
RUNOFF IMPACTS AND LID MITIGATION TECHNIQUES FOR MANSIONIZATION BASED STORMWATER EFFECTS IN FAIRFAX COUNTY, VA

Jessica A. Hekl

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Randel L. Dymond, Chair

Meredith T. Jones

Kathleen Hancock

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ABSTRACT

This study uses the Natural Resources Conservation Service (NRCS) TR-55 method to quantify the increase in stormwater runoff volume from infill residential redevelopment, or mansionization, in a 34-acre residential subwatershed of Fairfax County, Virginia. Analysis of 10 redeveloped lots in the subwatershed showed an average increase in impervious cover from 8% to 28% after redevelopment, resulting in an average increase in runoff volume of 18% for the 10-year, 24-hour storm. From 1997 to 2009, the total impervious cover in the subwatershed increased from 18% to 25%, resulting in a calculated 6% increase in runoff volume. Low Impact Development (LID) techniques were modeled as retrofits in the subwatershed to mitigate the increase in runoff volume. Measures modeled include bioretention basins, infiltration trenches, amended soils, permeable pavement, and cisterns. Results indicate that placing bioretention basins or infiltration trenches on 0.5% of the subwatershed or amending 20% of the open space with soil composts would reduce the runoff volume back to the 1997 quantity for the 1-year, 24-hour storm.

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1 INTRODUCTION

Owning a single-family home in the suburbs has long been emblematic for achieving the American Dream. For even longer, the size of a home has been a symbol of the owner's economic and social status. In order to "keep up with the Joneses", residents are building larger and larger homes in the suburbs of cities. The average size of a new single-family home in United States in 1973 was 1,525 square feet of floor area and in 2013, the average home size was approximately 1.5 times larger at 2,384 square feet (U.S Census Bureau 2013). With vacant lots becoming rare in highly developed areas, the trend in recent years is for older homes to be demolished or remodeled in order to create larger homes.

A major area where this redevelopment is occurring is in older suburban neighborhoods in the United States that were established from the late 1940s to the 1960s. Following World War II, there was a major population boom coupled with a lack of housing. Many of the homes were mass produced with a small footprint, and were often regarded as being the same in appearance (Miller 2012). As these post-war era homes degrade and affluent families move to the suburbs to buy a large single-family home, these existing, small homes have become a prime target for demolition and rebuild. This process is known as "mansionization", "teardowns", "bash and build", "residential redevelopment", "rebuilt", "knockdowns", etc. (Pond and Kacvinsky 2006). Many of these new, larger homes have been given derogatory names such as "McMansions", "mega homes", or "monster homes" (Nasar et al. 2007). While not all of the homes can be considered "McMansions", a significant number of older homes are gradually being replaced by larger homes.

The beginning time frame for this infill suburban redevelopment varies by location, but generally the teardown trend began in the late-1980s to mid-1990s. The Chicago metropolitan area claims that the development commenced in the late 1980s (CMAP 2008), whereas in Silicon Valley, the rise was more in the mid-1990s when there was a mass influx of immigrants (Lung-Amam 2013). This type of development is still occurring near cities all over United States and even globally. Because this practice has only been occurring in the past two decades, many communities are just starting to notice the social, economic, and environmental effects.

Some believe that these rebuilds benefit the community by boosting the economy and promoting development that increases property values and the local tax base. The new homes gentrify the area by replacing older, degrading homes with new ones (CMAP 2008). It is also argued that the infill development reduces sprawl and takes advantage of already existing infrastructure, which is in line with Smart Growth strategies (Nasar et al. 2007).

Opponents to the teardown practice claim it changes the community character and causes neighborhoods to be less affordable for the majority of the population. A major controversy in many neighborhoods are the rebuilt home's incompatibility with local and historic architecture in the community. Additionally, environmental impacts have become a significant concern. These include loss of mature trees, lack of open space, and changes to the stormwater runoff leading to erosion and flooding (CMAP 2008; Nasar et al. 2007; Pond and Kacvinsky 2006).

One-by-one these homes are being entirely rebuilt or renovated to have a much larger footprint. The cumulative environmental impact of rebuilt neighborhoods is becoming increasingly apparent to the localities that are responsible for stormwater quantity and quality control issues.

1.1 BACKGROUND

1.1.1 Impervious Surfaces and Watershed Hydrology

One intuitive relationship that has been well-studied in the literature is that as impervious area increases, the total volume and velocity of stormwater runoff increases. Impervious surfaces generally include roads and rooftops, but can also include sidewalks, patios, recreational surfaces, driveways, and even compacted soil (Arnold and Gibbons 1996). A thorough literature review of the various impacts of impervious surfaces on watershed hydrology was completed by Shuster et al. (2005). The review summarized that a higher percentage of impervious area limits rainfall infiltration into the ground. Additionally, a paved surface's hydraulic efficiency increases the speed at which the runoff travels downstream. These changes cause an increase in runoff volume, a decrease in water table recharge, and shorter times of concentration. This fast-moving, higher volume of runoff from a storm is known to cause stream bank erosion and flooding (Booth et al. 2002).

As this stormwater is traveling downstream during and following a storm, it accumulates dissolved and suspended solids. These contaminants have leaked from automobiles, been applied to plants as a fertilizer or pesticide, or were produced from erosion. The major stream pollutants from stormwater runoff are nutrients, noxious substances, sediment, and debris (Arnold and Gibbons 1996). Several studies have shown that imperviousness and water quality have a strong correlation (Brabec et al. 2002). As impervious cover increases, stream health diminishes (Schueler 1994). Pollutants from urban runoff are categorized as being from a nonpoint source and are considered a leading contributor to river and stream impairment by the United States Environmental Protection Agency (USEPA 2005).

Computing the impervious surface area within a drainage basin is one major method of determining the environmental degradation caused by development. Schueler (1994) summarized the results from several

studies, concluding that stream health significantly decreases when the impervious coverage exceeds 10 to 15% of a watershed. In the majority of urban areas, the percentage of impervious area is at or above this threshold. Therefore, it is important to determine the pre- and post-development land cover in order to define the change in watershed hydrology within the drainage area.

1.1.2 Stormwater Management Design Standards over Time

The approaches to stormwater management have changed significantly over time in order to adapt to urbanization and new federal legislation (Roy et al. 2008). In the 1950s to the 1970s, when the majority of these teardowns were first built, the main focus of localities and developers was to reduce the magnitude and frequency of floods (Anderson 1970). The concomitant design standards were to drain runoff offsite as quickly and efficiently as possible, typically with paved surfaces, and little attention to moderating water quality (Arnold and Gibbons 1996). These traditional stormwater management systems depend on storm sewer drains and large detention basins (Gilroy and McCuen 2009). As part of the 1987 Water Quality Act amendment to the Clean Water Act (CWA) (*33 USC 26 - Federal Water Pollution Control Act 1972*), the National Pollutant Discharge Elimination System (NPDES) created a two-phased stormwater program where select municipalities and industrial sites are required to obtain a permit to discharge stormwater into local water bodies. “Phase I” of the program, instituted in 1990, relates to Municipal Separate Storm Sewer Systems (MS4s) located in medium or large incorporated areas or counties, such as Fairfax County, VA. The specific legislation varies by state, but throughout the United States, identifying Best Management Practices (BMPs) for controlling the pollution from rainfall runoff has become the focus of stormwater management strategies in recent years (USEPA 2005).

Identifying BMPs that can mitigate water quality effects has resulted in the growing popularity of implementing Low Impact Development (LID) techniques in land development (Loftin et al. 2010; Madalon, Jr. 2007). Some of the tools and innovative BMPs that fall under the LID approach are infiltration trenches, bioretention areas, permeable pavement, and rain cisterns. LID methods control the runoff on-site rather than downstream and primarily focus on mimicking pre-development hydrology. This is achieved by attempting to infiltrate, evaporate, or detain runoff near the disturbed area (Prince Georges County, Maryland 1999). These changes in stormwater regulations and development strategies have become difficult to apply to home teardowns. Localities like Fairfax County struggle to comply with their NPDES MS4 permit when these redeveloped residential sites have minimal open space for BMPs within public areas and no required public stormwater improvements downstream. Implementing small structural and non-structural LID practices on individual residential lots has become the recent trend to help treat and slow down the rainfall runoff traveling from a development.

1.1.3 Conditions in Fairfax County, Virginia

Fairfax County is the most populous jurisdiction in the Commonwealth of Virginia, Washington Metropolitan area, and the Chesapeake Bay Watershed. In 2013, the population was estimated to be over 1.1 million and the average median income is over \$100,000. It is a densely populated, wealthy suburb of Washington, D.C. (Fairfax County, Virginia 2013a). According to the 2013 comprehensive plan, the County started as an agricultural producer for the nation’s capital, but “*after World War II, the County became a suburban bedroom community on the fringe of Washington, D.C.*” (Fairfax County, Virginia 2013b). Now, the 395-square-miles of land that makes up the county has nearly reached its built-out point, meaning there are few greenfield parcels left and redevelopment of large tracts of land is difficult. This lack of developable area, coupled with an influx of wealthy families, has led to the “mansionization” of older post-war developed residential parcels in Fairfax County. Figure 1 displays the location of the County within the Commonwealth of Virginia.

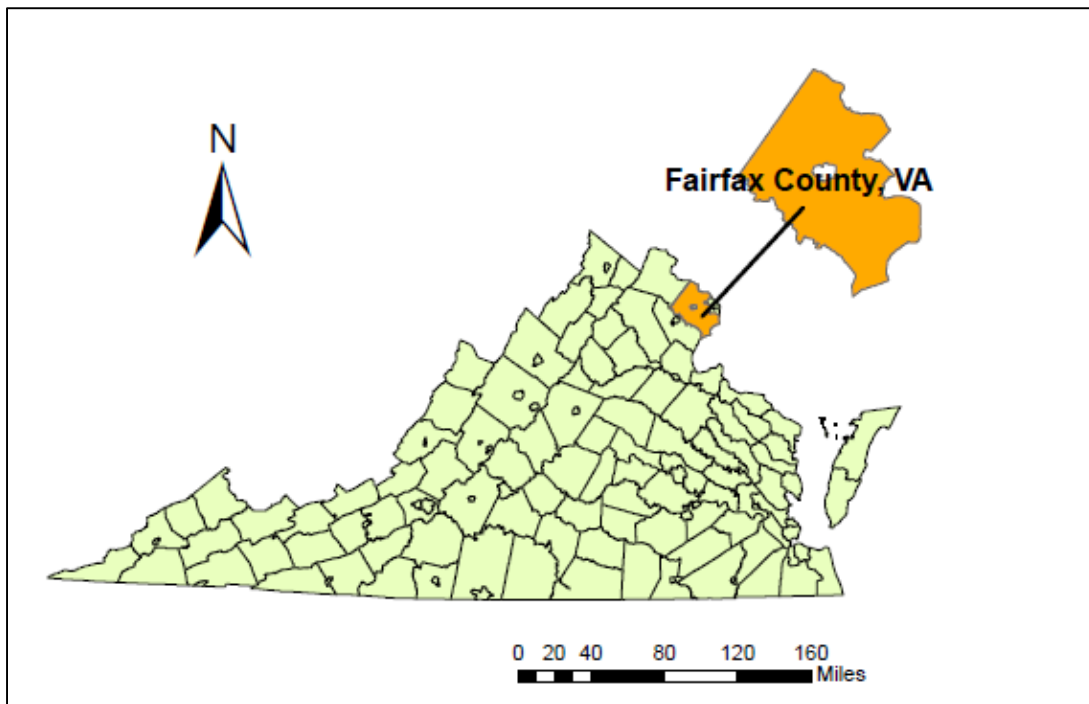


Figure 1 - Location of Fairfax County within the state of Virginia.

