Metropolitan Government of Nashville & Davidson County

Richland Creek Watershed Management Plan

Prepared by Metro Water Services Stormwater Division

12/20/2016

Contents

Watershed Characterization

General Overview

The Richland Creek Watershed consists of approximately 17,712 acres (~26.5 sq. miles). It is located in EcoRegion 4 (EPA); and the Outer Nashville Basin (TDEC ecoregion). The Richland Creek Watershed is within the city of Nashville in the southwestern portion of Davidson County approximately 4 miles from downtown (Figure 1). The 28.5 square mile basin is somewhat pear shaped and flows in a north to northwesterly direction from the community of Forest Hills to the confluence with the Cumberland River. The watershed includes 6 named tributaries; Vaughn's Gap Branch, Belle Meade Branch, Sugartree Creek, Bosley Springs Branch, Murphy Road Branch, Jocelyn Hollow Branch and two larger unnamed tributaries.

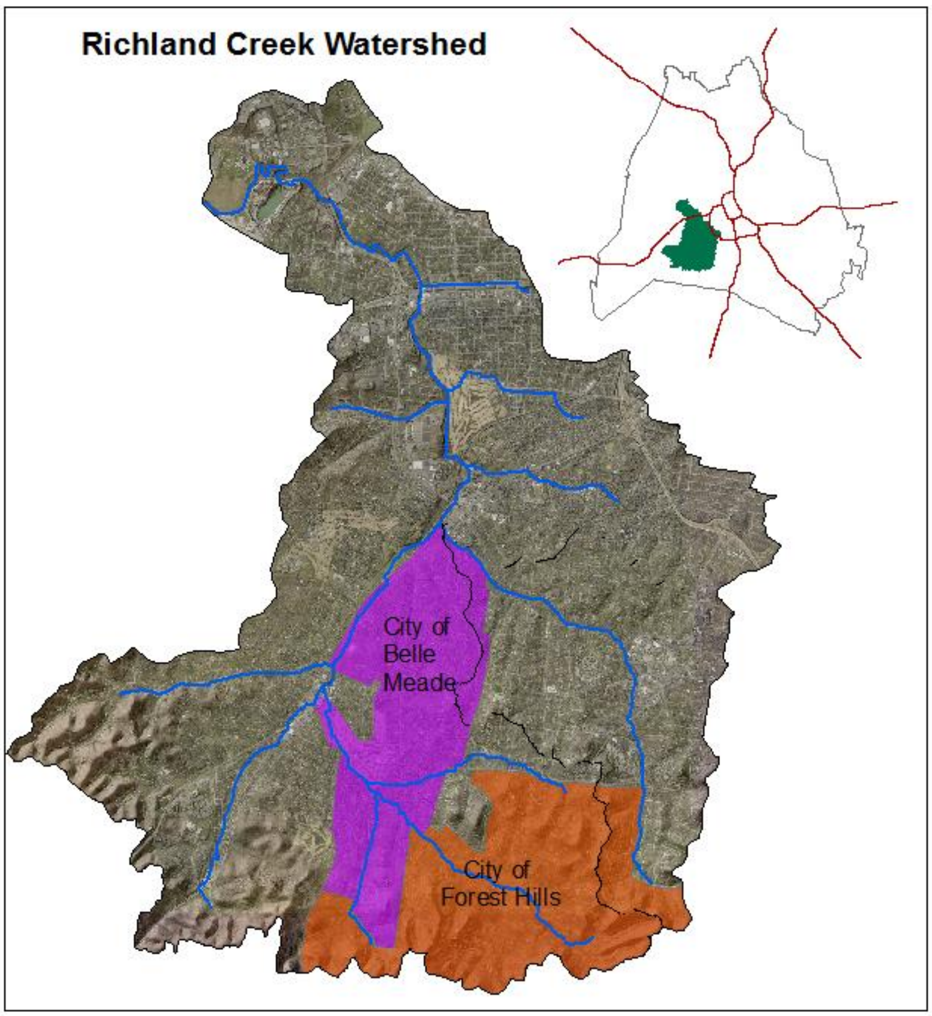


Figure 1. Richland Creek Watershed and its major tributaries. Satellite cities are highlighted.

The Outer Nashville Basin is a heterogeneous region with rolling, hilly topography. The dominant land covers include deciduous forest, pasture and cropland. Streams are low to moderate gradient, with productive, nutrient-rich waters, resulting in algae, rooted vegetation, and occasionally high densities of fish.

The region has areas of intense urban development and includes the City of Belle Meade and the City of Forest Hills which are both primarily residential. The watershed area includes a mix of urban and rural land uses. The north and east portions of the watershed are closer to the city center of Nashville and thus more densely populated and urban, while the south and west sections are more suburban and less densely populated. The majority of the Richland Creek's watershed, including that of the tributaries, is developed and the land use is predominantly medium-density residential. The existing commercial development largely consists of a number of shopping centers and strip developments along sections of major arteries, including Harding Pike, Hillsboro Pike, and Charlotte Pike. The largest areas of commercial development are the areas around Saint Thomas Hospital (between the confluence and river mile 0.6 of the tributary to Richland Creek), Green Hills Mall (between river miles 2.3 and 2.8 on Sugartree Creek), and the Harding Pike (Highway 70)/Highway 100 split (from the confluence to river mile 0.34 on Vaughn's Gap Branch). At present, the majority of industrial development is within the lower portions of Richland Creek Watershed, which includes a rock quarry, a concrete mixing facility, and several large petroleum bulk storage terminals. The pattern of urbanization in the Richland Creek Watershed has been influenced to some extent by existing natural features and the provision of certain major transportation links, as well as the provision of utility extensions.

Topography

The topography is characterized by flat to gently sloping plains in the northern portions of the watershed with occasional steep uplands in the southern portions. Elevations in the watershed range from 350 to 1,100 feet with streambed elevations ranging from approximately 380 feet above mean sea level (MSL) at the Richland Creek confluence with the Cumberland River to around 650 feet above MSL in the upper extremes of the watershed. As shown in Figure 2, the steeper slopes are concentrated in the headwaters of Jocelyn Hollow Branch, Vaughn's Gap Branch, Richland Creek and Belle Meade Branch.

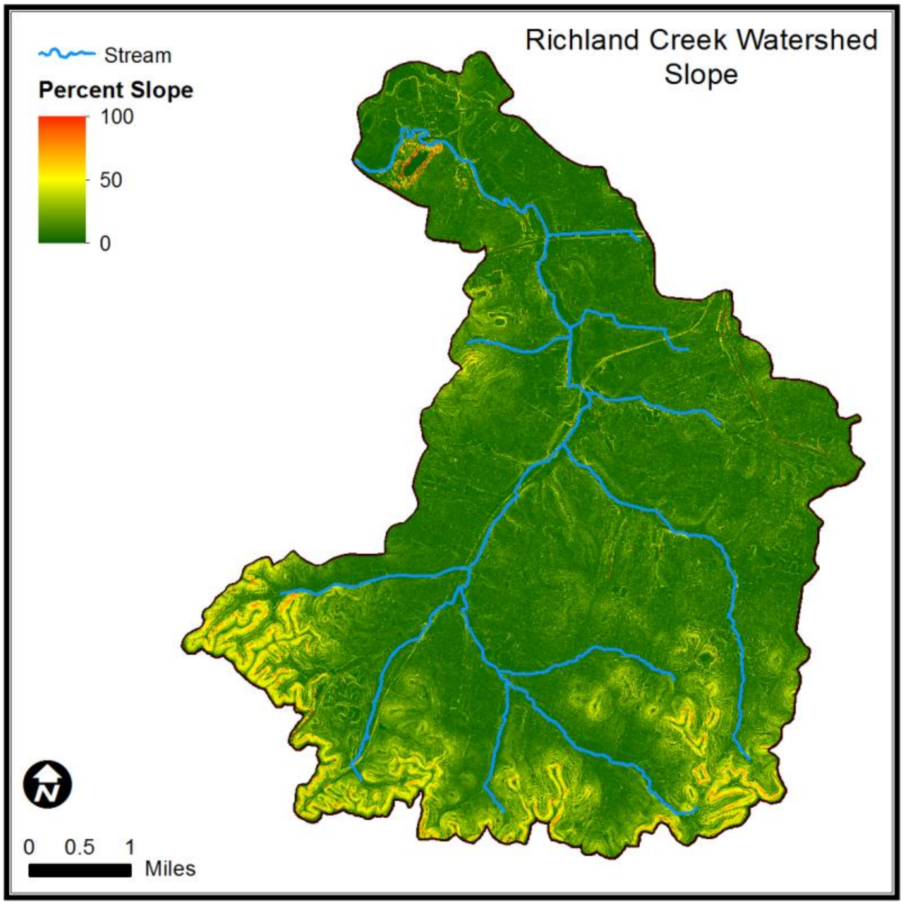


Figure 2. Richland Creek Watershed Slope

Geology

The Richland Creek basin is on the northwest dipping Ordovician limestone of the Nashville Basin. A low structural arch, called the Nashville Dome, exposes a large area of Ordovician rocks from which all overlying younger rocks have been removed by erosion. The majority of the northern portion of the Richland Creek Watershed is located in the Lower Cumberland Basin, which is underlain primarily by Ordovician-age fine to coarse grained interbedded limestone with the majority consisting of the Hermitage, Bigby-Canon and Leipers-Cathey formations. The higher hills and knobs mainly in the south western portions of the watershed are capped by the more cherty Mississippian-age layers, mainly the Fort Payne formation, and some Devonian-age Chattanooga shale, which are remnants of the western Highland Rim. The region's limestone rocks and soils are high in phosphorus, and historically phosphate has been mined commercially throughout the region.

The bedrock is characteristic of the Nashville Group, ranging in thickness from 50 to 175 feet and consisting predominantly of limestone and minor amounts of shale. The sedimentary rock is typically fractured or jointed and, where thick sequences of limestone occur near the surface, internal drainage may dissolve the rock and produce widened joints and sinkholes. Most of this watershed is underlain by bedrock with a low potential for karst development.

Soils

Soils in the area are mainly derived from limestone, with some shale and old alluvium. Depths range from 3 to 10 feet and subsoils generally consist of clay, silty clay, or silty-clay loam. Slopes are classified as low and high with low slopes containing less than a 10 percent grade, while high slopes containing greater than a 10 percent grade. Many of the high slopes are located in the headwaters of the Richland Creek watershed and are also located along reach and road corridors, as well as commercial and high residential land uses. Over 60 percent of the watershed consists of the Maury Urban Land complex and Mimosa Urban Land complex soils. These soils are deep to very deep, well drained, slowly to moderately permeable soils, formed from mainly weathered phosphatic limestone. These soil slopes range from 2 to 15 percent and are found on gently sloping to steep uplands with medium to rapid runoff. Less than 2 percent of the soils listed in the watershed are hydric soils, or soils that formed under conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper soil horizon. The soil variation within Richland Creek watershed can be seen in Figure 3.

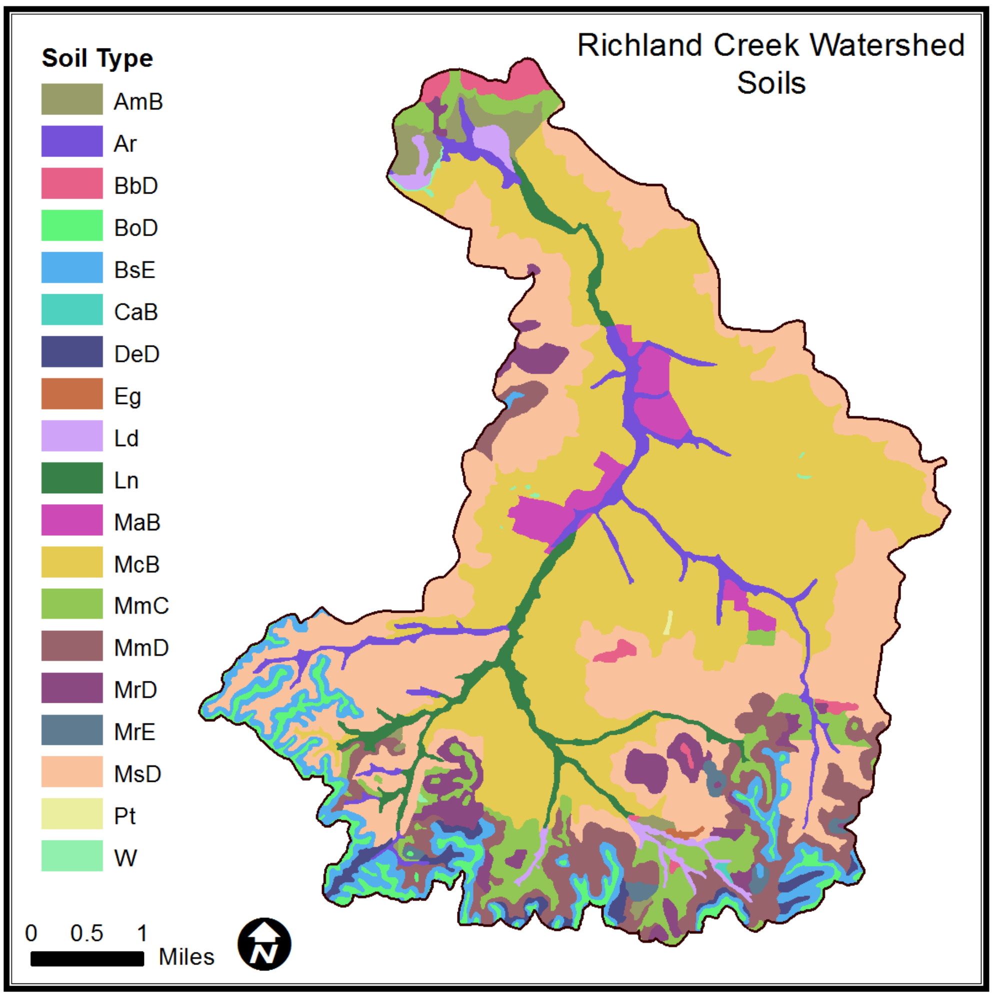


Figure 3. Soil geomorphology within Richland Creek Watershed.

Stream Characteristics

Streambeds of the basin are composed of limestone rock. Stream bank cover and condition varies depending upon adjacent land use. In urbanized areas along the streams, banks have been greatly disturbed. Structures have been built immediately adjacent to or over the channels, and the banks have been lined with stone. In the areas that are undeveloped, banks are either planted with grass or covered with brush and small trees. The stream channels average 20 to 50 feet in width with bank heights ranging from a gentle upslope to over 10 feet high. Streambed gradients increase from about 12 feet per mile near the downstream portion of Richland Creek to almost 35 feet per mile in the upstream reaches. The floodplain along Richland Creek has a mean width of 600 to 800 feet, while the floodplains along the tributaries have a mean width of 150 to 275 feet.

Environmental Setting

The Tributaries to Richland Creek flow through predominantly urban settings. Development density is greatest near West End Avenue, Harding Pike, Highway 100, and Hillsboro Pike. There is some commercial development in the floodplain around the White Bridge Road area on Richland Creek. In the undeveloped areas along the streams, the floodplain contains grasses and small woodland areas that serve as habitat for mammals, songbirds, and various reptiles and amphibians. Several threatened or endangered flora and fauna have been identified in Davidson County, which may likely be present within the urbanized Richland Creek study reach (Table 1). Most of the tributary reaches flow through residential areas. There are four golf courses in the Richland Creek Watershed. There are also several large parks located in the Richland Creek Watershed, including McCabe Park and Percy Warner Park.

Table 1. Species of concern in Davidson County.

Scientific Name[2]	Common Name	Major Group
**Apios priceana*	Price's Potato-bean	Flowering Plants
**Dalea foliosa*	Leafy Prairie-clover	Flowering Plants
Lilium michiganense	Michigan Lily	Flowering Plants
**Lesquerella globosa*	Lesquereux's Mustard	Flowering Plants
**Crataegus harbisonii*	Harbison's Hawthorn	Flowering Plants
Physaria globosa	Plant Short's bladderpod	Flowering Plants
Carex davisii	David’s Sedge	Flowering Plants
Crataegus harbisonii	Harbison’s Hawthorn	Flowering Plants
Perideridia americana	Thicket Parsley	Flowering Plants
Stellaria fontinalis	Water Stitchwort	Flowering Plants
Ambystoma barbouri	Streamside Salamander	Amphibian
**Etheostoma microlepidum*	Smallscale Darter	Freshwater and Anadromous
**Lampsilis abrupta*	Pink Mucket	Freshwater Mussels
**Obovaria retusa*	Ring Pink	Freshwater Mussels
**Plethobasus cooperianus*	Orangefoot Pimpleback	Freshwater Mussels
Epioblasma brevidens	Cumberlandian combshell	Freshwater Mussels
Aimophila aestivalis	Bachman’s Sparrow	Bird
Tyto alba	Common Barn Owl	Bird
Ophisaurus attenuates	Eastern Slender Glass Lizard	Reptile

*Historically identified in Richland Creek watershed.
Source: U.S. Fish & Wildlife Service Environmental Conservation Online System (ECOS) 2015

Impaired Waterbodies

According to TDEC, Richland Creek and its tributaries including Vaughn's Gap Branch, Belle Meade Branch, Sugartree Creek, Bosley Springs Branch, Murphy Road Branch and Jocelyn Hollow Branch are listed as impaired on TDEC's 303(d) List of Impaired Waterbodies (Figure 4). These are categorized as "impaired" by several pollutants meaning that humans and wildlife are currently threatened by the human activities in the watershed.

Historically, the levels of bacteria in the creek have suggested that humans who recreate in Richland Creek could become ill. The levels of nutrients have caused excessive algal growth, and excess sediment has contributed to degraded habitat for wildlife. A primary source of these pollutants is stormwater runoff, which flushes pollutants into Richland Creek from the surrounding neighborhoods and commercial areas during storms. In addition, secondary sources include random sewer failures and overflows and unpermitted or illicit discharges. In order to protect and restore Richland Creek watershed, it is imperative that the sources of pollutants responsible for water quality impairments to Richland Creek are identified and addressed.

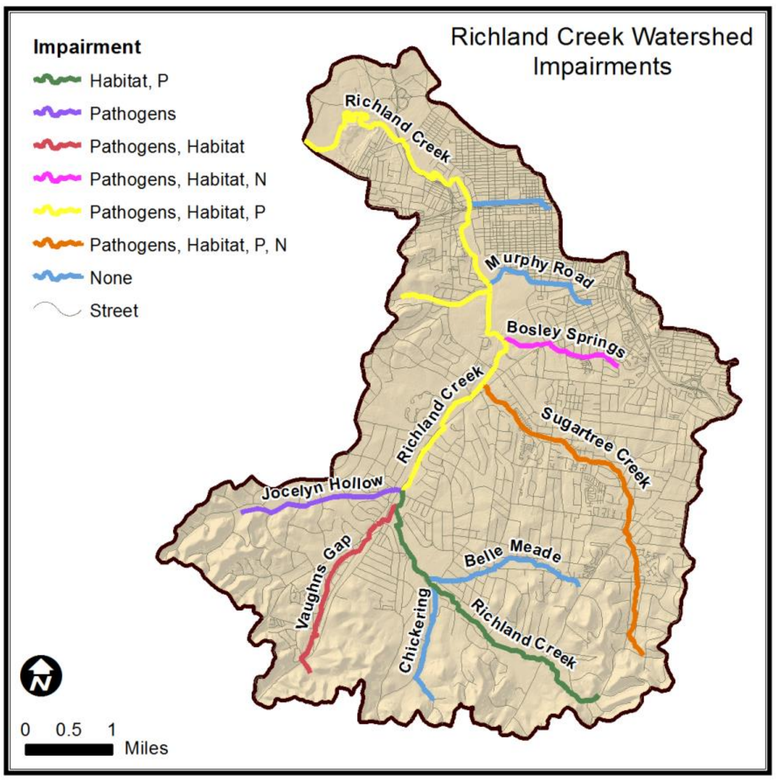


Figure 4. Impaired Streams within Richland Creek Watershed

Impairments within Richland Creek Watershed

Pathogens

The pathogen impairment in Richland Creek Watershed is a concern to public health and safety. One of the major sources of pathogens within urban creeks results from failures to the sanitary sewer collection systems. It is a high priority for MWS to address sewer problems within the watershed. The Clean Water Nashville (CWN) Project began in 2009, and many projects have been designed to reduce sewer overflows and address inflow and infiltration (I&I) into the sewer lines. Infiltration of groundwater or rainwater decreases the capacity of the sewer to perform efficiently. This reduction in capacity ultimately causes breaches and overflows into nearby creeks and tributaries. Extensive research has been done to identify solutions to eliminating overflows which will ultimately lower the bacteria levels in the streams. Detailed descriptions of CWN projects that are located in the Richland Creek Watershed are included in the Monitoring Data portion of this document. Other sources in urban environments that contribute to the pathogen loads are pets, septic tank failures, and wildlife. Programs such as educational mailings, scoop the poop campaigns, and dog park monitoring are some of the ways Metro Water educates the public about the pathogen impairment in their watershed. A more robust description of each program is described in later sections of this management plan.

Nutrients

Nutrient enrichment is another impairment of concern in many of the creeks within the Richland Creek Watershed. Streams that have elevated levels of nutrients typically exhibit abundant algae growth. The resulting low dissolved oxygen levels in the stream and creates a poor quality environment for aquatic life. Nitrogen is monitored as Nitrates, Nitrites, Ammonia, and TKN, and Phosphorus is monitored in the form of dissolved P and total Phosphorus. The streams that have currently been identified with elevated nutrient levels are the main stem of Richland Creek, Vaughn's Gap Creek, Sugartree Creek and Bosley Springs. Nutrient loads can come from numerous sources and often these are considered non-point sources. This means that the pollution does not necessarily come from one site or pipe. Some of the most common sources of nutrient pollutants are: fertilizers (commercial and residential products), pet waste, sediment loss and sanitary sewer breaches. Urban environments have increased impervious areas which increase the speed that rain water enters a stream. Increasing stormwater infiltration into the ground utilizes the soil as a filtering mechanism, thereby reducing the nutrient loads that enter the stream. Stormwater Control Measures (SCM's) formerly known as Best Management Practices (BMP's) are installed to increase infiltration, thus reducing nutrient loads. Examples of these SCM's include bioretention areas, stream buffers, grass swales and pervious pavement. A study has been conducted on Sugartree Creek watershed called SUSTAIN (SYSTEM for Urban Stormwater Treatment and Analysis IntegratioN). SUSTAIN is a decision making tool that selects the optimal SCM's for a watershed based on the effectiveness and cost of the SCM's. A more robust description of our Low Impact Development (LID) manual and results from the SUSTAIN model are available in the Set Goals and Identify Solutions section of this plan.

Habitat Alteration

Anthropogenic habitat alteration occurs when a stream channel is disturbed or altered as a result of human activity. Examples of this kind of habitat alterations include: dams, concrete channels, and sewer line crossings. In the past, the main aim in watershed management was moving water through a watershed as quickly as possible to reduce flood risk. This led to degradation of streams and often significant changes to the stream channel such as hard-armoring the banks with concrete or other materials. It can prove to be very difficult and expensive to undo some of the alterations that have been made especially when considering utility infrastructure and property owners. The streams within Richland Creek Watershed that have been identified as exhibiting major alterations include the main stem of Richland Creek, Sugartree Creek, Bosley Springs Branch, and Vaughn's Gap Branch.

Sedimentation

Sediment transport is a natural occurrence when a storm picks up sediment of all sizes (clay particles to boulders) and deposits it downstream in a river or reservoir. This occurs at a higher, unnatural rate in urban streams due to the increased amount of impervious surface, thus leading to a higher volume and intensity of water entering a stream during a storm. Improper controls during construction can also contribute to increased siltation in a stream. Excessive sediment in a stream results in loss of habitat for aquatic life. Many aquatic species require specific niche environments to thrive and reproduce. Therefore, elimination of these niches degrades the integrity and biodiversity of the receiving stream.

Monitoring Data

Bacteriological

Escherichia coli are bacteria that live in the guts of warm blooded animals. For this reason it is an indicator bacterium that EPA (Environmental Protection Agency) uses to determine whether a stream is meeting its designated uses. For a stream to meet the water quality standards for recreational use classification, EPA guidelines state that the geomean of 5 samples taken within 30 days should be below 126 colony forming units (cfu) and that any 1 sample should not exceed 960 cfu. In 2007, MWS began a bacteriological monitoring program that observes pathogen/*E. coli* levels within watersheds. In 2012 the monitoring protocol was established to sample 5 times within 30 days, 4 times per year on a 5 year rotation. This protocol maintains permit compliance while also looking at seasonal trends within each tributary that is impaired for pathogens. In some instances there are known sewer issues that are causing elevated pathogen levels, and projects are either in construction or being designed in order to remedy these sewer deficiencies. Our monitoring program provides assurance that these projects are remedying the known sewer problems and also identifies both private and utility sewer issues that have not yet been identified. It is important to keep in mind that many of the streams within Richland Creek Watershed have residences with pets that are adjacent to creeks. Pet waste can contribute significantly to elevated pathogen levels and it is important to educate homeowners on the importance of proper disposal of pet waste.

Sample locations are often located near the mouth of a stream so that the sample represents the entire watershed. When necessary, further sampling in upstream portions is done in order to hone in on the possible sources of pollutants(Figure 5). Another analysis that is performed on all bacteria samples is qPCR or real-time Polymerase Chain Reaction on *Bacteroides sp*. Bacteria species belonging to the genus *Bacteroides* are a large population of the fecal bacteria population. Dr. Alice Layton, with the University of Tennessee at Knoxville, developed a technique using qPCR technology to identify DNA markers that indicate all *Bacteroides sp.* (AllBac assay), human species (HuBac) and cows (BoBac) (Layton). In 2009, MWS began running the AllBac and HuBac assays on all *E. coli* samples in order to pinpoint the sources of pathogens within our samples. In more recent years, we have shifted to mainly using the HuBac analysis to indicate human/non-human differences in pathogen sources. This has been extremely helpful when investigating unknown pollutant sources and determining the necessary actions to locate illicit discharges.

