ROANOKE URBAN STORMWATER RESEARCH

PHASE I – DISCOVERY

FINAL REPORT

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EXECUTIVE SUMMARY

This report is the final product of an 8 month long collaboration between the City of Roanoke's Environmental, Engineering, Public Works, GIS, and Planning staff, and researchers in the Via Department of Civil and Environmental Engineering at Virginia Tech. This relationship was borne out of a mutual desire for improved urban stormwater science, with an anticipation that a long-term municipal-academic partnership would bring innovation to municipal stormwater management while providing opportunities to further the body of knowledge in this field.

This report illustrates the City of Roanoke's present political and environmental climate with respect to stormwater management by historical account and geographic context. It is descriptive and observational, providing both a foundation to proceed with future work, and a benchmark to measure success. The objective of this report is to characterize the regulations, people, and information that constitute stormwater management in the City of Roanoke.

The Introduction is a summary of the City of Roanoke/Virginia Tech Urban Stormwater Research collaboration, and introduces the City as a densely urbanized political entity in the Upper Roanoke River watershed. The Introduction leads into Section I, a review of the Federal and State regulations that compel the City to prevent and treat stormwater runoff pollution, and a description of the City's compliance strategies. Conversations with City staff and other stakeholders characterized these programs and helped contextualize stormwater management in the City and regionally; these conversations are recorded in Section II. City staff also supported the synopsis of City Geographic Information System data found in Section III by providing the necessary access. Section IV relates the quality and relevance of geographic datasets from external sources, and Section V does the same for water quality and quantity data. Section VI describes the pathways for general public engagement in stormwater in the City and regionally. The report body is bookended by Tables of Contents, Figures, and Tables at the front, and Index of Terms, References, and alphabetized Bibliography in the back. Supplemental information, including additional tables, figures, and text is found in the Appendices, organized using the same structure as the report.

The submission of this report marks the end of the initial Discovery Phase of this research relationship; the resources have been discovered, collected, and organized. This also marks the commencement of the second phase, which focuses on a single City watershed as a precedent for future watershed planning. The completion of this first Phase, and even the anticipated completion of the next, do not bring finality to this work, but represent benchmarks along the way to the now unified objective of improving water quality in the City's waterways – the terminal measure of success in this research project.

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INTRODUCTION

A. THE ROANOKE URBAN STORMWATER RESEARCH PROJECT

This report summarizes the outcomes of the Discovery Phase (Phase I) of the research partnership between the City of Roanoke (the City), and the Virginia Tech Department of Civil and Environmental Engineering (VT) beginning May 14, 2014 and ending December 24, 2014. This partnership was formed in recognition of a shared commitment to expanding the knowledge and capabilities of both organizations towards improving water quality and hydrology. The intention of this Discovery Phase was for the two organizations to gain an operational familiarity with each other, and to ascertain the City's objectives, capabilities, and institutional capacity towards stormwater management. This was done in anticipation of an ongoing collaborative stormwater partnership that will allow City Employees and VT Researchers to develop, implement, and report on the solutions agreed upon in the Discovery Phase.

The outcomes of the Discovery Phase are reported in the order that they appear in the Scope of Work dated March, 2014. The fulfillment of these six research tasks helped to familiarize the organizations with each other, and provided the objectives for future work. The structure of this report is as follows: first, a summary of the City with respect to hydrologic characteristics will be provided in this section, followed by the results of each of the six Discovery Phase tasks. These results have been synthesized into recommendations for Phase II of this work in a separate document entitled "Roanoke Urban Stormwater Research – Phase II Scope of Services;" this information is not included in this report. In order to make this document more accessible, information in the body of this report has been condensed to the most relevant details, and additional information, data, and background research is included in Appendices I – VI in the same order as the scope tasks.

Pursuant to the Scope of Work, the geographic focus of this report is the City of Roanoke, Virginia, and the topical focus is hydrology and water quality as they pertain to stormwater runoff, though ancillary information is included for context. Although the City is the primary focus of this work, much of this report uses the watershed that contributes to the Roanoke River at the confluence with Back Creek (referred to henceforth as the "Roanoke River Watershed") as the study area for two reasons: (1) water runoff does not obey jurisdictional boundaries, and an analysis of hydrology and water quality requires the use of physical boundaries; and (2) several of the regulatory programs relevant to the City are defined by this watershed.

B. The City of Roanoke and the Roanoke River Watershed

The complete drainage of the Roanoke River subdivided into its level 8 hydrologic units (HU-8)[1] is shown in Figure 1. The headwaters of the Roanoke River constitute the Roanoke River Watershed named in this report and are shown with its level 12 hydrologic units (HU-12) in Figure 2. The river flows through the City for 9.6 miles of the total 378 miles from the convergence of the North and South Forks of the Roanoke River, to its terminus at Albemarle Sound, North Carolina. The Roanoke River is the City's main water artery, entering the City to the west from the Town of Salem after its confluence with Mason Creek, transecting the City longitudinally, and receiving direct runoff from 27.8% of the City's land area. The areas north of the Roanoke River drain into Lick Run, Carvins Creek, Tinker Creek and Glade Creek before emptying into the Roanoke River at the City's political boundary with the Town of Vinton to the east.

The Roanoke River watershed is 365,547 acres in size, and the total land area of the City is 27,432 acres (7.5% of the total watershed area). Along with the Town of Vinton and City of Salem, the City shares a boundary with Roanoke County to the north and south, and is the largest urbanized area in Southwest Virginia, with a population of approximately 97,000 as of 2010 [1]. The City has relatively flat slopes as it transitions from the Appalachian Ridge and Valley to the Virginia Piedmont ecoregion [2]. Based on the National Elevation Dataset (NED) [3], the median land slope within the City is 2.1% while the median land slope of the upstream watershed is 6.7% as the City is bordered by Brushy Mountain, Fort Lewis Mountain, and Poor Mountain to the north and east of the City. The City is more heavily developed than the upstream watershed, with an estimated 86.5% developed area, while the upstream watershed is estimated to be 9% developed. The predominant land use classifications in the watershed are Deciduous Forest, constituting 40% of the watershed, Hay/Pasture (16%), and Evergreen Forest (8%). All land cover calculations are based on the 2011 National Land Cover Dataset (NLCD) [4].

[1] The United States Geological Survey (USGS) systematically divides the nation based on watersheds in their National Hydrography Dataset (NHD). Each watershed gets a two digit numeric identifier, and as watersheds are subdivided, the number of digits on the identifier increases. For example, the Upper Roanoke River Watershed shown in Figure 1 is number 03010101, meaning it is part of "03 – South Atlantic Gulf," and within this watershed, part of "0301 – Chowan/Roanoke," and so on. The NHD delineates watersheds to twelve digit resolution.

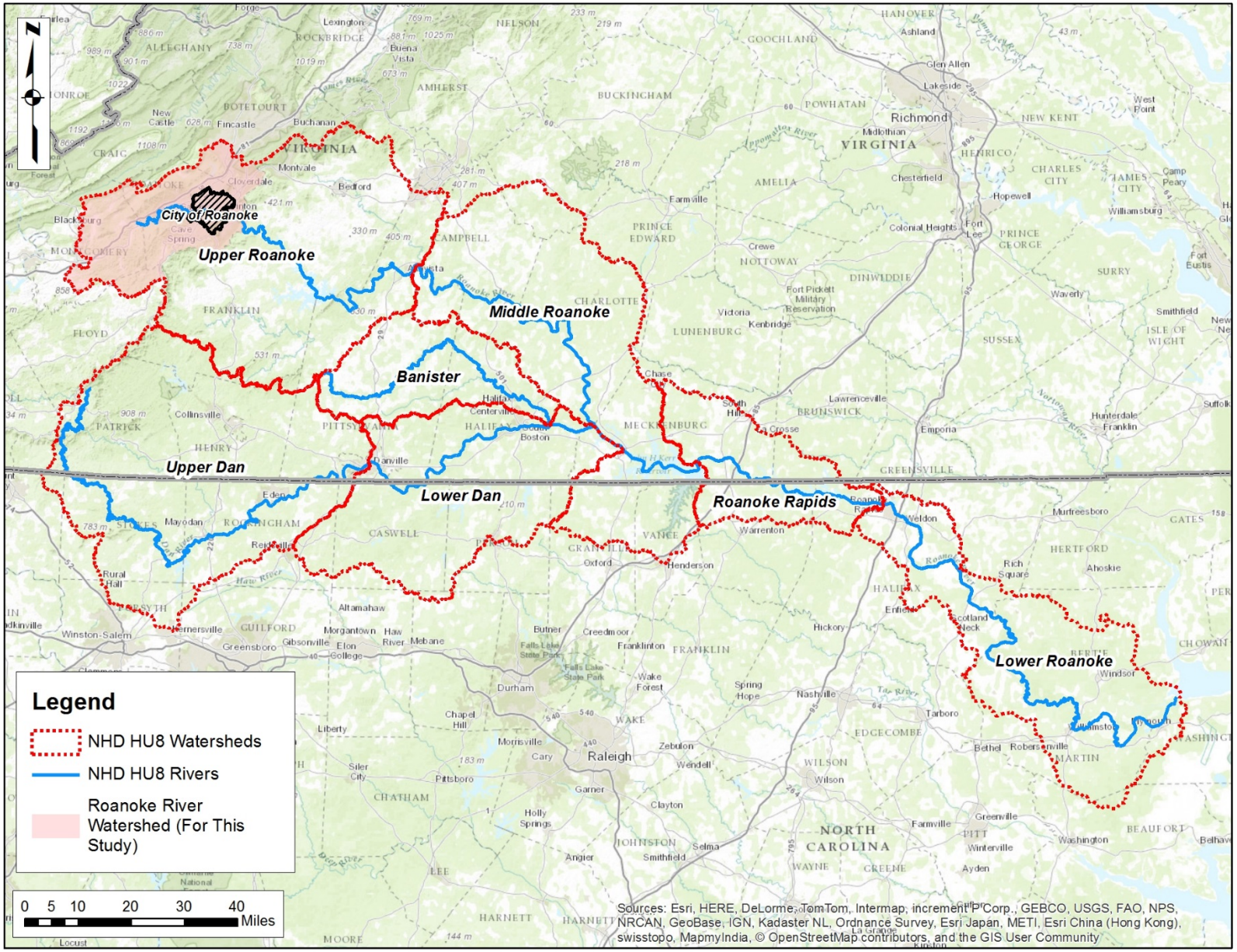

Figure 1 – The Roanoke River with Level 8 Hydrologic Unit Watersheds shown – Data from [5] **and as noted**

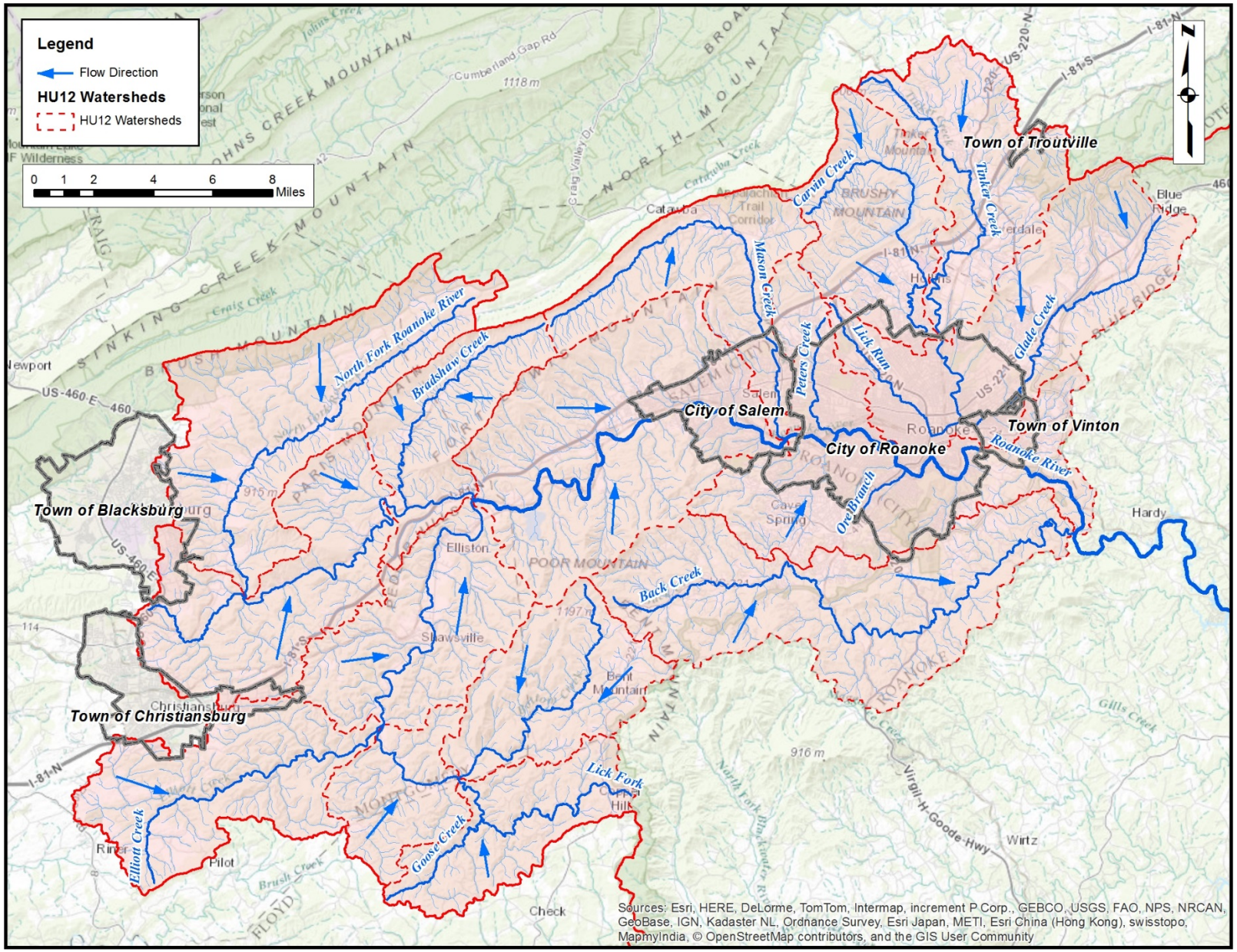

Figure 2 – The Roanoke River Watershed delineated to the confluence with Back Creek with HU-12 watersheds shown - Data from [5], [6] **and as noted**

I. Regulatory Review

A. Introduction

In 1972, the Environmental Protection Agency (EPA) established regulatory authority for the nation's waters by promulgating the Clean Water Act (CWA). This federal law provided the basis for two large national water quality programs related to surface water runoff – the Total Maximum Daily Load (TMDL) program, and the National Pollutant Discharge Elimination System (NPDES). The union in scope of these two programs is large, as the TMDL program creates numeric limits, known as "allocations" on pollution in all of the nation's waters, and the NPDES program regulates the activity of known sources of pollution, such as waste water treatment plants, concentrated animal feeding operations, and stormwater runoff from urban areas. For nearly thirty years, the priority of the NPDES program was point source waste water treatment plants, as the U.S. struggled to implement secondary wastewater treatment standards. The focus has shifted in recent decades, as runoff from stormwater wet weather events in urban areas has been identified as a major contributor to poor surface water quality in the U.S.

For simplicity, the NPDES program may be thought of as an upstream regulatory control, while the TMDL program controls the quality of water downstream of pollution. The intersection of these two pieces of legislation is the urbanized area, as over 7,000 cities, counties, towns, and other urban areas are required to comply with the NPDES Stormwater program, and approximately 50% of these urban areas either have a current TMDL, or discharge to bodies of water that will soon have a TMDL developed [7].

The purpose of this section is to review the stormwater regulatory environment in urbanized areas created by the TMDL and NPDES programs, and to explain the complex interactions of these two regulations in the City of Roanoke, Virginia. First, a brief review of the two EPA regulations will be provided (thorough reviews are available elsewhere), and the specific requirements of these regulations with respect to the City of Roanoke will then be described. In addition, this section includes a description of the Federal Emergency Management Agency's (FEMA's) National Flood Insurance Program (NFIP), and the City's flood-reduction strategies, as well as a brief section at the end describing the City's Comprehensive Plan for the term 2001 – 2020.

B. Regulatory Programs

1. The National Pollutant Discharge Elimination System (NPDES) Program

Section 402 of the CWA required that all discrete conveyances, known as 'point sources'[2], that discharge into waters of the United States be permitted. This included discharge from industrial facilities, municipal separate storm sewer systems (MS4s), construction sites, and other similar potential sources of water pollution, though the scope was largely restricted to manufacturing facilities by a 1975 rule that exempted stormwater discharges from permitting. This changed with the passing of the Water Quality Act of 1987, which provided the legal basis for the current regulatory environment: permits for both industrial and municipal sources. From this rule, Phase I of the permitting program for MS4s in urbanized areas[3] of population greater than 100,000 was created. The Phase I rule also included the legal basis for permitting stormwater runoff from construction sites under a "General Permit." These permits were industry specific, and were generally implemented by State governments, though that has since changed in Virginia.

Since the Phase I Program began, two important legislative changes have occurred that have transferred statutory implementation to the City of Roanoke. First, Phase II of the NPDES stormwater program was promulgated in 1999 for MS4s in urbanized areas with populations less than 100,000 [8]. Second, the Commonwealth of Virginia delegated the responsibility of development permitting, inspections, and enforcement of stormwater treatment facilities to local governments (mostly MS4s) under the 2014 Virginia Stormwater Management Act [9] – this is known as the Virginia Stormwater Management Program (VSMP). The third subsection below describes the various other discharges that the NPDES program regulates, that are not the direct responsibility of the City of Roanoke, but may be located within its jurisdiction.

(a) Municipal Separate Storm Sewer System (MS4) Phase II Permit

Phase II of the NPDES stormwater program required states to apply for and enforce a General Permit for stormwater discharges from small urbanized areas [10]. This means that every five years, jurisdictional areas classified as Phase II MS4 entities (including the City of Roanoke) are required to create and submit a document to the Virginia Department of Environmental Quality (DEQ) that describes actions to be taken towards improved water quality. These documents are called "Program Plans," and require MS4 operators to: (1) report on the progress made towards the Waste Load Allocation (WLA) in any relevant TMDLs, and (2) develop strategies in

[2] The term point source is defined in Section 502(14) of the CWA as "any discernable, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural stormwater discharges and return flows from irrigated agriculture [91]."

[3] An "urbanized area" is defined by the U.S. Census Bureau every decennial census as a densely settled core of contiguous census tracts or blocks that constitute a population of at least 50,000. The MS4 program also includes Urban Clusters – areas of population greater than or equal to 2,500 [92].

six categories of stormwater interventions, called "minimum control measures (MCMs)." These two requirements are described in the sub-sections below.

The MS4 permitting system requires that permitted entities make year-to-year progress towards goals set forth in their program plans, but does not set a benchmark against which compliance status might be determined. The built-in flexibility in the Phase II rules accommodates the wide range of socio-economic, governmental, and environmental conditions that characterize the approximately 7,000 Phase II MS4 entities nationwide, but the subsequent outcomes of the policy are equally as varied [11]. Furthermore, compliance status is based on an MS4 operator's reported implementation of stormwater control measures, not on the measured improvement of water quality [12].

(1) TMDL Action Plan Progress

Authority to enforce TMDLs is written into the General Permit for Phase II MS4 entities. The DEQ requires that MS4 operators include a specific action plan for TMDLs that have WLAs for the urban area permitted in the MS4 Program. This action plan includes a description of best management practices (BMPs) and other activities that will be implemented to reach the designated waste load.

(2) Minimum Control Measures

The 6 MCMs from the General Permit, along with the prescribed actions, are noted as follows. This discussion has been supplemented with some information from the academic literature.

(a) MCM 1 - Public Education and Outreach

The intent of MCM 1 is to educate the public on the consequences of pollution caused by urban stormwater runoff, and to control pollution by changed personal behaviors as a result of this education. Understanding about issues concerning runoff from urban areas varies. It has been found that while the general public may know that stormwater is not treated before discharge, few understand the concept of a watershed and that pollution is not strictly a point-source problem [13]. Success in environmental behavioral changes has been noted from intensive homeowner education programs (though this did not lead to an improvement in water quality) [14], and these programs are known to be flexible and cost-neutral [15]. The General Permit requires that operators identify a target audience for at least three high priority water quality issues, and attempt to reach 20% of each target audience with relevant educational material. This MCM is flexible in nature, and operators that do not reach 20% of their target audience are still in compliance unless an "insufficient effort" is made, in which case the permit states that there will be a "compliance issue." Beyond this, compliance is largely at the discretion of the operator.

(b) MCM 2 – Public Involvement and Participation

Compliance with MCM 2 requires two actions: (1) Posting copies of the MS4 Program Plan and Annual Report on the MS4 entity's webpage within 30 days of submittal to the DEQ and (2) Promote, sponsor, organize, or participate in four local activities related to stormwater pollution prevention. This includes stream or hazardous waste clean-up days, and meetings with watershed or environmental organizations. The former may provide the general public with a positive sense of engagement in government activities leading to support of programs [16], though the public is not actually involved with the creation of these management plans. This is especially important if a community plans to institute a stormwater fee [17]. The latter provides the basis for strategy sharing, though this has not been found to improve the quality of stormwater management plans [18].

(c) MCM 3 – Illicit Discharge Detection and Elimination

The requirements of this MCM are generally that the operators identify and map locations where the storm sewer system discharges to natural waterbodies, and collect information related to those bodies. The operator is required to design a local regulatory mechanism to prohibit illicit discharges into these natural waterbodies, and create a procedure to detect and track illicit discharges through field screening of 50 outfalls annually. Geographic Information Systems (GIS) have been found to provide a suitable framework for this MCM[19].

(d) MCM 4 – Construction Site Stormwater Runoff Control

The operator must control discharges into the storm sewer system using three mechanisms: (1) legal authority, (2) pre-construction plan approval, and (3) inspection and enforcement. This information must be thoroughly documented and included in the Program Plan. Requirements for this MCM are largely fulfilled by conformance to the VSMP.

(e) MCM 5 – Post-Construction Stormwater Management in New Development and Development on Prior Developed Lands

The operator is required to develop design criteria and post-construction inspection procedures for runoff control measures known commonly as structural BMPs that have been installed for long term water quantity or quality preservation. Privately owned facilities will need to be inspected once every five years, and publicly owned facilities once per year. Maintenance is on an as-needed basis. The regulations require tracking and reporting of the facilities and their upkeep using an electronic database or spreadsheet.

(f) MCM 6 – Pollution Prevention/Good Housekeeping for Municipal Operations

The pollution vectors that this MCM prevents are from normal operations and maintenance work (e.g. vehicle maintenance), runoff from municipal facilities (i.e. salt storage yards), and turf application and landscaping. This

MCM requires the creation of stormwater pollution prevention plans for the relevant operations.

