PROTECTING THE SOURCE AND MAINTAINING WATER AFFORDABILITY

Seneca State Park, Photo by Chesapeake Bay Program

PREPARED BY THE ECOLOGIX GROUP
FOR THE MARYLAND SIERRA CLUB

ECOLOGIX PROJECT TEAM:

DIANE CAMERON, PROJECT MANAGER
SYLVIA S TOGNETTI, PROJECT ANALYST
THAYER YOUNG, GIS CONTRACTOR

EcoLogix Group
An Environmental Strategy Firm

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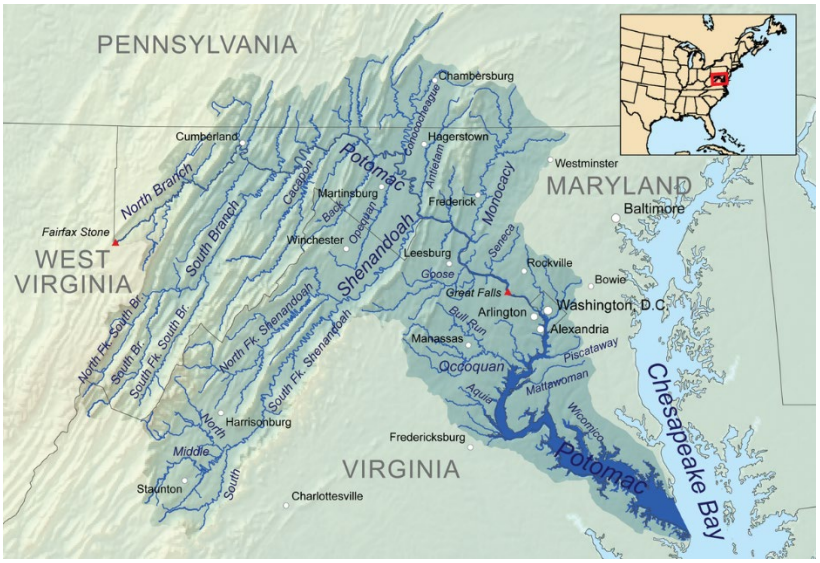
Acronyms

BMP	Best Management Practice
CAST	Chesapeake Assessment Scenario Tool (Computer Model)
CBF	Chesapeake Bay Foundation
CD	Consent Decree
CWA	Clean Water Act
DEP	Montgomery County Department of Environmental Protection
EPA	US Environmental Protection Agency
ICPRB	Interstate Commission on the Potomac River Basin
MDE	Maryland Department of the Environment
MEP	Maximum Extent Practicable
MS4	Municipal Separate Storm Sewer System
NPDES	National Pollution Discharge Elimination System
PRK	Potomac River Keeper
SCI	Submerged Channel Intake
SSO	Sanitary Sewer Overflow
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
WFP	Potomac Water Filtration Plant
WIP	Watershed Implementation Plan
WQPC	Water Quality Protection Charge
WSSC	Washington Suburban Sanitary Commission

Executive Summary

The Sierra Club Maryland Chapter engaged EcoLogix Group to examine forest cover trends and sediment loadings in three watersheds in Montgomery County -- Watts Branch; Muddy Branch; and Seneca Creek -- and drinking water quality in the mid-Potomac. These watersheds are located immediately upstream of the Washington Suburban Sanitary Commission's (WSSC's) Potomac Filtration Plant.

Interest in sediment loadings from these watersheds and their effect on drinking water supplies was sparked by the 2002 Source Water Assessment (SWA) report for the filtration plant and WSSC's recent re-initiation of its feasibility study for a Submerged Channel Intake project as the preferred solution to the drinking water treatment challenges posed by sediment and other pollution linked to stormwater runoff in Watts Branch. However a new intake would not provide source water protection, also recommended in the SWA, to reduce loads from the upstream Seneca Creek tributary which has a larger flow that is better mixed and would have an impact on water quality regardless of the location of the intake.



Potomac watershed. Image by K. Musser. Own work, Elevation data from SRTM, hydrologic data from the National Hydrography Dataset, urban areas from Vector Map, all other features from the National Atlas., CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=12568535

The study team examined available water quality and sediment loading data for the three watersheds, as well as related trends in the Potomac and Chesapeake Bay watersheds. This report summarizes the linkages between forest cover and sediment loadings and the costs and benefits of increasing forest and tree canopy cover. The focus is on sediment pollution because it increases the cost of treatment and solids handling for the drinking water supply. Sediment also carries other pollutants, including nutrients, bacteria, and heavy metals.

This study summarizes the information that is currently available and identifies additional information and analysis that is needed to answer the following questions:

Would the increase of forest cover in the watersheds immediately upstream of WSSC's Mid - Potomac River intake pipe reduce sediment loadings, and if so, to what extent and at what cost?

Forested lands play a key role in protecting water quality. They also provide many other co-benefits, including wildlife habitat and climate change mitigation. Forest cover is a key contributor to sediment reduction, but a forest cover strategy alone is not sufficient to address the sediment problem because much of the sediment load is from eroded stream channels and is associated with the legacy of past land uses. This is particularly true for urbanized watersheds such as Watts Branch, that have high levels of

imperviousness. Forest cover strategies provide a foundation for watershed protection that needs to be combined with other strategies.

The 2002 Source Water Assessment report for the mid-Potomac pointed to pollution problems in Watts Branch (which discharges to the Potomac close to the current intake pipe) and to expected future pollution increases from Seneca Creek, which discharges five miles upstream of the intake. The role of forest cover loss and increases in stormwater pollution from impervious areas were also discussed. Construction of a mid-river Submerged Channel Intake (SCI) was recommended to address challenges of poor water quality for water treatment by reaching farther into the middle of the Potomac River for cleaner water. This move was deemed necessary to avoid increased costs of water treatment associated with stormwater flows from the Watts Branch watershed and to protect public health.[1]

The cost of a new intake is now estimated to be over $83 million. Subsequently, in 2015, WSSC committed to a significant upgrade of the Water Filtration Plant (WFP) at an estimated cost of over $157 million.[2] At a combined estimated cost of $240 million, debt service on the first two projects alone would add 2.6% to current water rates. Neither of them addresses the source of the problem; and would not address increasing sediment loads from Seneca Creek associated with current development patterns.

Costs and benefits of forest retention and restoration to the drinking water supply are much more difficult to estimate. More study is needed to answer this part of the question. Conclusions from a recent study by the Interstate Commission on the Potomac River Basin (ICPRB) indicate that forest conservation and increases in forested buffers in the entire 11,560 mi^2 upper Potomac River basin would result in only slight improvements in water quality conditions and water treatment costs. However, this result could be different if considering watersheds closer to the intake, which also have higher levels of imperviousness, and are subject to more development pressure, and other kinds of costs.

Watershed model estimates from different forest protection scenarios indicated that there would be between one and five percent improvement in water quality near Washington area water supply intakes resulting in a decrease in daily chemical dose for treatment of total organic carbon and turbidity of 1.63 percent. Although the cost of treatment for these contaminants alone may not be sufficient to account for the cost of forest protection or installation of forest buffers, the ICPRB report noted that halogen ions and synthetic organics that are not effectively removed by conventional treatment would be more expensive to treat and suggests that it may make sense to focus source water protection on these contaminants. In addition to reduced treatment costs, water supplies would benefit from conserving

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[1] Becker and O'Melia, LLC. (2002). *Potomac River Source Water Assessments for Maryland Plants. Washington Suburban Sanitary Commission, Potomac Water Filtration Plant.* Prepared for the Maryland Department of the Environment and The Washington Suburban Sanitary Commission. http://mde.maryland.gov/programs/Water/water_supply/Source_Water_Assessment_Program/Documents/Potomac%20Water%20Filtration%20Plant.pdf f

[2] WSSC FY 2019-2024 Adopted CIP https://www.wsscwater.com/files/live/sites/wssc/files/Financial/Adopted%20FYs%202019-2024%20CIP_Electronic%20Version_Optimized%20Version.pdf

forests and establishing buffers in sensitive areas where runoff, industrial activity or the risk of spills is more likely to threaten the water supply.[3]

What do the 3 watershed studies indicate about the relation of forest cover to sediment loadings in the Mid Potomac?

Cicada Systems GIS Consulting analyzed the three watersheds for forest cover and tree canopy status and trends. Data sources included the EPA Chesapeake Bay Program's Phase 6 Land Use and Land Cover data, the Montgomery County Department of Environmental Protection, and the Maryland-National Capital Park and Planning Commission (Montgomery County Planning Department). A total of 12 maps were produced, including four showing canopy change by subwatershed.

1) *Tree canopy loss occurred in all three watersheds, over the study period (2009-2014)*

According to GIS analysis for this report, over a five-year period, loss of net canopy ("canopy" includes total acres of tree canopy, including forest along with other tree cover classes) compared with total acres of canopy gained via reforestation) was 2.42% (net loss of 202 canopy acres) in Watts Branch watershed; 1.03% (net loss of 431 canopy acres) in the Seneca Creek watershed; and 2.2% (net loss of 153 canopy acres) in Muddy Branch watershed.

Watershed	Total Area, Square Miles	Canopy, % of Total Area	Net Canopy Change, Acres	Net Change in Canopy, %
Watts Branch	22.2	58.6	-202	-2.42
Muddy Branch	19.6	55.2	-153	-2.20
Seneca Creek	129.6	50.6	-431	-1.03

2) *Stream biological decline is associated with canopy loss.*

When this GIS analysis was combined with an analysis of Montgomery County's biological stream condition data, the connection between water quality decline and canopy loss is demonstrated. A comparison of Montgomery County DEP's most recent stream condition map for 2011-2015, with a prior stream condition map for 1997 shows that for 10 out of the 11 sub-watersheds where the GIS analysis indicated a canopy cover decrease (between 2009 and 2014), there was a decrease in the stream biological rating. We note that in other sub-watersheds in our study area, there was some tree canopy loss where stream biological ratings remained the same or in some cases, improved. This points to the fact that stream biology (e.g. fish and insects) respond to multiple stressors (including imperviousness and chlorides along with tree and forest removal) in complex ways. And, total forest cover in a subwatershed is a key factor, that is related to but separate from incremental forest cover changes.

[3] Interstate Commission on the Potomac River Basin (ICPRB) 2018 Forest Cover Impacts on Drinking Water Treatment Costs in the Non-Tidal Potomac Basin. WRF #4651 Project Overview. http://www.potomacdwspp.org/priority-issues/watershed-protection/forests-and-source-water-protection/forests-and-water-treatment-costs/

3) *Forested lands contribute the least sediment and runoff volume compared with other types of land cover (urban and agricultural).*

The project team examined the Chesapeake Bay Program Chesapeake Scenario Assessment Tool (CAST) model and technical reports; scientific literature on forest cover and sediment relationships; Montgomery County water quality data on stream conditions; and available literature on the cost of preserving and enhancing canopy cover in the watersheds.

In the Chesapeake Bay Program's Phase 6 watershed model, the land use called "True Forest" has the lowest per-acre sediment loading assigned to it, compared with all other land uses except for wetlands.[4] Local and site-specific factors, including geology and soils, cause variations in forest sediment discharges. In developed watersheds, stream channel scour contributes about one-half of the total sediment yield while in forested watersheds there is much less stream channel scour.[5] The resultant doubling of sediment yield estimates for developed watersheds compared with forested watersheds is based upon the fact that developed watersheds generate more runoff, which causes stream channel scour.

What are the co-benefits from increasing forest and overall canopy cover?

In addition to sediment loadings reduction, there are many other water quality benefits from increasing forest cover, such as runoff volume and velocity reduction (integral in the reduced sediment loadings from forest cover); increased ground water recharge and dry-weather baseflow of small streams; protection of well water from contaminants, decreased nutrient loadings; avoidance of increases in drinking water treatment chemicals; and decrease in sediment handling costs. These co-benefits would help Montgomery County satisfy watershed protection, stormwater and Chesapeake Bay Watershed Implementation Plan (WIP) requirements and goals.

Tree canopy

Co-benefits beyond water quality include: carbon sequestration/ carbon capture in healthy forest canopies; understory; duff (leaf litter); soil conservation; reduction of urban heat island effects that benefit health and save energy; reduction of air pollution; reduction of flooding; provision of recreational and aesthetic amenities; wildlife habitat, increase in property values; job creation and stimulation of economic development.

What are the conclusions of this study?

1) Forests are the first line of defense in the multiple barrier approach to drinking water protection and provide a foundation for watershed protection, but need to be combined with other strategies, including implementation of land use plans and use of other BMPs as well as drinking water treatment, to completely address the sediment problem. Water treatment is in fact part of the multiple barrier approach.

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[4] Chesapeake Bay Program Phase 6 Watershed Model – Section 2 – Average Loads – page 2-26. ftp://ftp.chesapeakebay.net/Modeling/Phase6/Draft_Phase_6/Documentation/02%20Average%20Loads.pdf

[5] CBP CAST Sediment Simulation in Phase 6 - webinar presentation by Gary Shenk and Peter Claggett, USGS Chesapeake Bay Program, 4/19/2017. At 51:58 – Gary Shenk response to question by Karl Berger, MW-COG. https://epawebconferencing.acms.com/p8zzmxq6epd/?launcher=false&fcsContent=true&pbMode=normal

2) Canopy cover has declined in Watts Branch, Muddy Branch, and Seneca Creek during the study period (2009-2014), and this decline is associated with a decline in stream biological condition over the same general time period.
3) Increased forest and canopy cover would reverse this negative trend and would help to reduce sediment loadings to the Mid Potomac.
4) Costs of increased forest and canopy cover in the case study watersheds are estimated to range from $33,000 per acre for streamside forest buffers where the land is already publicly-owned, to $150,000 per acre for retention of existing forests.
5) Co-benefits will increase returns for an investment in increasing canopy cover significantly.
6) Additional information and analyses that are beyond the scope of this study are needed to quantify the benefits and costs of forest and canopy restoration and protection in the mid-Potomac for drinking water treatment, including:
    - Quantitative modeling of sediment yield from different forest and canopy cover scenarios in the three watersheds, including current conditions and future conditions under "business as usual" and with forest cover protection and enhancement.
    - Watershed modeling to estimate the reductions in sediment at the Potomac River water supply intakes.
    - Development of strategies and estimation of costs of improvements in forest and canopy cover.
    - Estimation of costs of drinking water treatment with potential sediment load reductions, other contaminant reductions, reducing incidence of spills, protecting public health, and other benefits of watershed restoration.
    - Estimation of the economic value of co-benefits.

Introduction

Forested lands provide the first line of defense and foundation for protecting water quality. Forested lands increase water infiltration, storage and evapotranspiration, and thereby reduce stormwater runoff that carries pollutants to water bodies. They also provide many other co-benefits, including wildlife habitat, climate change mitigation and other benefits described later in this report.

So far, in the mid-Potomac watershed forest conservation and reforestation have played only minor roles in local water resource programs to protect drinking water, reduce stormwater runoff, and achieve regulatory compliance with the Clean Water Act.

The Sierra Club Maryland Chapter engaged EcoLogix Group to examine forest and tree canopy cover trends linked to water quality in three watersheds in Montgomery County. These watersheds are upstream from the Washington Suburban Sanitary Commission (WSSC) water intake at the Potomac Water Filtration Plant, where WSSC is planning major projects to address water quality concerns stemming from sediment pollution. (Figure 1 - map of the study area showing major roads.)

This study was conducted to review and summarize available information and identify additional information and analysis that is needed to answer the following questions:

Would an increase of forest cover improve water quality by reducing sediment loading in the vicinity of WSSC's Mid - Potomac River intake pipe? And if so, to what extent and at what cost?

More than twenty years ago (1996), an amendment to the federal Safe Drinking Water Act required that states perform source water assessments for each public drinking water intake. The purpose of the source water assessments was to examine pollution threats and identify solutions to prevent or reduce those threats in the drinking water supply watersheds (the lands that drain into rivers and reservoirs). The focus was on the "multiple barrier" approach to drinking water protection.

