

Improving Urban Watershed Health Through Suburban Infill Design and Development

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ABSTRACT

Up to 75 percent of new construction between 2000 and 2030 may “be redirected inward or into more compact, mixed-use suburban developments (Nelson, 2004). If this assertion is even nearly true, and if the goals of the Clean Water Act are to be met in the next generation of American cities, then we must find feasible and effective ways of improving urban watershed health using retrofit and infill development as a primary means. The aim of this study is to evaluate the patterns and approaches of suburban infill developments in order to determine which methods and extents are deemed capable of improving the health, sustainability and natural services of urban streams and watersheds. Water is considered to be foundational to urban and suburban sustainability and is treated as a primary indicator of overall health and sustainability within the context of this study.

This thesis presents three pilot studies that examine urban watershed health using a single case as a vehicle. The studies, in the order they are presented, are: 1) Form- analyzing the relationship between landuse patterns and imperviousness, 2) Planning- relating questions of development scale planning and design to natural and cultural systems at the watershed scale and 3) Valuation- illustrating three possibilities for determining the economic value of improving urban watershed health.

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1

Introduction

By the Year 2050, the world population is expected to increase by 2.8 billion (United Nations 2004). Eighty six percent of that growth is expected to occur within urban and suburban areas worldwide. This prediction carries with it significant implications for the United States since it is one of few developed countries expecting population growth. Between 2012 and 2025 the population of the United States is expected to increase by 392,000 residents, of which 294,000 are likely to become urban dwellers(Nelson 2004).

In addition to population growth, there is growing evidence to suggest that housing demands are shifting. Nelson (2004) suggests that within the United States up to 75 percent of new construction between 2000 and 2030 may “be redirected inward or into more compact, mixed-use suburban developments.” A survey conducted by the National Association of Realtors (NAR) suggests that 50% to 67% of future housing demand may be for higher density opportunities (NAR 2001). Real estate tracking services are even advising clients to seek out centrally-located, mixed use, and transit oriented opportunities to maximize profit (ULI 2004).

The recent economic downturn makes predicting the extent of development resulting from United States population growth during the coming decades challenging. A number of researchers call into question the magnitude of Nelson’s 2004 projection that by 2030, as many as half of the buildings in which people live, work and play will

have been constructed after 2000. To accommodate the projected 2030 population, the United States would need an additional 127 billion square feet of built space, where 82 billion could be from redevelopment. Nonetheless, there is a growing recognition that the changes of the coming decades offer a thread of hope for improving the sustainability and livability of America's metropolitan areas.

Concerns for the maintenance condition and sustainability of the nation's infrastructure have arisen concurrently with American's desire to move back toward city centers. The majority of the anticipated redevelopments will strive to utilize existing site infrastructure, 50% of which is already at least 30 years old (Nelson 2004). Worn-out water systems leak away 20 gallons of clean water per day for every American and replacing these nearly worn out systems would cost \$11 billion more annually than all levels of government now plan to spend (Fallows 2010). Some types of the infrastructure that cities still operate is no longer considered acceptable; such as combined sewer systems. Around 40 million Americans utilize combined sewer systems and when large storm events cause combined sewers to overflow, these Americans are subject to serious water pollution. In 1994, the U.S. Environmental Protection Agency (EPA) issued a policy to reduce or eliminate pollution problems related to combined sewer overflows. In 2000, Congress amended the Clean Water Act requiring municipalities by law to comply with the EPA policy.

Urban water management has become an important topic in the comprehensive planning of many major cities where some municipalities are looking for alternative approaches for public health and well-being. The City of Portland, Oregon, provides grants, such as the Green Investment Fund Project to companies and individuals who

are making efforts to invest in green infrastructure and green building technologies. One of their completed projects reported a 42 % reduction in utility-provided water and a 100% reduction for irrigation. Some initiatives took planning efforts a step further; aligning environmental initiatives with Nelson's prediction of inward development. Connecticut's initiative for redevelopment titled, "*Together We Can Grow Better Smart Growth*" operates under the assumption that concentrating development within urban centers can preserve environmentally sensitive land. This Initiative also understands the advantages of infill development, such as limited ownership and utilization of existing infrastructure (EPA 2007). However, utilization of existing infrastructure may not be appropriate in all areas. For example, connecting new development into Philadelphia's combined sewer system will only add to the problem. As a cost effective solution to conventional stormwater solutions, Philadelphia decided to use green infrastructure to solve issues related to combined sewer overflow (PWD 2009).

If the United States continues to see population growth and inward urban migration over the next thirty years, then cities of the future must adapt. The growing trend and repopulation of many American city centers is an issue of environmental, social and financially sustainable considerations. One main investigation that arises from this trend is to evaluate how infill development in suburban centers can contribute to the sustainability of subsequent generations of urbanized areas.

The aim of this study is to evaluate the patterns and approaches of suburban infill developments in order to determine which methods and extents are deemed capable of improving the health, sustainability and natural services of urban streams and watersheds. This investigation suggests that if the hydrologic conditions of a site can

improve, then additional natural systems (e.g. urban forestry, wildlife habitat, microclimates, etc.) and human factors (e.g. quality of life, health and finances) could also improve. Therefore, water is a primary indicator of health and sustainability within the context of this study. This thesis presents three pilot studies that examine urban watershed health using a single case as a vehicle. The studies, in the order they are presented, are: 1) Form- analyzing the relationship between landuse patterns and imperviousness, 2) Planning- relating questions of development scale planning and design to natural and cultural systems at the watershed scale and 3) Valuation- illustrating three possibilities for determining the economic value of improving urban watershed health.

2

Literature Review

2.1 Smart Growth Theory and Urban Infill Development

Two or three landscape planning and design theories are likely to influence urban and suburban infill development in the coming decades. Most prominent among these is neo-traditional urbanism. Proponents of this form of development may operate under the banner of New Urbanism or Smart Growth. While the background and emphasis of New Urbanism and Smart Growth may differ, they share many of the same characteristics and aspirations. For instance, both see development density as a key to creating more sustainable human settlements. They both advocate new forms of development that concentrate growth into compact, walkable and centrally-located areas. New Urbanism and Smart Growth emphasize development that is focused on transit orientation, mixed-use building types and high levels of connectivity while maintaining a friendly and sustainable environment. These principles have been thoroughly endorsed by the EPA and relied upon as a foundation for infill development planning studies funded by the agency (EPA 2004).

Proponents of Smart Growth, including the EPA, also claim that these planning principles will help to reduce stormwater related impacts in urbanized watersheds. These claims mainly stem from the observation that higher density development provides more opportunity to protect hydrologically sensitive areas (e.g., steep slopes, porous soils, forests, wetlands and stream buffers). Clustering development in compact

patterns allows for reduced lot size, street lengths and less overall development infrastructure per dwelling unit compared to conventional development codes (Calthorpe, 1993; Duany & Plater-Zyberk, 1991). When calculated per unit, rather than per acre, the amount of impervious surface and the volume of runoff do tend to decrease as density increases (EPA, 2006). Water quality is also likely to improve as density increases. This occurs because, “[t]he reduction in impacted [watershed] area appears to more than offset the higher per acre pollutant loads that are generated from the denser development” (Jacob and Lopez, 2009).

A study in the Charleston Harbor Area of South Carolina compared runoff impacts of a conventional low-density development scenario to a new urban development scenario within the same watershed. In this case, the development site was a 'greenfield'- meaning a previously undeveloped location¹. Findings indicated that for the same amount of development, conventional development consumed eight times more land and generated 43% more runoff, three times as much sediment, and higher loading of nitrogen and phosphorous than the new urbanist design (South Carolina Coastal Conservation League, 1995)².

While practitioners of Smart Growth development are increasingly given more opportunities to craft development codes and building projects that embrace environmental protection, the emphasis is on greenfields, not urban infill sites

¹ As described by Berke P., Greenfield development is piece of previously undeveloped land, in a city or rural area, either currently used for agriculture or landscape design, or just left to nature. Greenfield land can be unfenced open fields or urban lots, or restricted, closed property kept off limits to the general public by a private or governmental entity

² This study only observed the effects of impervious surface and not the impacts related to the position of the development in the watershed, which affects watershed hydrologic functions and can change runoff and pollutant loads. A development's position in a watershed can be less intrusive if planned correctly. For example, if a development is proposed on the outer fringes of a watershed (outside of the 100 year flood plain), it can avoid flooding concerns through smart planning.

(Calthorpe, 1993; Duany & Plater-Zyberk, 1991). The benefits of dense development emerge in situations where urbanization is moving into previously undeveloped watershed areas. In such cases, it may be possible to effectively coordinate watershed planning with developmental controls to produce a given development program with less cost in infrastructure and better preservation of the natural system services across an entire watershed. However, these circumstances do not exist in the already highly urbanized watersheds, where most urban and suburban infill development is likely to occur. A different kind of study is required to determine the potential benefits of smart growth for urban watershed sustainability in these types of circumstances.

According to Berke (2002), most infill projects see significantly less hydrologic improvement compared to greenfield development. Streams in infill areas are also likely to be more seriously degraded and/or piped underground, making improvement difficult for developers and local municipalities (Berke 2002). For example, the Rockville Town Center redevelopment, located in the heart of Rockville, Maryland, reflects the transformation of 12.5 acres of aging strip retail into a vibrant mixed-use setting and community focal point. Environmental concern was minimal based on the amount of impervious surface implemented in pre and post development. This current practice assumes that since urban redevelopment does not further increase negative effects on the environment, then it is deemed acceptable.

In contrast, certain urban infill projects and redevelopments have been successful at integrating low-impact design techniques. The redevelopment of Port Royal in South Carolina utilized an integrated wetland protection and restoration strategy as a way to restore an ecosystem previously forgotten. A key element to the

design involved restoring wetlands from a fragmented to an interconnected system that supports pollution reduction, flood storage, and wildlife habitats (Berke, et.al, 2003).

Where the benefits of watershed health and natural systems system services are concerned, a distinction must be drawn between Smart Growth development occurring in previously undeveloped areas and suburban or urban infill development. For example, current stormwater regulations in Virginia require a balance between pre and post development hydrographs. Any additional runoff generated by a development must be captured on-site. A critical flaw of this strategy is evident with infill development, where environmental degradation is already high. Pre and post development hydrographs can be identical, meeting state compliance, while the degradation due to dense development only continues to occur at its previous rate. This “loop hole” allows developers to increase density and maintain pre-development imperviousness, which can also maintain urban watershed degradation.

In contradiction to Virginia regulations, the EPA has argued that these infill developments may require a nearly 50% reduction in impervious surface to improve urbanized watersheds (ACWSMP 2005). If one assumes that current state standards, like Virginia, are all that is necessary for sustainable watershed management, then federal mandates such as the one suggested by the EPA may seem ridiculous. However, if Americans aspire to a higher standard of sustainable watershed management, then either watershed wide planning for enhanced hydrologic services, or careful consideration of sustainable infill development practices is essential.

2.2 Stormwater Management

If water is understood as a cornerstone for urban sustainability, then the real value for infill redevelopment comes from appropriate stormwater management and hydrologic interventions. With new development rapidly adding to the environmental impacts of urban areas, the need to develop effective stormwater management programs is more urgent than ever. Virginia provides a germane example as a state that is trying to improve its current stormwater management policies. As part of Virginia's 2010 Stormwater Management Draft Handbook, methodology has shifted from dealing with pre to post development hydrology towards replicating the natural hydrology of the watershed (VASWMP 2010). As a regional watershed implication, Virginia's future stormwater compliance system will be held accountable to Chesapeake Bay nutrient reduction goals for urban land. Virginia serves as a good region for further hydrologic inquiry as it pursues a green approach to stormwater management in collaboration with the Center for Watershed Protection and the Chesapeake Stormwater Network. Therefore, Virginia's management strategies should be responsive to the best knowledge on stormwater issues to date.

2.3 Study Area: Fairfax Boulevard

The aging inner ring suburbs of Washington DC, which are located in Virginia are also the types of areas ripe for redevelopment and densification in the coming decades. Fairfax Boulevard is one of the most visible and economically viable streets in the Washington, D.C. region, making it a prime location for suburban infill development. Located in the city of Fairfax, Virginia, the boulevard is home to many retail, office and auto-related businesses. While the boulevard is an active commercial street, it is often

viewed as a declining asset. The boulevard is an aging strip-commercial district that fails to compete with the new development located just outside of the city limits. Due to this decline the city realized the need for a plan to guide redevelopment efforts and to encourage the Boulevards position in the regional economy.

In March 2007 the City and its citizens, along with the town planning firm of Dover, Kohl and Partners, gathered to create a plan for the redevelopment of Fairfax Boulevard. Dover, Kohl and Partners studied previous planning efforts, analyzed the study area and carried out a charrette. The results culminated into what became the proposed master plan of Fairfax Boulevard³ (Figure 1). The plan calls for the development of five pedestrian – oriented mixed use centers along a 3.5 mile street corridor. The entire master plan for Fairfax Boulevard lies within a Business Improvement District (BID)⁴ for attracting private investment while the city works to establish the infrastructure that will be necessary to support plan implementation.

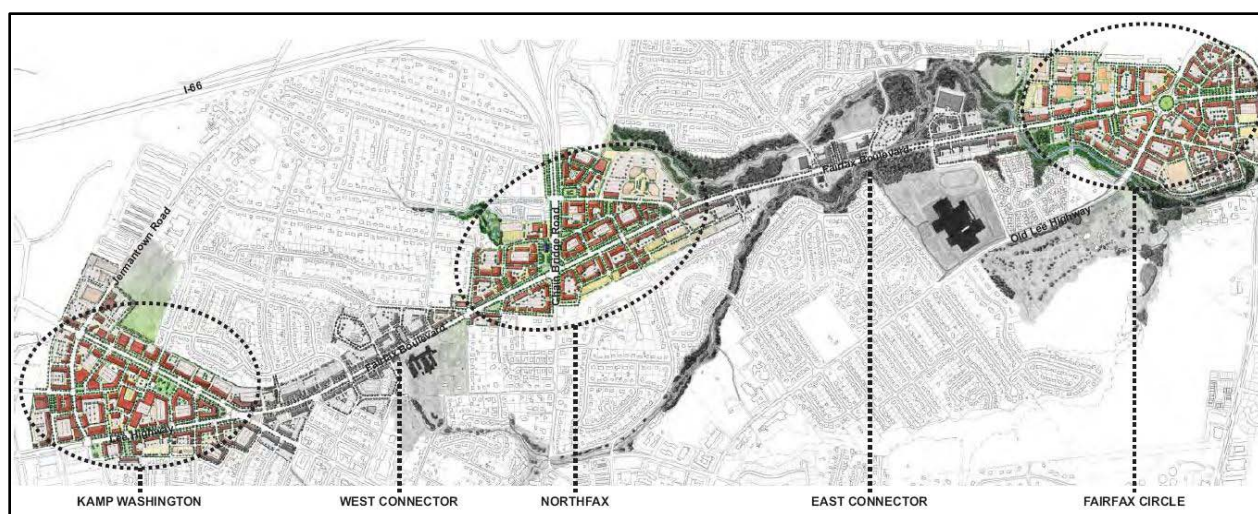


Figure 1: The Fairfax Boulevard. This master plan identifies five key nodes: Kamp Washington, West Connector, Northfax, East Connector and Fairfax Circle (left to right). (source: Dover, Kohl and Partners, 2007)

³ This came through several public meetings where community members were able to give their input for Dover, Kohl, and Associates.

⁴ A Business Improvement District (BID) is a special overlay district within the city of Fairfax deemed for redevelopment. This district provides little or no concern for environmental improvement.

The study area identified by this research includes the entire stretch of Route 50 (known as Fairfax Boulevard) within the city limits. Route 29 and Route 50 become one as they enter Fairfax from the east, splitting back into two streets at the Kamp Washington intersection.

The boulevard corridor lies within the Accotink Creek watershed (Figure 2). The 23 mile long watershed stretches from the City of Fairfax to the Potomac River at Fort Belvoir. The North Fork of Accotink Creek, a non-supporting urban stream, runs the



Figure 2: Accotink Creek. This map indicates the watershed boundary of Accotink Creek (red) with Fairfax County. Notice the position of the City of Fairfax and Fairfax Boulevard within upper reaches of the watershed. (source: Fairfax County Department of Public Works and Environmental Services, 2008)

entire length of the study area and lies almost entirely within the city's jurisdictional limits. According to the Accotink Creek watershed management plan a 49.7% reduction in runoff volume is necessary for the city of Fairfax to comply the TMDL endpoint established by the EPA.

The city is making a concerted effort to stabilize and recover the degraded condition of the stream. However, there is little undeveloped land available within the city and the stream valleys are relatively narrow

and steep. These conditions limit the opportunity for, and the potential effectiveness of, developing a watershed scale green infrastructure system. Consequently, watershed

improvement in the upper Accotink hinges primarily on reduction of impervious surface and development of hydrologic interventions (City of Fairfax Watershed Master Plan, 2005).

2.4 Implications for Hydrologic Analysis

The master plan redevelopment of Fairfax Boulevard as it passes through the City of Fairfax, Virginia provides an interesting perspective for urban redevelopments (Figure 1). The Fairfax Boulevard (BID) is contained entirely in the Upper Accotink Creek Watershed, a heavily urbanized tributary of the Chesapeake Bay. However, apart from proposing that Fairfax Boulevard be constructed as a green street, the master plan does not address urban watershed issues. Due to current policies between predevelopment and post development land use, any redevelopment that reduces impervious surface and provides flood storage will satisfy current environmental regulations of the Fairfax Boulevard BID. However, this does not mean the boulevard is not capable of much greater hydrologic improvement.

It is unknown to what extent proposed patterns of land redevelopment will accommodate better water quality improvement, flood control and channel erosion prevention. While it is accurate to claim that redevelopment of the suburban landscape “can produce a net improvement in regional water quality by decreasing total runoff”, those benefits are unlikely to be realized within an urbanized regional watershed that is 87% developed and experiencing additional growth pressure (EPA, 2006).

2.5 Significance of Hydrologic Services

So what is a city like Fairfax, or a highly developed region like Northern Virginia to do? Is any appreciable level of hydrologic recovery beyond the reach of projects such

as the redevelopment of Fairfax Boulevard? Or, is hydrologic sustainability only for people who live in lesser developed regions of the country where large, continuous areas of open space remain available to offset increases in density?

For urban redevelopment strategies (such as this Fairfax redevelopment) to truly claim sustainable approaches to urban redevelopment, then natural systems (specifically those relevant to urban hydrology) should become an integrated part of the decision-making process. Water is vital to the success of many natural environments and with its improvement; the performance of additional natural systems will undoubtedly also increase.

The sections that follow describe three different strategies for urban infill redevelopment targeted specifically in regards to urban watershed health. Each section describes one strategy as it pertains to urban watershed health in order to build a case for alternative proposals for infill redevelopment. The first section targeting form-based design speculates on how Smart Growth guidelines codified in the SmartCode can aid more hydrologically sensitive forms of design. Section two looks at issues relevant to planning-based initiatives and how integrating urban and natural systems at various scale can improve urban watersheds. The third section looks at green building practices and technologies to see how they may aid in urban watershed health.

2.6 Form-based Design

The EPA directly links smart growth principals to the ability of localities to comply with requirements of the Clean Water Act (EPA, 2004). The Congress for the New Urbanism (CNU) proposes that in order to be sustainable, “design must be rooted in and evolve from adaptations to local climate, light, flora, fauna, materials and human

culture as manifest in indigenous urban, architectural and landscape patterns” (CNU, 2009).