As stated in Fairfax County’s stormwater report (Fairfax County, Virginia 2014a), the County has a Phase 1 MS4 permit allowing discharge of stormwater runoff. To meet the requirements of this permit, annual reports must be submitted to the Virginia Department of Environmental Quality (VDEQ) that lists details of the County’s stormwater management program. Additionally, there are several streams within the county that are listed as impaired by the VDEQ and subsequently have a Total Maximum Daily Load (TMDL) of nonpoint source contributions. BMPs installed throughout the County are used to comply

with these standards, but in situations that involve teardowns, the new homes' large square-footage doesn't provide much extra space for stormwater management on the lot.

In July of 2000, Fairfax County published the "Infill and Residential Development Study", an interdisciplinary document written by multiple agencies in the County, which addressed items such as "compatibility, traffic, tree loss, and stormwater management" issues related to infill development. As listed in the report, the following activities are included under their definition of infill development:

- *Demolishing an existing home on a lot and building a larger home;*
- *Subdividing a single lot into two more building lots;*
- *Developing one or more new residences on an undeveloped or underutilized site within an existing, established neighborhood;*
- *Developing a relatively large subdivision that is surrounded by other recently developed subdivisions; and*
- *Redeveloping an existing subdivision (Fairfax County, Virginia 2001).*

Recommendations were made based off the listed problems in the report and many of them were employed as adjustments to the Fairfax County Public Facility Manual (PFM). The PFM is the technical manual used as a guiding document for design of all public facilities within the County. This was Fairfax County's first attempt to begin addressing infill development by instituting policy to help mitigate the impacts from the construction (Fairfax County, Virginia 2001).

Currently, a recent amendment to the stormwater ordinance specifically addresses residential infill development water quality requirements. It distinguishes residential infill with the following definition:

"Single-family dwellings separately built and disturbing less than 1 acre and not part of a larger common plan of development or sale, including: additions to existing single-family detached dwellings; accessory structures to single-family detached dwellings; and demolitions of single-family detached dwellings or accessory structures (Fairfax County, Virginia 2014b)."

These homes are required to meet specific stormwater wasteload allocations or WLA *unless* it meets one of the following:

1. The new imperviousness is less than 2,500 square feet or 18% of the total lot.
2. The total area is 0.5 acres or less and there is no more than 500 square feet of new impervious.
3. There are already water quality controls from the original subdivision that are still in place.
4. The property is served by an existing regional stormwater management facility that has water quality controls (Fairfax County, Virginia 2014b).

This amendment keeps homeowners that are only adding a small addition on their home from being required to address water quality control measures, but those homeowners in total who are significantly altering the land cover of the watershed to be subject to the water quality measures.

While there have been attempts to control the development in the County, issues related to stormwater still remain. The major issue in Fairfax County related residential infill redevelopment is that the construction of these homes is non-bonded and not subject to the County's subdivision ordinance. Typically, in land development projects, the subdivision ordinance would require a security bond with the locality that guarantees that public infrastructure improvements, such as stormwater management systems on public streets, will be built. However, these infill development homes are changing the land cover and altering historic drainage patterns without required mitigation downstream. The current standards for a redeveloped lot in the County require that the plans for a newly redeveloped home demonstrate there is adequate, non-impairing drainage from the site and that certain water quality criteria are met (Fairfax County, Virginia 2011). However, these standards do not necessarily account for the increased volume of sheet flow from each site. This increased volume accumulates from multiple redevelopments in the same vicinity and causes drainage issues downstream (Patteson and Meyers 2015).

Another concern of the County relates to existing and proposed stormwater facility maintenance. In a typical neighborhood development, there might be a large downstream management facility that is on County or Homeowner Association (HOA) property. These types of facilities are easy to maintain and to ensure proper operation. This maintenance becomes more difficult in the case of smaller facilities. Any BMP that is placed on the lots of these mansions to treat stormwater onsite needs to be maintained by the landowner and is subject to routine checks by the County in order to uphold compliance with the MS4 permit. The site plan's approval is subject to a Private Maintenance Agreement (PMA) where the private owner of the facility is legally obligated to maintain the facility to ensure proper functioning and the County is allowed right of entry every five years for routine inspection (Fairfax County, Virginia 2011). These agreements result in a large inventory of small BMPs that must be inspected by the County which require a substantial amount of money and time. It is necessary that this inspection burden be minimized while still ensuring that the LID techniques on each property are properly maintained

1.1.3.1 Patton Terrace Subwatershed Pilot Study

In areas of Fairfax County where there has been a significant amount of renovation to older single-family homes, some environmental impacts have already occurred. In 2007, the Stormwater Planning Division of the Fairfax County Department of Public Works and Environmental Services (DPWES) established a pilot program intending to address some of the drainage issues that have developed from mansionization throughout a neighborhood in McLean, VA. Originally built in the 1950s, the neighborhood has a

significant number of the homes that have been rebuilt or remodeled in the past two decades. The pilot program focuses specifically on a 34-acre, fully residential subwatershed in McLean called Patton Terrace. Within the catchment, around half of the homes have been rebuilt or remodeled. The cumulative increase in impervious surface from this new development is assumed to be the cause of significant property flooding and erosion as well as stream bank erosion reported within the neighborhood. Another contributor to the drainage issues specific to this neighborhood is the lack of curb and gutter and the elimination of some roadside ditches by “incidental filling and construction of parking pads” by residents. These ditches were part of the original stormwater management system and cannot convey the stormwater sufficiently once altered. Lastly, the neighborhood has many areas of steep slopes where stormwater sheet flows at a high velocity to the outfall. These effects combined have resulted in significant challenges for Fairfax County in this already established neighborhood.

Overall, the pilot program is to provide a holistic approach to solving the drainage problems local to the neighborhood. The primary goals of the project listed in its stormwater management study and conceptual plan are as follows:

- 1. Reduce local drainage problems which are associated with intermittent basement and yard flooding;*
- 2. Improve water quality and stream protection downstream of the County’s municipal separate storm sewer system (MS4) that outfalls to an unnamed tributary of Little Pimmit Run;*
- 3. Partner and develop a working relation with the community to make neighborhood improvements;*
- 4. Maintain and improve aging stormwater infrastructure that is over 50 years old;*
- 5. Develop recommendations on how to better manage and address drainage problems, stream protection and watershed management in communities experiencing similar infill residential redevelopment; and*
- 6. Improve environmental quality and enjoyment of the neighborhood (Versar and ATR Associates Inc. 2012).*

As of 2014, the final design has been completed to include several retrofits and improvements to the stormwater system of the neighborhood within the Virginia Department of Transportation (VDOT) Right-of-ways (ROWs) and County easements. They are to include the addition of several LID techniques to remediate the stormwater drainage issues within the neighborhood (Michael Baker Jr., Inc. 2014).

1.2 PROBLEM STATEMENT

Throughout the suburbs of cities all over the world, mansionization is occurring. Mansionization is defined as the full teardown of, or addition to, an older single-family home that creates a much larger footprint than the existing structure. The cumulative amount of impervious area added from each individual infill development is presumed to have an impact on the watershed hydrology. Currently, there is minimal literature describing this occurrence and its environmental effects. Furthermore, localities like Fairfax County, Virginia are trying to find ways to deal with the stormwater and environmental impacts of this type of development. This thesis uses modeling methods in a subwatershed of Fairfax County to quantify the cumulative impact of the infill redevelopment on total runoff volume, and evaluate LID BMPs for mitigating the greater volume of runoff associated with increased impervious area from infill redevelopment. The Patton Terrace catchment was the focus of the research methods and results found below.

1.3 OBJECTIVES

There are several main objectives of this study:

1. Quantify the stormwater drainage impacts from the infill redevelopment on each lot and cumulatively throughout a subwatershed of Fairfax County
2. Determine the mitigation capability of implementing LID techniques on properties throughout the same subwatershed.
3. Assemble recommendations of best practices for a locality to mitigate watershed impacts from mansionization.

2 LITERATURE REVIEW

There is very little mentioned about mansionization in academic literature, and there is even less that reports the impact of this type of development on watersheds. Most literature that does discuss these rebuilds are newspapers, magazines, and some locality planning documents; yet, only a few address their influence on stormwater. A review of the collected works that discuss the basic approach for assessing the watershed impacts from redevelopment is summarized below.

2.1 DETERMINING PRE AND POST-DEVELOPMENT LAND COVER

As previously mentioned, the major impact that development has on a watershed is due to the increase in impervious surface. The most basic way to quantify the impermeable area, especially in small watersheds, is by ground measurements or remotely sensed data (Weng 2012). This process can be slightly more automated by digitizing aerial photography, classifying remotely sensed images, and associating the percent of urbanization in a region with a percentage of imperviousness (Brabec et al. 2002). Fairfax County already has digitized, impervious planimetric data for the years 1997 and 2009 as well as aerial imagery for several years in the County. Using both the aerial imagery along with previously delineated buildings, roads, driveways, and other non-infiltrating surfaces, the approximate change in imperviousness from mansionization between 1997 and 2009 can be determined.

2.2 MODELING STORMWATER IMPACTS FROM REDEVELOPMENT

2.2.1 Calculating Stormwater Runoff

A main approach for calculating runoff from small watersheds is the Natural Resources Conservation Service (NRCS) TR-55 Model. Also called the NRCS Curve Number method, this model uses a runoff curve number (CN) and a unit hydrograph to convert rainfall depth from a 24-hour storm into runoff volume for a specified drainage area. The CN value is based off the land use or land cover, hydrologic conditions, and the hydrologic soil group (HSG). It is a convenient and widely used model in the field to calculate storm runoff volume. One of its major assumptions is that the initial abstraction term, I_a , “is generalized as a function of the runoff curve number based on data from agricultural watersheds” (VDCR 1999). The CN method has received some criticism in the past few years due to its age and generalized application to urban areas. However, it is still very commonly used in hydrologic modeling for watersheds of various sizes (Hawkins 2014). The NRCS runoff equation is:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad P > I_a \quad \text{Equation 1}$$

where

Q = runoff depth (in)
P = rainfall (in)
S = potential maximum retention after runoff begins (in)
I_a = initial abstraction (in)

and

$$S = \frac{1000}{CN} - 10 \quad \text{Equation 2}$$

where

CN = runoff curve number.