The 2002 Source Water Assessment report for the mid-Potomac, prepared by Becker and O'Melia for the Washington Suburban Sanitary Commission (WSSC) and Maryland Department of the Environment (MDE), pointed to pollution problems in Watts Branch (which discharges to the Potomac close to the current intake pipe), and also to expected future pollution increases from Seneca Creek, which discharges five miles upstream of the intake. The role of forest cover loss, and increases in stormwater pollution from impervious areas, were discussed. The report recommended that a stakeholder panel be established to craft a source water protection plan.[6]

In addition to the source water protection recommendation, the 2002 report recommended construction of a mid-river Submerged Channel Intake (SCI) to address challenges of poor water quality for water treatment by reaching farther into the middle of the Potomac River for cleaner water. This

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[6] Becker and O'Melia, LLC. (2002). *Potomac River Source Water Assessments for Maryland Plants. Washington Suburban Sanitary Commission, Potomac Water Filtration Plant.* Prepared for the Maryland Department of the Environment and The Washington Suburban Sanitary Commission. http://mde.maryland.gov/programs/Water/water_supply/Source_Water_Assessment_Program/Documents/Potomac%20Water%20Filtration%20Plant.pdf[7] Adopted FY 2019-2024 CIP

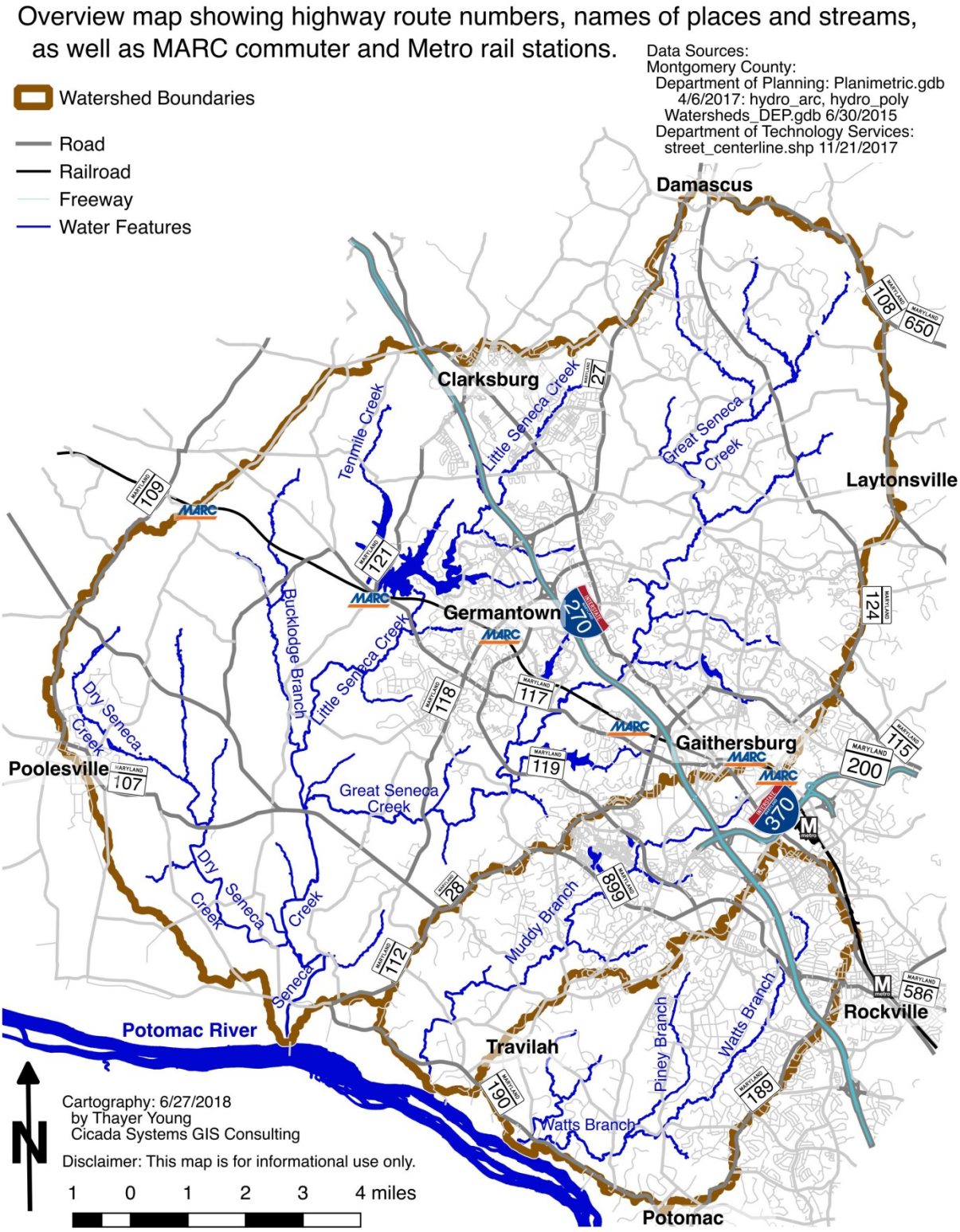

Figure 1: Map of the study area, showing the three watersheds along with major roads

move was deemed necessary to avoid increased costs of water treatment associated with stormwater flows from the Watts Branch watershed, and to protect public health. The cost of a new intake is now estimated to be over $83 million. Subsequently, in 2015, WSSC committed to a significant upgrade of the Water Filtration Plant (WFP) at an estimated cost of over $157 million.[7] This upgrade is required as part of a Consent Decree that resulted from a lawsuit for discharges of sediment and other pollutants in excess of levels permitted in the plant's NPDES or discharge permit under the Clean Water Act.[8] At a combined estimated cost of $240 million, debt service on the first two projects alone would add 2.6% to current water rates.

Although these proposed end-of-pipe solutions are expected to provide more consistent and predictable water quality at the intake pipe, making it easier to treat in the short term, they do not address the source of the problem – pollution in the contributing watersheds. Water quality and associated drinking water treatment costs are related to the amount of forest cover in a watershed. Treatment costs are likely to rise in the future because end-of-pipe solutions can mitigate, but not prevent, further degradation of water quality that is expected with continued increases in impervious surfaces, forest and canopy loss and more frequent heavy storms associated with climate change.

Along with the over-arching question, three additional questions frame the analysis for this report:

1. **What do the 3 watershed studies indicate about the relation of forest cover to sediment loadings in the Mid Potomac?**
2. **What contribution would increasing forest cover have on sediment loadings, and at what cost?**
3. **Are there co-benefits from increasing forest cover?**

Canopy cover change (including forest cover and tree canopy over turf and other tree cover types) was analyzed in three watersheds that enter the Potomac River upstream from the WSSC water intake: Watts Branch, Muddy Branch (which are part of the mid-Potomac) and Seneca Creek. Forest loss was then compared by sub-watershed with water quality trends as indicated by the Index of Biological Integrity (IBI). A review of the scientific literature on the relationship between forest cover and water quality with a focus on sediment pollution was also completed.

Sediment loads are a focus of this study primarily because sediment increases the cost of treatment for drinking water supplies. Sediment particles carry other pollutants including nutrients, bacteria and heavy metals. Technical literature was reviewed to investigate the benefits of increasing forest cover as a way to reduce sediment loadings to the Potomac Filtration Plant, and the potential costs of this approach.

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[7] Adopted FY 2019-2024 CIP
https://www.wsscwater.com/files/live/sites/wssc/files/Financial/Adopted%20FYs%202019-2024%20CIP_Electronic%20Version_Optimized%20Version.pdf

[8] United States District Court 2015 Potomac Riverkeeper, The Chesapeake Bay Foundation, Maryland Department of the Environment vs. Washington Suburban Sanitary Commission. Consent Decree, Civil Action No: 8:14-CV-00417-TDC. (re Potomac Water Filtration Plant) October 27, 2015.
http://www.montgomerycountymd.gov/COUNCIL/Resources/Files/REPORTS/2015-10-30FinalfiledConsentDecree.pdf

Current land use and water quality in Montgomery County and in the Upper Potomac Basin

In order to understand the relation of forest cover to sediment loadings in the mid-Potomac, it's important to understand land use trends and water quality conditions. The section describes trends in Montgomery County and the three case study watersheds, in context of broader trends in the Potomac Basin.

Montgomery County land use ranges from high-density urban and suburban areas to large up-county areas in the Agricultural Reserve that are buffered by areas zoned for low density. Master plans recommend low-density development in these up-county areas, in part because they are source areas for the public water supply. The Watts Branch, Muddy Branch and Seneca Creek watersheds all enter the Potomac upstream from the intake for the Potomac Water Filtration Plant (WFP). The trend toward urbanization of low-density, agricultural and forested watersheds is creating pressure to extend sewer infrastructure which runs through stream valleys and enables further urbanization, both of which would further degrade water quality.

Sediment and other pollutants from runoff create challenges for WSSC's Potomac Filtration Plant

Stormwater runoff associated with urbanization increases loads of sediment, bacteria, and nutrient pollution, contributing to the mid-Potomac basin being listed as impaired for sediment and subject to a Total Maximum Daily Load (TMDL) that requires development of a plan to control pollutants. These pollutants are also a source of operational difficulties at the Potomac WFP resulting in increased cost of water treatment and the cost of compliance with the plant's discharge permit. To address these issues, WSSC is planning to build a mid-river Submerged Channel Intake (SCI) at an estimated cost of over $83 million and is planning to upgrade of the WFP facility. The upgrade, at an estimated cost of $157 million, is required by a consent decree that was the result of a lawsuit brought by Potomac Riverkeeper's for the discharge of drinking water treatment "sludge" into the Potomac River in excess of permitted levels.

Long-term trend in Potomac Basin and Chesapeake Bay Watershed: sediment pollution is increasing in high-flow years at a significant number of monitored stations.

A study by Norbert Jaworski and others[9] on long-term water quality trends in the entire upper Potomac Basin from 1895 to 2005 showed a trend of decline in agriculture, from 75% to 35%, an increase in forest cover from 22% to 61%, and a 300% increase in population. The authors report that during this 110-year period, the concentration of sediment in the form of Total Suspended Solids (TSS), approximately doubled, possibly due to a combination of higher spring river flow pulses and the increase in impervious surfaces. The report also found that "recent short-term trends of improvement in some water quality parameters are leveling off or reversing, suggesting earlier accomplishments are becoming overwhelmed by continued population growth in the region."

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[9] Jaworski, Norbert et al. (2007) The Potomac River Basin and its Estuary: Landscape Loadings and Water Quality Trends 1895-2005. https://www.potomacriver.org/the-potomac-river-basin-and-its-estuary-landscape-loadings-and-water-quality-trends-1895-2005/

Overall, 37% of monitored stations in the entire Chesapeake Bay network of USGS show increasing sediment levels (e.g. conditions are degrading at these stations).[10] Sediment sampling data for the non-tidal upper Potomac River basin, collected at the Chain Bridge USGS monitoring station which is located at the fall line between tidal and non-tidal waters, shows that the suspended sediment load is "improving" over the long term (1985-2016), with "no trend" indicated for the short term (2007-2016). Data collected by USGS on sediment loads to the entire Chesapeake Bay from all sources shows that sediment loads in high flow years are increasing (see *Figure 2*).[11]

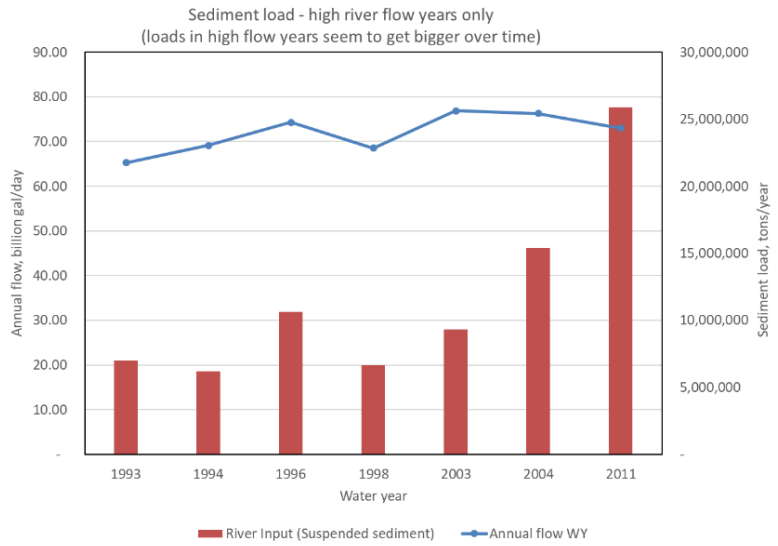

Figure 2: Chesapeake Bay River Input Monitored Sediment loads for high river flow years only, 1990-2016. Source: Moyer and Blomquist (2017)

Canopy cover change in case study watersheds

As case studies, we examined canopy loss in the three upper Montgomery County watersheds that discharge to the Potomac River upstream of the Washington Suburban Sanitary Commission's Potomac Filtration Plant: Watts Branch, Muddy Branch and Seneca Creek. GIS data was used to map changes in canopy cover in these three watersheds from 2009-2014, for each of 47 subwatersheds.

Thayer Young, Cicada Systems GIS Consulting, provided the Montgomery County land cover map series and analysis for this project.[12] Data sources included: The EPA Chesapeake Bay Program, Phase 6 Land Use and Land Cover data; and additional data from Montgomery County Department of Planning and Department of Environmental Protection.

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[10] Moyer, Douglas and Blomquist, Joel (2017) Summary of Nitrogen, Phosphorus, and Suspended Sediment Loads and Trends Measured at the Chesapeake Bay Nontidal Network Stations, Water Year 2016 Update U.S. Geological Survey; at https://cbrim.er.usgs.gov/data/NTN%20Load%20and%20Trend%20Summary%202016_Combined.pdf

[11] ChesapeakeProgress 2018. Pollution Loads and River Flow to the Chesapeake Bay (1990-2016). Chesapeakeprogress.com/clean-water/water-quality. See sediment data sheet: https://www.chesapeakeprogress.com/files/Data_2016_N_P_S_Loads_and_River_Flow_10-16-2017.xlsx

[12] The full set of maps can be accessed at: https://drive.google.com/drive/folders/0B0dzElzJ3ly7c0h6bXZIWW5HN2M

This section includes a set of maps for each of the watersheds, that illustrate:

- Subwatershed Locations
- Land Use Land Cover maps depicting a total of 15 land cover types, including a total of six forest and tree-based land cover types: Forest; Tree Canopy over Imperviousness; Tree Canopy over Floodplain Wetlands; Mixed Open; Tree Canopy Over Turfgrass; and Tree Canopy Over Other Wetlands. Together, these six land cover types are termed "canopy cover" in the present study.
- Canopy Change in each of the 47 subwatersheds

Figure 2 provides an overview map that includes all three watersheds in one map, and a table that summarizes the land use/land cover and canopy change data, based on the GIS analysis.

Overview of canopy loss across the three watersheds

The canopy change data analysis shows that with a few exceptions, the vast majority of the three watersheds experienced net canopy loss, across both urban and rural land cover classes, ranging from -1.03 to -2.42%, between the study years, 2009 to 2014. Not surprisingly, the highest percentage of loss was found in the more urbanized Watts Branch watershed, which enters the Potomac closest to the WSSC water intake, and the lowest in the least developed more rural Seneca Creek (see *Table 1*). However, an analysis of canopy cover changes in individual subwatersheds shows a concentration of canopy loss at -7% in the Clarksburg area of the Seneca Creek watershed, which is nearly double the second highest concentration of canopy loss, in the most urbanized part of Watts Branch, of -3.8% and over three times the average loss. Other areas of concentrated canopy loss are found in the other urbanizing areas of all three watersheds: Rockville, Gaithersburg, and Germantown (see *Figure 3*).

Forest and Tree Canopy Changes in Three Montgomery County Watersheds, 2009-2014						
Watershed	Total Area, Square Miles	Canopy, % of Total Area	Canopy Gain, Acres	Canopy Loss, Acres	Net Canopy Change, Acres	Net Change in Canopy, %
Watts Branch	22.2	58.6	36.8	239	-202	-2.42
Muddy Branch	19.6	55.2	30.5	183	-153	-2.20
Seneca Creek	129.6	50.6	300.4	731	-431	-1.03
Source: GIS analysis, March 2018, by Thayer Young, Cicada GIS Systems, using Montgomery County Land Cover data for 2009 and 2014.						

Table 1: Tree canopy changes in three Montgomery County Watersheds, 2009-2014

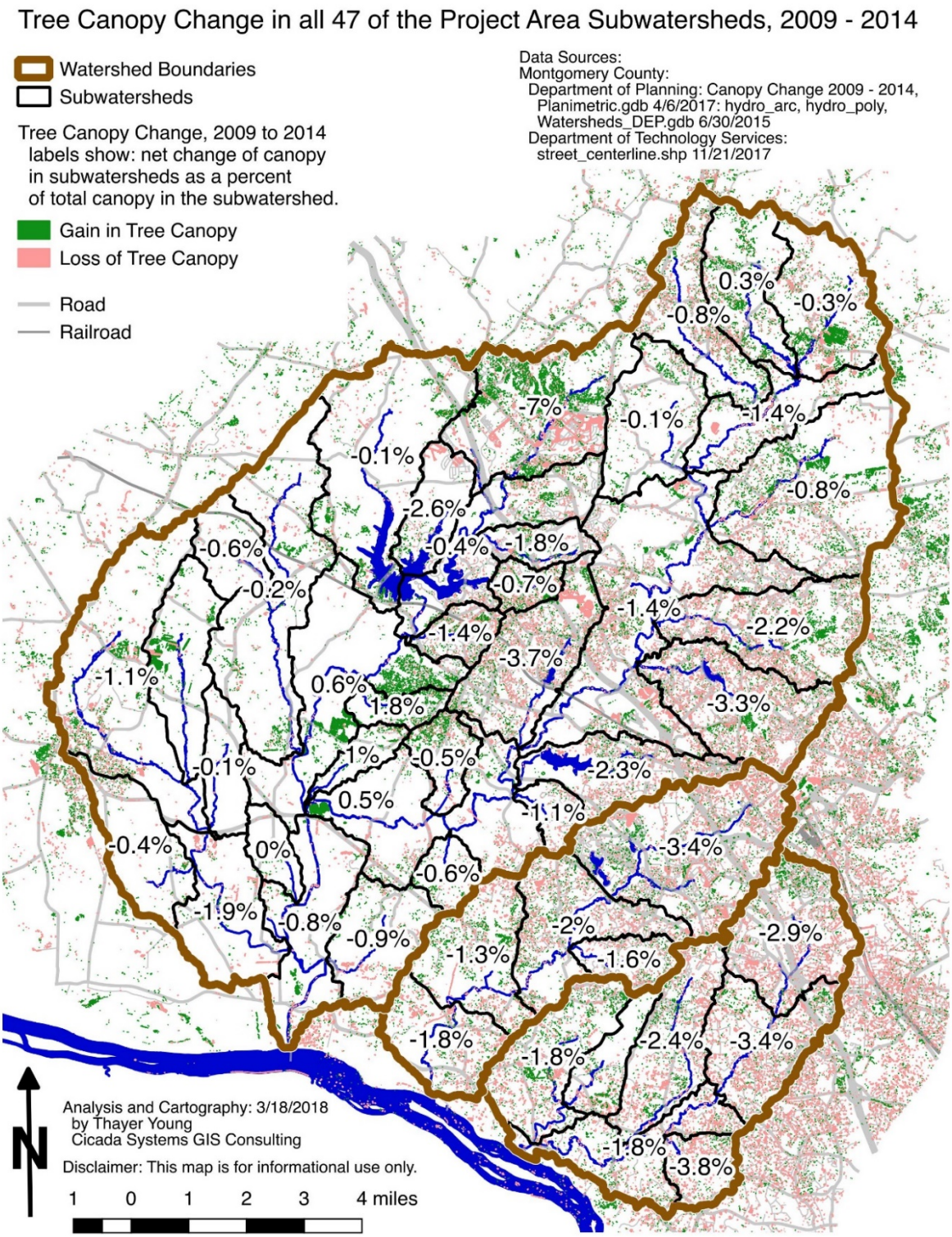

Figure 3: Tree Canopy Change in all 47 of the Project Area Subwatersheds, 2009-2014

Overview of Land Use and Land Cover across the three watersheds

Table 2 and *Figure 4* show existing Land Use and Land cover in all three watersheds. The Seneca Creek watershed, which is over three times as large as Watts Branch and Muddy Branch combined, has not only larger areas but also much higher percentages of land covered by forest, cropland, pasture, floodplain and other types of wetlands, tree canopy over floodplain and other types of wetlands, and mixed open land uses. Conversely, it has lower areas and percentages of land covered by structures, non-road impervious surfaces, roads, tree canopy over impervious surfaces, turf grass, and tree canopy over turf grass. Many of the floodplain wetlands, which are important for storing floodwaters, are located near existing transportation and development corridors, and a proposed new one, the M-83 or Mid-County highway. The large area of open water observed in the Seneca Creek watershed is the Little Seneca Reservoir, which was built as a drought backup for the area water supply.

