Greater Bonne Femme Watershed Modeling Report

Submitted to

Boone County, Missouri
Missouri Department of Natural Resources

Prepared by:

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engineers | scientists | innovators

December 3, 2020

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ACRONYMS AND ABBREVIATIONS

ACRONYM	DEFINITION
AWMS	Animal Waste Management System
BMP	Best Management Practice
CBP	Chesapeake Bay Program
cfu/100mL	Colony forming units per 100 milliliters
CPI	Catchment Prioritization Index
DEM	Digital Elevation Model
E. coli	Escherichia coli
GBFW	Greater Bonne Femme Watershed
HUC	Hydrological Unit Code
LDC	Load Duration Curve
MDA	Minnesota Department of Agriculture
MDC	Missouri Department of Conservation
MDNR	Missouri Department of Natural Resources
MST	Microbial Source Tracking
NAVD83	North American Vertical Datum of 1983
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NPS	Non-point Sources
NRCS	Natural Resources Conservation Service
PCPI	Pollutant Catchment Prioritization Index
POC	Pollutant of Concern
QAPP	Quality Assurance Project Plan
SELECT	Spatially Explicit Load Enrichment Calculation Tool
STEPL	Spreadsheet Tool for Estimating Pollutant Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
US EPA	US Environmental Protection Agency

ACRONYM	DEFINITION
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation
WBC	Whole Body Contact
WBID	Water Body Identification
WBP	Watershed-based Plan
WSS	Web Soil Survey
WQS	Water Quality Standards

SECTION 1

INTRODUCTION

1.1 Background and Problem Definition

The Greater Bonne Femme Watershed (GBFW) is comprised of 92.4 square miles of mixed-land use including: row cropping, livestock, residential development, and recreation. The GBFW is located between the rapidly developing cities of Ashland (south) and Columbia, Missouri (north), where population growth has increased by 40 percent over the last 10 years.

The Bonne Femme and Little Bonne Femme Creeks, along with their tributaries - Bass Creek, Turkey Creek, Fox Hollow Branch, Smith Branch, Devil's Icebox Branch, Gans Creek, Clear Creek, and Mayhan Creek - are the focus of development of watershed models of the GBFW (Figure 1). The watershed contains sensitive karst habitats, Outstanding State Resource Waters, and losing stream hydrology that are vulnerable to water quality degradation. Consequently, land-use and management practices have significant impacts on these unique ecosystems. Threats to these ecosystems include riparian area deforestation, failing on-site sewage systems, nutrients, pesticides, sediment in stormwater runoff from commercial and residential sites, and animal waste.

Water quality parameters of concern in the GBFW streams include *Escherichia coli* (*E. coli)*, nutrients, and total suspended solids (TSS). These are summarized below:

- The GBFW streams have elevated levels of microbial contamination as measured by *E. coli* bacteria. *E. coli* levels have exceeded the recreational season (April 1 through October 31) geometric mean criterion for whole body contact "A" (126 colony forming units per 100 milliliters, cfu/100 mL) and whole-body contact "B" (206 cfu/100 mL). The Missouri Department of Natural Resources (MDNR) has listed six stream segments in the GBFW as being impaired for *E. coli* on the state's 303(d) list of impaired waters. These include Little Bonne Femme Creek - Water Body Identification number [WBID] 1003; Gans Creek - WBID 1004; Bonne Femme Creek - WBID 750 and 753; Turkey Creek - WBID 751; and Bass Creek WBID 752. The locations of impaired stream segments are shown in Figure 1. Total maximum daily loads (TMDLs) have not been developed for these WBIDs.
- Missouri has not yet adopted instream criteria for nutrients. Water quality monitoring data from 2001 to 2006 collected as part of the previous watershed-based plan (WBP) show that reported total nitrogen (TN) and nitrate concentrations in several subwatersheds are higher than the lower end of nutrient criteria range recommended by the US Environmental Protection Agency (US EPA) in 2000 (Appendix G, BFSC, 2007). The targets are not water quality standards but were established by US EPA to be protective of aquatic invertebrate density, nuisance algal growth, and eutrophication.
- Elevated levels for phosphorus have been reported in Upper Bonne Femme Creek, Little Bonne Femme, and Fox Hollow over the last decade by the US Department of Agriculture (USDA).

A previous watershed plan indicated several sites in watershed had some level of nuisance algal growth associated with nutrient pollution (Appendix G, BFSC, 2007).

- High turbidity levels have been reported in the streams during wet weather indicating wash off of sediment from land (BFSC, 2007).

A previous watershed-based plan (WBP) for the GBFW was completed in 2007 and was approved by Boone County, the City of Columbia, the City of Ashland and the MDNR (BFSC, 2007). The 2007 WBP provided goals and general recommendations to preserve sensitive ecosystems, promote best management practices (BMPs), and maintain water quality while supporting economic development. This plan has led to improvements in the watershed; however, a more prescriptive 9-element watershed plan is needed to effectively restore water quality, protect the watershed and reduce pollutant loading to GBFW streams. Boone County is developing a 9-element WBP which will provide a road map towards achieving GBFW water quality improvement goals and be protective of the existing conditions in the watershed. The WBP will include recommendations for BMP implementation to strategically reduce impacts of non-point sources (NPS) on the stream water quality in the watershed.

Boone County engaged Geosyntec Consultants (Geosyntec) to develop pollutant loading/load reduction estimates to meet US EPA requirements for 9-element WBPs as identified by MDNR staff, specifically elements a-6 and b-1 through b-3 of US EPA's 9 required elements for a WBP (Westin, 2019). These elements state:

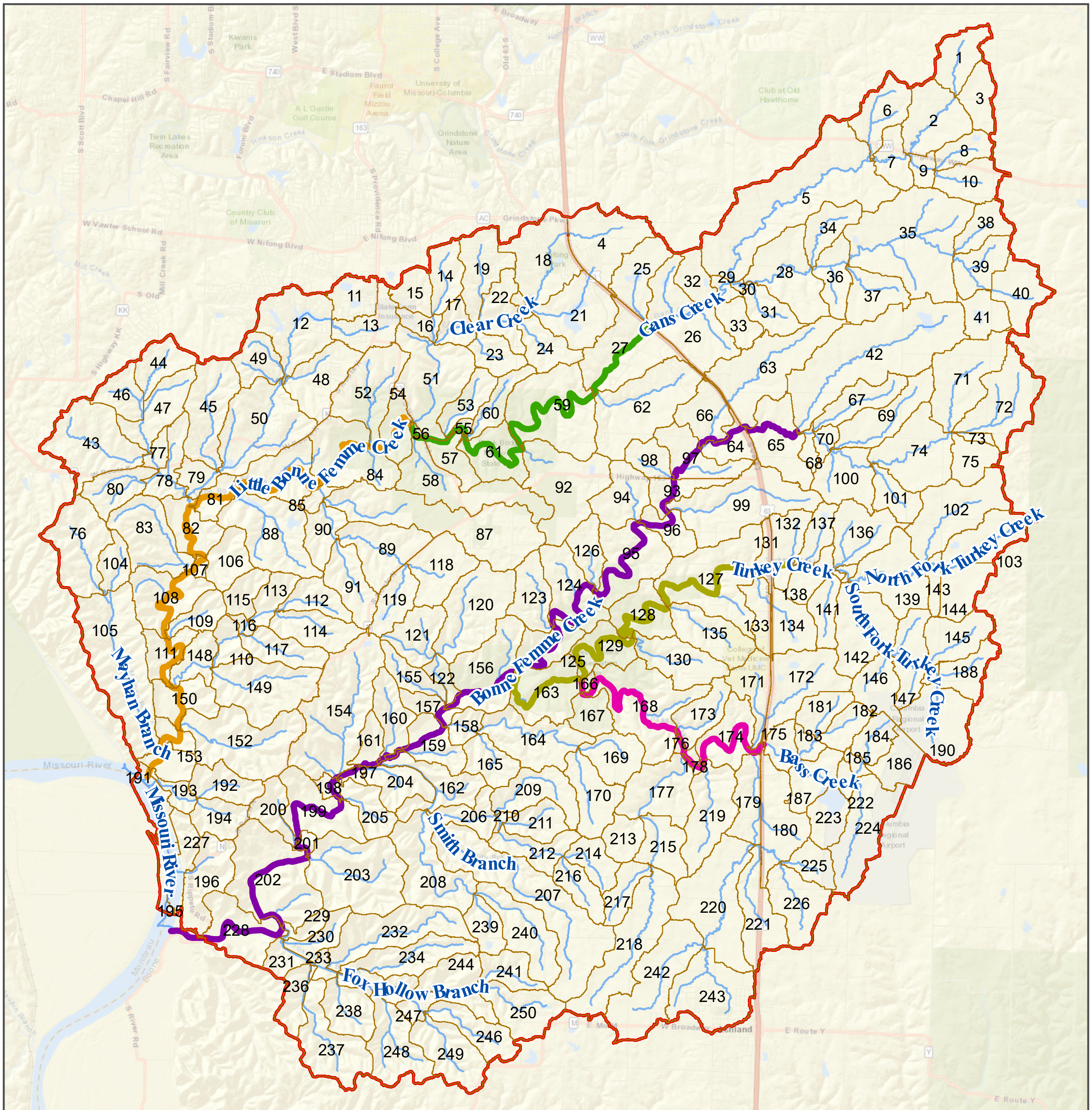
> "Causes of impairment are broken down by source and quantified by load, percentage, priority, or other method to identify the extent of the source treated (such as x number of animal feeding operations within segment y)." (Element a-6)
>
> "The watershed-based plan includes load reductions needed to meet water quality criteria or standards [for the 303(d) list or TMDL] in impaired streams and achieve the environmental goal." (Element b-1)
>
> "The source of the load reduction information (TMDL, modeling, monitoring) is identified to estimate pollutant load reductions (assumptions and limitations should be stated)." (Element b-2)
>
> "The plan provides estimates of potential load reductions for each pollutants cause/source, or groups of similar sources that need to be managed." (Element b-3)

This GBFW Modeling Report is submitted in support of Boone County's need for specific information to develop a 9-element WBP.

1.2 Modeling Objectives

The reason for developing watershed models is to generate information to support the development of a 9-element WBP. This information includes:

- Maps showing specific NPS which result in *E. coli* (by area category, facility type, etc.) impairments in the watershed (Element a-4).
- Existing condition load estimates for nutrients, total suspended solids, and *E. coli* from each land use in the watershed (Element a-6).
- Maps that identify specific, critical/targeted areas within the watershed for BMP implementation to mitigate NPS pollution, and to estimate the areas and/or length of their extent (Element a-7).
- List of recommendations for BMPs in the critical areas to reduce pollutant loading corresponding to land use practices in the critical areas, including prioritization of areas for implementation and rationale for BMP selection as optimal for *E. coli* loading mitigation (Elements c-1 and c-2).
- Documentation of locations where streambank erosion and riparian corridor degradation are concerns (Assessed as part of previous WBP).
- Documentation of pollutant load reduction estimates through the implementation of proposed BMPs at different implementation levels to improve water quality in the watershed and ultimately achieve instream water quality standards for *E. coli* (Element c-3).
- Report documenting data, assumptions, and literature sources for watershed model development; critical area identification; BMP selection; and estimation of load reductions from BMPs at different implementation levels.



Greater Bonne Femme Watershed Subwatersheds and Tributaries

Geosyntec consultants

Legend

Subwatershed

Greater Bonne Femme Watershed

E. coli Impaired Streams

Bass Cr.

Bonne Femme Cr.

Gans Cr.

L. Bonne Femme Cr.

Turkey Cr.

Tributaries

N

0 1 2

Miles

Figure

1

SECTION 2

MODEL FRAMEWORK

Two watershed models were developed and applied to meet the objectives of the project – one for nutrients and TSS and another for *E. coli*. Brief descriptions of the modeling frameworks are provided below.

2.1 Nutrients and TSS Model

Geosyntec developed the watershed model for nutrients and TSS using the US EPA Spreadsheet Tool for Estimating Pollutant Loads (STEPL) version 4.4 (TetraTech, 2018). STEPL simulates annualized estimates of total runoff volume and nutrient and TSS loads based on the Universal Soil Loss Equation (USLE), watershed characteristics (both default and user-specified), BMP implementation, and meteorology. STEPL has been used by MDNR to estimate NPS pollutant loads for several WBPs. STEPL currently does not simulate *E. coli*.

2.2 *E. coli* Model

Geosyntec simulated *E. coli* loads using the methodology of the Spatially Explicit Load Enrichment Calculation Tool (SELECT) developed by the Spatial Sciences Laboratory and the Biological and Agricultural Engineering Department at Texas A&M University (Teague et. al, 2009). SELECT has been applied to assess sources of bacteria contamination for WBPs and TMDL projects (Riebschleager et al., 2012; Borel et al., 2012; Borel et al., 2015; Roberts et. al, 2015; NTMWD et al., 2017; Glen et al., 2017). The methodology is consistent with the guidance provided by US EPA to estimate *E. coli* loading from NPS (US EPA, 2001). This methodology was selected for application in the GBFW since it is less data intensive and requires less effort as compared to complex mechanistic models such as HSPF and SWAT, but still provides information suitable for watershed planning purposes, similar to STEPL. A description of SELECT's methodology is provided below.

Daily *E. coli* loading from potential *E. coli* sources were estimated for each subwatershed using equations in Table 1. *E. coli* production rates are based on literature reported values from US EPA for fecal coliform (US EPA, 2001). A conversion factor was applied to convert the fecal coliform loading rate to an *E. coli* loading rate, which was estimated using water quality data from the GBFW. This methodology did not account for die-off of *E. coli* and hence provides a conservative estimate of loading. The calculation of loads for each potential source in the GBFW is described below.

Livestock
Livestock in the GBFW contributing to the *E. coli* impairment include cows and potentially other livestock included in ruminant category consisting of sheep and goats based on the results of

microbial source tracking (MST) results conducted by Boone County. Daily *E. coli* loads for livestock were calculated using equations in Table 1.

Wildlife

Wildlife in the GBFW contributing to the *E. coli* impairment was identified as deer (listed in the ruminant category) based on MST results conducted by Boone County. The MST results did not indicate contamination from geese. Daily *E. coli* loads for wildlife were calculated using the equation for deer in Table 1.

On-Site Wastewater Systems

Daily *E. coli* loading from failing on-site wastewater systems was calculated using the equation in Table 1. An average number of three people per household is assumed based on the STEPL data server input. The model assumes 60 gallons of sewer volume is generated per person per day. The areas of the GBFW not served by sewer systems were mapped by Boone County GIS department to identify the residential areas using the on-site wastewater systems.

Table 1: Equations for Estimating E. coli Load from Different Sources

Source	***E. coli* Load (colony forming units per day or cfu/day)**
Cattle	(#Cattle) * (10^{11} cfu/day/Cattle) * f^1
Goats	(#Goats) * ($1.2*10^{10}$ cfu/day/Goat) * f^1
Sheep	(#Sheep) * ($1.2*10^{10}$ cfu/day/Sheep) * f^1
Deer	(#Deer) * ($3.5*10^8$ cfu/day/Deer) * f^1
On-site septic wastewater systems	(#Households) * Malfunction Rate * (#Average people/household) * (Volume generated/person/day) * (10^4cfu/100mL) * (3758.2mL/gallon) * f^1

f^1- conversion factor to convert fecal coliform loading rate to *E. coli*

SECTION 3

MODEL DEVELOPMENT AND APPLICATION

The watershed model for the GBFW was developed as per the methodology described in approved modeling Quality Assurance Project Plan or QAPP (Geosyntec, 2020). Minor deviations from the approved QAPP were communicated to the Boone County Project Manager and MDNR, and subsequently approved. They are documented in this report, wherever applicable, along with the discussion of deviation on model quality. This section documents the data, assumptions, and methodology used to develop and apply the watershed model for the GBFW.

3.1 Existing Data Sources

The existing data utilized for the development of the watershed model for GBFW are summarized in Table 2 along with the data sources. Where available, data from Boone County and other local agencies in the watershed were used for model development to help ensure that model results are reflective of the existing conditions of GBFW. A brief description of each data type is also provided below.

3.1.1 Hydrology

Hydrology information for the GBFW such as Hydrological Unit Codes (HUCs), rivers, and streams were obtained from the United States Geological Survey (USGS) National Hydrography Dataset (NHD/NHD Plus, USGS, 2019). These data were used for delineation of GBFW into smaller subwatersheds.

3.1.2 Land Cover

The land cover data was downloaded from National Land Cover Database (NLCD, 2016). Table 3 shows the breakdown of the land use in the GBFW. Review of the land cover data shows that most of the watershed is rural and forested, with most development occurring close to cities of Ashland (south) and Columbia, Missouri (north), and some along the Highway 63 corridor (Figure 2). About 13% of the watershed is cropland, primarily east of Highway 63, where there is flatter land and deep soils. Pasture is about 33% of the total watershed area, spread throughout the watershed. Various forest types cover an additional 44%, most of it occurring west of Highway 63 in the areas with steeper terrain. Suburban and commercial development cover about 9% of the total watershed area. Other land use (open water, wetlands, shrub, grassland and barren land) covers about 2% of the total watershed area.

The land cover for the GBFW, presented in Table 3, was categorized as urban, cultivated crops, pasture/hay, forest and other based on land use categorizes defined in STEPL model. Other land use includes all land uses that do not fit into urban, cultivated crops, pasture/hay or forest. The acreage for open water was not included in the watershed model as open water was assumed to not contribute to pollutant loading.

Table 2: Existing Data Sources for Development of Watershed Models

Category	Required Data	Data Source
Hydrology	Watershed boundaries	National Hydrography Dataset
	Rivers	National Hydrography Dataset Plus
	Streams	
Land Use / Land Cover	Parcel GIS data with land use/land cover information	National Land Cover Database
	Land use zoning map (for urban land use distribution)	Boone County Zoning Information Viewer
Topography / DEM	Lidar	USGS 3D Digital Elevation Program (1 m resolution)
Soil Data	Soil coverage	SSURGO dataset
Meteorological	Temperature, cloud cover, dewpoint temperature, precipitation, solar radiation, wind, potential evapotranspiration	National Climatic Data Centre, Missouri Mesonet
Impairments	Impaired streams	Missouri Department of Natural Resources
Event Mean Concentration	Event mean concentration for nutrients and TSS associated with different land use	STEPL default values
Sediment wash off parameters	Universal Soil Loss Parameters	Default parameters in STEPL for Boone County, Missouri
On-site Wastewater System Information	Population per on-site wastewater system, septic failure rate	Columbia/Boone County Public Health & Human Services
Fecal production rates	Daily fecal production rates from different sources	US EPA (2001)
Animal Populations	Livestock and wildlife animal population	Boone County/MDC

Table 3: Existing Land Cover Breakdown for the GBFW

Land Use	Percent Land Use (%)
Urban	9
Cultivated Crops	13
Pasture/Hay	33
Forest	43
Other	2

3.1.3 Topography

A high resolution one-meter Digital Elevation Model (DEM) for GBFW downloaded through the USGS 3D Elevation Program, was used for watershed delineation. The DEM uses the North American Vertical Datum of 1983 (NAVD83).

3.1.4 Soils

The soils data for the GBFW was extracted using the Web Soil Survey (WSS) application by USDA NRCS (USDA, 2019). The soils data extracted as GIS shapefiles were used to identify the type of soil and assign hydrologic soil group to each of the delineated subwatersheds. The majority of GBFW consists of soil in hydrologic soil group D (Figure 3), characterized as soils having a very slow infiltration rate, high runoff potential and very slow rate of water transmission.

