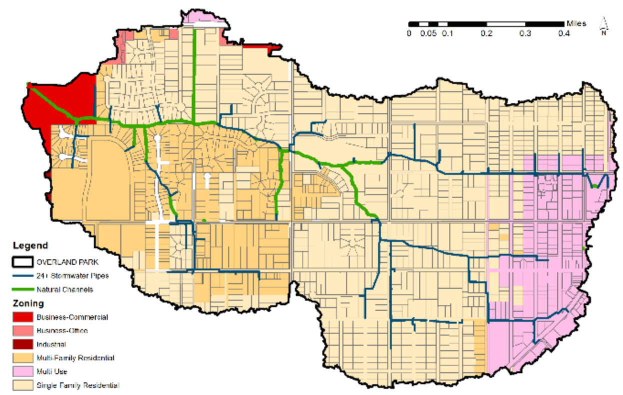
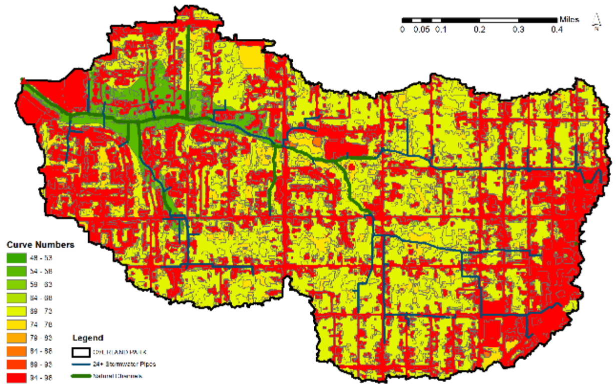


Figure 3.5: Map of Overland Park zoning areas. Business areas are correlated to areas of higher densities of impervious buildings and impervious other surfaces.

Overall, Overland Park's weighted curve number is 82 however, individual land use land covers range from 48 (scrub-scrub in B soils) to 98 (impervious surfaces) (Figure 3.6). PC-SWMM uses a weighted curve number per subcatchment visualized in Figure 3.7. Here, weighted curve numbers for subcatchments range from 69 to 98.



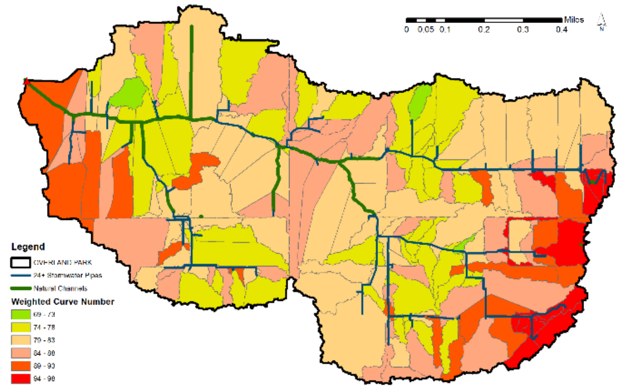


Figure 3.6: Map of Overland Park's SCS Curve numbers assigned to MARC NRI land cover/land use classifications with red areas representing high runoff and green areas representing low runoff.

Figure 3.7: Map Overland Park's SCS weighted curve number for each subcatchment with red areas representing high runoff and green areas representing low runoff for visualization of PC-SWMM model inputs.

Individual subcatchments in Overland Park saw overall reductions from 0-10% for the 10% "impervious other" reduced trial and 0-20% for the 20% reduced "impervious other" trial as expected. Average reductions were 5% and 10% respectively. With a 10% reduction in "impervious other," overall, a reduction of 2.7% (16.0 acres) of impervious surfaces was seen (Table 3.3). This 2.7 % was modeled as herbaceous areas with appropriate underlain soil hydrologic group. Similarly, with a 20% reduction in "impervious other," overall a reduction of 5.3 % (32.0 acres) in impervious areas was seen with "herbaceous" areas gaining 5.3% area.

Because of this change from impervious other to herbaceous areas, weighted curve numbers for each subcatchment were adjusted. For a the 10% reduced trial, weighted curve number for the entire watershed decreased by 0.8 points with individual subcatchments seeing 0-2.4 point decreases (Table 3.3). For 20% reduced trial, weighted curve number for the entire watershed decreased by 1.5 points with individual subcatchments seeing 0-4.7 point decreases.

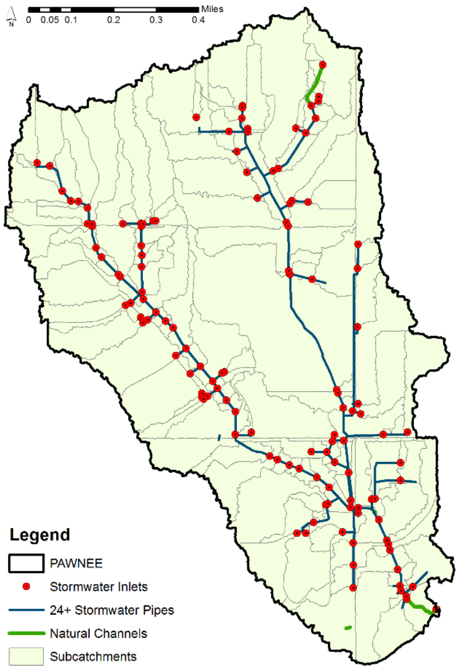
It should be noted that curve numbers were rounded to the nearest whole number when modeled and these decimal point drops were for analysis purposes only.

Table 3.3: MARC NRI land use/land cover percentages for Overland Park including 10% Reduced and 20% Reduced "impervious other" scenarios. Additionally, weighted curve numbers for entire watershed are listed with respect to scenarios.

LULC Classification	Current	10% Reduced	20% Reduced
Impervious Other	27%	24%	21%
Impervious Buildings	18%		
Total Impervious	45%	42%	39%
Upland Deciduous Forest	34%		
Herbaceous	9%	12%	15%
Mixed Forest	8%		
Shrub-Scrub	3%		
Lowland Deciduous Forest	0%		
Barren	0%		
Combined Herb/Cult	0%		
Subtotal Pervious/Other	*55%*	58%	61%
Weighted Curve Number	82.3	81.6	80.8

Pawnee

Pawnee, drains 0.96 square miles and runs primarily north to south. Here, 127 subcatchments drain into the 244 inlets and junction boxes and travel through 5.4 miles of pipes/concrete channels and 0.2 miles of natural channels (Figure 3.8). This amount of natural channels is drastically lower than the other two watersheds studied and could be indicative of older stormwater management practices when infrastructure was built starting in 1967. For rain barrel BMP treatment, Pawnee is highly residential with 1,571 single family residential properties, all of which have one 55 gal rain barrel modeled at them. This is roughly double the amount of rain barrels Overland Park and Westridge have. These rain barrels can detain up to 86,405 ft^3 of stormwater runoff from roofs. Additionally, Pawnee Elementary is located high in the watershed has a 125,000 ft^3 EDDB at it (Figure 3.9).



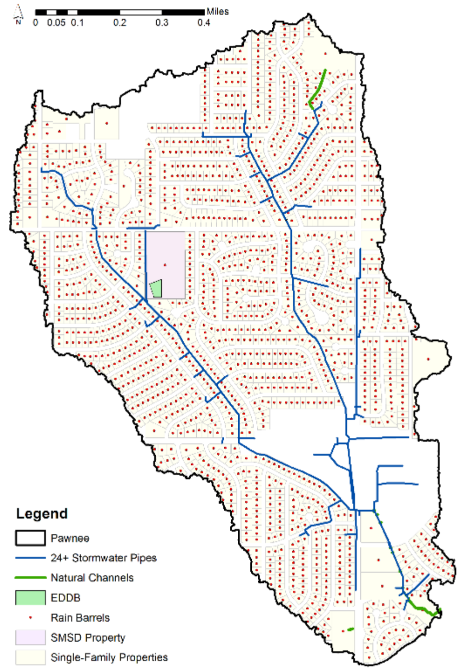


Figure 3.8: Map of Pawnee's watershed hydrology (subcatchments) and hydraulics (24+ inch conduits, natural channels, and accompanying stormwater inlets).

Figure 3.9: Map of modeled EDDB location at Pawnee elementary school and 1571 rain barrels dispersed across the watershed at each single family residence.

Land cover in Pawnee is 68% covered in impervious surfaces with the largest land cover being "impervious other" at 40% (Figure 3.10). With only 8% of the watershed zoned as business areas, this large percentage of impervious surface is unusual, but this impervious area is highly fragmented throughout the watershed with pervious surfaces well mixed in. The largest pervious land cover is "upland deciduous forest" at 43% which could be due to maturing residential areas since the watershed was developed in 1967. This large forested area, however, is highly fragmented throughout residential neighborhoods by individual yards and streets. With a lack of natural channels, there are no contiguous swaths of upland deciduous forest found along riparian areas. Impervious areas are heaviest near the outlet of the watershed and are associated with the business zonings here (Figure 3.11). Business zone areas only compose 8% of the watershed while the rest of the watershed is composed of 92% residential areas (Table 3.4, Figure 3.12).

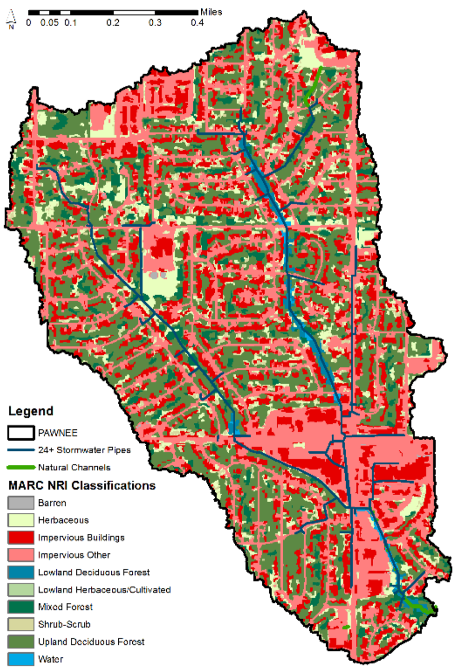


Figure 3.10: Map of Pawnee's MARC NRI land use/land cover classifications for current conditions.

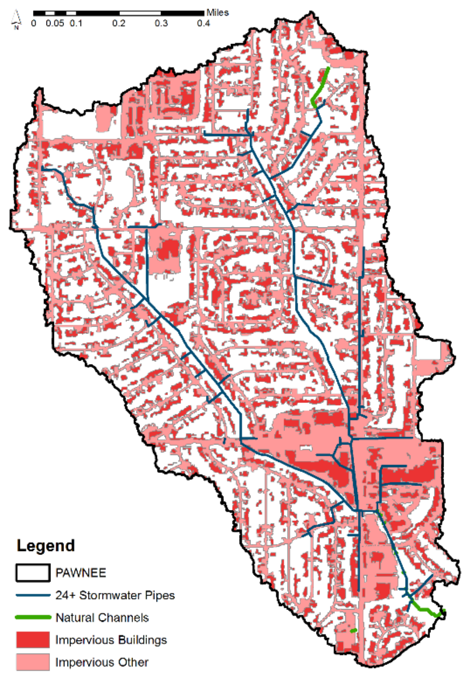


Figure 3.11: Map of isolated "impervious building" and "impervious other" under current conditions for visualization of impervious areas throughout Pawnee.

