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Prioritizing Stormwater Management: Comparing Integrated Best Management Practices in Urban and Suburban Neighborhoods

Danielle Kathleen Norman
University of Tennessee - Knoxville, dnorman5@utk.edu

To the Graduate Council:

I am submitting herewith a thesis written by Danielle Kathleen Norman entitled "Prioritizing Stormwater Management: Comparing Integrated Best Management Practices in Urban and Suburban Neighborhoods." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Landscape Architecture, with a major in Landscape Architecture.

Tracy Moir-McClean, Major Professor

We have read this thesis and recommend its acceptance:

Madhuri Sharma, Joanne Logan, Curtis Stewart

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

Prioritizing Stormwater Management: Comparing Integrated Best Management Practices in Urban and Suburban Neighborhoods

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DEDICATION

To my husband Darren, whose love, patience and encouragement have been the cornerstone of this success. To my family who has taught me to persevere through all obstacles and to never make a decision out of fear. To my God who gives me courage and whose grace is beyond what I had ever hoped for.

ABSTRACT

This thesis demonstrates a comparison of two design proposals that integrate Best Management Practices to address stormwater runoff volumes in urban and suburban neighborhoods. The thesis investigation includes the selection and comparison of two diverse neighborhoods to inform design decisions. It then assesses the environmental, social and economic implications of the design proposal in each neighborhood.

The site selection process is a method that overlays specific criterion such as residential land use, topographic features, and median household income (3) nested scales; the watershed scale, the sub-watershed scale, and the neighborhood scale. For the purposes of this paper, nested scales are defined as a study area that lies within a greater study area that was previously defined. The nested scales are used to identify two neighborhoods that reflect greater watershed and sub-watershed characteristics.

The first neighborhood selected is located in the suburban, Sinking Creek Watershed. This neighborhood reflects the high income and low density development characteristics of the greater watershed. The second neighborhood is located at Knoxville's urban core in the Second Creek Watershed. Conversely, this neighborhood is reflective

of the low income, high density development characteristics that are dominantly found in the greater Second Creek watershed. Both Knox County watersheds are associated with impaired water bodies due to stormwater runoff.

Neighborhood and stormwater inventories document conditions of the Sinking Creek and Second Creek neighborhood study areas that were identified by the nested scales process. The inventories and subsequent analyses help to identify issues within each community and inform stormwater goals. Each design proposal responds to the perceived needs of the neighborhood while managing stormwater volumes projected in a Hydro CAD model for a 1.29 inch, Type II 24 hour rain event. These proposals include a master plan of integrated Best Management Practices (BMP's), typical street sections showing the application of BMP's proposed within the public right-of-ways, and examples of individually selected BMP's assigned to these street applications to meet the volumetric demands of the modeled rain event.

After each design proposal has been established, a comprehensive analysis assesses and compares the social, environmental, and economic values of the design proposals.

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1. Introduction

This thesis is intended for designers, planners, developers and those who have the opportunity to work within a multi-disciplinary team to establish stormwater management goals within existing communities. It should be used solely to provoke thought and discussion about the implications of integrated Best Management Practices for stormwater management in existing communities. It is not to be used as a design guide or standard in any discipline nor used for any type of design, engineering, or construction specifications.

1.1 Thesis Statement

It has been shown in literature that if we manage stormwater runoff using integrated Best Management Practices (BMP's) then that community will benefit from the increased environmental, social and economic values of the design proposal (Water Environment Federation 2012; Collett 2013).

This thesis hypothesizes that because existing communities have unique characteristics, those environmental, social, and economic benefits may vary from one community to the next.

In order to test this speculation, this thesis compares and contrasts the characteristics of one urban and one suburban neighborhood in Knox County Tennessee and proposes a design that

addresses stormwater runoff volumes produced by the 95th percentile rain event by using integrated Best Management Practices (BMP's).

Both design proposals will be generally assessed and compared on three community value metrics to help understand the implications of using integrated BMP's for stormwater management in existing communities. General assessment of the environmental, social and economic values of the proposed designs is utilized to understand where resources may best be allocated towards improving impaired water bodies and existing neighborhoods.

In this thesis the environmental value is determined by the fulfillment of projected demand volumes of stormwater runoff to be met by the Total Design Storage proposed in each master plan. Social value of each design is assessed based upon the projected increase in walkability, while the economic value is assessed by the projected cost-effectiveness of design implementation. By assessing these three individual values, we can begin to prioritize integrated BMP's for improving water resources in Knox County while considering the implications of the design on the community.

1.2 Stormwater Management History

The history behind stormwater pollution stems from the collective realization of our need to improve the water quality of our surface

waters in the United States. In 1972 the EPA passed the Federal Water Pollution Control Act known as the Clean Water Act. Under this act, pollution was regulated by the National Pollutant Discharge Elimination System (NPDES) permitting process to protect our waters from further impairment. It was not until 1984 that stormwater runoff was declared a non-point source pollutant and was later regulated under the NPDES permitting process in 1987(Board 2009). A non-point source pollutant such as stormwater has no defined point of origin and is generated by multiple sources of developed land uses. Each land use produces unique contaminants that are transported by stormwater runoff into local surface waters (Cech 2010). Imperviousness of watershed surfaces is a characteristic associated with stream-system decline in the urban and urbanizing environments (Booth, Karr et al. 2001). As urban development increased, the EPA realized the need to further regulate stormwater runoff in urban areas. In 1990, Phase I Stormwater regulations were adopted under the Clean Water Act Amendments. Under Phase I, any urban area with a population above 100,000 were required to capture the first 1" of stormwater runoff under new development. Realizing the importance of how each subsequent watershed affects another downstream, the EPA endorsed the Watershed Protection Approach in 1991 (Board 2009). Phase II of

the stormwater regulations incorporated in 1999 requires urban populations of 50,000 and greater to also align with Phase I standards (Figure 1). The most recent amendment of these stormwater regulations was the compilation of the 303d list of impaired waters (Board 2009). The 303(d) list consists of impaired and threatened waters (stream/river segments, lakes) as submitted by each state. The Clean Water Act requires all states to submit this list for EPA approval every two years on even-numbered years. If the required pollution controls on the listed impaired waters are not sufficient, state agencies should aim to attain or maintain the applicable water quality

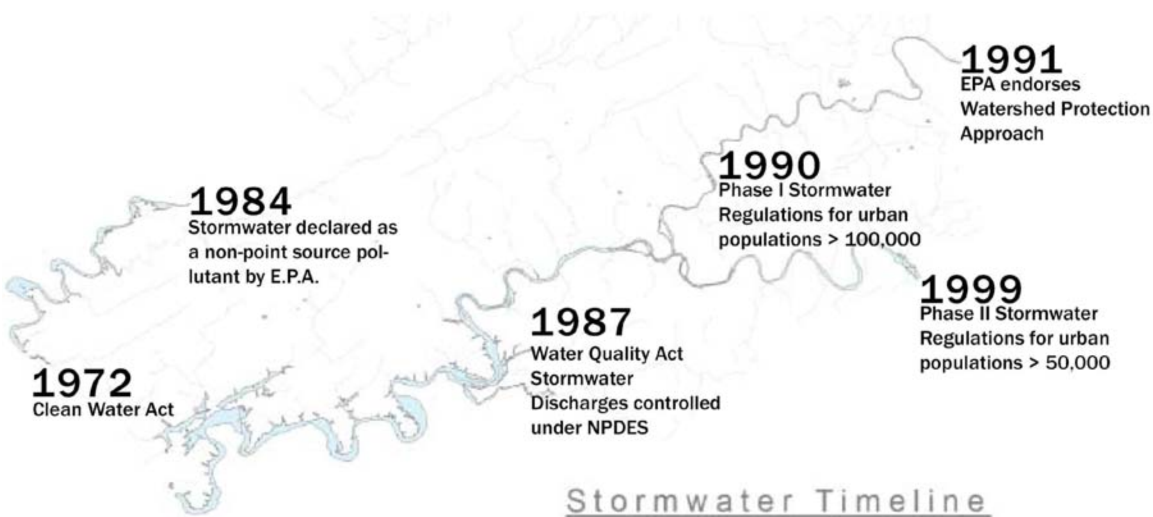


Figure 1. Stormwater Timeline

standards and establish priorities for improving water quality (U.S.E.P.A.).

Stormwater BMP’s may be implemented as a way of treating or limiting pollutants and other damaging effects of stormwater runoff in order to meet legislative and code requirements (North Carolina BMP Manual). In the State of Tennessee, the Tennessee Department of Environment and Conservation (TDEC) provides the technical basis for setting the state's water quality standards (TDEC 2013).

Locally, Best Management Practices (BMP’s) have been incorporated into site planning and design for rehabilitating or maintaining these water quality standards. The Knox County Stormwater Manual specifies that the goals of better site development design are to reduce the amount of runoff and pollutants that are generated from a development site (AMEC 2008). Best Management Practices used in site design may include wet ponds, dry detention basins, wetlands, bioretention areas that incorporate a combination of treatment methods. Manufactured devices are BMP’s that use some combination of baffles, swirl flow patterns, settling chambers, filtration, and other means to separate floatable and settleable solids from storm-water runoff (Jadlocki 2009).

1.3 Thesis Investigation Description

The Sinking Creek and Second Creek watersheds located within Knox County, Tennessee were selected as the basis for this thesis investigation. Both watersheds directly contribute to the greater Tennessee River watershed and have been reported in the Tennessee Department of Environment and Conservation's (TDEC) 303d list as having impaired water bodies attributed to stormwater runoff as a pollutant source group (Conservation 2012).

The Sinking Creek watershed has low-density, high-income suburban characteristics, while the Second Creek watershed has high-density, low-income, urban characteristics. Smaller catchment areas (sub-watersheds) located within the Sinking Creek and Second Creek watersheds were selected containing these characteristics and are directly associated with the impaired water bodies due to stormwater runoff from their surrounding land uses (U.S.E.P.A. 2010). Located within these two sub-watersheds, two neighborhoods were selected for this investigation that will pertain to the site inventory and analysis and the design portions of this document.

The first neighborhood is south of Cedar Bluff Ridge along George Williams Road, located within Sinking Creek's suburban watershed. The second neighborhood is located within Second Creek's

urban watershed south of Sharp's Ridge and is part of the Lincoln Park/Oakwood Neighborhood.

The Site Inventory and Analysis chapter of the investigation aims to identify the perceived needs of the community and some of the stormwater management issues affecting each neighborhood. It is divided into two parts called Neighborhood Inventory and Analysis and Stormwater Inventory and Analysis. These sections were used to help inform design decisions in the proposal.

The design proposal consists of a neighborhood master plan showing the locations of integrated BMP's in each site. It also includes typical street sections of the BMP's proposed within the public right-of-ways and detailed descriptions of individual BMP characteristics. The estimated storage volumes incorporated in each master plan proposal are required to retain the projected stormwater runoff volumes modeled in HydroCAD software for the 95th percentile Type II 24 hour rain event. The projected runoff volumes by the Hydro CAD model are compared to the estimated storage volumes incorporated in the master plan to assess if the design proposal meets this requirement in both neighborhoods. A general assessment of the environmental, social and economic implications is compared between the two design proposals.

2. Site Selection Methodology

The site selection methodology includes the use of nested watershed scales as a means of refinement to pin-point the neighborhood locations that will be established for the thesis investigation and design proposal. This process consists of Watershed Selection, Sub-watershed selection, and Neighborhood selection.

2.1 Refinement Using Nested Scales

Selecting the two neighborhood sites for analysis, design, and comparison was a process led by specific sets of criteria contained within each scale. Three scales, in descending order, were used to identify the location of the two neighborhoods being compared for analysis and design: the watershed scale, the sub-watershed scale, and the neighborhood scale (Figure 2). This method, using nested scales, utilized ArcMap Geographic Information Systems (GIS) as a tool to overlay maps of the selected criteria to help define the desired study areas.

After two comparable watersheds are selected, the watershed scale leads to a more refined, sub-watershed scale where another set of criteria is used for comparison. The selection process is most refined at the neighborhood scale within the sub-watershed.

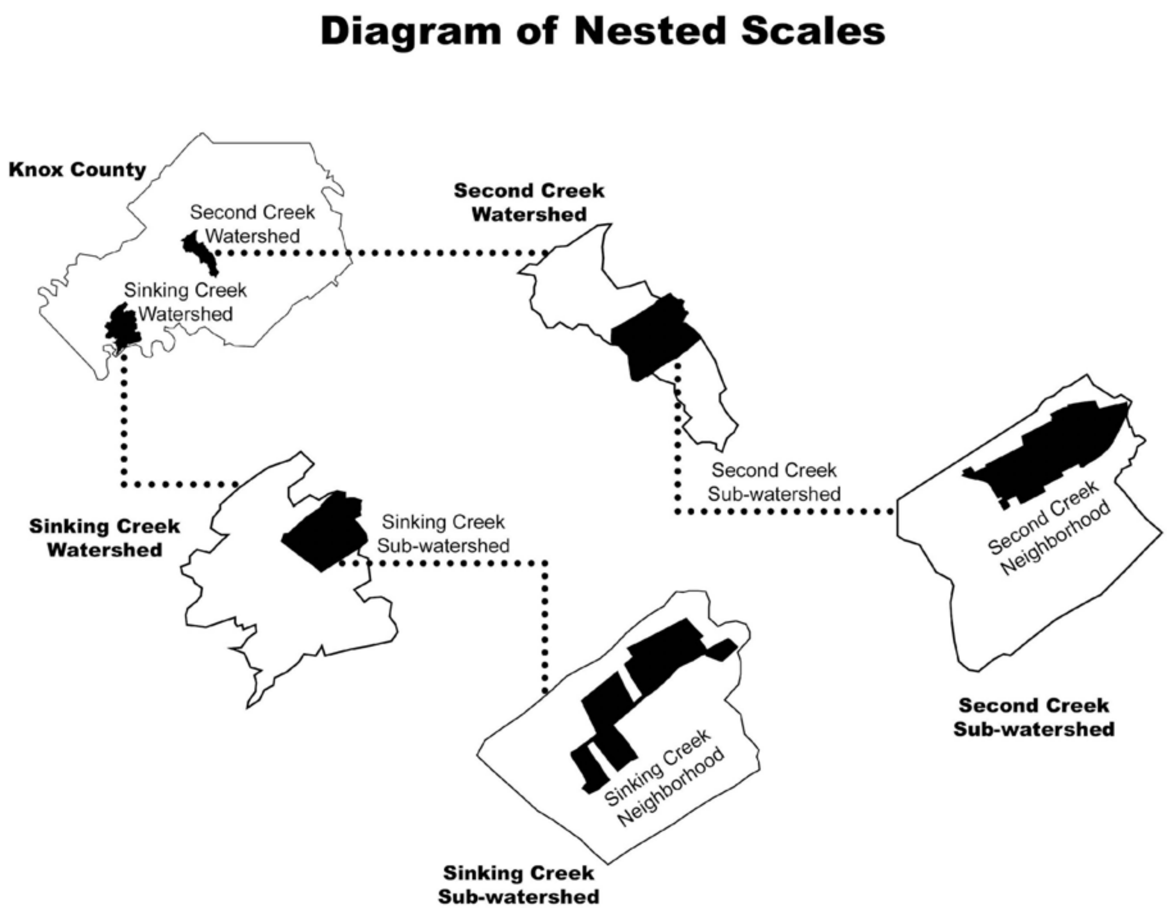


Figure 2. Nested Scales Diagram

2.2 Watershed Selection

The process of pairing watersheds before initiating a comparative analysis is important to achieve identification of cohesive characteristics. Several watershed pairs were identified within the initial selection process and then these selections were refined based upon specific similarities and diversities between watershed characteristics. The qualifying similar characteristics for comparison include existing land use types and impaired water bodies. The qualifying divergent characteristics are median household income and development density. Sinking Creek's low density, high-income suburban watershed is compared and contrasted to Second Creek's high density, low-income urban watershed. Both watersheds are located within Knox County and directly contribute to the greater Tennessee River watershed (KGIS).

The type of existing land use plays an important role in this watershed comparison because it is indicative of county-wide development trends and is the first set of similar criteria overlaid in this investigation. Residential units accounted for 94 percent of all new construction projects in Knox County between the years of 2000 and 2010 (Commission 2010) and continue to be the leading type of development countywide (Commission 2012). Therefore, the similar

land use type being selected as a priority for the comparison between the Sinking Creek and Second Creek watersheds is existing residential land use. The Existing Land Use map of Knox County (Figure 3) verifies that the majority of the existing land use fabric is residential in the Sinking Creek and Second Creek watersheds (KGIS).

The second similarity between the two watersheds is the presence of impaired water bodies due to stormwater runoff (Conservation 2012). The map of Impaired Water Bodies in Knox County (Figure 4) shows several portions of surface waters that are impaired or are considered for a non-attaining status within the Sinking Creek and Second Creek watersheds. It is important to identify that stormwater runoff is a source of impairment in both selected watersheds for the investigation to be pertinent.

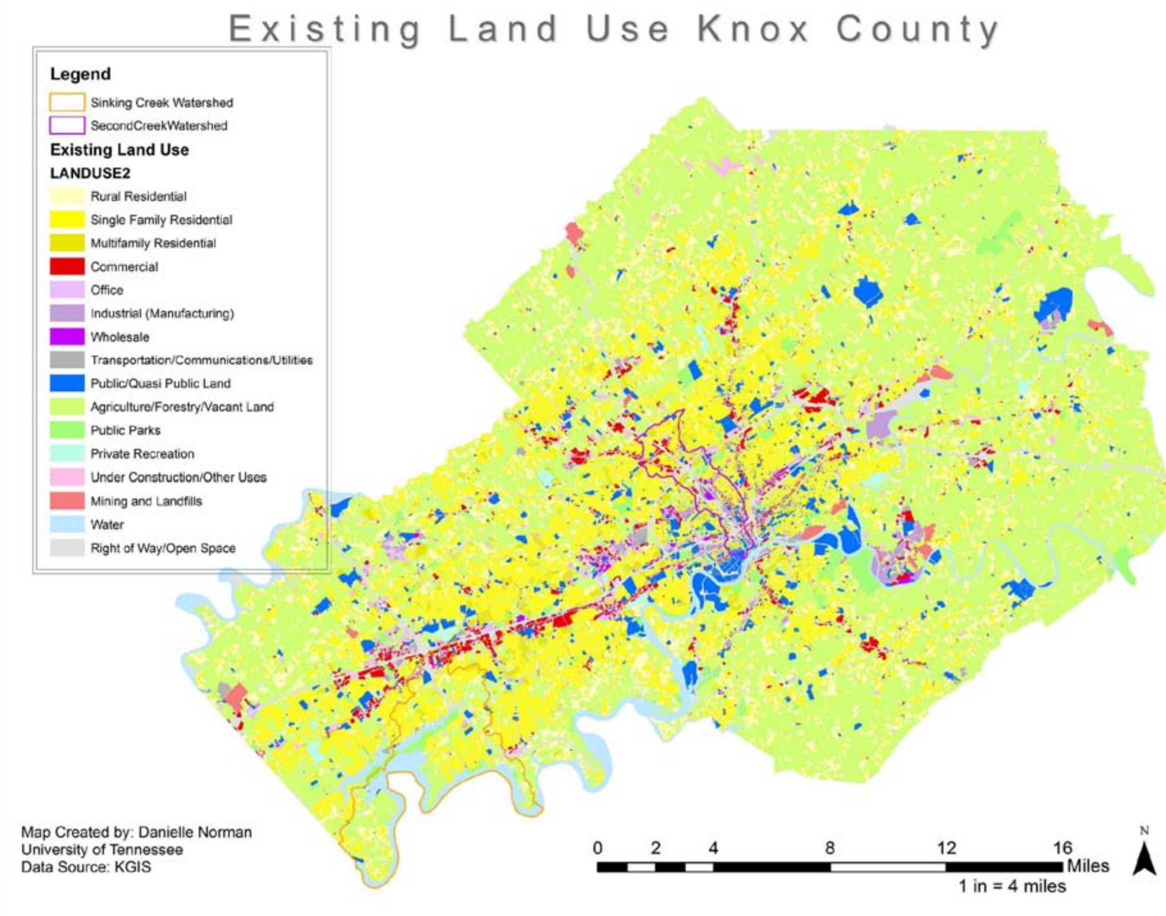


Figure 3. Existing Land Use Knox County

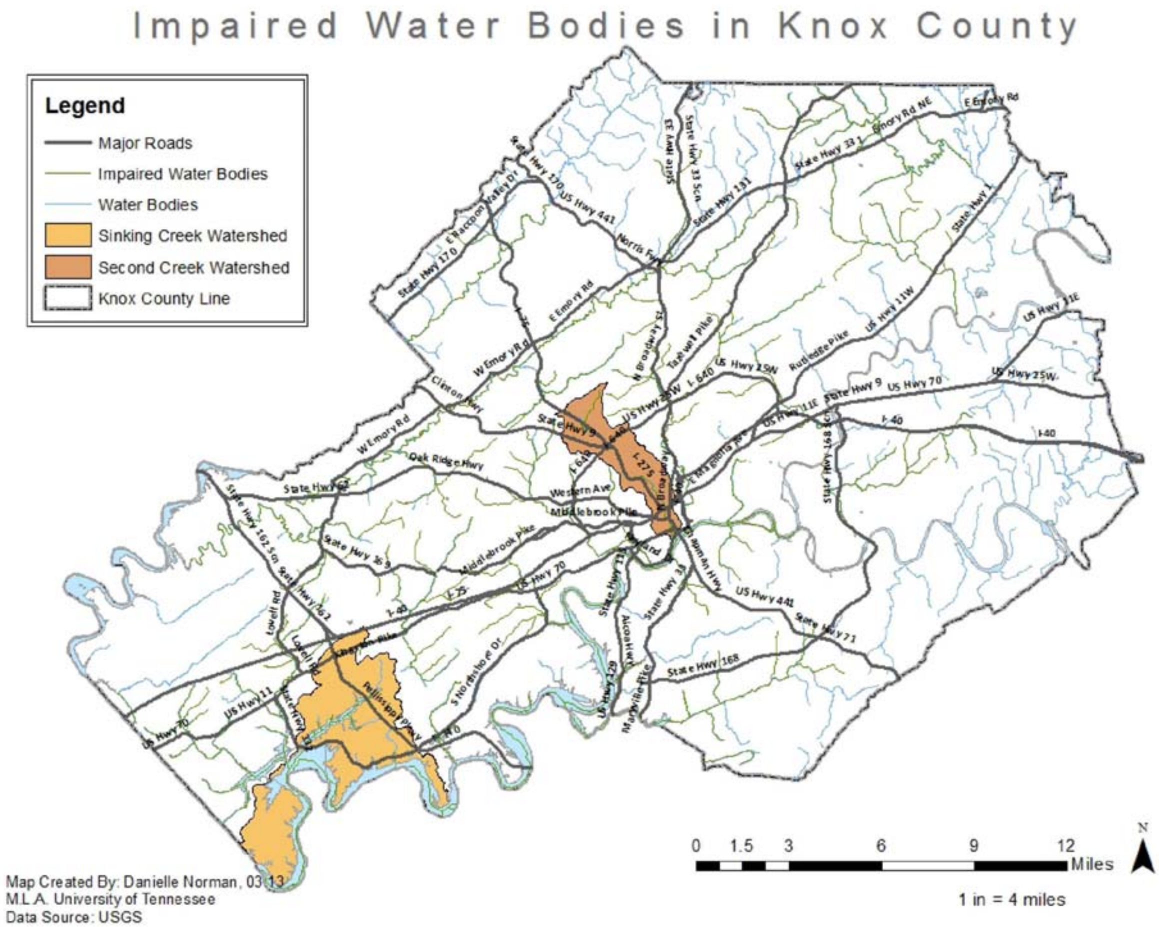


Figure 4. Impaired Water Bodies Knox County

The first set of selected divergent characteristics for the watershed comparison is median household income. Figure 5 shows a map of Knox County by census tract boundaries ranging from low, moderate, middle and upper median household income levels. The entire suburban Sinking Creek watershed consists of upper level income communities, highly contrasted by the majority of the communities in the Second Creek watershed, mostly containing low and moderate income levels (U.S. Department of Commerce and Branch 2010). In this investigation, divergent income levels are being used as an indicator to reflect diverse social and economic characteristics within the compared watersheds. The intention for the proposed design will aim to address stormwater management in communities that are socially and economically diverse so that the resources for the proposed master plan may be objectively considered while following the current trends of class divergence and residential segregation by income (Taylor 2012).

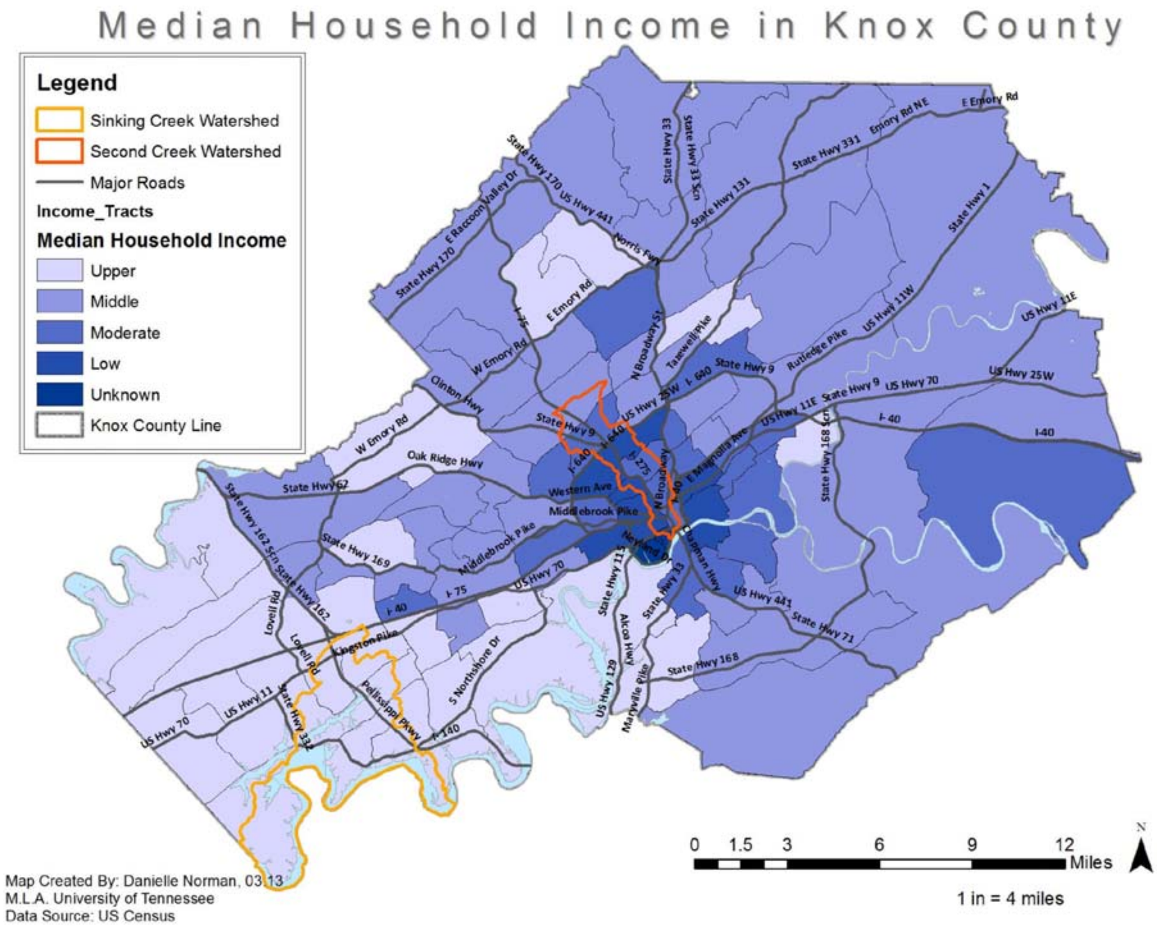


Figure 5. Median Household Income Knox County

The Land Cover and Development Density map of Knox County (Figure 6) illustrates the second set of divergent characteristics in the Sinking Creek and Second Creek watersheds. The legend indicates land cover types based upon vegetation and levels of impervious development. According to GIS data, the Sinking Creek watershed consists mostly of open space and low density development (from undeveloped to a range of 20%-49% impervious surfaces), while the Second Creek watershed consists mostly of high and medium density development (from 50% impervious surfaces to greater than 79% impervious surfaces)(USGS). This data verifies the assumption that urban development is associated with a higher level of imperviousness than the imperviousness in suburban development areas. Increased impervious cover indicates increased stormwater generation and pollutant loadings (AMEC 2008).

By overlaying these qualifying similar and qualifying divergent characteristics, the Sinking Creek and Second Creek watersheds were selected for this thesis investigation. The criteria for Sinking Creek's low density, high-income suburban watershed was compared and contrasted to the criteria of Second Creek's high density, low-income urban watershed to show how the similar and polar characteristics influenced the watershed selection process.

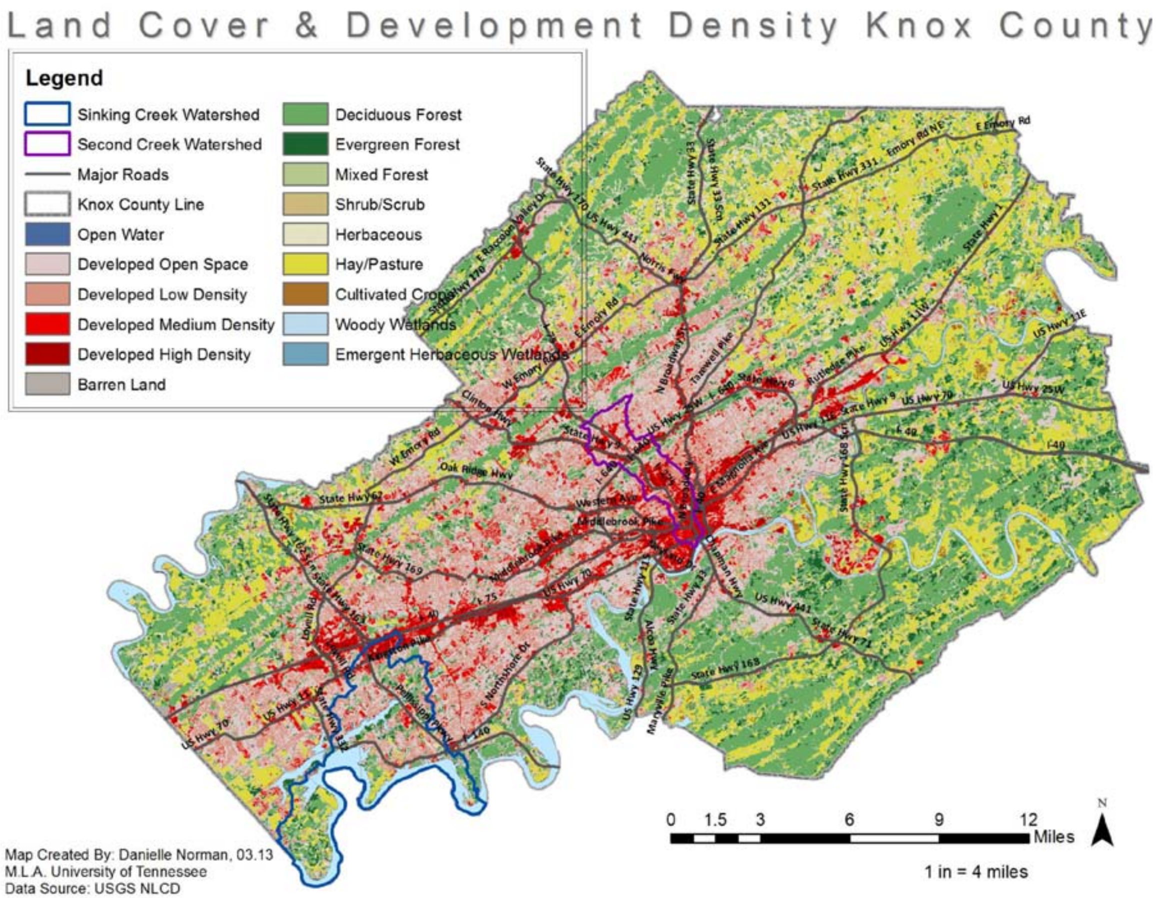


Figure 6. Land Cover & Development Density Knox County

2.3 Sub-watershed Selection

The sub-watershed scale is the second order of refinement in the site selection process. The sub-watersheds are contained within the Sinking Creek and Second Creek watersheds described in the previous sections (refer to Nested Scales Diagram Figure 2). The method of overlaying similar and divergent sets of criteria was continued in order to identify two comparative sub-watersheds. The qualifying similar characteristics are topographic features, sub-watershed gross area, and existing land use patterns. The qualifying divergent characteristic remains median household income, to identify sites that reflect communities with diverse social and economic characteristics. Overlaying these sets of criteria and locating the catchment areas in close proximity to the impaired water bodies, resulted in the locations selected for the two comparative sub-watershed areas. The Sinking Creek sub-watershed is located south of Cedar Bluff Ridge and north of Westland Road. The Second Creek sub-watershed is located south of Sharpe's Ridge and north of East Oakhill Avenue (KGIS).

