Prioritizing Stream Restoration Projects in the City of Roanoke: Peters Creek Case Study

Task 1: Literature Review
Task 2: Case Study Selection
Task 3: Data Review, Data Collection, and Results
Task 4: Biological Study Results
Task 5: Prioritization Process and Tools
Task 6: Funding

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VIRGINIA TECH

Executive Summary

The City of Roanoke (City) is currently evaluating potential stream restoration projects to achieve several watershed goals, including meeting total maximum daily load (TMDL) requirements, mitigating floods, recovering ecological function, and transforming the Roanoke River into a community asset. The City retained Virginia Tech (VT) researchers to develop a stream reach prioritization methodology to help maximize watershed benefits for funds spent on stream restoration. The overall project goal was to develop a prioritization process for stream restoration projects and to apply this process to one watershed as a case study (Peters Creek). Using the results of this case study, the methodology will be further adapted to apply to all City watersheds.

The stream assessment approach developed is based on indicator parameters for stream functions and biological stressors. A prioritization framework was developed based on City goals, current literature, and best practices in stream restoration. Peters Creek was selected as the case study for testing this assessment approach and prioritization framework. Peters Creek has relatively undeveloped headwaters and borderline aquatic life scores, thus it may offer the strongest potential for recovery of stream functions. Additionally, considerable data is available for this watershed, so stream functions may be more easily assessed here than in watersheds with less data available.

Using the indicator parameters identified, assessment data was developed through both desktop and field surveys of stream reaches. The desktop survey was conducted using GIS data and organized within the City stream GIS layers. City personnel developed watershed area, land cover, and land use metrics; Virginia Tech personnel developed reach length, floodplain width, and socioeconomic metrics. The field survey was conducted by Virginia Tech personnel from late February through early April of 2021. Field parameters included indicators for stream hydraulics, geomorphology, water quality, and hazards.

Key findings from the stream assessment include:

- **Impervious cover, a key metric, varies significantly by reach.** Although the average impervious cover for the entire Peters Creek watershed is 24%, when analyzed by reach, impervious cover ranges from 9% to over 40%.
- **Impaired hydraulics and geomorphology are present in multiple reaches**. Incised and eroding channels are present throughout the watershed; floodplain access is likewise impaired in many reaches.
- **Water quality is generally acceptable.** Water quality results were similar to previous studies, and water quality is not expected to prevent ecological restoration in reaches where projects may be appropriate.
- **Biological index scores for Peters Creek were borderline to low.** Relatively few mayflies were present in Peters Creek during the study period; seasonal variation in specific conductance (salinity) may be a cause.

Using this data, a three-step prioritization was applied: 1) reach condition assessment; 2) reach screening; and 3) project ranking. The initial stream condition ranking was a quantitative assessment, scoring and comparison of the stream conditions for each reach. A qualitative Best Professional Judgement assessment confirmed the reach condition assessment. The reaches were next screened based on the technical assessment of each function for each reach. This technical screening produced a short list of potential projects that were ranked according to technical and socioeconomic factors (which often indicate project feasibility). The seven projects identified, in ranked order, include: PC10, PC05, PC12, PC09, PC04, PC03, and PC08. A grant application has already been submitted to

implement a project along PC10. PC05 may be a candidate for the Virginia Stormwater Local Assistance Funding program.

Recommendations for future research on Peters Creek include comparison of a new rapid fine sediment assessment technique to traditional, labor-intensive measurements, development of additional biological data, evaluation of the Roanoke County reaches of Peters Creek, development of recommendations for retaining large woody debris, and evaluation of potential PCB remediation concurrent with restoration projects.

Contents

Prioritizing Stream Restoration Projects in the City of Roanoke

1. INTRODUCTION

The City of Roanoke (City) is currently evaluating potential stream restoration projects to achieve several watershed goals, including meeting total maximum daily load (TMDL) requirements, mitigating floods, meeting water quality standards, recovering ecological function, and transforming the Roanoke River into a community asset. The City has retained Virginia Tech (VT) researchers to help maximize watershed benefits for funds spent on stream restoration. The overall project goal is to develop a prioritization process for stream restoration projects within the City and to apply this process to one watershed as a case study (Peters Creek). Using the results of this case study, the methodology will be further adapted to apply to all City watersheds.

2. LITERATURE REVIEW

This literature review provides an overview of best practices for prioritizing stream restoration projects. Using this review, the City can build on lessons learned from the growing body of completed stream restoration projects worldwide, while developing a prioritization process unique to its environmental, social, and policy concerns. Based on this review and other data, the City has selected an initial stream as a case study for further review, gathered stream data (including biological sampling), and assessed stream restoration options for other watersheds.

This review focuses on three questions:

- How does the City establish priorities and specific objectives for stream restoration projects?
- Based on these priorities and objectives, what data are required for making prioritization decisions about restoration projects, and how can data collection be streamlined?
- How do stream restoration efforts support ecological function recovery, to address applicable aquatic life TMDLs?

This review also provides resources for staff members who may not be familiar with stream restoration principles and practices; each section includes a list of additional readings for further background on the topic. Note that the term "stream restoration" includes a variety of practices. The term is used broadly here to encompass practices such as channel stabilization, bank erosion control, revegetation, and habitat enhancement.

2.1 Stream Restoration: Lessons Learned

Since the 1990s, the number of stream restoration projects in the United States has increased exponentially (Bernhardt et al. 2005). As a result of the demand for these projects, the restoration industry has grown so quickly that accepted field practices have sometimes outpaced scientific research to support them (Shields et al. 2003). Additionally, a frequently noted problem with restoration projects is the lack of post-completion assessment, long-term monitoring, and data sharing for completed restoration projects to assess whether accepted practices result in sustainable stream functioning (Violin et al. 2011; Bash and Ryan 2002; Hession and Brown 2016). The science is now catching up and offers new opportunities to improve these practices (M. Palmer, Koch, and Benjamin 2014). Although stream restoration is a relatively new practice and science, several indicators for failure and principles for success have emerged, which can benefit future stream assessments, projects, and priorities.

2.2 Common Problems in Stream Restoration Projects

While restoration work has undoubtedly improved conditions in many streams, recent research indicates several persistent problems with conventional stream restoration practice. Two important themes have emerged in recent stream restoration literature: the need for a stream process- or function-based approach to restoration (M. Palmer, Menninger, and Bernhardt 2010; Doll et al. 2016b) and the recognition that recovery of hydraulic function, channel stability, or even habitat heterogeneity does not necessarily mean recovery of ecosystem function (Stranko, Hilderbrand, and Palmer 2012; M. Palmer, Koch, and Benjamin 2014; Kroll et al. 2019). Traditionally, stream restoration work has prioritized channel stability over other fluvial considerations. Even when channel form or channel stability is recovered, however, other watershed processes can undermine the restoration work over time. In some instances, pre-disturbance functions may not be attainable at all (M. Palmer, Koch, and Benjamin 2014; Fischenich 2006).

Additionally, the following are commonly noted problems:

- Lack of clear goals/objectives and clear metrics of success (M. A. Palmer et al. 2005).
- Lack of post-monitoring, long-term data to determine measurable outcomes/endpoints (Suding 2011).
- Failure to consider that a dynamic stream channel with some aggradation and degradation may be beneficial to stream ecology; a dynamic channel may be preferable to a fixed form channel or bank (Rubin, Kondolf, and Rios-Touma 2017; Habberfield et al. 2014).
- Failure to consider multiple spatial or temporal scales; focus on reaches without considering larger watershed processes (Bohn and Kershner 2002; Lake, Bond, and Reich 2007; J. Thompson et al. 2018).
- Failure to adequately consider ecological function, which results in a design focus on physics instead of biology (Beechie et al. 2010; Beck et al. 2019; Johnson et al. 2020).
- Failure to consider community/stakeholder input and effects (Sudduth, Meyer, and Bernhardt 2007).

2.3 Principles for Improved Outcomes

Research has also identified several keys to successful projects. Given some of the common problems with form-based restoration and the lack of ecosystem response for many of these projects (M. Palmer, Koch, and Benjamin 2014), several principles have emerged to guide restoration projects (Beechie et al. 2010):

- Address the root cause, not just the symptoms (again, an argument for process over form).
- Consider the physical and biological potential of the site and match the design to the site potential; consider river types suited to the site, rather than a particular aesthetic.
- Scale the restoration to match the scale of the problems.
- Clearly define the expected outcomes for the ecosystem and establish metrics to assess these outcomes.
- Seek stakeholder input early and often (Royer et al. 2020).

As the City moves forward in assessing its watersheds and prioritizing stream restoration projects, research supports a focus on stream processes and functions and, from the beginning, setting clear project objectives, expectations, and assessment metrics.

2.4 Defining Stream Processes and Functions

Historically, watershed management has focused on use-attainment, as required by the US Clean Water Act. By 2006, however, scientists, engineers, and practitioners recognized the value of incorporating stream functions into these projects and developed a functional framework to guide decision-making (Fischenich 2006). The functional analysis of stream restoration projects also points to a key reason for biological failure in restoration projects—the ecosystem cannot recover if the functions on which it depends are impaired. The Stream Function Pyramid (W. Harman et al. 2012) arose from this framework of functional hierarchy and emphasizes the concept of "functional lift" (measurable improvement of specific stream functions) rather than channel form alone in restoration practice (Figure 1). This framework and the interrelationship of stream functions that it presents have become an increasingly accepted guide for restoring degraded systems.

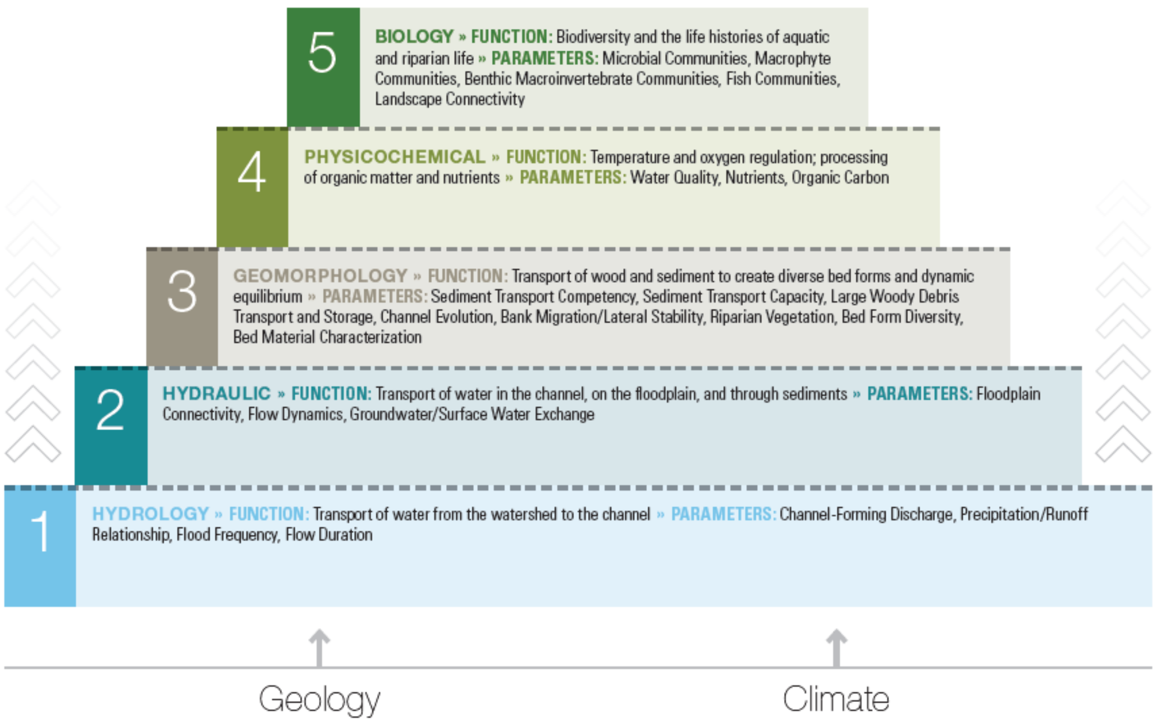


Figure 1. Stream Function Pyramid (Harman et al. 2012)

Stream functions exist in a hierarchy. Physical functions support chemical functions, which in turn support biological functions; the entire riverine ecosystem cannot thrive if functional impairments at each level are not addressed. Hydrology, hydraulics, and channel form—the traditional targets of restoration projects—form the basis for the higher order functions but are not the sole consideration. Note that habitat restoration (often a singular focus of stream projects) is most affected by lower levels while having the least effect upon these lower levels (Fischenich 2006). Physical habitat features are sustained by the lower-level functions; restoring habitat alone will likely fail without restoring the stream functions on which it relies (Hilderbrand, Watts, and Randle 2005).

2.5 Stream Function and the Biological Condition Gradient

Impaired stream functions create specific biological and ecological stressors. USEPA's Biological Condition Gradient (BCG) offers a framework for understanding the influence of impaired stream function on aquatic life. The BCG framework for decision-making also considers *cumulative* stresses on the ecosystem (USEPA 2016). The BCG ties the stream biological response to human-induced pressures. Human activity impairs stream function, which creates corresponding pressures on stream biology that result in changes in the biological condition of the stream (Figure 2).