Zone Classification	Current
Single-Family Residential	89%
Multi-Family Residential	3%
Subtotal Residential	92%
Business Commercial	7%
Business Office	0%
Subtotal Business	8%
Other	0%

Table 3.4: Property zoning percentage break down for Pawnee.

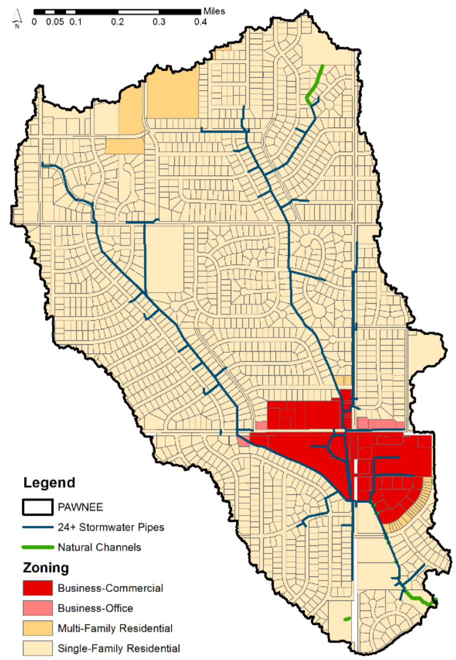


Figure 3.12: Map of Pawnee's zoning areas. Business areas are correlated to areas of higher densities of impervious buildings and impervious other surfaces.

Overall, Pawnee's weighted curve number is 81 however, individual land use land covers range from 48 (scrub- in B soils) to 98 (impervious surfaces) (Figure 3.13). PC-SWMM uses a weighted curve number per subcatchment visualized in Figure 3.14. Here, weighted curve numbers for subcatchments range from 59 to 98.

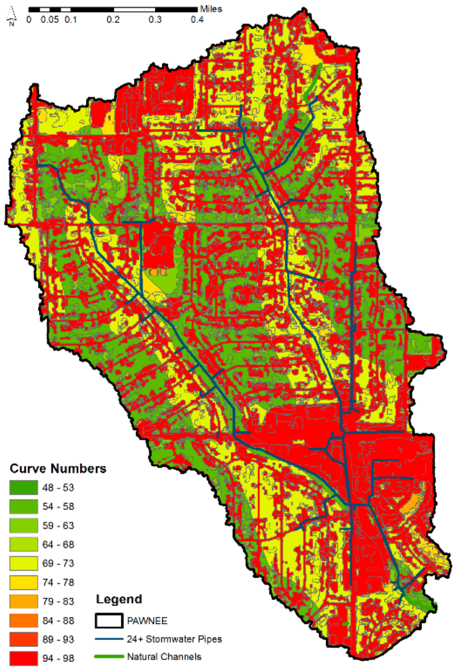


Figure 3.13: Map of Pawnee's SCS Curve numbers assigned to MARC NRI land cover/land use classifications with red areas representing high runoff and green areas representing low runoff.

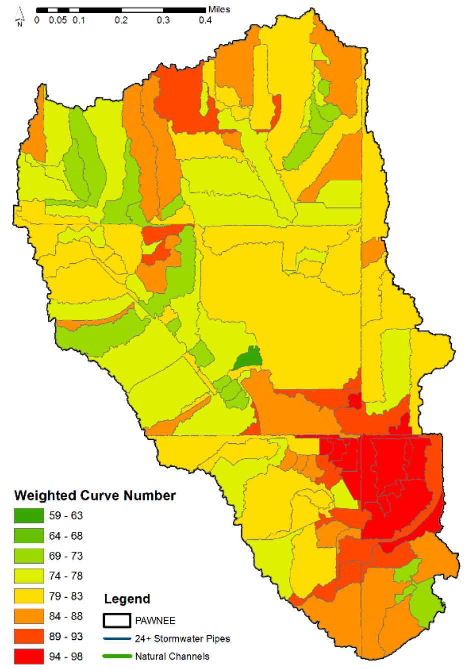


Figure 3.14: Map Pawnee's SCS weighted curve number for each subcatchment with red areas representing high runoff and green areas representing low runoff for visualization of PC-SWMM model inputs.

Pawnee saw similar impervious reductions. With a 10% reduction in "impervious other," overall, a reduction of 4.0% (24.3 acres) of impervious surfaces was seen and gained in herbaceous areas (Table 3.5). Similarly, with a 20% reduction in "impervious other," overall a reduction of 8.0% (49.3 acres) in impervious areas was seen with and gained in "herbaceous" areas.

For the 10% reduced trial, weighted curve number for the entire watershed decreased by 0.9 points with individual subcatchments seeing 0-2.8 point decreases (Table 3.5). For 20% reduced trial, weighted curve number for the entire watershed decreased by 1.7 points with individual subcatchments seeing 0-5.5 point decreases.

Table 3.5: MARC NRI land use/land cover percentages for Pawnee including 10% Reduced and 20% Reduced "impervious other" scenarios. Additionally, weighted curve numbers for entire watershed are listed with respect to scenarios.

LULC Classification	Current	10% Reduced	20% Reduced
Impervious other	40%	36%	32%
Impervious Buildings	27%		
Total Impervious	*68%*	63%	59%
Upland Deciduous Forest	43%		
Herbaceous	10%	14%	18%
Mixed Forest	6%		
Shurb-Scrub	5%		
Lowland Deciduous Forest	2%		
Water	1%		
Barren	0%		
Lowland Herb/Cult	0%		
Subtotal Pervious/Other	*33%*	37%	41%
Weighted Curve Number	80.9	80.1	79.2

Westridge

Westridge drains 1.02 square miles and runs primarily north to south. This watershed is slightly larger than the other two and incorporates a water level sensor at the outlet of the watershed. Here, 137 subcatchments drain into the 277 inlets and junction boxes and travel through 7.8 miles of pipes/concrete channels and 0.8 miles of natural channels (Figure 3.15). Some stormwater infrastructure dates all the way back to 1974. For rain barrel BMP treatment, Westridge is mildly residential with 773 single family residential properties, all of which have one 55 gal rain barrel modeled at them. These rain barrels can detain up to 42,515 ft^3. Additionally, Westridge Middle School at the top most part of the watershed has a 125,000 ft^3 EDDB modeled at it (Figure 3.16).

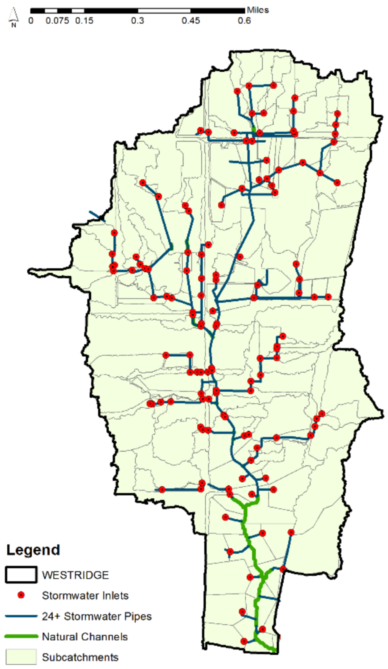


Figure 3.15: Map of Westridge's watershed hydrology (subcatchments) and hydraulics (24+ inch conduits, natural channels, and accompanying stormwater inlets).

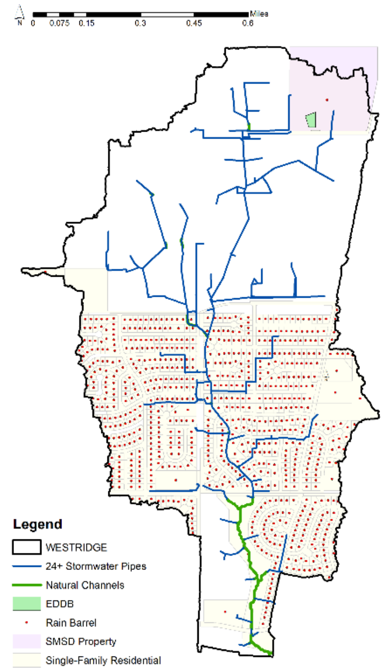


Figure 3.16: Map of modeled EDDB location at Westridge middle school and 773 rain barrels dispersed across the watershed at each single family residence.

Land cover in Westridge is 67% covered in impervious surfaces with the largest land cover being "impervious other" at 43% (Figure 3.17, Figure 3.18). This impervious area covers the upper third of the watershed because of Oak Park Mall and its surrounding shopping areas. The bottom two thirds of the watershed is residential. The last reach of the stormwater network drains through a natural channel with large riparian areas on either side. Business zones cover 32% of the watershed while the lower two thirds of the water shed are covered in 67% residential areas (Table 3.6, Figure 3.19).

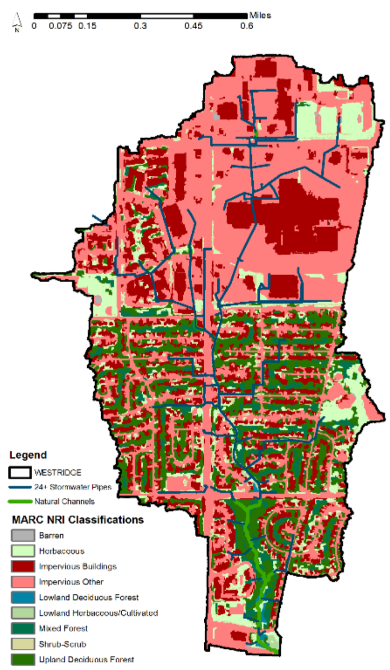


Figure 3.17: Map of Westridge's MARC NRI land use/land cover classifications for current conditions.

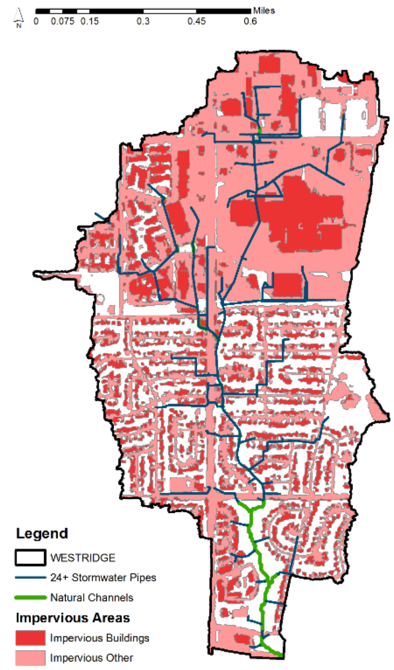


Figure 3.18: Map of isolated Westridge's "impervious building" and "impervious other" under current conditions. This is for a visualization of where impervious surfaces are distributed throughout the watershed.