(b) Construction General Permits

As of July 1, 2014 all MS4 entities[4] in Virginia were required to take on the administration of permitting construction projects that conformed to the rules of the Virginia Pollutant Discharge Elimination System (VPDES) Permit for Discharges of Stormwater from Construction Activities [20]. The new permitting structure is based on the Commonwealth's new Virginia Stormwater Management Program (VSMP) which requires owners/developers to:

- Create a Stormwater Pollution Prevention Plan (SWPPP) for their development sites including an:
    - Erosion and Sediment Control (ESC) Plan
    - Stormwater Management Plan that meets the new water quality and quantity requirements in [21]. This also requires that a long-term maintenance agreement be created.
    - Pollution Prevention Plan to contain and treat and/or dispose of common pollutants generated during construction
- Fill out Registration Forms
- Pay a fee to the local permitting authority (known as the VSMP authority)
- Pay a fee to the DEQ

The program is designed to delegate authority over private stormwater control measures to the local governments, while tracking development and the mitigation strategies at the state level. The local authorities are now responsible for assuring that the impact of development is mitigated from the design, through post-construction phase by approval (or not) of construction plans, inspection, and maintenance agreements.

The water quality design criteria requirements of the new stormwater laws [22] are based on a calculated load (pounds) of Phosphorus (P) released from a site per acre per year[5]. New developments cannot exceed a loading of 0.41 lbs./acre/year, and re-developments must decrease the annual load by a certain percentage given the site characteristics. Phosphorus loading, and the required stormwater control measures are determined using the Virginia Runoff Reduction Method [23] and a list of P removal efficiencies from the Virginia Stormwater BMP Clearinghouse [24].

[4] Localities that do not have MS4 permits can choose to opt-in to the program to become a permitting authority, though they are not required to. This may be helpful if rapid development is occurring in a community, and the permitting process through the DEQ does not accommodate this growth.

[5] Though P is the limiting nutrient in the Chesapeake Bay, and therefore the pollutant regulated, it has been found that P enrichment in lakes enhances the removal of Nitrogen (N), and inversely, the rapid reduction in P has been related with increased concentrations of N, possibly leading to decreased diversity and drinking water treatment problems [93].

In addition to controlling the amount of P leaving a site, the stormwater regulations also require that during frequent storm events, the peak volumetric flow rate, and the total volume of water leaving a site is controlled [25]. This has been done in order to protect downstream channels from excessive erosion, and to prevent flooding. For channel protection, the regulations require that:

$$Q_{developed} \times RV_{developed} \leq I.F. \times Q_{pre-developed} \times RV_{pre-developed} \quad \text{Eq. 1}$$

Where $Q_{developed}$ and $RV_{developed}$ are the estimated volumetric flow rate and total runoff volume respectively after development from a 24 hour long storm event that occurs every year; $Q_{pre-developed}$ and $RV_{pre-developed}$ are the same metrics before development; and $I.F.$ is an improvement factor. This factor represents the fractional reduction of the product of discharge and volume from the pre-development conditions. $I.F.$ equals 0.8 for sites larger than one acre, and 0.9 for sites smaller than or equal to one acre. Flood protection requirements control the impacts that a site will have on the hydrologic response and downstream effects of the 10 year storm[6].

(c) Other Permits

In addition to the permits required for municipal storm sewer discharges and construction sites, there is a variety of other VPDES permits that are not the direct responsibility of a local government, such as the City of Roanoke, but by virtue of their location within the City's watersheds, are relevant to this report. These permits are first divided into individual and general permits, based on the complexity and magnitude of potential discharge. Individual permits have requirements, conditions, limitations, and monitoring requirements that are unique to each facility, while general permits can be issued for a general classification of discharges (construction sites, for example). In Virginia, individual permits can be issued for municipal and industrial facilities, while general permits are issued for a wider variety of industries that have potential impacts on water quality, such as seafood processing facilities, concrete products facilities, and concentrated animal feeding operations. For the full list of regulated industries under VPDES, see Appendix I.

2. Total Maximum Daily Loads (TMDLs)

Section 303 of the Clean Water Act describes the legal responsibility of each State to determine uses for each body of water (called a designated use), and establish a standard of water quality that will allow for that use (water quality standards, WQSs). This means that the States are also responsible for evaluating their jurisdictional waters to assure that they meet these standards, and intervening if they do not. Individual States designate different uses, but in Virginia all waters are designated for recreational use; the propagation and

[6] The 10 year storm is a rainstorm event that has a 1 in 10 probability of occurring each year. It does not mean that the storm will occur once every 10 years.

growth of a balanced, indigenous population of aquatic life; and the production of edible and marketable natural resources [26]. If a Virginia waterbody cannot support any one of those uses, it is considered "impaired," and a plan to restore the waterbody must be created. These plans are collated in documents commonly known as Total Maximum Daily Loads (TMDLs), which describe the quantitative amount of pollution that a waterbody can receive before it will no longer be able to support the designated use, and the prescriptive measures that need to be taken towards restoration. When a State creates a TMDL, it is reviewed and approved by the EPA before planning for restoration begins. Once approved, the States generally delegate responsibility for TMDL compliance to local governments[7].

3. National Flood Insurance Program (NFIP)

The National Flood Insurance Program (NFIP) began in 1968, with the establishment of the Housing and Redevelopment Act. It is under the purview of the Federal Emergency Management Agency (FEMA), and provides subsidized flood insurance rates to home and business owners in communities that have created flood mitigation and land use policies [27]. Private, non-subsidized insurance was previously unsuccessful because losses in some areas are inevitable, can be catastrophic, and the cost of premiums to cover such pay-outs were prohibitively high [28]. The NFIP is a voluntary program, but in order to be eligible for insurance through the NFIP, communities must submit and implement compliant and legally enforceable land-use and floodplain policies. These policies are necessarily diverse across the U.S., as each locality must also comply with State land-use regulations [29].

The Community Rating System (CRS) was developed to further incentivize flood reducing policies at the community level. Flood insurance owners receive premium discounts based on their community's assessed level of commitment to flood reduction by FEMA authorities (Table I-1). Separate discount rates are offered for properties located inside or outside of the Special Flood Hazard Area (SFHA). There are 19 activities that receive credit from this system, organized into four categories: Public Information Activities, Mapping and Regulations, Flood Damage Reduction Activities, and Warning and Response.

[7] Section 303 requires development of a TMDL, but does not explicitly require implementation. This means that a TMDL document can be created and approved by the EPA, without a plan for implementation ever occurring. While this known gap in the TMDL program has led to varying implementation across States, Virginia (and several other states) has a law that requires the creation of implementation plans [94].

Table I-1 – Community Rating System (CRS) Classes, credit points, and premium deductions – adapted from Table 110-1 in [30]

CRS Class	Credit Points (cT)	Premium Reduction	
		In SFHA	Outside SFHA
1	4,500+	45%	10%
2	4,000–4,499	40%	10%
3	3,500–3,999	35%	10%
4	3,000–3,499	30%	10%
5	2,500–2,999	25%	10%
6	2,000–2,499	20%	10%
7	1,500–1,999	15%	5%
8	1,000–1,499	10%	5%
9	500–999	5%	5%
10	0–499	0	0

- The Public Information Activities credits educational programs regarding flood hazards, insurance, and ways to reduce flood damage. A locality can receive up to 981 points in this category, with the average locality receiving 268.
- The Mapping and Regulations series credits programs with regulatory controls on actions that affect flooding. This includes the preservation of open space and floodplain processes, and stormwater management. The maximum possible points achievable in this category is 5,841, with an average credit of 926 points.
- The Flood Damage Reduction Series provides credit for programs addressing existing development at risk for flood damage. This includes the creation of a floodplain management plan, and incentivizing the relocation or retrofitting of flood-prone structures. A locality can receive up to 4,692 points in this category, with average localities receiving 525.
- The Warning and Response Series allows communities to gain credit by implementing measures designed to protect life and property in the event of a flood through warning and response systems. The maximum possible credit points in this category is 790, with an average community score of 144.

C. Roanoke Watershed Regulatory Programs

Within the City of Roanoke and the Roanoke River Watershed, the requirements of the NPDES include a Phase II MS4 permit, a VSMP construction general permit, and several other permits for which the City is only indirectly responsible. The first MS4 permit for the City was submitted in 2003, and Program Plans are submitted on a five-year cycle. Information for this report is from the 2014 MS4 Annual Report [31], which is the first reporting year of the 2013 – 2018 permitting cycle. The permit year begins on July 1, and ends on June 30th of each year. This section also includes information regarding the City's National Flood Insurance Program and the City's Comprehensive Plan.

1. NPDES PERMITS

(a) Municipal Separate Storm Sewer System (MS4) Permit

(1) TMDL Action Plan Progress

To fulfill the requirements of the MS4 General Permit, the City of Roanoke has documented the preliminary stages of development of their TMDL Action Plan towards the end points set in the TMDL reports and implementation plan (see Section I.C.2). The TMDL Action Plan is due June 30th, 2015. To reduce sediment and bacteria pollution, the City identified potential sources including the Public Works Service Center, the Solid Waste Division "Ready Line," and several parks and green spaces where citizens play with their pets.

(2) Minimum Control Measures

The City of Roanoke's strategies towards fulfilling the requirements of the Minimum Control Measures area summarized as follows. The responsible party for each MCM is noted in parenthesis:

(a) MCM 1 - Public Education and Outreach (Christopher Blakeman)

The City's public education and outreach programs [32] are targeted towards the reduction of sediment and bacteria, and the City has contracted with the Clean Valley Council (CVC) to provide stormwater and water quality information for the region. As the City has recently implemented a stormwater utility fee, educational documents have been developed to inform the public of ways to reduce runoff from their properties (and receive a reduced fee). The City is distributing household materials and using social media to attempt to educate the public on stormwater pollution.

(b) MCM 2 – Public Involvement and Participation (Christopher Blakeman)

The City will participate in a stream cleanup day, as well as several other events related to the public awareness of stormwater. City employees attended and presented at the Roanoke River Currents Conference at Ferrum College, serve on the Roanoke Valley/Alleghany Regional Commission's Stormwater and Blueways Committee, and participated in the Upper Roanoke River TMDL Implementation Plan.

(c) MCM 3 – Illicit Discharge Detection and Elimination (Christopher Blakeman)

The City has developed a GIS based stormwater infrastructure map that has been made available to the public on the City's GISRE website [33]. In addition, ordinances regarding the elimination and detection of discharges into the storm sewer have been created. The City performed 50 dry weather outfalls for the 2014 permit year.

(d) MCM 4 – Construction Site Stormwater Runoff Control (Danielle Bishop)

In this MCM, all the City regulatory controls for stormwater are listed. This MCM includes substantial documentation of the City's design, plan review, inspection, and enforcement procedures. The City reports 46 land disturbance permits and 2,560 erosion and sediment inspections (896 after rain storms) for the 2014 permit year.

(e) MCM 5 – Post-Construction Stormwater Management in New Development and Development on Prior Developed Lands (Danielle Bishop)

The City documents the design manuals, plan review process, inspections, and enforcement of post-construction stormwater management facilities in this MCM. Out of 400 inspections, 95 notices of violation were reported for the 2014 permit year.

(f) MCM 6 – Pollution Prevention/Good Housekeeping for Municipal Operations (Christopher Blakeman, Dwayne D'Ardenne, Steve Taylor)

The City has developed standard operating procedures for important municipal operations, most of which take place at the Public Works Service Center. The City also trains employees in the environmental aspects of their jobs, to ensure that employees do not become sources of pollution. The City has a street sweeping program, maintains the storm sewers, is building pet waste collection stations, and awards employees for positive environmental behavior

(b) Construction General Permits

In the year 2014, 76 construction sites were permitted under the Construction General Permit in the City (see Section II.A.10 for further information). Information pertaining to these construction permits are available in Appendix I. The City is also responsible for inspecting 300 private and 20 City-owned post-construction stormwater BMPs to assure that they are maintained and operating correctly. This is largely a visual inspection of the vegetation and outlet structures, as there is no practical way to check the functionality of the soil media in infiltration practices.

(c) Other Permits

There are several individual VPDES permits for discharges from industrial facilities and municipal water and wastewater treatment plants in the City of Roanoke. These facilities are listed in Table I-2.

Table I-2 – Individual VPDES Permits for discharge in the City of Roanoke

Permit Number	Type	Facility Name	Owner Name
VA0091065	Industrial	Crystal Spring WTP	Western Virginia Water Authority
VA0001431	Industrial	Kinder Morgan Southeast Terminals LLC - Roanoke	Kinder Morgan Southeast Terminals LLC
VA0086541	Industrial	Magellan Terminals Holdings LP - Roanoke Terminal	Magellan Terminals Holdings LP
VA0001597	Industrial	Norfolk Southern Railway Co - Shaffers Crossing	Norfolk Southern Railway Company Incorporated
VA0001589	Industrial	RES dba Steel Dynamics Roanoke Bar Division	Roanoke Electric Steel Corp
VA0025020	Municipal	WVWA - WPCP	Western Virginia Water Authority

In addition, there are a number of general VPDES permits of different types that have been issued within the City's political boundaries. General permits for discharges of stormwater associated with industrial activity are included in the appendix to this section, but other regulated facilities are shown in Table I-3.

Table I-3 – General VPDES Permits for discharge in the City of Roanoke

Permit Number	Type	Facility Name
VAG750059	Car Wash	ProWash USA
VAG840067	Non-Metallic Mineral Mining	Rockydale Quarries Corporation - Rockydale Plant
VAG110018	Concrete Products Facility	Chandler Concrete Company Inc - Roanoke
VAG110125	Concrete Products Facility	Boxley Concrete Products - Roanoke
VAG110268	Concrete Products Facility	Blue Stone Block Supermarket Inc
VAG110269	Concrete Products Facility	Concrete Specialties Incorporated

2. TMDL Reports and Implementation Plan

There are four TMDL reports for sections of stream that receive drainage from the City of Roanoke. Chronologically, the first of these was prepared in 2004 by MapTech et. al. [34] for a fecal coliform impairment in Glade Creek, Tinker Creek, Carvin Creek, Laymantown Creek, and Lick Run (Figure I-1). Additional bacterial impairments on Wilson Creek, Ore Branch, and the Roanoke River were addressed in the second TMDL, written in 2006 by George Mason University and the Louis Berger Group [35] (Figure I-2). These two TMDLs will be discussed henceforth as the "Tinker Creek TMDL," and the "Roanoke River TMDL," respectively. In this section, they are described jointly as "Bacteria TMDLs," as the procedure taken to create these two documents was similar. A third TMDL, written by the Louis Berger Group [36] was approved in 2006 to restore the Roanoke River's ability to support a healthy ecosystem at the bottom of the river (known as "benthic life"). For this report, this TMDL will be referred to as "The Benthic TMDL," and is described in a subsection of its own, as the development procedure was different than the Bacteria TMDLs. Finally, high levels of Polychlorinated Biphenyls (PCBs), a toxic organic chemical compound, were observed in the Roanoke River, Peters Creek, Tinker Creek, and Smith Mountain Lake, and a TMDL by Tetra Tech was approved in 2009 [37] to address this pollutant. After the development of these TMDLs, State law requires that an Implementation Plan (IP) be created for the fulfillment of the allocations described. This plan is not a regulatory document, but describes in general terms the amount of stormwater pollution control that will be required to fulfill these allocations.

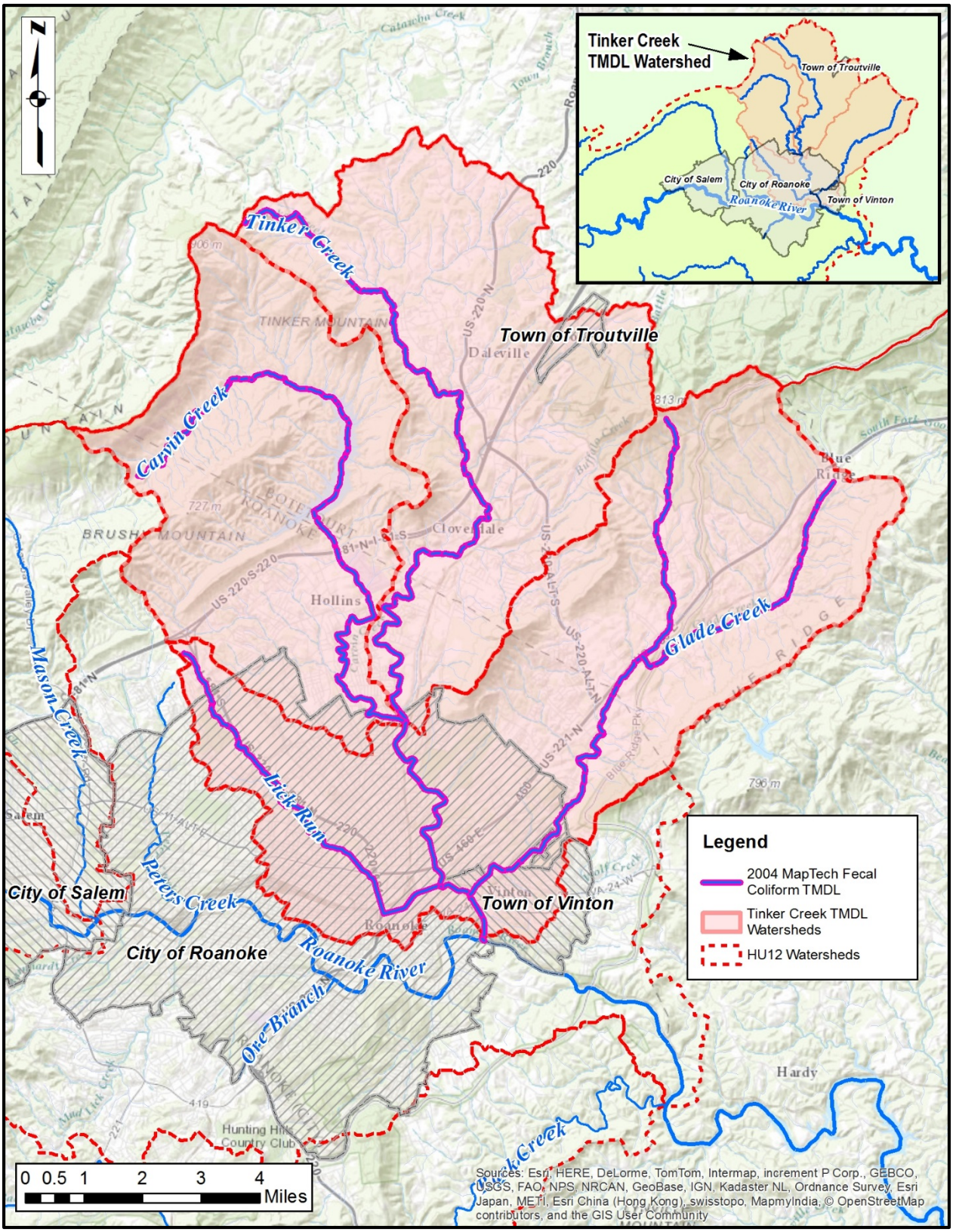

Figure I-1 – The Tinker Creek TMDL Watershed and Stream Reaches – Report by MapTech et. al in 2004 [34] **– GIS Data from NHD** [5] **and U.S. Census Bureau** [6]**, and as shown**

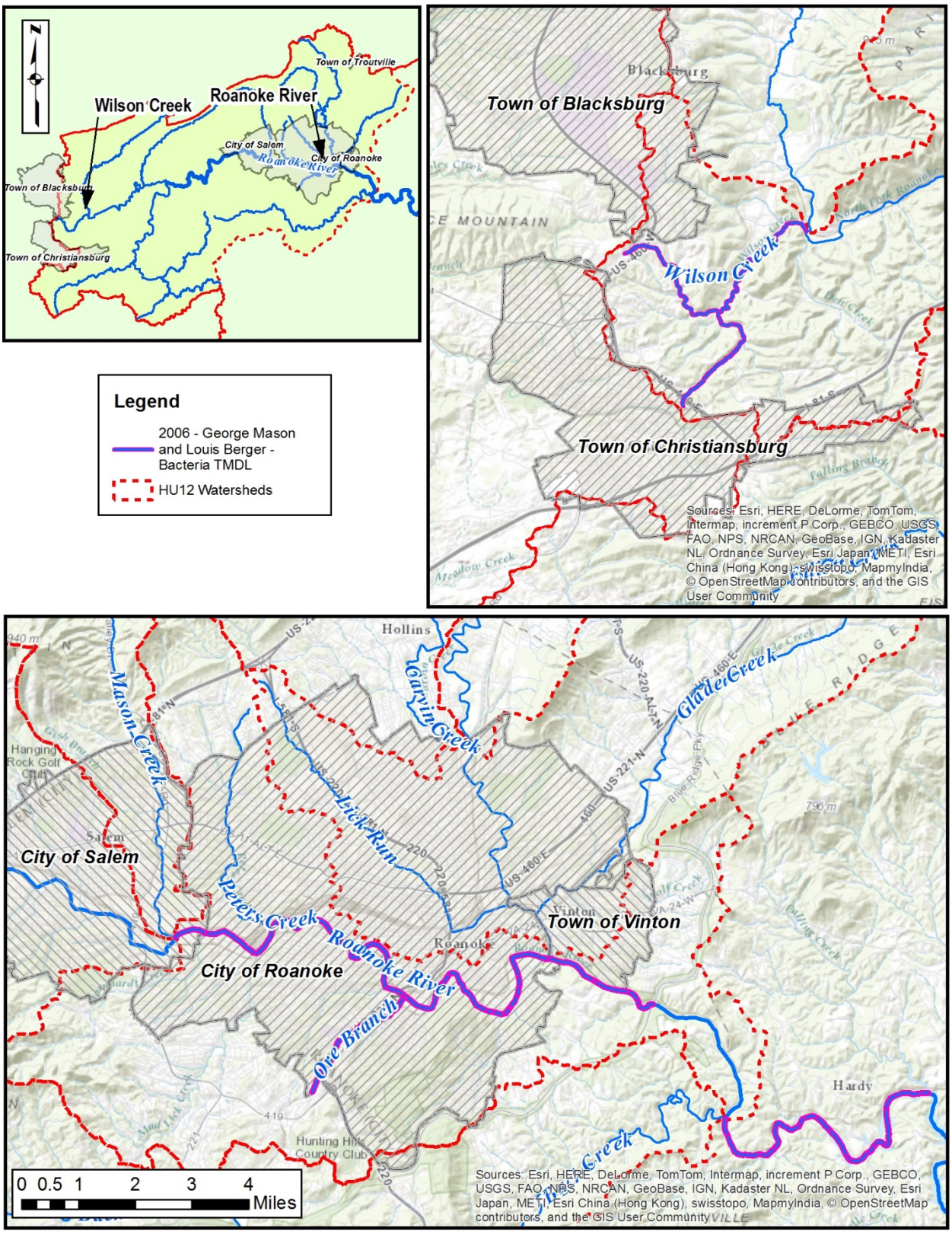

Figure I-2 – The Roanoke River TMDL Stream Reaches – Report by George Mason University and the Louis Berger Group, Inc. in 2006 [35] **- GIS Data from NHD** [5] **and U.S. Census Bureau** [6]**, and as shown**

(a) Bacteria TMDLs

The Bacteria TMDLs were created because the stream reaches were determined to be unsupportive of primary contact recreation (e.g. swimming). This means that the concentration of bacterial colonies in these streams was measured at levels above Virginia's water quality standard for recreation [38]. The streams in these two TMDLs were designated as impaired between 1996 and 2002 under a superseded standard that was based on fecal coliform concentration. This standard now uses the number of *E. Coli* bacteria colony forming units (CFUs) per 100 mL sample as a general indicator of the concentration of harmful bacterial life in freshwater. The Virginia *E. Coli* standard is two-fold:

- The monthly geometric mean[8] of samples shall not exceed 126 CFU/100 mL
- If data is not sufficient to calculate monthly geometric means, no more than 10% of total samples in an assessment period shall exceed 235 CFU/100 mL

These standards are based on the EPA's Ambient Water Quality Criteria for Bacteria report [39], and are supported by the conclusions in [40] that *E. Coli* is an adequate indicator of gastrointestinal illness in freshwater, but fecal coliform is not. The geometric mean is inadequate if fewer than two measurements are taken in a month; if this is the case, the latter standard would be used. As the streams in this TMDL were listed as impaired due to fecal coliform, but the standard changed to an *E. Coli* based standard before the TMDL could be written, the DEQ created a translator equation [41], [42] to convert fecal coliform concentrations to *E. Coli* concentrations.