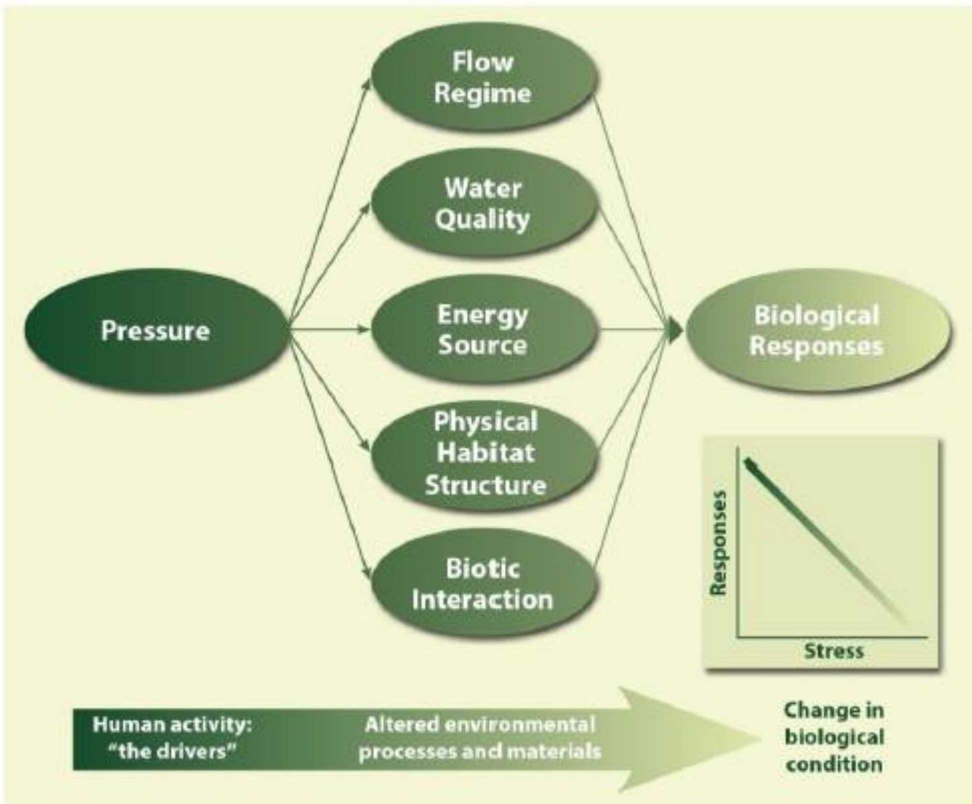


Figure 2. Model of Cumulative Stressors that Affect Aquatic Life (USEPA, 2016)

In this model, impaired hydrologic function corresponds to flow regime stressors, impaired hydraulic and geomorphic functions create physical habitat stressors, impaired water quality adds yet another stressor, and the cumulative stressors result in impaired biological functions and degraded biological condition. This model reinforces the need to consider multiple stream functions in the screening and prioritization approach. The Virginia Department of Environmental Quality (VADEQ) is currently in the process of adopting the stressor analysis model and has published general guidance on thresholds for specific stressor indicator parameters (VADEQ 2017). Note that each of the pressure pathways in the Figure 2 are accounted for in the screening parameters selected for this case study (see Section 4).

Indicators of ecological function include leaf decomposition and algal productivity, which are both relatively easy data to obtain (Young, Matthaei, and Townsend 2008). Leaf decomposition in particular is a robust indicator of changes in functional composition as opposed to taxa diversity alone (Sarvilinna, Lehtoranta, and Hjerppe 2017). The functional ecology study (described in Section 5) details the results of the leaf decomposition study on Peters Creek and its implications for ecological function.

2.6 Assessing Ecological Integrity

Typical assessments of aquatic life use taxonomic abundance and diversity as indicators of ecosystem health (Péru and Dolédec 2010). These indicators are "compositional" in that they describe what types of organisms are present and might include measures of taxonomic richness such as total taxa, Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness, or dominant taxa. The Virginia Stream Condition Index (VSCI) is an example of a compositional bioassessment (Burton and Gerritsen 2003).

Compositional assessments, however, do not measure ecological functions. Indicators that describe the functions that organisms perform in the ecosystem have received increasing attention as potentially more robust indicators of the biological health of streams (Laureto, Cianciaruso, and Samia 2015). The Péru and Dolédec (2010) study found functional diversity metrics to be more predictable indicators of response to stressors than compositional metrics. While compositional metrics are more likely to predict changes in habitat heterogeneity, the functional metrics are better predictors of response to changes in resources or contaminants. Additionally, the study found that taxa are not evenly distributed in nature, and that taxonomic richness does not necessarily guarantee a functioning ecosystem. A diversity of species' functions offers greater ecosystem resilience by increasing the "response diversity" of the ecosystem (Elmqvist et al. 2003). Response diversity describes the ability of multiple species to provide redundancy in ecosystem functions, offering "insurance" that these functions can recover in the face of environmental stress (Elmqvist et al. 2003). This redundancy of function is at least as important as diversity of species.

Ecological and Ecosystem Terms: Definitions

Terms describing stream ecology and ecosystems are often used interchangeably. Definitions for these terms, however, clarify the specific aspects of stream ecology that are being addressed.

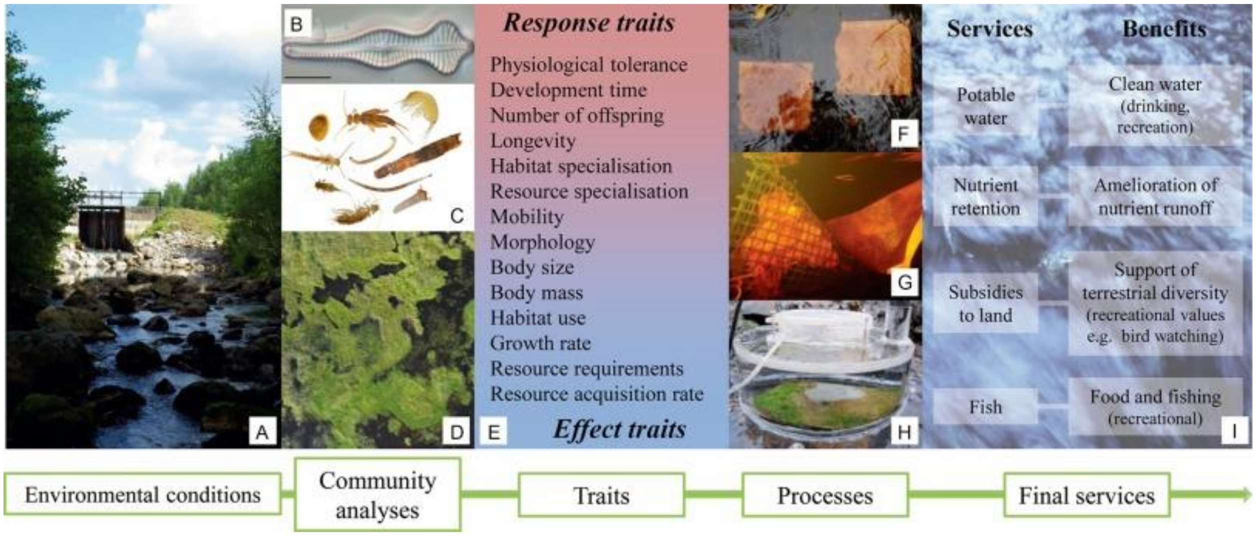
Ecological integrity: "The ability of an ecological system to support and maintain a community of organisms that has species composition, diversity, and functional organization comparable to those of natural habitats within a region" (Karr and Dudley 1981; Capmourteres *et al.* 2018)

Ecological health: "An ecological system is healthy…if it is stable and sustainable – that is, if it is active and maintains its organization and autonomy over time and is resilient to stress" (Costanza *et al.* 1992)

Ecosystem functioning: "The joint effects of all processes that sustain an ecosystem" (Truchy 2015).

Ecosystem process: "A process emerging at the ecosystem level and involving interactions between species within their food web, and with their environment, often involving transformations of nutrients and energy (e.g. primary production), generation of habitat structures (e.g. reef building), or maintenance of populations (e.g. pollination)" (Truchy 2015).

For aquatic life (one of the designated uses evaluated under water quality standards), assessment metrics can use indicators of key ecosystem functions that move energy and matter through the system rather than direct estimates of function. These assessed functions might include production (biomass production), nutrient cycling, carbon cycling, dispersal, and decomposition (N. L. et al. Poff 2006; Laureto, Cianciaruso, and Samia 2015). Choosing functional traits as proxies to assess ecosystem health also depends on the spatial scale selected (Laureto, Cianciaruso, and Samia 2015; Donatich et al. 2020). Specific traits can be used depending on the functions being assessed; for instance, a study characterizing detritivore functions used "(i) feeding strategy; (ii) mean per capita species biomass; (iii) emergence period; (iv) substrate preference; and (v) current velocity preference." (Frainer, McKie, and Malmqvist 2014; Frainer et al. 2018). The roles that functional traits play in stream ecology are illustrated in Figure 3 (Truchy et al. 2015). Note that gains in ecosystem functioning are beneficial, even if compositional scores such as the VSCI do not attain desired levels.



Linking anthropogenic stressors, species, and traits with supporting and final ecosystem services in stream habitats. Environmental conditions and stressors in a degraded stream (A) can have impacts on the composition of key organism groups, including algae (B), invertebrates (C), fish, and aquatic plants (D; seen here in an aerial view of a lake). This causes shifts in the composition of response traits, with stress often favouring species that are tolerant, generalist, develop rapidly, and short-lived. Associated functional effect traits also shift, as reflected in measures of ecosystem processes such as algal productivity, detritus decomposition, and the respiration of biofilms (F–H); and ultimately altering final ecosystem services supported by these processes (I). Methods for quantifying algal productivity (F—the tile method), leaf decomposition (G—the litter-bag method), and biofilm performance (H—respiration chambers) are illustrated. Quantitative information on true functional effect traits (e.g. growth and consumption rates) is rarely available, hence appropriate response trait proxies are often used, such as body size—both a key response (stress favours smaller size) and effect (due to mass-specific metabolic demands) trait. Photographs courtesy of (B) Dr. Steffi Gottschalk, (D) Dr. Frauke Ecke, and (H) Dr. Jon Benstead.

Figure 3. Functional Traits and Stream Ecosystem (Truchy *et al.*, 2015)

Recommended Readings

- “The science and practice of river restoration.” (Wohl, Lane, and Wilcox 2015). Provides a concise history of river restoration, as well as an overview of current science and challenges.
- “Is Urban Stream Restoration Worth It?” (Kenney et al. 2012). Examines outcomes and cost/benefits of restoration projects in an urban watershed (Baltimore, MD).
- “Ecological Restoration of Streams and Rivers: Shifting Strategies and Shifting Goals.” (M. Palmer, Koch, and Benjamin 2014). Details the shift towards functional restoration and ecosystem recovery.
- "Linking biodiversity, ecosystem functioning and services, and ecological resilience: towards an integrative framework for improved management." (Truchy et al. 2015). Describes a trait-based framework for assessing ecosystem functions.

2.7 Framework for Stream Functional Assessment and Project Prioritization

Any strategy for prioritizing stream projects must align with the City’s overall plans for watershed management. Stream restoration can achieve multiple watershed goals, but all watershed processes must be considered, not just individual reaches (Cockerill and Anderson 2014; Vietz et al. 2016). The City's watershed goals can help set the priorities for outcomes from stream restoration efforts. The published watershed master plans (WMPs) for Peters Creek, Lick Run, and Glade Creek include the following broad goals and objectives:

- **Maximize watershed resiliency and sustainability:** Restore natural stream processes; restore ecosystem health; increase resilience to drought and flood; and adapt to land development and climate change.
- **Minimize watershed hazards to public health, safety, and property:** Mitigate localized flooding and improve downstream water quality; increase Community Rating System (CRS) ratings; and delist all impaired streams from the 303d report.
- **Connect citizens, businesses, students, and other stakeholders to their watershed:** Provide community learning opportunities about the watershed; engage the community in watershed ecosystem revitalization; and encourage community outdoor recreation and stewardship.

These goals and objectives align well with the current research findings noted in Section 2. The City has already adopted a process-based approach to managing streams and has established specific and measurable objectives for each goal (detailed in Chapter 2 of the WMPs). The WMPs emphasize reconnection to floodplains and fine sediment removal. Since fine sediment is the stressor of concern in several benthic TMDLs in the City watersheds, this goal also addresses ecological function. Stakeholder engagement is another stated goal. Using these goals, a preliminary screening strategy can be applied to each stream to identify a target list of stream restoration projects that may achieve multiple objectives for resources expended.

The purpose of the initial screening (Figure 4) is to sort stream reaches into three categories: protect, potential project, or defer restoration. Screening also identifies projects that can potentially address several goals at once. The first screening question addresses nonnegotiable regulatory requirements, which automatically prioritize a given stream; stream priorities are frequently first a matter of legal or policy demands (Beechie et al. 2010). If a requirement such as TMDL is in place, then the stream has already been identified as a problem. Furthermore, these requirements are nonnegotiable, thus justifying funds, resources, and a high-priority ranking.

Second, impaired stream function and hazards are evaluated because addressing disruptions in stream functions before they become severe can prevent further degradation that results in an impairment or hazard. Impaired stream functions also create biological stressors, resulting in aquatic life impairments. Indicator parameters for assessing stream function are discussed in detail in Section 4. Note that although hazards such as extreme bank height or threats to infrastructure are assessed, stream restoration might not be the only means to mitigate the hazard (Kenney et al. 2012). The third screening question addresses the likelihood of recovery or mitigation for the impaired function or hazards that stream restoration projects can potentially mitigate.

If the answer to the first three screening questions is "no," then the stream or reach in question is maintaining ecological integrity and presumably expected function and should be protected to the extent possible; this stream or reach might serve as a reference reach for other work. Several studies have shown that simply protecting resources is a cost-effective means of maintaining water quality and ecosystem health (Postel and Thompson 2005). Protection of reaches might include signage, notation on maps, landowner outreach, conservation easements, city policy changes, or communication with public works staff regarding best practices to protect these reaches. The City stream layer under development should also identify high-quality stream reaches. Streams identified as potential restoration candidates ("yes" answers) must be further prioritized based on potential for functional recovery; this process is addressed in Section 6.

