BENNETT CREEK WATERSHED ASSESSMENT

March 20, 2008

ABSTRACT

The Bennett Creek Watershed, which is a subwatershed of the Lower Monocacy Basin, was the fourth watershed to be selected for a retrofit assessment by the Frederick County National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit program. The first part of the assessment involved gathering all available information on the condition of the watershed. The next step involved using this data to rank the fifteen Bennett Creek subwatersheds in order of priority for restoration. Stressors were then identified at random and targeted site locations throughout the watershed by using a series of logical steps based on the US EPA Stressor Identification Guidance Document. Impairments were evaluated, candidate causes of impairment were described, relationships between causes, stressors and biotic conditions were assessed, and probable stressors were identified based on strength of evidence. Stressors varied among subwatersheds, but nutrient enrichment and habitat degradation were the most commonly cited candidate causes of impairment, followed by excessive sediment and turbidity. The next phase of this analysis will involve identifying priority restoration sites and recommending projects to reverse, prevent, or slow stream and watershed degradation. Effectiveness of stressor reduction projects and best management practices will be evaluated by the county based on monitoring the stressors they are designed to control (sediment, water temperature, nutrients). Effectiveness of the overall watershed management will be evaluated based on the overall biological condition of the watershed as monitored through continued probabilistic sampling.

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1 WATERSHED CHARACTERIZATION

1.1 Background

Bennett Creek, which is a subwatershed of the Lower Monocacy Basin, is the fourth watershed to be selected for a retrofit assessment by the Frederick County National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit program. The goal of the retrofit assessment is to provide the County and community stakeholders with information on the condition of this watershed, to identify the most likely stressor sources in the watershed, and to recommend projects to reverse, prevent, or slow stream and watershed degradation. Implementation of any suite of retrofit/restoration projects in the Bennett Creek watershed will be with the ultimate goal of improving or maintaining environmental conditions, in particular, with reducing or eliminating stressors and stressor sources.

The retrofit assessment builds on the studies conducted by the Maryland Department of Natural Resources (MDNR) in the Lower Monocacy River watershed. These include a watershed characterization report, a nutrient synoptic survey and a stream corridor survey (MDNR 2003a, MDNR 2003b, Czwartacki et al. 2004). The reports were used in the development of the Lower Monocacy River Watershed Restoration Action Strategy (WRAS) (Frederick County DPW 2004), which listed twenty-three sites as priorities for restoration in the Bennett Creek Watershed.

1.2 Bennett Creek Watershed Overview

The Bennett Creek Watershed drains approximately 48 square miles. Stream gradients within the watershed vary with local relief patterns, but tend to be low and moderate. Elevations range from approximately 200 feet at the mouth of Bennett Creek to 1280 feet at the top of Sugarloaf Mountain. The watershed is divided into 15 subwatersheds and 105 catchment areas (Figures 1-1 & 1-2, Table 1-1). These delineations were developed by Versar, Inc. in 2007[1]. Bennett Creek is a fourth order stream when it flows into the Monocacy River (Strahler 1957). Major tributaries that flow into Bennett Creek include Fahrney Branch and Little Bennett Creek. Streams in four of the subwatersheds (Monocacy Direct-North, Monocacy Direct-South, Furnace Branch, Little Monocacy River) do not flow into Bennett Creek, but rather flow directly into the Monocacy River. Portions of five subwatersheds (Bennett Creek-Upper Mainstem, Little Bennett, Sugarloaf, Little Monocacy River and Monocacy Direct-South) are located in Montgomery County. Although outside the project area, these areas are included in the stressor source inventory because they provide valuable information about potential stressors affecting the project area.

[1] Bennett Creek watershed catchments were delineated primarily from Frederick County DEMs (2005). Catchments within or along the County boundary are approximately 200 to 500 acres in size, while areas entirely outside Frederick County are consolidated into larger catchments that extend to the topographic watershed divide. Further refinements, including alignment with stream confluences shown in Frederick County's stream layer (2000), were made based on 1:24,000 USGS topographic maps and boundary and elevation data from adjacent Montgomery County, MD

The Bennett Creek Watershed is located in the southeastern portion of Frederick County (Figure 1-3). It lies within the Northern Piedmont level III ecoregion, which is a transitional area bordered by the Appalachian mountains on the west and the coastal plain on the east (Figure 1-4) (U.S. EPA 2007a). The region has a warm temperate climate, and is largely forested with irregular plains, low rounded hills and ridges, shallow valleys, and scattered monadnocks. Its geology is characterized by deeply weathered, deformed metamorphic rocks that have been intruded by igneous material, and occasional sedimentary rocks. Shallow, acidic soils are common throughout the watershed and include ultisols, which tend to be clay-rich, acidic and relatively low in base saturation (MDNR 2003a, Woods et al. 1999). Areas of prime agricultural soil are scattered throughout the watershed, and stony soils are prevalent on Sugarloaf Mountain, which is located in the southwestern portion of the watershed. Thirty percent of these soils are categorized as highly erodible, and seven percent are considered to be hydric (MDNR 2003a).

The watershed is mostly rural, with forest and agriculture comprising approximately 85% of the land use (Figure 1-5, Table 1-2). Developed land consists mostly of low density residential areas, which occur mainly in the central and eastern portions of the watershed. Small areas of residential development also exist in the northwestern portion of the watershed. The Bennett Creek watershed has experienced fairly rapid urban and suburban growth in recent years, in part due to building restrictions and protected lands in neighboring Montgomery County (Frederick County DPW 2004). This follows a trend similar to the one seen in Frederick County as a whole, which experienced a population increase of 14.2% from 2000 to 2006 (U.S. Census Bureau 2006).

As population in Frederick County has increased, the number and size of farms in Frederick County has decreased (Census of Agriculture, NASS 2004). Yet agriculture remains a very important part of Frederick County's economy. It is Maryland's largest dairy producer and accounts for one-third of the state's milk production. The 2002 NASS report showed that it ranked first among Maryland Counties in crop production acres for forage, and first in the livestock inventory for beef cattle and milk cows. Common row crops include corn, soybeans, wheat, and barley (Census of Agriculture, NASS 2004).

Within the Bennett Creek watershed, zoning ordinances have been established that designate fifty percent of the land as agricultural (Figure 1-6, Table 1-3). The agricultural districts were created to "…preserve productive agricultural land and the character and quality of the rural environment and to prevent urbanization where roads and other public facilities are scaled to meet only rural needs" (Frederick County Government 2007). Resource conservation zoning districts comprise thirty percent of the watershed. Their purpose is to "…allow low intensity uses and activities which are compatible with the goal of resource conservation to be located within mountain and rural wooded area" (Frederick County Government 2007). The residential zoning districts, which comprise about 15% of the watershed, allow only low density residential developments, with a maximum of one dwelling unit per acre. The remaining five

percent of the watershed is comprised mostly of industrial zoning districts established for office, research and limited manufacturing uses.

In addition to the protections afforded by the zoning ordinances, several parcels of protected land exist within the watershed, mostly along its western side (Figure 1-7). The type of ownership and the extent of protection varies among the parcels, but they are considered to be protected because there is "…some form of long term limitation on conversion to urban / developed land use" (MDNR 2003a). Maryland DNR manages several parcels within the Bennett Creek watershed, the largest of which is the DNR Monocacy River Natural Resources Management Area. This area is comprised of 1,800 acres of natural areas and farmlands along the Monocacy River and is managed for recreational use such as hunting, fishing, hiking and horseback riding (MDNR 2007c). Federal lands exist at the northern tip of the watershed, where the National Park Service runs the Monocacy National Battlefield. Additional parcels in the watershed are protected through agricultural easements, the rural legacy program, private conservation easements and as county parks.

The largest protected area in the Frederick County portion of the watershed is the 3300-acre Stronghold Preserve on Sugar Loaf Mountain. The Stronghold Preserve is privately held by Stronghold Incorporated, a non-profit corporation organized in 1946 by the late Gordon Strong, and is protected by a conservation easement. The Stronghold Preserve was established for the public's "enjoyment and education in an appreciation of natural beauty" (Sugarloaf Mountain 2007). Sugarloaf Mountain has been designated a Registered Natural Landmark by the National Park Service because of its geological interest and striking beauty, and has been designated as a "Sensitive Species" habitat area (Frederick County DPW 2004).

The Stronghold Preserve is also worth noting because it contains Bear Branch, the only pristine trout-bearing stream in all of the Lower Monocacy River Watershed (MDNR 2003a). Bear Branch and Furnace Branch, which flows through the DNR Monocacy River Natural Resources Management Area, are designated for Natural Trout waters and Public Water Supply (Figure 1-8). The Monocacy River, which flows along the western boundary of the watershed, is designated for Recreational Trout waters and Public Water Supply. The majority of streams in the Bennett Creek watershed are designated for Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply.

Table 1-1. Sizes of the Bennett Creek subwatersheds, listed in order of largest (in project area) to smallest.

Subwatershed	In Project Area (acres)	Outside Project Area (acres)	Total Area (acres)
Fahrney	4417.3		4417.3
Monocacy Direct-North	3797.5		3797.5
Bennett Ck - Upper Mainstem	3314.6	7067.9	10382.6
Bennett Ck - Middle Mainstem	3274.9		3274.9
Monocacy Direct-South	2655.2	662.4	3317.7
Bennett Ck - Lower Mainstem	2535.5		2535.5
Sugarloaf	2020.6	595.1	2615.7
Lilypons	1617.4		1617.4
Little Bennett	1409.2	11693.8	13103.0
Pleasant Branch	1289.2		1289.2
Urbana	1273.4		1273.4
Furnace Branch	1267.7		1267.7
North	898.7		898.7
Bear	890.5		890.5
Little Monocacy River	417.2	11534.7	11951.9
Total	*31078.8*	*31554.0*	*62632.8*

Table 1-2. Summary of land use land cover in the Bennett Creek project area.

Land Use Category	Percent
Forest	45.9
Agriculture	38.5
Low Density Residential	11.4
Other developed land	1.2
Commercial	1.1
Water	0.8
Medium Density Residential	0.7
Institutional	0.4
Industrial	0.1
Total	*100*

Table 1-3. Summary of zoning districts in the Bennett Creek project area. Information was derived from Frederick County's official zoning maps and raster tax maps from the 2002 Maryland Property View package.

Code	Type	Purpose	%
A	Agricultural	To preserve productive agricultural land and the character and quality of the rural environment and to prevent urbanization where roads and other public facilities are scaled to meet only rural needs	50.6
RC	Resource Conservation	For low intensity uses and activities which are compatible with the goal of resource conservation to be located within mountain and rural wooded areas	30.0
R1	Residential District 1	For low density residential use, with a maximum of one dwelling unit per acre	14.6
ORI	Industrial - Office/Research	For office, research and limited manufacturing uses in high visibility locations along major highways	2.5
LI	Industrial - Limited	For operations that have a relatively minor nuisance value. This zoning provides a healthful operating environment secure from the encroachment of residential uses and protected from adverse effects of incompatible industries.	1.2
MM	Industrial	Mineral Mining	0.1
MXD	Mixed Use Development	To promote a compatible mixture of commercial, employment, residential, recreational, civic and/or cultural uses which are planned and developed as a unit	0.7
VC	Commercial - Village Center	To provide commercial services to the rural farm and rural non-farm population of the county by utilizing the established rural commercial areas within the various communities	0.3
GC	Commercial - General	For general retail commercial and business services	0.1
PUD	Planned Unit Development	To provide for small and large scale developments incorporating a variety of residential and related uses which are planned and developed as a unit	0.1
		Total	*100*

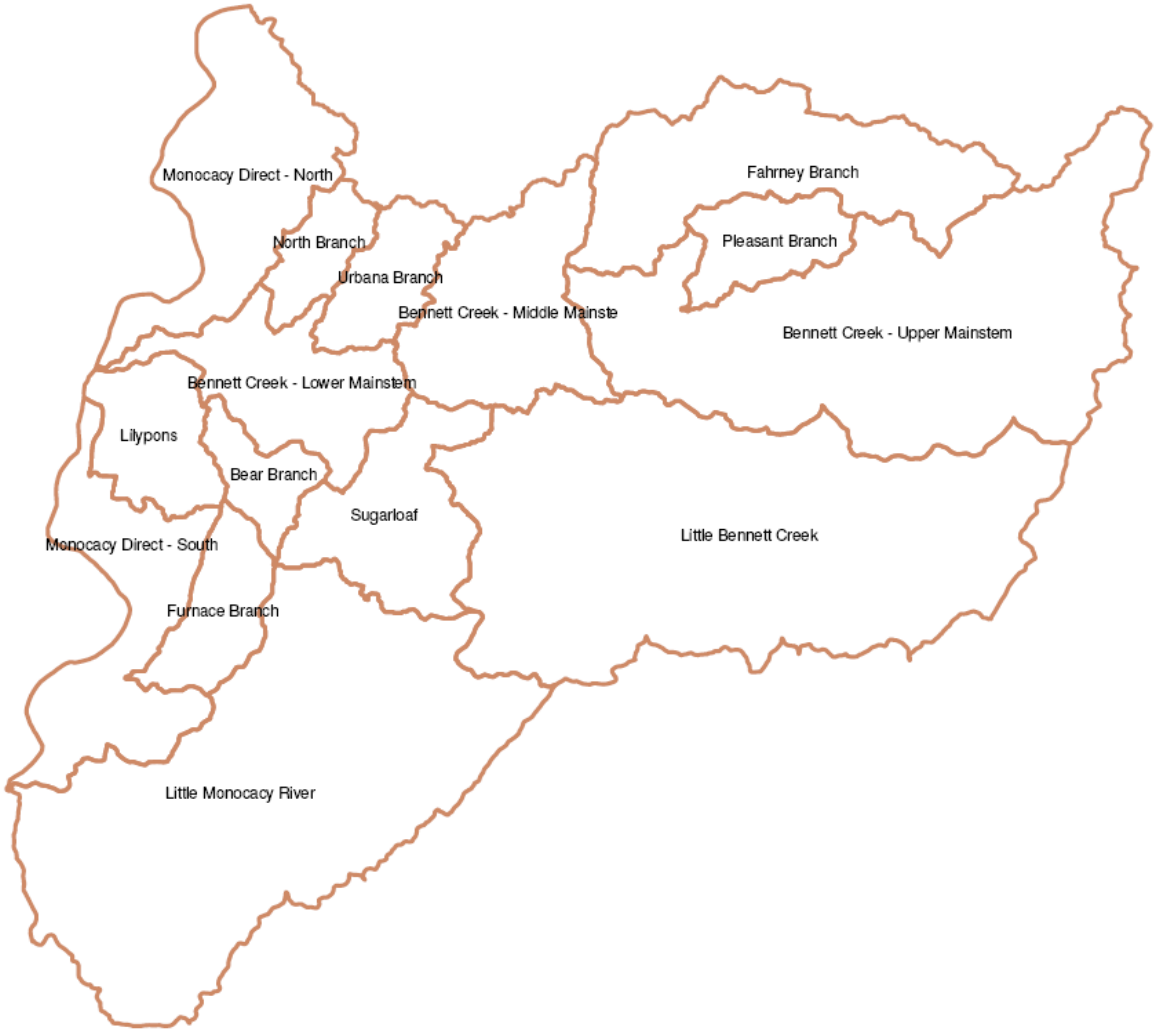

Figure 1-1. The Bennett Creek watershed is divided into 15 subwatersheds (delineations were developed by Versar, Inc. in 2007).