More explicitly:

Wetlands, other bodies of water and their natural watersheds shall be protected wherever possible, and the natural systems which promote recharge of aquifers and prevent flooding should be restored wherever possible, consistent with the urban-to-rural transect. (CNU, 2009)

2.6.1 SmartCode

The principles guiding smart growth are codified in an implementation guidance document known as the SmartCode. The SmartCode is:

“a unified development ordinance, addressing development at all scales of design, from regional planning on down to the building signage. It is based on the rural-to-urban transect rather than separated-use zoning, thereby able to integrate a full range of environmental techniques.”- (SmartCode Version 9.2, 2009)

Higher density mixed use development is addressed in the ‘T4’ and ‘T5’ zones of the rural-to-urban continuum (Figure 3). The ‘T4 General Urban Zone’ is defined as “mixed use but primarily residential urban fabric.” The “T5 Urban Center Zone” is comprised of “higher density mixed use building that accommodates retail, offices, row houses and apartments. It has a tight network of streets, with wide sidewalks, steady street tree

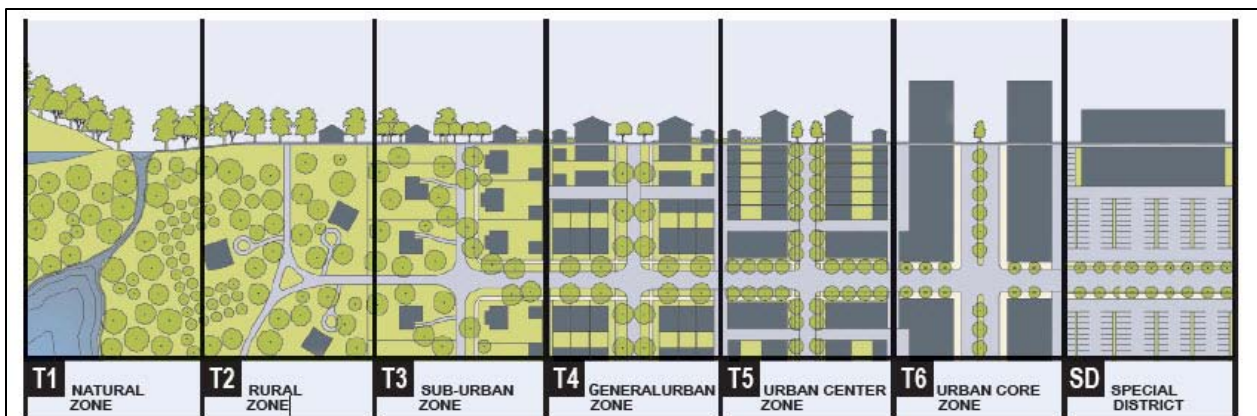


Figure 3: SmartCode Rural to Urban Transect.
(source: SmartCode Version 9.2, 2009)

planting and buildings set close to the sidewalks” (SmartCode Version 9.2, 2009) . This thesis focuses on ‘T5’ development because being more dense than ‘T4’ is likely to pose greater challenges for restoration of urban hydrology on redeveloping sites.

New Urbanism focuses its approach to urbanism on communitarian principles and historical development archetypes. These are expressed through the SmartCode which is geared toward controlling the form of private development. While smart growth proponents often talk about watershed health, the preservation or restoration of hydrologic systems is not codified along with other elements of the physical development pattern. If the ideas embraced by smart growth advocates are to be achieved in urban and suburban infill development areas, then a clear analysis of the guiding principles like the SmartCode and the resulting development patterns in relation to specific watershed conditions are necessary to determine environmental implications.

2.7 Planning-based Initiatives

Unlike form-based smart growth, incremental urbanism (as described in *Retrofitting Suburbia*) recognizes that development may occur through a succession of smaller projects rather than all at once (Dunham-Jones and Williamson 2009). Incremental urbanism realizes that the solution to healthier environments may come in the form of suburban and urban retrofits. While these retrofits provide an opportunity for small hydrologic improvements, they also highlight that a large scale plan must be implemented to guide the direction of watershed health. These retrofits have to power to incrementally redirect growth inward redeveloping underperforming suburban areas. By overlaying a region's network of sprawl, retrofitting can introduce healthier, more integrated networks of development.

2.7.1 LWARPS

The 'LWARPS: we can reverse sprawl' project provides an interesting illustration of incremental urbanism applied to a regional watershed (Figure 4). The LWARPS project is predicated on the notion that, “the larger, denser and more urban the redevelopment” the greater the potential “to change unhealthy suburban patterns and behaviors into more sustainable ones” (Dunham-Jones and Williamson, 2009). Accordingly, this project proposes to establish 1000 foot green buffers along all stream corridors in the Atlanta metropolitan region.. By implementing this strategy, the proposed outcome illustrates that Atlanta’s sprawling metropolitan region can be

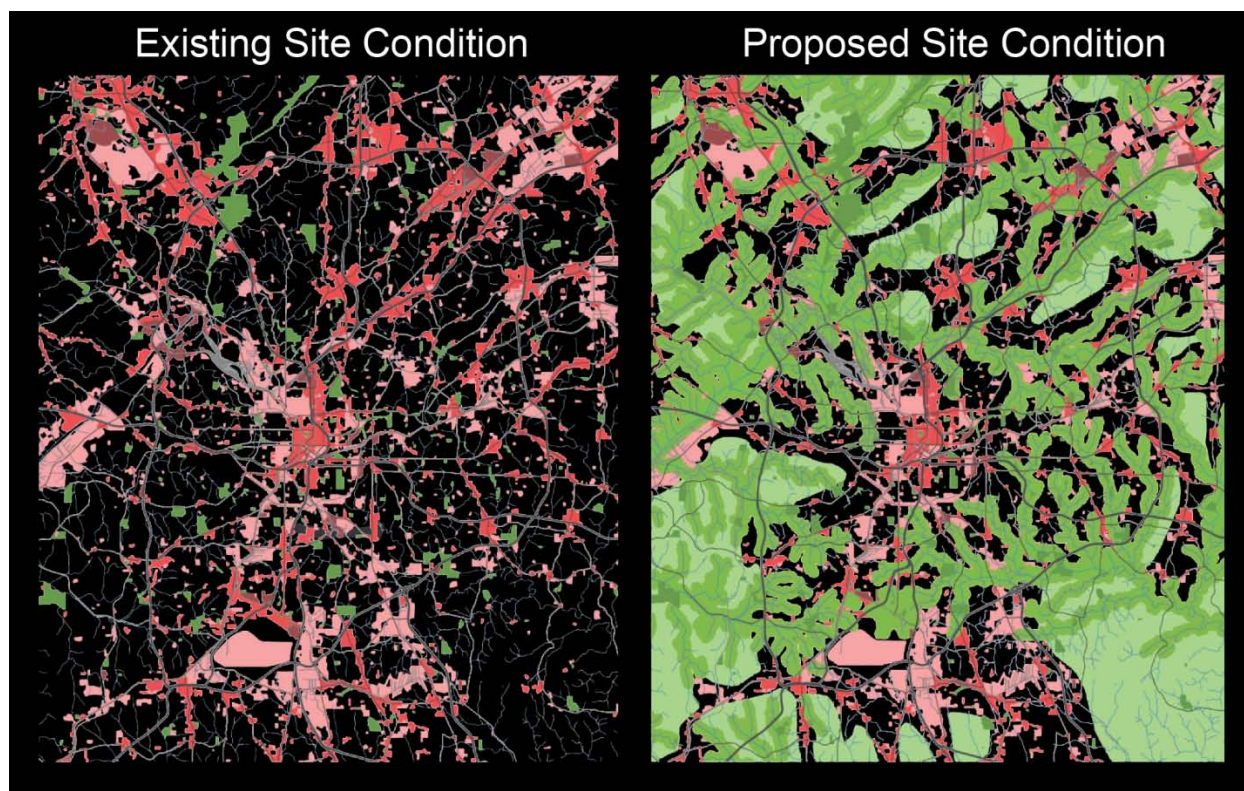


Figure 4: The LWARPS project. This project proposes to replace sprawl in the Atlanta metro region (left) with pockets of high density development contained within a network of 1000 foot wide stream corridor buffer strips (right).
(source: Dunham-Jones & Williamson, 2009)

converted to a landscape hosting multiple dense urban centers. These urban centers, while separated, would be interconnected by an extensive regional green infrastructure system.

Similar to the LWARPS project, Sprawl Retrofit is a recent initiative proposed by the Congress of New Urbanism that aligns with incremental urbanism. Sprawl Retrofit understands that green infrastructure and city systems must connect at site and regional scales, while preserving green space. While incremental urbanism and Sprawl Retrofit begin to highlight the importance of environmental preservation, little is drawn about their influence to the sustainability of urban watershed health. However, both initiatives acknowledge that natural systems are an integral part of sustainable urbanism. The extent of which is much less clear.

2.8 Green Building Practices and Technology

Yet another way to improve urban watershed health comes in the form of green building practices and technologies. One can argue that improving the consistency of hydrologic conditions is the critical role water plays within urban environments (Graham and Smith 2004, Sweeney et al. 2004). In fact, some estimate that just clean drinking water provides direct value to humans exceeding \$27 billion dollars per year. This means that in order to provide appropriate settings for urban environments, one must understand the advantages of green building practices and technologies to maximize a developments potential.

2.8.1 Dockside Green and City of Emeryville

Many examples exist currently that exemplify the integration of water within urban sites. One such example found in Victoria, B.C. challenges conventional water management by adopting a proactive approach for an infill redevelopment (Figure 5). Infill redevelopments are good sites for green building practices and technologies as conventional measures for watershed improvement, however, they may be difficult due

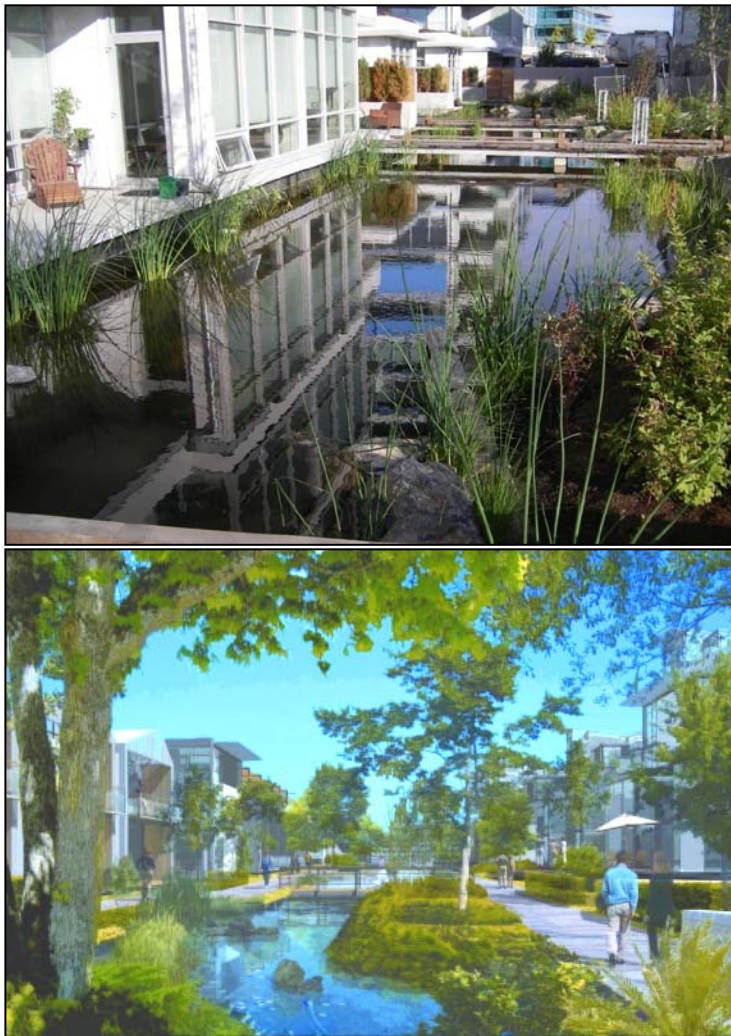


Figure 5: Dockside Green.
(source: used under fairuse guidelines, 2011)

to limited building space.

Dockside Green was designed to mimic the preexisting hydrology of the site. Just as natural elements (trees, shrubs, ponds streams etc.), store rainwater, this development incorporates green infrastructure to capture, store and reuse water onsite. Rainwater is captured and filtered through greenroofs and bioswales before it is stored in cisterns and circulated through a restored stream. Water is initially used for potable purposes and is then reused as many times as

possible throughout the site. Wastewater from the entire development is treated to an

acceptable level for unrestricted public access using a membrane bioreactor⁵. Reclaimed water is reused directly onsite for the purposes of, flushing toilets, irrigation of plant material (including onsite greenroofs), and expansion of a constructed urban stream. The water reclaimed annually onsite is equivalent to the amount used in the Greater Victoria area (population over 300,000) on even the driest day of the year (Lucey et al. 2010). Recycling water in one area has created a benefit for an entire region.

Public green spaces used for water management can also provide recreational and restorative spaces improving urban health benefits. One study shows that people with access to green spaces with enhanced connectivity exhibit diminished cases of obesity (Smith et al. 2008). Additional research suggests people with access to green space can reduce the severity of Attention Deficit Disorder (ADD) symptoms (Taylor et al. 2008) and levels of stress and violence (Sullivan and Kuo 1996).

An additional example demonstrating the importance of green infrastructure for urban watershed health comes from the City of Emeryville in California. The city describes dense green redevelopment as redevelopment and infill projects that create vibrant neighborhoods and provide ecological benefits. The logic behind dense green development is that urban infill projects can gain water resources by directing growth away from the undeveloped portions of the watershed. The City of Emeryville identifies at a site level how green infrastructure can provide more sustainable urban environments (Figure 6).

⁹ A membrane bioreactor refers to a process using a membrane for filtration in combination with a device encourages biological activity. These systems have gained popularity over the past 20 years and are now widely used with municipal and industrial water treatment. As membrane costs reduce membrane reactors are becoming a competitive alternative to conventional water treatment practices.

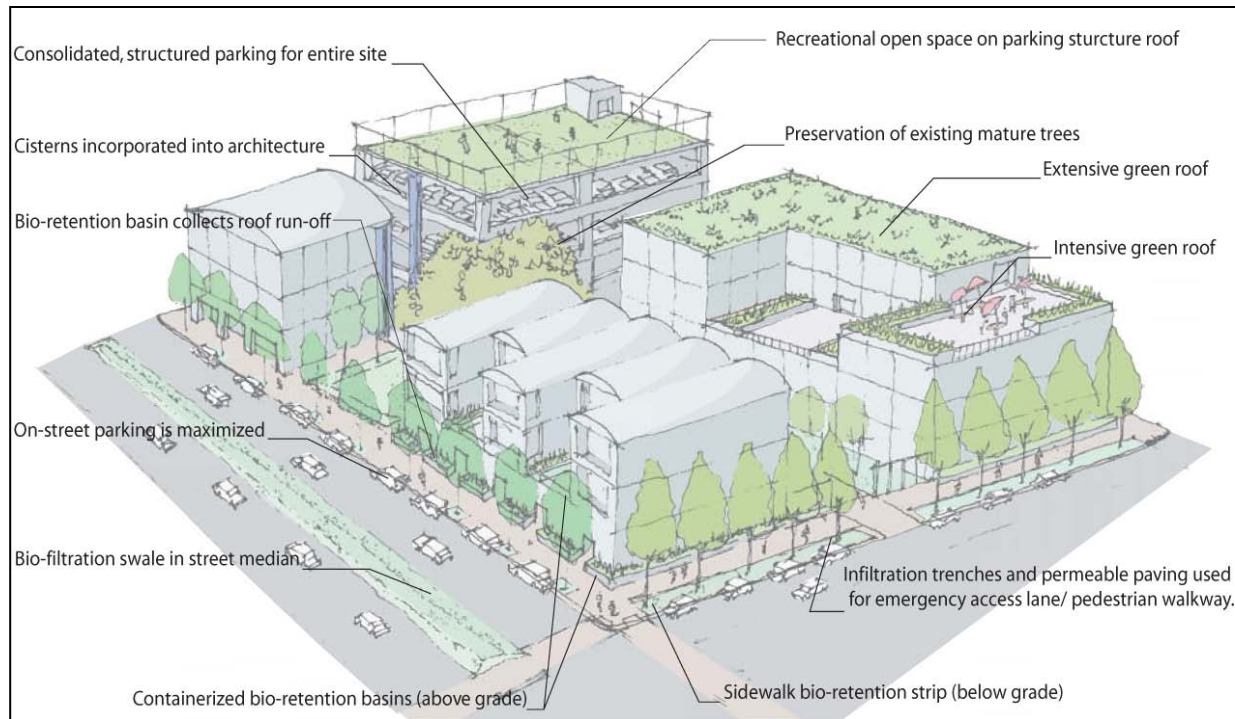


Figure 6: City of Emeryville Sustainable Development Guidelines .
 (source: City of Emeryville Department of Public Works)

The successful remediation and redevelopment of sites can depend on the degree to which efforts either protect or restore hydrologic services that contribute to human well-being. The remediation and redevelopment of a property requires more than just an analytical approach through science and economics. If the significance of water has been sufficiently explored and integrated into site analysis and design processes, appropriate measures of performance will be evident.

2.9 Purpose of Studies

This literature review shows that there are several ways of understanding and approaching sustainable watershed management. Understanding that human and environmental needs are not subject to individualistic approaches, how does one design spaces that successfully integrate the two? In the chapters that follow, this three study

investigation will illustrate three ways for more sustainable forms of urban water management within the context of infill development.

Study one examines the relationship between development patterns based on the SmartCode and the resulting amount of impervious surface. When development patterns are pushed to their maximum through manipulation of the SmartCode, opportunities arise for improving runoff characteristics of urban infill development. However, the manipulation of the SmartCode for urban watershed health also influences the character of urban environments. This suggests that people must either choose to live in different kinds of new urbanist settings or solve the problem through green infrastructure and green building technologies.

Study two recognizes that the form of the urban and suburban landscape is the result of complex and interconnected processes and that it ultimately reflects values of people. This study identifies that Resource Protection Areas (RPAs) should be extended beyond conventional sewer outfalls for improvement of urban stream quality. Study two illustrates that the SmartCode does not build in open space strategically. In many cases it appears that the open space available in new urbanist developments is often the residual land leftover after construction. According to Study two, the City of Fairfax is build upside down within the upper reach of the Accotink Creek Watershed. Fairfax's limitations can be witnessed from a watershed stance; where dense development, green infrastructure opportunities and stormwater management simultaneously compete for the same location. The lack of coordination between city, county and watershed plans may be partially responsible for this inverse development pattern.

Study three explores urban watershed management relevant to technology, sustainability and valuation. This study reveals the methods of future urban settings in relation to green infrastructure practices and values. Through an economic valuation of water related to monetization, modified cost-benefits, and combined benefits relationships between green technologies and conventional water treatment systems are explored within Fairfax, Virginia. Study three suggests that all areas of exploration provide some degree of cost effectiveness over conventional practices. These cost incentives may not be initially realized, but over time their advantages become clear. However, only in the combined-benefit approach can the maximum potential of valuing water be appreciated. This approach provides solutions to stormwater management that simultaneously improve human health and well-being allowing for maximum economic return.

3

STUDY 1: Form-based Hydrologic Design

3.1 Introduction

One basic question is whether the land development patterns common to suburban infill development are likely to benefit for urban hydrologic systems than the land use patterns they are replacing? Or, put differently, within the parameters of the SmartCode, a form-based code template for municipalities, how much improvement in watershed health can be attained?

To investigate these questions, Study one applies a series of scenarios to the Kamp Washington node, a selected sub-watershed of Accotink Creek along the Fairfax-Boulevard corridor. Five scenarios are identified and applied to the Fairfax watershed for hydrologic analysis. The scenarios analyzed include reduction of building footprint, parking lot reduction, impervious disconnects, enhanced green space and a combined criteria scenario. These scenarios provide some insights regarding the relationship of form (land use pattern) to probable hydrologic function.

3.2 Testing Rationale and Methods: Scenarios

The scenarios are organized by a tiered structure of rationale borrowed from the Virginia Runoff Reduction Methodology (VRRM) and the Uniform Stormwater BMP Sizing Criteria described in Chapter 10 of the Draft 2010 Virginia Stormwater Management Handbook. The VRRM is intended to, “(1) reduce the total volume of

runoff carrying pollutants and increasing the stormwater flow to receiving streams, and (2) to maintain groundwater recharge rates at development sites sufficient to preserve existing water table elevations and support natural base flows in streams and wetlands” (DCR, 2009).

The VRRM, developed in cooperation with the Center for Watershed Protection (CWP), is intended to allow optimum flexibility in meeting mandated water quality standards. This method gives first priority to reducing impervious surface area. Impervious surface is a primary indicator of watershed health as it is linked to such diverse impacts as increased peak rates and volumes of runoff, diminished groundwater recharge, stream channel degradation, poorer water quality, stream warming, and reductions in biodiversity (Schueler, 2004). Disconnection of impervious surfaces is the second priority. These strategies are aimed at reducing pollutant loads by reducing the total volume of runoff from redevelopment sites. Once better site planning practices are considered, best management practices (BMPs) are implemented as necessary to meet water quality improvement targets. Water quality BMPs often have the capability to further reduce the total volume of runoff. Finally, the VRRM requires flood abatement BMPs in cases where the residual peak rate of runoff exceeds the capacity of downstream channels. The scenarios examine the first three levels of intervention, in the same order, but exclude examinations of water quality and flood control BMPs.