The Sinking Creek and Second Creek sub-watersheds were initially identified by similar topographic features (Figure 7).

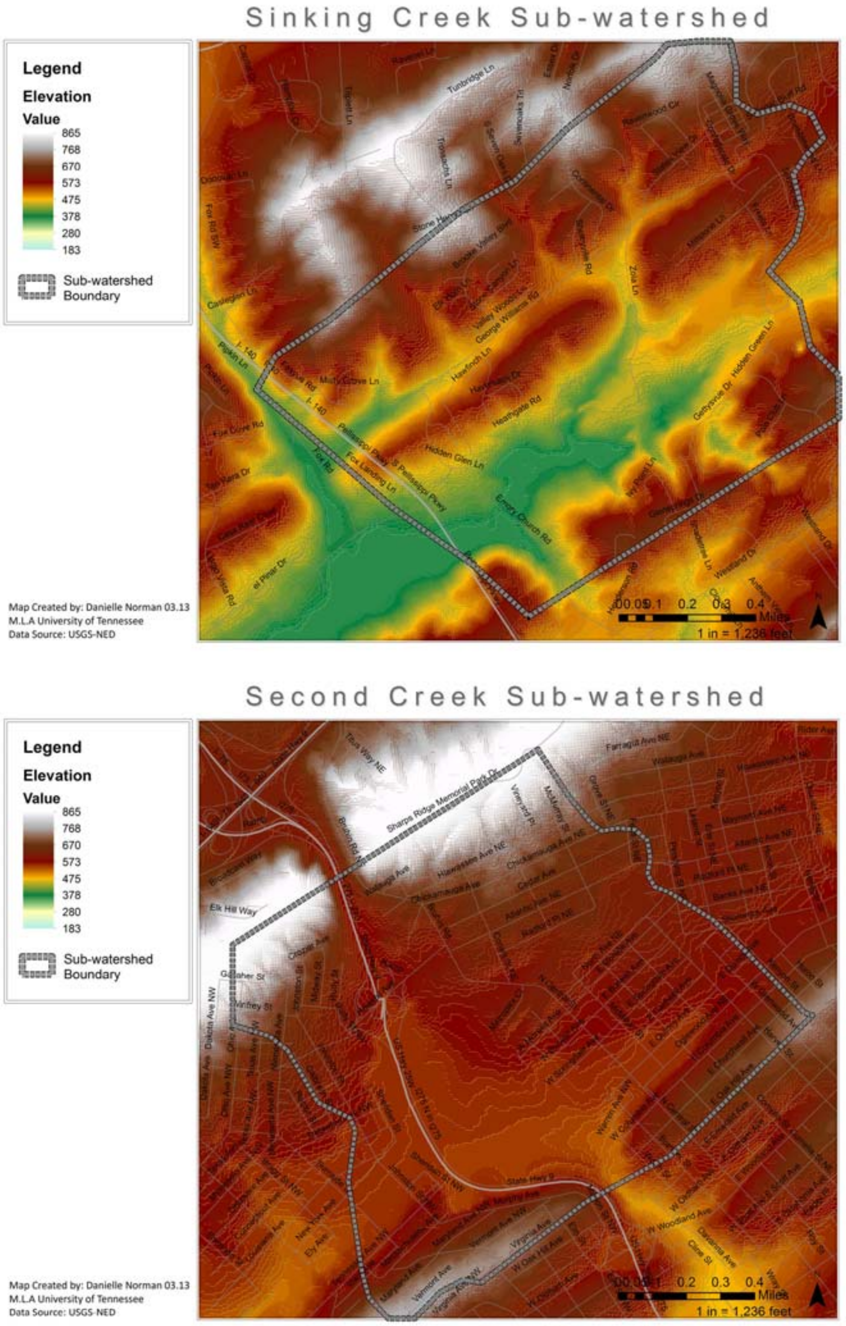


Figure 7. Digital Elevation Model Comparison

To make an equivalent comparison, the two sub-watersheds were defined between two ridgelines of similar changes in elevation from the top of the ridge to the receiving water body. The raster image shown by the GIS data indicates high changes in elevations for each sub-watershed. Sinking Creek's sub-watershed shows a 400 foot change in elevation while Second Creek's sub-watershed shows a 500 foot change in elevation. Topographic features are considered as part of the site selection process because they are one of the mechanisms of stormwater runoff generation and affect the hydrologic process (Gupta 2001).

The GIS flow accumulation analysis, based on topographic features, shows where runoff water may accumulate within each sub-watershed (Figure 8). The flow accumulation analysis shows that both catchment areas directly drain to the Sinking Creek and Second Creek water bodies.

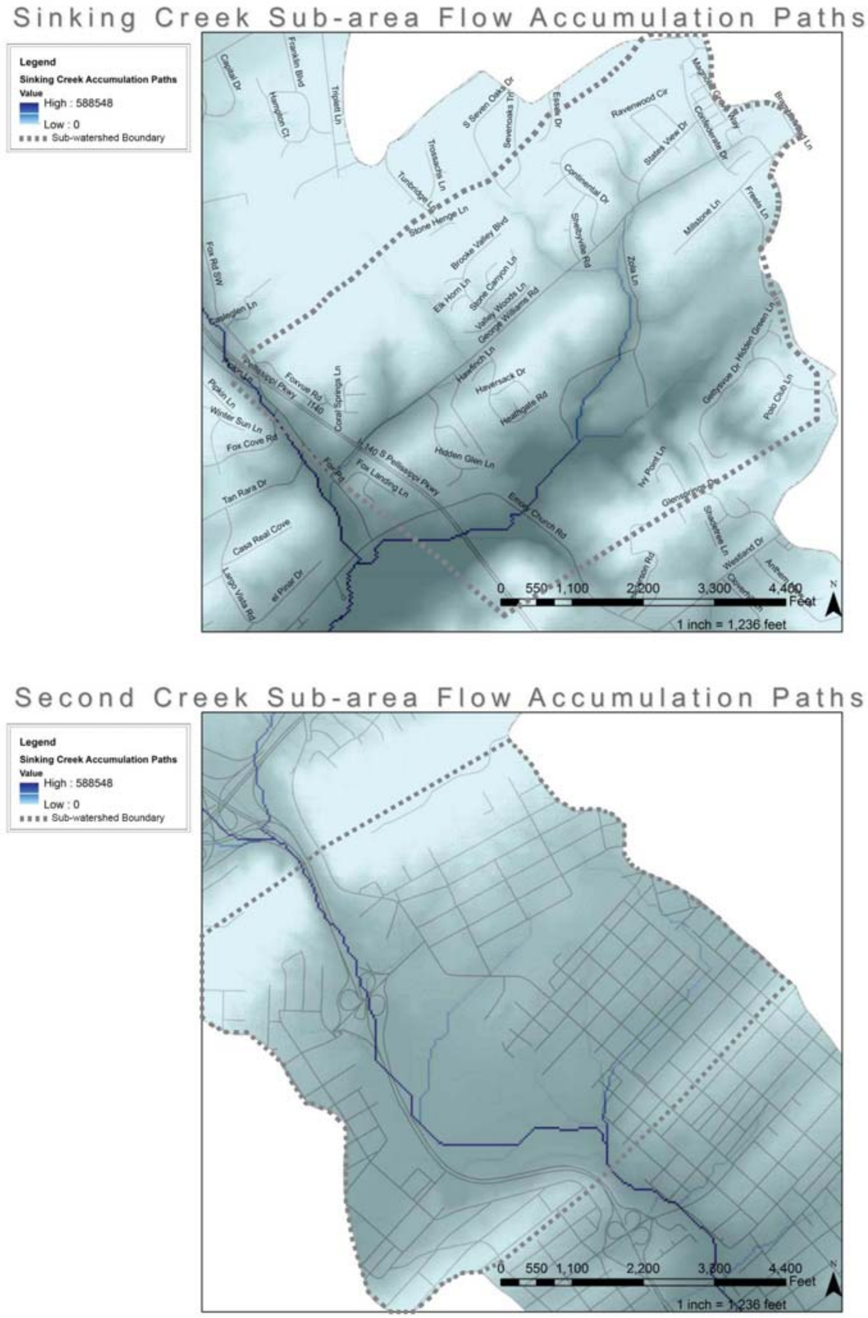
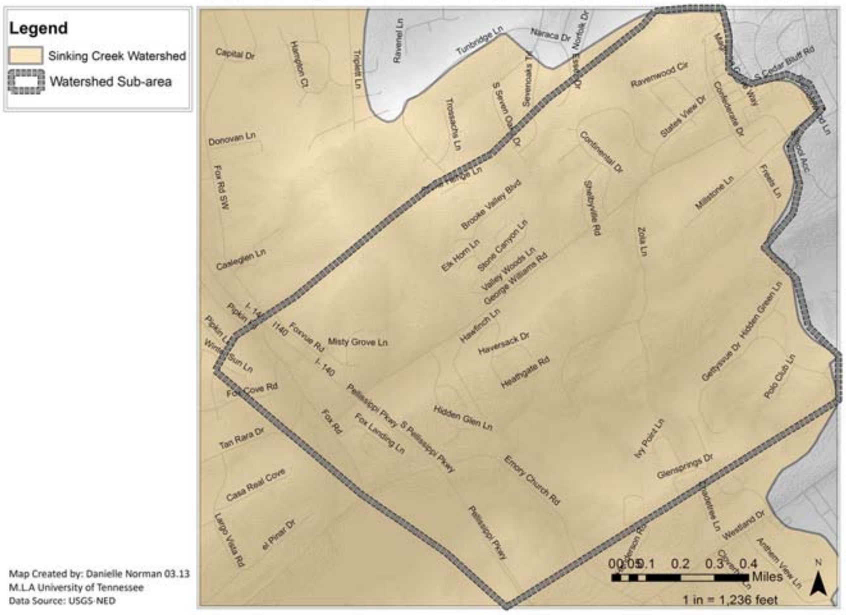


Figure 8. Sub-watershed Flow Accumulation Comparison

While both sub-watersheds were defined by topographic features, they were also required to meet similar gross areas for this investigation. Similar gross areas for the Sinking Creek and Second Creek sub-watersheds were estimated so that the anticipated volumes of precipitation collected over these areas are as similar as possible for any given rain event (Gupta 2001). The gross areas were limited by the greater watershed boundaries and the distances between the ridgelines.

The 1400 acre sub-watershed for Sinking Creek is defined by the watershed boundary on the northeastern edge (Figure 9). It is bound on the northwest and southeast, by ridgelines. Sinking Creek's final sub-watershed boundary on the southwest side was later determined by the limiting factor of Second Creek's sub-watershed gross area of 1300 acres (Figure 9). The Second Creek sub-watershed gross area was defined by the width of the watershed's northeast and southwest boundaries. The northwest and southeast sub-watershed boundaries were defined by those ridgelines identified in the previous section describing topographic features (refer to Figure 7).

Sinking Creek Watershed Sub-Area



Second Creek Watershed Sub-Area

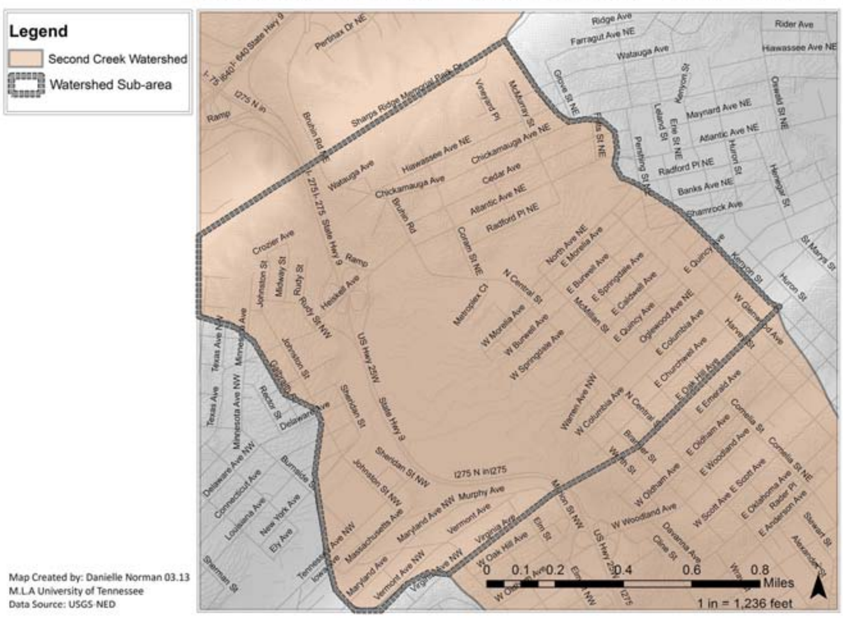
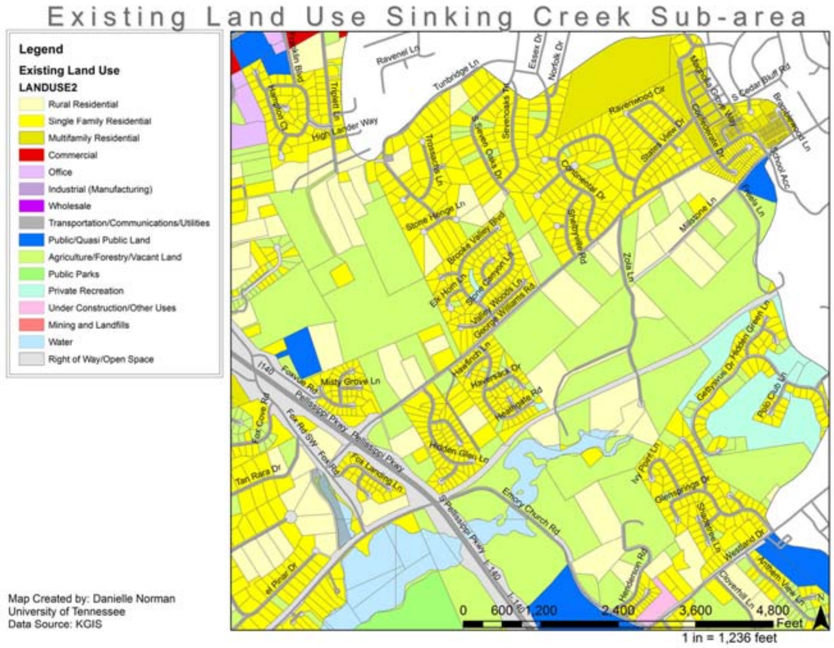


Figure 9. Sub-watershed Gross Area Comparison

The existing land use patterns reveal other land use types dispersed throughout the residential fabric at the sub-watershed scale (Figure 10). Although these other land use types may vary among the Sinking Creek and Second Creek sub-watersheds, massing the major land use types in the form of bubble diagrams makes them more relatable, revealing that both sub-watersheds have residential land uses oriented around an historic land use (Figure 11).

The existing land use patterns of the Sinking Creek sub-watershed show residential borders along the ridgelines that are oriented around the Sinking Creek water body. The water body is adjacent to agricultural land use, indicating it to be a functional and aesthetic piece for the surrounding neighborhoods. In Figure 11 two major transportation corridors divide the diagram shown by the crossing axis of Interstate 140 and the railroad.

In a similar pattern, the existing land uses in the Second Creek sub-watershed show residential orientation around its historic industrial core (Wood 2005). This industrial core is located adjacently to the Second Creek water body; however, according to windshield survey, it is minimally accessible to its surrounding residential community (Figure 11). The significance of Second Creek is based



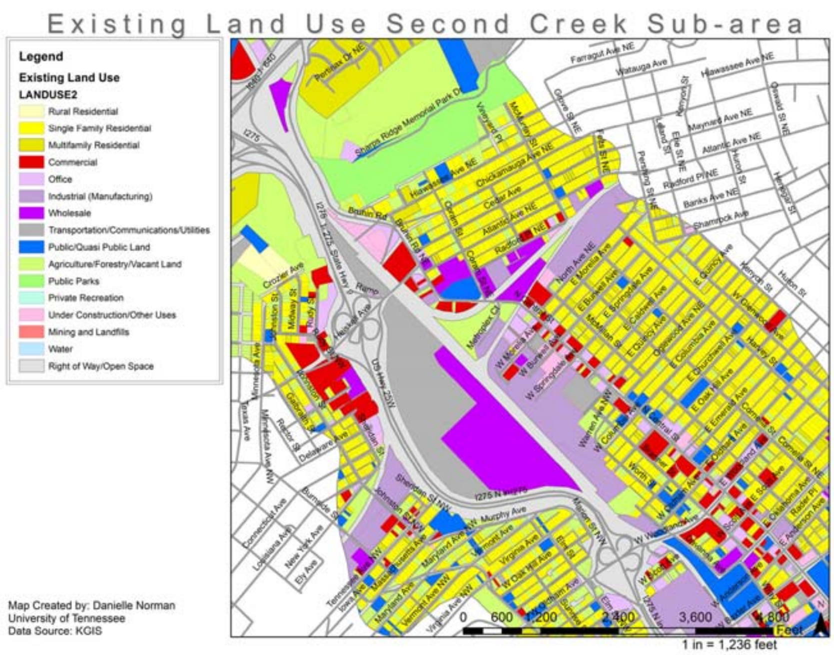
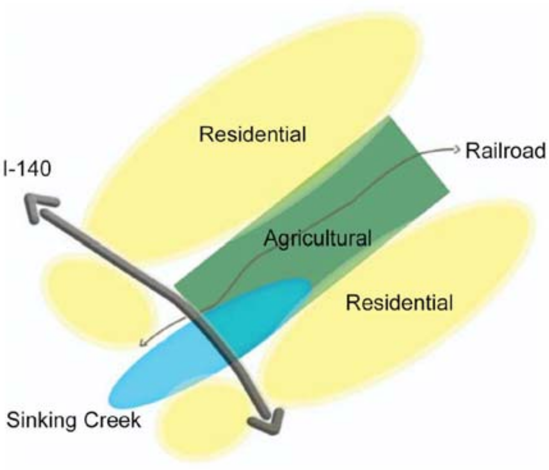
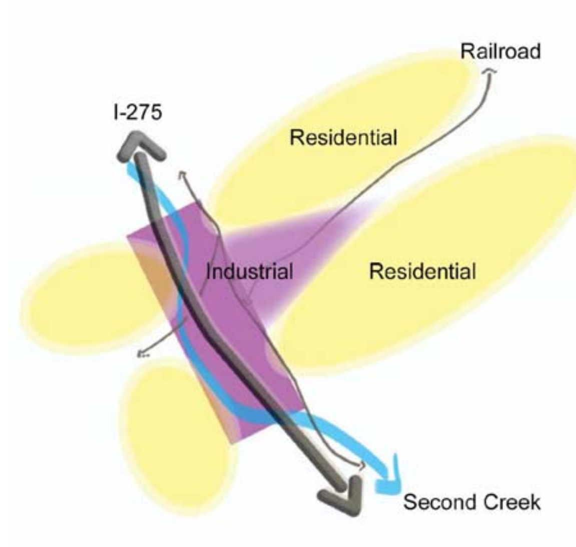


Figure 10. Sub-watershed Existing Land Uses Comparison

Existing Land Use Patterns Diagrams



Sinking Creek Sub-watershed



Second Creek Sub-watershed

Figure 11. Bubble Diagrams of Existing Land Use Patterns

upon its proximity to industrialized areas and subsequent attraction of residential development to those industries (Wood 2005) which is made more apparent by the relationship shown in the bubble diagram. The diagram in Figure 11 shows that the railroad and Interstate 275 in Second Creek's sub-watershed form an axis similar to the relationships shown in the diagram of Sinking Creek's sub-watershed.

The final overlay of criteria in the site selection process for the sub-watersheds is the comparison of Sinking Creek's upper median household income with that of Second Creek's lower median household income. Sinking Creek's sub-watershed area consists of three census tracts (KGIS). All tracts are considered to be in the upper level income range (Figure 12) ((FFIEC) 2013). The median household income levels in the Second Creek sub-watershed are defined by five census tracts (KGIS). These five tracts are made up of lower to moderate levels of median household income (Figure 12). Comparing median household incomes at the sub-watershed level reveals further distinction of diversities that occur between the Sinking Creek and Second Creek study areas, and also diversities occurring within the sub-watersheds themselves. By further establishing where diversities occur within the sub-watersheds, the neighborhood selections may

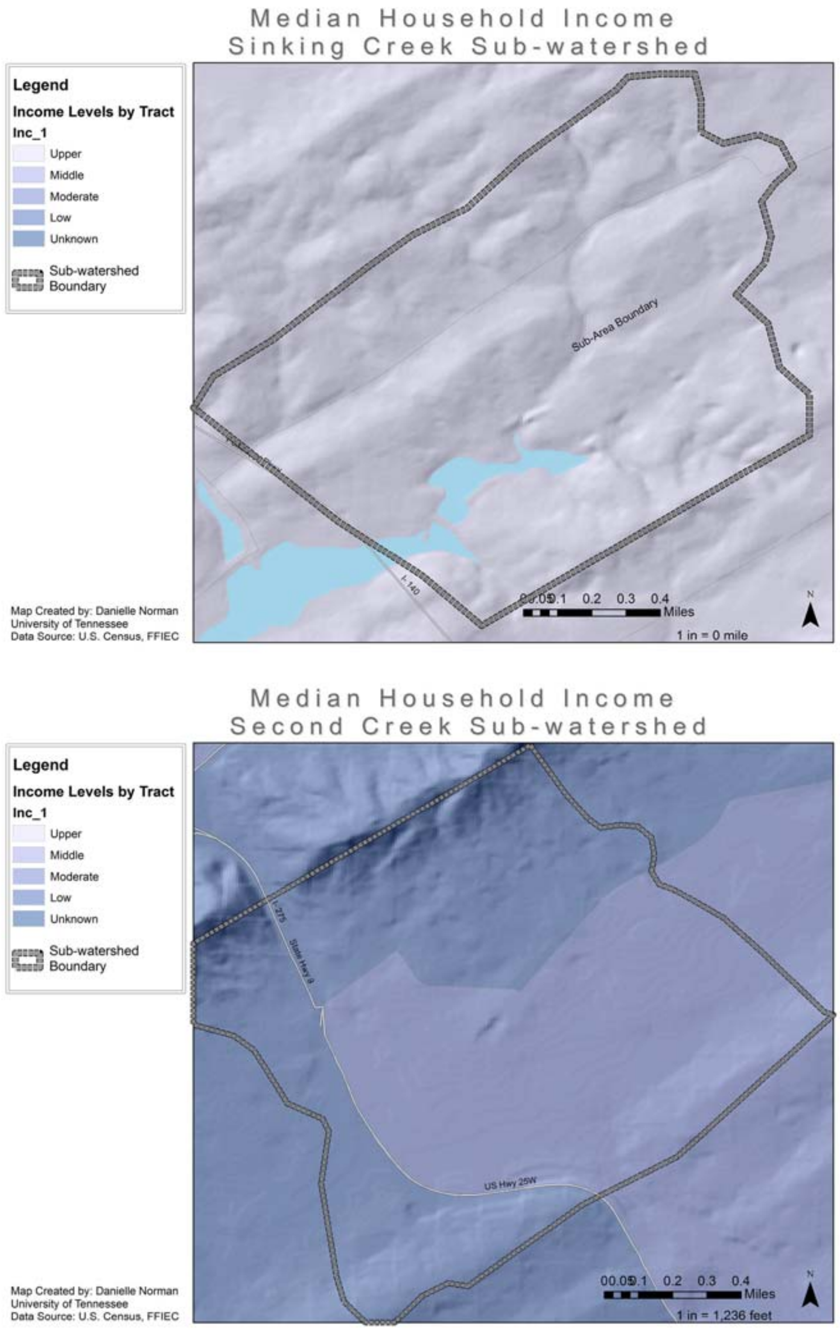


Figure 12. Sub-watershed Median Household Income Comparison

be consistent with the intention of contrasting social and economic characteristics for this investigation.

2.4 Neighborhood Selection

Two neighborhoods contained within the Sinking Creek and Second Creek sub-watersheds are the most refined scale used for comparing inventory and analysis for the proposed master plans. It has been established that these two neighborhoods reside within comparable topographic regions of similarly sized sub-watershed areas with suburban, high income qualities and urban, low income qualities. Delineating the comparable neighborhood site boundaries is based upon overlaying criteria such as similar topographic position, and similar neighborhood gross areas, while prioritizing the focal areas in the existing residential land use fabric.

Because this thesis aims at proposing strategies for stormwater management, similar topographic positions of the neighborhoods play an important role for the comparison (Figure 13). Selecting both neighborhood study areas higher up in their subsequent sub-watersheds is a desirable design strategy for integrating stormwater management, because stormwater management is more effective as it is closer to the source of runoff (U.S.E.P.A. 2007). To identify which

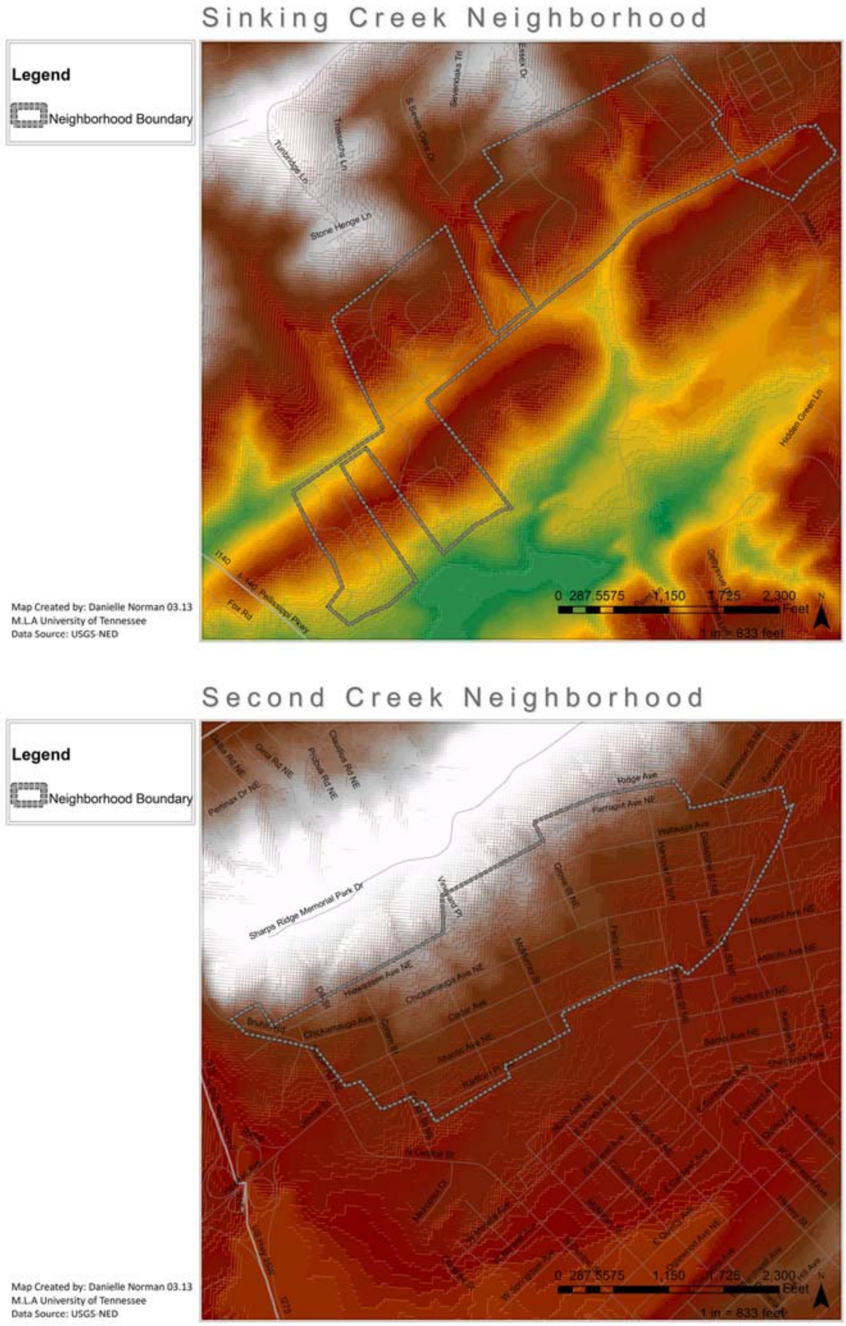
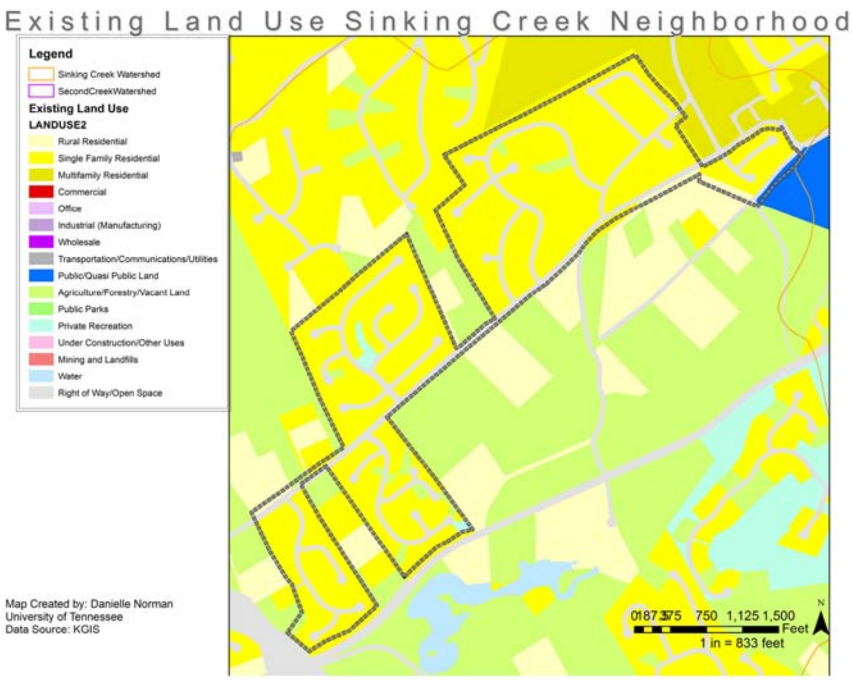


Figure 13. Digital Elevation Model Neighborhoods Comparison

ridgeline was most appropriate for locating the neighborhood site, further overlaying of existing residential land use and gross area criteria was required.

In the case of both Sinking and Second Creek, the residential neighborhoods are located along ridgelines with very few commercial, public, or other land use types within the existing fabric (Figure 14). The limited and defining factor for these neighborhoods was for each to have similar areas (Figure 15).

In a similar circumstance, the southeastern ridgeline for the Second Creek neighborhood selection was ruled out due to a lack of definitive neighborhood boundaries, while also being divided by the existing watershed boundary. Therefore, the northwestern neighborhood in Second Creek was established as more desirable selection for the neighborhood comparison. This northwest neighborhood in Second Creek became the limiting factor for determining the final gross area of the Sinking Creek neighborhood (Figure 15). The results of this iterative process are roughly 205 acres within the Sinking Creek Neighborhood and 204 acres in the Second Creek Neighborhood areas,



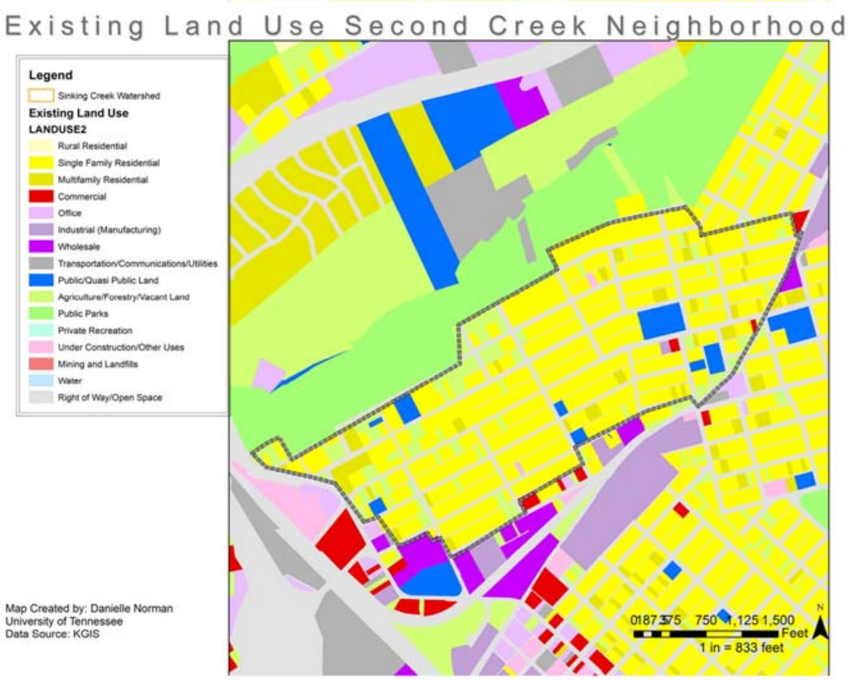


Figure 14. Existing Land Uses Neighborhood Comparison

Figure 15. Neighborhoods Gross Area Comparison

making them suitable for comparison in the inventory and analysis portion of this investigation.