In land use classification, it is important to distinguish tree canopy from forest lands, which are a subset of lands covered with tree canopy. The difference is that while any area with a mature tree that has a crown of leaves is counted as "Tree Canopy area," only areas that have large stands of trees, with forest soils, where tree roots form an underground network of interconnected roots, are considered forest lands. In the land use classification, Tree Canopy areas also include Tree Canopy Over Imperviousness, and Tree Canopy Over Turf Grass as well as Tree Canopy over Floodplain and over other wetlands. These classifications all provide different levels of runoff reduction.

Tree Canopy Over Imperviousness and Tree Canopy Over Turf Grass provide canopy interception, whereby the leaves and upper branches catch falling precipitation, allowing some of it to evaporate, depending upon weather conditions. Forest lands and tree canopy over wetlands also provide these same functions of canopy interception, and stem flow (whereby rainwater is slowed by trickling down multiple tree limbs and trunks); in addition, they also provide more water management functions beyond those provided by Tree Canopy Over Imperviousness and over turf grass. Forest lands store and infiltrate precipitation via leaf litter (a.k.a. "duff," also termed the "O" layer by soil scientists), and via the organic-rich topsoil layer with its "macropores" and fine tree and plant roots that create holes and channels that store and retain water, allowing it to slowly percolate downward through the clay-rich subsoil and into the crystalline fractured bedrock. Rainwater storage and infiltration provided by the organic-rich duff and topsoil layers is considered to be the "master hydrologic function" of healthy forests, since many other hydrologic functions of trees and forests, including evapotranspiration by leaves, and groundwater recharge and stream baseflow (stream flow during dry weather) depend upon the ability of the forest floor and top soil layers to capture, store, and infiltrate precipitation.

Forest floor and tree canopy

Phase 6 Chesapeake Bay Program Land Use / Land Cover	Watts Branch, square meters	Muddy Branch, square meters	Seneca Creek, square meters	Watts Branch, percent	Muddy Branch, percent	Seneca Creek, percent
Water	335,674	471,817	3,852,474	0.58	0.93	1.15
Structures	3,489,176	3,639,079	11,137,242	6.06	7.18	3.32
Impervious, Non-Road	4,608,391	4,388,392	16,174,767	8.00	8.65	4.82
Road	2,803,284	2,955,734	10,213,834	4.87	5.83	3.04
Tree Canopy over Impervious	2,841,992	2,153,818	7,548,159	4.93	4.25	2.25
Cropland	20,431	90,211	31,124,975	0.04	0.18	9.28
Pasture	637,766	1,669,869	32,440,718	1.11	3.29	9.67
Turf Grass	10,425,240	8,740,220	44,435,787	18.10	17.23	13.24
Floodplain Wetlands	94,034	72,056	1,240,610	0.16	0.14	0.37
Other Wetlands	48,849	12,924	844,045	0.08	0.03	0.25
Forest	13,860,974	12,827,728	108,609,678	24.07	25.29	32.37
Tree Canopy over Turf Grass	14,012,425	10,515,784	34,588,244	24.33	20.73	10.31
Mixed Open	3,604,403	2,384,670	23,424,122	6.26	4.70	6.98
Tree Canopy over Floodplain Wetlands	688,271	676,103	6,840,029	1.20	1.33	2.04
Tree Canopy over Other Wetlands	123,931	118,688	3,076,591	0.22	0.23	0.92
Total:	57,594,841	50,717,093	335,551,275	100.00	100.00	100.00

Table 2: Land Use/Land Cover classifications, areas and percentages for Watts Branch, Muddy Branch, and Seneca Creek - GIS analysis, March 2018 prepared by Thayer Young, Cicada GIS Systems using the Phase 6 Chesapeake Bay Program Land Use/Land Cover database.

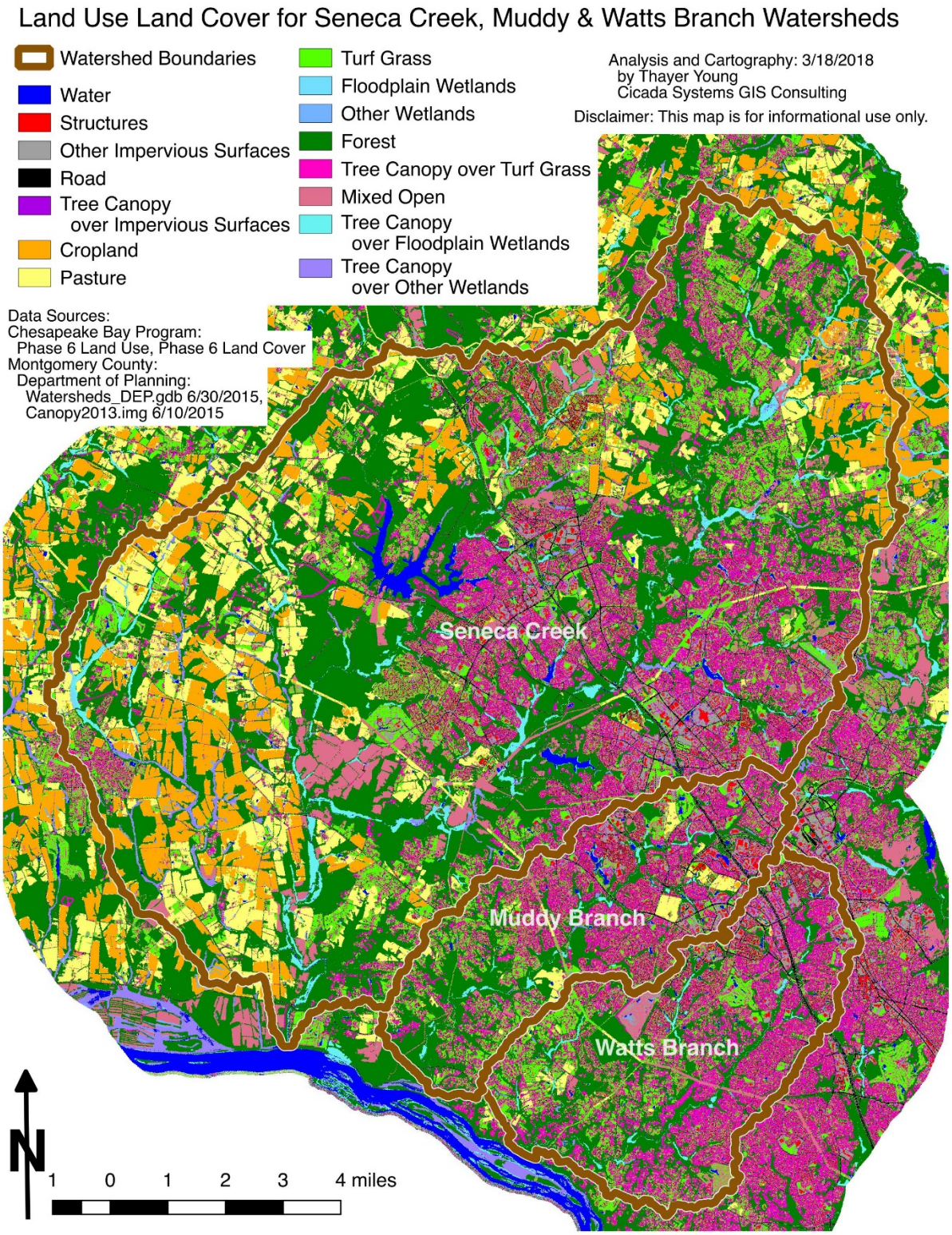

Figure 4: Land Use Land Cover for Seneca Creek, Muddy & Watts Branch Watersheds

Forest Cover and tree canopy differences

Figure 5: Close up view of Piedmont forest soil. This cross-section includes the following layers: tree canopy; understory; decaying leaf litter; topsoil; subsoil; weathered bedrock ("regolith"); and fractured bedrock. Each of these layers functions to attenuate and absorb precipitation. Graphic by Judy Hanks for Audubon Naturalist Society, 2013.

According to the Montgomery County Planning Department, a 2011 GIS study found that 157,219 acres of the County were covered by tree canopy, consisting of 50% of all land in the County.[13] An additional possible 43% of the County's area, could theoretically be modified to accommodate tree canopy. In

[13] Montgomery County Planning Department (2011), A Report on Montgomery County's Existing and Possible Tree Canopy. http://www.montgomeryplanning.org/environment/documents/TreeCanopy_Report_MontgomeryCountyFinal.pdf

contrast, forest cover percentages for the County as a whole are less – estimated at 29% according to information provided in March 2018 by Planning Director Gwen Wright, generated by Environmental Planner Katherine Nelson[14].

Figures provided by Planning Director Wright for the entire County's forest cover for the years 1951, 2008, and 2015, are in *Table 3* below.[15]

Year	Total forest cover	% of total land area (324,164)
1951	82,606	25.5
2008	93,368	28.8
2015	94,943	29.3

Table 3: Montgomery County Forest Cover (1951, 2008 and 2015)

Potomac Direct - lower (02140202)

Watts and Muddy Branch are both addressed in the implementation plan for Lower Potomac Direct, which also combines the Rock Run and Little Falls watersheds. They have a combined drainage area of 42.4 square miles or 27,152 acres, and both have headwaters in highly developed areas of Rockville and Gaithersburg.

Land uses in the combined watershed area is almost 70% residential, 11% forested, 7% rural, 6% commercial/industrial, and <3% institutional. Impervious surfaces cover 17%, or 4,719 acres.[16]

Watts Branch

The Watts Branch watershed, which covers 22 square miles, originates in Rockville, southeast of the Shady Grove Road and I-270 intersection in the King Farm urban development area. It flows 11 miles, merges with Sandy Branch and Piney Branch, and enters the Potomac just upstream from the Potomac WFP. Stormwater discharges from this watershed are therefore a key driver of plans for the submerged intake at the Potomac WFP. The headwater area has highly developed, commercial, high-density residential, research and development centers. The lower portions are lower density residential. Streams with higher water quality are found in the upper and western portions of the Piney Branch

King Farm

[14] Email from Montgomery County Planning Director Gwen Wright to Diane Cameron, February 28, 2018.
[15] Email from Montgomery County Planning Director Gwen Wright to Ginny Barnes, Jean Cavanaugh, Casey Anderson, and Diane Cameron, February 28, 2018.
[16] Montgomery County MD Department of Environmental Protection, Watts Branch and Muddy Branch Subwatersheds Implementation Plan, prepared for DEP by Horsley Witten Group (2012); https://www.montgomerycountymd.gov/DEP/Resources/Files/ReportsandPublications/Water/Watershed%20Studies/Muddy-Branch-Watts-Branch-Subwatersheds-Implementation-Plan-12.pdf

and Lower Sandy Branch tributaries. The Piney Branch Tributary was designated as a Special Protection Area SPA in 1995 because of these high-quality stream conditions.

Areas of higher density development patterns are also indicated by land use and land cover, loss of tree canopy, and by the sewer network[17] (see *Figure 6*, *Figure 7* and *Figure 8*). As is shown in *Figure 7*, the highest levels of forest loss are in the eastern, more urbanized subwatersheds.

A countywide tree canopy study done in 2011 for the Montgomery County Planning Department by the University of Vermont Spatial Analysis Laboratory concluded that riparian buffers of Upper Watts Branch have the least existing forest cover, which the analysis determined to be 54% forest cover. The authors stated that Upper Watts Branch has the highest "possible tree canopy" additional cover (36%).[18]

[17] Montgomery County Department of Environmental Protection (2017) Montgomery County 2017-2026 Comprehensive Water Supply and Sewerage Systems Plan. See Figure 4-F10 (Watts Branch sewer network), page 4-35. https://www.montgomerycountymd.gov/DEP/Resources/Files/Downloads/WS/2017-chapter4-draft.pdf

[18] University of Vermont Spatial Analysis Laboratory (2011)*A Report on the Montgomery County's Existing and Possible Tree Canopy.*
http://www.montgomeryplanning.org/environment/documents/TreeCanopy_Report_MontgomeryCountyFinal.pdf