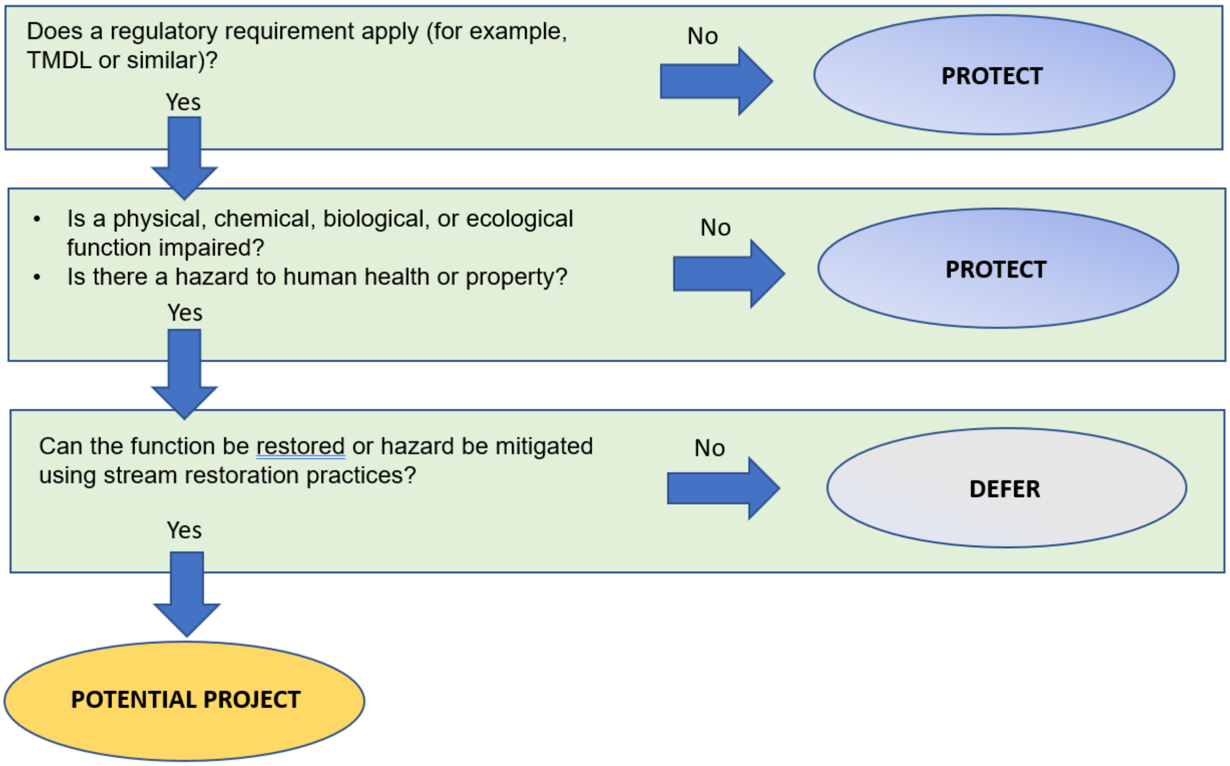


Figure 4. Functional Assessment Screening Process

Stream functions are not the only basis for prioritizing certain reaches. Stream restoration projects also have socioeconomic impact (Hawley 2018). After completing the initial functional assessment and screening, the potential projects are ranked based on City goals, and on social and economic factors. Projects that accomplish multiple goals, have less complex land ownership, or offer a community benefit such as education or neighborhood improvement take priority over those that do not. Funding eligibility must also be addressed. If a project meets eligibility requirements for grants or other funding, its priority becomes higher than one which lacks funding.

Finally, is the given stream or reach accessible? While accessibility is arguably the first priority, removing access issues from the initial screening allows all watersheds to be assessed and target reaches identified should circumstances change, and the reach becomes accessible later. Benefits identified such as hazard mitigation, community improvements, or funding availability might also form the basis for successful landowner outreach to allow access. Multiple adjacent landowners, however, may complicate accessibility, because the additional negotiations with these landowners may increase the difficulty of the project.

Deferred streams are streams for which there is less likelihood of functional recovery or for which funding and access may present barriers. It is worthwhile to record the reasons that these streams or reaches cannot be addressed through stream restoration and to revisit this list from time to time. Changes in ownership, land use, policy, or technology may at some point in the future make these projects viable.

The screening process is data-driven. A data set for use in assessing streams has been developed based on City goals, the stream function pyramid, and the biological condition gradient. Table 1 summarizes potential sources of data for decision-making for a given stream under assessment.

Table 1. Potential Screening Data Needs

Criteria	Data Requirements
1. Is there a regulatory standard or requirement that must be met for this stream that stream restoration can address?	**Desktop** - 303d Impairment list/TMDLs* - MS4/CWA requirements
2. Is a physical, chemical, biological, or ecosystem process disrupted? Is there a hazard to human health or property that stream restoration can mitigate? 3. What is the potential for recovery?	**Desktop** General o Imagery o Floodplain and floodway maps o Number of structures within FEMA floodplain o Water quality data o VDOT or city maintenance records Physical/Hydrology and Erosion o Channel morphology data (imagery and previous field measurements) o Bank erosion assessments o Data needed for prioritization models Chemical o Water quality data o Nutrient concentration/nutrient cycling data Biological o Benthic macroinvertebrate surveys o Riparian zone plant surveys (buffer zone width) o Invasive species surveys (composition) Ecosystem o Land cover, riparian zone cover o Biodiversity surveys if available **Field** o Visual assessment o Field assessment of conditions o Citizen complaints of flooding and erosion o Rapid assessment surveys of stream conditions o Biodiversity surveys
4. Are there other community benefits to stream restoration in this stream/reach?	**Desktop** o Imagery o Land use such as distance from parks, schools, existing trails, or greenways; potential for neighborhood greenspace o Socioeconomic data (can underserved neighborhoods benefit from this project?) o Stakeholder input and level of support for project
5. Is there funding specific to items No. 1-4 above?	o Depends on funding program pursued; might be combination of stream data and socioeconomic data
6. Can the City access the property?	o Imagery o Land ownership records; number of landowners o Cost of land acquisition ($/LF)

* TMDL- Total Maximum Daily Load
MS4- Municipal Separate Storm Sewer System
CWA- Clean Water Act
VSMP- Virginia Stormwater Management Program
FEMA-Federal Emergency Management Agency
VDOT -Virginia Department of Transportation

The Stream Function Pyramid (W. Harman et al. 2012) offers an approach that is increasingly accepted as a means of assessing potential stream improvements based on function. If the functional improvements can be estimated, then the reaches with the greatest potential for functional gains can be targeted as priorities.

One approach to applying Harman's pyramid that has gained some acceptance recently is the Stream Quantification Tool (SQT). Developed for mitigation projects and listed among USEPA's best practices (USEPA 2018), this tool offers a set of spreadsheet-based calculators that organize and streamline the functional analysis at each level of the pyramid. Using this tool, functional lift can be estimated to determine the restoration potential of stream reaches. The tool also organizes stream metrics for comparison and incorporates many physical indicators of ecosystem services (Swan et al. 2017). Although several states are currently using this approach (North Carolina, Tennessee, and Georgia, for example), research indicates that it may not yield consistent results in urban watersheds (Swan et al. 2017; Schwartz et al. 2020), can be overly complex, and over-emphasizes some parameters while omitting other parameters that are key indicators of biological function (Swan et al. 2017; Donatich et al. 2020; Schwartz et al. 2020). Recommended improvements to this method include (Swan et al. 2017):

- Simplify field parameters. The large number of correlated parameters unintentionally skews results to emphasize in-channel treatment.
- Focus on functional channel-floodplain processes. This focus would simplify parameters and emphasize resilience and dynamic stability. Simplified parameters include "riparian vegetation, channel and bank deformability, macroinvertebrates, and floodplain connectivity."

While the full SQT may not be appropriate for the City's needs, some aspects of this approach may prove valuable. For example, a spreadsheet tool that compares stream condition parameters to screening values is a simple assessment approach that can be readily implemented. Additionally, recent research indicates that this method can predict biological function restoration to a reasonable degree (Donatich et al. 2020). The Donatich study noted that a few key variables assessed according to SQT protocol were strongly predictive of biological function recovery: floodplain width (ER), channel shape (W/D), bankfull depth (d_{bkf}), bank shear stress and erosion susceptibility (NBS and BEHI), active streambank erosion, pool depth ratio, buffer width, adequate extent of riffle and run habitat (% riffle), substrate size (D84), and summer stream temperature.

Recommended Readings

- "Functional Objectives for Stream Restoration." (Fischenich 2006). Detailed discussion of the relationships between stream functions.
- "A Function-Based Framework for Stream Assessment and Restoration Projects." (W. Harman et al. 2012). Develops the stream pyramid concept in detail.

3. SELECTION OF CASE STUDY STREAM

While City streams have impairments based on temperature, bacteria, aquatic life (sediment), and PCBs, stream restoration projects are typically addressed at recovering functions that have the most impact on aquatic life. Based on the screening strategy, several candidate streams may be suitable for projects that are aimed at restoring conditions for aquatic life. Streams with TMDLs (first screening question) are an automatic priority, and streams with benthic impairments are logical choices for additional, more extensive sampling related to conditions supporting biological function. Roanoke has eight streams (other than the Roanoke River) with benthic TMDLs (City of Roanoke 2019), including those of particular concern listed in Table 2:

Table 2. City of Roanoke Selected Stream VSCI Scores

Stream	Range of Median VSCI Scores (City WMP)
Barnhardt Creek	44.9
Mud Lick Creek	28.8-34.4
Murray Run	30.0-30.5
Ore Branch	26.1
Peters Creek	53.4-57.3
Tinker Creek	44.3-67.9
Note: Data from Roanoke City Watershed Master Plan (City of Roanoke, 2019); only one median value available for Barnhardt Creek and Ore Branch	

Initial surveys performed as part of the watershed master plans indicate that stream functions are likely impaired for reaches in Peters Creek and Tinker Creek and hazards are present as well, which result in "yes" answers to the second set of screening questions (City of Roanoke 2019; Dymond et al. 2016). Is there potential for recovery of stream function? Additional assessments based on the stream function ranking are needed to make this decision for physical (hydrologic, hydraulic, and geomorphic) and chemical functions. Based on VSCI and SOS scores (City of Roanoke 2019), however, the borderline impairment for Peters Creek suggests that recovery of ecological function may be possible (third screening question). The City has also developed considerable data for this watershed, so potential recovery of other functions may be more easily assessed than watersheds with less data. Murray Run and Barnhardt Creek impairments are more severe, but these watersheds do not have as fully developed sets of stream data as Peters Creek. Finally, Peters Creek also offers undeveloped headwaters that may serve as locations for reference reaches. Based on initial screening, data availability, and potential for ecological recovery, Peters Creek was selected as the case study stream and for further assessment and analysis.

4. STREAM CONDITION SURVEY: DATA REVIEW, DATA COLLECTION, AND SUMMARY OF RESULTS

The data collected for stream restoration projects may serve several purposes: 1) to identify impaired reaches and select sites; 2) to design projects; and 3) to monitor the outcomes of restoration. The purpose of gathering assessment and screening data for this project was to evaluate stream conditions on Peters Creek and identify potential stream projects that will achieve City goals and objectives. For the initial survey and functional assessment, a focused set of parameters was needed, which was less extensive than the parameter set typically used for design. Detailed, reach-specific design data can be gathered when projects are implemented.

Ideal stream restoration project sites are those with few restoration constraints, healthy upstream watersheds, and impairments that can be addressed within the reach itself (W. Harman et al. 2012). Urban streams seldom offer ideal conditions. Constraints are often present in the form of infrastructure or property access, impairments may be the result of larger watershed processes, and upstream conditions may be no better than those in the target reach. In the urban environment, an "ideal" site may instead be one that offers opportunities to improve, if not fully restore, stream function, achieve urban planning goals, and/or offer social benefits. Given these constraints, data collection and analysis efforts for the City focus on parameters that indicate opportunities to achieve the following goals:

- *Support more robust stream ecology in order to delist streams from 303d.* The City maintains a goal of delisting all streams from the 303d impairment list. Aquatic life must improve on Peters Creek to achieve this goal.

- *Stabilize banks and minimize channel erosion*. The Watershed Management Plans (WMPs) for City streams note several reaches where banks are eroding, presenting threats to infrastructure and public safety. Channel erosion is also an increasingly significant source of fine sediment to urban streams (Russell, Vietz, and Fletcher 2017; Cashman et al. 2018). Minimizing fine sediment delivery from stream channels addresses the Roanoke River benthic impairment for which sediment is the primary stressor.
- *Mitigate flooding*. Where can additional floodplain storage be created through stream restoration? Restoring floodplain connectivity mitigates local flooding and recharges groundwater supplies, thus offering resilience to drought as well as floods. Flooding also supports ecological functions vital for many species (N. L. Poff et al. 1997).
- *Improve downstream water quality*. Improved water quality supports several regulatory, stream function, ecological, and quality of life objectives for the City.
- *Connect citizens, businesses, students, and other stakeholders to their watershed*. Stakeholder outreach and education are objectives of both the TMDL implementation plan and the City's MS4 program. Stakeholder factors also influence whether a given stream restoration project can be implemented.

Not only do urban stream projects present less than ideal conditions for restoration, these projects are also sometimes undertaken in a piecemeal, "opportunistic" approach, rather than in a coordinated manner that considers broader watershed and land use processes (Cockerill and Anderson 2014). The data analysis and collection efforts for this project also support the development of a comprehensive, total watershed approach to analyzing and documenting stream conditions, estimating recovery of function, and prioritizing stream restoration efforts.