3. Inventory and Analysis

The Inventory and Analysis Chapter is broken into two parts; Neighborhood Inventory and Analysis and Stormwater Inventory and Analysis. Both parts are used to inform design decisions based upon the investigated characteristics of the Sinking Creek and Second Creek Neighborhoods. The Neighborhood Inventory primarily assesses social and economic characteristics of each neighborhood while the Stormwater Inventory assesses environmental characteristics. The investigative methods, findings and analyses of the Neighborhood and Stormwater Inventories are given within each part to convey how they will inform design decisions.

3.1 Neighborhood Inventory and Analysis

Neighborhood characterization was achieved by a collection of inventory methods to help guide the design process for the master plan. Because both neighborhoods are unique in their own characteristics, it is not assumed that one design solution will be as equally appropriate for the other neighborhood. This characterization is both a qualitative and quantitative inventory study. Its methods include: an observational summary collected by windshield survey, a neighborhood density study, street inventory with photo inventory of

the typical neighborhood qualities, a neighborhood walkability study, and a socio-economic demographics comparison. This characterization helps to convey neighborhood qualities such as culture and diversity, class status, and inform about the perceived needs of the community to be addressed by the design of BMP's and the overall neighborhood master plans.

3.1.1 Neighborhood Observation Study

The first method is the neighborhood observation study which acts as a first-impression windshield survey of the Sinking Creek and Second Creek sub-watershed areas. The full observation study is located in the Appendix A1. however, a summary of general findings is provided in this section. The style of writing in the full study is that of a narrative, conveying qualitative observations that also integrate parts of the research to support these observations.

This study is inclusive of the neighborhoods within the delineated sub-watershed areas and gives an empirical assessment of the social, economic, and environmental context of these suburban and urban neighborhoods. The sub-watershed context of these neighborhoods is important for understanding because it is the context which surrounds a neighborhood that influences the neighborhood character itself. That character ultimately affects stormwater runoff and its transported

pollutants (Kibel 2007). For example, low income urban neighborhoods have been associated with poor water quality in urban rivers (Riley 1998; Kibel 2007). Conversely, middle to upper class suburban neighborhoods may be associated with more fertilizer applications to landscape areas, which can cause an increase in nitrates being transported by runoff into nearby water bodies (Cech 2010). As a result of urban growth and expansion, communities have become segmented and then confined to their own areas. The poor have remained in the congestion of the inner city where issues of polluted air and water have grown to be more extreme than those of the suburban communities (Birch 1970). Therefore, by understanding the social, economic, and environmental context which surrounds the selected neighborhoods, the issues affecting stormwater runoff may be more widely understood. Furthermore, appropriate design applications may be considered for stormwater management while considering the broader needs of the community.

The Sinking Creek sub-watershed observation study showed characteristics of well-kept yards and homes in good condition (Figure 16). These neighborhoods have median household incomes ranging from nearly $98,000 - $105,000 (USA.COM) and have maintained most of their existing infrastructure such as roads, sidewalks, and

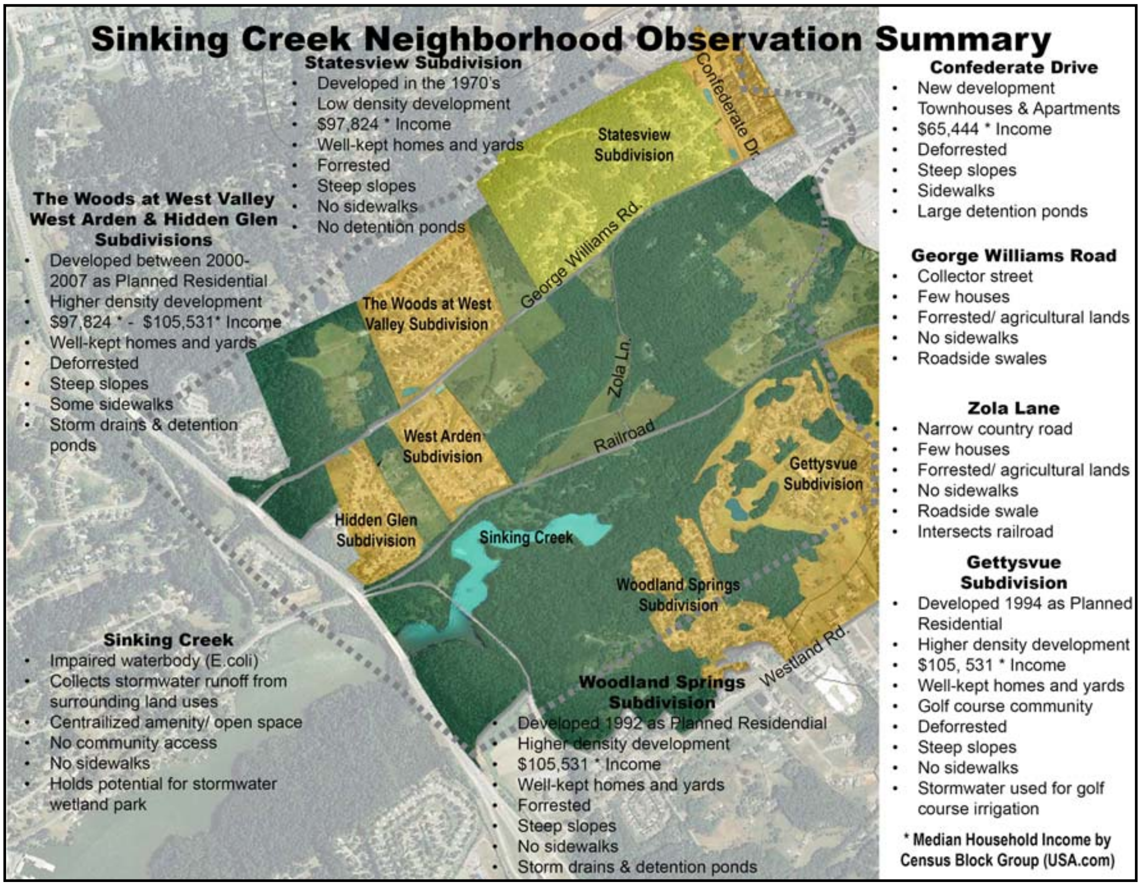


Figure 16. Sinking Creek Neighborhood Observations Summary

storm sewers. The environmental context of these neighborhood landscapes is characterized by steep slopes with forested and agricultural open space surrounding them. The Statesview subdivision, built in the 1970's, has maintained much of its native tree canopy however, stormwater is not detained before it is conveyed to the creek system, leaving it vulnerable to higher pollutant loads and peak flow volumes (Jeung 1978). The more recently developed neighborhoods, such as The Woods at West Valley, Hidden Glen and West Arden, were deforested during lot development and their native vegetation has mostly been replaced by lawn areas with fewer trees. Mowed lawns have a higher potential of producing runoff than the native forested areas, which help increase rainfall interception and infiltration (Jeung 1978). Centralized detention ponds have been designed to manage the runoff water conveyed by storm sewers before entering the creek system. Woodland Springs and Gettysvue subdivisions were developed in the 1990's and show a balance of good practices. For example, Woodland Springs has maintained larger forested areas within its developed space and Gettysvue stores stormwater in irrigation ponds.

While the majority of these higher income neighborhoods have been established as "planned residential" (KGIS 2012) with some internal accessibility to neighborhood services, a lack of pedestrian

accessibility outside of neighborhoods to nearby amenities such as parks, schools and churches may result in a lower quality of living than if access to these services were more readily available (Bright 2000).

The neighborhood observations in the Second Creek sub-watershed include the Lincoln Park neighborhood and Oakwood neighborhood (Figure 17). These neighborhoods are adjacent to industrial zones such as the railroad at Coster Yards, the SYSCO plant, and a waste center. The Lincoln Park and Oakwood neighborhoods are lower to moderate income communities with median household incomes roughly ranging between $26,000 - $40,000 (USA.COM). A portion of the Lincoln Park neighborhood is isolated from the other neighborhoods by the railroad on two sides and by Sharp's Ridge on the other side. This neighborhood has a gridded street system with back alleyways. The homes have historic character but many of them are un-kept or in disrepair. The majority of sidewalks are in poor condition, forcing pedestrians to walk in the streets to nearby churches, schools, and commercial areas. Stormwater collects in low points along the streets and alleyways and is then conveyed directly to Second Creek. The majority of the storm sewers are clogged with debris and sediment. Each of these factors are indicative of a lower quality of living (Bright 2000). The Lincoln Park

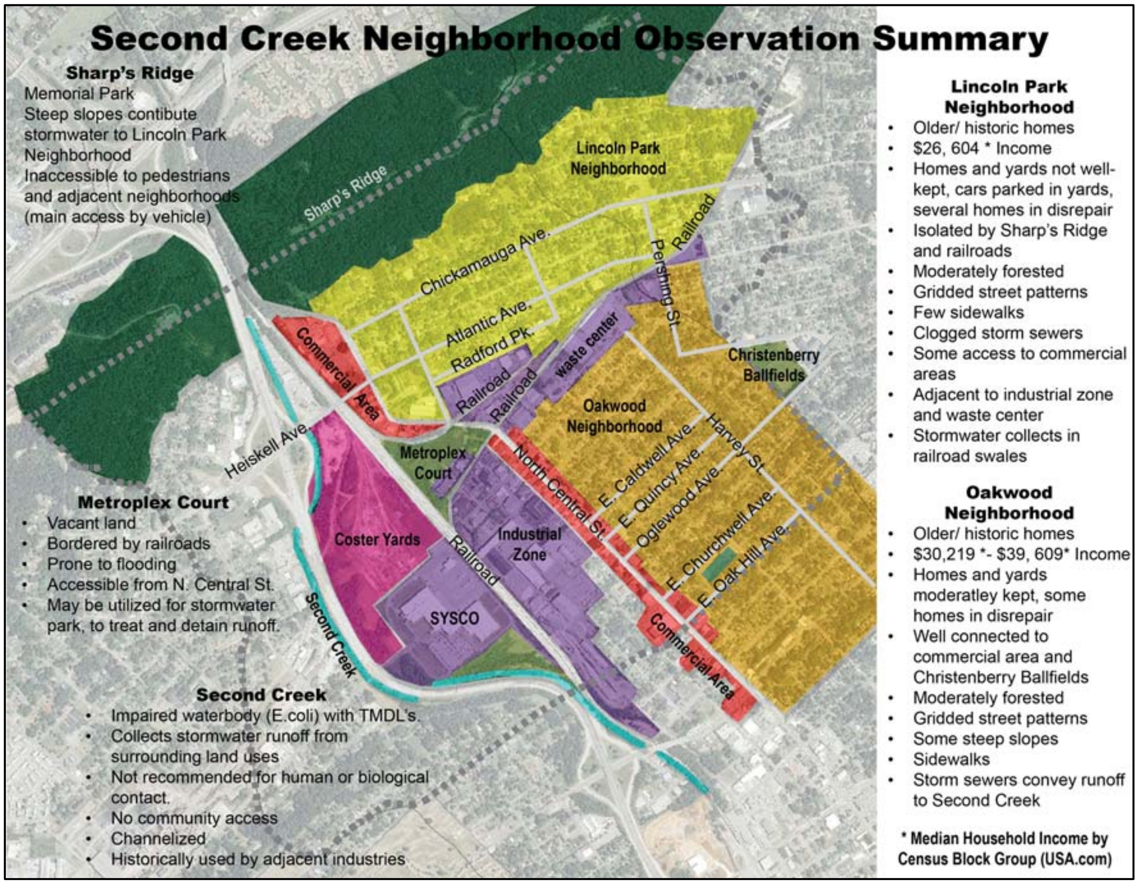


Figure 17. Second Creek Neighborhood Observations Summary

and Oakwood neighborhoods are moderately forested with mature trees. The Oakwood neighborhood is adjacent to North Central Street's commercial area. The conditions of the homes and yards are better kept than those of the more isolated Lincoln Park neighborhood and have better walkability to parks and public amenities. This assessment is based upon the conditions and availability of sidewalks throughout the Oakwood neighborhood. While the neighborhood infrastructure seems to be in better condition, storm sewers still convey runoff water directly to Second Creek without detention. Overall, the neighborhoods in the Second Creek Sub-watershed seem to need renovations of the existing infrastructure that has become degraded over time. This neighborhood may also need an integrated system of detention areas to intercept runoff before it is conveyed to the creek.

3.1.2 Neighborhood Density Study

Further investigation of existing infrastructure was conducted in the neighborhood density study. The neighborhood density study is the second method used for neighborhood characterization, and it focuses on the neighborhoods defined in the site selection process within the Sinking Creek and Second Creek sub-watersheds. This study reveals more specific development patterns within each neighborhood and

gives a comparison of the densities found between these suburban and urban environments.

Within the Sinking Creek neighborhood study area, the density characteristics vary based upon each individual subdivision. The Statesview Subdivision is zoned as RA, low density residential, under the Knox County Code of Ordinances Definitions. The average net density range of the Statesview Subdivision is between 1.5 to 2 developed units per acre. Net density is the total number of developed residential units per developed area and does not include the area within the right-of-way. The remaining neighborhoods are zoned as PR, planned residential, with different ranges of net density. The Millstone Subdivision has the highest net density of 6.2 because it is a townhouse development. The next highest densities are found in the Woods at West Valley, West Arden, and Hidden Glen Subdivisions. Each of these have a density range of 1 to 4 developed units per acre and are typically at the higher end of the density range (approximately 3 developed units per acre). This trend may follow the age of each subdivision, with the newer suburban developments containing higher densities than those subdivisions developed earlier.

The Second Creek neighborhood study area has more consistent density characteristics throughout. Again, this calculation does not

include areas within the street right-of-ways. The density of the urban development pattern is more regular due to the gridded block patterns as well as the time of neighborhood development which dates from the pre-war era; 1939 or earlier (USA.COM ; U.S. Department of Commerce and Branch 2010). The resulting total neighborhood density is 4.6 developed units per acre. Within these environments, more densely developed areas may produce higher concentrations of stormwater runoff (Jeung 1978). Design consideration will be given to more highly dense areas by implementing the disconnection of clustered impervious surfaces.

3.1.3 Street and Photo Inventory

A street and photo inventory is the third method of neighborhood characterization that takes a qualitative street-by-street observation from windshield survey of the existing conditions within the public right-of-way. “The perceived quality of a city is very much dependent on the quality of its streets” (Lang 2005). This includes conditions of streets, sidewalks, and stormwater control measures, or other issues that may impact the neighborhood. The quality of streets is also affected by the speed of vehicular traffic and the arrangement of parking (Lang 2005). The Sinking Creek street inventory study was

conducted grouping issues by subdivision. The Second Creek inventory study was done by first collecting information street-by- street, then grouping similar issues together. Table 1 shows the inventory summaries by street groups and subdivisions. The findings in both neighborhoods were consistent with those first impression observations on the sub-watershed level. Sinking Creek's subdivisions consisted of very steep slopes, large cul-de-sacs, discontinuous sidewalks, deforested lots, and instances of on-street parking issues. Second Creek's streets consistently showed instances of drainage issues and a lack of designated on-street parking areas, existing sidewalks and tree canopy. The photo inventory shown in Figure 18 helps to understand not only issues of neighborhood function but also the diversity of characteristics between the urban and suburban neighborhoods. These street and subdivision inventories will be used to develop a system of BMP's that address stormwater runoff volumes while integrating design solutions respond to these community issues.

Table 1. Neighborhood Inventories Comparison

Sinking Creek Neighborhood Inventory

Subdivision/ Street Names	Perceived Issues
Statesview	Wide streets, steep slopes, no sidewalks, large cul-de-sacs
The Woods at West Valley	Minimal tree canopy, high density development, steep slopes, discontinuous sidewalks
Hidden Glen	Minimal tree canopy, high density development, steep slopes, discontinuous sidewalks
West Arden	Minimal tree canopy, high density development, steep slopes, discontinuous sidewalks
Millstone	Moderate tree canopy, high density, no designated on-street parking, no sidewalks, large cul-de-sacs
George Williams Road	Moderate tree canopy, narrow streets, no sidewalks, drainage issues along roadway, high traffic

Second Creek Neighborhood Inventory

Subdivision/ Street Names	Perceived Issues
Chickamauga, Atlantic, Cedar, Hiawassee	Minimal tree canopy, no designated on-street parking, minimal existing sidewalks, high traffic
Watauga, Hiawassee, Grove, Gladstone	Minimal tree canopy, no designated on-street parking, minimal existing sidewalks, high traffic
Coram, Metler, McMurray, Felt, Pershing, Hanover, Farragut	Minimal tree canopy, minimal existing sidewalks, drainage issues along roadway
Radford	Minimal tree canopy, no existing sidewalks, drainage issues along roadway, narrow right of way, industrial adjacency

Photo Inventory of Neighborhood Issues & Characteristics


Steep Slopes


Large Cul-de-sacs


On-street Parking Issues


High Density New Development

Sinking Creek Neighborhood Inventory


Poor Sidewalk Conditions


Industrial Adjacencies


Inaccessible Destinations


Sparse Tree Canopy

Second Creek Neighborhood Inventory

Figure 18. Photo Inventory of Neighborhood Issues & Characteristics

3.1.4. Walkability Study

The walkability study is the fourth method of neighborhood characterization that shows the connections and conditions of the existing sidewalks to desirable destinations within the two communities and discusses factors previously observed which affect walkability. Walkability is defined as how comfortable an area is for walking (Institute 2012). Factors that affect walkability may include the physical condition of existing sidewalks, the extent of sidewalks are provided, parking, vegetation such as trees and other plantings, dirty lots, litter and trash, traffic, land use type, development density, and connectivity to nearby goods and services (Lang 2005; Institute 2012; Center 2013). The analysis of walkability for this study was conducted by mapping the extent of the existing sidewalk systems in the Sinking Creek and Second Creek neighborhoods and characterizing them using the neighborhood observation study and photo inventory from the previous sections.

Figure 19, shows the extent of sidewalk connectivity of Sinking Creek residents to destinations such as school bus stops, churches, West Valley Middle School, and the commercial and retail access along Ebenezer Road. The findings show that sidewalk connections for

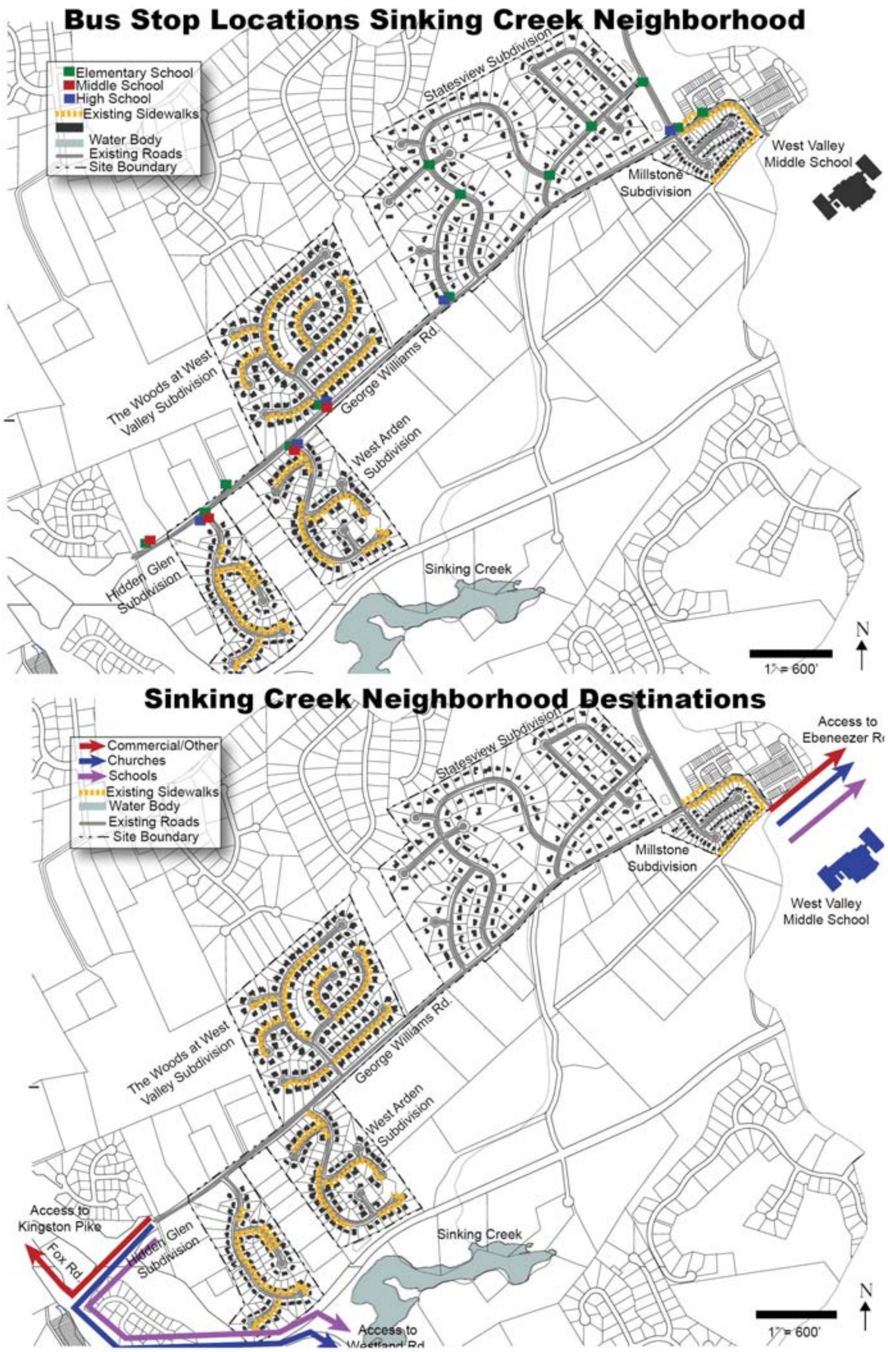


Figure 19. Sinking Creek Neighborhood Existing Connectivity Diagram

pedestrian access to nearby goods and services are almost nonexistent. Second Creek's lack of existing sidewalks conveys similar accessibility issues. School and public bus stops are frequently located throughout the neighborhood however, the lack of sidewalks on George Williams Road that terminates at West Valley Middle School disconnect these neighborhoods and restrict safe passage on this main road. Thus, the existing sidewalks fail to provide safe access for pedestrians (Figure 20). The same is evident with connections to local churches and educational establishments. The business and commercial corridor at the perimeter of the Second Creek site boundary is poorly connected to the residents at the neighborhood's core. Adjacent land use may also be a factor affecting walkability. For example, the Second Creek neighborhood is disconnected from the other neighborhoods due to the railroad (Figure 18).

In both Sinking Creek and Second Creek neighborhoods, parking may cause conflicts where facilities are not properly provided and therefore may prohibit safe walking opportunities (Institute 2012). In both neighborhoods it was observed that there are instances of sparse tree canopy along roadways. This may also affect walkability because street trees can provide a safety buffer between vehicles and pedestrians while improving the comfort of walking conditions by

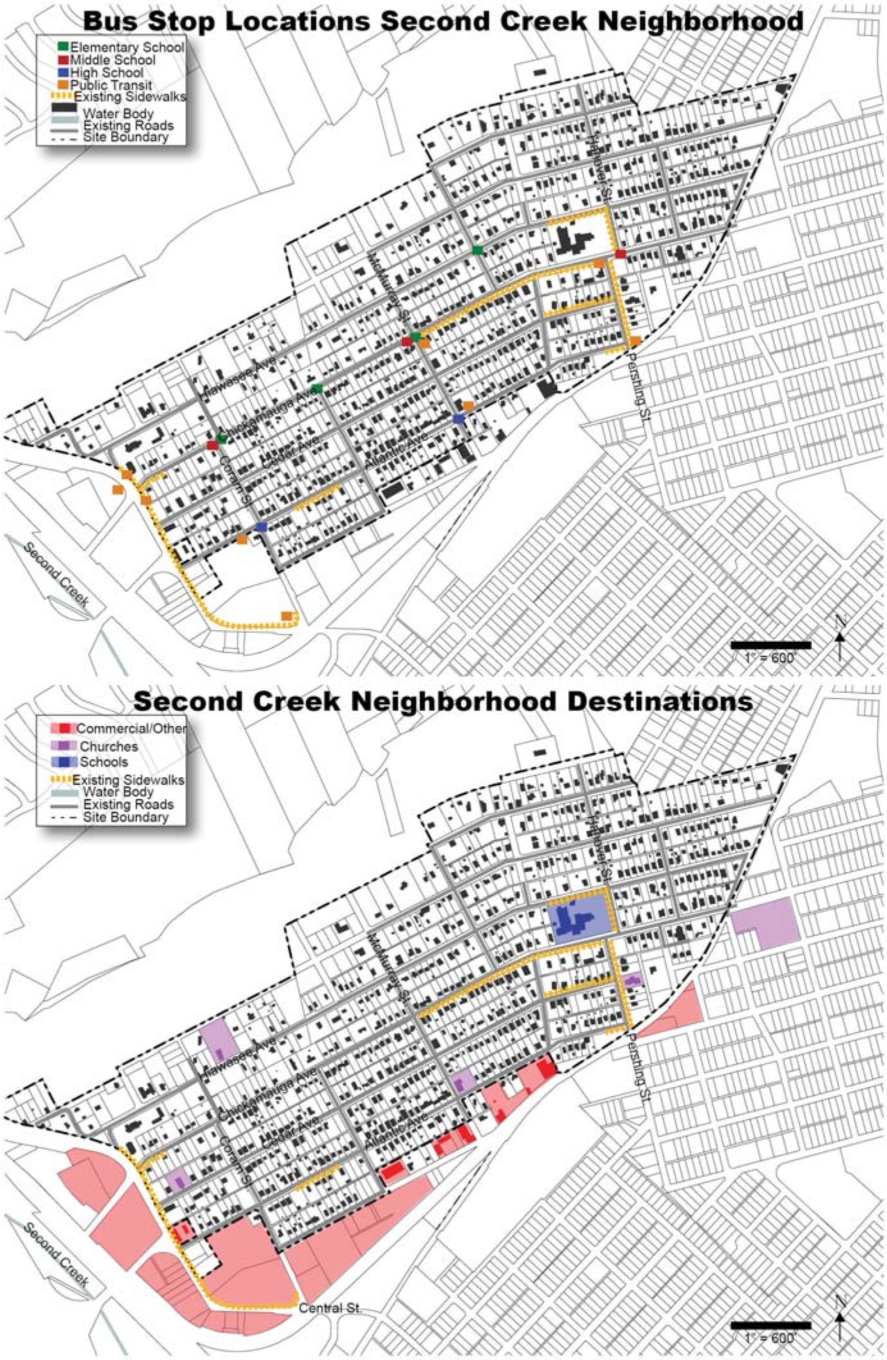


Figure 20. Second Creek Neighborhood Existing Connectivity Diagram

providing shade (Lang 2005). The overall assessment shows the lack of existing sidewalks provided to connect both neighborhoods to nearby goods and services resulting in poor walkability (Center 2013).

3.1.5. Socio-economic Demographics Comparison

The final method of neighborhood characterization is a socio-economic demographics comparison. Having an understanding of the people living in the proposed project area is important because, according to A.L. Riley, the greatest value of a restoration project may be the new sense of community identity or neighborhood pride created for the residents in the project (Kibel 2007). Previously, in the site selection methodology, demographic data such as the median household income was compared at the census tract level, as it applied to the watershed and sub-watershed scales. Census block group data is now being used at the neighborhood scale to reveal more accurate trends in the neighborhood demographics. Block Groups are statistical divisions of census tracts that generally defined to contain between 600 and 3,000 people and are used to present data and control block numbering. A block group consists of clusters of blocks within the same census tract (U.S. Department of Commerce and Branch 2010).

The demographics being compared are median household income, racial composition, common occupations, and housing data.

The data that has been tabulated is shown at the block group level which has resulted in two block groups representing the Sinking Creek neighborhood while the Second Creek neighborhood is fully represented within one block group (Inc. 2011). The average values of the two Sinking Creek block groups have been calculated for ease of comparison. Tables 2 and 3 show tabular data for comparing these neighborhood characteristics (Inc. 2011).

Median household income and housing values provide a platform of understanding how social and economic values of the design proposal may be assessed. For example, although there is a lower value of household income and a lower percentage of owner occupied units in the Second Creek community (Table 2), this is not an indication of willingness by community members to incur costs for remediating neighborhood issues and furthermore, addressing issues of stormwater management. A study released by the Knoxville-Knox County Metropolitan Planning Commission reports that members of The Oakwood-Lincoln Park Neighborhood Association developed goals and a strategic plan for improving the community that include reducing on-street parking issues, improving aesthetics with plantings of trees

Table 2. Second Creek Socio-economic & Demographic Values

Second Creek Neighborhood	
Second Creek Racial Demographics	Block Group
Whites	79.1%
Blacks	12.5%
Hispanics	6.4%
Asians	0.7%
Other	7.7%
Median Household Income	
Second Creek Neighborhood	$26,604
Knoxville	$29,903
Tennessee	$41,461
National	$50,046
% Below Poverty Level	24.2%
Median House Value and Year Built	
Median House/Condo Value	$67,400
Knoxville Median Value of Owner Occupied Houses	$112,300
Tennessee	$139,000
National	$179,900
Median Year Houses Built	
Second Creek Neighborhood	1939 or earlier
Knoxville	1973
Tennessee	1981
United States	1975

Source:
2010 Census Data from USA.com (http://www.usa.com/knoxville-tn-income-and-careers.htm#Poverty-Level), Accessed 06.2013
*Average value was calculated for comparative values.
Na (not applicable)

and shrubs, creating more sidewalk connections, and correcting drainage issues. Addressing stormwater management was one of the priorities identified by the neighborhood association (Wood 2005). Similarly, stormwater management has become a growing concern for residents in the communities surrounding Sinking Creek. In a recent article regarding a newly proposed residential development, citizens have voiced their concern about the potential effects of stormwater runoff on the Sinking Creek Watershed (Davis 2013). Therefore, income level should not be used as a platform to indicate community desires nor willingness to invest in neighborhood improvements for stormwater management; nor should it be used to indicate the willingness of that community to protect its water resources. By understanding neighborhood demographics, a strong platform is built for well-informed design decisions.

In this study it has been confirmed that the median year of houses built is a reflection of the existing neighborhood infrastructure that is out of date and in disrepair. An example of outdated infrastructure is made evident when comparing two subdivisions in the Sinking Creek community (Table 3) such as Statesview and Hidden Glen. The average age of home in the Statesview subdivision is 1975 (KGIS). In this subdivision stormwater runoff is directly conveyed to

Table 3. Sinking Creek Socio-economic & Demographic Values

Sinking Creek Neighborhood			
Sinking Creek Racial Demographics	Northern Block Group	Southern Block Group	Average*
Whites	91.2%	87.1%	89.2%
Blacks	2.1%	2.4%	2.3%
Hispanics	1.5%	2.0%	1.8%
Asians	5.1%	9.0%	7.1%
Other	1.6%	1.6%	1.6%
Median Household Income			Average*
Sinking Creek Neighborhood	$97,824	$105,531	$101,678
Knoxville	$29,903	$29,903	$29,903
Tennessee	$41,461	$41,461	$41,461
National	$50,046	$50,046	$50,046
% Below Poverty Level	0.7%	0.8%	0.75
Median House Value and Year Built			Average*
Median House/Condo Value	$246,819	$354,935	$300,877
Knoxville Median Value of Owner Occupied Houses	$112,300	$112,300	$112,300
Tennessee	$139,000	$139,000	$139,000
National	$179,900	$179,900	$179,900
Median Year Houses Built			
Sinking Creek Neighborhood	1975	2000	Na
Knoxville	1973	1973	Na
Tennessee	1981	1981	Na
United States	1975	1975	Na

Source:
2010 Census Data from USA.com (http://www.usa.com/knoxville-tn-income-and-careers.htm#Poverty-Level), Accessed 06.2013
*Average value was calculated for comparative values.
Na (not applicable)

the nearby creek whereas the Hidden Glen subdivision, that was developed around 2003, conveys stormwater to a detention pond before it enters the creek system. The median year of houses built in Knoxville is 1973, closely related to those houses built in the Statesview subdivision (Inc. 2011). This relationship implies that the proposed BMP applications that will be presented in Chapter 4, may also be appropriate to consider in a high percentage of Knoxville neighborhoods with similar characteristics. A full description of these data comparisons is located in the Appendix A2.