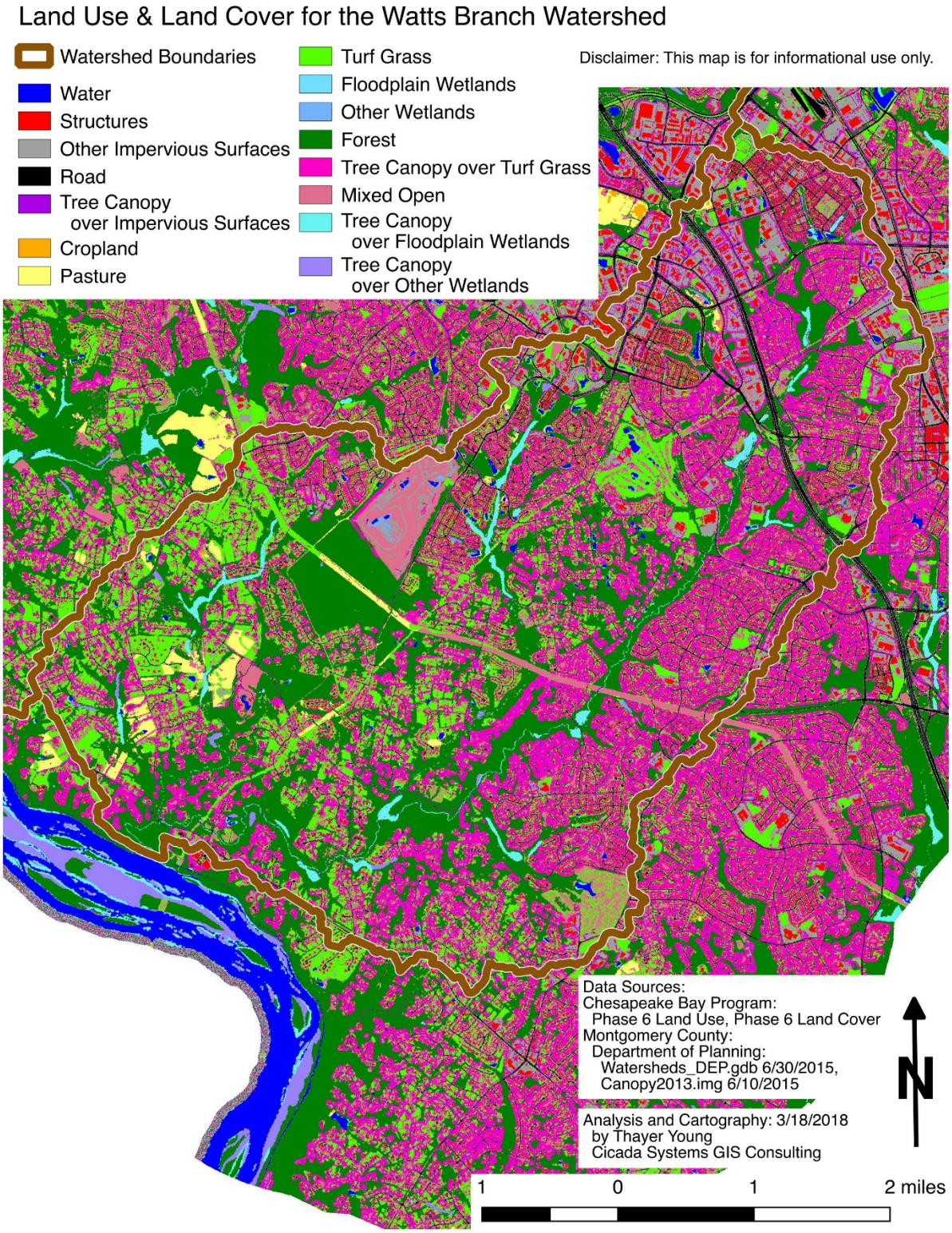

Figure 6: Land Use & Land Cover for the Watts Branch Watershed

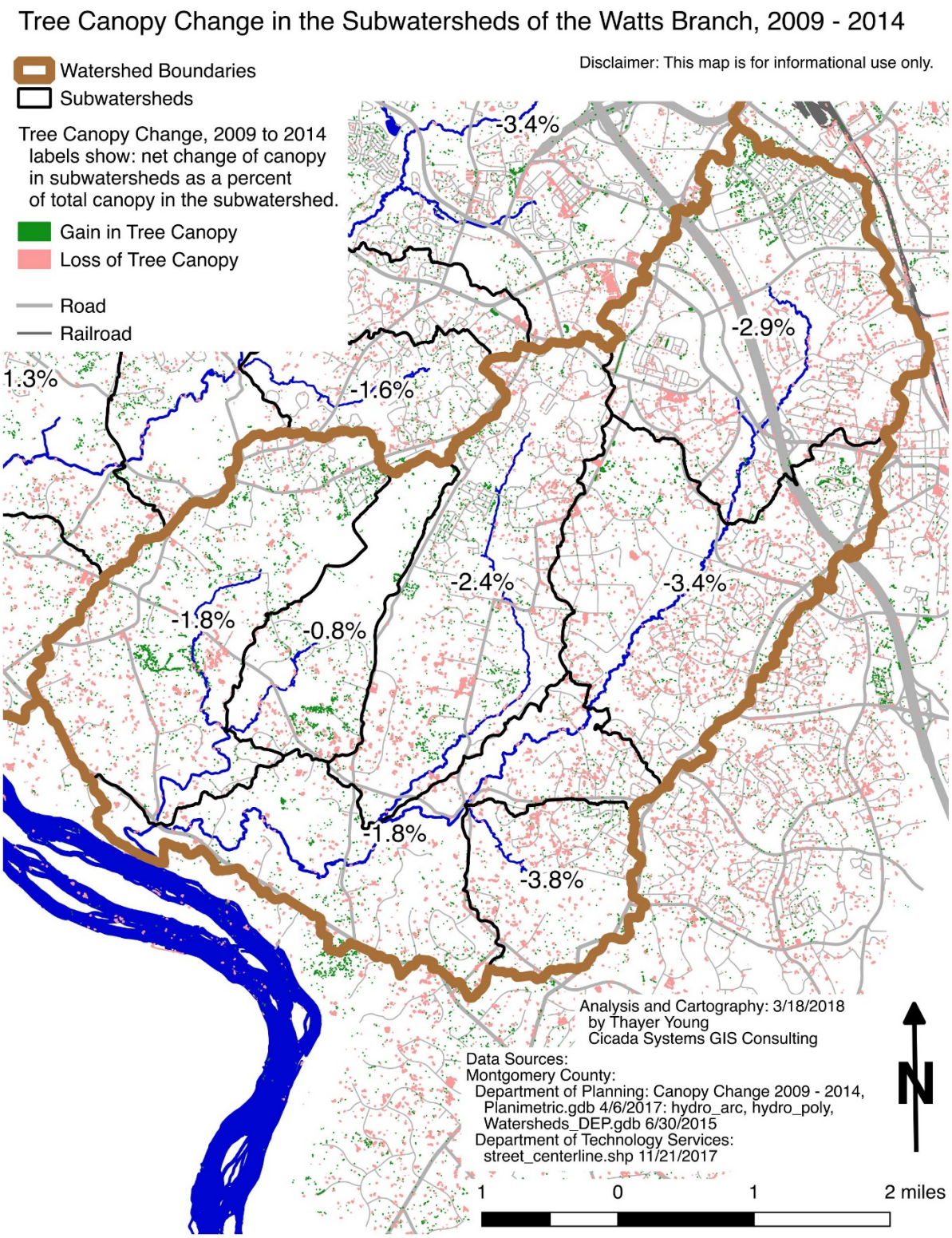

Figure 7: Tree Canopy Change in Watts Branch, 2009-2014

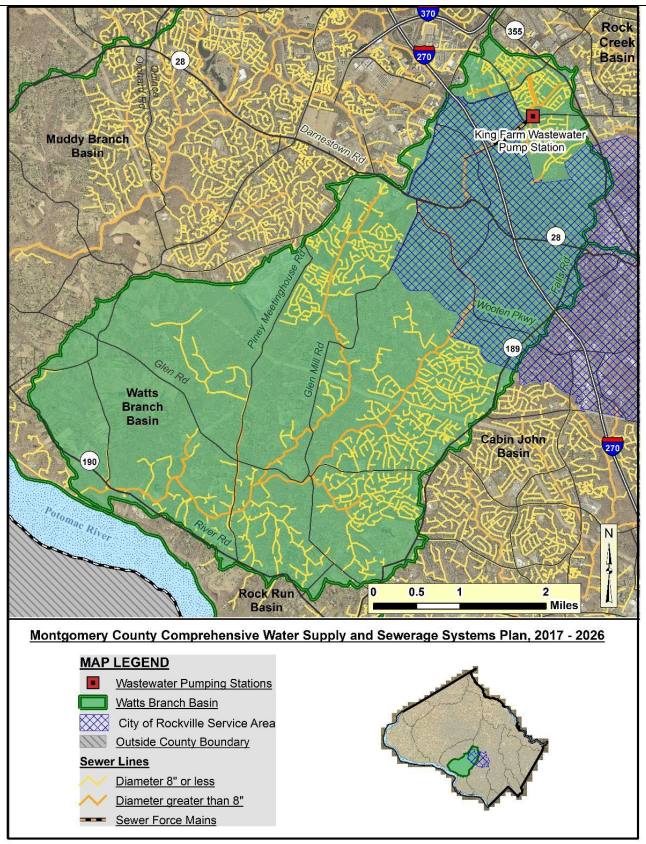

Figure 8: Watts Branch Sewer Network

Muddy Branch

The Muddy Branch watershed originates in Gaithersburg historic district, has a stream length of 13 miles. Just as Watts Branch, it's headwaters are crossed by major transportation corridors: MD route 355 and the CSX railroad. Rapid development occurred after 1970, prior to the establishment of environmental standards for development. After 1985, developments were required to have stream buffers and on-site stormwater BMPs and MNCPPC acquired large areas of stream valley to maintain the stream buffers. The lower watershed, downstream of route 28, has lower development densities and a higher level of stream protection. This lower density zoning serves as a buffer area around the Agricultural Reserve in the Seneca Creek watershed. Large impervious areas are associated with the Shady Grove research and development commercial corridor.

Areas of higher and lower density development patterns are also indicated by the sewer network[19]; land use and land cover, and loss of tree canopy (see *Figure 9*, *Figure 10* and *Figure 11*). As shown in

[19] Montgomery County Department of Environmental Protection (2017) Montgomery County 2017-2026 Comprehensive Water Supply and Sewerage Systems Plan. See Figure 4-F9 (Muddy Branch sewer network), page 4-33. https://www.montgomerycountymd.gov/DEP/Resources/Files/Downloads/WS/2017-chapter4-draft.pdf

Figure 10, the northernmost sub-watershed has forest loss levels similar to those in more urbanized area of Watts Branch.

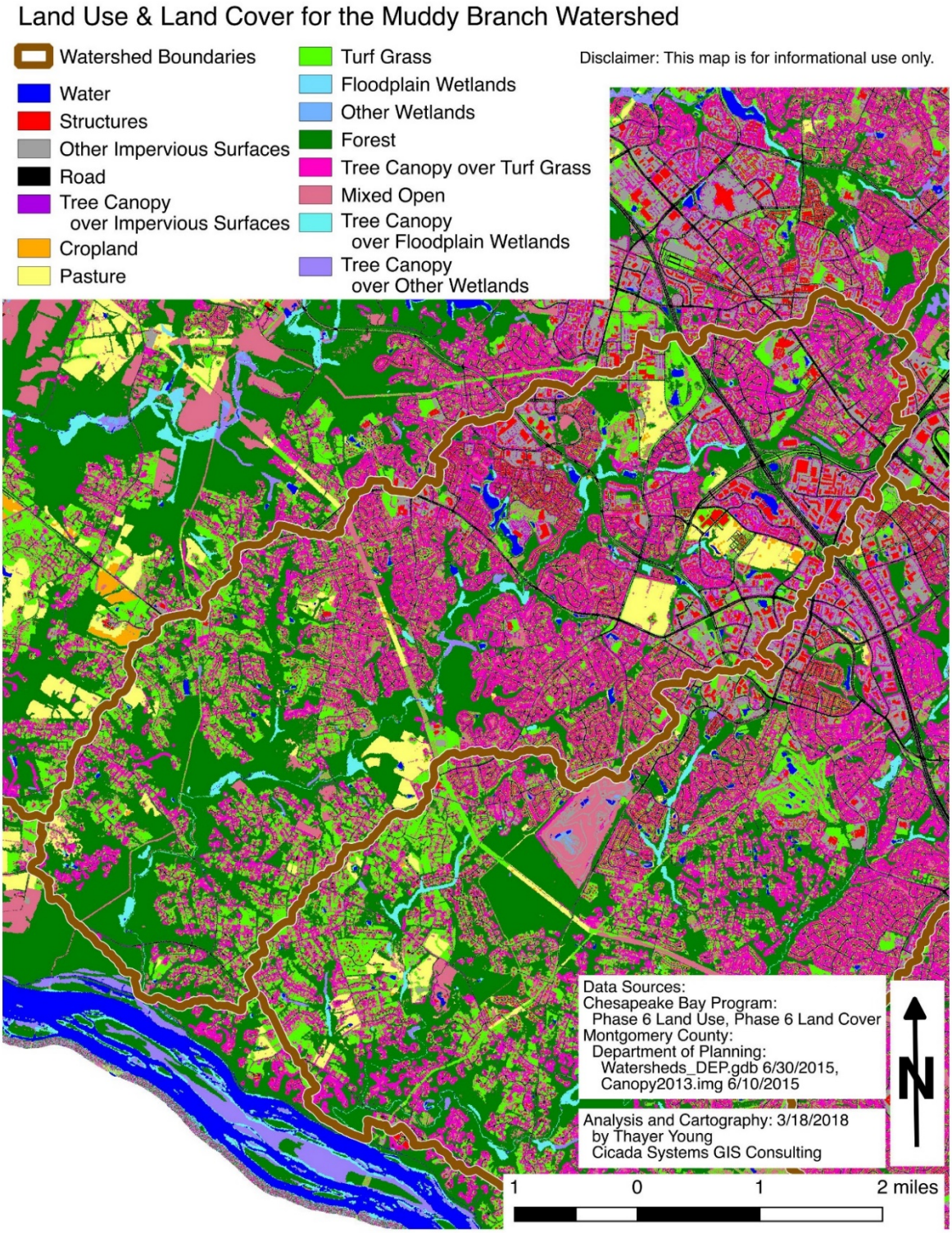

Figure 9: Land Use & Land Cover for the Muddy Branch Watershed

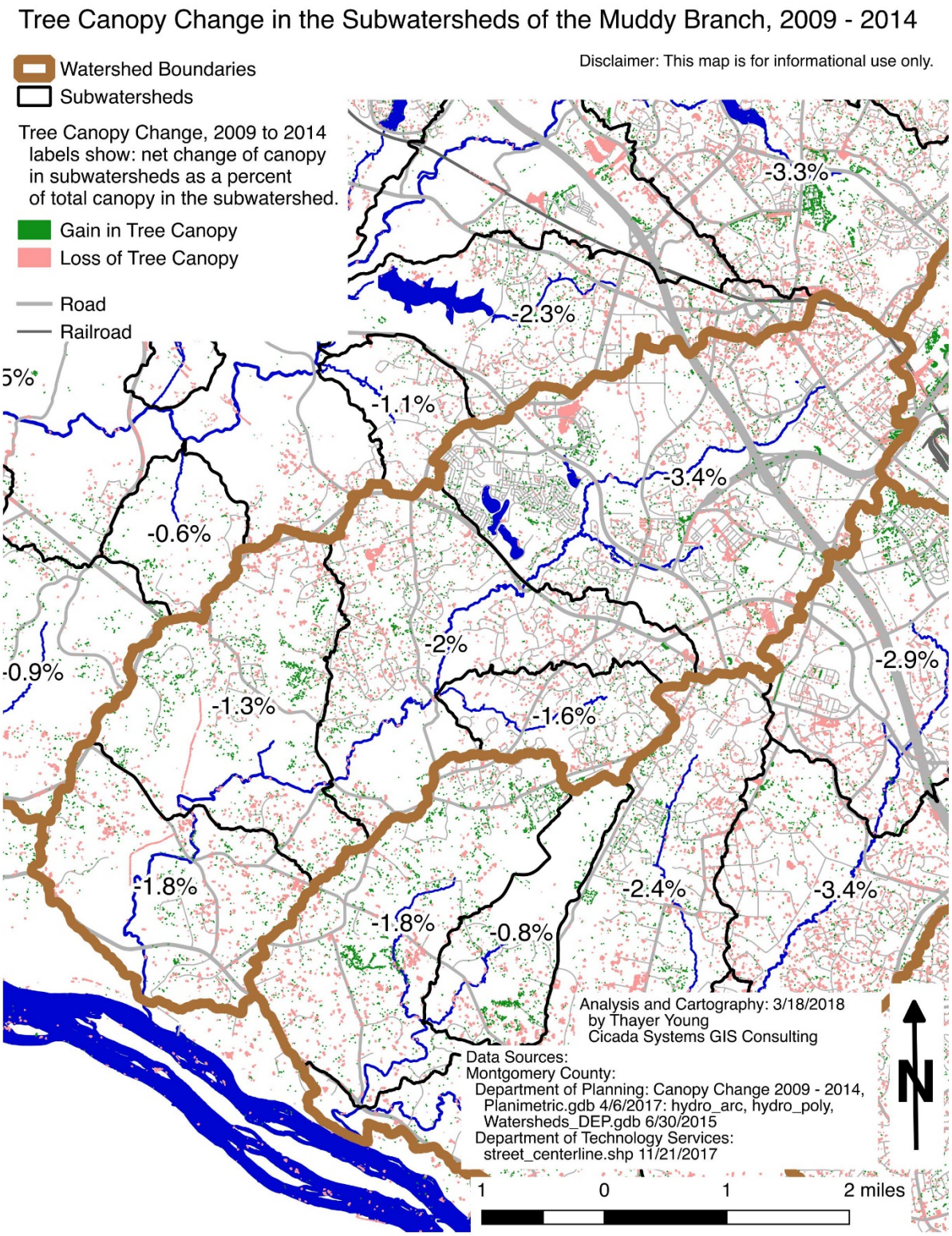

Figure 10: Tree Canopy Change in the Subwatersheds of the Muddy Branch, 2009-2014

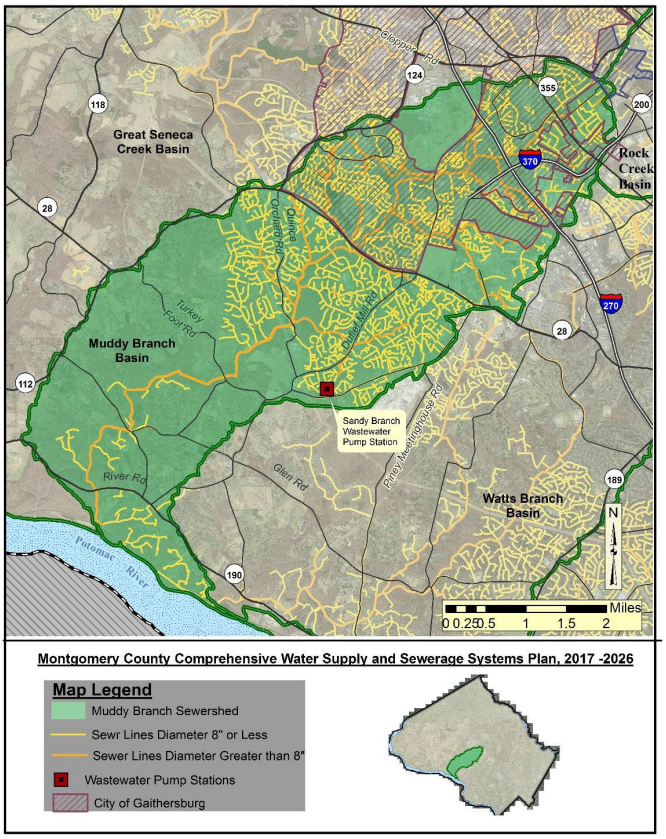

Figure 11:Muddy Branch Sewer Network

Seneca Creek (02140208)

The Seneca Creek watershed is over three times the size of Muddy Branch and Watts Branch combined, covers 129 square miles, and has a stream length of 27 miles through the Great Seneca sub-watershed. It is joined by tributaries from two other sub-watersheds: Little Seneca Creek and Dry Seneca Creek. The Little and Great Seneca watersheds cover approximately 80% of the Seneca Creek Watershed. Dry Seneca covers the remaining 20%.

It is more urbanized in the central areas, which include Germantown, parts of Gaithersburg, and rapidly developing areas around Clarksburg, which is in a sub-watershed that has the single largest percentage of forest loss across all three of the case study watersheds (-7%). A large area on the eastern side has been set aside as an Agricultural Reserve and is permanently protected through the transfer of development rights and easements in perpetuity.

Areas of higher and lower density development patterns can be seen in figures of land use and land cover, loss of tree canopy, and also by the sewer network[20] (see *Figure 12*, *Figure 13* and *Figure 14*). It is now 25% sewered as shown in *Figure 14* and is expected to become 35% sewered as master plans are fulfilled.

[20] Montgomery County Department of Environmental Protection (2017) Montgomery County 2017-2026 Comprehensive Water Supply and Sewerage Systems Plan. See Figure 4-F19 (Seneca Creek sewer network), page 4-57. https://www.montgomerycountymd.gov/DEP/Resources/Files/Downloads/WS/2017-chapter4-draft.pdf