The expense of collecting bacteria samples limits the number that can be taken, so to ascertain the total flux of bacteria through the Tinker Creek watershed, a computer model must be used that reasonably estimates the measured concentrations based on environmental factors. Since TMDLs are assigned on an annual load (CFU/year) basis, the model needs to integrate the volumetric flow rate with the concentration of bacteria in the water. This means that the model needs to be able to predict flow and *E. Coli* concentration at each time step. The model used to estimate pollutant loading in the Bacteria TMDLs is called the Hydrologic Simulation Program – Fortran (HSPF). It is a commonly used software for hydrologic modeling and TMDL development, as it is capable of estimating (1) how much bacteria is being transported to streams under existing conditions, (2) where that bacteria is coming from, (3) the amount of water quality treatment or hydrologic attenuation that needs to be made to the watershed so that the Virginia WQS is no longer exceeded, and (4) in what part of the watershed those improvements need to be made.

[8] A geometric mean is the mean of the data after it has been transformed to the log-scale (i.e., the log of each measurement is taken, and these values are averaged).

The general process of developing the two Bacteria TMDLs from modeling software, and additional information specific to the documents is included in the Appendix to this section. The modeling process begins by gathering spatial data relevant to the transport of bacteria from the land surface and other sources. This includes location information regarding land cover, hydrology, VPDES permit holders, septic systems, livestock, manure application, biosolids application, wildlife, and pets. As the bacterial transport mechanisms vary with the source, HSPF includes separate modeling methods for the different processes.

Once the model is built, it is then adjusted to more closely represent measured data, known as model calibration and validation. Once this is done, the model is assumed to be able to estimate the existing bacteria loading processes of the watershed. The sources are then iteratively reduced, and the model is re-run until the WQS is no longer violated by the output of the model. The reduced loads from each source are known as "Waste Load Allocations" (WLAs) for point sources and "Load Allocations" (LAs) for non-point sources. Every TMDL is required to include a Margin of Safety (MOS), which is intended to account for the uncertainty in the modeling process. The MOS can be accounted for implicitly by conservative assumptions, or as an explicit percentage at the end of the modeling procedure. The two bacterial TMDL studies have an implicit MOS. The TMDL is the sum of the three components, as shown in Equation 1.

$$TMDL = \sum WLA + \sum LA + MOS \qquad \textbf{Equation 1}$$

Although the two TMDL documents were developed separately, the allocations from the two documents are summarized by subwatershed in Table I-4.

Table I-4 – Bacteria Allocations (Colony Forming Units/Year) in the Roanoke River Watershed - Adapted from Table 5.16 [34] **and Table E-2** [35]

Document	Watershed	Point Sources (WLA)	Non-Point Sources (LA)	Margin of Safety (MOS)	TMDL
George Mason and Louis Berger, 2006	Wilson Creek	6.65E+09	3.64E+11	Implicit	3.70E+11
	Ore Branch	2.17E+10	8.15E+10	Implicit	1.03E+11
	Roanoke River	1.10E+14	3.02E+13	Implicit	1.40E+14
MapTech et. al, 2004	Carvin Creek	5.24E+12	2.61E+13	Implicit	3.13E+13
	Glade Creek	4.33E+11	4.20E+13	Implicit	4.24E+13
	Laymantown Creek	4.36E+11	6.15E+12	Implicit	6.59E+12
	Lick Run	7.17E+10	1.31E+13	Implicit	1.32E+13
	Tinker Creek	5.07E+12	7.56E+13	Implicit	8.07E+13

As it may be difficult to visualize the quantities described in Table I-4, the values are shown on the log-scale in Figure I-3. It is notable that in every subwatershed, except the Roanoke River and Ore Branch, the non-point source allocation is at least ten times larger than the point-source allocation. A known gap in TMDL

implementation is that there are no federal legal controls for non-point source pollution [43], so while the MS4 and other VPDES permit holders must document progress towards the TMDL endpoint in their MS4 yearly report, rural areas that contribute large amounts of non-point source pollution are not under any legal obligation to take action towards the TMDL endpoints (though in some cases they constitute a majority of the load). Again, note that the Y scale in Figure 6 is logarithmic so that each successive value is a factor of 10 higher than the previous value.

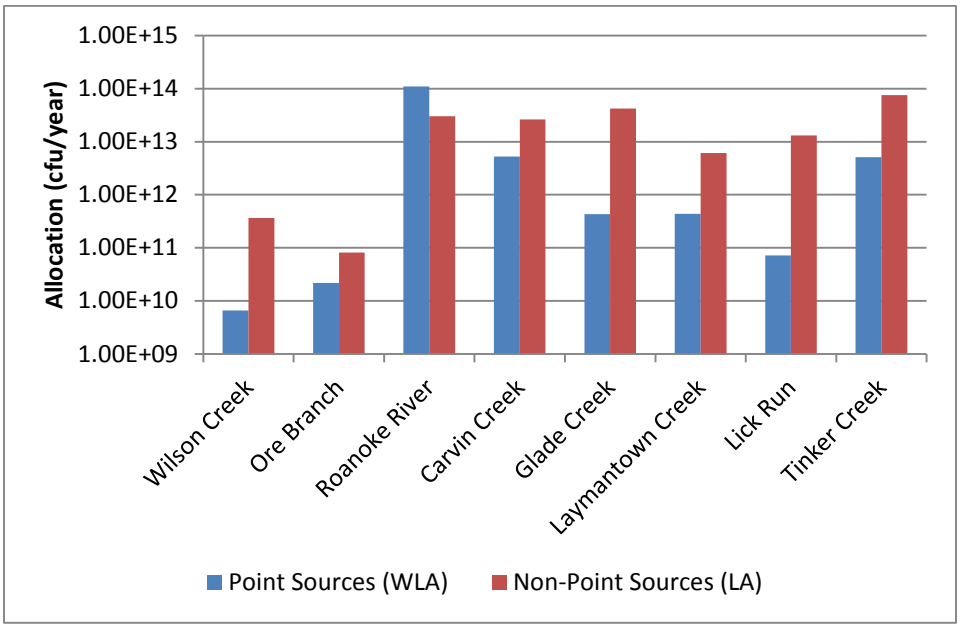

Figure I-3 – Logarithmic Bacteria Allocations in the Roanoke River Watershed by subwatershed

Although the MS4 component of the TMDL is considered a point source, it is calculated based on each municipality's share of the contributing urbanized area in each watershed. Waste load allocations for industrial permits are based on the numeric limits set in the permits, and on the presumption of compliance by these permittees. The load allocation is calculated based on the total area of each land cover type and its associated loading rate, plus the non-land based sources calculated for each watershed.

An MS4 entity that is not entirely within an urbanized area is responsible for meeting the waste load allocation for their MS4 permit, but is also responsible for meeting the load allocation (non-point source load) calculated based on the areas not within an urbanized area. Roanoke County, for example, holds an MS4 permit, though only 19.5% of the County is within the census-defined urbanized area. The County is therefore responsible for meeting the WLA for its urbanized area, and the LA for the 80.5% of the County that is not in an urbanized area. More information on the allocation of loads to different permittees and associated costs can be found in the discussion of the TMDL Implementation Plan (Section I.C.2(d)). Additional

information regarding the development of the Bacteria TMDLs can be found in Appendix I.

(b) The Benthic TMDL

The Roanoke River Benthic TMDL developed by The Louis Berger Group in 2006 (henceforth known as the Benthic TMDL) [36] was created to address violations on the Roanoke River of the State of Virginia's General Standard. Part I, Section 20 of General Criteria in the Virginia Water Quality Standards states the following:

> *State waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life* [44].

A common method used by Virginia and many other states to assess river and stream quality is by surveying the benthic organisms living in the waterbody. Benthic organisms consist of invertebrates such as worms, insect larvae, and crustaceans which live in or on the streambed, a transition layer known as the benthic zone [45]. These macroinvertebrates, known as the "benthos," constitute one portion of the bottom-dwelling community in a stream, spanning multiple levels of the food chain and providing a food source for other organisms such as fish. The state of Virginia has developed their own benthic impairment designation, similar to the EPA's guidelines [46], which defines a benthic impairment as a significant difference in benthic communities between a sample site and a non-impaired reference site with similar hydrologic and ecological characteristics [45].

The DEQ used two similar methods to assess the quality of benthic life in the Roanoke River. First the DEQ performed an assessment of benthic life across several monitoring stations on the Roanoke River itself. This assessment followed the EPA's guidelines for testing outlined in the Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers (RBPII) [46], and generated scores from an aggregated index of testing metrics selected to determine whether or not impaired benthic communities were present in the river. The DEQ also calculated the Stream Condition Index (SCI) for the benthic communities at these monitoring stations; the SCI is a regional assessment technique developed by the Virginia DEQ which compares 8 metrics from the RBPII list at monitoring stations across the state, providing an overview of the condition of the Roanoke River compared to other regional watersheds. From these assessments it was determined that benthic life was impaired in two sections of the Roanoke River located on the main stem between the confluence with Mason Creek, the Western Virginia Water Authority outfall, and the Niagara Dam impoundment, and include river miles that run through parts of the Cities of Salem and Roanoke (Figure I-4).

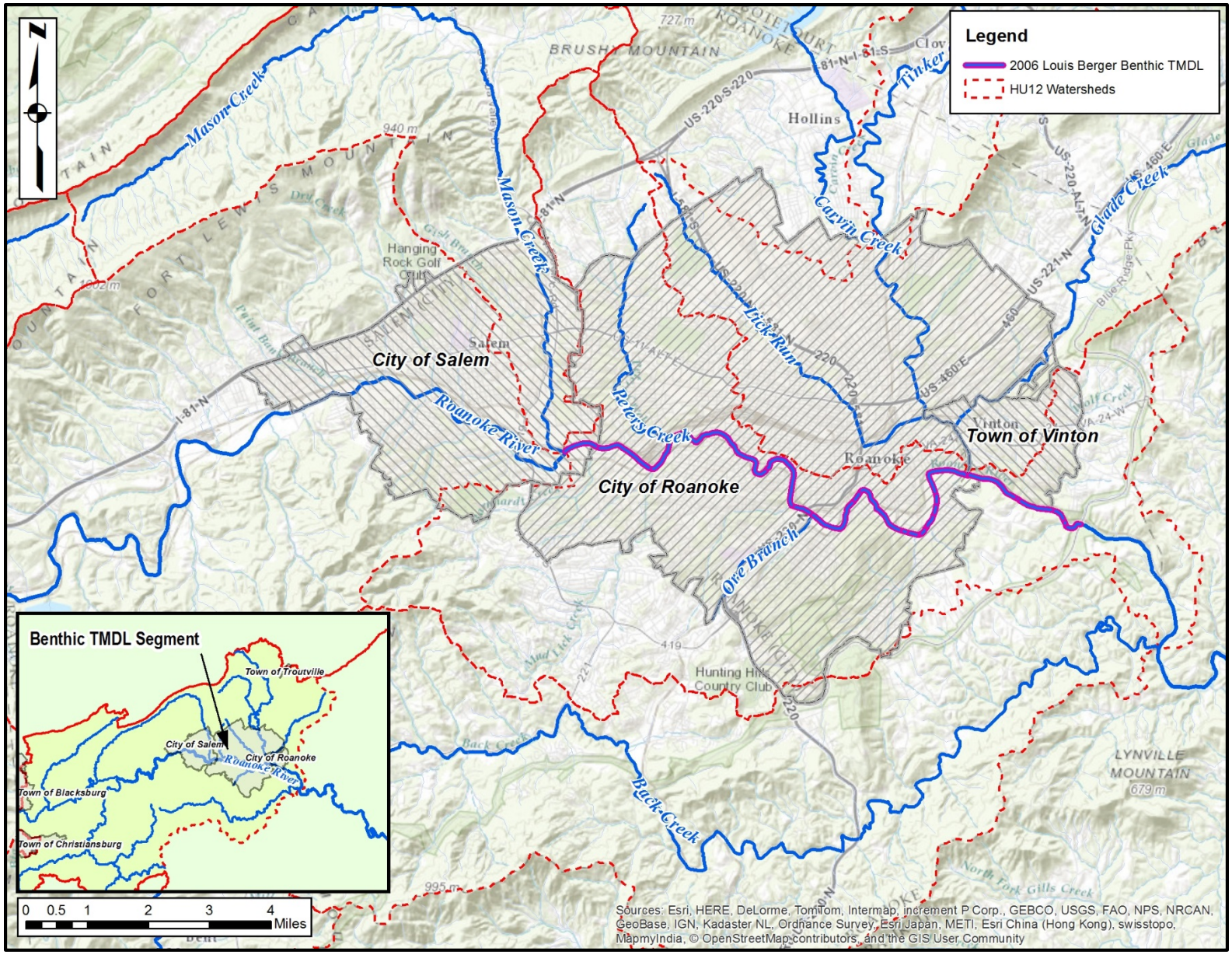

Figure I-4 - The Benthic TMDL Stream Segments along the Roanoke River – Report by the Louis Berger Group, Inc. in 2006 [36] **- – GIS Data from NHD** [5] **and U.S. Census Bureau** [6]**, and as shown**

Since the biological assessments only provide information about the benthic population, they give no direct indication of the cause of impaired benthic communities. In order to determine the probable cause for the decline in benthic macroinvertebrates, the Benthic TMDL included a "stressor identification analysis," in which the Benthic TMDL developers analyzed biological assessments, ambient water quality data, Discharge Monitoring Reports (DMRs) from permitted facilities, and toxicity and stormwater studies performed on the Roanoke River. After considering this data and other physical characteristics of the watershed, factors were ranked as "non-stressors," "possible stressors," or "most probable stressors," for benthic life. Dissolved Oxygen (DO), temperature, pH, and nutrients were all listed as non-stressors because few if any violations of these criteria were observed. Although metals, organics, and toxics were listed as possible stressors, no conclusive data could directly link them to impaired benthic life. Sediment was ultimately determined to be the most probable stressor for benthos in the Roanoke River based on poor habitat quality scores in biological assessments. This analysis is supported by evidence that sediment has significant effects on benthic life [47].

Since Virginia does not have a standard or numeric criteria for sediment concentrations, the Benthic TMDL developers used the "Reference Watershed Approach" (RWA) to estimate the current sediment loadings and the TMDL endpoint for sediment in the Roanoke River. This approach requires selection of a non-impaired watershed with similar hydrologic and ecological characteristics to the impaired watershed, which will act as a reference point. Sediment loading rates are modeled for both the reference and impaired watersheds, and the reference watershed loading rate is taken as the endpoint for the TMDL which the impaired watershed must attain. The selected reference watershed for the Benthic TMDL was the section of the Roanoke River watershed above biological monitoring station 4AROA224.54, which is situated downstream from the confluence of the North and South Forks of the Roanoke River. This reference watershed is a non-impaired upstream sub-basin within the greater impaired Roanoke River watershed.

Point, non-point, and in-stream sediment loads were factored into the endpoint calculation. Point sources were identified as facilities with permit limits for total suspended solids (TSS), and loadings were calculated using the permitted facility's allowable loading rate for TSS. Non-point sources consisted of land use categories to account for total land cover over the watershed, including MS4 permitted areas. Non-point source loadings were estimated using the Generalized Watershed Loading Functions (GWLF) model and the BasinSim 1.0 Windows Interface. In-stream sediment loads were estimates of bank erosion developed using a method from Evans et al. [48].

Modeling was conducted using GWLF to evaluate sediment loads from non-point land sources in the watershed. The GWLF model simulates watershed hydrology

and non-point source nutrient and sediment loading using input parameters such as weather and precipitation data, and physical watershed characteristics [49]. The model was calibrated for hydraulics using stream flow data collected from a USGS gage within one of the Roanoke River impaired sections. The model was simulated over a ten year period from 1993-2003 in order to compare simulated and observed conditions during the biological assessment period. The daily time steps allowed for seasonal and annual variability in the simulations.

The TMDL endpoint was determined by combining the point, non-point, and in-stream contributions for the reference watershed. At this stage the non-point source and in-stream loads were split among rural lands and MS4 entities using an area-weighted distribution. Once initial estimates for the reference and impaired watersheds were determined, the model was run through an iterative reduction process until the sediment loads in the impaired watershed reached the TMDL endpoint. The developers then specified load and waste load allocations for the final TMDL; a 10% explicit margin of safety (MOS) was also included to account for uncertainty in the model and calculations (Table I-5).

Table I-5: Sediment TMDL for the Roanoke River (tons/year)[36]

TMDL	Load Allocation	Waste Load Allocation	10 % Margin of Safety
21,079	13,782	5,189	2,108

In order to further illustrate the changes proposed in this TMDL, a comparison was made between the existing and allocated loads for the Roanoke River watershed (Figure I-5). The figure shows permit-based or estimated loads from all point and non-point sources considered in the TMDL, with non-point sources split between MS4 and Nonurban Land contributions. The sediment load values on the Y-axis are on a log scale such that each value is ten times more than the previous value. The differences in the MS4 and Nonurban Land categories represent a required reduction of more than two thirds in each category to meet the TMDL endpoint.

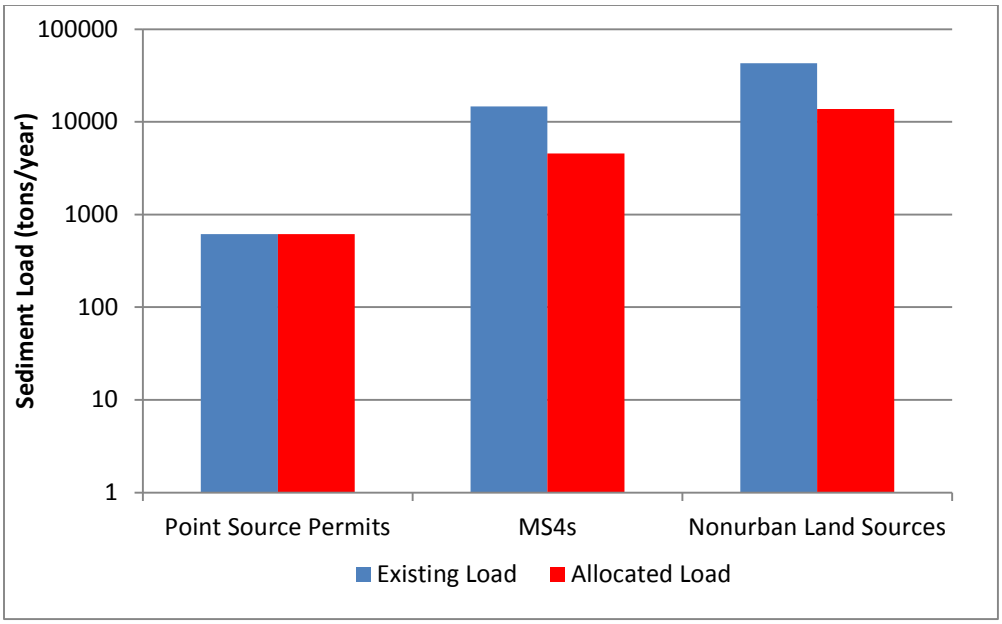

Figure I-5 - Comparison of existing sediment loads and allocated loads from the Benthic TMDL. Note that the Y-axis is on a log scale and that each successive value is ten times the previous value. Numbers adapted from [36]

The MS4 allocation shown in Figure I-5 is further broken down in the TMDL document and summarized here by MS4 entity (Figure I-6). Each entity is given an allocation for their own stormwater permit, and a smaller allocation that accounts for individual and general permits within their jurisdiction, such as industrial sites, car washes, mines, etc. Again, note that the Y-axis is on a log scale such that values on the scale increase by a factor of ten every interval. More than two thirds of the MS4 allocations lie within Roanoke County and the City of Roanoke, while the remaining fraction is distributed among the other nine MS4s.

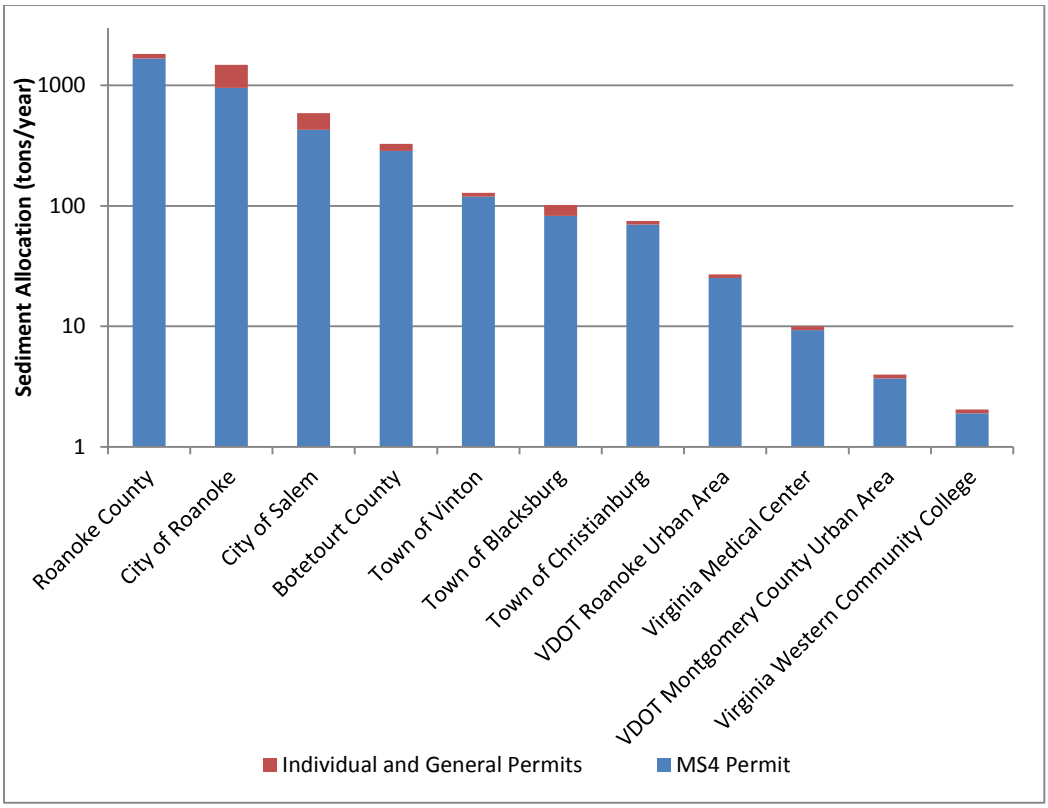

Figure I-6 - MS4 allocations in the Benthic TMDL broken down by MS4 jurisdiction and permit type. Note that the Y-axis is on a log scale such that intervals increase by a factor of ten. Numbers adapted from [36]

For additional information regarding the development of the Benthic TMDL, see Appendix I.