The year of houses built in Second Creek is a reflection of outdated existing infrastructure in poor condition. This neighborhood dates back to the pre-war era before 1939. The existing infrastructure in the Second Creek neighborhood is therefore much older than the existing infrastructure in the Sinking Creek neighborhood. Stormwater is piped directly into Second Creek without causing an increase in peak flows and pollutant loads. Poor conditions of decaying stormwater infrastructure were discussed in the Neighborhood Observation Study (refer to Figure 17). Decaying water infrastructure increases pollutants in waters and affects the health and safety of the community (Emily Gordon 2011). In this study it is evident that the housing ages in the

Sinking Creek and Second Creek neighborhoods reflect the conditions of the existing stormwater infrastructures that are in need repair.

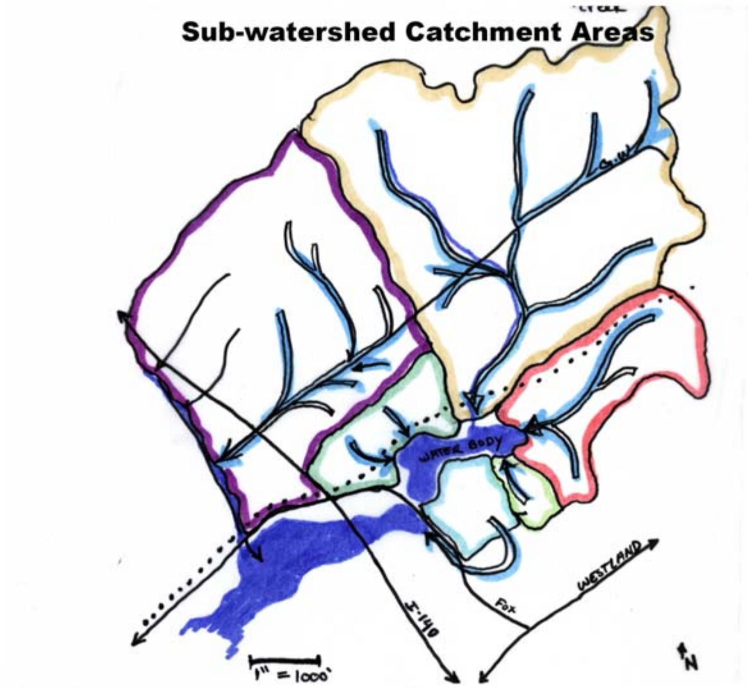
3.2 Stormwater Inventory and Analysis

The stormwater inventory and analysis is both a qualitative and quantitative study of stormwater behavior at the sub-watershed and neighborhood scales. The analysis includes a study of surface flow and drainage patterns, a stormwater observation study that identifies local stormwater issues, and a water quality comparison. At the end of the section, a summary is provided of the stormwater issues and goals that will be considered for the design proposal.

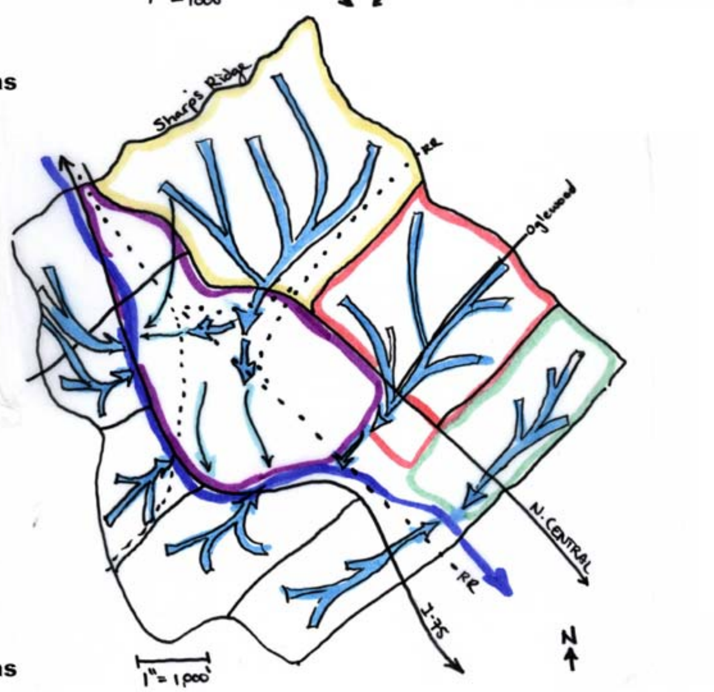
3.2.1 Surface Flows and Drainage Patterns

The study of surface flows and drainage patterns is the first method that informs the stormwater analysis. The first part of this method shows the general hydrologic behavior of surface runoff at the sub-watershed scale. This topographically based diagram shows flow patterns of smaller sub-catchment areas that drain to Sinking Creek and Second Creek (Figure 21).

The second part of this method determined flow patterns along the streets, showing high and low points defined by spot elevations. High points indicate where all stormwater runoff on the streets flows.



Sinking Creek
Sub-watershed
Catchment Areas



Second Creek
Sub-watershed
Catchment Areas

Figure 21. Sub-watershed Catchment Areas Comparison

away from that point; low points indicate a point of collection on the streets where runoff water becomes concentrated (Figure 22). These flow patterns along the existing streets give an indication of where localized flooding issues may occur and where preventative measure may be taken to address runoff at the source of where it is being generated.

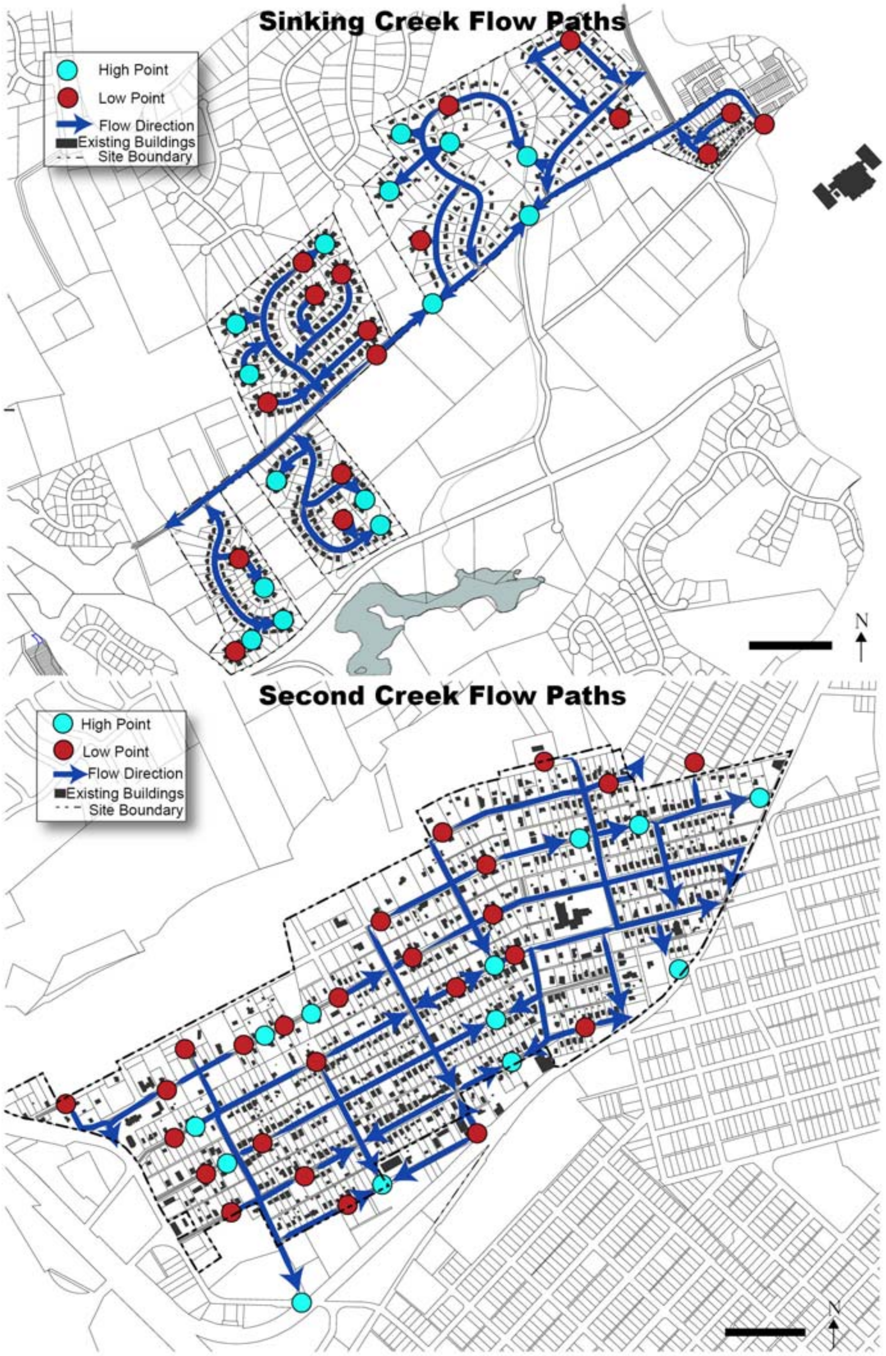


Figure 22. Neighborhood Street Flow Patterns Comparison

3.2.2 Stormwater Observation Study

The stormwater observation study further verifies the stormwater runoff issues that were previously identified by windshield survey in each neighborhood (Section 3.1). Each of these issues has an impact on society, economy, and the environment in the Sinking Creek and Second Creek Neighborhoods. General stormwater goals will be identified in response to the observed issues to better inform a design proposal that is unique to each community. The observation study first assesses contributing factors that increase peak flows and runoff volumes such as minimal existing tree canopy, steep slopes, stormwater conveyances, and connected impervious surfaces. It then discusses how high peak flows and runoff volumes contribute to the stormwater runoff issues such as erosion and localized flooding. A photo inventory shows some of the observed issues related to stormwater runoff.

High peak flows of stormwater runoff are attributed to precipitation that produces high volumes of runoff over a short period of time. Factors that influence peak flows are existing tree canopy, impervious surfaces, steep slopes, and stormwater conveyances (AMEC 2008). The impacts of high peak flows may include localized

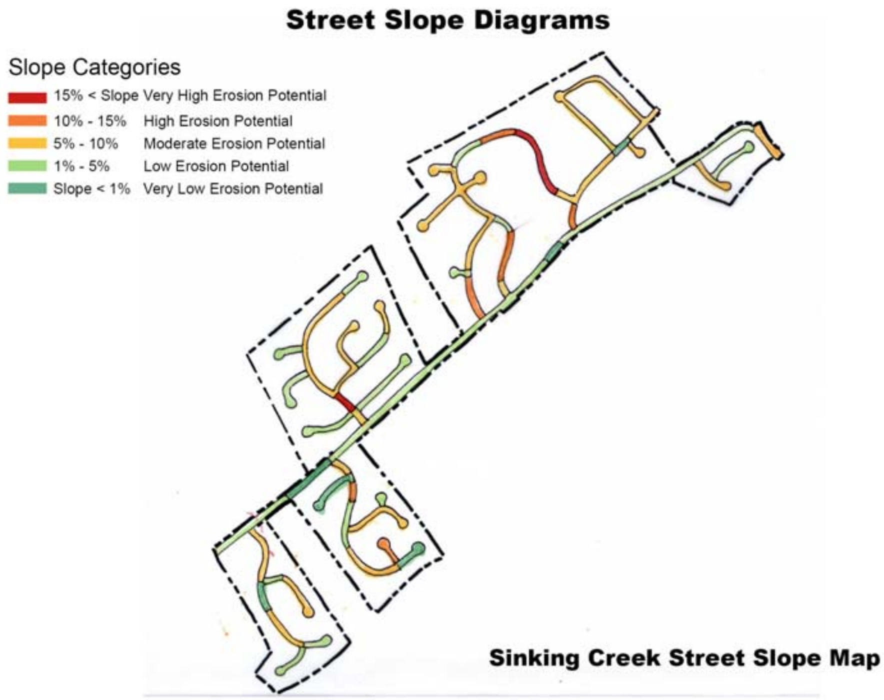
flooding and channel erosion, posing a threat to existing infrastructures (Jeung 1978).

The first issue being observed is the minimal extent of existing tree canopy in the Sinking Creek and Second Creek neighborhoods. This issue was also previously noted in the neighborhood observation study, but is now being looked at as a contributing factor to high peak flows and runoff volumes. In the Sinking Creek neighborhood, The Woods at West Valley, West Arden and Hidden Glen subdivisions are planned residential developments where the older, natural forested conditions have been cleared and replaced by young landscape materials such as mowed turf grass and smaller trees and shrubs. Because of the clearing and grading practices, all of the existing tree cover, vegetation and topsoil are removed; dramatically altering both the natural hydrology and drainage of the site (AMEC 2008). These practices also reduce the capacity of the ground to retain water and resist erosion (Organization 1991).

Second Creek’s tree canopy is more mature in age, although it is sparse in several areas where the urban forest has died off. A reduction in tree canopy decreases interception, thereby increasing runoff volumes (Jeung 1978; Organization 1991).

The steep slopes located within these neighborhoods also contribute to higher peak flows (Figure 23). Street slopes range from less than 1% up to as much as 16.3%. When intense rain events occur, the steep impervious roadways act as conveyances that increase the velocity of the stormwater runoff, thereby decreasing the time of concentration. The decrease in time of concentration causes stormwater volumes to accumulate over a shorter period of time, which can cause localized flooding in low points throughout the neighborhood (Jeung 1978; Prince George's County 1999; Gupta 2001).

A similar situation was evident along each of the roads running perpendicular to Sharp’s Ridge in the Second Creek Neighborhood where slopes range from less than 1% up to 12.5% (Figure 23). As the street slopes increase, so does the velocity of the stormwater being conveyed through the drainage ways, most of which are located along front yards and run underneath driveways. As a result of high peak flows attributed to steep slopes and larger stormwater volumes, the channel erosion has begun to encroach upon front yards and may compromise the structural integrity of the driveways that are built over the top of these drainage ways.



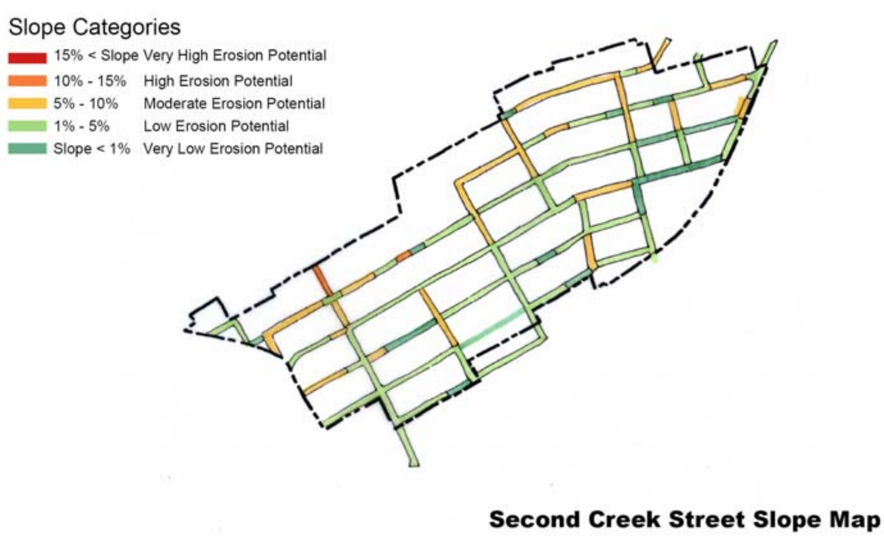


Figure 23. Street Slope Diagrams

Stormwater conveyance methods are another issue associated with stormwater runoff in these neighborhoods. Structural drainage systems and storm sewers are designed to be hydraulically efficient in removing stormwater from a site. This type of system tends to increase peak runoff discharges, flow velocities, and pollutant loading to downstream waters. (AMEC 2008).

Most of the stormwater runoff in the Sinking Creek neighborhood is conveyed into natural drainage ways and transported directly to the Sinking Creek water body without the use of a detention pond or treatment system. This is evident along George Williams Road and within the Statesview Subdivision. Most storm drains within the subdivision are located at the lowest points along the road that direct runoff water into natural drainage ways nearby. The rest of the stormwater sheet flows to the neighborhood entrances where the volumes concentrate along George Williams Road and Continental Drive. This poses a threat to receiving waters because pollutant loads generated by impervious surfaces are directly conveyed to Sinking Creek.

The issues of stormwater conveyance methods in the Second Creek neighborhood are similar in some cases. The existing storm drains in the Second Creek neighborhood are out-dated, clogged with

debris, and directly carry stormwater pollutants into the Second Creek water body (Figure 24). Very few efforts of detaining or slowing down stormwater runoff are made with the existing infrastructure. Curb and gutter storm drain systems allow for the quick transport of stormwater, which results in increased peak flows and localized flooding downstream (AMEC 2008). The stormwater runoff in the Second Creek neighborhood that is not conveyed by storm drains is collected by roadside swales and intercepted by the existing swales along the railroad. The railroad swales conveying stormwater were not investigated but should be considered in further study regarding water quality impacts on Second Creek.

High peak flows and stormwater runoff volumes are also attributed to the high percentages of connected impervious surfaces in both the Sinking Creek and Second Creek neighborhoods. The areas cover by impervious surfaces such as rooftops, parking lots, roadways, and sidewalks diminish the areas that rainfall is able to infiltrate into the soil, thereby increasing stormwater volumes and increasing pollutant loadings in receiving waters (AMEC 2008). Impervious surfaces cause an increase in the rate these volumes are discharged to receiving waters compared to areas covered by native vegetation (Collett 2013).

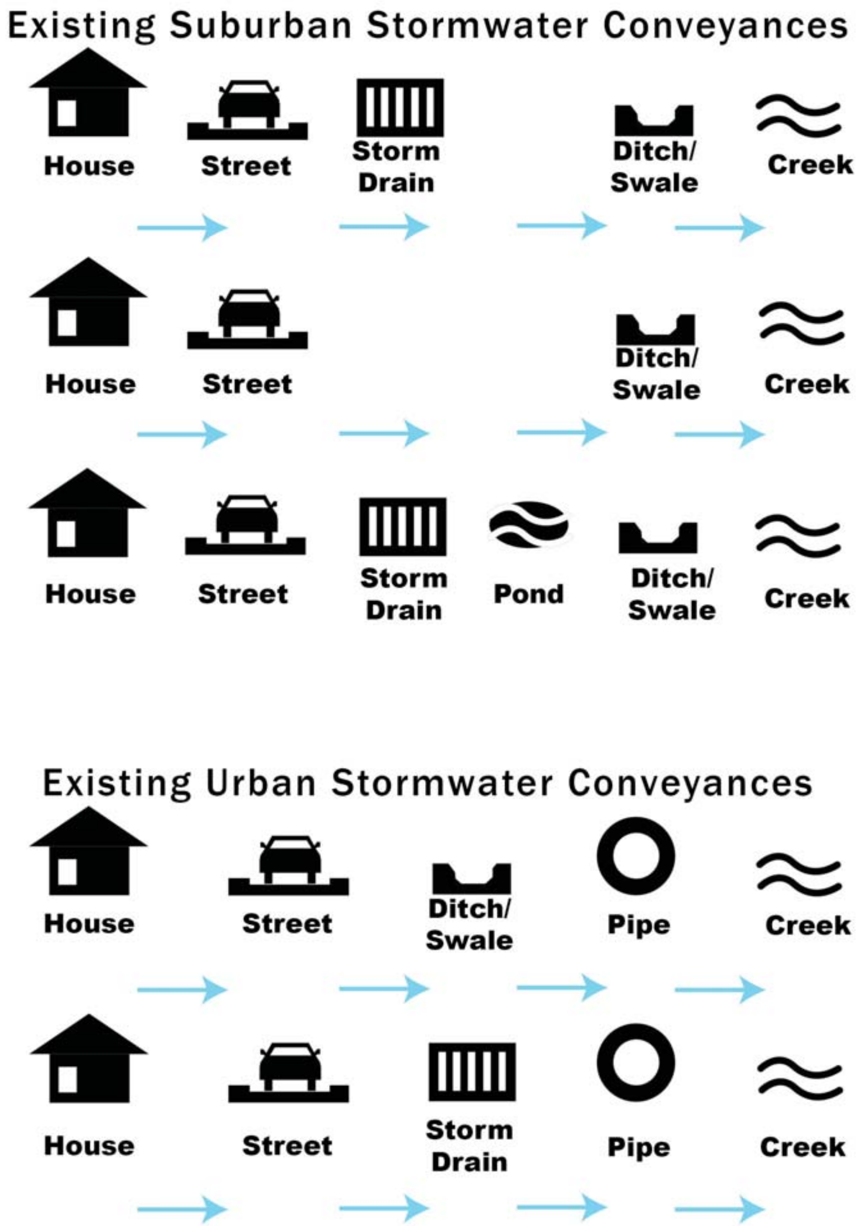


Figure 24. Existing Stormwater Conveyances Comparison

Sinking Creek's suburban developments contribute 26% (53.3 acres) of connected impervious surfaces out of the 205 acres of gross area (Figure 25). This is a higher percentage than the 24% (48.9 acres) found within Second Creek's 204 acre urban neighborhood. The extent of impervious connections between the houses, driveways and roadways allows for runoff volumes to combine as they travel down through the neighborhoods. The combined volumes cause an increase peak flows, runoff velocity, and increase damage to the existing conveyances.

Issues related to high peak flows and volumes during intense rain events include channel erosion and localized flooding throughout the neighborhoods (AMEC 2008; Water Environment Federation 2012). Channel erosion along George Williams Road in the Sinking Creek neighborhood is an indication of highly concentrated volumes of stormwater runoff that are generated by the impervious surfaces of the contributing neighborhoods (Figure 26). This erosion causes sediment to build up in receiving water bodies. The adverse effects of sediment on water quality and existing infrastructure influence the health, safety and welfare of the surrounding community (Jeung 1978; Chapra 1997; Cech 2010). This channel erosion has exposed and collapsed several stormwater pipes. The channel erosion has begun to

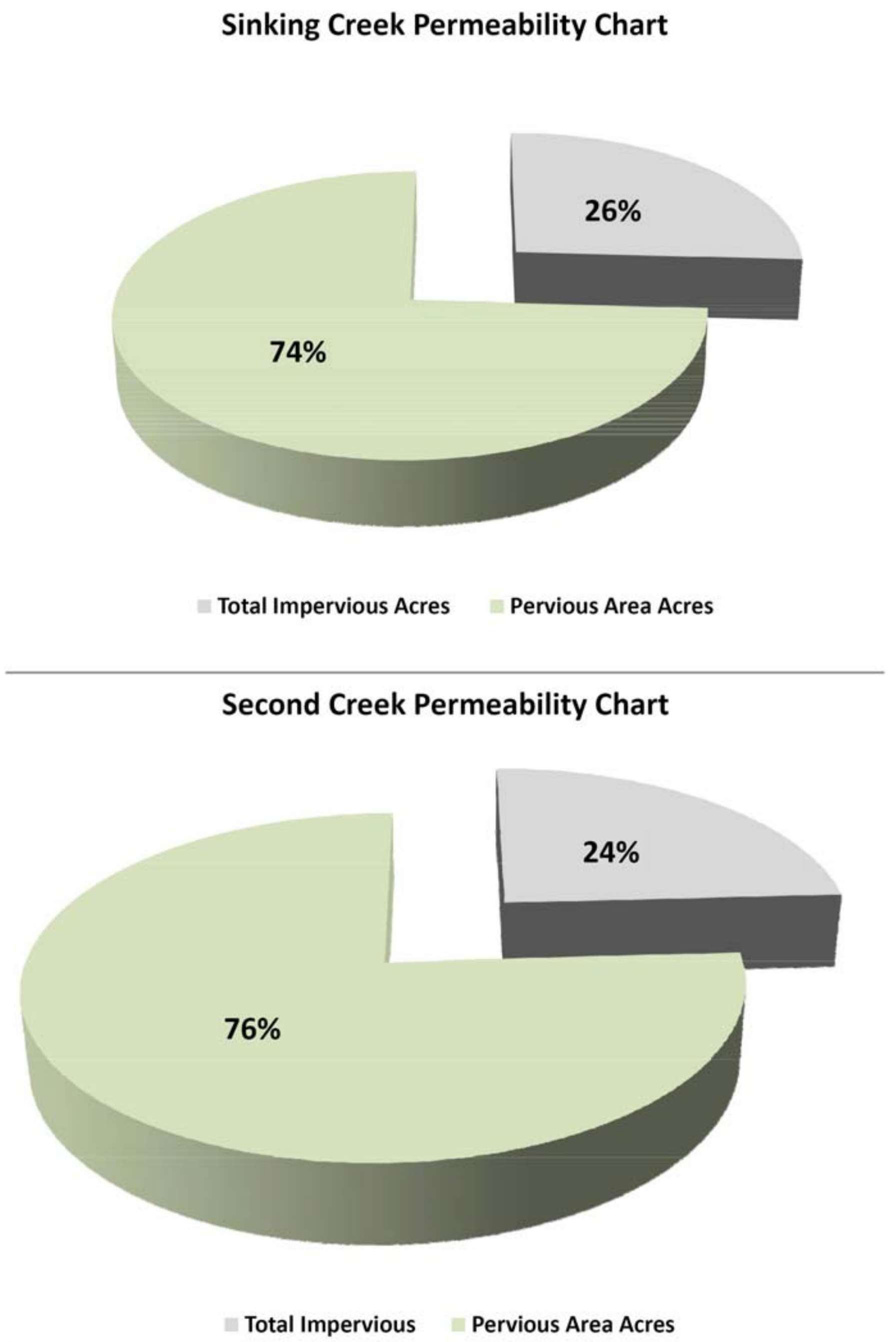


Figure 25. Pervious and Impervious Surface Percentages Comparison

Photo Inventory of Stormwater Issues


Channel Erosion


Clogged Stormwater Pipe


Culvert inlet to natural drainageway


Steep slopes

Sinking Creek Stormwater Issues


Steep slopes


Culvert under driveway


Clogged storm drain


Sediment deposit from flooding

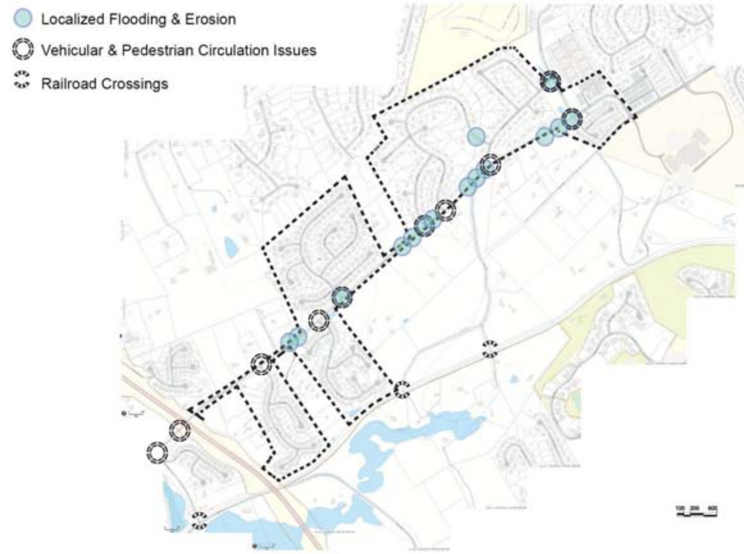
Second Creek Stormwater Issues

Figure 26. Photo Inventory of Stormwater Issues

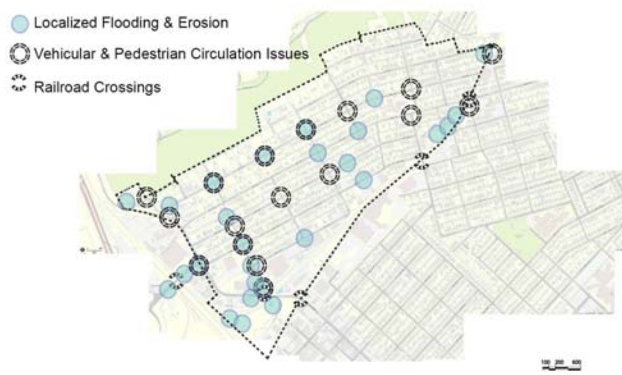
encroach upon the pavement edge of George Williams Road, which will eventually impede upon vehicular circulation and has already limited pedestrian accessibility. Similarly, the channel erosion issues in the Second Creek neighborhood impede upon residents, as those channels running through the front yards of homes and underneath driveways are failing. A photo inventory of these adverse effects in both neighborhoods is shown in Figure 26.

The observed localized flooding issues typically occur at low points along the roadways that do not provide necessary means for drainage. This localized flooding further impedes upon vehicular and pedestrian circulation and causes large sediment deposits to accumulate on the roadways. A map was created to diagram these overlapping issues and where they occur throughout the Sinking Creek and Second Creek neighborhoods (Figure 27).

Locations of Stormwater Issues



Sinking Creek Stormwater Issues Map



Second Creek Stormwater Issues Map

Figure 27. Localized Flooding and Circulation Issues

3.2.3 Water Quality Comparison

The Tennessee Department of Environment and Conservation (TDEC), is responsible for managing, protecting and enhancing the quality of the state's water resources through voluntary, regulatory and educational programs (TDEC 2013). TDEC's watershed management program is designed to identify and restore impaired water bodies and to help achieve water quality standards. The 2012 303(d) List, reports a compilation of the streams and lakes that are "water quality limited" or are expected to exceed water quality standards in the next two years and need additional pollution controls (TDEC 2013). A Total Maximum Daily Load is a regulatory term in the U.S. Clean Water Act, describing a value of the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards (U.S.E.P.A.). Some water bodies on the 303(d) list already have established a Total Maximum Daily Load (TMDL's) for select pollutants.

Both Sinking Creek and Second Creek are included on the 303(d) list due to their impairment status and do not meet water quality standards (Conservation 2012). Both water bodies share impairments due to urban development and stormwater runoff discharged by Municipal Separate Storm Sewer Systems (MS4's) (Table 4). The

Table 4. Water Quality Summary and Definitions

Upper Tennessee River Watershed 303(d) List

Waterbody ID	Impacted Waterbody	Miles/Acres Impaired	CAUSE / TMDL Priority	Pollutant Source	Comments
TN0601020 1097- 1000	Second Creek	12.8	Other Anthropogenic Habitat Alterations/ NA , Nitrate+Nitrite /L , Loss of biological integrity due to siltation/ NA , Escherichia coli /NA	Discharges from MS4 area, Urbanized High Density Area, Collection System Failure	Water contact advisory. Category 5. Impaired, but EPA approved siltation, pathogen, and habitat alteration TMDLs that address some of the known pollutants.
TN0601020 11330 – 1000	Sinking Creek	4.1	Escherichia coli / M	Discharge from MS4 area	Stream is Category 5. (One or more uses impaired.)

Definitions:

Upper Tennessee River Basin: This basin contains the following USGS Hydrologic Unit Codes: 06010201 (Watts Bar Res., Fort Loudoun Res., and Little River).

TMDL: A Total Maximum Daily Load (TMDL) is a study that (1) quantifies the amount of a pollutant in a stream, (2) identifies the sources of the pollutant, (3) and recommends regulatory or other actions that may need to be taken in order for the stream to no longer be polluted.

TMDL Priority: It should be noted that TMDL priorities are parameter specific and methodologies have not yet been developed for all substances or conditions.
Thus a stream that has multiple causes of impairment may be high priority for one cause, but low priority for another.

High - H: Tools are available to produce the TMDL and the stream is in one of the watersheds being studied in the next two years. The TMDL will be produced in the next two years.

Medium - M: Tools are available to produce the TMDL, but the stream is not in a watershed being studied in the next two years. TMDL will be produced in the next five years.

Table 4 Continued

Definitions:	
Low - L:	Tools are not currently available to produce the TMDL and the stream is not in the watershed being studied in the next two years. TMDL will be produced in the next twelve years.
Not Applicable - NA:	4a - A TMDL has already been completed, submitted to EPA, and approved by EPA. 4b - A TMDL is not needed because a different type of control strategy is in place which will bring about compliance with the criterion in a reasonable amount of time. 4c – The impact to the stream is not being caused by a pollutant.
***MS4:**	A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains) owned by a state, city, town, or other public body that is designed or used for collecting or conveying stormwater, which is not a combined sewer nor part of treatment works.
Category 5:	One or more uses are not being met. A TMDL is needed for the listed pollutants.