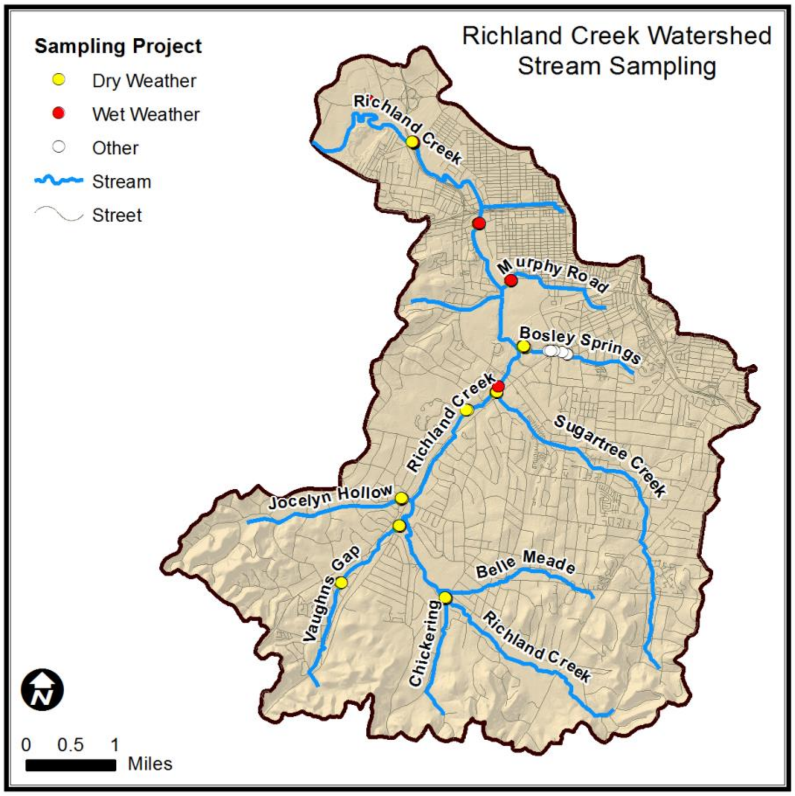


Figure 5. Metro Water Sampling Sites throughout Richland Creek Watershed

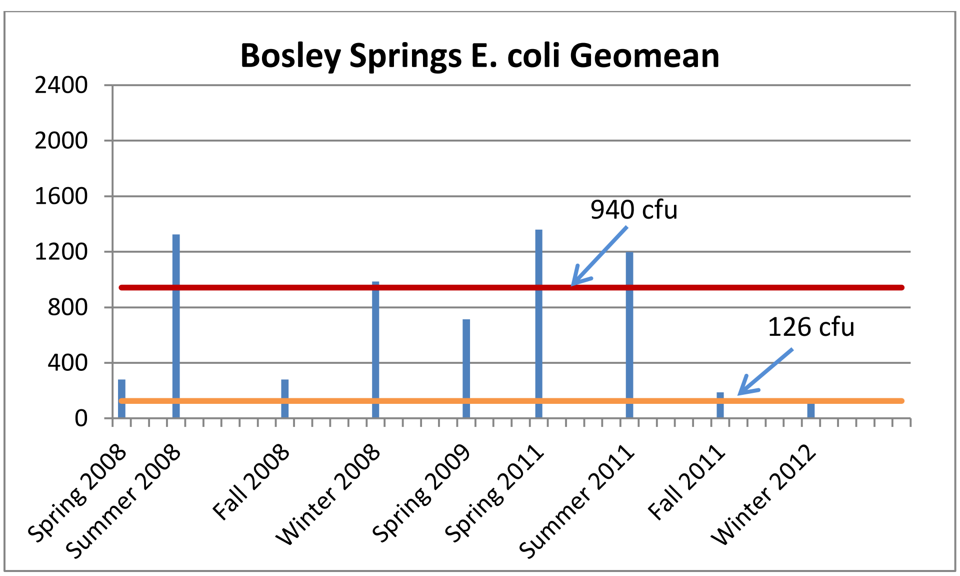


Figure 6. Calculated geomeans to show seasonal trends in E.coli

As shown in Figure 6, Bosley Springs had elevated values of *E. coli* repeatedly over a number of years. PCR results also indicated on numerous occasions that there was a human signature in the samples that were collected. However, despite significant investigation the source of the pollution remained elusive. In 2011, Montgomery Bell Academy began work on a geothermal installation in an area of their property that is adjacent to West End Ave. During the drilling process, sewage surfaced where the work was being done. Finally, it was determined that when remodeling a neighboring fire station, the sewer lines were mistakenly routed to an abandoned storm sewer instead of the sanitary sewer. The sewage was finding its way underground to the groundwater where it was entering the stream. The *E. coli* values have dropped significantly since the repair was made to the sewer at the fire house and continued monitoring will hopefully show that Bosley Springs will support its designated use in the near future.

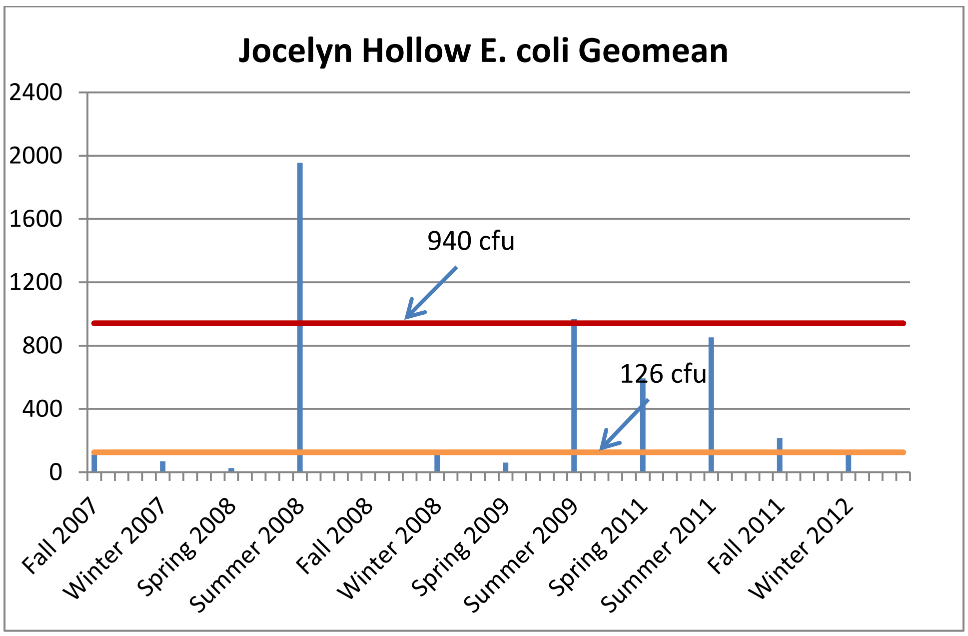


Figure 7. Calculated geomeans to show seasonal trends in E.coli

There have also been some issues identified by monitoring data from Jocelyn Hollow as seen in Figure 7. *E. coli* values have been elevated on multiple occasions and tend to be more elevated during the summer season. Investigations of the sewers in the area indicate that repairs need to be made to a number of manholes because there are cracks and inflow of groundwater where the manhole connects to the sewer. A project has been designed and is scheduled to repair these issues in 2017. Another possible source of contamination is the residential pet waste from yards that are adjacent to the creek. This watershed is dominated by residential land use. Picking up dog/pet waste and disposing in a trash receptical can significantly affect the receiving waters when it rains.

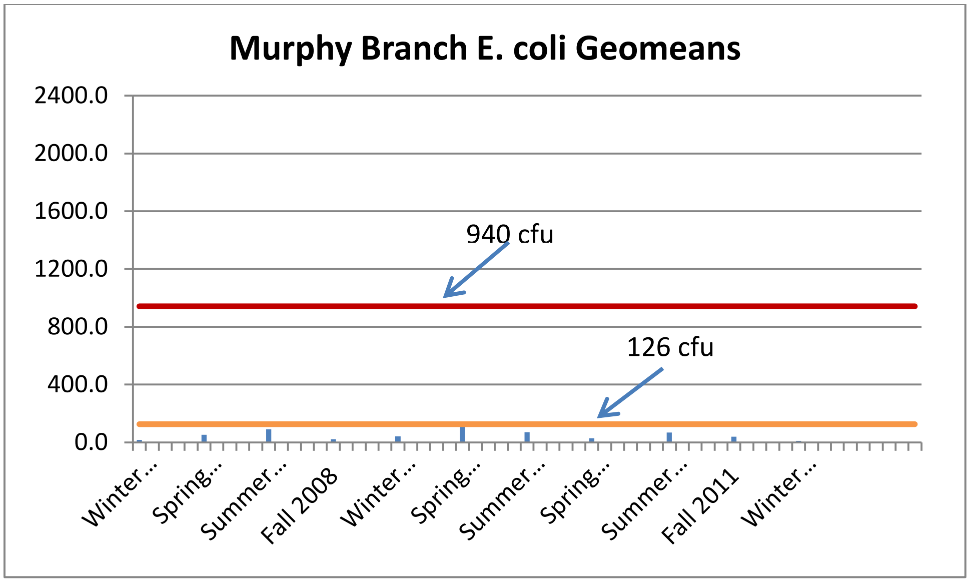


Figure 8. Calculated geomeans to show seasonal trends in E.coli

Figure 8. illustrates that Murphy Branch has had geomeans consistantly under the 126 cfu water quality standard. For this reason TDEC removed it from the 303d list in 2010.

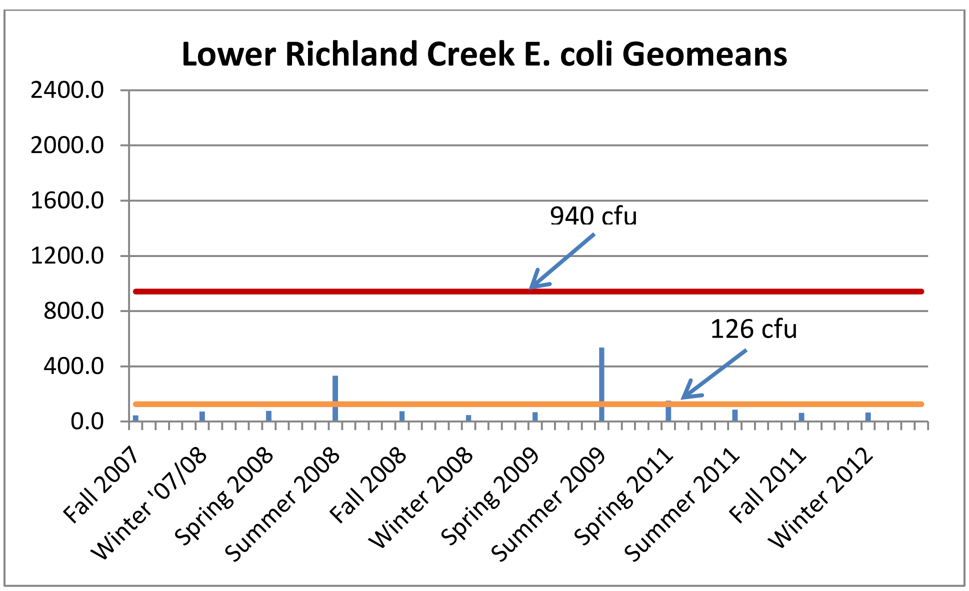


Figure 9. Calculated geomeans to show seasonal trends in E.coli

Lower Richland Creek has historically received overflows from West Park Sewer Pump station. In 2009 construction began on the West Park Equalization Basin and Wet Weather pump station. Phase I of the project provided a 10 million gallon equalization storage tank and a wet weather pump that is rated 30 million gallons per day capacity and was completed in November of 2010. Phase II is currently under construction and will provide an additional 21 million gallons of storage and the wet weather pump will be upgraded to a 45 million gallon per day rate. The sample location for this section of Richland Creek is just downstream of the West Park facility. Figure 9 shows that since the completion of Phase I, the *E. coli* geomean values have fallen below the 126 cfu threshold. Completion of Phase II should further result in further pathogen reductions within the watershed. Currently there is a public health and safety contact advisory placed on Richland Creek because of chronic sewer issues. If the data shows that values within Richland Creek continue to remain below the criteria, then it is likely that this advisory will be lifted and subsequently removed from the 303d list.

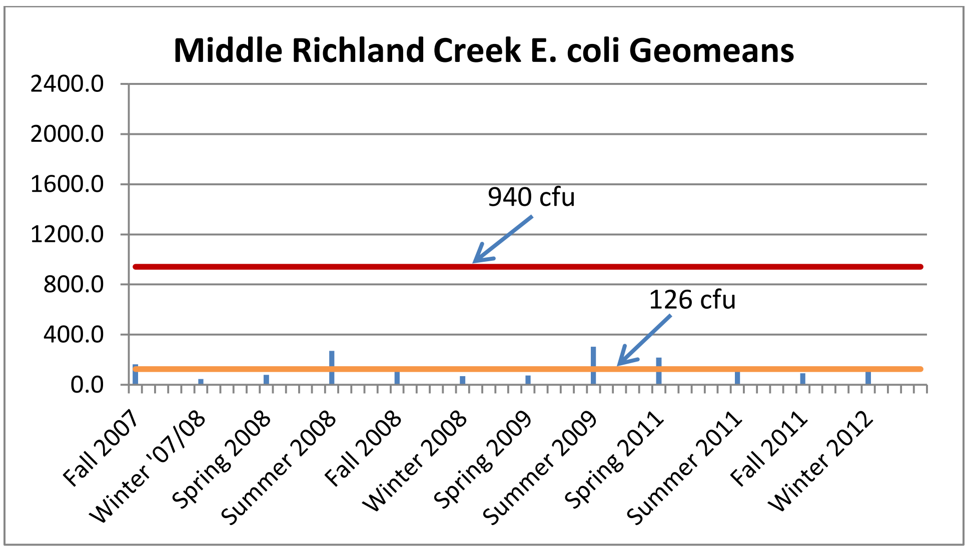


Figure 10. Calculated geomeans to show seasonal trends in E.coli

The sample site for this section of Richland Creek is just upstream of the Charlotte Pike overpass. This section of Richland Creek receives waters from many of the impaired tributaries in the watershed including, Bosley Springs, Sugartree Creek, and the upper portions of Richland Creek watershed, which includes Jocelyn Hollow Branch and Vaughn's Gap Branch. The West Park project that was described in the previous paragraph also included sewer improvement within the drainage area to this section of the creek. Over 2.5 miles of sewer lines were rehabilitated with cured in-place pipe liner (CIPP) and 45 manholes were also included in the rehabilitation work. These projects eliminated many chronic wet weather overflows, thereby greatly reducing pathogen loads to Richland Creek. Figure 10 shows that the most recent samples fall below the 126 geomean threshold which indicates that the efforts of the Clean Water Nashville project is improving pathogen levels as intended.

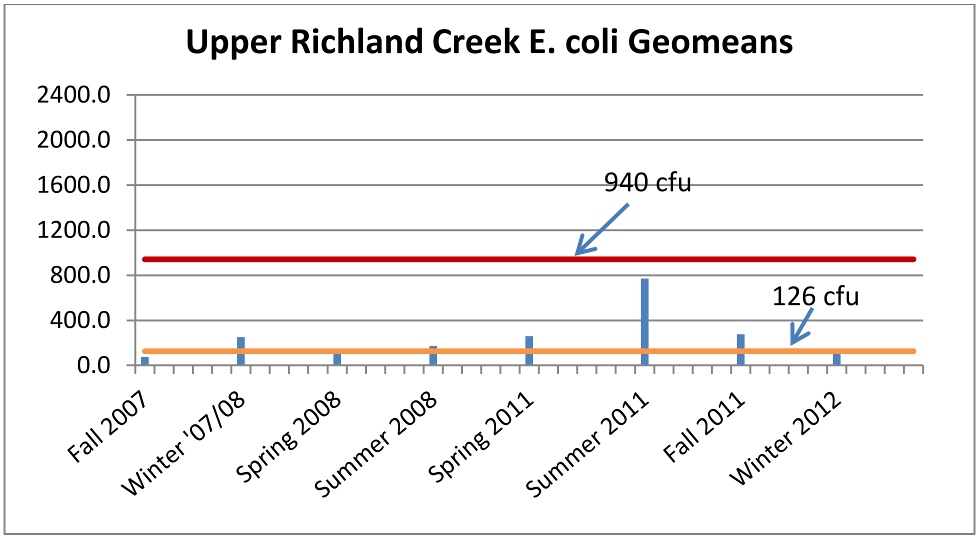


Figure 11. Calculated geomeans to show seasonal trends in E.coli

Figure 11 illustrates bacteriological monitoring data for the upper portion of Richland Creek. This refers to the segments of the creek on the south side of Harding Pike; the majority of this portion is located within the City of Belle Meade. Metro Water provides water and partial sewer services to the City of Belle Meade, however they are responsible for the stormwater management and do not fall under the jurisdiction of the Metro MS4 NPDES permit. The sample location for this segment is adjacent to the intersection of W. Tyne Blvd and Belle Meade Blvd. Thirty two thousand linear feet of sewer lines were identified as in-need of remediation within this drainage to Richland Creek. The Highway 100 and Tyne Rehab Project addressed these issues. The project began in August 2014 and was completed in September 2015. Evaluation of this project is currently underway and will determine if additional work is required. Continued bacteriological monitoring will aid in the evaluation of this and similar projects.

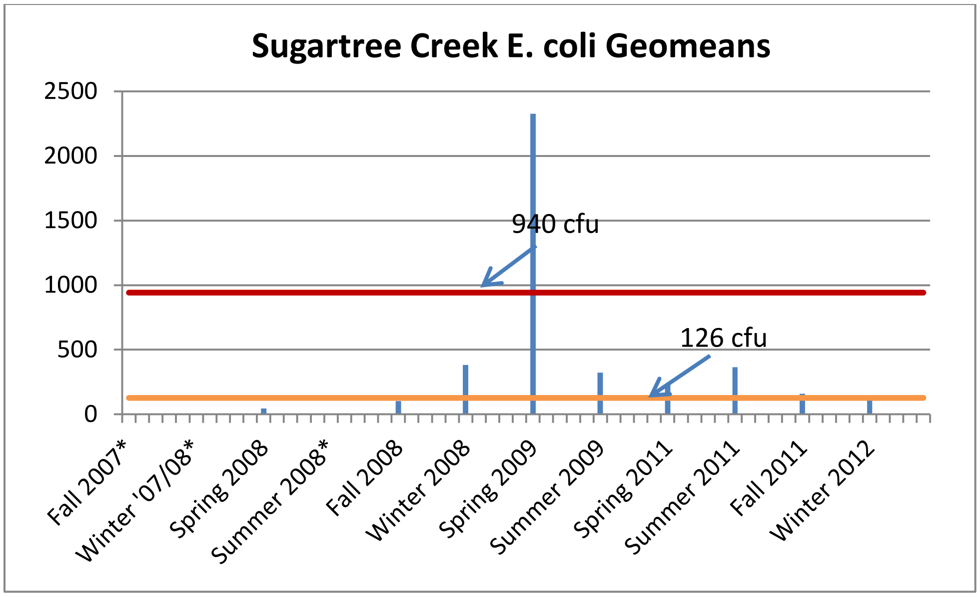


Figure 12. Calculated geomeans to show seasonal trends in E.coli

The data collected in Sugartree Creek (Figure 12) indicates that at times samples have been elevated above desired levels. There was likely a sewer discharge that was undetected during the Spring of 2009. There are also samples during the other seasons which were above the 126 threshold. It is common in urban environments to see elevated pathogens due to the increased runoff from impervious surfaces combined with increased densities of pets and yard waste.

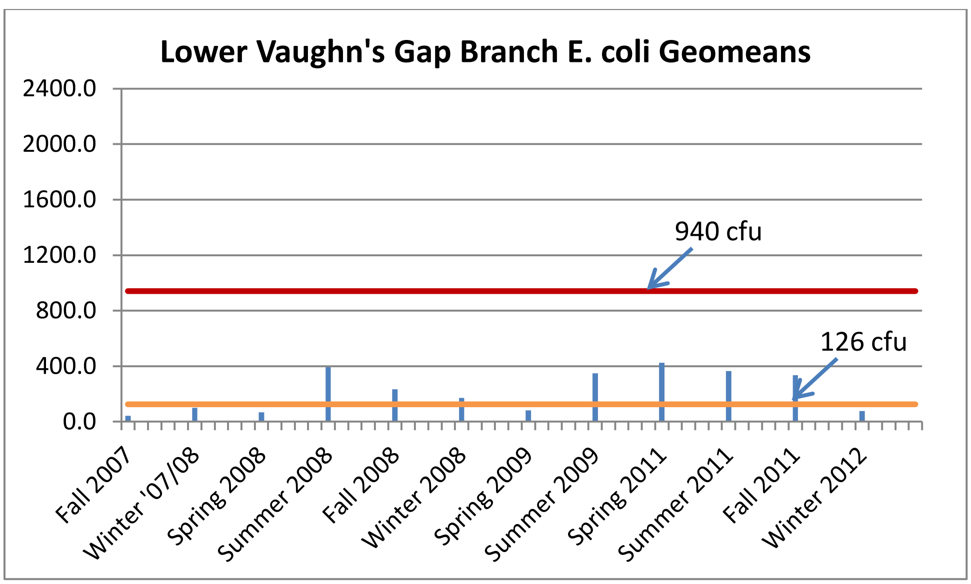


Figure 13. Calculated geomeans to show seasonal trends in E.coli

The lower portion of Vaughn's Gap Creek flows from the residential neighborhood of Warner Parks downstream to the confluence of Richland Creek near the intersection of Harding Place and Harding Road. It has a higher concentration of commercial and transportation land use than other portions of upper Richland Creek Watershed. The Tyne Blvd and Highway 100 Clean Water Nashville sewer rehabilitation projects may have improved water quality to this portion of Vaughn's Gap. It is also likely that the increased impervious area along this stream corridor is contributing to the elevated pathogen levels (Figure 13), which are above EPA expected geometric mean.

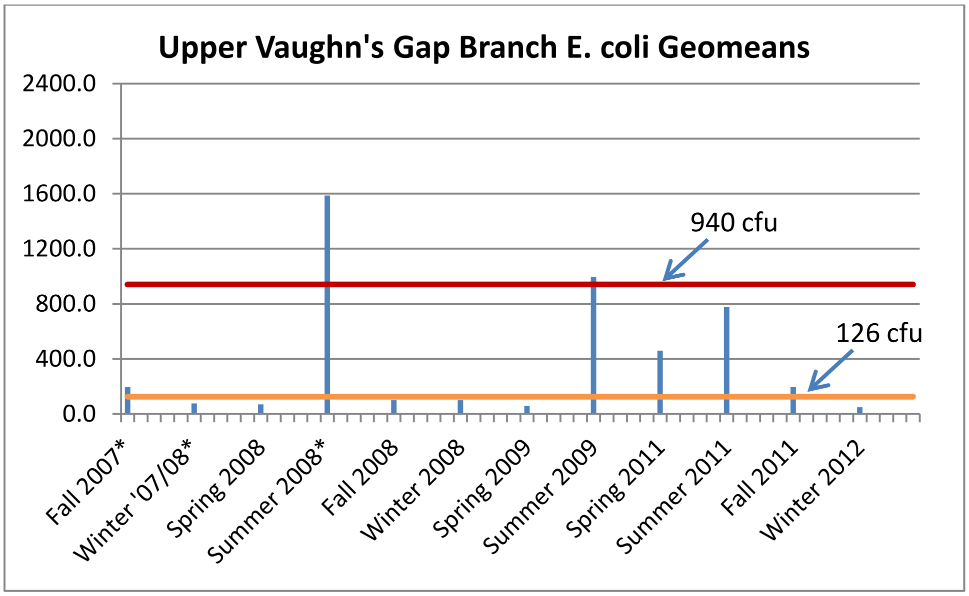


Figure 14. Calculated geomeans to show seasonal trends in E.coli

The upper portion of Vaughn's Gap Creek is located where the creek intersects with St. Henry Drive to the headwaters of the creek, which are located within Percy Warner Park. Approximately 235 feet of sewer lines were rehabilitated directly upstream from the sample location for this segment in November 2005. Increased pet waste due to residential land use along the creek buffers could be the source of the elevated *E. coli* values. As mentioned before, collection and disposal of pet waste in trash receptacles can greatly decrease the pathogen loads to a creek during a storm event.

Biological

Overview

Macroinvertebrates are small organisms that inhabit the substrates of water bodies and can be analyzed to evaluate the biological integrity of the aquatic ecosystem. Different species of macroinvertebrates possess various levels of sensitivity to pollution and other impairments and therefore are important biological indicators of water quality. For example, pollution sensitive organisms may require high levels of dissolved oxygen, clear water, or adequate substrate to survive. Macroinvertebrates are used by the state of Tennessee's Department of Environment and Conservation (TDEC) Division of Water Resources as indicator organisms to determine if a stream supports fish and aquatic life.

TDEC has approved two types of macroinvertebrate surveys for assessing the biological integrity of streams. These include biorecons (BR) and semi-quantitative single habitat (SQSH) assessments. According to TDEC's Quality System Standard Operating Procedure for Macroinvertebrate Surveys (2011), the SQSH method is required for any macroinvertebrate survey that is being conducted for permit compliance. The SQSH protocol is also used whenever a defensible and/or definable assessment is needed, and this method is recommended to outside agencies that will be submitting data to TDEC for further review. For all these reasons the SQSH method will be used for all future macroinvertebrate surveys in the Richland Creek Watershed.

Habitat assessments are required to be conducted at the same time as any type of biological survey, because habitat often plays a big role in determining the health of a benthic community. By conducting this type of assessment, habitat can either be confirmed or eliminated as a source of stress to the macroinvertebrate population.

Methods

Upon arrival at a site, an approximately 100-meter reach area is established and a riffle area is chosen to sample. Field measurements are taken and recorded, normally including: dissolved oxygen, temperature, pH, conductivity and flow. A habitat assessment/stream survey is conducted using TDEC's QSSOP for Macroinvertebrate Surveys, 2011, Protocols D and E. Lastly, the chosen riffle area is sampled for macroinvertebrates using Protocol G of TDEC's QSSOP for Macroinvertebrate Surveys, 2011. Samples are preserved on site and then sent to a qualified consultant (Pennington and Associates, Inc. Cookeville, TN) for identification of organisms.

The 10 parameters considered during the habitat assessment are totaled and the overall score is compared to TDEC's Habitat Assessment Guidelines. In addition, 7 biometrics (Table 2) are calculated and then rated to determine a Tennessee Macroinvertebrate Index (TMI) score for each stream. The sample stream's TMI is then compared to the Target TMI for the specific ecoregion.

Table 2. Biometrics used for determination of the Tennessee Macroinvertebrate Index (TMI). Adapted from Arnwine, 2009.

Category	Biometric	Description	Predicted response to increase in disturbance
Richness Metrics	Taxa Richness (TR)	Measures the overall variety of the macroinvertebrate assemblage	Decrease
	EPT Richness (EPT)	Number of taxa in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies).	Decrease
Composition Metrics	%EPT-Cheum	Total number of EPT excluding Cheumatopsyche species	Decrease
	%OC	Percent of the composite of oligochaetes (worms) and chironomids (midges).	Increase
Pollution Tolerance Metrics	NCBI	North Carolina Biotic Index uses tolerance values to weight abundance in an estimate of overall pollution (Arnwine, 2009)	Increase
	%TNUTOL	Percent of the composite of nutrient tolerant taxa in Tennessee (TDEC, 2011)	Increase
Habit Metrics	% Clingers	Percent of the macroinvertebrates having fixed retreats or adaptations for attachment to surfaces in flowing water.	Decrease

Existing Data

Richland Creek was assessed and sampled by MWS on May 3, 2012 as part of the first permit year ambient sampling requirement of the current NPDES permit. A habitat assessment score of 138 was given to the sampled reach, which is above the ecoregion guideline of ≥127 for a stream >2m². All 10 habitat assessment parameters were rated as suboptimal. However, it was not evident from the individual scores that one parameter was more or less responsible for impairment compared to the others. The TMI score calculated from the raw benthic data was 30 (Table 3) .The target TMI for this ecoregion (71h) is 32 and a perfect TMI score is 42. Richland Creek will be sampled again in September, 2016 to fulfill permit requirements.

Table 3. Richland Creek Macroinvertebrate Biometrics May 3, 2012-Metro Water.

Biometric	Score	TMI Score
Taxa Richness	15	2
EPT	4	2
%EPT-Cheum	46.8	4
%OC	4.0	6
NCBI	5.1	4
% Clingers	60.3	6
%TNUTOL	21.4	6
TOTAL		30

Tennessee state agencies (TDEC and Tennessee Wildlife Resources Agency) conducted a total of 14 macroinvertebrate samples within the Richland Creek Watershed between 2001 and 2012. In addition to the main stem of Richland Creek, samples were collected from Vaughn's Gap Branch, Jocelyn Hollow, Bosley Springs Branch, and Sugartree Creek (Figure 5). Prior to 2012 the SQSH method was not the only standard method of sampling used by TDEC to collect macroinvertebrates. Therefore all samples (n=7) collected by TDEC from 2001 to 2011 were collected using TDEC's biorecon method, and no TMI was calculated. Instead, 3 biometrics (taxa richness, EPT and intolerant taxa) were used to calculate a biorecon score. Depending on where this score falls within a range of 0-15 will determine whether the stream is severely impaired (≤5), ambiguous (6-10) or non-impaired/supporting (11-15). Three of the 7 biorecon samples scored in the ambiguous range, and the remaining four scored as severely impaired (Table 3). Habitat scored poorly at all sites as well (< 127) (Table 4).