Overall, Westridge's weighted curve number is 88 however, individual land use land covers range from 48 (scrub-scrub in B soils) to 98 (impervious surfaces) (Figure 3.20). PC-SWMM uses a weighted curve number per subcatchment visualized in Figure 3.21. Here, weighted curve numbers for subcatchments range from 59 to 98.

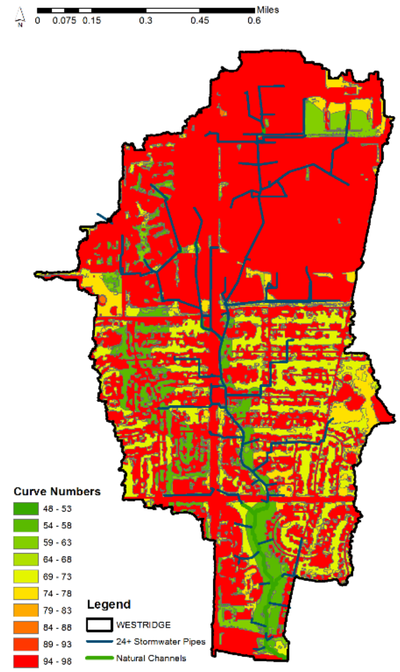


Figure 3.19: Map of Westridge's SCS Curve numbers assigned to MARC NRI land cover/land use classifications with red areas representing high runoff and green areas representing low runoff.

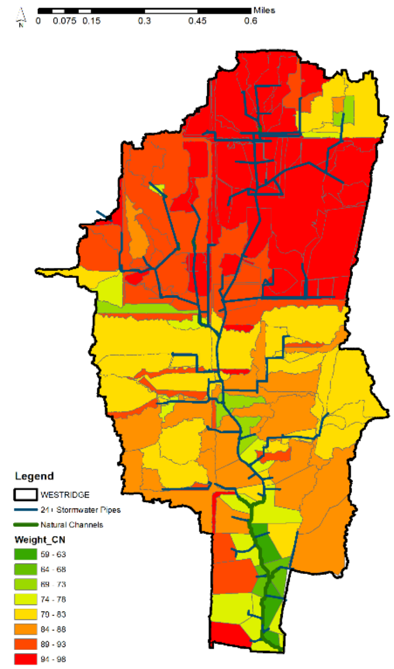


Figure 3.20: Map Westridge's SCS weighted curve number for each subcatchment with red areas representing high runoff and green areas representing low runoff for visualization of PC-SWMM model inputs.

Westridge saw similar impervious reductions. With a 10% reduction in "impervious other," an overall reduction of 4.4% (28.8 acres) of impervious surfaces was seen and gained in herbaceous areas (Table 3.7). Similarly, with a 20% reduction in "impervious other," an overall reduction of 8.7% (56.96 acres) in impervious areas was seen and gained in "herbaceous" areas.

For the 10% reduced trial, weighted curve number for the entire watershed decreased by 1.2 points with individual subcatchments seeing 0-3.7 point decreases (Table 3.7). For 20% reduced trial, weighted curve number for the entire watershed decreased by 2.4 points with individual subcatchments seeing 0-7.4 point decreases.

Table 3.6: MARC NRI land use/land cover percentages for Westridge including 10% Reduced and 20% Reduced "impervious other" scenarios. Additionally, weighted curve numbers for entire watershed are listed with respect to scenarios.

LULC Classification	Current	10% Reduced	20% Reduced
Impervious other	44%	39%	35%
Impervious Buildings	24%		
Subtotal Impervious	*67%*	63%	59%
Upland Deciduous Forest	16%		
Herbaceous	10%	14%	18%
Mixed Forest	4%		
Shurb-Scrub	3%		
Lowland Deciduous Forest	0%		
Barren	0%		
Lowland Herb/Cult	0%		
Subtotal Pervious/Other	*33%*	37%	41%
Weighted Curve Number	87.5	86.3	85.1

Conclusions

All three watersheds are different yet have commonalities. Pawnee has double the amount of rain barrels than Overland Park and Westridge but this only increases rain barrel detention from one acre-foot of detention to two – miniscule compared to watershed size. All school properties modeled with EDDBs are located in the upper half of the watersheds. These systems are able to detain 2.87 acre-feet of water and are modeled after an existing educational EDDB at one of the SMSD area high schools. With rain barrels only adding 1 or 2 additional acre feet of storage spread across entire square mile watersheds, it is thought that these systems are more heavily influenced by the EDDB and all three watersheds will function similarly.

Although Pawnee is only 8% business zoned, it has nearly similar percentages of impervious and pervious areas compared to the 32% business zoned Westridge. However, the distributions of these impervious areas are vastly different. Pawnee is fairly heterogeneously mixed because of its large residential zoning. Here, pervious yards are fragmented by impervious houses, driveways, sidewalks, and streets. Alternatively, Westridge's top third of the watershed is homogeneously impervious. Parking lots, roads, and rooftops aren't fragmented by pervious surfaces and there are no known stormwater BMPs at this location. While Pawnee's and Westridge's percentage of impervious area is nearly the same at 68% and 67% respectively, their watershed weighted curve numbers are significantly different. Pawnee has a much lower watershed weighted curve number of 81 compared to Westridge's 88. This is due to Pawnee's higher amount of upland deciduous forest (43% at SCS curve number of 70 for "C" soils) compared to Westridge (16%). Other differences between these two watersheds include Westridge having two additional miles of conduits, pipes, and natural channels to flow through compared to Pawnee. Overall, Pawnee saw similar impervious other reductions at 4.0% and 8.0% for 10% and 20% reduced simulations while Westridge saw reductions at 4.4% and 8.8%. Due to these two watersheds having the same impervious surface amounts, it is thought that these two will function most similarly together.

Overland Park on the other hand is more evenly mixed with respect to impervious (45%) and pervious (55%) surfaces. This is the only watershed with pervious surfaces dominating. Interestingly, Overland Park and Pawnee function most similarly with respect to overall weighted curve number. Pawnee again is comprised of a weighted curve number of 81 while Overland Park is just above it at 82. With respect to impervious area reductions, watersheds with the highest amounts of "impervious other" areas saw the largest changes. Overland Park only saw 2.7% and 5.3% total impervious surface reduction for 10% and 20% reduction simulations. With this watershed's impervious area significantly lower than the other two, it is thought that Overland Park function distinctly different with fewer changes from current conditions.

Although these watersheds selected because of their varying levels of business zoned areas which correlate to denser impervious areas, it can be seen that there are many other factors complexly influencing the hydrology and hydraulics of how these systems function.

Chapter 4 - Results & Discussion

The PC-SWMM model was run at each of the three watersheds for four increasing precipitation events (both in volume and duration) amongst current conditions and three additional BMP simulations. These BMPs included RB+EDDB, 10pctR, and 20pctR simulations. It should be noted that the following water balance equation holds true for this watershed model:

Surface Runoff = Precipitation – Infiltration - Surface Storage

Notably, ET is missing. Here, the model assumed there was no ET accumulation because rainstorm events were only run during hours where precipitation was falling. While green these BMP simulations may have significant effects on evapotranspiration, especially the swapping of impervious areas for herbaceous areas, this study was only interested in storm generated. This section first compares the PC-SWMM model outputs (watershed infiltration, surface runoff, and surface storage; outlet average flow, maximum flow, and total volume) within each watershed and later compares the model outputs for each individual rainstorm.

Overland Park

Overland Park saw tight clustering of infiltration increases for each BMP regardless of the storm chosen with the exception of the RB+EDDB simulation under a 7 day storm (Figure 4.1, Table 4.1). Infiltration generally increased from RB+EDDB to 10pctR to 20pctR simulations peaking at 16.7% increase from current conditions. Surface runoff decreased for all simulations but was more scattered (Figure 4.2, Table 4.1). RB+EDDB saw a tight clustering of surface runoff decreases around 4%. The 10pctR and 20pctR simulations saw greater surface runoff decreases as cumulative precipitation decreased. Maximum surface runoff decrease was seen at 12.6% for 20pctR simulation under a 6 hour, 2.23 inch storm.

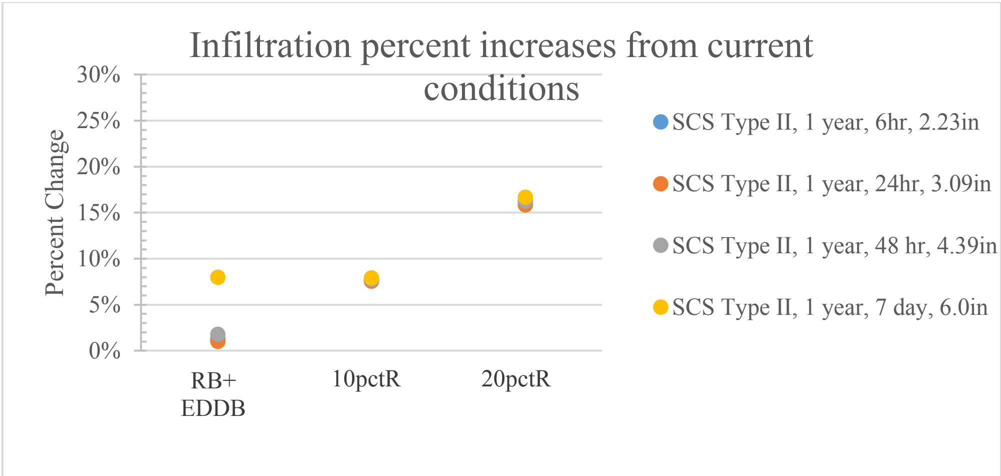


Figure 4.1: Graph of Overland Park's infiltration percent increases from current conditions for each SCS Type II storm.

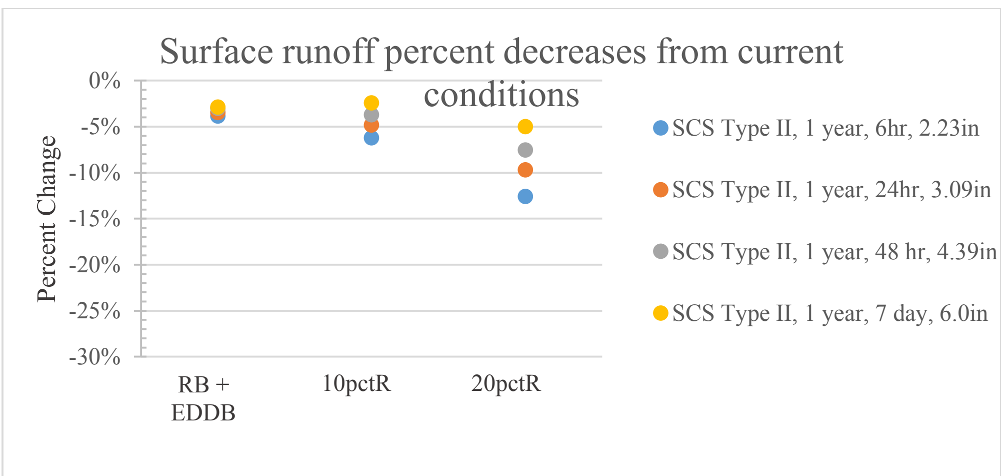


Figure 4.2: Graph of Overland Park's surface runoff percent decreases from current conditions for each SCS Type II storm.