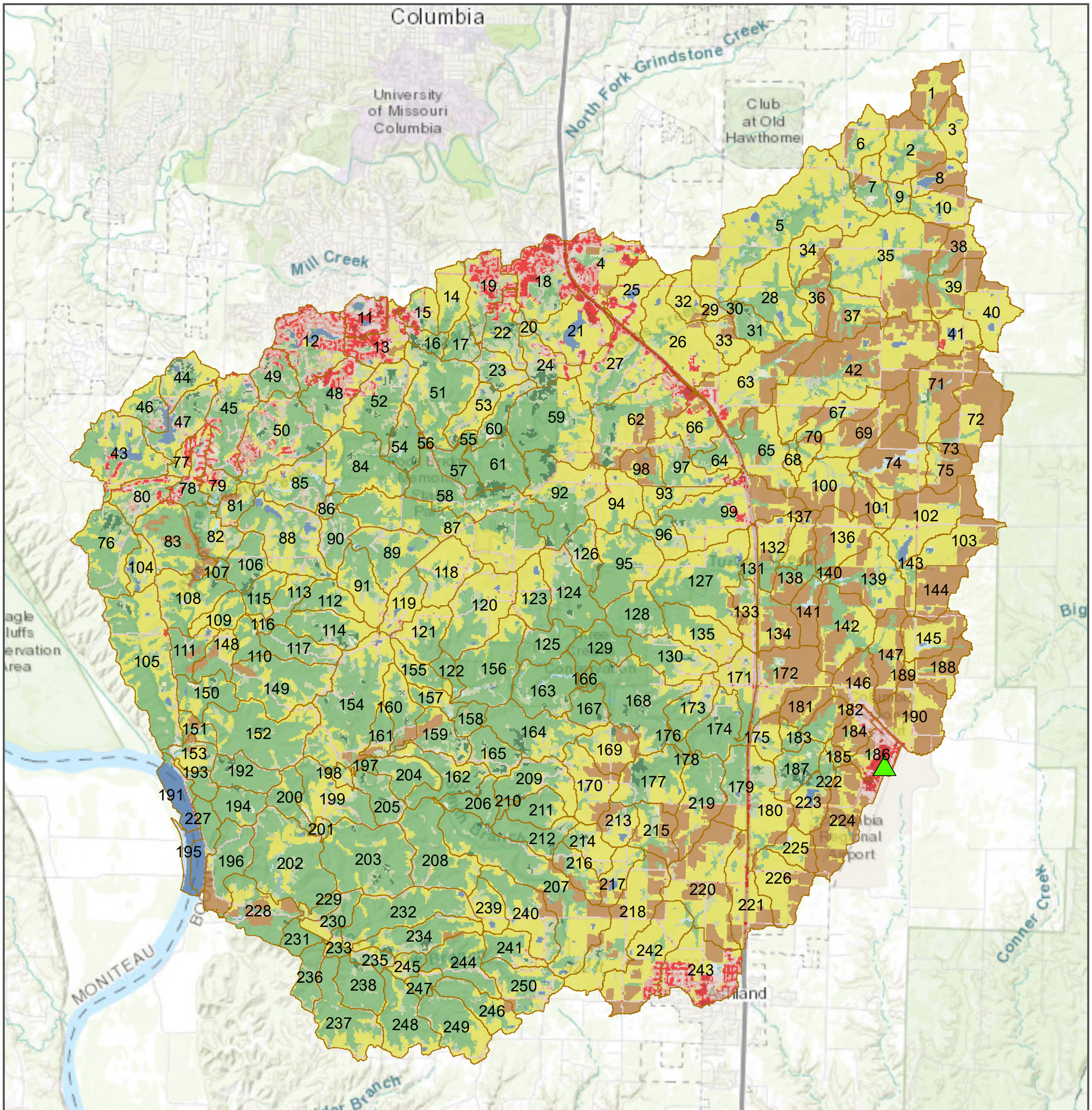
3.1.5 Meteorology

For the GBFW, the STEPL model uses mean meteorological data from Columbia Regional Airport weather station (Station Id: GHCND: USW00003945, latitude/longitude: 38.8169/-92.2183). The location of the weather station is shown in Figure 2.

3.1.6 Septic Systems

A non-sewered parcel layer and building location point shapefile received from Boone County was used to determine number of households in Boone County that rely on-site wastewater systems. The areas of the GBFW not served by sewer systems were mapped by Boone County GIS department to identify the residential areas using the on-site wastewater systems (Figure 4). Boone County also provided building location and use data. The building uses of residential 1- and 2-family houses, house, mobile home, livestock operation home, farm in use & farm residential, double wide on acreage, and residential structures in the non-sewered parcels were assumed to be on-site wastewater systems. The number of households were determined to be 1,498 using this information. The use of building data for determining the number of households represents a minor deviation from the approved QAPP, which included the use of Census data for this purpose. Geosyntec determined that Census data were too coarse for application at the subwatershed level. The use of building data provided a more accurate estimate of number of households using on-site wastewater systems, which improved the quality of model.

An average of three persons per on-site wastewater system was used based on the STEPL data input server. A septic failure rate of 10 percent was assumed for the GBFW based on the results of MST which indicated a very low signature of human source in *E. coli* measurements.



Greater Bonne Femme Watershed Land Cover

Geosyntec consultants

Legend

- Columbia Regional Airport Weather Station
- Subwatersheds

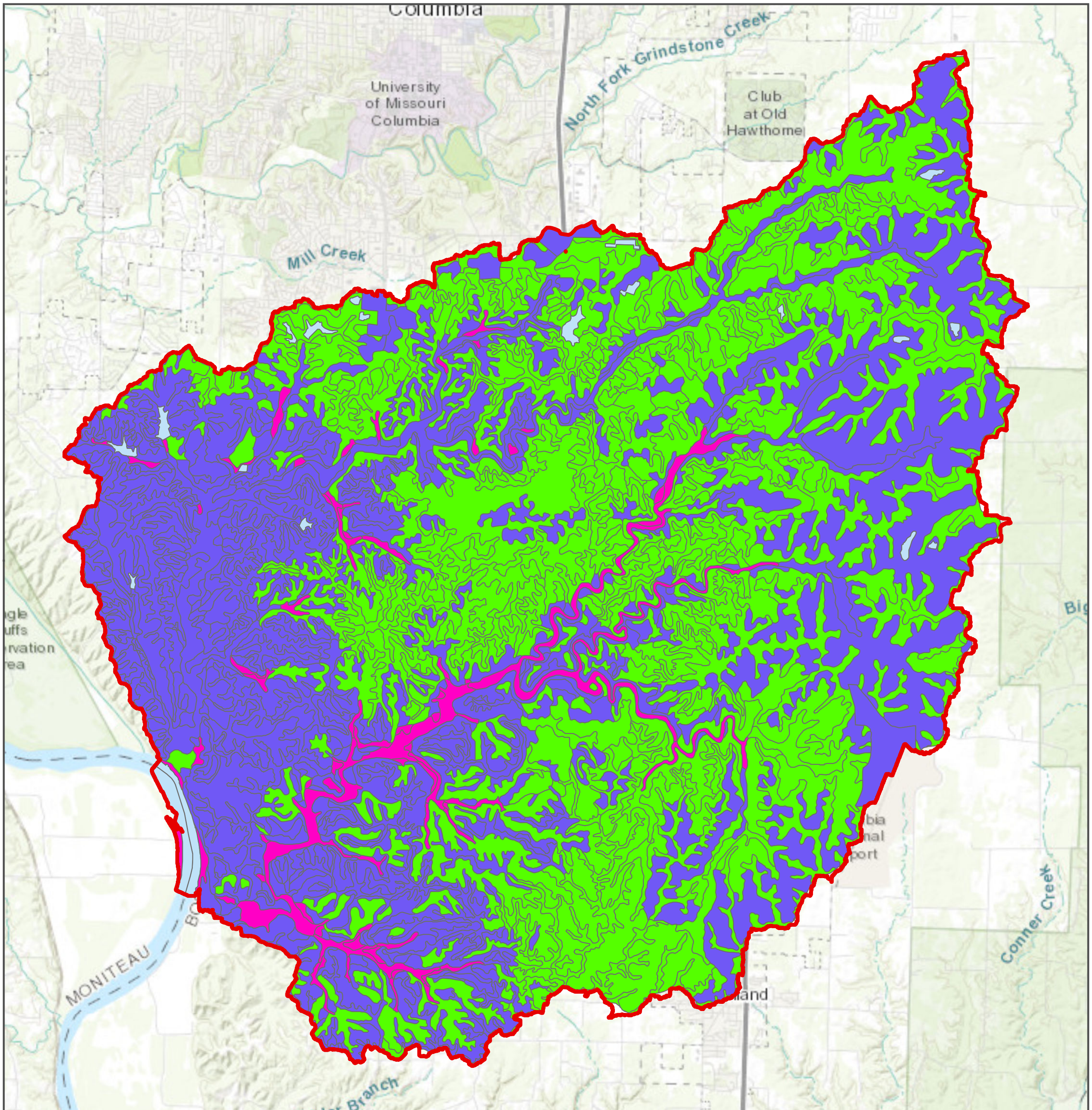
Land Cover, NLCD 2016

- Barren Land
- Cultivated Crops
- Deciduous Forest
- Developed, High Intensity
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, Open Space
- Emergent Herbaceuous Wetlands
- Evergreen Forest
- Hay/Pasture
- Herbaceuous
- Mixed Forest
- Open Water
- Shrub/Scrub
- Woody Wetlands

0 1 2 Miles

N

Figure 2



Greater Bonne Femme Watershed
Hydrologic Soil Group

Geosyntec consultants

Legend

Greater Bonne Femme Watershed

Hydrologic Soil Group

B

C

D

W*

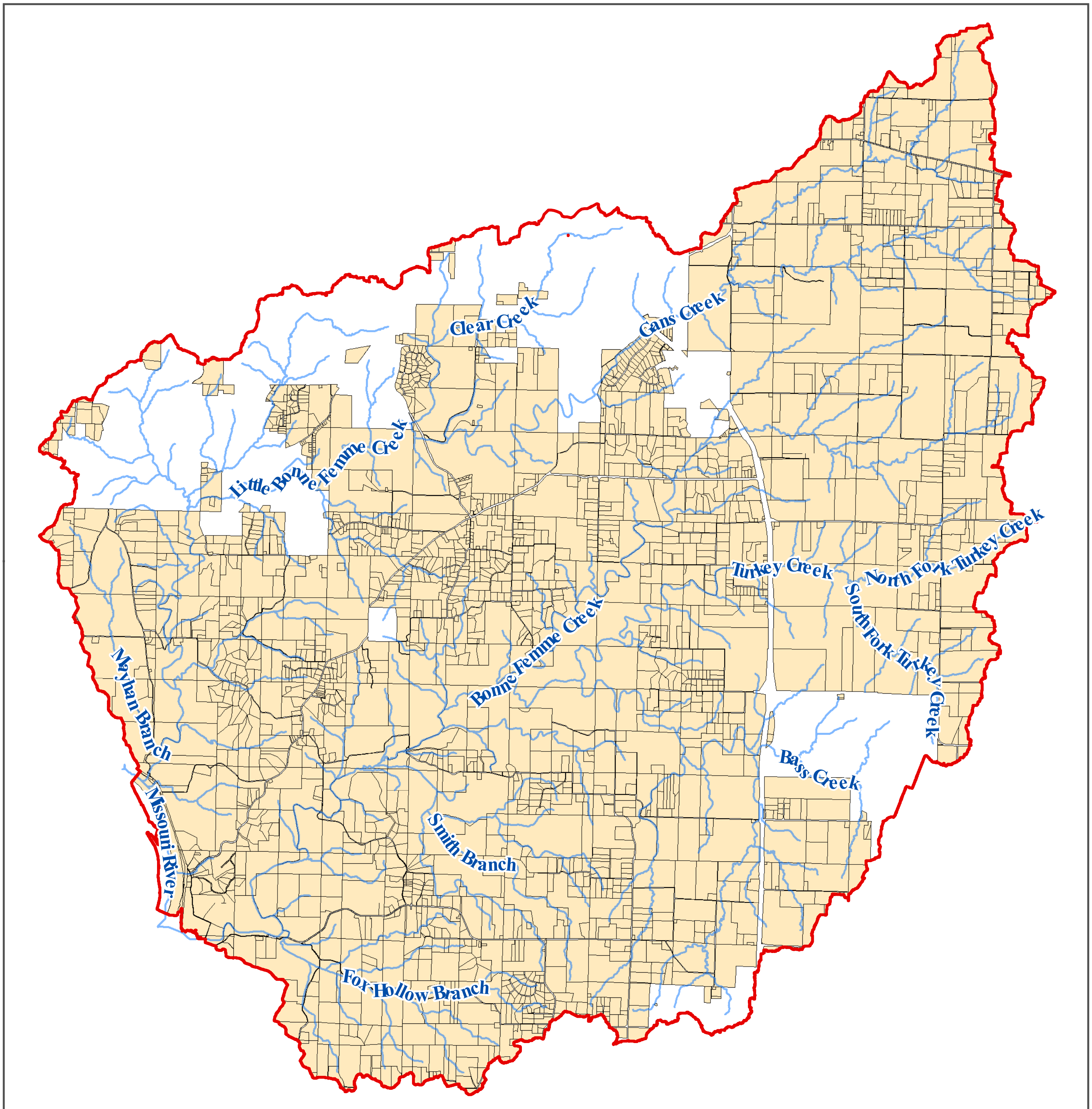
*Indicates Open Water

N

0 1 2

Miles

Figure 3



Greater Bonne Femme Watershed
Non-Sewered Portions
Mapped by Boone County GIS Department

Geosyntec consultants

Legend

- Tributaries
- Greater Bonne Femme Watershed
- Non-Sewered Parcels

N

0 1 2
Miles

Figure 4

3.1.7 Animal Population

Boone County has geographically referenced count data for cattle, goat and sheep[1] for the calendar years 2017 and 2018. The average of livestock counts from 2017 and 2018 were used to calculate *E. coli,* nutrient, and TSS loads from livestock for each subwatershed.

The deer population for Boone County was calculated using an estimate of 36 deer per square mile provided by Missouri Department of Conservation (MDC) for Boone County (per email correspondence with Jason Isabelle, the Cervid Program Manager at MDC on July 23, 2020).

3.2 Identification and Mapping of *E. coli* Pollutant Sources

Major potential NPS of *E. coli* pollutant loading were identified and mapped (element a-4 of the WBP). The NPS of *E. coli* that were investigated include livestock (cows, sheep and goat) and wildlife (deer), and failing on-site wastewater systems. MST results from Boone County were used with other information such as land use and animal density to map specific NPS of *E. coli* (by area category, facility type etc.) in the GBFW. Based on this investigation, the detectable sources of *E. coli* in the GBFW are livestock, wildlife, and failing on-site wastewater systems, which are mapped in Figure 5.

3.3 Watershed Delineation

The GBFW was delineated into subwatersheds using the Arc Hydro Tool in GIS. The delineation for the watershed consisting of 250 subwatersheds is shown in Figure 6. Subwatersheds with areas less than 10 acres were merged with adjoining subwatersheds based on drainage pattern to avoid very small subwatersheds. This is a minor deviation from the MDNR approved QAPP (Geosyntec, 2020) and was done to ensure that subwatersheds do not show up as critical hotspots for load per acre because of their size. The area of the delineated subwatersheds ranges from 11 acres to 1,097 acres. The average subwatershed area is 240 acres. The estimation of pollutant load at the fine resolution subwatershed level allowed better identification of critical areas with greatest load generating potential.

3.4 Watershed Modeling of Baseline

Geosyntec developed watershed models to estimate the existing loads for *E. coli,* nutrients, and TSS (element a-4 of WBP). Pollutant loads were estimated for each of the subwatersheds shown in Figure 6. Nutrient and TSS loads were estimated using US EPA's STEPL framework version 4.4 (TetraTech, 2018). *E. coli* loads were simulated using the methodology of SELECT. SELECT simulates the annualized loading of *E. coli* from various sources within a mixed land use watershed

[1] Boone County reported data for lambs and ewes and llamas. The count of ewes and llamas was used for sheep and lamb count was used for goat

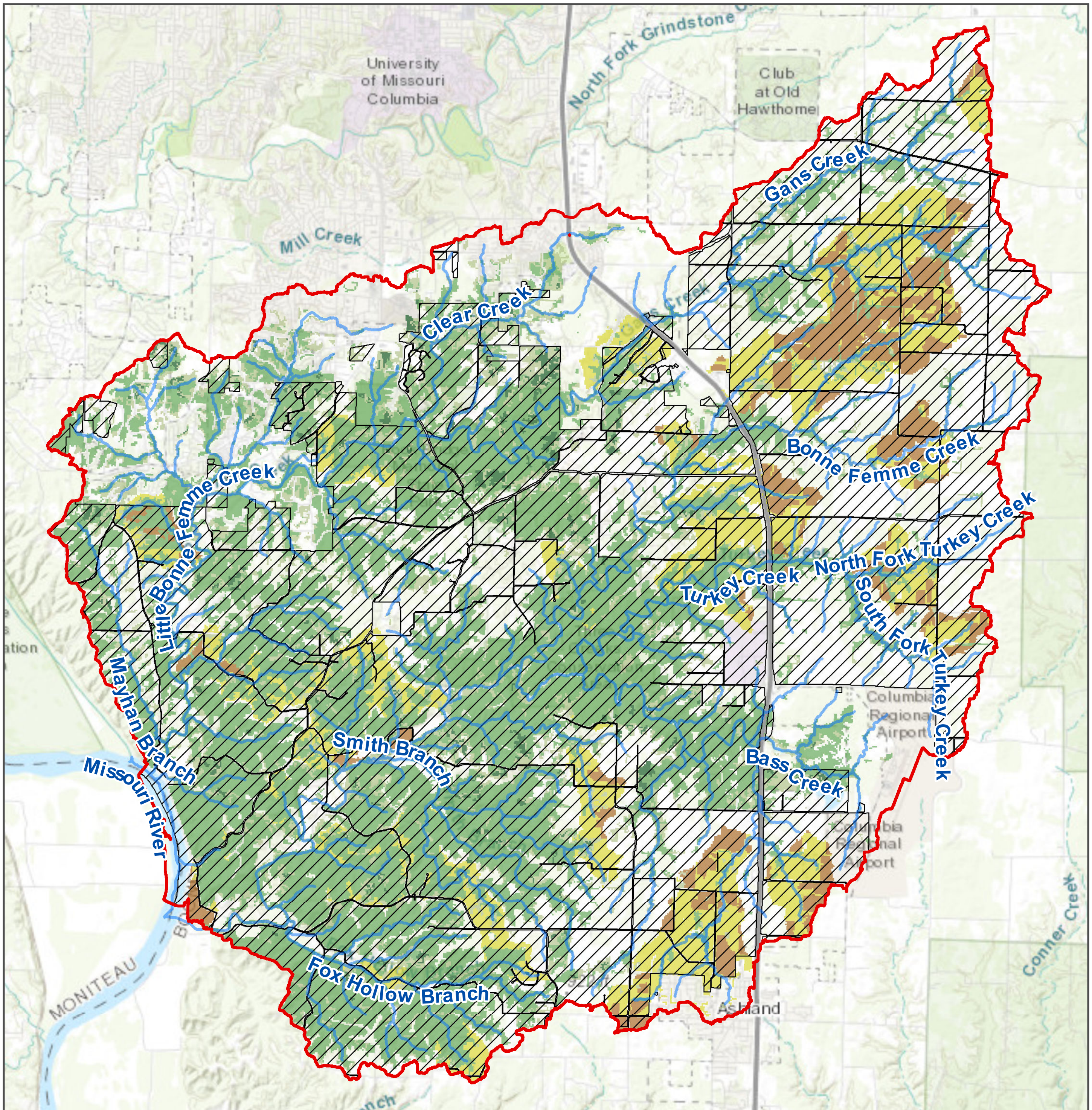
based on spatial inputs such as, animal population density and septic systems. Additional details about STEPL and SELECT are provided in Section 2.1.

3.4.1 Nutrients and TSS

The STEPL model Excel workbook can only simulate 50 subwatersheds at a time. Hence 5 STEPL workbooks were set up for the 250 delineated subwatersheds. The simulated loading results for nutrients and TSS were combined from the 5 STEPL workbooks with 50 subwatersheds each. Existing BMPs provided by City of Columbia, Boone County and University of Missouri were also input into the BMP input for the GBFW model. Default model input data, such as BMP treatment efficiency, event mean concentrations, and sediment wash off parameters, were checked for applicability in GBFW based on values reported in peer reviewed studies in the Midwestern US (Section 3.7). Electronic files for model inputs and STEPL models are provided with this report (Appendix A).

3.4.2 *E. Coli*

The methodology described in Section 2.2 was implemented in a single Excel spreadsheet for 250 subwatersheds to calculate the *E. coli* daily loading for each subwatershed. Major potential NPS of *E. coli* pollutant loading that are likely causing the water quality impairment are shown in Figure 5. An electronic file for the *E. coli* model is provided in Appendix B.