The main stem of Richland Creek was sampled 3 times by TWRA and twice by TDEC between 2009 and 2011, using the SQSH method. All sample locations were within a 3 mile radius of each other (Figure 15). TDEC also sampled Sugartree Creek at the same location, twice, on March 12, 2012, using the SQSH method. None of these samples scored a TMI greater than 16 (Table 5). The target TMI is 32 for this ecoregion (71h). Only the 4 TDEC samples were assigned habitat assessment scores, and none of these were above the ideal score for this ecoregion (≥127).

Table 4. Biorecon and Habitat Assessment Scores for Streams within Richland Creek Watershed-TDEC (2001-2011)

Site	Date	Biorecon Score	Habitat Score
Bosley Springs 0.4	6/30/2001	5	73
Bosley Springs 0.4	1/30/2006	3	81
Jocelyn's Hollow 0.2	1/31/2006	9	111
Jocelyn's Hollow 0.2	3/25/2011	7	101
Vaughn's Gap 1.2	6/30/2001	3	97
Vaughn's Gap 1.2	1/31/2006	3	99
Vaughn's Gap 1.2	3/25/2011	7	100

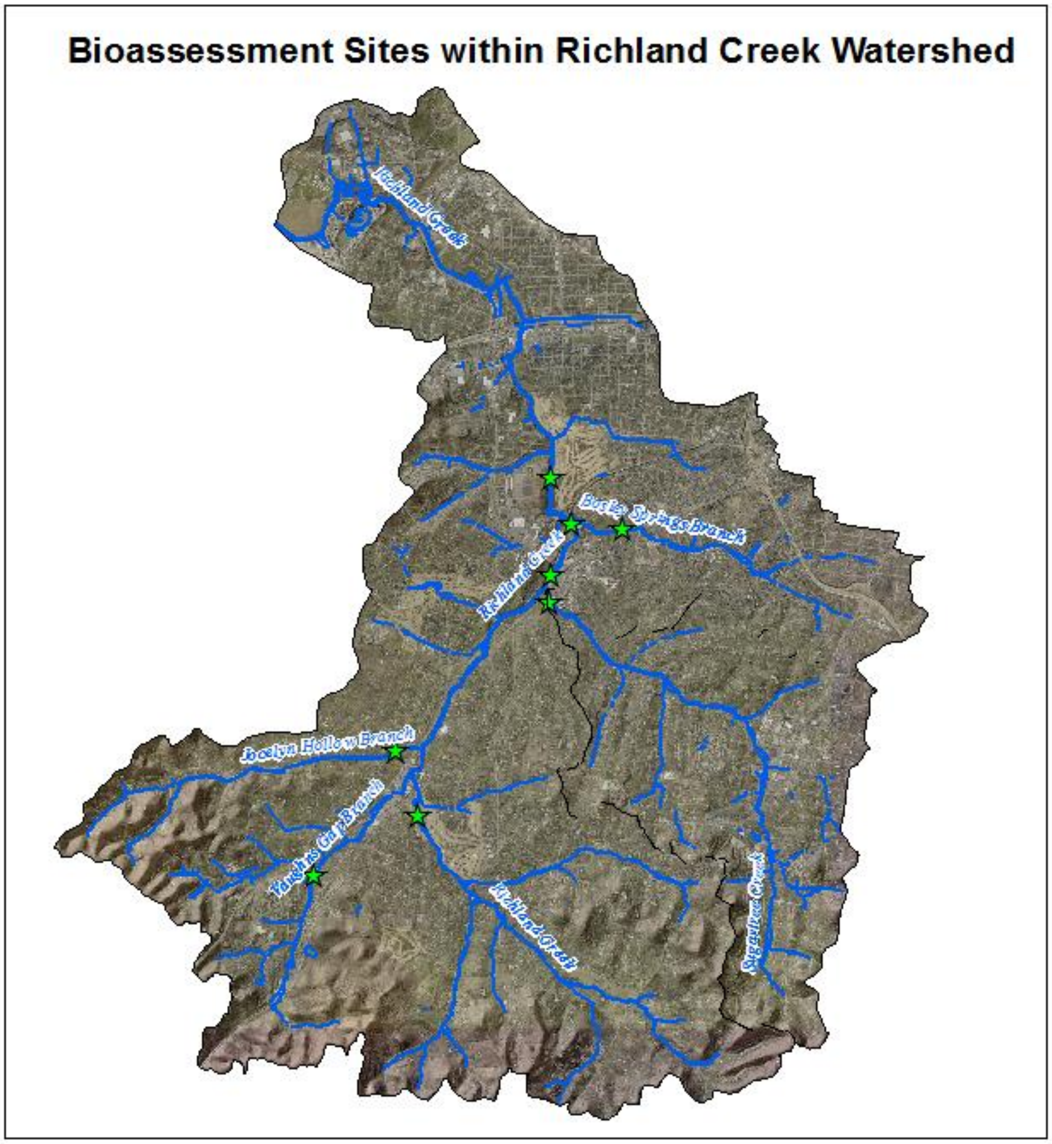


Figure 15. Location of State and Metro bioassessment sites.

Table 5. SQSH and Habitat Assessment Scores for Streams within Richland Creek Watershed (2009-2012)

Site	Date	TMI	Habitat Score	Sampling Organization
Richland Creek 4.5	10/1/2009	12	n/a	TWRA
Richland Creek 5.0	10/1/2009	16*	n/a	TWRA
Richland Creek 5.0	10/1/2010	14	n/a	TWRA
Richland Creek 5.4	3/12/2012	12	124	TDEC
Richland Creek 7.8	4/12/2011	14	119	TDEC
Sugartree Creek 0.1	3/13/2012	12	104	TDEC
Sugartree Creek 0.1	3/13/2012	16	105	TDEC

* Sample size too small to score accurately (67 versus typical sample size of 200) Target TMI=32

Visual Stream Assessments

Stream assessments are conducted in order to provide a quick evaluation of both in-and near-stream habitat conditions so that comparative assessments can be made of the condition of different stream segments. Visual assessments have been performed on five (5) streams located within the Richland Creek watershed.

This program has been beneficial for many reasons such as the discovery of many illicit discharges and missing sewer manholes and cleanout covers are found during these assessments. Often these stream segments are not accessed by people and because they are out of sight these issues will have been going on for long periods of time. There is tremendous value to the stream in solving these issues even if it is as simple as replacing a manhole cover.

The visual stream assessment program provides a score for a reach of stream based on the following factors: in/near stream construction, barriers and blockages, channel alteration, pipes/outfalls, vegetation, erosion, and correctability. This program is a modified version of the Maryland protocol and, in addition to tracking the mentioned parameters, also accounts for cleanup sites, odors, livestock, bank heights/conditions, stream widths, etc. The scores for each parameter range from 1 to 5, 1 being the best and 5 being the worst. The segments are typically 500 feet in length and measurements are taken at the beginning and end of each segment. Canopy cover is measured at the beginning, middle, and end of each segment. Pictures are taken from the midpoint of each segment and include upstream, downstream, left and right banks. All data is stored in a geodatabase and pictures are stored in a separate folder.

Table 6 shows the total score for the stream segments throughout the watershed. The satellite cities are shaded purple. As you can see, the stream scores vary throughout the watershed. Figures 16 and 17 shows the distribution of scores when grouped from best to worst. The majority of the scores fall between 8 and 21. This means that most segments within the watershed are somewhat to moderately impaired. There are no segments with scores above 28 (which would be the indicator of severely impaired segments), and there are 2 segments in which no impairment were observed. The average scores for each stream

are as follows:

Table 6. Average Assessment Scores for Each Major Stream within Richland Creek Watershed

Stream Assessment Score					
Bosley Springs Branch	Jocelyn Hollow Branch	Richland Creek	Sugartree Creek	Unnamed Tributary (near White Bridge Rd.)	Vaughn's Gap Branch
21	**13**	**14**	**16**	**19**	**15**

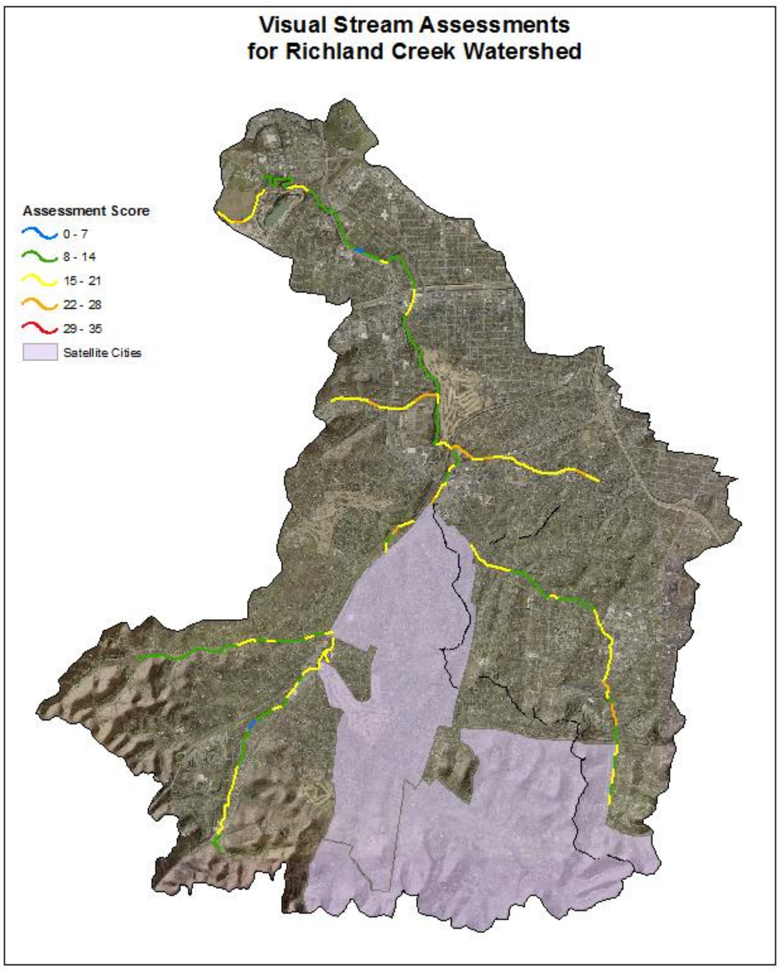


Figure 16. Distribution of scores spatially within Richland Creek Watershed.

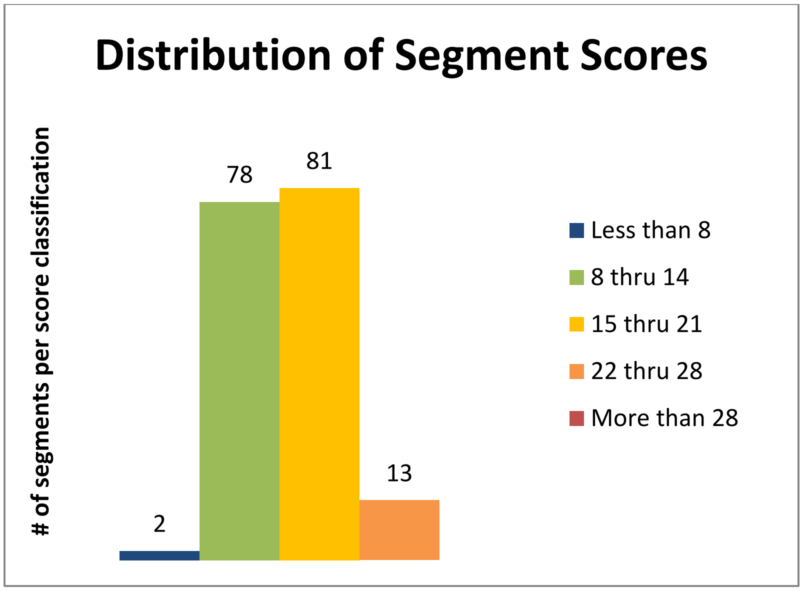


Figure 17. This graph indicates how the majority of streams scored within Richland Creek Watershed.

As mentioned above, seven major factors assessing streams are rated to include in/near stream construction, barriers and blockages, channel alteration, pipes/outfalls, vegetation, erosion, and correctability. Ratings for the individual factors reveal the most impact to the streams in this watershed deal with channel alteration, inadequate vegetation and erosion. Each of these categories along with respective scores for individual streams are described below.

In/Near Stream Construction

In or near stream construction data sheets are used to document the locations of major disturbances located in or near the stream corridor at the time of the survey as well as evidence of inadequate sediment control measures or if sediment pollution from the site has affected the stream. All five streams scored low for this component with little to no construction in or near the assessed streams (Table 7).

Table 7. Average score for construction zones in or near streams within each impaired stream in Richland Creek Watershed**.**

In/Near Stream Construction Score					
Bosley Springs Branch	Jocelyn Hollow Branch	Richland Creek	Sugartree Creek	Unnamed Tributary	Vaughn's Gap Branch
1	**1**	**1**	**1**	**1**	**1**
1=minimal impact 3=moderate impact 5=heavy impact					

Channel Alteration

Channelization refers to the once common practice of dredging, straightening and/or widening stream channels in an attempt to reduce flooding or to lower the ground water table. While channelization can be partially effective at reducing flooding or lowering the ground water table in an area, it can also have a variety of negative environmental impacts. Channelized streams often have poor instream habitat for aquatic organisms. They can be a barrier to fish migrations, and in areas where the riparian buffer has been removed, the water in the stream can be heated by the sun during the day reducing its oxygen holding capacity and raising water temperatures above the tolerance limits of some fish species. In addition, while channelization may be able to reduce flooding in one specific stream reach, often it increases flooding downstream. Bosley Springs Branch and an unnamed tributary near Nashville State Community College scored moderately high with regard to channel alteration, mainly due to portions of the stream having been replaced with concrete channels. Historically, reducing the roughness of the stream channel by constructing a straight and smooth channel out of stone or concrete was an attempt to improve the hydraulic capacity of the stream to transport flood waters through an area. Many streams within the Richland Creek watershed have moderate to heavy channel alterations (Table 8).

Table 8. Average score for channel alteration within each impaired stream in Richland Creek Watershed

Channel Alteration Score					
Bosley Springs Branch	Jocelyn Hollow Branch	Richland Creek	Sugartree Creek	Unnamed Tributary	Vaughn's Gap Branch
4	**2**	**3**	**3**	**4**	**3**
1=minimal alteration 3=moderate alteration 5=heavy alteration					

Barriers/Blockages

Fish migration barriers are anything in the stream that significantly interferes with the upstream movement of fish. Unimpeded upstream movement is also important for resident fish species, many of which also move both up and down stream during different parts of their life cycle. Without free fish passage, some sections in a stream network can become isolated. If a disturbance occurs in an isolated stretch of stream, such as a sewage spill on a small tributary, some or all fish species may be eliminated from that isolated section of stream. With a fish blockage present and no natural way for a fish to repopulate the isolated stream section, the diversity of the fish community in an area will be reduced and the remaining biological community may be out of natural balance. Fish blockages can be caused by man-made structures such as dams or road culverts, and by natural features such as waterfalls or beaver dams. Fish blockages occur for three main reasons. Firstly, there is a vertical water drop such as a dam that it is too high for fish to swim over. The second reason a structure may cause a fish passage problem is because the water is too shallow. This can often occur in channelized stream sections or at road crossings where the water from a small stream has been spread over a large flat area and the water is not deep enough for fish. Finally, a structure may be a fish blockage if the water is moving too fast. This can occur at road crossings where the culvert pipe has been placed at a steep angle and the water moving through the pipe has a velocity higher than a fish's swimming ability. Barriers and blockages were scored by the impact from man-made structures/alterations, rather than natural impediments. All stream average scores were below moderate impact and some scored minimal impact (Table 9).

Table 9. Average score for unnatural barriers within each impaired stream in Richland Creek Watershed.

Barriers/Blockages Score					
Bosley Springs Branch	Jocelyn Hollow Branch	Richland Creek	Sugartree Creek	Unnamed Tributary	Vaughn's Gap Branch
2	**1**	**2**	**1**	**2**	**1**
1=minimal impact 3=moderate impact 5=heavy impact					

Pipes/Outfalls

Since streams are located at the lowest points in the local landscape, engineers often build sewer lines parallel to streams to collect sewage from adjacent neighborhoods. While the pipes are stationary, streams can migrate and over time can expose previously buried pipelines. When this occurs, the pipeline becomes vulnerable to being punctured by debris in the stream. Fluids in the pipes can then be discharged into the stream causing a serious water quality problem. Exposed pipes are any pipes that are either in the stream or along the stream's immediate banks that could be damaged by a high flow event.

Outfalls include any pipes or small man-made channels that discharge into the stream through the stream corridor. Pipe outfalls are considered a potential environmental problem in the survey because they can carry uncontrolled runoff and pollutants such as oil, heavy metals, and nutrients to a stream system. Bosley Springs Branch had the highest score with moderate impact for pipes and/or outfalls. The remaining streams had minimal impact (Table 10).

Table 10. Average score for impacts of pipes or stormwater outfalls within each impaired stream in Richland Creek Watershed.

Pipes/Outfalls Score					
Bosley Springs Branch	Jocelyn Hollow Branch	Richland Creek	Sugartree Creek	Unnamed Tributary	Vaughn's Gap Branch
3	**1**	**2**	**2**	**1**	**1**
1=minimal impact 3=moderate impact 5=heavy impact					

Inadequate Vegetation

Forested stream buffers are very important for maintaining healthy Tennessee streams. Forested buffers help shade the stream, preventing excessive solar heating, and the roots stabilize the stream banks. Forest buffers remove nutrients, sediment and other pollutants from runoff, while the natural loading of leaves from riparian trees are a major component of the stream's food web. In prioritizing future buffer planting, emphasis is given to stream reaches without trees along the edge of the stream. Four of the five streams assessed were scored as having moderately to moderately high levels for inadequate abundance of vegetation within the stream corridor (Table 11).

Table 11. Average score of vegetation (canopy cover and buffer width) within each impaired stream in Richland Creek Watershed.

Inadequate Vegetation Score					
Bosley Springs Branch	Jocelyn Hollow Branch	Richland Creek	Sugartree Creek	Unnamed Tributary	Vaughn's Gap Branch
4	**2**	**3**	**3**	**4**	**3**
1=minimal buffer disturbance 3=moderate buffer disturbance 5=heavy buffer disturbance					

Erosion

Erosion is a natural process and necessary to maintain good aquatic habitat in a stream. Too much erosion, however, can have the opposite effect, destabilizing stream banks, destroying in-stream habitat and causing significant sediment pollution problems downstream. This often occurs when land use in a watershed changes. As a watershed becomes more urbanized, forest and agricultural fields are developed into residential housing complexes and commercial properties. As a result, the amount of impervious surfaces in a drainage basin increases, which in turn causes the volume and intensity of runoff entering a stream to also increase. The stream channel will adjust over time to the new flows by eroding the stream bed and banks to increase its size. This channel readjustment can extend over decades during which excessive amounts of sediment from unstable eroding stream banks can have very detrimental impacts on the stream's aquatic resources. All streams assessed had moderate to moderately low scores for erosion issues (Table 12). Projects that restore buffers and canopy cover will result in lower averages when streams are reassessed.

Table 12. Average score for severity of erosion within each impaired stream in Richland Creek Watershed.

Erosion Score					
Bosley Springs Branch	Jocelyn Hollow Branch	Richland Creek	Sugartree Creek	Unnamed Tributary	Vaughn's Gap Branch
3	**3**	**2**	**2**	**3**	**2**
1=minimal impact 3=moderate impact 5=heavy impact					

Correctability

Correctability ratings provide a relative measure on how easily the field teams believe it would be to correct a specific problem. This rating can be helpful in determining which problems to initially examine when developing a restoration plan for a drainage basin, as well as identifying simple projects that can be done by volunteers, as opposed to projects that require more significant engineering efforts. One restoration strategy would be to initially target the severest problems that are the easiest to fix. This rating also takes into account ease of access to the stream as well as land use along the stream. For example, public land is more easily accessible for a project than segments surrounded by private land. Correctability for all streams assessed indicated moderate planning, timing and funding would be required (Table 13).

Table 13. Average score for ability to correct impaired stream in Richland Creek Watershed.

Correctability Score					
Bosley Springs Branch	Jocelyn Hollow Branch	Richland Creek	Sugartree Creek	Unnamed Tributary	Vaughn's Gap Branch
3	**2**	**3**	**3**	**3**	**3**
1=minimal effort 3=moderate effort 5=extensive effort					

Set Goals and Identify Solutions

As previously mentioned, the identified impairments in Richland Creek watershed include pathogens, nutrients, habitat alteration and sedimentation. In 2012, Nashville's Mayor's office, Metro Water Stormwater, The Cumberland River Compact, and the Nature Conservancy joined forces to develop the Watershed Stewardship Plan. The plan consists of a white paper that reviews the state of the watersheds within Davidson County, a Watershed Improvement Fund Feasibility Study, Development of the DSS (Decision Support System) to prioritize water quality improvement efforts within Richland Creek watershed, and SUSTAIN (System for Urban Stormwater Treatment and Analysis Integration) to identify the SCM's within Sugartree Creek Watershed that will provide the most efficient pollution reduction in order to meet use classification. Together, the Decision Support System and SUSTAIN provide information to help guide decisions for improving Richland Creek watershed.

Decision Support System for Richland Creek Watershed

A Decision Support System (DSS) for the Richland Creek watershed was developed by Paradigm Environmental to identify the areas where targeted efforts by the community would be most beneficial. This system leverages sophisticated computer modeling to highlight those areas where water quality protection and improvement efforts such as source control and stormwater capture could provide the most benefit. Stormwater runoff is often a main contributor to pollutants within urban streams. Identification of the sources of these pollutants is important in order to create source control initiatives and stormwater capture projects that will address the problems. Examples of some of these source control initiatives would be dog waste stations or programs that promote reductions of fertilizer use in residential areas. The stormwater capture projects could include a rain garden installation program or construction of multi-use detention basins or "green streets" to reduce stormwater runoff.

Objectives

The DSS is built upon watershed modeling as the primary tool for quantifying the areas where pollutants originate, evaluating their downstream impact and estimating the amount of stormwater capture that could remove the impairments to Richland Creek and its tributaries. The objectives identified were:

- Develop a watershed model that can simulate storm flows in the watershed and corresponding concentrations of pollutants that are impairing Richland Creek watershed. The model should have sufficient spatial resolution to guide targeted water quality improvements at the neighborhood-scale.
- Compare the simulated concentrations and loads (flow times load) to applicable water quality criteria developed by TDEC. These criteria are used to determine whether waterbodies in the state of Tennessee are impaired, and thus can be used to estimate the amount of stormwater capture that would address impairments.
- Determine areas that are contributing relatively high levels of pollutants to their nearby waterbody/tributary, and also quantify the downstream travel of pollutants in order to highlight those areas that have the biggest "overall" impact on lower Richland Creek and the Cumberland River.

Hydrologic model

One benefit of the Watershed Stewardship Plan was being able to utilize an existing watershed model that was created by Tetra Tech and commissioned by Metro Water Stormwater Department. The model software that was used was LSPC++, which includes algorithms that simulate watershed processes like hydrology, sediment erosion, and water quality. The key elements of the model developed by Metro Water were: representation of land uses, representation of weather, and calibration to demonstrate model performance.

Paradigm enhanced the original watershed model in order to greatly reduce the size of the subwatersheds. This was done in order to meet the objective of identification of pollution sources on a neighborhood scale. Figure 18 shows the increase in catchments from the original model to Paradigm's enhanced version. The original model delineations are noted with the thick grey lines and the new model delineations are noted with white lines.

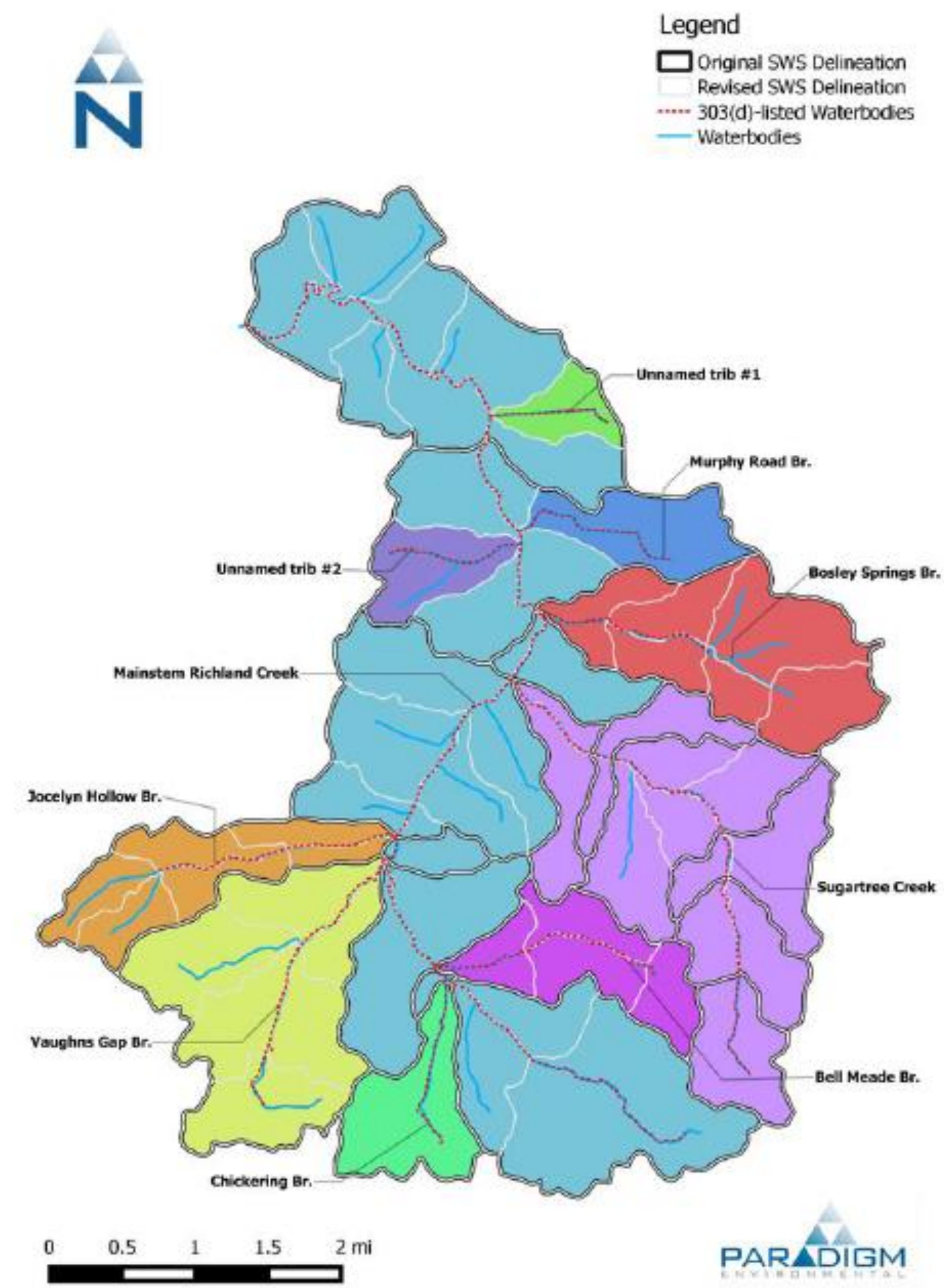


Figure 18. This map shows Richland Creek watershed, divided into subwatersheds (SWS in legend). The thick lines show the subwatersheds in the original model and the white lines show the subdivided subwatersheds. The spatial resolution of the catchments was increased by a factor of three, from 19 to 66 subwatersheds, in order to allow the Richland Creek DSS to highlight smaller areas to target for water quality improvement. Creation of smaller catchment areas also required verification that the original model calibration was still valid

Table 14 highlights the different number of catchments in the original model compared to the enhanced version that Paradigm created, and table 15 shows the differences in the flow simulations before and after changes were made. There were nominal divergence between the original and the revised model which verifies that the original calibration is valid for the revised model and can provide an accurate foundation for the Richland Creek DSS.