4.1 Technical Assessment Parameters and Tools

The City maintains a significant existing data set that can support the screening and prioritization effort. Appendix A includes the City's initial data set relevant to Peters Creek (City of Roanoke, 2019). Using this existing data set, a focused set of parameter screening was developed. Technical screening parameters were selected based on their estimated prediction of stream function recovery and with an additional emphasis on their correlation with recovery of biological function. When several parameters could potentially serve as indicators for a given function, the parameter selection was based on independence from other parameters, relevance to additional functions (for example, LWD indicates both channel function and biological function), and ease of data collection for City staff. Screening parameters associated with each stream function are summarized in Table 3.

Table 3. Stream Assessment Indicator Parameters

Stream Function/Biological Stressor	Parameter	Data Source	References
Hydrology/Flow Regime			
	Land Use/Land Cover	Desktop	Harman *et al.*, 2012; Donatich *et al.*, 2020; Stammel et al., 2020, Jeznach and Granato, 2020
	Watershed area	Desktop	Bezak, 2008; Helms *et al.*, 2016
Hydraulics/Physical Habitat			
	Width to Depth ratio	Field measurements at water quality sampling sites	Doll *et al.*, 2016a; Donatich *et al.*, 2020
	100-year floodplain width & related metrics	Desktop	Doll *et al.*, 2016a; Hawley, 2018
	% forested buffer in riparian buffer	Desktop	Lorenz and Feld, 2013; USEPA, 2011; Sweeney and Newbold, 2014; Forio *et al.*, 2020
	Large woody debris (LWD)	Field survey	Harman *et al.*, 2017; Wohl *et al.*, 2016
Geomorphology/Physical Habitat			
	Modified BEHI	Field survey	Newton and Drenton, 2015
	Bed material assessment	Field survey	New method: induced turbidity
	Riparian buffer width	Desktop/field verification	Sweeney and Newbold, 2014; Sweeney, Bott, Jackson, Kaplan, Denis Newbold, *et al.*, 2004
	LWD	Field survey	Harman *et al.*, 2017; Wohl *et al.*, 2016
Water Quality			
	Temperature, pH, dissolved oxygen, specific conductivity, and turbidity.	Desktop for historical values Field survey for current conditions	Standard water quality assessment parameters
Biology/Energy Sources & Biotic Interaction			
	VSCI/SOS scores	Desktop, historical benthic macroinvertebrate surveys (data available at 2 locations; citizen science assessments at 5 locations). Field survey, current conditions	VSCI (Burton and Gerritsen 2003)
	Leaf decomposition	VT leaf bag data	Peters Creek Case Study
	Forested buffer		Bernhardt and Palmer, 2007; Moore and Palmer, 2005

4.1.1 Hydrology

Hydrology function assessment indicates whether the current hydrologic conditions may prevent recovery of other functions. Watershed hydrology is generally addressed in the City's stormwater management program, and the WMP for Peters Creek details flow regime and land use characteristics noted in Appendix 1 of the Peters Creek WMP. Usually, stormwater BMPs are used to manage hydrology rather than restoration projects. Although stream restoration projects are affected by hydrology, individual projects may have little influence on runoff dynamics and stream discharge (W. Harman et al. 2012). On the other hand, hydrology can indicate the likelihood of success for stream restoration projects. One study found that stream restoration projects seeking to improve or restore geomorphic function generally are more successful as watershed impervious cover decreases (Withers 2019). Land use similarly indicates stream health and the chances of success for a given project.

4.1.2 Hydraulics

Hydraulic function assessment is focused on assessing floodplain connectivity and potential recovery of connectivity. Floodplain width can also be an indicator of space available for project work and for future channel migration. As noted previously, many restoration projects have channel stabilization as a primary goal to prevent, for instance, lateral channel migration from threatening urban infrastructure. Natural streams move, however, and if ample room is available for the stream, then lateral migration is less of a concern and other dynamics can be prioritized in the restoration design.

4.1.3 Geomorphology

Geomorphological parameters selected indicate bank erosion, a source of fine sediments that impair aquatic life and channel dynamics (Cashman et al. 2018). Channel erosion is indicated in this study with a modified Bank Erosion Hazard Index (BEHI), modeled on the standard BEHI assessment widely used in stream work (Rosgen 2001; Hawley 2018). The modified BEHI was developed by Cleveland Metroparks and is useful in urban settings because it does not require bankfull identification, which is often difficult in urban watersheds (Newton and Drenten 2015). The modified BEHI screening consists of six questions that assess bank conditions; "yes" responses to two or more questions indicates moderate or worse erosion is likely. The Cleveland study describing this method indicates good agreement between the questionnaire and full BEHI results.

Modified BEHI Screening Questionnaire

1. Does the uniform section of bank exhibit less than or equal to 50% protection at the toe of the bank?
2. Does 50% or more of the bank exhibit an undercut of 0.5 feet or more?
3. Does 50% or more of the bank exhibit stratification?
4. Does 50% or more of the bank have a bank height of ten feet or more with 50% or more soil exposure?
5. Does 50% or more of the bank exhibit bare roots (roots lacking bank material/soil)?
6. Is 50% or more of the bank void of rooted vegetation?

Bed material in general and fine sediments in particular are difficult and time consuming to measure, which complicates mitigation efforts (Hedrick et al. 2013). The primary established method for fine sediment analysis is total suspended solids (TSS), which must be performed in a laboratory for best results. Bed material is usually assessed with pebble counts, a labor-intensive method that does not fully account for the smallest sediment particle sizes. While bed material size distribution is a valuable indicator of channel condition, rapid assessment by nonexpert personnel is typically biased towards larger diameter particles. Embeddedness is another indicator parameter which describes the relative abundance of fine sediments in the surface layer; however, this assessment requires expert judgement and is a subjective rather than quantitative evaluation. For this study, a new assessment parameter, induced turbidity, was used to characterize the relative quantity of fine sediment in the stream bed.

Induced turbidity sampling consists of placing an enclosure in the stream bed (the "sampling well"; see Figure 5), then disturbing the bed sediment within the sampling well while observing and recording maximum turbidity in NTU with a YSI ProDSS multiparameter water quality field instrument (with optical turbidity sensor). As the bed sediment is disturbed, the turbidity reading observed on the meter will rise, stabilize at some higher value, then decline once the disturbance ends and the bed material resettles. In practice, the sampling technician disturbs the stream bed material and observes the meter for turbidity stabilization at a higher value. Once the turbidity stabilizes, the technician stops disturbing the bed material. Measurement recording ends when the turbidity reading consistently falls below the maximum reading.

Figure 5. Induced Turbidity Sampling Well

Finally, riparian buffer width and condition were included as additional indicators of channel geomorphology dynamics. Riparian vegetation influences multiple stream characteristics, but has a particularly strong effect on channel width (Hession et al. 2003), sediment trapping, meander, and bank erosion (Sweeney et al. 2004; Kroll et al. 2019; Sweeney and Newbold 2014).

4.1.4 Water Quality

For screening purposes, physicochemical functions can be assessed using standard water quality indicators. The selected standard indicators used for this study were temperature, pH, dissolved oxygen, specific conductivity, and initial turbidity. Historical data for these parameters is available at several locations on Peters Creek. Additional values for other locations were assessed with a YSI ProDSS multimeter.

4.1.5 Biology and Functional Ecology

The physical and chemical stream functions listed above are also predictors of biological functions, thus the screening parameters for biological function include these, as well as indicators listed for other functions such as VSCI/SOS, leaf decomposition, forested buffer, and LWD.

Additionally, as part of the rapid assessment tool development, leaf decomposition bags (Figure 6) were placed in Peters Creek and subsequently analyzed as an indicator of stream biological function. Fifteen decomposition bags were deployed in November to measure leaf mass loss rates and associated macroinvertebrates. Bags were recovered after day 10, 20, 37, and 62. The leaves were dried and weighed, and all macroinvertebrates were identified from bags collected on days 37 and 62.

Figure 6. Leaf Decomposition Bags

4.2 Data Collection: Desktop and Field Surveys

Using the indicator parameters identified, assessment data was developed through both desktop and field surveys of stream reaches. The desktop survey was conducted using GIS data and organized within the City stream GIS layers. City personnel developed watershed area, land cover, and land use metrics; Virginia Tech personnel developed reach length, floodplain width, and socioeconomic metrics. The field survey was conducted by Virginia Tech personnel from late February through early April of 2021.

4.2.1 Stream Study Reaches

Segmenting the main channel and tributaries helps to organize stream data, consistently analyze stream conditions, and identify specific projects. The City watershed management plans identify stream segments in general terms. For assessment purposes, identifying specific reaches allows more detailed data collection and analysis. The definition of stream "reach" varies with context and regulatory agency. For this study, the broader definition as a continuous length of stream with uniform characteristics is used (United States Department of Agriculture 2015).

Division of the stream into reaches begins at the confluence of the Roanoke River and ends at Green Ridge Road, where Peters Creek crosses the City limit. Reach break points include road crossings, in-stream structures such as culverts and bridges (which strongly influence stream dynamics), piped portions of the creek, significant changes in land use/land cover, and changes in geomorphic characteristics. Some small crossings (driveway bridges, footbridges) were not used for breaks because of their minimal influence on stream characteristics. Reach identification ends at the city limit, with a total of 27 reaches identified. Main stem reaches are numbered PC01 to PC13, and tributaries are identified as PCA, PCB, and PCC, consistent with current City terminology used in the WMP for Peters Creek. Appendix B includes the reach locations and reach ID numbers.

4.2.2 Water Quality Sample Locations

Water quality samples were collected for each study reach at a distance of at least 20 channel widths from in-stream structures to reduce the impact of structures on results. Riffles were selected for sampling due to the greater stability of riffles and their value as reproductive sites for aquatic organisms. Samples were collected from riffles in all reaches except PCA04, where no riffles were present, and the stream bed was sampled instead. Sample locations are included in the GIS layers submitted with this report.

4.2.3 Field Data Collection Tools

Field survey data was initially collected using data collection survey sheets (see Appendix C). This survey data was manually transferred to the detailed stream technical screening spreadsheet and manually added to the GIS layers for the project. After conferring with the City regarding additional tools for data collection, ArcGIS Collector (the ESRI field data entry application) was used to enter all field parameters (except for water quality data) directly into the project GIS layers. Water quality data was downloaded from the YSI ProDSS multimeter, and the detailed output is included in the MS Excel spreadsheets submitted with this report.

4.3 Summary of Key Data Results

Complete data collection results, including detailed desktop survey results, field survey data tables, and water quality data tables from the YSI multimeter, are summarized in Appendix D and the MS Excel spreadsheets submitted with this report. The data used to assess stream condition are summarized in Section 6.2, Reach Condition Scoring. Field survey observations (bank erosion locations, hazard locations, water quality sample locations) are included in the GIS layers submitted with this report.

Key findings of the data collection effort include:

- **Impervious cover, a key metric, varies significantly by reach.** Although the average impervious cover for the entire Peters Creek watershed is 24%, when analyzed by reach, impervious cover ranges from 9% to over 40%. Figure 7 illustrates the spatial variability of impervious cover in the watershed. Two tributaries to Peters Creek (PCB and PCC) each had impervious cover over 30%.

- **Impaired hydraulics and geomorphology are present in multiple reaches**. Incised and eroding channel is present throughout the watershed. The modified BEHI screening predicts over 7500 linear feet of moderate or worse BEHI scores. Floodplains are likewise disconnected from the stream in multiple reaches; vertical bank heights of 3 to 5 ft are common.

- **Water quality is generally acceptable.** Water quality results were in line with previous studies, and water quality is not expected to prevent restoration in reaches where projects may be appropriate. Some pH and dissolved oxygen readings were higher than historical values; these results most likely indicate the influence of time of day sampled (afternoon). Late day samples occur during times of higher primary productivity, which increases dissolved oxygen and raises pH. Specific conductance values in Peters Creek were often higher than literature reference values based on Level 3 Ecoregion (Ridge & Valley) data; however, these values were generally within background values based on Level 4 Ecoregion data (Govenor et al. 2019; Griffith 2014). The Peters Creek headwaters lie in the Level 4 Ridges ecoregion, while the reaches located within the City are in the Level 4 Limestone & Shale Valleys ecoregion. Reference value ranges for specific conductance for these ecoregions are approximately <200 µS/cm and <375 µS/cm, respectively; differences in geology may explain the variation in these values (Griffith 2014).

- **Biological index scores for Peters Creek were borderline to low.** Relatively few mayflies were present in Peters Creek during the study period; seasonal variation in specific conductance (salinity) may be a cause. Table 4 summarizes the biological survey results; a VSCI score below 60 is considered impaired. The biological study is described in detail in Section 5.