Source:
Conservation 2012

Sinking Creek water body has been declared impaired due to Escherichia coli (*E. coli*) levels that exceed water quality standards. *E. coli* is an indicator of bacteriological quality in the water. It indicates possible contamination by fecal matter that may contain disease-causing agents such as pathogenic bacteria (Jeung 1978; Jadlocki 2009). This indicator bacteria is transported to receiving waters by stormwater runoff (Jadlocki 2009). Recreation in the impaired parts of Sinking Creek is discouraged by the EPA because of the possible public health issues. Table 4 shows that Sinking Creek has a medium TMDL

priority level and therefore a TMDL will not be produced for another five years (Conservation 2012). According to a North Carolina study published by the ASCE Journal, storm-water best management practices (BMP's) may be an important tool in treating indicator bacteria in runoff (Jadlocki 2009). This study monitored and tested nine different BMP's for fecal coliform and *E.coli*. The results showed that bioretention areas may be successful in bacterial treatment and significantly reduced both fecal coliform and *E. coli* concentrations (Jadlocki 2009). With this information, the proposed BMP's will consider bioretention as a favorable method for stormwater management in the Sinking Creek neighborhood. Contaminant removal is a goal that is secondary to detaining stormwater runoff volumes.

The Second Creek water body has been declared impaired due to several constituents including E. Coli, Nitrate/Nitrite, and Sediment (U.S.E.P.A. 2010). Total Maximum Daily Loads (TMDL) have been put into place by the EPA to keep the water body from further degradation and therefore Table 4 shows Second Creek with TMDL priorities as non-applicable. Nutrients such as Nitrate and Nitrite do not yet have TMDL restrictions and have been set as a low TMDL priority (Conservation 2012). Nitrate, if found in higher concentrations, can seriously or fatally effect infants due to methemoglobinemia (blue

baby syndrome). These nutrients also have habitat and biological altering potentials by producing algae blooms in water bodies, diminishing dissolved oxygen levels for aquatic animals. Nitrate concentrations have the potential of being compounded, as chemical fertilizers are transported by stormwater runoff into receiving waters (Chapra 1997; Cech 2010). While this is a low priority TMDL, temporal and spatial aspects of contaminants should be recognized to properly understand the nature of pollution issues (Jeung 1978). For example, nutrients are capable of being transported regionally and may persist in water bodies for months and possibly up to a decade (Jeung 1978). Native plants, trees and shrubs used as an integral part of proposed BMP's may require fewer applications of fertilizers and have the ability to filter nutrients transported by stormwater (Chapra 1997).

Sediment is a primary cause of impairment in the Second Creek watershed (Conservation 2012). It is a type of suspended solid that has been considered the most significant pollutant due to its adverse affects on water quality. Sediment acts as a transport medium because it is capable of adsorbing pesticides, nutrients, and other organic matters (Jeung 1978). This water body is not recommended for recreation, consumption, or human interactions; nor does it support ecological habitats. Total Suspended Solids are (TSS) are the primary

causes of water body impairment addressed in Knox County's Stormwater Management Manual. The BMP's recommended for addressing sediment in the Knox County manual will be considered as guidelines for the BMP's proposed in the Second Creek neighborhood.

3.2.4 Summary of Issues and Goals

The stormwater inventory and analysis generally assessed stormwater runoff behavior of the existing conditions at the sub-watershed and neighborhood scales. The analysis of surface flow and drainage patterns gave an indication of where localized flooding issues may occur and will help to inform where preventative measure may be taken to address runoff at the source of where it is being generated by the existing impervious surfaces.

The stormwater observation study helped assess the contributing factors that increase peak flows and runoff volumes such as sparse existing tree canopy, steep slopes, stormwater conveyances and connected impervious surfaces. These observations helped to establish design goals for managing stormwater such as increasing storage for runoff volumes, increasing tree canopy, and providing alternative forms of stormwater conveyances that disconnect impervious surfaces and encourage infiltration. Addressing stormwater runoff volumes

produced by the existing conditions in each neighborhood may begin to address the water quality issues of the receiving water bodies in both the short term and the long term (Water Environment Federation 2012).

4. Design

The overall design aims to improve stormwater management within each neighborhood using integrated Best Management Practices to retain stormwater runoff volumes while addressing the perceived needs of the Sinking Creek and Second Creek Neighborhoods. The design proposal for each neighborhood includes a master plan of integrated BMP's, typical street sections of proposed BMP applications, and diagrams of the proposed BMP functions. The design proposal responds to the inventory and analysis and is projected to manage the projected runoff volumes and improve walkability. The projected storage volumes of each proposed master plan are estimated and compared to the projected stormwater runoff volumes discussed in section 4.1 Design Approach.

4.1 Design Approach

The methods of the design approach for developing the neighborhood master plan first includes the use of HydroCAD to project stormwater runoff volumes produced by the 95th percentile rain event. The stormwater runoff volumes projected by the HydroCAD model for the Sinking Creek and Second Creek neighborhoods are then used as the Demand Volumes to be met by the Total Design Storage

estimated for each proposed master plan. The Total Design Storage consists of the cumulative Storage Volumes of individual BMP's by street or subdivision. Typical street sections show the combination of proposed BMP's at the street level. The BMP estimated Storage Volumes include the BMP types such as Bio-swales, Cul-de-sac bioretention cells, Curb Extension bioretention cells, and Tree Boxes. These BMP's were selected in response to the neighborhood and stormwater inventories discussed in Chapter 3.

4.2 Projected Runoff Volumes

The projected runoff volumes of each neighborhood were generated in a Hydro CAD model and are described in this section. Hydro CAD uses values such as a selected rain event, areas of impervious and pervious surfaces, soil type, hydraulic length, and average slope within the neighborhood watersheds.

This model uses the 95th percentile rain event of 1.29 inches, representing "a precipitation amount for which 95 percent of all rainfall events for the period of record do not exceed" (U.S.E.P.A. 2009). According to the EPA's *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act*, "retaining all

storms up to and including the 95th percentile storm event is analogous to maintaining or restoring the pre-development hydrology with respect to the volume, flow rate, duration and temperature of the runoff for most sites" (U.S.E.P.A. 2009). This 95th percentile approach was identified and recommended because this storm size "represents the volume that appears to best represent the volume that is fully infiltrated in a natural condition and thus should be managed onsite to restore and maintain this pre-development hydrology for duration, rate and volume of stormwater flows" (U.S.E.P.A. 2009). Therefore, for the purposes of this study the 95th percentile design storm of 1.29 inches is being used in this Hydro CAD model to estimate the pre and post-development runoff volumes.

This model assumes a Type II 24 hour rain event, based upon NRCS Rainfall Distributions (Prince George's County 1999). Because the proposed BMP's will aim to address the stormwater runoff volumes generated by the existing impervious surfaces, only these values were modeled within the neighborhoods. The areas for impervious surfaces include existing streets, sidewalks, roof tops, driveways, and parking lot areas. The areas of impervious surfaces were estimated using KGIS imagery that was imported and traced into AutoCAD (Refer to calculations in Appendix A4.). Discrepancies may have occurred while

calculating values of impervious areas therefore; these areas are considered as estimated values. In Sinking Creek impervious surfaces were estimated to be 53.76 acres where the majority of imperviousness was attributed to roof tops (Figure 28). The impervious areas contributing to the runoff volumes in Second Creek were estimated to be 49.2 acres, where the majority is attributed to existing roadways (Figure 28). Soil type C was assumed for both neighborhoods in the Hydro CAD model (AMEC 2008).

According to the Hydro CAD User Manual, the time of concentration is the time required for a particle of water to travel from the most hydrological remote point in the watershed to the point of collection. The distance along this path was used as the hydraulic length and the average slope was determined by averaging the slope values across the neighborhood watershed. These values were plugged into Hydro CAD to determine the time of concentration. The hydraulic length used for Sinking Creek's neighborhood watershed was 3,200 feet and 6,940 feet for Second Creek's hydraulic length. The large difference in the hydraulic lengths is a result of the flows being diverted differently in each watershed (refer to Figure 22). The

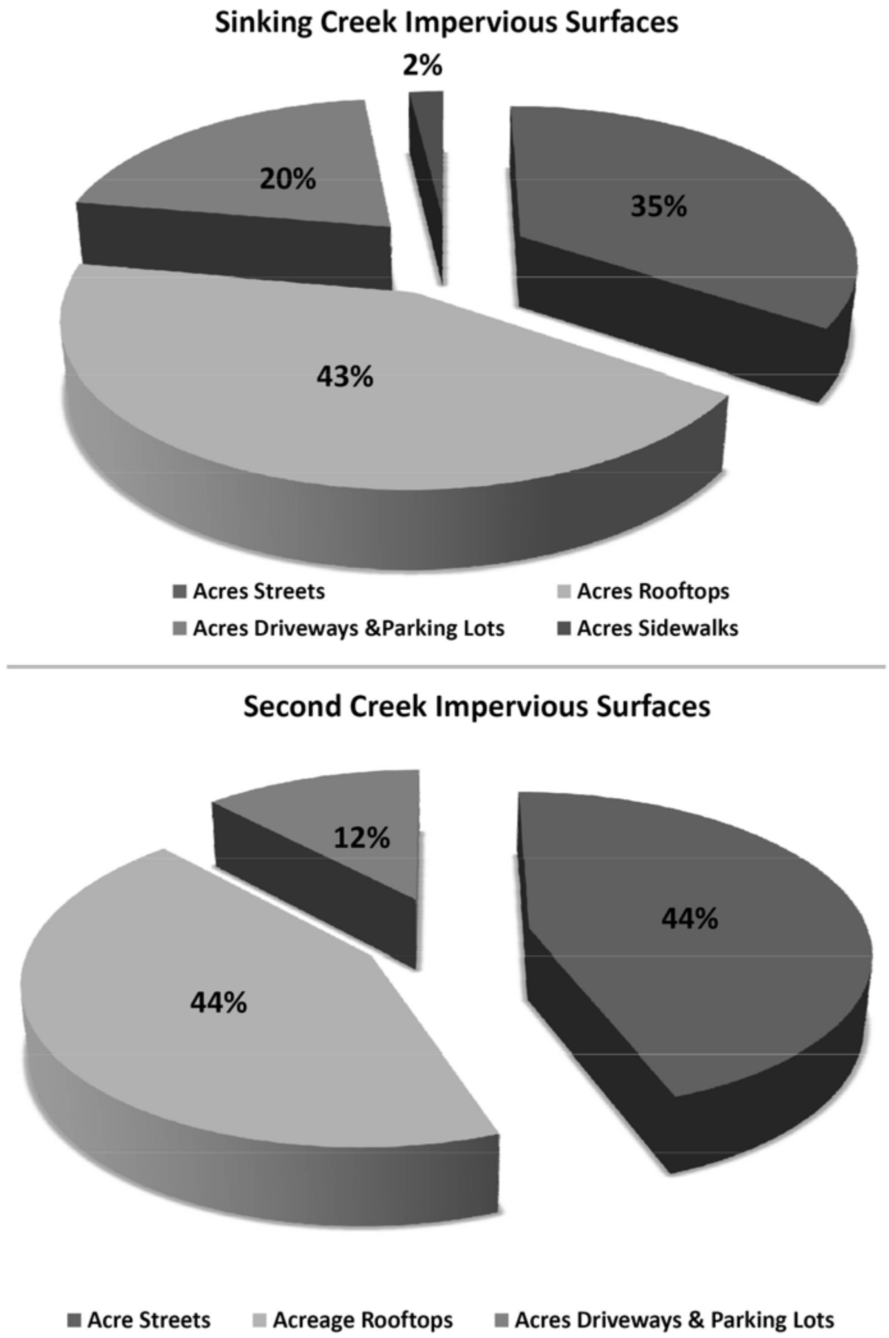


Figure 28. Impervious Surface Percentages Comparison

average slope over Sinking Creek's neighborhood watershed was estimated to be 5.8% and a lower slope average of 4.1% was estimated over Second Creek's neighborhood watershed. Plugging each of these values into the Hydro Cad model gave a projection of the runoff volumes produced by the impervious surfaces in the Sinking Creek and Second Creek neighborhood watersheds.

Sinking Creek's projected volume produced by impervious surfaces is estimated at 4.5 acre-feet from the Hydro CAD model. Second Creek's projected volume produced by impervious surfaces is estimated at 4.1 acre-feet. The Runoff Hydrographs that are shown Appendix A3. were produced in Hydro CAD are a result of the modeled characteristics for each neighborhood.

For both neighborhoods it is assumed that their antecedent (or native) conditions prior to development were woodlands in good condition. The projected runoff volumes produced by the antecedent conditions are 0.2 acre-feet in Sinking Creek's neighborhood watershed and 0.1 acre-feet in Second Creek's neighborhood watershed.

The projected stormwater runoff volume to be managed by each design proposal is calculated by subtracting the projected runoff volumes produced by the antecedent conditions from the projected

runoff volumes produced by the existing impervious surfaces. This is because the goal of distributed BMP's is to mimic the natural hydrologic conditions of each site prior to development (Prince George's County 1999). The projected stormwater runoff volumes will now be considered as the demand volumes to be met by the proposed neighborhood master plans. The demand volume for the Sinking Creek neighborhood is 4.3 acre-feet and 4.0 acre-feet for the demand volume in the Second Creek neighborhood. For this study, these demand volumes are to be met by the estimated storage volumes that will be discussed in Section 4.4 Projected Storage Volumes.

4.3 Design Proposal

The design proposal for each neighborhood consists of a master plan of integrated BMP's, typical street sections of proposed BMP applications, and diagrams of the of the proposed BMP functions. The design proposal aims to provide storage for the stormwater runoff volumes projected by the Hydro CAD model (Section 4.2) while addressing the perceived needs of each community that were identified in the Neighborhood Inventory (Chapter 3). The design proposal will also attempt to increasing infiltration, restore tree canopy, and disconnect impervious surfaces in efforts to begin to

improve the water quality of the receiving water bodies and reduce localized flooding. The design proposal will incorporate the perceived needs of the community by improving walkability such as providing sidewalks that increase pedestrian connectivity to local goods and services, providing designated on-street parking and increasing tree canopy to provide shade (Institute 2012).

4.3.1 Proposed Master Plans

The proposed neighborhood master plans incorporate design applications that are unique to the urban and suburban communities. Diagrams are used to show the distribution of proposed BMP's applications within each neighborhood. Collectively the proposed BMP's provide storage for the projected Demand Volumes produced by the 1.29" rain event in each neighborhood. In order to improve neighborhood walkability, the master plans also propose sidewalks to provide pedestrian access to local schools, churches, retail or business services, and bus stops.

The diagrams of proposed BMP locations and proposed sidewalk locations in the Sinking Creek neighborhood are shown in Figure 29. The Sinking Creek master plan incorporates BMP's such as Bioretention Swales (Bio-Swales), Cul-de-sac Bioretention Cells, Curb Extension

Cells. The distribution BMP types in the Sinking Creek neighborhood are listed by street or subdivision under the document's Attachments.

Figure 30 shows the proposed master plan for BMP applications in the Second Creek neighborhood. The Second Creek master plan incorporates BMP's such as Bioretention Swales (Bio-Swales), Cul-de-Curb Extension Cells, and Tree Boxes. The distribution BMP types in the Second Creek neighborhood are listed by street or subdivision under the document's Attachments.

In both urban and suburban applications, increasing tree canopy along sidewalks provides shade for local users and increases the performance of stormwater BMP's (AMEC 2008). Street trees act as a buffer between pedestrians and the roadway, increasing safety and walkability (Wood 2005; Institute 2012). The configuration of BMP's proposed in each street or subdivision will be discussed in Section 4.3.2 Proposed BMP applications.

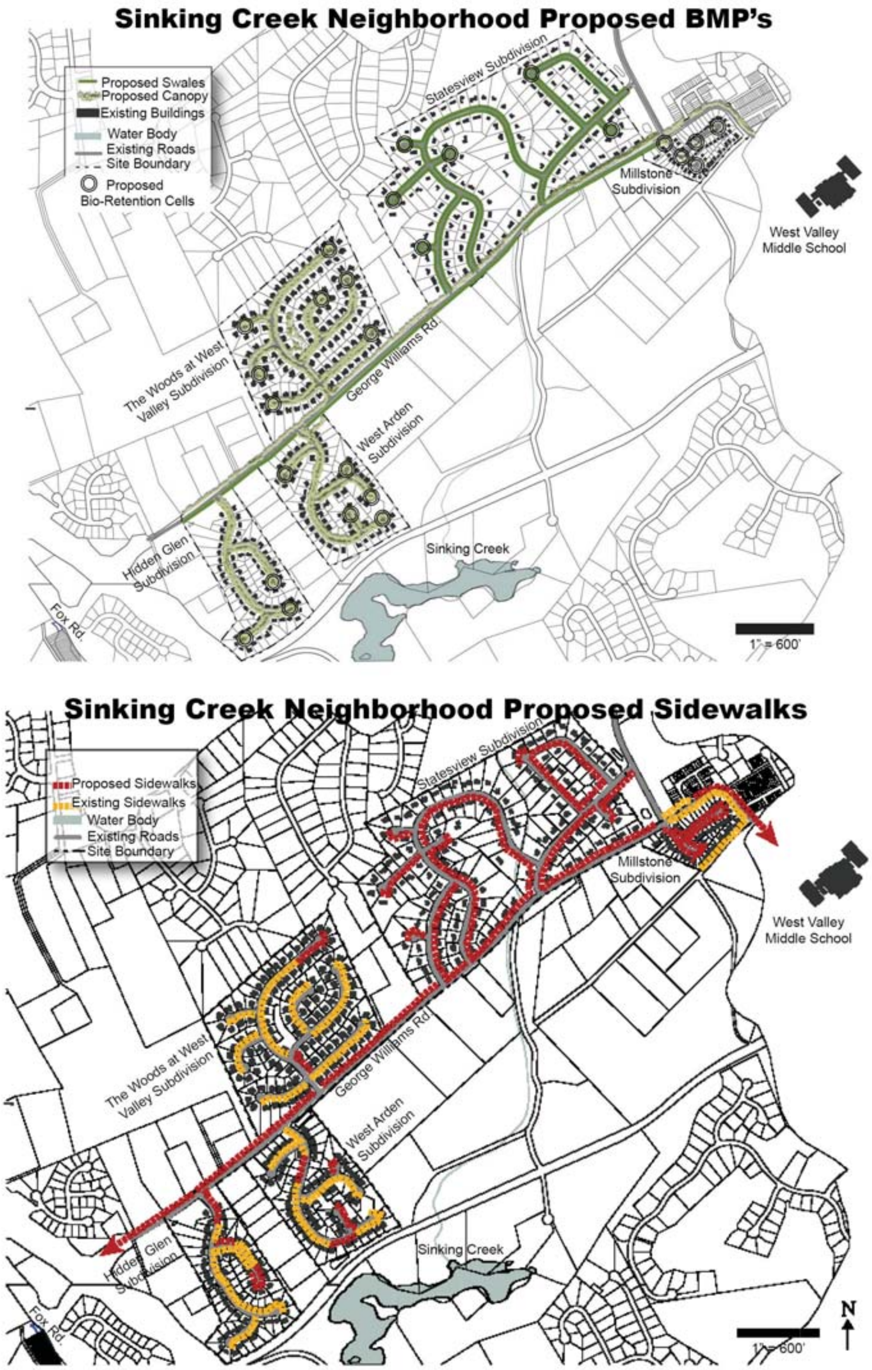


Figure 29. Sinking Creek Neighborhood Proposed Design Applications

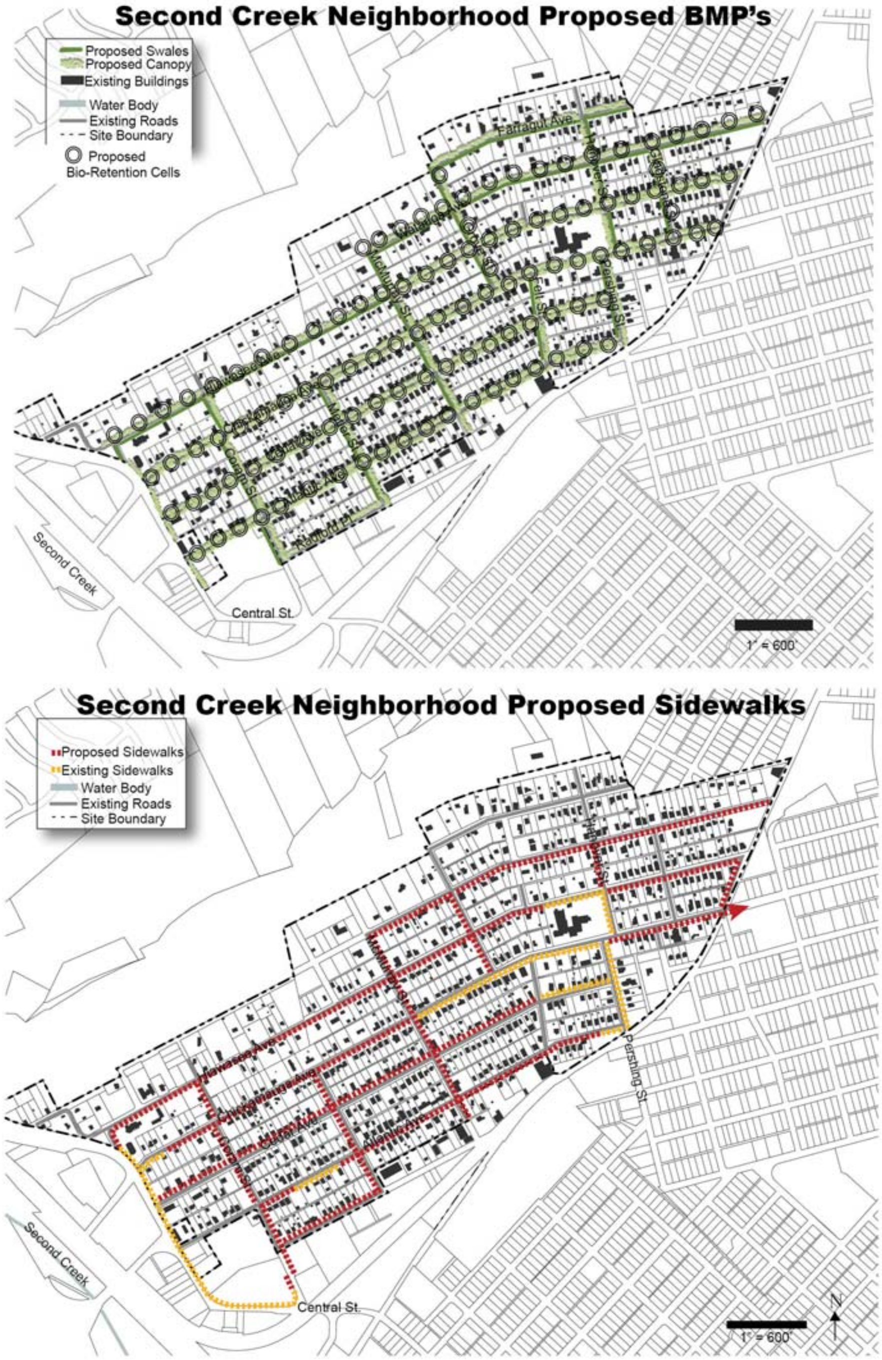


Figure 30. Second Creek Neighborhood Proposed Design Applications

4.3.2 Proposed BMP Applications

Typical street sections were developed to show how the design responds to neighborhood issues and incorporates BMP's that address stormwater runoff volumes within the public right-of-way. These typical street sections were developed by grouping similar needs of the neighborhood so that they are applicable in multiple locations. Table 5 shows streets or subdivisions grouped together by assigned letters A through D. These letters correspond to the typical street sections that show the combination of BMP design applications within the 50 foot right-of-way. Individual BMP functions are shown in diagrams referenced within the discussion of typical street sections.

Urban design applications have been proposed in the Second Creek neighborhood. Typical Urban Section A applies to streets with

Table 5. Typical Design Applications

Sinking Creek Design Applications

Typical Section	Subdivision/ Street Names
A	Statesview
B	The Woods at West Valley
B	Hiden Glen
B	West Arden
C	Millstone
D	George Williams Road

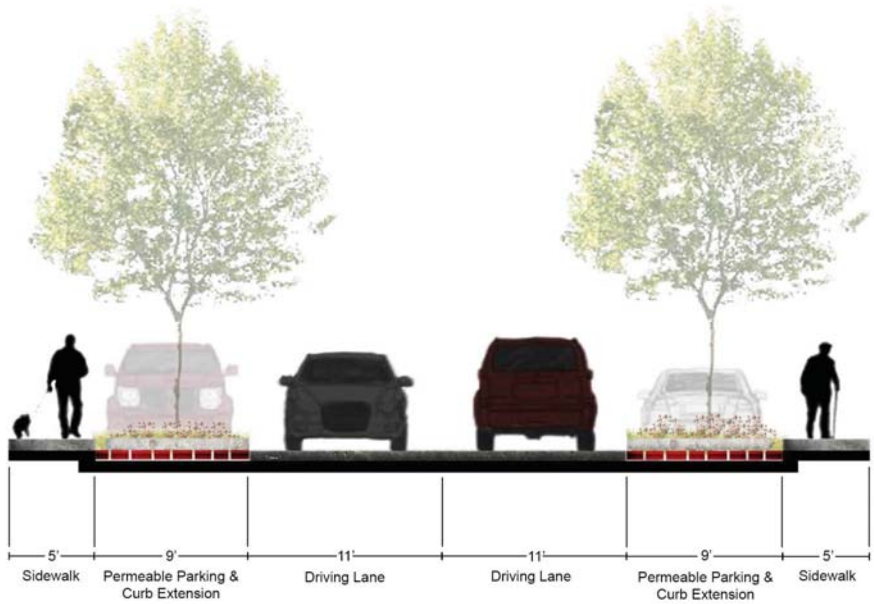
Second Creek Design Applications

Typical Section	Subdivision/ Street Names
A	Chickamauga, Atlantic, Cedar, Hiawasee
B	Watauga, Hiawasee, Grove, Gladstone
C	Coram, Metler, McMurray, Felt, Pershing, Hanover, Farragut
D	Radford

similar needs such as Cedar Avenue and Atlantic Avenue where parking and sidewalks are proposed on both sides of the roads (Figure 31). Proposing Curb Extension cells every 100 feet provides storage areas for the stormwater runoff that is conveyed by existing curb and gutter systems. These Curb Extensions provide opportunities for safer crossing at street intersections and provide on-street parking areas for local residents (Wood 2005; Institute 2012). On-street parking areas are designated by permeable pavement that is projected to increase stormwater infiltration (AMEC 2008). Designating these parking areas may reduce traffic speeds through the neighborhood and help to increase walkability by providing separation between pedestrians and moving vehicles (Institute 2012). Driving lane widths are reduced to from 13 feet to 11 feet in most applications to allow for the BMP's to be proposed within the extent of the public right-of-way. Narrowing driving lane widths may also act as a method of traffic calming (Wood 2005).

Bioretention swales (Bio-swales) with checkwalls are proposed on the downhill side of roads to run perpendicular to sheet flow patterns wherever possible as to increase runoff volume capture. An example of this application is shown in Typical Urban Section B (Figure 31) along streets such as Hiawassee Avenue and Watauga Avenue.

Typical Urban Section A



Typical Urban Section B

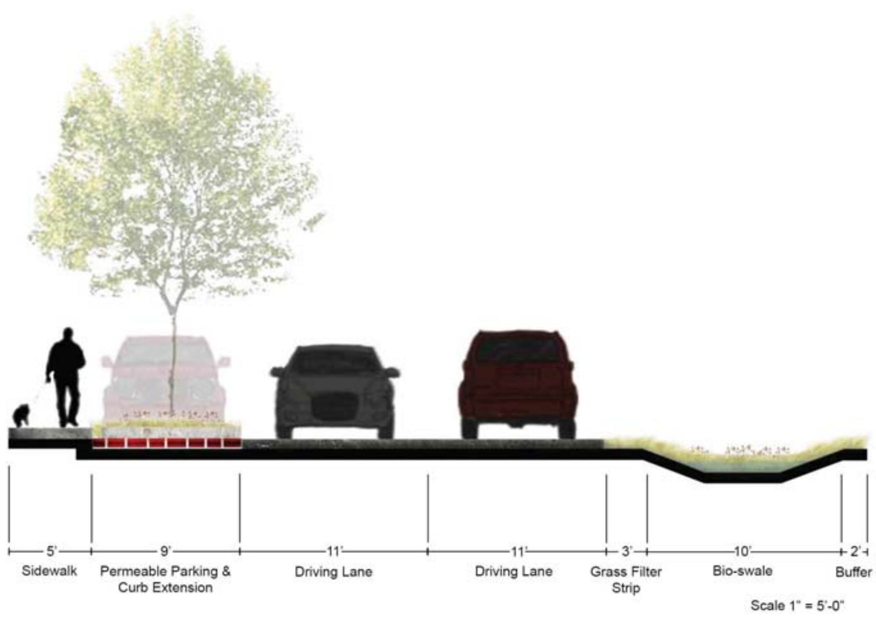


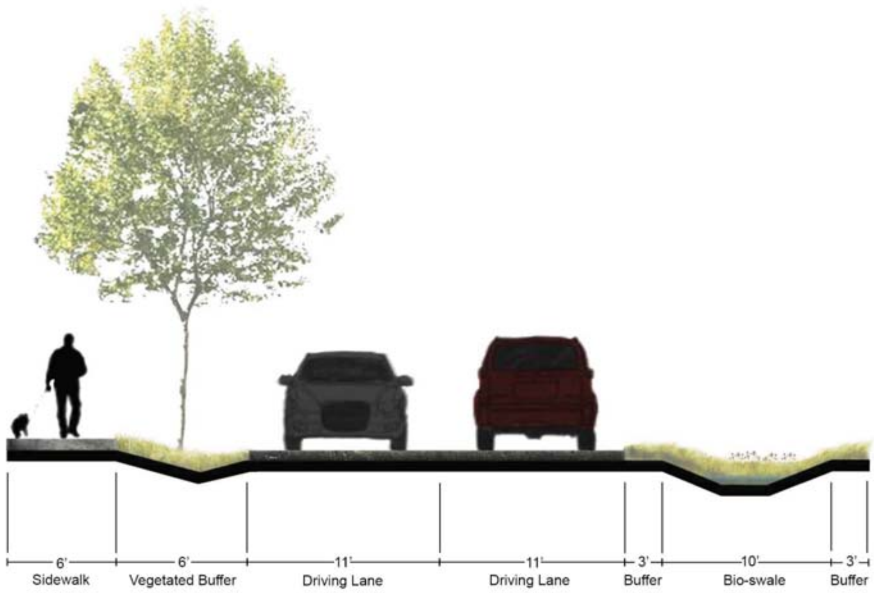
Figure 31. Typical Urban Sections A & B

A grass filter strip between the swale and roadway filters out suspended solids carried by runoff before stormwater enters the swale (AMEC 2008). This grass strip also provides a soft shoulder for drivers. Permeable parking is designated on one side of the road in Typical Urban Section B as it responds to the inventory discussed in Chapter 3, Table 1.

Typical Urban Section C (Figure 32) also utilizes Bio-swales for capturing runoff volumes on one side of the street however; parking was recorded as not needed for this group of streets (Table 1). The vegetated buffer containing street trees separates pedestrians from traffic. This helps to increase safety and improve walkability (Institute 2012). Street trees provide shade which can decrease stormwater runoff temperatures while increasing rainfall interception and the potential for stormwater runoff to infiltrate the soil (Water Environment Federation 2012).

Tree Boxes shown in Typical Urban Section D (Figure 32) are unique to Radford Place. This is because of the residential-industrial interface that is present which limits the available area for BMP installation. Tree Boxes are a BMP application that may be used where space is limited (Association 2008). This design shows a 6 foot

Typical Urban Section C



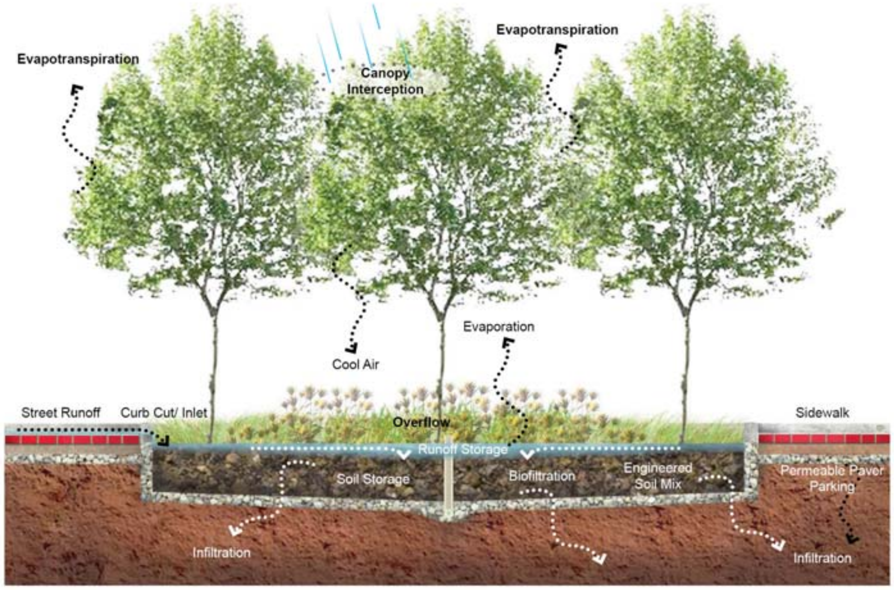
Typical Urban Section D

Figure 32. Typical Urban Sections C & D

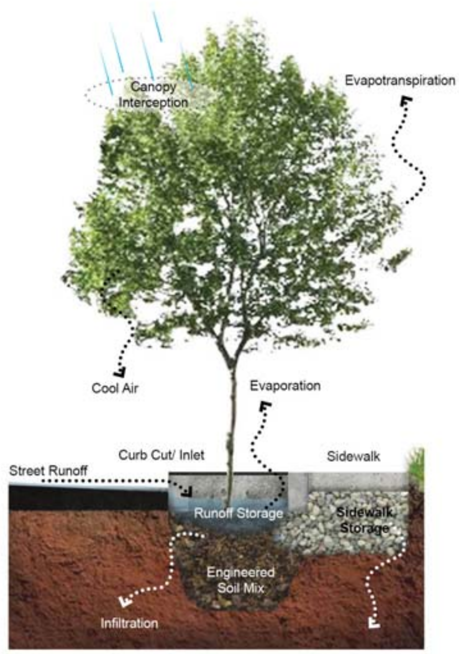
sidewalk where the Tree Boxes are embedded to help separate the residential and pedestrian front from the adjacent industrial properties.