(c) The PCB TMDL

In 2009, Tetra Tech wrote a TMDL report to address impairments in the Roanoke River Watershed, and other areas downstream for a chemical pollutant called Polychlorinated Biphenyls (PCBs). PCBs are persistent organic chemicals that were used in lubricants, hydraulic fluids, landfills, and old transformer fluids until they were banned in 1979; they appear in several varieties but are referred to collectively as total PCBs (tPCBs). The impairment area is larger than the other three TMDLs, but this report will focus on the stream segments relevant to the City of Roanoke (See Figure I-7). PCBs have been found to have adverse effects to humans, including cancer, inhibited reproduction, neurological development disorders, and decreased liver function [50]. High levels of these organic chemicals have also been correlated to acute and chronic toxicity in aquatic life and some small mammals [51]. As such, several agencies including the DEQ, the Virginia Department of Health, and the U.S. Fish and Wildlife Service have created WQSs for PCBs. As these chemicals appear at very low concentrations, regulators sample fish tissue and sediment as a surrogate to determine the concentration in the water column.

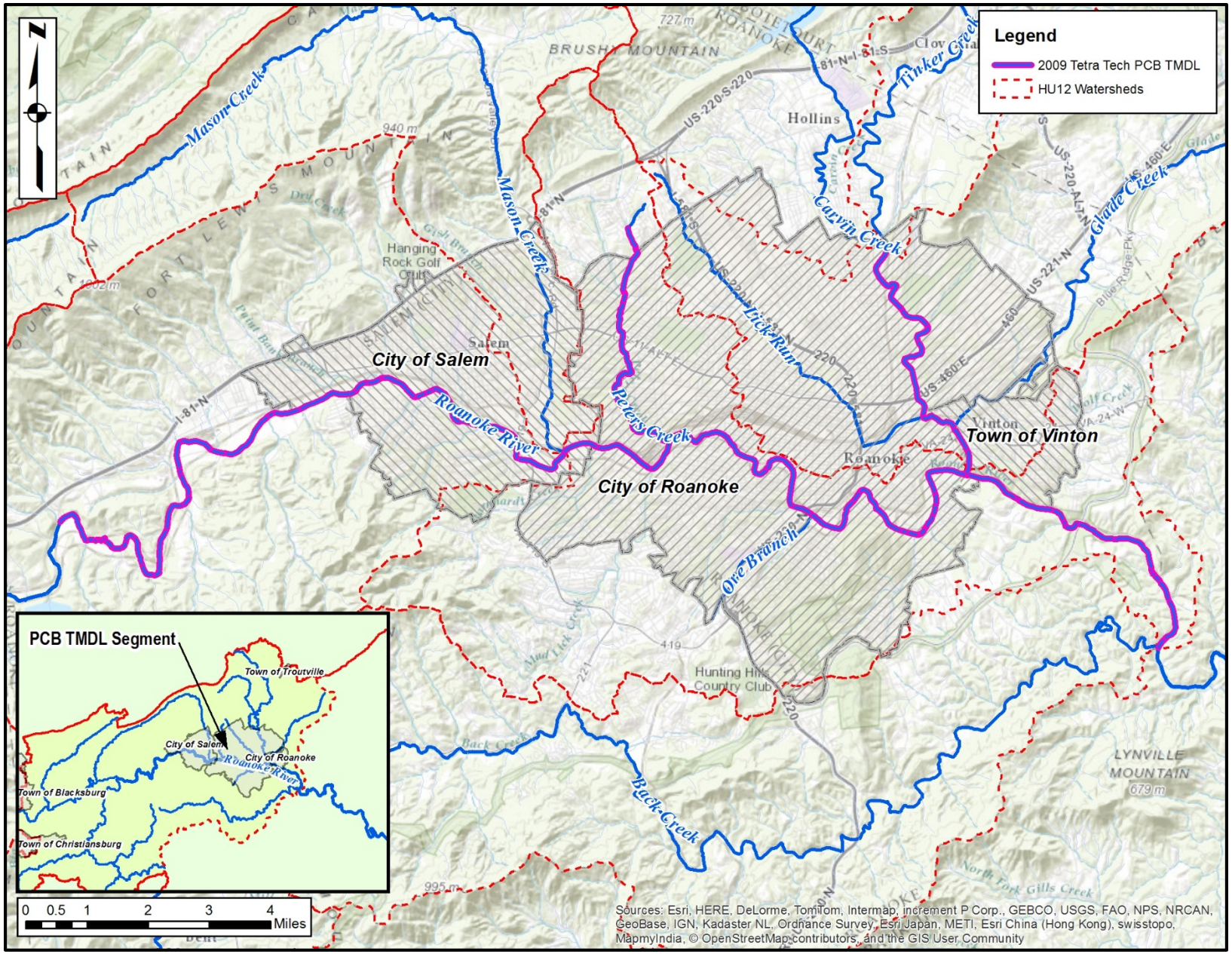

Figure I-7 – The PCB TMDL Stream Segments – Report by Tetra Tech in 2009 [37] **- GIS Data from NHD** [5] **and U.S. Census Bureau** [6]**, and as shown**

The PCB TMDL is designed similarly to the Bacteria TMDLs – a model is built to simulate existing conditions in the watershed, and that model is iteratively adjusted until the WQSs are no longer violated. PCB is different from the other pollutants because it is no longer being introduced to the environment. Therefore the sources of PCBs are locations where the chemical exists either in the sediment, or at industrial waste facilities. The Tetra Tech document includes an acknowledgement that source investigation is ongoing (p.36). The allocations for the PCB TMDL are shown in Table I-6.

Table I-6 - Average Annual tPCBs TMDL for Upper Roanoke River Source Categories. Adapted from Table ES-3 in [37]

Source Category	Baseline (mg/yr)	WLA (mg/yr)	LA (mg/yr)	% Reduction
VPDES Discharges	17,665.8	28,267.1		-60.0
Individual Industrial/General Permits	6,827.4	5.3		99.9
MS4 Entities	109,622.4	332.7		99.7
Contaminated Sites	7,853.5		1.0	100.0
Urban Background (Unknown Sites)	12,082.4		114.4	99.1
Atmospheric Deposition	8,862.5		8,419.4	5.0
Total	162,914.1	28,605.0	8,534.8	77.2

(d) The Roanoke River Implementation Plan (IP)

The Code of Virginia requires that implementation plans (IPs) be created as a procedure to work towards the goal of fulfilling the allocations described in a TMDL [52]. IPs are documents that estimate the type and number of stormwater control measures from an approved list of BMPs that are necessary to reduce pollution to the allocated amounts. These plans, though required by regulation, are not regulatory documents. They are descriptive of the magnitude of effort required to meet the TMDL endpoints, but not prescriptive, as they do not directly require action by any of the associated jurisdictions. Indirectly, however, permitted entities (including MS4 entities) are required to report progress made towards TMDL endpoints in the "TMDL Action Plan Progress" section of their MS4 permits.

The process of development of the IP for Phase I of the Roanoke River watershed (Figure I-8) began in November, 2013, with a steering committee meeting held by DEQ and the Louis Berger Group, Inc., and since then, residential/agricultural, business, and government working group committees have been formed who have also held meetings to determine the means of reaching the endpoints found in the Tinker Creek, Roanoke River, and Benthic TMDLs[9].

[9] The PCB TMDL is not included in this implementation plan, as the PCB TMDL is of a substantially dissimilar geographic scope, timeline, and pollutant than the other three.

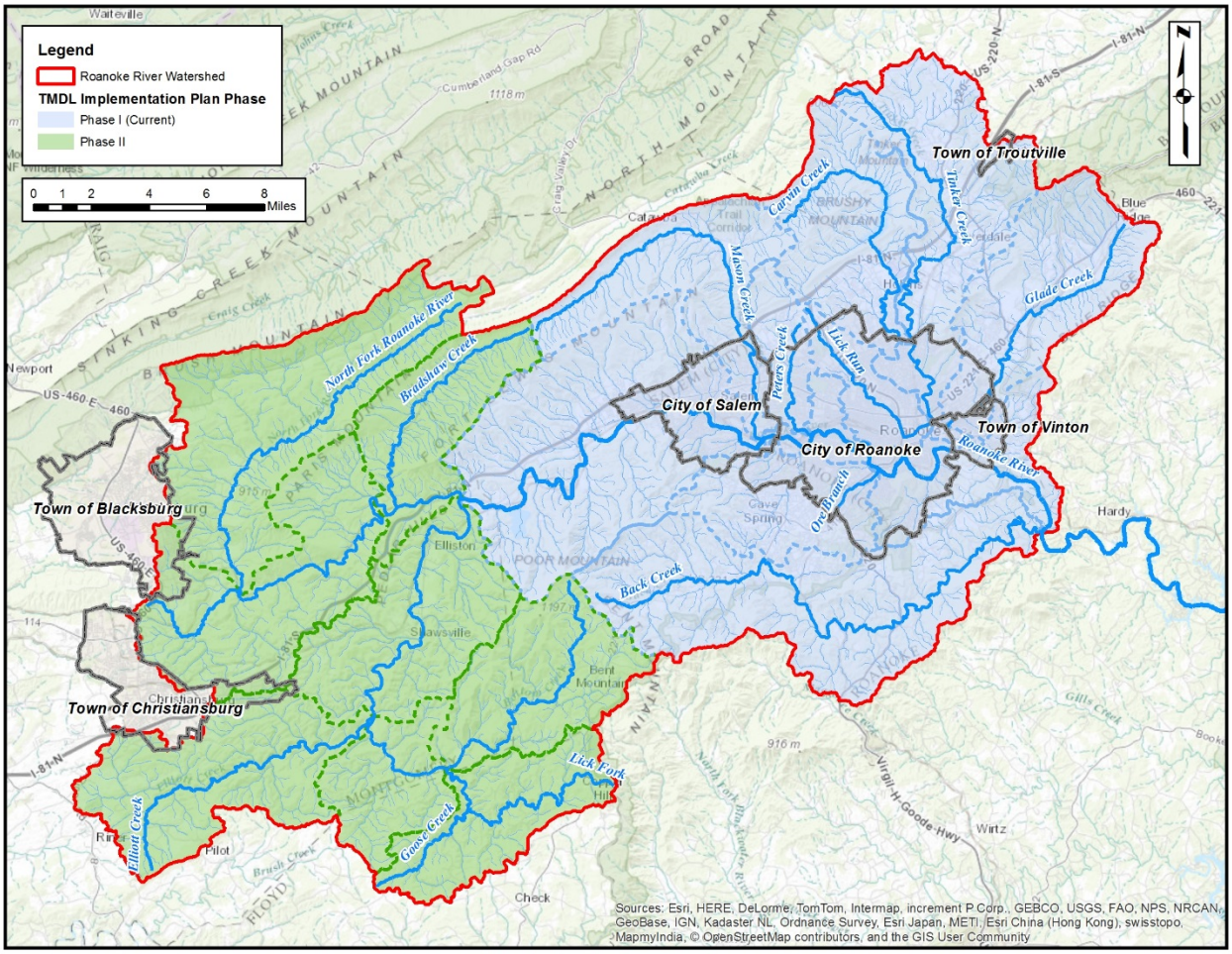

Figure I-8 – TMDL Implementation Plan (IP) Phases shown on the Roanoke River Watershed as defined in this Report

Based on general allocations determined in the TMDL documents, the allocations are further distributed based on land use and MS4 area using the unit-area load (UAL) approach. This provides a more specific estimate for the location and amount of stormwater treatment facilities, though the IP is not more detailed than the subwatershed scale. It is up to MS4 entities, and other VPDES permit holders to determine exactly how the allocations will be met (i.e. the specific location, type, and installation specifications of the treatment facilities). The DEQ and the Louis Berger Group have provided estimates of the cost of the IP based on reported costs and efficiencies in the gray literature[10]. The total estimated cost of implementing Phase I of the IP is approximately $474 million, with the City of Roanoke responsible for $103 million based on a spatial intersection of watershed and jurisdictional boundary GIS layers. The area-distributed total cost for the remaining stakeholders is shown on a log-scale in Figure I-9, and per-acre cost of the IP by locality is shown in Figure I-10.

[10] These tables are available from the DEQ [53]. They have been adapted for readability and uploaded to the project Scholar Site.

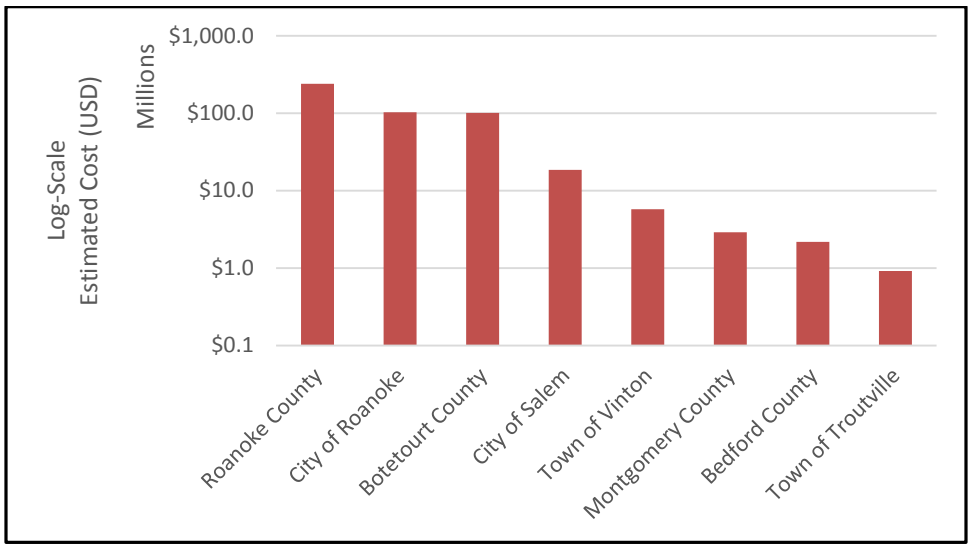

Figure I-9 - Estimated Cost in Millions of 2014 US Dollars of Roanoke River TMDL IP Phase I by Stakeholder – numbers adapted from [53]

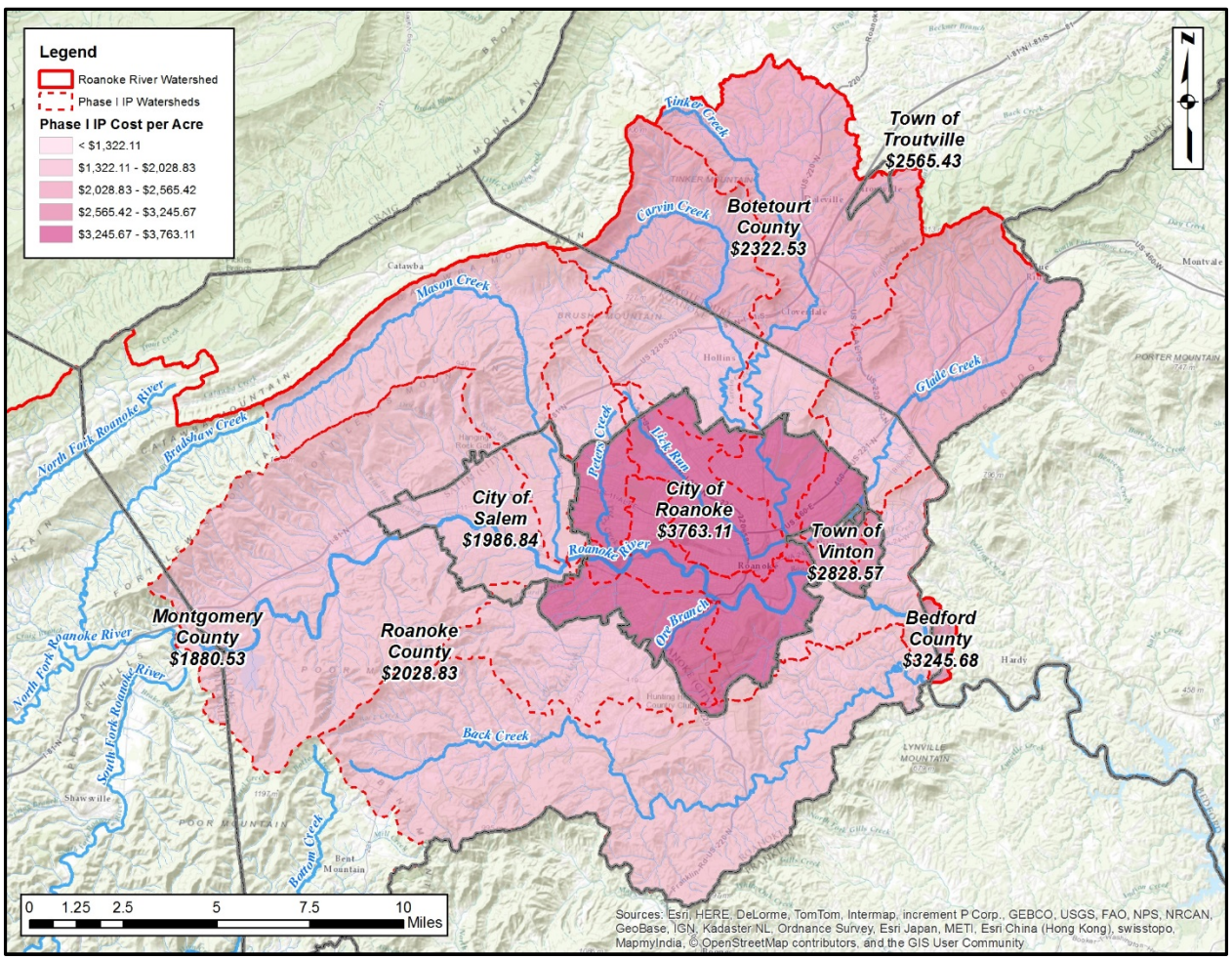

Figure I-10 – Per-acre costs for portion of each locality in Roanoke River Phase I Watershed of the TMDL Implementation Plan (IP) – Color Scale Indicates per acre cost by locality– numbers adapted from [53]

As of the submittal of this report, the cost estimates in the IP indicate that approximately 80% of the total cost required to install water quality improvements in Phase I of the watershed will be stormwater BMPs such as bioretention, detention ponds, and other similar practices, and detention pond retrofits. Phase I of the IP is expected to be completed during the winter of 2014-15, and Phase II is scheduled to begin immediately after.

3. NFIP Program

The City of Roanoke's initial Flood Insurance Rate Maps (FIRMs) were finalized in November, 1981, and at that time the City registered with the NFIP. Based on the current FIRM data available as GIS shapefiles [54], 3.3% of the City lies in the FEMA delineated 'Floodway', and 5.2% lies in Zones A, AE, or AO (but not within the Floodway).[11]

Roanoke is a CRS Class 7 community with a 15% flood insurance discount for properties in the Special Flood Hazard Area (SFHA) and a 5% discount for properties outside the SFHA. There are four other Class 7 communities in Virginia, and only one with a higher Class – the City of Alexandria is a Class 6 community, and receives 20 and 10 percent discounts on flood insurance for SFHA and non-SFHA properties respectively [55]. The CRS program creates an economic incentive for communities to implement flood-reducing policies, though it is not capable of incentivizing upstream communities. The City of Salem, for example, is an upstream community that does not participate in the CRS.

FEMA reviews a community's application on an annual basis to assure that the programs are in place, and performs verification visits every five years, to audit the documents that have been submitted. The City will be audited sometime in the next year, and may need additional programs to maintain CRS Class 7 status, as the requirements have increased since the previous audit. The City's current CRS program is described in a recertification report [56] and confirmation letter from FEMA [57]. The City's program is shown graphically in Figure I-11 as compared to national statistics regarding the program.

[11] The 'Floodway' is operationally defined as the channel of a river or other watercourse and adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation by more than a designated height. Zones A, AE, and AO are subject to inundation by the 1% annual chance flood event (i.e. the 100-year flood). Areas in Zone A are based on approximate methodologies, and areas in Zone AO may have floods with high velocities. Less than 0.001% of the City is in Zone A and AO.

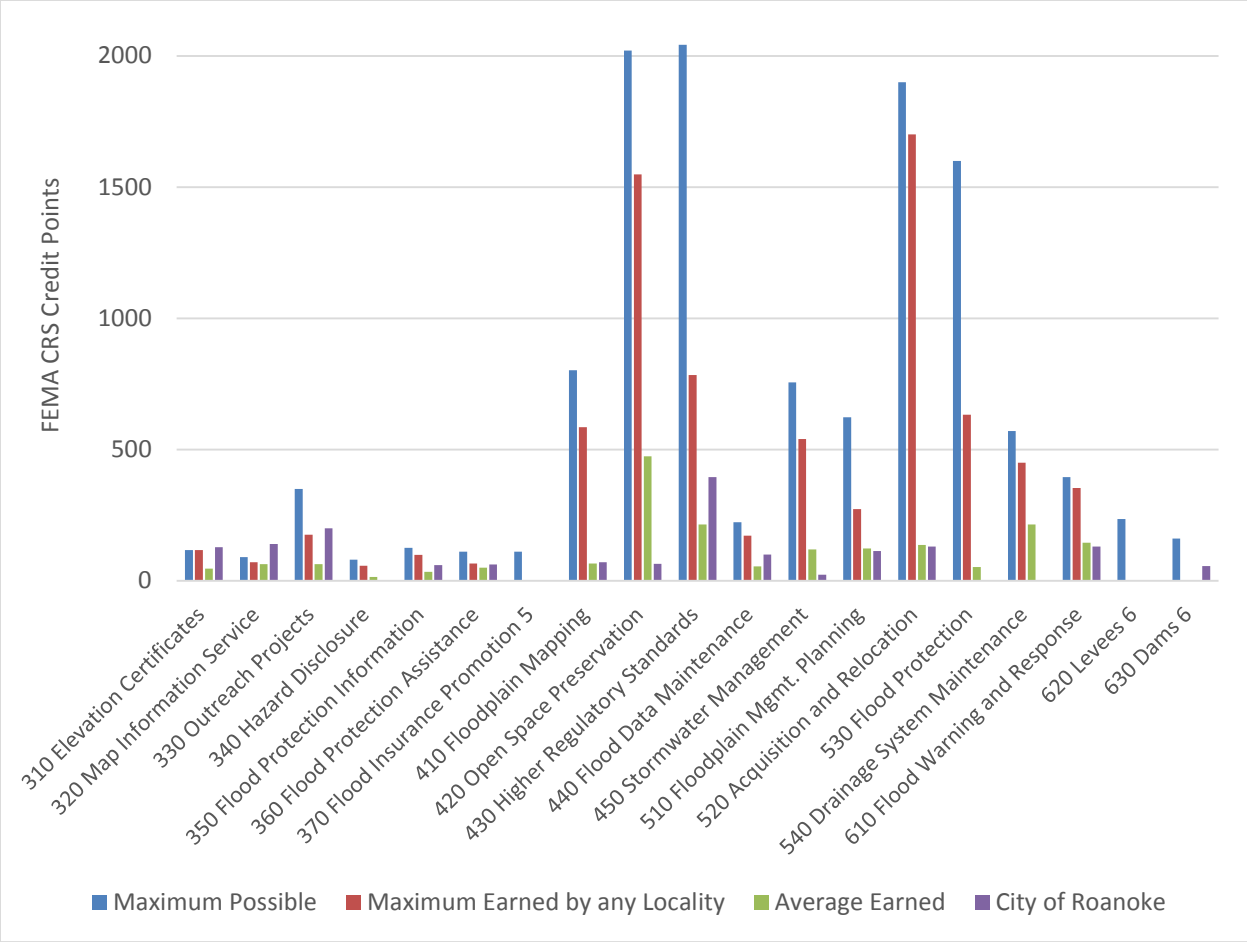

Figure I-11 – FEMA's Community Rating System (CRS) point system with maximum points possible, maximum points earned by any locality nationally, average points earned nationally (data from [30]**), and points earned by the City of Roanoke based on the City's Verification Report** [57]

D. The Comprehensive Plan

The City of Roanoke has adopted "Vision 2001-2020, the City's Comprehensive Plan" [58], in which City officials and citizens have laid out the vision for the future of Roanoke at the turn of the 21st century. This plan places emphasis on several key factors for Roanoke's healthy development including greenway development, equitable distribution of housing types, and accommodation of bicycle and pedestrian modes of transportation. The City of Roanoke has organized their planning efforts around the idea of neighborhood plans, at a rate of 4 – 6 neighborhoods each year. These neighborhood plans dissuade urban sprawl by encouraging infill development of vacant or underutilized lots within the City, and provide for more densely zoned village centers in each neighborhood to provide services for the community.