Table 4. Biological Survey/VSCI Scores Collected December 2020–February 2021

Stream (type, location)	Jabs (6)	Hess (4)	Leaf Bags (6)
Peters Creek (PC10)	55.8	33	29
Lick Run (Urban, by Valley View mall)	45.5	43	24
Flatwoods Branch (rural, upstream of City)	71.4	69	37

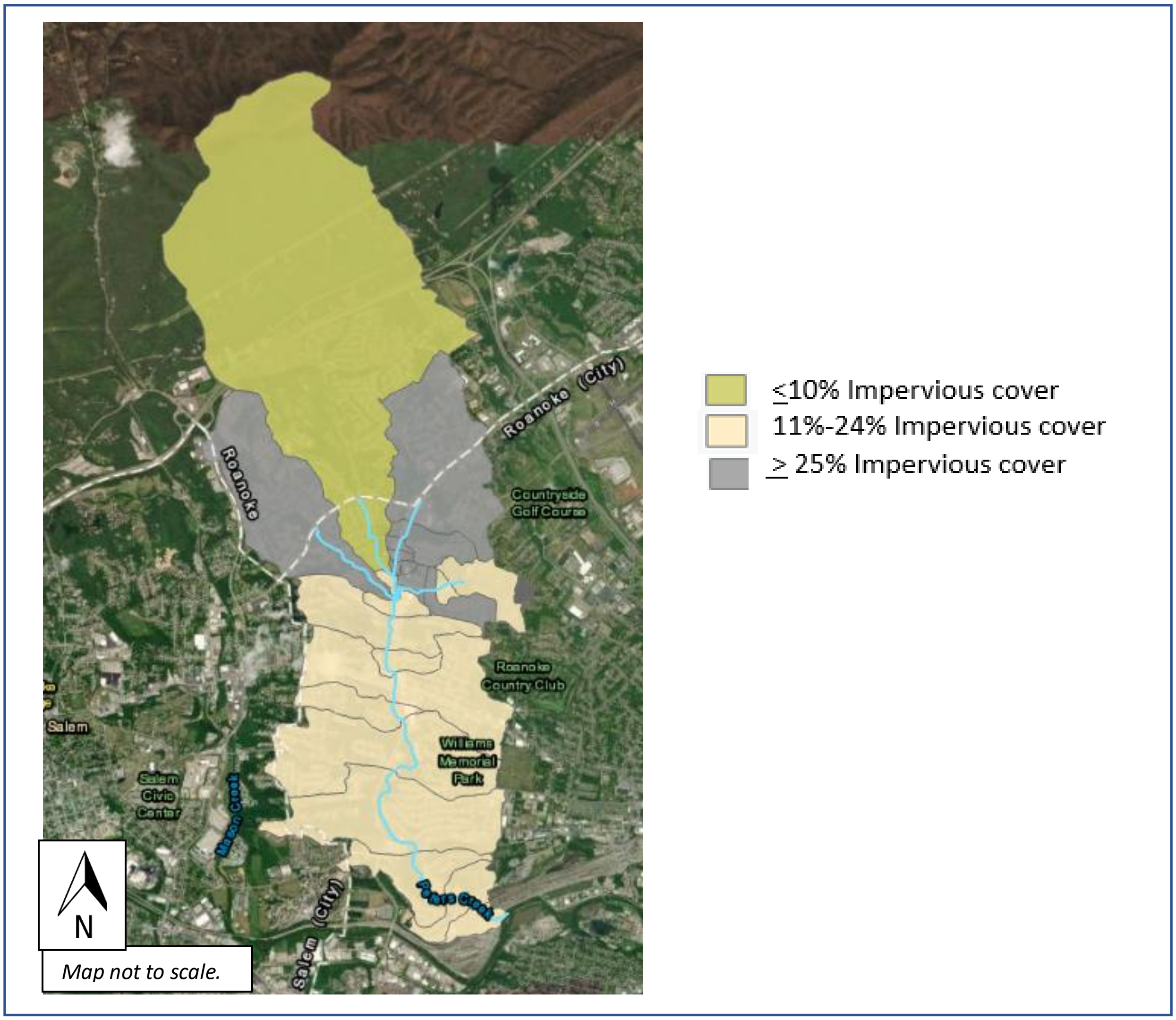


Figure 7. Distribution of Impervious Cover in the Peters Creek Watershed

5. BIOLOGICAL STUDY RESULTS

The goal of the biological study was to compare leaf decomposition rates and the index of biotic integrity (IBI) in two second order urban and one forested Roanoke River tributaries to assess alignment between macroinvertebrate community structure and ecological function (Table 5). Macroinvertebrate jab samples for the IBI were taken according to Virginia state rapid bioassessment protocols as described by the Virginia Stream Condition Index (VSCI). Hess samples were taken for taxonomic community analysis, and decomposition bags were deployed in each stream for leaf mass loss. Spring 2020 VSCI scores in the two urban streams were 45 and 49, and shredder average abundances were 2 and 5, respectively. In Winter 2020, VSCI scores taken using state methods were 56 and 46, respectively, while the VSCI score was 71 in the forested stream (see Appendix E). In Peter's Creek, shredder abundance ranged from a total of 7 (in leaf bags) to 77 (in Hess samples) depending on the sample method type. Decomposition rates for the two urban streams were 1% and 0.6% per day, which is relatively fast compared to forested streams (Webster and Benfield 1986). Low shredder abundances in leaf bags and relatively fast leaf mass loss rates suggest a mismatch between VSCI scores and function.

Leaf mass lost in each creek (Figure 8) shows fast rates of breakdown in Peters Creek compared to the other urban stream and the forested stream. Because macroinvertebrates that eat leaves were scarce in Peters Creek, a combination of microbes and physical abrasion from storm flows likely contributed the most to these fast rates (Peters Creek: 0.0042, Lick Run: 0.0014, Flatwoods Branch: 0.0015).

Table 5. Objectives, hypotheses, and rationale for the biological assessment conducted in Peters Creek as compared to a comparable urban stream (Lick Run) and a forested stream (Flatwoods Branch)

Objective	Hypothesis	Rationale
Calculate VSCI scores for each stream to assess ecological condition according to the State.	VSCI scores for the two urban streams (Peters Creek and Lick Run) will be considered impaired, not reaching a threshold of 60, and Flatwoods Branch, a rural and forested site, will achieve a VSCI score of 60 or higher.	Increased sedimentation and chemicals from urban runoff will inhibit the presence of sensitive taxa, such as EPT, that result in higher VSCI scores and promote the presence of tolerant taxa, such as many Diptera, that result in decreased VSCI scores.
Assess decomposition rates in each stream to estimate ecosystem function.	Peters Creek and Lick Run will have slower rates of leaf mass loss than Flatwoods Branch.	Sensitive taxa that make up the "shredder" functional feeding group will be extirpated, resulting in lower organic matter processing and ultimately slower decomposition rates.
Conduct a taxonomic community analysis to compare macroinvertebrate community structure between the streams.	Peters Creek and Lick Run will have lower taxa richness and evenness, regardless of their abundances, and abundances will likely be higher in tolerant taxa.	Due to environmental stressors, only tolerant taxa will remain in these streams in higher abundances due to decreased competition with sensitive taxa.

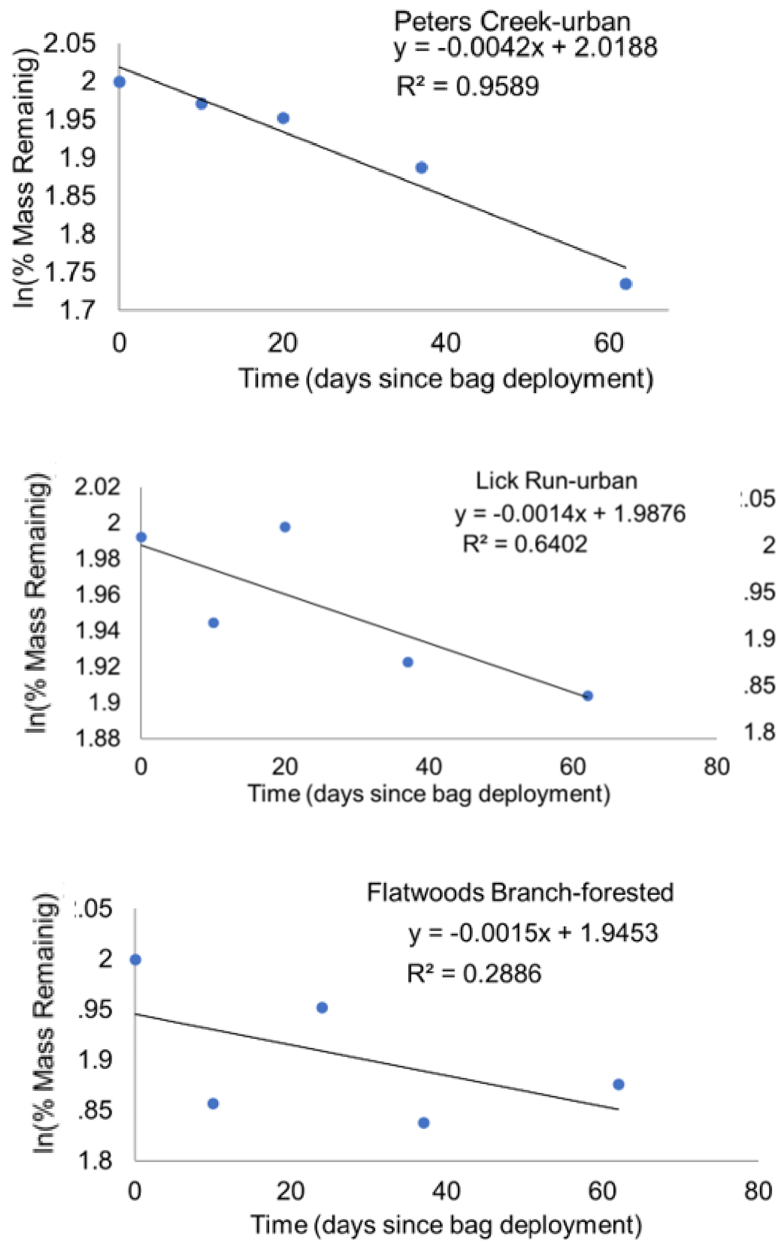


Figure 8. Leaf Mass Loss Rates

In Peter's Creek, the low abundance of shredders, low VSCI regardless of sampling technique, and faster than normal leaf mass loss rates (Tank et al. 2010) indicate biological impairment and accelerated carbon cycling. Microbial activity fueled by nutrients, combined with storm flows are likely interacting to increase the rate of leaf decomposition. In this case, Peters Creek maintains the function of carbon cycling, although with a "tighter" cycle because higher invertebrates are not available to transfer and assimilate this carbon through a longer and more diverse food web. While the pilot study suggests biological impairment in all the study streams, Lick Run had both biological impairment and correspondingly low decomposition rates. The Lick Run results indicate that either lower nutrient inputs are limiting microbial activity or contamination present is affecting the microbial community. Because there is no established reference condition for decomposition rates in these streams, the rate of leaf mass loss must be interpreted in combination with the macroinvertebrates associated with the study. The combined community and functional assessment allow for a more mechanistic understanding of the potential stressors affecting the streams.

6. PRIORITIZATION PROCESS AND RESULTS

The prioritization process consists of three steps: 1) reach condition assessment; 2) reach screening; and 3) project ranking. The initial stream condition ranking is a quantitative assessment, scoring, and comparison of the stream conditions for each reach. Using the stream condition ranking, the reaches are next screened based on the technical assessment of each function for each reach. This technical screening produces a short list of potential projects that are finally ranked according to technical and socioeconomic factors (which often indicate project feasibility).

6.1 Reach Condition Scoring

The reach condition assessment offers a composite score that indicates existing stream condition based on stream functions. This score can be used to estimate and compare potential functional lift for the reach. The functional assessment (FA) of stream condition was performed for each reach using the values summarized in Table 6, then compared with a qualitative Best Professional Judgement (BPJ) evaluation of the reaches (criteria shown in Table 7) to calibrate the results. The BPJ assessment consists of a field evaluation and scoring from 1 (worst) to 3 (best) of bed structure, substrate, cover/refuge, bank stability, riparian vegetative cover, EPT, and floodplain access for a reach score of 7 to 25. The EPT score was based on the presence of pollution-sensitive taxa. Table 8 summarizes the FA and BPJ scores; the rankings by both methods are compared in Table 9, with notes on how the results agree or differ. Note that if reaches are within 1 level on the BPJ and FA rankings, the ranks are considered to agree. In general the two reach rankings agreed, and the FA was not adjusted beyond the original assessment.

Table 6. Stream Condition Functional Assessment Values

Score	%Imp. Land Cover[1]	W/D Ratio[2]	Max 100 yr FPW/Sqrt. Watershed Area[3]	%Forest w/in 30 ft Buffer[4]	Max. IT (FNU)[5]	Specific Conductance (µS/cm)[6]
1 (worst)	>40%	<4	<0.02	<15	>600	>600
2	25 to 40%	4 to <8	02 to <0.05	15 to <25	450 to <600	500 to <600
3	11 to 24%	8 to <12	0.05 to <.07	25 to <50	300 to <450	400 to <500
4	6 to 10%	12 to <16	0.07 to <0.1	50 to <75	150 to <300	250 to <400
5 (best)	0 to 5%	≥16	≥0.1	75 to 100	<150	<250

1. Schueler *et al.*, 2009; USEPA, 2016; VADEQ, 2017
2. USDA/NRCS, 2007
3. Comparison to other reaches; higher value is better stream condition
4. Lorenz and Feld, 2013. Comparison to other reaches; higher value is better stream condition.
5. Comparison to other reaches; lower value is better stream condition
6. Griffith, 2014; VADEQ, 2017

Table 7. Stream Condition Best Professional Judgement Assessment Values

	Bad	Fair	Good
Bed structure	Uniform bed with lack of stable structures	Mix of uniform bed and bed features	Diversity of bed features appropriate to position within the watershed
Substrate	Significant embedded areas, poor gradation, loose, soft areas	Some fine sediment embeddedness	Well graded particle size distribution, minimal embeddedness
Cover/refuge	Few number and type of refuge areas, lack of cover	Some refuge areas	Presence of plentiful refuge areas of diverse types (undercut banks, root mats, oxbows/backwaters)
Bank stability	High banks, steep bank slopes, evidence of mass wasting	High, steep banks, no evidence of mass wasting	Low bank slopes, good riparian vegetation cover and no evidence of mass wasting
Riparian veg cover	Little riparian vegetation or predominance of herbaceous/invasive vegetation	Combination of woody and herbaceous vegetation or narrow riparian buffer	Dense, native, woody vegetation for distance of at least 10 m from top of bank
EPT			
Floodplain	Little evidence of flow access where floodplains are expected	Some evidence of flow access	Clear evidence of flow access (rack lines, sediment deposition on floodplain)

6.2 Reach Functional Assessment Screening

Following the initial reach condition assessment, reaches are next screened into three categories: protect, consider for a project, or defer (as described in Section 2.7). The reach technical screening uses the data and screening breakpoints developed in the stream condition assessment described above to categorize reaches and identify projects. Additional screening factors for floodplain width, the presence/absence of LWD, and 100 ft forested buffer are included. Using the values in Table 6, scores in the 1-2 range result in "Defer" for the functional analysis; 3 is "Impaired" and a score of 4-5 results in "Protect." Note that there is not a "Defer" value for LF BEHI; if over 200 ft of impaired channel is present, the reach is considered "Impaired" for this function. Table 10 summarizes the functional screening for each reach. The spreadsheet accompanying this report includes the detailed screening values for each function.