In order to calculate the runoff volume, Q must be multiplied by the contributing drainage area (NRCS 1986).

2.2.2 Modeled Stormwater Impacts from Teardowns

While urbanization and its effect on stormwater has been well-studied in literature, the effect of infill residential redevelopment or mansionization is rarely mentioned. However, in 2006, Pond and Kacvinsky attempted to quantify the cumulative stormwater impact of rebuilds in a predominately residential, 338-acre drainage basin. The paper briefly mentions the issues surrounding teardowns and their influence on “stormwater runoff rates, velocities, and flow patterns”. In addition to summarizing the impacts from redevelopment, Pond and Kacvinsky analyzed a hypothetical situation where they increased the average impervious area on each residential parcel within the drainage basin. In order to determine the impact, the parcels were separated into six categories distinguished by size. The cumulative impact on downstream runoff within the watershed was modeled by increasing the average home square footage in each category by 10% increments, up to 50%. In order to complete the analysis, the hydrologic modeling software, HEC-HMS, and the TR-55 method were used to estimate existing runoff. Using the assigned CNs of 69 for pervious area and 98 for impervious area, the HEC-HMS model was run to analyze the increases in peak flow with each 10% increment. The time of concentration was assumed to remain the same. The conclusion was that on average, for each 10% increase in average impervious area within each category, the total impervious area in the drainage basin will increase 6.7%, and consequently there will be a 7.0% increase in peak flows downstream. Figure 2 shows the results of this analysis on increasing home size. Depending on the characteristics of the drainage basin, the small increase in impervious area on each lot from rebuilds can be used to estimate the combined stormwater effect on the entire watershed.

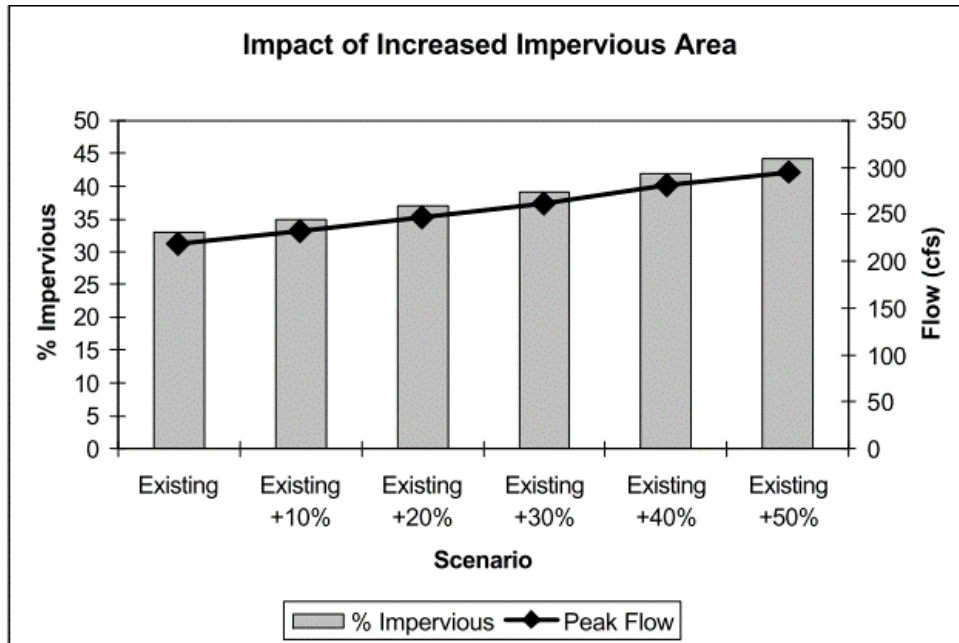


Figure 2 - Modeled increase in impervious area and its impact on stormwater peak flow rate.
 Source: Pond, M. C., and Kacvinsky, G. (2006). "Tear-Downs - Controlling Stormwater Impacts." StormCon, <<http://waterbucket.ca/gi/files/2013/03/Teardowns-controlling-stormwater-impacts.pdf>>. Used under fair use, 2015.

2.3 MANAGING THE MANSIONIZATION TREND

In areas where mansionization is occurring, some localities have adopted policies that restricts the development. However, these strategies are typically driven by the desire to preserve the character and architecture of the community. In 2004, more than 70 communities in the United States had already adopted or considered adoption of a "McMansion" regulation policy (Nasar et al. 2007). These ordinances mainly limit the scale or slow down the rate of development. Since 2004, numerous other communities, especially in the suburbs of major cities, have also started regulating mansionization. However, the majority of these policies do not specifically address the impacts on the stormwater system. A summary of the major planning tools mentioned in literature that could address the ensuing watershed impacts of mansionization are the following:

- Implementing zoning ordinance language and land use regulations to guide development;
- Targeting specific neighborhoods of concern with overlay or conservation districts;
- Implementing a tiered county review process to enable more stringent review of residential teardown requests;
- Mandating a teardown fee or tax; and

- Employing stormwater ordinance regulations that ensure certain water quantity and quality requirements are met (CMAP 2008; Montgomery County Department of Planning 2006; Nasar et al. 2007; Pond and Kacvinsky 2006).

Each of these planning tools could reduce the amount of mansionization development that occurs and help minimize the stormwater impacts. Individually, these tools could limit the impervious area added during redevelopment, ensure certain stormwater management standards are met, or provide extra funds for alleviating possible future drainage issues. However, these tools are preventative measures; a means to mitigate the impacts already occurring in neighborhoods is necessary.

2.3.1 Mitigation through Low Impact Development

Small-scale LID BMPs have been shown to provide flood and erosion protection in addition to water quality benefits when placed on single-family residential lots. In Fairfax County, VA, Loftin et al. (2010) modeled the installation of LID retrofits in two established residential communities where there is limited open space for construction. The study considered the use of several LID techniques configured on one site, including soil amendments, vegetated swales, gravel detention galleries, reforestation, and cisterns. The results showed that if five percent of the residents in the neighborhood incorporated LID retrofits onto their property, the 2-year storm quantity of rainfall would be captured. In the City of Frontenac, Missouri, Madalon (2007) looked at mitigating the increase impervious area on redeveloped, residential lots by infiltration of the 1-year storm into a multiple rain gardens. The results, calculated with XPSWMM, showed that the incorporation of the rain garden minimally reduced the 1-year peak discharge and it was recommended that additional rain gardens and other BMPs be used. In both the Fairfax County and Missouri studies, it was concluded that the LID techniques were not able to mitigate drainage issues resulting from the 100-year storm. Moreover, the results from Gilroy and McCuen's study (2009) showed the modeled use of both cisterns and bioretention (also called rain gardens) on a single-family lot were effective at reducing the peak runoff and volume from the lot for both the 1-year and 2-year storms. However, the efficiency of runoff reduction was highly dependent on the return period of the storm analyzed as well as the location they were sited.

2.4 SUMMARY

There is little in academic literature that has specifically looked at the watershed impacts from the mansionization trend or best practices for mitigating its effects. A common approach for determining the increase in runoff volume from land cover change is the NRCS Curve Number method. Pond and Kacvinsky (2006) used this method to quantify the relationship between the incremental increase in impervious area on each home in a large residential watershed and the peak runoff. In the paper, they

suggest new legislation as a possible means of mitigating the stormwater impacts from future mansionization projects. Many localities have implemented policy to restrict this development, but they are typically for aesthetic reasons (Nasar et al. 2007). In addition to instituting regulation, retrofitting a residential neighborhood where drainage issues already exist with BMPs focused on LID has been shown to mitigate the peak discharge and volume of rainfall runoff for watersheds during smaller, more frequent storms (Gilroy and McCuen 2009; Loftin et al. 2010; Madalon, Jr. 2007). This research attempts to use the NRCS method to quantify the cumulative impact of the residential infill redevelopment on a subwatershed as well as investigate LID practices for managing drainage issues resulting from the increased impervious area.

3 MANSIONIZATION AND ITS EFFECT ON STORMWATER

3.1 INTRODUCTION

The size of the American single-family home has more than doubled from 983 ft² in 1950 to 2,598 ft² in 2013. (NAHB 2006; U.S Census Bureau 2013). With vacant lots becoming rare in highly developed areas, the trend in recent years is for older homes to be demolished or remodeled in order to create larger homes. This process is known as “mansionization”, “teardowns”, “bash and build”, “residential redevelopment”, “rebuilt”, or “knockdowns” (Pond and Kacvinsky 2006). Redevelopment has been most common in older suburban neighborhoods established post-World War II (1940s-1960s) and has been occurring since the late 1980s (CMAP 2008; Miller 2012).

The enlargement of these homes is presumed to have an impact on watershed hydrology. The increased impervious area from roofs, deck/patios, and driveway footprints limits groundwater infiltration and recharge. With minimal infiltration, there is a resultant increase in stormwater runoff volume and velocity. This faster moving, higher volume of runoff is known to cause stream bank erosion and flooding (Booth et al. 2002). Energy associated with this increased velocity of runoff is transferred downstream, causing accumulation of dissolved and suspended pollutants that can alter and degrade the natural habitat. It has been shown that as impervious cover increases, stream health diminishes (Booth and Jackson 1997; Schueler 1994).

While impervious surface and its effect on stormwater quantity and quality has been well-studied in the literature, the effect of infill residential redevelopment, or mansionization, is rarely mentioned. Pond and Kacvinsky (2006) attempted to quantify the cumulative stormwater impact of residential redevelopment in a predominately residential, 338-acre drainage basin. Using the hydrologic model HEC-HMS and the Natural Resources Conservation Service (NRCS) TR-55 method, the increase in runoff flow from increased imperviousness within the basin was calculated. Results from the model indicated that average peak flows at the outlet of the study’s drainage area would increase by 7% if the average impervious area on each lot increased by 10%. These small increases in impervious area on each lot from redevelopment can be used to estimate the combined effect on the entire watershed. In addition to Pond and Kacvinsky, several locality planning documents and journal articles described these watershed impacts from the mansionization trend (CMAP 2008; Madalon, Jr. 2007; Montgomery County Department of Planning 2006). While some impacts are mentioned, the literature offers minimal quantitative analysis of the effect on stormwater or mitigation techniques.