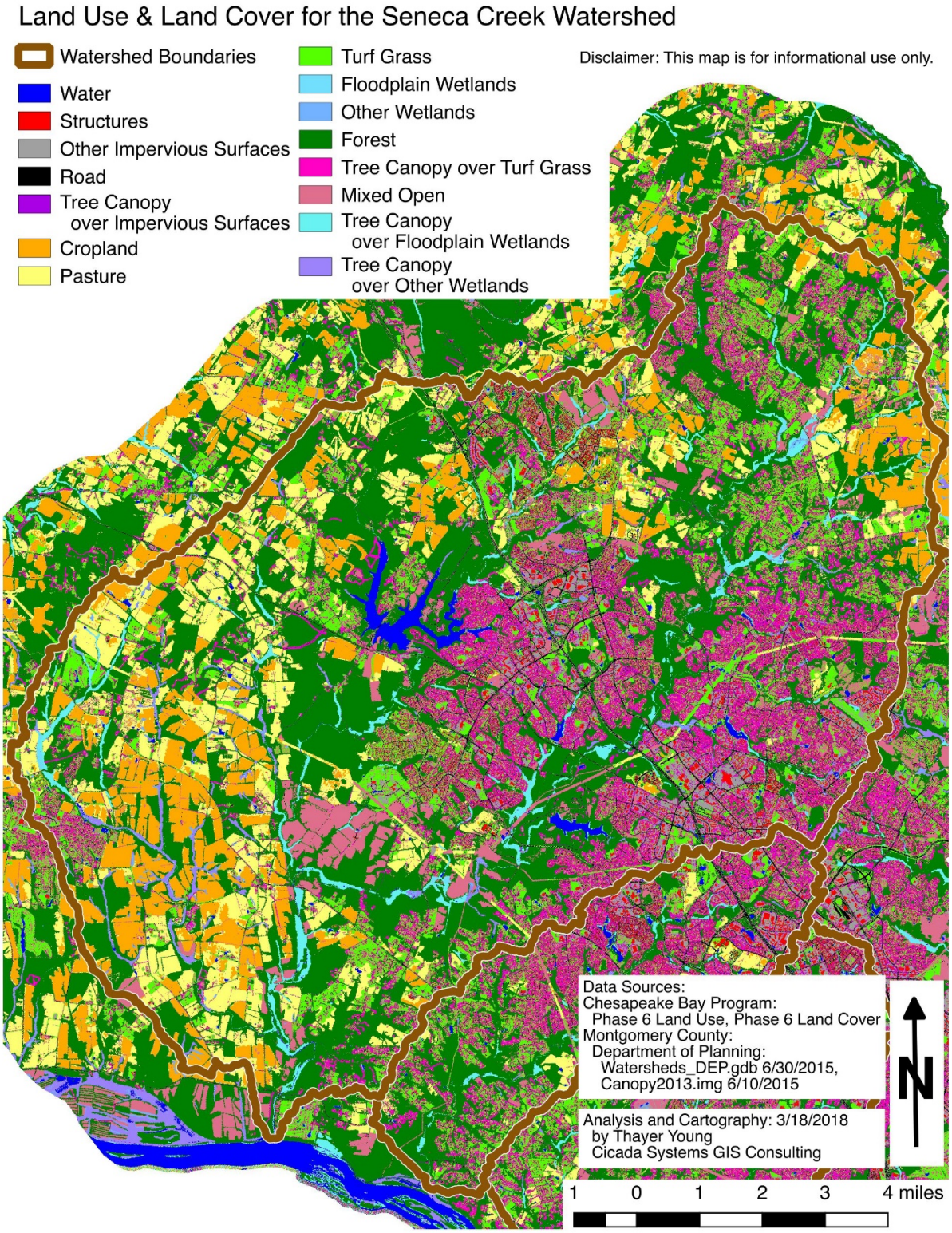

Figure 12: Land Use & Land Cover for the Seneca Creek Watershed

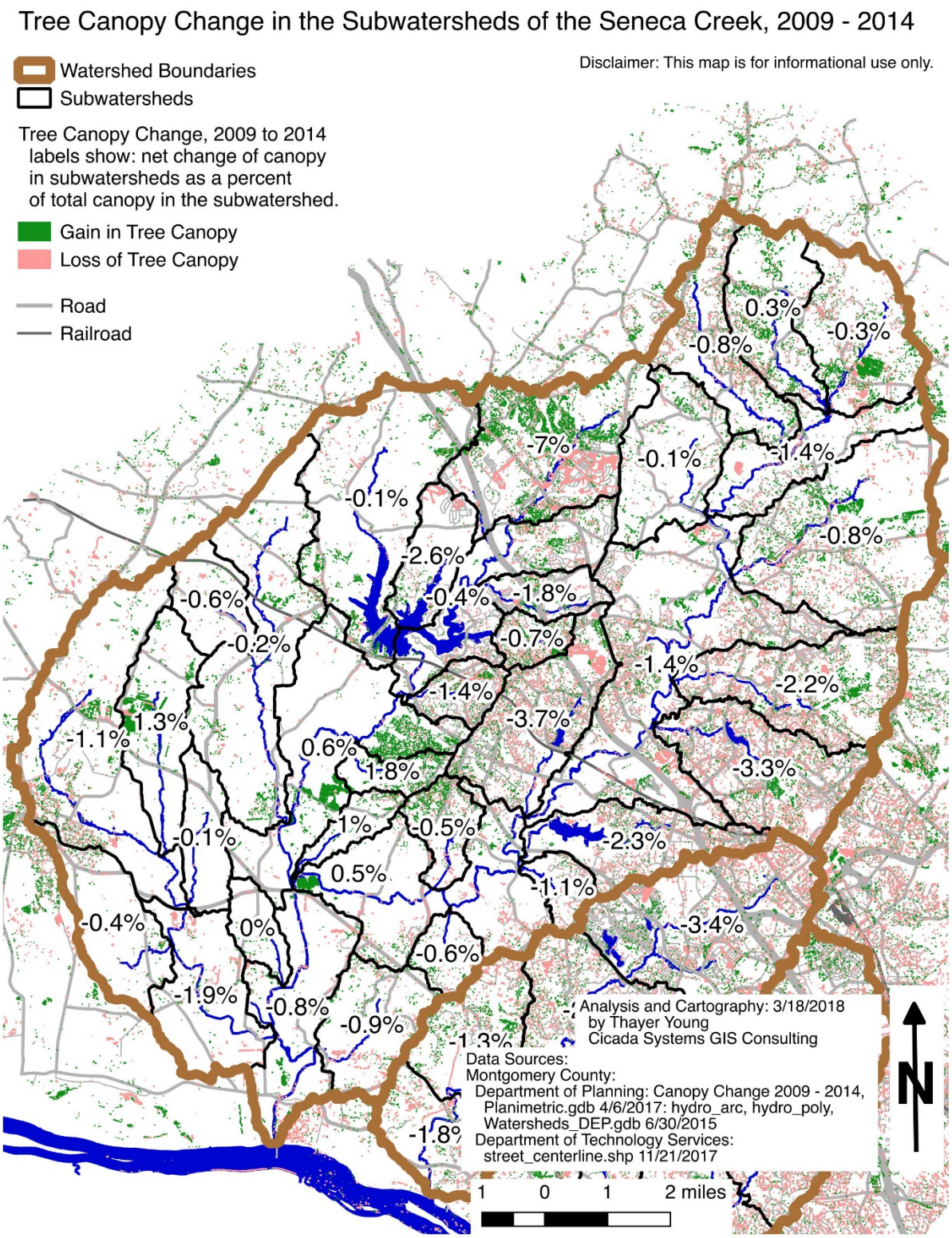

Figure 13: Tree Canopy Change in the Subwatersheds of the Seneca Creek, 2009-2014

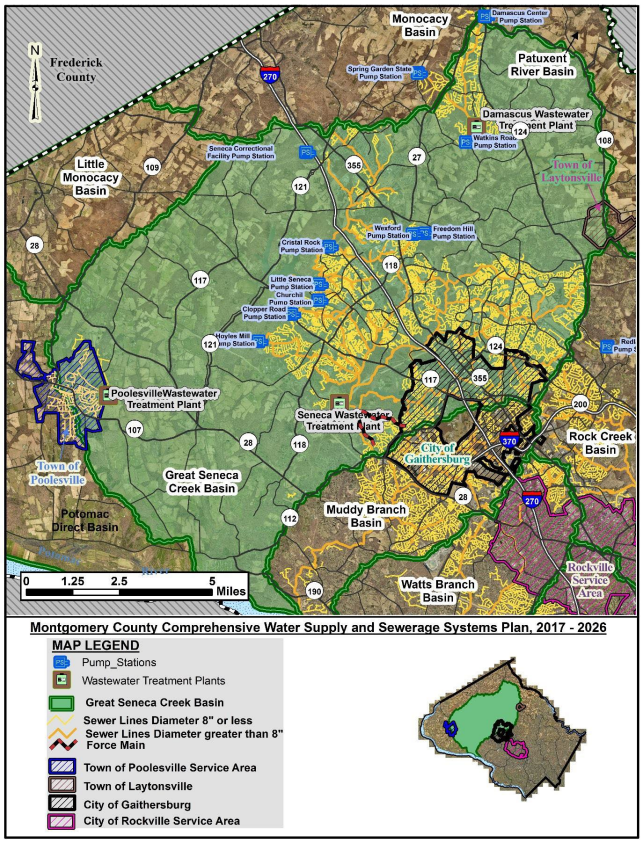

Figure 14: Seneca Creek Sewer Network

Drivers and potential drivers of further development in this area include proposals for a new Potomac river bridge, the M83 highway, development induced by the Inter-County Connector, and pressure for sewer extensions, all of which could facilitate further sprawl and urbanization in low density areas that buffer the agricultural reserve and increase stormwater runoff.

Dry Seneca Creek

The Dry Seneca Creek subwatershed, which covers 12,397.6 acres, is dominated by agriculture (59.8% of land cover) followed by open urban land (32.2%). Impervious surfaces cover 2.3%, 289.2 acres, and are primarily found in the town of Poolesville. In 2000, the Creek was found Biologically impaired downstream from the Poolesville WWTP, which was upgraded to correct the source of impairment.[21]

[21] Montgomery County Department of Environmental Protection (DEP) (2011), Dry Seneca and Little Seneca Pre-assessment report, May 2011 at https://www.montgomerycountymd.gov/DEP/Resources/Files/ReportsandPublications/Water/Watershed%20studies/Seneca%20Creek/Dry-Seneca-Creek-and-Little-Seneca-Creek-watershed-pre-assessment-report-11.pdf

Great Seneca Creek

Montgomery County's stormwater retrofit and watershed restoration approach is described in the Great Seneca Subwatershed Implementation Plan.[22]Great Seneca Creek starts at Mt Lebanon in Damascus and has a rapid drop in elevation between its headwaters and Montgomery Village, from 787 to 371 feet, which affects stream velocity (see *Figure 15*). A comparison of rainfall to peak flood data shows a trend of increases in flood discharge relative to precipitation amounts since 2012 that appears to be associated with the increase in impervious surfaces and is likely to be also carrying an increased sediment load (see *Figure 16*)[23]

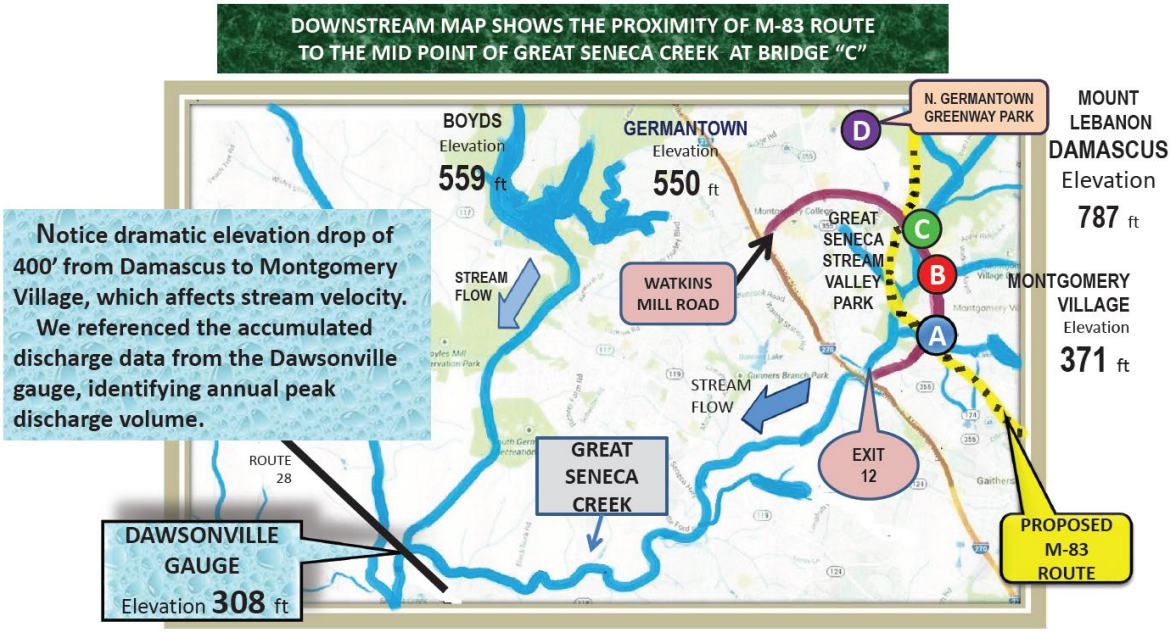

Figure 15: Seneca Creek sub-watersheds, indicating elevations and route of proposed M-83

[22] Montgomery County Department of Environmental Protection (DEP) (2012) Great Seneca Subwatershed Implementation Plan. At https://www.montgomerycountymd.gov/DEP/Resources/Files/ReportsandPublications/Water/Watershed%20studies/Great-Seneca-subwatershed-implementation-plan-12.pdf

[23] Smith, Ann and Miller, Edna (undated) slide presentation on M-83 Flood Plain Impact. https://www.slideshare.net/redaphid/seneca-tributaries prepared for the Coalition for Transit Alternatives to Mid-County Highway Extended (TAME Coalition).

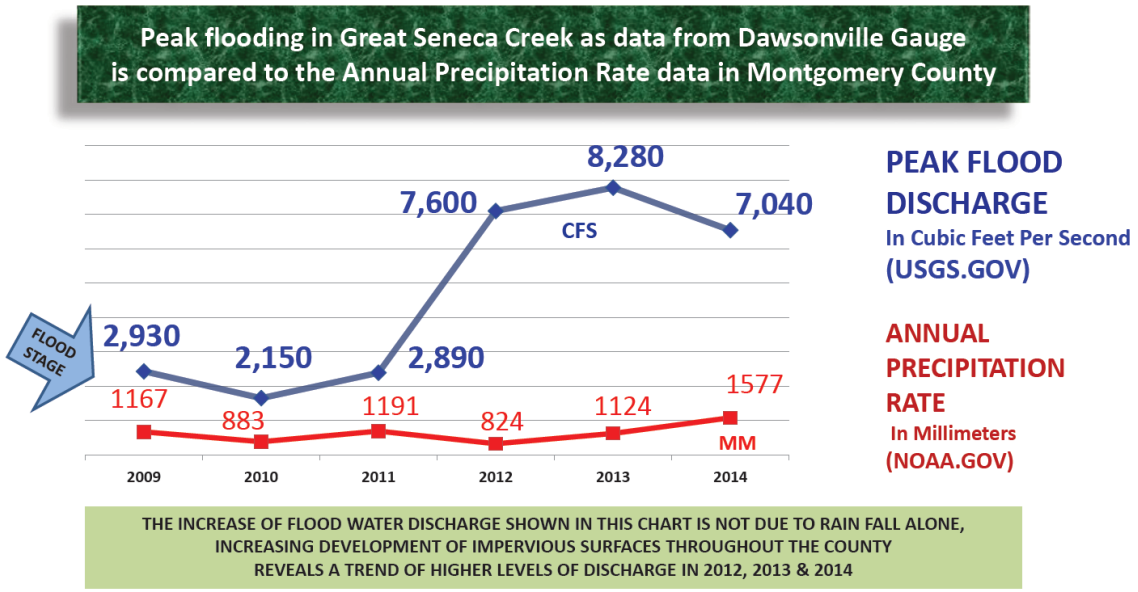

Figure 16: Peak flooding in Great Seneca Creek compared to Annual precipitation rate data in Montgomery County (2009-2014)[24]

Little Seneca Creek

The Little Seneca Creek sub-watershed covers 25,221.8 acres, with agriculture accounting for 71.3% of land cover. Impervious surfaces cover 7.0% (1758.8 acres) and are primarily in Germantown. Land uses ranging from mixed rural and agricultural to newer high-density residential and commercial areas in the Germantown and Clarksburg Town Center areas. It also contains the Little Seneca Reservoir, which was built in response to a major drought in the 1960s, as part of a water supply backup plan. This was a cooperative effort to assure adequate water supplies by the Washington area water utilities, who continue to jointly manage the reservoir and water supply through cooperative agreements put in place at that time.

To protect it from effects of ongoing urbanization, there have been extensive planning efforts including density limitations, stream valley park acquisition, reforestation, and designation of part of Clarksburg as a Special Protection Area (SPA).

Relationship between forest cover, sediment loading and water quality

Current water quality trends

Montgomery County Department of Environmental Protection's biological stream monitoring program uses fish and aquatic insect abundance and diversity as indicators of stream health. We compared DEP's stream data from 1997 with data from 2011/15 for Watts Branch, Muddy Branch, and Seneca Creek sub-watershed. For this study stream quality was compared with the percent of imperviousness in each subwatershed. [See Appendix A]

[24] Smith and Miller (undated) slide presentation at https://www.slideshare.net/redaphid/seneca-tributaries; see also: http://www.tamecoalition.org/p/home.html

In these three up-county watersheds, water quality biological indicators declined for 11 of 44 monitored sub-watersheds, 8 of which are in the larger and more rural Seneca Creek watershed, covering 34.29 square miles, or 26% of its land area, or 20% of the land area of all three of these watersheds combined. Twenty-five (25) sub-watersheds show no change, of which 21 are in the Seneca Creek watershed, and 8 show improvement, of which 3 are in the Seneca Creek watershed. An additional 3 sub-watersheds, also in Seneca Creek, are not monitored. New data gathered in 2014 by the MD Biological Stream Survey will be important in determining whether there is a trend but has not yet been published.

According to our GIS analysis of data for 2009 and 2014, canopy cover declined in 10 out of the 11 of the sub-watersheds where stream health declined between 1997 and 2011-2015. Although there are many factors that can influence water quality, forest cover (a component of canopy cover) is known to be a key factor in the decline of stream health, as is shown in studies that are further discussed in the next section, as part of our literature review.

When the current GIS analysis was combined with an analysis of Montgomery County's biological stream condition data, the connection between water quality decline and canopy loss is demonstrated. A comparison of Montgomery County DEP's most recent stream condition map for 2011-2015, with a prior stream condition map for 1997 shows that for 10 out of the 11 sub-watersheds where the GIS analysis indicated a canopy cover decrease (between 2009 and 2014), there was a decrease in the stream biological rating (Index of Biotic Integrity that uses fish and macroinvertebrate indicators).

We note that in other sub-watersheds in our study area, there was forest and tree canopy loss where stream biological ratings remained the same or in some cases, improved. This points to the fact that stream biota respond to multiple stressors (including imperviousness and chlorides along with tree and forest removal) in complex ways. And, total forest cover in a subwatershed is a key factor, that is related to, but separate from incremental forest cover changes. The present study looked at incremental forest cover changes, but did not examine total forest cover in relation to stream biological condition. The work of Goetz et al. shows a clear and strong relationship between IBI ratings for Montgomery County streams, and three land cover factors: total subwatershed forest cover; riparian buffer forest cover; and imperviousness[25].

BMPs and Water Quality

In FY 2017, the County reported a 23% reduction of sediment loads for Seneca Creek relative to the TMDL baseline, and 4.3% for the mid-Potomac watersheds[26]. This appears to be based on estimated efficiencies of planned BMPs reported in the 2012 sub-watershed implementation plan for the Great

[25] Goetz, Scott J., Robb K. Wright, Andrew J. Smith, Elizabeth Zinecker, and Erika Schaub. 2003. "IKONOS Imagery for Resource Management: Tree Cover, Impervious Surfaces, and Riparian Buffer Analyses in the Mid-Atlantic Region." *Remote Sensing of Environment* 88 (1–2): 195–208. https://doi.org/10.1016/j.rse.2003.07.010. See also the powerpoint presentation by Goetz, et al., of these findings pertaining to Montgomery County at: https://calval.cr.usgs.gov/JACIE_files/JACIE04/files/3Goetz5.pdf

[26] Montgomery County Department of Environmental Protection (2018) FY2017 Annual Report NPDES MS4 Permit https://www.montgomerycountymd.gov/DEP/Resources/Files/downloads/water-reports/npdes/AnnualReport-FY17-2-20-18-Final.pdf

Seneca sub-watershed, that are now complete. These BMPs consisted of 37 stormwater pond retrofits and nine ESD projects and did not include any riparian reforestation or stream restoration projects.[27] .