The BMP's designated in the typical street sections all encourage processes such as infiltration, evaporation, and evapotranspiration in addition to providing surface and sub-surface storage volume. The Curb Extension Bioretention Cell Detail (Figure 33) shows the interface of the existing curb and gutter system along the sidewalk and permeable pavements surrounding the cell. While the cell intercepts the street runoff from the gutter system, the adjacent permeable pavement encourages infiltration. Engineered soil mixture is typically applied to all proposed BMP's as a soil amendment for increasing subsurface storage and infiltration (Dickinson 2008).

The application of Tree Boxes shown in Typical Section D along Radford Avenue is another BMP application which can incorporate sub-surface storage. The Tree Box detail in Figure 33 shows runoff from the street that is captured at the Tree Box inlet and is infiltrated through the engineered soil mixture. Drain rock underneath the sidewalk may provide additional drainage to prevent overflow.



Curb Extension Bio-retention Cell Detail



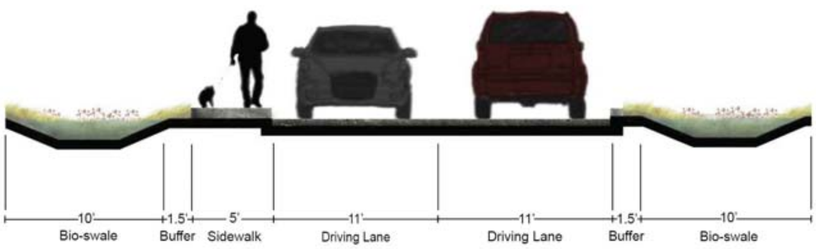
Tree Box & Sidewalk Storage Detail

Figure 33. Curb Extension and Tree Box Details

Suburban design applications are proposed in the Sinking Creek neighborhood. Typical BMP applications were grouped by subdivision rather that by streets due to their homogenous nature (refer to Table 5). Typical Suburban Section A (Figure 34) is an example applied to the Statesview subdivision where steep slopes were determined as contributors to stormwater runoff issues. The section shows Bio-swales on both sides of the streets aimed at capturing flows produced by driveways, roof tops and roadways. Cutting existing curbs will allow for stormwater flows to enter the swale system. These swales incorporate check walls to help retain some of the runoff volumes and act as a secondary measure to slow down the flow in more major storm events. In addition to Bio-swales, 30 foot bioretention cells are located within cul-de-sacs to provide runoff storage and treatment.

Typical Suburban Section B (Figure 34) shows applications in the newer subdivisions such as The Woods at West Valley, West Arden and Hidden Glen. This BMP configuration aims to increase the tree canopy on both sides of the street and along existing and proposed sidewalks. Cuts along existing curbs will again allow for stormwater to be intercepted by vegetated areas before entering the existing storm sewers.

Typical Suburban Section A



Typical Suburban Section B

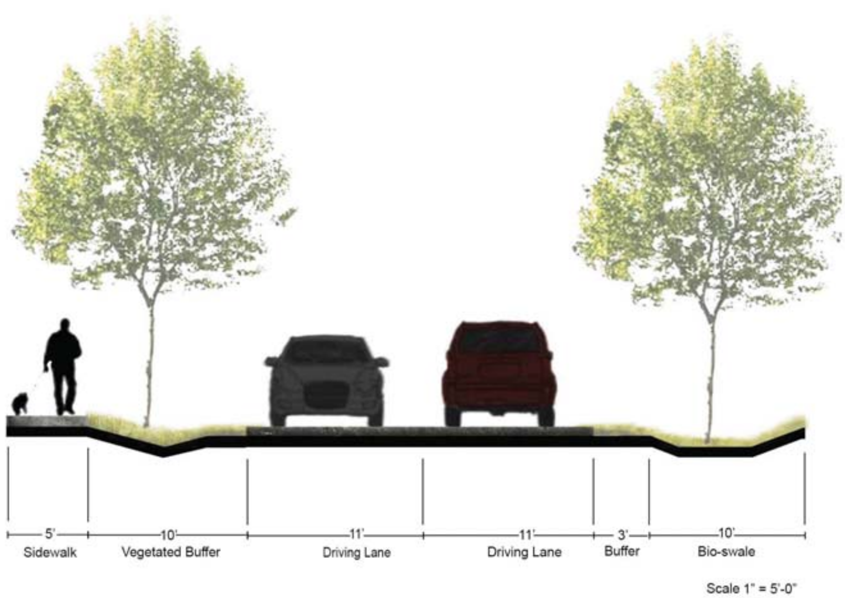


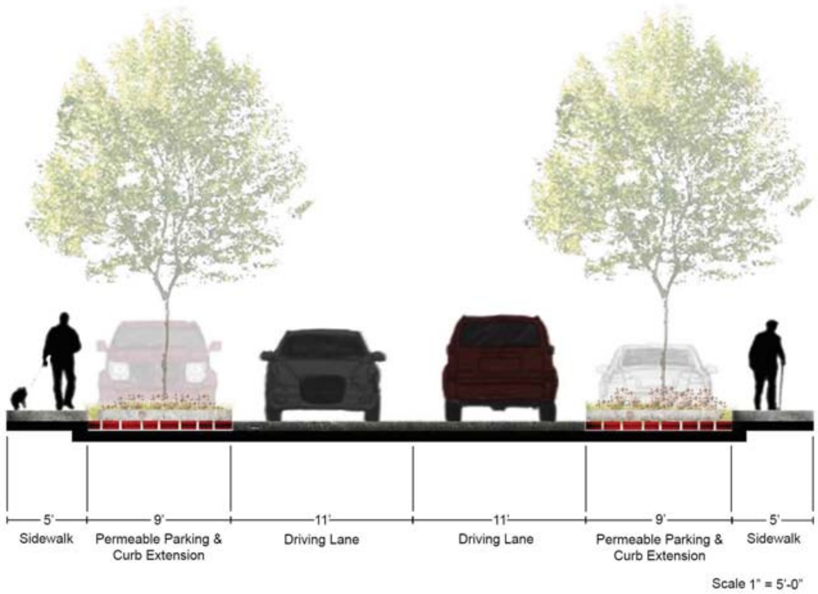
Figure 34. Typical Suburban Sections A & B

Typical Suburban Section C (Figure 35) is proposed for the Millstone Subdivision where detached town homes are provided with urban-like parking and sidewalk applications. The use of bio retention cells within curb extension and inside cul-de-sacs provide stormwater volume storage areas.

Proposed BMP applications are shown by Typical Suburban Section D (Figure 35), where a 6 foot sidewalk is located along the upper side of George Williams Road providing pedestrian connections to bus stop locations and access to West Valley Middle School. A 6 foot vegetated buffer provides addition safety for pedestrians and provides shade by the proposed tree canopy. The lower side of the road utilizes the Bio-swale with check walls to help detain stormwater before it is conveyed to the upper reaches of Sinking Creek.

Bio- swales along the roadways act as both stormwater conveyances and storage cells. Each cell within the Bio-swale is distinguished by checkwalls that are spaced according to the existing slopes while maintaining a 6 inch water level (Figure 36). These walls not only provide additional storage for runoff volumes but also may increase detention time during larger storm events (Prince George's County 1999).

Typical Suburban Section C



Typical Suburban Section D

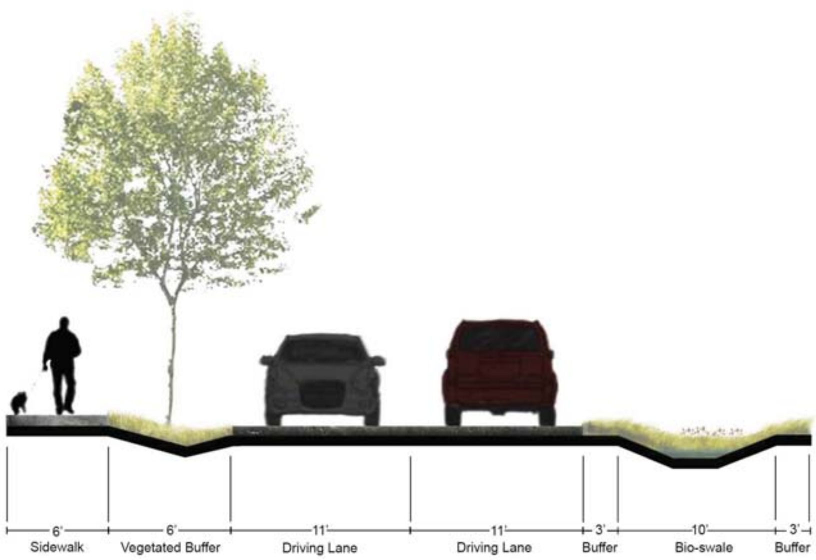
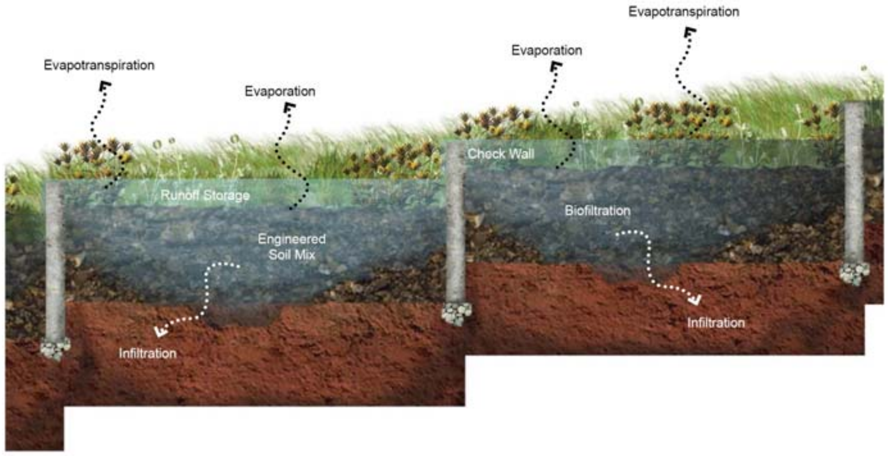
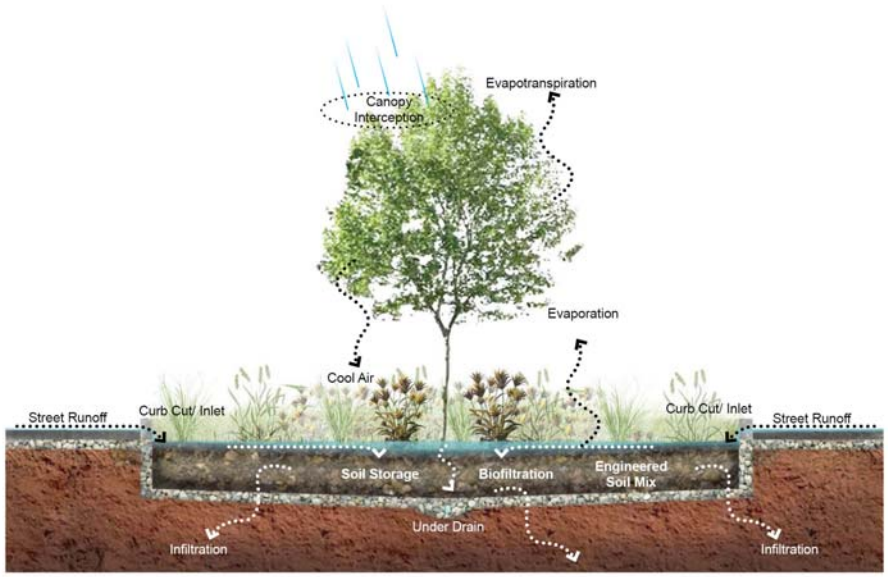


Figure 35. Typical Suburban Sections C & D



Vegetated Swale Detail



Col-de-sac Bio-retention Cell Detail

Scale 1" = 5'-0"

Figure 36. Bio-swale and Cul-de-sac Bioretention Details

The Cul-de-sac Bioretention cells (Figure 36) in the suburban applications act similarly to the curb extension cells discussed previously. These cells are centered in the existing cul-de-sacs, improving the aesthetic of the large paved area while reducing the impervious surface area (Collett 2013). The cells incorporate vegetation to increase evapotranspiration and stormwater filtration (Hinman 2012; Collett 2013). The under drain connects to the existing storm drains after filtering out suspended contaminants.

4.4 Projected Storage Volumes

The estimated storage volumes projected for each proposed master plan is a cumulative value of storage provided by a combination of integrated BMP's. The BMP types used to estimate the storage volumes are Bio-swales, Cul-de-sac Bioretention cells, Curb Extension cells, and Tree Boxes. The geometry and sizing of these BMP's was based upon existing street slopes, the available design space within the public right-of-ways and a combination of published BMP manuals. The storage volumes include surface and subsurface storage for reducing stormwater runoff volumes (A. M. Thompson 2007; Hinman 2012). All estimated storage values pertaining to each master plan are included in the Attachments.

4.4.1 Bio-swale Storage

The estimated storage volumes for the proposed Bio-swales were dependent upon the existing street slopes. The diagram in Figure 37 shows the Bio-swale Geometry to help convey the dimensions of the design and how they contribute to the storage volume calculations in this section. Tables showing slope and storage calculations, are located under Attachments.

The street slopes (S%) were calculated using spot elevations on the existing roadways to find the difference in elevation (DE) over the measured length (L)(spot elevation data provided by the KGIS's Interactive Maps). The slopes were then categorized into ranges of 5% increments previously shown in Figure 22. The slope (S%) was used to estimate the Cell Length while maintaining 6 inch high checkwalls within the proposed bio-swales along any given slope (S%). Equation 1 was used to calculate the Cell Length values.

Equation 1:

$$Cell\ Length\ (ft.) = \frac{0.5\ (ft.)}{(S\%/100)}$$

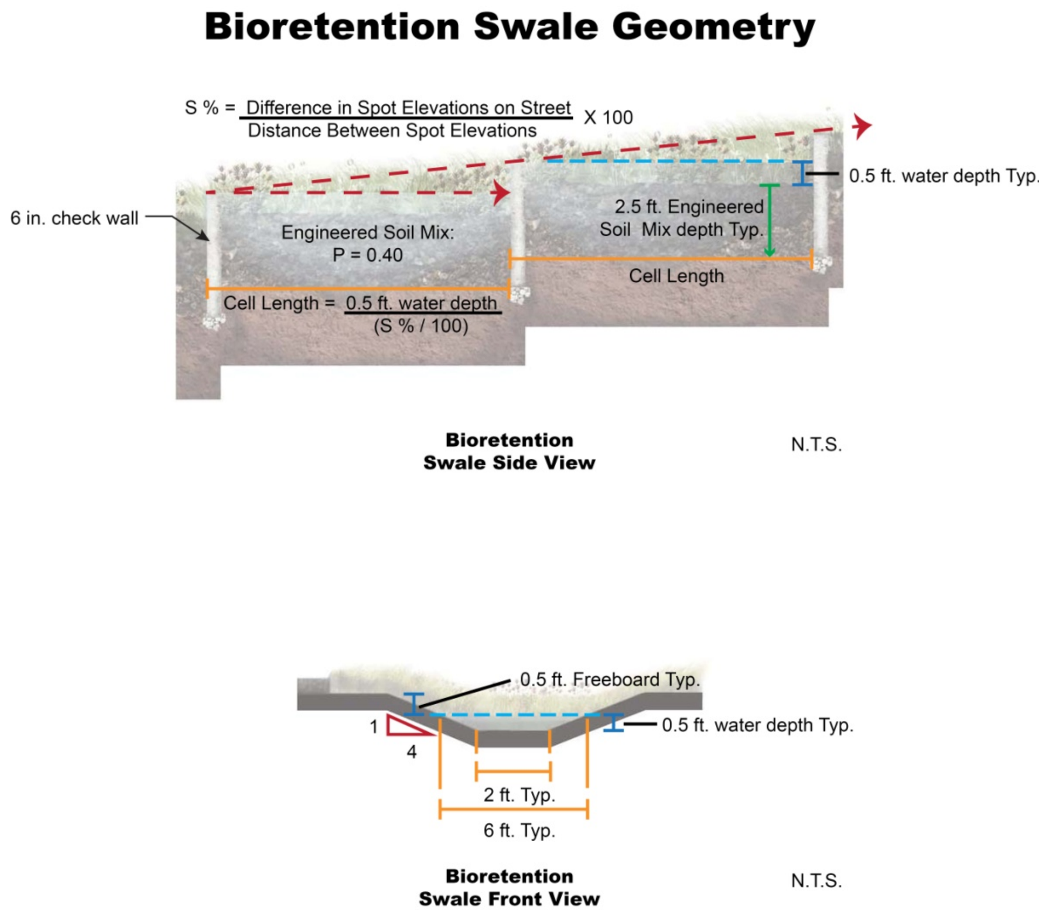


Figure 37. Bioretention Swale Geometry

The relationship was found that as the slope percentage increases, the cell length decreases. As a result of this inverse relationship, less storage volume per cell was able to be provided for steeper slopes (S%>5%) than slopes that are less steep (S%<5%) (Organization 1991). The checkwalls act as a barrier to retain a 6 inch depth of stormwater before flowing into the next cell (Prince George's County 1999; Hinman 2012). Concentrated runoff down steep slopes can flow at rates that cause channel erosion. The stair stepped design helps to decrease the velocity of flow in the swale (Organization 1991). Another 6 inches of freeboard from the top of each checkwall helps to prevent overflow into the adjacent streets during larger events while maintaining a 4:1 side slope (Bio-swale Front View of Figure 37) (AMEC 2008).

The 4 foot average width (Equation 2) of the Bio-swale was used to help calculate the Top Area (s.f.) of each cell for estimating Surface and Sub-surface Storage Volumes (Equation 3). The Top Area of Cell subtracts the 6 inch (0.5 ft.) checkwall thickness from the individual Cell Length. The average width was obtained by:

Equation 2

$$Average\ Width\ (ft.) = \frac{6\ ft. + 2 ft.}{2}$$

Therefore the Top Area of Cell is given by:

Equation 3

$$Top\ Area\ of\ Cell\ (s.f.) = \left(Cell\ Length\ (ft.) - 0.5\ (ft.)\right) \times Average\ Width\ (ft.)$$

The Surface Storage volume was calculated assuming a water depth of 6 inches (0.5 ft.) and is given by Equation 4:

Equation 4

$$Surface\ Storage\ (cu.ft.) = Top\ Area\ of\ Cell\ (s.f.) \times 0.5\ (ft.)$$

Engineered Soil Mix encourages the stormwater to infiltrate into the ground and provides sub-surface storage. Engineered soil mix may contain a blend of sand, soil, and compost (A. M. Thompson 2007).This design follows the recommended soil depth of 2.5 feet with Porosity P = 0.40 (Hinman 2012). The storage volume of a single bio-swale cell (Cell Storage) is given by adding the Surface Storage and the Sub-surface storage (Equation 6). Assuming 100% soil saturation after infiltration, the Sub-surface Storage volume is estimated by multiplying the Porosity by the Top Area of Cell and 2.5 foot soil depth (Das 2006) and is given by Equation 5:

Equation 5

$$Sub - surface\ Storage\ (cu.ft.) = Top\ Area\ of\ Cell \times 2.5' \times 0.40$$

Therefore, Cell Storage is given by:

Equation 6

$$Cell\ Storage\ (cu.ft.) = Surface\ Storage + Sub - surface\ Storage$$

The Total Cell Storage (Equation 8) is storage provided by a chain of cumulative Bio-swale cells along a given slope category (refer to Attachments and Figure 22). The number of cells (# Cells) along the given slope category is determined by the available street length (L) and the Cell Length, given by Equation 7:

Equation 7

$$\#\ Cells = \frac{L\ (ft.)}{Cell\ Length\ (ft.)}$$

Therefore, Total Cell Storage is given by:

Equation 8

$$Total\ Cell\ Storage\ (cu.ft.) = Cell\ Storage\ (cu.ft.) \times \#\ Cells$$

The Total Cell Storage for an existing slope of a given street or subdivision is totaled then added to any additional Bioretention Storage Values (Attachments). The additional Bioretention Storage Values may include runoff managed by BMP's such as Curb Extension cells, Tree Boxes, and Cul-de-sac Bioretention cells. Each of the methods used to estimate storage volumes provided by these BMP's are described in the following sections.

4.4.2 Cul-de-sac Storage

The Cul-de-sac Bioretention cells were exclusively used in the Sinking Creek Neighborhood design proposal. This is due to the nature of the suburban street patterns that do not exist in Second Creek's urban neighborhood characteristics. Therefore, the design considerations for Cul-de-sac Bioretention cell sizing were solely based upon characteristics found within the Sinking Creek Neighborhood.

The storage sizing for a single Cul-de-sac cell was initially based upon the available space within the right-of-way and the desired width of the roadway. Using KGIS Interactive Maps the existing cul-de-sacs were estimated to have an 80 foot diameter (Appendix A4.)The

desired roadway width is 20 to 24 feet, with a central 30 foot Bioretention cell diameter (Joseph De Chiara 1984; Russ 2002). Figure 38 shows the Cul-de-sac Bioretention Cell Geometry. The cell diameter includes a 6 inch curb with inlets between the existing roadway and the storage area. Another 6 inches of freeboard is provided before tying into an overflow connected to the existing storm drains, typically located at the back of the existing cul-de-sac. The estimated Surface Storage volume for the Cul-de-sac Bioretention cell assumes and average water depth of 6 inches (0.5 ft.) multiplied by the Cul-de-sac Area.

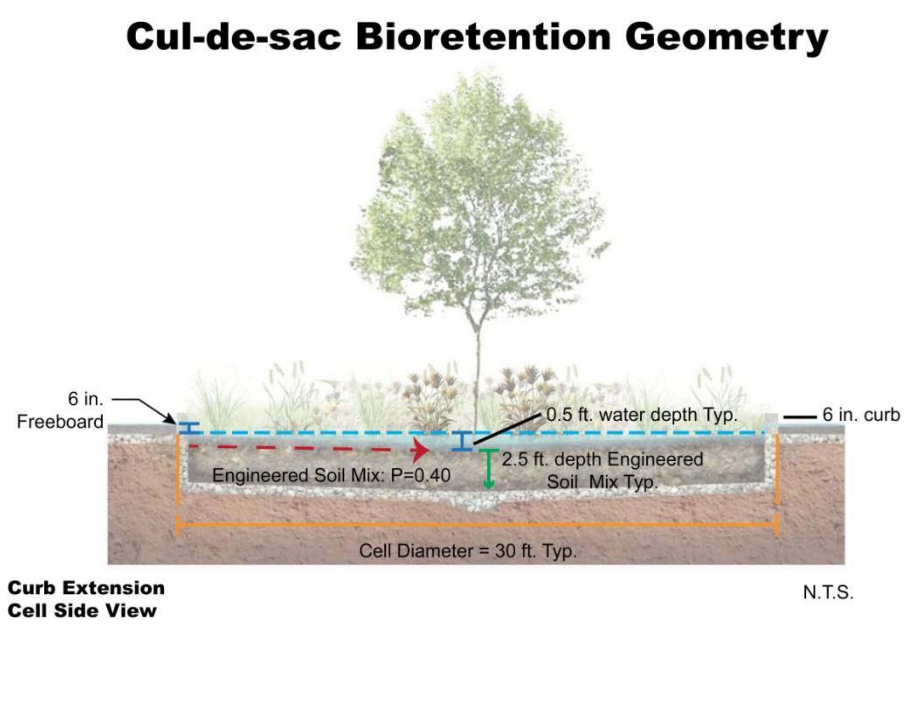


Figure 38. Cul-de-sac Bioretention Geometry

The Cul-de-sac Area subtracts the 6 inch (0.5 ft.) curb thickness from the 15 foot outer cell radius. In Equation 9 the Surface Storage is given by :

Equation 9

$$Surface\ Storage\ (cu.ft.) = 0.5\ ft.\ \times (\pi \times (15\ ft. - 0.5\ ft.)^2)$$

The proposed Engineered Soil Mix has a depth of 2.5 feet with a Porosity of 0.40 (Dickinson 2008). Assuming 100% soil saturation after infiltration, the Sub-surface Storage volume is estimated in Equation 10 by multiplying the Porosity by the total volume (Das 2006) and is given by:

Equation 10

$$Sub - surface\ Storage\ (cu.ft.) = 2.5\ ft.\ \times\ 0.40\ \times (\pi \times (15\ ft. - 0.5\ ft.)^2)$$

The storage volume for a single Cul-de-sac Bioretention cell (Single Cell Storage) is 990 cubic feet, given by adding the Surface Storage and the Sub-surface storage values shown in Table 6. This Storage Volume (see Attachments) is the collective volume of the Cul-de-sac cells per neighborhood Subdivision.

Table 6. Cul-de-sac Storage

Cul-de-sac Storage:	
Engineered Soil Mix Depth (ft.)	2.5
Sub-surface Storage (cu.ft.)	660
Surface Storage (cu. ft.)	330
Average water depth (ft.)	0.5
Cul-de-sac Area (s.f.)	660
Single Cell Storage (cu.ft.)	**990**

The estimated volume for a single cell is multiplied by the number of existing cul-de-sacs to acquire a cumulative Cul-de-sac Storage Volume. This Storage volume in Equation 11 is given by:

Equation 11

$$\mathit{Storage\ Volume\ (cu.ft.)} = \#\ \mathit{Cul-de-sac\ Cells} \times \mathit{Single\ Cell\ Storage\ (cu.ft.)}$$

The Cul-de-sac Storage estimated per neighborhood subdivision is added to the subdivision storage values of the proposed Bio-swales (Section 4.2.1 Bio-swale Storage).

4.4.3 Curb Extension Storage

Curb Extensions are proposed in the Millstone Subdivision of the Sinking Creek Neighborhood and more extensively proposed in the Second Creek Neighborhood. The dimensions of the Curb Extension cells are therefore based upon characteristics found in the Second

Creek Neighborhood such as the average lot width, the average driveway width, and the proposed on-street parking. Curb Extension Storage (Table 7) shows the values used to estimate the total storage of a single Curb Extension cell (Single Cell Storage).

A 30-foot cell length was determined to be shared by two lots (or one-half cell per lot). This estimate was based upon an average lot width of 50 feet, an average driveway width of 15 feet, and 20 feet designated for on-street parking per lot. The cell width at 8.5 feet was determined by the width of the proposed on-street parking (Russ 2002). This configuration is only used to help estimate the sizing

Table 7. Curb Extension Storage

Curb Extension Storage:	
cell length (ft.)	30
cell width (ft.)	8.5
water depth (ft.)	0.5
Engineered Soil Mix Depth (ft.)	2.5
Porosity	0.4
Surface storage (cu. ft.)	128
Sub-surface Storage (cu. ft.)	255
Single Cell Storage (cu. ft)	**383**

of the Curb Extension cells and does not reflect the exact characteristics of each lot. For example, some lots may not have driveways due to the access provided behind the house via alleyways

or backyard parking areas. Figure 39 shows the Curb Extension Cell Geometry.

The water depth is assumed to be 6 inches (0.5 ft.) with the Engineered Soil Mix Depth at 2.5 feet (Dickinson 2008). The estimated Surface Storage is 128 cubic feet given by Equation 12:

Equation 12

$$Suface\ Storage\ (cu.ft.) = 0.5\ ft. \times 30\ ft. \times\ 8.5\ ft.$$

Assuming 100% soil saturation after infiltration and the Porosity of the soil mix is 0.40, the estimated Sub-surface Storage is 255 cubic feet given by Equation 13:

Equation 13

$$Sub - surface\ Storage\ (cu.ft.) = 2.5\ ft.\ \times 30\ ft.\ \times 8.5\ ft.$$

By adding the Surface Storage and Sub-surface storage volumes, the total estimated storage volume for a given Curb Extension cell is 383 cubic feet (Table 7, Single Cell Storage). The cells are proposed every 100 feet, or every two lots, for the given street length (L) values shown in Attachments. The number of cells (# Cells) per Total Street Length is given by Equation 14:

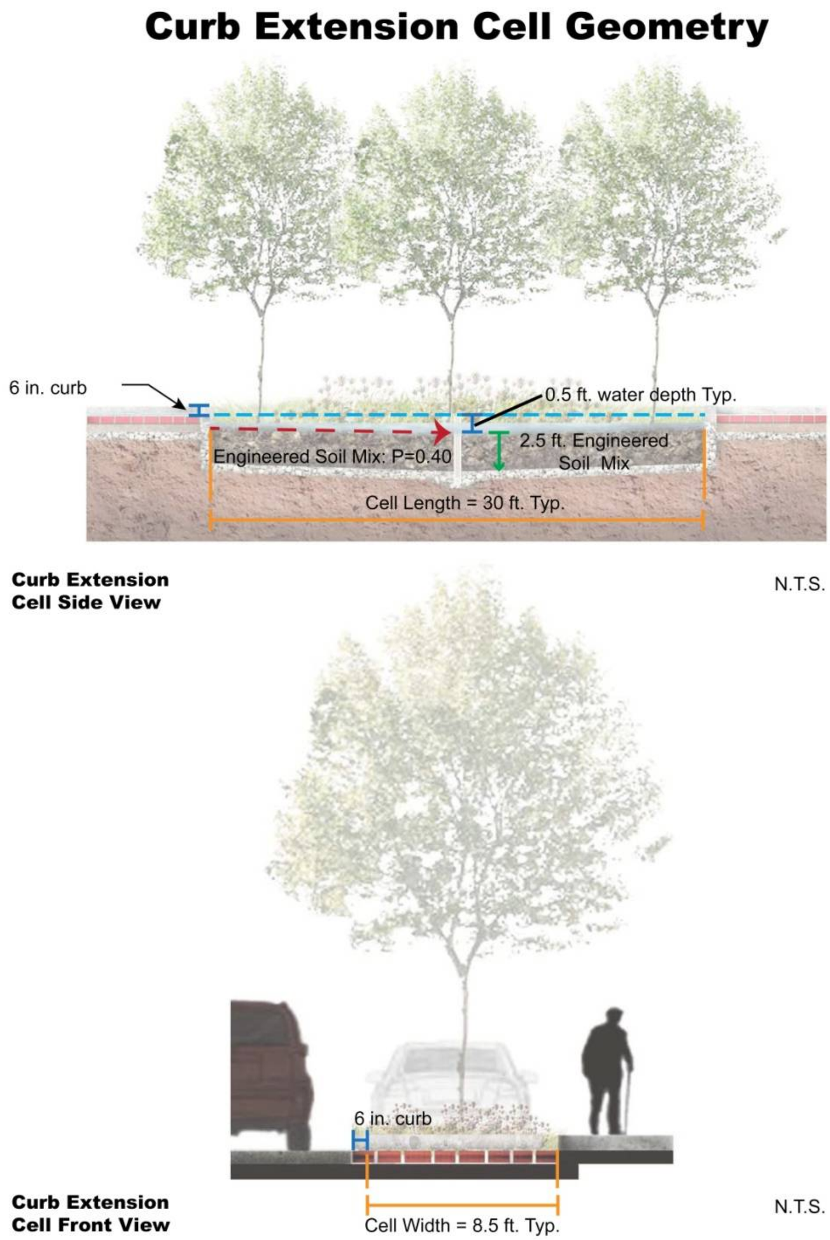


Figure 39. Curb Extension Cell Geometry

Equation 14

$$\# \, Cells = \frac{(Total \, Street \, Length \, (ft.) - (22 \, ft. \times \# \, Intersections))}{100 \, ft.}$$

Therefore, the cumulative Storage Volume of the Curb Extensions cells for the given street or subdivision is calculated by Equation 15:

Equation 15

$$Storage \, Volume \, (cu.ft.) = Single \, Cell \, Storage \, (cu.ft.) \times \#Cells$$

This Storage Volume for the Curb Extension cells is added to the storage volumes of the other BMP's for the given street or subdivision. These cumulative values may be found in Attachments.