The approaches to stormwater management have changed significantly over time in order to adapt to urbanization and new federal legislation (Roy et al. 2008). In the 1950s to the 1970s, when the majority of the redeveloped homes were first built, the main focus of localities and developers was to reduce the magnitude and frequency of floods (Anderson 1970). The accompanying design standards were intended to drain runoff offsite as quickly and efficiently as possible, typically with paved surfaces, and little attention to moderating water quality (Arnold and Gibbons 1996). These traditional stormwater management systems depend on storm sewer drains and large detention basins (Gilroy and McCuen 2009). As part of the 1987 Water Quality Act amendment to the Clean Water Act (CWA) (33 USC 26 - Federal Water Pollution Control Act 1972), the National Pollutant Discharge Elimination System (NPDES) created a two-phased stormwater program where select municipalities and industrial sites are required to obtain a permit to discharge stormwater into local water bodies. “Phase I” of the program, instituted in 1990, relates to Municipal Separate Storm Sewer Systems (MS4s) located in medium or large incorporated areas or counties (USEPA 2005). Specific implementation of this regulation varies by permitting authority (frequently state environmental agencies), but throughout the United States, identifying Best Management Practices (BMPs) for controlling the pollution from rainfall runoff has become the focus of stormwater management strategies in recent years (Freni et al. 2010)

Selecting BMPs that can mitigate water quality effects has resulted in the growing popularity of implementing Low Impact Development (LID) techniques in land development (Dietz 2007; USEPA 2000; Zimmer et al. 2007). Some of the tools and innovative BMPs that fall under the LID approach are infiltration trenches, bioretention areas, permeable pavement, and rain cisterns. LID methods control the runoff on-site rather than downstream and primarily focus on mimicking pre-development hydrology. This is achieved by attempting to infiltrate, evaporate, or detain runoff near the disturbed area (Prince Georges County, Maryland 1999). These changes in stormwater regulations and development strategies have become difficult to apply to residential redevelopment. Compliance with the NPDES MS4 permit becomes a challenge in localities like Fairfax County, Virginia when these older neighborhoods have minimal public open space for BMPs and few sources of funding for their construction and maintenance (M. Meyers, Fairfax County, personal communication, January 12, 2015). Implementing small structural and non-structural LID practices on privately-owned lots rather than public areas has become a recent approach toward stormwater management in residential subdivisions (Bedan and Clausen 2009; Bowman et al. 2012).

Small-scale LID BMPs have been shown to provide flood and erosion protection in addition to water quality benefits when placed on single-family residential lots. In Fairfax County, VA, Loftin et al. (2010) modeled the installation of LID retrofits in older residential communities where there is limited open

space for construction. The study considered the use of several LID techniques configured on one site, including soil amendments, reforestation, and cisterns. These techniques were placed on various properties throughout the study area in order to model the effect on stormwater runoff. The model demonstrated the ability of LID retrofits to reduce the flooding for all events less than the 2-year storm in the two communities analyzed. Madalon (2007) specifically investigated incorporating rain gardens (not considered by Loftin) in single-lot residential developments on a watershed level in the City of Frontenac, Missouri. The modeled rain gardens were shown to provide a 10% reduction in peak runoff flow for the 1-year, 24-hour storm if every home in the drainage area installed a rain garden of similar size. Additionally, the results from Gilroy and McCuen's study (2009) showed the modeled use of both cisterns and bioretention (also called rain gardens) on a single-family lot were effective at reducing the peak runoff and volume from the lot for both the 1-year and 2-year storms. However, the efficiency of runoff reduction was highly dependent on the return period of the storm analyzed as well as the site location.

The cumulative environmental impact of adding more impervious area on individual residential lots is becoming increasingly apparent to the localities responsible for stormwater quantity and quality control issues (CMAP 2008; Montgomery County Department of Planning 2006; J. Patteson, Fairfax County, personal communication, March 17, 2014). As infill redevelopment of single-family homes is a small construction project on one lot, typically less than 1 acre, it is most likely not subject to subdivision ordinances that require public improvements to the stormwater system downstream. Nevertheless, these homes are being rebuilt or renovated to have a much larger footprint with minimal stormwater management. As continuing upgrades increase the impervious cover, this could result in an almost entirely rebuilt neighborhood with an inadequate, outdated stormwater system. This paper presents a case study that uses modelling methods to 1) quantify the cumulative impact of the infill redevelopment on total runoff volume, and 2) evaluate LID BMPs for mitigating the greater volume of runoff associated with increased impervious area from infill redevelopment.

3.1.1 Patton Terrace Catchment Study Area

In Fairfax County, VA, mansionization has become prevalent throughout numerous neighborhoods since the early 1990s. In 2007, the Stormwater Planning Division of the Fairfax County Department of Public Works and Environmental Services (DPWES) established a pilot program to mitigate drainage issues that have developed from mansionization throughout a neighborhood in McLean, VA (J. Patteson and M. Meyers, Fairfax County, personal communication, January 12, 2015). Originally built in the 1950s, the neighborhood has a significant number of homes that have been rebuilt or remodeled in the past two decades. The pilot program focuses specifically on a 34-acre, residential subwatershed in McLean called

Patton Terrace shown in Figure 3. There are 89 parcels included in the drainage area, 55 of which are fully encompassed by subwatershed boundary.

During a public hearing held by the County in 2010, the homeowners in Patton Terrace confirmed that drainage issues in the catchment existed and were becoming worse. From this public meeting, citizen reported drainage complaints to the Fairfax County Maintenance and Stormwater Management Division (MSMD), and field surveying for the pilot program, it was summarized that from 2007 to 2010, ten properties in the drainage area repeatedly encountered yard flooding and erosion from stormwater runoff (Versar and ATR Associates Inc. 2012). These properties are indicated on Figure 3.

The cumulative increase in impervious surface from redevelopment is assumed to be the cause of the significant property flooding and erosion as well as stream bank erosion that has been reported to occur within the neighborhood and local stream. It was determined from Fairfax County land cover data that from 1997 to 2009, the percent of impervious coverage in the subwatershed increased from 18% to 25% with a total increase in impervious area of over 100,000 square feet. Some degree of impervious change occurred on just over 50% of the parcels, as illustrated in Figure 3. A limitation to the land cover dataset used is that it does not include sidewalks. However, it is assumed that the sidewalk area is such a small percentage of the entire impervious area throughout the basin that its inclusion would be negligible. Due to the available historical land cover information and significant amount of impervious change, Patton Terrace subwatershed was used for this study.

The Fairfax County Stormwater Planning Division has begun addressing some of the drainage issues through the pilot study in Patton Terrace by proposing the design of Low Impact Development (LID) measures along the street right-of-way (ROW) and retrofits to the existing stormwater conveyance system. Rather than providing LID retrofits in public areas similar the pilot study, the second part of this study investigates the mitigation ability of placing these retrofits on properties within the Patton Terrace catchment.

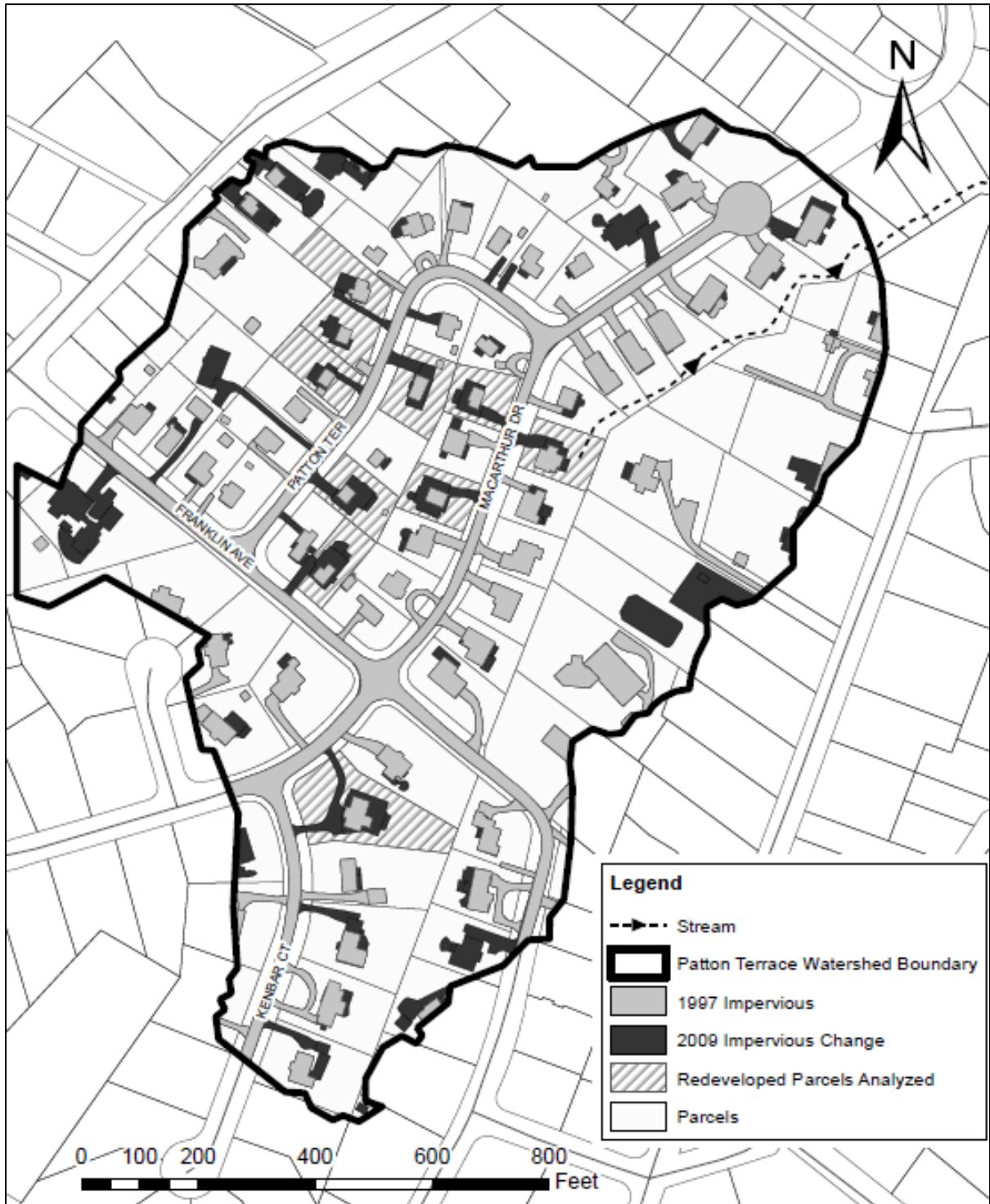


Figure 3 - Patton Terrace catchment impervious change from 1997 to 2009 with indicated redeveloped parcels.

3.2 METHODS

3.2.1 Modeled Stormwater Impacts in Patton Terrace Subwatershed

Using Patton Terrace's change in impervious area and soil information, the NRCS TR-55 method was used to determine the increase in runoff volume from 1997 to 2009 (NRCS 1986). A curve number (CN) was assigned for each land cover type and underlying hydrologic soil group (HSG) throughout the drainage area to determine an area-weighted runoff depth for both years. The resulting depths multiplied by the contributing drainage area were used to estimate the total increase in runoff volume for the 1-year and 10-year, 24-hour storms. The 10-year storm was specifically analyzed because of its typical use for localized flood control, while the 1-year storm was evaluated for the LID modeling in second part of this study since it is the current stormwater requirement in Virginia for erosion evaluation (Battiata et al. 2010; Gilroy and McCuen 2009; VDCR 1999). The increase in runoff volume for the 10-year storm was calculated both on a lot scale and cumulatively throughout the drainage area.