The resulting category assigned is based on the evaluation of the impairment in the context of the stream functional hierarchy. If stream restoration can mitigate a functional impairment, and the resulting stream is functional for subsequent categories, then the reach is considered for a possible project. Note that projects are deemed possible in reaches with impaired hydrology; literature indicates that fair to good stream conditions are at least possible in the 10-25% impervious cover range, depending on other variables such as condition of riparian buffer (Schueler et al. 2009).

Based on this screening assessment, seven reaches are identified as potential projects: PC12, PC10, PC09, PC08, PC05, PC04, and PC03. Note that although several potential projects may be possible in two of the tributaries (PCB and PCC, impaired for floodplain connectivity and geomorphology), the impervious cover that impairs the watershed hydrology for these reaches may undermine any potential projects. Hydrology is a foundational stream function that influences all other functions, and stream restoration projects have minimal impact on watershed hydrology. Consequently, reaches that are assessed as "defer" for this function may have overriding watershed processes that restoration projects cannot overcome (see Section 2.2). Projects in these reaches may have less potential for success than projects in other reaches.

Finally, although PC13 screens as a “Protect” reach, channel erosion is present. If PC12 is implemented as a project, the City may wish to concurrently work with the landowners in PC13 (at least one of which owns property on PC12) to target channel erosion and bank stabilization in this reach.

Table 8. Best Professional Judgement (BPJ) and Functional Assessment (FA) Scores

Reach	BPJ Score (% of max. score)	FA Score (% of max. score)
PC01	NA	54%
PC02	NA	66%
PC03	NA	66%
PC04	NA	66%
PC05	NA	60%
PC06	NA	57%
PC07	NA	77%
PC08	NA	57%
PC09	NA	60%
PC10	NA	63%
PC11	76%	91%
PC12	62%	60%
PC13	67%	66%
PCA01 (piped)	33%	37%
PCA02	33%	43%
PCA03	33%	46%
PCA04	33%	46%
PCA05	33%	60%
PCB01	62%	71%
PCB02	48%	51%
PCB03	52%	57%
PCB04	52%	54%
PCC01	81%	54%
PCC02 (piped)	33%	34%
PCC03	57%	54%
PCC04	67%	49%
PCC05	48%	46%

Table 9. BPJ and FA Rank Comparison

Reach	BPJ Condition Rank (Score), best to worst	FA Condition Rank (Score), best to worst	Agreement/Possible Sources of Difference
PCC01	1 (17)	4 (21)	Differ/Lower FA ranking due to poor hydrology and hydraulics scores
PC11	2 (16)	1 (32)	Agree
PC13	3 (14)	3 (23)	Agree
PCC04	3 (14)	8 (17)	Differ/Lower FA ranking due to poor hydrology, hydraulics, and geomorphology scores
PC12	4 (13)	4 (21)	Agree
PCB01	4 (13)	2 (25)	Slight difference/Lower BPJ ranking due to low bed structure, substrate, and EPT scores
PCC03	5 (12)	6 (19)	Agree
PCB03	6 (11)	5 (20)	Agree
PCB04	6 (11)	6 (19)	Agree
PCB02	7 (10)	7 (18)	Agree
PCC05	7 (10)	9 (16)	Slight difference/Lower FA ranking due to poor hydrology and geomorphology scores
PCA02	8 (7)	10 (15)	Slight difference/FA ranking slightly higher due to lack of channel erosion
PCA03	8 (7)	9 (16)	Agree
PCA04	8 (7)	9 (16)	Agree
PCA05	8 (7)	4 (21)	Differ/FA ranking higher due to better geomorphology scores
PCA01 (piped)	8 (7)	11 (13)	Agree
PCC02 (piped)	8 (7)	12 (12)	Agree (lowest rank for each scale)

6.3 Project Ranking

Technical screening has identified seven reaches which offer potentially successful sites for stream restoration projects based on the evaluation of stream processes and functions. The ranking approach for these sites incorporates City goals and priorities, potential project benefits, potential functional gains, and social or economic factors which might impede project completion.

For the initial analysis, all parameters are assigned equal weights. City management may decide to assign alternate weighting values to ranking parameters based on project-specific goals, funding opportunities, or stakeholder input. For example, some funding mechanisms, such as SLAF, prioritize mitigating channel erosion, thus “City Goals” might receive a higher weighting if projects are ranked in the context of which might be most likely to acquire funding under the SLAF program. On the other hand, if delisting is the overarching goal, then biological indicators receive higher weighting values because the VSCI scores (on which listing is based) must improve. Technical factors used in the ranking include factors which relate to city goals and potential functional lift, including goals, location in watershed, stream condition, and potential to increase forested buffer.

Table 10. Reach Technical Screening Results and Potential Projects

Reach	Hydrology/ Flow Regime	Hydraulics &Geomorphology/Habitat Structure						Water Quality	Result
	%Imp	FP width (no structures)	FP width/ Sqrt WSA	LF BEHI	%FB30	%FB100	LWD	SpCond	
PC01	Impaired	Impaired	Defer	Protect	Protect	Protect	Protect	Protect	Protect
PC02	Impaired	Impaired	Defer	Protect	Protect	Protect	Protect	Protect	Protect
PC03	Impaired	Protect	Impaired	Impaired	Protect	Protect	Protect	Protect	Project
PC04	Impaired	Protect	Impaired	Impaired	Protect	Protect	Protect	Protect	Project
PC05	Impaired	Protect	Protect	Impaired	Protect	Protect	Protect	Protect	Project
PC06	Impaired	Defer	Defer	Impaired	Protect	Protect	Protect	Protect	Protect
PC07	Impaired	Defer	Protect	Protect	Defer	Defer	Defer	Protect	Defer
PC08	Impaired	Defer	Impaired	Impaired	Protect	Protect	Protect	Protect	Project
PC09	Impaired	Protect	Impaired	Impaired	Protect	Protect	Protect	Protect	Project
PC10	Impaired	Protect	Protect	Impaired	Protect	Protect	Protect	Protect	Project
PC11	Protect	Protect	Protect	Protect	Protect	Protect	Defer	Protect	Protect
PC12	Protect	Protect	Impaired	Impaired	Protect	Protect	Protect	Protect	Project
PC13	Protect	Defer	Impaired	Impaired	Protect	Protect	Protect	Protect	Protect
PCA01	Defer	Defer	Defer	Protect	Protect	Protect	Defer	Defer	Defer
PCA02	Defer	Defer	Defer	Protect	Defer	Defer	Defer	Protect	Defer
PCA03	Defer	Defer	Defer	Protect	Defer	Defer	Defer	Protect	Defer
PCA04	Impaired	Defer	Defer	Protect	Defer	Defer	Defer	Protect	Defer
PCA05	Impaired	Defer	Defer	Protect	Protect	Protect	Protect	Protect	Protect
PCB01	Defer	Impaired	Impaired	Protect	Protect	Protect	Protect	Protect	Protect
PCB02	Defer	Defer	Impaired	Protect	Protect	Protect	Defer	Protect	Defer
PCB03	Defer	Defer	Protect	Impaired	Protect	Protect	Defer	Protect	Defer
PCB04	Defer	Defer	Protect	Impaired	Protect	Protect	Defer	Impaired	Defer
PCC01	Defer	Defer	Defer	Protect	Protect	Protect	Protect	Protect	Protect
PCC02	Defer	Defer	Defer	Protect	Defer	Defer	Defer	Defer	Defer
PCC03	Defer	Defer	Defer	Protect	Protect	Protect	Defer	Protect	Protect
PCC04	Defer	Defer	Defer	Protect	Defer	Defer	Protect	Protect	Protect/Defer*
PCC05	Defer	Defer	Defer	Protect	Defer	Defer	Defer	Protect	Defer

*Protect or defer depending on function

Socioeconomic parameters are those which may render potential stream restoration projects infeasible. In the prioritization ranking, additional parameters such as proximity to community centers are also considered. Additional ranking parameters include landowner complexity and land value, which both can preclude restoration projects.

Table 11 summarizes the ranking analysis. Each ranking criterion is scaled to a value between 0 and 1. The spreadsheet for this analysis is included in the MS Excel files submitted with this report. Based on this initial ranking, PC10 offers the most benefits with the fewest socioeconomic drawbacks. The City has already applied for FEMA funding for a significant portion of this reach for a constructed wetland to alleviate flooding in the area. Stream restoration may be incorporated into this project.

Connected riverine corridors have multiple ecological benefits (Fremier et al. 2015). Implementing PC12, PC10, PC09, and PC08 results in 1.5 miles of continuous stream that would be classified as “Protect” on almost every metric. Implementing PC05, PC04, and PC03 results in 2.5 miles of “Protect” stream reaches, for a total of over 4 miles of high-quality stream condition if all projects are completed. The “Defer” reaches in between the segments of restored stream (PC06 and PC07), while not priority projects, might be candidates for additional selected mitigation of specific conditions to improve connectivity for aquatic life. Additionally, if aquatic life communities recover in Peters Creek, then the creek might supply aquatic species to neighboring streams such as Mason’s Creek (west) and Lick Run (east).

7. FUNDING CONSIDERATIONS

Ultimately, funding availability may be the deciding factor in which, if any, projects are completed. As part of this project, City staff were consulted about programs that have funded watershed projects in the past, existing programs that might be appropriate, and the relevance of emerging funding mechanisms.

7.1 Existing Programs

Table 12 summarizes programs that the City has identified as potential sources of funding for stream restoration. Among these programs, the Virginia Stormwater Local Assistance Fund, managed by DEQ, offers the most likely and most immediate source of funding for stream restoration projects. SLAF distributes more than $20 million dollars to localities each year for stormwater management and watershed improvement projects. For 2021, more SLAF funding may be available for fiscally stressed communities; Roanoke is 17^{th} among the 20 most fiscally distressed communities, with a “high” fiscal stress rating (Virginia Department of Housing and Community Development 2020). This rating adds 75 points in the SLAF project scoring framework. The SLAF scoring system also prioritizes projects with channel erosion; BEHI and NBS methods are used to assess erosion. PC05, the second project in the preliminary ranking, may score well in the application for this program given the extensive length of stream bank (1997 LF) that screened as moderate or worse under the modified BEHI assessment.

7.2 Emerging Programs

In addition to the existing programs, several emerging funding mechanisms may be applicable to the Peters Creek watershed and are worthy of further investigation and monitoring as these programs become better developed.

7.2.1 Environmental Impact Bonds

Environmental impact bonds (EIBs) are an emerging, performance-based mechanism to fund public sector green infrastructure. These bonds are appropriate for large projects; upfront development is complex and can be expensive (A. Thompson 2020). While the current City projects are smaller than the typical EIB project, some localities are bundling multiple projects and this mechanism (or similar ones) may be adapted for smaller localities in the future. The City of Hampton recently closed on an EIB to fund $12 million in green infrastructure and flood mitigation projects (City of Hampton 2020).

Table 11. Summary of Unweighted Ranking Analysis

Ranking Criteria	PC12	PC10	PC09	PC08	PC05	PC04	PC03	Notes
Technical Factors								
City Goals Achieved	1	1	1	0.33	1	0.67	1	Reduce channel erosion, reconnect floodplain, aquatic life supply/lift; 1 point for each, divided by maximum score of 3
Location in Watershed (upstream of confluence)	0.95	0.84	0.77	0.72	0.58	0.44	0.26	Rivermile/total river miles
Stream Condition Score	0.60	0.63	0.60	0.57	0.60	0.66	0.66	Score/35, max. score; indicates potential condition functional lift
Max. Potential % Forest added w/in 100 ft buffer	0.51	0.45	0.48	0.54	0.39	0.33	0.11	(1-%FB)/100; indicates potential lift in Aquatic Life/LWD, habitat
Socioeconomic Factors								
Land Ownership Complexity	0	0.59	0	0	0.25	0.33	0	1-(Private Parcels/total parcels); more private ownership is more complex, thus lower score
Land Value	0.67	0.67	0.67	0.33	1	1	1	Publicly owned parcels are valued at “0” (no acquisition cost); low=<$25k/ac, medium= $25-$50k/ac; high=>$100k/ac
School or Community Center w/in half mile [~10 min. walk]	1	1	1	0	1	1	1	Yes=1; No=0
Score	**4.73**	**5.18**	**4.51**	**2.50**	**4.82**	**4.43**	**4.02**	
Rank	**3**	**1**	**4**	**7**	**2**	**5**	**6**	

Table 12. City of Roanoke Potential Funding Sources (Source: City of Roanoke Stormwater Utility Department)