Seneca State Park

Due to timing of BMP implementation and collection of water quality monitoring data, we cannot draw any conclusions as the role of BMPs in water quality. An unanswered question is how this reduction of sediment load compares with additional sediment loading associated with new development, i.e., growth that has not been accounted for in the Seneca Creek and mid-Potomac watersheds. A comparison of sediment delivery reported in the Chesapeake Bay Program CAST model for 2009 and 2017 shows an overall 4% decrease in sediment load across all sectors for the Seneca Creek and lower mid-Potomac watersheds combined. However, the model shows an increase from the developed sector of 772,581 pounds per year for these watersheds, (out of a total of 19,174,390, or 4%). For just the Seneca Creek watershed, the CAST model shows a minor decrease in sediment load, of 36,047 pounds/year, (out of a total of 10,208,601, or .3%), compared with a 6% reduction across all sectors.

Although ESD or "Environmental Site Design" projects are more effective than stormwater ponds because they promote water infiltration and evaporation rather than detention, neither of these approaches is as effective as maintaining or restoring forest cover. Studies of the effectiveness of BMPs show that, while these do significantly reduce pollution loads, they do not replicate the hydrology of forested land areas.[28] Therefore new development or growth, even using ESD practices, combined with increases in stormwater runoff because of heavier storms associated with climate change, are expected to increase pollution loads beyond the baseline, and also need to be accounted for.

Forests and stream health

As a general rule, landscape changes associated with loss of forests and urban development lead to increases in stormwater runoff as a result of increases in impervious and compacted surfaces which, in turn, reduce infiltration. In what has come to be known as the "urban stream syndrome", this leads to an increase in "flashiness" – i.e., a more rapid rise and fall of stream flow in response to precipitation, and flooding, along with erosion and scouring of stream channels.[29] This runoff carries increased sediment and nutrient loads along with other pollutants to water bodies.

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[27] Montgomery County Department of Environmental Protection 2012, Great Seneca Watershed Implementation Plan. Rockville MD At https://www.montgomerycountymd.gov/DEP/Resources/Files/ReportsandPublications/Water/Watershed%20studies/Great-Seneca-subwatershed-implementation-plan-12.pdf

[28] Hogan, Dianna M., S. Taylor Jarnagin, J.V. Loperfido, and Keith Van Ness. 2014. "Mitigating the Effects of Landscape Development on Streams in Urbanizing Watersheds." *JAWRA Journal of the American Water Resources Association* 50 (1): 163–78. https://doi.org/10.1111/jawr.12123.

[29] Walsh, Christopher J., Allison H. Roy, Jack W. Feminella, Peter D. Cottingham, Peter M. Groffman, and Raymond P. Morgan II. 2005. "The Urban Stream Syndrome: Current Knowledge and the Search for a Cure." *Journal of the North American Benthological Society* 24 (3): 706–723.

GIS analysis conducted for this study did not include modeling of the relationship between forest cover and runoff pollution, because of the difficulty and time required to obtain the necessary data. High-resolution position and alignment of underground sections of streams, the so called hidden-hydrology layer, is incomplete and requires a tedious interpolation process to be useful with the available high-resolution elevation and land cover data. The National Hydrography Database, though complete, is very low resolution and is much less accurate. Montgomery County DEP indicated they will be using the new CBP CAST model to present results from a similar type of modeling in the 2018 annual report, which would enable us to update this report with an addendum when it is published in 2019.

However, we can make some very rough estimates of implications of forest loss for water quality based on Chesapeake Bay Program estimates of sediment delivery associated with different land uses, published studies on forest cover-water quality relationships, and paired watershed studies being done to determine BMP performance in selected watersheds in Montgomery County compared to similar forested watersheds.

In a study of central Maryland, Goetz et al (2003)[30] correlated satellite imagery of land cover with stream biological indicators developed by Montgomery County, and found a direct relationship between levels of imperviousness and stream health. They concluded that streams with an "excellent" rating had levels of imperviousness below 6%, with at least 50% overall forest cover and 75% forest cover in riparian areas (see figure 17). However, based on an analysis of data from Maryland streams, King et al (2011)[31] found substantial degradation and loss of diversity beginning at much lower levels of imperviousness, between 0.5 and 2%. GIS analysis conducted for this study shows a 17% level of imperviousness across the three watersheds.[32] Imperviousness by sub-watershed ranges from 1.36% to 50.61%. As can be seen in Appendix A, those with lowest levels of imperviousness are found in the Seneca Creek watershed.

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[30] Goetz, et. al (2003) op cit at footnote 27. Scott J., Robb K. Wright, Andrew J. Smith, Elizabeth Zinecker, and Erika Schaub. 2003. "IKONOS Imagery for Resource Management: Tree Cover, Impervious Surfaces, and Riparian Buffer Analyses in the Mid-Atlantic Region." *Remote Sensing of Environment* 88 (1–2): 195–208. https://doi.org/10.1016/j.rse.2003.07.010. See also the powerpoint presentation by Goetz, et al., of these findings pertaining to Montgomery County at: https://calval.cr.usgs.gov/JACIE_files/JACIE04/files/3Goetz5.pdf

[31] Baker, Matthew E., and Ryan S. King. 2010. "A New Method for Detecting and Interpreting Biodiversity and Ecological Community Thresholds: Threshold Indicator Taxa ANalysis (TITAN)." *Methods in Ecology and Evolution* 1 (1): 25–37. https://doi.org/10.1111/j.2041-210X.2009.00007.x

[32] This figure includes the land use categories: structures, impervious non-road, road, and tree canopy over impervious. Other land use categories have various degrees of perviousness/imperviousness, depending on the amount of soil compaction (e.g., cropland, pasture and turf grass).

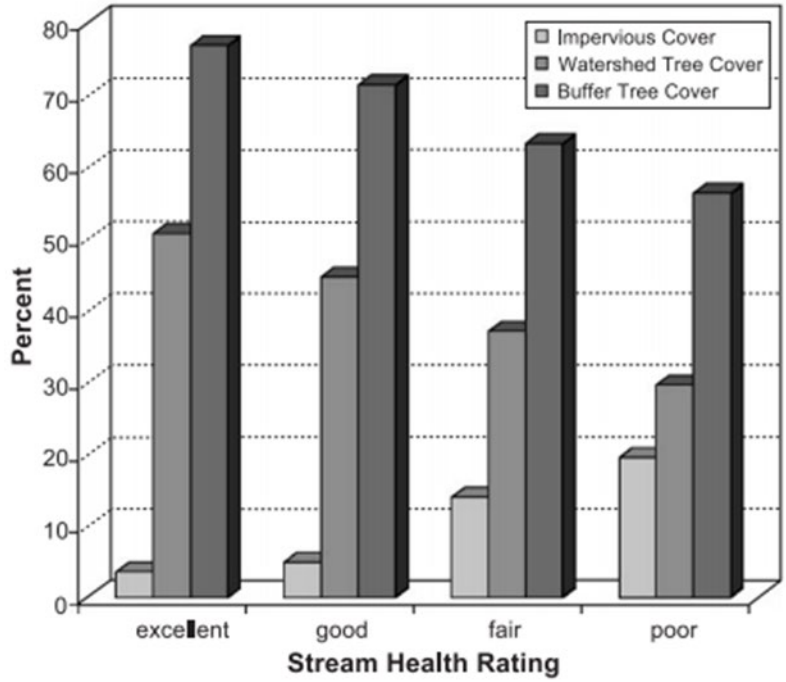

Figure 17: Stream health rankings in relation to (a) impervious surface cover, (b) watershed tree cover, and (c) riparian buffer tree cover, each derived from the IKONOS image data. Source: Goetz 2004

Variation in runoff from pervious and impervious areas.

Stormwater runoff pollution occurs from both paved (impervious) and unpaved (pervious) areas which have varying degrees of capacity for water infiltration depending on prior soil compaction, erosion, and geological characteristics. Although the focus of Maryland's MS4 permits has been on installation of stormwater retrofit practices to treat runoff from impervious surfaces, pervious area strategies are needed alongside improved runoff reduction from impervious areas, including for forests and the entire tree canopy, as well as turf.

Like turf areas, forests and tree groves vary in their ability to soak up and prevent runoff. Healthy forests have ample mature trees forming a canopy; an understory of native shrubs; native herbaceous plants; and a thick ground cover of decaying leaves and logs. Healthy forests also have dark-colored topsoil, rich in organic carbon with an uncompacted structure, networked with holes called "macropores" formed by living organisms. A 2016 study of forest soils at the Smithsonian Environmental Research Center in Maryland compared an old-growth "uncut" forest with old and young forests that had been cleared and then allowed to regrow.[33] The study found that of the three forests, only the old-growth, uncut forest had an intact Organic "O" layer consisting of leaves and other detritus at the surface in a state of decay. The uncut old-growth forest also had a significantly lower "bulk

[33] Yesilonis et al. (2016) Historical Land Use and Stand Age Effects on Forest Soil Properties in the Mid-Atlantic U.S. Forest Ecology and Management 370 (2016) 83-92. At: https://www.fs.fed.us/nrs/pubs/jrnl/2016/nrs_2016_yesilonis_001.pdf

density" compared with the other two forests, meaning that the soil was uncompacted and had a macropore structure that enabled rapid uptake and storage of water during rainstorms.

These reports confirm the work of forest soil hydrologist Charles Hursh (1944) who documented the water storage limitations of forest soils at Coweeta in North Carolina, where oldfield forests grew up after abandonment of farms in the Piedmont Plateau and southern Appalachia. [34] Hursh found that eroded soils that have been abandoned after many years of agriculture, "may have less than one-third the macro-pore storage in the first 36 inches than is found in comparable soil types that have not been cleared for agriculture. Consequently, the young pine stands, that invade badly eroded land do not have the initial water control and groundwater storage found in the un-cleared forest."[35]

In Montgomery County, as in the North Carolina Piedmont studied by Hursh, forest clearing followed by generations of farming resulted in a widespread loss of organic-rich topsoil and compaction of the clay-rich subsoil. As a result, many local forests, dominated by tulip, white oak, and other trees that grew back after farms were abandoned, are typically growing in heavy clay subsoil, with less ability to soak up, store, and filter runoff than the original forest soils of the pre-colonial era.

Yet, even degraded second- and third-growth forests provide significant runoff capture and reduction. And in some areas, the ability of a forest to absorb nearly all incoming precipitation survived into the Twentieth Century. Hydrologists Luna Leopold, M. Gordon Wolman and John Miller in 1961 measured the runoff in a rill of then-fully-forested Sisters Creek subwatershed, consisting of second-growth tulip, hickory, and beech trees in the Cabin John Watershed of Montgomery County Maryland. They reported that:

> "The drainage area is about 2.3 acres and the rill, with a mean gradient of 0.17 foot per foot, has a width of 1.5 feet near the mouth. Both the forest floor and the channel are carpeted with fallen leaves. In 1961, during which there was 37.6 inches of precipitation, there were 11 events during which runoff occurred in the rill, and this runoff totaled about 0.21 inch, or less than 0.6% of the precipitation."[36]

Leopold, Wolman and Miller documented the fact that mature forests in Montgomery County can provide nearly 100% absorption of annual precipitation. At least eight separate hydrologic functions of mature forests have been documented, ranging from canopy interception, to soil-mediated infiltration and groundwater recharge.[37] A green infrastructure strategy with a core role for forests in reducing runoff pollution in Montgomery County must look at the role of forest soils, and literally make amends for past abuses through new techniques, including use of organic soil amendments like compost.

Overview of studies in Montgomery County watersheds

The Watts Branch watershed has the distinction of a having been observed over a 41-year period by one of its residents, Luna Leopold, also known as the father of geomorphology, and his colleagues. Beginning

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[34] Hursh, Charles (1944) Water Storage Limitations in Forest Soil Profiles. Soil Science Society of America. At: http://coweeta.uga.edu/publications/797.pdf

[35] Hursh (1944) Op.Cit..

[36] Leopold, Wolman and Miller (1964) Fluvial Processes in Geomorphology. (Dover). P.85.

[37] Cameron, D. (2012) "Maintaining Pre-Development Hydrology: The Eight Hydrologic Functions of Forests and Trees." Blog post on the deeproot.com website, at: http://www.deeproot.com/blog/blog-entries/maintaining-pre-development-hydrology-the-eight-hydrologic-functions-of-forests-and-trees-2

in 1953, they began to record changes associated with urbanization along one of its streams, in what was then a primarily agricultural watershed with some secondary growth tree cover. Summarizing changes over three decades, Leopold observed an increase in the average of highest peak discharges per year, and that overbank flows increased from two to seven per year, as the number of houses increased from 140 to 2060, between 1950 and 1984. He also noted that sewer manholes provided more reliable benchmarks for observing the movement of stream channels because those installed by his team were often carried away by floods, lost with the death of trees, or eroded by chemical action. Another observation was a change in the composition of material in streambeds, and a considerable widening of stream cross-sections after 1961.[38] In addition to over-widening of streams, Montgomery County DEP later reported that, as a result of inadequate stormwater management streams have become entrenched and have lost their connection to floodplains, have eroding banks, sedimentation, and riffle habitat impairment. [39]

As part of its stormwater permit requirements, Montgomery County carries out monitoring studies to assess the effectiveness of stormwater management practices in new developments in the Clarksburg area of the Little Seneca Creek watershed, by comparing these sites to an undeveloped forested watershed. The studies also enable an assessment of land use impacts on streams in headwater areas where changes in streamflow and conditions are expected to be more prominent.[40] Since 2004, these studies have been carried out by the Clarksburg Monitoring Partnership (CMP). In addition to the County, partners include: U.S. EPA, USGS, and UMD. The work of the CMP is briefly reported on in the MS4 Annual reports published by DEP and has also resulted in several published studies. In addition, the County monitors changes in stream morphology, and biological indicators in streams, which are discussed above, in the section on water quality trends.

Results from monitoring of changes in geomorphology (longitudinal profiles, cross sections, bed composition, sinuosity) between 2002 and 2015 show that "the construction phase of development impacted the test area channel morphology, as evidenced by straightening, down-cutting, and enlargement of the channel." [41] Sediment export was also shown to increase during the construction period. Time of concentration (TOC), i.e., the time between when rainfall starts and when discharge increases at the gaging station, is higher in the forested watershed than the developed watershed.

Some more specific results reported in published studies that compared distributed and centralized stormwater management facilities to the forested watershed are found in Hogan et al 2014, Jones et al 2014, Loperfido et al 2014, Rhea et al 2015, Bhaskar et al, 2016, Sparkman et al 2017, and Hopkins et al 2017.[42]

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[38] Leopold, Luna B., Reed Huppman, and Andrew Miller. 2005. "Geomorphic Effects of Urbanization in Forty-One Years of Observation." *Proceedings of the American Philosophical Society*, 349–371.

[39] Montgomery County Department of Environmental Protection 2012 Muddy Branch and Watts Branch Subwatersheds Implementation Plan

[40] Hogan, Dianna M., S. Taylor Jarnagin, J.V. Loperfido, and Keith Van Ness. 2014. "Mitigating the Effects of Landscape Development on Streams in Urbanizing Watersheds." *JAWRA Journal of the American Water Resources Association* 50 (1): 163–78. https://doi.org/10.1111/jawr.12123.

[41] Montgomery County DEP MS4 Annual Report (2018) FY2017 Op Cit at Footnote #26.

[42] Hogan, Dianna M., S. Taylor Jarnagin, J.V. Loperfido, and Keith Van Ness. 2014. "Mitigating the Effects of Landscape Development on Streams in Urbanizing Watersheds." *JAWRA Journal of the American Water Resources Association* 50 (1): 163–78. https://doi.org/10.1111/jawr.12123.

Hogan et al (2014) found that use of best available sediment and erosion control practices did not replace the ecosystem functions of natural floodplain and wetland areas during intense landscape changes that take place during the construction period. Observation of higher sediment deposition and altered geomorphology while these practices were used confirmed that "even the best maintained and functioning sediment and erosion control Best Management Practices (BMPs) cannot replicate predevelopment conditions or completely mitigate the stormwater flow and sediment generation consequences of intense landscape change" and that these BMPs "are not as effective at protecting stream geomorphology and biota as limiting impervious cover, and preservation of natural cover in the riparian zone."

In a comparison of the effectiveness of centralized stormwater management practices with distributed practices[43] and with the undeveloped forested site, Hopkins et al 2017 found that distributed practices performed better than centralized practices for small events. Forested watersheds performed better than both for smaller storm events with respect to runoff yield, maximum specific discharge and flow duration. Except for the largest storm events, the forested watershed also had much lower export of

Eroding stream bank

Jones, Daniel K., Matthew E. Baker, Andrew J. Miller, S. Taylor Jarnagin, and Dianna M. Hogan. 2014. "Tracking Geomorphic Signatures of Watershed Suburbanization with Multitemporal LiDAR." *Geomorphology* 219 (August): 42–52. https://doi.org/10.1016/j.geomorph.2014.04.038.

Loperfido, J. V., Gregory B. Noe, S. Taylor Jarnagin, and Dianna M. Hogan. 2014. "Effects of Distributed and Centralized Stormwater Best Management Practices and Land Cover on Urban Stream Hydrology at the Catchment Scale." *Journal of Hydrology*, Water governance across competing scales: Coupling land and water managementIncorporating water resources in integrated urban and regional planning, 519, Part C (November): 2584–95. https://doi.org/10.1016/j.jhydrol.2014.07.007.

Rhea, Lee, Taylor Jarnagin, Dianna Hogan, J. V. Loperfido, and William Shuster. 2015. "Effects of Urbanization and Stormwater Control Measures on Streamflows in the Vicinity of Clarksburg, Maryland, USA: Effects on Streamflows." *Hydrological Processes* 29 (20): 4413–26. https://doi.org/10.1002/hyp.10505.

Bhaskar, Aditi S., Dianna M. Hogan, and Stacey A. Archfield. 2016. "Urban Base Flow with Low Impact Development: Urban Base Flow with Low Impact Development." *Hydrological Processes* 30 (18): 3156–71. https://doi.org/10.1002/hyp.10808.