The Comprehensive Plan includes policies and actions designed to develop healthy neighborhoods and a high quality of life. For example, neighborhood planning procedures consider land use and multimodal transportation, and funding was increased for streetscape

and infrastructure improvement projects. While the infrastructure section of the plan discusses reductions in rainwater-sewer connections and limitations on impervious parking surfaces, stormwater is briefly addressed when the City makes mention of the potential need to investigate the creation of a regional stormwater management utility, then again with respect to flooding and water quality issues [59, p. 44]. Since the creation of the Comprehensive Plan, the City has increased its involvement in stormwater infrastructure to adapt to the new regulations imposed on water bodies within the City. Efforts to improve the City's stormwater management include the recent restructuring of the Stormwater Division within the Public Works Department and the 2014 rollout of the Stormwater Utility Fee.

This document reports the City's commitment to the natural environment as an important marketing resource for eco-tourism, but also as an enhancement of quality of life. The Plan describes the vision for the Greenway system (now in place) as a means of connecting the region geographically, but also as a way of reconnecting the citizenry to the Roanoke River [60, p. 8]. A specific policy mentioned that may be relevant to stormwater management is [59]:

> **EC P4. Environmental quality.** Roanoke will protect the environment and ensure quality air and water for citizens of the region. Special emphasis will be placed on the Roanoke River and its tributaries. Storm water management will be addressed on a regional as well as a local level.

Several water quality strategies were also mentioned in the same section:

> **EC A13.** Limit the amount of impervious surfaces to reduce runoff.
>
> **EC A14.** Plant natural vegetation, preferably indigenous plant species, on land adjacent to the Roanoke River.
>
> **EC A15.** Ensure integrity of the storm and waste water systems.
>
> **EC A16.** Protect and stabilize creek banks by controlling storm water flow and preventing discharge through vegetative buffers, bioengineering, and other related methods.
>
> **EC A17.** Protect the shorelines of the Roanoke River to enhance their scenic quality and protect water quality through a river conservation overlay and other appropriate tools.

Finally, for the purposes of economic development, the plan describes a new economic initiative [61, p. 57] that states that Roanoke will invest in critical amenities, including the environment, though no specific policies or actions are given to this end.

II. Meetings with City of Roanoke Staff

The objective of this scope task was to facilitate collaboration between Virginia Tech (VT) and the City of Roanoke employees by holding periodic meetings, through phone conversations and other communications. This task provided VT with an understanding of the roles of City personnel with respect to stormwater management and water quality. An organization chart (Figure II-1) was created based on provided documentation from City employees.

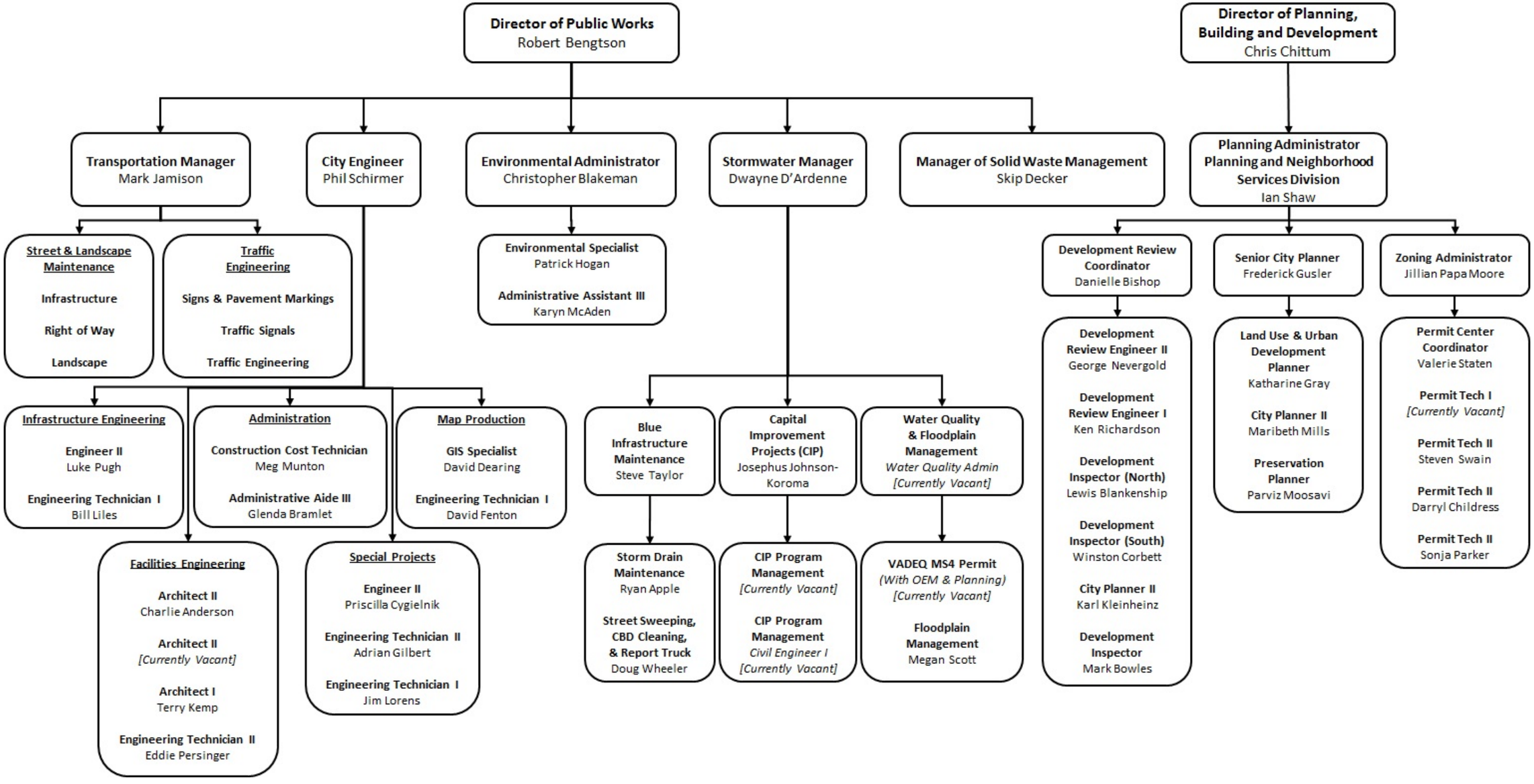

Figure II-1 - Organization Chart of City of Roanoke Employees related to Stormwater Management – Note that this is not a complete chart for the City, but only includes employees with roles relating to stormwater management

In the course of this work, it became clear that in order to have a holistic understanding of the regulatory position of the City, meetings would be required with authorities working for other organizations in the region. This scope task is organized into two sections: (1) correspondence and site visits with City of Roanoke personnel, and (2) correspondence with outside organizations which interact with the City. Brief summaries of meetings and discussion topics are provided in these sections, while more detailed minutes can be found in Appendix II.

A. City of Roanoke Correspondence and Site Visits

1. Project Startup Meeting – May 21st, 2014

Attendees: Randy Dymond, Clayton Hodges, Marcus Aguilar, VT; Bob Bengtson, Christopher Blakeman, Dwayne D'Ardenne, Kennie Harris, Patrick Hogan, Mark Jamison, Tracey Leet, Phil Schirmer, Megan Scott, City of Roanoke

The purpose of this meeting was to introduce stormwater stakeholders at the City of Roanoke to the VT researchers, and to begin the process of discovery. Christopher Blakeman described the development of the project, and the general scope of work. All present gave brief introductions, then Randy Dymond presented an introduction to the breadth of work in his research group at VT. Several City employees asked questions about this presentation, and then the conversation transitioned to the Discovery Phase scope of work. Several ideas were discussed, including the characterization of water entering the City jurisdiction, and ideas for engaging the DEQ regarding TMDL requirements.

Other specific ideas discussed were (1) the integration of various data into GIS and the resources necessary to do so, (2) the creation of Watershed Implementation Plans, (3) information sharing protocol for the project[12], and various other ideas noted in the detailed meeting minutes in Appendix II.

2. Visit One – June 24-25th, 2014

Attendees: Marcus Aguilar, VT; Kennie Harris, David Dearing, Megan Scott, City of Roanoke

This series of meetings introduced VT to the GIS resources available from the City. Several GIS databases were downloaded, along with aerial photography from previous surveys, for VT to assess and analyze. VT also discussed the relationships between GIS and other personnel in the City's network, and job responsibilities of the attending employees.

David and Kennie gave a thorough review of the City's effort to develop the impervious surfaces data, and the different challenges associated with implementing the Stormwater Utility Fee.

Megan provided an overview of her role at the City as the floodplain manager, and described her responsibilities in assuring that any changes made to the floodplain do not affect the base-flood elevation. In addition, Megan is responsible for taking drainage

[12] The stakeholders decided that VT would develop a project website to be shared with City staff. This site serves as an access controlled, permanent repository for data for this project.

complaints, and creating capital improvement projects if necessary and possible. She is also responsible for the Federal Emergency Management Agency's Community Rating System (FEMA CRS) for the City.

This visit also included a field visit to the Roanoke River from Bridge St. to the Franklin Rd. bridge; georeferenced photographs were taken on this trip.

3. Visit Two – July 2nd, 2014

Attendees: Marcus Aguilar, VT; Phil Schirmer, Patrick Hogan, Dwayne D'Ardenne, City of Roanoke

The three main aspects of the City's stormwater program, as described in this meeting are:

1. Capital Improvement Projects – The planning for these is generally based on citizen flooding complaints and some assessed need. The City would like to be ahead of complaints rather than behind them.
2. Maintenance – The City is perpetually performing repairs to the storm sewer system, but again, would like to be proactive in preventing problems.
3. Water Quality – The City is required to implement water quality BMPs towards the objectives of the TMDLs, and would like to consider BMPs that may not be on the DEQ's approved list.

The City would like to develop watershed master plan documents for each subwatershed, to be added to the City's comprehensive plan. The City would also like to develop stream quality guides. Finally, measuring and monitoring the current conditions on the Roanoke River and its tributaries; and investigating right-of-way scale interventions that can be used to improve water quality in the City are goals of the stormwater program.

This visit also included a field visit to the Roanoke River near Salem Park, Mason Creek, and Peters Creek. Georeferenced photographs were taken on this trip.

4. Visit Three, Float Trip, Part 1 – July 18th, 2014

Attendees: Marcus Aguilar, VT; Dwayne D'Ardenne, Christopher Blakeman, Megan Scott, Joe Koroma, Ryan Apple, Danielle Bishop, Karl Kleinheinz , City of Roanoke; Liz Belcher, Roanoke River Blueways

This trip was organized to familiarize VT and the City of Roanoke with the physical state of the Roanoke River. Photographs of important locations along the river were taken to aid in identifying sources of runoff, especially during dry weather conditions.

5. Visit Four, Roanoke River Steering Committee Meeting – August 20th, 2014

Attendees: Marcus Aguilar, Paul Bender, VT; Mary Dail, Jay Roberts, Diana Hackenberg, Kip Foster, Charlie Lunsford, DEQ; Nick Tatalovich and Erin Hagan, Louis Berger Group; Dave Henderson, Tarek Moneir, Roanoke County; Christopher Blakeman, Megan Scott, City of Roanoke; Anita McMillan, Town of Vinton; Sarah Baumgardner, Mike McEvoy, WVWA; Bill Modica, Bill Tanger, Upper Roanoke River Roundtable; Margie Lucas, Mill Mountain Garden Club; Wendy Jones, Williamson Road Area Business Association; Liz Belcher, Roanoke Valley Greenways/(Blueways?); Tom Dale, Lumsden Associates; Staci Merkt, Mountain Castles SWCD;

Ashley Hall, EEE on behalf of VDOT; Larry Iceman, Smith Mountain Lake Association; Kafi Howard, Town of Blacksburg; Ed Wells, Roanoke Valley Alleghany Regional Commission; Josh Pratt, City of Salem; Tom Cain, Lick Run Watershed Association
VT attended this steering committee meeting to observe stakeholder involvement in the development of the TMDL Implementation Plan for the Roanoke River watershed. Stakeholders from the business, agricultural/residential, and governmental sectors gave input on different aspects of the IP and expressed concerns about various issues. Confusion about the regulatory relationship of the IP to MS4 Action Plans and credit programs was a key topic discussed, along with types and costs of BMPs to be considered for implementation, and the degree to which this IP would facilitate or complicate MS4 permit holders' ability to carry out stormwater improvement projects.

6. Visit Five, Float Trip, Part 2 – August 21st, 2014

Attendees: Marcus Aguilar, Paul Bender, Walter McDonald, Jessica Hekl, Kandace Kea, VT
This trip provided VT with a glimpse at another section of the Roanoke River, from Smith Park in the City of Roanoke up Tinker Creek to a take-out at the Public Works boat ramp in the Town of Vinton. More photographs were taken of outfall structures along this stretch of the river, with GPS coordinates assigned. Observations were also made regarding the river's flow stage, adjacent geography and land use, and amount of litter pollution present.

7. Phone Call – September 11th, 2014

Attendees: Marcus Aguilar, VT; Ian Shaw, City of Roanoke
The purpose of this phone call was to determine Ian's primary role at the City, and how that is connected with the stormwater program. Ian's job is to consider the long-term goals of the City, and determine how best to create ordinances that steer the organization and the public in that direction. He was integral in the formation of the City's Comprehensive Plan, and is likely to be involved in the upcoming Comprehensive Plan steering committee.

8. Phone Call – September 12th, 2014

Attendees: Marcus Aguilar, VT; Joe Koroma, City of Roanoke
The purpose of this phone call was to ascertain Joe's role at the City, and how that relates to the stormwater program. In general, Joe works on localized flooding issues, and resolves these problems through capital improvement projects. If the project is small enough, the City will perform the engineering design internally, otherwise it is contracted out. Joe performs project management duties that encompass the full spectrum of services for these capital projects. Challenges to Joe's work usually pertain to the acquisition of right-of-way for capital projects.

9. Phone Call – September 15th, 2014

Attendees: Marcus Aguilar, VT; Bob Bengtson, City of Roanoke
The objective of this phone call was to learn Bob's role at the City, and what capacities he has with respect to stormwater management. Bob is the director of Public Works, and oversees the operations of five divisions: Transportation, Engineering, Solid Waste, Environmental, and the new Stormwater division. He is the conduit of information between

these departments and the City Manager's office, and also assures that within Public Works, the divisions are communicating. With respect to stormwater, Bob needs to assure that the new stormwater group has the necessary resources to overcome the logistical difficulties of creating a new division.

10. Phone Call – September 18th, 2014

Attendees: Marcus Aguilar, VT; Danielle Bishop, City of Roanoke

Danielle's role at the City is to administer the VSMP Construction General Permit for construction projects. She is responsible for stormwater and erosion and sediment plan review, construction site inspections, post-construction inspections, maintenance, and enforcement. This includes 76 development plans and approximately 300 existing facilities that require inspection. The City has used software called "PermitsPlus" since 2001 that tracks the status of permits, creates reports and notifications. It does not have a spatial interface, and the City may be in the process of looking for new software for this task.

One of the biggest challenges to implementation of the VSMP is the details of how the program is to be implemented in specific development situations that are not well defined in the program. The VSMP also does not appear to be self-funding, as even with the fees from the new regulations, Danielle's group is at 34% recovery.

11. Visit Six – September 19th, 2014

Attendees: Marcus Aguilar, Paul Bender, VT; Phil Schirmer, Dwayne D'Ardenne, Christopher Blakeman, Patrick Hogan, City of Roanoke

The first portion of this visit was spent with Phil and Dwayne, as an introduction for Paul. In this discussion, some clarification was given regarding some of the GIS data retrieved from Kennie Harris, and a discussion about how collaborate with the DEQ toward the TMDL endpoints occurred. There was also a brief discussion about the comprehensive plan, and how watershed master plans developed before the comprehensive plan would be helpful in implementing innovative stormwater strategies.

The second part of this visit was spent with Christopher and Patrick. The bulk of the discussion was centered on the requirements of the TMDLs, especially the lack of specificity regarding how the BMPs described in the IP are to be implemented within local governments. Other topics were also discussed, including how the City might quantify small scale effects of BMPs, including municipal education programs.

12. Phone Call – September 22nd, 2014

Attendees: Marcus Aguilar, VT; Patrick Hogan, City of Roanoke

In this phone call, the possibility of implementing a new mobile GIS device for inspections was discussed. The City is considering a Trimble GPS unit (either a Juno 3 or 5 series) with software called TerraFlex. The City is considering the different departments that might use this device, and what sort of services they require to best fit their needs.

13. Phone Call – October 17th, 2014

Attendees: Marcus Aguilar, VT; Steve Taylor, City of Roanoke

This conversation introduced VT to the stormwater infrastructure and maintenance branch of the City Stormwater Division. Steve Taylor informed VT about storm drain inspection, cleaning, and repair carried out by his work crews. Street sweeping technology and practices employed by the City were discussed, and the storm drain inspection process was explained. Ryan Apple is in charge of storm drain maintenance, and his crew performs robotic CCTV inspection, cleaning, and repairs on stormwater infrastructure in the City. The Stormwater Division is interested in video inspecting all City infrastructure in a ten year cycle, in addition to verifying known infrastructure and documenting unknown or new construction.

14. Visit Seven, Stormwater Maintenance Field Trip – November 7th, 2014

Attendees: Marcus Aguilar, Paul Bender, VT; Steve Taylor, Ryan Apple, Bill Jones, Tyree and Steve, City of Roanoke

This trip was organized as a follow-up from VT's phone call to Steve Taylor in order for VT to get exposed to what the stormwater maintenance crews are up against in the field. Bill Jones, one of the maintenance supervisors, provided a yard tour of the street sweeping fleet that the City uses, and demonstrated how a traditional mechanical sweeper works. Tyree and Steve, two CCTV field operators for Ryan Apple, ran the camera truck and vactor truck in a local neighborhood to demonstrate how a typical storm sewer inspection and maintenance trip is carried out. They also described from their own experience the typical problems encountered, solutions employed, and data gathered on stormwater infrastructure while in the field.

Afterwards, time was spent with Ryan Apple to review in more detail the current technology and workforce available for stormwater inspection, and planned upgrades and expansion that will be occurring in the next year. Much of the discussion, which was geared towards planning for Phase II of the VT/City partnership, was about software-GIS compatibility, types of data to be collected, and structure of the planned GIS database for stormwater infrastructure.

15. Visit Eight, DEQ Stream Monitoring Meeting – November 12th, 2014

Attendees: Marcus Aguilar, Paul Bender, VT; Anita McMillan, Vinton; Dwayne D'Ardenne, Megan Scott, Christopher Blakeman, City of Roanoke; Cindy Traywick, Dave Henderson, Tarek Moneir, Roanoke County; Josh Pratt, City of Salem; Greg Anderson, Mary Dail, Jason Hill, Cody Boggs, Mike McLeod, James Moneymaker, Larry Willis, DEQ

VT attended this meeting which provided local MS4s with more information on the DEQ's procedures for stream monitoring. DEQ described six (6) of their most common types of sampling programs related to the impairment listings and the development and implementation of TMDLs. Details included station selection, sampling frequency, and parameters measured. DEQ also discussed how they attempt to quantify sediment as a

pollutant. DEQ and MS4s gave input and discussed ways to bring about progress on TMDL Action Plans and to work further with the DEQ to understand the data behind the TMDLs.

B. Correspondence with Other Agencies and Organizations

1. Phone Call – July 21st, 2014

Attendees: Marcus Aguilar, VT; Liz McKercher, TMDL Program Manager, DEQ- Richmond
Liz was contacted in order to gather more information about the Benthic TMDL. She confirmed that it had been approved and directed VT to Mary Dail and the VEGIS website for more information about TMDLs and related GIS data.

2. ASCE Dinner Meeting and Presentation – August 21st, 2014

Attendees: Marcus Aguilar, Paul Bender, Randy Dymond, Clay Hodges, VT; other various Roanoke area stormwater stakeholders
Several members of the VT Roanoke project team attended an ASCE-Roanoke Chapter meeting, where Fred Cunningham of the DEQ presented the new VSMP Construction General Permit regulations which were updated on July 1st, 2014. Clay Hodges also presented an example development site and stepped through the new calculations required by the VSMP program.

3. Phone Call – September 4th, 2014

Attendees: Marcus Aguilar, Paul Bender, VT; Mary Dail, TMDL Project Coordinator, DEQ
Mary was contacted after the Roanoke River Steering Committee Meeting on August 20th to provide further clarification about the TMDL Implementation Plan as it relates to MS4s. She confirmed that the TMDL IP is descriptive without any legal enforcement behind it and serves as a guide to illustrate the extent of SCM implementation needed to meet the TMDL endpoint. MS4 Action Plans are prescriptive and integral to fulfilling the requirements of the MS4 permit, where permit holders must describe in detail the SCMs they have put in place towards meeting a TMDL endpoint. Also, she confirmed that there is no legal device for areas outside of the MS4 jurisdictions to implement any changes; in these regions action is completely voluntary.

4. Stormwater Monitoring Cost Estimate Phone Calls – September 22nd, 2014

Attendees: Marcus Aguilar, VT; Dr. Roger Glick, City of Austin, TX; Harry Post, Occoquan Watershed Monitoring Laboratory, Virginia Tech
These two phone calls served to supplement the cost data that VT is collecting for municipal storm sewer monitoring programs. Dr. Glick is an engineer who leads the monitoring program for the City of Austin, TX. Harry Post is a researcher at the Occoquan Watershed Modeling Laboratory in Northern Virginia, and has experience in the procurement, installation, and maintenance of various stormwater monitoring devices.

5. Phone Call – September 23rd, 2014

Attendees: Marcus Aguilar, VT; Dan Widner, VGIN

The purpose of this phone call was to ascertain the forthcoming GIS data collection projects by the Virginia Geographic Information Network (VGIN). The following data will be available in the coming years:

- New aerial photography will be flown in the spring of 2015 at 1 ft. resolution. This will be available near the end of 2015. A digital terrain model will be developed alongside the aerial photos.
- Upgrades are available for this coverage if desired, including LiDAR, land cover, and planimetrics. These are available on a per acre cost.
- A state wide land cover dataset is being rolled out in three phases: (1) a pilot phase in several small portions of the state (available next May), (2) the Chesapeake Bay watershed will be available by the end of 2015, and (3) the rest of the state will be available in 2016
- VGIN is also working with the USGS and others to gather funding for statewide LiDAR, and so far there are funds for the eastern 48% of the Commonwealth. They are also applying for grant funding from the USGS under the 3D elevation program (3DEP)

6. Phone Call – October 29th, 2014

Attendees: Marcus Aguilar, VT; Phil McClellan, MapTech President

This conversation supplied VT with more information about the IFLOWS program discussed further in Scope Tasks 4 and 5 of this report. The discussion focused on the capabilities of the current system's infrastructure with regards to supporting stormwater monitoring and water quality sondes.