Program	Agency	Total Amount Available	Grant Contribution %	Reasonable Project Scale
Community Flood Preparedness Fund (Preliminary as of 4/14/21)	Virginia DCR	$18M Statewide	50 - 75% depending on level of GI used. Can be up to 90% for low income area projects	Minimum $50K for projects, $25K for capacity building...no upper limit
VA Dam Safety, Flood Prevention and Protection Fund (Dam Safety)	Virginia DCR	$600K	50%	~$50K
VA Dam Safety, Flood Prevention and Protection Fund (Flood Prevention)	Virginia DCR			
Five-Star and Urban Watershed	National Fish and Wildlife Foundation (NFWF)	$50k		
Stormwater Local Assistance Fund (SLAF)	Virginia Dept. of Environmental Quality		50%	
Building Resilient Infrastructure and Communities (BRIC)	Federal Emergency Management Agency (FEMA)	$446.4M National Competition + $33.6M divided by 50 states	75%	Up to $600K for state competition; Up to $50M for national competition
Revenue Sharing	Virginia Dept. of Transportation (VDOT)			
Land and Water Conservation Fund (LWCF)	Virginia DCR	$8M	50%	
Surface Transportation Block Grants	FHWA		100%	
Forest Service Urban & Community Forestry	USDA/USFS		50%	Awards from $100-300K
Open Space Recreation and Conservation Fund	Virginia DCR			Awards from $20 - 50K
People for Bikes Community Grant	People for Bikes		50% Max	$10K/Grant
National Fish Passage Program in the Northeast	US Fish and Wildlife Service	$1M	Partners match FWS dollars 5:1	$50-75K
Section 106 Supplemental Disaster Funding (Hurricane Florence Fund)	Virginia DEQ	$226K Statewide	75%	$50 - 100K
Virginia Program	Virginia Environmental Endowment	18 grants totaling $5M in VA and WVA in 2020		$5K - $1.6M

7.2.2 Business Environmental Outreach

Peters Creek has numerous commercial and industrial landowners. These landowners may be an untapped resource for improving stream health. Many corporations seeking to improve environment, social, and governance (ESG) scores. Funding environmental projects is one method of improving these scores or for businesses to contribute to their local community. Additionally, the City may wish to offer incentives to businesses that support watershed improvement projects. For example, in the Elizabeth River watershed, the Elizabeth River Project offers the "River Star Business" program, which encourages, assists, and recognizes businesses that fund watershed improvement projects. The program website lists several recent projects, including an award-winning living shoreline project implemented by Norfolk Southern Corporation. Norfolk Southern included this project in its annual Corporate Responsibility Report (Norfolk Southern Corporation 2020) and Green Financing Framework (Norfolk Southern Corporation 2021). Norfolk Southern is also a landowner on Peters Creek. Steel Dynamics, another corporate riparian landowner, also has a well-developed sustainability program that publicly commits to environmental and community programs (Steel Dynamics Inc. 2019).

7.2.3 Environmental Justice

Environmental justice programs are also an emerging source of funding, or an addition to existing funding mechanisms. The population in the Peters Creek watershed is 57% Black, and the largest age demographic by decade is children under 10 (City of Roanoke 2019). Stream restoration projects typically benefit rural communities; however historically underserved urban communities can also realize benefits from improved stream health (Moran 2010; Dernoga et al. 2015; Angermeier et al. 2021). One example of a source of environmental justice funding is USEPA's Environmental Justice Small Grants program (USEPA 2021b, 2021a). Although this program is directed at incorporated nonprofits rather than municipal government, USEPA encourages partnering with eligible community groups to qualify for funding. This program regularly funds watershed improvement projects (USEPA Office of Environmental Justice 2021a). For example, a grant from this program to a community organization in Buffalo, NY, funded the installation of a riparian buffer and erosion control measures on an urban industrial site (USEPA Office of Environmental Justice 2021b).

8. CONCLUSIONS AND RECOMMENDATIONS

The Peters Creek Case Study clearly identified several stream restoration projects that may mitigate impaired stream functions and move Peters Creek towards a condition suitable for delisting. City staff can implement the assessment and prioritization approach used in this study on other streams without relying on additional expertise or tools other than those that the City already has in place. The approach developed in this study also identified several projects that may be missed by typical traditional evaluations, such as identifying projects based on sediment load reduction alone.

Based on the results of this study, the following additional actions are recommended to implement these methods across the City watershed:

- **Extend the Peters Creek reach condition assessment into Roanoke County.** The scope of this project was limited to the portion of the Peters Creek watershed within the City of Roanoke. About 40% of the watershed lies in Roanoke County, including the headwaters of Peters Creek. A preliminary, drive-by survey indicates that stream conditions are less degraded in Roanoke County. A formal survey and monitoring of these conditions, however, may help to alert the City to upstream changes that might affect downstream conditions in the City. The City may wish to explore partnering and sharing resources with Roanoke County in this effort.

- **Refine bed/substrate assessment.** Induced turbidity is an experimental parameter that shows promise as a quantitative, rapid assessment indicator for fine sediments. Additional research is needed, however, to determine how well induced turbidity agrees with TSS, embeddedness, or other traditional measures of fine sediment. Additionally, it may be possible to develop a field questionnaire for bed/substrate condition similar to the modified BEHI questionnaire.

- **Compare modified BEHI to full BEHI for Peters Creek.** If the City seeks funding for Peters Creek projects under SLAF, a full BEHI assessment will be required for the project application. The modified BEHI assessment can be compared with the full BEHI to confirm that the modified method applies to the Roanoke watershed. Although the methods agreed in the City of Cleveland watershed analysis, these results should also be confirmed in the City of Roanoke watershed.

- **Develop additional biological and ecosystem data.** This study was limited by limited biological data. Two recent VSCI scores and three Citizen Science scores were available, but several values were for the same reaches of the creek. Additional biological data, such as baseline VSCI scores for the projects identified or additional baseline leaf decomposition data should be developed.

- **Apply the assessment and prioritization method to another creek/watershed.** For comparison, another stream should be evaluated using the methodology developed in this case study. Lick Run, which was another stream considered as a possible case study, may be a good candidate for the next assessment. Additionally, the next assessment should align the analysis with potential funding mechanism and verify that screening breakpoints used in the Peters Creek study are appropriate for other watersheds. Peters Creek parameters and breakpoints happened to align with SLAF; the next study may evaluate additional parameters based on the requirements of other funding programs. The assessment and ranking approach for Peters Creek can be applied to individual streams in the City and across watersheds to rank the streams themselves. Although cross-stream ranking is not developed in this project, once data is available for multiple streams, the ranking/suitability tool can be populated with reaches for multiple streams and these reaches compared to one another. For instance, ranking might show more benefit in a headwater reach of Mason's Creek as compared to a reach on Tinker Creek near the confluence with the Roanoke River.

- **Evaluate retention/placement of large woody debris (LWD).** An increasing body of research indicates that retaining or placing large woody debris in streams improves multiple stream functions and supports aquatic life (Wohl et al. 2019). The field assessment notes multiple reaches where LWD is present or has the potential to be present. City staff have noted that the current policy regarding LWD in City streams is under review. It is recommended that LWD be allowed to remain in streams if it does not present human or property hazards; some available research offers guidance on developing LWD hazard assessment and retention/removal policy (Wohl et al. 2016).

- **Evaluate including PCB remediation in stream projects.** Peters Creek is also impaired based on PCB concentrations in the creek. Can PCB remediation be incorporated into stream restoration activities? Passive or in-situ remediation of PCBs may be possible to include in some reach restoration activities and should be considered in project design if PCBs are present in the reach.

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APPENDIX A: SUMMARY OF EXISTING DATA FOR PETERS CREEK

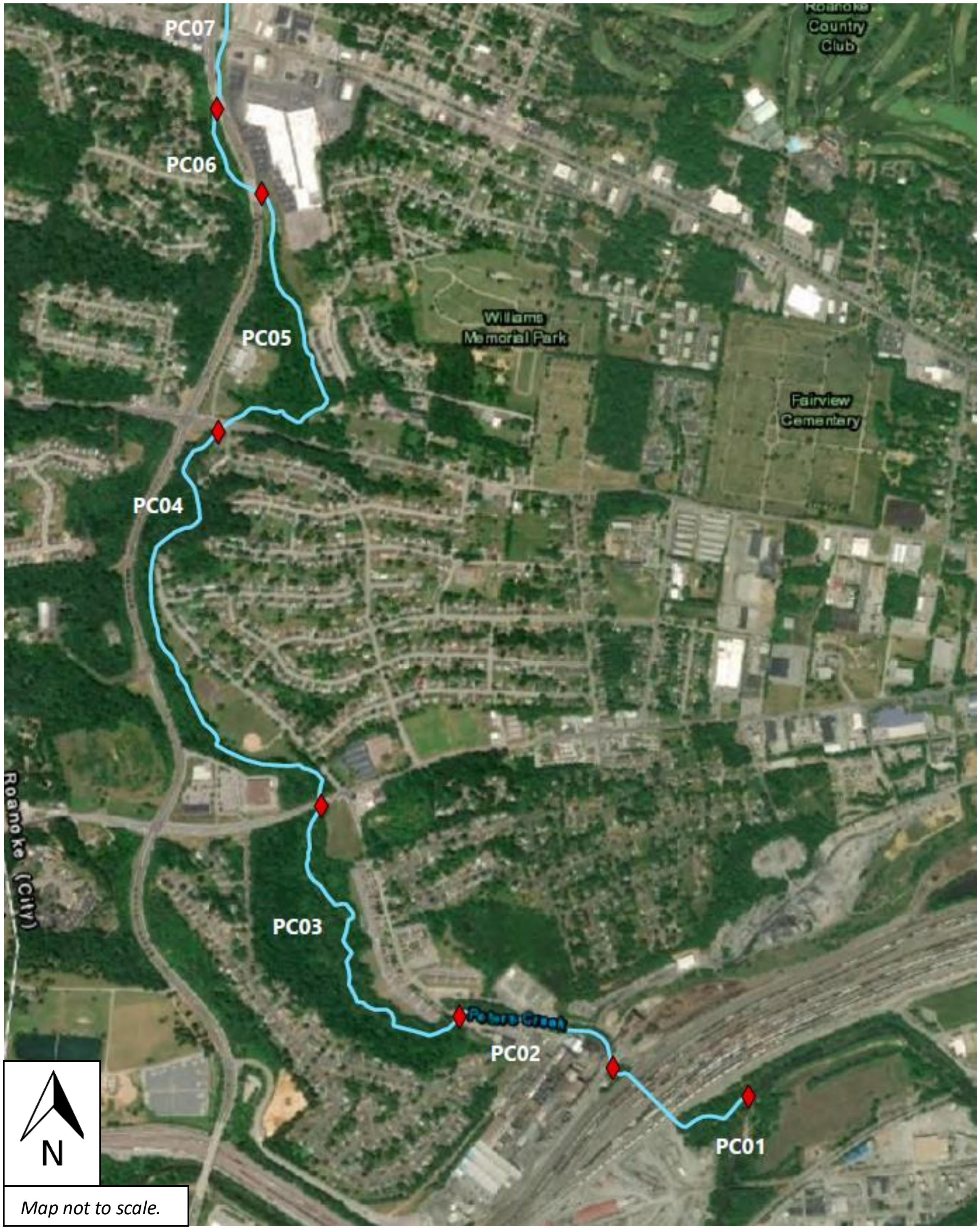
Summary of Stream Function Data Available for Peters Creek

Stream Function	Data Available
Hydrology	
Precipitation	• 2 NOAA gages (Carvins Cove WTP and Airport) • 9 USGS gages
Discharge	• Depth readings from a new flood sensor located at intersection of Peters Creek Rd and Rt. 460/11; 1 storm recorded. Future results will be used to develop a stage-discharge rating curve based on sensor data • 5 days of stream gage data from temporary USGS gage on Peters Creek in 2018 (Hurricane Florence) • Flow estimates performed during biological sampling, 2x per year
Land cover	GIS layer, VSLCD
Land use	GIS layer; parcel layer shows zoning
Soils	GIS layer; 51% HSG D, 8% Urban Udorthents, remainder is mixed. Headwaters & south of Hershberger Rd. are type D; Have K value estimates.
Digital Elevation Mapping (DEM)	GIS layer; 1 m x 1 m, VGIN, no post-processing.
Stormwater infrastructure/BMP locations	GIS layer showing BMPs, stormwater conveyances, and nodes
CN estimate	59-98, Weighted estimate = 80.4; although forested, headwaters have high CN because of soil type D
Hydraulics	
Stream morphology ID	GIS; Survey of streams organizing segments into piped, channelized, re-routed, or natural condition
Floodplain/Floodway	GIS; FEMA floodplain/floodway location
Floodplain connectivity	GIS; survey notes for selected reaches regarding "erosion depth"
Transects	GIS; FEMA and city transects/cross sections for 5 locations; bank height ratios, bank angles. Cross sections can also be generated from the DEM layer.
Geomorphology	
Bank Stability	GIS survey notes on erosion length and depth for selected points (about 40, some at R/L bank for same location); RBP assessment at sampling points. Note: More complete survey data may be available in the future. The City has expressed a need for a systematic means of assessing bank stability and erosion
Riparian vegetation	GIS; Land cover
Bed material	RBP assessment at 2 biological sampling points
Bed diversity	RBP assessment at 2 biological sampling points
Physicochemistry	
Bacteria	12 sampling points, 9 of which have more than 3 samples
pH/Temp/DO/Conductivity	2 sampling points, conducted with biological surveys 8 total locations for various other sampling events (DEQ, City)
PCBs	2 samples; median 14.9 ug/l (no fish data)
Other parameters (nutrients, TSS, organic carbon, etc.)	See Peters Creek WMP, p. 81, Figure 3.57 for data summary

Stream Function	Data Available
Biology	
Benthic Macroinvertebrates Survey/VSCI	Data available for 2 sampling locations, 2x per year since 2015 (Excel tables and report for each event)
USEPA RBP scores	GIS; Scores at sampling locations, 2x per year since 2018 (Excel table and report for each event)
Citizen Science monitoring	GIS; SOS scores
Ecological function	Leaf decomposition rate; S. Entrekin project/ongoing