Greater Bonne Femme Watershed
E. coli Sources

Geosyntec consultants

Legend

Greater Bonne Femme Watershed

Tributaries

Potential E. coli Sources

Areas with Septic System

Livestock

Pasture/Hay

Cultivated Crops

Wildlife

Deciduous Forest

Evergreen Forest

Mixed Forest

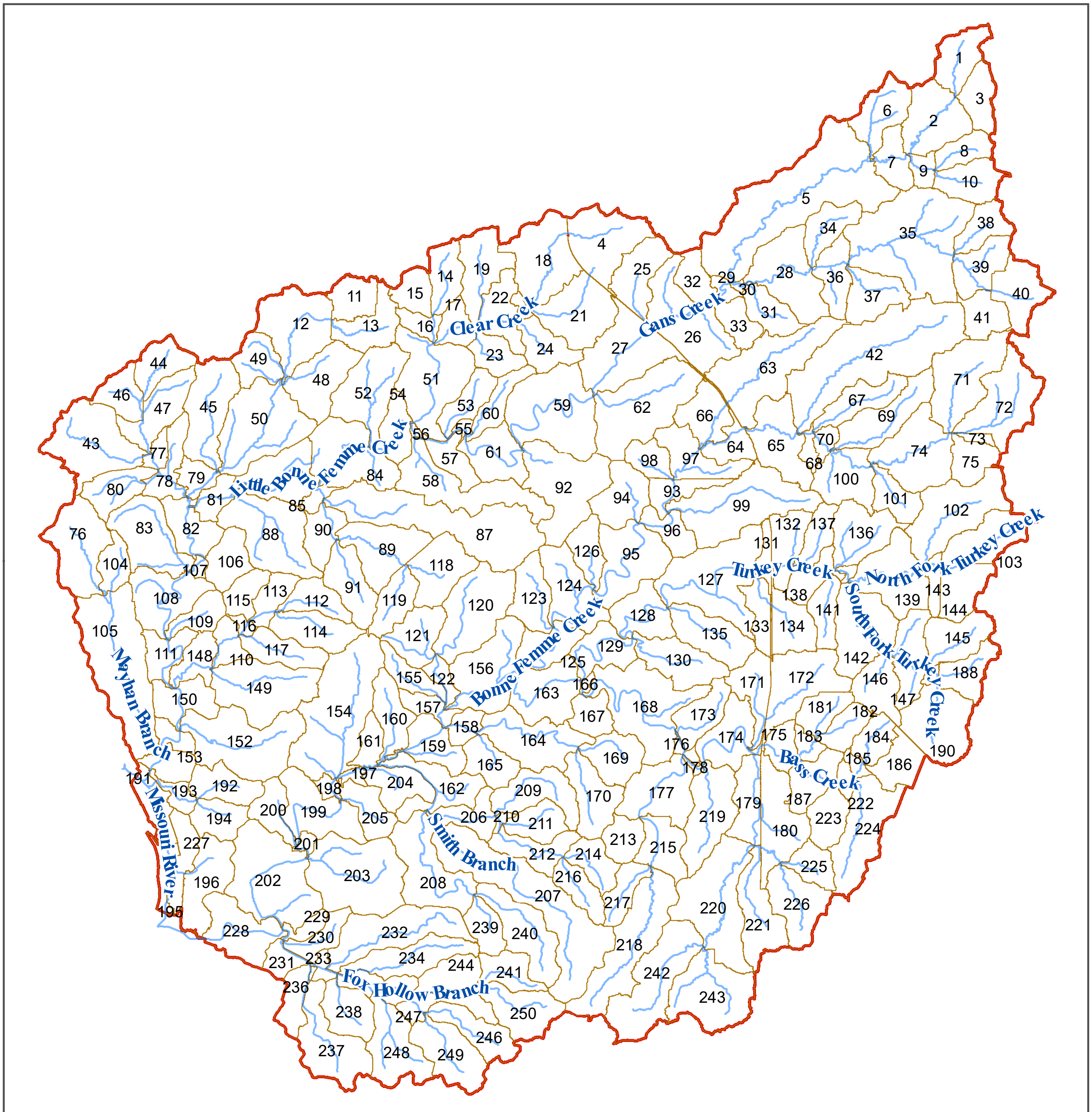
N

0 1 2

Miles

Figure

5



Greater Bonne Femme Watershed
Subwatershed Delineation

Geosyntec consultants

Legend

- Tributaries
- Subwatershed
- Greater Bonne Femme Watershed

N

0 1 2
Miles

Figure

6

3.5 Identification of Critical Areas

Critical areas in the GBFW for BMP implementation were identified, prioritized, and mapped as per the guidance from US EPA (US EPA, 2018) to satisfy the requirements of a 9-element WBP (elements a-7 and c-1 of WBP).

Geosyntec applied a Catchment Prioritization Index (CPI) that was developed for watershed planning. The CPI prioritizes BMPs when addressing multiple pollutants (Geosyntec, 2006) to identify critical areas for BMP implementation. A CPI was calculated for the subwatersheds shown in Figure 6 based on pollutants of concern, pollutant loading, and impairments. A higher CPI score would indicate higher priority of a subwatershed for BMP implementation.

The steps for calculating the CPI are:

1. For each pollutant of concern (POC), i.e., *E. coli*, TN, total phosphorus (TP), and TSS, the pollutant catchment prioritization index ($PCPI_s^i$) was calculated using the following equation:

$$PCPI_s^i = \frac{L_s^i}{Max(L_s^i)}$$

where, L_s^i is the estimated unit acre load for subwatershed s and pollutant of concern i.

2. PCPIs were weighted by a weighting factor for each POC and summed to calculate the Total PCPI for each subwatershed. Proposed weighting factors for different pollutants of concern are provided in Table 4 below. The use of the selected weighting factors in Table 4 puts the strongest emphasis on addressing the *E. coli* impairments, with a secondary emphasis on optimizing TSS and nutrient load reductions.

$$Total\ PCPI_s = \sum_i^N (PCPI_s^i \times F)$$

Table 4: Proposed Weighting Factors for Pollutants of Concern

Pollutant of Concern	Weighting Factor (F)
E. Coli	10
Total Nitrogen	5
Total Phosphorus	2
TSS	2

3. For subwatersheds with downstream impairments, the Total PCPI are multiplied by aa factor for each downstream impairment. A sensitivity analysis was conducted to assess the impact of magnitude of downstream impairment factor and location of downstream impairment on the prioritization of subwatersheds. A factor of 1.1 was deemed appropriate for Bonne-Femme watershed in consultation with MDNR and Boone County. This is minor deviation from the approved QAPP, which included using a factor of 2 for each downstream impairment. The change was necessitated because using a factor of 2 was resulting in higher weighting of subwatersheds with low simulated loads but located upstream of multiple impaired streams. The use of factor of 1.1 prioritized subwatersheds with higher simulated pollutant loading located downstream of the impaired streams. This change improved the identification and prioritization of subwatersheds for BMP implementation

4. The CPI for each subwatershed is calculated by normalizing the Total PCPI, scaling by five (5), and rounding to nearest integer:

$$CPI_s = \text{Round}\left(\frac{Total\ PCPI_s}{Max(Total\ PCPI_s\ )} \times 5\right)$$

The normalization and scaling of CPI results in binning of subwatersheds with CPI scores in the range of 1 to 5. This approach provides the stakeholders with more options for BMP implementation in the critical areas corresponding to higher CPI bins.

Subwatersheds with the highest CPIs are identified as critical areas for BMP implementation. The use of the CPI scoring approach allowed subwatershed prioritization for implementation of BMPs.

Other critical areas in the watershed include areas that are particularly sensitive to runoff and erosion. These areas were identified using the sensitivity analysis conducted as part of the previous WBP (BFSC, 2007). These critical areas were mapped along with the critical areas identified using the CPI methodology described above.

3.6 BMP Selection

A BMP is defined as an environmental protection practice used to control pollutants. For the critical areas identified using the methodology described above, the feasibility and effectiveness of cropland, pastureland, forestry, streambank, on-site wastewater systems, and urban BMPs were assessed. The POC in the GBFW include *E. coli*, TN, TP, and TSS. Many BMPs have positive effect on reducing load of multiple POCs. A brief description of each BMP assessed for implementation in the GBFW is provided below.

3.6.1 Cropland BMPs

Cropland BMPs control the runoff from agriculture fields resulting in reduced sediment and nutrient loading. Six types of BMPs were assessed for implementation in the cropland areas of the GBFW:

- **Cover Crops** are short-term crops grown after the main cropping season to reduce nutrient and sediment loss from the farm fields.
- **Nutrient Management** helps the farmer maximize profits by balancing crop yields and nutrient inputs. Using a nutrient management plan, farmers can optimize the economic returns from nutrients used in production and minimize nutrient loss and water quality at the same time.
- **Conservation Tillage** involves the planting, growing, and harvesting of crops with minimal disturbance to the soil. This practice uses seeders and techniques that are more precise and require fewer passes, reducing the amount of fuel used for farm equipment.
- **Terraces** are earth embankments and/or channels constructed across the slope of the field to intercept runoff and trap sediment contained in runoff.
- **Vegetated Buffers** are areas of crop fields maintained in permanent vegetation to help reduce nutrient and sediment loss from croplands.
- **Retention Ponds** trap sediment and nutrients in runoff and provide habitat for wildlife.

3.6.2 Pastureland BMPs

Five types of pastureland BMPs were assessed for implementation in the pasture areas of the GBFW. Some of these BMPs limit the source of POC from feeding operations and others reduce the pathways for the POC to enter the adjacent waterbodies.

- **Manure Management** or animal waste management systems involve manure storage, transportation off-site, and improvements in manure recoverability. This practice reduces the source of nutrients and bacteria in the runoff.
- **Grazing Management** involves controlling the movement of animals on the field. Grazing, movement and manure deposition by the animals encourages growth of pasture vegetation. However, animals can overgraze a pasture if they are not moved to a fresh area frequently enough. By rotating animals to other areas or pastures, the recently grazed vegetation has an opportunity to regrow, which improves the soil nutrient content. This reduces the need for fertilizer application in the field and reduces nutrient loading
- **Fencing** of streams and other waterbodies is designed to prevent livestock from entering the waterbody. This prevents livestock from depositing manure directly into the waterway.
- **Vegetative Filter Strips** are vegetated areas that receive stormwater runoff from a pastureland with animal feeding operations.

- **Wetland restoration or creation** projects on pastureland provides numerous crucial environmental functions such as wildlife habitat, flood protection, and water quality improvements.

3.6.3 Forestry BMPs

Forest is one of the major land covers in the GBFW. Logging activities are also common across the watershed. As a result, forestry BMPs, including pre-harvest planning, forest road management, and improved harvesting practices, can reduce the nutrient and sediment load from runoff in forestry subwatersheds in the GBFW. An additional forestry BMP would be exclusion of livestock from forested land which is funded by MDC through a cost-share program.

3.6.4 Streambank BMPs

Streambank BMPs are installed along the banks of streams to reduce POC loadings into the receiving streams, improve water quality, and improve the biological condition along the stream bank. Two types of streambank BMPs were considered for implementation in the GBFW:

- **Stream Restoration** includes natural channel design, regenerative stream channel projects, and legacy sediment removal. These approaches are carefully designed interventions to improve the hydrologic, hydraulic, geomorphic, water quality, and biological condition of degraded urban streams.
- **Streambank Buffers** include forest and grass buffers, sometimes implemented with stream exclusion fencing to restrict animal access to the stream, to improve the biological condition of the streambank.US Department of Agriculture provides cost share for stream buffer practices through federal programs such as the Conservation Reserve Program, Environmental Quality Incentives Program and Wildlife Habitat Incentives Program.

3.6.5 On-site Wastewater System BMPs

On-site wastewater system BMPs address the POC loading from failing on-site wastewater systems that leak bacteria or nutrients into surface water and groundwater. This practice involves replacing old systems with more reliable systems and/or repairing malfunctioning treatment systems, failing drain fields, or waste lagoon systems.

3.6.6 Urban BMPs

Urban BMPs are designed to reduce the quantity and improve the quality of stormwater runoff from impervious surfaces in urban areas. The selection and implementation of urban BMPs are subject to site-specific constraints such as local hydrology, soil infiltration feasibility, and space restrictions. Four commonly used urban BMPs assessed for implementation in GBFW include:

- **Bioretention systems** consist of a soil bed planted with suitable native vegetation. Stormwater runoff entering the bioretention system is filtered through the soil planting bed before being discharged downstream.
- **Grass swales,** or ditches, can be placed in residential areas or along major roadways to help reduce peak runoff through infiltration and storage.
- **Wetland basins** are man-made systems engineered to approximate the water-cleansing process of natural wetlands. They are used to filter runoff from urban impervious areas and provide habitat for some wildlife.
- **Detention ponds** hold stormwater runoff until pollutants settle to the bottom. The water is then released slowly into the stream, reducing flooding and POCs in the discharge.

3.7 Pollutant Load Reduction and Feasibility Assessment

The effectiveness of load reduction and feasibility of implementation of the BMP types selected in Section 3.6 were described below

3.7.1 BMP Pollutant Load Reduction Effectiveness

Percent load reduction efficiency data was extracted from literature review to estimate the load reduction of the selected BMPs for the GBFW. The literature review includes summary of paired watershed case studies, watershed plans for similar watersheds and agricultural BMP reference guides. Percent load reduction was extracted for each BMP to reduce the load for each POC in the GBFW.

3.7.1.1 Literature Review

A literature review was conducted to estimate the BMP percent removal efficiencies for the four POCs in the GBFW. Due to the limited performance data available for *E. coli* treatment and forestry and agricultural BMPs in general, no single source of data covers the performance of all types of BMPs listed in Section 3.7. Six sources of data were analyzed, from which BMP performance data is extracted:

a) Spring River Nonpoint Source Watershed Plan

The WBP was written for the Spring River Watershed to address impairments caused by nutrients and sediment (MDNR, 2015). The list of considered BMPs in the Spring River Watershed study is similar to the list presented in Section 3.7 for the GBFW, including urban, agricultural, streambank and on-site wastewater system BMPs. The BMP removal efficiency data for nutrients and sediment from this WBP was utilized for this project, where applicable.

b) International Stormwater BMP Database 2016 Summary Statistics

The International Stormwater BMP Database (the Database) is a publicly accessible repository for BMP performance, design, and cost information. Since the initial development of the BMP Database in 1996, a portfolio of more than $200 million in water quality research is represented in the Database. The 2016 summary statistics of the Database include treatment performance of urban BMPs for TN, TP, and TSS (Clary. J. et al. 2017). The median removal percentage for each BMP-POC pairing for all case studies in the Database was extracted from the report and used in this evaluation to estimate load reductions.

c) Effectiveness of BMPs for Bacteria Removal Developed for the Upper Mississippi River Bacteria TMDL

A literature review was conducted to inform the selection of the most practical and effective implementation strategies to improve water quality in the Upper Mississippi River Bacteria TMDL project area in the state of Minnesota (Tilman, L. et al., 2011). This literature review evaluated research findings regarding the effectiveness of various BMPs to reduce bacteria loading to surface waters. Only a limited number of BMPs were reviewed in this data source, but multiple studies were analyzed for each type of BMP. The median load reduction performance for indicator bacteria from all studies included in the data source for each type of BMP was extracted and used in this project for determining *E. coli* load reduction.

d) The Agricultural BMP Handbook for Minnesota

This literature review, published by the Minnesota Department of Agriculture (MDA), included empirical research on the effectiveness of 30 conservation practices, i.e., agricultural BMPs (MDA, 2012). Nutrient, sediment, and limited bacteria removal performance data for the 30 BMPs is available in this data source.

e) Chesapeake Bay Quick Reference Guide for BMPs

The Chesapeake Bay Program (CBP) is a regional partnership that leads and directs Chesapeake Bay restoration and protection. This reference guide provides summarized profiles for each CBP-approved BMP, including the effectiveness in pollutant load removal, cost and feasibility of implementation (CBP, 2018). In this data source, BMP load reduction percentages are often summarized for specific land use, crop types, or sub-type of the BMP. For the purpose of this project, the median value of the load reduction for each BMP-POC pairing was extracted from this reference guide.

f) Efficiencies of Forestry BMPs for Reducing TSS and Nutrient Losses in the Eastern United States

Compared to urban and agricultural BMPs, the available performance data for forestry BMPs is limited. This study from 2010 included three paired forested watershed studies in the eastern

United States through an exhaustive literature search. No individual practices were isolated in the study. Instead, the combined effectiveness of multiple forestry BMPs in each paired forested watershed study to reduce TSS, TN, and TP was summarized in this study and used in this project (Edwards, P. J. et al., 2010).

3.7.1.2 POC Load Reduction Efficiencies

Table 5 summarizes the load reduction percentage of each BMP listed in Section 3.7 for *E. Coli*, TN, TP, and TSS and the corresponding source of data from the six sources listed in Section 3.8.1.1.

Table 5: BMP Pollutant Load Reduction Efficiencies Used for Calculating Load Reductions through BMPs

BMP Type	BMP	*E. Coli*	TN	TP	TSS
Cropland	Cover Crops	0 [e]	0.23 [e]	0.07 [e]	0.1 [e]
	Nutrient Management	0 [e]	0.05 [e]	0.05 [e]	0.25 [b]
	Conservation Tillage	0 [e]	0.08 [e]	0.35 [e]	0.47 [e]
	Terrace	0 [e]	0.38 [b]	0.3 [b]	0.36 [b]
	Vegetated Buffer	0.59 [d]	0.36 [b]	0.5 [b]	0.5 [b]
	Retention Pond	0.7 [c]	0.5 [b]	0.5 [b]	0.5 [b]
Pastureland	Manure Management	TP, TN and *E. Coli* removal based on percent of manure removed from the feedlot.			
	Grazing Management	0.3 [d]	0.09 [d]	0.24 [d]	0.3 [d]
	fencing	0.35 [c]	0.34 [e]	0.42 [e]	0.56 [e]
	vegetative filter strip	0.7 [c]	0.32 [e]	0.5 [b]	0.56 [e]
	Wetland	0.78 [c]	0.42 [e]	0.4 [e]	0.31 [e]
Forestry	Pre-Harvest Management, Road Management, Improved Harvesting	0 [f]	0.53 [f]	0.85 [f]	0.6 [f]
Streambank	Streambank Stabilization	0 [e]	0.075 lbs/ft/yr [e]	0.068 lbs/ft/yr [e]	248 lbs/ft/yr [e]
	Streambank Buffer	0.7 [c]	0.34 [e]	0.42 [e]	0.56 [e]
Urban	Bioretention	0.8 [a]	0.16 [a]	0 [a]	0.75 [a]
	Grass Swale	0 [a]	0 [a]	0 [a]	0.16 [a]
	Wetland Basin	0.64 [a]	0.04 [a]	0.25 [a]	0.55 [a]
	Detention Pond	0.64 [a]	0 [a]	0.17 [a]	0.64 [a]
On-site Wastewater	Repair/Replace program	TN, TP and TSS removal based on percent of on-site wastewater system repaired/replaced			

The data source for the load reduction rate for each BMP-POC pairing is from one of the six data sources listed in Section 3.8.1.1:

a - International Stormwater BMP Database 2016 Summary Statistics;

b – Spring River Nonpoint Source Watershed Plan;

c - Effectiveness of BMP for Bacteria Removal Developed for the Upper Mississippi River Bacteria TMDL;

d – The Agricultural BMP Handbook for Minnesota;
e – Chesapeake Bay Quick Reference Guide for BMP;
f – Efficiencies of Forestry BMP for Reducing Sediment and Nutrient Losses in the Eastern United States.

As shown in Table 5, load reduction percentage of all BMPs listed in Section 3.7 for each of the four POCs are extracted from the literature review, except for manure management, streambank stabilization, and on-site wastewater system BMPs. The load reduction resulting from manure management depends on the amount of manure collected, stored, transferred, or removed from the feedlot. The load reduction resulting from streambank stabilization is a function of the length of streambank stabilized. The load reduction resulting from on-site wastewater system BMPs is a function of the percentage of on-site wastewater systems repaired or replaced. As a result, the load reduction of these three types of BMPs cannot be represented as percent of load removal from the BMPs' tributary areas.

3.7.2 BMP Implementation Feasibility Assessment

In addition to selecting the appropriate types of BMPs most effective for the POC in the GBFW, the location for each type of BMP implementation was also assessed. The feasibility of implementing a certain type of BMP in a subwatershed was assessed based on factors including the land use, space constraint, slope and vegetation of the subwatershed, proximity of the source of POC to the stream, cost-effectiveness and stakeholder involvement. The feasibility assessment process is summarized below:

3.7.2.1 Cropland BMPs

Cropland BMPs are feasible for subwatersheds with a larger proportion of cropland land use. Cover crops, nutrient management and conservation tillage can generally be implemented in cropland areas of the watershed without space constraints since these BMPs do not reduce the existing footprint of the cropland. Terraces, vegetated buffers, and retention ponds require extra space to implement. In addition, terraces can only be implemented in cropland areas with moderate to high slopes.

3.7.2.2 Pastureland BMPs

Pastureland BMPs are suitable for subwatersheds with dominant pasture/hay land use. Manure management requires construction of structures designed for collection, transfer, and storage of manures and associated wastes. As a result, the practice requires space for the facility, including operation and maintenance. Grazing management involves rotating paddocks which requires sufficient pastureland area relative to the animal population in the subwatershed. Vegetative filter strips and wetlands also require extra space to be installed adjacent to the pastureland, while fencing requires a limited amount of space for implementation.

3.7.2.3 Forestry BMPs

Forestry BMPs, including pre-harvest planning, road management, livestock fencing and improved harvesting practices, are feasible for forested subwatersheds in GBFW where logging activities exist.