Standardized methods are used to determine the hydrologic characteristics of each scenario. Each scenario incorporates the same built density, number of parking spaces, and street pattern. Impervious surface areas are measured directly from the plan drawings. Runoff volume calculations assume a one inch rainfall depth and utilize

the VRRM standardized runoff coefficients. The VRRM considers three cover types: Forest or Undisturbed Open Space, Managed Turf or Landscape Areas, and Impervious Surfaces. Unique runoff coefficients are specified for each combination of cover type and SCS hydrologic soil classification. Class 'C' soils are assumed in all cases. The runoff reduction efficacy of impervious disconnections and soil amendment practices is calculated using VRRM coefficients.

3.3 Hydrologic Analysis: Kamp Washington

The Kamp Washington study site is located in the headwaters of the North Fork Accotink Creek near the intersection of Fairfax Boulevard and Lee Highway. The FBMP includes a concept plan for the Kamp Washington urban center zone in keeping with 'T5' guidelines (Figure 8). The concept plan can be interpreted as one possible future condition against which alternative implementation scenarios may be tested. There are a total of 157.2 acres in the drainage area encompassing the Kamp Washington urban center. The BID within Kamp Washington occupies 96.9 acres lying within this drainage area boundary (Figure 7). The concept plan and scenarios are compared on the basis

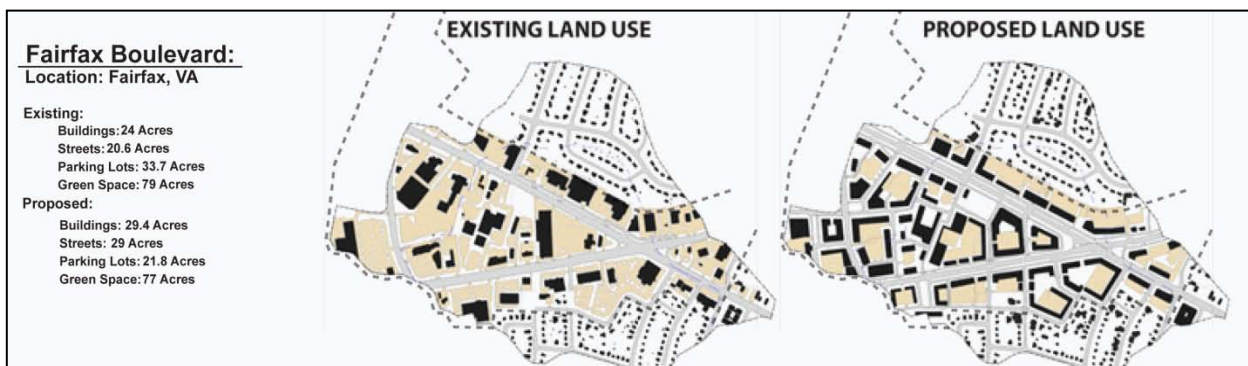


Figure 7: Kamp Washington Existing Condition and Concept Plans.
(source: Joshua C Franklin)

of this smaller land area where redevelopment is proposed. Of the 96.9 acres about 51 percent is impervious surface.

3.3.1 Experimental Design

The Kamp Washington concept plan contains about two percent more impervious surface than the existing suburban commercial site. At an average of three stories in height, a maximum build-out of the concept plan will yield approximately 30,000 square feet of built space per gross acre – nearly tripling the existing use of the site. The amount of land devoted to parking is reduced from the existing 33.6 acres to 21.8 acres. From a local hydrologic perspective, the concept plan is not preferable to the existing conditions because it increases impervious surface. To what extent can the land use pattern be adjusted within the framework of ‘T5’ guidelines to reduce imperviousness?



Figure 8: Kamp Washington Concept Plan. The Fairfax Boulevard BID is indicated by the gray dashed line surrounding the development. (source: Joshua C Franklin)

3.3.2 Building Height

The FBMP proposes a three story height restriction for buildings in the boulevard corridor - except by special permission (FBMP, 2007). In contrast, the 'T5' code permits heights to five stories without special exceptions. It suggests that building footprints can be reduced by about forty percent if the built density is held constant and the maximum building height is constructed in all instances. Figure 9 shows the Kamp Washington scheme with forty percent of the proposed building footprints converted to green space. Maximizing building height eliminates up to 8.8 acres of impervious roof surface and reduces the volume of runoff by 12 percent.



Figure 9: Building Height Scenario. This image represents a possible outcome if building heights were pushed to five stories and the remnant land reverted to a forested condition. (source: Joshua C Franklin)

3.3.3 Minimize Surface Parking

Both the FBMP and the SmartCode seek to reduce the amount of land devoted to parking by emphasizing on-street parking, encouraging structured parking and reducing requirements when certain land uses occur in proximity to one another. The parking depicted in the concept plan occurs as a combination of parking structures and surface lots occupying 21.8 acres - 35% less than the suburban commercial development currently occupying the site. The FBMP and SmartCode do not specify the proportion of off-street parking that may be placed in structures versus surface parking lots. If all off-street parking is placed in structures, the site coverage for off-street parking can be further reduced by 10.6 acres (Figure 10). This reduction decreases the runoff volume by nearly 15 percent.



Figure 10: Minimize Surface Parking Scenario. This image represents a scenario if parking structures were maximized to limit surface parking. The dark tan areas indicate parking structures initially proposed by Dover, Kohl and Associates
(source: Joshua C Franklin)

Table 1 shows the reductions in impervious surface and runoff volume that can be achieved as the scenarios are implemented independently or simultaneously. When

Reduce Impervious Surface	Impervious Surface (acres)	Runoff Volume (acre feet)
Forested	0	0.32
Existing Suburban	63.9	5.66
KW Concept Plan	65.9	5.79
Minimum Building	57.1	5.09
Minimum Parking	55.3	4.95
Combined Strategies	46.5	4.61

both building height and structured parking are increased to allowable limits, impervious surface is reduced to 46.5 acres and the

Table 1: Reduction of Impervious Surface. This table compares impervious surface to runoff volume reduction through the manipulation of building and parking footprints. (source: Dean R. Bork)

runoff volume drops to 4.61 acre feet. This represents a 20 percent reduction in runoff volume compared to the concept plan and an 18.5 percent reduction compared to existing site conditions.

3.3.4 Impervious Surface Disconnects

Rooftop runoff has an opportunity to infiltrate when it is routed into green spaces rather than entering a drainage system directly. Increases in infiltration result in reductions to the total runoff volume. In redevelopment situations the amount of reduction may be small because the level of compaction on developed sites is usually quite high. In addition, on densely developed sites, the amount of receiving land available is typically smaller than the amount of runoff produced. By reducing the building footprints additional acres of receiving green space are created.

Table 2 shows the reduction in runoff achieved when the reduced building and parking footprints (from the scenarios above) are effectively routed to green spaces. The reduction increases as the amount of rooftop area disconnect increases. In the combined scenario, with all of the parking structures and buildings disconnected, the

Disconnect Impervious Surface	Impervious Surface (acres)	Runoff Volume (acre feet)
Forested	0	0.32
Existing Suburban	63.9	5.66
KW Concept Plan	65.9	5.79
Minimum Building	57.1	4.83
Minimum Parking	55.3	4.73
Combined Strategies	46.5	4.13

Table 2: Impervious Disconnects. This table compares impervious surface to runoff volume reduction through impervious surface disconnects. (source: Dean R. Bork)

volume of runoff diminishes to approximately 4.1 acre feet. The combined scenario produces 29 percent less runoff

volume than the concept plan (for which impervious surface reductions and disconnections are not included in the calculations).

3.3.5 Enhanced Green Space

The runoff coefficient for maintained landscape spaces is higher than for forested or undisturbed areas on similar soils. According to the VRRM, 22 percent of the rain falling on landscaped areas over class ‘C’ soils becomes runoff compared to 4 percent in forested areas. Compacted soils in maintained landscape areas can be amended during site redevelopment. The infiltration capacity of the soils can be increased by as much as 100 percent when amended according to VRRM specifications. The concept plan includes 31 acres of maintained open space where soils can be enhanced in this way.

Open space created when building and/or parking footprints are reduced can be considered ‘surplus’ because it does not exist in the concept plan. Since it is not required for any specific purposes it may be relocated within the plan and reverted to forest condition. Table 3 shows the changes in runoff volume that occur when the 31 acres of green space soils in the concept plan are amended. In each scenario, soils are amended on 31 acres of maintained green space while additional green space

Enhanced Green Spaces	Impervious Surface (acres)	Runoff Volume (acre feet)
Forested	0	0.32
Existing Suburban	63.9	5.66
KW Concept Plan	65.9	5.48
Minimum Building	57.1	4.81
Minimum Parking	55.3	4.68
Combined Strategies	46.5	4.01

Table 3: Enhanced Green Spaces. This table compares impervious surface to runoff volume reduction through Enhanced Green Spaces. (source: Dean R. Bork)

generated through footprint reductions is reverted to forested condition (disconnection of impervious surfaces is

not considered). Amendment of soils in landscape spaces and creation of new forest areas proves to be slightly more effective than impervious surface disconnections in each instance.

3.3.6 Combined Strategies

All of the strategies tested above can be implemented simultaneously (Figure 11). In this case the residual open space gained by diminishing building and parking footprints is restored to forested condition. The infiltration capability of maintained

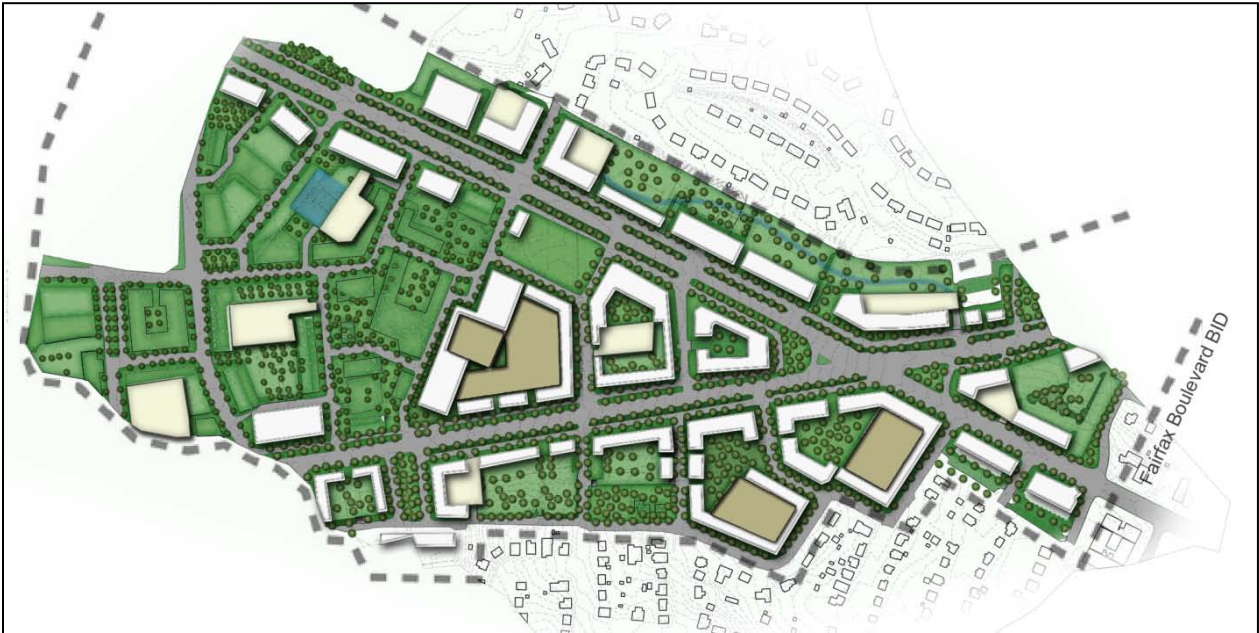


Figure 11: Combined Scenario. This image represents a possible outcome if all buildings were maximized, surface parking were minimized and all additional green space were reverted to forest. (source: Joshua C. Franklin)

landscaped spaces is enhanced through soil amendment. In addition, runoff from building and parking structures is routed to abundant and permeable green spaces. The combination of disconnection, increased soil permeability, and enhanced forest cover produces a compounded reduction in the rate of runoff.

The combined scenario has the same number of built square feet and the same number of parking spaces as the concept plan. In addition, only simple soil amendment practices and downspout disconnections are incorporated. This

Combined Strategies	Impervious Surface (acres)	Runoff Volume (acre feet)
Forested	0	0.32
Existing Suburban	63.9	5.66
KW Concept Plan	65.9	5.60
Minimum Building	57.1	4.29
Minimum Parking	55.3	4.24
Combined Strategies	46.5	3.24

combination of strategies reduces the volume of runoff to 3.24 acre-feet (Table 4). The runoff coefficient in the combined scenario is 40

Table 4: Combined Strategies. This table compares impervious surface to runoff volume reduction through both impervious disconnects and soil amendments. (source: Dean R. Bork)

percent. This compares to 72 percent in the Kamp Washington concept plan and 70 percent under existing site conditions. With a 40 percent runoff coefficient, the volume of runoff from the combined scenario is comparable to the entire site planted with a healthy row crop of soy beans. The combined scenario is enhanced if the 96.9 acre



Figure 12: Figure-ground of Kamp Washington. Moving from the Existing Conditions (left) to the Kamp Washington Concept Plan (middle) one can see the density increase and impervious surface stay nearly the same. Better design solutions may develop from density increases expanding vertically reducing the required impervious square footage (right). (source: Joshua C. Franklin)

redevelopment area is placed back into the context of the 157.2 acre drainage area (Figure 12). The land area outside of the BID is comprised mainly of single family detached residential neighborhoods. These neighborhoods contain approximately 24 percent impervious surface. Consequently, when the combined strategies scenario (comprised of 96.9 acres) is considered in its drainage area context (157.2 acres) the

Combining Strategies Scenario in Drainage Area	Impervious Surface (Acres)	Impervious Surface Percent
Forested Pre-development	0	0
Existing Suburban Commercial	78.2	0.50
Kamp Washington Concept Plan	80.2	0.51
Combining Strategies Scenario	60.8	0.39

percentage of impervious surface is reduced. When all of the strategies for the combined scenario are considered, the

Table 5: Combined Strategies within Drainage Area. This table compares the percent of impervious in the Existing, Concept and Combined Scenarios. (source: Dean R. Bork)

total volume of runoff represents a 31 percent reduction in runoff from current land use conditions (Table 5).

3.4 Conclusion

Within the 'T5' framework, the scenarios demonstrate successful examples of substantially reduced runoff volumes in the Kamp Washington drainage area. Opportunities to further reduce runoff exist if various green infrastructure systems are added to the site. For example, the scenarios do not account for runoff from the street system - the largest single component of impervious surface present in the concept plan. Constructing green streets could reduce runoff from this portion of the site by 80 percent. Additional BMP strategies such as rainwater harvesting would produce greater reductions than simply disconnecting downspouts from constructed drainage systems. With additional alternative stormwater strategies, further reduction in runoff volume for rainfall events of one inch or less can be achieved. Consequently, these strategies can also enable the site to attain approximate predevelopment forested conditions.

4

STUDY 2: Planning-based Hydrologic Design

4.1 Introduction

In August 2010, graduate students from a class titled: *Watershed Sensitive Site Design* at Virginia Tech, conducted a second study of the Kamp Washington area. Whereas Study one tested the limits of the form-based code with respect to the reduction runoff volumes resulting from impervious surface, this second study uses planning and design methodologies to explore alternative futures for the Kamp Washington area. This study produced several important findings that move beyond the limits of form-based codes and existing environmental regulations and have specific importance for this thesis investigation.

4.2 Optimal Use of Open Space Networks

Study one clearly illustrates that form-based codes are focused primarily on the environment of the street. In so doing, they tend to overlook the critical role of open space in urban watershed health. So, how could the open space network of Kamp Washington be improved while still adhering to the requirements of the 'T5' code?

Under the Chesapeake Bay Preservation Act all perennial streams within the bay watershed are required to have Resource Protection Buffers. However, the Kamp Washington area exists above the headwaters of the first order perennial stream.

Under existing conditions, Kamp Washington relies on a complex subsurface stormwater drainage system that bypasses natural drainage patterns. The first order perennial stream begins at a headwall where two 72 inch culverts empty the drainage system into a badly eroded streambed. To address this issue, the student team sought to optimize the green space network within the Kamp Washington study area, using natural drainage courses as much as possible. In order to identify these natural flow patterns, the team utilized a Geographic Information System (GIS) method, which derives flow networks based on site topography. Much of the hydrologic improvement in the two redevelopment alternatives developed in Study two hinge on a partial restoration of the site's drainage area natural flow regime, thus protecting the first order stream from its source. The first design alternative simply seeks to optimize the benefit of this open space network while remaining within the requirements of the 'T5' form-based code.

4.2.1 Systems Oriented Design

The second alternative developed by the Study two team challenges the assumptions of the 'T5' code with respect to transportation. This study questions changes in developmental patterns according to alterations in future transportation models. With relevance to urban hydrology, the majority of impervious surface in urban and suburban areas is attributable to streets and parking.

A key argument for Smart Growth is that mixed-use development and higher density help to enhance walkability and consequently, reduce local vehicular trips.

Concentrating development in dense nodes enhances the efficiency of public transportation systems. Form-based code focuses primarily on streets as human

environments, but overlooks the evolving role streets may have in connection to pedestrian movement. Fairfax Boulevard demonstrates an exemplary depiction of an evolving regional artery. Furthermore, considering infill developments in such terms produces concerns that may only be understood within the context of particular development project limits. While it is evident that transportation and open space systems overlap, it is imperative to additionally note the correlation between open space and healthy urban hydrologic systems.

The map in Figure 13 illustrates the limits of the Fairfax Boulevard BID and the boundary of the Accotink Creek Watershed where it is located. Existing public open spaces are indicated in green and a quarter mile walking radius from each of these sites is shown with a dashed red circle. The green dotted hatch pattern indicates a continuous riparian buffer along the stream corridor. This hatch pattern connects the majority of open space and proposed green infrastructure into a consolidated greenway. The existing trail system intermittently follows the existing stream network within the study area. Public parks and green spaces are present, but neither abundant nor equally accessible from all areas of the Fairfax Boulevard corridor and abutting residential neighborhoods. A large depiction of the regional green infrastructure plan can be seen in Appendix 2.

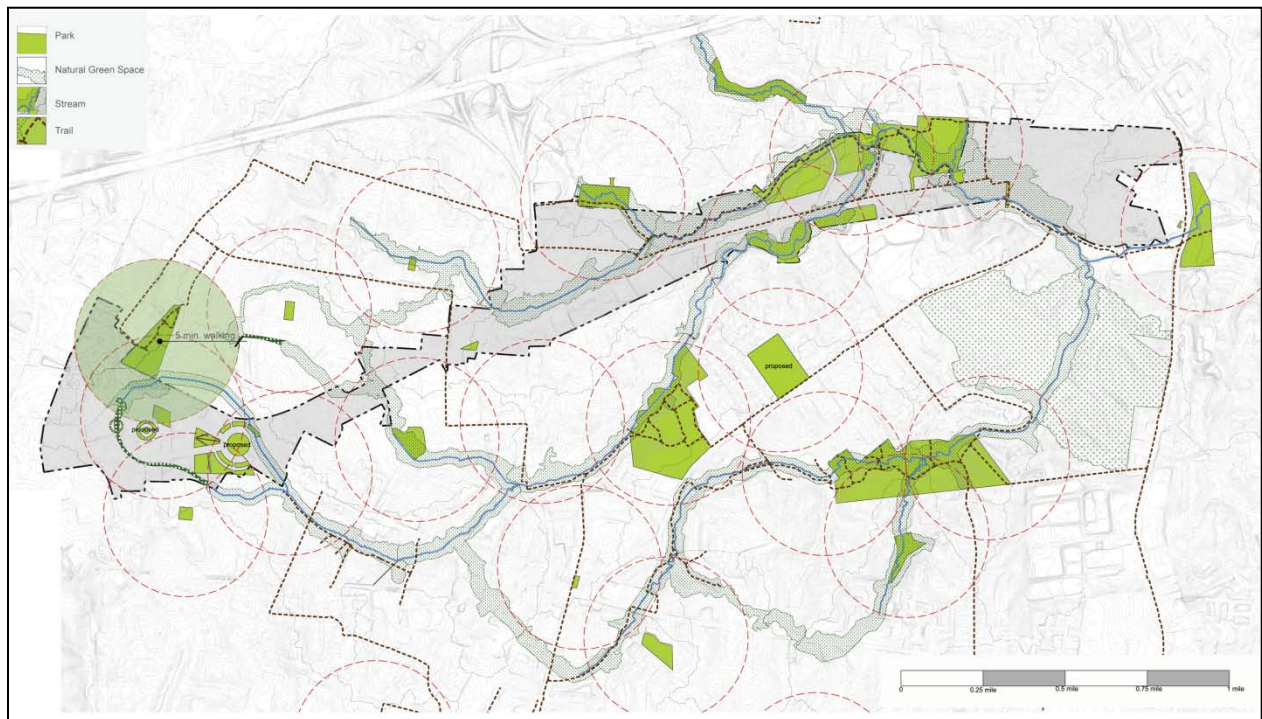


Figure 13: Regional Green Infrastructure System. (source: *Watershed Sensitive Design Studio, 2010*)

Another key for the success of site scale design is appropriate zoning and landuse. For this reason, each design alternative is placed within a specific landuse map. This allows a designer to see the larger picture of individual developments, a key for successful watershed planning. Appendixes 3 and 4 show the proposed regional landuse of Design Alternative 1 and 2 respectively.