Surface storage generally saw percent increases from current conditions with the exception of the 6 hour storm which saw percent decreases for both of the impervious reduction simulations (Figure 4.3, Table 4.1). Ignoring the 6 hour storm, RB+EDDB surpassed all of the surface storage of the 10pctR and some of the 20pctR simulations. The 6 hour storm changed from a surface storage of 0.30 inches at current conditions to 0.33 inches for RB+EDDB, and 0.29 and 0.28 inches for 10% and 20% reduced simulations respectively. With respect to the total 2.23 inches rainfall event, a 0.01-2 inch shift in surface for the impervious other reduction simulations is negligible.

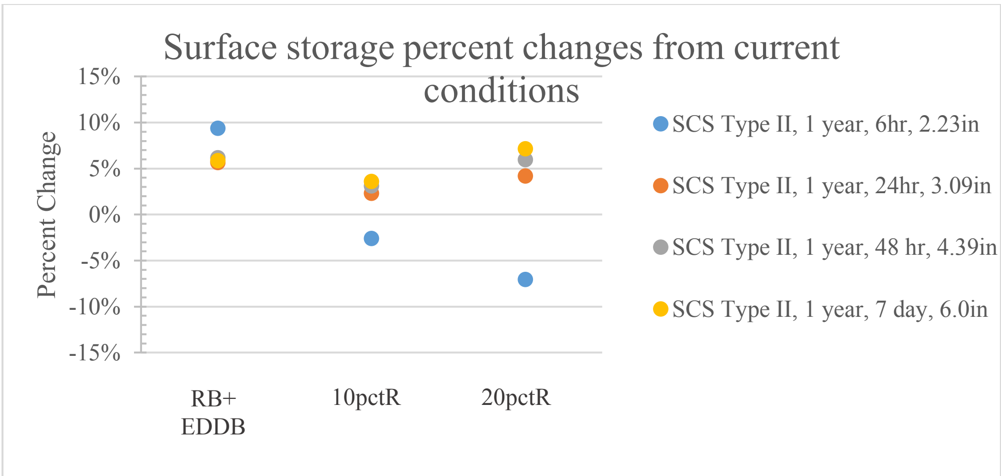


Figure 4.3: Graph of Overland Park's surface storage percent changes from current conditions at for each SCS Type II storm.

Table 4.1 additionally records average flow, maximum flow, and total volume at the outlet of the watershed. Here, it can be seen that each BMP positively impacts the outlet with general increased incremental change from RB+EDDB to 10pctR to 20pctR simulations. One exception includes 10pctR simulation being the lowest change in all outlets characterizes for the 7 day storm, even lower than rain barrels. This could be due to the fact that the EDDB was better at infiltrating captured runoff throughout the entire 7 day back-to-back alignment of storms than the small chunks of 10% reductions in impervious other surfaces throughout each subcatchment. Overall, 20pctR simulations saw the highest reductions while rain barrels saw the lowest reductions. These BMPs were more effective at smaller rainstorm events.

Table 4.1: Overland Park's percent changes of each BMP compared to current conditions for each SCS Type II storm.

	Current	RB + EDDB	10pctR	20pctR	Current	RB+ EEDDB	10pctR	20% Reduced
	SCS Type II, 1 year, 6hr, 2.23in				SCS Type II, 1 year, 24hr, 3.09in			
Runoff Quantity Continuity	**Depth Inches**				**Depth Inches**			
Total Precipitation	2.23				3.09			
Infiltration Loss	0.92	1.3%	7.7%	16.2%	0.72	1.0%	7.6%	15.8%
Surface Runoff Loss	1.01	-3.9%	-6.2%	-12.6%	1.54	-3.5%	-4.8%	-9.7%
Final Surface Storage	0.30	9.4%	-2.6%	-7.1%	0.84	5.7%	2.3%	4.2%
Outfall Loading	-				-			
Average Flow CFS	27.0	-5.0%	-7.2%	-14.6%	41.8	-4.1%	-5.5%	-11.2%
Max Flow CFS	139.5	-3.3%	-4.3%	-8.5%	233.8	-3.2%	-3.8%	-7.9%
Total Volume 10^6 gal	16.3	-4.0%	-6.3%	-12.7%	24.6	-3.6%	-4.9%	-9.8%
	SCS Type II, 1 year, 48 hr, 4.39in				SCS Type II, 1 year, 7 day, 6.0in			
Runoff Quantity Continuity	**Depth Inches**				**Depth Inches**			
Total Precipitation	4.39				5.99			
Infiltration Loss	0.81	1.8%	7.7%	16.3%	0.89	8.0%	7.9%	16.7%
Surface Runoff Loss	2.55	-3.0%	-3.7%	-7.5%	4.22	-2.9%	-2.4%	-5.0%
Final Surface Storage	1.03	6.2%	3.1%	6.0%	0.88	5.9%	3.6%	7.1%
Outfall Loading	-				-			
Average Flow CFS	43.4	-3.7%	-4.5%	-9.2%	15.8	-3.2%	-2.5%	-5.1%
Max Flow CFS	282.2	-3.3%	-4.2%	-8.5%	50.5	-2.8%	-2.2%	-4.4%
Total Volume 10^6 gal	41.1	-3.1%	-3.7%	-7.6%	68.6	-3.2%	-2.4%	-5.0%

Pawnee

Pawnee again saw a relatively tight clustering of infiltration increases for each BMP regardless of storm chosen with the exception of the RB+EDDB simulation under a 7 day storm (Figure 4.4, Table 4.2). Infiltration generally increased from RB+EDDB to 10pctR to 20pctR simulations peaking at 17.4% increase from current conditions. Surface runoff decreased for all simulations and was more scattered (Figure 4.5, Table 4.2). RB+EDDB saw a tight clustering of surface runoff decreases around 1%. The 10pctR and 20pctR simulations saw greater surface runoff decreases as cumulative precipitation decreased. Maximum surface runoff decrease was recorded at 11.3% for the 20pctR simulation under a 6 hour, 2.23 inch storm. Surface storage saw percent increases from current conditions again with the 20pctR simulation seeing the greatest increase at 11.9% (Figure 4.6, Table 4.2).

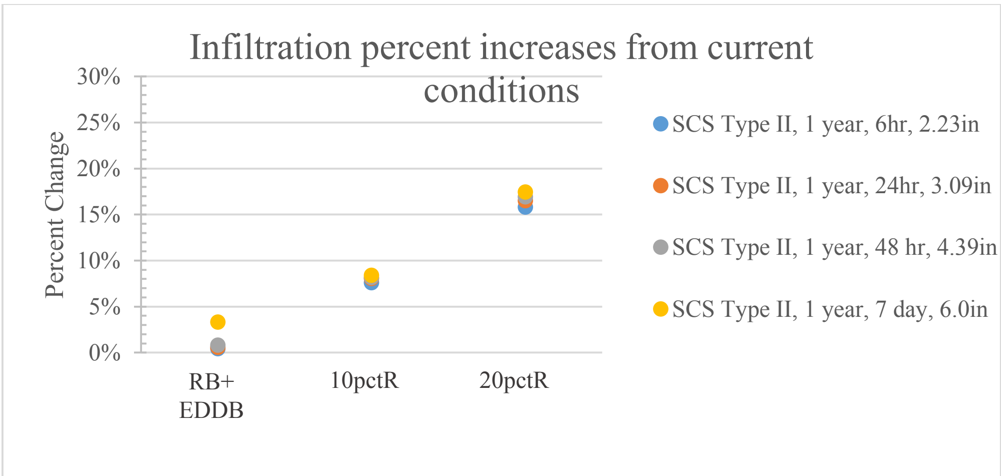


Figure 4.4: Graph of Pawnee's infiltration percent increases from current conditions for each SCS Type II storm.

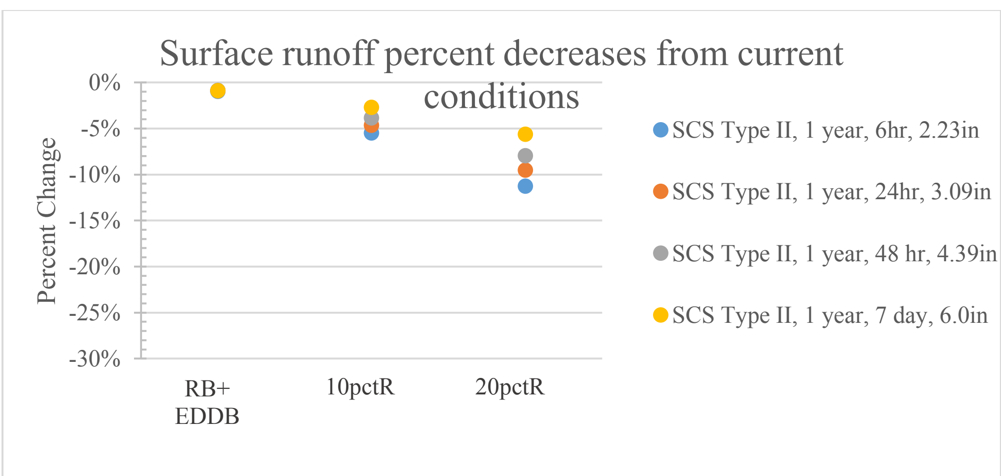


Figure 4.5: Graph of Pawnee's surface runoff percent decreases from current conditions for each SCS Type II storm.

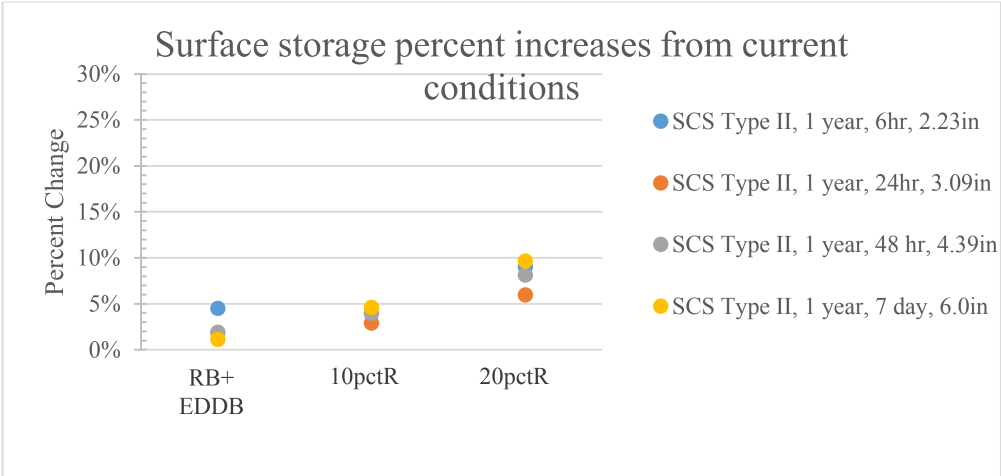


Figure 4.6: Graph of Pawnee's surface storage percent changes from current conditions for each SCS Type II storm.