In order to determine increase in runoff from mansionization on a single lot, ten parcels in the Patton Terrace catchment with a significant increase in impervious area were analyzed (See Figure 3). These parcels have an average lot size of 0.3 acres. Using the TR-55 method, the increase in the average ratio of runoff depth/rainfall depth and the resulting average increase in runoff volume from 1997 to 2009 for the 10-year storm was computed for the sampled lots. Figure 4a and 4b depicts the aerial imagery and land cover delineation for one of these analyzed lots in 1997 and 2009. This property, located in the Patton Terrace drainage basin, saw an impervious cover change from 6% to 32% and illustrates the typical development pattern occurring in the area.



Figure 4a and 4b - Aerial imagery and impervious area delineation of the same property in the Patton Terrace subwatershed in 1997 and 2009.

In order to quantify the cumulative impact from redevelopment, the same method of using the soil information and delineated impervious area to calculate an area-weighted runoff volume from the NRCS method was applied to the entire Patton Terrace subwatershed. This resulted in an estimated total increase in runoff volume within the drainage area that has occurred from development between 1997 and 2009.

A build-out analysis was also completed for the subwatershed in order to project the potential increase in runoff volume if all the homes were redeveloped. Two assumptions had to be made to analyze the build-out scenario. The first assumption was that the internal lots of the watershed where there was minimal or no development would have a final average impervious lot coverage of 28%, which was the average impervious coverage of the 10 redeveloped lots in the subwatershed. Along the subwatershed boundary, where the parcels were cut by the boundary line, further analysis revealed that the redeveloped partial parcels from 1997 to 2009 had a 72% increase in total impervious area. A second assumption for the build-out scenario used this 72% increase applied to the remaining partial parcels along the border that had not been redeveloped. A process diagram for the individual lot and cumulative subwatershed runoff calculations is illustrated in Figure A-1 in the appendix.

3.2.2 Low Impact Development for Mitigation

Four types of LID techniques were modeled as retrofits within the Patton Terrace subwatershed in order to determine their mitigation ability for runoff within the area. The 1-year and 10-year, 24-hour storms were evaluated to determine the flood and channel protection from runoff volume reduction. The following LID techniques were examined:

1. Bioretention/rain gardens,
2. Infiltration trenches,
3. Permeable pavement and amended soils, and
4. Rain cisterns.

The runoff reduction of each practice was compared to the increased volume of runoff generated from development between 1997 and 2009 within the subwatershed. The calculated increase in runoff volume from the NRCS methods discussed above is equivalent to 14,800 cubic feet for the 1-year, 24-hour storm. This return period was used rather than the 10-year storm because LID practices have been shown to be more effective during smaller, more frequent storms as mentioned above. The goal was to model LID techniques throughout the properties in the subwatershed that can mitigate the 2009 runoff volume back 1997 levels.

3.2.2.1 Bioretention

In order to provide adequate runoff reduction, bioretention basins were modeled on a portion of the Patton Terrace drainage area. The basins were designed based on the Virginia Bioretention Design Specifications for Level 2 Design (VDCR 2011a). Bioretention basins generally consist of 6 to 12 inches of ponding depth above 3 feet of engineered soil media (25% voids), and 12 inches of gravel (40% voids). In this model, 12 inches of surface storage (the maximum allowable for a Level 2 Design) was used to minimize the facility footprint. The objective was to determine the cumulative area throughout the drainage basin that would need to be retrofit with rain gardens in order for the runoff volume in 2009 to be equal or below the 1997 levels.

While it is typical of bioretention designs to have an underdrain, this model was designed without an underdrain and assumes that none of the water stored in the structures returns to the drainage system. The validity of this assumption is based on the infiltration rate of the stormwater into the ground water system. The design standards specify that the subsurface soil infiltration rate should be at least 0.5 inches per hour to allow for this slow percolation process. As the rate of soil infiltration is slow relative to the peak rate of the direct runoff, the infiltration processes from this practice was excluded in this model.

3.2.2.2 Infiltration Trenches

Infiltration trenches were considered to mitigate the increase in runoff as an alternative to bioretention. This small-scale infiltration practice has been found to reduce runoff volume anywhere from 50-90% (Battiata et al. 2010). The infiltration trenches modeled within the Patton Terrace catchment were designed according to the Virginia design specification as a small-scale, underground reservoir used to treat impervious areas of 2,500 to 20,000 square feet (VDCR 2011b). The depth of the trench was set to 5 feet, the maximum allowed by the design standards. The void ratio of the stone within the trench is 40%. The same procedure as with the bioretention was followed to find the percentage of the Patton Terrace drainage area that would need to be covered with infiltration trenches in order to store a runoff volume equal to or greater than the increase in runoff from 1997 to 2009. These trenches were also modeled without an underdrain and the infiltrated stormwater was excluded from the volume calculations.

3.2.2.3 Permeable Pavement and Amended Soils

In this approach, the land cover in the drainage area was modified to allow for greater rainfall infiltration. Two practices, permeable pavement and amended soils, were modeled on the properties' driveways and lawns, respectively. Approximately 23% of the impervious surface coverage within the catchment in 2009 consists of driveways. The first infiltration practice took advantage of this significant percentage by retrofitting a portion of the driveways with permeable pavement. This practice has been shown to reduce runoff by 45-75% when used in place of typical driveway paving material (Battiata et al. 2010). The second practice applied soil compost amendments in conjunction with tree planting on property lawns. Soil compost amendments reduce runoff from compacted lawns after construction and allow reforested areas to establish a mature tree canopy for further runoff reduction.

In order to determine the runoff reduction ability of these two practices, the NRCS curve numbers (CNs) were adjusted for the proposed area where they would be implemented. For permeable pavements, the equivalent CN was assumed to be 74, equivalent to open space in good condition for hydrologic soil group (HSG) C (the most prevalent soil group in the drainage area). The amended soils, accompanied with tree planting, were assumed to have a conservatively adjusted CN of 55, equivalent to woods in good condition with B type soils. This method of treating permeable pavement and soil compost amendments as open space and forest, respectively, is explicitly mentioned in the Public Facilities Manual (PFM) for Fairfax County (2011). However, the PFM (2011) also mentions that "a loss of 30% of the treated area over time is assumed for soil compost amendments and 50% of the pervious pavement to compensate for future conversions or disturbance of the area". This loss was not accounted for and is a limitation for this model. Various scenarios of providing permeable pavement and amended soils, both alone and together, were modeled throughout the subwatershed to determine their runoff reduction capability.

3.2.2.4 Rain Cisterns

An effective way to reduce runoff from the rooftop is by installing a rain cistern or barrel that is connected to a downspout. The actual reduction is based on the chosen cistern size as well as drawdown from water re-use but has been found to be up to 40% (Battiata et al. 2010). In order to model the installation of rain cisterns throughout the Patton Terrace subwatershed, it was determined that the first one inch (first flush) of rainfall that falls onto the rooftops in 2009 would be stored within one or multiple appropriately sized cisterns. The rain cisterns are assumed to be empty before the rain event occurs.

3.3 RESULTS

Using the methodology described for the individual lot modeling, the cumulative catchment modeling, and the build-out scenario for mansionization, the following results were obtained.

- Examining the results for the 10 redeveloped lots illustrated in Figure 5a, the average percent impervious area rises from 8% to 28% from 1997 to 2009. The maximum change in impervious cover that occurred on one lot was 32% (7% to 39% overall). These changes in impervious cover increased the average ratio of runoff depth/rainfall depth from 0.53 to 0.63 shown in Figure 5b, which corresponds to an average increase in runoff volume from the 10 lots of 18% for the 10-year storm. To summarize, for the 10 parcel analysis, an average 20% rise in impervious area leads to an 18% increase in runoff volume per parcel.

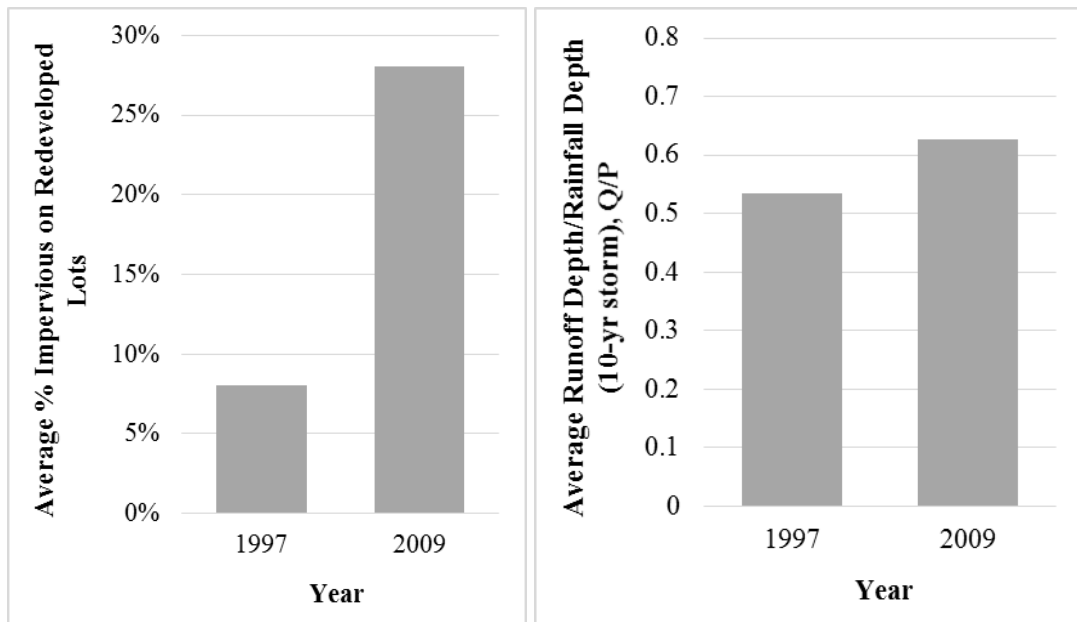


Figure 5a and 5b - Average increase in impervious area and runoff depth/rainfall depth for the 10 redeveloped parcels.

- Examining the entire Patton Terrace subwatershed, the 7% increase in impervious area from 18% in 1997 to 25% in 2009 resulted in a 5.6 % increase in the overall runoff volume (approximately 20,300 cubic feet) for the 10-year storm, as illustrated in Figure 6.