4.2.2 Design Alternative #1

Alternative 1 builds upon the established topographic and hydrologic analysis while attempting to stay within the intent of the original Fairfax Boulevard Master Plan (Figure 14). Green space in the BID is increased with slightly taller buildings, multi-modal transportation options are promoted with a pedestrian-oriented commercial district and the green network features a trail system connecting the metro station to the Kamp Washington commercial center. Additional green spaces accumulate through the

extension of a daylighted stream network. The studio team used the one hundred year floodplain data to extend the Chesapeake Bay Resource Protection Area (RPA) by one hundred feet on either side of the existing and proposed stream channels.

Another design element and mitigation strategy is the addition of traffic circles. Traffic circles are introduced at the Highway 50 /Highway 29 intersection and the Fairfax Boulevard /Jermantown Road intersection. The importance of the automobile is de-emphasized to raise pedestrian, bicycle and high-occupancy vehicles to equal importance with the single-driver vehicle.

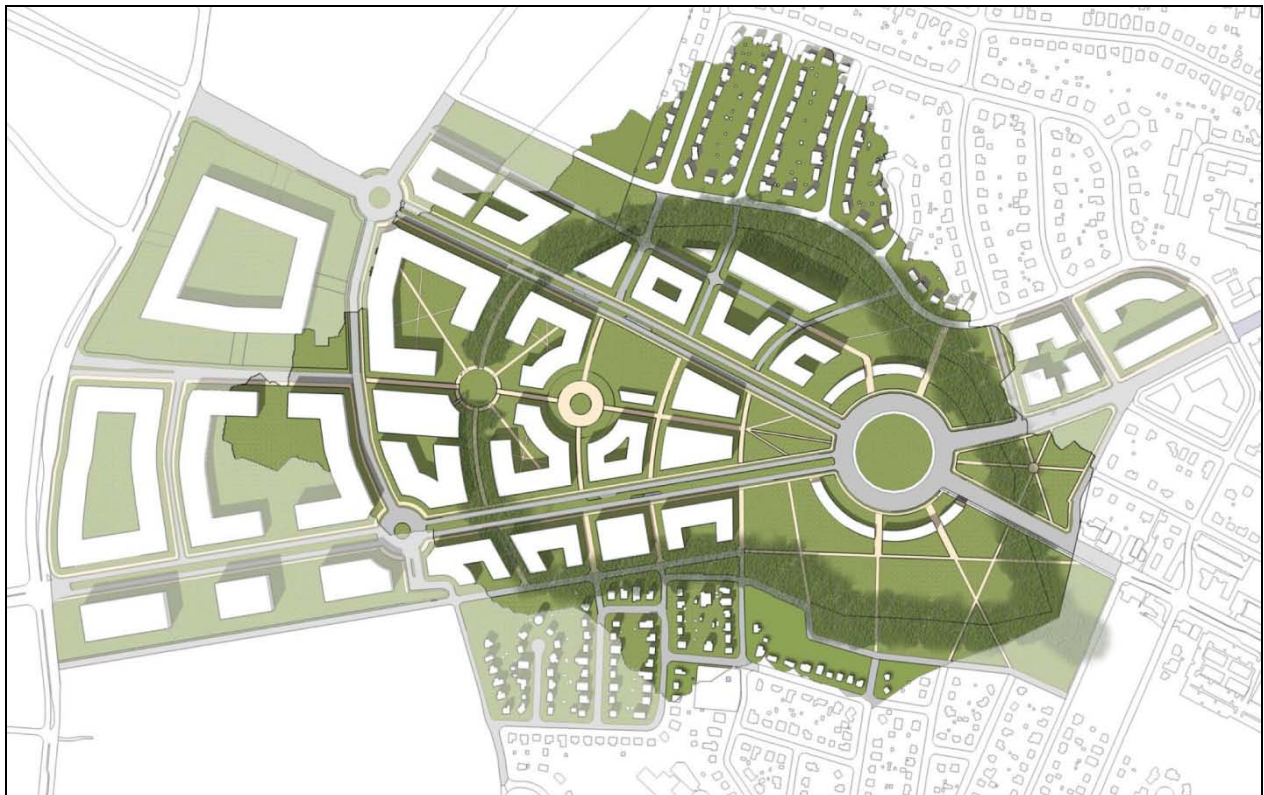


Figure 14: Alternative #1. (source: *Watershed Sensitive Design Studio, 2010*)

Alternative 1 proposes three strategies for achieving its goals: utilizing green infrastructure, improving the transportation network and appropriate land use and urban design. In addition to daylighting the stream and extending the RPA, the green infrastructure system of Alternative 1 also includes additional green spaces, forested

areas and buffers in lower elevations. Wherever possible, public green spaces, courtyards, and maintained turf were placed inside and around building footprints. Existing trail network is extended through adjacent residential neighborhoods to follow the shape of the open channel and RPA; the trail loop is completed within the central development area, linking pedestrians, cyclists, public spaces and commerce. In addition, the road median on Fairfax Boulevard was converted to managed turf.

To improve transportation, Alternative 1 converts three main intersections into traffic circles to both decrease congestion and allow a critical section in the sub-watershed to revert to a more natural condition. Another addition to Kamp Washington are “Pedestrian only” roads just wide enough to accommodate emergency, service and delivery vehicles. To encourage public transit, increased opportunities are available in this scheme to park and ride public transportation. This was accomplished through detailed and strategically placed parking lots and bus stops. Impervious cover from original parking lots was reduced by creating parking garages.

The third strategy of Alternative 1 focuses on issues of convenience relative to urban design. Buildings were placed along major arterial roads and within close proximity to parking garages to accommodate the automobile. The development density was increased by using two-story building heights throughout the entire area.

4.2.3 Design Alternative #2

Alternative 2 features higher density than Alternative 1 in all landuse zones, constraining commercial development to the T5 transect of the SmartCode. The single-occupant automobile is considered a lower priority mode of transportation than other options such as bus, rail, bicycle, and walking. Highway 29 (Fairfax Boulevard) is

transformed into a light rail, beneath which lies a large swale, which runs the length of the railway within the City of Fairfax. The rail swale⁶ transforms a substantial amount of impervious surface into green infrastructure and accommodates pedestrian passage from one side to the other. The transportation network was a central consideration when the team redeveloped Alternative 2. The metro station is a focal point that serves area residents with light rail, rapid bus line, and neighborhood bus line. Time between available buses as well as distance between bus stops is decreased from Alternative 1. The green median with covered bus shelters remains.

Just as Alternative 1, Alternative 2 utilizes the same three strategies to achieve its design objectives: green infrastructure, transportation and urban design. Alternative 2 uses the same green infrastructure model established in Alternative 1 and strategically increases green infrastructure in a number of ways. Public green space around mixed-use areas is increased, and several parks are designated adjacent to the RPA, providing additional stormwater benefits. Lee Highway is converted to a light rail line, beneath which lies a linear BMP to be used both for stormwater detention and pedestrian travel from one side of the railway to the other.

⁶ This term describes the green space (in this case a dry swale) located below the light rail line as this system is raised above the ground plain.

In Alternative 2, infrastructure for multi-modal forms of transportation is greatly increased (Figure 15). Lee Highway becomes a light rail line with stops every half mile near commercial districts. Fairfax Boulevard now includes a Metro Rapid Bus line, High



Figure 15: Alternative #2. (source: *Watershed Sensitive Design Studio, 2010*)

Occupancy Vehicle (HOV) lane, expanded bike lanes and sidewalks. Residential areas of Kamp Washington are within one quarter mile of the development center as well as public transit stops, served by the Metro Local Bus line. Road widths and speed limits in residential areas are decreased to encourage use of alternative transportation and to increase safety. Traffic circles are eliminated due to reduced importance of cars in this plan.

From an urban design stance, Alternative 2 reduces impervious cover and increases development density by allowing buildings taller than five stories and

eliminating parking lots and the parking garages proposed under Alternative 1. The majority of single family detached housing are consolidated into denser multi-family residential buildings. Street-Width-to-Building-Height ratios are adjusted to create both pedestrian scale and livable urban space: taller and more condensed buildings increase available open space and minimize impacts.

4.3 Conclusion

Through the alternative proposals of Study two one realizes several key points. Primarily, this study indicates that an urban environment devoid of the automobile has a large opportunity for hydrologic improvement, as automobiles can be directly related to impervious surface. It is also apparent that a threshold exists between environmental sustainability and the character of urban environments because urban environments altered for improved hydrologic function begin to take on more suburban qualities.

Though the quantitative analysis associated with hydrologic volume reduction in Study one was integrated into the studio project, from a planning stance it may not be as significant as other conclusions. This planning-based study raises much larger questions such as appropriate landuse, regional green infrastructure systems and integration of site and regional scale design. Another issue of importance is the integration of urban and natural systems, such as incorporating green infrastructure within transportation networks. In the case of Study two, one key for this successful integration came in the form of extended RPA's, which have huge environmental implications for the health of headwater streams. Planned-based designs can yield yet another perspective into sustainable urban design and water management.

Increasing density will almost always mean increased load on water resources. Current stormwater management regulations focus on site by site solutions while the integrity of the system as whole often goes unexamined. If a systems approach is ultimately necessary for improving the health of urban watershed, then questions of coordinated strategies, proper planning and design scales become relevant. While it is not clear which approach to urban water management is most appropriate, it is clear that questions of alternative strategies need to be raised.

5

STUDY 3: Value-based Hydrologic Design

The scenarios and alternatives presented in Studies one and two demonstrate that, if proper planning and design practices are utilized to their advantage, infill development can allow for improved urban watershed health and increases in important natural system services. Neither study considers the problem from a conventional stormwater management point of view. A staff member of the EPA stated in public lectures that there is some appropriate combination of green infrastructure or low impact development strategies suitable for every development project and capable of achieving the Chesapeake Bay water quality requirements. This claim may well be true. But, it is also the case that constructed infrastructure systems, whether they are 'green' or otherwise, are rarely self-sustaining. There are always costs involved in their construction and maintenance over their service life. The question then arises, what types of publicly acceptable stormwater strategies provide the greater ecological benefit for the dollars spent to operate them over their lifetime? Can treating water as a resource throughout the hydrologic cycle provide urban environments and individuals with multiple opportunities to benefit? The following sections will uncover exactly what water can provide Kamp Washington in terms of value for human and environmental purposes. In this study, three value based approaches are applied to Kamp Washington. Each approach uses economics as a primary means of comparison, but

treats economic valuation in a different way. The three approaches are monetization, modified cost-benefit and combined benefits. The monetization approach assigns a dollar value to a particular set of objects or services. Monetization will be investigated and illustrated by focusing on the economic benefits of water storage and reuse. The modified cost-benefit approach tackles economic benefits from a problem specific perspective. It compares costs associated with alternative ways of solving one narrowly specified problem. Similar to the monetization approach, the combined benefit approach provides a direct comparison for those dimensions of a proposed plan that can be easily assigned a dollar value. However, the benefits and liabilities of a plan that cannot be easily converted to dollar valuations are also considered. The three approaches are each applied to a specific piece of the overall site. The monetization approach uses the Kamp Washington Concept Plan for economic comparisons of water storage and reuse. The modified cost benefit and combined benefit approaches will investigate and illustrate a green infrastructure approach to a conventional stormwater management approach.

5.1 Monetization

One of the most common measures for associating value with ecosystem services involves economic valuation. Expressing value in monetary terms allows direct comparison of the ecosystem service with willingness to pay or willingness to accept monetary compensation (EPA 2009). For example, the USDA Forest Service suggests that the direct value of national forest water to humans exceeds \$27 billion per year (Smail and Lewis 2009).

The rainwater falling in the Kamp Washington area can be understood in terms of its economic value as a potable water supply. Collecting stormwater, sometimes referred to as rainwater harvesting, is a smart way to provide costs savings as every gallon of rainfall captured is a gallon that an individual doesn't pay for city water. Usually, rainwater collected is of acceptable quality for household needs such as taking showers, washing dishes and irrigating plants. Rainwater harvesting can also assure an independent water supply during water restrictions, though this is somewhat dependent on end use and maintenance

From a stormwater management perspective, collecting rainwater reduces peak stormwater runoff and processing costs. In municipalities with combined sewer systems, reducing storm runoff is especially important, because excess runoff during heavy storms leads to the discharge of raw sewage from outfalls when treatment plant capacity cannot handle the combined flow. Storage of rainwater results in less water discharging to sewage treatment plants, which can significantly reduce processing costs during smaller storm events, and downstream water pollution during larger storms.

In some cases, recycling water at a regional level can be successful. In Fairfax County, adjacent to the City of Fairfax and the Kamp Washington development, one such project is already underway. A proposed Water Reuse Project will use reclaimed water from the Norman M. Cole Jr. Pollution Control Plant for irrigation and process purposes (Figure 16). 560 million gallons of treated reused/reclaimed effluent waters will be directed to the Covanta Fairfax Inc. Energy Resource Recovery Facility. An additional 24 million gallons of water will be allocated to both the Laurel Hill Golf Course and the Lower Potomac Ball Fields for irrigation purposes. This project has undergone

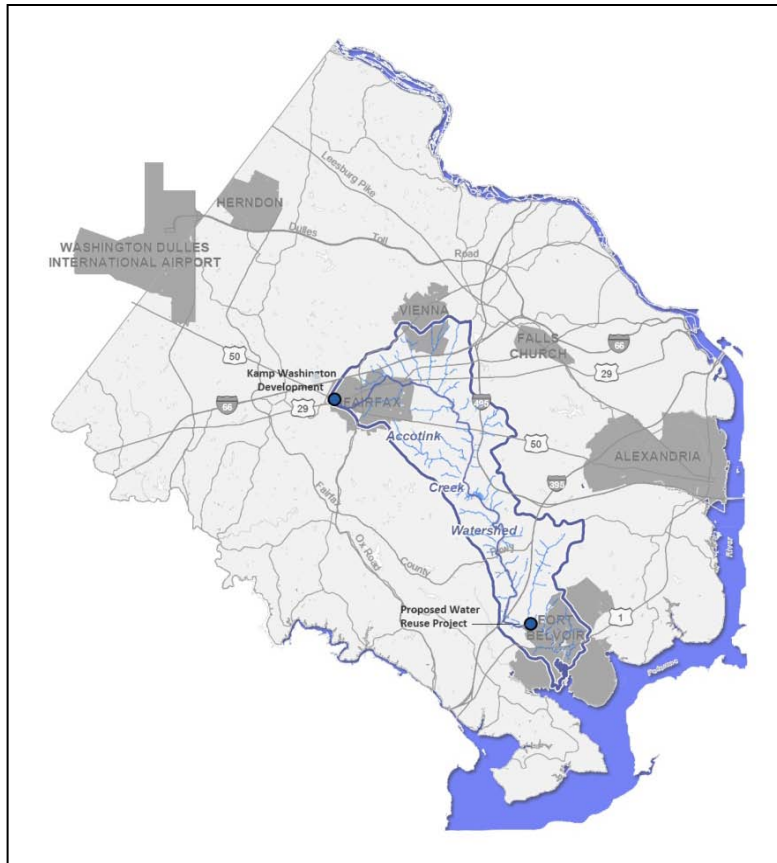


Figure 16: Accotink Creek Context Map. Accotink Watershed is outlined in blue above. Notice the position of the Kamp Washington development and the Water Reuse Plant with the context of the drainage area. (source: Joshua C. Franklin)

substantial coordination with the Virginia Department of Environmental Quality as well as other local, state and federal agencies. In addition, this project received \$6.5 million in federal stimulus funds through the American Recovery and Reinvestment Act through the Virginia Department of Environmental Quality Clean Water Revolving Fund Loan Program (Chapin, and Bongiovanni).

Urban irrigation constitutes a large portion of urban water demand for many businesses across the United States, representing an estimated 28% of commercial and industrial water use (Billings and Jones 2008). While the redevelopment of Kamp Washington does not resemble the character or form of an industrial park the landscape would still need to maintain a certain aesthetic, which often times means seasonal watering. According to Virginia Tech turf specialist, Mike Goatley (2009), watering demand varies somewhat by grass type. However, Goatley states one inch per week is a general recommendation during droughts. Assuming a rate of one inch per week is required through the months of June, July and August, one foot of water is necessary to

supplement the green space of Kamp Washington. Multiplying the acreage of green space in the Kamp Washington Concept Plan (77 acres) by the 12 inches of supplemental water, yields an irrigation demand of 3,354,120 gallons per year for Kamp Washington.

According to the Fairfax Water Authority, an established customer can expect to pay \$95.94 over a 3 month winter period on 24,000 gallons of residential water use (Fairfax Water 2010). This means residents of Fairfax can expect to pay \$.004 dollars per gallon. Using this rate as a standard, water used for irrigation totals \$13,400 annually⁷.



Figure 17: Kamp Washington Water Storage Plan. If Kamp Washington were to incorporate water storage tanks, the majority of the development would benefit from central locations. Tanks 1, 2, and 3 could provide this development with an additional 3.3 million gallons of recycled water. (Source: Joshua C. Franklin)

⁷ This assumes the standard customer fee of \$.004 dollars per gallon of residential water. While large demands for commercial and industrial purposes are usually discounted over residential use, the price per gallon is relatively close.

Figure 17 represents a possible configuration of water storage in relation to building footprints. A sizing standard of capturing 100% of the water necessary for irrigation (3.3 million gallons) was utilized for placement of three storage tanks across the development.

There are 5 major components to a water harvesting system: tanks, gutters, roof washers, filtration, pumps and pressure tanks. Each of these components can be associated with a cost, storage being the largest. Table 6 displays the costs for implementing each rainwater systems, which is divided according to each tank displayed in Figure 21. Assuming the cheapest systems will work for irrigation purposes, the average cost per system is 1.5 million.

The major cost that causes such a variation is material choice. Two materials were chosen first, because of their ability to support volumes over a million gallons and second, their lower cost per foot relative to other materials. The two materials chosen were fiberglass with a unit cost of \$1.25 per gallon and welded steel with a unit cost of

Kamp Washington Rainwater Harvesting Installation Costs for each Storage Tank and associated Infrastructure						
	Storage	Tank*	Distance from Tank**	Pipes***	Roof Washer	Pump and Pressure Tank
System #1	0.85 million gallons	\$1-\$4.4 million	700 feet	\$22,500-\$81,000	\$600-\$1,350	\$1,000
System #2	1.4 million gallons	\$1.7- \$7.4 million	1100 feet	\$116,000-\$377,000	\$600-\$1,350	\$1,000
System #3	1.05 million gallons	\$1.2- \$5.4 million	950 feet	\$80,500-\$276,000	\$600-\$1,350	\$1,000
Total Cost Per System:						
System #1	\$1.10-\$4.42 million		treats 33,752 gallons			
System #2	\$1.75-\$7.75 million		treats 626,962 gallons			
System #3	\$1.75- \$5.75 million		treats 490,526 gallons			
*reflects the cost range of fiberglass and welded steel tanks at \$1.25 and \$5.25 per gallon, respectively						
**reflects average horizontal distance from central storage tank						
*** reflects the cost range of material per foot (\$3.50-\$12) multiplied by distance from tank						

Table 6: Rainwater Harvesting Installation Costs. This table shows that the cost to implement rainwater harvesting varies between 1 and 9 million dollars per system, with the most expensive cost coming from storage. In fact, if a developer wants to consider rainwater harvesting, simply estimate the storage and multiple by 3.2% to estimate for total system costs. (Source:

\$5.25 per gallon. Based on their unit cost, these two materials make up over 90% of the total cost for each rain water harvesting system (Table 6).