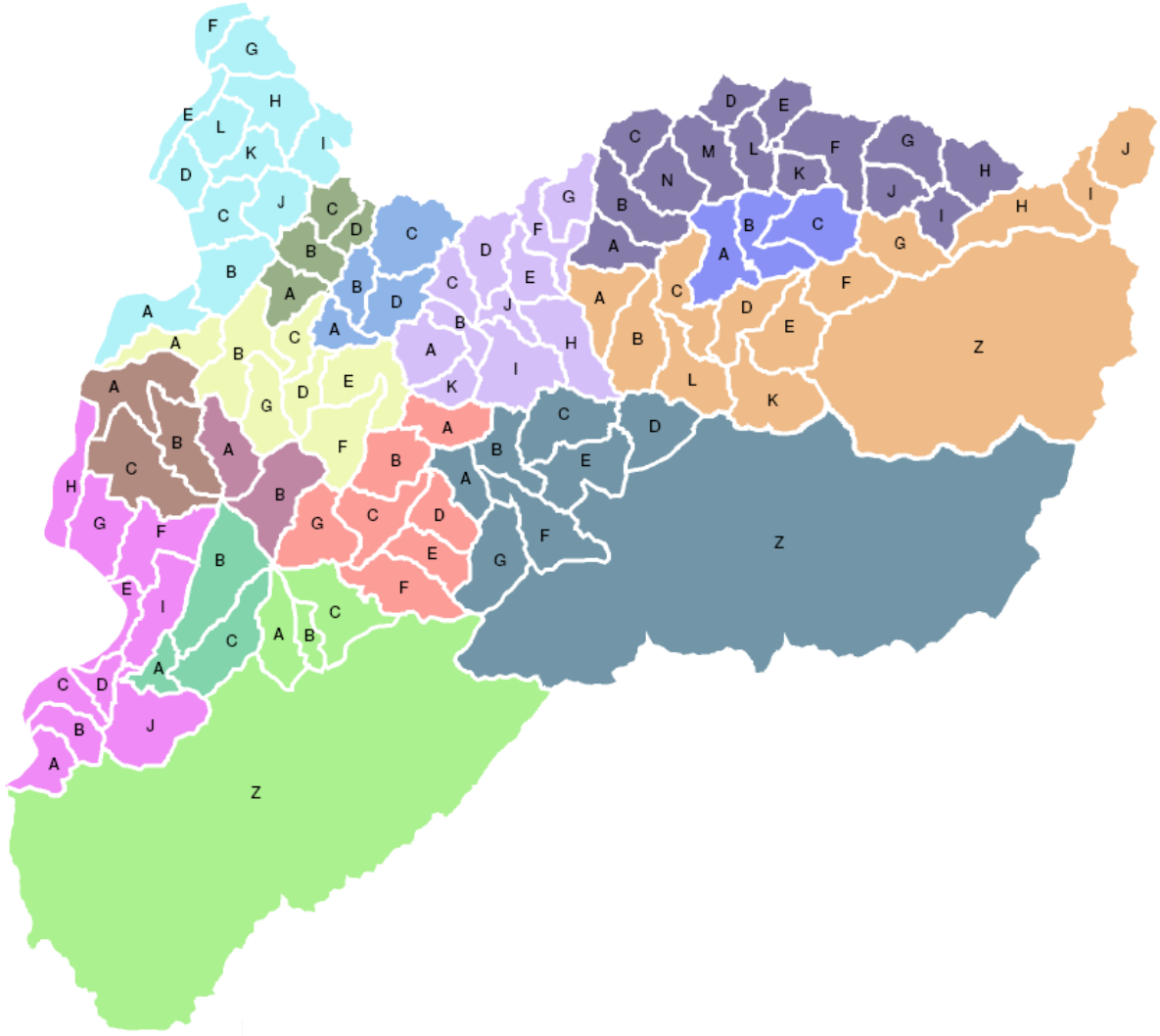

Figure 1-2. The Bennett Creek watershed is divided into 105 catchment areas (delineations were developed by Versar, Inc. in 2007).

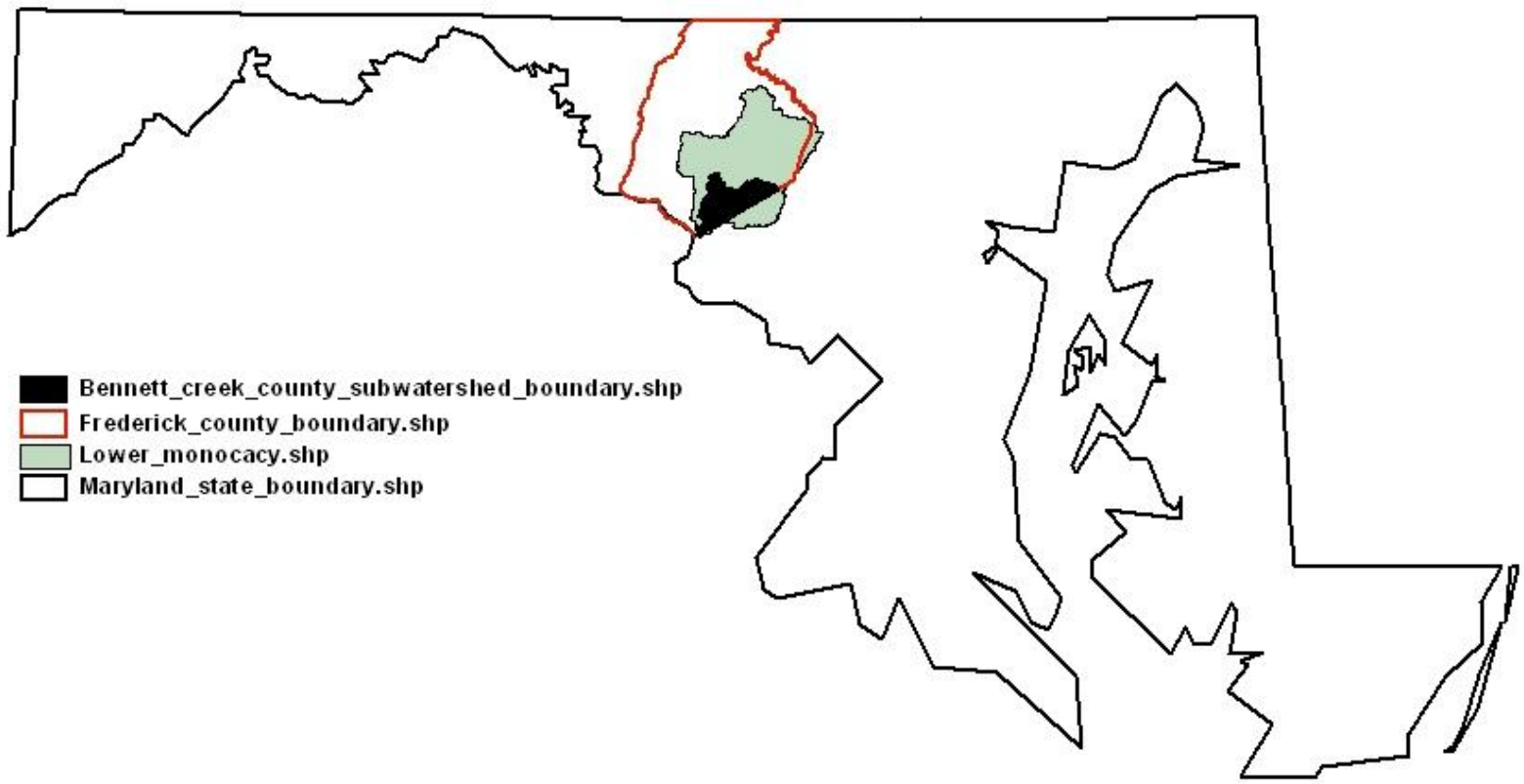

Figure 1-3. Location of the Bennett Creek project area in Frederick County, which lies within the Lower Monocacy watershed.

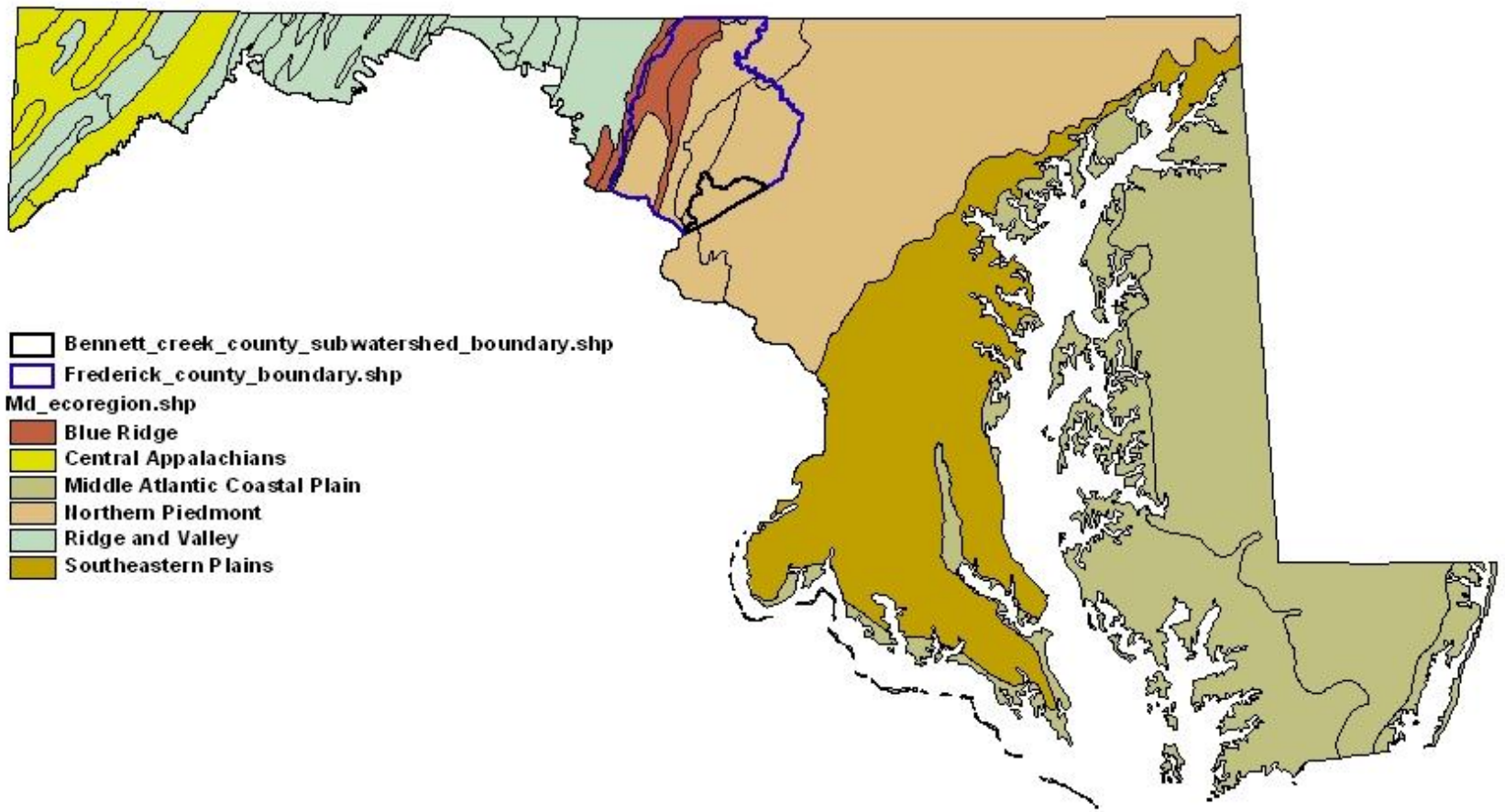

Figure 1-4. The Bennett Creek watershed is located in the Northern Piedmont ecoregion (U.S. EPA 2007a).

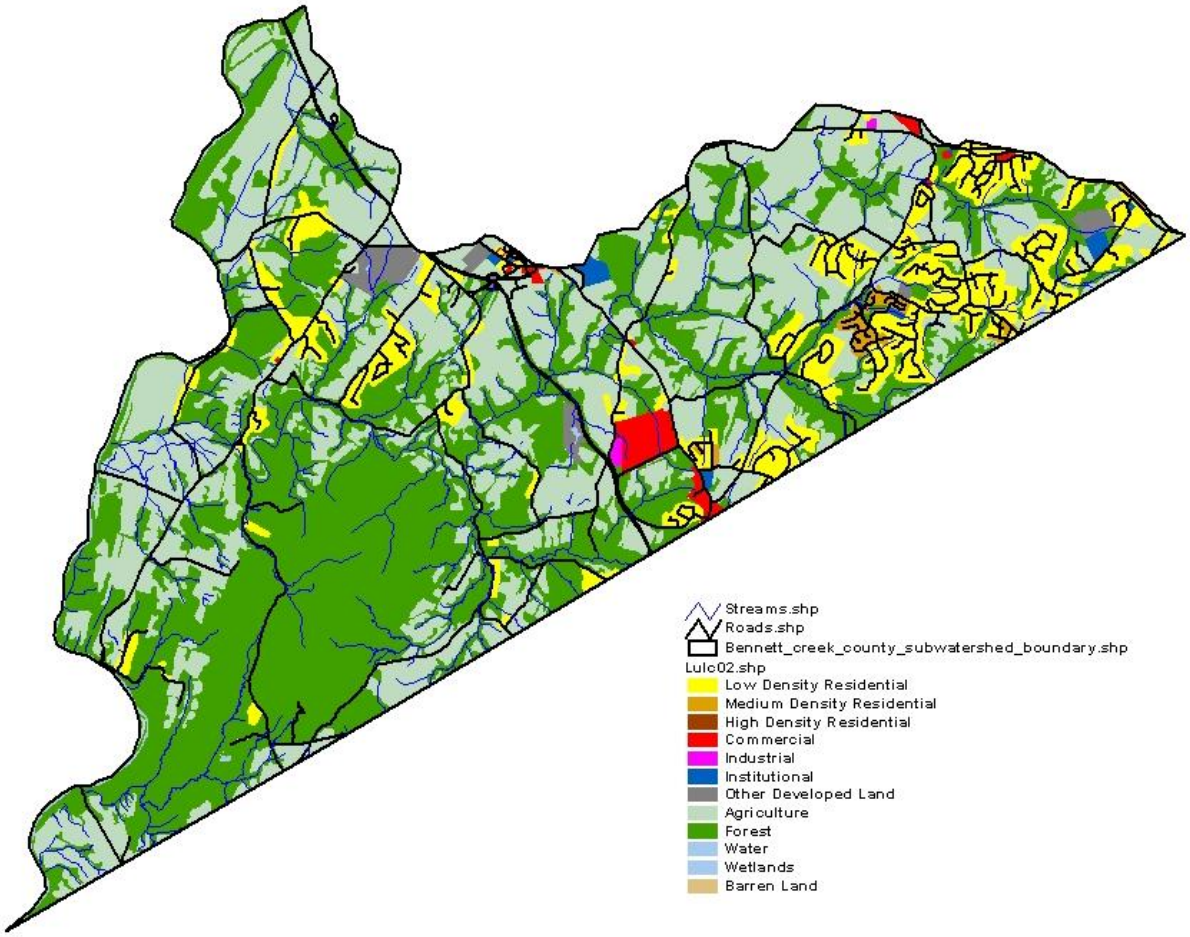

Figure 1-5. Land use land cover within the Bennett Creek project area, based on 2002 data (MDNR 2007d).