4.4.4 Tree Box Storage

Tree Boxes are exclusively proposed along Radford Place in the Second Creek Neighborhood. This was limited by the restricted space within the right-of-way as well as the demand for roadway widths to accommodate for industrial truck traffic. The neighborhood inventory in Chapter 3, Table 1 showed that sidewalks and street trees are appropriate in along Radford Place however on-street parking is not. These factors helped determine the sizing and spacing of the proposed Tree Boxes. The spacing of the proposed Tree Boxes was determined

by maximizing the number of Tree Boxes that could be spaced at 20 feet on center. This spacing was determined by an estimated canopy width of large street trees able to tolerate both urban and wet conditions. Large street trees have a better capacity to accommodate stormwater volumes than smaller street trees due to the increase in root uptake of available soil water and their greater capacity to intercept and evopotranspire precipitation (Dickinson 2008). Examples of large trees that are tolerant in both wet and urban conditions such as the Willow Oak (*Quercus phellos*) are recommended by the City of Knoxville. The full list of recommended species tolerant of specific site conditions is given in the Appendix A5.

The number of Tree Boxes (# Tree Boxes) proposed every 20 feet along Radford Place is given by Equation 16:

Equation 16

$$\#\,Tree\ Boxes = \frac{Total\ Street\ Length\ (ft.)}{Tree\ Spacing} = \frac{1669\ ft.}{20 ft.} = 83$$

The dimensions of a single Tree Box are based upon a 3ft. X 3ft. concrete box with 4 feet of Engineered Soil Mix (0.40 Porosity) to increase the soil storage capacity. The bottom of the box is open to maximize infiltration and to allow for tree roots to become well-established (Figure 40) (U.S.E.P.A.). A surface water depth of 6 inches

(0.5 ft.) is assumed inside the 3 ft. X 3 ft. Tree Box. In Equation 17 the storage volume for a Single Tree Box is 19 cubic feet given by:

Equation 17

$$\mathit{Single\ Tree\ Box\ Storage}\ (cu.ft.) = (3ft. \times 3ft. \times 0.5ft.) + (3ft. \times 3ft. \times 4ft \times 0.40)$$

By multiplying the Single Tree Box Storage with the number of Tree Boxes, the total storage provided by Tree Boxes along Radford Place is 1557 cubic feet (See Table 8, Storage Volume).

No other BMP's were proposed along Radford Place however the Tree Box Storage is added to the Total Design Storage estimated for the Second Creek neighborhood.

Table 8. Tree Box Storage

# Tree Boxes	83
Single Tree Box Storage (cu.ft.)	19
Storage Volume (cu. ft)	**1577**

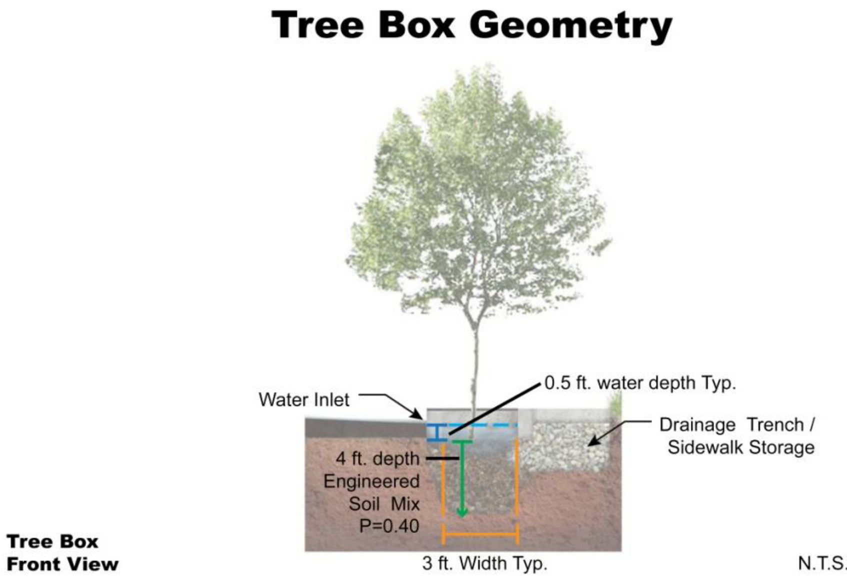


Figure 40. Tree Box Geometry

4.4.5 Total Design Storage

The Total Design Storage estimated for the Sinking Creek and Second Creek Neighborhoods is a cumulative value of the storage provided by the proposed BMP's per street or subdivision. The resulting values are shown in Table 9 below. The complete tables for Slope and Storage Calculations (located in Attachments) show the types of BMP's distributed throughout the neighborhood to meet the Demand Volume. The Demand Volume is given in Section 4 as determined by the Hydro CAD model for the 1.29 inch rain event. The results in Table 9 project that the Demand Storage may be exceeded by the Total Design Storage in both neighborhoods. The implications of these results will be further discussed in the Results and Conclusions portion of this thesis.

Table 9. Total Design Storage

Sinking Creek Total Design Storage		**Second Creek Total Design Storage**
Total Design Storage* (cu. ft.)	**231,761**	**232,634**
(acre-ft)	**5.3**	**5.3**
Demand Volume (acre-ft)	**4.3**	**4.1**
Excess Storage (acre-ft)	**1.0**	**1.2**

*This value does not consider volume retained by permeable parking or sidewalk storage

4.5 Design Summary

The extent of the design proposal in the Sinking Creek and Second Creek neighborhoods was based upon stormwater and neighborhood goals that were identified in the Chapter 3 inventories. The goals were to meet storage demands of runoff volumes produced by the 95th percentile rain event while improving the walkability within the neighborhoods. The two neighborhood master plans aimed to address these goals using integrated Best Management Practices (BMP's). Each neighborhood master plan consisted of typical street sections of BMP configurations with the public right-of-way. The BMP's such as Bio-swales, Cul-de-sac Bioretention cells, Curb Extensions, and Tree Boxes were used to estimate the cumulative storage volumes. These cumulative storage volumes make up the Total Design Storage provided by each master plan. Both Sinking Creek and Second Creek master plans were able to provide 5.3 acre-feet of Total Design Storage which exceeded the projected Demand Volumes determined from the modeled rain event. The implications of these results will be discussed in Chapter 5.

5. Results and Discussion

The results are determined by the ability of the proposed master plans to provide integrated storage that meets the projected runoff volumes produced by the 95th percentile rain event. The implications the design proposal will be discussed based upon the compared environmental, social, and economic values assessed for each neighborhood.

The main objective of this thesis was to convey the importance assessing priorities in stormwater management, based upon a holistic value system (environment, society, and economy). This thesis demonstrates that stormwater goals can be met while also addressing other important community needs and that the implications of such design proposals may vary when comparing one community to the next. By understanding the environmental, social, and economic implications of integrated Best Management Practices (BMP's), stakeholders may begin to prioritize where resources might be best allocated in order to rehabilitate impaired water bodies, while addressing the needs of the communities within the watershed.

Priorities must first be identified in an objective manner before determining which communities benefit from redevelopment projects (Kibel 2007) such as this one. Priorities might be established by

determining the highest collective value of the investment. The highest collective value of the investment may be determined by projecting the collective environmental, social, and economic values resulting from the proposed redevelopment project.

This thesis discusses the potential environmental, social and economic values of Sinking Creek (a suburban) and Second (urban) design proposals however, exploring the potential environmental, social, and economic values in depth goes beyond the scope of this thesis. Some of these factors are noted that in the following sections as areas with potential for further study.

5.1 Projected Environmental Value

The projected environmental values of the proposed designs are primarily assessed as the extent to which the design meets the volumetric demands of the 1.29 inch rain event. If the design did not fully meet the demand, but rather only reduced the runoff volume based upon storage capacity of the proposed BMP's, the design with the most capacity would be selected as the one with greater environmental value.

From the modeled hydrograph of impervious surfaces in the Sinking Creek neighborhood, the projected volume of runoff produced by the 1.29 inch rain event was 4.3 acre-feet. The volume of storage

provided by the design proposals in each neighborhood is 5.3 acre-feet (Table 9). The hydrograph modeled for the Second Creek Neighborhood projected runoff volumes produced by the 1.29 inch rain event to be 4.1 acre-feet. After estimating the proposed design volumes, the urban design also projected to exceed the volumetric requirements by providing 5.3 acre-feet of runoff storage. Because this value exceeds the volumetric goals, a high environmental value is projected.

With their unique BMP distributions, both suburban Sinking Creek and urban Second Creek master plan proposals roughly meet estimated storage volume targets for their respective neighborhoods. Thus, both are considered to be equally environmentally valuable in managing stormwater runoff volumes for the 1.29 inch rain event at the neighborhood scale. If both designs were proposed and modeled at the watershed scale, the environmental values may vary.

A second environmental value factor to consider is the feasibility of water quality improvement in receiving waters if the design proposals were implemented at a watershed scale rather than the neighborhood scale. Given the severity of impairments in Second Creek, implementation of BMP's may not be a viable investment for improving the overall watershed health in the short term. Conversely,

the water quality status of Sinking Creek is relatively better than that of Second Creek and therefore may be a more viable investment for improving the overall watershed health in both the short term and long term. This conclusion has been verified based upon water quality reports produced by the Tennessee Department of Environment and Conservation (Conservation 2012) and the city of Knoxville has declare Sinking Creek as a "critical watershed" which requires the retention of stormwater runoff from development (Division 2013).

5.2 Projected Social Value

The projected social values of the proposed master plans in both neighborhoods were primarily based upon improving walkability by providing access to nearby goods and services and improving pedestrian comfort and safety (Institute 2012).

The newly proposed sidewalks in the Sinking Creek neighborhood were estimated to provide a 200% increase in connectivity between subdivisions and nearby destinations such as West Valley Middle School and further provides links for pedestrians to the access public and commercial amenities on Ebenezer Road (Figure 29). This increase was determined by comparing the existing lineal footage of sidewalk to the newly proposed lineal footage of sidewalks. Restoring the tree canopy in the Sinking Creek Neighborhood was also

projected to help increase walkability by providing shade and a buffer between pedestrians and traffic (Institute 2012; Center 2013).

In the Second Creek Neighborhood, the design proposal shows similar results. The sidewalk connectivity in this area resulted in an estimated increased over 200% when compared to the existing conditions (Figure 30). Providing sidewalks throughout the neighborhood has increased pedestrian connectivity to Central Avenue's commercial corridor, the Lincoln Park Technology Trade Center, local churches, and public transportation hubs. Street trees, on-street parking and curb extensions proposed in the Second Creek neighborhood are all factors that contribute to improved walkability (Institute 2012).

Because walkability is a value measured by a combination of factors such as accessibility, sidewalk connectivity and conditions, aesthetics, safety and comfort, it was not able to be fully quantified in this study nor is it able to be compared between the two neighborhoods. However, a walkability checklist created by University of North Carolina Highway Safety Research Center has provided a method for pedestrians to score walkability based upon existing neighborhood conditions (Center 2013). This may be a tool which could be used for a pre-design and post-design proposal survey that

measures the projected success of increased walkability from the perspective of the community member. In a similar case, a Walkability Workbook was published by the Walkable and Livable Communities Institute which contains a guide to facilitate community workshops, a tool box to explain concepts that can improve walkability, and walking audit survey which helps to document the issues affecting walkability (Institute 2012).

Other projected social benefits of the neighborhood design proposals may be an increase in neighborhood aesthetics, an increase in opportunities for improving health and wellness, and increased social interactions between community members (Water Environment Federation 2012). While aesthetic improvement was perceived to be a stronger social benefit in the Second Creek Neighborhood, social connectivity seemed to be lacking more within the Sinking Creek Neighborhood. Overall, the social values of the proposed designs are perceived to be equally important based upon the described observations.

A more conclusive evaluation of social value may be based upon the projected increase in quality of living. Elise Bright, author of *Reviving America's Forgotten Neighborhoods*, provides a table of factors that are considered Quality of Life Determinants (Bright 2000).

These factors include categories under safety, services, shelter, and social capital. Bright's conclusions are comprehensive about the level of success for a revitalization project and rejected a quantitative approach (Bright 2000). Some of these factors may be relatable to projects which propose to implement Best Management Practices for stormwater management while redeveloping existing communities. For example, some the factors Bright lists are "degrees of exposure to environmental toxins" which could be related to pollutant loads in stormwater, "quality of landscaping" and "conditions of streets and sidewalks" which could be addressed using Best Management Practices.

While the proposed designs address the perceived needs of these communities (assuming the new infrastructure is accepted as an amenity), understanding the social value of these proposed designs would encompass further engagement with community members through surveys, home owner associations, and neighborhood activist groups to understand their true needs and desires. For this study to say that a design proposed in one neighborhood would have greater social benefits than if it were proposed in the other may be an assumption based upon social norms, rather than an accurate

assessment of the needs and desires of those communities that may be met.

5.3 Projected Economic Value

Economic value can be defined as the maximum willingness to give up a good or service to have another good or service (Donald G. Newman 2004). The projected economic values of the proposed designs have been based upon a general assumption of cost-effectiveness. A thorough cost-benefit analysis that is beyond the scope of this thesis should be conducted to better understand which design proposal would hold more economic value than the other to implement and evaluated from a stand point of both the residents and investors.

The designs were proposed within the public right-of-way to avoid some of the direct costs associated with acquiring additional lands to meet stormwater goals. This was also done in order to minimize opportunity costs for the existing communities. Within this context it is assumed that the design proposal for Sinking Creek may be more cost-effective to implement based upon the existing infrastructure. Fewer infrastructures may exist in Sinking Creek in comparison to the existing infrastructure of Second Creek, which may result in fewer direct costs for design implementation. From the stand

point of the investor, opportunity costs should not be evaluated based upon the economic status of community members because it has been found that both the Sinking Creek and Second Creek communities consider stormwater management to be a priority (Chapter 3). In both cases, Sinking Creek and Second Creek may benefit from factors such as increased housing values and more opportunities to reduce costs related to transportation, health, and energy savings (Water Environment Federation 2012).

Street trees are one factor of integrated BMP's which affect cost savings according to a recent study published by the American Society of Landscape Architects. They report that a California study measured the annual energy cost saving by $15.00 per tree (Water Environment Federation 2012). The same published document discusses a case study of Seattle Public Utilities that indicates a design incorporating green infrastructure (BMP's) to replace portions of aging public streets was $217,253 less than conventional street construction costs, resulting in a cost savings equivalent to $329 per square foot (Water Environment Federation 2012). While it has been proven in several studies that green infrastructure has a lower long term cost savings (Water Environment Federation 2012), more case studies should be collected that compares cost estimates of redevelopment using

integrated BMP's since "cost estimates vary dependent on the type of technology deployed" (Water Environment Federation 2012).

While these assessments are comprehensive, they are meant to provoke discussion about how to approach Best Management Practices for redevelopment and prioritizing stormwater management to improve impaired water bodies in Knox County.

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Appendix

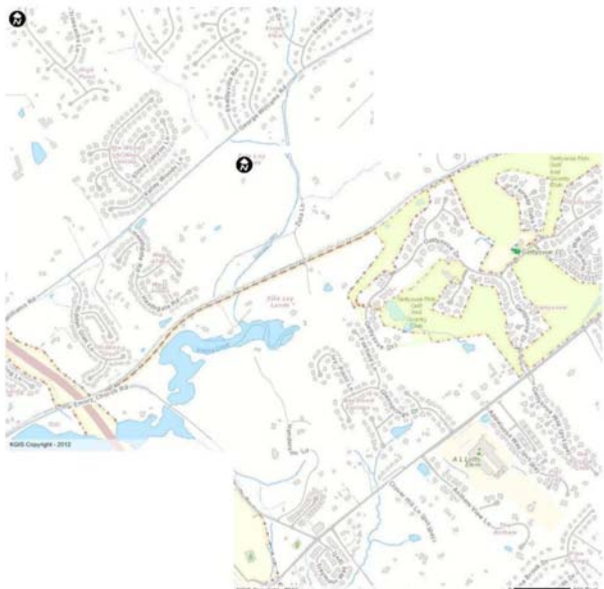
A1. Neighborhood Observation Study

A1.1 Sinking Creek Neighborhood Narrative

On a cloudy weekday morning in October, everyone had already gone to work and everything was quiet (Figure A1). I was headed southbound on Continental Drive descending from the Cedar Bluff ridgeline. Continental was lined with a newly developed community of townhomes and apartment complexes. Sidewalks and large detention ponds were adjacent to the roadway. I pulled off the side into one of the parking lots to get a better look at the existing stormwater devices when I was approached by the property manager. After explaining my business there, she shared with me that the properties on both sides of George Williams were all under the same ownership. This explained the cohesive styles of the newly developed area.

The Statesview Neighborhood entrance was located off of Continental Drive between the two detention ponds of the apartment developments. What I would call typical suburban 70’s style homes, were spread out where the mature trees had been carved away to make room. This was a more pleasant neighborhood feel than the drive down the cleared out properties lining Continental Drive. The houses were set back about 30’ from the road with grass lawns

Neighborhood Observation Study Reference Maps



Sinking Creek Neighborhoods Map

Figure A 1.Sinking Creek Neighborhood Observation Study Reference Map

stretching out to the curb but were not lined with sidewalks. Most of the backyards seemed to be forested. The roads curved around in loops with a pastoral-like style, up and down very steep slopes. Every so often a large cul-de-sac was revealed off of a side road. Observing the existing stormwater features, I noticed there were only storm drains at the lowest points on each road or at the back of a cul-de-sac. These drains were directly connected to a natural drainage ways that accumulated at Sinking Creek or were conveyed to the roadside swale along George Williams Road. The same was evident at the back edge of the majority of the cul-de-sacs. No means of stormwater detention or storage was present in the neighborhood unlike the newer, adjacent developments.

Driving westbound down George Williams Road, the wooded area made it feel like I was far out in the country somewhere and every so many miles a driveway would reveal itself but the house would remain hidden. Heading Southbound on Zola lane Sinking Creek follows the right side on the lane branching off from the roadside swale of George Williams. An older man was walking his dog down the narrow lane and he stopped as I slowly pulled around him. It seemed only the people who live down the lane were seen driving there. Soon the trees and a

gentle bend in the road revealed an open pasture with horses grazing behind the split rail fence that held the perimeter. At this point the creek bent westward away from the main road and into the pastureland. Still no homes were in sight. Eventually I arrived at the railroad crossing and on the other side of the tracks a sign was posted; “Private Property. Keep Out”. I hardly had enough road to turn around on but as I made a three point turn, while construction workers stared at me. It looked as though they were grading the site for a new house or driveway. I had seen from a real estate posting that the land was zoned for residential and future subdivision development. Although little was able to be explored in this part of the sub-watershed, the neighborhood character revealed very little social interactions and conveyed that the rural nature of its residents valued the privacy of their homes and find equity in pastureland as an amenity.

Continuing down George Williams I came across three newer looking neighborhood subdivisions: The Woods at West Valley, West Arden, and Hidden Glen built between the years 2000 and 2007. Each one had a brick façade-like entry with the neighborhood names anchored to them. It was the gateway to mark the exclusive community. The median income for these neighborhoods ranges from $86,000 to $97,000 per year (Inc. 2011). The houses were large all

with matching architecture styles of brick with white trim and charcoal shingles. The average house is roughly 3,500 square feet on .3 acres (approximations from measure tool in KGIS (KGIS 2012)). They densely stacked up the deforested, steep slopes at 20 feet apart. The front yards had an average length of 30' from the sidewalk with variations of the same plants such as boxwood hedges, miscanthus grass, and azaleas. According to zoning maps, these subdivision developments range in gross density of 1-4 Developed Units per acre (KGIS Zoning (KGIS 2012)) which is higher than some of their older, neighboring subdivisions. That is because they fall under a Planned Residential Zone, which helps justify my brief qualitative observations. According to local zoning ordinances, these residential areas "are to be characterized by a unified building and site development program, open space for recreation and provision for commercial, religious, educational, and cultural facilities which are integrated with the total project by unified architectural and open space treatment" (General Description (Knoxville October 2012)) After a brief assessment, the general zoning code descriptions for these subdivisions, provides opportunities where stormwater BMP's may be implemented or improved upon.

On the South side of Sinking Creek, I was able to access other contributing neighborhoods to stormwater runoff from Westland Rd such as the Woodland Springs and Gettysvue subdivisions. Woodland Springs Subdivision has an average of 3500 square foot, building footprint and has 1-4 Dwelling units per acre gross density (KGIS 2012), an equal density to those planned residential neighborhoods previously observed. This neighborhood was developed in 1992 as a planned residential neighborhood preceding the Woods at West Valley, West Arden, and Hidden Glen subdivisions (KGIS, Google Earth Historic Imagery (KGIS 2012)). A detention pond has been located on its southern slope however; stormwater seems to be conveyed into the natural drainage paths leading to Sinking creek without first collecting in a detention pond on the northern slope. The planned neighborhoods on the North side of Sinking Creek have implemented detention ponds at neighborhood catchment areas on both the north and south sides of the subdivision before the stormwater is conveyed into swales or natural drainage ways. The Woodland Springs neighborhood also varied in character because it remained forested following the perimeter of the lots as opposed to the newer, northern neighborhoods that deforested the entire extents of the property.

The Gettysvue planned residential subdivision is oriented around the Gettysvue Polo, Golf and Country Club. These houses were much larger, averaging a 5000 square foot building footprint, than the homes I had seen in the previous neighborhoods. Each house had multiple levels and grand entrances giving them a castle-like appearance. The houses were located on half-acre lots (average lot size) with an average 30 foot setback from the street. The gross density in this subdivision was 1-3 Developed Units per acre (KGIS 2012). The street width measured 25 feet across, giving a cozy feeling to the neighborhood however sidewalks were not present a the street interface. People walked in the street to visit their neighbors, exercise, and walk their dogs. It seemed that the sense of community here was strong however, seemed to lack accessible neighborhood open space apart from the Gettysvue Country Club. Stormwater management in the Gettysvue neighborhood was handled in conjunction with the golf course, which used drainage swales to convey stormwater into irrigation ponds. The outflows for these ponds are then conveyed to forested, natural drainage ways on the back sides of the lots that terminate at Sinking Creek.

In each case of the planned residential subdivisions that were observed, stormwater management practices were conventional with

storm sewers and centralized detention ponds, and most of these planned subdivisions had very little tree canopy preserved. Each neighborhood also revealed a lack of accessible recreational open spaces, apart from the amenities provided by the Gettysvue's Country Club. West Arden and The Woods at West Valley subdivisions seemed to provide indoor amenities for community members however, Hidden Glen and Woodland Springs subdivisions did not. All the subdivisions were disconnected from one another at the vehicular and pedestrian levels yet were developed in close proximity. Interviews with residents or distributed surveys are methods that may be employed for further study, to indicate the community's desire to remain isolated or not from their neighboring subdivisions at the pedestrian level.

My desire would be to provide a shared amenity oriented around Sinking Creek, which may allow community members to connect on a recreational level through a wetland, stormwater park. The interwoven agricultural lands of the Sinking Creek sub-watershed study area provide the opportunity to implement best management practices, such as a shoreline wetland, for the management and treatment of stormwater runoff from the contributing residential and agricultural land uses. This may provide an inter-neighborhood

recreation area for those residents in near-by subdivisions while strengthening a sense of community.

A1.2 Second Creek Neighborhood Narrative

The communities within Second Creek's sub-watershed study area have a median income range from $15,000 to $40,000 per year (Inc. 2011). These income levels are much lower than the income levels of the neighborhoods studied in the Sinking Creek sub-watershed area however with a broader range of income levels (Figure A2). This may be an indication of higher social diversity upon observing the selected neighborhoods near Second Creek. The neighborhoods surveyed include parts of the Lonsdale and Beaumont Neighborhoods West of Second Creek and parts of the Woodland and Lincoln Park neighborhoods to the East of Second Creek.

From the Heiskell Avenue exit driving eastbound, I could see a train bridge tunnel ahead that concealed the Lincoln Park neighborhood from my sight. I emerged from the train tunnel to discover a bustling community. Approaching the intersection of Heiskell Avenue and North Central Street, I entered a commercial district. The auto shop was busy with customers, people walked around with grocery bags in hand and others sat on their front porches enjoying the sunny morning.

From North Central Street I followed the base of Sharp's Ridge down Chickamauga Avenue. This part of the neighborhood had

Neighborhood Observation Study Reference Maps

Second Creek Neighborhoods Map

Figure A 2.Second Creek Neighborhood Observation Study Reference Map

a median household income level of roughly $26,000 (Inc. 2011). I wove through the gridded streets and they were easy to read and maneuver. Many of the houses in this neighborhood were wooden with soft colors of blue yellow and gray and were run down. There were no sidewalks amongst the grid between Chickamauga and Atlantic Avenues and there was no curb or gutter to define where the street met the front yards. The stormwater inlets were typical, concrete catchment basins with drains overgrown by grass and clogged with sediment. It was evident that stormwater sheet flowed down streets running from north to sound and terminated on the streets running parallel to the Sharp's Ridge such as Atlantic Avenue and Radford Pike because of the large sediment deposits along grass edges. This part of the Lincoln Park/Oakwood Neighborhoods is isolated by Sharp's Ridge on the north side and a sliver of an industrial-zoned corridor that the railroad runs through on the neighborhood's southern edge. In order to access the rest of the Oakwood neighborhood, I had to drive down Pershing Street and cross the railroad tracks.

Heading Southeast on Harvey Street, the roads and houses seemed to be in better condition. The median income of this part of the Oakwood Neighborhood is $30,000 which is slightly higher than the other part of the neighborhood (Inc. 2011). Mature trees

dominated the front yards like old monuments. On one of the streets two boys were playing basketball; it was a school holiday so many kids were at home. The nearest park for recreation in this neighborhood is Christenberry Ballpark, two blocks from Harvey Street down Oglewood Avenue. The majority of the Oakwood and Lincoln Park Neighborhoods are within a 1/4mile radius of the park. The street widths are 30' across with on-street parking. Sidewalks with grass borders line each block, and on the backside of each lot is a 10' alleyway running perpendicular between North Central Street and Harvey Street making this neighborhood highly walkable with few constraints between residents and amenities. This residential zone is categorized at R-2/I-H1, a general residential zone with an industrial historic overlay (Knoxville October 2012) with a gross density of 2 Deveoped Units per acre. At the intersection of Harvey St and Oglewood Ave are several stormwater inlets due to the flow coming down from the East Oak Hill Avenue along the ridgeline that mirrors Sharps Ridge. Climbing the steep hill from Oglewood Ave, the houses become less dense under zoning code R-1A/I-H1 which is low density residential with industrial historic overlay (Knoxville October 2012). Back alleys continue to step up the hill between residential lots, running parallel to the ridgeline. Some retaining walls are utilized for slope stabilization. At the top of

the ridge down East Churchwell Avenue is the old Oakwood Elementary School. According to a Knox News article by Lance Coleman, Oakwood Elementary School was built in three phases in 1914, the 1950s and the 1960s. It closed 15 years ago (Coleman 2012).

Continuing southwest down the hill, Churwell Avenue meets North Central Street. North Central Street runs through the commercial district between the two ridgelines and parallel to the industrial zone bordering Second Creek. The commercial district borders the southwest side of the Oakwood neighborhood and may be seen as a buffer between the residents and the industries. This may be an appropriate place for low impact development interventions for stormwater runoff. A catchment area that may be considered for these interventions is between the blocks of East Quincy and East Caldwell Avenues. This may be a good location for bio-swales which can filter the water, then be conveyed to a wetland retention pond located between Second Creek and the SYSCO plant. This would be one of multiple stormwater wetlands that would filter stormwater runoff before entering the creek system. The second site has been selected for a potential stormwater park located at Metroplex Court. This area would collect stormwater runoff from the waste facilities on the

northeast side of North Central Street. The railroad straddles this open lot of land before entering Coster Yards. Both legs of the railroad's right of way may also potentially serve as a stormwater interceptor and filter the water through a bioswale as it is conveyed to the Metroplex Stormwater Park. Further investigations should be made about using railroad rights-of-way for stormwater management purposes. On the ridge opposite of Sharps Ridge, the back alley's stepping upward towards East Oak Hill Avenue may also be utilized as stormwater interceptors when considering the program design solutions for the Oakwood neighborhood.

A2. Socio-demographics Comparison Study

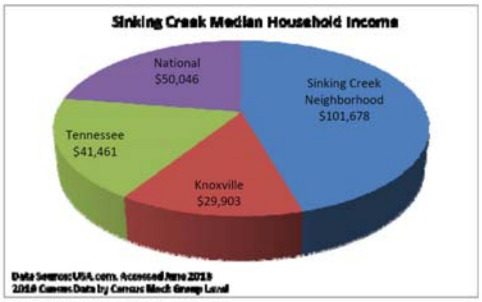
A2.1 Median Household Income by Census Block Group

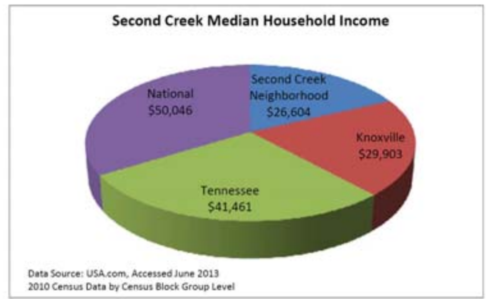
Much of the demographic data presented is a reflection of the Median Household Income trends that were selected for polarization of the neighborhood comparisons (Figure A3). The Median Household Income for the Second Creek Neighborhood is $26,604 which is comparable to Knoxville's Median Household Income level of $29,903. A significant percentage of this population lives below the poverty level at 24.2%. In contrast, average Median Household Income for the Sinking Creek Neighborhood is at a much higher level of $101,678. The average percentage of this population below the poverty level is a mere 0.7%. While these numbers consistently reflect the income levels that were polarized through the site selection process, they have slight discrepancies that may not fully reflect the characteristics within both neighborhood boundaries.

The data representing the Second Creek neighborhood is consistent with a low income community; however, it may be slightly skewed from the true values due to adjacent communities that are included within the same Census Block Group. For example, the Block Group that includes Second Creek's neighborhood study area also includes a public housing community just north of Sharp's ridge. This

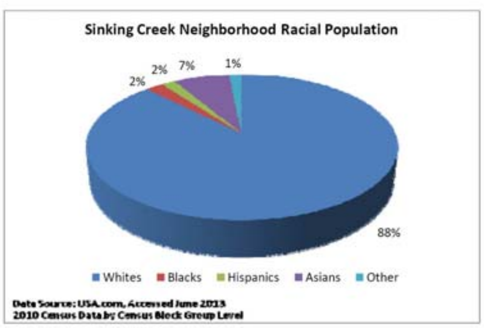
Neighborhood Socio-economic Demographics Study

Median Household Income By Block Group





Racial Compositions



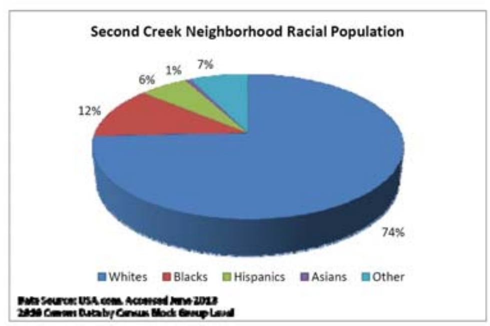


Figure A 3.Neighborhood Socio-economic Demographics Comparison Charts

may reflect a higher percentage in the neighborhood's poverty level and a lower median household income level than is actually present in the study area. Similarly the data representing the median household income levels for Sinking Creek's neighborhood may be slightly higher than what is accurate within the study area. This is due to the site selection being represented by two separate census block groups. The two block group values for median household income were averaged for simplifying the comparison between neighborhoods.

A2.2 Racial Compositions

The majority of the Sinking Creek and Second Creek neighborhoods are composed of similar racial populations (Figure A3). The white populations are dominant in both communities relative to the other ethnicities shown in each chart. When comparing both communities' demographics, Sinking Creek has a higher percentage of White and Asian populations while Second Creek has a higher percentage of White and Black populations.

A2.3 Common Occupations

The common types of employment for each neighborhood are important for understanding class status. The Sinking Creek

Neighborhood shows a high percentage of professional, business, financial and management related occupations. These jobs typically require higher levels of education. The Second Creek Neighborhood shows very low to zero percentages in these types of occupations. Sales, Office, and Service related positions are the most common occupations found here. While some of these positions may require a higher form of education, they typically only need a high school diploma or previously acquired work experience.