Table 14. Summary of original and revised subwatersheds in Richland Creek watershed model

Watershed Model Version	**Catchment Area Count**	**Average Area** (acres)	**Median Area** (acres)
Original Model	19	973	803
Revised Model	66	268	236

Table 15. Summary of flow simulations by original and revised watershed models Annual

Average Flow Metrics (01/01/2000 - 12/31/2013): Richland Creek at Charlotte Avenue					
ORIGINAL MODEL:	*Annual*	*Winter*	*Spring*	*Summer*	*Fall*
Total Volume (inches of runoff)	18.987	6.023	6.166	3.027	3.770
Highest 10% of Flows (inches of runoff)	7.662	2.299	3.256	0.971	1.137
Lowest 50% of Flows (inches of runoff)	2.560	0.516	0.678	0.720	0.646
REVISED MODEL:	*Annual*	*Winter*	*Spring*	*Summer*	*Fall*
Total Volume (inches of runoff)	18.977	6.022	6.165	3.026	3.764
Highest 10% of Flows (inches of runoff)	7.661	2.298	3.255	0.971	1.137
Lowest 50% of Flows (inches of runoff)	2.559	0.515	0.678	0.719	0.646
RELATIVE DIFFERENCE: (Revised Model / Original Model)	*Annual*	*Winter*	*Spring*	*Summer*	*Fall*
Seasonal Total Volume	-0.05%	-0.02%	-0.02%	-0.03%	-0.18%
Seasonal Storm Volume	-0.09%	-0.01%	-0.01%	-0.01%	-0.36%
Seasonal Baseflow Volume	-0.09%	-0.02%	-0.02%	-0.03%	-0.37%

Simulation of Flows and Pollutant Concentrations

The next step in creating the DSS was to simulate flows and pollutant concentrations. Specifically, the analyses focused on the highest priority impairing pollutants – sediment, *E. coli* and nitrogen. The tool focused on two viewpoints: (1) the impact of flows and pollutant loads on their most nearby waterbody/tributary and (2) the downstream impacts of flows and pollutant loads on lower Richland Creek and the Cumberland River. In watersheds, certain pollutants (e.g. sediment) are subject to processes like settling, resuspension and decay during downstream transport. Therefore, in the case of the Richland Creek, the amount of pollutant that reaches the watershed outlet and Cumberland River can differ greatly from the amount of pollutant initially discharged into an upstream tributary like Jocelyn Hollow Branch. To provide viewpoint #2 the "delivered" pollutant load was quantified for each catchment area in Richland Creek watershed. The delivered load represents the amount of pollutant from runoff that reaches a downstream point of interest, which in this case is the mouth of Richland Creek and the Cumberland River. In other words, if it were possible to tag pollutants at the source where they originate and follow that load as it travels through the watershed, the amount that finally reaches the mouth of Richland Creek watershed (and the Cumberland River) is the delivered pollutant load.

Delivered loads can have important water quality management implications because not all pollutants are delivered equally to a downstream point of interest in the stream network. In general, the farther away a catchment area is from the watershed outlet, the smaller the fraction of its discharged pollutants that is delivered to that location. However, far-away subwatersheds with relatively large pollutant loads can have a bigger downstream impact than nearby subwatersheds that have relatively small pollutant loads. Some of the factors affecting delivered pollutant load include:

- Stream channel geometry (i.e. cross-section shape, slope, and sinuosity)
- Size of the stream network
- Stream bottom materials/ roughness
- Stream bank conditions
- Hydraulic structures or other modifications
- Point source discharges or withdrawals

For each of the highest-priority pollutants (sediment, *E. coli*, nitrogen), pollutant loading and delivered loading were simulated, as shown in Figures 19, 20, and 21, respectively. For the highest priority pollutants, the difference in pollutant loading and delivered pollutant loading, from highest to lowest, was sediment (on median, 17% of the subwatershed loading reach is delivered to the outlet of Richland Creek), nitrogen (67%) and *E. coli* (99%). These differences can be observed by looking across Figures 19, 20. For example, sediment generally settles before reaching the lower watershed (as reflected by the most upstream subwatersheds in Figure 19 , which are dark shaded for pollutant loading and light shaded for delivered loading). On the other hand, *E. coli* loading generally makes it far downstream and impacts the outlet of Richland Creek (as reflected by relatively little difference in right and left panels in Figure 21. One of the reasons that *E. coli* exhibits such a high rate of delivery is bacteria are not a sediment-associated pollutant, and there is very little settling as *E. coli* travels downstream.

As described previously, pollutant loading and delivered pollutant loading serve as the basis for the DSS's consideration of two viewpoints, respectively: [1] managing water quality in each of the individual tributaries to Richland Creek and [2] managing water quality by protecting the lower reaches of Richland Creek and preventing discharges to the Cumberland River.

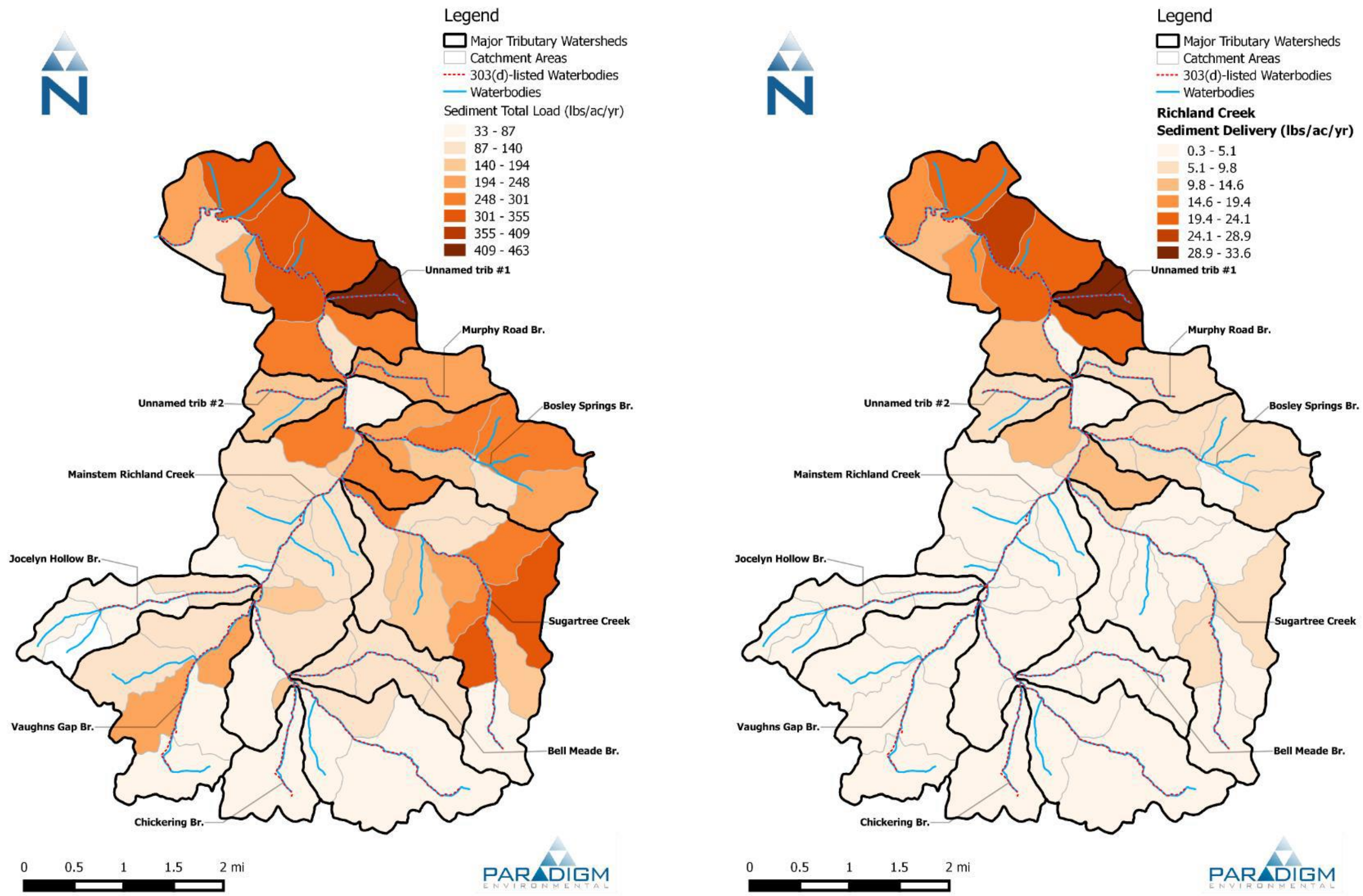


Figure 19. Suspended Sediment: Generated load (left) and delivered load (right) for the Richland Creek watershed on an annual-average basis.
These two maps present [1] the pollutant load that is generated from each subwatershed and discharged to its adjacent waterbody (left panel, "generated load") and [2] the pollutant load that ultimately impacts the lower reaches of Richland Creek and the Cumberland River (right panel, "delivered load"). For sediment, there are significant differences between the left and right panels (focus on the most upstream subwatersheds at the bottom of the map) – across the subwatersheds, the median percentage of generated sediment load (left panel) that is delivered to the outlet of Richland Creek (right panel) is 17%.

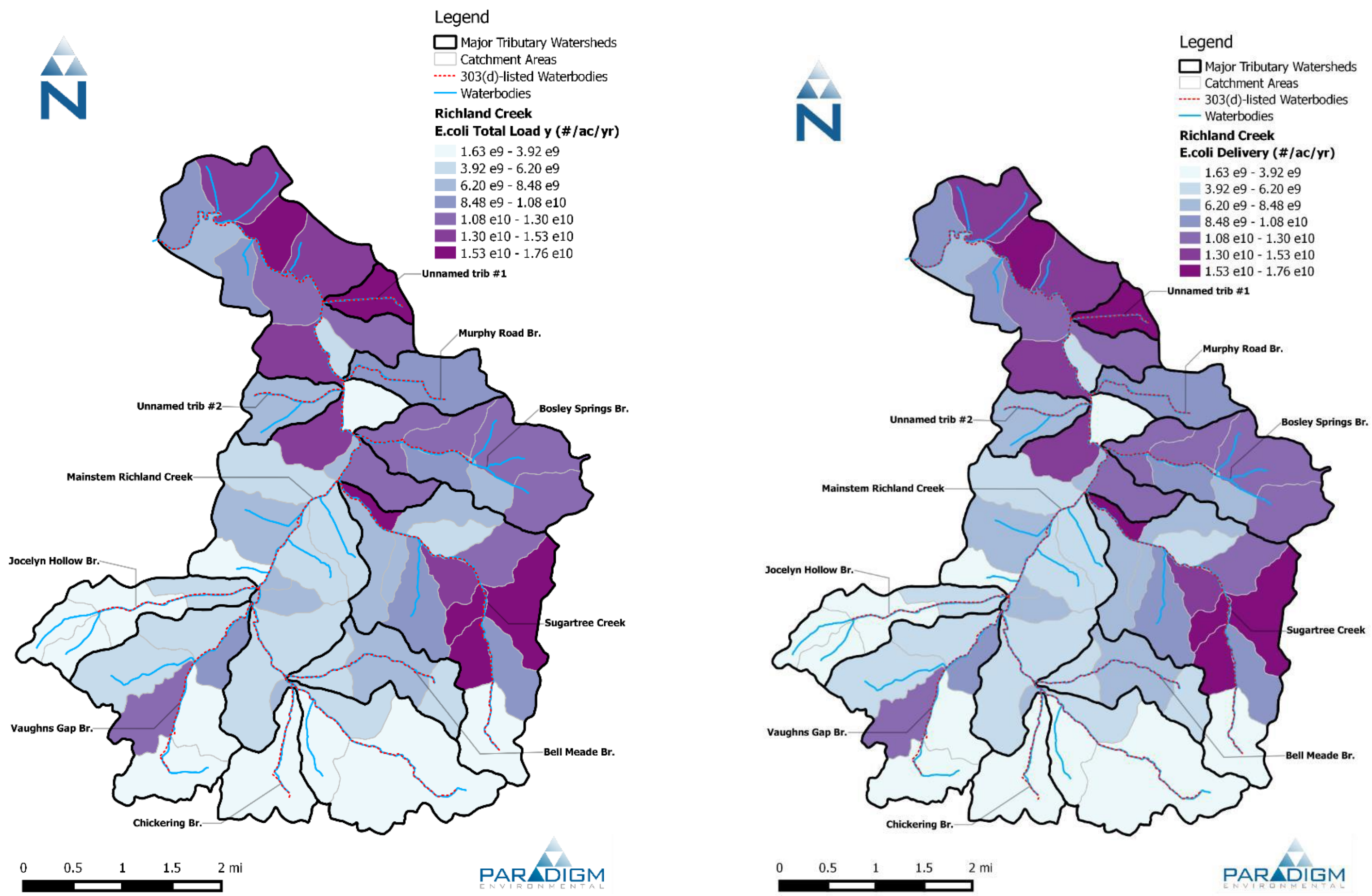


Figure 20. ***E. coli***: **Generated load (left) and delivered load (right) for the Richland Creek watershed on an annual-average basis.**
These two maps present [1] the pollutant load that is generated from each subwatershed and discharged to its adjacent waterbody (left panel, "generated load") and [2] the pollutant load that ultimately impacts the lower reaches of Richland Creek and the Cumberland River (right panel, "delivered load"). For *E. coli*, there is relatively little difference between the left and right panels – across the subwatersheds, the median percentage of generated sediment load (left panel) that is delivered to the outlet of Richland Creek (right panel) is 99%. One of the reasons that *E. coli* exhibits such a high rate of delivery is bacteria are not a sediment-associated pollutant, and thus there is very little settling as *E. coli* travels downstream.

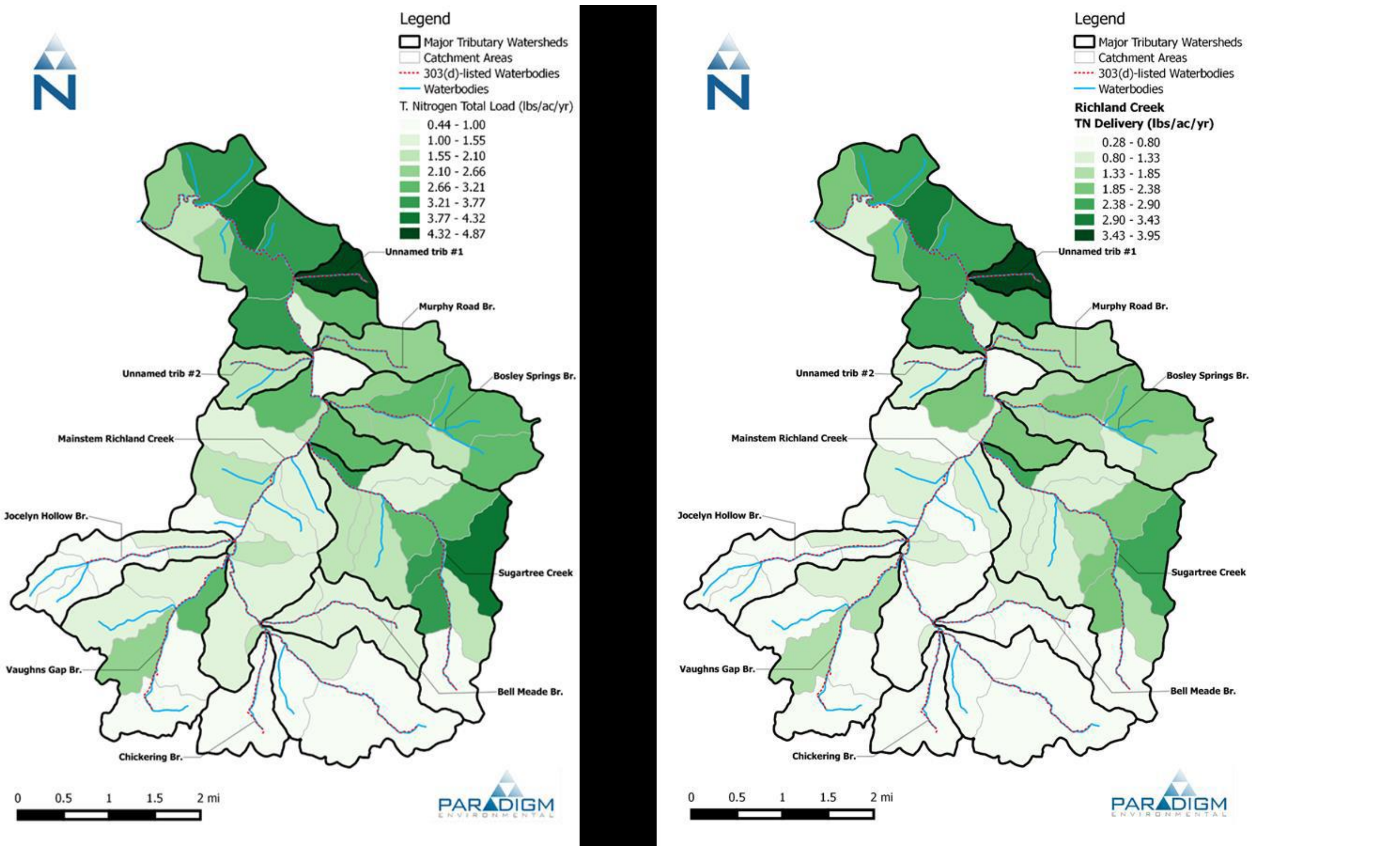


Figure 21. Total Nitrogen: Generated load (left) and delivered load (right) for the Richland Creek watershed on an annual-average basis. These two maps present [1] the pollutant load that is generated from each subwatershed and discharged to its adjacent waterbody (left panel, "generated load") and [2] the pollutant load that ultimately impacts the lower reaches of Richland Creek and the Cumberland River (right panel, "delivered load"). For nitrogen, there are moderate differences between the left and right panels (focus on the most upstream subwatersheds at the bottom of the map) – across the subwatersheds, the median percentage of generated sediment load (left panel) that is delivered to the outlet of Richland Creek (right panel) is 67%.

Analysis of Pollutant Reductions to Address Impairments

In order to determine how much of that loading is "excessive" and causing impairments, the pollutant concentrations and loads can be compared to water quality targets, shown in Table 15, which are based on TDEC water quality criteria or TMDLs. By capturing sufficient stormwater and implementing effective source control programs, the water quality targets could be achieved and the impairments to Richland Creek could be addressed.

Different pollutants have different time periods over which their loading causes impairments. Sediment and nitrogen loading are generally evaluated on annual average basis because siltation and eutrophication occur over long time periods. In contrast, *E. coli* concentrations of indicative of an illness risk that could be present instantaneously (if water contact occurs). As such, different approaches were used to evaluate the required pollutant reductions for sediment, *E. coli* and nitrogen, as described below:

- **Sediment**: Determination of excess sediment loading was based on comparison to loading that occurs in reference streams, which is consistent with the methodology of sediment/siltation TMDLs developed around the state by TDEC (e.g., the Stone River Sediment TMDL – TDEC, 2002). For ecoregion 71i, the Inner Nashville Basin, the natural sediment loading is estimated to be 220 pounds per acre per year (Table 16). To determine how much of the sediment loading in Richland Creek is excessive, the annual average sediment load (lbs/year) was determined for each subwatershed, divided by the subwatershed area and compared to 220 pounds per acre per year. One strategy for addressing sediment impairments would be to reduce the excessive sediment loading to be below 220 pounds per acre per year. The excessive sediment loading is shown in Figure 22.
- ***E. coli***: Exceedances of *E. coli* criteria were assessed by tracking the simulated *E. coli* concentration and flow rate, and flagging periods when *E. coli* concentrations were above the criteria of 941 MPN per 100mL (Table 16). During these exceedance periods, the "Exceedance Volume" was calculated, which is simply the volume of runoff generated when *E. coli* concentrations exceeded the criteria. Rolling, 24-hour periods were used across the 15-year simulation. The Exceedance Volume is a very useful metric for stormwater management, as it directly relates to the cumulative size of stormwater capture projects that would address impairments. The highlighted Exceedance Volume is the 85th percentile, 24-hour[2] Exceedance Volume – a network of stormwater projects that manages that volume in each subwatershed (i.e., retain the volume and/or treat *E. coli* concentrations to be below the criteria prior to discharge) would eliminate exceedances in all but 15% of storm events. One strategy for addressing *E. coli* impairments would be to manage the 85th percentile Exceedance Volume, which is presented in Figure 23. For Richland Creek watershed, the 85th percentile Exceedance Volume corresponds to a storm size of approximately 0.23 inches or less[3].

[2] The 85th percentile was selected because it often used for stormwater management regulations. For example, the 85th percentile storm event, which is often targeted by stormwater BMPs required to be implemented by developers for new/redevelopment. However, it should be noted the 85th percentile, 24-hour Exceedance Volume event corresponds to a 24-hour rainfall of 0.23 inches or less, which is much less than the 85th percentile storm.

[3] The storm size for Exceedance Volume is dependent on the criteria. TDEC applies an *E. coli* single sample criterion of 941 MPN per 100mL (Table 2-3). Many other states use 235 MPN per 100mL – if that criterion was applied to Richland Creek (instead of 941 MPN per 100mL), the storm size would be much larger, likely over 0.5 inches (instead of 0.23 inches).

- **Total nitrogen**: exceedances of nitrogen were assessed on an annual-average basis by comparing simulated loading to "allowable loading". The allowable loading was assumed to be the annual average runoff multiplied by the nitrogen target of 1.026 mg/L, which is derived from TDEC's narrative nutrient criterion for ecoregion 71i (Table 2-3). One strategy for addressing nutrient impairments would be to address excessive nitrogen loading, or the portion of the annual loading that is above the allowable loading, which is presented in Figure 24.

Future water quality improvement efforts may use these estimates to plan the source control programs and stormwater capture projects for addressing water quality impairments.

Table 16. Water quality targets used to evaluate required pollutant reductions to address impairments

Pollutant	Water Quality Target	Units	Source
Total Sediment	220	pounds per acre per year	Sediment loading from reference streams in ecoregion 71i (TDEC, 2002)
Total Nitrogen	1.029	mg/L	TDEC narrative nitrogen criteria based on reference streams (TDEC, 2001)
E. coli	941	MPN/100mL	TDEC criteria for single samples collected from recreational waters that are not a lake, reservoir, scenic river or exceptional water (TDEC, 2008)

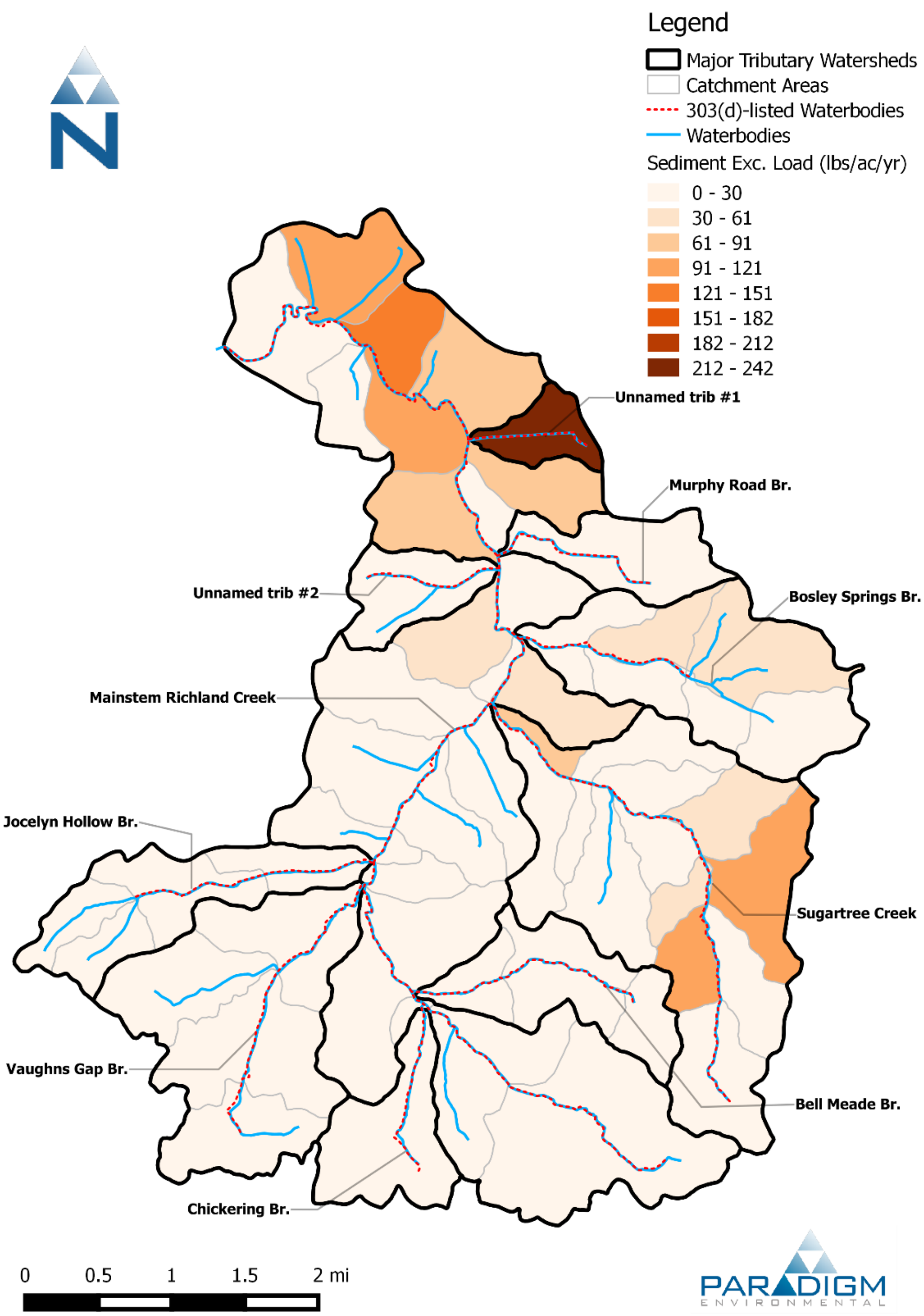


Figure 22. Sediment: Excessive loading that could be managed to address water quality impairments. The excessive sediment loading presented here is based on comparison of current annual average loading to sediment loading from reference streams for middle Tennessee. One strategy for addressing sediment impairments would be to identify source control programs and stormwater capture projects that reduce the excessive sediment loading to be comparable to reference streams.