Current Virginia stormwater regulations require treatment of the “first flush” or the first inch of runoff to meet water quality standards. Taking the total runoff of 7.7 acre-feet (Appendix #1) generated from the Kamp Washington Concept Plan results in a water quality volume of .64 acre- feet. Dividing the water quality volume by the total monthly storage suggests that storing the entire Kamp Washington water quality volume requires only 6% of the total monthly storage capacity. Without water harvesting some other strategy must be in place for water quality. One potential approach to treat the specified water quality volume would be the use of best management practices (BMPs). According to the Mid-Atlantic Water Program and the EPA, a dry swale is the cheapest BMP practice to meet water quality standards. Dry swales have a unit cost of \$18,150 dollars per impervious acre (Schueler 2007). Measuring costs by impervious acres makes sense for a stormwater as imperviousness is a key indicator for urban watershed health. The total number of impervious acres from the concept plan is 80.2 acres which would cost a minimum of 1.4 million to install and maintain.

It is important to note that in order to maintain the water quality and flood storage benefit of harvesting rainwater, each system must operate 12 months per year. The rainwater harvesting systems must empty enough water from each storm event, so the necessary volume is available for the next storm event. Since the ground does not freeze for extended periods of time in northern Virginia, water can be applied to the ground nearly 12 months per year.

In addition to water quality, rain water harvesting can also provide flood reduction. Capturing 3.3 million gallons of runoff is the equivalent of 10.1 acre- feet or

Land Value Best Management Practices in Kamp Washington		
Design of BMP	Acreage required for BMP	Intial Cost of BMP's
Assumes 5 ft storage depth	1.5	\$ 2,495,000 - 3,853,390
Assumes 10 ft storage depth	0.7	\$ 2,704,915 - 2,071,000
Assumes 20 storage depth	0.38	\$ 1,901,400 - 2,245,525
Kamp Washington Current Land Value per Acre		
Land Type	Commercial	Residential
Value/ Acre	\$ 1,435,593	\$ 530,000

Table 7: Land Value For Fairfax BMP's. This table suggests the range in costs associated with land value for a BMP approach to stormwater management within Kamp Washington. The land are required depends on the depth of storage available.

37% more storage than VRRM methodology requires for the Kamp Washington Concept Plan. The cheapest best management practice for

flood reduction is a detention pond which costs \$3,800 dollars per impervious acre (Schueler 2007). Given that the concept plan has 80.2 acres of impervious surface, it would cost a minimum of \$305,000 dollars to meet flood storage.

The cost to manage stormwater through BMP's totals 1.7 million, but fails to estimate land value. The cost per acre for land in Kamp Washington currently varies between .53 and 1.43 million per acre for residential and commercial land respectively. Given that BMP's can be designed at different depths, a range of depths were utilized to suggest the necessary acreage (Table 7).

The cost to store rain water varies between 1 and 8 million, while the cost for stormwater BMP's varies between 1.9 and 3.8 million. It is clear that the initial cost of water harvesting is high compared to conventional water management. Also, it may not seem economically feasible to pay for rainwater harvesting when city water can be provided at a much lower cost. However, this model assumes that conventional BMP's can be constructed within an urban area that is nearly built out and that prices for municipal water will remain constant. While currently the new technology of rainwater

harvesting may not seem feasible, it is just a matter of time before factors related to urban growth suggest otherwise.

If water is stored it presents an excellent opportunity for water reuse as these to processes can be interrelated within the infrastructure of buildings. As another example

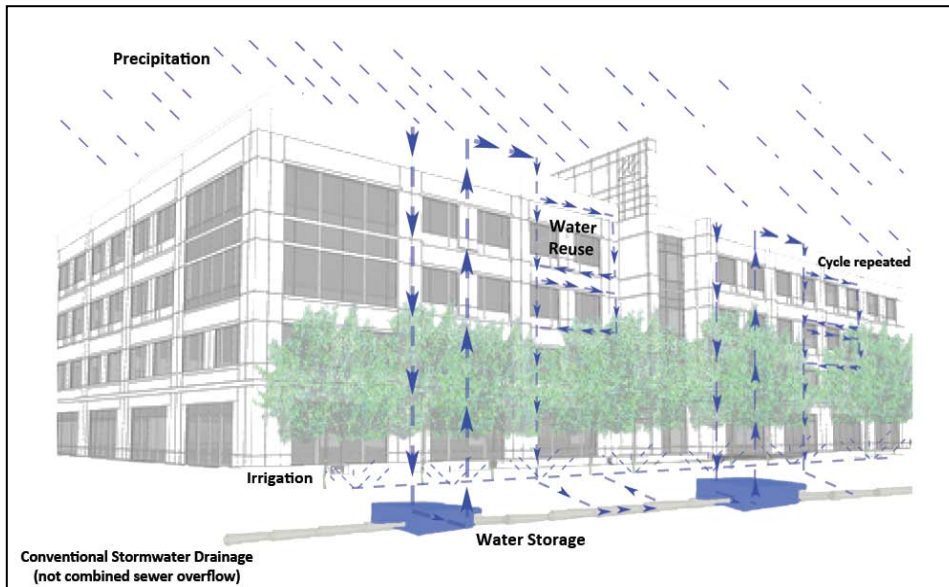


Figure 18: Water Reuse Diagram. If Kamp Washington were to incorporate water a water reuse system within major buildings water use would exponentially decrease, significantly improving cost savings. (Source: Joshua C. Franklin)

of monetization, water reuse is explored for its benefits. Figure 18 suggests an approach to water management where the same gallon of water can be reused

multiple times within the same building. This approach would decrease demand for water as a portion of the monthly water usage can be redistributed to support more people.

When considering the implication for water reuse it is important to understand what is being recycled. Clean water can only be used one time before it becomes greywater. Greywater or water that can be repurposed for domestic activities such as laundry, dishwashing, and bathing is the resource utilized in water reuse systems. Grey water makes up between 50% and 80% of the water generated from household equipment. This means that every resident living in Kamp Washington has a water bill

where between \$47 and \$75 monthly can be eliminated through water reuse, an annual savings of \$564 and \$900 per resident. Assuming that a 3 to 5 story building within Kamp Washington would recycle water a minimum of 4 times, the value of that water in theory is quadrupled per gallon. Although unlikely, if the recycle rate of four uses per gallon were reflected in residents' water bills, annual savings could range from \$2256 to \$3600.

While infrastructure costs increase to reuse water within buildings compared to receiving water from the city, over time the water reuse system would pay for itself through the cost savings suggested in this section. Residents of Kamp Washington spend an average of \$13,400 annually for irrigation. Implementing rainwater harvesting to remove this demand would cost a minimum of 4.5 million. If additional uses, such as collecting the water quality and flood storage volumes, are attributed to this system more value is added ranging between 2 and 4 million dollars. This means that in as little as two years rainwater harvesting systems could recuperate the initial construction costs from the additional benefits received. Furthermore, greywater reuse removes water from a system where it's overabundance can be detrimental to the environment and repurposes it to provide additional uses for human consumption.

In a typical development, water demand per unit area increases with density. Capturing and reusing water that falls within a watershed means costs otherwise incurred for larger potable purposes can be deferred. This understanding presents a different way of thinking about public infrastructure and ways to fund and operate distributed infrastructure that will be important for infill redevelopment projects.

5.2 Modified Cost-Benefit

The modified cost-benefit approach examines a design issue and compares the cost and benefit of alternative solutions. The method is referred to as ‘modified because it only accounts for cost and benefits within the scope of a narrowly defined problem – an approach common to traditional engineering practice.

In 2009, the Philadelphia Department of Water introduced an alternative approach to stormwater management based on cost savings over conventional management. That approach called “*Green City, Clean Water*” determined that alternative green infrastructure would provide the maximum economic return in

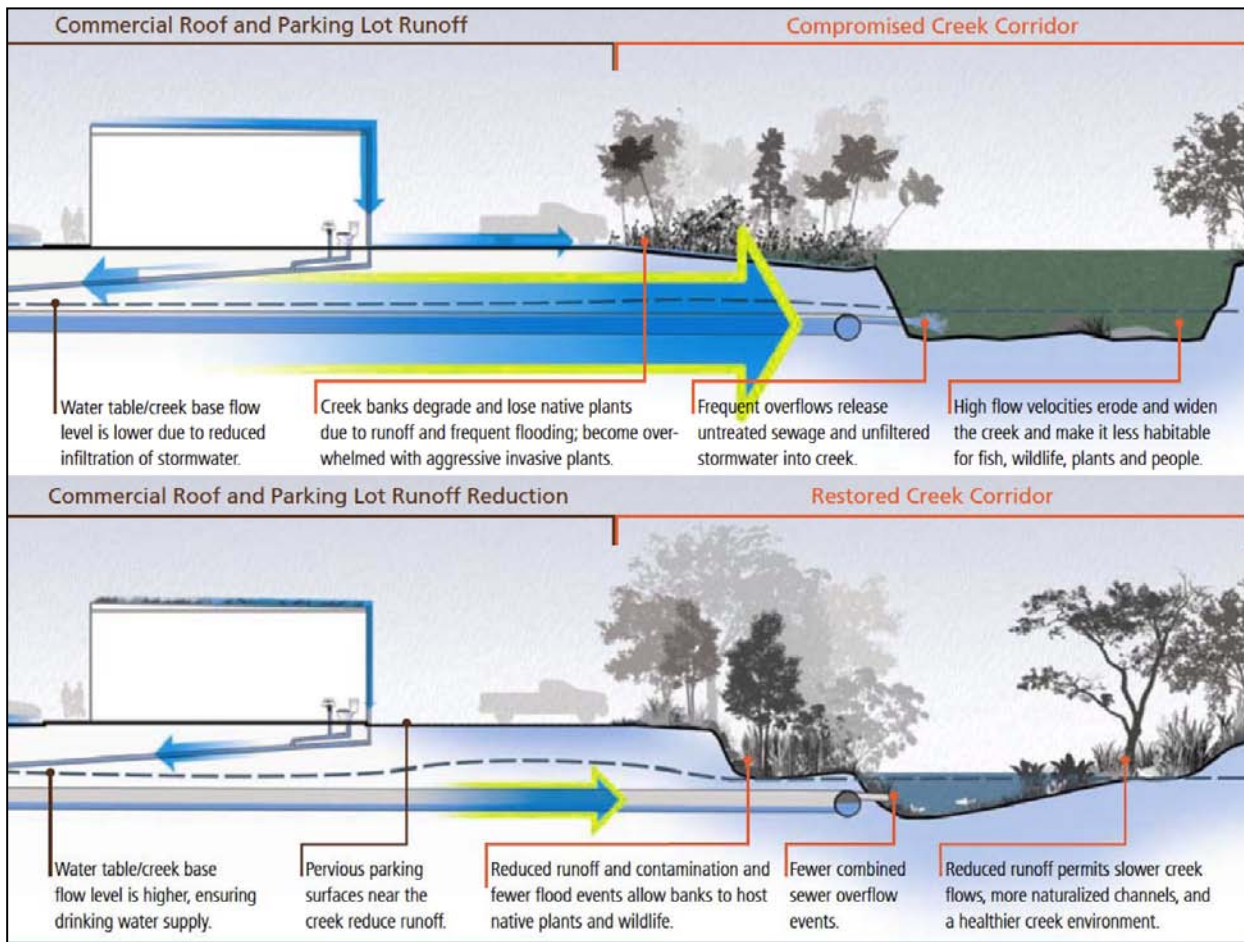


Figure 19: Green City, Clean Water. This alternative approach to runoff reduction actually saves the city money as the alternative approach to runoff reduction (Bottom) actually costs less when compared to conventional methods of stormwater management (Top)

comparison to conventional practices for updating combined sewer overflow (Figure 19). Over the next 20 years, Philadelphia looks to spend over 1 billion dollars to improve water related issues. A feasibility analysis conducted as part of this study suggests that a conventional approach to Philadelphia’s combined sewer problems would cost 10 billion while green infrastructure would cost 2.5 billion.

The cost benefits of alternative approaches to stormwater management are not localized to the city of Philadelphia. In fact, a study conducted by the EPA suggests that Low Impact Development (LID)⁸ reduced costs compared to conventional stormwater management in 10 out of 11 case studies with an average cost savings of 39% (Table 8). This is not an exhaustive list of case studies; however, the studies used were selected on the basis of the quantity and quality of economic data, quantifiable impacts,

Cost Comparison between Conventional and Low Impact Development Approaches to Stormwater Management				
Project	Conventional Development Cost	LID Cost	Cost Difference ^b	Percent Difference ^b
2 nd Avenue SEA Street	\$868,803	\$651,548	\$217,255	25%
Auburn Hills	\$2,360,385	\$1,598,989	\$761,396	32%
Bellingham City Hall	\$27,600	\$5,600	\$22,000	80%
Bellingham Bloedel Donovan Park	\$52,800	\$12,800	\$40,000	76%
Gap Creek	\$4,620,600	\$3,942,100	\$678,500	15%
Garden Valley	\$324,400	\$260,700	\$63,700	20%
Kensington Estates	\$765,700	\$1,502,900	-\$737,200	-96%
Laurel Springs	\$1,654,021	\$1,149,552	\$504,469	30%
Mill Creek ^c	\$12,510	\$9,099	\$3,411	27%
Prairie Glen	\$1,004,848	\$599,536	\$405,312	40%
Somerset	\$2,456,843	\$1,671,461	\$785,382	32%
Tellabs Corporate Campus	\$3,162,160	\$2,700,650	\$461,510	15%

Table 8: Stormwater Management Cost Comparison. This table illustrates cost savings associated with green infrastructure in Low Impact Developments compared to conventional stormwater management. Conventional development cost refers to costs incurred or estimated for a traditional stormwater management approach, whereas LID cost refers to costs incurred or estimated for using LID practices. Cost difference is the difference between the conventional development cost and the LID cost. Percent difference is the cost savings relative to the conventional development cost. (source: EPA 2007)

⁸ Low Impact Development or LID is a term used to describe land planning and design approach to stormwater management to emphasize conservation and the use of onsite natural features such as green infrastructure (EPA 2007).

and types of LID practices used.

Analyzing alternative approaches to water management similar to “*Green City Clean Water*” can yield different results for the redevelopment of Kamp Washington as well. The Green infrastructure scenario for Kamp Washington proposes an open channel system for the conveyance of water. Restoring an open drainage network would require a certain amount of land, but such a system would basically eliminate the need for a conventional stormwater system.

5.2.1 Green Infrastructure Alternative

In this study the costs and benefits of a green infrastructure alternative plan are compared to a conventional stormwater management system for the Kamp Washington concept plan. The green infrastructure alternative plan maintains much of the same land use pattern as the original concept plan, but consciously attempts to arrange open spaces to enhance the natural systems services that can be provided within the same general development footprint.

The green infrastructure alternative maintains a similar building and street layout compared to the concept plan proposed by Dover Kohl and Partners, while introducing an open drainage system. Buildings footprints were not manipulated, but their placement was slightly altered within the watershed. Sections of some streets were manipulated or removed to allow for the continuous green space required for daylighting.

This alternative begins to address tradeoffs between environmental implications and built form. As more land is devoted to green space, less land is available for development. Figure 20 represents a redevelopment strategy that maintains built

Kamp Washington Concept Plan and Green Infrastructure Alternative

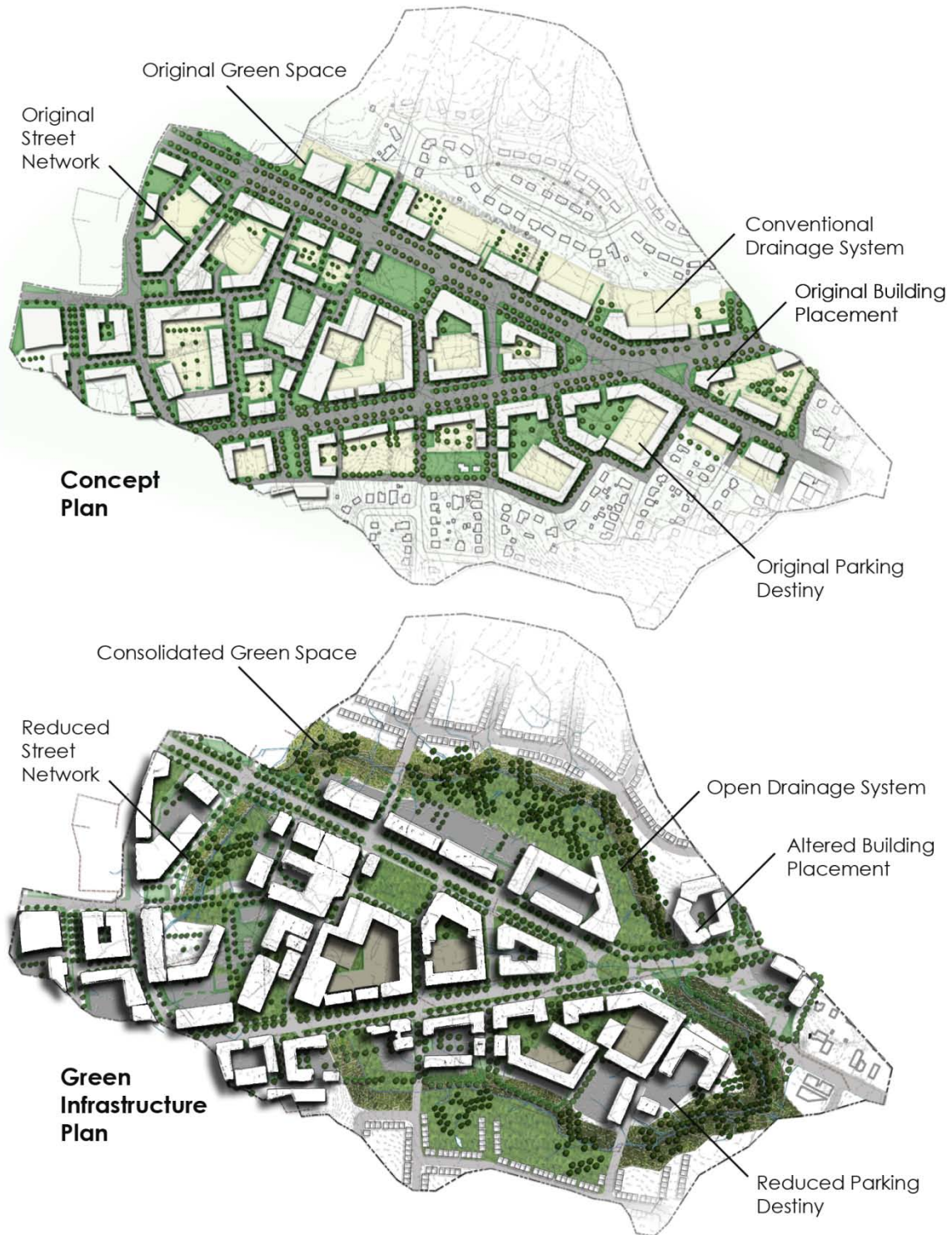


Figure 20: Kamp Washington Green Infrastructure Alternative. The image illustrates the differences between the Kamp Washington Concept Plan and the Green Infrastructure Alternative. The key criterion for the differences is the consolidation of green space necessary for the success of the green infrastructure alternative. (source: Joshua C. Franklin)

density. However, in order to the area of open space it is necessary to reduce street area and surface parking. In the proposed alternative street area is reduced by 20% (23.4 acres) and surface parking area by 23% (16.9 acres) when compared to the Kamp Washington Concept Plan. However, the overall connectivity of the street network is reasonably maintained and with the addition of two small parking structures consuming an additional 3 % (each less than 35,000 sq. ft.) of the watershed, parking density can also be held consistent with the Kamp Washington Concept Plan. The objective of the value-based alternative is to explore the cost benefits and liabilities of green infrastructure versus conventional stormwater management in a design that maintains adherence to the ‘T5’ section of the Smart Code. One could argue that an open drainage system costs significantly more than just retrofitting a conventional system to operate at higher capacities. However, conventional systems cannot offer the range of cost savings compared to open drainage systems. As a key component of open drainage systems, natural infrastructure reduces the amount of money needed to create and maintain conventional infrastructure (Lucey et al. 2010). For example, the majority of the existing Kamp Washington development has conventional concrete pipe networks. These pipes last an average of 70 to 100 years. Given that the majority of construction within Kamp Washington occurred in the 1950’s, means the conventional system has an effective life cycle of 10 to 40 years (FBMP 2007). In the near future the conventional system put in place for Kamp Washington will be outdated. Assuming concrete pipe is used to restore and maintain the conventional system, the City of Fairfax is looking at a cost burden between 1 million to 2 million dollars (Appendix #3).