3.7.2.4 Streambank BMPs

Streambank restoration projects are feasible for stream segments that are eroded severely or composed with karst formation in the streambed. The Subwatershed Sensitivity Analysis done as part of the previous WBP (BFSC, 2007) was used to identify areas that are suitable for streambank restoration projects, which include:

- Clear Creek
- Upper Little Bonne Femme Creek before confluence with Clear Creek
- Mayhan Branch
- Bonne Femme Creek between U.S. Route 63 and confluence with Turkey Creek
- Turkey Creek
- Lower Bass Creek between U.S. Route 63 and confluence with Turkey Creek
- Fox Hollow Branch

The feasibility of implementing streambank buffers in a subwatershed depends on the distance from the source of pollutants (e.g., animals) to the waterbody and whether vegetation already exists adjacent to the waterbody which can be enhanced for implementation of the practice.

3.7.2.5 On-site wastewater System BMPs

On-site wastewater system BMPs are only suitable for areas with existing on-site wastewater system with documented complaints of failure.

3.7.2.6 Urban BMPs

Urban BMPs are feasible for urban subwatersheds with a significant amount of stormwater runoff from impervious surfaces. Space, soil infiltration feasibility, local hydrology, and stormwater regulatory requirements are some of the major factors that affect the feasibility and design of urban BMPs. Urban areas in the GBFW watershed include the southern part of the City of Columbia, the northern part of the City of Ashland, the Columbia Regional Airport, and the Community of Deer Park along U.S. Route 63.

SECTION 4

RESULTS

This section documents the estimated baseline loading, identified critical areas, recommended BMP strategy and estimated load reduction from the implementation of recommended BMPs in the GBFW.

4.1 Baseline Loads

Baseline unit loads (per unit acre per day or year) were estimated using the two watershed models, STEPL and SELECT, for each subwatershed as described in the following sections.

4.1.1 *E. coli*

The potential sources of *E. coli* load in the GBFW include livestock, wildlife, and failing on-site wastewater systems. Daily *E. coli* unit loads simulated using the SELECT modeling approach are shown in Figure 7 for each subwatershed. The daily *E. coli* unit load ranges from 0 to 8.90 x 10^{13} cfu/per acre/per day. Loading from livestock (specifically cows) constitutes the largest proportion of simulated loads. Failing on-site wastewater and wildlife contribute a small portion of the simulated *E. coli* unit loads. These results are in agreement with the results of MST conducted by Boone County.

4.1.2 Total Nitrogen

TN is commonly found in surface waters and serve as primary nutrient for aquatic species. Major sources that deliver TN to streams within GBFW include runoff from agricultural fields, on-site wastewater systems, urban runoff, and animal agriculture.

Yearly TN unit loads were simulated using the STEPL model and are mapped in Figure 8. The TN unit loads in the GBFW ranges from 1.0 to 51.2 lb/acre/year. The subwatersheds with maximum loading for TN have pastureland and cropland as their dominant landuses. Hence, the greatest reduction in TN nutrient loading would be achieved by implementing BMPs in subwatersheds with a majority of pastureland and cropland.

4.1.3 Total Phosphorus

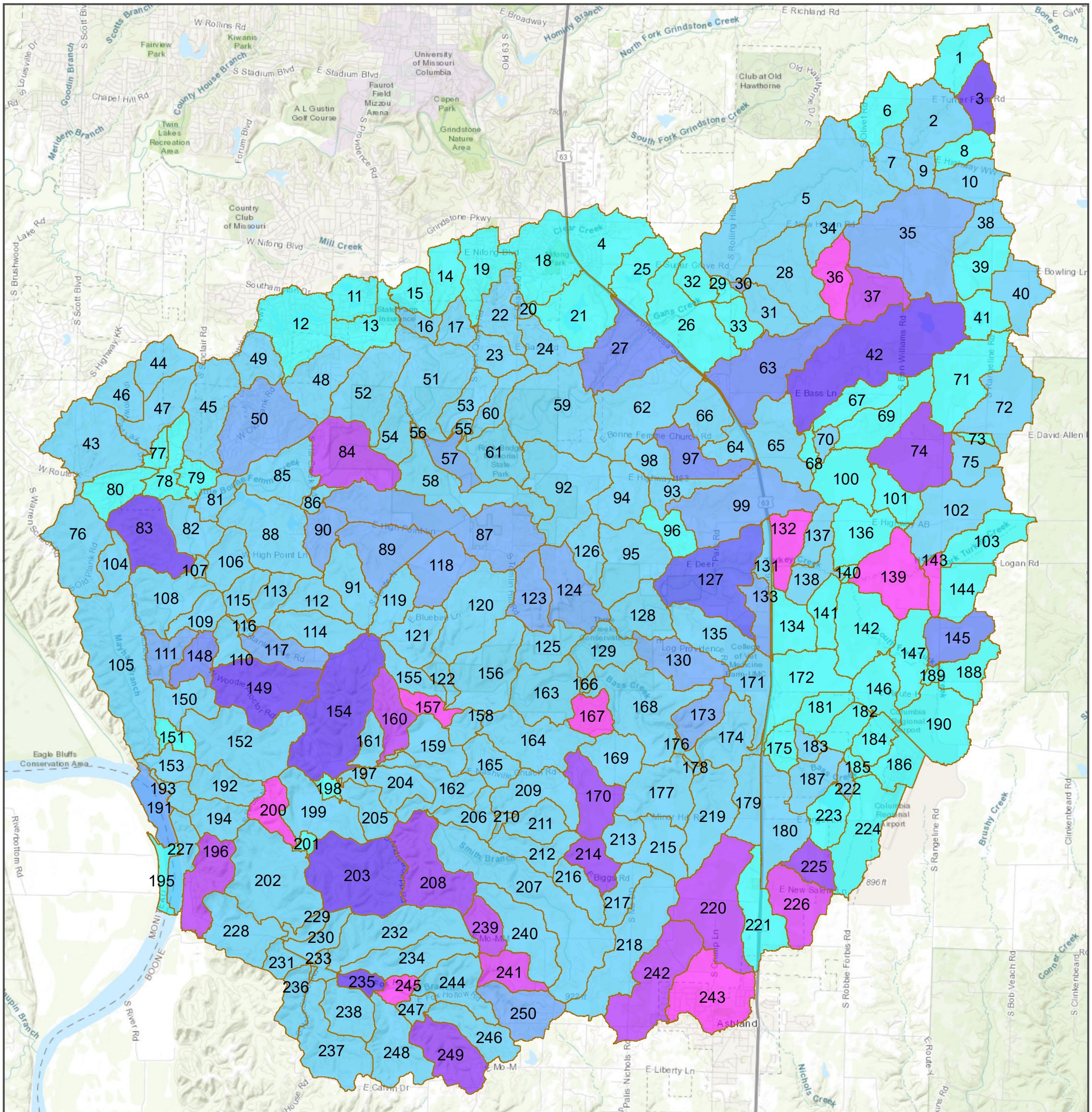
Similar to TN, TP serves as primary nutrient for aquatic species. Major sources that deliver TP to streams within the GBFW include fertilizer lost from croplands, agricultural fields, on-site wastewater systems, urban runoff, and animal agriculture.

Yearly TP unit loads simulated using the STEPL model are mapped in Figure 9. The TP unit loads range from 0.2 to 10.9 lb/acre/year. Similar to TN, the subwatersheds with maximum loading for TP have pastureland and cropland as their dominant landuses.

4.1.4 Total Suspended Solids

Major sources that deliver TSS to streams within GBFW include cultivated areas, and highly impervious land uses such as roads, industrial, residential, and urban areas.

Yearly TSS unit loads simulated using the STEPL model are mapped in Figure 10. The TSS unit loads range from 0.4 to 7.1 tons/acre/year. The figure suggests that the greatest reduction in TSS loss would be achieved by implementing BMPs in watersheds with majority cultivated crop and transportation land use.



Greater Bonne Femme Watershed
Simulated *E. coli* Unit Acre Load

Geosyntec consultants

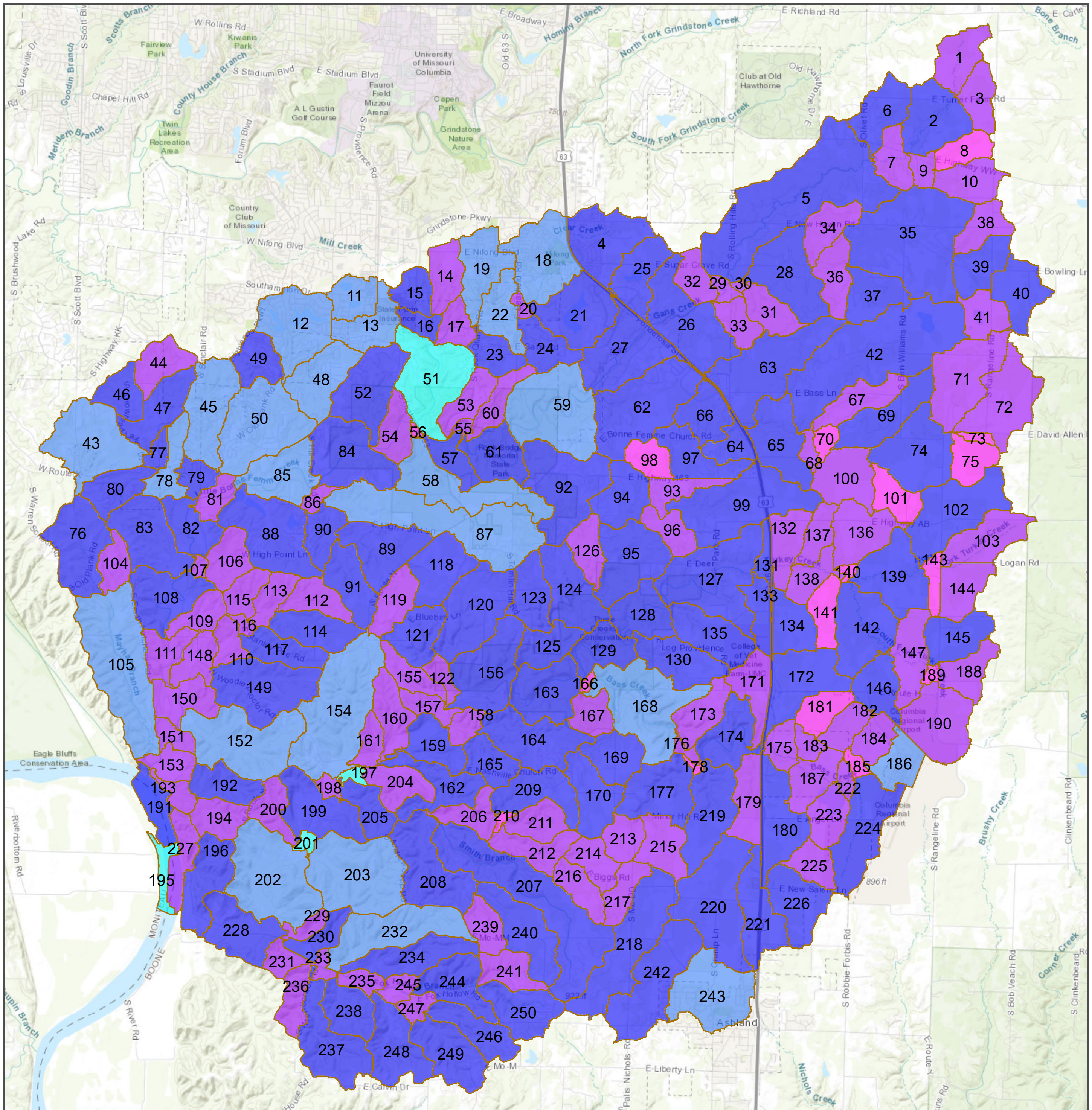
Legend

Subwatersheds	500 - 1,000
E.Coli Load (10^6 cfu/acre/day)	1,000 - 2,000
10	2,000 - 5,000
10 - 50	5,000 - 10,000
50 - 100	10,000 - 20,000
100 - 500	> 20,000

N

0 1 2
Miles

Figure
7



Greater Bonne Femme Watershed
Simulated Total Nitrogen Unit Acre Load

Legend

Subwatersheds

TN Load (lb/acre/yr)

- 0 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- > 40

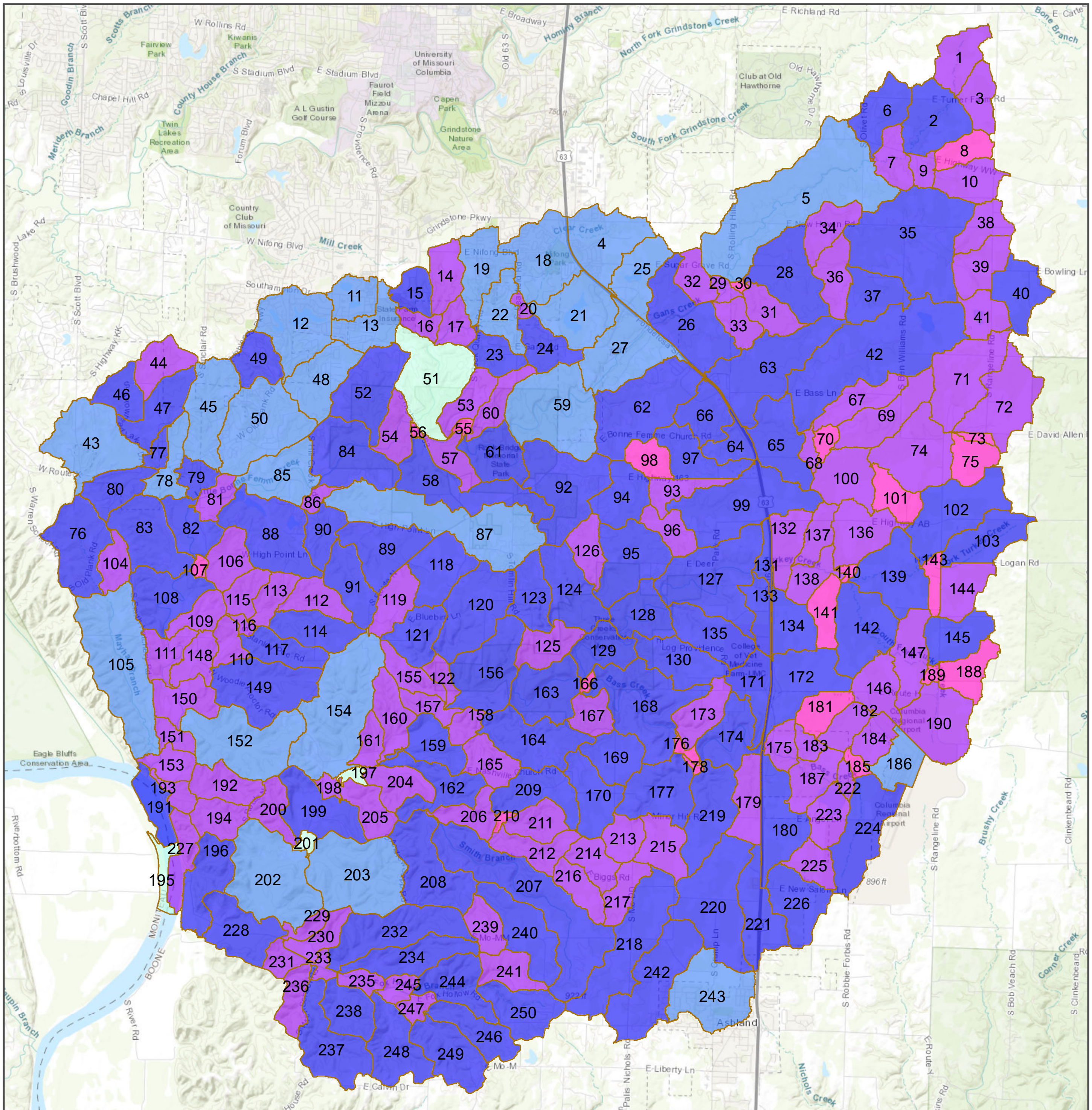
Geosyntec consultants

N

0 1 2
Miles

Figure

8



Greater Bonne Femme Watershed
Simulated Total Phosphorus Unit Acre Load

Geosyntec consultants

Legend

Subwatersheds

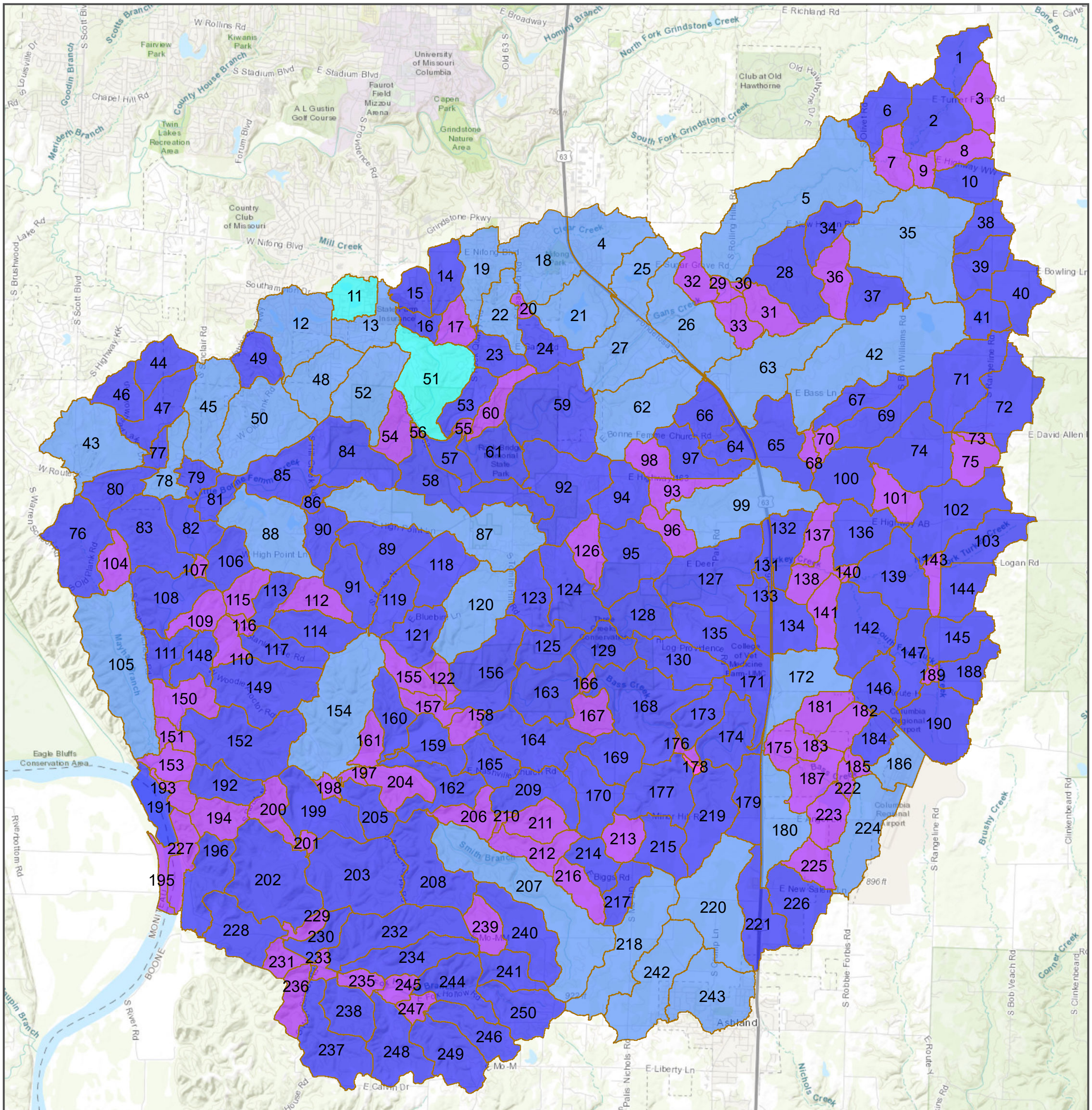
TP Load (lb/acre/yr)

- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- > 8

N

0 1 2
Miles

Figure 9



Greater Bonne Femme Watershed
Simulated Total Suspended Solids Unit Acre Load

Geosyntec consultants

Legend

Subwatersheds

TSS Load (lb/acre/yr)