A2.4 Housing

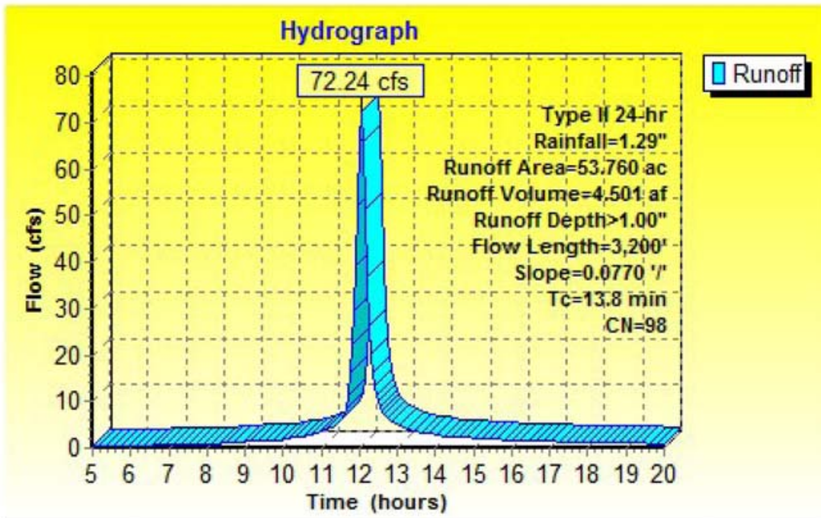
This section compares neighborhood housing data such as: Median House Value, Median Year of House Built, and Owner Occupied Units.

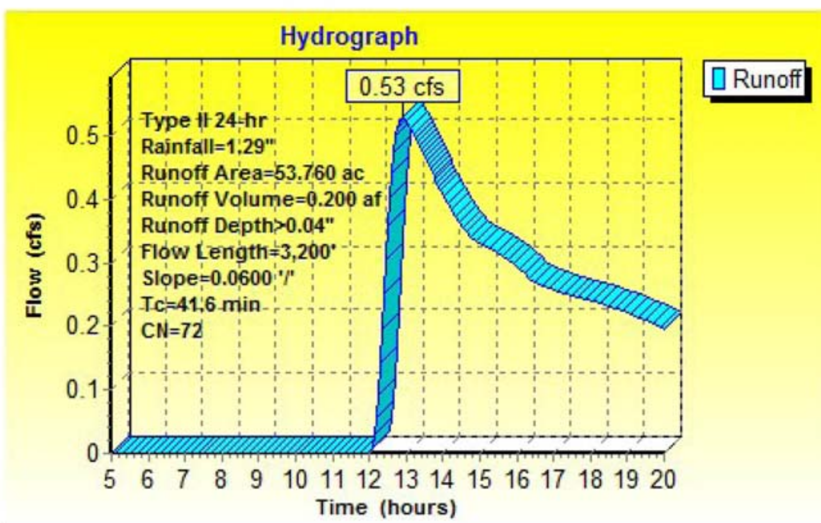
The Median Housing Values for the Sinking Creek Neighborhood average to be $300,877 which is a stark comparison to Second Creeks Median Housing Value of $79,016. The majority of houses currently existing in this historic neighborhood were built before 1939. Unlike Second Creek's historic neighborhood, the subdivisions within Sinking Creek vary by year of development. The majority of the houses built in the Statesview Subdivision were established in 1975 on average. The remaining subdivisions such as Hidden Glen, The Woods and West Valley, and West Arden were all developed between the years 2000

and 2007. The median year of houses developed in Knoxville is 1973, closely resembling those in the Statesview Subdivision. Additionally, the percentages of owner occupied units versus renter occupied units are similar when comparing these two neighborhoods. The majority of both consist of owner occupied units, although Sinking Creek's percentages, at 96%, are much higher than Second Creek's 54%.

A3. HydroCAD: Hydrographs and Summaries

A3.1 Sinking Creek Hydrographs





Caption 1: The Sinking Creek Hydrographs show the peak flows that are generated by developed (top) and antecedent conditions (bottom) from the Hydro CAD model (Chapter 4.2 Projected Runoff Volumes)

A3.2 Sinking Creek Hydrograph Summaries

Sinking Creek Hydrograph Summary

Summary for Subcatchment 1S: Sinking Creek Total Developed

Runoff = 72.24 cfs @ 12.05 hrs, Volume= 4.501 af, Depth> 1.00"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Type II 24-hr Rainfall=1.29"

Area (ac)	CN	Description
23.250	98	Roofs, HSG C
18.540	98	Paved roads w/curbs & sewers, HSG C
0.350	98	Paved parking, HSG C
1.020	98	Paved parking, HSG C
10.600	98	Paved parking, HSG C
53.760	98	Weighted Average
53.760		100.00% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
13.8	3,200	0.0770	3.88		**Lag/CN Method, Statesview**

Summary for Subcatchment 2S: Sinking Creek Antecedent 53.76 acres

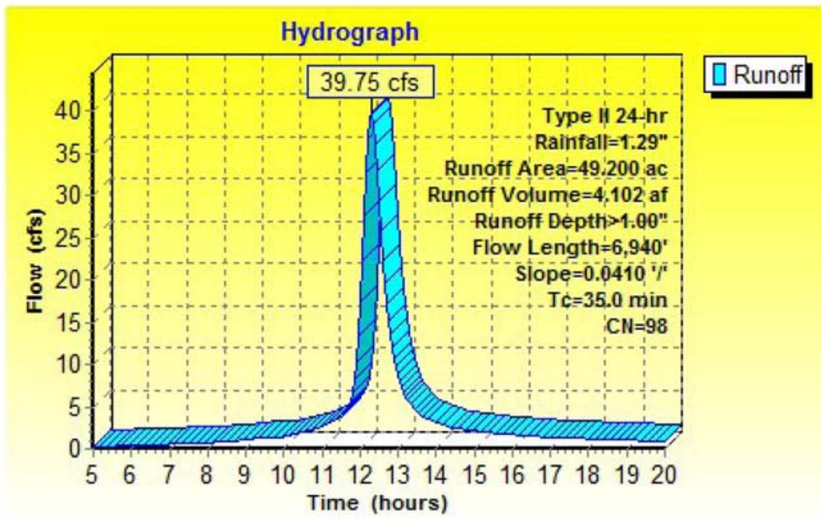
Runoff = 0.53 cfs @ 12.90 hrs, Volume= 0.200 af, Depth> 0.04"

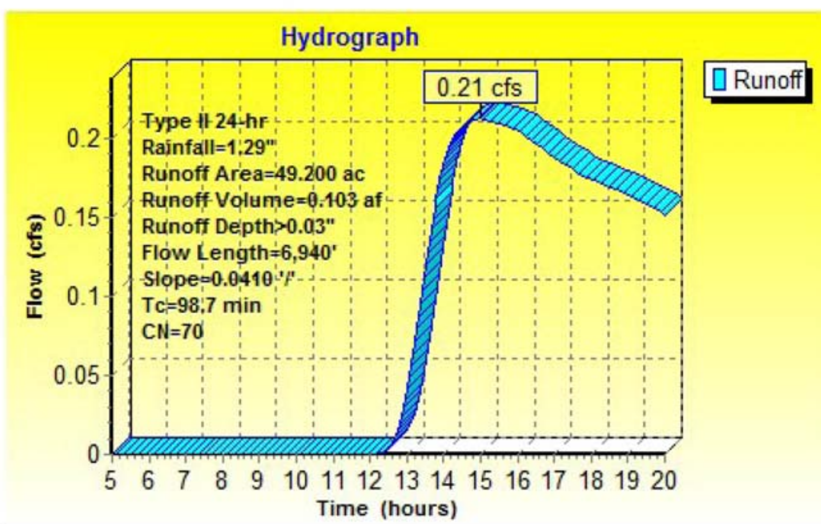
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Type II 24-hr Rainfall=1.29"

Area (ac)	CN	Description
53.760	72	Woods/grass comb., Good, HSG C
53.760		100.00% Pervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
41.6	3,200	0.0600	1.28		**Lag/CN Method, Wooded Area Statesview**

A3.3 Second Creek Hydrographs





Caption 2 The Second Creek Hydrographs show the peak flows that are generated by developed (top) and antecedent conditions (bottom) from the Hydro CAD model (Chapter 4.2 Projected Runoff Volumes)

A3.4 Second Creek Hydrograph Summaries

Second Creek Hydrograph Summary

Summary for Subcatchment 1S: Impervious Areas

Runoff = 39.75 cfs @ 12.29 hrs, Volume= 4.102 af, Depth> 1.00"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Type II 24-hr Rainfall=1.29"

Area (ac)	CN	Description
21.830	98	Paved roads w/curbs & sewers, HSG C
21.450	98	Unconnected roofs, HSG C
5.920	98	Paved parking, HSG C
49.200	98	Weighted Average
49.200		100.00% Impervious Area
21.450		43.60% Unconnected

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
35.0	6,940	0.0410	3.30		**Lag/CN Method, Second Creek Total Area**

Summary for Subcatchment 2S: Second Creek Antecedent 49.2 acres

Runoff = 0.21 cfs @ 14.99 hrs, Volume= 0.103 af, Depth> 0.03"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 5.00-20.00 hrs, dt= 0.05 hrs
Type II 24-hr Rainfall=1.29"

Area (ac)	CN	Description
49.200	70	Woods, Good, HSG C
49.200		100.00% Pervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
98.7	6,940	0.0410	1.17		**Lag/CN Method, Second Creek Total Area**

A4. Land Cover Areas and Density Calculations

A4.1 Sinking Creek Land Cover Areas and Density Calculations

Sinking Creek Street Measurements				
Total Study Area Acres	205.5			
Neighborhood Subdivisions	Street Widths Feet	R.O.W Feet	Street Lengths Feet	Cul-de-sac Diameter
Millstone	26	50	820	80
States View	26	50	8775	80
The Woods at West Valley	26	50	5185	80
West Arden	26	50	3150	80
Hidden Glen	26	50	2500	75
*George Williams Rd 1530 total LF	21-26	50-72	7262	0
Totals			**27692**	**0.58**
Source	KGIS	CAD	KGIS	KGIS

Sinking Creek Area Calculations						
Streets Acres	Rooftops Acres	Average Acreage Driveways	Parking Lot Acres	Sidewalk Area Acres	Total Impervious Acres	Total Pervious Acres
0.71	1.34	0.50	0.00	0.00	2.54	6.16
5.93	7.43	5.1	0.00	0.00	18.45	70.55
3.90	8.00	3.8	0.13	0.39	16.18	30.12
2.46	3.47	0.84	0.21	0.21	7.19	19.81
1.84	3.01	0.41	0.00	0.27	5.54	18.96
3.70	0.00	0.00	0.00	0.14	3.84	6.16
18.54	**23.25**	**10.6**	**0.35**	**1.02**	**53.76**	**151.75**
		Driveways and Parking Lot Areas	**10.9**			

Sinking Creek Neighborhood Density Calculations						
Knox County Zoning Types	**Total # DU**	**Gross Area Acres**	**Gross Density**	**Net Area Acres**	**Net Density**	**Percent Impervious**
PR	54	8.7	6.2	8.7	6.2	29.2%
RA	148	89	1.7	79	1.9	20.7%
PR	117	46.3	2.5	x	1 - 4	34.9%
PR	60	27	2.2	x	1 - 3	26.6%
PR	67	24.5	2.7	x	1 - 4	22.6%
NA	NA	10	NA	x	NA	38.4%
NA	**446**	**205.5**	**2.2**	**NA**	**NA**	**NA**
KGIS	KGIS	CAD	CAD	KGIS	KGIS	Sources

EPA Definitions for Density

Gross Density=Tot # Res Units/Tot. Developed Land Area
Net Density=Total # Res. Units/ Res. Land Area (does not include R.O.W)

Knox County Code of Ordinances Definitions

RA	Low Density Residential
PR	Planned Residential
NA	Not Applicable

All values were obtained by exporting GIS data sets into AutoCAD and using Measure tool from KGIS Maps Interactive.

All lengths, widths, areas and measures were extracted using these two tools.

All building footprints were individually traced using map underlays in AutoCAD.
For this reason these values are to be considered as estimates. Methods for obtaining values were equally applied to both sites.

*Driveways and roofs of George
Williams are included in States View Values

A4.2 Second Creek Land Cover Areas and Density Calculations

Second Creek Street Measurements				
Total Study Area Acres	**203.91**	Source: KGIS/CAD		
Streets & Alleys	**Street Widths Feet**	**R.O.W Feet**	**Total Street Lengths Feet**	**R.O.W Area Square Feet**
Hiawassee Ave.	21	30-50	**5300**	212000
Alley	12	12	1900	22800
Chickamauga Ave.	23	35-60	**5000**	225000
Alley	12	12	4480	53760
Cedar Ave.	24	40	3660	146400
Alley	12	12	3660	43920
Atlantic Ave.	24	40	3625	145000
Alley	12	12	1830	21960
Radford Pl.	24	50	1680	84000
Watauga Ave.	21	50	3418	170900
Alley	12	12	3557	42684
Bruhin Rd. (begins at Heiskell) & Central	25	60-155	1730	0
Fox St.	15	30	225	6750
Ferguson St.	20	50	200	10000
Coram St.	18	30-50	2210	88400
Metler St.	20	50-55	1025	53300
McMurray st.	20	50	1853	92650
Grove St.	25	50	1025	51250
Felts St.	12	50	165	8250
Hanover St.	25	50	1650	82500
Gladstone St.	20	50	700	35000
Pershing St.	30	50	730	36500
Totals			**47893**	**37.49**
			Total Lineal Feet	**Total Acreage**

Second Creek Area Calculations

Streets/ Alleys	Acres Streets	Acres Rooftops	Acres Driveways/ Parking Lots	Acres Sidewalks	Total Impervious	Total Pervious
Hiawassee Ave.	2.56					
Alley	0.52					
Chickamauga Ave.	2.64					
Alley	1.23		These values were determined as a total based upon area calculations grouped and added together using Auto CAD			
Cedar Ave.	2.02					
Alley	1.01					
Atlantic Ave.	2.00					
Alley	0.50					
Radford Pl.	0.93					
Watauga Ave.	1.65					
Alley	0.98					
Bruhin Rd. (begins at Heiskell) & Central	0.99					
Fox St.	0.08					
Ferguson St.	0.09					
Coram St.	0.91					
Metler St.	0.47					
McMurray st.	0.85					
Grove St.	0.59					
Felts St.	0.05					
Hanover St.	0.95					
Gladstone St.	0.32					
Pershing St.	0.50					
Totals	**21.83**	**21.45**	**5.92**	**Negligible**	**49.2**	**154.7**
				Percentage	**24.13**	**75.87**

	Second Creek Neighborhood Density Calculations					
Streets/ Alleys	**Zoning**	**Tot # DU**	**acres Gross Area**	**Net Area Acres**	**Gross Density**	**Net Density**
Hiawasee Ave.	**R-1A/IH-1**					
Alley	|					
Chickamauga Ave.	|					
Alley	|					
Cedar Ave.	|					
Alley	|					
Atlantic Ave.	|					
Alley	|					
Radford Pl.	|					
Watauga Ave.	|					
Alley	V					
Bruhin Rd. (begins at Heiskell) & Central	|					
Fox St.	|					
Ferguson St.	|					
Coram St.	|					
Metler St.	|					
McMurray st.	|					
Grove St.	|					
Felts St.	|					
Hanover St.	|					
Gladstone St.	|					
Pershing St.	V					
Totals:	**R-1A/IH-1**	**774**	**203.91**	**166.42**	**3.80**	**4.65**
Sources:	KGIS	CAD	CAD	CAD	CAD	CAD

EPA Definitions for Density

Gross Density=Tot # Res Units/Tot. Developed Land Area
Net Density=Total # Res. Units/ Res. Land Area (does not include R.O.W)

Knox County Code of Ordinances Definitions

R-1A/IH1 Low Density Residential with Industrial Historic Overlays
PR Planned Residential
NA Not Applicable

Notes:

All values were obtained by exporting GIS data sets into AutoCAD and using Measure tool from KGIS Maps Interactive.

All lengths, widths, areas and measures were extracted using these two tools.

All building footprints were individually traced using AutoCAD.
For this reason these values are to be considered as estimates. Methods for obtaining values were equally applied to both sites.

A5. Street Trees

Small Tree Notes

A. Plant small trees 10 to 20 feet away from utility lines
B. Plant small trees 10 feet away from buildings
C. Plant small trees 10 to 20 feet away from other small trees
D. Recommended root space is approximately 40 square feet of lawn
E. Most small growth trees are suitable for planting near overhead utility lines; but may still need to be pruned if they grow into utility safety zones

SMALL TREE GROUP: Mature Height Less than 30'

	Form	Growth Rate	Aestetic Flowers	Fall Color	Recommended Street Tree	Urban Areas***	Wet Tolerant	Drought Tolerant	Shade Tolerant
Amur Maple (*Acer ginnala*)	Variable	Slow	Yes	Yellow	Minimal Use	No	No	No	Intermediate
Paperbark Maple (*Acer griseum*)#	Upright to Oval	Slow	No	Red	Minimal Use	Yes	No	No	Intermediate
Japanese Maple (*Acer palmatum*)#	Variable	Slow to Medium	No	Red	No	No	No	No	Yes
Red Buckeye* (*Aesculus pavia*)	Round	Medium	Yes	Indistinct	Minimal Use	No	No	No	Yes
Serviceberry* (*Amelanchier* spp.)#	Variable	Medium	Yes	Various	Minimal Use	No	Intermediate	No	Intermediate
Pawpaw* (*Asimina triloba*) !	Pyramidal to Upright	Medium	No	Yellow	No	No	No	No	Yes
Eastern Redbud* (*Cercis canadensis*)# !	Round to Spreading	Medium	Yes	Yellow	Yes	Yes	No	Yes	Intermediate
Chinese Fringetree (*Chionanthus retusus*)#	Round to Spreading	Slow	Yes	Yellow	Minimal Use	No	No	No	Intermediate
American Fringetree* (*Chionanthus virginicus*)#	Round to Spreading	Slow	Yes	Yellow	Minimal Use	No	No	No	Intermediate
Pagoda Dogwood (*Cornus alternifolia*)	Spreading	Slow to Medium	Yes	Purple	Minimal Use	No	No	No	Yes
Flowering Dogwood* (*Cornus florida*)# !	Spreading	Medium	Yes	Purple	Minimal Use	No	No	No	Yes
Kousa Dogwood (*Cornus kousa*)#	Vaseshape to Round	Slow	Yes	Red	Minimal Use	Yes	No	Yes	Yes
European Smoketree (*Cotinus coggygria*)	Upright to Spreading	Medium	Yes	Various	Minimal Use	No	No	No	No
American Smoketree* (*Cotinus obovatus*)#	Upright to Oval	Medium	Yes	Various	Minimal Use	No	No	No	No
Cockspur Hawthorn (*Crataegus crusgalli*)	Round to Spreading	Slow to Medium	Yes	Bronze	Yes	Yes	No	No	No
Carolina Silverbell* (*Halesia tetraptera*) !	Round	Medium	Yes	Yellow	Minimal Use	No	No	No	Intermediate
Witch-hazel* (*Hamamelis virginiana*)	Round to Open	Medium	Yes	Yellow	No	No	No	No	Intermediate
Foster Holly (*Ilex* x *attenuate* 'Fosteri')	Pyramidal to Upright	Slow	No	Evergreen	No	No	No	No	Intermediate
Crapemyrtle (*Lagerstroemia indica*)# !	Vaseshape	Fast	Yes	Various	Yes	Yes	No	Yes	No
Amur Maackia (*Maackia amurensis*)#	Round to Spreading	Slow	Yes	Indistinct	Yes	Yes	No	Yes	No
'Little Gem' Magnolia (*Magnolia grandiflora*)#	Upright to Oval	Slow	Yes	Evergreen	Yes	No	Intermediate	No	Intermediate
Flowering Crabapple (*Malus* spp.) !	Round	Medium to Fast	Yes	Yellow	Yes	No	No	No	No
Persian Ironwood (*Parrotia persica*)#	Upright to Oval	Medium	Yes	Yellow	Yes	Yes	No	Yes	Intermediate
Oriental Cherries (*Prunus serrulata*)#	Variable	Medium	Yes	Various	Yes	Yes	No	Yes	No
Mountain Stewartia (*Stewartia ovata*)	Round to Oval	Slow	Yes	Orange	No	No	No	No	Intermediate
Rusty Blackhaw* (*Viburnum rufidulum*)	Oval to Open	Medium	Yes	Burgundy	No	No	Intermediate	Yes	Yes

* Native to Tennessee
***These trees are recommended for downtown planting spaces and wells
Recommended for narrow planting areas (single stem only)

! Some cultivars may grow over 30 feet in height

Medium Tree Notes

A. Plant medium trees 20 to 50 feet away from utility lines
B. Plant medium trees 20 to 30 feet away from buildings
C. Plant medium trees 20 to 30 feet away from other medium trees
D. Recommended root space is approximately 166 square feet of lawn

MEDIUM TREE GROUP: Mature Height 30' - 50'

	Form	Growth Rate	Aestetic Flowers	Fall Color	Recommended Street Tree	Urban Areas***	Wet Tolerant	Drought Tolerant	Shade Tolerant
Hedge Maple (*Acer campestre*)	Round to Oval	Slow	No	Yellow	Yes	Yes	No	Yes	Intermediate
Trident Maple (*Acer buergerianum*)	Round to Oval**	Slow to Medium	No	Orange	Yes	Yes	No	Yes	No
River Birch* (*Betula nigra*)	Pyramidal to Round**	Medium to Fast	No	Yellow	Minimal Use	No	Yes	No	No
European Hornbeam (*Carpinus betulus*)	Upright to Oval	Slow to Medium	No	Yellow	Yes	Yes	No	No	Intermediate
American Hornbeam* (*Carpinus caroliniana*)	Oval	Slow	No	Various	Yes	No	Intermediate	No	Intermediate
Catalpa* (*Catalpa speciosa*)	Oval	Medium to Fast	Yes	Indistinct	Minimal Use	No	No	Yes	Intermediate
Atlas Cedar (*Cedrus atlantica*)	Pyramidal**	Slow	No	Evergreen	No	No	No	No	Intermediate
Deodar Cedar (*Cedrus deodara*)	Pyramidal	Medium	No	Evergreen	No	No	No	No	No
Atlantic White Cedar (*Chamaecyparis thyoides*)	Pyramidal to Upright	Medium	No	Evergreen	No	No	Intermediate	No	No
Yellowwood* (*Cladrastis kentukea*)	Round**	Medium	Yes	Yellow	Yes	Yes	No	No	No
Turkish Fibert (*Corylus colurna*)	Pyramidal	Medium	No	Indistinct	Yes	Yes	No	yes	No
Cryptomeria (*Cryptomeria japonica*)	Pyramidal**	Medium	No	Evergreen	No	No	No	No	Intermediate
American Persimmon* (*Diospyros virginiana*)	Oval	Slow to Medium	No	Yellow	Minimal Use	No	No	No	No
Hardy Rubber Tree (*Eucommia ulmoides*)	Round	Medium	No	Indistinct	Yes	Yes	No	Yes	Intermediate
American Holly* (*Ilex opaca*)	Pyramidal**	Slow to Medium	No	Evergreen	Minimal Use	No	No	No	Yes
Eastern Red Cedar* (*Juniperus virginiana*)	Upright to Oval	Medium	No	Evergreen	No	No	No	Yes	No
Golden Raintree (*Koelreuteria paniculata*)	Round	Medium to Fast	Yes	Yellow	Yes	Yes	No	Yes	No
Sweetbay Magnolia* (*Magnolia virginiana*)	Upright to Open	Medium	Yes	Yellow	No	No	Yes	No	Yes
Eastern Hophornbean* (*Ostrya virginiana*)	Pyramidal to Round**	Slow	No	Yellow	Yes	Yes	Intermediate	No	Yes
Sourwood* (*Oxydendrum arboreum*)	Pyramidal to Oval	Slow	Yes	Various	Minimal Use	No	No	No	Intermediate
Austrian Pine (*Pinus nigra*)	Pyramidal	Medium	No	Evergreen	No	No	No	Yes	No
Japanese Red Pine (*Pinus densiflora*)	Upright to Open	Slow to Medium	No	Evergreen	No	No	No	No	No
Chinese Pistache (*Pistacia chinensis*)	Round	Medium	No	Orange	Yes	Yes	No	Yes	No
Overcup Oak* (*Quercus lyrata*)	Round to Spreading	Medium	No	Yellow	Yes	Yes	Intermediate	Yes	No
Black Locust* (*Robinia pseudoacacia*)	Upright to Oval	Fast	Yes	Indistinct	No	No	No	Yes	No
Weeping Willow (*Salix babylonica*)	Round to Weeping	Fast	No	Indistinct	No	No	Yes	Yes	No
Sassafras* (*Sassafras albidum*)	Oval to Open	Medium to Fast	Yes	Various	No	No	No	No	No
Japanese Pagoda (*Sophora japonica*)	Upright to Spreading	Medium to Fast	Yes	Indistinct	Yes	Yes	No	Yes	No
Little-leaf Linden (*Tilia cordata*)	Pyramid to Oval	Medium	No	Yellow	No	No	No	Yes	No
Silver Linden (*Tilia tomentosa*)	Pyramid to Oval	Medium	No	Yellow	Yes	Yes	No	Yes	No
Smooth Leaf Elm (*Ulmus carpinifolia*)	Upright to Spreading	Medium	No	Yellow	Yes	Yes	No	No	No
Lace-bark Elm (*Ulmus parvifolia*)	Vaseshape to Spreading**	Medium to Fast	No	Yellow	Yes	Yes	No	Yes	No
Zelkova (*Zelkova serrata*)	Vaseshape**	Medium	No	Various	Yes	Yes	No	Yes	No

* Native to Tennessee
** Some cultivars are recommended to plant next to buildings
***These trees are recommended for downtown planting spaces and wells

Large Tree Notes

A. Plant large trees 50 feet away from utility lines
B. Plant large trees 30 to 40 feet away from buildings
C. Plant large trees 30 to 40 feet away from other large trees
D. Recommended root space is approximately 250 square feet of lawn

LARGE TREE GROUP: Mature Height More than 50' tall and more

	Form	Growth Rate	Aestetic Flowers	Fall Color	Recommended Street Tree	Urban Areas***	Wet Tolerant	Drought Tolerant	Shade Tolerant
Red Maple* (*Acer rubrum*)	Rounded to Oval**	Medium	Yes	Red	Minimal Use	No	Yes	No	Intermediate
Sugar Maple* (*Acer saccharum*)	Rounded**	Medium to Slow	No	Yellow	Minimal Use	No	No	No	Yes
Yellow Buckeye* (*Aesculus flava*)	Rounded	Medium to Fast	Yes	Orange	Minimal Use	No	Intermediate	No	Yes
Pecan* (*Carya illinoinensis*)	Oval	Medium	No	Yellow	No	No	Intermediate	Yes	No
Common Hackberry* (*Celtis occidentalis*)	Pyramidal to Round	Medium to Fast	No	Yellow	No	No	No	Yes	Intermediate
American Beech* (*Fagus grandifolia*)	Round to Open	Slow	No	Bronze	No	No	No	No	Yes
European Beech (*Fagus sylvatica*)	Upright to Oval**	Slow to Medium	No	Bronze	Minimal Use	No	No	No	Intermediate
Ginkgo (*Ginkgo biloba*) **MALE ONLY**	Pyramidal to Round**	Medium	No	Yellow	Yes	Yes	No	Yes	no
Thornless Honeylocust* (*Gleditsia triacanthos*)	Round	Medium to Fast	No	Yellow	Yes	Yes	No	Yes	No
Kentucky Coffeetree* (*Gymnocladus dioica*)	Oval to Open**	Slow to Medium	No	Yellow	Yes	Yes	No	Yes	No
Sweetgum* (*Liquidambar styraciflua*)	Pyramidal to Oval	Medium to Fast	No	Various	Yes	No	Yes	No	No
Tulip Poplar* (*Liriodendron tulipifera*)	Pyramidal to Oval	Fast	Yes	Yellow	Yes	No	No	No	No
Cucumbertree Magnolia (*Magnolia acuminata*)	Pyramidal to Spreading	Medium to Fast	Yes	Brown	Minimal Use	No	No	No	Intermediate
Southern Magnolia* (*Magnolia grandiflora*)	Pyramidal**	Slow to Medium	Yes	Evergreen	No	No	No	Yes	Intermediate
Dawn Redwood (*Metasequoia glyptostroboides*)	Pyramidal**	Medium to Fast	No	Yellow	Yes	No	No	No	No
Blackgum* (*Nyssa sylvatica*)	Pyramidal	Slow to Medium	No	Various	Yes	No	Yes	No	Intermediate
Shortleaf Pine* (*Pinus echinata*)	Conical to Oval	Medium	No	Evergreen	No	No	No	Yes	No
Pitch Pine* (*Pinus rigida*)	Conical to Oval	Medium	No	Evergreen	No	No	No	Yes	No
White Pine* (*Pinus strobus*)	Conical to Oval**	Medium to Fast	No	Evergreen	No	No	No	No	Intermediate
Loblolly Pine* (*Pinus taeda*)	Conical to Oval	Fast	No	Evergreen	No	No	Intermediate	Yes	No
Virginia Pine* (*Pinus virginiana*)	Conical to Open	Slow	No	Evergreen	No	No	No	Yes	No
London Planetree (*Platanus* X *acerifolia*)	Pyramidal to Open	Medium	No	Yellow	Yes	Yes	No	No	Intermediate
American Sycamore* (*Platanus occidentalis*)	Pyramidal to Open	Medium to Fast	No	Yellow	No	No	Yes	No	Intermediate
Sawtooth Oak (*Quercus acutissima*)	Round	Medium	No	Yellow	Yes	Yes	No	Yes	No
White Oak* (*Quercus alba*)	Round to Spreading	Slow to Medium	No	Red	Minimal Use	No	No	No	No
Swamp White Oak* (*Quercus bicolor*)	Round	Medium	No	Yellow	Yes	No	Yes	Yes	No
Scarlet Oak* (*Quercus coccinea*)	Round	Medium	No	Red	Minimal Use	No	No	No	No
Laurel Oak (*Quercus hemisphaerica*)	Pyramidal to Spreading	Medium	No	Brown	Minimal Use	Yes	No	Yes	No
Southern Red Oak* (*Quercus falcata*)	Spreading	Slow to Medium	No	Red	No	No	No	No	No
Bur Oak* (*Quercus macrocarpa*)	Round to Spreading	Slow	No	Yellow	Minimal Use	No	No	Yes	No
Swamp Chestnut Oak* (*Quercus michauxii*)	Round	Medium	No	Orange	No	No	Yes	No	No
Chinkapin Oak* (*Quercus muehlenbergii*)	Round	Slow to Medium	No	Indistinct	Minimal Use	No	No	No	No
Pin Oak* (*Quercus palustris*)	Pyramidal to Rounded	Medium to Fast	No	Various	No	No	Yes	No	No
Willow Oak* (*Quercus phellos*)	Pyramidal to Rounded**	Medium	No	Yellow	Yes	Yes	Yes	Yes	No
Chestnut Oak* (*Quercus prinus*)	Rounded	Medium	No	Orange	Yes	No	No	Yes	No
English Oak (*Quercus robur*)	Upright to Round**	Slow to Medium	No	Indistinct	Minimal Use	No	No	No	No
Northern Red Oak* (*Quercus rubra*)	Rounded	Medium to Fast	No	Red	Yes	No	No	No	No
Shumard Oak* (*Quercus shumardii*)	Rounded	Medium	No	Red	Minimal Use	Yes	No	Yes	No
Black Oak* (*Quercus velutina*)	Round to Open	Slow to Medium	No	Red	Minimal Use	No	No	Yes	No
Bald Cypress* (*Taxodium distichum*)	Pyramidal**	Medium	No	Orange	Yes	Yes	Yes	No	No
American Basswood* (*Tilia americana*)	Pyramidal to Rounded	Medium	No	Indistinct	Minimal Use	No	No	No	Intermediate
Winged Elm* (*Ulmus alata*)	Vaseshape to Round	Medium	No	Yellow	Minimal Use	No	No	No	No
American Elm* (*Ulmus americana*)	Vaseshape	Medium to Fast	No	Yellow	Yes	Yes	Yes	Yes	Intermediate

* Native to Tennessee
** Some cultivars are recommended to plant next to buildings
***These trees are recommended for downtown planting spaces and wells

Vita

Danielle Norman was born in Napa, California and was raised in the Sierra Nevada Mountains near Lake Tahoe. She holds a Bachelor of Science Degree in Civil Engineering from the University of Nevada, Reno since 2008, and worked as an intern for Washoe County Department of Water Resources for three and half years in engineering and water quality. Danielle relocated to Knoxville, Tennessee in 2010 with her husband Darren and two hound dogs in order to pursue her graduate studies in Landscape Architecture. During her studies at the University of Tennessee, she conducted research for the University's low impact development design manual under the direction of Professor Brad Collett.

With her background in design, engineering and water resources she hopes to pursue a career that will positively impact the quality of living in her local community.