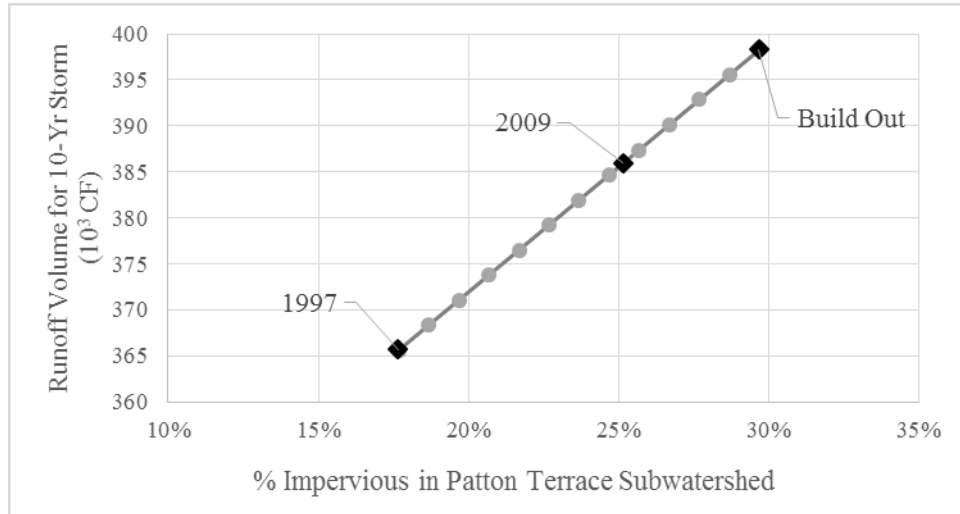


Figure 6 - Cumulative increase in impervious area and runoff volume in the Patton Terrace Subwatershed during 1997, 2009, and at build out.

- The build-out scenario concluded that the total impervious coverage of the subwatershed could increase to 30% from the original 18% in 1997 if development continues in the 1997-2009 pattern. This 12% increase in the percent impervious area would result in an 8.9% cumulative increase in runoff volume from 1997 for the 10-year storm as shown in Figure 6.
- There is a linear relationship between impervious coverage in the Patton Terrace subwatershed and total runoff volume. As the percent impervious in the subwatershed increases by 1%, there is a resulting 0.7% increase in runoff volume.

Analyzing the results of bioretention versus infiltration trenches in Figure 7 illustrates that a similar percentage of the Patton Terrace subwatershed would need to be covered with either bioretention or infiltration trenches in order to provide comparable runoff volume reduction. For the 1-year, 24-hour storm, about 0.5% (7,200 square feet) of the entire drainage area would need to be covered with either practice to reduce the 2009 runoff below the 1997 quantity. This is equivalent to providing close to 130 square feet of either practice on each of the 55 internal parcels within the subwatershed. While the results are similar, the bioretention modeled provides slightly more storage than the infiltration trench, most likely due to its surface storage component. Intuitively, if either practice was designed with a shallower depth, the percent coverage necessary to provide the same volume of storage would increase.

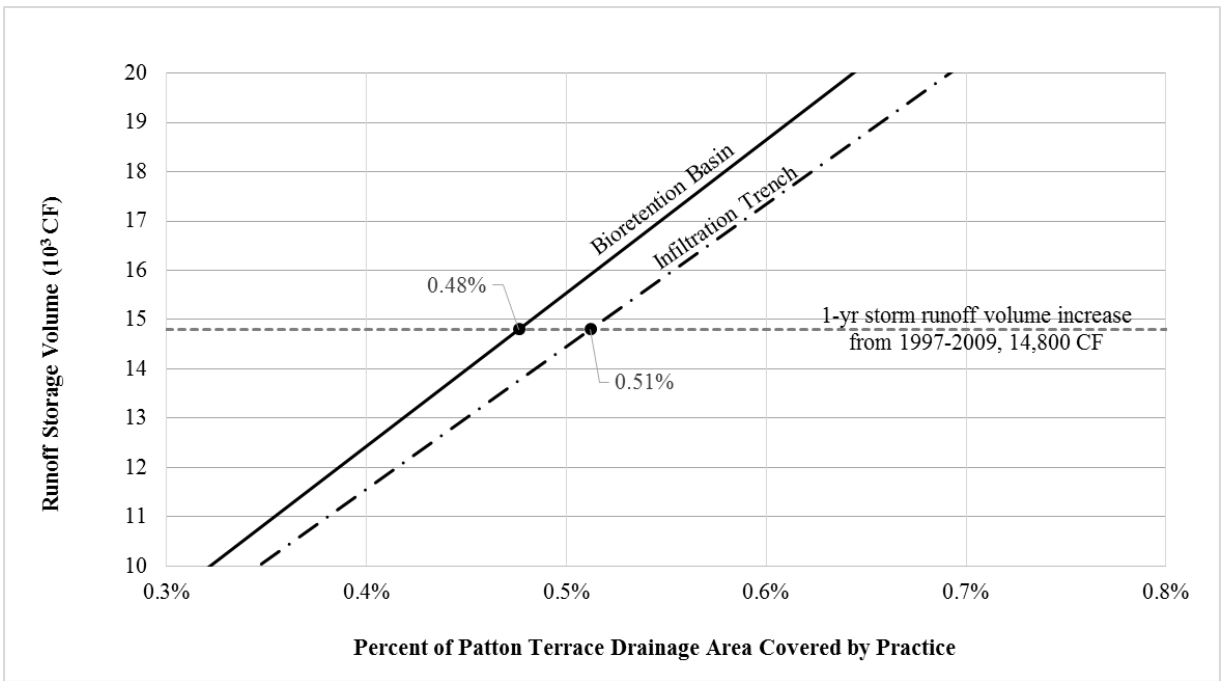


Figure 7 - Runoff storage capability of providing bioretention and infiltration trenches on a percentage of the Patton Terrace subwatershed in order to capture the increase in runoff volume in the drainage area from 1997 to 2009.

Figure 8 shows the results of various scenarios in the Patton Terrace subwatershed where a percent of the total driveway area is repaved as permeable pavement and a percent of the total open space is integrated with soil composts and new trees. Each scenario was analyzed for its ability to mitigate the runoff increase in the drainage area from 1997-2009. The figure illustrates that if permeable pavement alone were required of all driveways in 2009, the runoff volume would not be mitigated below the 1997 storm levels. Whereas, only instituting amended soils with planted trees on 18% of the open space throughout the entire subwatershed (equivalent to about 195,000 square feet or 13% of drainage area) brings the 2009 1-year storm runoff volume below the 1997 level. The other scenarios shown include various percentages of permeable pavement and soil compost amendments that can all mitigate the 1-year runoff volume to pre-redevelopment levels.

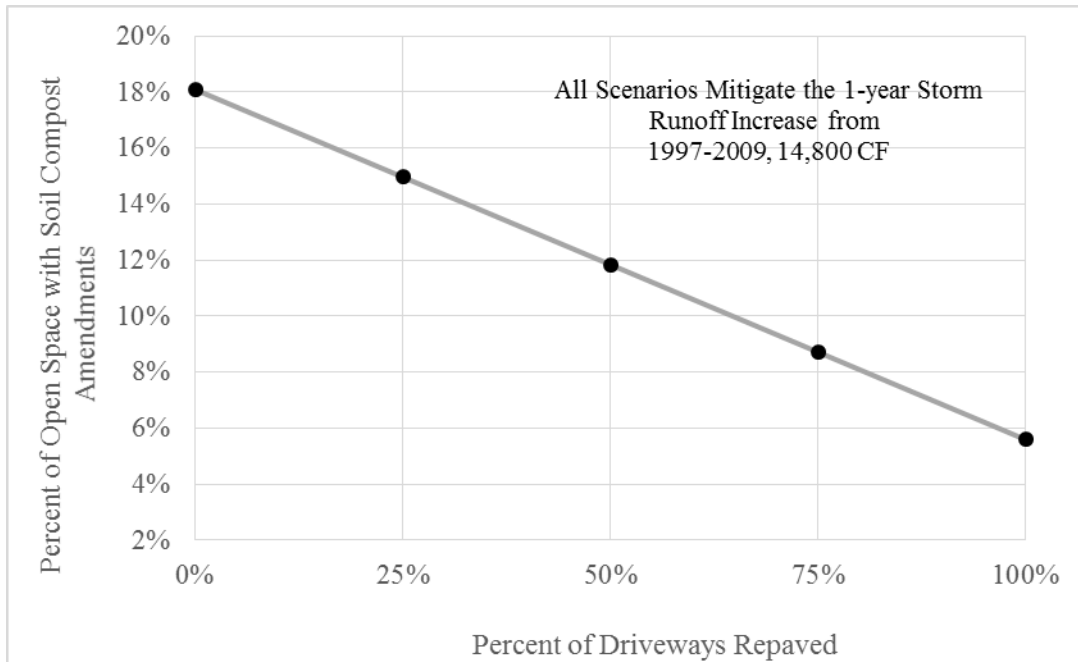


Figure 8 - Runoff reduction capability of providing permeable driveways and/or amended soils with reforestation in the Patton Terrace subwatershed in order to capture the increase in runoff volume in the drainage area from 1997 to 2009.

The modeling results for solely using rain cisterns to store the first flush of rainfall from the rooftops indicate that this option cannot adequately moderate the increased runoff volume from development. If cisterns were placed on each home in 2009 to treat the first inch of rainfall on the rooftops, only about 12,000 cubic feet of runoff would be stored (84% of the increase in runoff from 1997 to 2009 for the 1-year storm). In order to capture this increase, 1.2 in of rainfall on the rooftops would need to be captured.

As a rule of thumb, to reduce the first flush of rainfall over 1,000 square feet of rooftop, a cistern would need to store approximately 630 gallons of stormwater. Some of the Patton Terrace homes in 2009 had more than 3,000 square feet of rooftop, yielding close to 2,000 gallons of required rainwater storage. While multiple cisterns could be placed on a home, in the case of a larger rooftop, the first one inch of rainfall might not feasibly be stored on every site. Due to their small volume reduction capability and design limitations, it is typical in practice for rainwater harvesting to be combined with a secondary BMP, possibly in series, for further runoff reduction (VDCR 2011c).

3.4 DISCUSSION

If the single-family homes continue to be redeveloped as they have for the past two decades, the Patton Terrace subwatershed is likely to continue to have intensified yard flooding and significant erosion in the local stream channels. The current standards in Fairfax County require that the plans for a newly redeveloped home demonstrate there is adequate, non-impairing drainage from the site and that certain

water quality criteria are met (Fairfax County, Virginia 2011). However, these standards do not necessarily account for the increased volume of sheet flow from each site that is calculated in this study. This increased volume accumulates from multiple redevelopments in the same vicinity and causes drainage issues downstream (J. Patteson and M. Meyers, Fairfax County, personal communication, March 20, 2015).

With the multitude of options to mitigate the flooding effects from mansionization, it is important to choose which practice or practices are best suited for a property. The main factors that influence LID design are cost, effectiveness of improving water quality and reducing water quantity, maintenance requirements, infiltration conditions on the site, and space constraints (Prince Georges County, Maryland 1999).

The costs of implementing the considered LID practices are shown in Table 1 and 2. Table 1 lists the approximate unit costs in 2009 for the various LID techniques used in the scenarios. Table 2 uses the unit costs from Table 1 to estimate the total cost of implementing the various scenarios attempt to mitigate the increase in runoff volume from 1997 to 2009 in the Patton Terrace subwatershed as described in the four practices analyzed above. In order to compare the cost of practices with the same mitigation capability, the cost of implementing sufficient rain cistern storage to capture the 1-year runoff volume increase (1.2 in of rainfall) was used in Table 2 rather than the first flush (1 in) on the rooftops.