- 0 - 1
- 1 - 3
- 3 - 5
- 5 - 7
- > 7

N

0 1 2
Miles

Figure

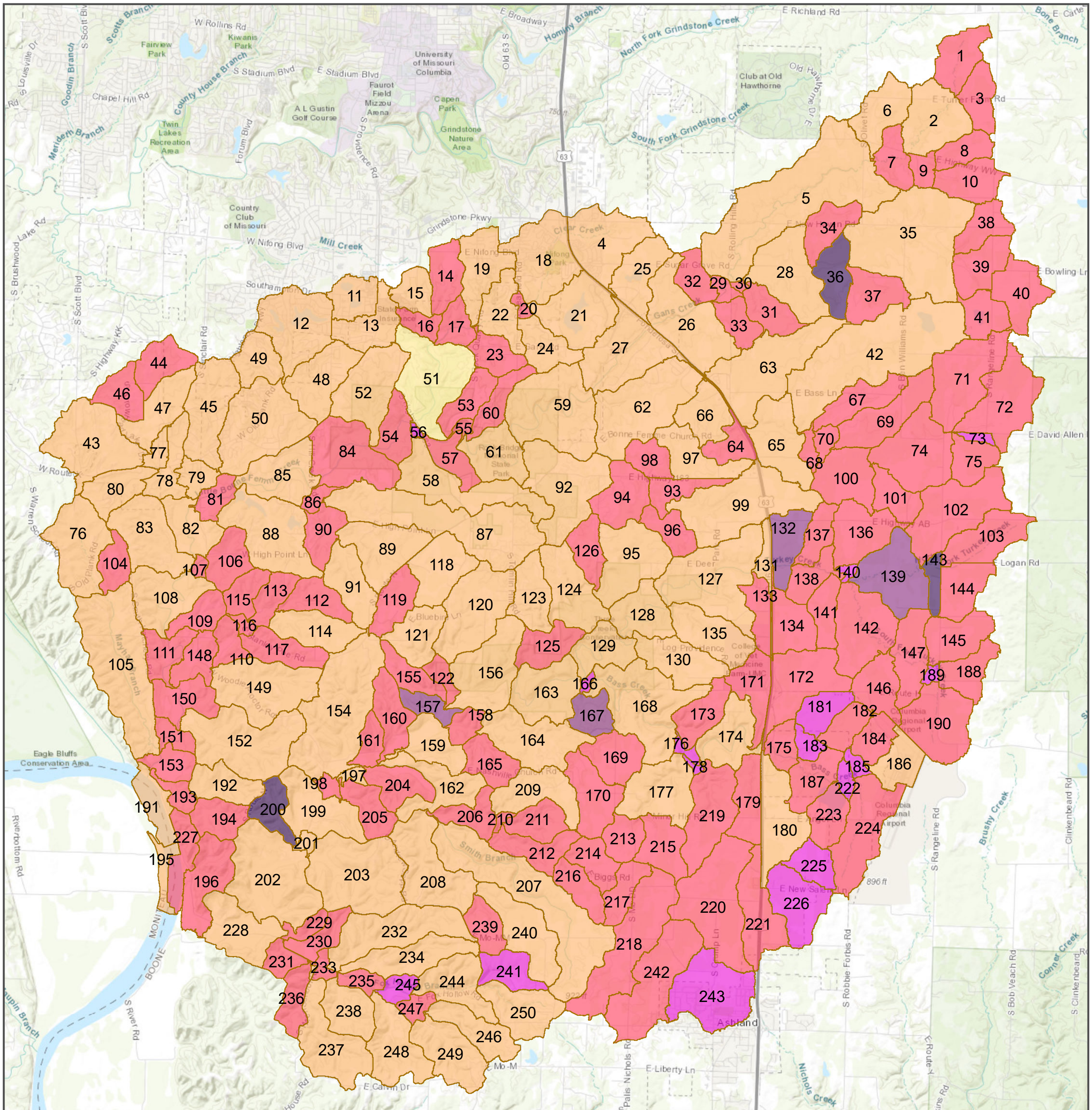
10

4.2 Identified Critical Areas

The CPI was calculated for each subwatershed using the methodology described in Section3.5. The calculated CPIs are shown in Figure 11. The CPI scores range from 1 to 5, and a higher CPI indicates a higher priority for the subwatershed. The subwatershed with the largest CPI score drains to Bass Creek. Twenty-three subwatersheds had CPIs equal to or greater than 3 – these were identified as critical areas for BMP implementation in the GBFW. The POCs for each of the identified critical subwatershed and the downstream impaired stream are shown in Table 6.

Table 6: Pollutants of Concern in Critical Areas

Subwatershed ID	CPI Score**	Downstream Impaired Stream	Pollutant*			
			TN	TP	TSS	*E. coli*
36	5	Gans Cr.	x	x	x	x
56	3	Gans Cr. & L Bonne Femme Cr.	x	x	x	x
73	3	Bonne Femme Cr.	x	x	x	
132	4	Turkey Cr. & Bonne Femme Cr.	x	x	x	x
139	4	N. Fork Turkey Cr.	x	x	x	x
140	3	Turkey Cr. & Bonne Femme Cr.	x	x	x	
143	5	N. Fork Turkey Cr.	x	x	x	x
157	4	Bonne Femme Cr.	x	x	x	x
166	3	Turkey Cr. & Bonne Femme Cr.	x	x	x	x
167	4	Bass Cr.	x	x	x	x
176	3	Bass Cr.	x	x	x	
178	3	Bass Cr.	x	x	x	
181	3	Bass Cr.	x	x	x	
183	3	Bass Cr.	x	x	x	
185	3	Bass Cr.	x	x	x	
189	3	S. Fork Turkey Cr.	x	x	x	
200	5	Bonne Femme Cr.	x	x	x	x
222	3	Bass Cr.	x	x	x	x
225	3	Bass Cr.	x	x	x	x
226	3	Bass Cr.	x	x	x	x
241	3	Fox Hollow Br.	x	x	x	x
243	3	Bass Cr.	x	x	x	x
245	3	Fox Hollow Br.	x	x	x	x
*TN = total nitrogen; TP = total phosphorus; *E. coli* = *Escherichia coli*; TSS = total suspended solids. **CPI = Catchment Prioritization Index (ranges from 1-5)						



Greater Bonne Femme Watershed
Catchment Prioritization Index

Legend

Sub-Catchment

Catchment Prioritization Index

- 0 - Low Priority
- 1
- 2
- 3
- 4
- 5 - High Priority

N

0 1 2

Miles

Figure

11

4.3 Recommended BMP Implementation Strategy

Two categories of BMP implementation are recommended for the critical areas in the GBFW: watershed wide BMPs and site-specific BMPs. Watershed-wide BMPs represent future potential projects that were not specifically identified as part of this project. The BMPs may be implemented anywhere in the watershed at the discretion of Boone County and other stakeholders. Site-specific BMPs are recommended for individual properties, stream segments, forest logging activity areas, or cattle production areas in the subwatersheds. The location of the BMPs and the tributary areas to the BMP which would benefit from the load reduction provided by the BMPs are delineated. Site-specific BMPs are proposed for 10 identified critical subwatersheds.

4.3.1 Watershed Wide BMP Strategy

One BMP type is proposed for each of the 23 identified critical subwatersheds in GBFW identified as critical areas from the loading analysis. A watershed wide BMP of fencing is recommended for subwatershed# 42 in the Upper Bonne Femme watershed (which was not identified as a critical area) to address the *E. coli* impairment and protect the sensitive the Devil's Icebox Cave system from pollutants. The BMP type is selected based on the POC in the subwatershed as shown in Table 7 and the land use distribution of the subwatershed. For this project, load reduction resulting from the proposed watershed wide BMPs were estimated for three implementation milestones

1) 7-Year Implementation Milestone: selected BMPs are implemented at 30% of the applicable land use area or stream length in the subwatershed.

2) 14-Year Implementation Milestone: selected BMPs are implemented at 60% of the applicable land use area or stream length in the subwatershed.

3) 21-Year Implementation Milestone: selected BMPs are implemented at 90% of the applicable land use area or stream length in the subwatershed.

An example watershed BMP for subwatershed# 36 is shown in Figure 12. A watershed-wide BMP practice of fencing along the streambank is recommended for this subwatershed for the cropland land use.

4.3.2 Site-Specific BMPs

In addition to the watershed-wide BMP recommendations, ten site-specific BMPs are also recommended for ten critical subwatersheds in the GBFW. The location of site-specific BMPs is shown in Figure 13. Six of the ten site-specific BMPs are specially targeted at reducing the *E. coli* loading in the identified critical subwatershed. For example, a site-specific BMP practice of streambank buffer is recommended for subwatershed# 36 to reduce the access of livestock to streams and reduce pollutant loading (Figure 12). The details of the site-specific BMP locations are shown in maps in Appendix C and are summarized in Table 8.

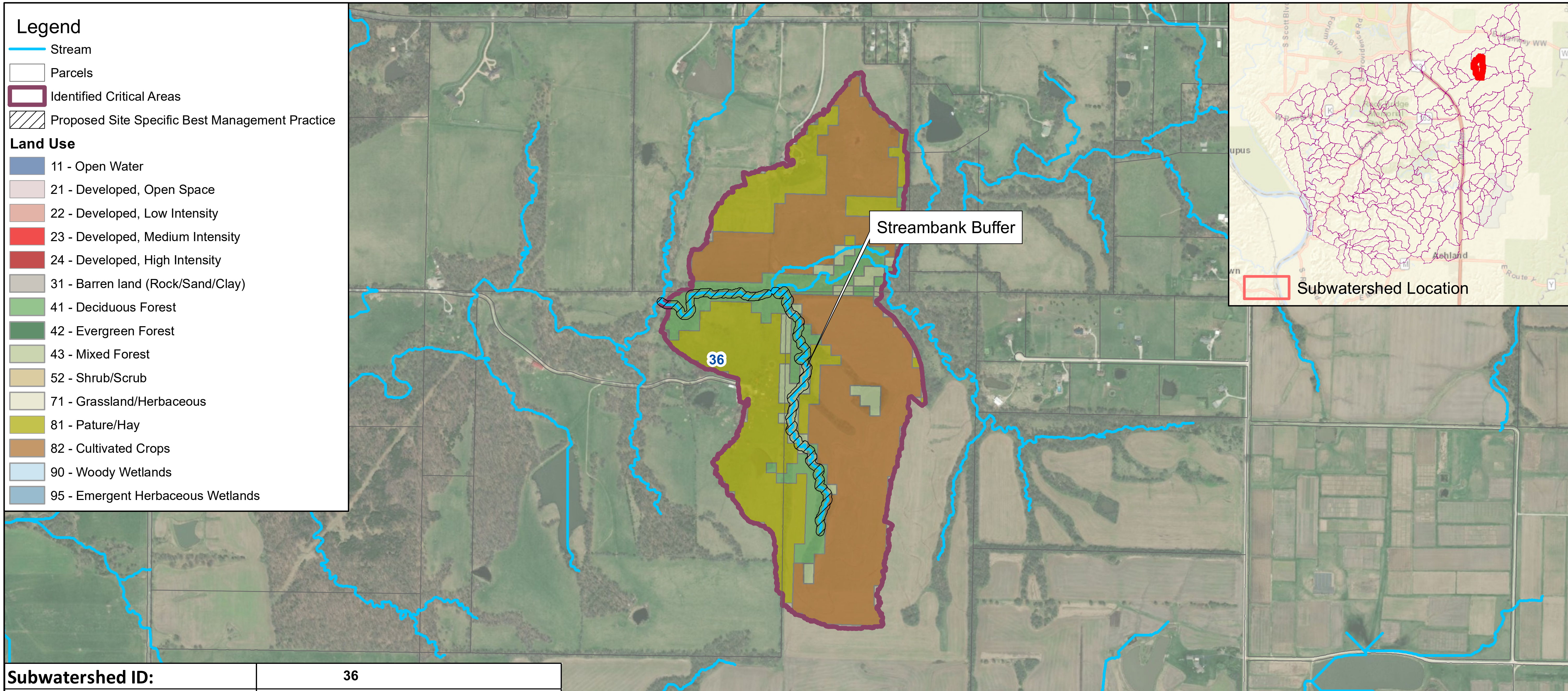
Table 7: Watershed-Wide BMP Recommendations

Subwatershed ID	Watershed-Wide BMP Recommendation	Applicable Land Use
36	Conservation Tillage	Cropland
56	Harvest Planning	Forest
73	Vegetated Buffer	Cropland
132	Grazing Management	Pasture
139	Vegetative filter strip	Pasture
140	Vegetated Buffer	Cropland
143	Vegetative filter strip	Pasture
157	Fencing	Pasture
166	Harvest Planning	Forest
167	Forestry BMPs	Forest
176	Forestry BMPs	Forest
178	Streambank Stabilization	Streambank[1]
181	Conservation Tillage	Cropland
183	Streambank Stabilization	Streambank[1]
185	Retention Pond	Cropland
189	Retention Pond	Cropland
200	Fencing	Pasture
222	Streambank Stabilization	Streambank[1]
225	Conservation Tillage	Cropland
226	Manure Management	Pasture
241	Wetland	Pasture
243	Retention Pond	Urban
245	Grazing Management	Pasture
42[2]	Fencing	Pasture

[1] Streambank stabilization BMPs are implemented in stream segments located in the subwatersheds instead of on a certain type of land use.
[2] Not Identified as a Critical Area

Table 8: Recommended Site-Specific BMPs in the GBFW

Watershed	Site Specific BMP	Recommended Location of Implementation
36	Streambank Buffer	South bank of Gans Creek and west bank of the south branch
73	Cover Crops	Entire cropland area in the watershed
132	Streambank Buffer	North branch of Turkey Creek adjacent to the pastureland
167	Manure Management	Pastureland south of the forest road
178	Forestry BMPs	Majority of the subwatershed where logging activities exist
185	Conservation Tillage	Cropland on the north side of Bass Creek
189	Conservation Tillage	Entire cropland area in the watershed
200	Grazing Management	Animal feeding operation in the northwestern part of the watershed
226	Grazing Management	Pastureland on both sides of the stream can be divided and rotated for animal feeding operations.
243	Fencing	Along the stream bank to the north of the urban area in the City of Ashland



Subwatershed ID:	36	
Tributary Area of:	Gans Cr.	
Pollutant(s) of Concern:	N, P, TSS, EC	
Proposed Site Specific BMP:	Streambank Buffer	
Proposed Site Specific BMP Location:	Pasture	
Tributary Area to Site Specific BMP (Acre):	40.48	
Load Reduction Performance	Load Reduction	Percent Reduction
E. coli (cfu/day)	3.59e+12	49%
Total Nitrogen (lb/yr)	767	11%
Total Phosphorus (lb/yr)	152	10%
Total Suspended Solids (t/yr)	116	12%

Proposed Watershed-wide BMP:	Conservation Tillage	
Proposed Watershed-wide BMP Location:	Cropland	
Tributary Area to Watershed-wide BMP (Acre):	90%	
90% Implementation to Applicable Land Use	Load Reduction	Percent Reduction
E. coli (cfu/day)	0.00e+00	0%
Total Nitrogen (lb/yr)	278	4%
Total Phosphorus (lb/yr)	264	18%
Total Suspended Solids (t/yr)	405306	21%

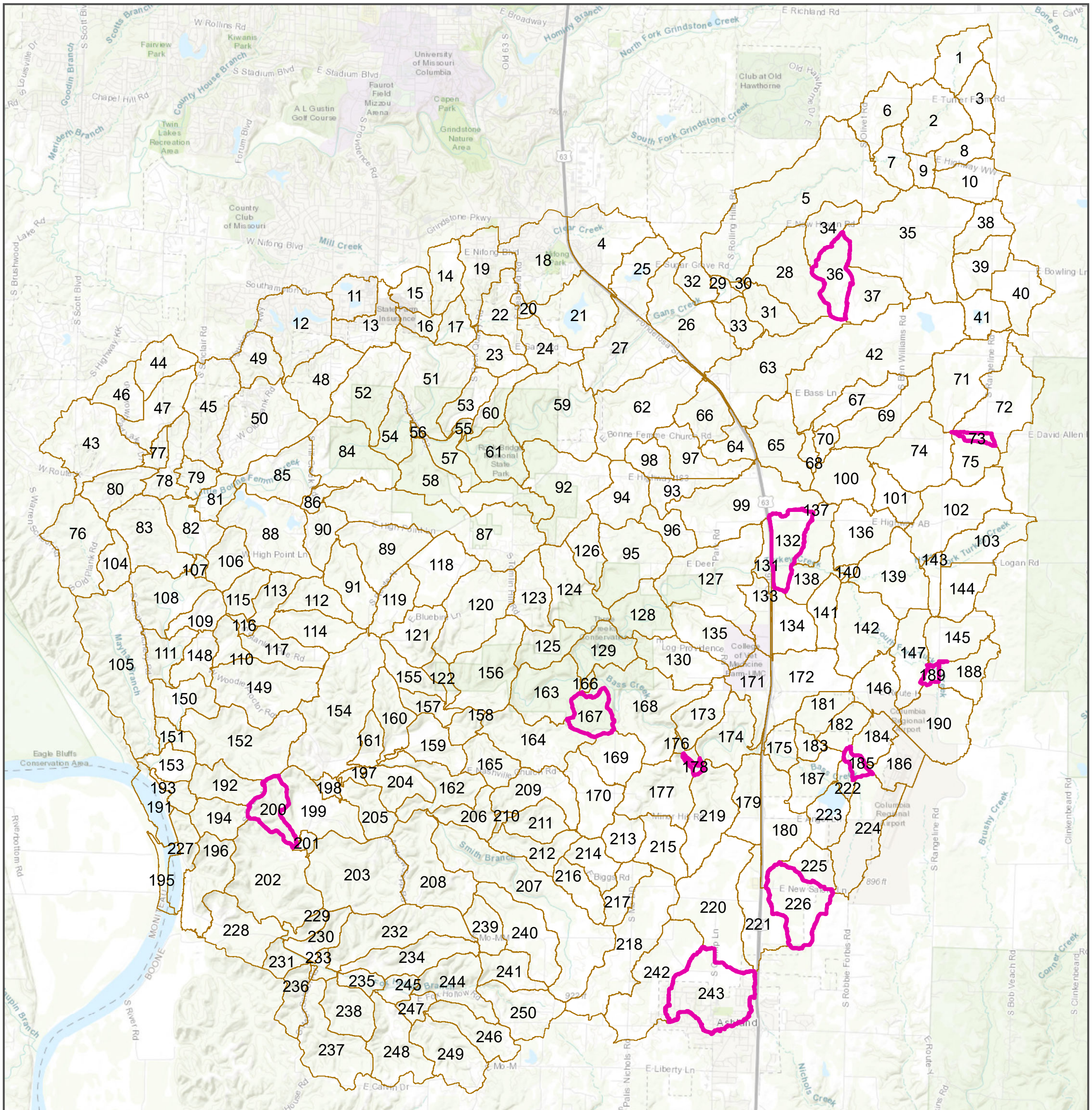
0 0.1 0.2 0.4 Miles

Subwatershed 36
BMP Implementation on Critical Areas in GBFW
Boone County, Missouri

Geosyntec consultants

Figure 12

Chicago 09-Sep-2020



Greater Bonne Femme Watershed
Recommended Site-specific BMPs

Geosyntec consultants

Legend

- Recommened Site-Specific Best Management Practices
- Subwatersheds

N

0 1 2
Miles

Figure 13

4.4 Pollutant Load Reduction Estimation

The pollutant load reductions from the implementation of recommended watershed wide and site-specific BMPs were estimated using the methodology in Section 3.7.

4.4.1 Watershed-Wide BMPs

To estimate the load reduction from watershed wide BMPs for TP, TN and TSS, the loadings from each type of land use in each of the 23 identified critical subwatersheds were extracted from the STEPL models. For each subwatershed, the load reduction from the selected BMP for a POC is calculated using the following equation, with exception of streambank restoration and manure management:

$$Load\ Reduction_{WS,\ POC}$$

$$= BMP\ Removal\ \%_{POC} \times BMP\ Adoption\ \%_{WS} \times Load\ from\ Applicable\ Land\ Use_{WS,POC}$$

Where ***WS*** is the subwatershed ID;

POC is the pollutant of concern (TP, TN or TSS);

BMP Removal % $_{POC}$ is the load reduction efficiency of the BMP for a certain type of POC from Table 5;

BMP Adoption % $_{WS}$ is the percent of the applicable land use in the area that implements the watershed-wide BMP; and

Load from Applicable Land Use $_{WS,\ POC}$ is the total loading of a certain type of POC in a type of land use where the watershed wide BMPs would be implemented.

Streambank stabilization is implemented at the stream waterbody instead of on a certain type of land use. To estimate the load reduction from streambank restoration, the length of streambank that is proposed to be restored in the subwatershed is multiplied by the unit-length POC load removal rates of implementing streambank restoration.

Manure management reduces TN and TP loading by eliminating the source of these POCs in the animal waste. As a result, the load reduction resulting from manure management is a function of the percentage of manure removed from the feedlot and it is not estimated in this project.

To estimate the load reduction from watershed wide BMPs for *E. coli*, the loading in each subwatershed is extracted from the *E. coli* loading model. Based on the result of the *E. coli* model, the largest proportion of the *E. coli* loading in the GBFW is from animals instead of from a specific type of land use. For each subwatershed, the load reduction for *E. coli* is calculated by multiplying the total *E. coli* load by the removal rate of the selected BMP in Table 5.