Table 4.2 additionally shows that each BMP positively impacts the outlet with increased incremental change from RB+EDDB to 10pctR to 20pctR simulations. Reductions in average flow, maximum flow, and total outlet volume all decreased as cumulative precipitation decreased with the 6 hour storm seeing the greatest reductions.

Table 4.2: Pawnee's percent changes of each BMP compared to current conditions for each SCS Type II storm.

	Current	RB+ EDDB	10pctR	20pctR	Current	RB+ EDDB	10pctR	20pctR
	SCS Type II, 1 year, 6hr, 2.23in				SCS Type II, 1 year, 24hr, 3.09in			
Runoff Quantity Continuity	**Depth Inches**				**Depth Inches**			
Total Precipitation	2.23				3.09			
Infiltration Loss	0.91	0.4%	7.6%	15.8%	0.72	0.6%	8.0%	16.5%
Surface Runoff Loss	1.15	-1.0%	-5.5%	-11.3%	1.68	-0.9%	-4.6%	-9.5%
Final Surface Storage	0.18	4.5%	4.0%	9.0%	0.67	1.9%	2.9%	6.0%
Outfall Loading	-				-			
Average Flow CFS	30.2	-0.7%	-4.8%	-10.0%	37.5	0.3%	-4.6%	-9.6%
Max Flow CFS	172.3	-1.1%	-3.2%	-6.4%	284.9	-0.8%	-3.0%	-6.5%
Total Volume 10^6 gal	18.2	-1.0%	-5.7%	-11.6%	26.9	-0.9%	-4.8%	-9.8%

	SCS Type II, 1 year, 48 hr, 4.39in				SCS Type II, 1 year, 7 day, 6.0in			
Runoff Quantity Continuity	**Depth Inches**				**Depth Inches**			
Total Precipitation	4.39				5.99			
Infiltration Loss	0.81	0.8%	8.2%	16.9%	0.91	3.3%	8.4%	17.4%
Surface Runoff Loss	2.67	-0.9%	-3.8%	-7.9%	4.25	-0.9%	-2.7%	-5.6%
Final Surface Storage	0.91	1.9%	4.0%	8.1%	0.83	1.1%	4.6%	9.6%
Outfall Loading	**-**				**-**			
Average Flow CFS	37.6	-0.3%	-3.5%	-7.2%	16.7	-0.5%	-2.3%	-4.7%
Max Flow CFS	349.3	0.1%	-2.8%	-4.1%	56.6	-1.1%	-1.6%	-3.5%
Total Volume 10^6 gal	43.0	-0.9%	-3.9%	-8.1%	69.3	-0.9%	-2.7%	-5.7%

Westridge

Westridge additionally saw a relatively tight clustering of infiltration increases for each BMP regardless of storm chosen with the exception of the RB+EDDB simulation under a 7 day storm (Figure 4.7, Table 4.3). Infiltration generally increased from RB+EDDB to 10pctR to 20pctR simulation peaking at 25.5% increase from current conditions. This was by far the highest increase in infiltration compared to the other two watersheds. Surface runoff decreased for all simulations and was more scattered (Figure 4.8, Table 4.3). RB+EDDB saw a tight clustering of surface runoff decreases around 2.5%. The 10pctR and 20pctR simulations saw greater surface runoff decreases as cumulative precipitation decreased. Maximum surface runoff decrease was recorded at 10.0% for the 20pctR simulations under a 6 hour, 2.23 inch storm. Surface storage saw percent increases from current conditions again with 20pctR simulation seeing the greatest increase at11.3% (Figure 4.9, Table 4.3). Interestingly, RB+EDDB saw greater storage increases for decreasing cumulative precipitation volumes whereas the 10pctR and 20pctR simulations saw greater storage increases with increasing cumulative precipitation volumes. This could be attributed to the fact that the RB+EDDB can only detain a finite volume of water, thus with a smaller precipitation event, there would be a greater storage increase. The

10pctR and 20pctR simulations may have an upper limit to volumes of water stored on the vegetative surfaces and it is unknown if this volume was achieved in any of the simulations.

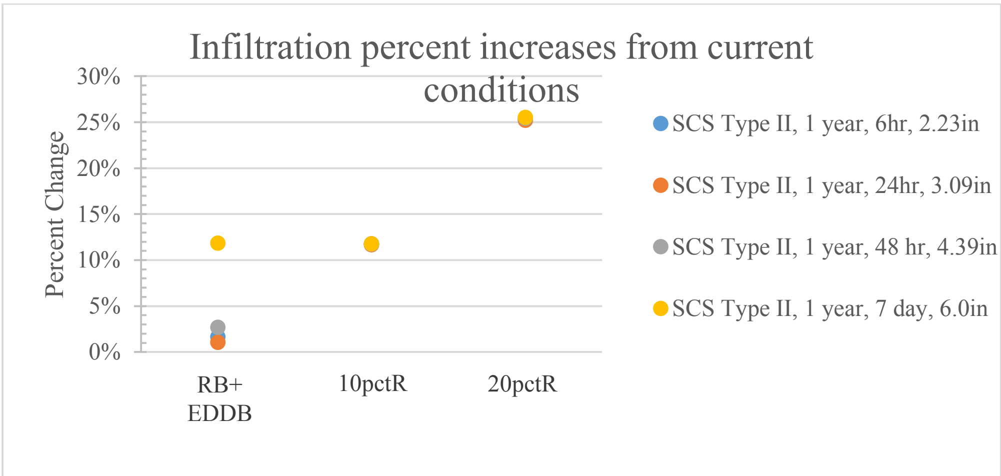


Figure 4.7: Graph of Westridge's infiltration percent increases from current conditions for each SCS Type II storm.

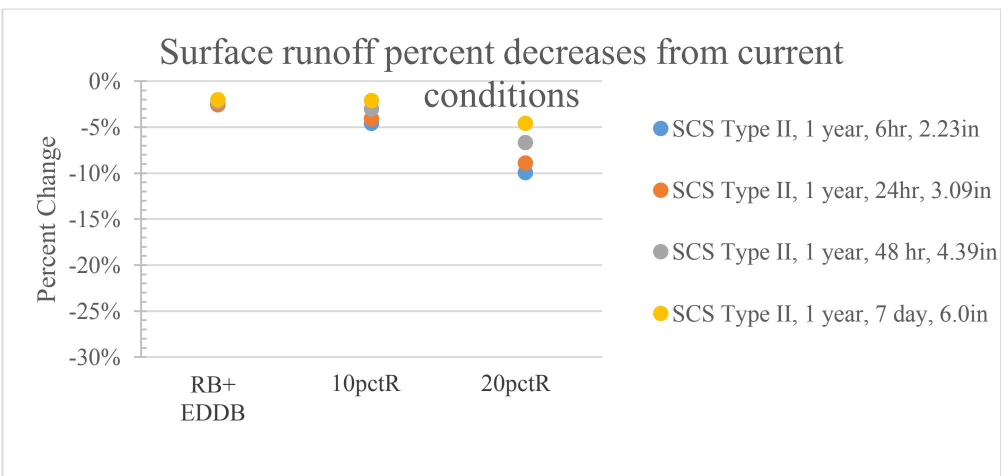


Figure 4.8: Graph of Westridge's surface runoff percent decreases from current conditions for each SCS Type II storm.

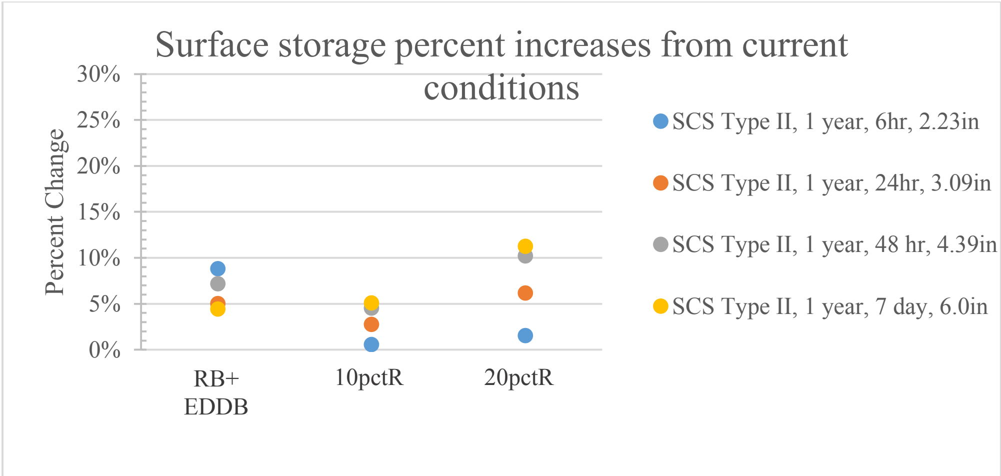


Figure 4.9: Graph of Westridge's surface storage percent increases from current conditions for each SCS Type II storm.

Table 4.3 additionally shows that each BMP positively impacts the outlet with increased incremental change from RB+EDDB to 10pctR to 20pctR simulations. Reductions in average flow, maximum flow, and total outlet volume all decreased as cumulative precipitation decreased with the 6 hour storm seeing the greatest reductions. Maximum reductions seen were 10.6%, 7.8%, and 10.2% decreases for average flow, maximum flow, and total outlet volume respectively for the 6 hour 20pctR simulation.

Table 4.3: Westridge's percent changes of each BMP compared to current conditions for each SCS Type II storm.

	Current	RB+ EDDB	10pctR	20pctR	Current	RB+ EDDB	10pctR	20pctR
	SCS Type II, 1 year, 6hr, 2.23in				SCS Type II, 1 year, 24hr, 3.09in			
Runoff Quantity Continuity	**Depth Inches**				**Depth Inches**			
Total Precipitation	2.23				3.09			
Infiltration Loss	0.52	1.6%	11.8%	25.4%	0.44	1.1%	11.7%	25.2%
Surface Runoff Loss	1.39	-2.6%	-4.6%	-10.0%	1.82	-2.5%	-4.1%	-8.9%
Final Surface Storage	0.32	8.8%	0.6%	1.6%	0.83	5.0%	2.8%	6.2%
Outfall Loading	-				-			
Average Flow CFS	53.4	-2.7%	-4.9%	-10.6%	70.7	-2.0%	-4.3%	-9.5%
Max Flow CFS	203.5	-2.6%	-3.8%	-7.8%	341.9	-2.4%	-3.5%	-7.1%
Total Volume 10^6 gal	24.1	-2.6%	-4.7%	-10.2%	31.3	-2.6%	-4.2%	-9.1%
	SCS Type II, 1 year, 48 hr, 4.39in				SCS Type II, 1 year, 7 day, 6.0in			
Runoff Quantity Continuity	**Depth Inches**				**Depth Inches**			
Total Precipitation	4.39				5.99			
Infiltration Loss	0.50	2.7%	11.7%	25.4%	0.55	11.9%	11.8%	25.5%
Surface Runoff Loss	3.11	-2.2%	-3.0%	-6.7%	4.76	-2.0%	-2.1%	-4.6%
Final Surface Storage	0.78	7.2%	4.5%	10.2%	0.68	4.4%	5.1%	11.3%
Outfall Loading	-				-			
Average Flow CFS	59.6	-2.0%	-3.4%	-7.5%	19.2	-1.7%	-2.1%	-4.6%
Max Flow CFS	416.8	-2.4%	-3.4%	-7.7%	64.3	-2.0%	-1.6%	-3.5%
Total Volume 10^6 gal	54.5	-2.2%	-3.1%	-6.8%	83.9	-2.0%	-2.1%	-4.6%

SCS Type II, 1 year, 6 hour, 2.23in

The SCS Type II, 1 year, 6 hour 2.23 inch cumulative storm centered around the 3 hour mark, generally saw the greatest changes in infiltration, surface runoff, and surface storage due to the fact that it had the lowest cumulative precipitation amount. Even though models had a higher rainfall intensity falling during the 6 hour storm than the other simulations, these watersheds were better able to infiltrate and intercept/store precipitation on the ground surface because of the lower volume of water falling on the system.