An open drainage system requires very few if any pipe networks to maintain drainage. However, there are also construction costs to consider for stream restoration.

In order to achieve the consolidated green space necessary for the green infrastructure alternative parking density and streets were reduced by 736,164 sq. ft (16.9 acres), and 1,019,304 sq. ft. (23.4 acres), respectively. Construction cost will increase to maintain parking density as the average cost difference for using structured parking rather than surface parking increases in price by \$48.83 per square foot⁹ (VTPI 2011). This reflects an increase in construction costs for parking of \$35,946,888. However, the cost of constructing fewer streets can be subtracted from this increase in parking. The average cost for street construction is \$14.83 per square foot (VDOT 2000)¹⁰. This reflects a cost reduction in street construction of \$15,116,278. The total increase in construction costs is represented by the difference between structured parking costs and street costs as \$20,830,610.

To implement the entire open channel drainage system it is also necessary to consider the cost of the Best Management Practices. The green infrastructure alternative assumes a 100 foot forested buffer along each side of a 63 foot wide, 6 foot deep dry swale constructed along the center. It is important to note here that the 100 foot buffer aligns with the Chesapeake Bay Resource Protection Area (RPA) standard for perennial streams. While the majority of the buffer proposed in the green

⁹ According to the National Parking Association's Parking in America; *Annual Review of Parking Rates in the United States and Canada* (2009) the average cost for structured parking is \$19,650 per space and the average cost for surface parking is \$5,000 per space. The difference between these two numbers represents the average cost of \$14,650 per space to utilize structured parking instead of surface parking. By dividing this difference by the typical area required for off street parking (including access lanes) at 300 square feet per space, this estimate results in a cost difference of \$48.83 per square foot of structured parking in place of surface parking.

¹⁰ According to the Virginia Department of Transportation (VDOT) the construction of an urban road costs \$779,775 per lane mile. Assuming the urban roads of Kamp Washington would average 10 ft in width, the average cost foot for urban road construction is \$14.83 per square foot.

infrastructure alternative does not exhibit perennial flow, consolidating green space around this area provides combined benefits described later in this chapter.

It costs \$.50 dollars per square foot to construct a dry swale. Costs range between \$218 and \$729 dollars per acre to plant and maintain a forested buffer (Lynch and Tjaden 2000)¹¹. The total cost for the construction of a 63 foot wide dry swale is \$206,700. The total cost for a 200 foot wide forest buffer ranges for \$6,700 to \$22,300. The cost of structured parking, the dry swale and the forested buffer reflects the total cost of the open drainage system at 21 million (Tables 9 and 10).

It is also important to note that conventional drainage systems mainly move stormwater through the system. Open drainage systems not only move water through the system, but remove water through natural processes such as infiltration and transpiration. When compared to Kamp Washington Concept Plan (7.7 acre-feet of total runoff), the green infrastructure alternative (6.6 acre-feet of total runoff) reduces necessary stormwater runoff by 1.10 acre-feet (Table 11). In a document published by the EPA titled: *Costs of Urban Stormwater Controls*, surface storage cost (C) is derived from the runoff volume (V) by the equation $C = 4.52V^{0.826}$. This equation is the composite of several surface storage cost estimates applicable to urban environments ranging from concrete reservoirs, tanks, and tunnels to earthen basins; each part of an individual study estimating construction costs (US Army Corp of Engineers 1981;Gummerman et al. 1979). If one assumes that this equation can also be applied to

¹¹ This measure assumes between 436- 550 trees per acre with an 80% survival rate. This estimate also considers costs for site preparation labor and maintenance.

dense mixed-use suburban infill development, then the EPA estimates that 1.1 acre-feet represents a cost-savings of \$175, 792 dollars per storm for surface storage¹².

With a conventional drainage system already in place, it would make little sense not to utilize it in some fashion. A potential design response to this would be to utilize the conventional system as a flood storage system (Figure 21). If the 72” outlet pipes

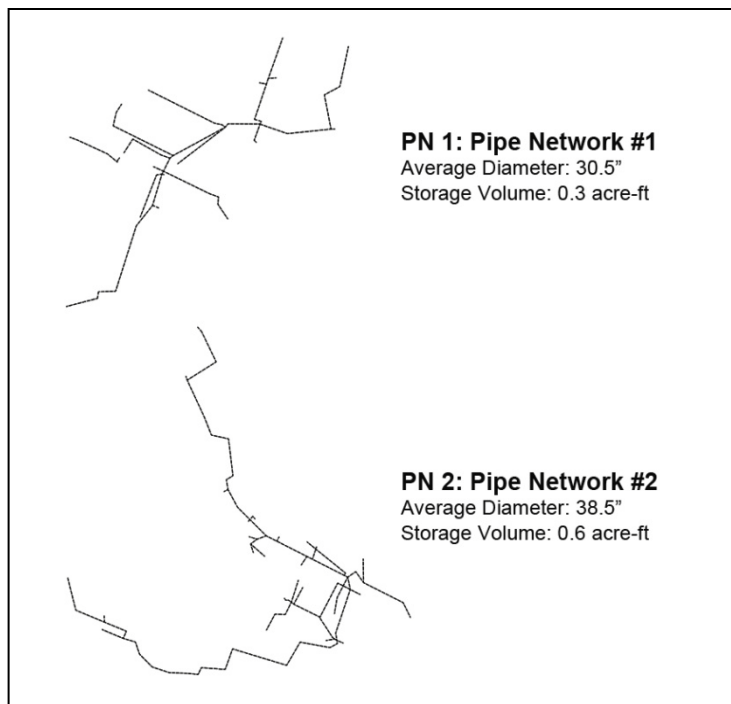


Figure 21: Repurposed Pipe Networks. Conventional drainage systems can still serve a purpose as water storage within an open drainage system. Pipe Networks 1 and 2 can store nearly 1 acre-foot of water to recycle. (source: Joshua C Franklin)

that discharge into Accotink creek are restricted to limit flow, stormwater will back up throughout the pipe network where overflow would just empty into the open channel conveyance system (Appendix 6). The Kamp Washington development would receive an additional 0.9 acre ft of storage (a cost savings of \$148,940 dollars per storm) and a conventional

system could be retrofitted to maintain a function. This solution reinforces the idea inherent within the green infrastructure alternative that sustainable design and water management can link urban and natural systems more harmoniously across multiple scales of design.

¹² This equation probably overstates the cost of storm water management in suburban infill areas. It is used for illustrative purposes in this example with the recognition that an actual cost accounting of two specified design alternatives may produce different results.

Table 9 compares the cost differences between the conventional drainage practices of the Kamp Washington Concept Plan to the open channel drainage of the

Total Cost of Green Infrastructure Open Drainage System		
Category	Type of Cost	Actual Cost
Development	Structured Parking	\$ 35,946,888
Development	Street Construction	\$ -15,116,278
Stormwater	Forested Buffer	\$ 6,700 - 22,300
Stormwater	Dry Swale	\$ 206,700
	Total Cost:	\$ 21,044,010 - 21,059,610
Total Cost of Concept Plan Conventional Drainage System		
Category	Type of Cost	Actual Cost
Development	Pipe Network	\$ 1,108,928.30
Development	Manholes	\$ 102,420.00
Development	Bedding	\$ 156,382.01
Development	Excavation	\$ 294,568.20
Stormwater	Storage	\$ 761,028- \$877,104
Stormwater	Water Quality	\$ 1,040,000 - 17,806,875
	Total Cost:	\$ 3,463,327 - 20,346,277

Table 9: Kamp Washington Drainage System Initial Cost Comparison .This table calculates the total cost to implement an open channel drainage system or replace a conventional drainage system. The construction costs associate meeting storage and water quality volumes are also calculated. (source: Joshua C Franklin)

Green Infrastructure Alternative. While the range in costs may suggest that conventional water management can be achieved at lower costs Table 10 highlights the added value of the increased flood storage of the Green Infrastructure Alternative. Adding the volume reduction of the Green Infrastructure Alternative (1.1 ac-ft) valued at \$175,792 with the added storage of the repurposed pipe network (.9 ac-ft) valued at 148,940 equals an increased net value of \$324,733 per storm over the conventional drainage of the Kamp Washington Concept Plan. Table 11 considers volume reduction as value for the comparison of initial costs and stormwater performance over time. According to Runoff Reduction Methodology, the treatment volumes displayed in Table 12 represent storms as part of the 90th percentile rainfall event. The rational for using the 90th

Cost Data For Drainage System Comparison-Table 10

Kamp Washington Cost of Pipe Network				
Pipe Diameter (in)	Pipe Length(ft)	Cost per Foot (\$/ft)*	Total Cost	
12	358	15.7	\$	5,620.60
15	6606	16.6	\$	109,659.60
18	4139	19	\$	78,641.00
24	1477	23	\$	33,971.00
30	351	55.8	\$	19,585.80
36	3455	74.4	\$	257,052.00
42	858	85.4	\$	73,273.20
48	1383	102.3	\$	141,480.90
60	1376	146.7	\$	201,859.20
72	975	192.6	\$	187,785.00
*taken from RS Means 1999			Total:	\$ 1,108,928.30
Kamp Washington Excavation Costs				
Avg depth calculated as difference in surface elevation subtracted from difference in pipe elevations, each at the top and bottom of the watershed				
Pipe Diameter (in)	Pipe Length(ft)	Trench Width (ft)	Excavation Amount (Yds ³)*	Total Cost**
12	358	3	397.8	\$ 2,820.24
15	6606	3	7340.0	\$ 52,040.55
18	4139	4	6131.8	\$ 43,474.79
24	1477	4	2188.1	\$ 15,513.95
30	351	6	780.0	\$ 5,530.19
36	3455	7	8957.4	\$ 63,507.96
42	858	7	2224.4	\$ 15,771.30
48	1383	8	4097.8	\$ 29,053.22
60	1376	10	5096.3	\$ 36,132.70
72	975	12	4333.3	\$ 30,723.30
			Total:	\$ 294,568.20
* This amount reflects the pipe length multiplied by the trench width and an average pipe depth of 10 feet				
**uses a fixed cost of \$7.09/yd ³ for clay soils. This cost factors labor, maintenance, materials, blasting and backfilling				
Kamp Washington Bedding Costs				
Pipe Diameter (in)	Pipe Length(ft)	Trench Width (ft)	Cost (\$/ft)	Total Cost
12	358	3	2.12	\$ 758.96
15	6606	3	3.51	\$ 23,187.06
18	4139	4	3.62	\$ 14,983.18
24	1477	4	5.44	\$ 8,034.88
30	351	6	5.55	\$ 1,948.05
36	3455	7	9.98	\$ 34,480.90
42	858	7	11.49	\$ 9,858.42
48	1383	8	13.01	\$ 17,992.83
60	1376	10	16.23	\$ 22,332.48
72	975	12	23.39	\$ 22,805.25
			Total:	\$ 156,382.01

Cost Data For Drainage System Comparison-Table 10 (continued)

Kamp Washington Manhole Costs					
Diameter(ft)	Depth (ft)*	Number of Manholes	Unit Cost**	Total Cost	
4	10	19	\$ 3,970.00	\$ 75,430.00	
5	10	4	\$ 5,070.00	\$ 20,280.00	
6	10	1	\$ 6,710.00	\$ 6,710.00	
Total:		24	Total:	\$ 102,420.00	
*An average depth of 10 feet is assumed across the watershed					
**RS Means 1999 cost data					
Cost of Conventional Stormwater Management for Kamp Washington Concept Plan					
Urban Stormwater Storage Costs					
Category	Equation*	Volume (gallons)	Cost		
Surface Storage	$C = 4.546V^{0.826}$	2509055	\$	877,104.35	
Deep Tunnels	$C = 6.22V^{0.795}$	2509055	\$	761,028.60	
*measured in million gallons		Cost Range:	\$761,028- \$877,104		
Urban Stormwater Water Quality Costs					
Category	Stormwater Practice	Equation	Cost		
Least Expensive BMP Practice	Dry Swale	$C=18,150/ \text{Imp-Acre}$	\$	1,040,000.00	
Most Expensive BMP Practice	Detention Pond	$C = 55,000V^{0.69}$	\$	1,432,269,404.02	
Multi-Chambered Treatment Train	Underground Vault	$C=\$1,875/m^3$	\$	17,806,875.00	
Total Cost of Concept Plan Conventional Drainage System					
Category	Type of Cost	Actual Cost			
Development	Pipe Network	\$ 1,108,928.30			
Development	Manholes	\$ 102,420.00			
Development	Bedding	\$ 156,382.01			
Development	Excavation	\$ 294,568.20			
Stormwater	Storage	\$ 761,028- \$877,104			
Stormwater	Water Quality	\$ 1,040,000 - 17,806,875			
		Total Cost:	\$ 3,463,327 - 20,346,277		
Green Infrastructure Stormwater Costs					
Category	Stormwater Practice	Equation	Area	Cost	
BMP Practice	Forested Buffer Strip	$C= \$218- \$729 / \text{Acre}$	31 acres	\$ 6,700 - 22,300	
BMP Practice	Dry Swale*	$C= .\$50 \times \text{sq. ft.}$	413431 sq.ft.	\$ 206,700	
			Total:	\$ 213,400 - 229,000	
*Swale is designed at 3 feet deep, 21 feet wide with a side slope of 2%					
Total Cost of Green Infrastructure Open Drainage System					
Category	Type of Cost	Actual Cost			
Development	Structured Parking	\$ 35,946,888			
Development	Street Construction	\$ -15,116,278			
Stormwater	Forested Buffer	\$ 6,700 - 22,300			
Stormwater	Dry Swale	\$ 206,700			
		Total Cost:	\$ 21,044,010 - 21,059,610		

Table 10: Cost Data For Drainage System Comparison. This table analyzes all of the cost data for the ranges suggest in table 11. The large variance in cost for conventional water quality is subject to the practice selected (e.g. Dry Swale, Detention Pond and Underground Vault). The major cost to establish the green infrastructure system associated with that alternative comes from maintaining a similar parking density to the Kamp Washington Concept Plan. (source: Joshua C. Franklin)

Green Infrastructure Cost Savings			
System	Volume(ac-ft)	Cost Savings*	Annual Cost Savings**
Site Design	1.1	\$ 175,792.00	\$ 7,910,640.00
Reused Pipe Network	0.9	\$ 148,940.00	\$ 6,702,300.00
Totals:	2	\$ 324,732.00	\$ 14,612,940.00
*Cost savings generated from the Narayanan and Pitt (2005) urban stormwater equation: $C = 4.546V^{0.826}$			
Cost Savings are based on flood storage per storm event			
** Annual Cost Savings are generated by multiplying the cost savings by the assumption of 45 storms per year			

Table 11: This table suggests the value generated from the additional 2 acre-feet the green infrastructure plan provides over the Kamp Washington Concept Plan (source: Joshua C Franklin)

percentile is that it represents the majority of runoff volume on an annual basis. The variability of storm

events per year is difficult to predict as it varies with location. In order to reference the total annual value of Table 7 an assumption was made to illustrate the number of storms per year in Eastern Virginia. This assumption assumes that the 45 inches of rainfall Virginia receives annually, comes from around 45 storms¹³. This would suggest the cost savings of the green infrastructure alternative save 14.6 million annually in stormwater reduction. 14.6 million that the Kamp Washington Concept Plan would have to spend to mitigate flooding.

Kamp Washington Drainage System Comparison				
	Conventional Drainage		Open Channel Drainage	
Initial Cost Range	\$3,463,327 – \$20,346,277		\$21,044,010 – \$21,059,610	
Operating Cost	\$ 887,104.00	per storm	\$ 552,461.00	per storm
Annual Operating Costs	\$ 39,919,680.00	45 storms per year	\$ 24,860,745.00	45 storms per year
Cost Range Per Year	Low Estimate	High Estimate	Low Estimate	High Estimate
2011	\$ 3,463,327.00	\$ 20,346,277.00	\$ 21,044,010.00	\$ 21,059,610.00
2012	\$ 43,383,007.00	\$ 60,265,957.00	\$ 45,904,755.00	\$ 45,920,355.00
2013	\$ 83,302,687.00	\$ 100,185,637.00	\$ 70,765,500.00	\$ 70,781,100.00
2014	\$ 123,222,367.00	\$ 140,105,317.00	\$ 95,626,245.00	\$ 95,641,845.00

Table 12: This table compares the initial and operating costs of a conventional and open drainage system applied to the Kamp Washington Concept Plan and Green Infrastructure Alternative, respectively. This table suggests that in a mere three years the open drainage system will operate for less than the conventional system. (source: Joshua C Franklin)

Using tables 9 and 10 as a guide, total costs can be compared for performance over time. Considering only stormwater storage the Kamp Washington Concept Plan generates 7.7 acre-feet of runoff and utilizing the urban stormwater storage equation

¹³ If the cost savings from value based design are multiplied by the 45 storms per year, annually savings would gross just over 14.6 million.

provided by EPA it costs \$887,104 to treat that runoff. The green infrastructure alternative generates 6.6 acre-feet, but the open drainage system proposed can reduce runoff by up to 2 acre-feet. This means the green infrastructure alternative is only responsible for 4.6 acre-feet of runoff and utilizing the same methodology it costs \$552,461 to treat that volume. These costs serve as the operating costs for both drainage systems displayed in Table 12. This table does not account for all costs as water quality would be necessary to meet Virginia stormwater regulations and would increase operating costs. However, water quality was not considered in an attempt to establish a simple comparison and limit the variability of cost associated with water quality. The initial cost for total construction of the open drainage system and the conventional drainage system are \$21,044,010 – \$21,059,610 and \$3,463,327 – \$20,346,277, respectively. By adding the annual operating costs per year with the initial costs for each system it would only take 3 years for the open channel drainage system to operate for less compared to the conventional system. Divide the open channel operating cost by the conventional operating cost from an given year and the result suggests the Kamp Washington Concept Plan costs 62% more annually than the green infrastructure alternative.

5.3 Combined-Benefits

Considering strictly dollar amounts and how alternative approaches to water management save money still only marginally grasps the potential of a green infrastructure approach to water management. Water can create savings as well as many additional benefits simultaneously. An example of this combined benefit philosophy is inherent in the City of Portland's Watershed Management Plan (PWMP).

“The watershed approach relies on integrating the activities of multiple City bureaus, and maximizing limited resources by looking for solutions that meet multiple interests. The approach incorporates City values of improving public safety, economic vitality and community stewardship into decision-making. This approach will guide the activities of each City bureau and program that affects watershed health to improve watershed conditions while addressing a wider range of community priorities.”- (PWMP 2005)

The PWMP considers all activities that affect a watershed, such as transportation, redevelopment and open space within the same document (Figure 22). This holistic

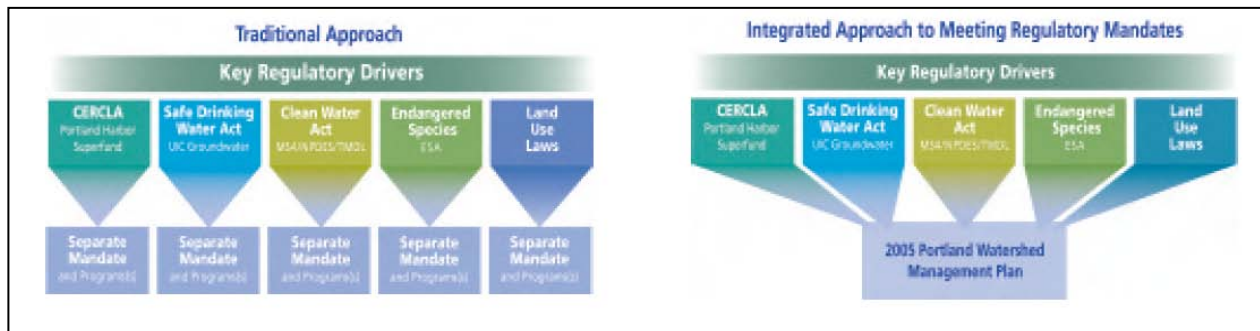


Figure 22: Integrated Approach to Watershed Management. This image compares a typical approach to watershed management with the integrated approach of the 2005 Portland Watershed Management Plan (source: Portland Department of Public Works)

approach integrates the work of various city bureaus, private citizens, businesses, and local non-profit to improve watershed health (PWMP 2005). The results of this approach acknowledge the opportunity of combined-benefits for all parties participating while simultaneously improving watershed conditions.