Table 9, 10 and 11 summarize the load reduction and percent load reduction from watershed wide BMPs for each POC in each subwatershed in the GBFW that was identified as a critical area under three levels of BMP implementation as described in Section 4.3.1.

Table 9: Watershed-Wide BMPs Load Reduction Summary in 30% Implementation Scenario (7-Year Implementation Milestone)

Subwatershed	Recommended Watershed-Wide BMP	Applicable Land Use	Area/Stream Length with BMP Implemented (Acres/Linear Feet)	*E. coli*		TN		TP		TSS	
				Load Reduction (cfu/day)	Percent Reduction	Load Reduction (lb/yr)	Percent Reduction	Load Reduction (lb/yr)	Percent Reduction	Load Reduction (lb/yr)	Percent Reduction
36	Conservation Tillage	Cropland	28	0.00E+00	0%	93	1%	88	6%	135,102	7%
42	Fencing	Pasture	120	1.90E+11	10%	936	4%	199	4%	376,356	7%
56	Harvest Planning	Forest	3	0.00E+00	0%	114	26%	24	26%	39,012	27%
73	Vegetated Buffer	Cropland	6	0.00E+00	0%	341	27%	74	27%	84,220	26%
132	Grazing Management	Pasture	29	5.50E+11	9%	88	1%	46	4%	88,048	5%
139	Vegetated Filter Strip	Pasture	49	1.93E+12	21%	1391	14%	236	12%	330,607	14%
140	Vegetated Buffer	Cropland	3	0.00E+00	0%	166	17%	36	17%	41,360	15%
143	Vegetated Filter Strip	Pasture	9	4.45E+11	21%	393	13%	72	12%	107,243	14%
157	Fencing	Pasture	12	2.51E+11	11%	474	14%	87	12%	128,132	12%
166	Harvest Planning	Forest	5	0.00E+00	0%	192	30%	41	30%	65,825	30%
167	Forestry BMPs	Forest	35	0.00E+00	0%	587	14%	203	23%	226,705	17%
176	Forestry BMPs	Forest	9	0.00E+00	0%	171	16%	59	25%	66,585	18%
178	Streambank Stabilization[1]	N/A	559	0.00E+00	0%	42	7%	38	30%	138,643	69%
181	Conservation Tillage	Cropland	34	0.00E+00	0%	124	2%	118	9%	168,364	11%
183	Streambank Stabilization[1]	N/A	997	0.00E+00	0%	75	3%	68	14%	247,283	34%
185	Retention Pond	Cropland	5	0.00E+00	0%	127	7%	28	8%	30,902	7%
189	Retention Pond	Cropland	4	0.00E+00	0%	225	19%	49	20%	55,717	18%
200	Fencing	Pasture	5	7.44E+11	11%	195	4%	35	4%	52,119	4%
222	Streambank Stabilization[1]	N/A	733	0.00E+00	0%	55	3%	50	14%	181,751	33%
225	Conservation Tillage	Cropland	12	0.00E+00	0%	42	1%	40	4%	61,742	4%
226	Manure Management	Pasture	56	*E. coli*, TN and TP load reduction based on the percent of manure removed from the pastureland.							
241	Wetlands	Pasture	17	6.06E+11	23%	668	13%	121	12%	178,197	11%
243	Retention Pond	Urban	73	0.00E+00	0%	278	4%	48	4%	13,101	1%
245	Grazing Management	Pasture	9	1.66E+11	9%	332	13%	65	13%	100,943	13%

[1] Streambank stabilization implementation level in a watershed is based on the linear feet of stream in the watershed where streambank restoration projects are implemented, instead of acres of land.

Table 10: Watershed-Wide BMPs Load Reduction Summary in 60% Implementation Scenario (14-Year Implementation Milestone)

Subwatershed	Recommended Watershed-Wide BMP	Applicable Land Use	Area/Stream Length with BMP Implemented (Acres/Linear Feet)	*E. coli*		TN		TP		TSS	
				Load Reduction (cfu/day)	Percent Reduction	Load Reduction (lb/yr)	Percent Reduction	Load Reduction (lb/yr)	Percent Reduction	Load Reduction (lb/yr)	Percent Reduction
36	Conservation Tillage	Cropland	56	0.00E+00	0%	186	2%	176	12%	270,204	14%
42	Fencing	Pasture	240	3.80E+11	20%	1872	8%	398	8%	752,712	14%
56	Harvest Planning	Forest	5	0.00E+00	0%	228	53%	49	53%	78,025	53%
73	Vegetated Buffer	Cropland	13	0.00E+00	0%	681	53%	148	54%	168,440	52%
132	Grazing Management	Pasture	58	1.10E+12	18%	176	2%	92	8%	176,096	10%
139	Vegetated Filter Strip	Pasture	98	3.87E+12	42%	2782	28%	472	24%	661,214	28%
140	Vegetated Buffer	Cropland	6	0.00E+00	0%	332	35%	72	35%	82,720	30%
143	Vegetated Filter Strip	Pasture	19	8.90E+11	42%	786	27%	144	24%	214,486	27%
157	Fencing	Pasture	23	5.03E+11	21%	948	27%	173	25%	256,263	24%
166	Harvest Planning	Forest	9	0.00E+00	0%	383	59%	82	59%	131,649	59%
167	Forestry BMPs	Forest	70	0.00E+00	0%	1174	28%	406	46%	453,410	34%
176	Forestry BMPs	Forest	18	0.00E+00	0%	342	32%	118	50%	133,170	36%
178	Streambank Stabilization[1]	N/A	1118	0.00E+00	0%	84	14%	76	60%	277,286	>100%[2]
181	Conservation Tillage	Cropland	68	0.00E+00	0%	248	4%	236	18%	336,728	22%
183	Streambank Stabilization[1]	N/A	1994	0.00E+00	0%	150	6%	136	28%	494,566	68%
185	Retention Pond	Cropland	10	0.00E+00	0%	254	14%	56	16%	61,804	14%
189	Retention Pond	Cropland	8	0.00E+00	0%	450	37%	98	39%	111,434	35%
200	Fencing	Pasture	10	1.49E+12	21%	390	9%	71	8%	104,238	7%
222	Streambank Stabilization[1]	N/A	1466	0.00E+00	0%	110	6%	100	28%	363,502	66%
225	Conservation Tillage	Cropland	24	0.00E+00	0%	84	2%	80	8%	123,484	8%
226	Manure Management	Pasture	112	*E. coli*, TN and TP load reduction based on the percent of manure removed from the pastureland.							
241	Wetlands	Pasture	34	1.21E+12	47%	1336	26%	242	24%	356,394	23%
243	Retention Pond	Urban	146	0.00E+00	0%	556	8%	96	8%	26,202	2%
245	Grazing Management	Pasture	18	3.31E+11	18%	664	27%	130	26%	201,887	25%

[1] Streambank stabilization implementation level in a watershed is based on the linear feet of stream in the watershed where streambank restoration projects are implemented, instead of acres of land.
[2] Load reduction from streambank stabilization is calculated based on the length of streambank. The BMP adoption percentage is the ratio of stream length that would be restored in the subwatershed over the total length of stream length in the watershed. Since the load reduction is not calculated based on the existing loading in the subwatershed, streambank restoration BMPs may result in >100% load reduction.

Table 11: Watershed-Wide BMPs Load Reduction Summary in 90% Implementation Scenario (21-Year Implementation Milestone)

Subwatershed	Recommended Watershed-Wide BMP	Applicable Land Use	Area/Stream Length with BMP Implemented (Acres/Linear Feet)	*E. coli*		TN		TP		TSS	
				Load Reduction (cfu/day)	Percent Reduction	Load Reduction (lb/yr)	Percent Reduction	Load Reduction (lb/yr)	Percent Reduction	Load Reduction (lb/yr)	Percent Reduction
36	Conservation Tillage	Cropland	112	0.00E+00	0%	279	3%	264	18%	405,306	21%
42	Fencing	Pasture	480	5.70E+11	30%	2808	12%	597	12%	1,129,068	21%
56	Harvest Planning	Forest	11	0.00E+00	0%	342	79%	73	79%	117,037	80%
73	Vegetated Buffer	Cropland	26	0.00E+00	0%	1022	80%	222	81%	252,660	79%
132	Grazing Management	Pasture	116	1.65E+12	27%	264	3%	138	12%	264,144	15%
139	Vegetated Filter Strip	Pasture	195	5.80E+12	63%	4174	41%	708	36%	991,821	41%
140	Vegetated Buffer	Cropland	12	0.00E+00	0%	498	52%	108	52%	124,080	45%
143	Vegetated Filter Strip	Pasture	37	1.34E+12	63%	1180	40%	217	37%	321,729	41%
157	Fencing	Pasture	46	7.54E+11	32%	1422	41%	260	37%	384,395	36%
166	Harvest Planning	Forest	19	0.00E+00	0%	575	89%	123	89%	197,474	89%
167	Forestry BMPs	Forest	140	0.00E+00	0%	1761	42%	609	69%	680,115	51%
176	Forestry BMPs	Forest	36	0.00E+00	0%	513	48%	177	75%	199,755	54%
178	Streambank Stabilization[1]	N/A	2236	0.00E+00	0%	126	21%	114	90%	415,929	>100%[2]
181	Conservation Tillage	Cropland	136	0.00E+00	0%	372	6%	354	27%	505,092	33%
183	Streambank Stabilization[1]	N/A	3988	0.00E+00	0%	225	9%	204	42%	741,849	>100%[2]
185	Retention Pond	Cropland	20	0.00E+00	0%	381	21%	84	24%	92,706	21%
189	Retention Pond	Cropland	17	0.00E+00	0%	675	56%	147	59%	167,151	53%
200	Fencing	Pasture	20	2.23E+12	32%	585	13%	106	11%	156,358	11%
222	Streambank Stabilization[1]	N/A	2932	0.00E+00	0%	165	9%	150	42%	545,253	99%
225	Conservation Tillage	Cropland	48	0.00E+00	0%	126	3%	120	12%	185,226	12%
226	Manure Management	Pasture	224	*E. coli*, TN and TP load reduction based on the percent of manure removed from the pastureland.							
241	Wetlands	Pasture	68	1.82E+12	70%	2005	39%	363	36%	534,591	34%
243	Retention Pond	Urban	292	0.00E+00	0%	834	12%	144	12%	39,303	3%
245	Grazing Management	Pasture	35	4.97E+11	27%	996	40%	195	38%	302,830	38%

[1] Streambank stabilization implementation level in a watershed is based on the linear feet of stream in the watershed where streambank restoration projects are implemented, instead of acres of land.
[2] Load reduction from streambank stabilization is calculated based on the length of streambank. The BMP adoption percentage is the ratio of stream length that would be restored in the subwatershed over the total length of stream length in the watershed. Since the load reduction is not calculated based on the existing loading in the subwatershed, streambank restoration BMPs may result in >100% load reduction.

4.4.2 Load Reduction Effectiveness for Site-Specific BMPs

The load reduction for TN, TP, and TSS from site-specific BMPs are calculated using the STEPL models. The BMP removal rate from Table 5 and estimated land use area treated by the BMP were used as inputs into the STEPL models. The result from the existing condition STEPL models and the STEPL models with site-specific BMP implementation are compared to estimate the load reduction resulting from the ten site-specific BMPs.

The *E. coli* load reduction from site-specific BMPs are calculated using the same methodology as the load reduction calculation for the watershed wide BMPs as presented in Section 4.4.1.

Table 12 summarizes the load reduction and percent load reduction from site-specific BMPs for each POC in each subwatershed in the GBFW that was identified as critical area.

4.4.3 Compliance with Water Quality Standards

MDNR required demonstration of compliance with instream water quality standards (WQS) for *E. coli* through the implementation of recommended BMPs in the watershed plan. MDNR had calculated load duration curves (LDCs) for *E. coli* using the estimated flow and measured *E. coli* concentration for the impaired streams in the GBFW (MDNR, 2020). MDNR recommended comparing the LDC values at WQS with estimated load reduction post-BMP implementation to demonstrate compliance with WQS. However, this approach was not valid for the current analysis because of following reasons

- The LDC was calculated using estimated flows from two reference watersheds. A comparison of measured flows by Boone County and MDNR estimated flows for the GBFW streams showed that flows are underpredicted by this method, sometimes even by an order of magnitude of 2.
- The existing daily loads calculated using the LDC methodology and the SELECT model differ by an order of magnitude of 2. The difference of two-order of magnitude between existing load calculated by LDC methodology and SELECT model can be explained by the fact that LDC method uses underpredicted flows.
- The existing load calculated by LDC and SELECT methodology differ by an order of magnitude of 2, hence, it would not be fair to compare the load duration value at WQS and estimated load post BMP reduction

A comparison of target load reduction from MDNR LDCs with estimated load reduction for all the impaired WBIDs was made to demonstrate compliance with WQS through the implementation of proposed BMPs in the GBFW. The target load reduction was calculated based on the difference between the existing load and loading capacity under the flow condition with the greatest load exceedance in the LDC. This approach was discussed with MDNR and subsequently approved. (per Boone County's email correspondence with Mike Kruse, MDNR TMDL Unit Chief on September 11, 2020).The estimated load reduction for the recommended BMPs is about two orders of magnitude greater than the target load reduction (Table 13). This analysis shows that WQS for *E. coli* will likely be met over time through the implementation of recommended BMPs in the GBFW.

Table 12: Site-Specific BMPs Load Reduction Summary

Subwatershed	Proposed Site-Specific BMPs	Applicable Land Use	BMP Tributary Area (Acres)	*E. coli*		TN		TP		TSS	
				Load Reduction (cfu/day)	Percent Reduction	Load Reduction (lb/yr)	Percent Reduction	Load Reduction (lb/yr)	Percent Reduction	Load Reduction (lb/yr)	Percent Reduction
36	Streambank Buffer	Pasture	40.48	3.6E+12	49%	767	11%	152	10%	116	12%
73	Cover Crops	Cropland	21.35	0.0E+00	0%	153	12%	22	8%	14	9%
132	Streambank Buffer	Pasture	28.76	1.3E+12	21%	520	8%	105	8%	82	9%
167	Manure Management	Pasture	N/A	*E. coli*, TN and TP load reduction based on the percent of manure removed from the pastureland.							
178	Forestry BMP	Forest	14.01	0.0E+00	0%	345	59%	74	59%	59	59%
185	Conservation Tillage	Cropland	8.23	0.0E+00	0%	150	9%	40	11%	24	10%
189	Conservation Tillage	Cropland	14.01	0.0E+00	0%	270	23%	70	29%	44	28%
200	Grazing Management	Pasture	16.46	2.1E+12	30%	164	4%	35	4%	26	4%
226	Grazing Management	Pasture	92.52	1.7E+12	30%	625	8%	132	9%	98	10%
243	Fencing	Pasture	39.36	3.3E+12	35%	179	2%	33	2%	24	4%

Table 13: Comparison of Target Load Reduction with Estimated Load Reduction for E. coli through the implementation of recommended BMPs

WBID	WB Name	Target Load Reduction, cfu/day	Scenario	Estimated Load Reduction, cfu/day
750	Bonne Femme Cr.	1.89E+10	Site Specific BMP + 30% Implementation of Watershed Wide BMP	1.33E+1313
			Site Specific BMP + 60% Implementation of Watershed Wide BMP	1.82E+1313
			Site Specific BMP + 90% Implementation of Watershed Wide BMP	2.31E+1313
751	Turkey Cr.	3.06E+10	Site Specific BMP + 30% Implementation of Watershed Wide BMP	4.23E+12
			Site Specific BMP + 60% Implementation of Watershed Wide BMP	7.16E+12
			Site Specific BMP + 90% Implementation of Watershed Wide BMP	1.01E+1313
752	Bass Cr.	1.52E+11	Site Specific BMP + 30% Implementation of Watershed Wide BMP	5.00E+12
			Site Specific BMP + 60% Implementation of Watershed Wide BMP	5.00E+12
			Site Specific BMP + 90% Implementation of Watershed Wide BMP	5.00E+12
1003	Little Bonne Femme Cr.	2.66E+12	Site Specific BMP + 30% Implementation of Watershed Wide BMP	3.60E+12
			Site Specific BMP + 60% Implementation of Watershed Wide BMP	3.60E+12
			Site Specific BMP + 90% Implementation of Watershed Wide BMP	3.60E+12
1004	Gans Cr.	2.70E+10	Site Specific BMP + 30% Implementation of Watershed Wide BMP	3.60E+12
			Site Specific BMP + 60% Implementation of Watershed Wide BMP	3.60E+12
			Site Specific BMP + 90% Implementation of Watershed Wide BMP	3.60E+12
753	Bonne Femme Cr. (Upper)	2.14E+09	Site Specific BMP + 30% Implementation of Watershed Wide BMP	1.93E+11
			Site Specific BMP + 60% Implementation of Watershed Wide BMP	3.87E+11
			Site Specific BMP + 90% Implementation of Watershed Wide BMP	5.80E+11

SECTION 5

SUMMARY

Geosyntec developed a watershed model for the GBFW to estimate TN, TP, TSS, and *E. coli* average annual loads in 250 subwatersheds. The loads for TN, TP, and TSS were estimated using STEPL and loads for *E. coli* were estimated using the SELECT methodology. The estimated loading per unit acre was used to calculate a CPI. Subwatersheds with a CPI of three or higher were identified as critical areas for a BMP implementation. A BMP implementation strategy consisting of watershed wide and site-specific BMPs was recommended based on the POCs and landuses in the critical subwatersheds. The watershed BMPs are recommended to be implemented over a 21-year period with two interim milestones. Pollutant load reductions were estimated for the recommended BMPs in the GBFW. These recommended BMPs would serve to eliminate the *E. coli* impairments in the GBFW streams and be protective of the existing condition for nutrients and TSS in the affected subwatersheds.

SECTION 6

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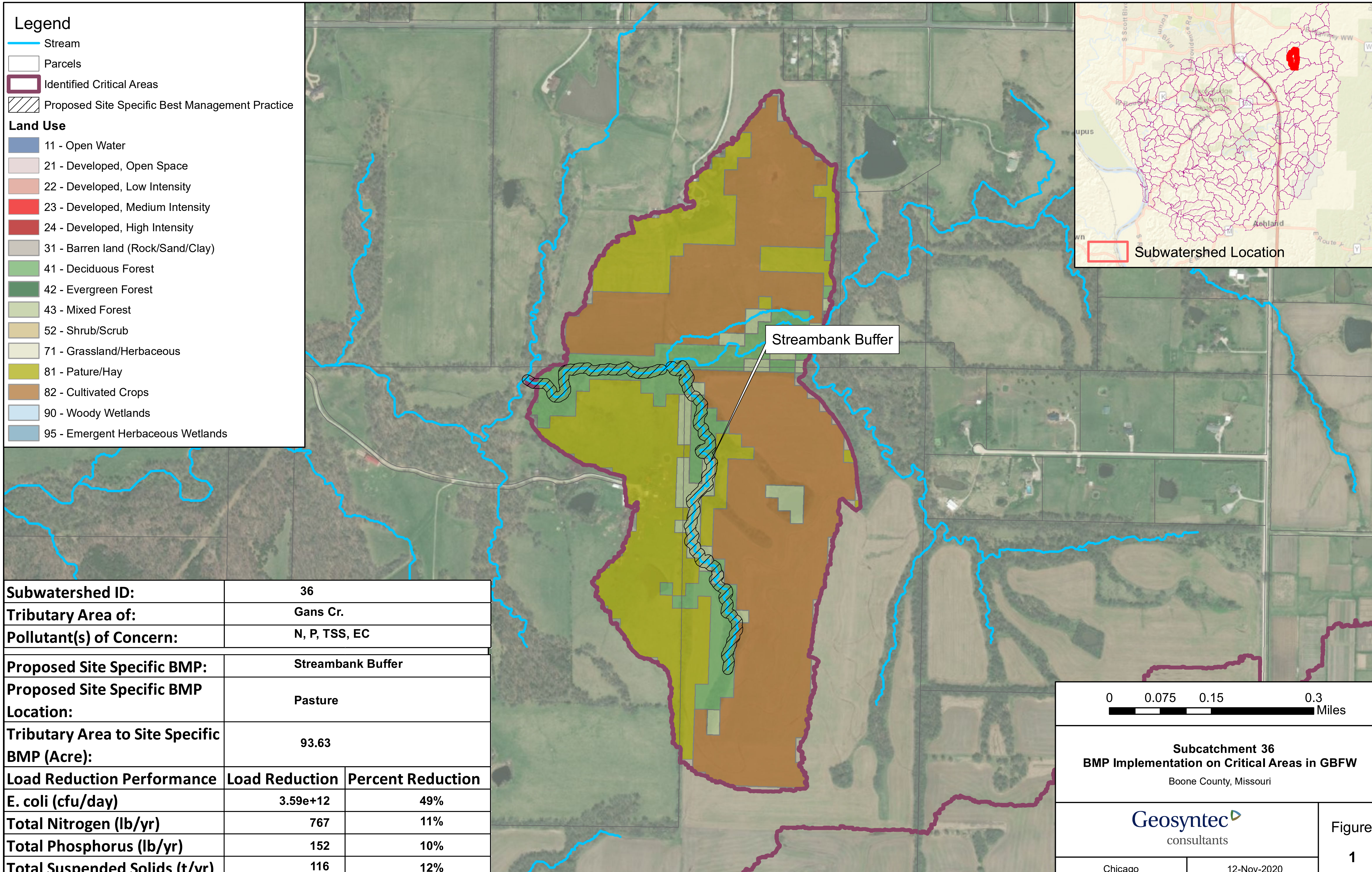
APPENDIX A: ELECTRONIC FILES FOR MODEL INPUTS AND STEPL MODELS