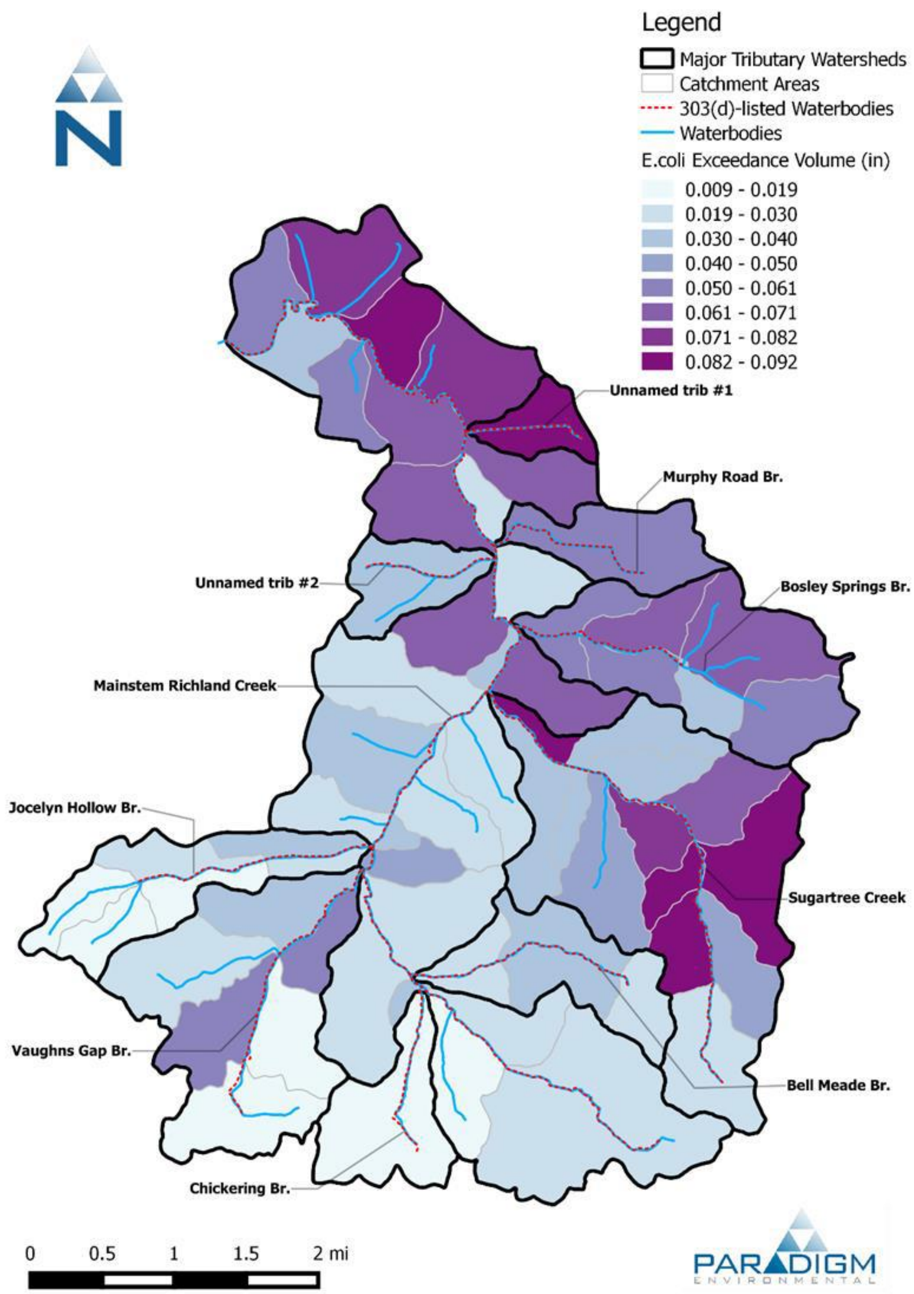


Figure 23. *E. coli*: Volume of runoff that could be managed to address water quality impairments. The volumes presented here are the 85th percentile, 24-hour Exceedance Volumes for each subwatershed. One strategy for addressing *E. coli* impairments would be to identify stormwater capture projects for each subwatershed that manage these runoff volumes. By "manage", the projects would either retain/filtrate the runoff or treat *E. coli* such that concentrations are below the applicable criteria prior to discharge from the subwatersheds. The volumes are expressed in inches to normalize by area, otherwise the volume would largely be driven by subwatershed size. The 24-hour runoff volumes are less than 0.1 inches in all subwatersheds. For reference, runoff of 0.1 inches from most subwatersheds would correspond to a 24-hour rainfall that is less than 0.23 inches**.**

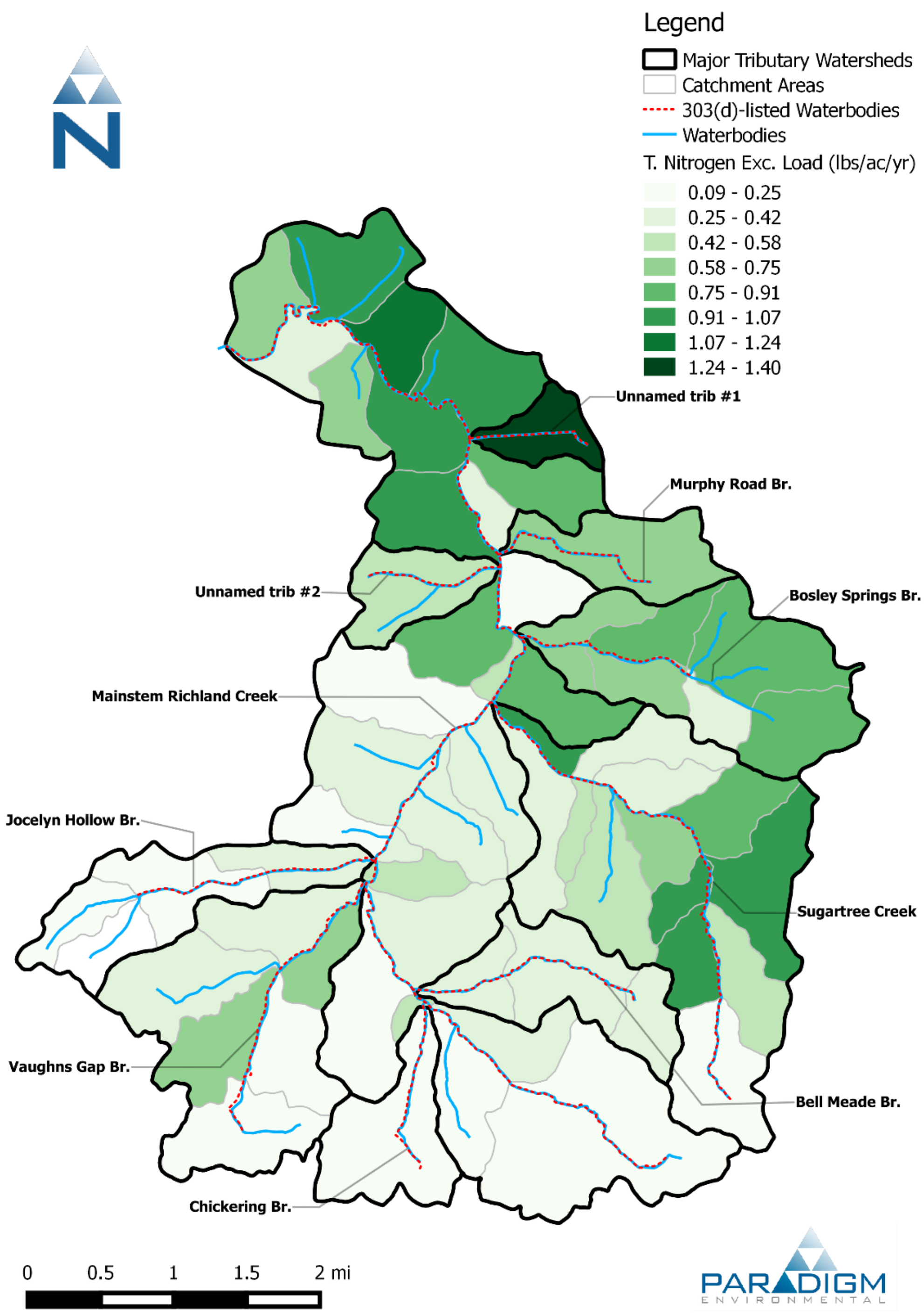


Figure 24. Total nitrogen: Excessive loading that could be managed to address water quality impairments. The excessive nitrogen loading presented here is based on comparison of current annual average loading to the allowable loading using TDEC narrative criteria for nutrients. Those criteria are based on monitoring of reference streams for middle Tennessee. One strategy for addressing sediment impairments would be to identify source control programs and stormwater capture projects would reduce the excessive nitrogen loading to be comparable to reference streams.

Application of the DSS for Watershed Management

Given the large number of subwatersheds and tributaries in the Richland Creek watershed, coupled with differing characteristics among the impairing pollutants, a quantitative tool is needed to support watershed management decisions. The analyses presented in previous sections provide the technical basis for the Richland Creek DSS. For the initial application of the DSS, the following watershed management questions are addressed:

1. Which subwatersheds should be prioritized for water quality improvement efforts to address impairments due to excessive sediment, *E. coli* and nutrients in Richland Creek?

2. Which subwatersheds should be prioritized for water quality improvement efforts to address impairments due to excessive sediment, *E. coli* and nutrients in the tributaries to Richland Creek?

3. Within a multi-pollutant approach, which subwatersheds in the Richland Creek watershed should be prioritized for targeted source control programs and stormwater?

Each of these questions is addressed in the following subsections.

Prioritization of Subwatersheds to address Sediment, *E. coli* and Nutrient Impairments in Richland Creek Watershed

The DSS considers two viewpoints – the first based on protection of lower Richland Creek and thereby the Cumberland River and the second based on protection of the *tributaries* to Richland Creek. Due to the differences in *generated* pollutant loads and *delivered* pollutant loads these two viewpoints can lead to different priorities for managing water quality. As such, prioritization of areas/subwatersheds in Richland Creek watershed by the DSS considers both [1] managing water quality to address impairments in the lower reaches of Richland Creek and to prevent discharges to the Cumberland River (Question #1 above) and [2] managing water quality to address impairments in the individual tributaries to Richland Creek (Question #2, above).

The Richland Creek subwatersheds were ranked in order of priority for management, with one (1) being the highest priority and four (4) being the lowest. The rankings and priorities for each subwatershed were determined based on how the excessive pollutant load (as described in Section 2.4) compares to the average excessive load across all subwatersheds, as follows:

- Subwatersheds with the highest pollutant loading are considered Priority 1 = “highest;
- Subwatersheds with pollutant loading above the average but below Priority 1 are considered Priority 2 = “high”;
- Subwatersheds with pollutant loading near but below average are considered Priority 3 = “medium”; and
- Subwatersheds with lowest pollutant loading are considered Priority 4 = “low”.

An illustration of the methodology for this ranking system is presented in Figure 25.

The results of the DSS prioritization for sediment, *E. coli* and nutrients are presented in Figure 26, 27, and 28 respectively. These figures are the answers to watershed management Questions #1 and #2. Each figure presents the priorities based on the two DSS viewpoints – water quality management of lower Richland Creek/Cumberland River and management of the major tributaries. For the tributary-centric viewpoint, the major tributaries are the focus of the analysis – Sugartree Creek, Vaughn's Gap Branch, Bosley Springs Branch, Belle Meade Branch and Jocelyn Hollow Branch.

Due to differing fate/transport characteristics and differing levels of water quality criteria imposed by TDEC, some subwatersheds may be a high priority for one pollutant but not another. Overall, however, the subwatershed prioritization is not drastically different among pollutants because hydrology is a driver of pollutant loading – those subwatersheds with high levels of imperviousness tend to be problematic across all the three pollutants.

For efforts that are focused on individual pollutants (sediment, *E. coli* or nutrients), the highest priority subwatersheds in Figure 26, 27, and 28 are the recommended areas to target for water quality improvement efforts.

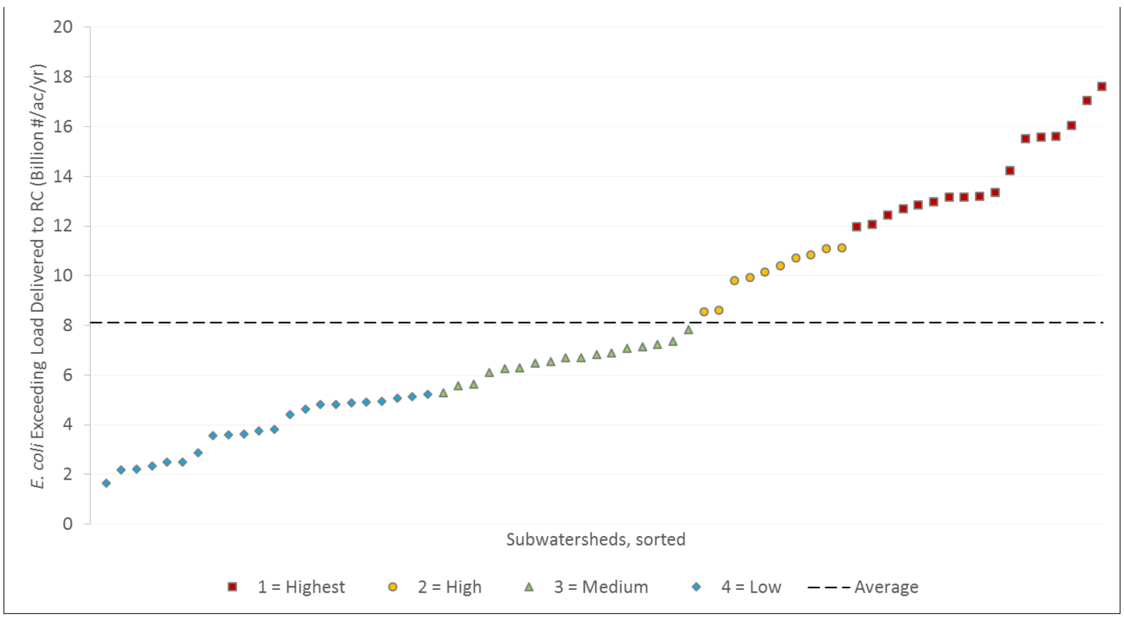


Figure 25. Example ranking approach for prioritizing Richland Creek subwatersheds to address impairments.

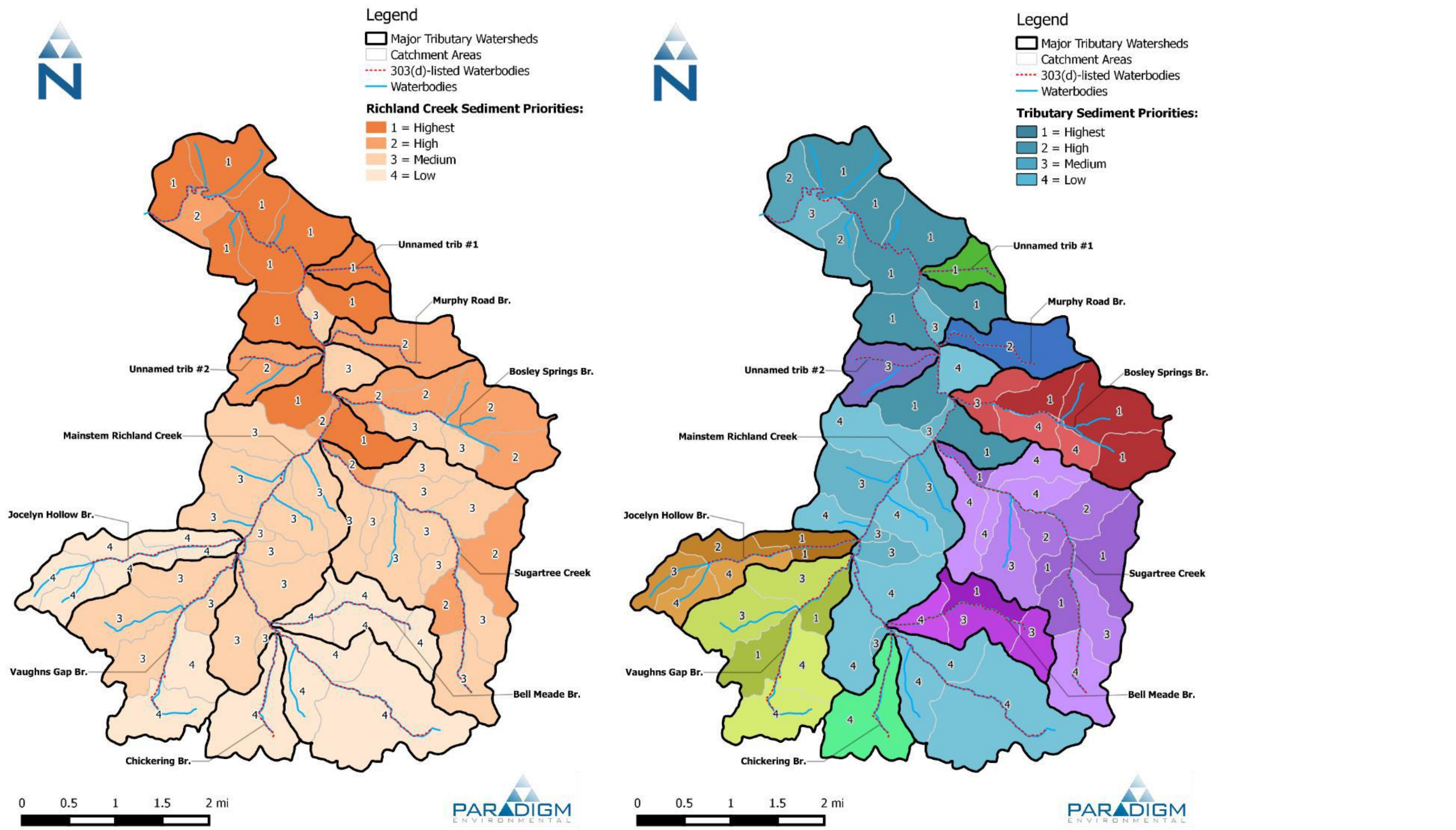


Figure 26. Sediment: Prioritization of subwatersheds for managing the water quality of lower Richland Creek (left) and the major tributaries (right).

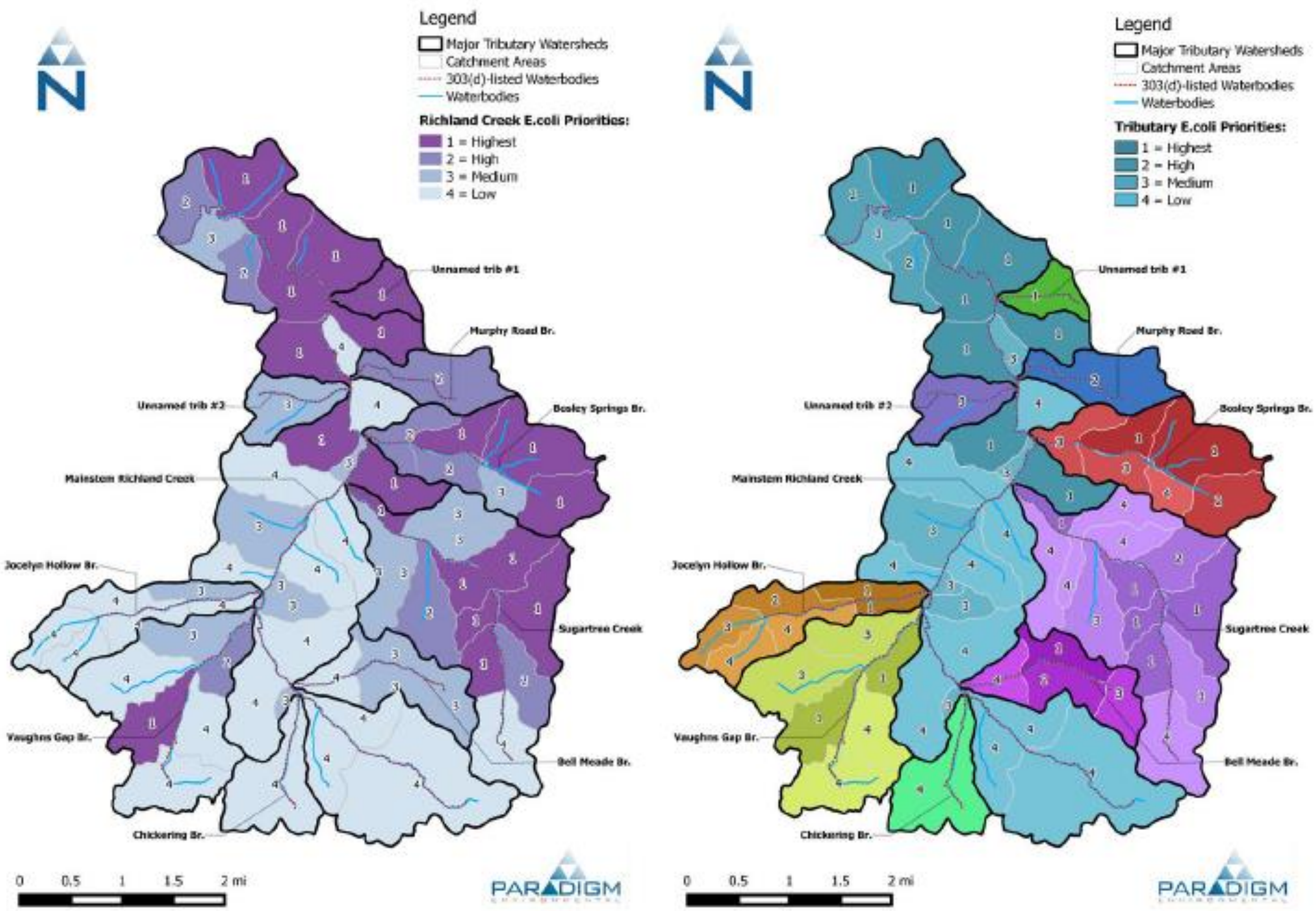
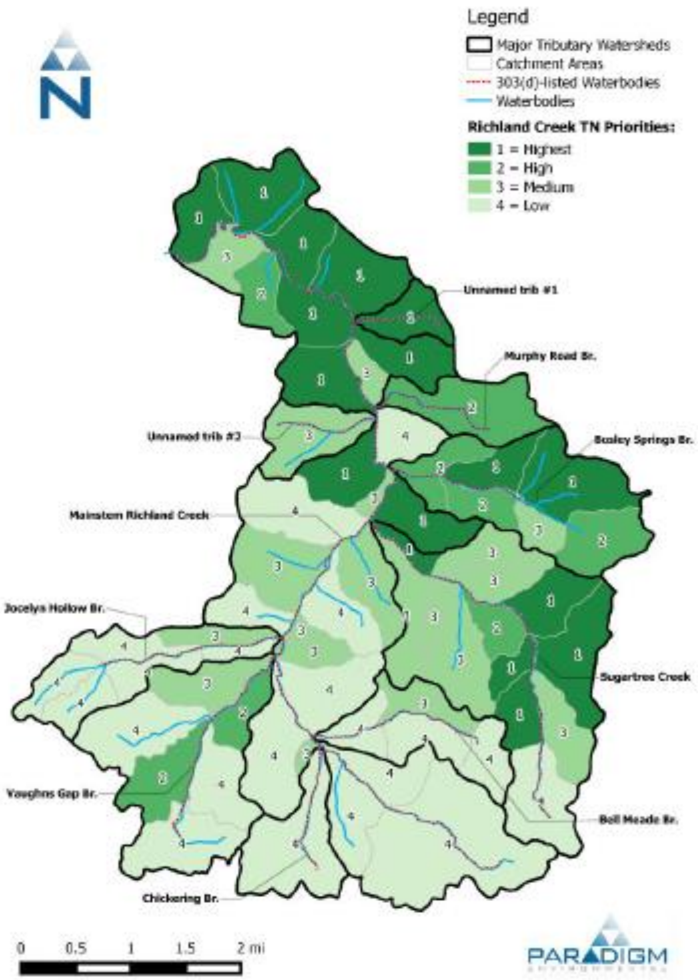


Figure 27. ***E. coli*: Prioritization of subwatersheds for managing the water quality of lower Richland Creek (left) and the major tributaries (right).**



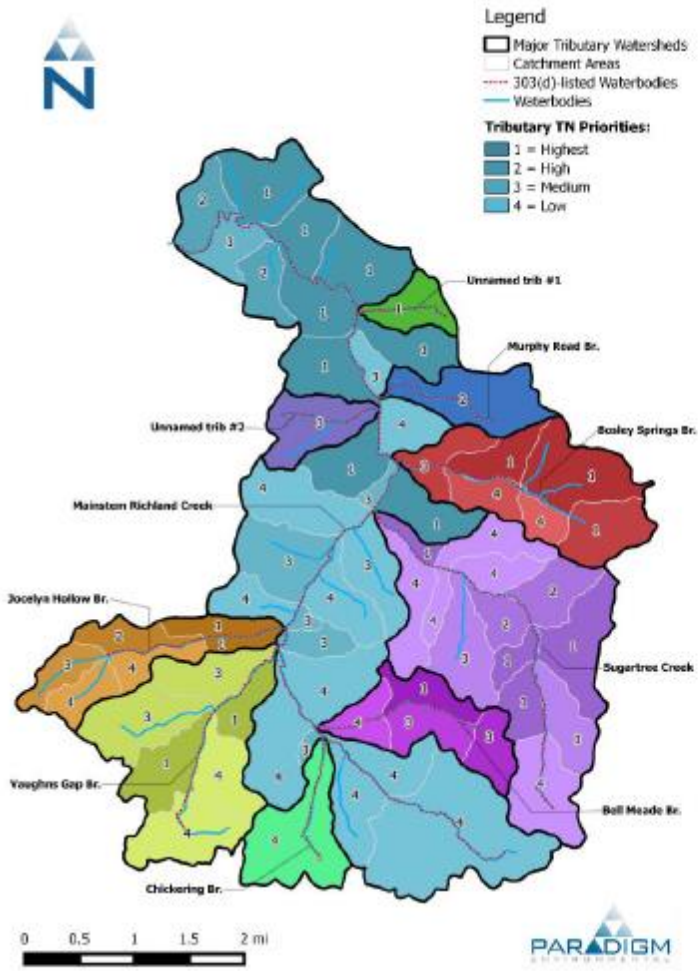


Figure 28. Nutrients: Prioritization of subwatersheds for managing the water quality of lower Richland Creek (left) and the major tributaries (right).

Multi-Pollutant Approach: Prioritization of Subwatersheds for Targeted Source Control Programs and Stormwater Capture

In many cases, water quality improvement efforts do not target a single pollutant – instead they are driven to comprehensively address impairments by multiple pollutants. To address watershed management Question #3, the DSS was applied to prioritize subwatersheds across all three prioritized pollutants (sediment, *E. coli* and nutrients). A subset of the subwatersheds in Richland Creek was highlighted as the Highest priority for multi-pollutant activities. Namely, the subwatersheds that are recommended as priorities for multi-pollutant activities are those subwatersheds that were a Priority 1 = Highest for sediment, *E. coli* and nutrients (all three).

Shown in Figure 29 is the multi-pollutant prioritization for protection of lower Richland Creek / Cumberland River, while Figure 30 shows the prioritization for the major tributaries. These figures are the answer to watershed management Question #3. The highlighted subwatersheds are the recommended areas to target during the earliest phases of programs implemented to control sources and capture stormwater. Overall, these figures are the culmination of the DSS analysis for this initial phase – representing analyses across multiple pollutants while considering several sets of applicable water quality criteria. Over time, as pollutant loads are addressed from these subwatersheds, then a second tier of subwatersheds could be evaluated for water quality improvement efforts in the Richland Creek watershed.