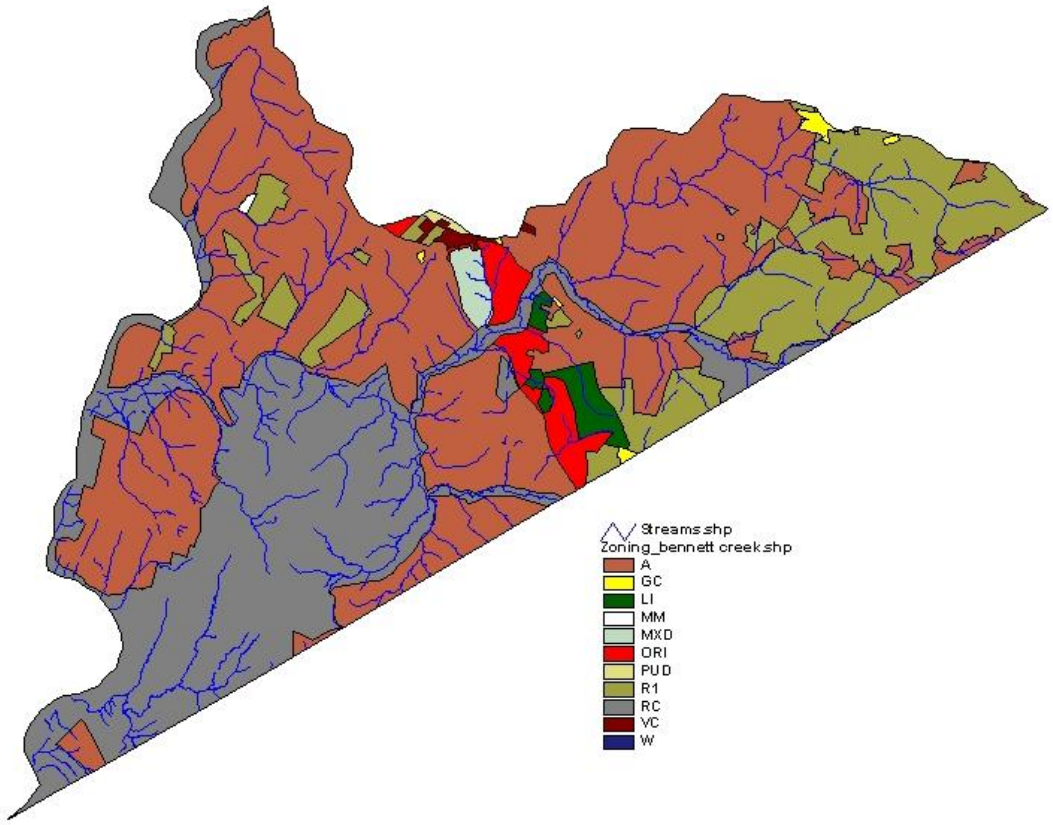

Figure 1-6. Zoning districts in the Bennett Creek project area. Boundaries were derived from Frederick County's official zoning maps and the raster tax maps from the 2002 Maryland Property View package. A=agricultural, GC & VC=commercial districts, LI & MM & ORI=industrial districts, MXD=mixed use development, PUD=planned unit development, R1=residential district 1, and RC=resource conservation.

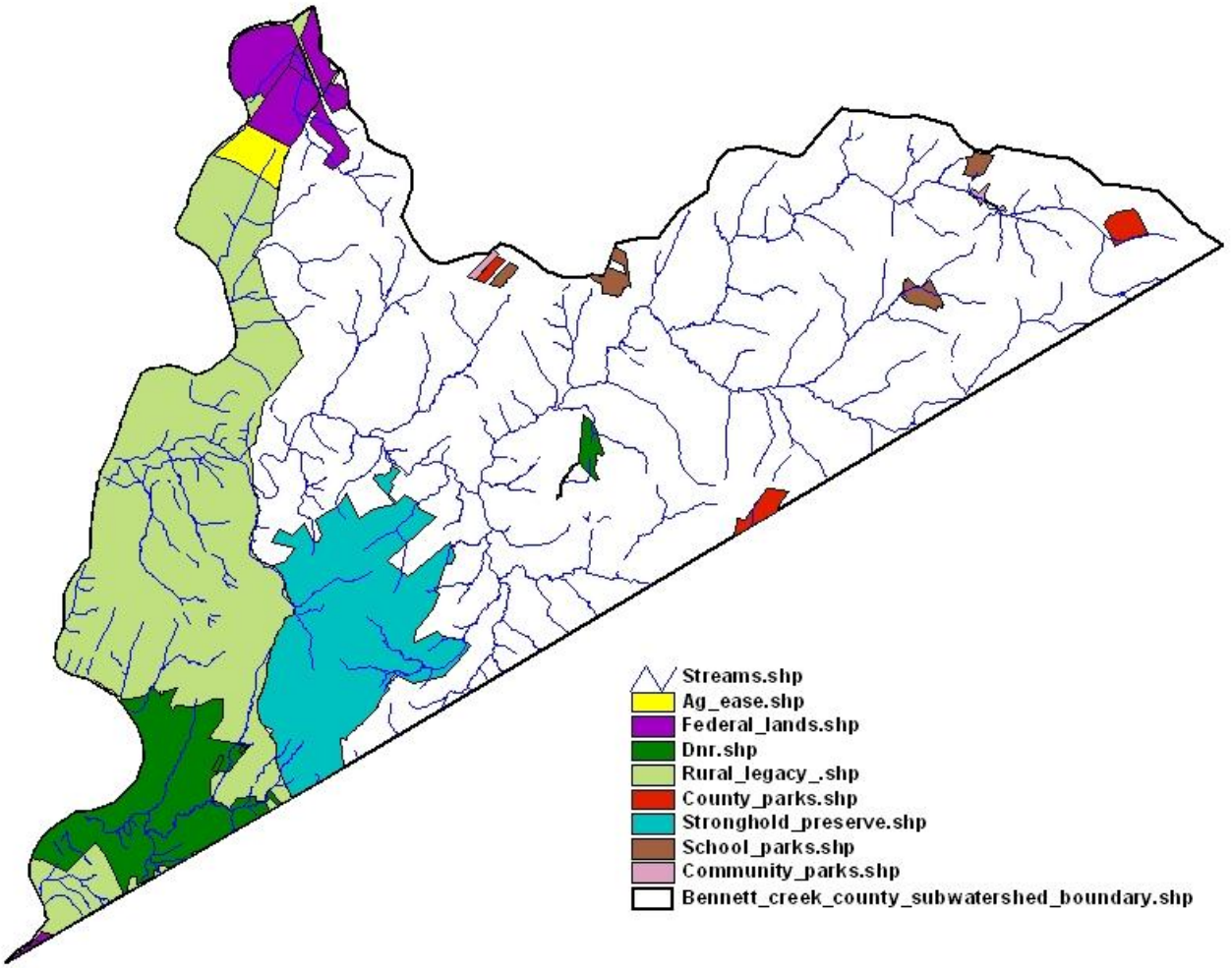

Figure 1-7. Protected lands in the Bennett Creek project area.

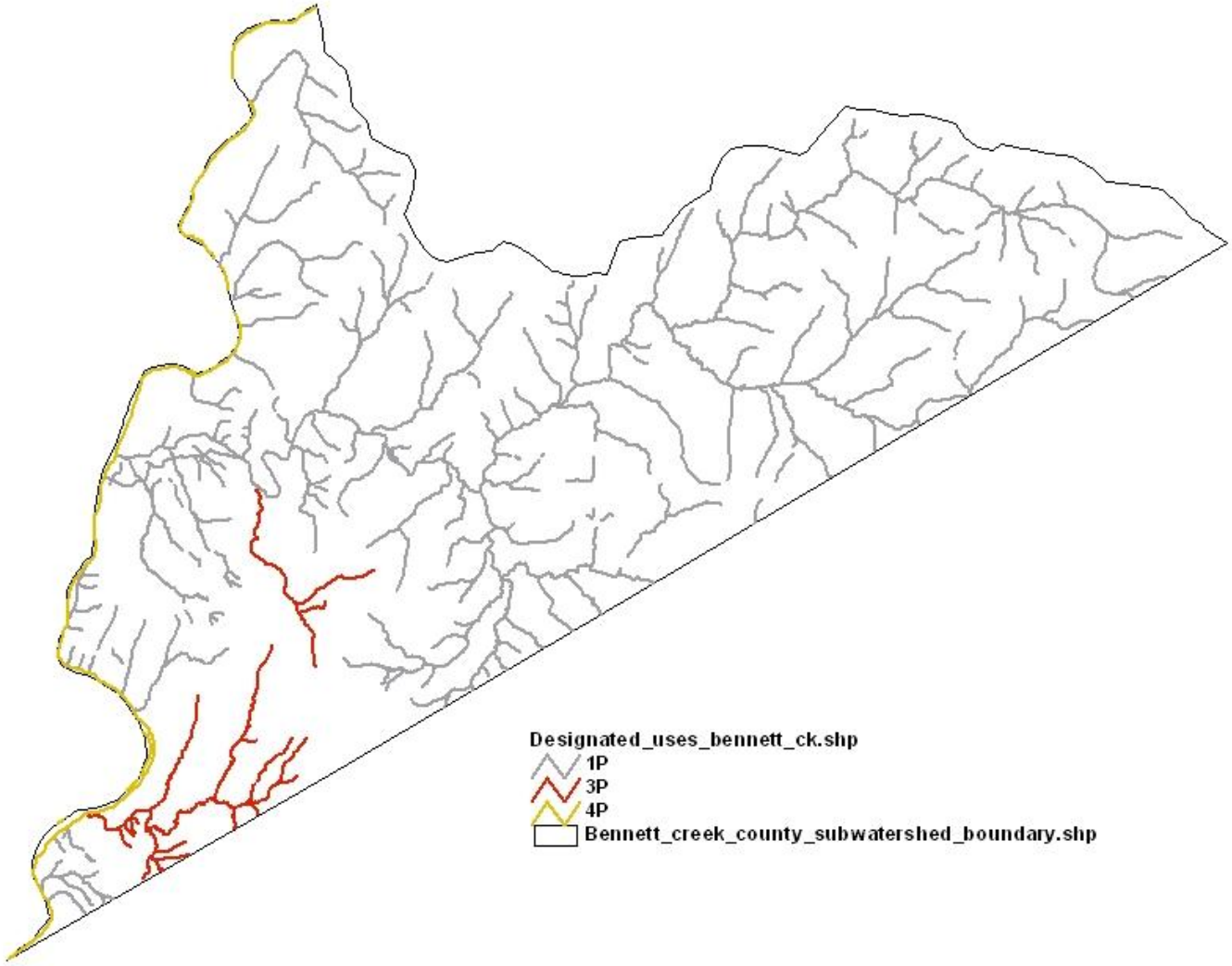

Figure 1-8. Designated uses of the water bodies in the Bennett Creek project area. Type 1P = Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply; Type 3P = Natural Trout waters and Public Water Supply; Type 4P = Recreational Trout waters and Public Water Supply.

2 STRESSOR SOURCE INVENTORY

2.1. Overview

The purpose of the stressor source inventory is to gather, organize and analyze all available information on the Bennett Creek watershed. This information may come from sites located in the project area, sites located in areas that are similar to the project area, or from general biological knowledge. Data gathered for this project include biological surveys, analyses of water chemistry and habitat, land use land cover, and information on permitted pollutant discharges from facilities located in the project area. These data are then used to identify areas of biological impairment, to develop a list of candidate causes and to generate causal evidence for the stressor source identification (Norton et al. 2002, U.S. EPA 2000b).

The data that were gathered for the stressor source inventory are divided into three tiers (Table 2-1). Tier 1 data come from sites in the project area that were surveyed for biology, chemistry and habitat. Tier 2 data come from sites in the project area that lack biological data but have chemistry or habitat data. Tier 3 data come from sites that are located outside of the project area but in the same (Northern Piedmont) ecoregion.

2.2. Response indicators (biological)

Sampling crews from the Maryland Biological Stream Survey (MBSS), Versar, Inc. and Montgomery County have performed biological surveys at various sites in the Bennett Creek watershed, using standardized sampling methods and index periods. Benthic macroinvertebrates were sampled during the spring, from March 1 to approximately May 1, using a 600-micron Mesh D-net. A combination of habitats supporting the most diverse macroinvertebrate assemblage within the 75-meter sample segment was sampled qualitatively, over a total sampling area of 20 ft^2. Sorting, subsampling (100 organisms) and taxonomic identification were performed in the laboratory to genus or lowest practical taxon. Fish were sampled in the same 75-meter segment during the summer, from June 1 through September 30, using double-pass electrofishing (Kazyak et al. 2001, Mercurio et al. 1999).

Biological impairment was identified using the Index of Biotic Integrity (IBI) for fish (FIBI) and benthic macroinvertebrates (BIBI), which are multi-metric indices used to assess the biological condition of Maryland's non-tidal streams. The most current IBIs, which were developed in 2005, were used to rate the biological condition of the streams in the Bennett Creek watershed (Southerland et al. 2005)[2]. Their component metrics are

[2] BIBI and FIBI scores for the sites sampled by Versar were provided by Morris Perot of Versar. BIBI scores for the MBSS and Montgomery County data were calculated using the Maryland EDAS database (Tetra Tech). FIBI scores for the MBSS data were also calculated in EDAS. FIBI scores for the Montgomery County data were calculated using a combination of metrics calculated by EDAS and by Jen Stamp of Tetra Tech. At several sites, BIBI and FIBI scores that were provided by MBSS differed slightly from the values derived from EDAS. MBSS calculates the IBI using SAS software, and the slight scoring differences may be due to differences in software and programming.

shown in Tables 2-2a and 2-2b. IBI scores range from 1 (worst) to 5 (best) (Table 2-3). Sites scoring less than 3.00 are considered to be impaired.

Sampling years for data used in the analyses range from 1996 to 2007. Sites were either chosen randomly as part of a probability-based sampling program or were permanent, non-random sites selected for long-term monitoring. A total of fifty-five biological sampling sites exist in the Bennett Creek watershed (Figure 2-1, Tables 2-4a and 2-4b). Thirty-one of these sites are located in Frederick County. All of these sites were sampled for benthic macroinvertebrates, and sixteen were sampled for fish. Twenty-four sites that were sampled for benthic macroinvertebrates and fish are located in Montgomery County.

Within the project area, BIBI scores ranged from 1.50 to 4.25 and FIBI scores ranged from 1.67 to 4.67. Fifteen of the thirty-one sites sampled for benthic invertebrates had BIBI scores of less than 3.00, while one out of the fifteen sites sampled for fish scored less than a 3.00. FIBI scores were higher than BIBI scores at all but one site (MONY-102-N-2004). The mean BIBI score for the randomly selected sites within the project area was 2.95, and the mean FIBI score was 4.14. Five of the subwatersheds (Monocacy Direct-North, Fahrney, Monocacy Direct-South and Bennett Creek - Upper and Middle Mainstem) had mean BIBI scores (at randomly selected sites) of less than 3.00 (Table 2-5).