III. Review of City of Roanoke Geographic Information System (GIS) Data

The City of Roanoke uses GIS data, and the purpose of the following section is to provide an overall review of the City's use of GIS data, with a focus on stormwater related data. The first subsection describes what sort of data is currently available, how it is organized, and who is responsible for its management and use. The second subsection focuses specifically on the content and quality of stormwater GIS data. Detailed information and descriptions of layers within the City of Roanoke Master Geodatabase can be found in Appendix III.

A. General

The City's GIS data is largely stored in an ESRI ArcSDE[13] Database, which is managed in-house by the Office of Information Technology, in the GIS Division. The GIS Division manages the data, and has both read and write access, and David Dearing manages data that is directly related to the Engineering Division.

Information to be made publicly available is extracted nightly from this database, and served on the City's Real Estate GIS website [33]. This website uses ESRI's ArcGIS Application Programming Interface (API) 3.3 for Flex to display spatial information in a digestible form for a basic user. Data cannot be retrieved from this website, nor can any analysis be performed, though the website provides information useful for citizens and City employees. Based on dialog with City staff, most employees in the Public Works Department use the City's Real Estate GIS website (GISRE), and do not access the data directly with desktop GIS software.

GIS Data, was initially retrieved through direct transfer from Kennie Harris in ESRI geodatabase format on June 24th as described in Table III-1. These data are largely maintained by the GIS division, with the exception of the "STORM WATER HUC6" geodatabase, the origin of which could not be verified. The "Pavement" geodatabase is a city-wide delineation of roadway pavement, but excludes driveways, alleys, sidewalks, and other small paved features. Merged with the "impervious_surface" feature class in the master geodatabase, a large portion of the City's impervious surface could be estimated. Aerial photography for years 2011 and 2013 were also provided as a single MrSID[14] file at 3 and 6 inch resolution respectively – this data is a product of the Virginia Base Mapping Program (VBMP) at the Virginia Geographic Information Network (VGIN).

[13] ArcSDE is a proprietary software created by Environmental Systems Research Institute (ESRI), and is a server software that leverages the concepts of relational database management systems (RDBMS) to structure and access spatial data. It extends the traditional database approach by allowing multi-user access and editing capabilities through various RDBMS packages, which provides organizations with a more suitable workflow.

[14] MrSID stands for multi-resolution seamless image database, and is patented by LizardTech. It is a file format for storing various types of compressed images that allows for rapid visualization of these images without decompression.

Table III-1 – GIS Data retrieved on June 24th, 2014

Feature Datasets, Feature Classes, or Folder	Description
City of Roanoke Master Geodatabase	
Demographics	Census data from 1990 – 2010
HazMat	Known locations of materials hazardous to air or water environment, including facilities with high risk of illicit discharge to storm sewer system
LandFeatures	Important historical places and other various data including driveways, fences, pools
LandRecords	Parcel data with easements
NeighborhoodServices	Zones and Districts, including code enforcement, conservation rehabilitation, neighborhoods, and rental inspection districts
ParksRec	All facilities related to City parks, including, benches, grills, restrooms, public art, etc.
Planning	City jurisdiction divided in various manners – by character districts, enterprise zones, historic districts, etc. Includes future land use features
PublicBoundaries	City limits, quadrants, mail quadrants, school zones and zip codes
PublicFacilities	Emergency shelters, fire stations, hospitals, libraries, post offices, and schools
Services	Parking, snow, social services, solid waste, and street sweeping zones
StormWater	Inlets, manholes, culvert ends, open channels, pipes, and detention ponds. Also includes the impervious surface polygon
Topography	10 and 2 foot contours with GPS control monuments. Also includes regional SSURGO data
Transportation	Roads and appurtenances, railroads, bridges, and airport
Utilities	Electrical, fiber optic, and wireless internet infrastructure
WaterFeatures	Rivers, wetlands, and FEMA's DFIRM maps
Zoning	Zoning districts
Pavement Working Geodatabase	
Pavement	Polygon showing all pavement in the City. Not QA/QC'd
Regional Geodatabase	
Botetourt	Parcel map
RoanokeCounty	Creeks, fire stations, magisterial districts, parcels
RoanokeValley	Regional hydrography, boundaries, IFLOWS, streets, watersheds, and zip codes
Salem	City boundary and parcels
Vinton	Fiber optic cable
Virginia	State boundary, counties, cities, towns, major rivers, places, congressional districts, house of representative districts, senate districts
STORM WATER HUC6 Geodatabase	
BMP_LOCATIONS	212 privately owned stormwater control measures. Ownership data, but no further information
Impaired_waters	Geometry showing impaired water locations. Attribute table incomplete
MS4_Locations_SpatialJoin	Unclear. Same attributes as BMP_Locations
ROANOKE_SUB_WATERSHEDS	100 subwatersheds in the City limits. No hydrologic information
Watersheds	20 watersheds in the City limits. No hydrologic information
2011 MrSID	
vbmp_2011_roanoke_city1.sid	Aerial photograph coverage of the City circa 2011 as a single MrSID raster image. Cell size is 3 in. x 3 in., with RGB color format and 8 bit unsigned integer pixels
2013 MrSID	
VAROAN12-CITY-OF-ROANOKE –SID-6INCH.sid	Aerial photograph coverage of the City circa 2013 as a single MrSID raster image. Cell size is 6 in. x 6 in. with RGB color format and 8 bit unsigned integer pixels

A Digital Terrain Model (DTM) created by the Virginia Geospatial Information Network as part of the VBMP, was provided by David Dearing on September 22, 2014. This 30.5 MB file consists

of 948 Microstation .dgn files (one for each VBMP tile) with elevation points and breaklines. The DTM was developed from imagery acquired in spring 2011 under contract to Sanborn Map Company, and conforms to the Model Virginia Map Accuracy Standards of 1992. The 10 and 2 ft. contours in the City's geodatabase were built based on these data as shown in Figure III-1.

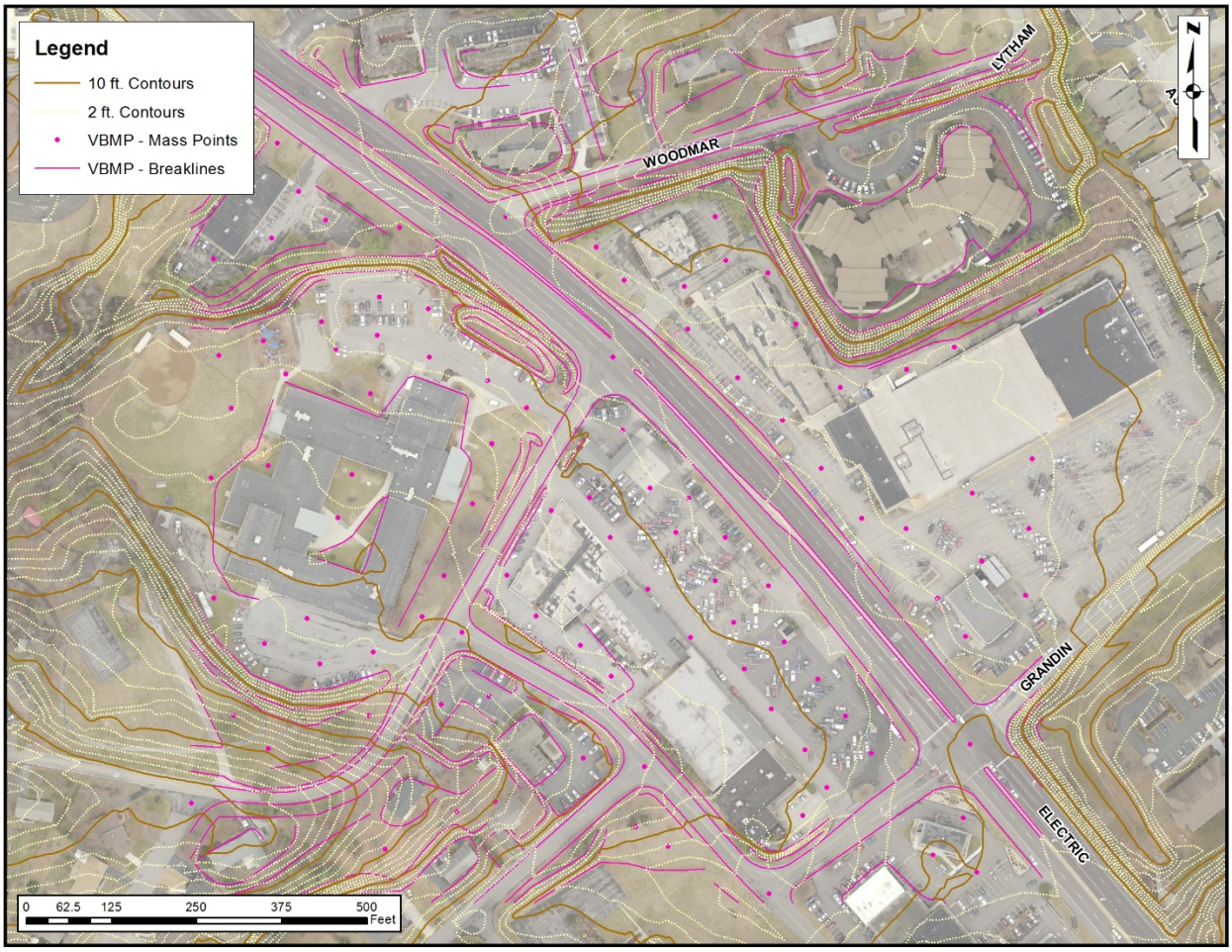

Figure III-1 – Derived 2 and 10 ft. Contours overlaid on VBMP Mass Points and Breaklines

B. Stormwater Data

David Dearing also provided a shapefile from the 1997 Valleywide Stormwater Management Plan [62] called "basin-m.shp" that shows the RVARC area divided into small scale watersheds. This shapefile did not include a projection, however some of the attributes match the features in the "Watersheds" feature class in the STORM WATER HUC6 geodatabase.

The "StormWater" feature dataset in the master geodatabase contains 1097 culvert ends, 231 detention ponds, 8663 inlets, 2643 manholes, 1158 pipe ends, 40 miles of open channels, and 239 miles of pipes. These data were created by City interns, and though the data provides a general overview of storm sewer infrastructure, no quality control measures were taken, and it should therefore not be used for planning purposes. Invert depth information was collected for manholes, but not for inlets, and pipe dimensions are not in consistent units, and in some cases

include erroneous text. Pipe features do not follow the topological rule that they must begin and end at a point feature (such as an inlet or manhole), so it is not possible to create a network from the current data. The additional watershed data in the "STORM WATER HUC6" geodatabase includes watershed delineation to a scale that is smaller than the NHDPlusv2 watersheds, and appear to have been delineated by hand. As noted above, these watersheds match those delineated for the RVARC's 1997 Valleywide Stormwater Management Plan, though the only information in the attribute table is a unique identifier for the subwatershed.

The current status of data representing the City's gray stormwater infrastructure, as well as streams, ponds, and other features can be described as partially complete though not verified, and without appropriate controls on data integrity. This appears in several ways. First, the structure of the feature classes makes it difficult to find information. For example, point features are divided into four feature classes – culverts, inlets, manholes, and pipe ends – though it is not clear how to distinguish between culverts and pipe ends. These layers could be combined into a single layer with a single field schema to allow for more effective attribute and spatial querying. Second, the accuracy of the location and attributes of the data is not verified and attributed, which does not necessarily mean that it is inaccurate, but simply that it should not be used until it is verified. Third, information in attribute tables needs to be constrained and unified – for example, pipe dimensions should be stored in integer fields with a known unit (e.g. inches), without any text or other symbols (Figure III-2). This allows for more effective querying of the data. Finally, the geometry of the data needs to follow certain topological rules – for example, each pipe should begin and end at a node of some variety (e.g. inlet, manhole, or outfall). In summary, the existing GIS data for stormwater infrastructure provides a basis for future work, but without refinement and restructuring, cannot be used for planning or design.

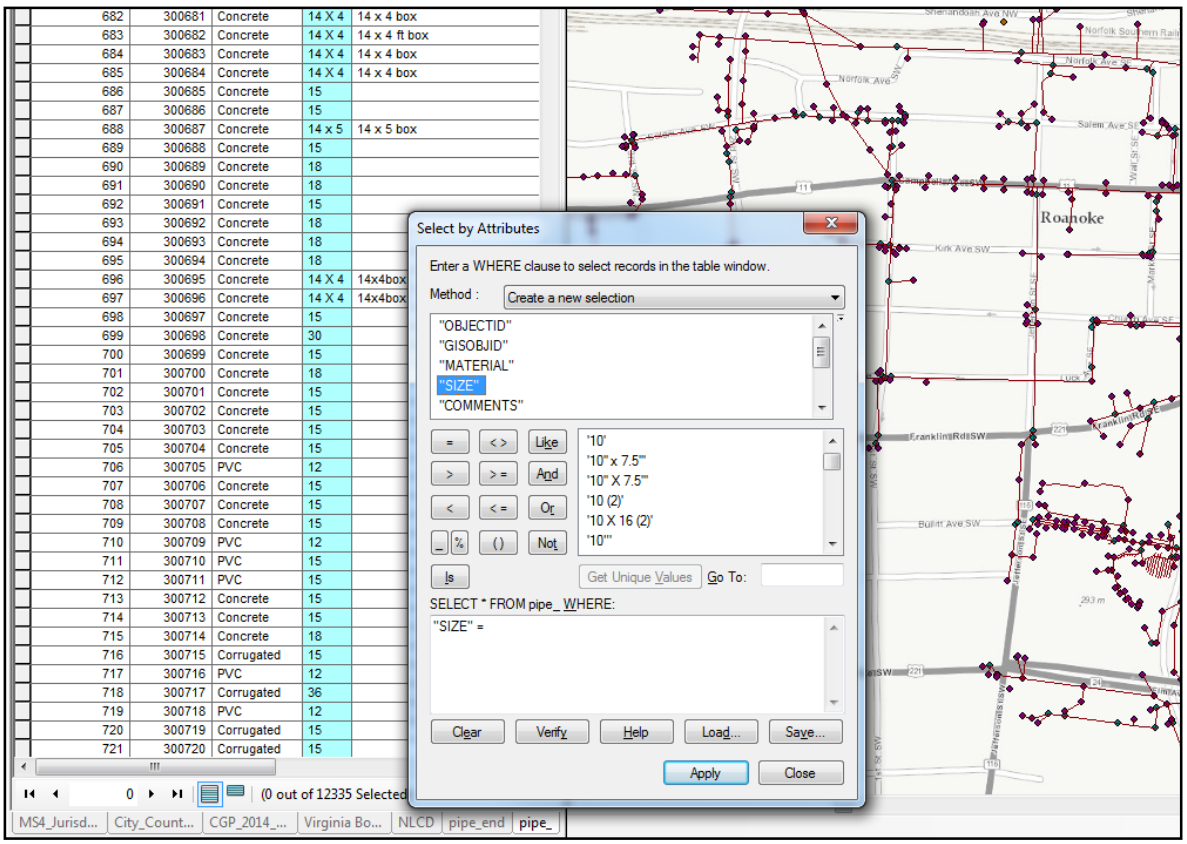

Figure III-2 – Screenshot of the "pipe_" layer from the City's Stormwater feature dataset. The highlighted field shows pipe dimensions, though the sizes are not in a unified format. This prevents effective data querying, and should be reformatted.

IV. Review of Other Sources of GIS Data

Geographic data has increased in abundance and accessibility as software for the collection and analysis of spatial data has improved in quality. In the U.S., there are many sources of geographic data related to hydrology and water quality that are freely available, and while gateways such as The National Map Viewer and CUAHSI HIS[15] were created to simplify access to these data, extracting and manipulating data to suit the needs of a specific project and location still requires substantial effort. This section describes the different sources of geographic data available, and how it might be relevant to stormwater management in the City of Roanoke. The section is arranged based on the arrangement of data by source in the geodatabase created for this work, and links to the data sources can be found in the table in Appendix IV.

A. DCR – Department of Conservation and Recreation

These data were retrieved from the DCR's Natural Heritage website, and demonstrate conservation land, conservation easements, and scenic river stream segments. The Roanoke River from Shawsville to Smith Mountain Lake is considered a "qualified" scenic river in the Commonwealth of Virginia. This means that localities adjacent to the river can submit a report on various characteristics of the River to the DCR to try to achieve "designated" status as a Scenic River. This provides some additional rights to riparian landowners, and further restricts the use of the river for hydroelectric power. This program is not to be confused with the federal Department of the Interior's Wild and Scenic Rivers program.

B. DEQ – Department of Environmental Quality

The Virginia DEQ stores GIS information in a single location, called the Virginia Environmental GIS (VEGIS) [63]. From this location in the DEQ's website, data can be viewed through an online web mapping application (called "What's in My Backyard"), or downloaded as shapefiles for use in desktop GIS applications. The online application contains the same data that is available for download, but it is not possible to download or analyze any of the data in this environment – the main function of this environment is viewing data. The VEGIS includes a link to GIS resources developed for the 2012 305(b)/303(d) Water Quality Assessment Integrated Report (the link is broken, see [64]). The data available for download from the VEGIS pertains to the spatial locations of TMDL streams and watersheds, and of VPDES permits across the state.

Other data concerning the locations of construction sites that have been permitted under the Construction General Permit are available from the Construction General Permits resource of the DEQ's website [65]. Although these data are not directly spatial in nature, latitude and

[15] The National Map Viewer [95] is an online map service created and maintained by the USGS as a way to view and access Federal GIS data at a single location. CUAHSI HIS, an acronym for the Consortium of Universities for the Advancement of Hydrologic Science Hydrologic Information System [96]. This organization developed a desktop tool to access and extract hydrologic information from various online servers.

longitude coordinates for each construction site are included in the records, so the data can be georeferenced. The coordinate information for active construction sites are inconsistent in the method of recording, and therefore the locations of these sites as portrayed on a map document are only partially correct.

C. EPA – Environmental Protection Agency

The EPA provides access to spatial information from four different locations as shown below.

1. Environmental Dataset Gateway

The Environmental Dataset Gateway (EDG) is a web based service that is organized into a folder system. Users can browse the folders to find pertinent information, though the same information is available on EPA's "Clip N Ship" web map service. This service is similar to the National Map Viewer, though not as robust. It allows the user to select an area for analysis, and select data layers for download.

The EDG provides only limited data relevant to the City of Roanoke's stormwater management program, as much of the available information is a repetition of information on the DEQ's website. Three notable feature classes were obtained from the EDG that enumerate the details of the stormwater control measures found in the International Stormwater BMP Database [66]. Although none of these studies occurred in the Roanoke River Watershed, the information in this database is considered to be the most thorough repository for information regarding Stormwater Control Measures, and may therefore be relevant to City of Roanoke stormwater management.

2. Ecoregions

This feature class was developed by EPA's Western Ecology Division, and is a delineation of ecosystems based on characterization of geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology. It follows a hierarchical system, where a Level I Ecoregion is the most general, and Level IV the most specific. Level III Ecoregions associated with the Roanoke River Watershed are described here, though a complete description of all levels of Ecoregions can be found in Woods et al. [2].

The Roanoke River Watershed is located just outside the western boundary of the Virginia Piedmont, at the intersection of the Blue Ridge and Ridge and Valley Level III Ecoregions (Figure IV-1). The Blue Ridge Ecoregion constitutes the narrow strip of mountainous ridges that are forested and drained by steep, cold, heavily riffled mountain streams. The Roanoke River is a geologic, climatologic, and vegetative boundary for this Ecoregion. Soils and growing season change as the mountains proceed from southwest to northeast across the River, and vegetation transitions from a variety of Oak, Hickory and Pine Forest to predominantly Appalachian Oak Forest. The Ridge and Valley Level III Ecoregion lies to the northwest of the Blue Ridge Ecoregion, and to the southeast of the Allegheny and Cumberland plateaus. It shares many characteristics with the Blue Ridge Ecoregion, with the exception being that agricultural valleys are more prominent. The stream networks are

notably trellised in this Ecoregion, as mountain streams of high gradient plunge into flat agricultural valleys at nearly perpendicular angles (see Bradshaw Creek, Figure IV-1). Finally, the Piedmont represents the transition zone between the Appalachian Mountains to the west, and the flatter coastal plains to the east. The Piedmont is largely wooded, and consists of low rolling hills and shallow valleys, though the region was heavily cultivated during settlement in the 17th century, leading to heavy soil loss [67]. Streams are of moderate gradient in the area closest to the Roanoke River Watershed, mirroring the moderate relief in topography.

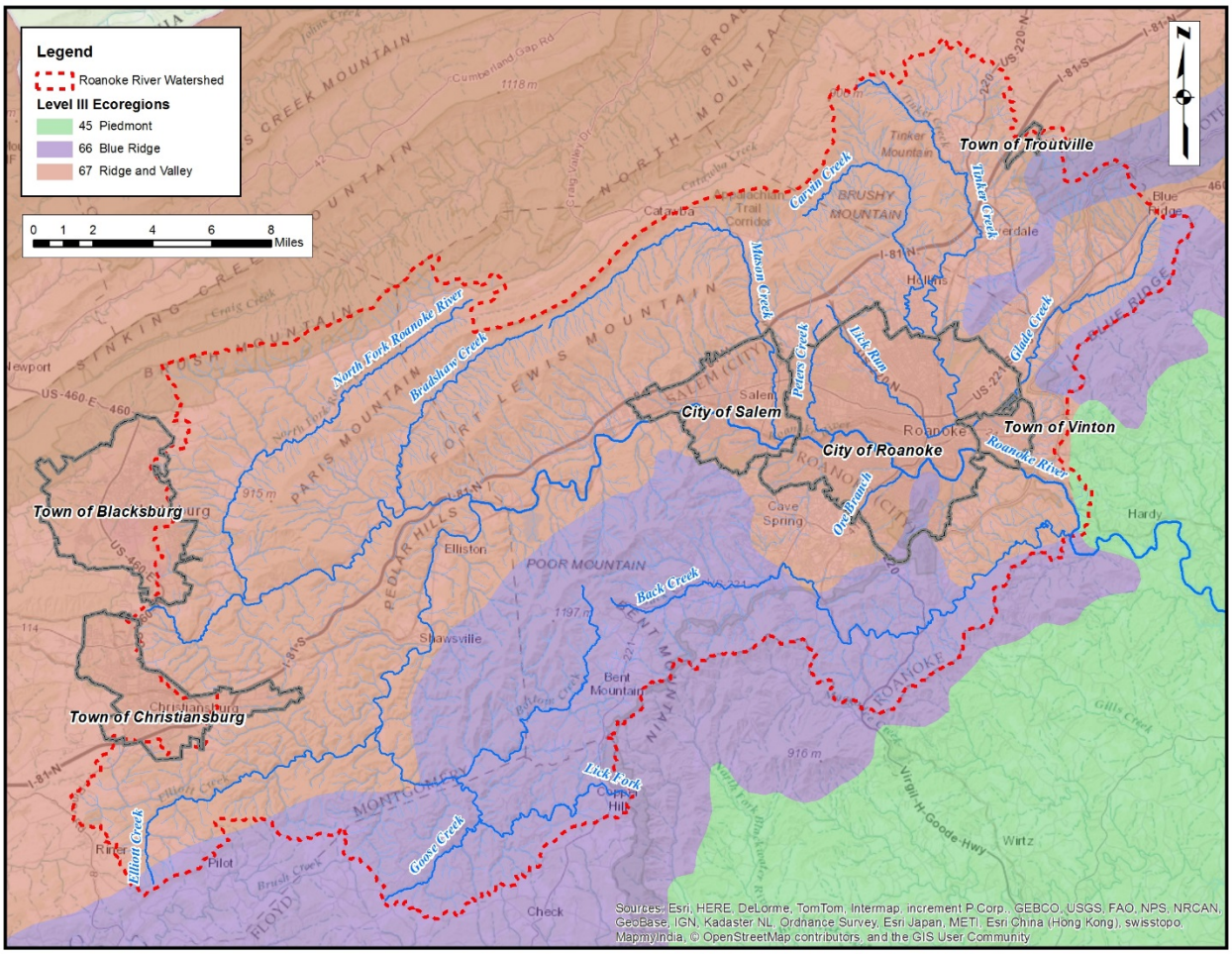

Figure IV-1 – Level III Ecoregions of the Roanoke River Watershed. Ecoregions from [2]**, Other GIS Data from U.S. Census Bureau** [6] **and the National Hydrography Dataset** [5]**.**

Ecoregions are important for water quality evaluation, as a stream's ability to support a healthy ecosystem is based on geophysical features described in the Ecoregion framework. This is especially true for the assessment of nutrient concentrations and benthic life in a stream (see page 2-8 in the Benthic TMDL [36], for example). It has been suggested that although the watershed is the unit of study, control measures should be implemented based on Ecoregion [68].