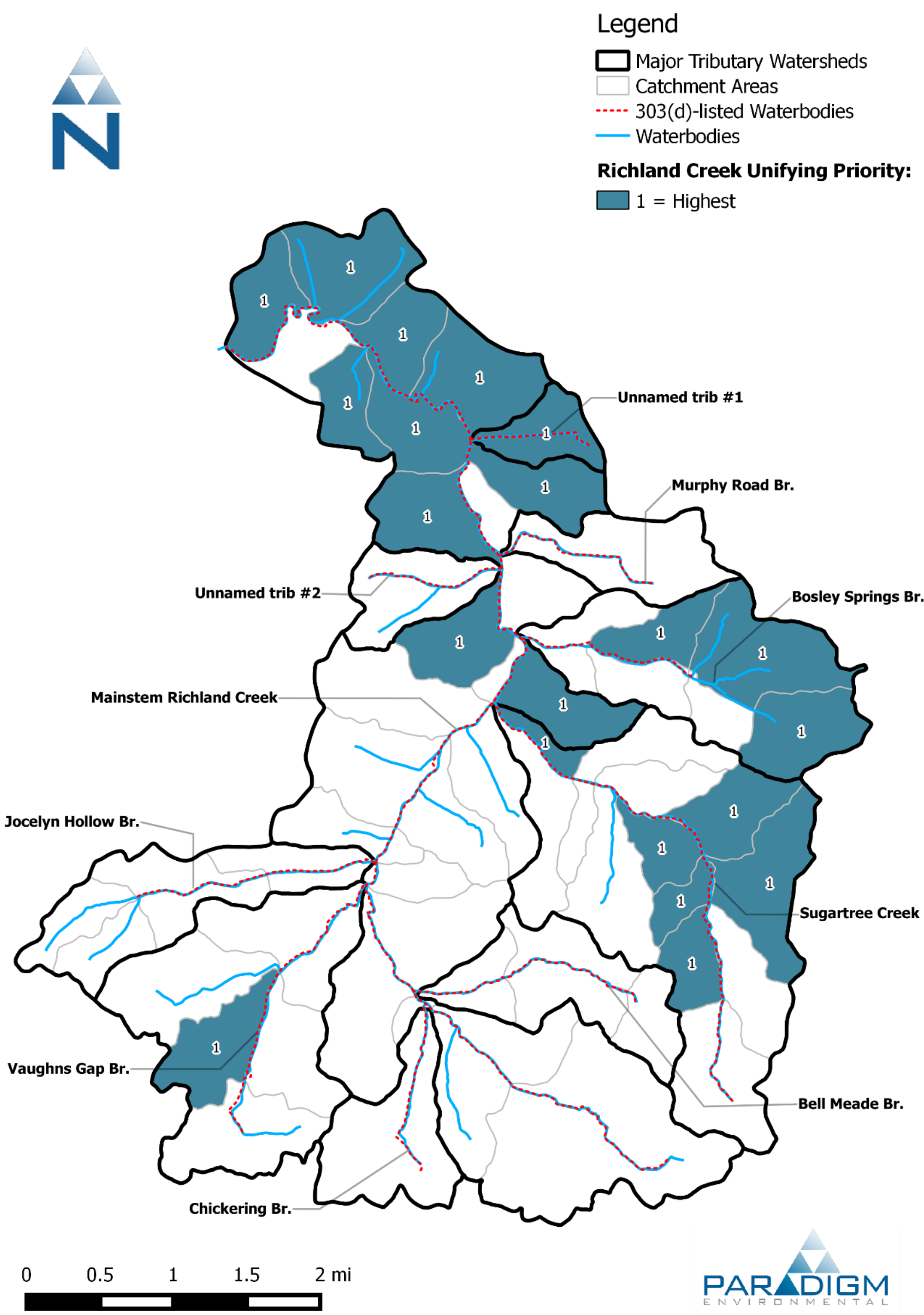


Figure 29. Lower Richland Creek: Prioritized subwatersheds for multi-pollutant implementation activities.

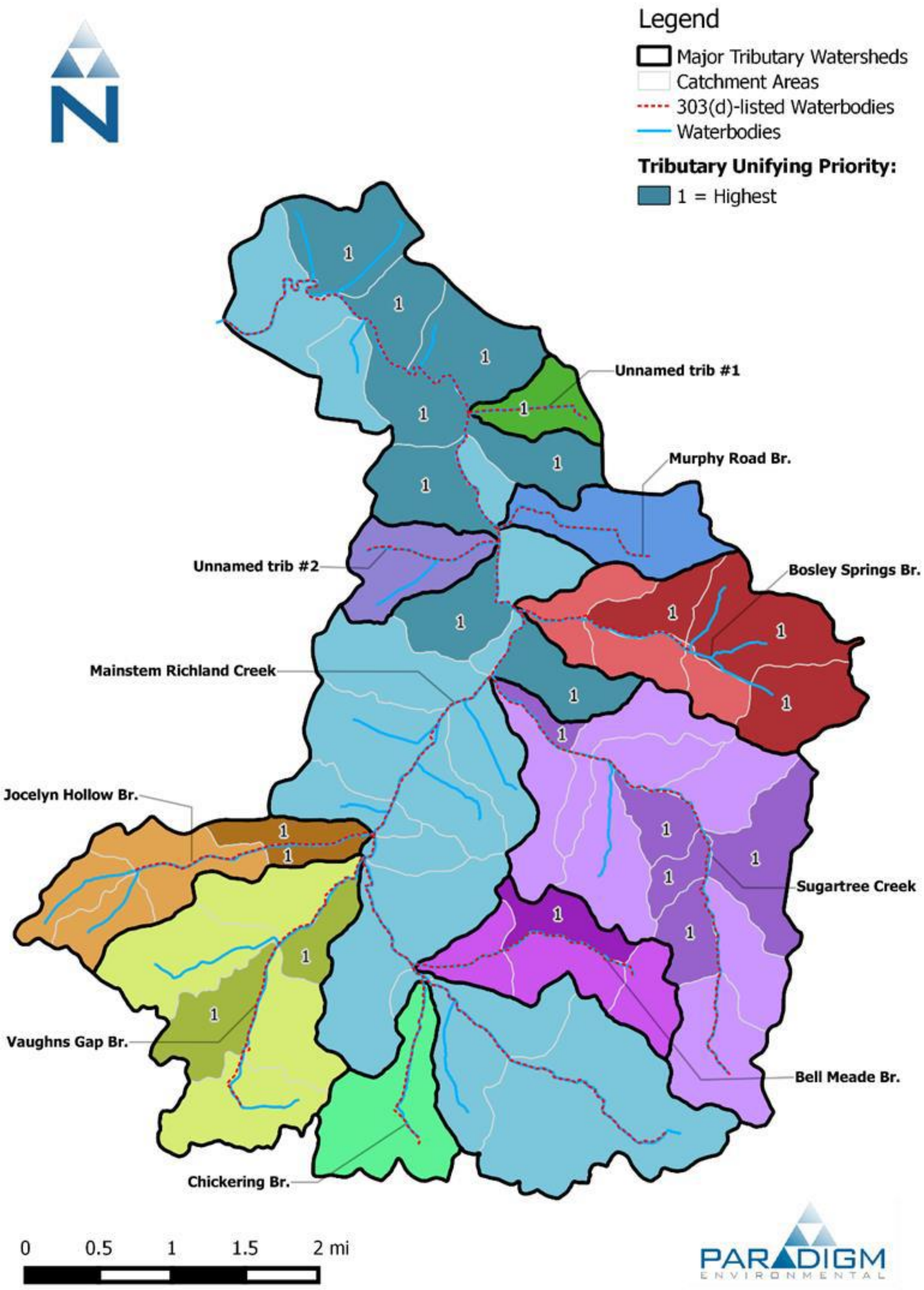


Figure 30. Major tributaries: Prioritized subwatersheds for multi-pollutant implementation activities

Conclusion

The Richland Creek DSS provides a technical basis for prioritizing water quality improvement efforts under the Watershed Stewardship Plan, which is a collaborative effort by The Nature Conservancy, Cumberland River Compact, Metro Water Services, and the Mayor's Office. The DSS considered a variety of pollutants and water quality criteria to recommend specific "Highest Priority" areas in Richland Creek watershed to target for source control programs and stormwater capture projects. The next step for implementation would be to identify the specific programs and capture projects that could be employed within the Highest Priority subwatersheds. Stormwater capture projects could be identified based on known locations where there is an efficient implementation opportunity (e.g., sites were capital improvement projects are already being considered, or locations where homeowners or schools are engaged and willing to allow rain gardens to be constructed on their parcels) or by conducting more detailed BMP modeling to support BMP selection decisions. Over time, the DSS could be updated to incorporate the effect of pollutant reductions achieved by the implemented programs/projects, if monitoring shows that impairments remain. Finally, the Richland Creek DSS provides a demonstration of a simple, robust tool that can guide and greatly improve the effectiveness of watershed/water quality management efforts in Nashville/Davidson County.

SUSTAIN – System for Urban Stormwater Treatment Analysis and Integration

Background Information

SUSTAIN is a model that was developed by the U.S. EPA and can be used to evaluate alternative plans for water quality management and flow abatement techniques in urban areas. SUSTAIN has provided a much needed tool for assessing, selecting and placing BMPs in urban watershed areas and is capable of calculating optimal location, type, and cost of stormwater BMPs needed to meet water quality goals. SUSTAIN takes user-provided watershed hydrology and water quality data and couples it with a water quality model, Loading Simulation Program in C++ (LSPC). LSPC includes algorithms for simulating a host of processes (e.g., pollutant loading, erosion, and in-stream transport). Through this integration process LSPC and SUSTAIN models are able to generate the most appropriate suite of BMPs to achieve the necessary pollutant and loading reductions through cost optimization.

Sugartree Creek watershed was chosen for a pilot study using SUSTAIN to determine the optimal suite of BMPs in terms of cost and effectiveness. The Sugartree Creek watershed is a 3,054 acre area and is located within Richland Creek watershed in the western portion of Nashville, Tennessee in Davidson County. The creek flows northwest towards its confluence with Richland Creek, located near the intersection of Highway 155 and U.S. Route 70 South. Sugartree Creek watershed is located in the Outer Nashville Basin Ecoregion and consists of rolling hills and low to moderate streams. The bedrock and soil parent material is limestone, which is high in phosphorus. The area receives precipitation year round, however, the wettest periods are typically in winter and spring.

Sugartree Creek watershed is located in the Green Hills neighborhood, an affluent suburb of Nashville, Tennessee, which includes the City of Belle Meade. The Green Hills neighborhood consists chiefly of large residential lots, with some commercial areas located near The Mall at Green Hills and along Hillsboro Pike, which runs adjacent to the mall. Approximately 30 percent of Sugartree Creek watershed is covered with impervious surfaces from roofs, roads, driveways, and sidewalks, indicating that it is a highly developed and urbanized watershed. Sugartree Creek is listed as impaired on the 2012 303(d) list for nutrients, *E. coli*, and habitat alterations due to discharges from the MS4 area and the municipal high density area (TDEC, 2014).

The underlying goals of the Sugartree Creek SUSTAIN Pilot project were to provide technical support for local planning, as well as, results which would help to reinforce management decisions regarding BMP types, locations and costs to effectively address water quality impairments and achieve water quality targets. A major benefit of this analysis was the development of baseline hydrologic and water quality conditions of the entire Richland Creek watershed. This was a product of the LSPC model, and ultimately assisted with determining the reduction of nutrients (Total Phosphorous and Nitrogen) and *E. coli* needed to meet the recommended concentrations (TDEC).

Water Quality Results

TDEC recommended water quality target concentrations for this region are 0.92mg/L for Nitrate/Nitrite (NOx) and 0.18 mg/L for Total Phosphorous(TP) (Denton, et al. 2001). In addition, the regional E.coli target is a five day geomean of 126cfu or less. Therefore these concentrations were used as thresholds for the model along with a rainfall retention factor of the first inch of rainfall to reduce sediment concentrations. To determine the reduction of nutrients and *E. coli* needed to meet the recommended standards, water quality was evaluated during normal flow years when both flow and water quality data was collected (2001 through 2003) (Tables 17 and 18).

Table 17. Modeled water quality results compared to Metro water quality standards during normal flow years 2001 through 2003 at Station 1, Harding Place.

	Nitrate-Nitrite (mg/L)	Total Phosphorus (mg/L)	*E. coli* (cfu)
Minimum	0.18	0.10	47
10th Percentile	0.54	0.30	57
50th Percentile	0.69	0.38	79
Average	0.75	0.42	212
90th Percentile	1.10	0.63	577
Maximum	2.63	1.56	1655
Metro Standard	**0.92**	**0.18**	**126**

Table 18.. Measured water quality results compared to Metro water quality standards during normal flow years 2001 through 2003 at Station 1, Harding Place.

	Nitrate-Nitrite (mg/L)	Total Phosphorus (mg/L)	*E. coli* (cfu)
Minimum	0.42	0.02	34
10th Percentile	0.50	0.05	43
50th Percentile	1.22	0.57	800
Average	1.25	0.53	867
90th Percentile	1.83	0.90	1780
Maximum	2.36	1.00	2100
Metro Standard	**0.92**	**0.18**	**126**

Using the modeled data, the NOx concentrations fell below the 0.92mg/L standard approximately 86% of the time. The modeled *E. coli* concentrations were below the 126 cfu standard approximately 66% of the time. Concentrations for these two parameters are greatest during storm events, and it is the goal that, by attenuating storm flow, concentrations should be reduced to below the standard. However, the model indicated that the TP standard would be difficult to achieve in this watershed, especially considering that the modeled TP concentrations were less than the measured concentration in recent years. It should also be taken into account that in the suggested nutrient concentration criteria (Denton, et al. 2001), TDEC notes that TP often exceeds the recommended criteria in the Nashville Basin, and that this region has naturally high TP concentrations in stream.

When the maximum concentration for normal flow years was used, target reductions to meet the recommended values for NOx, TP and E.coli were similar for both the modeled and measured data (Table 19). Total Phosphorous was the limiting nutrient, as the percent reduction was calculated as 88% and 82% for the measured and modeled data, respectively, as compared to the NOx percent reduction of 65% and 61% for the measured and modeled data, respectively. Therefore, TP reductions were targeted in the SUSTAIN optimization model with the hope that reductions in TP will result in reductions in NOx, and therefore help to meet both targets.

Table 19. Percentage reduction needed to meet Metro water quality standards during normal flow years 2001 through 2003 at Station 1, Harding Place.

	Nitrate-Nitrite (mg/L)		Total Phosphorus (mg/L)		*E. coli* (cfu)	
	Modeled Data	Measured Data	Modeled Data	Measured Data	Modeled Data	Measured Data
Reduction using 90th Percentile Concentration	16%	50%	71%	80%	78%	93%
Reduction using Maximum Concentration	65%	61%	88%	82%	92%	94%

E. coli concentrations were found to be below the criteria of 126 cfu approximately 66% of the time, yet had the highest percent reduction at 92% and 94% as calculated using the modeled and measured data, respectively. This is due to the high concentrations during storm events, which are approximately 60 times greater than low flow periods.

BMP Opportunities Assessment Results

A wide variety of stormwater management practices can be modeled, including; infiltration, trenches, bio-retention areas, vegetated swales, porous pavements, and green roofs. However, not all BMPs are equally suitable to all site conditions and performance goals across watersheds. For example, Sugartree Creek is predominately residential, and consist of narrow two-lane roads that use open channel swales to convey water from the road. While this system provides better attenuation than the curb and gutter system, it greatly limits the area where trees could be planted, or street sweeping could occur. On the other hand, the presence of a large network of open channel grassed swales presents an excellent opportunity for BMP retrofits. These grassed swales could be developed into vegetated water quality swales which could provide additional infiltration to improve water quality. Furthermore, because the open channel swale network is already present, water quality swales could be installed at a lower cost than normal.

Potential BMPs for Sugartree Creek watershed were selected by evaluating property ownership, impervious and pervious areas, conditions of stream and/or conveyances, and location in the watershed. Locations were selected using aerial imagery, land use datasets, and Google Earth Street View. As a result, the potential for a few large, regional and several small, distributed BMPs in commercial and residential areas throughout Sugartree Creek watershed were identified. Because Sugartree Creek watershed is largely developed, there are not many vacant lots. This limits the ability to create large regional scale BMPs, such as detention ponds or wetlands.   However, there are plenty of opportunities for distributed BMPs in both residential and commercial areas in the watershed.

As defined by the SUSTAIN pilot study regional BMPs are large-scale BMPs, such as riparian wetland and stream restorations, that can treat flow in tributaries and main stems on a large scale level. Alternatively, distributed BMPs treat storm runoff from small areas of land, such as an individual parking lot, rooftop, or small section of road, and are typically dispersed throughout a watershed. All together eight potential regional BMP locations (Table 20), and 168 potential distributed BMP locations (Table 21) were identified in the Sugartree Creek watershed. The average treated area for each of the potential distributed BMP was calculated by evaluating the estimated drainage area of each BMP type. In addition, each distributed BMP location within the modeled subwatershed and regional subwatershed boundaries was identified.   As part of the pilot study field reconnaissance is being conducted to determine if the identified BMPs can be installed at the selected locations.

Table 20. Identified regional BMPs in the Sugartree Creek Watershed

Regional BMP ID	Waterbody	Upstream Area (acres)	Reach Length (m)	Regional BMP(s)	Property Owner
1	Tributary	87	320	Riparian Wetland	Metro Schools
2	Tributary/Piped Conveyance	281	40	Riparian Wetland	YMCA
3	Piped Conveyance	17	40	Riparian Wetland	Metro Teachers
4	Sugartree Creek	1,372	400	Riparian Wetland/Stream Restoration	YMCA/Metro Teachers
5	Tributary	384	150	Riparian Wetland	Elder & Burlington HOAs
6	Tributary	163	25	Riparian Wetland	Chestnut Hill HOA
7	Tributary	196	125	Riparian Wetland	Metro Water & Sewer
8	Sugartree Creek	2,952	500	Riparian Wetland/Stream Restoration	Metro Right of Way/HOA

Table 21. Number and type of identified distributed BMPs in the Sugartree Creek Watershed

Distributed BMPs	Metro	Commercial	Residential	Total Treated Area (acres)
Bio-retention	7		4	51.1
Concrete Channel Conversion			11	48.8
Grass Swale Conversion	2		33	686.0
Green Roof	2	4		17.9
Green Street	4			28.5
Pervious Pavement	4	37	2	49.9
Riparian Buffer	1	2	9	5.8
Tree Planting	6	8	3	7.5
Water Quality Swale	12	6	11	153.2

Regional BMP Locations

Several potential opportunities for regional BMPs were found on Metro owned property throughout the watershed. For example, three adjoining properties located immediately south of the Green Hills Mall, two of which are owned by Metro and the third by the YMCA (Regional BMP ID 4). Sugartree Creek runs through all three properties and appears to be severely degraded at this location due to lack of riparian buffer and erosional activities in the stream. This stretch of stream presents a good location for a regional BMP such as Stream Restoration. Another example of a Metro property that was identified by SUSTAIN is Hillsboro High School property which has several small tributary drainages on site that are eroding and lack canopy cover (Regional BMP ID 1). Small riparian wetlands could be constructed here which could also provide educational opportunities for the high school.
Most of the other large parcels of land that could potentially be used within the watershed are managed by Home Owners' Associations (HOA), and involve converting concrete lined areas of the stream into riparian wetland or undertaking a full stream restoration. Development of BMPs in these locations would need collaboration between Metro, the land owners and the individual HOA .

Distributed BMP Locations

As far as distributed BMPs are concerned, there are numerous roads in the commercial section of Sugartree Creek watershed near Green Hills Mall that have several characteristics that make them ideal for green street implementation, which could incorporate many distributed BMP features into their development. Also, because the existing residential areas use grass swales instead of curbs and gutters, there is a large network of swales in place in the Sugartree Creek watershed that could be strategically converted to vegetated swales to allow for infiltration and water quality treatment of a large portion of the watershed. Additionally, there are two Metro-owned buildings that were identified as potentially suitable for green roof BMPs (the two schools and library located within this watershed), and porous pavement could be used in the parking lots of several Metro owned facilities.

Dozens of locations were identified at both commercial and residential properties where tree plantings and installation of pervious pavement and water quality swales could be implemented. As far as residential areas are concerned, many of the tributaries and conveyances to Sugartree Creek flow through concrete lined channels. Removing the concrete conveyance systems and restoring the stream channel offer a great opportunity for restoration that can improve water quality. However, full restoration is costly and most of these channels are located on residential property, which may prevent Metro receiving permission to do restoration. Potentially, the concrete could be removed in these locations and replaced with large boulders and rip-rap, which would slow the velocity of water in the channels and allow for some infiltration.

The SUSTAIN pilot project provided suggestions for implementing non-structural BMPs in Sugartree Creek watershed, as well. Non-structural BMPs provide cost-effective ways to reduce pollutants into streams, and are especially useful in areas where it can be difficult to place regional or distributed BMPs.

Non-structural BMPs include programs such as; public education, street sweeping, and pet waste management to name a few, and can reduce nutrients and fecal coliform on the land surface before it enters Sugartree Creek. The majority of recommendations provided by the SUSTAIN pilot involved increasing frequency in already existing non-structural BMPs within the Sugartree area, such as; street sweeping, homeowner education, and pet waste management systems.

As mentioned before, Metro Water Services already implements a number of these BMPs throughout the Sugartree watershed. For example, Metro currently sweeps most public roads with curbs and gutters once a month, which helps to reduce nutrients and sediments collected on the roads. Metro Water Services is also presently performing quarterly, five day bacteria sampling in Richland Creek watershed. One of the creeks sampled in this rotation is Sugartree Creek. These samples can help provide information on current E.coli levels, and if levels are alarmingly high, PCR analyses can be used to determine if contamination is from a human source.

For some time now, Metro Water Stormwater Division has had a relatively robust public education program. All types of Stormwater issues are addressed in a variety of ways. For instance, if a stream has high bacterial levels that are determined to be from a non-human source, and the area surrounding it is highly residential, there will be a educational mailings regarding the proper disposal of pet waste to all the properties surrounding the stream. Areas around streams are also targeted for educational mail outs focusing on proper use and disposal of lawn care chemical and yard debris.

As another non-structural BMP, Metro Water could evaluate ordinances to determine if there are any barriers to BMP construction or any incentives that can be provided to developers in the future to encourage the use of additional BMPs in their designs. As an example, ordinances that currently require curb and gutters along streets and parking lot islands, could instead, offer rewards to allow cuts in the curb and encourage building water quality swales or bio-retention areas along roads or parking lots.

BMP Optimization Analysis Results

The SUSTAIN model was applied to the Sugartree Creek watershed to allow for a detailed spatial analysis of possible BMP implementation scenarios and to determine the most cost effective set of BMPs for total phosphorus reduction. A key feature of the SUSTAIN model is its ability to evaluate numerous potential combinations of BMPs to determine the optimal combination that meets a pre-specified objective. To do so, SUSTAIN develops cost-effectiveness curves that evaluate different sets of practices (e.g. varying combinations and sizes of BMPs) to achieve a reduction in peak stream flow.

The model simulates the performance of each BMP practice individually, and in combination, to reduce flow (volume and/or peak) and nutrient loads, taking into account the site-specific characteristics of the project area (e.g.) soil types, land uses, precipitation patterns). Scenarios can be specified with varying practices (Stormwater wetland at given location, X number of houses with rain gardens of Y storage volume), or less specific. Algorithms are used to compute infiltration, evapotranspiration, and runoff, as well as pollutant loading. Calculations are made at an hourly scale over a multi-year period to provide a full assessment of the response to each individual storm event. At the same time, SUSTAIN assigns a locally-derived cost to each practice to achieve a total cost for each scenario. SUSTAIN model simulation methods and algorithms are described in the U.S. EPA report, SUSTAIN- A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality (USEPA 2009).

BMPs were simulated in SUSTAIN according to design specifications, which were obtained from Metro Water Service BMP Manual, along with professional knowledge of design criteria used in previous projects. SUSTAIN predicts BMP performance as a function of its physical configuration, storm size and associated runoff intensity and volume, and moisture conditions in the BMP. BMP cost estimation is a major component of the optimization process, because the cost-effectiveness of one scenario relative to others must be compared. Therefore, a standard unit cost was defined for each BMP category, since the range of BMPs was unknown and expected to vary significantly.

The decision variables used in the study included the surface area size of the distributed BMPs and the storage capacity of the regional BMPs. Two optimization objectives were defined in this application: (1) to minimize the TP load at the assessment points, and (2) to minimize the BMP total cost. Watershed scale optimizations were performed for three selected assessment points at the water quality stations along the Sugartree Creek main stem.

The drainage area for the potential regional BMP 5 (Riparian Wetland) was selected as the pilot area for SUSTAINS model setup. The pilot area is comprised of 384 acres of mixed land uses dominated by trees/forested area (49%). The total impervious area (buildings, roads, driveway/paved area, and parking lots) is around 25% and the dominant soil types are B and C hydrologic soil group. The entire selected pilot area drains through a tributary to Sugartree Creek.

A cost-effectiveness curve was developed using the aforementioned data to generate approximately 5,000 model runs analyzing potential BMP combinations (Figure 31). Every dot on this curve represents a unique combination of BMP types and sizes. The dots on the far left and top of the curve (i.e. the curve frontier) show the optimal solutions with minimum BMP cost and maximum load reductions. This curve can be used by managers within Metro Water to select a preferred solution to obtain a specific target at the lowest modeled cost.

Three best solutions were selected on the frontier of the curve by the SUSTAIN pilot to demonstrate the cost versus percent TP load reduction benefits (Figure 31). However, this application must be accompanied by an intimate understanding of the study area and the identification of influential factors that affect the decision making to achieve Stormwater management goals. For example, the Best Solution 1 chosen by the SUSTAIN model would cost $389,115 to achieve an estimated 71% TP annual load reduction, whereas the Best Solution 2 chosen by the model would cost $56,916 less than Best Solution 1 but will still achieve 70% load reduction. Best Solution 3, however, costs 36% less ($140,191) than Best Solution 1 with only 5% less load reduction. The small reduction in nutrients may not be worth the additional cost, which in this case is equal to $28,000 per additional percent in TP load reduction.

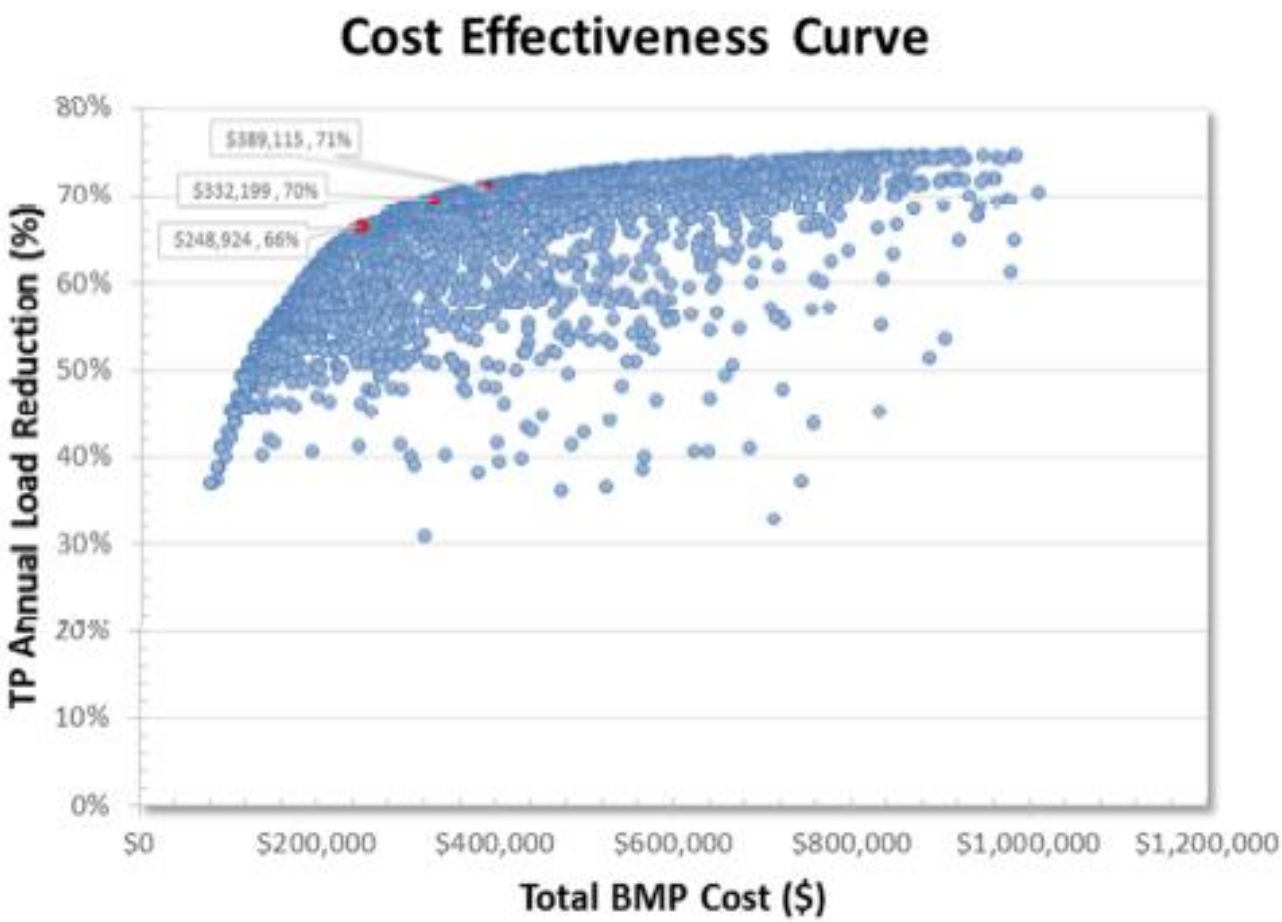


Figure 31. Cost effectiveness curve for potential bmp combinations.