2.3. Stressor indicators (physical, chemical, hydrologic, biological)

A variety of water chemistry parameters were measured at the sites where biological surveys were conducted. At the sites sampled by MBSS, grab samples were taken in the spring during the benthic macroinvertebrate sampling. Parameters include pH, acid neutralizing capacity (ANC), conductivity, sulfate, nitrate and dissolved organic carbon (DOC) (Mercurio et al. 1999). More recent samples include additional parameters, such as nitrite, ammonia, total nitrogen (dissolved and particulate), ortho-phosphate, total phosphorus (dissolved and particulate), and chloride (Kazyak et al. 2001). When field crews from Versar Inc. sampled benthic macroinvertebrates in 2007, they collected many of the same parameters.

Different parameters were measured during summer sampling events. MBSS crews collected *in situ* field measurements such as dissolved oxygen, temperature, pH, turbidity and conductivity during fish sampling events. Field crews from Versar Inc. collected similar *in situ* measurements when sampling benthic macroinvertebrates and fish during spring and summer of 2004 and 2005. Montgomery County sampling crews also collected various *in situ* measurements during their biological sampling events.

Water chemistry data are also available for sixteen sites in the Bennett Creek watershed that were not sampled for biology (Table 2-6, Figure 2-2). The data were collected for the 2003 nutrient synoptic survey in the Lower Monocacy watershed (MDNR 2003b). The report showed nitrogen ratings to be high at eight sites, moderate at seven, and baseline at one (Table 2-7). The report states that the majority of the elevated nitrogen

concentrations and yields appeared to be associated with animal and row crop agriculture (MDNR 2003b). Phosphorus ratings were baseline at eleven sites, moderate at four sites, and high at one site. The report states that elevated orthophosphate concentrations and yields appeared to be associated with phosphorus-rich soils in systems that had fine suspended sediment loads lingering in the water column several days after rain events, possibly due to drainage from ponds (MDNR 2003b). High nutrient ratings in the Bennett Creek watershed occurred in the four of the subwatersheds - Fahrney , Pleasant and Bennett Creek – Upper and Lower Mainstem.

In situ water quality measurements were also taken during the 2003 nutrient synoptic survey. Values for sites in the Bennett Creek watershed appeared to be normal, with neutral or basic pH values, conductivities ranging from 82 to 279 µS/cm, dissolved oxygen values ranging from 9.44 to 13.32 mg/L, and water temperature values ranging from 14.78 to 20.77°C (Table 2-8).

Physical habitat was also assessed at sites where biological data were collected, using the MBSS stream habitat assessment protocols. For the assessments, the following qualitative metrics are evaluated at each site: instream habitat, epifaunal substrate, velocity/depth diversity, pool/glide/eddy quality, and riffle/run quality. Each metric is scored on a scale of 0 (worst) to 20 (optimal). A variety of additional qualitative and quantitative measurements were taken at the sites, such as embeddedness, shading, stream gradient, extent and severity of erosion, bar formation, presence/absence of various substrate size classes, wetted width, thalweg depth, amount of large woody debris, number of root wads, flow velocity, and presence/absence of exotic plants. Also recorded are buffer width, riparian vegetation, land use in the adjacent area and in the upstream catchment area, remoteness and aesthetics ratings, and evidence of channel alteration or blockage (Kazyak et al. 2001, Mercurio et al. 1999).

Habitat data are also available for several tributaries in the Bennett Creek watershed that were surveyed as part of the 2003 Lower Monocacy Stream Corridor Survey (Czwartacki et al. 2004). During the stream corridor assessment surveys (SCA), trained field crews walk the stream corridors and record information on observable environmental problems in the watershed. These problems include: inadequately buffered stream banks, erosion sites, fish barriers, pipe outfalls, channel alterations, trash dumping sites, exposed pipes and unusual conditions/comments. Field crews evaluate and score all problems on a scale of 1 to 5 in three separate areas: problem severity, correctability, and accessibility. In addition, field teams collect descriptive data for habitat conditions at representative sites spaced at approximately 1-mile intervals along the streams (Czwartacki et al. 2004, Yetman 2002). The stream corridor assessment surveys are limited in that they are not detailed scientific surveys and their ratings are subjective. However, they are valuable in helping to target future restoration efforts.

Approximately thirty-eight miles of stream were walked in the Bennett Creek watershed. Streams within the Fahrney, Bear, Urbana, North and Pleasant Branch subwatersheds were assessed (Figure 2-3). The most prevalent problems were inadequate buffers (15.3 miles) and erosion (12.4 miles), and many of the problem sites were rated ‘severe’ and

'very severe' (Table 2-9). Twenty-three of the sites were identified as priority restoration sites in the Lower Monocacy WRAS report (Figure 2-4) (Frederick County DPW 2004). Problems cited at these sites include fish migration barriers, inadequate riparian buffers, free access of livestock (horses, cattle) to streams, exposure to future development, areas of accelerated erosion due to golf courses and residential developments, and failing septic systems.

During the habitat assessments, information on introduced or otherwise nonnative species was also collected. Exotic organisms can be harmful to ecosystems because they may displace native species, reduce biodiversity, upset the natural balance of established ecosystems, and degrade habitats (USGS 2008). Relative abundances of exotic plants such as multiflora rose, mile-a-minute, Japanese honeysuckle, phragmites, thistle, and Japanese stilt grass were recorded on the assessment sheets. The presence or absence of Corbicula, an exotic Asian clam, was also documented.

2.4. Source indicators (land use/land cover, NPDES permits, other)

Information on sources of pollution in the Bennett Creek watershed (in both Frederick and Montgomery Counties) was gathered from several sources: the EPA Envirofacts website; the Lower Monocacy Watershed Characterization report; Frederick County; and the Maryland Department of Natural Resources (U.S. EPA 2007c, MDNR 2003a, MDNR 2007d). The EPA Envirofacts website provides information on facilities and sites that are regulated by the EPA through four of its national programs: Superfund National Priorities List (NPL); Resource Conservation and Recovery Act (RCRA) – Treatment, Storage, Disposal Facilities; Toxic Release Inventory Program; and National Pollutant Discharge Elimination System (NPDES). Queries for the Envirofacts data were executed in May 2007[3].

Both point and nonpoint sources of pollutants are important considerations when identifying and prioritizing potential restoration measures. The National Pollutant Discharge Elimination System (NPDES) data were used to identify facilities in the Bennett Creek watershed that have permits to make discharges into surface water or groundwater. Land use land cover data, stormwater data and Envirofacts data on permitted air releases, toxic releases and hazardous waste handlers were used to identify nonpoint sources of pollutants.

The Lower Monocacy WRAS report notes several likely sources of nonpoint source pollution, such as residential developments, golf courses, large new commercial developments, and agricultural parcels (Frederick County DPW 2004). Some of the older

[3] The data should be accurate and current. However it should be noted that there is always the possibility that permits have since been added or removed, or that the original data was not entirely accurate. The Envirofacts data were verified by Ed Gertler from the Maryland Department of the Environment (personal communication with Jen Stamp, January 2008).

residential developments were built prior to storm water management requirements, and some may have failing septic systems. Other sources were reported in the Stream Corridor Assessment (Czwartacki et al. 2004). Problems cited included livestock accessing the stream and trash dumps in or along the stream.

No land fills or Superfund sites are located in the Bennett Creek project area. Only one facility, the Pleasant Branch WWTP, is currently permitted to make discharges into surface water or groundwater (Figure 2-5, Table 2-10) (U.S. EPA 2007c). The Pleasant Branch WWTP is located in the Pleasant Branch subwatershed and discharges less than one million gallons of effluent per day. Another wastewater treatment plant, Hyattstown WWTP, is located outside of the project area in Montgomery County in the Little Bennett subwatershed. Wastewater treatment plants are of particular interest because sewage effluent may contribute nutrients or microbes that consume oxygen, which reduces oxygen available for other aquatic life (U.S. EPA 2008). Five other facilities in the project area have had NPDES Non-Major permits within the last five years, but the permits have expired. These facilities include a swimming pool, two schools and three commercial or industrial facilities. They are located in the Fahrney, Bennett Creek-Middle Mainstem and Monocacy Direct - North subwatersheds.

Twenty-three facilities in the Bennett Creek project area are permitted to make air releases (Figure 2-6, Table 2-11) (U.S. EPA 2007c). Twenty-two of these facilities have permits to make 'potential uncontrolled emissions of less than 100 tons per year.' The Fannie Mae Data Center has the class code 'potential emissions below major source thresholds if complies with federal regulations/limits.' These facilities are scattered throughout the watershed, and include schools, cleaners, gas stations, and clusters of businesses in small commercial and industrial districts. Eight facilities in the project area have permits to generate, transport, treat, store and dispose of hazardous waste (Table 2-12) (U.S. EPA 2007c). They are all small generators or conditionally exempt small generators. Four are located in small commercial districts in the Little Bennett subwatershed. Also located in the Little Bennett subwatershed are four facilities that are permitted to manufacture or store toxic chemicals, but three of these are located outside of the project area (Table 2-13) (U.S. EPA 2007c).

2.5. Spatial and temporal distribution of data

The data that is available for each subwatershed (within the project area) is summarized in Table 2-14. Six of the subwatersheds (Monocacy Direct-North, Fahrney, Bennett Ck – Lower and Upper Mainstem, Bear, Pleasant) have more than one biological sampling site. If the targeted sites are excluded, no biological data are available for Pleasant Branch. Habitat and water chemistry data were collected during the biological sampling events. In addition, SCA surveys were performed in three of these subwatersheds (Pleasant, Fahrney and Bear).

Three of the fifteen subwatersheds (Bennett Middle Mainstem, Sugarloaf and Monocacy Direct-South) have one biological sampling site. The biological sampling event in Bennett Middle Mainstem occurred in 1996. The sampling events in the other two

subwatersheds occurred more recently (2003 and 2007). The remaining six subwatersheds have no biological data, but SCA and nutrient synoptic data are available for the Urbana and North subwatersheds. Information for the Little Monocacy, Furnace, Lilypons, and Little Bennett subwatersheds was derived mainly from land use land cover data and aerial photographs.

Biological sampling sites are not evenly distributed in several of the subwatersheds. Five of the randomly selected sites that were sampled as part of the 2007 surveys were clumped on the same stream in the Monocacy Direct-North subwatershed, in an area largely protected by the National Park Service. This also appeared to occur in the Bennett Lower Mainstem subwatershed. Several of the 2007 randomly selected sites were clumped in one area, which is protected by the Stronghold Preserve. No sites were sampled in the Urbana and North subwatersheds, which are currently undergoing development and contain several priority restoration sites (Frederick County DPW 2004).

2.6. Data sufficiency for stressor identification

There is limited biological data available for many of the subwatersheds. When targeted and randomly selected sites and sites outside the project area are included, sufficient data are available to do stressor source identifications for eight subwatersheds: Pleasant, Bennett Ck – Upper, Middle and Lower, Fahrney, Monocacy Direct-North, Little Bennett, and Bear.

Table 2-1. Summary of the different types of data included in the stressor source inventory, categorized into three tiers.

Tier 1 - Data from sites in Bennett Creek study area where biological data *ARE* available						
Sample Year	**Biology**	**Chemistry**	**Physical Habitat**	**Other**	**Source**	**Credibility**
Spring	Benthic IBI	*Grab samples:*	PHI habitat metrics		MBSS	High
1996-2007	Benthic metrics	pH, conductivity, nutrients,	various morphological data		Versar	High
	Benthic taxa list	ANC, SO4			Montgomery County	High
Summer	Fish IBI	*Insitu:*	PHI habitat metrics		MBSS	High
1996-2007	Fish metrics	Field temp	some pebble count data		Versar	High
	Fish taxa list	DO	various morphological data		Montgomery County	High
	Aquatic Vegetation	Field pH	% LULC			
	Reptiles and Amphibians	Field conductivity				
	Mussels	Turbidity				
Tier 2 - Data from sites in Bennett Creek study area where biological data are *NOT* available						
Sample Year	**Biology**	**Chemistry**	**Physical Habitat**	**Other**	**Source**	**Credibility**
Spring	None	*Nutrient Synoptic Survey:*	None		MDNR/WRD	High
2003		NO2+NO3, PO4				
2003	None	None	SCA stream walk data		MDNR/WRD	Low
2007	None	None	None	Envirofacts	EPA	High
Tier 3 - Data from sites in the same ecoregion, but *NOT* in the Bennett Creek study area						
Sample Year	**Biology**	**Chemistry**	**Physical Habitat**	**Other**	**Source**	**Credibility**
Spring	Benthic IBI	*Grab samples:*	PHI habitat metrics		MBSS	High
1995-2007	Benthic metrics	pH, conductivity, nutrients,	various morphological data		Versar	High
	Benthic taxa list	ANC, SO4			Montgomery County	
Summer	Fish IBI	*Insitu:*	PHI habitat metrics		MBSS	High
1995-2007	Fish metrics	Field temp	various morphological data		Versar	High
	Fish taxa list	DO	% LULC		Montgomery County	
	Aquatic Vegetation	Field pH				
	Reptiles & Amphibians	Field conductivity				
	Mussels					

Table 2-2a. Benthic macroinvertebrate IBI metrics for the Combined Highlands and their threshold values (Southerland et al. 2005).

Benthic IBIs (metrics)	**Thresholds**		
Combined Highlands	**5**	**3**	**1**
Number of Taxa	≥ 24	15 - 23	< 15
Number of EPT Taxa	≥ 14	8 - 13	< 8
Number of Ephemeroptera	≥ 5	3 - 4	< 3
Percent Intolerant Urban	≥ 80	38 - 79	< 38
Percent Tanytarsini	≥ 4	0.1 - 3.9	< 0.1
Percent Scraper	≥ 13	3 - 12	< 3
Percent Swimmer	≥ 18	3 - 17	< 3
Percent Diptera	≤ 26	27 - 49	> 50

Table 2-2b. Fish IBI metrics for the Warmwater Highlands and their threshold values. The 'Number of Benthic species' metric was adjusted for catchment size (Southerland et al. 2005).

Fish IBIs (metrics)	**Thresholds**		
Warmwater Highlands	**5**	**3**	**1**
Abundance per square meter	≥ 0.65	0.31 - 0.64	< 0.31
Number of Benthic species	≥ 0.25	0.11 - .024	< 0.11
Percent Tolerant	≤ 39	40 - 80	> 80
Percent Generalist, Omnivores, Insectivores	≤ 61	62 - 96	> 96
Percent Insectivores	≥ 33	1 - 32	< 1
Percent Abundance of Dominant Taxa	≤ 38	39 - 89	> 89

Table 2-3. MBSS Index of Biological Integrity (IBI) scores range from 1.0 (worst) to 5.0 (best) (MDNR 2003a).

Index of Biological Integrity	**Very Poor**	**Poor**	**Fair**	**Good**
Fish (FIBI) & Benthic (BIBI)	1.0-1.9	2.0-2.9	3.0-3.9	4.0-5.0

Table 2-4a. Sites in the Frederick County portion of the Bennett Creek watershed that have biological data.