Table 1 - Approximate Costs of Various Best Management Practices in 2009.

Practice	Unit Costs (USD)
Bioretention	\$7 per cubic foot ¹
Infiltration Trenches	\$5 per cubic foot ¹
Amended Soils	\$1-4 per square foot without plants ²
Permeable Pavement	\$6-12 per square foot ²
Rain Cisterns	\$1.50-3 per gallon of storage ³

¹USEPA (1999)

²LID Center (2007)

³USEPA (2013)

Table 2 - Approximate Installation Cost of Modeled LID scenarios.

Practice	Description	Cost (USD)^a
Rain Gardens	Design volume for storage of 1-year storm runoff increase	\$240,000
Infiltration Trenches	Design volume for storage of 1-year storm runoff increase	\$190,000
Permeable Pavement and Amended Soils	100% of driveways replaced with permeable pavement and 6% of open space with amended soils	\$1,300,000
Permeable Pavement and Amended Soils	75% of driveways replaced with permeable pavement and 9% of open space with amended soils	\$1,100,000
Permeable Pavement and Amended Soils	50% of driveways replaced with permeable pavement and 11% of open space with amended soils	\$1,000,000
Permeable Pavement and Amended Soils	25% of driveways replaced with permeable pavement and 15% of open space with amended soils	\$900,000
Amended Soils	18% of open space with amended soils	\$780,000
Rain Cisterns	Design volume for storage of 1-year storm runoff increase	\$330,000

** For the unit costs that are a range of values, the higher value was used for calculating the total cost.*

The values in Table 2 are an estimation and meant to provide a means to compare the cost of installing various BMP retrofits relative to each other in the studied drainage area. It may not be realistic to assume that all landowners would be willing to adopt a single strategy, however, a situation where a mixture of these BMPs, possibly in series, are distributed throughout the properties within the subwatershed could provide adequate runoff reduction. Which practices are selected in addition to their orientation and cost would all be highly variable and based on conditions of the site. Nevertheless, Table 2 shows that permeable pavement and amended soils can cost almost 3-5 times more than rain gardens or infiltration trenches in order to provide similar runoff reduction.

In addition to cost, pollutant removal efficiency typically plays a significant role in determining which BMPs are used for a development. The importance of a BMP's pollutant removal efficiency mainly stems from the federal regulation requiring municipalities to meet certain water quality requirements issued in their MS4 permit. While water quality is not addressed in this paper, it has been shown that reduction in runoff volume decreases the mass of pollutants that would typically be released into the downstream water bodies (Battiata et al. 2010).

3.4.1 Limitations of LID

As previously mentioned, while these LID practices are known to slow down and reduce the volume of runoff from the properties, they are most effective for smaller, more frequent rain events up to the 2-year storm (Loftin et al. 2010, Gilroy and McCuen 2009). The on-site practices still assist in runoff reduction during larger storms, but in order to fully mitigate flooding and erosion, there would need to be additional improvements or retrofits to the existing stormwater system that was installed in the 1950s. These would most likely need to be constructed throughout the drainage easements and ROWs in the Patton Terrace subwatershed as they have currently been proposed for Fairfax County's pilot program.

It should also be noted that LID practices focused on infiltration, such as bioretention, infiltration trenches, and permeable pavers, require adequate soil conditions on site. Compaction from previous development and the predominance of HSG C in the Patton Terrace subwatershed could cause the soil infiltration rates to be below the threshold where these practices can be designed without an underdrain. Soil infiltration rate testing and proper installation would be required to ensure that sufficient infiltration would be possible where these practices are constructed (VDCR 2011a; b; c).

3.4.2 Implications

Fairfax County believes an incentive is needed for homeowners to install retrofits on their redeveloped property similar to those analyzed in this study because currently few citizens will voluntarily invest in these techniques (J. Patteson and M. Meyers, Fairfax County, personal communication, March 20, 2015). With little participation from the homeowners, this places the burden on the County to provide improvements elsewhere as in the Patton Terrace Pilot Program.

If homeowners do participate, they would be responsible for the retrofit facilities maintenance and subject to County inspection. According to current Fairfax County Standards, each BMP placed on the property would be subject to a Private Maintenance Agreement (PMA) where the private owner of the facility is legally obligated to maintain the facility and Fairfax County is allowed right of entry every five years for routine inspection (Fairfax County, Virginia 2011). The homeowner-county agreement is used to assure compliance for the County's MS4 permit. However, these agreements result in a large inventory of small BMPs that must be inspected by the County which require a substantial amount of money and time. It is necessary that this inspection burden be minimized while still ensuring that the LID techniques on each property are properly maintained.

Instituting a program that can provide monetary assistance and education to homeowners who are interested in reducing stormwater pollution from their properties could solve both of the County's low citizen participation and inspection burden issues. Several of these programs already exist in the area including StormwaterWise Landscapes in Arlington County, Virginia and RiverSmart Homes in

Washington D.C (Arlington County, Virginia 2014; DDOE 2015). A similar stormwater program would incentivize homeowners to invest in these BMP facilities. Furthermore, it would reduce the number of small-scale BMPs that must be checked by the County for their MS4 permit as the proper functioning of each facility would be ensured by the property owner's agreed participation.

The four LID practices analyzed in this paper are considered as if they were retrofits to the existing system for lots that are already redeveloped. However, there are new mansionization projects occurring throughout Fairfax County which need to account for their increase in runoff. Ideally, a new redeveloped lot should incorporate various innovative structural and non-structural BMPs, similar to those mentioned in this study, to reduce the volume of runoff on the site to the pre-redevelopment levels for at least the 1-year, 24-hour storm. Providing retrofits to existing systems as well as requiring that new redevelopment projects are designed to meet this runoff reduction would significantly lessen the drainage issues in the neighborhoods where mansionization is occurring.

3.5 CONCLUSION

This study has demonstrated that in the 34-acre Patton Terrace subwatershed of McLean, Virginia, mansionization has a significant impact on stormwater volume. Collectively, the relatively small increases in impervious area on a lot-by-lot basis caused an increase in runoff volume for the 10-year storm of 5.6% from 1997 to 2009. This uncontrolled increase in stormwater runoff from the redeveloped homes is most likely the cause of flooding and erosion reported within the Patton Terrace study area and other gentrifying, older subdivisions. If the development in McLean proceeds in the same manner, the runoff volume in the subwatershed at build-out could see an increase of 8.9% from 1997. It was determined that for each 1% increase in the percent impervious throughout the subwatershed, there is a resulting 0.7% increase in total runoff volume.

When considering methods to restore the drainage volume to previous levels in these older neighborhoods, this study has demonstrated through modeled retrofits in the McLean subwatershed, that small on-site LID practices have a significant influence in reducing runoff volume. Comparing the various LID practices modeled to mitigate the increase in runoff between 1997 and 2009 for the 1-year storm, the results show that a single-lot developer should most likely choose between installing bioretention basins or infiltration trenches due to their similarly effective runoff volume reduction and price. Infiltration trenches tend to cost less, but provide slightly less runoff reduction. If non-structural practices are preferred, amended soils supplemented with tree planting would provide significant volume reduction. Rain cisterns or permeable pavement alone would not reasonably mitigate the increase in runoff from development but could provide adequate runoff reduction in addition to other practices. Aside

from the four LID practices mentioned here, there are many other innovative BMPs and LID practices that could also be investigated for mitigating stormwater after redevelopment.

4 CONCLUSION

4.1 IMPLICATIONS

This study has shown that in the small region of the Patton Terrace subwatershed in McLean, Virginia, mansionization has a significant impact on stormwater. Collectively, the small increases in impervious area on a lot-by-lot basis overwhelm the existing stormwater system that was built for the original development. This uncontrolled increase in stormwater runoff from the larger, redeveloped homes is most likely the cause of flooding and erosion reported within the study area as well as within other gentrifying older subdivisions. Currently, the design standards in place are not adequate to prevent these drainage issues from occurring. The few, small scale, on-site systems that are existing cannot be practically maintained by both the homeowner and the County.

Furthermore, this study has shown that the use of LID techniques on “mansionized” lots could provide significant runoff volume reduction and possibly prevent flooding and erosion from occurring. Requiring retrofits to existing neighborhoods where mansionization has occurred and/or mandating the use of these techniques for new redevelopment can significantly reduce a locality’s need for future stormwater management improvements or stream restoration downstream. An incentive based program for homeowners to implement these LID practices on their redeveloped property could target mansionization and help prevent watershed impacts from occurring within a locality. This program would further reduce the burden on the County to ensure that LID practices are properly maintained.

4.2 FUTURE WORK

While this paper attempts to quantify impacts and provide suggestions for mitigation in regards to the stormwater issues arising from residential redevelopment, future research should be conducted to predict which areas will have a significant amount of mansionization within a locality. These areas could be targeted to project the level of residential infill that might occur and determine what effect it will have on watershed hydrology for budgeting purposes. Funds could then be designated toward future stormwater management improvements or programs to provide mitigation. Predicting where future mansionization is occurring could also help determine how to regulate new residential development that could occur within a locality.

In order to more accurately calculate runoff volume and assess peak flows at the outlet, a more detailed stormwater model could be created for the Patton Terrace subwatershed. LID techniques could be incorporated in the model to more effectively evaluate their mitigation ability. The impacts of these

techniques could be analyzed for the 10-year storm as well as the 1-year storm in order to evaluate the flooding effects. Further improvements to the stormwater management system in combination with retrofitting small-scale, on-site practices in the study area could also be modeled. Additionally, the water quality benefits of the modeled mitigation techniques could be investigated.

This study briefly discusses the cost of the various LID techniques used. It would be beneficial to have more detail on the cost of installation in relation to the soil type and infiltration rate where the practice is placed. Further discussion about the cost and difficulty of maintaining these facilities would also be helpful to the homeowners who would be responsible for them. Moreover, there could be a price comparison between providing LID retrofits on the properties versus placing them along the public streets and/or improving the existing outdated stormwater conveyance system. A full Life Cycle Analysis (LCA) of the LID practices would be good to evaluate as part of the comparison.

It would also be beneficial to investigate the success or failure of implementing different stormwater management regulations or programs that address mansionization. This would provide localities that are attempting to mitigate stormwater impacts with proven best practices for handling residential redevelopment.

4.3 FINAL WORDS

As people continue to consume the limited natural resources on this earth, there needs to be awareness of the environmental impacts that stem from desires for luxury. This study attempts to bring awareness to one of these impacts that is seldom discussed. If homes in gentrifying, older residential neighborhoods continue to be built up in the same manner, they are likely to cause environmental degradation to their encompassing watershed. As a homeowner, developer, or a locality, it is imperative to be aware of these consequences of development and understand how implementing Low Impact Development techniques can minimize the degradation to our natural water systems.