In many places stream corridors have developed as greenways, providing opportunities for walking and biking as well as observing nature adding value to places with a primary purpose of stormwater management (Kaplan, Kaplan and Ryan 1998). It is important to recognize that appreciation diminishes as the quality of streams become degraded.

“Of particular importance in how water is perceived is the water’s edge. A waterway that overflows its edge can look less attractive. And while [unkept] or eroded edges have resulted in lower preference ratings, hard surface solutions for containing the water can also generate unfavorable public reactions.”
 - (Kaplan, Kaplan and Ryan 1998)

So one way of placing combined benefits for watershed health involves maintenance to preserve public appreciation. One such organization within Fairfax County that could aid in the restoration of Accotink Creek around the Kamp Washington development is the Northern Virginia Soil and Water Conservation District (NVSWCD). NVSWCD promotes the physical rehabilitation of streams through restoration or stabilization techniques. In Fairfax County, many streams have suffered as a result of upstream development. The district works with county, state, and federal agencies as well as homeowner associations to identify streams with economically feasible rehabilitation potential. Once streams are identified, NVSWCD collaborates with these agencies to do the restoration or stabilization work. The district provides project coordination, grant writing and support, technical advice, and publicity for the projects. Since 1999, NVSWCD has completed two stream restoration projects including: Kingtowne Stream (1999) and Snakeden Branche (2003).

While preserving the urban character of a city is important, so is allowing people to interact with natural spaces. Allowing an open channel drainage system and preserving the urban density provides a unique opportunity illustrated in Figure 23. While people can still interact within the urban community, the open channel drainage system provides an excellent site for an urban greenway, increasing recreational space within Kamp Washington.

While saving a huge amount of money for stormwater management, the open channel drainage system can also add an economic amenity for human health, culture and recreation. For example, if a mature forest surrounded the open channel drainage system it could regulate climate and flooding through microclimates and infiltration, and



Figure 23: Advantage of Open Channel Green Space. Using an open channel drainage system can provide an opportunity for additional societal benefits. While the street life can be maintained through conserving urban density, a greenway can also be incorporated into the network of green space surrounding the open channel drainage system (source: Joshua C Franklin)

reduce air, noise and water pollution simultaneously. While these benefits are difficult to quantify, some studies suggest their economic benefits. For example, in Chicago, planting three trees per building per lot suggests \$50 to \$90 dollars in energy savings for heating and cooling each building per year. The same trees providing energy savings are also contributing to the cost savings of around 9 million annually for reduction of air pollution within Chicago's entire urban forest (McPherson et al 1997).

This forest example also provides recreational and cultural benefits for those that appreciate nature. Monetizing the benefits associated with recreational and cultural opportunities can be quite subjective as a community's opinion in one area may not be shared in others. One study from Switzerland suggests that people are willing to pay between \$600 and \$1000 annually for access to green space (Kline 2006). Another study in Indianapolis, suggested that residents were only willing to pay around \$550 dollars per year. Assuming that on average a person is willing to pay between \$400 and 600 annually for access to green space, the green infrastructure alternative would

provide Kamp Washington with a large economic asset. Regardless of the amount, these studies show that people do appreciate nature and their willingness to pay suggests that it has value to support their lifestyles.

Consolidation of green space requires an importance for design at the site scale. For example, Figure 24 compares the same intersection of Kamp Washington between the Concept Plan and the Green Infrastructure Alternative. When compared to the Kamp Washington Concept Plan, the green infrastructure alternative requires 47% less impervious surface while still maintaining similar, if not better traffic circulation.

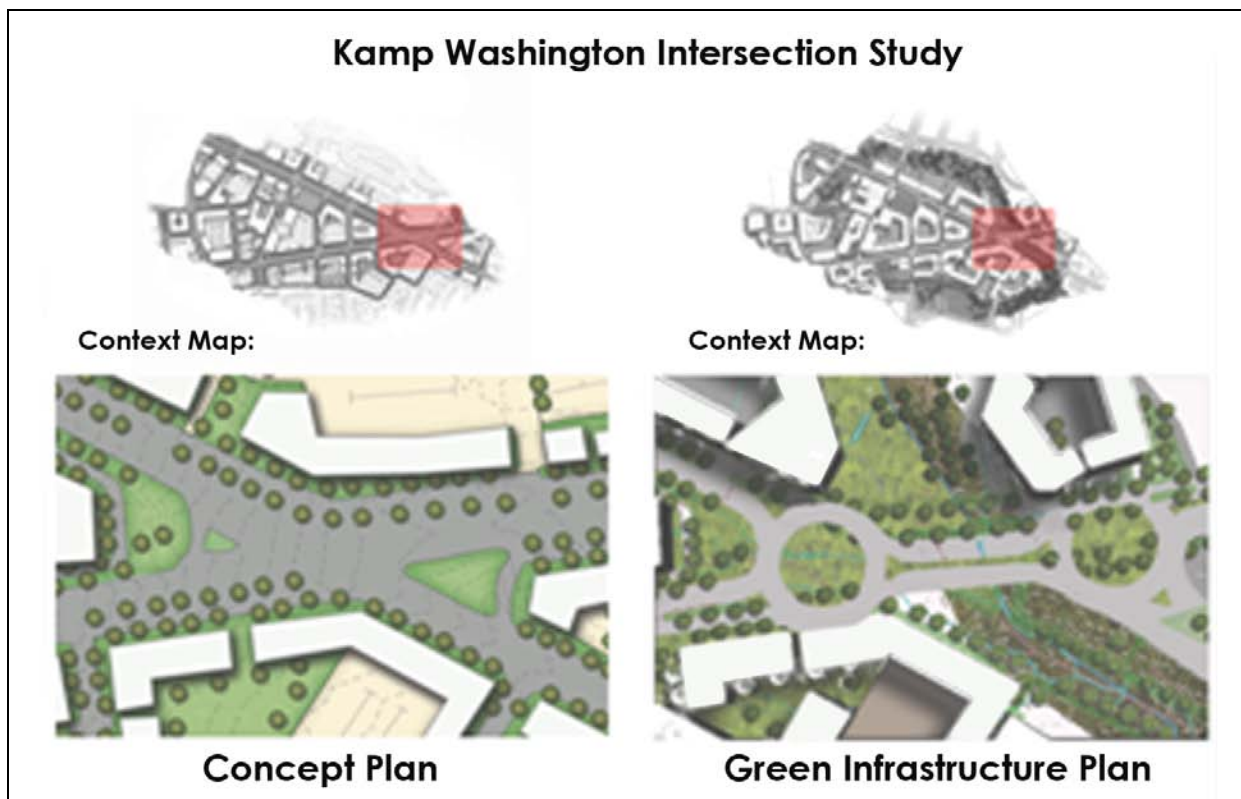


Figure 24: Kamp Washington Intersection Study. This image begins to suggest that the Green Infrastructure Alternative not only provides more green space, but considers how to consolidate that green space to provide additional environmental benefits (source: Joshua C. Franklin)

Developing solutions to maintain consolidated green space has significance for stormwater management and recreational spaces, but perhaps its greatest value comes in the form of ecological benefits for headwater streams. Freshwater ecosystems



North Fork Accotink Creek heads underground when it reaches Fairfax Shopping Center.



Implementing dry swales in Accotink Creek may be a better urban solution than conventional pipe networks



Improving the upper reaches of the Accotink Creek can lead to healthier Watersheds

Figure 25: Results of Open Drainage. This image illustrates the existing conventional drainage (top) and proposed open drainage (middle). The results of open channel drainage can lead to healthier watersheds (bottom) (source: FBMP 2009)

regulate hydrologic flows, store and retain water, treat pollution through filtration and biotic relationships and regulate local climate (Lucey et al. 2010). In urbanized areas sediment delivery accelerates to receiving waters which can have a smothering effect on stream channel substrates limiting their performance. Furthermore, subsurface drainage systems add to the problem, by bypassing any attenuation achieved through surface flows over vegetation. If headwater streams play a key ecological role in larger streams, then inadequate protection may not only harm headwater streams, but would also impact the integrity and sustainability of downstream environments.

Many key aquatic relationships for freshwater streams in the eastern United States are established in the headwaters. The source of many such relationships is organic matter (large wood, detritus and dissolved organic matter), a key input for freshwater biodiversity. In fact, the micro and

macro-organisms that feed on organic matter are often considered indicators of water quality due to the direct relationship with their stream environment.

In urban settings like Fairfax, headwater streams that are channelized and piped often produce a “dead zone” at their outfall as allochthonous inputs that partially drive energy flow and food webs are initially removed. The “dead zone” is the stretch immediately below the outfall where biodiversity slowly improves as primary organic materials become more available. What this means within the context of Fairfax is that RPA’s terminating against existing pipe networks can only marginally improve the health of immediate perennial streams without the primary inputs of headwaters. This advantage of open channel drainage is illustrated in Figure 25.

In addition to increases in biodiversity, there is a direct relationship between healthy headwater streams and human wellbeing. Over half of the accessible freshwater runoff in the United States is appropriated for human-use (Jackson et al. 2001). This demand creates an urgent need to ensure sufficient water for human wellbeing, while minimizing declines in biodiversity, the deterioration of freshwater ecosystems, and the loss of ecosystem services (Allan and Castillo 2009).

5.4 Conclusion

Though a workable method for making comprehensive comparisons of monetary versus environmental benefits for alternative proposals is still lacking, these three methods are not without their uses. In all three cases there is some indication of the economic benefits to using green infrastructure strategies to enhance natural system services in the Kamp Washington area. If simply considering the economics of capturing and reusing water, a lot of money can be saved. And while green building practices like

open channel water conveyance may not seem cost effective in the short term, modified cost and combined benefit estimates can suggest otherwise. In the combined-benefits approach provides the more comprehensive illustration of the benefits that can be provided to the public when the value of water as a resource is appreciated and plans ensure its wise use. Conventional practices may seem cheaper, but they cannot offer the same range of potential benefits. Providing solutions to stormwater management that simultaneously improve human health and well-being allows for the maximum economic return. While each of the three green infrastructure approaches looked at different areas of stormwater management (such as water storage, water management and water conveyance), there is no reason these practices cannot be implemented within one watershed management plan. An appropriate Accotink Creek watershed management plan that values water as a resource would combine the benefits of water storage, water management and water conveyance into an approach that maximizes benefits to humans and the environment simultaneously.

6

DISCUSSION AND CONCLUSIONS

Infill development, reclamation of abused urban lands, and redevelopment of underutilized sites are likely to play a notable role in shaping American cities and suburbs in the coming decades. How important that role will be depends on how much development actually occurs and where Americans choose to live. Estimates of the amount of development that will occur vary widely among researchers. However, numerous studies agree that demand for single family detached housing will diminish while smaller residential units in denser, more walkable, mixed use settings will become increasingly desirable (Litman, 2010; Nelson, 2004; Myers and Gearin, 2001). Arthur C. Nelson has proposed that up to 75 percent of new construction between 2000 and 2030 may “be redirected inward or into more compact, mixed-use suburban developments” (Nelson, 2004).

6.1 The Future Looks Dense

Nelson’s prediction carries with it two possibilities that are important to proponents of sustainable urbanism. As the density of development increases less land is devoted to serving a given population. Concurrently, for any level of development that does occur, inward growth means less sprawl intruding into ‘greenfield’ sites. To the

extent that this occurs, and Smart Growth actually leads to protection of lands in other portions of regional watersheds, greater numbers of people can be accommodated in urbanized areas without increasing stormwater related watershed impacts. As long as these stipulations are met, suburban redevelopment, guided by smart growth principles, can improve watershed health and water quality.

However, it is also likely, and probably desirable, that much of the redevelopment activity will occur in already highly impacted urban and suburban watersheds. Barring the type of sweeping redevelopment proposed in the LWARPS project, the compensatory effects of density are likely to be minimal in such watersheds. While growing attention is given to the future of urbanism the emphasis appears to be on curbing sprawling greenfield development - not design of urban and suburban in fill sites (Calthorpe, 1993; Duany & Plater-Zyberk, 1991).

There has been little study of how well community designs patterned on smart growth principles promote environmental protection, especially effective stormwater management and watershed protection (Berke, 2002). An examination of case studies demonstrates that redevelopment projects guided by 'T5' principles consistently produce land use patterns that are denser than the pre-existing suburban conditions. Since increased density is achieved without notable increases in impervious surface 'T5' development can be said to generally promote better hydrologic conditions per unit of built program than suburban sprawl. But, it is somewhat misleading to claim that mixed-use urban center zones designed in compliance with smart growth improve watershed health.

6.2 Conclusions

All three pilot studies demonstrate that urbanism can be more sustainable from a hydrologic perspective. As indicated in Study One form-based codes can, but do not necessarily account for urban watershed health. To reduce urban impervious surface and contiguous impervious surface is a function of land use pattern. It becomes evident when altering land use that there is a tension between the urban character deemed desirable by New Urbanism and the reality that taller buildings, less surface parking, and reduced street right of ways are required to recover the health of heavily urbanized watersheds. That is unless as in the LWARPS study, large areas of the watershed are recovered to open space and natural system services in future years. With Study Two one realizes several things. First, there is a tension between maintaining a continuous urban fabric which is probably important to the social and economic life of the city, and the continuity of open space systems which are important to urban ecology. Second, sometimes well intended environmental regulations don't address critical problems- for example, the absence of RPA buffers in headwater streams. Third, form-based development planning needs to be grounded in, or coordinated with, a broader systems oriented understanding, which raises questions of proper planning and design scales. Study three explains that within the context of Studies One and Two green building practices and technologies can provide economic incentives. When considering these technologies, the combined economic advantages of water are the most feasible solution. It also becomes apparent that infill development can actually decrease the health and sustainability of a watershed, especially when water resource needs as a

whole are accounted for (e.g. potable water, waste water, and storm water management).

Development changes the way people perceive their environment. If a link is necessary between urbanism and substantial environmental improvement, populations must understand that urban form dictates environmental performance. The question of environmental health and the places that humans inhabit is really more of a question of tradeoffs. As this thesis demonstrates, it is possible to offset and actually exceed the degradation of development through smart planning, design and management. For sustainable urbanism to truly achieve its potential, humans must decide what kinds of spaces and places they wish to inhabit. Whether this aligns with the ideals of incremental urbanism or proponents of Smart Growth requires a fundamental understanding of what is required for successful urban living. Without this understanding, it does not matter what form of urbanism is pursued as urban dwellers will determine the success or failure of their environments, not the guidelines or theories directing them.

This thesis utilizes three different studies that achieve huge environmental improvements as alternatives to conventional development. While these studies only scratch the surface of implications for urban design, all three do suggest that if people wish to live in sustainable environments then decisions must be made about where and how we live. This thesis demonstrates that density can improve environments even within heavily degraded urban watersheds. For density to be effective, clear understandings of the regional relationships between natural and urban systems should dictate where development is appropriate. In addition to smart design and planning, new

technologies can improve environmental benefits, while simultaneously adding a wide range of value from economics to health and safety.

Ultimately, the future of sustainable urbanism requires an understanding of to what degree people wish to be stewards of the environment. If large portions of current populations relocate in urban areas, then people must create alternative ways of living to sustain that population for future generations.

Belmar Lakewood

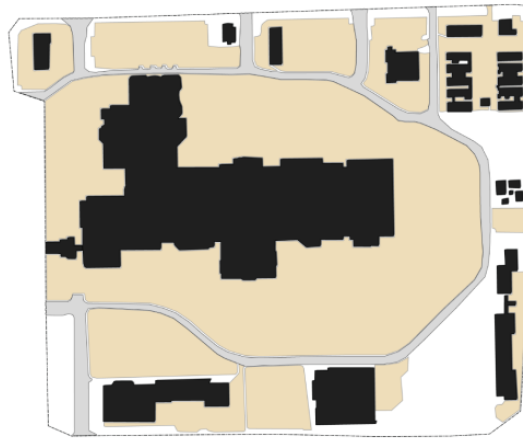
Location: Lakewood, CO

Existing:

Buildings: 24.6 Acres
Streets: 6.8 Acres
Parking Lots: 57.7 Acres
Green Space: 3.5 Acres

Proposed:

Buildings: 28.1 Acres
Streets: 20.8 Acres
Parking Lots: 51.6 Acres
Green Space: 14.9 Acres



Westwood Station

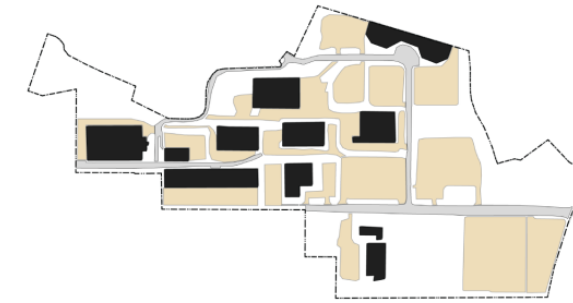
Location: Westwood, MA

Existing:

Buildings: 24 Acres
Streets: 20.6 Acres
Parking Lots: 33.7 Acres
Green Space: 79 Acres

Proposed:

Buildings: 29.4 Acres
Streets: 29 Acres
Parking Lots: 21.8 Acres
Green Space: 77 Acres



Cottonwood

Location: Holladay, UT

Existing:

Buildings: 13.4 Acres
Streets: 0 Acres
Parking Lots: 33.1 Acres
Green Space: 10.5 Acres

Proposed:

Buildings: 23.7 Acres
Streets: 12.6 Acres
Parking Lots: 8.5 Acres
Green Space: 12.1 Acres



Temple Terrace

Location: Lakewood, FL

Existing:

Buildings: 15.2 Acres
Streets: 15 Acres
Parking Lots: 31.9 Acres
Green Space: 32.7 Acres

Proposed:

Buildings: 33.8 Acres
Streets: 25.7 Acres
Parking Lots: 10.5 Acres
Green Space: 24.8 Acres



Fairfax Boulevard:

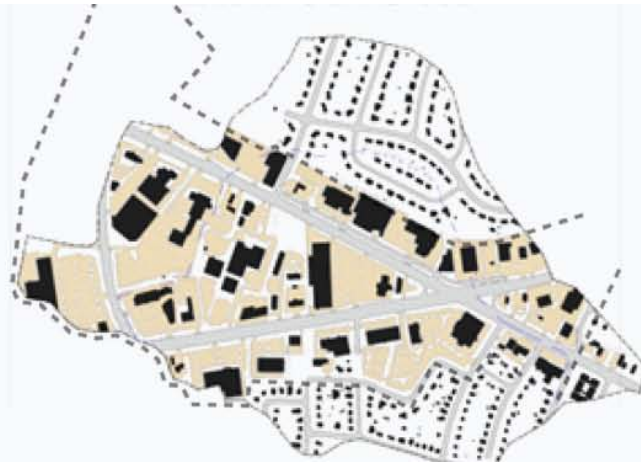
Location: Fairfax, VA

Existing:

Buildings: 24 Acres
Streets: 20.6 Acres
Parking Lots: 33.7 Acres
Green Space: 79 Acres

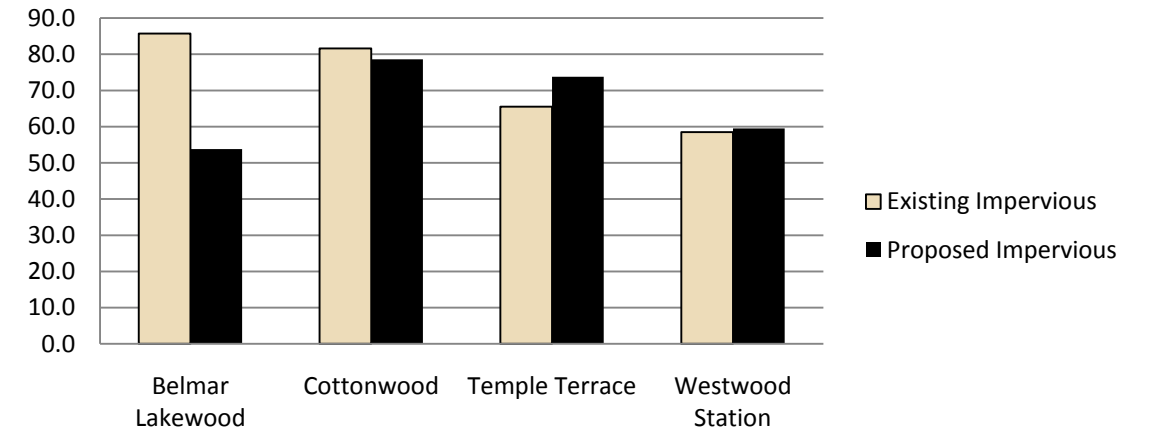
Proposed:

Buildings: 29.4 Acres
Streets: 29 Acres
Parking Lots: 21.8 Acres
Green Space: 77 Acres

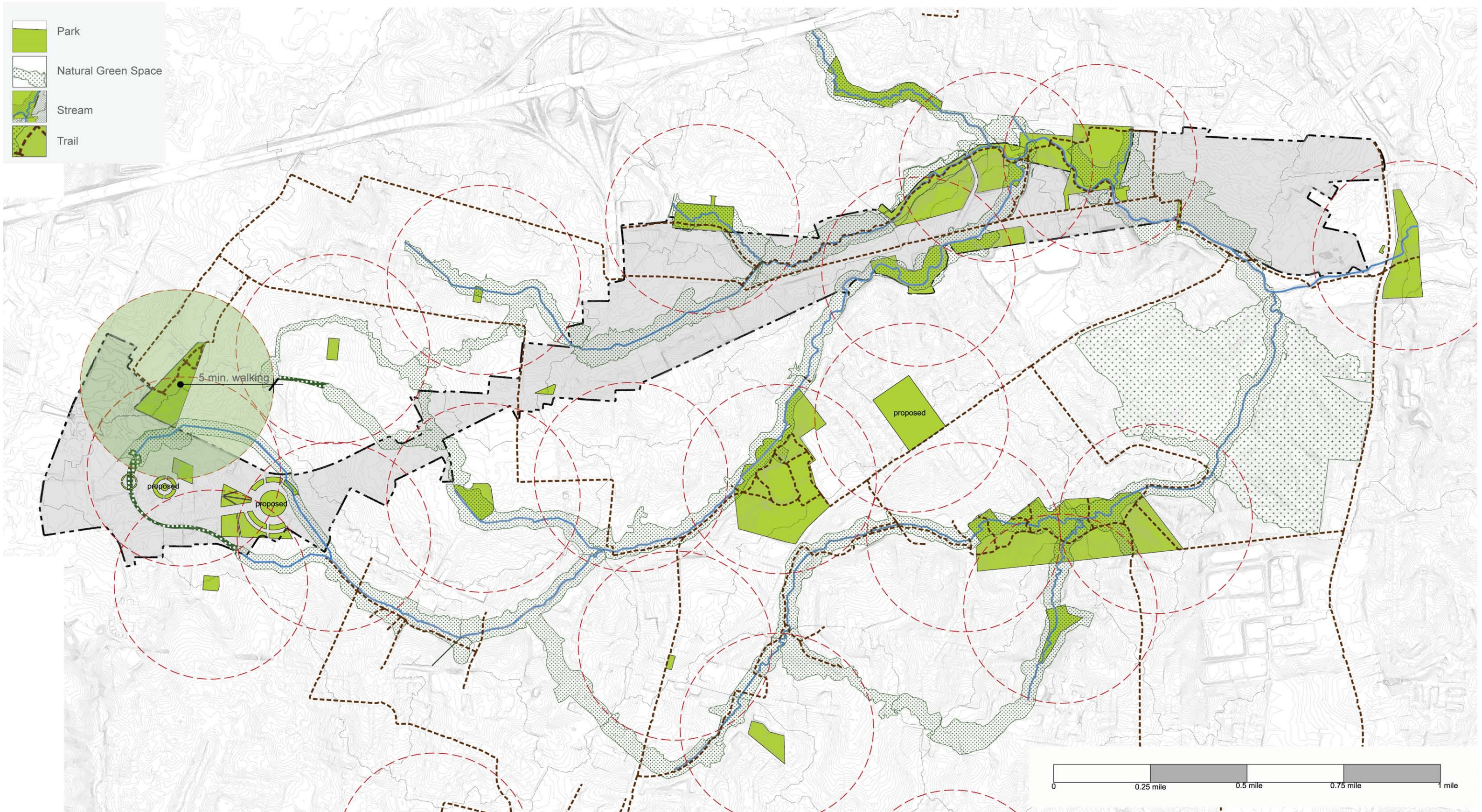


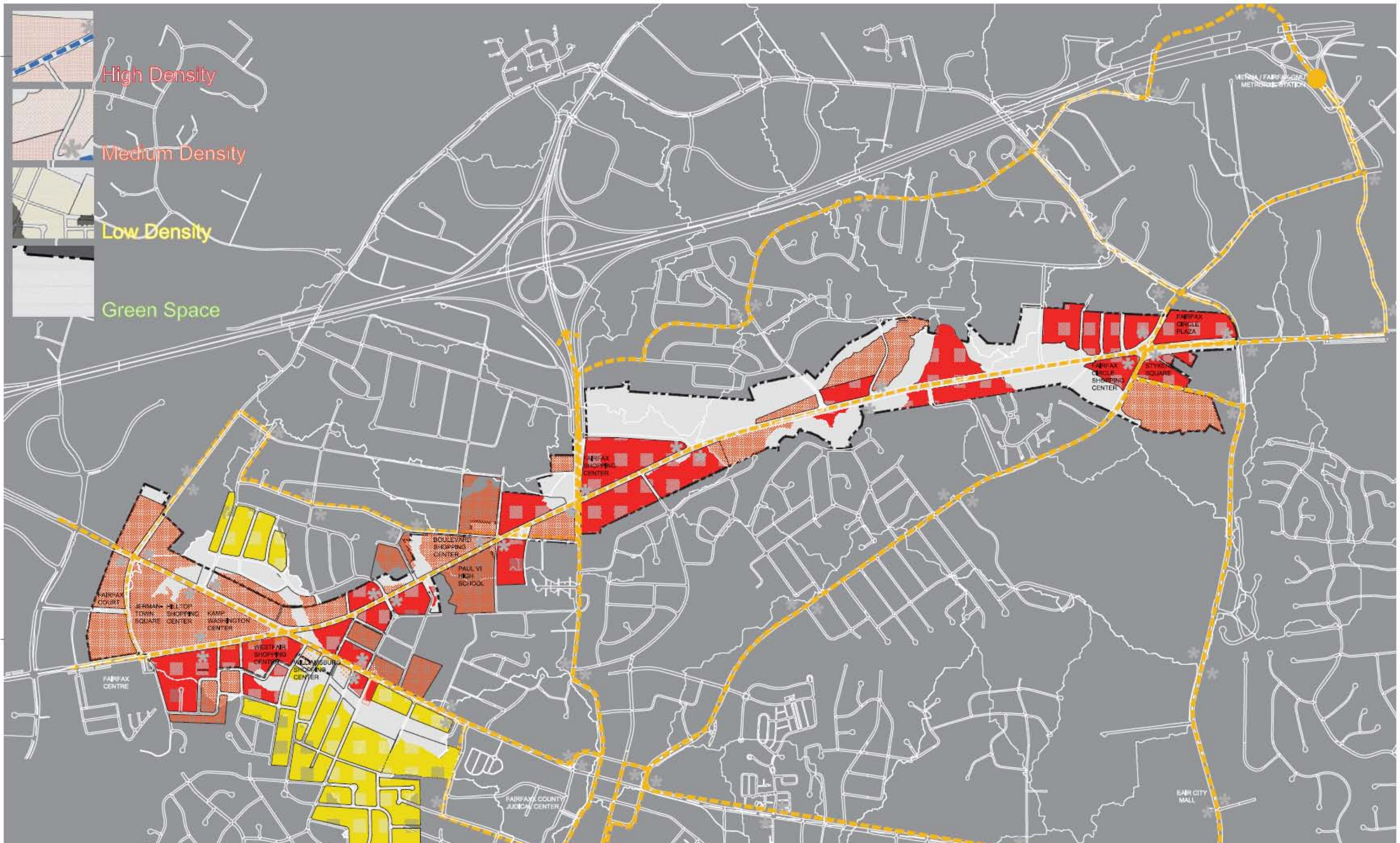
Streets Green Space Parking Buildings

Total Percent Impervious

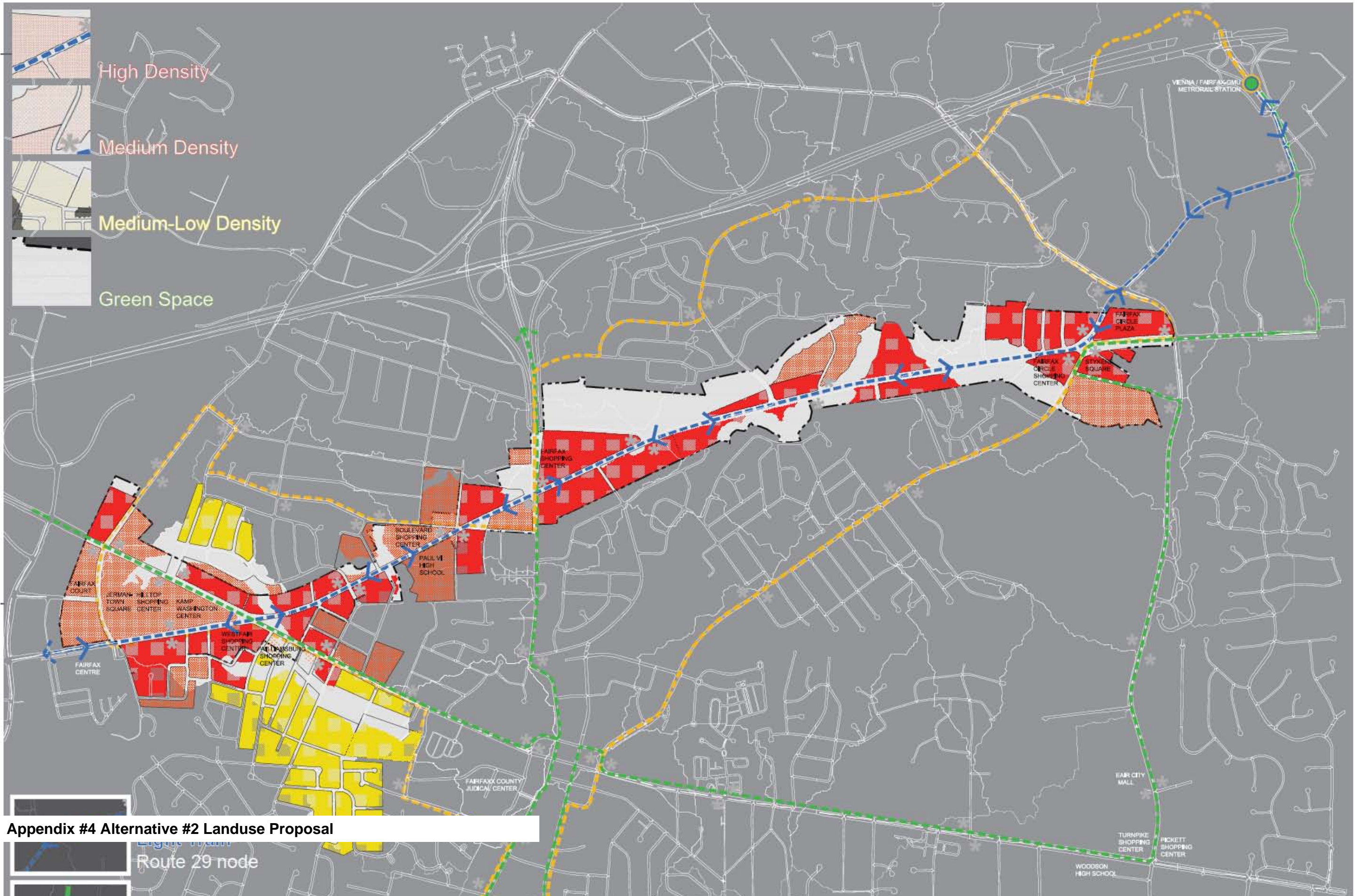


This graph indicates the changes in impervious surface between existing and proposed development for each case study. (source: Dean R. Bork)





Appendix #3 Alternative #1 Landuse Proposal



Appendix #4 Alternative #2 Landuse Proposal

Light Rail
Route 29 node

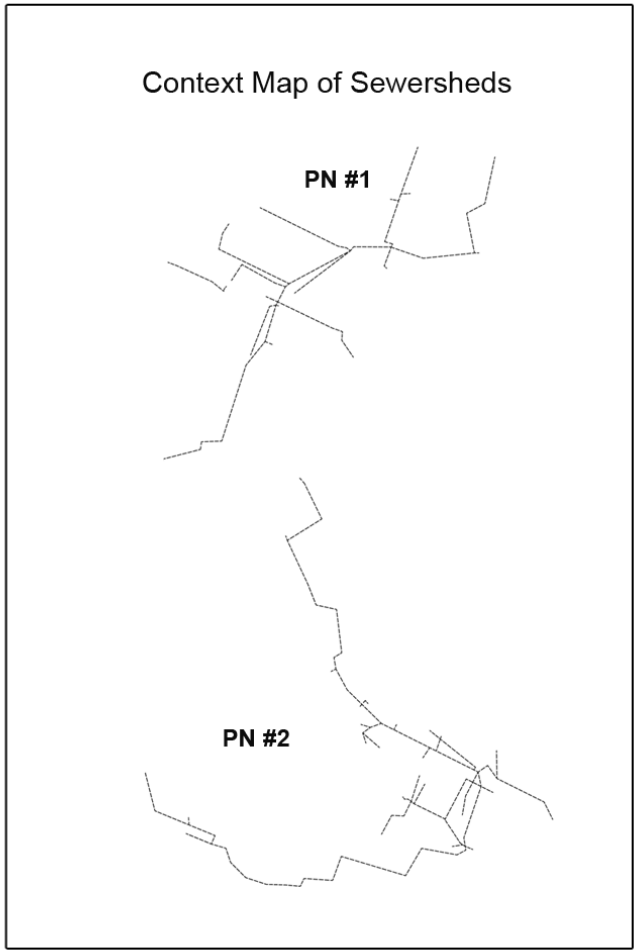
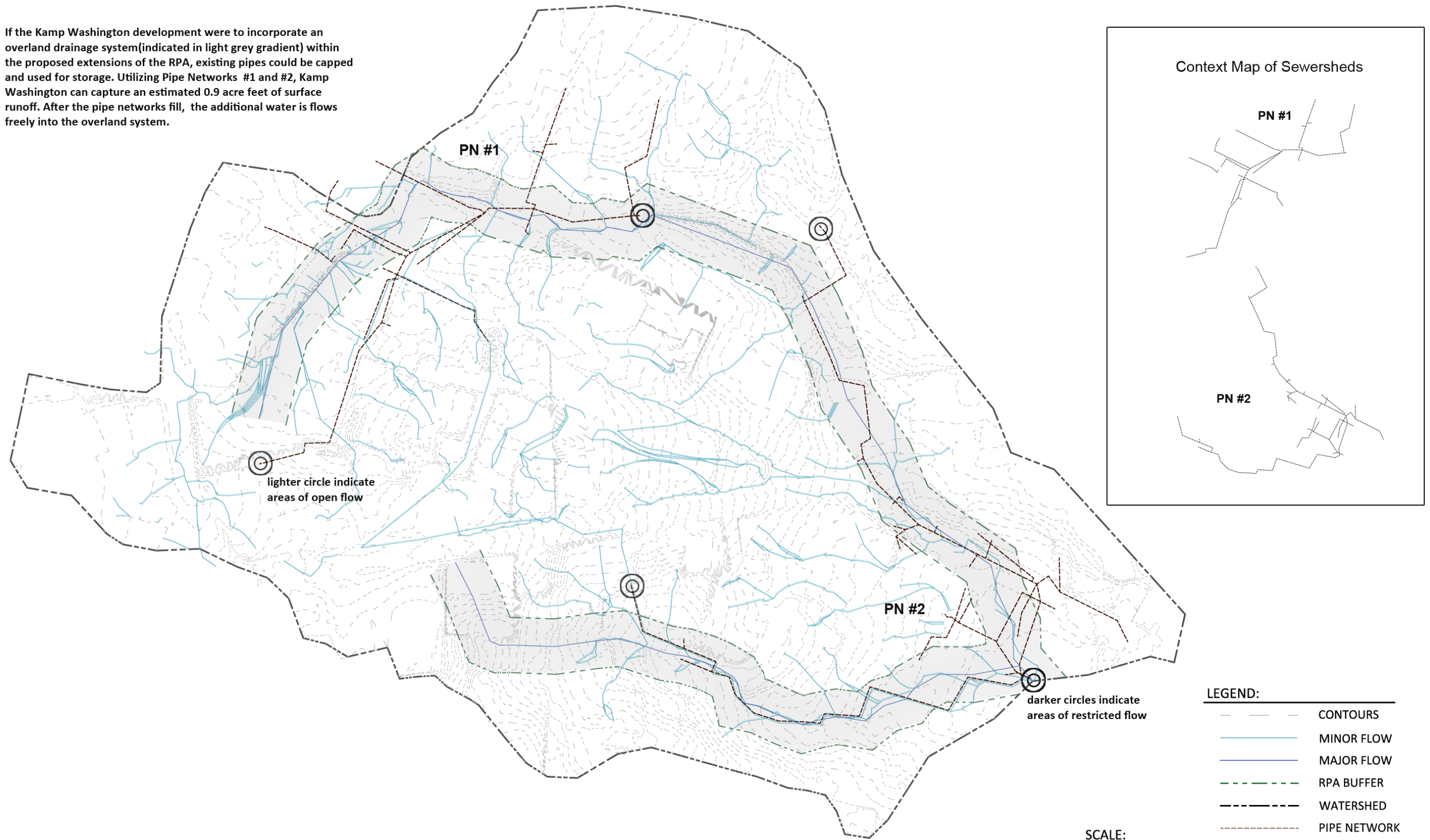
Study #1 Scenarios

Cover Type	Impervious surface (acres)	Percent Impervious	Maintained Landscape (acres)	Percent Maintained	Forested (acres)	Percent Forest	Runoff Volume (acre-feet)
Forested Condition	0.0	0%	0	0%	157.2	100%	0.50
Existing Suburban	78.2	50%	77.5	49%	1.5	1%	7.60
Proposed Condition	80.2	51%	77	49%	0	0%	7.70
Scenario 1- Maximize Building Height	71.5	46%	85.7	54%	0	0%	7.20
Scenario 2- Surface Parking Reduction	69.7	45%	87.5	55%	0	0%	7.10
Scenario 1 + Scenario 2 Combined	60.9	39%	96.3	61%	0	0%	6.60
Scenario 3- Impervious Disconnects	78.2	50%	79	50%	0	0%	6.10
Scenario 3 + Scenario 1 Combined	71.5	46%	85.7	54%	0	0%	5.50
Scenario 3 + Scenario 2 Combined	69.7	45%	87.5	55%	0	0%	5.40
Scenario 3 + Scenario 1 & 2 Combined	60.9	39%	96.3	61%	0	0%	4.70
Scenario 4- Enhanced Greenspace	78.2	50%	0	0%	79	50%	5.50
Scenario 4 + Scenario 1 Combined	71.5	46%	0	0%	85.7	54%	4.80
Scenario 4 + Scenario 2 Combined	69.7	45%	0	0%	87.5	55%	4.70
Scenario 4 + Scenario 1 & 2 Combined	60.9	39%	0	0%	96.3	61%	4.20
Scenarios 1, 2, 3 & 4 Combined	60.9	39%	0	0%	96.3	61%	3.20

Study #2 and #3 Alternatives

Cover Type	Impervious surface (acres)	Percent Impervious	Maintained Landscape (acres)	Percent Maintained	Forested (acres)	Percent Forest	Runoff Volume (acre-feet)
Alternative 1	59.7	38%	70.8	45%	26.7	17%	6.10
Alternative 2	31.4	20%	97.5	62%	28.3	18%	4.30
Alternative 3	69.7	45%	56.1	35%	31.4	20%	6.60

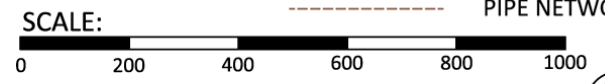
If the Kamp Washington development were to incorporate an overland drainage system (indicated in light grey gradient) within the proposed extensions of the RPA, existing pipes could be capped and used for storage. Utilizing Pipe Networks #1 and #2, Kamp Washington can capture an estimated 0.9 acre feet of surface runoff. After the pipe networks fill, the additional water is flows freely into the overland system.



lighter circle indicate areas of open flow

darker circles indicate areas of restricted flow

- LEGEND:**
- CONTOURS
 - MINOR FLOW
 - MAJOR FLOW
 - - - RPA BUFFER
 - - - WATERSHED
 - - - PIPE NETWORK



KAMP WASHINGTON
FAIRFAX, VIRGINIA

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