3. National Rivers and Streams Assessment

These data were published as a report completed in 2013 where approximately 2,000 river and stream sites across the country were sampled for biological, chemical and physical quality [69]. Streams are evaluated based on this array of indicators, and described as "least", "intermediate", or "most disturbed". None of the studied stream locations were in the Roanoke River watershed, though a location downstream of Leesville Lake on the Roanoke River was studied, and a site immediately outside the watershed boundary on Brush Creek near Huff, Virginia was studied as well. Both of these streams were determined to have intermediate disturbance.

4. STORET/WQX

The Storage and Retrieval System (STORET) and Water Quality Exchange (WQX) [70] are the EPA's current tools for integrating water quality, biological, and physical data from different sources across the nation. Information is retrieved through an extensive filtering process, and data is delivered to an e-mail address after the EPA server has processed the request. Though these data are not explicitly spatial, they are packaged with latitude and longitude information, and can therefore be easily georeferenced. Much of these data come from the National Rivers and Streams Assessment, though bacteria and sediment data from the Virginia DEQ is available as well. Data from this source are discussed in Section V.

D. FEMA – Federal Emergency Management Agency

The FEMA dataset includes information used to produce the Flood Insurance Rate Maps (FIRMs), including the elevation of the base flood (100 yr. flood), and the estimated limits of the base flood on the land surface. These elevations and flood boundaries are used to determine the cost of flood insurance premiums, and are generally based on hydrologic modeling.

E. IFLOWS – Integrated Flood Observing and Warning System

These data were provided by Mark Slauter at the Virginia Department of Environmental Management as an Excel table with GPS coordinates. The data includes spatial point locations for IFLOWS gauges throughout Virginia, and the table information includes Gage name, location, and calibration information. There are 30 IFLOWS gages within, or immediately outside the Roanoke River Watershed – 10 rain and stream gages, 19 standalone rain gages, and 1 standalone stream gage.

F. NCDC – National Climatic Data Center

The National Climatic Data Center Climate Data Online (NCDC CDO) provides historical climate information for 504 stations in Virginia. A weather gage has been continuously operated at the Roanoke Regional Airport since 1948 (with the exception of 1956), and the average annual precipitation at this station is 41.3 inches. There is also a station located on I-81 at the exit for Plantation Rd. (Hwy. 115), known as Roanoke 8 N; this station has been in operation since 1998. Precipitation data are discussed more extensively in Section V.

G. NED – National Elevation Dataset

The National Elevation Dataset (NED) [3] is a product of the USGS that is the digital continuation of the long-standing USGS quadrangle program. The elevation data is delivered in the form of a raster – an orthogonal grid that contains an elevation at each row and column location. These rasters come in various resolutions based on availability, though the highest resolution available for the Roanoke River watershed has a grid size of 1/3 arc-second (approximately 10 meters x 10 meters). The USGS also publishes 1/9 arc-second elevation data (approximately 3 meters x 3 meters), though this resolution is not available for the study area. Elevation information is based on the best available information, and is continuously being updated as new data is made available.

In a review of DEM sources on the outcomes of hydrologic modeling, Li and Wong [71] found that for a regional model, the use of Light Detection and Ranging (LiDAR) data is only marginally better than using the 10, or even 30 meter NED. However, in urbanized areas, and at smaller scales, a 10 meter NED will fail to represent abrupt discontinuities in the land surface, and may therefore be insufficient for modeling runoff for City subwatersheds.

H. NHD – National Hydrography Dataset

The National Hydrography Dataset (NHD) [5] is a product of the USGS that uses a vector system (i.e. polylines and points) to represent the network of streams and rivers in the U.S. It was originally developed as an integration of USGS digital line graph hydrography and EPA's Reach File version 3.0 in 2001. Although the Watershed Boundary Dataset (WBD) was originally a different product, they are now packaged together, and are included in the same feature dataset in the geodatabase.

When NHD information is retrieved, it arrives in a package that includes stream network topology – the direction and connectivity of the polylines and nodes that represent stream reaches and junctions in the network [72]. This information has provided the basis for hydrologic modeling under several frameworks, though the stream network should be used with caution, due to constantly changing stream morphology [73].

The WBD was created as a coordinated effort with the U.S. Department of Agriculture, and is based on best available NED information from each State. It is aggregated into a seamless product that divides the U.S. into watersheds, then further divides them five times into subwatersheds. Each watershed gets a two digit numeric identifier, and as watersheds are subdivided, the number of digits on the identifier increases. For example, the Upper Roanoke River Watershed shown in Figure 1 is number 03010101, meaning it is part of "03 – South Atlantic Gulf," and within this watershed, part of "0301 – Chowan/Roanoke," and so on. The NHD delineates watersheds to twelve digit resolution, though the NHDPlus increases this resolution.

I. NHDPLUSV2

The NHDPlus [74] datasets were created by Horizon Systems Corporation under contract to the EPA and USGS in 2004 (version 1) and 2012 (version 2). They are designed to be an extension of the original NHD and WBD, and watershed boundaries generally agree across products. The NHDPlus v2 integrates the best features of the original NHD, with the NED, and utilizes a technique called "hydro-enforcement" for hydrologic derivatives from digital elevation models. The v2 includes several value-added attributes, such as enhanced upstream-downstream topology, and estimates of mean annual flow and velocity. The v2 also includes an extended watershed boundary dataset that delineates subbasins to the NHD HU 12 basins. The USGS uses the v2 in several applications including the Spatially Referenced Regressions on Watershed Attributes (SPARROW), and the web-based StreamStats program.

J. RVARC – ROANOKE VALLEY/ALLEGHANY REGIONAL COMMISSION

These data were delivered by Shane Sawyer, and include a single polyline feature class of all trails located in the RVARC's purview. This includes line features with distances for the Carvins Cove trail system, the Havens Wildlife Management Area, the Greenway Trails, the Mill Mountain Trails, and others. The attribute tables describe the type, surface, and distance of each trail, and provide source data and hyperlinks to maps if available.

K. SSURGO – SOIL SURVEY GEOGRAPHIC DATABASE

The Soil Survey Geographic Database (SSURGO) [75] is a product of the US Department of Agriculture's Natural Resource Conservation Service. It includes a polygon shapefile that was created at 1:12,000 scale, and is useful for planning at this scale. Soils were described by field inspection and some laboratory sampling, and attributes of the soil in this dataset are: water capacity, soil reaction, electrical conductivity, etc. As it pertains to stormwater, soils are defined based on their infiltrative capacity in a simple A – D system, as described in Table IV-1; percentage of total City area is also shown in this table.

Table IV-1 – USDA's Hydrologic Soil Group Classifications from TR-55 [76] **with Percentage of City Area**

Hydrologic Soil Group	Soil Textures	Infiltration Rate (in/hr)	Description	Percentage of City Area*
A	Sand, loamy sand, or sandy loam	>0.30	Low runoff potential, high infiltration rates even when thoroughly wetted. Chiefly deep, well to excessively drained sand or gravel and have a high rate of water transmission.	<1%
B	Silt loam or loam	0.15 – 0.30	Moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. Moderate rate of water transmission	37%
C	Sandy clay loam	0.05 – 0.15	Low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. Low rate of water transmission	2.8%
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay	0 – 0.05	High runoff potential. Very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a high water table, soils with a claypan or clay layer near the surface, and shallow soils over nearly impervious material. Very low rate of water transmission	38%

*Note – This column does not total 100%, as 22% of the City's area was not included in the survey. This is because large areas of imperviousness are not included in the survey.

This classification helps generalize the ability of a soil to infiltrate water and inversely, the runoff potential of a soil. These classifications are used in the well-known TR-55 method from the USDA's Soil Conservation Service (now the Natural Resources Conservation Service, NRCS) [76] to develop a parameter called the Curve Number (CN). This method was developed for estimating runoff from agricultural land in the Midwest United States, but has since been modified for use in regions with different climate and hydrologic conditions [77]. Figure IV-2 shows that the City is primarily underlain by types B and D soils, with D soils constituting the US 220 and US 460 corridors.

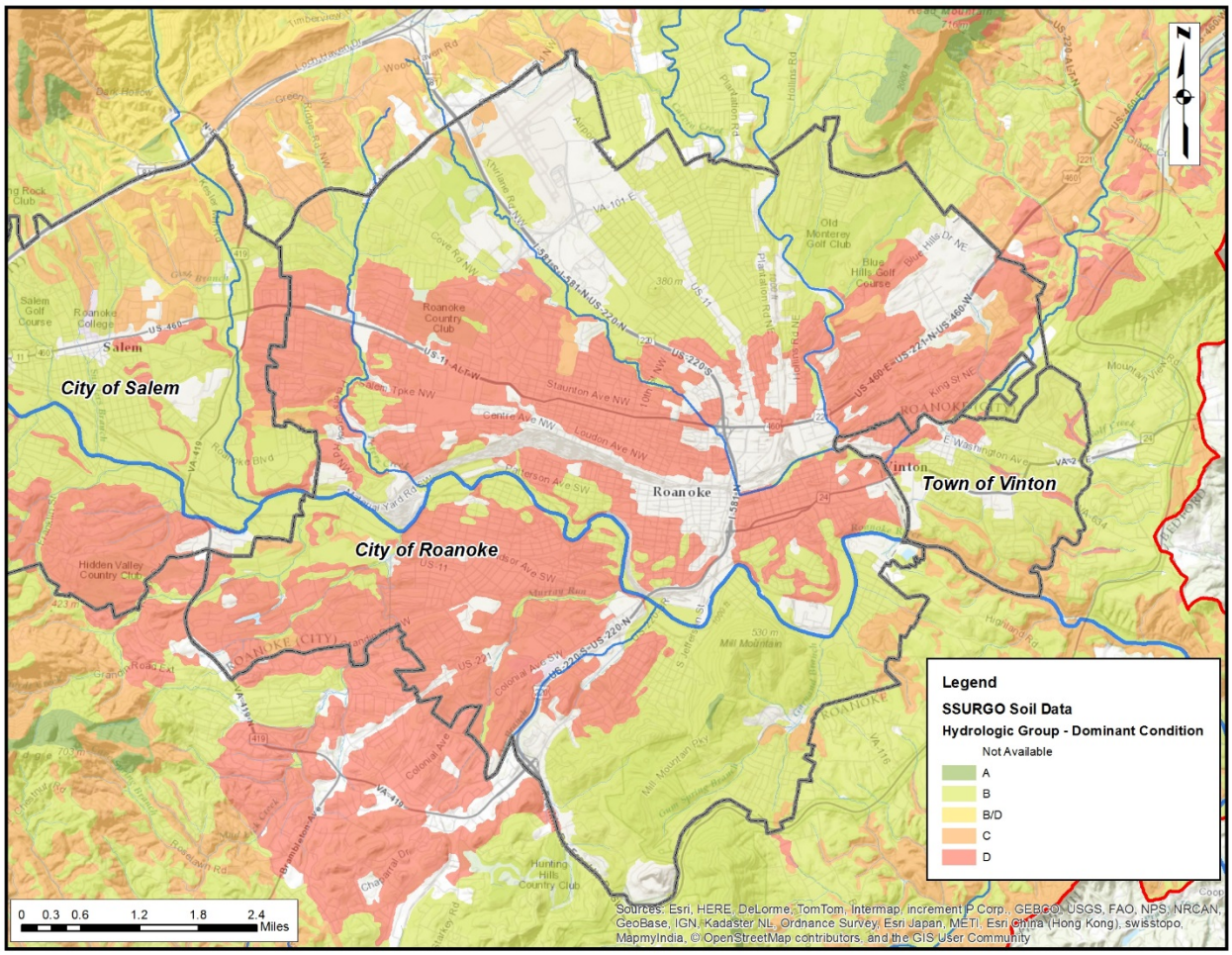

Figure IV-2 – SSURGO Soils in the City of Roanoke – SSURGO data from [75]

L. TIGER – Topologically Integrated Geographic Encoding and Referencing

The U.S. Census Bureau's (USCB's) system of relating census information to spatial locations is called the Topologically Integrated Geographic Encoding and Referencing (TIGER) [78] system. The country is organized into over 11 million units called census blocks – the smallest unit used by the USCB for 100 percent data. These blocks are aggregated into block groups, then census tracts, all of which are represented by feature classes in the TIGER system. Each of these features has a unique identifier, called a "GEOID" that can be used to join census tables of demographic information from the American FactFinder. As of the 2010 census, there are 3,603 blocks in the City of Roanoke, with population densities ranging from 0 – 85,564 people/sq. mi., excluding the blocks that contain the Roanoke Rescue Mission and the County Jail. The total population based on the sum of all block groups is 96,949.

M. USGS – US Geological Survey

The USGS are contributors to several of the other datasets in this section, including the National Hydrography Dataset, and National Elevation Dataset. The USGS also provides spatial location for each of its hydrologic and water quality measurement stations that can be georeferenced.

The drainage areas to many of the USGS stations were delineated by Hayes and Wiegand [79], so that hydrologic analysis for these gages can be performed.

N. NLCD – National Land Cover Dataset

This raster dataset retrieved from the Multi Resolution Land Characteristics Consortium (MLRC) [80] is a grid of 30 meter x 30 meter cells, each classified into one of sixteen land cover categories based on Landsat satellite data. These categories were modified by the USGS from Anderson's Level I and Level II classifications [81], and have been used for 2001, 2006, and 2011 to allow for comparison. Based on the most current dataset created in 2011 [4], the City is 86.5% developed, and the distribution of land cover is described in Table IV-2. Dense development is generally located in the central business district, along the US 460 and US 11 corridors, and in the north part of the city near the Roanoke Regional Airport.

Table IV-2 – Land Cover Percentage of Total City Jurisdictional Area based on National Land Cover Dataset (NLCD), 2011 [4]

NLCD Land Cover Type	% of Total City Area
Open Water	0.07
Developed, Open Space	18.44
Developed, Low Intensity	39.38
Developed, Medium Intensity	19.71
Developed, High Intensity	9.01
Barren Land	0.07
Deciduous Forest	7.91
Evergreen Forest	1.11
Mixed Forest	0.81
Shrub/Scrub	0.06
Herbaceuous	0.01
Hay/Pasture	3.40
Cultivated Crops	0.02

Although the NLCD is useful for regional or national projects, caution should be taken when using the NLCD for analysis at a scale of ten square miles or less [82]. As City drainage basins range from 0.001 – 12.0 mi^2, a finer resolution land cover dataset would be needed for hydrologic analysis at the City subbasin scale. This may be possible through a manipulation of the existing GIS data that the City has created in support of the stormwater utility.

O. VDGIF – Virginia Department of Game and Inland Fisheries

This polyline feature class shows all the cold-water stream segments in Virginia, and the classification given by the VDGIF designating each stream as wild (Class I-IV) or stockable (Class V and VI). These classifications give the streams special management considerations and protection.

V. Water Quality and Quantity Data

Data characterizing the hydrologic and water quality conditions in the Roanoke River watershed is available from four different sources. The USGS has eight current discharge measurement stations, and has monitored bed sediment at fifteen sites, and water quality at six sites in the watershed. The NCDC has six stations in, or immediately outside the watershed, though only five of them are active. IFLOWS is a partnership between the National Weather Service and the Virginia Department of Environmental Management, that provides continuous precipitation and discharge measurements at thirty additional sites in the watershed. Finally, the Virginia DEQ has 136 sites in the watershed where water quality has been characterized for various constituents and objectives. The location of these sites and stations are shown in Figure V-1.

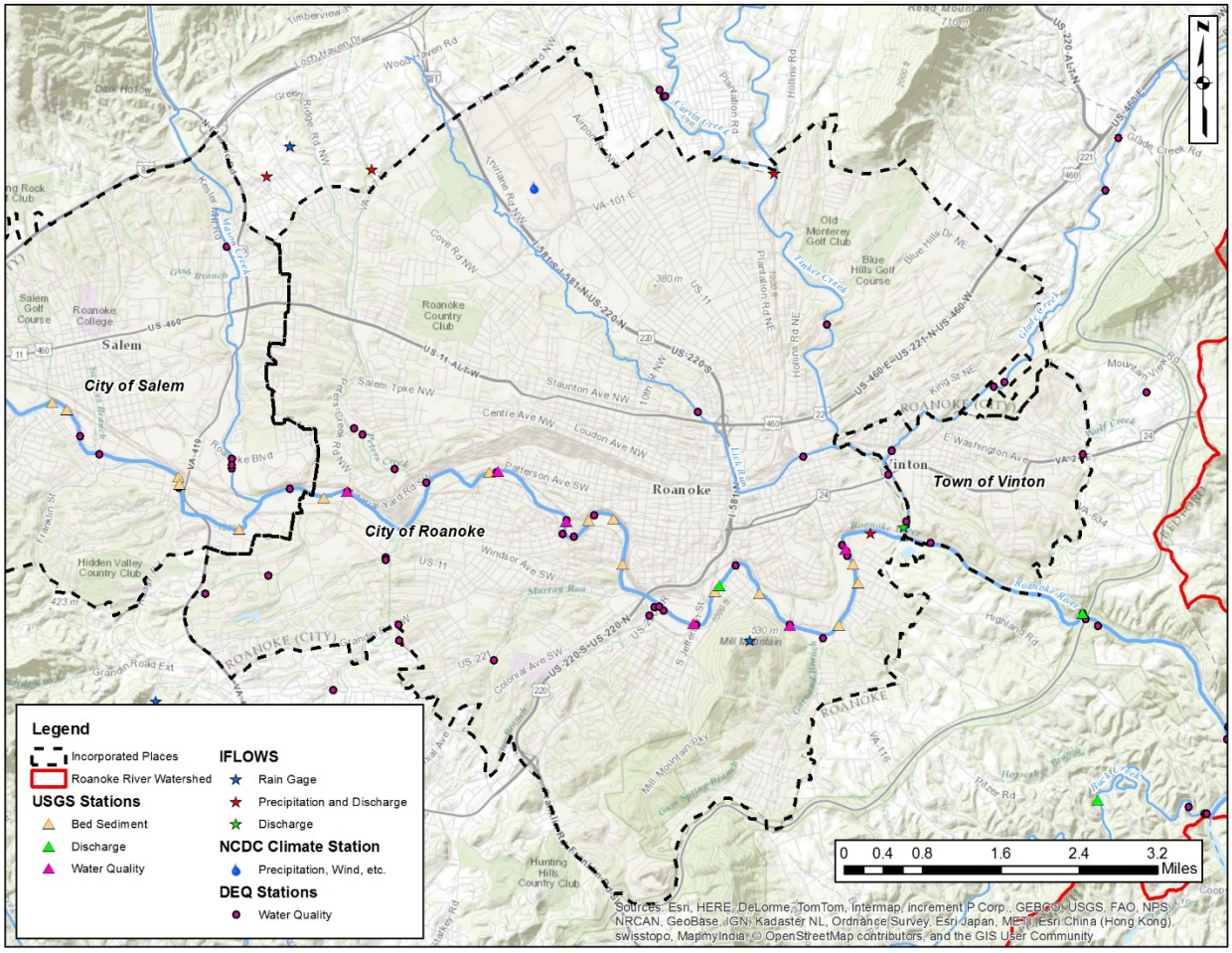

Figure V-1 – Hydrologic and Water Quality Measurement Stations and Sites in the City of Roanoke

A. United States Geological Survey

The USGS operates eight stream gages within the Roanoke River Watershed (Table V-1), one of which is located within the City (USGS 02055000 – Roanoke River at Roanoke, VA). These gages have been operating for different lengths of time, but use the same principle of a

relationship between depth and discharge at any given time [83]. A gaging station will monitor the depth of the stream continuously using a pressure transducer mounted in a stilling well, which is transmitted to a central USGS server, and there converted into a discharge measurement based on the established rating curve. These stations provide the basis for studying the long term hydrologic response to changes in a watershed.

Table V-1 – USGS Discharge Monitoring Stations in the Roanoke River Watershed and their Respective Periods of Record

Gage Number and Name (From Upstream to Downstream)	Period of Record
02053800 - Roanoke River near Shawsville, VA	1960 - 2014
02054500 - Roanoke River at Lafayette, VA	1943 - 2014
02054510 - Roanoke River near Wabun, VA	1994 - 1999
02054530 - Roanoke River at Glenvar, VA	1991 - Present
02055000 - Roanoke River at Roanoke, VA	1899 - Present
02056000 - Roanoke River at Niagara, VA	2007 - Present
02055100 - Tinker Creek near Daleville, VA	1956 - 2005
02056650 - Back Creek near Dundee, VA	1974 - 2014

In addition, two water quality measurement stations were installed on the Roanoke River near the City's upstream (Route 117) and downstream (13th St. Bridge) jurisdictional boundaries during the period of record 4/14/2005 – 4/15/2012. These gages were developed to monitor the effects of the Roanoke River Flood Reduction Project [84]. The gages collected water temperature (°C), specific conductance (µS/cm), pH, and turbidity (FNU). These stations also have grab samples collected across the period of record. The methods for this data collection are recorded in [85]. The grab sampling included both turbidity and suspended sediment concentration, allowing for the estimation of suspended sediment concentration at each station based on turbidity. Regression models were built for suspended sediment concentration at each station [86] and applied to the daily reported turbidity data (Figure V-2). This work provides the basis for developing a sediment pollutograph and mass loadings, though this work has not yet been performed or published.