As seen earlier in comparison of storms within each watershed, RB+EDDB saw the lowest changes in infiltration and surface runoff (Figure 4.10, Figure 4.11). The 10pctR and 20pctR simulations saw greater changes. Westridge saw the greatest infiltration increases, a full 9.6 percentage points higher than the nearly identical Pawnee and Overland Park 20pctR simulations. Across the board, surface runoff decreased the most for Overland Park (Figure 4.11) peaking at 12.6% for the 20pctR simulation.

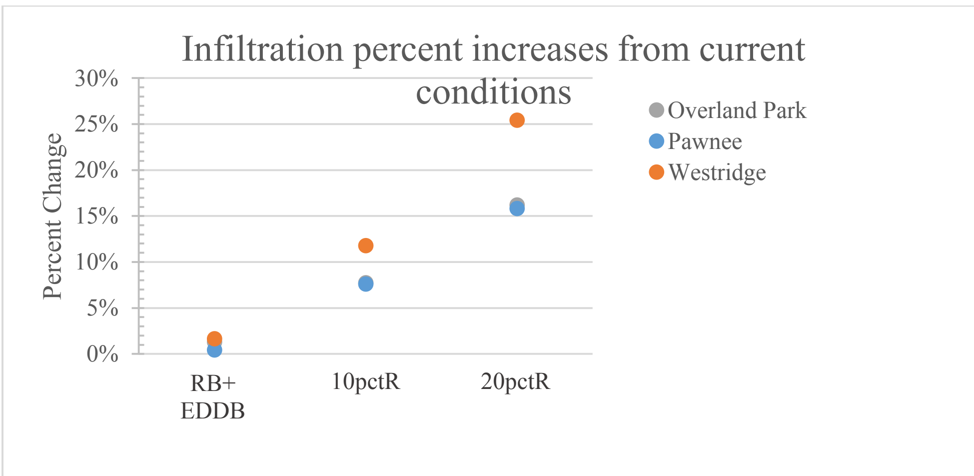


Figure 4.10: Graph of percent increases in infiltration from current conditions for all three BMPs across all three watersheds for the SCS Type II, 1 year, 6hr, 2.23 inch storm.

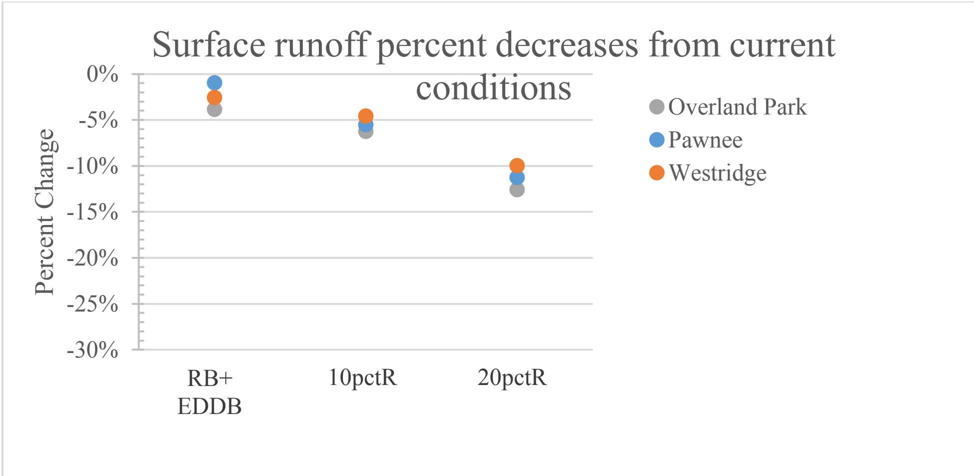


Figure 4.11: Graph of percent decreases in surface runoff from current conditions for all three BMPs across all three watersheds for the SCS Type II, 1 year, 6hr, 2.23 inch storm.

Across all watersheds, surface storage saw different results than expected (Figure 4.12). Pawnee and Overland Park saw surface storage decrease with impervious reductions contrary to logical explanation. Here, the model is implying that impervious surfaces have greater surface storage than herbaceous surfaces. Again, this anomaly in the model was primarily seen only for this 6 hour rainstorm event.

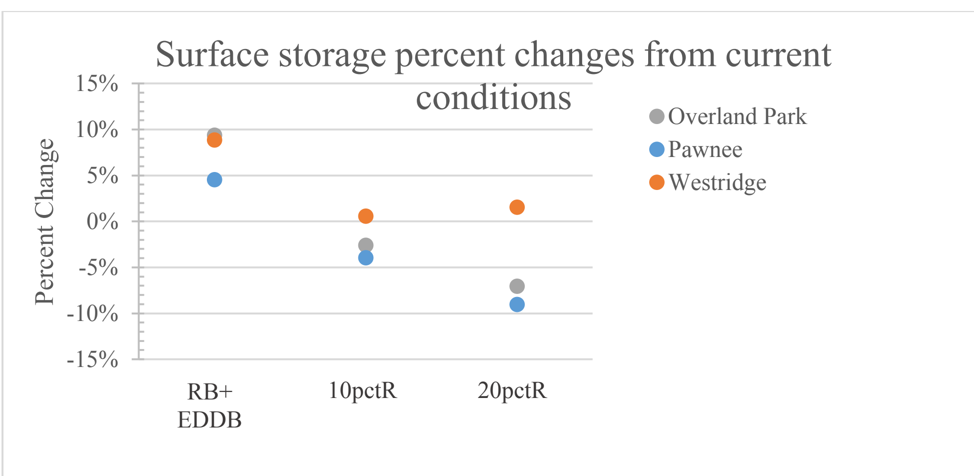


Figure 4.12: Graph of percent changes in surface storage from current conditions for all three BMPs across all three watersheds for the SCS Type II, 1 year, 6hr, 2.23 inch storm.

SCS Type II, 1 year, 24 hour, 3.09in

The SCS Type II 1 year, 24 hour 3.09 inch cumulative storm centered around the 12 hour mark generally saw modest changes in infiltration, surface runoff, and surface storage because its lower precipitation volume amount. Here the precipitation event had a lower intensity than the 6 hour storm, but lasted four times as long with a higher cumulative rainfall volume.

Again, within each watershed, rain barrels saw the lowest changes in infiltration and surface runoff (Figure 4.13, Figure 4.14). Incrementally, these results became more noticeable with the 10pctR and 20pctR simulations. Westridge saw the greatest infiltration increases, a full 8.7 percentage points higher than the nearly identical Pawnee and Overland Park 20pctR simulations. All three watersheds were tightly clustered around 9% reduction in surface runoff for the 20pctR simulation.

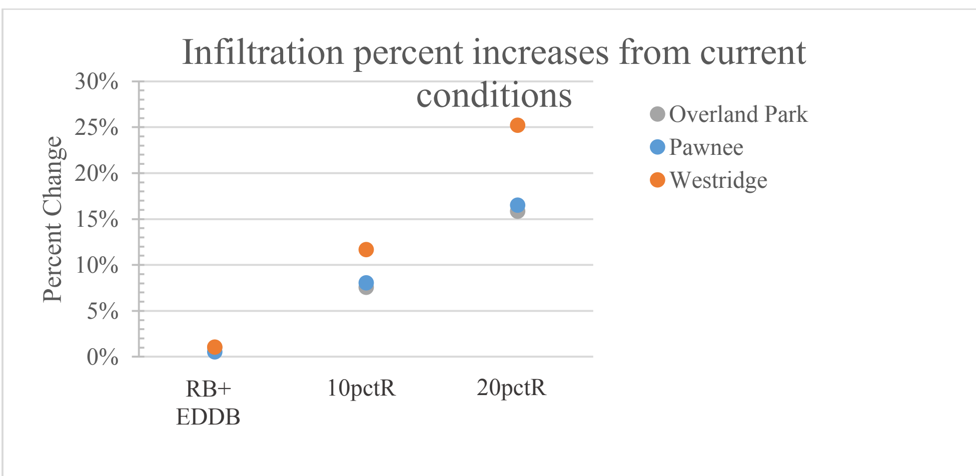


Figure 4.13: Graph of percent increases in infiltration from current conditions for all three BMPs across all three watersheds for the SCS Type II, 1 year, 24hr, 3.09 inch storm.

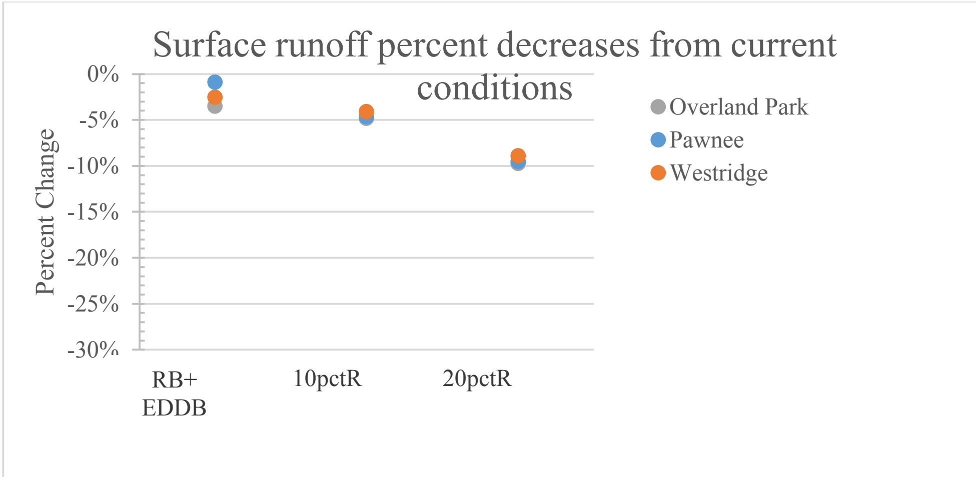


Figure 4.14: Graph of percent decreases in surface runoff from current conditions for all three BMPs across all three watersheds for the SCS Type II, 1 year, 24hr, 3.09 inch storm.