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APPENDIX A - RUNOFF VOLUME CALCULATIONS

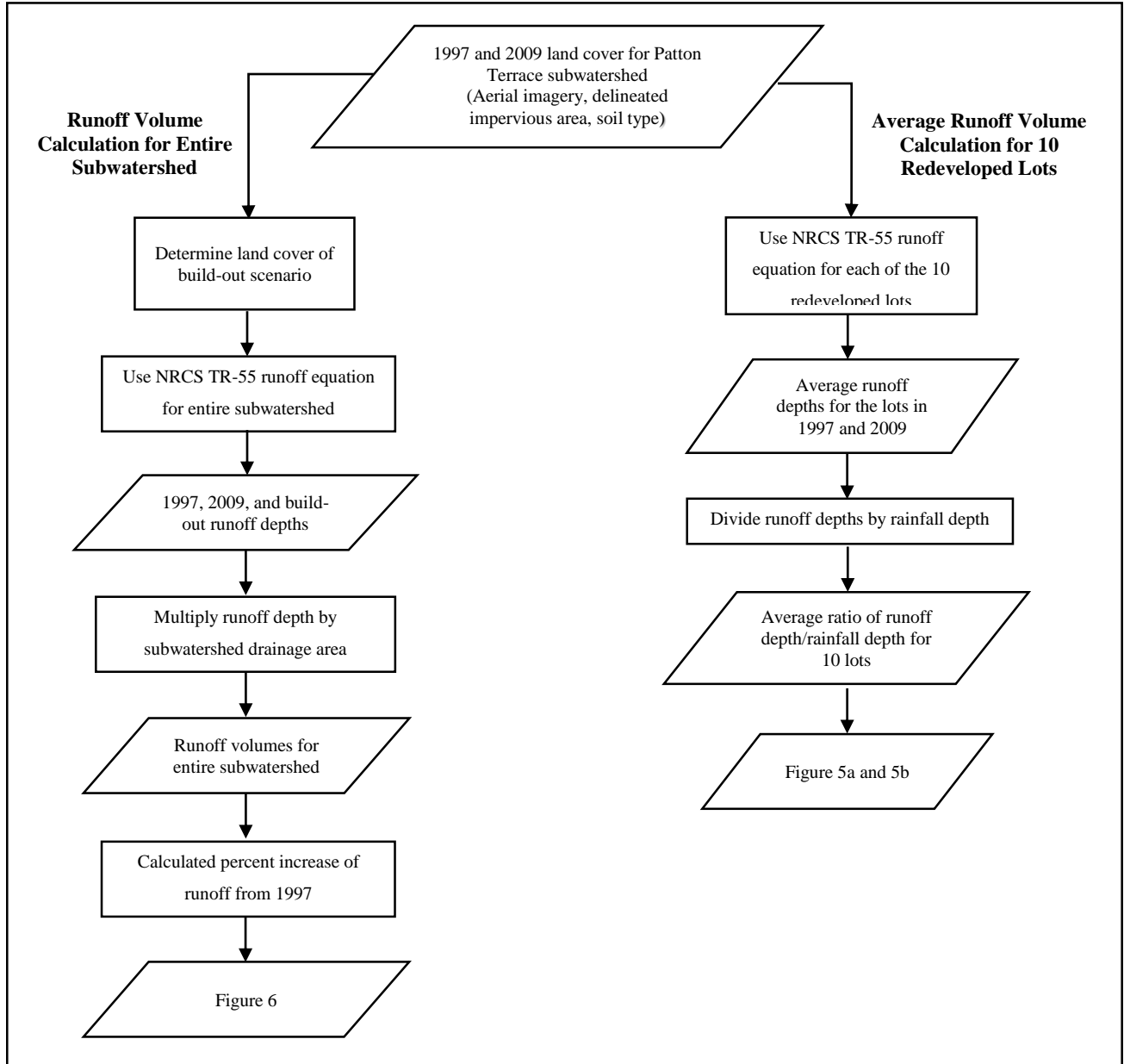


Figure A-1 - Process Diagram for Calculating Runoff Volume

Table A-1 - NRCS Assigned CN Values

Land Cover	Soil Type (HSG)		
	B	C	D
Buildings	98	98	98
Driveways	98	98	98
Open Space	61	74	80
Roadway	98	98	98

Table A-2 – 1997, 2009, and Build-Out Land Cover Patton Terrace Subwatershed

1997 Land Cover Area (ft ²)				
Soil Type	B	C	D	TOTAL
<i>Buildings</i>	2826	80887	31535	115249
<i>Driveways</i>	787	30755	20537	52079
<i>Open Space</i>	99659	690507	399981	1190148
<i>Roadway</i>	0	78061	10223	88284
2009 Land Cover Area (ft ²)				
Soil Type	B	C	D	TOTAL
<i>Buildings</i>	3625	124509	61985	190119
<i>Driveways</i>	912	57176	27142	85230
<i>Open Space</i>	98736	620488	362903	1082126
<i>Roadway</i>	0	78061	10223	88284
Build-Out Land Cover Area (ft ²)				
Soil Type	B	C	D	TOTAL
<i>Impervious</i>	-	-	-	429113
<i>Open Space</i>	98736	576835	341076	1016646

Sample Calculations using NRCS TR-55 Runoff Equation

Table A-3 - Sample Calculations for Runoff Volume for 1 and 10-year, 24-hour Storm in 2009

Land Cover	Area (ft ²)	CN Value	Q _{1-year} (in)	Q _{10-year} (in)	Q _{1-year} *Area	Q _{10-year} *Area
Impervious	363,633	98	2.47	4.96	898,044	1,804,660
Open Space (HSG B)	98,736	61	0.26	1.49	25,523	147,190
Open Space (HSG C)	620,488	74	0.72	2.52	449,162	1,566,608
Open Space (HSG D)	362,903	80	1.03	3.07	373,713	1,113,405
Total Area (ft²) = 1,445,759			Q_{weighted} (in)		1.21	3.20
			Volume (ft³)		145,537	385,989

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad S = \frac{1000}{CN} - 10$$

$$S = \frac{1000}{98} - 10 = 0.20in$$

$$Q_{1-year} = \frac{[2.7in - 0.2(0.2in)]^2}{2.7in + 0.8(0.2in)} = 2.47in$$

$$Q_{weighted} = \frac{\sum(Q * Area)}{Total Area} = \frac{1746443 in * ft^2}{1445759ft^2} = 1.21in$$

$$Volume = \frac{Q_{weighted}}{(12in)/(1ft)} * (Total Area) = \frac{1.21in}{(12in)/(1ft)} * (1445759ft^2) = 145,537 ft^3$$

Table A-4 - 1-year, 24-hour storm runoff for entire subwatershed in 1997 and 2009

Year	Runoff Depth, Q _{weighted} (in)	Runoff Depth/Precipitation Depth, Q/P	Runoff Volume (ft ³)
1997	1.09	0.40	130,733
2009	1.21	0.45	145,537
Increase in Runoff =			140,804

Table A-5 - 10-year, 24-hour storm runoff for entire subwatershed in 1997 and 2009

Year	Runoff Depth, Q _{weighted} (in)	Runoff Depth/Precipitation Depth, Q/P	Runoff Volume (ft ³)
1997	3.03	0.58	365,643
2009	3.20	0.62	385,989
Increase in Runoff =			20,346

Summary of 10 Redeveloped Lots and their Runoff

Table A-6 – Land Cover and Runoff Depth from Analyzed Internal Redeveloped Infill Lots in 1997 and 2009

Parcel PIN	1997				2009			
	Impervious (ft ²)	Open Space (ft ²)	% Impervious	Q _w -10yr	Impervious (ft ²)	Open Space (ft ²)	% Impervious	Q _w -10yr
0411 10 0006	1508	10006	13%	2.52	3062	8453	27%	2.85
0411 11 0013	724	9981	7%	2.85	1905	8800	18%	3.12
0411 11 0014	871	9564	8%	2.89	2578	7857	25%	3.26
0411 11 0015	982	10602	8%	3.18	2224	9360	19%	3.40
0411 11 0023	739	9340	7%	2.70	3945	6134	39%	3.48
0411 11 0024	651	10405	6%	2.67	3537	7519	32%	3.30
0411 11 0026	1077	11702	8%	2.73	3083	9696	24%	3.11
0411 11 0029	708	9226	7%	2.70	2990	6944	30%	3.26
0411 11 0031	807	9560	8%	2.71	4011	6356	39%	3.47
0411 24 0013	1917	25329	7%	2.86	7597	19649	28%	3.37
<i>Average</i>	999	11571	8%	2.78	3493	9077	28%	3.26

APPENDIX B – MODELED LID TECHNIQUES

MODELED LID TECHNIQUES

Table B-1 – Square Footage and Volume of Storage for Modeled Infiltration Trenches and Bioretention Basins

Percentage of Drainage Area	Area Covered by Practice (ft ²)	Infiltration Trench	Bioretention Basin
		Storage (ft ³)	
0.30%	4,337	9,325	9,325
0.40%	5,783	12,434	12,434
0.48%	6,886	13,771	14,804
0.50%	7,229	15,542	15,542
0.51%	7,402	14,804	20,346
0.60%	8,675	18,650	18,650
0.70%	10,120	21,759	21,759
0.80%	11,566	24,867	24,867

Sample Calculation for Infiltration Trench Storage

$$\begin{aligned}
 \text{Volume of Storage} &= \text{Surface Area} * 0.4 (\text{porosity}) * 5 \text{ ft (depth)} \\
 &= 7,402 * 0.4 * 5 = \mathbf{14,804 \text{ ft}^3}
 \end{aligned}$$

Sample Calculation for Bioretention Basin Trench Storage

$$\begin{aligned}
 \text{Volume of Storage} &= \text{Surface Area} [1\text{ft (ponding depth)} + \\
 &\quad 3\text{ft} * 0.25 (\text{soil media with 25\% porosity}) + \\
 &\quad 1\text{ft} * 0.4 (\text{gravel layer with 40\% porosity})] \\
 &= 6,886(1 + 3 * 0.25 + 1 * 0.4) = \mathbf{14,804 \text{ ft}^3}
 \end{aligned}$$

Table B-2 - Alteration of Land Cover Scenarios

Scenario #	% Driveways w/Permeable Pavement	% Open Space w/Amended Soils
1	100%	5.6%
2	75%	8.7%
3	50%	11.8%
4	25%	15.0%
5	0%	18.1%

All scenarios mitigate the 1-year, 24-hour storm increase (14,800 ft³)

Table B-3 - Sample Calculations for Alteration of Land Cover Scenario 1

Land Cover	Area (ft ²)	CN Value	Q _{1-year} (in)	Q _{1-year} *Area
Impervious	278,403	98	2.47	687,557
Permeable Pavement (100% of Driveways)	85,230	74	1.03	87,769
Amended Soils (5.6% of HSG D Open Space)	60,533	55	0.12	7,407
Open Space (HSG B)	98,736	61	0.26	25,523
Open Space (HSG C)	620,488	74	0.72	449,162
Open Space (HSG D)	302,370	80	1.03	311,376
Total Watershed Area (ft²) =	1,445,759		Q_{weighted} (in)	1.09
			Volume (ft³)	130,733
			Reduction from 2009 (ft³)	14,804