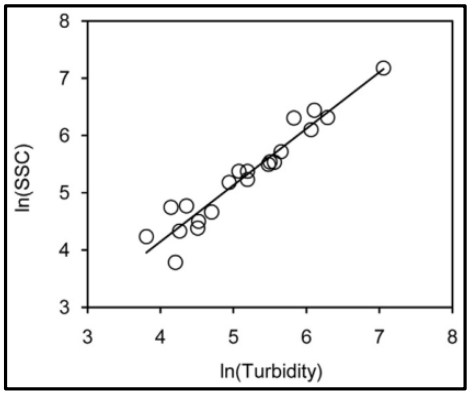

Figure V-2 – Data from Jastram et. al [86] **showing the log-linear relationship between the concentration of suspended sediment and turbidity, measured by a water quality sonde in the Roanoke River at the Peters Creek Rd. bridge. This work could be used to develop long-term sediment balances on the River**

A tabular summary of all USGS stations, their periods of record, and the parameters they measure can be found in Appendix V.

B. National Climatic Data Center

The National Climatic Data Center (NCDC) is a division of the National Oceanic and Atmospheric Administration (NOAA) located in Asheville, North Carolina, and is the keeper of climate data that has been collected in the past century. Various types of information is available from the NCDC relevant to hydrology, including precipitation, evaporation, temperature, and wind data at weather stations. Radar technology has also allowed the collection and archiving of spatially distributed radar rasters for the same parameters. This data can be accessed through the Climate Data Online interface [87], where data can be downloaded based on a desired geography or variable.

There are six active weather stations in, or immediately outside the Roanoke River Watershed, with the most relevant station for the City of Roanoke located at the Roanoke Regional Airport. Average annual precipitation at this station from 1981 – 2010 is 44.5 inches. Total Annual Precipitation and Mean Monthly Precipitation at this station are plotted in Figure V-3.

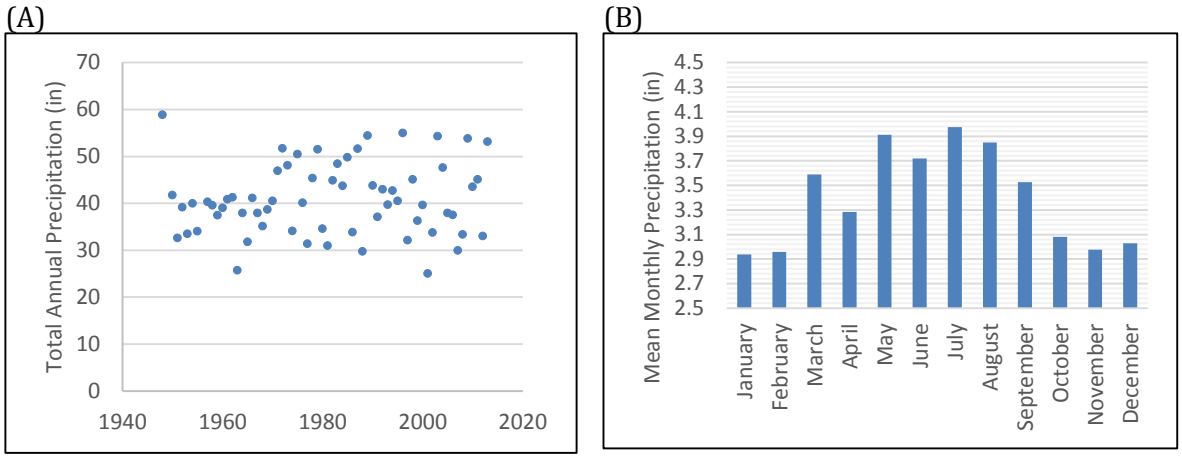

Figure V-3 – (A) Total Annual Precipitation and (B) Mean Monthly Precipitation at COOP:447285 – Roanoke Regional Airport – Data from Climate Data Online [87]

C. IFLOWS

The IFLOWS program [88] had its early beginnings after heavy floods along the borders of Kentucky, West Virginia, and Virginia led to loss of life and property damage. The National Weather Service (NWS) collaborated with the participating states to develop the concept of a flood warning system, which has now taken shape as the Integrated Flood Observing and Warning System (IFLOWS). The program began in a twelve county pilot area in 1980, but has since expanded to approximately 1,500 sensors in twelve Mid-Atlantic and New England states.

In Virginia, the IFLOWS system is a partnership between the NWS, and the Virginia Department of Emergency Management (VDEM), where the NWS provides program management at the

national level, and VDEM coordinates with local agencies for the procurement of necessary land for the field equipment. In some cases, private organizations have agreed to assist in the operation and maintenance of gages.

IFLOWS uses rain gages and stream gages to monitor hydrologic conditions. A tipping bucket rain gage is used to measure rainfall to 0.01", and the gage is installed in a ten foot tall by one foot diameter pipe. Stream discharge is estimated by developing a depth-discharge relationship at a location, and measuring depth continuously using a pressure transducer mounted in the stream, stilling basin, or reservoir. Rainfall and discharge measurements are sent to a telemetry unit, where data is transmitted by VHF radio to a receiving computer system, where a time stamp is added to the data. The system is extensible, such that additional sensors (such as a water quality sonde) could be added to a remote transmitter, given that the technology uses a 1,200 baud Serial/Digital interface (SDI-12), and that additional power was added through solar panels or otherwise.

MapTech, Inc. in Blacksburg, Virginia is the contractor for the maintenance of IFLOWS software and hardware, though the VDEM is responsible for cleaning stream and rain gages.

D. Virginia DEQ

The Virginia DEQ has collected various types of water quality data for streams and lakes, since June, 1941. Water monitoring is organized into programs, which are codified in the DEQ's datasets. Sampling locations are referred to as "stations" by the DEQ, and a single station can be part of several different programs. Sampling for all of these programs was described as biased towards base-flow conditions[16], and therefore the results are not descriptive of the large impulse effects of rainstorm events. The DEQ water quality monitoring programs relevant to the City of Roanoke are described below.

1. Ambient (A or AW)

The Ambient program is designed to provide spatial coverage of the entire State. The DEQ covers each HUC 12 watershed in the state based on a six year sliding reporting window. One third of the sites are sampled once every two months over a time period of two years, before moving to another third of the sites for years three and four, and the final third in years five and six. The objective of this program is to sample a site twelve times, and a station is designated as impaired on the 303(d) list if 2/12 samples collected are below the Commonwealth's water quality standard for a constituent. Parameters measured are pH, dissolved oxygen (DO), temperature, and some chemical measures. There are 26 ambient stations in the Roanoke River Watershed.

2. Trend (TR)

Trend stations are sites sampled at regular time intervals (monthly or bi-monthly) for an extended period of time. The purpose of these sites is to demonstrate changes in water quality longitudinally, as some sites have been regularly sampled since August, 1967. Water

[16] This from Larry Willis, Water Monitoring Coordinator, Virginia DEQ.

quality samples are flow corrected, and tested for trends using a statistical method called the seasonal Kendall-tau procedure [89]. Parameters collected are Fecal Coliform (FC), E. Coli, Nitrogen, Phosphorus, Total Suspended Solids (TSS), Total Solids (TS), Turbidity, DO, pH, and temperature. There are five trend stations in the Roanoke River watershed:

- The North Fork of the Roanoke near the confluence of Wilson Creek. The station is located near the Den Hill Rd. Bridge crossing of the river, southeast of Blacksburg.
- Immediately downstream of the confluence of the North and South Forks in Lafayette. The station is adjacent to the USGS Stream Gage (USGS 02054500).
- On the Roanoke River at the 13th Street Bridge in the City of Roanoke.
- On Tinker Creek at the Dale Avenue Bridge, downstream of the Glade Creek confluence, on the border of the City of Roanoke and Town of Vinton.
- On the Roanoke River at the Blue Ridge Parkway Bridge in Niagara. This station is downstream of the confluence with Back Creek, and located adjacent to the USGS Stream Gage (USGS 02056000)

3. Biological (B or RB)

Biological stations are selected by DEQ employees based on professional judgment. A station constitutes a 2 m^2 sample area in a location thought to have the best available ecosystem, such as a riffle. All benthic life is removed from the stream substrate, and counted and classified in a lab. This is performed one time each in the spring and fall. If one of the two samples falls below a Virginia Stream Condition Index (SCI) score of 60/100, the stream can be considered impaired, though a biologist is allowed to use his or her judgment and resample if necessary. If both samples fall below a score of 60, the stream is required to be listed as impaired. There are twenty biological monitoring stations in the Roanoke River Watershed, seven of which have been designated as impaired stations.

4. Freshwater Probabilistic (FP or FPM)

The Freshwater Probabilistic program samples random points on the stream network, and these points are different every year. This is designed to be an unbiased assessment of statewide streams, as opposed to the ambient program which is biased towards higher order streams at points of hydrologic significance. Although it is not possible to study a stream location longitudinally in this way, a survey of the state by watershed or ecoregion is possible using these data. This provides a background which can be used to compare data collected from other programs to the watershed in which the station resides. Parameters sampled are nutrients, TSS, TS, anions/cations, benthic community, fish count, algae characterization, and a quantitative physical habitat assessment. There were ten probabilistic sites in the Roanoke River Watershed in the sampling period from January 1, 2005 to December 31, 2010.

5. TMDL Development (TM) and Implementation (IM)

These data are collected as special study data required to develop a model for a TMDL, or observe the effects of a watershed implementation plan. They are supplemental to other datasets, and can be used to determine how far up and downstream a water body is

impaired, and for model calibration and validation. Implementation data is taken after action has begun in a watershed towards a TMDL endpoint. Currently, these two types of data are not separated in the DEQ's databases, but going forward they will be. There are sixteen TMDL stations in the Roanoke River Watershed, one of which is the trend station at the confluence of the North and South Fork of the Roanoke River.

VI. Review of Outreach and Education Materials

The objective of this task was for VT to become familiar with the City's current strategy for outreach and education pertaining to the employees and the citizens of the City of Roanoke, as well as to determine the extent of outreach and education performed by outside organizations not affiliated with the City. The first section of this scope task summarizes information about the City's education and outreach programs from personal communications and MCMs 1 and 2 of the City's MS4 Annual Report [31]. The second section describes outside organizations which interact with the City and provide additional resources for education and outreach.

A. City of Roanoke Outreach and Education

As an entity regulated by the MS4 program, the City is required to perform education and outreach efforts as specified in MCMs 1 and 2 of the MS4 permit. In MCM 1, the City identified the top three water quality issues affecting their MS4 region as sediment, bacteria, and nutrients. The City was then able to use these priorities to identify high risk polluters and businesses for targeted awareness mailings. These mailings, among other media awareness activities, are coordinated through the Clean Valley Council (CVC), which contracts with the City to provide education and outreach support for the MS4 permit. City representatives also attend local conferences and public events related to stormwater and water quality, and the City uses social media and a resource library to collect information on stormwater and make it available to the public. This library also contains information mailed to citizens about the City's new stormwater utility (SWU) describing the fee and procedures to implement source control BMPs for credit towards the fee.

In MCM 2 of the MS4 permit the City lays out strategies for public participation and involvement. This includes multiple different volunteer, service-based, and educational events organized by the CVC and geared towards adults and children within the City. The City runs a Drug Take Back Day for expired and unused medications, performs storm drain marking, and participates in regional household hazardous waste collection programs. In addition, the City actively participates in regional meetings with stakeholders, legislators, and neighboring jurisdictions concerning the development of stormwater regulations, technology, and educational programs.

In addition to these programs for public education and involvement, the City also provides stormwater training and education for its employees. In the past, the City has produced pre-recorded presentations to provide employees with general awareness about stormwater at home and in the workplace, including such topics as types of stormwater infrastructure, locally applicable regulations on runoff, and basic knowledge about watersheds. The City wants to expand on this and has begun a contract with Excal Visual to pilot more rigorous training presentations that can be utilized by employees whose work is directly related to stormwater. Roanoke County already makes use of Excal's training products, and the City plans to selectively

utilize similar modules from Excal and tailor them to meet their MS4 training needs. These modules would cover more job-specific topics such as recognition and reporting of illicit discharges, or road, street, and parking lot maintenance.

The City has also been exploring opportunities to expand on its Erosion and Sediment Control (ESC) education. While designated City ESC inspectors already receive state approved training, the City wants to educate additional employees, such as building inspectors and storm sewer maintenance personnel, to provide them with information to help them be proactive towards ESC. Discussions with City personnel revealed that many small scale sources of sediment in the City are unregulated and when aggregated, contribute a significant sediment load to stormwater. Public employees with basic training could potentially recognize these sources and prevent their occurrence or at least reduce their impact on runoff. The City is willing to explore coordinating a "Public Works Day" with other local municipalities to introduce personnel to various types of ESC and stormwater control measures, proper installation procedures, and problems to look out for while working in the field.

Citizen reporting and improving the efficiency of field inspections are two other important aspects to the City's plan for improved public involvement and IDDE practices. The City has several technological platforms in place for reporting and investigation of stormwater issues, while others are still in the development phase. The first is the Q-Alert program, which started out as a complaint hotline for citizens to phone in problems in their neighborhood. Now the program includes an online reporting system and an application called iRoanoke, developed for use with Apple and Android products. The new reporting system makes it easier for citizens to report illegal dumping, spills, or maintenance issues from anywhere with a data or internet connection. The report submitted to the City automatically generates a work order, forwards it to the appropriate department, and places it on an employee task list. This new method of citizen reporting speeds up response time and ensures that the City remains accountable to citizen concerns.

Another program furthering the City's IDDE efforts is the Permits Plus program. This program, while still in development, is intended for internal use by City employees and inspectors. This program tracks data about permit citations and complaints, and links this information with an owner tax ID. This data can be readily integrated with the City's GISRE online database to provide inspectors in the field with more valuable information when they investigate citations and complaints. Another internal program called Trimble Terraflex is used primarily by the Office of Environmental Management for generating outfall reports. This program has an online interface and a smartphone application. Forms containing various types of questions are created online and later filled out in the field via smartphone. Data from the form and GPS location data from the smartphone are uploaded to the cloud, processed in the office, and exported in one of multiple available file types. The City's goal is to eventually link this information with a GIS outfall feature layer so that reports can be accessed within GIS software.

B. Regional Organizations Performing Education and Outreach

Information from the City about their education and outreach programs from personal communications and MCMs 1 and 2 of the City's MS4 Annual Report [31] was combined with information from other programs run by affiliated organizations to provide a full overview of the opportunities and resources available to citizens of the City. A list of organizations involved with stormwater and water quality issues in the Roanoke region (Table VI-1) was developed in order to guide the VT researchers in their efforts to contact coordinators and discuss programs. Brief descriptions of these organizations and their programs follow, while more detailed minutes can be found in Appendix VI.

Table VI-1 – Organizations Participating in Outreach and Educational Programs in the City of Roanoke

Organization	Contact
Clean Valley Council	Cristina Siegel, Executive Director
Western Virginia Water Authority	Sarah Baumgardner, Environmental Communications Coordinator
Roanoke Valley Alleghany Regional Commission	Shane Sawyer, Regional Planner
Roanoke Valley Greenways Commission	Liz Belcher, Greenway Coordinator
Upper Roanoke River Roundtable	Megan Scott, Board Member
Virginia Save Our Streams	Wes Jargowsky

1. Clean Valley Council

The Clean Valley Council (CVC) is a non-profit organization providing public education and outreach services to the cities of Salem and Roanoke, the counties of Botetourt and Roanoke, and the Town of Vinton. They offer educational programming and coordinate volunteer and service events focused on topics including litter, stormwater, and natural resource protection. Some examples include the Recycled Regatta and Watershed Festival held in the spring, and participation in conferences and events such as the Green Energy Expo. Their programs help to bring continuity to public outreach efforts by facilitating coordination among school systems, citizens, and municipalities in the region. Part of this coordination involves working with other interest groups in the community including the Upper Roanoke River Roundtable and Virginia Save Our Streams.

With respect to the City of Roanoke, the CVC maintains individual contracts with the City, Roanoke County, and the town of Vinton to organize education and outreach efforts pertaining to fulfilment of the requirements set forth in the MS4s for these municipalities. There are five (5) general types of services that the CVC coordinates for the City of Roanoke, which are described in more detail in the annual contract [90]. First, the CVC produces educational material and programs directed at both child and adult audiences. Child programs typically consist of in-class lessons and field trip activities, all of which are aligned with the Virginia Standards of Learning (SOLs) for the respective grade level at which the program is offered. Adult programs often consist of media-based publications which reach that audience more readily. Second, the CVC hosts youth and adult storm drain marking programs to discourage dumping. A third targeted CVC program focuses on reducing

stormwater pollution from high-risk business establishments such as car washes or dry cleaners. The CVC develops and mails out publications to these businesses informing them of the possible risks and providing helpful tips on how to reduce their impact on stormwater. The CVC also holds two public service events each year, namely the Fall Waterways Cleanup and Clean Valley Day in the spring, which get the public involved in efforts to reduce littering in and around public green space and water ways. The final service the CVC provides, is the conducting of meetings of a local Citizen Stormwater Advisory Committee. Although this committee is inactive at present, it has previously served as an effective workgroup for public commentary on stormwater ordinances, activities, and issues. The City has expressed interest in reviving this committee to facilitate citizen input in stormwater planning and improvement projects.

Besides the contract activities that the CVC performs for the City, the two entities submitted a grant proposal in October 2014 for funding to start a Citizen Science Water Quality Monitoring Program. If funded, the program will focus on providing training and equipment for volunteers to perform preliminary bacteria and limited benthic sampling in an effort to identify key stretches of stream with poor water quality which can be further assessed.

2. Western Virginia Water Authority

The Western Virginia Water Authority (WVWA) provides water and wastewater services to customers in the City of Roanoke, and Roanoke and Franklin Counties. Although the WVWA does not directly deal with stormwater in these jurisdictions, their office does occasionally receive phone calls from citizens regarding stormwater concerns. WVWA directs these concerns to the Stormwater Division at the City or the most relevant group to handle the issue.

As part of its mission to promote awareness of water resource protection and preservation, the WVWA offers K-12 educational programs and field trips to Carvins Cove, as well as tours of its treatment facilities to college classes and community groups. These programs, run free of charge and open to all WVWA customers, reach about 12,000 students every year. The educational programs are aligned with the Virginia standards of learning, and they teach school children about the properties of water, supply and conservation, and watersheds. Although the WVWA coordinates with the CVC and other community organizations to conduct field trips, programs run by the WVWA are separate and unaffiliated with programs run by CVC under its contract with the City. The underlying goals of the WVWA's educational and outreach programs are to expose school children to the surrounding natural environment and teach them the differences between water services or "piped water" and stormwater.

In addition to educational programs, the WVWA reaches out to community groups such as the boy scouts and the Upper Roanoke River Roundtable (URRR) to perform projects on their grounds. The WVWA maintains a stormwater permit for its treatment facilities and therefore is required to install BMP measures on site to improve runoff quality and

quantity. Where possible, the WVWA has worked with these organizations in the past to carry out these stormwater improvement projects.

3. Roanoke Valley Alleghany Regional Commission

The Roanoke Valley Alleghany Regional Commission (RVARC) is a regional planning commission that works with governments and organizations on local, county, and state levels to coordinate economic, transportation, and environmental development in the Roanoke Valley. They also serve as a central forum for information sharing between these groups. One of the ways that RVARC facilitates the distribution of information and knowledge in the stormwater field is by hosting the Regional Stormwater Advisory Committee. This group of stakeholders, consists of governments (including the City of Roanoke), regulators, academic institutions, business owners, and citizens from the community. The committee has no voting powers or decision-making abilities, but instead provides a semi-annual forum for Q&A with regulators about stormwater policies, and a platform to discuss and debate local stormwater issues and regulations. The committee is broken into two branches known as the Technical and Management Committees. The technical committee consists of stormwater program managers, inspectors, engineers, and other stakeholders working on the ground and dealing directly with stormwater issues. The Management Committee is primarily elected officials, regulators, and administrative personnel responsible for stormwater policies.

RVARC does not provide any educational programs, but instead focuses its efforts on outreach. They serve as a resource for grant opportunities, passing information about available grants to municipalities and other eligible groups. RVARC occasionally writes its own grants for regional projects, including grants used to fund TMDL studies and IP programs such as the ongoing Roanoke River TMDL IP project. RVARC does not take a decision-making role in these types of projects, but commission employees participate in the IP process in order to become familiar with the regulations and policies surrounding stormwater and communicate these more effectively to other governing bodies and citizens.

RVARC also coordinates with the Roanoke Valley Greenways Commission regarding the formation and GIS documentation of greenways and blueways in the Roanoke Valley. They currently host the Roanoke River Blueways website which, when fully developed, will become its own entity providing information about recreational opportunities on the Roanoke River and its tributaries. The goal of the blueways is to provide the public with a stronger connection to their local waterways and encourage increased individual stewardship and a proactive mentality towards stormwater pollution.

4. Roanoke Valley Greenways Commission

The Roanoke Valley Greenways Commission was established in 1997 to promote communication between local governments (City of Salem, City of Roanoke, Town of Vinton, and Roanoke County) and to oversee the development of greenways in the Roanoke Valley. Currently the planning, design, and construction work is largely handled by the municipality in which the greenway is located, while the Greenways Commission is more involved in the

site selection and planning process. They provide input towards planning, design, and operational decisions, as well as funding and volunteers to help carry out greenway projects.

The Pathfinders for Greenways organization was established in parallel with the Greenways Commission in 1997, and serves as a citizen volunteer group for greenway education, maintenance, and fundraising. Although most greenways are paved or cinder trails, the Pathfinders coordinate with the Greenways Commission and the local Parks Departments to perform maintenance and construction work primarily on natural surface trails in the region. They also provide volunteers for stream restoration and riparian buffer grant projects coordinated through the Greenways Commission. In addition to the Pathfinders, the Greenways Commission coordinates with other groups such as Clean Valley Council to participate in community action events including the Fall Waterways Clean-up and Clean Valley Day.

5. Upper Roanoke River Roundtable

The Upper Roanoke River Roundtable (URRR) is a citizen volunteer organization concerned with environmental awareness and watershed protection. The primary focus of URRR is developing watershed protection or improvement projects, and seeking grants, donations, and volunteers to help carry out these projects. Projects, which can vary from pet waste stations to stream restorations and riparian buffers, are implemented along the Roanoke River and its tributaries, and they involve coordination with local and county governments including the City of Roanoke. Projects are advertised to the general member body and the public in order to promote awareness and participation. In addition to these volunteer projects, URRR co-hosts a watershed conference with Clean Valley Council and several other groups, located at Ferrum College in Ferrum, VA.

6. Virginia Save Our Streams

The Virginia chapter of Save Our Streams (SOS) was created as an interest group concerned with protecting the state's natural stream habitats for recreation and wildlife. They have coordinated volunteer benthic monitor training and data collection for streams throughout Virginia. Data collected by SOS volunteers is submitted to the DEQ and used as a preliminary indicator for stream reaches which may be impaired and need further study. DEQ is required by recent Virginia legislation to utilize water quality sampling data collected by volunteer and citizen science programs. In this way data contributed by groups like SOS help not only to reduce the workload on the DEQ's monitoring staff, but also to satisfy legislative requirements regarding water quality data and citizen involvement. However, in recent years Virginia SOS has experienced a significant reduction in volunteer monitors due to reduced recruiting abilities. In the Roanoke region, Carvin Creek is one of the few remaining tributaries monitored by SOS, although further downstream, more data are collected near Smith Mountain Lake and Ferrum College, both outside of the study area for benthic and bacteria TMDLs on the Roanoke River.

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