All watersheds saw surface storage increases as expected (Figure 4.15). All values across all BMPs ranged from 1.9 to 6.2 % with rain barrels seeing the lowest and 20% reduced simulation seeing the highest. The 10% reduced simulation saw the tightest scattering around 2.8%.

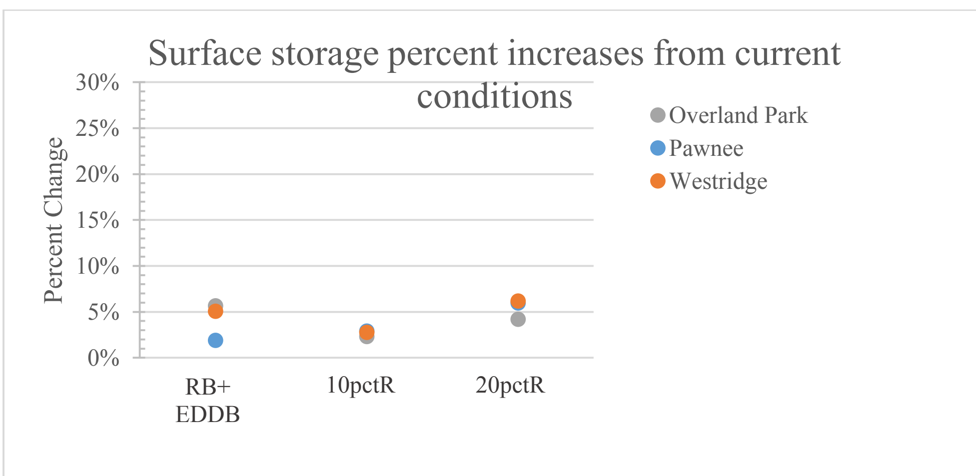


Figure 4.15: Graph of percent increases in surface storage from current conditions for all three BMPs across all three watersheds for the SCS Type II, 1 year, 24hr, 3.09 inch storm.

SCS Type II, 1 year, 48 hour, 4.39in

The SCS Type II 1 year, 48 hour 4.39 inch cumulative storm centered around the 24 hour mark generally saw modest changes in infiltration, surface runoff, and surface storage because its low precipitation volume amount spread across a long time frame.

Again, within each watershed, RB+EDDB saw the lowest changes in infiltration and surface runoff (Figure 4.16, Figure 4.17). Incrementally, these results became more noticeable with the 10pctR and 20pctR simulations. Westridge saw the greatest infiltration increases, a full 8.5 percentage points higher than the nearly identical Pawnee and Overland Park 20pctR simulations. Pawnee saw the highest surface runoff reduction at 7.9% for the 20pctR simulation.

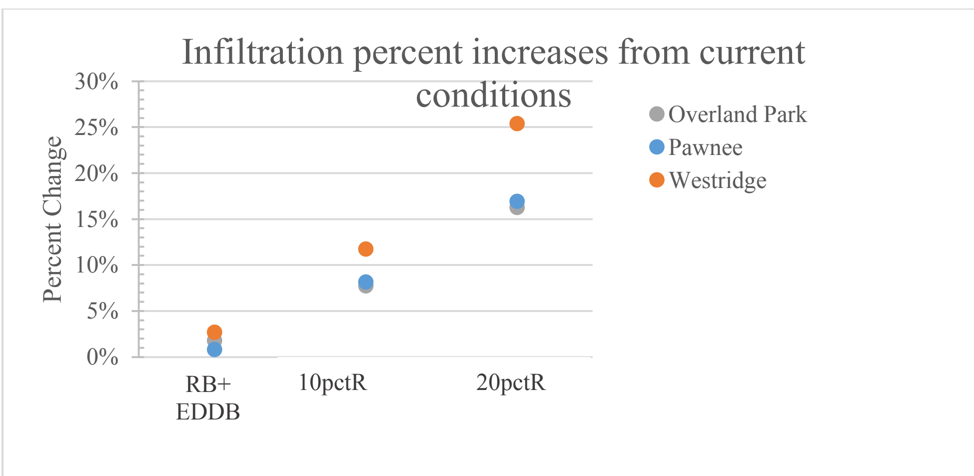


Figure 4.16: Graph of percent increases in infiltration from current conditions for all three BMPs across all three watersheds for the SCS Type II, 1 year, 48hr, 4.39 inch storm.

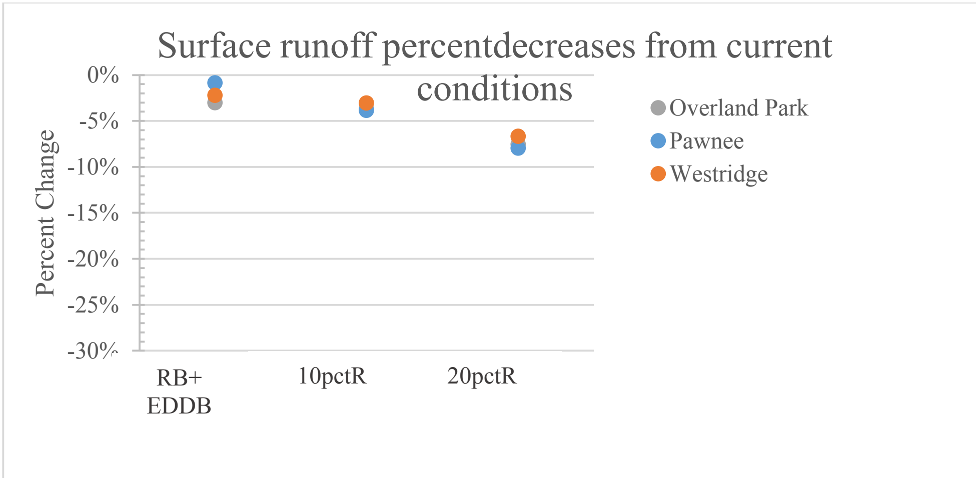


Figure 4.17: Graph of percent decreases in surface runoff from current conditions for all three BMPs across all three watersheds for the SCS Type II, 1 year, 48hr, 4.39 inch storm.

All watersheds saw surface storage increases as expected (Figure 4.18). All values across all BMPs ranged from 1.9 to 10.2 % with rain barrels seeing the lowest and 20pctR simulation seeing the highest. The 10pctR simulation saw the tightest scattering all around 4.0%. Contrary to belief, Pawnee who had double the amount of rain barrels modeled throughout its watershed saw significantly lower surface storage results compared to Overland Park and Westridge.

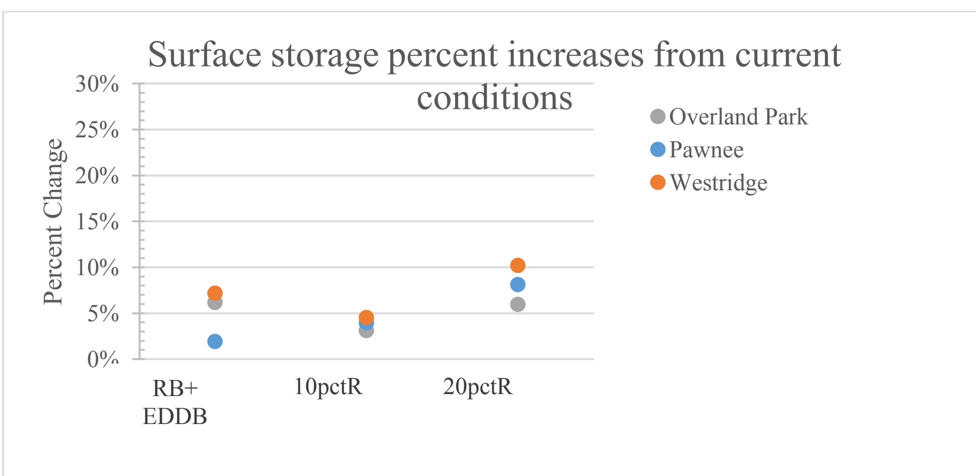


Figure 4.18: Graph of percent increases in surface storage from current conditions for all three BMPs across all three watersheds for the SCS Type II, 1 year, 48hr, 4.39 inch storm.

SCS Type II, 1 year, 7 day, 6.0in

The modified SCS Type II 1 year, 7 day 6.0 inch cumulative storm centered around each day's 12 hour mark generally saw modest changes in infiltration, surface runoff, and surface storage because its moderate precipitation volume amount spread across a long time frame.

Again, within each watershed, RB+EDDB simulations saw the lowest changes in infiltration and surface runoff (Figure 4.19, Figure 4.20). Incrementally, these results became more noticeable with the 10pctR and 20pctR simulations. RB+EDDB saw the greatest range in infiltration values ranging from 3.3% Pawnee to 11.9% Westridge. This could be attributed towards better functioning EDDBs at the Westridge location with better contributing catchment properties (time of concentration, infiltration, and runoff). Westridge again saw the greatest infiltration increases, a full 8.1 percentage points higher than the nearly identical Pawnee and Overland Park 20pctR simulations. Pawnee saw the highest surface runoff reduction at 7.9% for the 20pctR simulation.

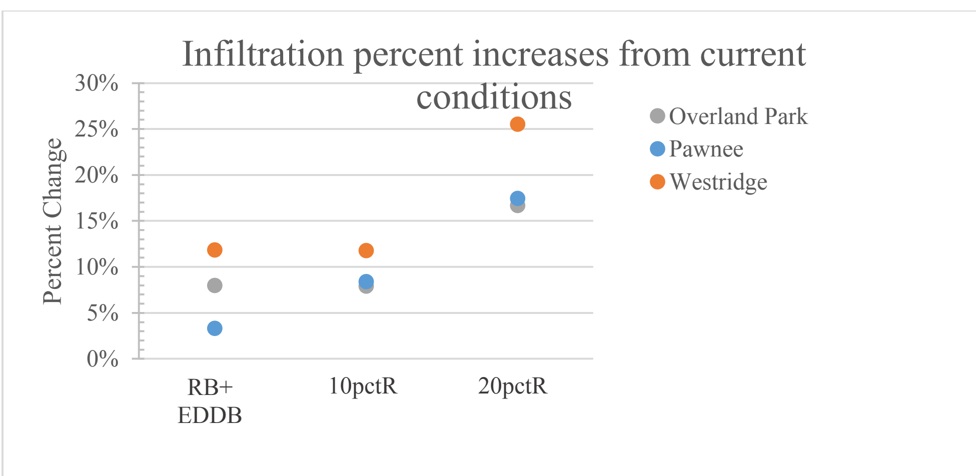


Figure 4.19: Graph of percent increases in infiltration from current conditions for all three BMPs across all three watersheds for the SCS Type II, 1 year, 7 day, 6.0 inch storm.