APPENDIX B: ELECTRONIC FILE FOR *E. COLI* MODEL

APPENDIX C: SITE-SPECIFIC BMPS



Subwatershed ID:	36
Tributary Area of:	Gans Cr.
Pollutant(s) of Concern:	N, P, TSS, EC

Proposed Site Specific BMP:	Streambank Buffer
Proposed Site Specific BMP Location:	Pasture
Tributary Area to Site Specific BMP (Acre):	93.63

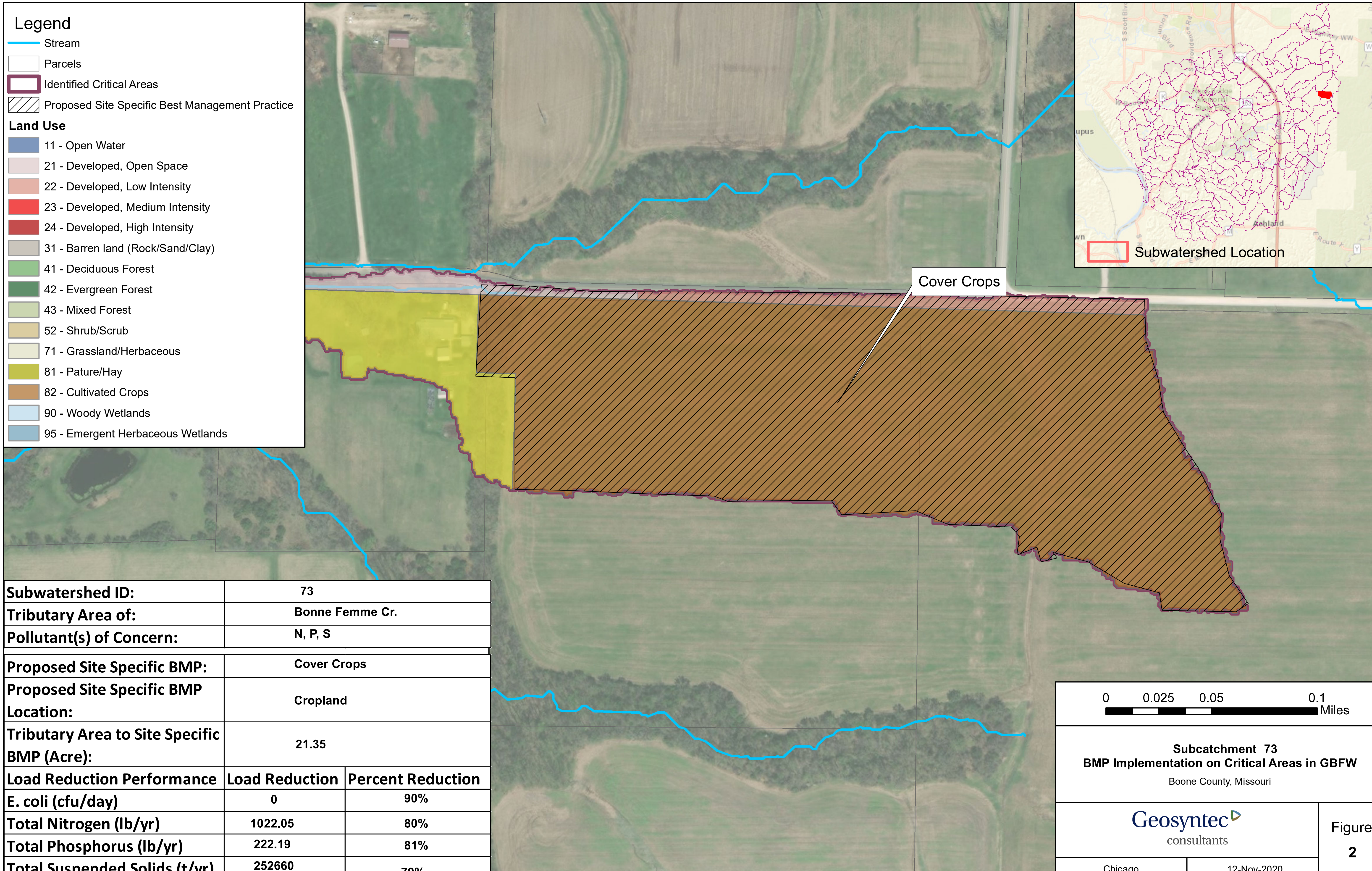
Load Reduction Performance	Load Reduction	Percent Reduction
E. coli (cfu/day)	3.59e+12	49%
Total Nitrogen (lb/yr)	767	11%
Total Phosphorus (lb/yr)	152	10%
Total Suspended Solids (t/yr)	116	12%

Subcatchment 36
BMP Implementation on Critical Areas in GBFW
Boone County, Missouri

Geosyntec consultants

Chicago | 12-Nov-2020

Figure 1



Subwatershed ID:	73	
Tributary Area of:	Bonne Femme Cr.	
Pollutant(s) of Concern:	N, P, S	
Proposed Site Specific BMP:	Cover Crops	
Proposed Site Specific BMP Location:	Cropland	
Tributary Area to Site Specific BMP (Acre):	21.35	
Load Reduction Performance	Load Reduction	Percent Reduction
E. coli (cfu/day)	0	90%
Total Nitrogen (lb/yr)	1022.05	80%
Total Phosphorus (lb/yr)	222.19	81%
Total Suspended Solids (t/yr)	252660	79%

Subcatchment 73
BMP Implementation on Critical Areas in GBFW
Boone County, Missouri

Geosyntec consultants

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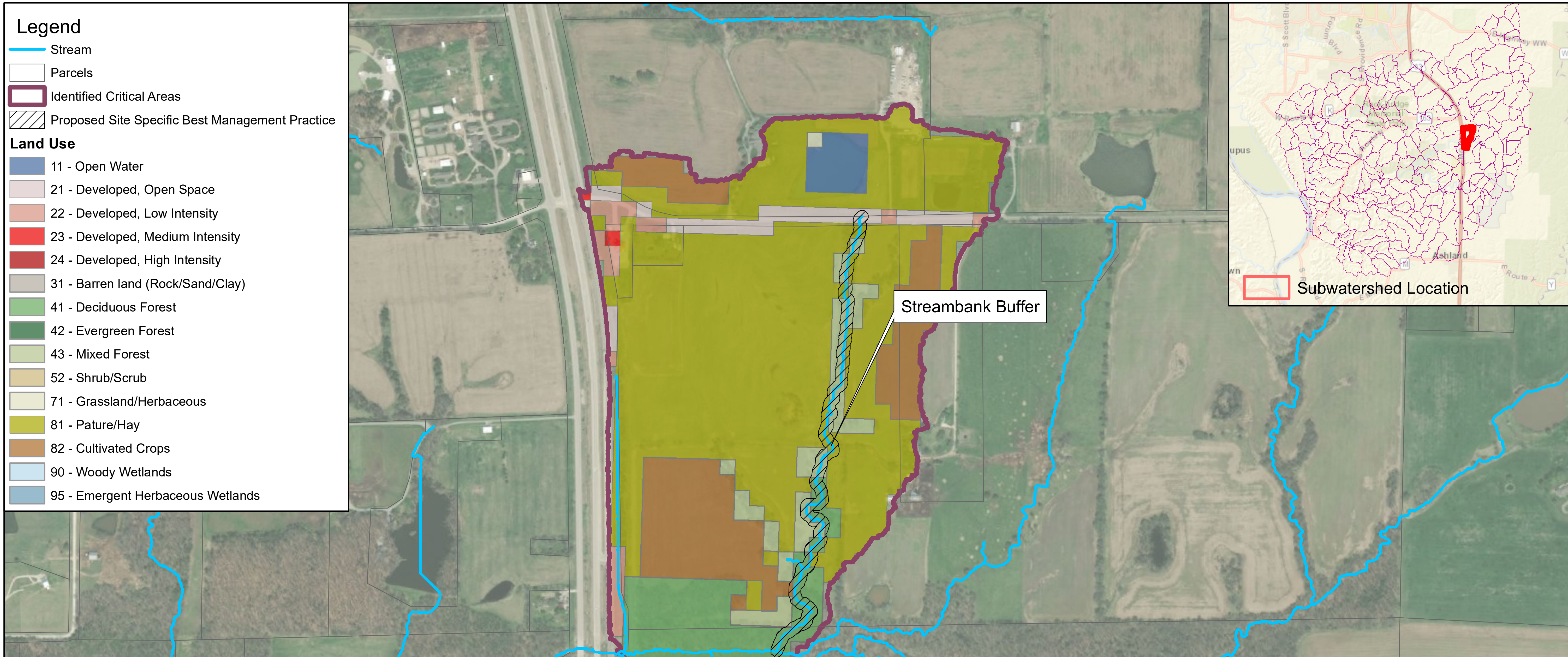
Figure 2



Subwatershed ID:	132
Tributary Area of:	Turkey Cr. & Bonne Femme Cr.
Pollutant(s) of Concern:	N, P, TSS, EC

Proposed Site Specific BMP:	Streambank Buffer	
Proposed Site Specific BMP Location:	Pasture	
Tributary Area to Site Specific BMP (Acre):	95.85	
Load Reduction Performance	**Load Reduction**	**Percent Reduction**
E. coli (cfu/day)	1.28e+12	21%
Total Nitrogen (lb/yr)	520	8%
Total Phosphorus (lb/yr)	105	8%
Total Suspended Solids (t/yr)	82	9%

Subcatchment 132
BMP Implementation on Critical Areas in GBFW
Boone County, Missouri

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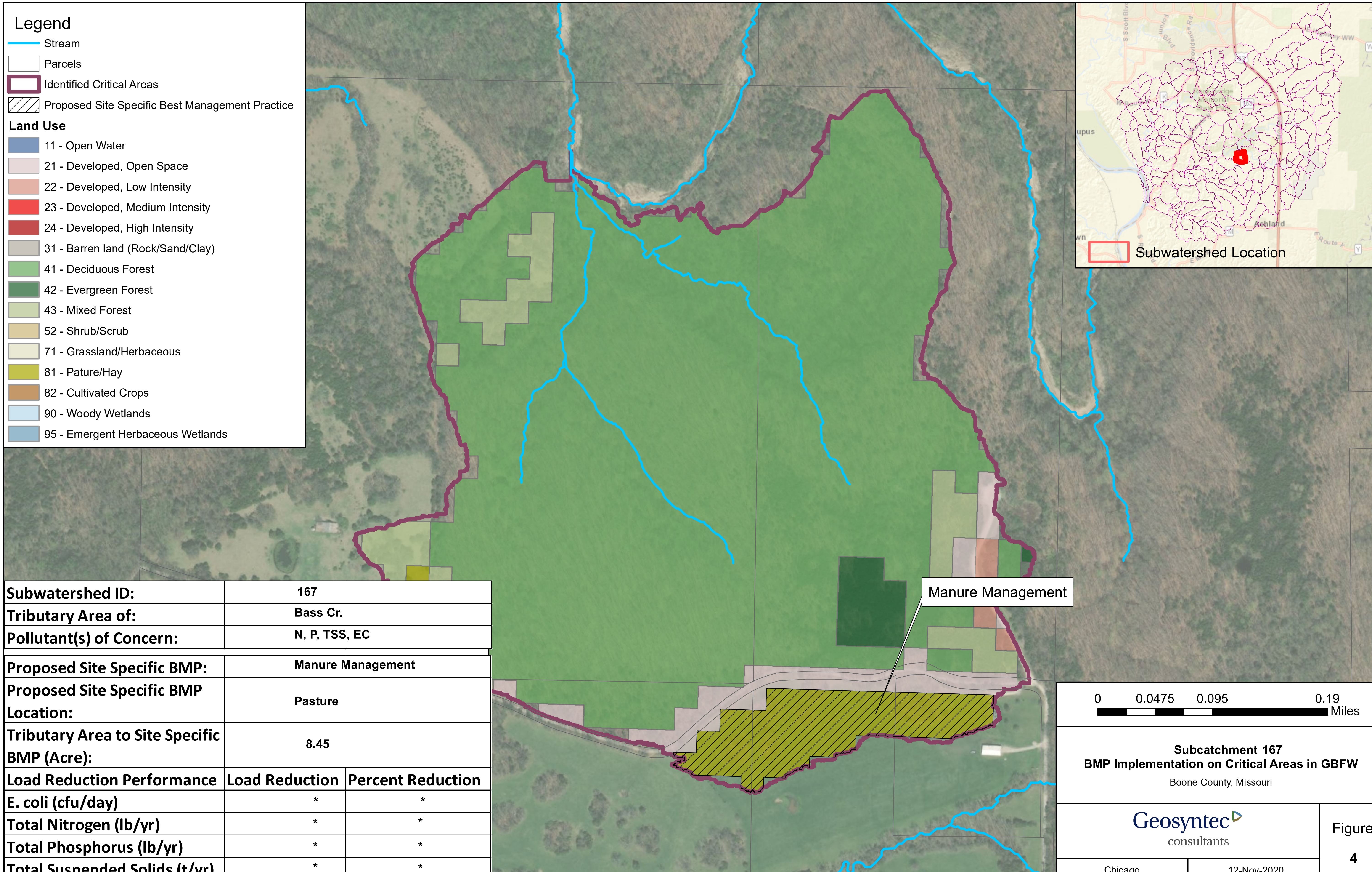
Figure 3



Subwatershed ID:	167	
Tributary Area of:	Bass Cr.	
Pollutant(s) of Concern:	N, P, TSS, EC	
Proposed Site Specific BMP:	Manure Management	
Proposed Site Specific BMP Location:	Pasture	
Tributary Area to Site Specific BMP (Acre):	8.45	
Load Reduction Performance	**Load Reduction**	**Percent Reduction**
E. coli (cfu/day)	*	*
Total Nitrogen (lb/yr)	*	*
Total Phosphorus (lb/yr)	*	*
Total Suspended Solids (t/yr)	*	*

*Reduction will be dependent on the amount of manure managed.

Subcatchment 167
BMP Implementation on Critical Areas in GBFW
Boone County, Missouri

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Figure 4

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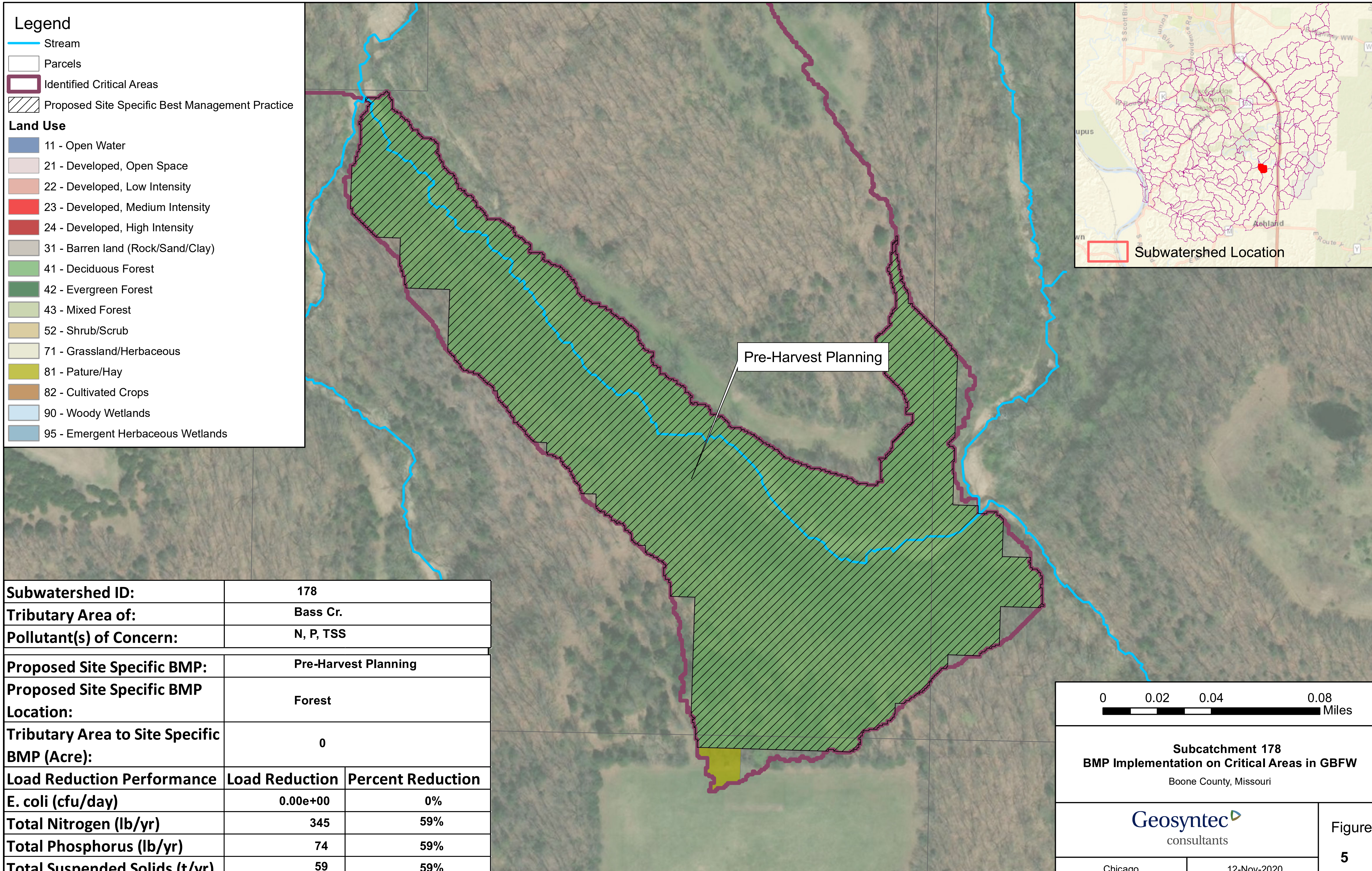

Subwatershed ID:	178	
Tributary Area of:	Bass Cr.	
Pollutant(s) of Concern:	N, P, TSS	
Proposed Site Specific BMP:	Pre-Harvest Planning	
Proposed Site Specific BMP Location:	Forest	
Tributary Area to Site Specific BMP (Acre):	0	
Load Reduction Performance	Load Reduction	Percent Reduction
E. coli (cfu/day)	0.00e+00	0%
Total Nitrogen (lb/yr)	345	59%
Total Phosphorus (lb/yr)	74	59%
Total Suspended Solids (t/yr)	59	59%

Subcatchment 178
BMP Implementation on Critical Areas in GBFW
Boone County, Missouri