Among the BMPs chosen by the model for the three selected solutions, the regional riparian wetland was fully utilized by all three (Table 22). In regards to distributed BMP types, grass swale conversion, water quality swale, and tree planting were consistently utilized. The overall BMP opportunities and the treated drainage area for the entire watershed are summarized in (Table23). It is noteworthy that grass swale conversion and water quality swales control the largest drainage area, 103.3 acre and 12.4 acre respectively.

Table 22. Acreages needed per bmp to meet TP reduction for each best solution.

	Best Solution 1	**Best Solution 2**	**Best Solution 3**
Total Cost ($)	$389,115	$332,199	$248,924
TP annual load reduction (%)	71%	70%	66%
BMPs (acre)			
Bio-Retention			
Concrete Channel Conversion	0.01		
Grass Swale Conversion	1.00	1.00	0.60
Green Roof			
Pervious Pavement	1.05	0.52	0.17
Riparian Buffer	0.16		0.16
Tree Planting	0.26	0.30	0.30
Water Quality Swale	0.27	0.18	0.18
Riparian Wetland	0.75	0.75	0.75

Table 23. Total area of opportunities for each bmp selected and the total area that each would treat.

Distributed BMPs	BMP Opportunity Area (acres)	BMP Treatment Area (acres)
Bio-Retention	0.210	7.584
Concrete Channel Conversion	0.100	3.177
Green Roof	1.000	1.471
Grass Swale Conversion	2.070	103.332
Pervious Pavement	1.750	4.155
Riparian Buffer	0.330	0.928
Tree Planting	0.430	0.423
Water Quality Swale	0.451	12.423

Summary and Conclusions

By using the information provided in the optimization curve, an informed decision can be made about which cost effective solution will be used to reduce nutrients in the Sugartree Creek watershed. The SUSTAIN model can also be used in other watersheds to solve similar problems.

Overall, the pilot study provided a numeric goal for achievable TP reduction (between 35% and 50%) within Sugartree Creek, as well as, a projected cost to remove an estimated 45.1% of the TP load. The optimization analysis also revealed that regional BMPs (mainly riparian wetland) should be largely utilized, and among the distributed BMPs, the grass swale conversion, pervious pavement, and water quality swales should be prioritized to achieve the best cost-benefits for pollutant removal.

Despite the large estimated reductions in TP, the SUSTAIN model indicates that the recommended TP numeric nutrient standard (an 82% reduction in TP) is not achievable in both the pilot watershed (regional BMP 5 drainage area) and the Sugartree Creek watershed given the BMP opportunities identified. Because the 0.18mg/L standard is the suggested nutrient concentration criteria and TDEC acknowledges that this concentration is often violated in reference streams in the Nashville Basin due to the phosphatic limestone presence and a more feasible TP standard should be adopted for the watershed.

Pathogen Reduction

As previously mentioned, pathogens are of great concern because of the health risk that elevated bacteria levels can pose to the public when recreating in streams. There are often multiple contributors to pathogens within a watershed and they are grouped into point-source and non-point source categories. A pollutant from a pipe is considered a point-source pollutant, where as a non-point source pollutant is more difficult to track. The point source pollutants from Metro Water's sewers are being addressed by the Clean Water Nashville Program.

Clean Water Nashville Program

The mission of the Clean Water Nashville Overflow Abatement Program is to fulfill the Consent Decree requirements by planning, designing, and constructing system improvements in a cost-effective manner to enhance the quality of water for the Nashville community. Much of our sewer system is old and lacks the capacity to handle the current volume of sewage and stormwater. The Clean Water Nashville Overflow Abatement Program, established in 2011, and building upon decades of work in addressing sewer capacity issues, will update infrastructure to reduce sewer overflows, reduce health risks associated with exposure to bacteria and contaminants, and improve water quality in the Cumberland River and Davidson County's extensive network of streams, creeks and tributaries. This Program to improve the wastewater system infrastructure will provide lasting benefits for future generations, improve water quality, and provide a clean, healthier environment for our citizens.

Program History

The sewer system in Nashville dates back to the late 1800s and originally consisted of a combined sewer system, later transitioning to separate sanitary and storm sewers. A combined sewer system consists of a single set of pipes that conveys both sanitary sewage and stormwater. Combined sewer systems were common in cities that developed in the 19th century to address public health problems caused by lack of proper sanitation. Since there were no facilities for treating wastewater in that era, it was common practice that sewage and stormwater were both discharged directly to the rivers and streams.

The treatment of wastewater began in the 20th century when pipelines were constructed to convey sanitary sewage along with stormwater to treatment plants to improve water quality. Wastewater treatment plants have limitations, however, to the volume of flow that can be effectively treated during rainfall events. Intense rainfall often leads to flows of stormwater in the combined sewer system that exceeds treatment plant capacity. These high flows of primarily stormwater are discharged without treatment and referred to as combined sewer overflows or CSOs. The CSOs are permitted by EPA and TDEC under the terms of a permit issued under the Clean Water Act.

Separate sanitary sewers are intended to convey only sanitary sewage, but the piping systems deteriorate over time and allow rainwater to leak into the lines. During extreme rainfall events, the volume of rainwater entering these older sewers can overwhelm the capacity of the system, leading to sanitary sewer overflows (SSOs).

Metro Water Services began an aggressive program of infrastructure improvements in 1990 to reduce the number of CSOs and SSOs, making tremendous progress toward improving water quality in the

Cumberland River and its tributaries. However, despite these improvements, a significant number of overflows still remained, prompting state and federal regulatory agencies to approach Metro in 2007 about the need for additional work within the sewer system.

Consent Decree

In March 2009, a Consent Decree between the United States of America, the State of Tennessee, and the Metropolitan Government of Nashville and Davidson County was approved and entered with the United States District Court for the Middle District of Tennessee. The Consent Decree was filed on behalf of the United States Environmental Protection Agency (EPA) and the Tennessee Department of Environment and Conservation (TDEC), and it requires Metro to use its best efforts to achieve the following goals:

- Full compliance with National Pollutant Discharge Elimination System (NPDES) permits, the Clean Water Act, the Tennessee Water Quality Control Act, and their regulations.
- Addressing the conditions contributing to sanitary sewer overflows (SSOs), with the goal of eliminating the 27 overflows listed in the Consent Decree.
- Compliance with EPA's combined sewer overflow (CSO) Control Policy.

The schedule for the Consent Decree was amended in August 2010 to provide additional time because of the impacts of the May 2010 flood. The amended schedule includes the following requirements:

- 2 ½ years to develop a *Corrective Action Plan/Engineering Report* (CAP/ER) to address conditions causing overflows in the separate sanitary sewer system with the goal of eliminating the 27 overflows listed in the Consent Decree. The CAP/ER was submitted to EPA and TDEC in September 2011.
- 2 ½ years to develop an updated *Long Term Control Plan* (LTCP) to mitigate overflows from the combined sewer system and reduce water quality impacts to the Cumberland River. The LTCP was submitted to EPA and TDEC in September 2011.
- 11 years after approval of each of these documents to complete the recommended improvements

The Consent Decree also includes provisions for civil penalties for past violations and stipulated penalties for violations that may occur in the future. In lieu of the full civil penalty, Metro agreed to conduct and has completed Supplemental Environmental Projects to improve public health and the environment.

At an estimated cost of $1.0–1.5 billion, the Clean Water Nashville Overflow Abatement Program represents a major investment in the community and provides the following benefits:

- Renews and improves aging infrastructure
- Enhances the environment for Nashville

- Improves water quality in the Cumberland River and its tributary watersheds throughout Davidson County
- Provides major engineering and construction projects to boost the local economy

Corrective Action Plan/Engineering Report (CAP/ER)

To meet Consent Decree requirements, Metro Water Services developed a *Corrective Action Plan / Engineering Report*, addressing conditions causing overflows in their sanitary sewer system. These sanitary sewer overflows, known as SSOs, have the potential to contribute to the impairment of Nashville's creeks, streams, and rivers and potentially pose a risk to public health.

The CAP/ER development began with a characterization of Metro's sanitary sewer system through extensive monitoring and modeling to understand the existing system's limitations. The need for improvements to address both current and future sewer capacity needs was then assessed, and potential alternatives were evaluated with the most efficient and cost effective solutions recommended for construction. These recommended projects, which include infrastructure rehabilitation, additional conveyance capacity, and storage of wet weather flows, have already begun to be implemented through the Clean Water Nashville Overflow Abatement Program.

Long Term Control Plan

As a result of the Consent Decree, Metro Water Services completed an update of the *Long Term Control Plan* for the combined sewer system which provides a plan for reducing overflows into the Cumberland River.

The focus of the planning was to reduce the occurrence and impact of overflows into the Cumberland River during wet weather events. MWS followed EPA's CSO Policy in implementing a rigorous engineering, quantitative, and scientific process for identifying and evaluating alternatives to reduce combined sewer overflows. Consideration included financial and engineering analyses to develop recommended improvements in conjunction with four key objectives that were established early in the planning process:

- Improve the water quality of the Cumberland River by reducing impacts from combined sewer overflows.
- Provide a level of CSO controls that results in improvements in water quality that are consistent with the community’s use of the Cumberland River.
- Align investment in CSO controls to be commensurate with the contribution of CSOs to water quality relative to other sources.
- Consider the impact of the overall program cost on the ratepayers in the current economic climate.

A map of Nashville’s combined sewer system and overflow discharge locations can be found on the web at http://www.cleanwaternashville.org/content/learn/pdfs/MWS_LTCP_Overflow_Locations.pdf.

These goals and objectives were developed based on feedback provided by representatives from MWS, local government, and the community through a public engagement process developed to solicit input from affected stakeholders.

Project Types

Projects specified in the *Long Term Control Plan* and *Corrective Action Plan/Engineering Report* involve rehabilitation and improvements to the system in order to increase capacity and reduce overflows. These methods include:

Sewer Rehabilitation

Figure 32. This picture shows a sewer lining project that is used to reduce infiltration into the sewers.

Sewer rehabilitation projects address overflows by reducing the extent of peak wet weather flows in the system through the identification and repair of defective components of the sewer system and sources of rainfall-derived infiltration and inflow (RDII), such as broken manhole covers or cracks in pipes (Figure 33). Each area targeted for rehabilitation will be assessed to determine the level and extent of repairs necessary to achieve the goals established by the Clean Water Nashville Overflow Abatement Program. The optimal sewer rehabilitation approach may differ from one project area to another and is dependent upon the condition of the existing sewer and other factors.

In many areas, comprehensive evaluation and rehabilitation will be conducted to repair main sewer pipes, manholes, and laterals within Metro's rights-of-way and easements with the goals of reducing RDII and renewing existing infrastructure. Where possible, the construction of these improvements will consist of trenchless techniques that minimize excavation and disruption to the surrounding community.

Conveyance Improvements

Figure 33. This picture shows a new conveyance being installed that will increase carrying capacity of undersized sewer mains.

Pipe conveyance improvement projects will address overflows by improving the system's ability to carry increased volumes of wastewater to treatment plants or to downstream equalization facilities. These projects may include the installation of larger pipes or the construction of parallel pipes to handle both existing and future peak flows (Figure 34).

Equalization Facilities

Figure 34. This equalization basin was installed to store sewer during times of peak flow and when sewer capacity is at a maximum.

Equalization Facilities offer a means of addressing wet weather overflows by temporarily storing peak flows in excess of the downstream sewer or treatment capacity (Figure 35). The peak flows are stored until the flows in the system recede and the stored volume can be conveyed through the system for treatment. These facilities, which typically consist of a diversion structure, a pumping station, and pre-stressed or cast-in-place concrete structures, may be constructed within the sewer system, at pump stations, or at treatment plants.

Pump Stations

Pump station improvement projects will address overflows by improving a pump station's ability to carry increased volumes of wastewater to treatment plants or to downstream facilities. These projects may include modifications to an existing pump station or the construction of a new pump station to handle existing and future peak flows.

Other Projects

In addition to rehabilitation, conveyance, pump station, and equalization facility projects, additional types of projects may be needed to address specific issues leading to SSOs, CSOs, or water quality impacts. These projects may include modifications to the treatment plants, replacement of screening facilities, or other improvements to the collection system.

Projects within Richland Creek Watershed

Highway 100/Tyne Boulevard- Trimble Rehabilitation

This project was developed to renew aging infrastructure and to address downstream overflows by reducing the amount of rainfall that can enter the system through defects. It consisted of the evaluation of approximately 63,000 linear feet of gravity sewer, associated manholes, and service laterals within Metro's right-of-way and easements. The resulting construction project includes the rehabilitation of approximately 33,000 linear feet of 8 to 12-inch gravity sewer, associated manholes, and service connections.

Bandywood – Green Hills Rehabilitation

This project was developed to renew aging infrastructure and to address downstream overflows by reducing the amount of rainfall that can enter the system through defects. It consists of the evaluation and rehabilitation (as necessary) of approximately 47,000 linear feet of gravity sewer, associated manholes, and service laterals within Metro's right-of-way and easements.

West Park Equalization Facility

The project is a partnership between Metro Parks and Metro Water Services to accomplish two significant goals for the community: 1) improve and expand the recreational opportunities within West Park and 2) provide an additional storage tank for the benefit of improving Richland Creek's water quality by addressing existing overflows.

The West Park project will include the construction of a 260 foot diameter, 37 foot high circular wet weather storage tank similar to the one existing on site. The storage tank will be utilized when sewer flows exceed the capacity of the West Park Pump Station. The peak flows are stored until the flows in the system recede, and the stored volume can be conveyed through the pump station to treatment. Without the construction of this facility, flows in excess of the pump station capacity resulted in sanitary sewer overflows.

Park improvements include a new 300 foot adult softball field, basketball court, large restroom/picnic pavilion, walking trail, and 6,000 square foot youth playground with a rubberized safety surface. The softball field will be completely renovated with fencing, an irrigated outfield, and new sports lighting. A

12 foot wide perimeter greenway trail will follow along Richland Creek and create a loop within the park for walking, running, and bicycling. Outdated restrooms will be replaced with a new building complete with a covered picnic area. Open space and landscaping will be enhanced throughout the park to improve its overall aesthetic appearance.

Design and Implement a Plan

Stormwater Management Plan

The Stormwater Management Plan is a comprehensive plan that describes the programs that are in place to fulfil Metro Water Service's Stormwater NPDES permit. Many of the programs go above and beyond the requirement of the permit with the ultimate goal of protecting Nashville's streams and watersheds.

Watershed Monitoring Program

The evaluation of stream health is important to characterize a watershed and determine the effectiveness of programs and stormwater regulations. There has been a monitoring program within the Stormwater program since 1998. Over time sampling plans have changed and we have a robust program that evaluates the Metro Stormwater Program over time.

Wet weather Monitoring Program

The goal of this program is to calculate loading of specific land uses during wet weather events. To do so, five outfalls were selected within drainages that had homogenous land uses. These included: Residential, Commercial, Transportation, Industrial, and Open Space. In each event that is sampled, the First Flush sample is captured and a 1-hour grab sample is it subsequently captured. Table 24 shows the location of the outfalls for each land use. Metro's NPDES MS4 permit dictates that 3 samples are collected each year. The parameters include: BOD, COD, Metals, Nutrients, *E. coli*, TSS, TDS, and Oil and Grease.

Table 24. Location of each stormwater outfall that is sampled for wet weather monitoring.

Type	Location	Coordinates	Waterbody	Frequency
Residential	Culvert street drain near the address of 841 Russleo Drive	-86.877607 36.138553	Cumberland River	3 storm events occurring at different seasons during each permit year
Commercial	Behind the Bellemeade Kroger Shopping Plaza	-86.85033132 36.12449873	Sugartree Creek	3 storm events occurring at different seasons during each permit year
Industrial	Intersection of Cockrill Bend Bvld. and West Belt Drive	-86.87703781 36.17095549	Richland Creek	3 storm events occurring at different seasons during each permit year
Transportation	On the north side of Ashland City Highway near the address of 4882 Ashland City Highway	-86.9069884 36.21046404	Cumberland River	3 storm events occurring at different seasons during each permit year
Open/ Undeveloped	parking area of Bells Bend Park located off Old Hickory Blvd.	-86.925799 36.2423647	Cumberland River	3 storm events occurring at different seasons during each permit year

Ambient Sampling

Ambient sampling is done during dry periods on the main stems of the major streams within Davidson County. The chemical analyses include BOD, COD, Metals, Nutrients, TSS, TDS, and Oil and Grease and biological include *E. coli*. These samples are collected four times per year and the streams rotate on a 5 year basis. The schedule is shown in Table 25. In addition to these samples, bioassessments along with macroinvertebrate collection using the Semi-Quantitative Single Habitat (SQSH) method is performed in the spring and fall. This program provides a robust dataset that aids in characterizing watersheds and identifying pollutants of concern.

Table 25. Rotation of creeks that are sampled in the Ambient Sampling program.

Year	Waterbody	Location	Frequency
1	Browns Creek Richland Creek Davidson Branch	At least 1 point within the main stem of the creek	4 Dry weather sampling events per year
2	Whites Creek Manskers Creek	At least 1 point within the main stem of the creek	4 Dry weather sampling events per year
3	Gibson Creek Neely's Branch Dry Creek	At least 1 point within the main stem of the creek	4 Dry weather sampling events per year
4	Pages Branch Cooper Creek Harpeth River	At least 1 point within the main stem of the creek	4 Dry weather sampling events per year
5	Mill Creek Stones River	At least 1 point within the main stem of the creek	4 Dry weather sampling events per year

TMDL Pathogen Monitoring

Streams that have TMDLs for pathogens require Metro to collect 5 samples within 30 days between the months of June through September. Flow is calculated and the samples are analyzed for *E. coli* using the IDEXX method. In addition to the required samples, quarterly samples are collected during the fall, winter and spring to identify seasonal trends and also illicit discharges that could occur throughout the year.

TMDL Biological sampling

Streams that have TMDL's for nutrients, sediment, or habitat alteration require 1 biological assessment within a 5 year period. These assessments include a visual habitat assessment using TDEC's protocol and a macroinvertebrate collection using the SQSH method. Samples are currently being analyzed by Pennington and Associates.

Visual Stream Assessments

Visual stream assessments are performed on all streams that are on the 303d list. The protocol was derived from the Maryland's Stream Corridor Assessment Survey. The assessment scores stream segments that are typically 500 feet long. Factors that are taken into account include: In/Near Stream Construction, Channel Alteration, Barriers/Blockages, Pipes/Outfalls, Inadequate Vegetation, Current Erosion, and Correctability. Canopy cover, presence of sewer infrastructure, livestock access, algae abundance, trash, illicit discharges, and channel measurements are recorded for each segment. There have been over 250 miles of streams assessed. Once all streams are completed, a reassessment will be done to ensure that conditions have not changed. There have been numerous findings from this program that varies from locating sites for stream clean-up to sewer line breaks.

Post Construction BMP Monitoring Program

A sampling program is in place to evaluate the pollutant reduction performance of post-construction BMPs. The BMP's of concern include: Bioretention, Dry Detention, Proprietary Water Quality Unit, Green Roof, Wet Pond, and Pervious Pavement. Samples are taken at the inlet and outlet points and are analyzed for TSS, Nutrients, and Oil and Grease. Flow reductions are calculated for green roofs, bioretention, and pervious pavement in lieu of grab samples.

Industrial Monitoring Program

One industrial facility that has a Tennessee Multi Sector Permit (TMSP) or Ready Mix Concrete Permit (RMCP) is selected each year to monitor stormwater runoff from the sight. The sample is analyzed for parameters that match the requirements of the facility.

Public Education

MWS has developed a Public Information/Education (PIE) Plan to implement specific permit requirements. This plan details public education activities as well as geographic "hot areas" based on land use and TMDL/303d status. The map below (Figure 36) depicts the hot areas/areas of concern.

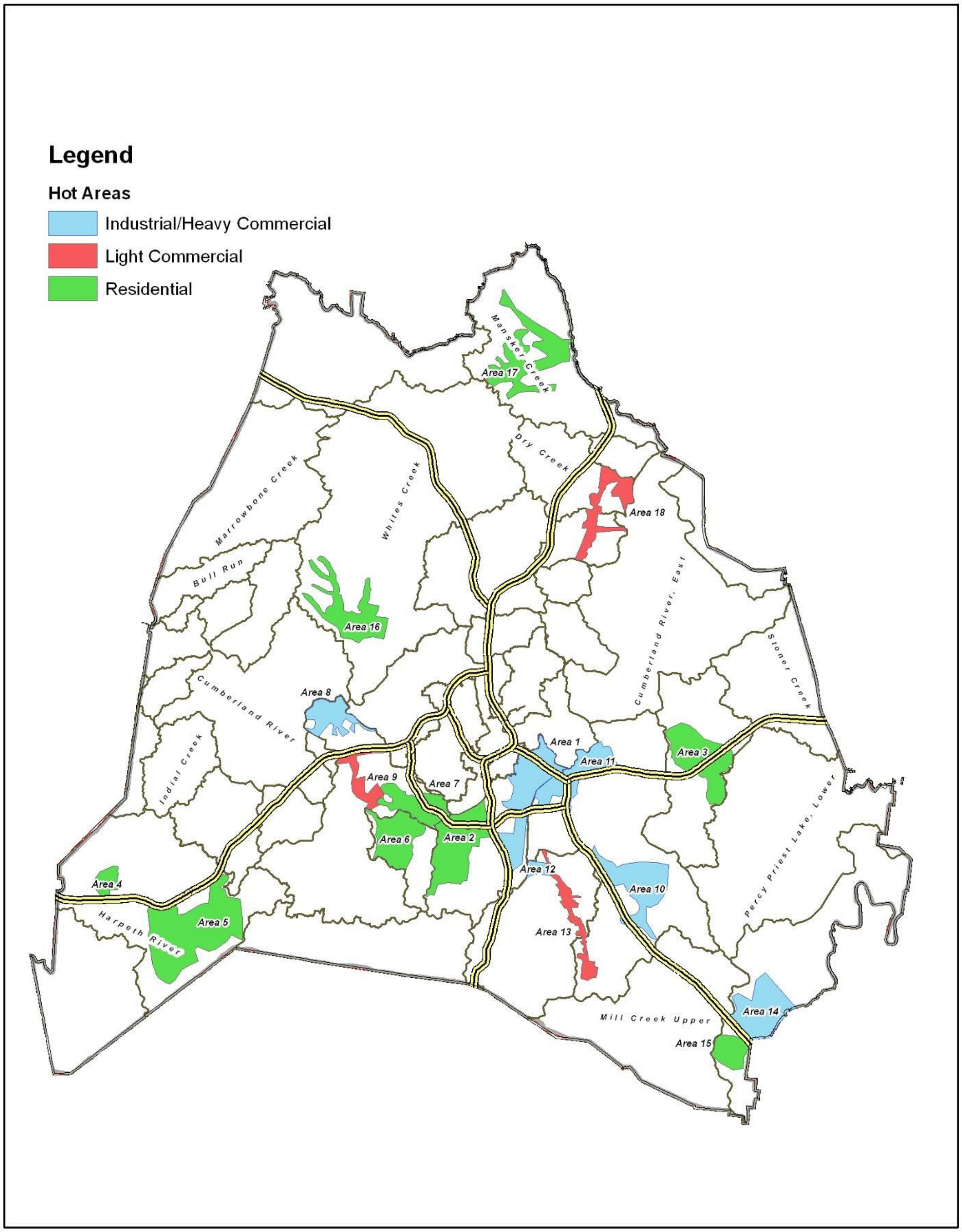


Figure 35. Hot areas designated by the PIE plan to target stormwater education. These areas are selected based on their land use and proximity to an impaired stream.

Public education and outreach provides information about pollution reduction and the impacts of citizen have on local waterways. Multiple issues that relate to a wide audience are covered through educational events throughout the year. Such events include water quality festivals, lawn and garden shows, school presentations and awareness through participation in local events. Information is also targeted to audiences in order to raise awareness about specific pollutants. Table 26 shows the target audience with the education/outreach strategy for each. Additional activities include stream clean up events, the Adopt-a-Stream program, storm drain stenciling, and tree plantings.

Table 26. Description of public education activities and methods used for each.

Targeted Audience Group	Public Education/Outreach Technique
School Groups /Youth Camps	• In-person presentations/demonstrations • Distribution of educational materials designed for youth. (i.e. games, puzzles, tests, etc.)
Geographic-Designated “Hot Areas”`	• Mail-outs (area-specific) • Outbound calling (area-specific) • Soliciting help from local non-profit watershed groups in distributing educational materials • Co-host community meetings with local non-profit watershed groups
Community/Business Type “Hot Areas”	• Mail-outs (business-specific) • Handing out materials • Hosting workshops
High Citizen Complaint Zones	• Mail-outs (problem/complaint-specific) • Outbound calling (problem/complaint specific)
Large Community Events	• Manning stormwater educational booths • Performing stormwater demonstrations • Handing out educational materials
Post Construction BMP Owners	• Mail-outs • Handing out materials/Drop in visits by NPDES
Grading Contractors/Development Community	• Face to face during Grading Permit process

	• Participate in TDEC's Level 1 EPSC Workshop
Municipal Maintenance Employees	• In-person presentations • Handing out materials
General Metro Residency (General Stormwater Education)	• Channel 3 Public Service Announcements (PSAs) • Public signage (vehicle decals, billboards, etc.)

Field Screening

This program was created to inspect outfalls for potential illicit discharges within the permit area. The permit area is divided into ¼ mile grids that contain parcels with various land-use codes that can be generally considered "industrial" or "commercial". Outfalls are selected for inspection within these grids. The first grids to be screened are those determined to be within "hot areas", areas known for high water pollution concentrations and impaired streams. All "hot areas" will be screened by June 31st, 2014, with the remaining grids to be completed by February, 2017.