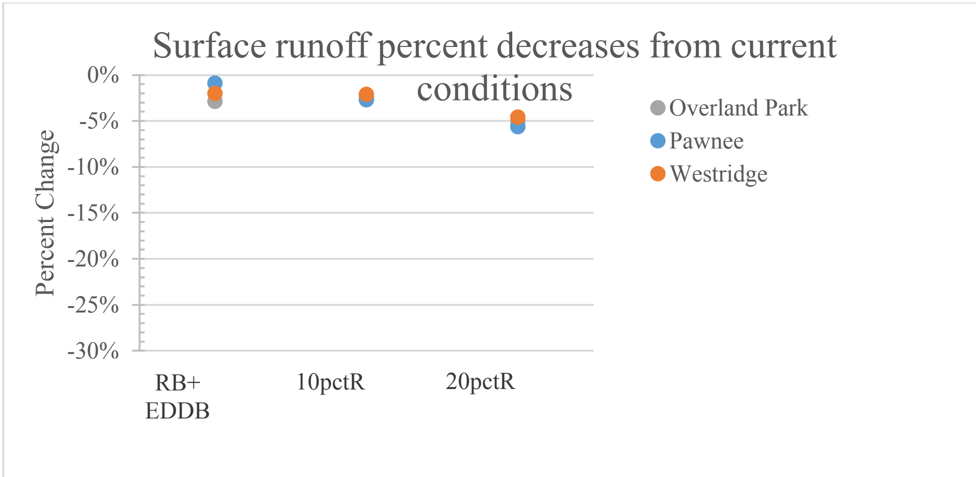


Figure 4.20: Graph of percent decreases in surface runoff from current conditions for all three BMPs across all three watersheds for the SCS Type II, 1 year, 7 day, 6.0 inch storm.

All watersheds saw surface storage increases as expected (Figure 4.21). RB+EDDB and 10pctR simulations saw low surface storage reduction values. Again, Pawnee unexplainably saw the lowest surface storage even though it has twice the number of rain barrels than the other two systems. The 20pctR simulation saw the highest surface storage with Westridge at 11.3%. Interestingly, Pawnee who had double the amount of rain barrels modeled throughout its watershed saw significantly lower surface storage results compared to Overland Park and Westridge. This could be due to the fact that the functionality of the EDDBs greatly dwarfs the storage capacity of the rain barrels.

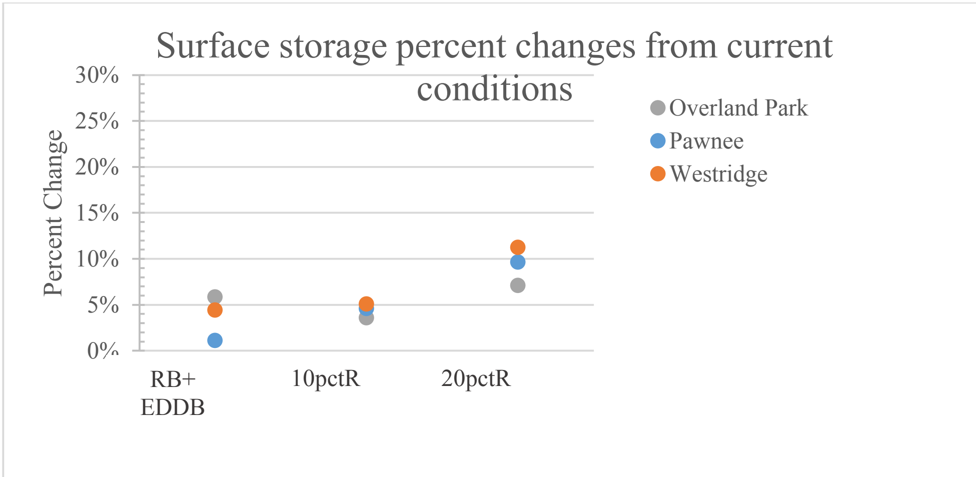


Figure 4.21: Graph of percent increases in surface storage from current conditions for all three BMPs across all three watersheds for the SCS Type II, 1 year, 7 day, 6.0 inch storm.

Outlet loadings saw greatest reductions at lower precipitation events because of soils not being saturated as long compared to larger precipitation events. Additionally, RB+EDDB saw the lowest improvements, 10pctR simulations saw better improvements, and 20pctR simulations saw the best reductions. These reductions however maxed out at 10.2% to 12.7% reduction in total outlet discharge volume with respect to the 20pctR simulations. Additionally, max flow and average flows were able to be reduced 6.5 to 8.5% and 10.0 to 14.6% respectively for the 20pctR simulations. This noticeably reduces the volume of water hitting these urban streams, reducing the degree and rate at to which urban streams are down cutting, incising, and eroding.

Discussion

Overall, all three types of BMPs (RB+EDDB, 10pctR, and 20pctR) generally saw improvements compared to current conditions. Of primary interest are the reduction in each watershed's outlet properties (including average flow, max flow, and total volume). These were greatly influenced by the increase in watershed infiltration and decrease in surface runoff. The

20pctR saw reduced average flow, mean flow, and total volume by roughly 10%. This reduction can greatly reduce the downcutting, incising, and eroding stream habitats that support macroinvertebrates, although it is unknown by what degree macroinvertebrate populations will be improved.

With respect to rain barrels, it was expected that Pawnee would see the highest improvements because it employed roughly double the amount of rain barrels than the other two watersheds; however, this was not seen in the model. The rain barrel + EDDB simulations appear to be largely dominated by the functionality of the EDDB. Here, the EDDB can detain more than ten times the volume of water than all of Pawnee's 1571 rain barrels can detain and the EDDBs can detain more than 20 times the volume of water than Overland Park or Westridge's rain barrels can. Although 55 gallon rain barrels can solve runoff issues on the site scale, they do not appear to have major effects on the watershed scale. With EDDBs largely influencing the results, it would be logical if all three watersheds saw identical results. This was not the case and can be contributed toward differences in catchment properties dictating when and how much runoff was routed into the EDDBs. Here, time of concentration, infiltration, and runoff could have highly dictated how quickly, when, and by how much the EDDBs filled with runoff. It should be noted that the roughly 11 acre catchment properties draining into each of the EDDBs were fairly similar.

With respect to infiltration and surface storage, Overland Park and Pawnee functioned most similarly. This could be due to the more dominating effect of watershed infiltration properties than the percent impervious area. Overland Park and Pawnee's watershed weighted SCS curve number were 82 and 81 respectively, much higher than Westridge's 88. Overland Park and Pawnee had very different impervious areas at 45% and 68% respectively. Westridge was most similar to Pawnee's impervious area at 67% and these two were thought to function most similarly. With infiltration mutually exclusive from the PC-SWMM model's hydraulic calculations insight into hydrology characteristics must be made. Both Pawnee and Westridge have the same percent slope so underlying soil hydrologic group could explain the differences. When creating the model, impervious areas were reduced by 10 and 20% of the MARC NRI's "impervious other" classification. This land cover was exchanged for herbaceous land cover with the correlating soil "B," "C," or "D" hydrologic group underneath it. Westridge must have seen more amounts of better infiltrating "B" soils associated with the newly added herbaceous land coverings compared to Pawnee.

While modeling the hydrology, the SCS curve number method and percent impervious areas were working together to determine surface runoff and infiltration which might be causing the unexpected results. With respect to model outputs, the watershed SCS curve numbers were more indicative of model outputs than percent impervious area. It is thought that using the Green-Ampt infiltration properties would have seen more logical results because infiltration would have been fairly homogeneous across all watersheds and the infiltration model inputs would not have changed with the reducing impervious areas. Using this Green-Ampt method, infiltration and runoff could be more solely impacted by impervious surfaces but may not be describing the complexities of the watershed as well. It is believed that the Green-Ampt method is more limited a comparison between the SCS Curve Number Method vs. Green ampt would be a simple analysis and of interest to the urban watershed modeling community. Next steps would include analyzing if these reductions are scalable to larger watersheds with outlets in ecological areas of interest.

Chapter 5 - Conclusions

This experiment was able to model and compare three different BMPs to current hydrologic and hydraulic conditions in mature suburban watersheds. Here, rain barrels coupled with an EDDB seemed to be largely controlled by the functionality of the 125,000 ft^3 EDDB and its accompanying catchment. The PC-SWMM model suggests there is a better relationship between 10pctR and 20pctR simulations with changes in the watershed's SCS curve numbers and not the watershed's changes in impervious areas like what was expected. Ranking from least to most effective across the outlet's average flow, maximum flow, and total volume and supporting watershed infiltration, surface runoff, and surface storage are as follows: RB+EDDB, 10pctR, and 20pctR. All three of these BMPs can help decrease runoff, increase infiltration and surface storage. This will subsequently decrease the frequency of streams seeing bank full events which are the most channel forming and erosive stream events. Increased infiltration would also see improvements to stream base flow conditions and could sustain habitats longer during periods of drought that are expected to occur more frequently with climate change. These watershed scale BMPs are most effective during smaller rainfall events and would see accompanying water quality improvements.

Unfortunately, with maturely developed suburban watersheds, existing impervious buildings greatly dictate the amount and placement of impervious other surfaces. What is the best solution to reduce negative suburban impacts on watersheds – grassroots or policy? Well, either BMP strategy could have been intensified to match the results of the other BMP strategy. Here the answer comes down to a mix of both strategies because both campaigns need each other to maximize and sustain success. By implementing EDDBs and other green infrastructure at schools, students can learn about localized watershed issues and preventative measures. This education can transcend from students to parents creating a more watershed conscious population, especially in this area of educational need. This watershed conscious population can propose and vote for pro-sustainability policies as well as take action at their own homes. Policies initiated by the government will also be needed to reassure residents that their individual efforts are part of a collective initiate, further sustaining success.

These collective movements need to span more than just the city level to reduce the negative correlated effects of political fragmentation on watersheds. In our case, a large school district was chosen because it was able to direct the focus of multiple levels of watershed managers (independent cities, county programs, and a regional planning group) to a shared area of environmental need while also targeting a specific population for educational purposes.

Overall, Johnson County is in need of an environmental shift that moves away from "pro-growth." Like most of the Midwest, Johnson County is not at the forefront of sustainability. Yes, some notable sustainability projects have been implemented, but overall, area residents and governing officials have not wholeheartedly adopted sustainable practices. Part of the issue could stem from the fact that there is no keystone species to protect or habitat to preserve. Luscious prairie was turned into farmland long ago and farmland being urbanized is seen as an "improvement." Once land is developed on, there's no going back because of the increased property values and effort it would take to repair the natural ecosystem services. Additionally, there are no major environmental crises (e.g. droughts or floods) that panic citizens into taking concerned action (yet). In honesty, Johnson County's stormwater networks are functioning well if their sole goal is to reduce and eliminate flooding from suburban streets. When looking at larger goals of creating sustainable stormwater networks that harmoniously balances the built environment into the suburban, it can be seen that more progressive watershed BMPs need to be implemented to repair the 62 USEPA 303(d) listed impaired or potentially impaired waterbodies in Johnson County while buffering against the negative impacts of climate change.

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