SITE ID	SUBSHED	Benthic Sample Year	B_IBI Score	Fish Sample Year	F_IBI Score	Site Selection	Source	North_83m	East_83m
LMON-130-T-2000	Bear Branch	2000	3.75	2000	no fish	Targeted	MBSS	177924.50	365857.00
BENN08-2007	Bear Branch	2007	3.00			Random	Versar	178286.64	365828.27
BENN06-2007	Bear Branch	2007	4.00			Random	Versar	178942.44	366121.06
LMON-421-T-2000	Bennett Ck - Lower Mainstem	2000	2.75	2000	3.67	Targeted	MBSS	181197.60	362569.50
BENN29-2007	Bennett Ck - Lower Mainstem	2007	4.25			Random	Versar	180183.64	365886.27
BENN13-2007	Bennett Ck - Lower Mainstem	2007	3.25			Random	Versar	180312.64	366350.27
BENN32-2007	Bennett Ck - Lower Mainstem	2007	4.00			Random	Versar	180514.64	366326.27
BENN27-2007	Bennett Ck - Lower Mainstem	2007	4.25			Random	Versar	180733.64	366464.27
FR-P-015-304-96	Bennett Ck - Middle Mainstem	1996	2.25	1996	4.33	Random	MBSS	183403.40	371259.41
FR-P-377-242-96	Bennett Ck - Upper Mainstem	1996	1.25	1996	4.00	Random	MBSS	181677.98	375906.21
BCBC314	Bennett Ck - Upper Mainstem	2003	2.50	1997, 1999, 2003	4.33, 3.67, 4.33	Random	MO	181861.90	375106.00
BENN11-2007	Bennett Ck - Upper Mainstem	2007	3.00			Random	Versar	182626.88	375589.06
BENN-03-2005	Fahrney	2005	2.75	2005	3.67	Targeted	Versar	184944.81	379257.72
BENN-04-2005	Fahrney	2005	3.25	2005	3.67	Targeted	Versar	185490.78	375839.97
BENN06P2007	Fahrney	2006, 2007	2.75, 3.00	2006	4.00	Targeted	Versar	184853.70	372942.02
FR-P-101-233-96	Fahrney	1996	1.75	1996	4.00	Random	MBSS	184334.57	372908.87
FR-P-351-112-96	Fahrney	1996	3.00	1996	3.67	Random	MBSS	186030.21	375939.31
BENN03-2007	Fahrney	2007	2.50			Random	Versar	185156.63	377772.24
BENN25-2007	Fahrney	2007	1.75			Random	Versar	184374.63	379043.24
NCRW-115-N-2004	Monocacy Direct-North	2004	2.00	2004	2.67	Targeted	MBSS	187802.00	365286.00
MONY-102-N-2004	Monocacy Direct-North	2004	2.50	2004	1.67	Targeted	MBSS	187799.00	365789.00
BENN01-2007	Monocacy Direct-North	2007	3.25			Random	Versar	185751.63	366690.27
BENN17-2007	Monocacy Direct-North	2007	3.00			Random	Versar	187184.63	364849.27
BENN18-2007	Monocacy Direct-North	2007	3.25			Random	Versar	187913.62	365410.27
BENN30-2007	Monocacy Direct-North	2007	1.50			Random	Versar	187571.63	365805.27
BENN33-2007	Monocacy Direct-North	2007	3.75			Random	Versar	185997.63	366501.27
LMON-210-R-2003	Monocacy Direct-South	2003	2.25	2003	4.33	Random	MBSS	174908.90	362371.50
BENN-01-2004	Pleasant Branch	2004	4.00	2004	4.67	Targeted	Versar	183725.14	375616.39
BENN-02-2004	Pleasant Branch	2004	2.75	2004	4.33	Targeted	Versar	184071.67	376122.83
BENN05P2007	Pleasant Branch	2006, 2007	3.00, 2.75	2006	3.67	Targeted	Versar	182451.34	374234.35
BENN15-2007	Sugarloaf	2007	4.00			Random	Versar	178165.64	368434.26

Table 2-4b. Sites in the Montgomery County portion of the Bennett Creek watershed that have biological data.

SITE ID	SUBSHED	Benthic Sample Year	B_IBI Score	Fish Sample Year	F_IBI Score	Site Selection	Source	North_83m	East_83m
MO-P-111-136-96	Little Bennett	1996	2.75	1996	2.00	Random	MBSS	176593.88	375593.47
MO-P-495-312-96	Little Bennett	1996	2.25	1996	4.67	Random	MBSS	179114.55	373062.45
LMON-240-T-2000	Little Bennett	2000	3.50	2000	3.00	Targeted	MBSS	177924.50	377626.20
LMON-119-R-2003	Little Bennett	2003	3.00	2003	1.33	Random	MBSS	176026.00	375728.70
LMON-215-R-2003	Little Bennett	2003	2.75	2003	3.00	Random	MBSS	177127.30	376973.50
LMON-322-R-2003	Little Bennett	2003	3.25	2003	4.00	Random	MBSS	178678.80	374201.40
MO-P-248-125-96	Bennett Ck - Upper Main	1996	3.25	1996	4.00	Random	MBSS	181525.63	381409.94
BCBC305	Bennett Ck - Upper Main	1999	2.25	1997, 1999	4.33, 4.00	Random	MO	182517.80	379531.00
BCBC306	Bennett Ck - Upper Main	1999	3.50	1997, 1999	3.33, 3.00	Random	MO	180273.00	379175.00
BCBC210	Bennett Ck - Upper Main	1999, 2003	2.75, 2.00	1999, 2003	3.67, 4.00	Random	MO	181106.30	377326.00
BCBC211	Bennett Ck - Upper Main	1999, 2003	3.50, 3.75	1999, 2003	2.67, 3.33	Random	MO	181175.60	375375.00
BCBC301	Bennett Ck - Upper Main	1999, 2003	4.00, 3.75	1997, 1999, 2003	3.67, 4.00, 3.67	Random	MO	182230.10	380785.00
BCBC308/308R	Bennett Ck - Upper Main	1999, 2003	2.25, 1.25/2.25	1997, 1999, 2003	3.33, 3.33, 3.00	Random	MO	181767.40	378326.00
BCBC401	Bennett Ck - Upper Main	1999, 2003	2.00, 1.25	1997, 1999, 2003	4.67, 3.67, 3.67	Random	MO	181929.10	378108.00
LMON-131-R-2003	Bennett Ck - Upper Main	2003	3.25	2003	3.00	Random	MBSS	181450.40	381310.40
MO-P-064-328-97	Little Monocacy	1997	2.00	1997	4.33	Random	MBSS	171944.21	362181.52
MO-P-251-115-97	Little Monocacy	1997	3.75	1997	2.67	Random	MBSS	172661.51	368403.04
PRMO-114-R-2002	Little Monocacy	2002	3.25	2002	3.00	Random	MBSS	169947.50	363538.60
PRMO-115-R-2002	Little Monocacy	2002	4.25	2002	3.00	Random	MBSS	169940.20	363416.10
PRMO-120-R-2002	Little Monocacy	2002	2.25	2002	2.67	Random	MBSS	171916.40	361378.00
PRMO-304-R-2002	Little Monocacy	2002	3.75	2002	4.00	Random	MBSS	173691.40	365140.60
PRMO-307-R-2002	Little Monocacy	2002	3.25	2002	4.00	Random	MBSS	171953.40	361673.20
PRMO-311-R-2002	Little Monocacy	2002	3.00	2002	4.33	Random	MBSS	172623.10	361217.00
PRMO-323-R-2002	Little Monocacy	2002	2.75	2002	4.33	Random	MBSS	173422.40	365068.20

Table 2-5. Descriptive statistics for B_IBI and F_IBI scores in each subwatershed. Only randomly selected sampling sites in the project area were used in these calculations.

Subwatershed	B_IBI					F_IBI				
	N	Mean	St Dev	Min	Max	N	Mean	St Dev	Min	Max
Fahrney	4	2.25	0.61	1.75	3.00	2	3.84	0.23	3.67	4.00
Monocacy Direct-North	5	2.95	0.86	1.50	3.75	0				
Bennett Ck - Lower Mainstem	4	3.94	0.47	3.25	4.25	0				
Bear	2	3.50	0.71	3.00	4.00	0				
Bennett Ck - Upper Mainstem	3	2.25	0.80	1.50	3.00	2	4.06	0.08	4.00	4.11
Bennett Ck - Middle Mainstem	1	2.25				1	4.33			
Monocacy Direct-South	1	2.25				1	4.33			
Sugarloaf	1	4.00				0				
Overall Totals	**21**	**2.95**	**0.69**	**1.50**	**4.25**	**6**	**4.14**	**0.16**	**3.67**	**4.11**

Table 2-6. List of sites where nutrient samples were taken in the Bennett Creek watershed during the 2003 nutrient synoptic survey (MDNR 2003b).

Station	Subwatershed	Longitude	Latitude	Location
65	Lilypons	-77.711750	39.497700	Bennett Cr below Lili Pons
66	Bennett Creek - Lower Mainstem	-77.677533	39.489233	Bennett Cr at Mt Ephram Rd
67	Bear Branch	-77.677800	39.488807	Bear Br at Mt Ephram Rd
68	North Branch	-77.656033	39.508517	N Br Bennett Cr at Peters Rd
69	Bennett Creek - Lower Mainstem	-77.656033	39.508517	Bennett Cr at Peters Rd
70	Urbana Branch	-77.639800	39.502800	Urbana Br at Peters Rd
71	Bennett Creek - Lower Mainstem	-77.604267	39.490167	Bennett Cr at Thurston Rd
72	Fahrney Branch	-77.544083	39.530217	Fahrney Br at Big Woods Rd
73	Bennett Creek - Upper Mainstem	-77.544083	39.530217	Bennett Cr at Big Woods Rd
74	Fahrney Branch	-77.507950	39.551833	Fahrney Br at Prices Distillery Rd
75	Bennett Creek - Upper Mainstem	-77.497800	39.514617	Bennett Cr at Rt 75
76	Bennett Creek - Upper Mainstem	-77.426283	39.508300	Bennett Cr at Barnes Rd
77	Sugarloaf	-77.597883	39.468283	Little Bennett at Covel Rd
78	Monocacy Direct - South	-77.724850	39.406350	Furnace Br off Rt 28
94	Fahrney Branch	-77.450117	39.565783	Fahrney Br. at Md. Rt. 75
95	Pleasant Branch	-77.468600	39.538183	Pleasant Br at Windsor Knolls MS

Table 2-7. Results from the 2003 nutrient synoptic survey in the Bennett Creek watershed (MDNR 2003b).

Station	Subwatershed	Sampling Date	PO4 (mg/L)	P Rating	NO2 + NO3 (mg/L)	N Rating	PO4 (kg/h/d)	P Rating	NO2 + NO3 (kg/h/d)	N Yield Rating
72	Fahrney Branch	1-May-03	0.006	moderate	4.22	**high**	0.000073	baseline	0.051035	**excessive**
74	Fahrney Branch	2-May-03	0.011	**high**	4.40	**high**	0.000168	baseline	0.067343	**excessive**
94	Fahrney Branch	2-May-03	0.005	moderate	4.75	**high**	0.000089	baseline	0.084177	**excessive**
78	Monocacy Direct - South	30-Apr-03	0.004	baseline	1.58	moderate	0.000043	baseline	0.017021	**moderate**
77	Sugarloaf	1-May-03	0.003	baseline	1.87	moderate	0.000787	moderate	0.490863	**excessive**
65	Lilypons	30-Apr-03	0.003	baseline	2.28	moderate	0.000030	baseline	0.022571	**high**
66	Bennett Creek - Lower Main	1-May-03	0.003	baseline	1.96	moderate	0.000030	baseline	0.019377	moderate
67	Bear Branch	1-May-03	0.006	moderate	0.14	baseline	0.000078	baseline	0.001816	baseline
68	North Branch	1-May-03	0.002	baseline	1.99	moderate	0.000020	baseline	0.020093	**high**
69	Bennett Creek - Lower Main	1-May-03	0.002	baseline	2.43	moderate	0.000020	baseline	0.024781	**high**
70	Urbana Branch	1-May-03	0.003	baseline	1.89	moderate	0.000026	baseline	0.016520	moderate
71	Bennett Creek - Lower Main	1-May-03	0.003	baseline	3.26	**high**	0.000035	baseline	0.038200	**excessive**
73	Bennett Creek - Upper Main	1-May-03	0.004	baseline	3.25	**high**	0.000048	baseline	0.038968	**excessive**
75	Bennett Creek - Upper Main	2-May-03	0.003	baseline	3.20	**high**	0.000039	baseline	0.041836	**excessive**
76	Bennett Creek - Upper Main	2-May-03	0.007	moderate	3.12	**high**	0.000087	baseline	0.038625	**excessive**
95	Pleasant Branch	2-May-03	0.003	baseline	4.86	**high**	0.000042	baseline	0.068275	**excessive**

Table 2-8. *In situ* water quality variables that were measured during the 2003 nutrient synoptic survey in the Bennett Creek watershed (MDNR 2003b).

Station	Subshed	Sampling Date	Time	Water Temp (°C)	pH	pH category	DO (mg/L)	Conductivity (µS/cm)
72	Fahrney Branch	1-May-03	900	15.08	7.40	neutral	9.88	171
74	Fahrney Branch	2-May-03	1530	20.77	7.59	basic	9.44	158
94	Fahrney Branch	2-May-03	1600	19.06	7.43	neutral	9.90	144
78	Monocacy Direct - South	30-Apr-03	1315	15.80	8.04	basic	13.32	82
77	Sugarloaf	1-May-03	1015	15.22	7.52	basic	10.23	173
65	Lilypons	30-Apr-03	1345	16.15	7.82	basic	10.32	174
66	Bennett Creek - Lower Main	1-May-03	1300	17.98	7.98	basic	10.77	158
67	Bear Branch	1-May-03	1250	17.90	7.89	basic	9.45	86
68	North Branch	1-May-03	1125	16.85	8.15	basic	11.21	226
69	Bennett Creek - Lower Main	1-May-03	1135	17.93	8.03	basic	10.90	172
70	Urbana Branch	1-May-03	1215	18.05	8.22	basic	10.46	279
71	Bennett Creek - Lower Main	1-May-03	1100	15.98	7.77	basic	11.03	170
73	Bennett Creek - Upper Main	1-May-03	905	14.78	7.47	neutral	10.75	153
75	Bennett Creek - Upper Main	2-May-03	1510	19.11	7.35	neutral	9.80	135
76	Bennett Creek - Upper Main	2-May-03	1415	19.29	7.45	neutral	9.80	147
95	Pleasant Branch	2-May-03	1445	17.55	7.23	neutral	9.78	143

Table 2-9. Summary of the results of the Stream Corridor Assessment Survey (SCA), which was conducted in areas of the Bennett Creek watershed in 2003 (Czwartacki et al. 2004).