Sparkman, Stephanie A., Dianna M. Hogan, Kristina G. Hopkins, and J.V. Loperfido. 2017. "Modeling Watershed-Scale Impacts of Stormwater Management with Traditional versus Low Impact Development Design." *JAWRA Journal of the American Water Resources Association* 53 (5): 1081–94. https://doi.org/10.1111/1752-1688.12559.

Hopkins, Kristina G., J.V. Loperfido, Laura S. Craig, Gregory B. Noe, and Dianna M. Hogan. 2017. "Comparison of Sediment and Nutrient Export and Runoff Characteristics from Watersheds with Centralized versus Distributed Stormwater Management." *Journal of Environmental Management* 203 (December): 286–98. https://doi.org/10.1016/j.jenvman.2017.07.067.

[43] Centralized stormwater management practices involve detention with pipes and ponds. Distributed practices are those which involve the use of green infrastructure or Low Impact Development (LID) that is designed to treat and retain stormwater where it falls by mimicking natural hydrologic processes to promote infiltration.

sediment (40% less than distributed BMPs, which had 70% less than from centralized BPMs). However, for single large events, all three watershed types were similar in terms of sediment export which is driven by large events even in forested watersheds. Based on studies carried out in Virginia[44] which show much higher stream bank erosion during large storm events, the authors believe that it is likely that this higher level of sediment export can be attributed to higher stream bank erosion during large events. To confirm this, they compared sediment samples from outfalls of treatment trains to samples taken instream during a large storm event and found much lower suspended sediment concentrations in samples taken from the outfalls than in the stream channel. They concluded that sediment discharges could be reduced with greater capacity to attenuate peak flows. An important consideration is the condition of the forest, which is growing on land previously cleared for agriculture, which also led to erosion of the stream channel.

Despite the fact that most forests are on agricultural legacy land with degraded soils, even these forests still generate significantly less sediment loadings on larger watershed scales, compared with developed lands.

There are two factors that help to explain the higher sediment loadings from the forested watershed during the largest storms (and that help in relating the Hopkins et al 2017 paper, to other papers and larger-scale studies):

1) Runoff discharge volume matters. The Hopkins et al 2017 study showed that even for the largest storms, the forested watershed (regrown after longtime farming) generated significantly less runoff than either of the two developed watersheds. Since forested watersheds (even those on agricultural legacy land) generate less total runoff volume per large storm, and per year when doing annual calculations, then they contribute much less runoff volume to the large downstream watersheds -- where channel scour has a bigger effect.

2) Watershed scale matters. The Hopkins et al 2017 study is with very small subwatersheds. When these small areas are viewed on a larger watershed scale, like that of Little Seneca, Muddy Branch,or the Potomac Basin , then it's the aggregate, cumulative effects downstream of the runoff from all of the contributing source areas that come into play.
A 2015 survey of sediment accumulation in mid-Atlantic Piedmont ponds and reservoirs compared watersheds with different dominant land cover types: forested; agricultural; or suburban (Smith and Wilcock 2015). The authors concluded that for small zero-order and first-order watersheds, sediment yield is greatest from suburban land cover, followed by agricultural and forest.[45]

These studies show that the net effect on the scale of larger watersheds like Seneca, Muddy or Watts, and the Potomac Basin and Chesapeake Bay, is that forest land contributions to sediment loading are significantly less than developed and agricultural land contributions to sediment loading.

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[44] Gellis, A.C., M.K. Myers, G.B. Noe, C.R. Hupp, E.R. Schenk, and L. Myers. 2017. "Storms, Channel Changes, and a Sediment Budget for an Urban-Suburban Stream, Difficult Run, Virginia, USA." *Geomorphology* 278 (February): 128–48. https://doi.org/10.1016/j.geomorph.2016.10.031.

[45] Smith and Wilcock, 2015. Upland sediment supply and its relation to watershed sediment delivery in the contemporary mid-Atlantic Piedmont (U.S.A.) in *Geomorphology* 232(2015) 33-46. http://dnr.maryland.gov/ccs/Documents/MDStreamExchange_Smith.pdf

The most significant sources of sediment in the Chesapeake Bay watershed, were identified using a sediment model developed by USGS known as the "SPAtially Referenced Regressions on Watershed attributes" or SPARROW model.[46] These are:

- small streams above the fall line, which yield an average of 0.29/Mg/km2/year, which accounts for 8% of total sediment loads
- urban/suburban development, which contributes an average 3,928 Mg/km2/year or 70 times the average yield from agriculture, which accounts for 39% of total loads, and
- agriculture, which contributes an average 57 Mg/km2/year, accounting for 51% of sediment loads **Forests, which yield an average of 1 Mg/km2/year and account for 2% of the total load, were not deemed significant.**

Factors that account for variation in sediment transport to streams are slope, soil permeability, and reservoirs per unit area. The case study watersheds reviewed for this current study are also in the Piedmont uplands, which have higher erosion and sediment delivery due to the agricultural legacy of the area combined with a unique geology, topography and geomorphic history. As shown in Figure 18, developed areas in the Piedmont account for higher sediment loads than agriculture not only in terms of load per unit area (labeled yield on Figure 18) but also total load (labeled flux).

[46] Brakebill et al 2010 Sources of Suspended-Sediment Flux in Streams of the Chesapeake Bay Watershed: A Regional Application of the SPARROW Model. *Journal of the American Water Resources Association.* https://onlinelibrary.wiley.com/doi/full/10.1111/j.1752-1688.2010.00450.x

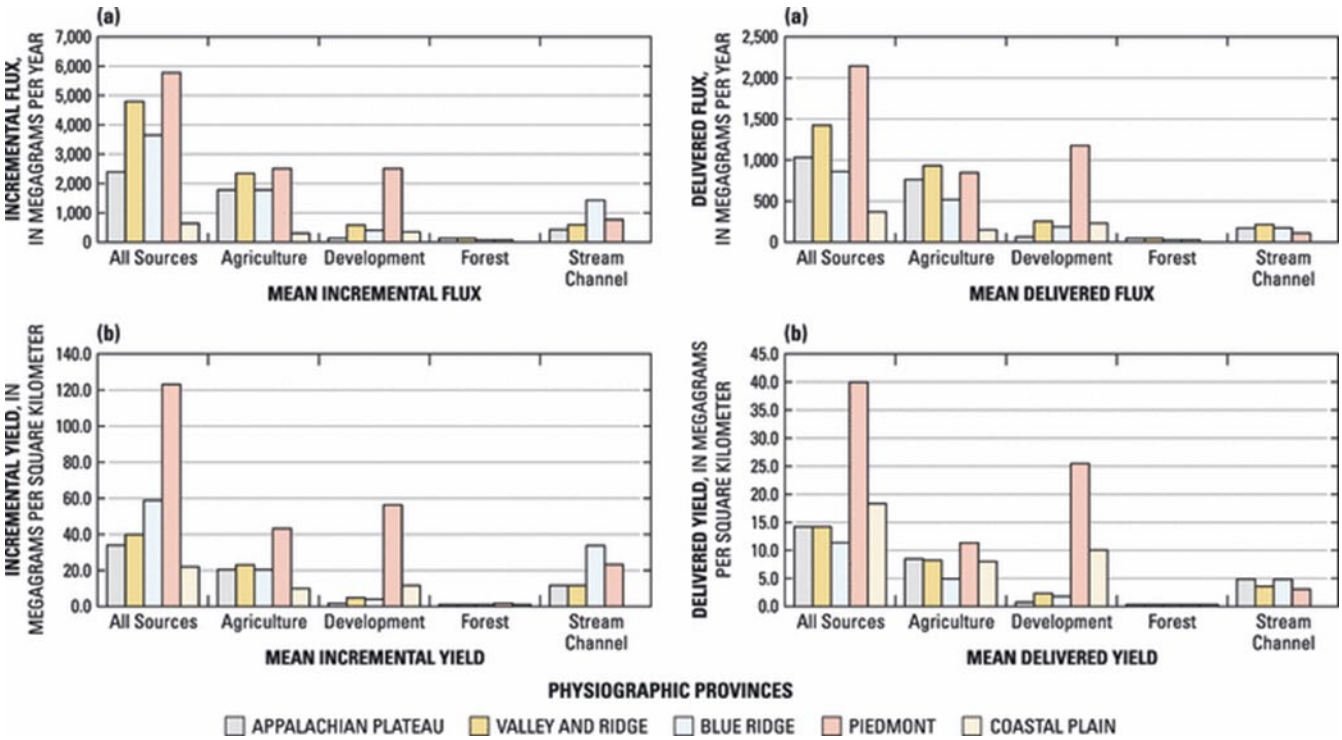

Figure 18: Mean Incremental and Delivered (a) Flux and (b) Yield by Sediment Source and Physiographic Province Source: Brakebill et al 2010 [47]

Forests and water treatment costs

Forested areas provide natural filtration and storage for approximately two thirds of US water supplies,[48] and still provide the best and the most cost-effective protection of drinking water sources, along with many other co-benefits or "ecosystem services." Natural floodplain and wetland areas remove and retain nutrients and sediments from stormwater runoff, increase water infiltration, reduce flooding, and protect the physical characteristics of receiving streams. Conversely, urbanization of forested and agricultural areas leads to increases in runoff and storm flow which lead to scouring of stream channels, streambed and bank erosion, habitat destruction, decreases in the health as well as diversity of biotic communities, and increases in sediment and nutrient loads that are carried to downstream water bodies.[49]

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[47] *I*ncremental represents the amount of sediment generated locally independent of upstream supply and contributed to each stream reach. Delivered represents the amount of sediment generated locally for each stream reach weighted by the amount of aquatic retention that would occur in transport to the bay.

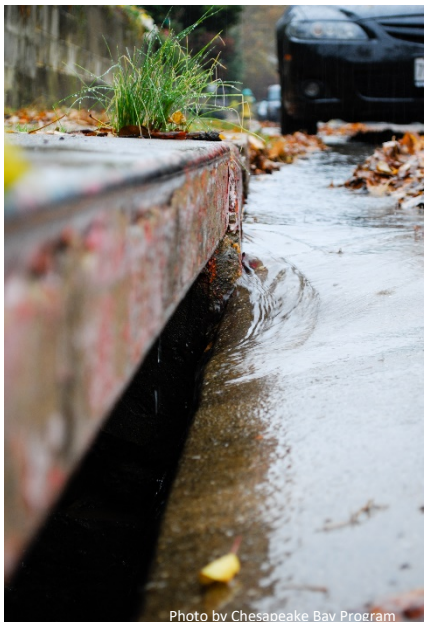
[48] National Academy of Sciences (2008) "Hydrologic Effects of a Changing Forest Landscape." Washington, D.C.: National Academies Press. http://dels.nas.edu/Report/Hydrologic-Effects-Changing-Forest/12223

[49] Hogan, Dianna M., S. Taylor Jarnagin, J.V. Loperfido, and Keith Van Ness. 2014. "Mitigating the Effects of Landscape Development on Streams in Urbanizing Watersheds." *JAWRA Journal of the American Water Resources Association* 50 (1): 163–78. https://doi.org/10.1111/jawr.12123.

A general rule is, "the less forest in a source water drainage area, the higher the water treatment costs".[50]

A 2004 study by Trust for Public Land found that a 10% increase in forest cover reduces treatment costs by approximately 20%, and that 50–55% of the variation in treatment costs can be explained by the percentage of forest cover in the source area[51]. Since then, numerous reviews and case studies have been conducted to confirm and better understand this relationship.

Conclusions released this summer from an ICPRB study also indicate that forest increases in the Potomac River basin would result in a small decrease in water supply treatment costs when considering the entire 11,560 mi^2 upper Potomac River basin. Under the scenario of maximum forest protection, in which all forests are protected that are expected to otherwise be lost, the study estimated savings of up to $94,831 or $1.09 per acre of forest conserved for protecting 86,733 acres, which amounts to 2 to 3% of forest land in the basin. However, the study was limited to considering the amount and cost of chemical treatments, which depend on turbidity and total organic carbon. The results would likely differ if the cost of removing other pollutants that cannot be readily treated with the existing systems, such as chlorides (e.g., road salts), capital costs for new infrastructure and treatment processes and protection and restoration of forests closer to water intakes are considered.[52]



Stormwater runoff

Among the takeaways from the review of the literature, not limited to the Potomac River is that infrastructure for treatment and delivery of drinking water must be combined with other measures in order to keep drinking water safe. This is the "multiple barrier" approach under the federal Safe Drinking Water Act. It combines source water assessment and protection, with adequate treatment operations, in order to protect public health[53]. Therefore, good land use planning can be considered a preventive measure for protecting public health, similar in concept to the shift from treatment to prevention in traditional medicine.[54] Also, that greater attentions needs to be given to small headwater streams, as these account for over 70% of stream channel length, and therefore their watersheds have a greater cumulative impact on

[50] Freeman, J., Madsen, R., & Hart, K. (2008). *Statistical Analysis of Drinking Water Treatment Costs, Source Water Quality, and Land Cover Characteristics*. Trust for Public Land. Retrieved from http://www.tpl.org/land-use-and-drinking-water-treatment-costs-0

[51] Ernst, C. (2004). *Protecting the Source: Land Conservation and the Future of America's Drinking Water*. San Francisco: Trust for Public Land and American Water Works Association.

[52] Interstate Commission on the Potomac River Basin (ICPRB) 2018 Forest Cover Impacts on Drinking Water Treatment Costs in the Non-Tidal Potomac Basin. WRF #4651 Project Overview. http://www.potomacdwspp.org/priority-issues/watershed-protection/forests-and-source-water-protection/forests-and-water-treatment-costs/

[53] U.S. EPA webpage entitled "What are drinking water standards?" at https://www.epa.gov/dwregdev/how-epa-regulates-drinking-water-contaminants#standards

[54] Reiter, Lawrence W, ed. 2004. *From Source Water to Drinking Water Workshop Summary*. Washington, D.C.: National Academies Press.

maintaining water quality than downstream areas[55]. Lastly, heavier storms, which will increase stormwater runoff, are not only expected as a consequence of climate change but are already occurring. In the northeastern US, the amount of precipitation falling in heavy storm events increased by 71% between 1958 and 2012 (NCA 2014).

Forest increase approaches - Cost comparisons

Table 4 below provides rough estimates of the costs of forest and tree-based practices; units are the initial cost per impervious acre (of runoff from a 1" storm) captured and treated in a given practice. A few other BMPs, including bioretention and stream restoration, are included for comparison purposes. Land purchase requirements are a potentially large factor in the total cost of forest cover and tree planting programs. Publicly-owned lands, such as parkland, school, and other public lands, are the low-hanging fruit that can be surveyed for reforestation and tree planting opportunities, in order to minimize costs. Forest retention for privately-owned forests can be significantly more expensive, depending upon site-specific costs of land purchase or easement acquisition. The *Forest Retention*, and *Urban Tree Planting with Land Purchase* Practices in the chart below, include costs or cost ranges for purchase of land. The remaining Practices listed in the cost chart do not include land purchase.

Practice	**Total Initial Cost per Impervious Acre Treated**	**Notes** All unit costs are from King and Hagan (2011), ("K&H") unless otherwise noted[56].
Planting Trees in Dry Ponds[57]	$14,000	Based on Riparian Reforestation figure derived from information supplied by DEP Tree Expert Laura Miller (2011), with additional 10% to account for additional measures to plant trees in dry ponds.[58]
Forest Retention	$29,063 - $150,000	Low-end figure based on average of Montgomery County Legacy Open Space costs over 17 years and total acres of land preserved;[59] high-end figure from King and Hagan (2011)

[55] Lowe, W. and Likens, G. 2005. Moving Headwater Streams to the Head of the Class. BioScience. http://www.bioone.org/doi/abs/10.1641/0006-3568(2005)055%5B0196:MHSTTH%5D2.0.CO%3B2

[56] King and Hagan (2011) at http://www.mde.state.md.us/programs/Water/TMDL/TMDLImplementation/Documents/King_Hagan_Stormwater%20Cost%20Report%20to%20MDE_Final%20Draft_12Oct2011.pdf

[57] Cost figure is from Cameron et al (2012) "Green Stormwater Retrofits: Objectives and Costing," in the American Society of Civil Engineers Conference Proceedings entitled "Low Impact Development Technology: Design Methods and Case Studies, from the 2011 conference; Proceedings at: https://ascelibrary.org/doi/10.1061/9780784413883.021 , and is based on information supplied by Montgomery County tree and stormwater experts.

[58] Personal communication from Laura Miller to D.Cameron, 2011.

[59] Montgomery County Office of Management and Budget – FY14 Capital Budget - Legacy Open Space – Document PO18710 at: https://reports.data.montgomerycountymd.gov/reports/CIP/Legacy-Open-Space-P018710 Figure of $29,063 is a unit cost per acre of land preserved via outright purchase, or Conservation Easement acquisition. The figure is based on this budget document statement: "the program successfully protecting over 3,200 acres of open space in the County, including 3,031 acres of in-fee acquisition and 1,167 acres of easements." This figure of 3200 acres preserved was divided into the total expenditure of $92,969,000, since the LOS Program's inception in 2001, to derive the average per-acre purchase cost of $29,063.

This number will be submitted for review by LOS officials, and is likely to increase considerably as it's updated, due to several factors including: * land prices in Montgomery rising faster than inflation; * the LOS cumulative budget is not the total amount

Riparian Reforestation	$20,000	Figure from Cameron et al.(2012); is based on Schueler (2011)[60] Does not include land purchase costs.
Compost Amendment to Turf	$7276 (1/4" thick compost layer) - $29,232 (1" thick compost layer).	Number derived from: K. Gage and D. Cameron, workshop titled "Many, Cheap and Easy Stormwater Retrofits," at the 2016 Chesapeake Watershed Forum. Based on: $83.63/500 sq.ft. roof quadrant runoff treated w/ ¼" of compost, X 87 = one Impervious Acre.
Urban Forest Buffers	$33,000	K&H; excludes land purchase.
Urban Tree Planting	$33,000	K&H; Cost excludes land purchase.
Urban Tree Planting w/land purchase	$183,000	K&H; includes land purchase costs @$150,000 per acre.
Regenerative Stormwater Conveyance[61] – on hillslopes	$45,000	Unit cost figure from the Anacostia Watershed Society's RSC at the William Wirt Middle School in Prince George's County.
Urban Stream Restoration	$64,500	K&H
Wet Ponds and Wetlands – Retrofit	$65,998	K&H
Bioretention – Urban Retrofit	$186,750	K&H

Table 4. Unit costs of forest and canopy protection/restoration and selected stormwater controls.