APPENDIX B: PETERS CREEK REACH MAP

Upper Peters Creek Reaches



Lower Peters Creek Reaches

APPENDIX C: FIELD SURVEY SHEETS

PC08 Field Survey

Channel Erosion	
RB	LB

WQ Sample	LWD	Hazard

Notes

Stream Field Survey

Reach	
Surveyor name	
Date	
Time	

Walk the length of the reach, note locations of the following features on the survey map:

<table>
<tr><th>Parameter</th><th colspan="5">Notes</th></tr>
<tr><td>a. Hazard</td><td colspan="5"></td></tr>
<tr><td>• Vertical bank height 5 feet or greater</td><td colspan="5"></td></tr>
<tr><td>• BEHI: 2 yes answers within 15 feet of public or private infrastructure</td><td colspan="5"></td></tr>
<tr><td>• Exposed sanitary or storm sewer lines</td><td colspan="5"></td></tr>
<tr><td>b. Bank Conditions</td><td colspan="5"></td></tr>
<tr><td colspan="6">If the answer to two or more of the following questions is “yes,” then note the location on the survey map and the extent of the eroded bank.</td></tr>
<tr><td></td><td>_Bank _</td><td>_Bank _</td><td>_Bank _</td><td>_Bank_</td><td>_Bank_</td></tr>
<tr><td>1. Does the uniform section of bank exhibit less than or equal to 50% protection at the toe of the bank? The toe is located at the base of the bank where it meets the water during base flow conditions; on average the bottom six to eight inches of the bank. Protection includes embedded boulders, embedded large woody debris, and rooted vegetation. Bedrock counts as toe protection; however, easily breakable bedrock is not toe protection.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2. Does 50% or more of the bank exhibit an undercut of 0.5 feet or more? An undercut bank is a streambank that has undergone erosion beneath the ground surface.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3. Does 50% or more of the bank exhibit stratification? Stratification is a clearly defined horizontal break in geology. One layer of the stratification must be composed of an erodible material (sand, gravel, or matrix).</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4. Does 50% or more of the bank have a bank height of ten feet or more with 50% or more soil exposure?</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>5. Does 50% or more of the bank exhibit bare roots (roots lacking bank material/soil)?</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>6. Is 50% or more of the bank void of rooted vegetation?</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>c. Large Woody Debris</td><td colspan="5">Present/Notes</td></tr>
<tr><td>If no LWD is present on the reach, note “none” at right. If LWD is present, then note “Present” and locate on the survey map the area of the reach that has the most LWD. LWD is defined as woody material that is nonliving, longer than 1 m (3 ft.) and greater than 10 cm (5 in.) in diameter at the largest point. LWD must be In the channel, touching the banks of the channel, or bridged over the channel.</td><td colspan="5"></td></tr>
<tr><td>d. Water Quality Sampling Sites</td><td colspan="5">Site/W-D</td></tr>
<tr><td>See page 2 for WQ sampling site selection and instructions. Note the number of samples at right and locations on the survey map; note width to depth ratio at right.</td><td colspan="5"></td></tr>
</table>

Stream Field Survey, p. 2

Water Quality Sampling Procedure:

- Sample location must be at least 20 channel widths distance from a bridge, culvert, or other crossing. For instance, if the channel is 10 feet wide, then the location must be 200 feet from a crossing.
- Additional samples are recommended where the channel type changes or stream bed material changes significantly (for instance, a change from bedrock to gravel).
- Choose sampling locations in riffles if riffles are present. If riffles are not present, sample a location in the middle of the stream that represents conditions in that section of the reach.
- Water depth must be at least 4 in. so that sampling probe is submerged.

Water quality sampling instructions:

1. Turn the multimeter on and enter the reach ID and sample ID.
2. Attach the sonde of the water quality meter to the horizontal rod in the sampling well. Make sure that the bottom of the sonde is even with the bottom of the sampling well.
3. Carefully lower the sampling well and sonde into the stream, to a point just above the stream bed but not touching or disturbing bed materials. Start the sample logging by pressing the "Enter" button.
4. Allow the initial reading to stabilize.
5. Lower the sampling well onto the stream bed. Press and rotate the sampling well to embed it in the stream bottom.
6. Using the stirring rod, disturb the stream bed around the multimeter sonde. Dig into the bed and dislodge as much material as possible.
7. Watch the meter reading for turbidity values. When turbidity reaches a maximum, stop disturbing the bed material. When the turbidity value begins to consistently decline, press "Enter" to stop logging.

Width-to-Depth Ratio

At the water quality sampling site, measure stream width from top of bank on each side and measure depth from top of bank. Note measurements in the field survey form.

APPENDIX D: STREAM CONDITION DATA (DESKTOP AND FIELD SURVEY)

Peters Creek Stream Condition Data

	PC01	PC02	PC03	PC04	PC05	PC06	PC07	PC08	PC09	PC10	PC11	PC12	PC13	PCA01	PCA02	PCA03	PCA04	PCA05	PCB01	PCB02	PCB03	PCB04	PCC01	PCC02	PCC03	PCC04	PCC05
Reach Length	1414	1494	2922	4253	2890	853	1160	1118	1401	1576	557	1981	1137	504	1019	447	599	680	865	571	1584	1531	548	489	522	701	900
Rivermile	0.3	0.6	1.1	1.9	2.5	2.6	2.8	3.1	3.3	3.6	3.7	4.1	4.3	3.6	3.8	3.8	4.0	4.1	3.6	3.7	4.0	4.3	3.7	3.8	3.9	4.0	4.2
Reach Watershed Area (ac)	5784.1	5740.1	5650.7	5487.7	5046.9	4586.4	4486.6	4099.9	4055.4	3835.1	2464.9	2461.7	2391.0	213.1	211.1	189.3	128.4	113.0	512	504.6	492.6	469.3	594.7	587.2	579.0	569.2	493.4
Hazard present?	N	N	N	Y	Y	N	N	Y	Y	Y	N	Y	Y	N	Y	N	N	N	N	N	N	N	N	Y	N	Y	N
Hazards	1	0	0	2	2	1	0	4	2	3	0	3	2	0	0	1	0	0	0	0	1	2	0	1	1	1	0
Hydrology																											
%Forest	43.8	44.1	44.4	44.6	45.9	47.6	48.0	50.6	50.9	51.5	67.2	67.3	68.7	22.0	22.1	22.8	28.6	30.0	26.1	25.5	25.2	24.8	20.7	20.5	20.4	20.7	19.2
%Impervious	23.9	23.4	23.1	22.9	22.2	21.5	21.1	18.8	18.5	18.1	9.9	9.9	9.1	27.6	27.5	25.0	19.4	18.1	33.6	34.0	34.1	34.0	33.7	33.5	33.1	33.1	33.7
%MgdTurf	32.3	32.6	32.5	32.5	31.9	30.9	30.8	30.6	30.6	30.4	22.9	22.9	22.2	50.4	50.3	52.2	52.0	51.9	40.3	40.5	40.7	41.2	45.6	46.1	46.5	46.2	47.1
%Agricultural	25.1	25.3	25.7	26.4	28.7	31.6	32.3	35.4	35.7	37.8	58.8	58.9	60.6	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
%Comm/Ind	11.8	11.2	10.6	10.7	10.1	10.5	10.5	8.9	8.7	8.1	2.4	2.4	2.2	8.8	8.2	2.7	3.0	3.4	15.8	16.0	16.4	17.2	23.5	22.7	22.2	21.7	20.8
%Park/ROW	12.7	12.8	12.9	12.7	12.0	10.8	10.7	9.6	9.5	9.4	6.9	6.9	6.6	13.0	12.9	12.5	9.4	9.4	11.9	12.0	11.9	11.7	15.8	15.8	15.7	15.7	15.4
%Residential	50.4	50.8	50.8	50.1	49.1	47.1	46.5	46.2	46.1	44.7	31.9	31.9	30.6	78.2	78.9	84.8	87.6	87.2	72.3	71.9	71.7	71.1	60.7	61.4	62.1	62.7	63.8
Hydraulics																											
W-D Ratio	4.5	1.2	6	8.5	6	4.9	12	5.3	5.25	4.9	20	6	6.5	NA	4	2	5.5	4.5	9.3	5.5	3.9	4	5.6	NA	3.5	9.5	8
100 yr FP width max (ft)	335	659	1123	738	1225	189	1284	649	783	1638	1030	642	514	NA	NA	NA	NA	NA	215	288	365	341	219	NA	NA	NA	NA
100 yr FP width max (ft), no structures	335	201	658	701	1225	121	107	185	695	872	418	582	115	NA	NA	NA	NA	NA	215	125	147	116	191	NA	NA	NA	NA
Max 100 yr FPW/ Sqrt WS Area	0.02	0.04	0.07	0.05	0.08	0.01	0.09	0.05	0.06	0.13	0.10	0.06	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.06	0.08	0.08	0.04	0.00	0.00	0.00	0.00
Geomorphology																											
BEHI-LF	173	110	1415	2328	1997	282	0	825	1244	498	0	759	737	0	0	0	0	0	112	139	361	453	105	0	0	0	0
%Forest-30 ft buffer	41.9	38.8	96.3	84.8	77.4	81.8	11.2	62.4	64.4	71.9	54.8	71.1	64.4	17.6	12.5	5.3	11.2	69.0	93.1	46.0	55.0	59.0	74.6	0.0	21.6	0.0	1.8
%Forest-100 ft buffer	39.3	22.6	88.8	66.9	61.2	74.6	7.5	46.1	51.9	54.7	36.7	48.6	29.5	17.3	13.4	2.8	5.5	55.6	88.1	39.3	47.0	40.9	47.2	2.0	48.9	2.2	2.7
LWD/Supply Present	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	P	Y	Y	N	N	N	N	Y	N	N	N	N	Y	N	N	Y	N

	PC01	PC02	PC03	PC04	PC05	PC06	PC07	PC08	PC09	PC10	PC11	PC12	PC13	PCA01	PCA02	PCA03	PCA04	PCA05	PCB01	PCB02	PCB03	PCB04	PCC01	PCC02	PCC03	PCC04	PCC05
Water Quality																											
Temperature (F), avg	57	59	61	57	53	52	55	54	57	55	51	52	51	NA	63	63	61	60	53	52	64	50	55	NA	55	53	51
pH (min)	8.71	9.6	9.31	8.84	8.66	8.7	8.9	8.8	9.41	8.8	9.26	8.19	7.55	NA	9.29	9.57	9.69	9.4	9.25	9.43	9.89	8.01	9.25	NA	9.12	9.38	9.25
pH (max)	10.45	9.81	9.49	9.1	9.21	9.16	9.01	9.37	9.72	9.89	9.74	10.48	9.98	NA	9.34	9.87	10.1	9.63	9.31	9.56	10.1	9.42	9.39	NA	9.26	9.6	9.85
DO (mg/l), max	11.3	12.89	12.65	13.32	13.54	13.28	12.77	13.02	11.66	13.47	12.55	12.44	12.25	NA	9.71	9.75	9.09	9.11	14.05	14.26	11.06	13.51	11.8	NA	12.86	13.77	13.17
Sp. Conductance (us/cm), max	363.9	339	338	453	457	469	448	446	433	411	306	315	207	NA	468	476	472	416	493	494	451	501	403	NA	486	457	465
Turbidity (FNU), min	-4.56	-4.98	-4.73	-5.87	-5.44	-5.41	-4.81	-4.77	-0.36	-5.18	-4.94	-4.82	-2.54	NA	-1.24	-4.25	-4.57	-1.37	-4.8	-3.82	-4.76	0.83	-3.73	NA	-4.93	-4.77	-4.81
Turbidity (FNU), max disturbed	625	55	310	139	308	190	117	267	122	363	117	465	112	NA	670	321	1594	446	147	484	382	564	257	NA	83.83	594	985
Biology																											
VSCI (most recent)			53.4							57.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CS (most recent)				8						10	NA	NA	11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

APPENDIX E: BIOLOGICAL SURVEY DATA

Summary of Results

Stream (type, location)	Jabs (6)	Hess (4)	Leaf Bags (6)
Peters Creek (PC10)	55.8	33	29
Lick Run (Urban, by Valley View mall)	45.5	43	24
Flatwoods Branch (rural, upstream of City)	71.4	69	37

Detailed VSCI Metrics

VSCI metrics generated from Hess samples			
Metric	Peters Creek	Lick Run	Flatwoods Branch
Taxa Richness	15	15	26
Abundance	431	261	239
EPT Index	5	5	14
%Ephemeroptera	1.62	1.53	10.88
%P+T-Hydropsych.	7.42	2.68	40.59
%Scrapers	6.03	26.82	8.79
% Chironomidae	78.19	53.64	40.59
% 2 DXminant	80.97	61.30	55.65
MFBI	5.60	5.66	3.85
VSCI metrics generated from jab samples			
Metric	Peters Creek	Lick Run	Flatwoods Branch
Taxa Richness	18	16	25
Abundance	177	135	531
EPT Index	7	6	13
%Ephemeroptera	4.52	2.96	14.50
%P+T-Hydropsych.	24.29	2.22	46.14
%Scrapers	12.43	14.07	3.58
% Chironomidae	38.42	31.85	22.03
% 2 DXminant	57.63	53.33	54.24
MFBI	4.64	5.76	3.41
VSCI metrics generated from leaf bags			
Metric	Peters Creek	Lick Run	Flatwoods Branch
Taxa Richness	11	10	16
Abundance	762	705	1364
EPT Index	3	4	8
%Ephemeroptera	0.26	0.14	0.88
%P+T-Hydropsych.	0.79	0.43	1.25
%Scrapers	0.13	5.82	0.66
% Chironomidae	74.02	63.83	84.38
% 2 DXminant	93.70	90.50	95.89
MFBI	6.45	6.57	6.17