Potential Problems	Number	Estimated Length	Very Severe	Severe	Moderate	Low Severity	Minor
Channel Alterations	4	1167 ft (0.22 miles)	0	0	0	0	4
Erosion Sites	44	80880 ft (15.32 miles)	15	13	5	9	2
Exposed Pipes	0	NA	0	0	0	0	0
Fish Barriers	20	NA	0	0	1	6	13
Inadequate Buffers	56	63350 ft (12.38 miles)	23	8	8	10	7
Pipe Outfalls	15	NA	0	1	2	1	11
Trash Dumpings	3	NA	0	3	0	0	0
Unusual Conditions	8	NA	0	4	0	4	0
Total	150		38	29	16	30	37
Comments	3						
Representative Sites	22						

Table 2-10. Facilities in the Bennett Creek watershed that have current or expired NPDES permits (U.S. EPA 2007c, MDNR 2003a). MGD is millions of gallons per day.

Facility	Camp Eagle (swimming pool)	American Telephone & Telegraph	Kemptown Elementary School	Pleasant Branch WWTP	Jack Gresham Residence	Etron	Hyattstown WWTP
Subwatershed	Fahrney	Fahrney	Fahrney	Pleasant	Monocacy Direct - North	Bennett Creek - Middle Main	Little Bennett
In Project Area	Yes	Yes	Yes	Yes	Yes	Yes	**No**
Category	AMUSEMENT & RECREATION SERVICES	TELEPHONE COMMUNICATIONS	ELEMENTARY & SECONDARY SCHOOLS	SEWERAGE SYSTEMS	OPER OF DWELL OTHER THAN APART	REFUSE SYSTEMS	SEWERAGE SYSTEMS
Flow (MGD)	NA	0.0009	0.0050	0.1000	NA	NA	0.0200
Permit Status	expired	expired	expired	**current**	expired	expired	**current**
Permit Expiration Date	12/27/2006	11/30/2003	3/31/2006	7/31/2009	5/24/2007	9/30/2002	8/31/2009
Last Issuance Date	7/18/2002	12/1/1998	4/1/2001	8/1/2004	5/24/2002	6/1/1997	9/1/2004
NPDES Tracking #	MDG766258	MD0066273	MD0056481	MD0065269	MDG918121	MDG912999	MD0067768
Town	Ijamsville	Monrovia	Monrovia	Ijamsville	Adamstown	Ijamsville	Clarksburg
Longitude	-77.3064	-77.2815	-77.2378	-77.2931	-77.4012	-77.3330	-77.3142
Latitude	39.3410	39.3475	39.3322	39.3169	39.3098	39.2980	39.2776

Table 2-11. Locations of permitted sources of air pollution in the Bennett Creek watershed (U.S. EPA 2007c). Class codes for all facilities except for the Fannie Mae Data Center are 'potential uncontrolled emissions < 100 tons/yr. The Fannie Mae Data Center is classified as 'potential emissions below major source thresholds if fed regs/limits are complied with.'

Subwatershed	Facility	In Project Area	TOWN	LONG	LAT
Bennett Creek - Middle Main	Designer Kitchen and Baths	Yes	Ijamsville	-77.3332	39.2976
Bennett Creek - Middle Main	Etron	Yes	Ijamsville	-77.3330	39.2980
Bennett Creek - Middle Main	Line Woodworking	Yes	Ijamsville	-77.3319	39.2983
Bennett Creek - Upper Main	Day's Distillery	Yes	Ijamsville	-77.2606	39.3153
Bennett Creek - Upper Main	Amoco	No	Damascus	-77.2071	39.2878
Bennett Creek - Upper Main	Mont. Co. Govt.	No	Damascus	-77.1981	39.3180
Bennett Creek - Upper Main	Sam's Custom Body	No	Damascus	-77.2064	39.2904
Fahrney	American Telephone & Telegraph	Yes	Monrovia	-77.2815	39.3475
Fahrney	Citgo	Yes	Monrovia	-77.2548	39.3439
Fahrney	Green Valley Cleaners	Yes	Monrovia	-77.2548	39.3439
Fahrney	Green Valley Elementary School	Yes	Monrovia	-77.2647	39.3449
Fahrney	Green Valley Garage	Yes	Monrovia	-77.2606	39.3442
Fahrney	Kemptown Elementary School	Yes	Monrovia	-77.2378	39.3322
Little Bennett	Damascus Elementary School	No	Damascus	-77.2111	39.2853
Little Bennett	Bob's Cabinets	Yes	Ijamsville	-77.3143	39.2915
Little Bennett	Crafted Interiors	Yes	Ijamsville	-77.3144	39.2908
Little Bennett	Custom Design Woodworks	Yes	Ijamsville	-77.3144	39.2897
Little Bennett	Design by Lightfoot	Yes	Ijamsville	-77.3145	39.2914
Little Bennett	Manufacturing Solutions	Yes	Ijamsville	-77.3144	39.2897
Little Bennett	Rick's Cabinets	Yes	Ijamsville	-77.3145	39.2914
Little Bennett	Superior Laminates	Yes	Ijamsville	-77.3145	39.2914
Little Bennett	Damascus High School	No	Damascus	-77.2113	39.2822
Little Bennett	Burdette Bros	Yes	Clarksburg	-77.3131	39.2883
Little Bennett	Gas Mart	Yes	Clarksburg	-77.3131	39.2882
Monocacy Direct - North	Flinthill Grocery	Yes	Adamstown	-77.4012	39.3098
Pleasant	Windsor Knolls Middle School	Yes	Ijamsville	-77.2784	39.3220
Urbana	Fannie Mae Data Center	Yes	Frederick-Urbana	-77.3568	39.3236
Urbana	Urbana Elementary School	Yes	Frederick-Urbana	-77.3564	39.3267

Table 2-12. Permitted hazardous waste handlers in the Bennett Creek watershed (U.S. EPA 2007c).

Subwatershed	Facility	In Project Area	TOWN	LONG	LAT	Class
Fahrney	American Telephone & Telegraph	Yes	Monrovia	-77.2815	39.3475	Conditionally Exempt Small Generator
Fahrney	Green Valley Cleaners	Yes	Monrovia	-77.2548	39.3439	Small Generator
Bennett Creek - Upper Main	Nu-Look One Hour Cleaners	No	Damascus	-77.2093	39.2857	NA
Monocacy Direct - North	Flint Hill Auto	Yes	Adamstown	-77.4011	39.3099	Conditionally Exempt Small Generator
Urbana Branch	7 Eleven	Yes	Frederick-Urbana	-77.3547	39.3245	Small Generator
Little Bennett	Biological Research	Yes	Ijamsville	-77.3158	39.2894	Small Generator
Little Bennett	Myers Press	Yes	Ijamsville	-77.3143	39.2915	Conditionally Exempt Small Generator
Little Bennett	Pathology Associates	Yes	Ijamsville	-77.3148	39.2913	Small Generator
Little Bennett	Ryan Inc Central	Yes	Ijamsville	-77.3147	39.2913	Conditionally Exempt Small Generator
Little Bennett	Damascus High School	No	Damascus	-77.2113	39.2822	Conditionally Exempt Small Generator
Little Bennett	Damascus Elementary School	No	Damascus	-77.2111	39.2853	Conditionally Exempt Small Generator

Table 2-13. Locations of facilities in the Bennett Creek watershed that manufacture or store toxic chemicals (U.S. EPA 2007c).

Subwatershed	Facility	In Project Area	TOWN	LONG	LAT
Little Bennett	Burdette Bros	Yes	Clarksburg	-77.3131	39.2883
Little Bennett	Oliver L P & Sons	No	Clarksburg	-77.3027	39.2608
Little Bennett	Pleaseant Excavating Co.	No	Clarksburg	-77.2976	39.2497
Little Bennett	Rentals Unlimited Inc.	No	Clarksburg	-77.2974	39.2493

Table 2-14. Summary of the data available for each subwatershed. Only sites within the project area are included in this table.

Subwatershed	# of Biological Sampling Sites		# of nutrient survey sites	SCA data	# of priority restoration sites
	Random	Targeted			
Monocacy Direct-North	5	2	0	no	0
Fahrney	4	3	3	yes	6
Bennett Ck - Lower Mainstem	4	1	3	no	0
Bennett Ck - Upper Mainstem	3	0	3	no	0
Bear	2	1	1	yes	1
Pleasant Branch	0	3	1	yes	10
Bennett Ck - Middle Mainstem	1	0	0	no	0
Monocacy Direct-South	1	0	1	no	0
Sugarloaf	1	0	1	no	0
Urbana	0	0	1	yes	3
North	0	0	1	yes	3
Furnace Branch	0	0	0	no	0
Lilypons	0	0	1	no	0
Little Bennett	0	0	0	no	0
Little Monocacy River	0	0	0	no	0

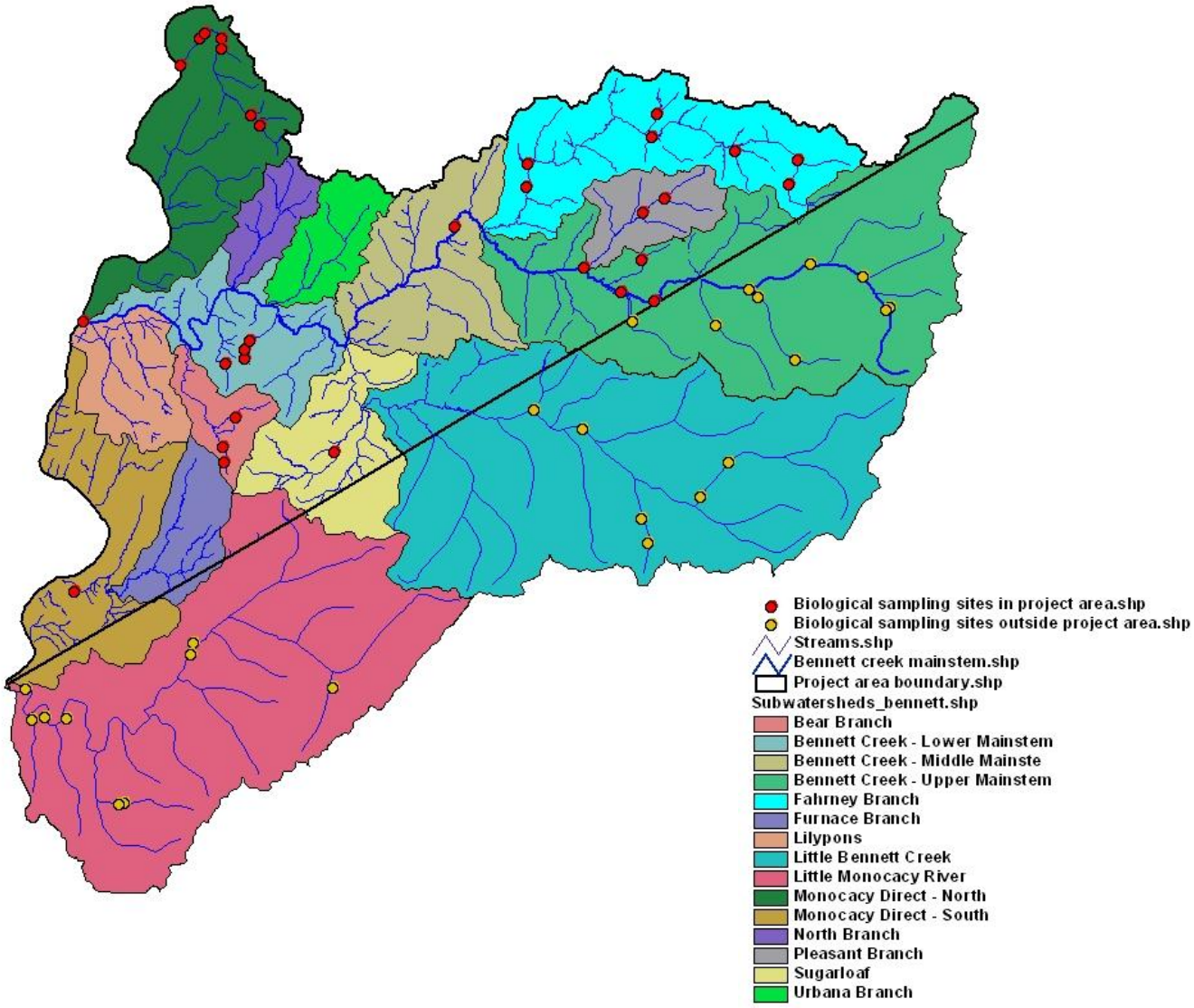

Figure 2-1. Locations of biological sampling sites in the Bennett Creek watershed.

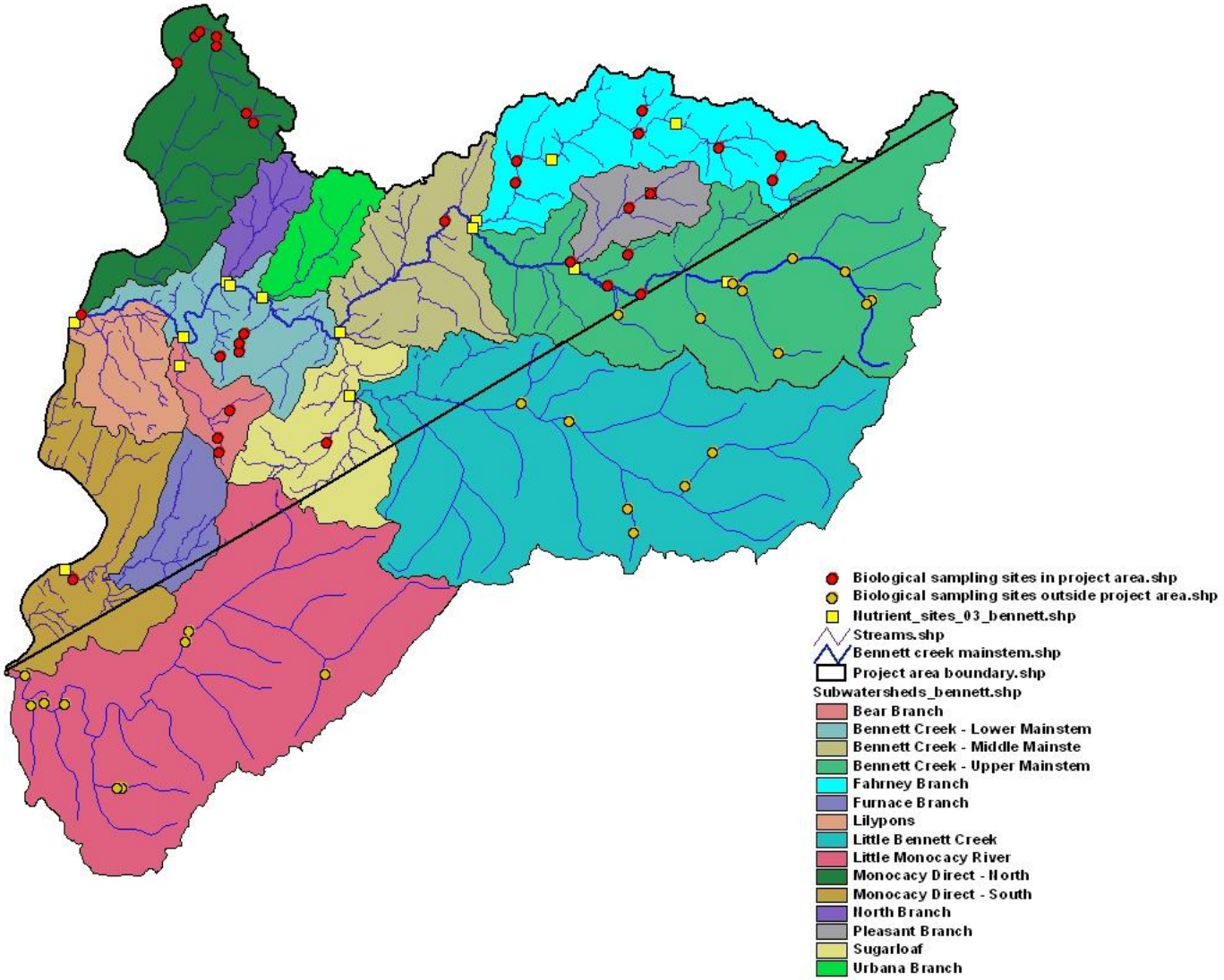

Figure 2-2. Locations of nutrient synoptic survey sites in the Bennett Creek watershed (MDNR[2] 2003).