Co-benefits

In contrast with gray infrastructure, which is designed for a single purpose, forests and other forms of green infrastructure that promote water infiltration and evaporation can provide multiple social and economic as well as environmental or "triple-bottom-line" co-benefits. These include a full range of water quality benefits, beyond reduction of sediment loads. The other water quality benefits from increasing forest and overall canopy cover, include runoff volume and velocity reduction (integral in the reduced sediment loadings from forest cover); increased dry-weather baseflow of small streams; protection of well water from contaminants, decreased nutrient loadings; avoidance of increases in drinking water treatment chemicals; and decrease in sediment handling costs. Protection of well water is critical in the case study watersheds, which are primarily rural, and where many residents depend on well water from a sole-source aquifer.

Co-benefits beyond water quality include: carbon sequestration/ carbon capture in healthy forest canopies; understory; duff (leaf litter); soil conservation; reduction of urban heat island effects that benefit health and save energy; reduction of air pollution; reduction of flooding; provision of

spent to acquire conservation lands, as private donations also contributed to the acquisitions; and * conservation land protection opportunities in Watts Branch, Muddy Branch and Seneca Creek are likely to be for smaller parcels for which the per-acre price is higher than for large farm acquisitions made in the past in and near the Agricultural Reserve.

[60] Schueler (2011) Memo from Tom Schueler to Meo Curtis, Montgomery County Department of Environmental Protection, Re: Implementation Plan Guidance Document on behalf of Chesapeake Stormwater Network and Biohabitats, Inc. (April 22, 2010, Revised February, 2011.)

[61] Cost figure from Anacostia Watershed Society President Jim Foster, 2015. Based on an RSC built by AWS at a public school site in Prince George's County.

recreational and aesthetic amenities; wildlife habitat, increase in property values; job creation and stimulation of economic development.[62]

Many of these co-benefits would also help Montgomery County satisfy watershed protection, stormwater and Chesapeake Bay Watershed Implementation Plan (WIP) requirements and goals.

Avoidance of stormwater management facility costs (construction and maintenance) is an example of the co-benefits of retaining and adding forest and tree canopy in a given watershed. A 2015 study performed under the auspices of the Chesapeake Bay Healthy Watersheds Goal Implementation Team, examined alternative growth and forest retention scenarios in a portion of the Rappahannock river basin in Virginia.[63]

The study team reported that "The results of the alternative development model scenario runs confirmed the water quality and healthy watershed value of forestland retention and demonstrate that a range of potential offsets are possible depending on the investment made early in BMPs that retain forestland. The study team concluded that "Quantification of the offset economic values demonstrated possible savings of $125 million depending on the land use planning decisions made and will be used to inform discussions with local government leaders, EPA, and pertinent Chesapeake Bay Program Goal Implementation Teams."[64] The possible savings of $125 million (in avoided stormwater management/ Baywide TMDL compliance costs) is based on an assumption of an additional 10% forest retention over a "sprawl development pattern" scenario[65].

Many of the potential and often cited co-benefits of forests and other green infrastructure have been better quantified in cities that have adopted innovative green infrastructure practices to reduce costs of implementing multi-billion-dollar consent decrees to avoid or reduce Combined Sewer Overflows (CSOs). Although Montgomery County does not have a combined sewer system, as mentioned above, the utility is implementing a $2 billion consent decree across the bi-county service area to prevent Sanitary Sewer Overflows by repairing pipes, some of which are exposed and damaged by stormwater. An important but often overlooked benefit of green infrastructure is that it buffers and protects gray infrastructure assets, thereby reducing maintenance and replacement costs.

In Philadelphia, the Green City Clean Waters initiative, is enabling the city to reduce the cost of CSO control by $8 billion, through a $2.2 billion plan that includes a $1.67 billion investment in green

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[62] A useful analysis tool for comparing the various benefits of green infrastructure for urban stormwater programs is provided by the Chicago-based Center for Neighborhood Technology at: http://www.cnt.org/sites/default/files/publications/CNT_Value-of-Green-Infrastructure.pdf A recent study in England outlined the benefits of green infrastructure across a wide range of issues and social needs including climate change mitigation and adaptation. https://www.forestry.gov.uk/pdf/urgp_benefits_of_green_infrastructure.pdf/$FILE/urgp_benefits_of_green_infrastructure.pdf

[63] Virginia Department of Forestry (2015) Healthy Watersheds Forestry TMDL Forest Retention Study: Methodology, Status and Recommendations Phase I Status Report, September 23, 2015 https://www.chesapeakebay.net/channel_files/23112/15-9-21_healthy_watershed_forest_tmdl_phase_i_project_status_report_final.pdf

[64] Ibid at pp. 9 and 10.

[65] Ibid at p.21.

infrastructure.[66] An analysis of environmental, social and economic, or "Triple Bottom Line" benefits of green infrastructure compared with building a 30-foot diameter tunnel, identified expected benefits of green jobs, increases in recreational opportunities and property values, reduction of heat-related fatalities, improved air quality, energy savings, and water quality and habitat improvements. It also found a higher Willingness-To-Pay for the additional water quality and habitat improvements that would not have been provided by the tunnel option.[67] An analysis of economic benefits conducted after the fifth year of the program found that the program did in fact increase property values, by an aggregate of $1.3 billion, generating an increase of $18 million in property taxes. It also found that the stormwater management regulations helped to catalyze a best-in-class Green Stormwater Infrastructure industry cluster that supports 430 local jobs, generates $1 million in local tax revenue, and has created opportunities for export. As a result of regulations and incentives, the initial public investment is expected to stimulate additional private investment in redevelopment and to produce an impact of $3.1 billion over the 25-year life of the program. In addition, per acre environmental benefits of green space were estimated at $10.5 million/year, for water quality, aquatic habitat enhancement, wetlands enhancement and creation, and removal of air pollutants. Non quantified benefits included reductions in violence and criminal activity, recreational opportunities, improved physical, mental and emotional health, and aesthetics.[68] Important components of the program include new stormwater rules that apply to redevelopment, grants and incentives for private property owners to adopt on-site stormwater management practices, are the Green 2015 Action Plan, for which the goal is to have parkland within a 10-minute walk from any part of the city, and training and job placement support for at-risk youth, through a partnership with the PowerCorpsPHL Americorps Program.[69]

In some cases, the ability to demonstrate and quantify these co-benefits has also made it possible to leverage additional funding sources. For example, in Portland Oregon, flood mitigation benefits of floodplain restoration enabled the city to use FEMA disaster-avoidance grants for this work, as well as to work with the Parks department to create amenities, and to work with the Housing Bureau and economic development offices to stabilize affordable neighborhoods that had been subject to repetitive flooding.[70] However, these benefits are place-based. Therefore, a key challenge is to determine the significance of these benefits for particular stakeholders, which depends on location of the practices, and the scale at which they are significant. Whether they are valued will also depend on confidence that benefits will be delivered and equitably distributed.

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[66] PWD 2011 *Amended Green City, Clean Waters: The City of Philadelphia's Program for Combined Sewer Overflow Control – Program Summary*. Amended June 1, 2011. http://www.phillywatersheds.org/doc/GCCW_AmendedJune2011_LOWRES-web.pdf

[67] Stratus Consulting, *Final Report: A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds*, 2009, Prepared for Howard M. Neukrug, Director, Office of Watersheds, City of Philadelphia Water Department, under contract to Camp Dresser and McKee.

[68] Green Stormwater Infrastructure Partners, *The Economic Impact of Green City, Clean Waters: The First Five Years*. Sustainable Business Network of Greater Philadelphia, 2016.

[69] Hogan, Dianna M., Carl D. Shapiro, David N. Karp, and Susan M. Wachter. *Urban Ecosystem Services and Decision Making for a Green Philadelphia.* U.S. Geological Survey, 2014. http://dx.doi.org/10.3133/ofr20141155. Ballard Spahr – Environmental Law Institute 2016.

[70] National Academy of Public Administration 2017. *Developing a New Framework for Community Affordability of Clean Water Services.* Washington DC https://www.napawash.org/studies/academy-studies/environmental-protection-agency

Cost is a key consideration for both WSSC, which faces limits on the ability to recover costs by raising water rates due to concerns about water affordability, and for the County, which has a limited willingness to raise stormwater fees used for water quality protection.

For WSSC, the advantage of gray over green infrastructure, is that, regardless of the cost comparison and multiple benefits, they would have control over management of the facility for the next 50 or more years and have a responsibility to provide safe water, regardless of the quality in which it is received. [71] In contrast, green infrastructure is associated with more decentralized approaches to watershed management which relies on partnerships and collaboration, Therefore, a decision whether to forgo the submerged intake is expected to depend at least as much on governance and institutional capacities of the various actors to manage the watershed, as on the technical efficiency and cost-effectiveness of green BMPs.

For the County, a key consideration is the ability to demonstrate benefits and cost-savings of green infrastructure to residents. A full and transparent assessment, comparing specific benefits of green and gray alternatives for Montgomery County residents as well WSSC ratepayers, can increase public understanding and also support willingness to pay for the program. It could also help to identify complementary funding sources, beyond water rates and the Water Quality Protection charge, such as funds for recreation, open space, wildlife habitat protection, and flood mitigation.

[71] Gary Gumm, WSSC Chief Engineer, remarks at Water Forum

What are the conclusions of this study?

1) Forests are the first line of defense in the multiple barrier approach to drinking water protection and provide a foundation for watershed protection, but need to be combined with other strategies, including implementation of land use plans and use of other BMPs as well as drinking water treatment, to completely address the sediment problem.

2) Canopy cover has declined in Watts Branch, Muddy Branch, and Seneca Creek during the study period (2009-2014), and this decline is associated with a decline in stream biological condition over the same general time period.

3) Increased forest and canopy cover would reverse this negative trend and would help to reduce sediment loadings to the Mid Potomac.

4) Costs of increased forest and canopy cover in the case study watersheds are estimated to range from $33,000 per acre for streamside forest buffers where the land is already publicly-owned, to $150,000 per acre for retention of existing forests (including land purchase costs).

5) Co-benefits will increase returns for an investment in increasing canopy cover significantly.

6) Additional information and analyses that are beyond the scope of this study are needed, in order to quantify the benefits and costs of forest and canopy restoration and protection in the mid-Potomac for drinking water treatment, including:

- Quantitative modeling of sediment yield from different forest and canopy cover scenarios in the three watersheds, including current conditions and future conditions under "business as usual" and with forest cover protection and enhancement. Until quantifiable data is available to know how much sediment loads will be reduced by increased reforestation in the three watersheds, it is not possible to directly compare this approach to WSSC's pipe relocation project.

- Watershed modeling to estimate the reductions in sediment at the Potomac River water supply intakes. Monitoring to determine sediment loads from tributaries and calibrate the model is also an important program in support future modeling efforts.

- Identification of site-specific opportunities and strategies as a basis for estimating costs, benefits and co-benefits of improvements in forest and canopy cover.

- Estimation of costs of drinking water treatment with potential sediment load reductions, other contaminant reductions, spill reductions, protection of public health, and other benefits of watershed restoration.

- Estimation of the economic value of co-benefits.

Appendix A: Stream conditions by subwatershed, in order by percentage of imperviousness

	Subwatershed Name	Watershed Name	Total sub-watershed area	Total impervious, sq meters	Percent Impervious	Total Canopy, sq. meters	Net Change Canopy, sq. meters	Net Change canopy, percent	IBI 1997	IBI 2011/2015	Stream Condition Change, 1997 to 2011-2015
16	Darnall Tributary	Seneca Creek	4414376	60046	1.36%	1581437	-1598	-0.10%	Good	Fair	-1
13	Dawsonville Tributary	Seneca Creek	2753448	47950	1.74%	897726	-166	-0.02%	Good	Good	0
18	Peach Tree Tributary	Seneca Creek	8495793	168110	1.98%	3617794	47854	1.32%	Good	Unmonitrd	-
17	Lower Dry Seneca Creek	Seneca Creek	9627241	231148	2.40%	3333056	-64206	-1.93%	Good	Good	0
15	Lower Seneca Creek	Seneca Creek	10741345	282979	2.63%	6179909	-47333	-0.77%	Good	Unmonitrd	-
27	Little Seneca Creek - Bucklodge Branch	Seneca Creek	18779720	582932	3.10%	8442289	-14455	-0.17%	Good	Good	0
30	Shofar Creek	Seneca Creek	4745708	168106	3.54%	1773289	-11071	-0.62%	Good	Good	0
28	Little Seneca Creek - Cabin Branch	Seneca Creek	5223309	202148	3.87%	2745848	-70289	-2.56%	Good	Good	0
29	Little Seneca Creek - Ten Mile Creek	Seneca Creek	19482440	897517	4.61%	11415811	-13264	-0.12%	Good/Excel	Good	-1
19	Russell Branch	Seneca Creek	7933976	399897	5.04%	3288828	-13478	-0.41%	Good	Good	0
20	Upper Dry Seneca Creek	Seneca Creek	19739503	1034814	5.24%	7840039	-83820	-1.07%	Good	Good	0
44	Upper Great Seneca Creek	Seneca Creek	7774654	426003	5.48%	3807416	-53904	-1.42%	Good	Good	0
31	White Ground Mainstem	Seneca Creek	16699426	1020115	6.11%	10093187	55983	0.55%	Good	Good	0
47	Upper Great Seneca Creek - Wildcat Branch	Seneca Creek	9649455	607659	6.30%	4334287	-3041	-0.07%	Excellent	Good	-1
37	Lower Great Seneca Creek	Seneca Creek	15537795	1109466	7.14%	9746992	46516	0.48%	Good	Good	0
42	Etchison Tributary	Seneca Creek	10281046	737597	7.17%	5185112	-14171	-0.27%	Good	Excellent	1
33	Dead Cow Run	Seneca Creek	2468759	179851	7.29%	663405	6907	1.04%	Good	Excellent	1
14	Hookers Branch	Seneca Creek	7879446	582247	7.39%	4507924	-40437	-0.90%	Good	Good	0
32	Darnestown Branch	Seneca Creek	2846502	213137	7.49%	1714592	-10013	-0.58%	Good	Good	0
46	Upper Great Seneca Creek - Goshen Branch	Seneca Creek	19819005	1522303	7.68%	9953889	-78516	-0.79%	Good	Good	0
10	Pennyfield Mainstem	Muddy Branch	7640194	658219	8.62%	5493687	-96334	-1.75%	Good	Good	0
45	Upper Great Seneca Creek - Damascus	Seneca Creek	8804760	824546	9.36%	4513563	12344	0.27%	Good	Good	0

	Tributary										
9	Esworthy Tributaries	Muddy Branch	9669644	973130	10.06%	6174308	-83106	-1.35%	Good	Good	0
1	Greenbrier Branch	Watts Branch	4182076	563633	13.48%	2288988	-18823	-0.82%	Fair	Good	1
6	Sandy Branch	Watts Branch	9933901	1426087	14.36%	5312033	-95713	-1.80%	Good/Fair	Good	1
3	Lower Watts Branch	Watts Branch	8812033	1376895	15.63%	6484935	-114256	-1.76%	Fair	Good	1
26	Hoyles Mill Tributary	Seneca Creek	2583236	445847	17.26%	1160211	20559	1.77%	Good	Fair	-1
21	Black Hill Mainstem	Seneca Creek	10461633	1858959	17.77%	5974672	-25164	-0.42%	Good	Good	0
35	Ho-Ching Branch	Seneca Creek	3787393	674171	17.80%	1836357	-9306	-0.51%	Good	Good	0
43	Magruder Branch	Seneca Creek	9014201	1632904	18.11%	5602284	-43907	-0.78%	Fair	Fair	0
2	Kilgour Branch	Watts Branch	3704396	744185	20.09%	2216539	-83136	-3.75%	Excellent	Fair	-1
5	Piney Branch	Watts Branch	9650090	2002420	20.75%	5697373	-138088	-2.42%	Good/Excel	Fair	-1
38	Quince Orchard Tributary	Seneca Creek	2479493	530611	21.40%	1671758	-18258	-1.09%	Good	Fair	-1
39	Middle Great Seneca Creek	Seneca Creek	25298988	5418581	21.42%	16354098	-223779	-1.37%	Good	Fair	-1
8	Dufief Mainstem	Muddy Branch	10727232	2491897	23.23%	6145344	-124618	-2.03%	Good/Fair	Good	1
23	Clarksburg Tributary	Seneca Creek	15253436	3770672	24.72%	5468689	-381579	-6.98%	Excellent	Fair	-1
4	Middle Watts Branch	Watts Branch	9970980	2485449	24.93%	6188845	-207660	-3.36%	Fair	Fair	0
40	Middle Great Seneca Creek - Cabin Branch	Seneca Creek	12277454	3629604	29.56%	6014516	-132544	-2.20%	Fair	Fair	0
11	Rich Branch	Muddy Branch	3518347	1044333	29.68%	2019887	-31967	-1.58%	Good	Poor	-1
36	Long Draught Branch	Seneca Creek	8457948	2897897	34.26%	4481054	-102916	-2.30%	Fair	Fair	0
34	Gunners Branch	Seneca Creek	11238757	4054894	36.08%	5965347	-223155	-3.74%	Fair	Fair	0
25	Germantown Estates Tributary	Seneca Creek	2991419	1087127	36.34%	1524509	-21824	-1.43%	Fair	Fair	0
12	Upper Muddy Branch	Muddy Branch	19161676	7969444	41.59%	8186443	-281617	-3.44%	Fair	Fair	0
41	Middle Great Seneca Creek - Whetstone Run	Seneca Creek	12338261	5184765	42.02%	6044818	-200527	-3.32%	Fair/Poor	Fair	1
24	Crystal Rock Tributary	Seneca Creek	3356987	1418211	42.25%	1314738	-24197	-1.84%	Excellent	Fair	-1

7	Upper Watts Branch	Watts Branch	11341365	5144174	45.36%	5547115	-159417	-2.87%	Fair	Good	1
22	Churchill Tributary	Seneca Creek	2314362	1171188	50.61%	879987	-6193	-0.70%	Unmonitrd	Fair	-