The inspections are performed to identify non-stormwater discharges such as water leaks, sanitary sewer leaks, illicit discharges or potential cross connections. Samples are taken if flow is present 72 hours after a rainfall event larger than 0.1 inch and no obvious source of the discharge is present (i.e. air conditioner condensate). Analysis for multiple parameters such as chlorine, detergents, dissolved oxygen, temperature, E.coli concentrations, and pH are carried out in order to determine the source of the discharge. If the outfall is located within a known stream, wetland, pond or other water body, this sampling is not required unless it is suspected that the water body is contaminated.

If upon investigation, the source of the discharge is a water leak or sanitary sewer overflow, MWS dispatch is notified with the address and any other info that will help find the location, dispatch will create an SR and send a leak investigator. After entering the data in Cityworks, the data should be logged in the map book as usual, and updated accordingly in the GIS layer frame with a point at the outfall and corresponding data, then updating the grid to complete. A picture should also be taken of the outfall. However, if the inspection indicates that the source of the flow is an illicit discharge, then the investigation will follow illicit discharge guidelines to identify the source and deal with it accordingly.

Construction Oversight/Grading Permit

Metro has municipal code/ordinances specifically addressing stormwater management regulations within Davidson County, some of which have been in place more than three decades. While there are some development categories exempt from obtaining grading permits, most public and private development activities are required to obtain grading permits if the area of proposed disturbance is greater than 10,000 square feet, they are proposing bringing more than 100 cubic yards of fill to the site, or if they are making major alterations to the MS4. The grading permit process requires permittees to attend pre-construction meetings in which they are granted temporary grading privileges to install the erosion and sediment controls. Actual grading permits are not issued until the erosion and sediment controls are inspected by MWS Stormwater NPDES construction inspectors.

Metro's regulations involving oversight of construction activity is consistent with TCA 68-221-1106. Metro has adapted the following ordinance *15.64.220 - Violations—Penalties*, which allows penalties to be assessed to non-compliant construction activities. It is important to note that non-compliant construction activities resulting in large illicit discharges of sediment to creeks can also receive enforcement actions for violations of *Metro Code 15.64.205 - Non-stormwater discharges*, allowing penalties to be assessed for up to $5,000 per day.

During the first year of the new permit, Metro reviewed the grading permit regulations and determined that they are consistent with TDEC's General Construction Permit for construction stormwater runoff. While there may be some slight differences in the permitting processes, Metro's requirements on construction activity are actually more stringent than TDEC's General Construction Permit for construction stormwater runoff. In addition, Metro's Volume IV lists specifications for EPSC BMPs that are consistent with the TDEC EPSC Handbook. Based on a review of Metro's stormwater regulations, Metro believes no adjustments are necessary.

Infill Regulations

Infill refers to development of land that is vacant or undeveloped within an existing community. Land development permanently alters the way in which stormwater flows across a site due to grading compaction and installation of impervious cover. In order to mitigate the impacts, Metro Nashville requires, in accordance with Municipal Code 15.64.010 et seq. , post development stormwater management reassures be utilized when constructing a new home or an addition that meets the criteria outlined this Stormwater Management Manual.

Projects that are included in these guidelines are:

Tier I – Projects creating between 800 and 2,500 square feet of net additional impervious area (IA) , without regard to total lot impervious area percentage exceeding 30% must treat by meant of capture of the first inch of rainfall runoff, an impervious area equal to the net increase of added impervious area.

Tier II – Projects creating between 2,500 and 8,000 square feet of net additional impervious area, without regard to total lot impervious area percent must treat, by means of capture of the first inch of rainfall runoff, an impervious area equal to the net increase of added impervious area.

Tier III – Projects creating 8,000 and 15,000 square feet of net additional impervious area, without regard to total lot impervious area percent, must treat by means of capture of the first inch of rainfall runoff, an impervious area equal to the net increase of added impervious area. Additionally, the project design must insure there is not increase in the 10-year storm peak flow from the site, and a professional engineer must certify the design.

Exemptions include:

1.) Add less than 800 square feet of net new IA,
2.) Add more than 15,000 square feet of net new IA,
3.) Are on lots larger than 40,000 square feet, or

4.) Are on lots with a grading permit previously filed with the Metropolitan Water Services, as long as the post-construction IA conforms to the original grading plan.

Low Impact Development Regulations

Metro Water Services released its Low Impact Development (LID) Manual in August of 2012. The LID Manual was designed to meet the NPDES MS4 Permit requirement that post construction stormwater control measures "are designed, built and maintained to infiltrate, evapotranspire, harvest and/or use, at a minimum, the stormwater runoff generated by the first inch of every rainfall event preceded by 72 hours of no measureable precipitation." The LID Manual was a voluntary compliance path until it became a requirement on February 1, 2016. Prior to becoming a requirement, approximately 24% of grading permit sites voluntarily used the LID Manual methodology for site design.

An estimate of infiltration at 53 sites developed under the LID Methodology shows that these sites infiltrated over 30 million gallons more than sites developed under the old standard. Since over half of the sites in the calculation were previously developed, the LID sites also infiltrated more stormwater runoff than if they had not been redeveloped (see Figure 36). Metro Water Services will continue to track the runoff benefits of LID to quantify the impacts of the program.

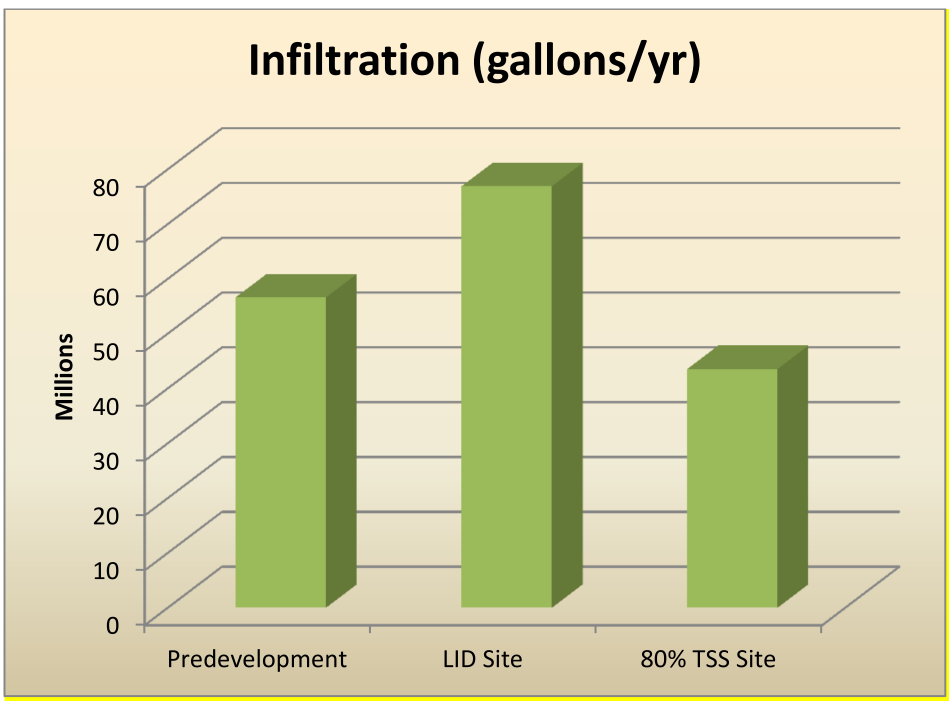


Figure 36. Estimated infiltration at sites developed under the LID Manual along with the infiltration prior to development and if developed using the 80% Total Suspended Solids (TSS) methodology.

MWS created a redevelopment credit to encourage projects to use previously disturbed properties with existing infrastructure instead of greenfield sites. This credit was also designed to compensate for limitations installing green infrastructure on impervious parcels. The credit allows projects on previously developed sites to reduce their water quality requirement by 25%. MWS may adjust the credit in the next revision to account for site constraints that limit infiltrative practices.

Figure 37. Installation of bioretention at McCabe Community Center.

If a project cannot meet their LID requirement, MWS staff may approve an alternate practice where site limitations exist. Criteria to determine the circumstances under which alternatives are available shall not be based solely on the difficulty or cost of implementing practices. The determination may be based on the following site limitations:

i. Where the potential for introducing pollutants into groundwater exists, unless pretreatment is provided;
ii. Where pre-existing soil contamination is present in areas subject to contact with infiltrated runoff;
iii. Presence of sinkholes or other karst features on a site;
iv. Where pre-development infiltrative capacity of soils precludes runoff reduction measures;
v. A site-use that is inconsistent with capture and reuse of stormwater or a green roof.

Projects that cannot meet the LID requirement must be designed to remove at least 80% of the average annual post-construction total suspended solids (TSS) load.

Thermographs

The Thermograph Program uses infrared cameras to detect heat signatures in water bodies that could signify pollutants entering streams/rivers. Metro Nashville Police Department's helicopter (Figure 38) is equipped with a FLIR camera and flies with an NPDES employee who maps the flight. The video is reviewed and anomalies are mapped using ArcGIS.

Figure 38. MNPD helicopter with FLIR camera

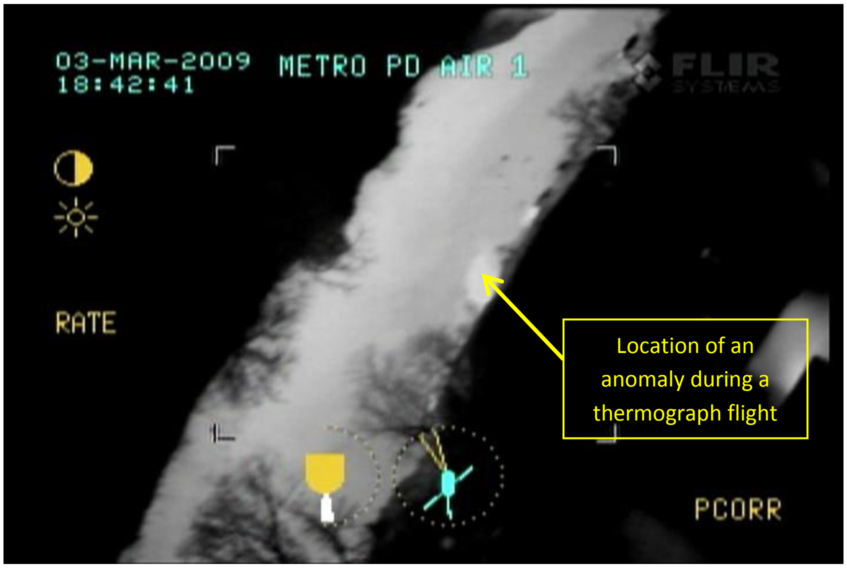


Figure 39. Example from a video where an anomaly is located and investigation initiated.

Investigations are performed on each anomaly and if necessary samples are taken to determine the inflow is natural (Figure 39). When a pollutant is identified, then the investigation moves forward as does any illicit discharge to a stream. Water line breaks, sewer leaks, missing manhole have all been identified by the thermograph program.

Richland Creek Watershed Alliance

Richland Creek Watershed Alliance (RCWA) is a stream conservation group whose focus is the environmental sustainability of the Richland Creek Watershed. It is dedicated to providing action and leadership for long-term restoration and preservation of its ecosystem. It has been an advocate for Richland Creek on numerous occasions in pursuit of protecting stream habitat. Since its inception in 2007, RCWA has removed 51 tons of trash from Richland Creek and its tributaries during stream clean-ups (Figure 40). Additionally, 1,730 trees have been planted along stream corridors within the watershed. Another project that began in 2014 was invasive species removal from stream buffers.

In addition to these volunteer based projects, RCWA has partnered with local and state entities along with other NGO's on numerous projects. It has conducted studies to identify deficiencies in dissolved oxygen and flow in conjunction with TWRA. These were used to limit water withdrawal permits out of the main stem of Richland Creek which in turn led to the removal of a low-head dam. Also, RCWA and MWS partnered to identify headwater springs to tributaries of Richland Creek with the goal of protecting their integrity.

Figure 40. Debris from clean up held on Richland Creek and a Tributary.

RCWA provides public outreach and education to the community through study reports, commentary, eNews, and has engaged over 2000 volunteers with their work. Richland Creek and its tributaries have been improved and continue to improve thanks to the dedication and hard work that Richland Creek Watershed Alliance does.

Watershed Stewardship Plan

As mentioned previously, Metro Water Services, the Cumberland River Compact, the Nature Conservancy, and Nashville's Mayor's Office formed a partnership to assess the current of Nashville's waterways and develop a path forward that empowers Nashville's citizens to promote healthy streams and rivers in an economically thriving city. The plan's intent is to improve and maintain the health of rivers and streams that flow within Metro Nashville.

The outcomes of the plan have been:

1. 2 watershed models- SUSTAIN and the Richland Creek DSS

2. Water quality improvement projects

3. The Watershed Improvement project Funding study (WIF)

4. Public Outreach and Education Campaign

The two models have been extensively covered in previous sections of this plan. They were very critical in making this watershed management plan. SUSTAIN provided information about the most useful SCM in terms of nutrient reduction while keeping cost in mind. This information will be translated to similar areas within the county with opportunities for SCM installations. As redevelopment occurs in well-established areas of the city, opportunities for water quality stormwater control measures will arise thereby reducing the pollutant loads within those watersheds.

The Richland Creek Decision Support Tool has been helpful in pinpointing areas within the watershed where restoration efforts should be focused. As funding is provided, this tool will be key in locating sites within the most critical sections of the watershed.

There have been numerous water quality improvement projects as a result from the Stewardship Plan. One major project within the Richland Creek watershed was the removal of a low-head dam within the main stem of Richland Creek. This dam was initially installed to aid in the withdrawal of water for Metro owned McCabe Golf Course. It created a fish barrier, decreased dissolved oxygen within this stretch of the stream, and assumedly lowered the biodiversity of aquatic life due to the lack of natural substrate. Following removal of the dam, the stream banks were stabilized with rock and vegetation (Figure 41). The stream will naturally create habitat over time.

Figure 41. Richland Creek following dam removal**.**

The Green Alley Project is located within the Nations neighborhood. 100 rain gardens were built within alleyways of this neighborhood which is located within the lower portions of Richland Creek (Figure 42). It is estimated that each rain garden infiltrates 42,000 gallons of rain water each year. The project as a whole treats 4,200,000 gallons of rain each year.

Figure 42. Volunteers working on installation of a Green Alley rain garden

One large rain garden project has been planted along Sugartree Creek at the end of Hilldale Drive. This project is part of the implementation phase of the SUSTAIN model. As shown in the picture (Figure 43), it will provide treatment for the stormwater runoff before the water enters the stream.

Figure 43. Recent installation of a rain garden at the end of Hilldale Drive.

Currently there are two de-paving projects at 2 properties within the Green Hills neighborhood. Permeable pavement will be installed in sections of the Woodmont Christian Church and the Centennial Club. Additionally, a parking island will be converted to a rain garden in the Calvary Church parking lot. Hopefully, these projects are a precursor to many projects in the near future.

The Watershed Improvement Fund (WIF) is a study that evaluated opportunities for creating a fund within the Stormwater Department of Metro Water Services. This fund would be dedicated to building projects that improved water quality within watersheds that showed impairment. A full description of the WIF is included in the following section of this plan.

Currently, there is a public outreach and education plan that is being funded by a local foundation. There are five environmental non-profit organizations working on this campaign that will utilize social marketing to decrease non-point source pollution.

The watershed stewardship plan has proven to be a useful tool in establishing partnerships and initiating water quality improvement projects throughout the Davidson County. Public and private partnerships are important because they utilize the strengths of each entity in order to accomplish a common goal. It is important to continue this stewardship and also look for other opportunities throughout the county to partner with the NGO sector.

Watershed Improvement Fund (WIF)

The Stormwater and Engineering Divisions of Metro Water Services jointly explored the feasibility of developing and operating a Watershed Improvement Fund (WIF), within Metropolitan Nashville Davidson County (Metro Nashville), solely dedicated to performing projects that will improve water quality in Metro Nashville's watersheds. The projects, termed "Watershed Improvement Projects" or WIPs in this report, would encompass a broad range of structural and non-structural projects including:

- Retrofitting existing drainage systems to treat stormwater runoff
- Installation of local/regional bio-retention basins (rain gardens, wetlands, etc.)
- Ongoing maintenance of structural WIPs that are implemented
- Replanting of riparian buffers
- Retention pond enhancement/retrofit for water quality
- Stream channel stabilization/restoration
- Green Infrastructure (GI) practices currently listed in the MWS *Low Impact Development Manual*
- Curriculum development and training for water quality education;
- Educational seminars
- Educational signage on strategically located WIPs

While MWS currently implements a variety of these water quality projects, the WIF will allow the Stormwater Division's Water Quality Section to escalate the number and expand the scope of the various watershed improvement projects and assist the Engineering Division's Clean Water Nashville Overflow Abatement Program (OAP) to integrate green infrastructure into Nashville's Consent Decree – Long Term Control Plan. This joint goal for water quality improvement within Metro Nashville led to a coordination of efforts to implement this WIF Feasibility Study.

As shown in Figure 44, various inputs were considered as sources for the WIF. Once in place, the funds would be available for either private WIP projects or public WIP projects.

The options were all weighed and scored based on Ease of Implementation, Revenue capacity, Ease of Operation and Stability of Revenue Stream. The final recommendations were based on these scores and comparison with peer cities and separated into two tiers – Tier 1 being the highest scores and Tier 2 being the lower scores.

The recommendations are as follows:

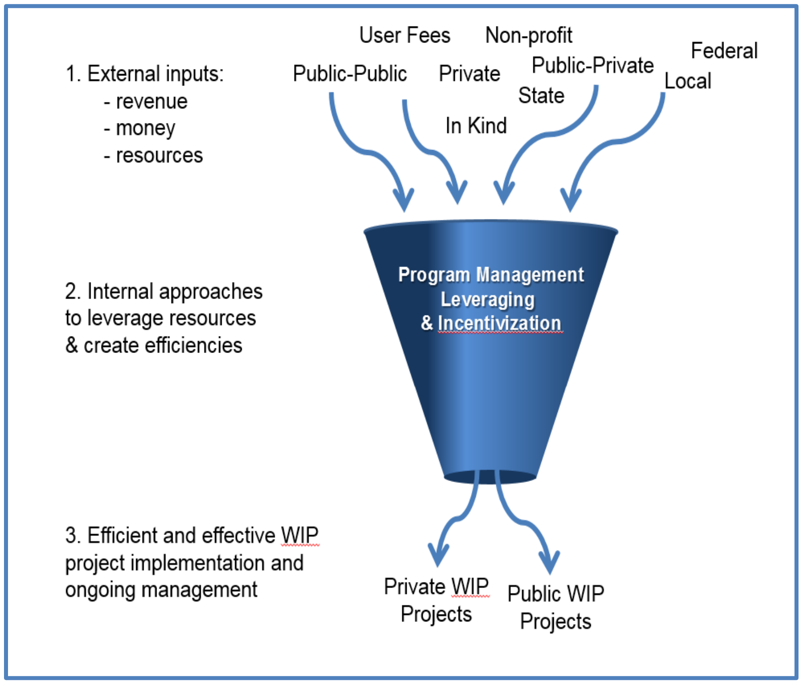


Figure 44. Illustration of inputs into the WIF and the 2 types of projects that will result.

1. A general WIF account and financial administrative procedures should be established within MWS that could allow for the deposit of funds and assigning them to various projects. This account should be administered by the Stormwater NPDES Section and a staff member dedicated to administering/overseeing the fund, which would include project identification, project implementation, and project tracking/reporting. The WIF account should be set up as a funnel that will also be able to receive other funds that may be generated in the future as Tier II approaches are further developed.

2. A WIP project tracking methodology should be established to streamline reporting under the MS4 permit. The methodology should be flexible enough to include WIP-type projects from all sources, public and private, CSS and MS4, development-related.

3. Under the Tier 1 approach **Stormwater User Fee Capital Budget,** capital construction funds (minimum of $100,000 per year) should be earmarked or deposited within the WIF general account from the current stormwater small projects account, projects should be identified and the implementation and/or design-construction process begun.

4. With the future anticipated depletion of bond funding for the MWS stormwater budget, a review of the department revenues, current rate structure, and funding potentials should be initiated.

5. Under the Tier 1 approach **MWS Maintenance Small Project Construction,** a key decision point for evaluation of WIP-related projects should be identified, along with a stronger checklist, set of WIP-related consideration requirements, and better accounting for the small projects should be initiated and better records kept. A priority should be given to those projects identified for construction within impaired watersheds.

6. Under Tier 1 approach **CSS-Related Water Quality/Green Infrastructure Projects,** MWS Clean Water Nashville OAP should create a tracking or reporting to be able to at least record the OAP WIP-related projects that have been developed. This approach should also be taken with <u>other departments under city government</u> (e.g. Public Works, Parks) that develop WIP-related projects.

7. Under Tier 1 approach **Incentive Grants/Rebates Plus Sewer Fee Credits,** OAP staff should look into or study an approach that would leverage OAP funds similar to that used in other cities to extend the use of GI as a CSS reduction measure and leverage OAP funds.

8. Following implementation of the Tier 1 initiatives, MWS should begin to investigate the feasibility of the Tier 2 approaches. This would include, but not be limited to:

9. Establishment of stakeholder groups to analyze **incentive grant program** development details, compensatory **variance fees**, and the **fee-in-lieu program**.

10. Coordination with Metro Public Works and other Metro Nashville Departments regarding the potential for a joint approach to new development and the inclusion of WIP-related and GI projects, as well as coordination with the private sector for overlapping design, functionality, and maintenance issues.

11. For the **Federal/state grant sources**, the NPDES Section of MWS should assign a staff member the responsibility to identify potential grant opportunities and schedules for application submittal. The NDPES Section together can determine, based on grant application requirements and existing project potential, if further participation in the grant processes is warranted each grant cycle. Furthermore, before beginning the grant application process, fully developed scopes of work should be prepared for any project identified through either SUSTAIN modeling or NPDES Section initiatives. This includes detailed description of the proposed project, timeline or work schedule, a detailed cost estimate, and maintenance plan. Coordination with MWS Accounting Department should be considered to ensure proper financial recordkeeping and reporting.

12. Continued partnerships and concentrated stewardship efforts to engage non-profit organizations in the fulfilment of water quality goals across Metro Nashville.

Evaluation of Plan Effectiveness

Continued monitoring

Richland Creek Watershed will be continually monitored as per the NPDES monitoring plan. This includes: bacteriological, biological, chemical and visual assessments. As time progresses, trends in data will denote whether the Management Plan is effectively improving water quality conditions. Table 45 describes the monitoring activity and the impairment that is targeted.

Table 45. NPDES monitoring activities and the associated impairments each program addresses.

Monitoring Activity	Impairment Addressed
Visual Stream Assessments	Channel/Flow alteration, Streambank stability, Vegetation/Buffers, Illicit discharges,
Bacteria Monitoring	Pathogens
Chemical Monitoring	Nutrients
Biological Assessments	Siltation, Habitat Alteration, Nutrients,
Illicit Discharge Detection	All pollutants
Thermographs	All pollutants
Education	All pollutants

Frequency and location of samples will be evaluated in order to provide the information set needed to make decisions both for projects and regulations. As resources allow, before and after monitoring of projects will be conducted to see the effects that they have on receiving streams. Finding successful water quality improvement projects is crucial to making the best decisions in the future.

Regulatory Revisions

Metro Nashville's Stormwater regulations are contained in the Stormwater Management Manual (SWMM). The original version of the SWMM was released in 1979 with revisions in 1987, 1988, 1991, 1999, 2006, 2009, 2012, 2013, and 2016. The 1999 revision was prompted by requirements in Metro's National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit issued by the Tennessee Department of Environment and Conservation (TDEC). The SWMM was updated in 2006 to more comprehensively address stormwater management throughout the jurisdiction of Metro and to clarify certain aspects of the program. The 2006 revision included the recommendations of the Stormwater Regulations Review Committee (SR2C), a group of stakeholders convened by the Metropolitan Department of Water and Sewerage Services (MWS). The 2009 revision contained minor editorial changes and updates of policies and procedures to align the manual with current departmental practices. In 2012, Volume 5, the Low Impact Development (LID) Manual, was added to the Stormwater Management Manual. The 2013 revision includes improvements to the proprietary device approval policy and corrections to the LID Manual. In 2016, Volumes 1 and 5 were revised to comply with Metro's MS4 permit runoff reduction requirement. The SWMM will continue to be revised as needed to address permit requirements, reflect policy changes, and recognize advances in the field of stormwater management.

References

Amec Foster Wheeler. (2015). *The Metropolitan Government of Nashville and Davidson County Metro Water Services Watershed Improvement Fund (WIF) Feasibility Study Final Report.* Nashville, TN: Metropolitan Government of Nashville.

Arlington Virginia County Government. Department of Environment. (2016). *Macroinvertebrates.* Retrieved from: https://environment.arlingtonva.us/streams/macroinvertebrates/

Elkin, K., Lanier, S., & Rebecca. M. (2012). The interrelationship of hydrology and biology in a Tennessee stream, USA. *Ecohydrology.* doi: 10.1002/eco.1282

Layton, A., McKay, L., Williams, D., Garrett, V., Gentry, R., & Sayler, G. (2006). Development of *Bacteroides* 16S rRNA Gene TaqMan-Based Real-Time PCR Assays for Estimation of Total, Human, and Bovine Fecal Pollution in Water. *Applied and Environmental Microbiology. 72 (6),* 4214-4224. doi: 10.1128/AEM.01036-05

Maryland Department of Natural Resources. Chesapeake and Coastal Watershed Services Watershed Restoration Division. (2001). *Stream Corridor Assessment Survey: SCA Survey Protocols.* Annapolis, MD: Maryland Department of Water Resources.

Metropolitan Government of Nashville and Davidson County. Department of Water and Sewerage Services Stormwater Division. (2016). *Low Impact Development Stormwater Management Manual (Volume 5).* Nashville, TN: Metropolitan Government of Nashville.

Metropolitan Government of Nashville and Davidson County. Department of Water and Sewerage Services Stormwater Division. (2016). *Stormwater Management Manual (Volume 1-Regulations).* Nashville, TN: Metropolitan Government of Nashville.

Metropolitan Government of Nashville and Davidson County. Department of Water Services. (2015). *Cleanwater Nashville Overflow Abatement Program.* Retrieved from: http://www.cleanwaternashville.org/

Paradigm Environmental. (2015). *Richland Creek Watershed Decision Support System.* Submitted to: The Nature Conservancy, Nashville, TN.

State of Tennessee Department of Environment and Conservation. Division of Water Pollution Control. (2011). *Quality System Standard Operation Procedure for Macroinvertebrate Stream Surveys (Revision 5)*. Nashville, TN: State of Tennessee.

Tetra Tech, Inc. (2015). *Pilot BMP Analysis and SUSTAIN Modeling Report for the Sugartree Creek Watershed, Nashville, Tennessee.* Prepared for: Metro Water Services NPDES & Environmental Compliance, Nashville, TN.

Tetra Tech, Inc. (2014). *Watershed Hydrology and Water Quality Modeling Report for the Richland Creek Watershed, Nashville, Tennessee.* Prepared for: Metro Water Services, NPDES & Environmental Compliance, Nashville, TN.

Unified Government of Athens-Clarke County. Department of Transportation and Public Works. (2010). *Watershed Management Plan Hunnicutt Creek.* Athens, GA: Government of Athens-Clarke County.

United States Army Corp of Engineers (USACE) Nashville District. (2008). Draft Richland Creek Watershed FIS Update

United States Climate Data. http://www.usclimatedata.com/climate/nashville/tennessee/united-states/ustn0357

United States Fish & Wildlife Service. (2015) Environmental Conservation Online System (ECOS) http://ecos.fws.gov/ecp/

United States Geologic Survey (USGS). National Geologic Map Database. https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

University of Tennessee Institute of Agriculture. Tennessee Smart Yards. https://ag.tennessee.edu/tnyards/Pages/default.aspx