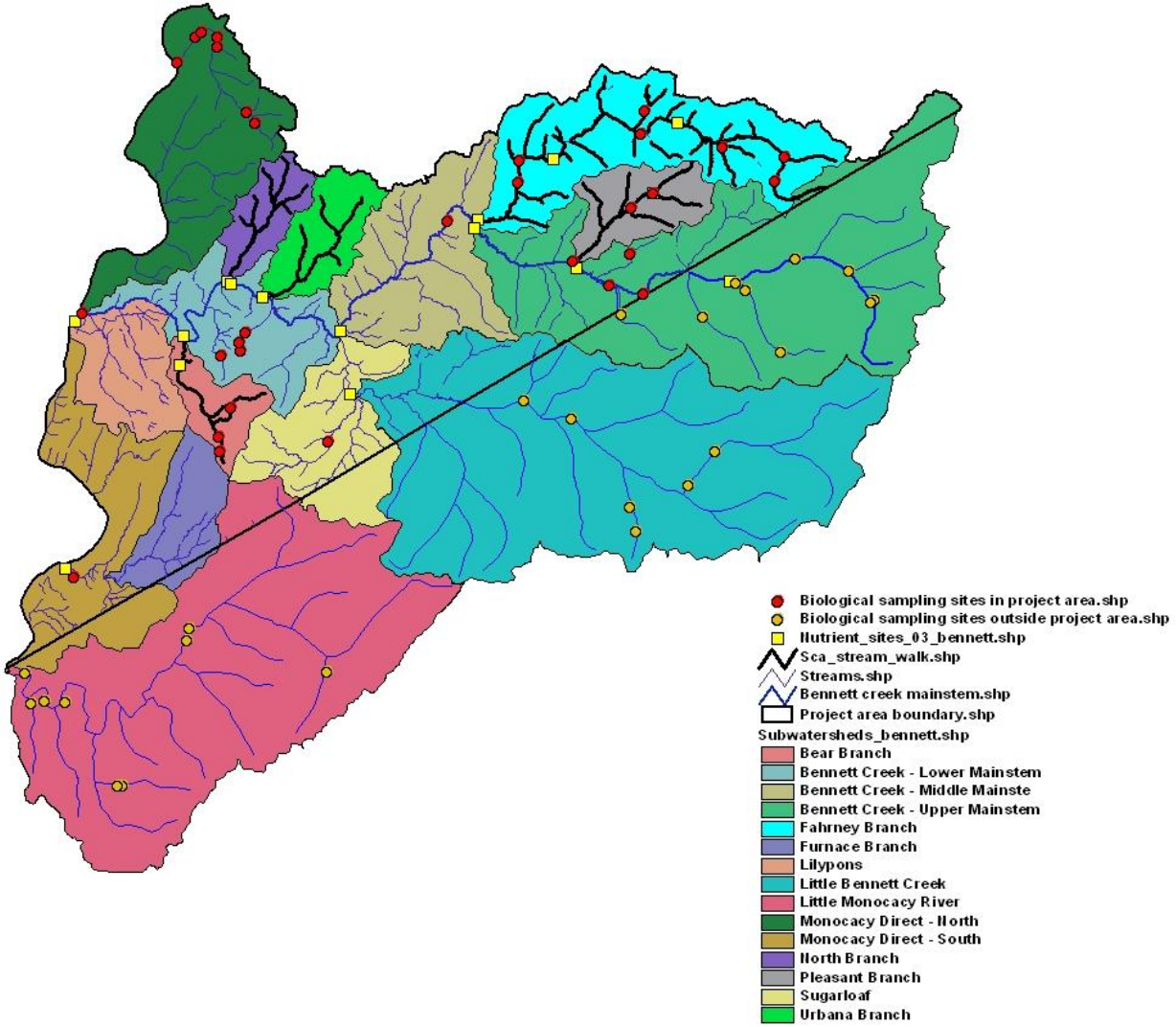

Figure 2-3. Locations of the stream segments that were walked during the 2003 Stream Corridor Assessment in the Bennett Creek watershed (Czwartacki et al. 2004).

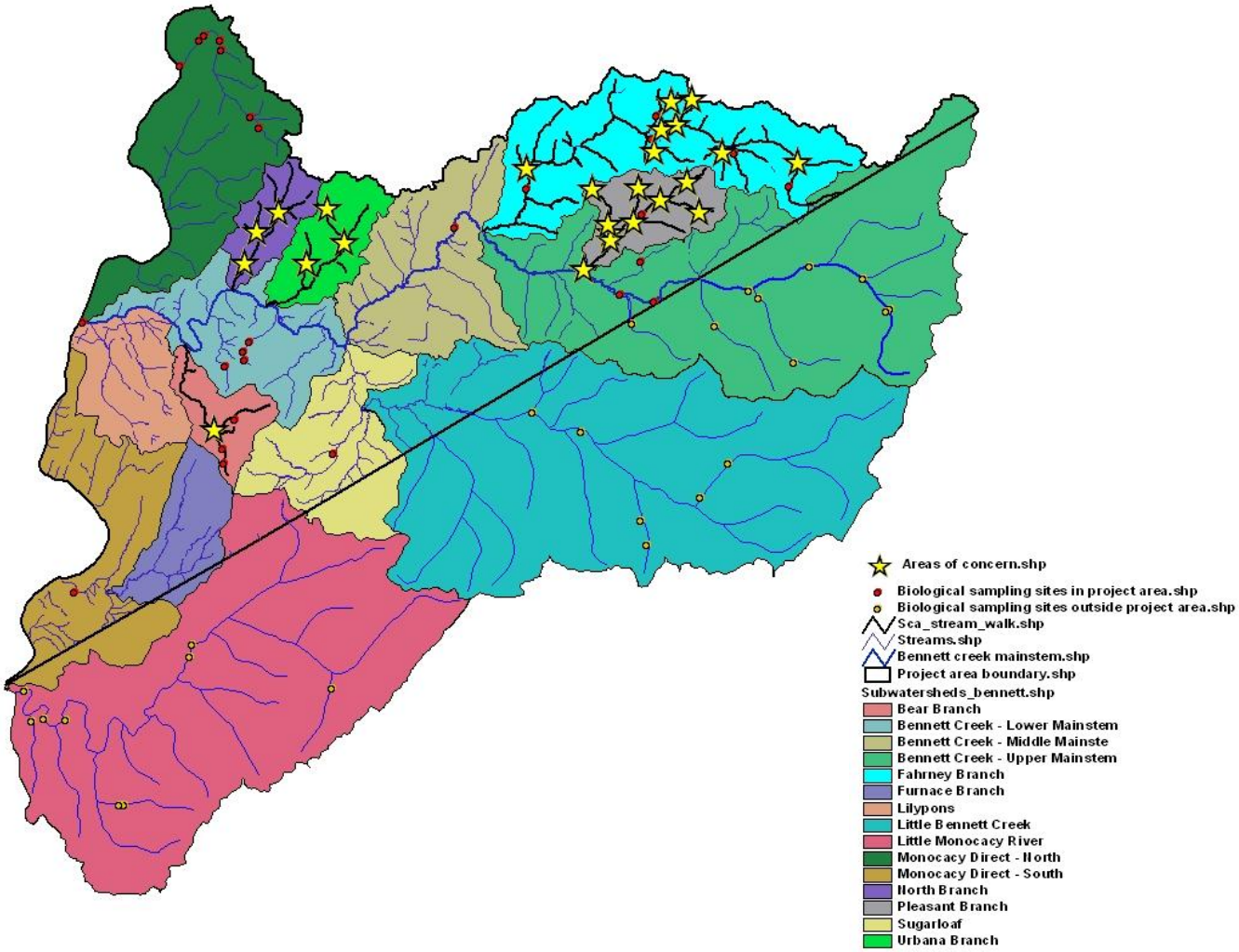

Figure 2-4. Locations of the Bennett Creek Watershed Priority Restoration Sites, which were identified in the Lower Monocacy Watershed Restoration Action Strategy (2004).

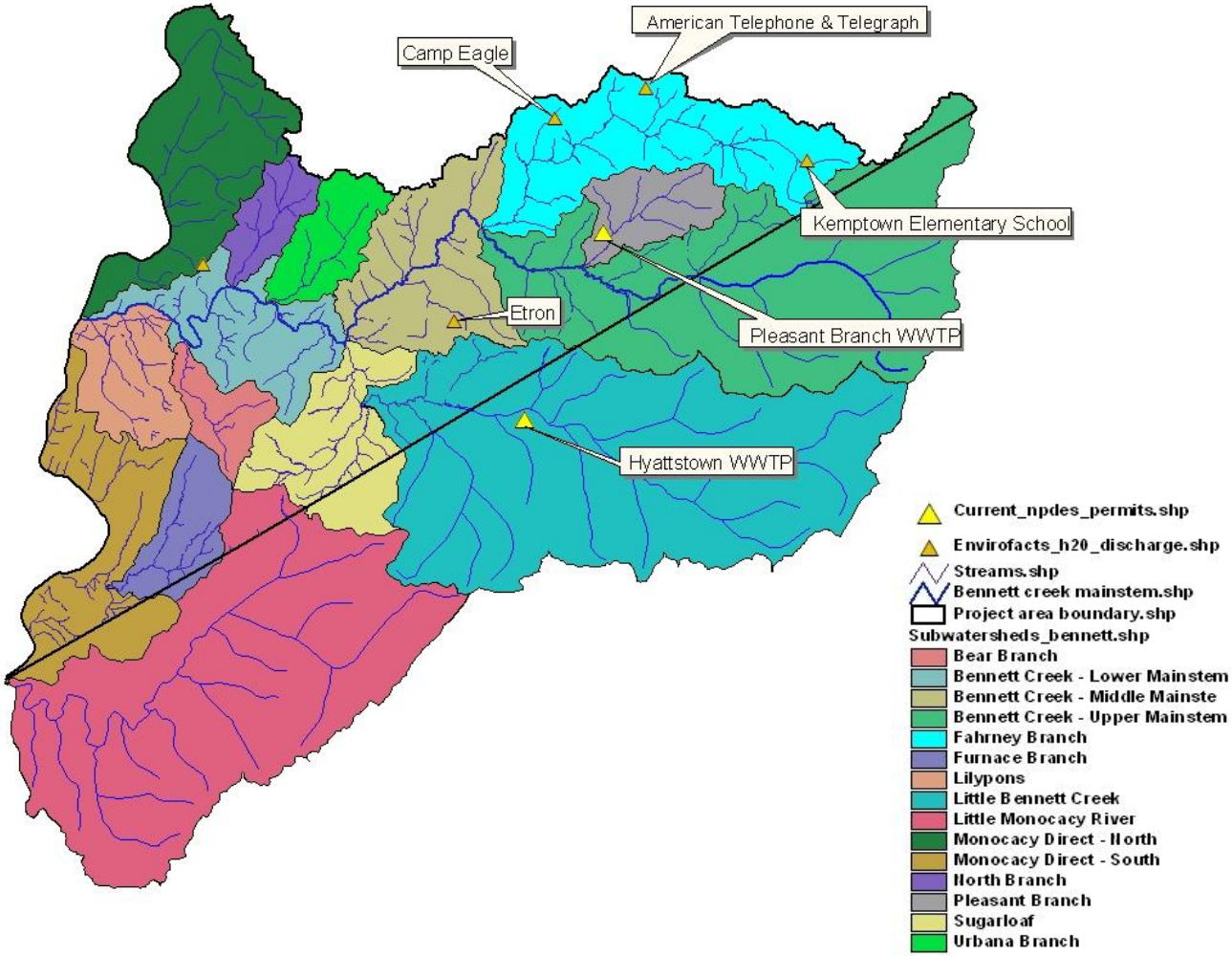

Figure 2-5. Locations of facilities in the Bennett Creek watershed that have been issued National Pollutant Discharge Elimination System (NPDES) permits (U.S. EPA[3] 2007). Only two of the discharge permits in the Envirofacts database were current (Pleasant Branch WWTP and Hyattstown WWTP, which is outside the project area).

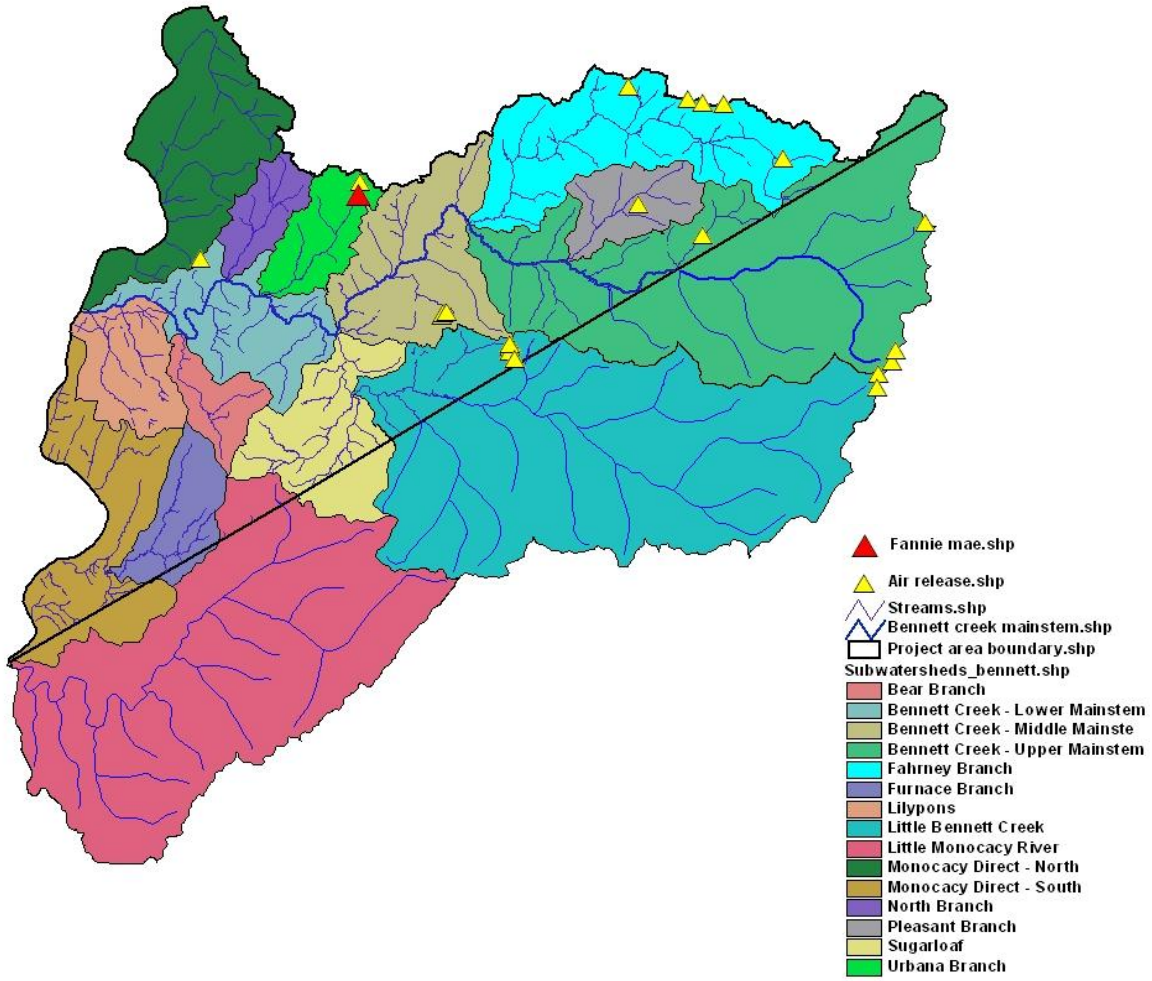

Figure 2-6. Locations of the twenty-eight facilities that are required to report air releases in the Bennett Creek watershed (U.S. EPA[3] 2007). Twenty-two of the facilities in the project area have permits to make 'potential uncontrolled emissions of less than 100 tons per year.' The Fannie Mae Data Center has the class code 'potential emissions below major source thresholds if complies with federal regulations/limits.'