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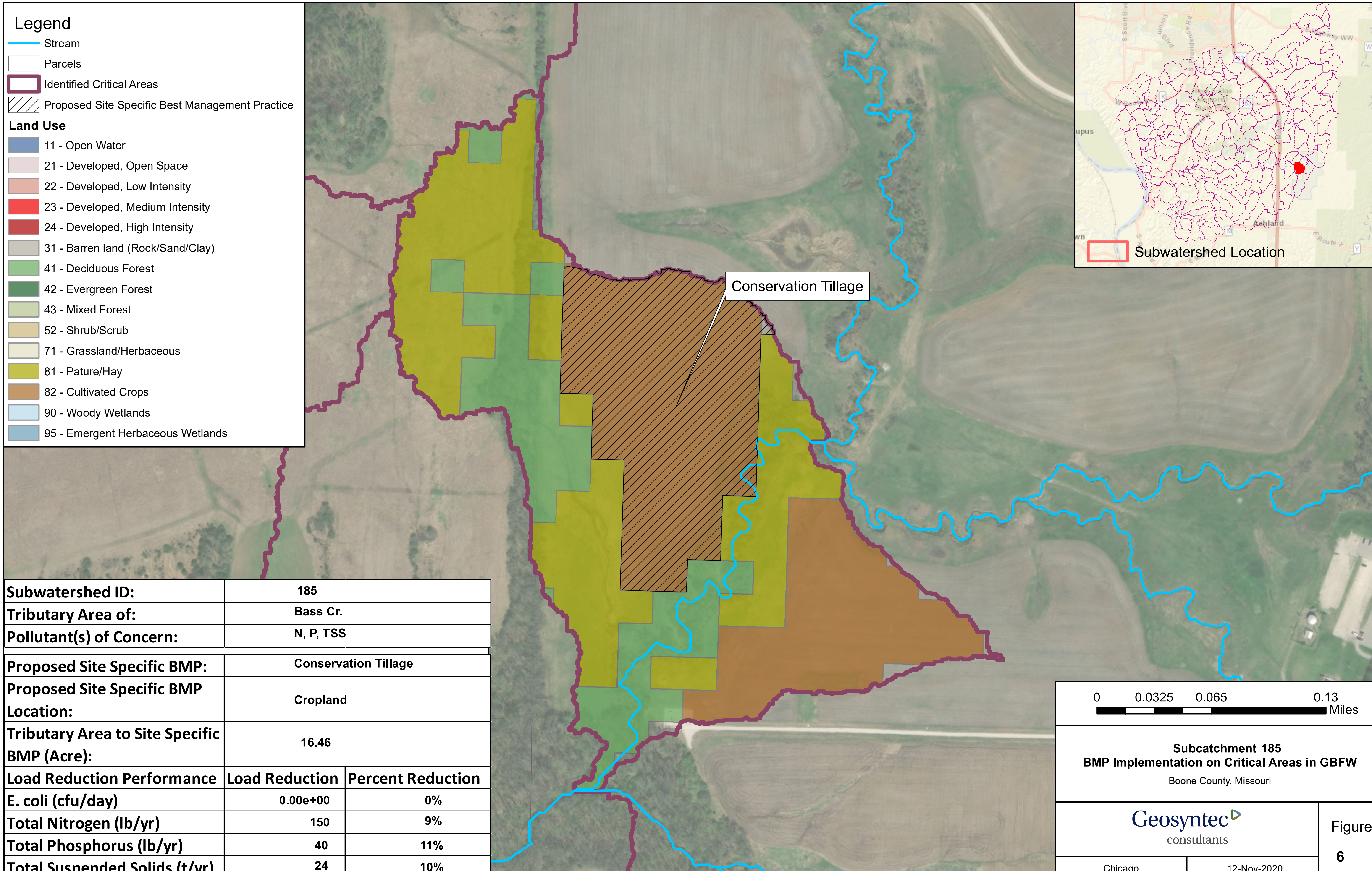
Figure 5



Subwatershed ID:	185
Tributary Area of:	Bass Cr.
Pollutant(s) of Concern:	N, P, TSS

Proposed Site Specific BMP:	Conservation Tillage	
Proposed Site Specific BMP Location:	Cropland	
Tributary Area to Site Specific BMP (Acre):	16.46	
Load Reduction Performance	Load Reduction	Percent Reduction
E. coli (cfu/day)	0.00e+00	0%
Total Nitrogen (lb/yr)	150	9%
Total Phosphorus (lb/yr)	40	11%
Total Suspended Solids (t/yr)	24	10%

Subcatchment 185
BMP Implementation on Critical Areas in GBFW
Boone County, Missouri

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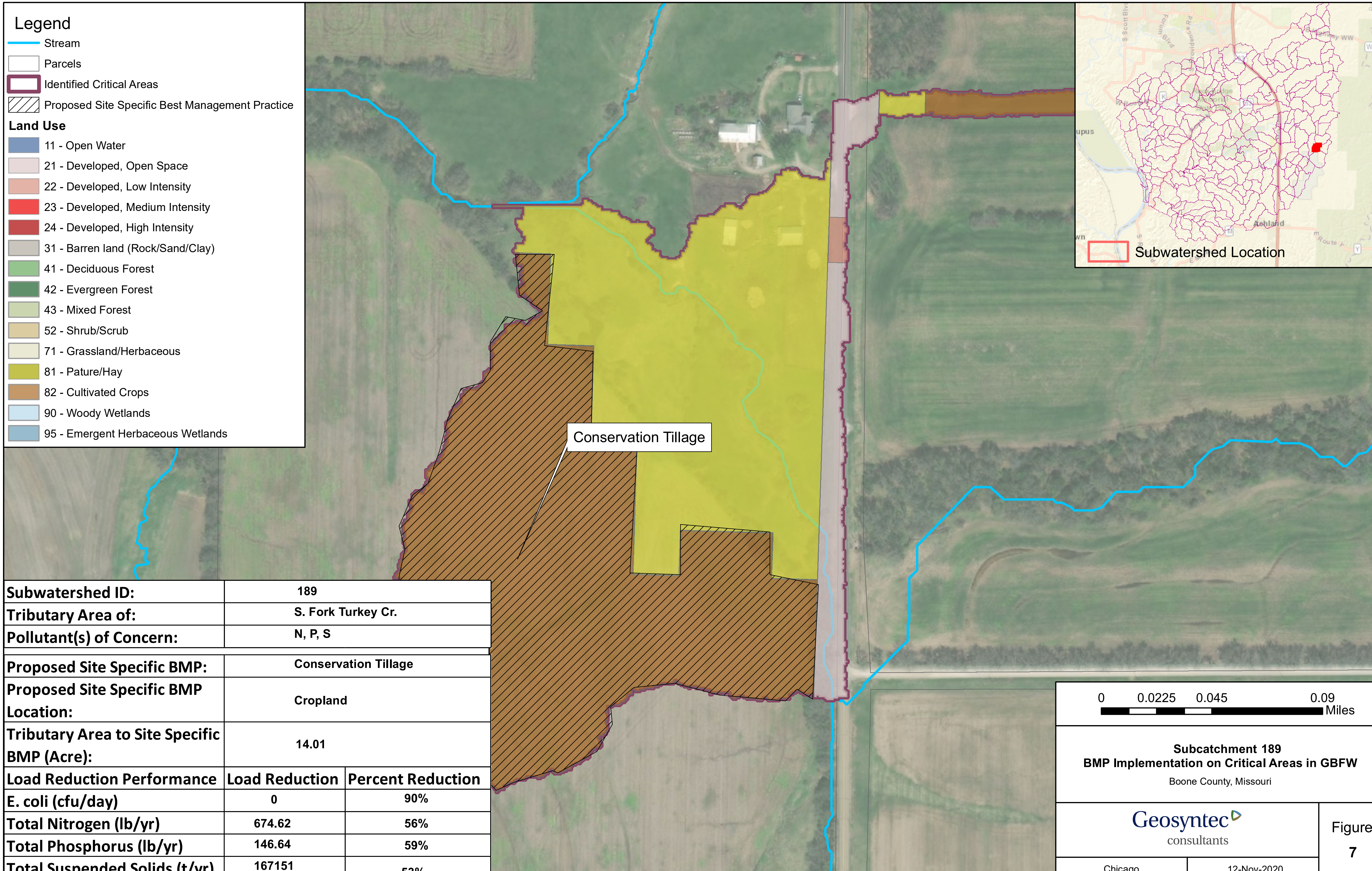
Figure 6



Subwatershed ID:	189	
Tributary Area of:	S. Fork Turkey Cr.	
Pollutant(s) of Concern:	N, P, S	
Proposed Site Specific BMP:	Conservation Tillage	
Proposed Site Specific BMP Location:	Cropland	
Tributary Area to Site Specific BMP (Acre):	14.01	
Load Reduction Performance	**Load Reduction**	**Percent Reduction**
E. coli (cfu/day)	0	90%
Total Nitrogen (lb/yr)	674.62	56%
Total Phosphorus (lb/yr)	146.64	59%
Total Suspended Solids (t/yr)	167151	53%

Subcatchment 189
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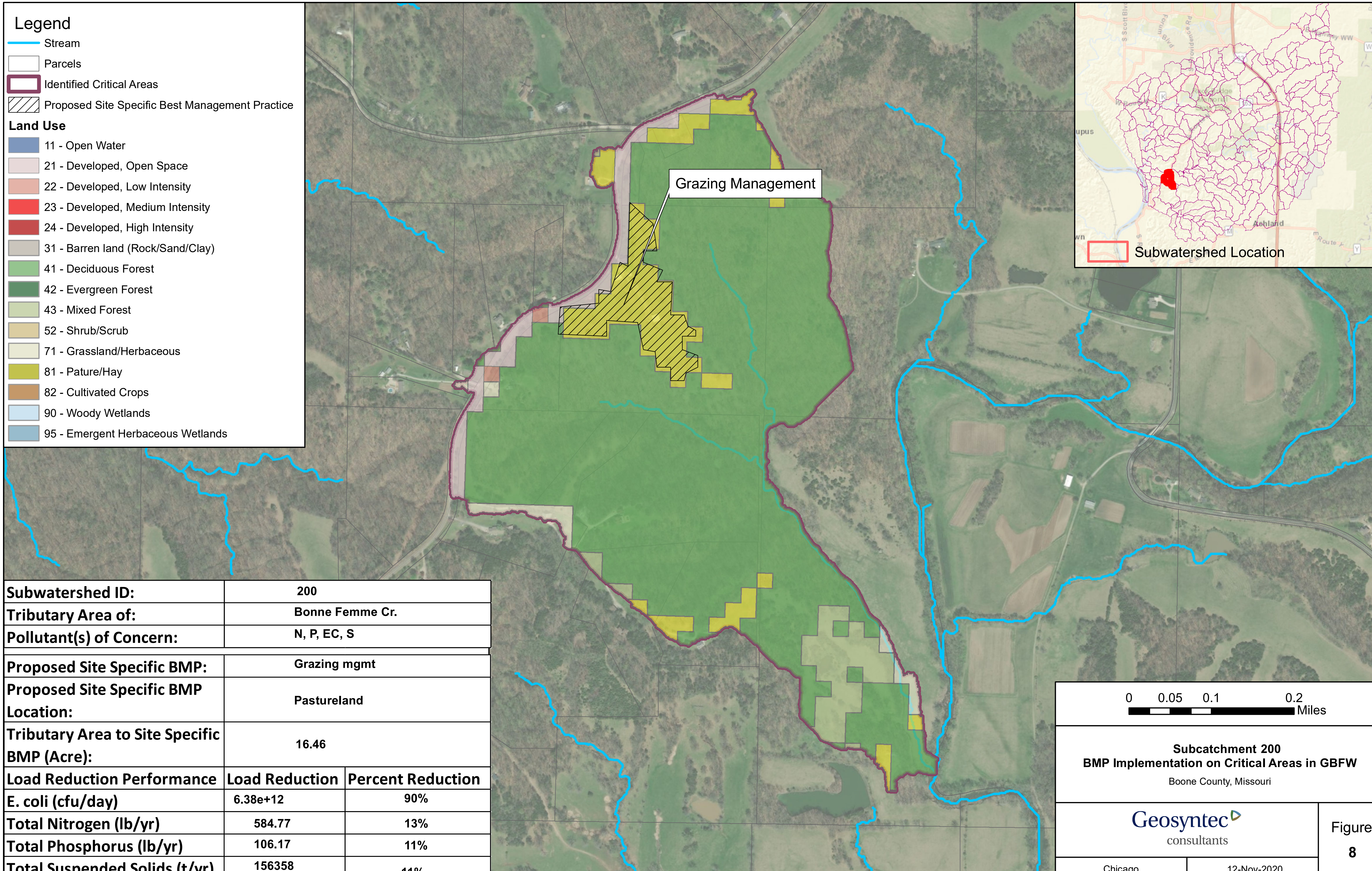
Figure 7



Subwatershed ID:	200
Tributary Area of:	Bonne Femme Cr.
Pollutant(s) of Concern:	N, P, EC, S

Proposed Site Specific BMP:	Grazing mgmt
Proposed Site Specific BMP Location:	Pastureland
Tributary Area to Site Specific BMP (Acre):	16.46

Load Reduction Performance	Load Reduction	Percent Reduction
E. coli (cfu/day)	6.38e+12	90%
Total Nitrogen (lb/yr)	584.77	13%
Total Phosphorus (lb/yr)	106.17	11%
Total Suspended Solids (t/yr)	156358	11%

Subcatchment 200
BMP Implementation on Critical Areas in GBFW
Boone County, Missouri

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Figure 8

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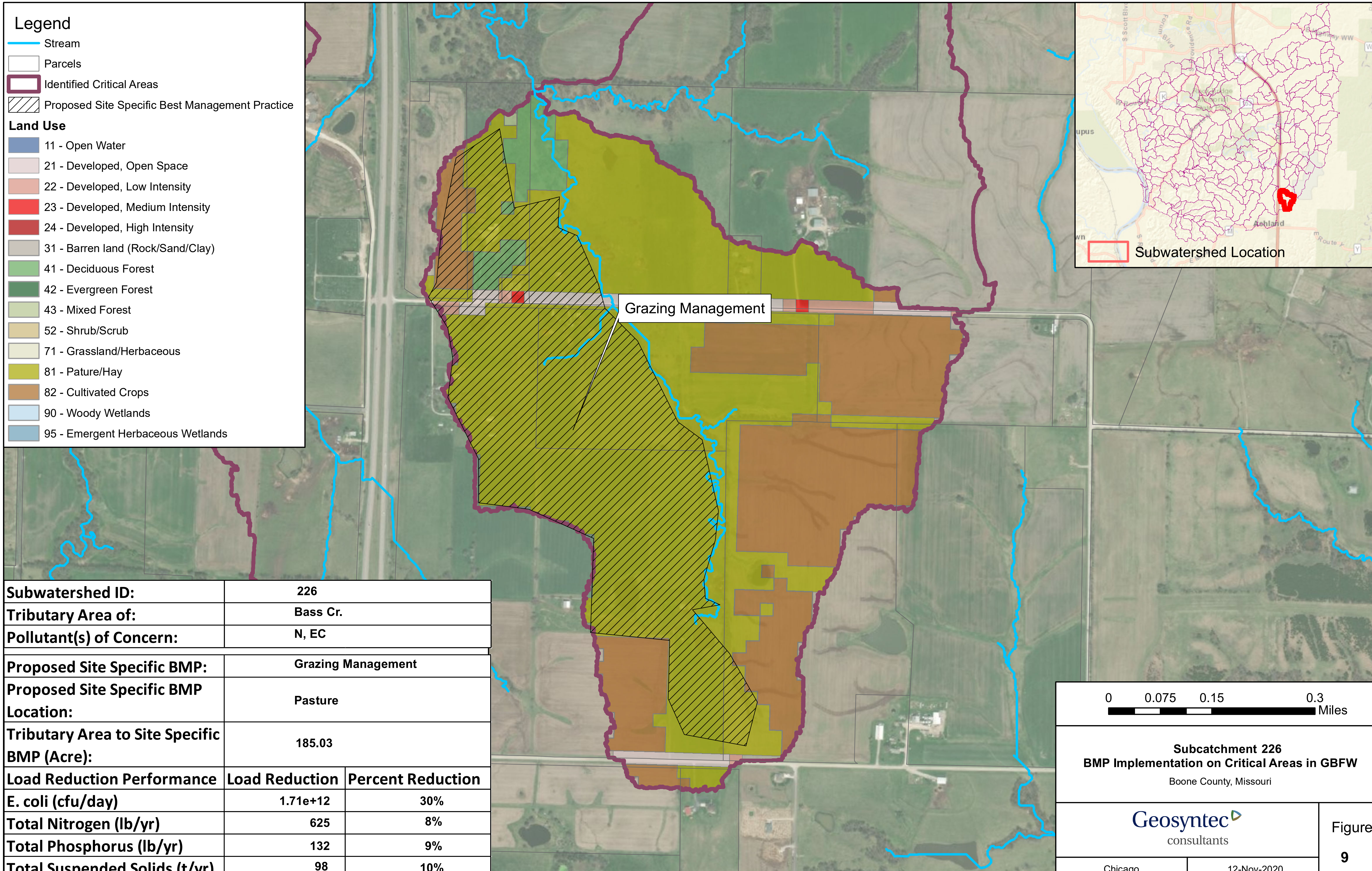

Subwatershed ID:	226
Tributary Area of:	Bass Cr.
Pollutant(s) of Concern:	N, EC

Proposed Site Specific BMP:	Grazing Management
Proposed Site Specific BMP Location:	Pasture
Tributary Area to Site Specific BMP (Acre):	185.03

Load Reduction Performance	Load Reduction	Percent Reduction
E. coli (cfu/day)	1.71e+12	30%
Total Nitrogen (lb/yr)	625	8%
Total Phosphorus (lb/yr)	132	9%
Total Suspended Solids (t/yr)	98	10%

Subcatchment 226
BMP Implementation on Critical Areas in GBFW
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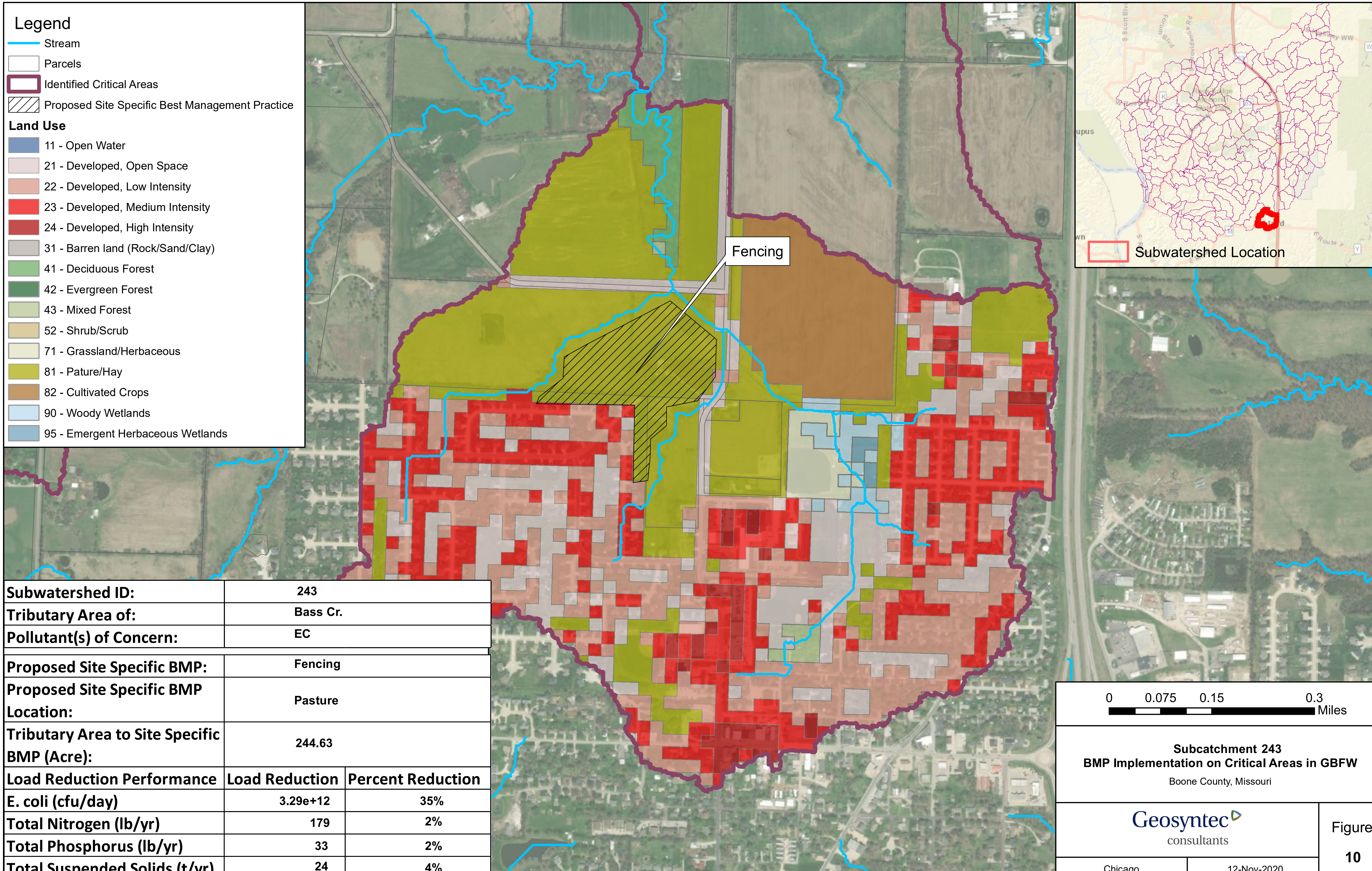
Figure 9



Subwatershed ID:	243
Tributary Area of:	Bass Cr.
Pollutant(s) of Concern:	EC

Proposed Site Specific BMP:	Fencing
Proposed Site Specific BMP Location:	Pasture
Tributary Area to Site Specific BMP (Acre):	244.63

Load Reduction Performance	Load Reduction	Percent Reduction
E. coli (cfu/day)	3.29e+12	35%
Total Nitrogen (lb/yr)	179	2%
Total Phosphorus (lb/yr)	33	2%
Total Suspended Solids (t/yr)	24	4%

Subcatchment 243
BMP Implementation on Critical Areas in GBFW
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Figure 10