3 IDENTIFICATION OF STRESSORS

3.1. Methods

3.1.1. Stressor Identification Process

The purpose of this stressor identification (SI) project is to identify those stressors and sources most likely causing degradation of instream biological conditions. Using SI methods (Suter et al. 2002, USEPA 2000), biological, chemical, and physical conditions were evaluated for the Bennett Creek watershed. The process entails describing impairments, identifying candidate causes of impairment, evaluating relationships of those causes with observed biological characteristics (Norton et al. 2002), and identifying the most likely causes of impairment using elimination and strength of evidence analyses (Cormier et al. 2002). Based on the stressor identification analysis, steps are recommended for future research that may be needed to more specifically identify stressors and their sources. This stressor identification process does not describe a definitive cause and effect relationship between stressors and biological conditions. Instead, it identifies those stressors and stressor sources most likely contributing to observed conditions.

a. Identify impairment

Impairment of the benthic macroinvertebrate and fish assemblages were identified using the BIBI and FIBI (Southerland et al. 2005). Sites with a score of less than 3.00 are considered impaired.

b. List candidate causes

Candidate causes were suggested by observations of field biologists, land use coverages, stream corridor assessment data, site photographs, aerial photographs, topographic maps and EPA Envirofacts data. Vegetative coverage and land use patterns suggested possible sources of nonpoint source pollution. Field observations were most important in identifying point sources of pollution and for confirming land uses suggested by photos and maps. A conceptual model showing candidate causes, the stressors they induce, and the effects of the stressors was depicted in a diagram tracing pathways of causal agents.

c. Analyze evidence

The levels or intensities of potential stressors at the study sites were compared to those of reference sites in the Northern Piedmont ecoregion and to state water quality standards (if they existed) to determine which stressors had the greatest potential of causing impairment (Norton et al. 2002). Correlations between stressors and BIBI and FIBI scores within sites in the Bennett Creek watershed and Northern Piedmont ecoregion were also assessed. Correlation analysis shows whether the gradient of a potential stressor is consistently associated with a gradient of biological integrity.

d. Characterize causes

The final step of the stressor identification process used the available data and analyses to logically characterize the causes of biological impairment (Cormier et al. 2002). Candidate causes were eliminated if all indications showed the stressors to be less intense in the sites in question than

reference conditions. If potential stressor intensities were different from reference intensities, then strength of evidence analysis was used to identify the stressors that were most likely to be the cause of biological impairment.

3.1.2. Data Analysis

Causes of biological impairment were analyzed at the subwatershed scale. As candidate causes were identified, a conceptual model specific to each subwatershed was developed to explain the linkages between sources of stress, exposure of biologic communities to the stressors, and responses of the assemblages to exposure. Most of the candidate causes had more than one environmental variable as indicators of stress (e.g., nutrient enrichment was indicated by concentrations of nitrate-nitrite, total nitrogen, and total phosphorus). The analysis consisted of two core statistical methods for evaluating responses to exposures and an evaluation of the strength of evidence for each cause.

The first statistical method was a simple comparison of stressor values from samples in each subwatershed to sample values from fifty-one reference sites in the Northern Piedmont ecoregion (of which Bennett Creek is a part). The 25th and 75th percentiles of reference values were used as thresholds for comparison because values in the intra-quartile range of the reference distribution were considered to be truly representative of reference conditions. If the potential stressor was observed at values better than the worst quartile of reference, then the stressor was considered to be ineffective at the site. When potential stressor values were outside of the intra-quartile range, the degree of departure from the threshold gave an indication of the relative intensity of the stressor. Reference values can be found in Appendix A.

The second statistical method involved performing correlation analyses of stressors versus BIBI and FIBI scores for sites within the Bennett Creek watershed and for sites within the Northern Piedmont ecoregion (all samples were included in this analysis, not just reference). The dataset used in the Bennett Creek correlation analyses can be found in Appendix B. The correlation analyses were performed using the STATISTICA data analysis software system, version 8.0 (StatSoft 2007) using pairwise missing data deletion. Significant correlations (p-level < 0.05) indicated that a biological gradient coincided with a stressor gradient and thus, the stressor may be at least partially responsible for biological impairment. Correlations were considered to be strong if $|r| > 0.4$. It should be noted that correlation analyses were performed on the FIBI scores and nutrient data even though sampling events for each occurred at different times. It was assumed that the fish were present in the streams when the spring nutrient sampling occurred, and that nitrogren concentrations were at lower levels in the summer than in the spring (MDNR 2003b).

The strength of evidence analysis (Suter et al. 2002, Cormier et al. 2002) was used to describe the importance of various relationships between stressors and biological metrics and to prioritize stressors regarding probable cause. The strength of evidence analysis is represented by a matrix of causes and lines of logic that link stressors and biological responses. If a line of logic is particularly strong for a candidate cause, the logic/cause cell of the matrix would receive a high score: "++". Other scores were used to indicate evidence that is not particularly strong (+), no evidence (NE), or evidence against the stressor-response linkage (-). Composite scores are used to prioritize the candidate causes. The strength of evidence lines of logic are as follows:

a. Co-occurrence

This pertains to the spatial and temporal coincidence of the candidate cause and its effects (whether the biological effects are evident at the same time and place as the candidate cause). Biological impairment was observed in samples collected in the Bennett Creek watershed. Therefore, if stressors were evident at a site (through comparison to reference stressor intensities), then co-occurrence was positive.

b. Temporality

A cause must precede its effects. If the effects were noticed before the candidate cause was active then there would not be evidence that the candidate cause is responsible for effects. In the current analysis, temporality was not investigated, as all samples were collected simultaneously and causes and effects were assumed to be invariable over time.

c. Consistency of association

A consistent association of an effect with a candidate cause is likely to indicate true causation (USEPA 2000). A consistent biological response to a candidate cause over several sites is strong evidence for causation, however, dissimilarity of sites and multiplicity of candidate causes can weaken the evidence for causation. For the strength of evidence table, consistency of association between stressors and biological impairment was considered for the samples in each of the Bennett Creek subwatersheds. If all biologically impaired samples were associated with high stressor intensities (compared to reference stressor intensities), the association was considered consistent.

d. Biological gradient

A stressor is more likely to be causing an effect if effects are observed to increase with increasing exposure. Correlation analyses of stressors and biological measures in the Bennett Creek watershed and the Northern Piedmont ecoregion showed the strength and significance of relationships.

e. Complete exposure pathway

An exposure pathway is complete if the physical course taken by a stressor between its source and its biological receptor can be demonstrated. In the current study, relationships were examined between sources and stressors through land use analysis. The stressors were measured in the stream channel, water column, or the immediate riparian area, so exposure was assumed to reach the relatively immobile benthic macroinvertebrate assemblage.

f. Plausibility

The plausibility that a stressor was having an effect was determined in terms of a plausible mechanism and a plausible stressor response at the observed level of stressor intensity. A plausible mechanism describes the way in which a stressor reduces biological potential of the receptor organism. Mechanisms can be direct (physiological reactions) or indirect (habitat degradation reduces resource availability). Stressor response plausibility pertains to known effects at the observed level of stressor intensity. Toxicological evidence may be appropriate to demonstrate stressor response relationships, though the context of the impairment may be different between the laboratory and the field. State or federal water quality standards would be appropriate for comparison of stressor levels when they exist.

g. Specificity of cause

If an effect has only one or few known causes, then the occurrence of one of those causes in association with the effect is strong evidence of causation. Evidence of specificity of cause is only applicable if the candidate cause is plausible or if it has been consistently associated with the effect. Effects observed in the biological assemblage are not very useful at diagnosing stressors because metrics (and the organisms they represent) can respond to several types of stress.

h. Analogy

Analogy examines whether the hypothesized relationship between cause and effect is similar to any well-established cases. Analogy would be a strong tool if specificity were also evident.

i. Experiment

Experiment refers to manipulation of a cause or exposure and recording subsequent changes in effects. Experiments were not conducted in the current study.

j. Predictive performance

Predictive performance can only be assessed if multiple sampling events occurred and a prediction was made between sampling events. This was not the case in the current study.

k. Consistency of evidence

Agreement among the multiple lines of evidence would show consistent evidence. When one or more line of evidence refutes the others or evidence is consistently weak, then the candidate cause may not be responsible for the effects.

l. Coherence of evidence

When evidence is inconsistent, it can still be coherent if the inconsistencies can be explained. Interactions between stressors and the environment may mask or accentuate effects. This is a weak line of evidence, though it may lead to more detailed studies that will strengthen evidence in future iterations of causal analysis.

3.2. Results and Discussion

3.2.1. Description of Impairment

Impairment of the fish and benthic macroinvertebrate assemblages was identified using BIBI scores and FIBI scores. Sites with IBI scores greater than or equal to 3.00 were not considered to be impaired. Detailed descriptions of the impaired sites can be found in the subwatershed analyses that follow.

3.2.2. Conceptual Model/Candidate Causes

Conceptual models were developed for each subwatershed to show the stressor sources, the stressors they induce, and the effects on the biological assemblage. Sources include agricultural practices (row crops and pasturelands/grazing), urban land cover, failing septic systems, effluent from waste-water treatment plants, construction, and atmospheric deposition. The induced stressors include nutrient enrichment, excessive sediment/turbidity, habitat degradation, ammonia toxicity, thermal loading, dissolved oxygen deficit, increased ionic strength and pH imbalance. Organic loading, metals and toxins are also potential stressors, but there is not enough evidence in the Bennett Creek watershed to do strength-of-evidence analyses for these.

Effects are all measures of the benthic macroinvertebrate and fish communities, which are known to be responsive to a wide range of stressors. BIBI and FIBI scores were not expected to respond specifically to particular stressors. Rather, all were expected to respond equally to all stressors. This is a somewhat simplified assumption because evidence exists to suggest that some taxa groups are more sensitive to particular stressors (e.g. EPT taxa are thought to be sensitive to low dissolved oxygen). However, EPT taxa are also sensitive to other stressors and cannot be used diagnostically. The FIBI and BIBI in the Northern Piedmont ecoregion were used as evidence of effects.

Stressors

Based on the stressor sources in the watershed, a list of candidate chemical and physical causes (stressors) was developed, along with a list of available measurements relevant to each candidate cause (Table 3-1). The list is as follows:

Nutrient Enrichment

Nutrients can enter the water column from sources such as fertilizers, animal wastes, failed septic systems, discharge from waste-water treatment plants and atmospheric deposition. The measures available for analysis in the Bennett Creek watershed (sample sizes vary) include: nitrate, nitrite, nitrate-nitrite, total nitrogen, total phosphorus, ortho-phosphate and ammonia. These nutrients encourage algal growth, which can deplete dissolved oxygen as they respire at night and as they decompose. Other indirect effects include food chain effects caused by excessive algal food resources and alteration of stream habitat due to excessive aquatic plant growth (Dodds and Welch 2000, Munn et al. 2003).

Excess Sediment/Turbidity

Sediment condition is addressed separately from habitat quality because estimates of substrate size class distribution and percent embeddedness give more reliable estimates of silt/clay coverage than the habitat variables that address substrate.

Fine sediment and turbidity sources include erosional runoff from disturbed land, bank failure caused by instream disturbance (e.g., cattle access) and altered hydrological patterns. Various studies have documented the negative effects of excessive sediments and turbidity on benthic macroinvertebrates and fish (Zweig and Rabeni 2001, Whiting and Clifford 1983, Lloyd 1987). For example, it can interfere with their respiration, their sensory abilities and their feeding and movement patterns (Resh and Rosenburg 1984, Henley et al. 2000, Lloyd 1987). High turbidity also

reduces photosynthetic activity and primary production, reducing food resources available to herbivores.

Substrate that is predominately fine silt and clay is adequate for some benthic macroinvertebrate species, but is inadequate for those that rely on hard substrate with interstitial spaces for maintaining position in storm flows or hiding from predators (Waters 1995). Excessive sediment in the stream bottom may affect fish by preventing the proper flow of water and oxygen over redds (fish spawning sites) and may stop the emergence of fry (Lloyd 1987). Also, fine sediments are able to retain adsorbed contaminants more efficiently than coarser substrates, increasing the potential for long-term bioavailability of contaminants.

Habitat Degradation

Degradation of instream, morphological, or riparian/bank habitat features can deprive benthic macroinvertebrates and fish of essential resources such as food, adequate flow, and suitable substrate for dwelling, hiding, or protection from storm flows (Yoder and Rankin 1995, Barbour et al. 1996, Gerritsen and Jessup 2001). Habitat degradation may result from land use or vegetative disturbance in riparian areas (Budd et al. 1987, Sweeney 1984), instream disturbance such as road crossings or cattle access, and altered hydrologic patterns resulting from intensive upland land uses (Richards and Host 1994).

Ammonia Toxicity

Ammonia can form through biological degradation in nutrient enriched systems or can be introduced from concentrated animal wastes and fertilizers (Russo 1985). Ammonia can be toxic to aquatic life in the un-ionized form and is a nutrient to aquatic plants in the ionized form. The prevalence of each form is dependent on total concentration, temperature, and pH, with higher toxicity in high pH systems.

Thermal Loading

Water temperatures vary diurnally, seasonally, from stream to stream, and within a stream (i.e cold water seep). Increased temperatures may result from the removal of riparian canopy cover, industrial discharges, runoff from hot paved surfaces and impoundments. An increase in temperature may cause an increase in algal production, an increase in the decomposition of organic matter and a decrease in dissolved oxygen concentrations (Beschta et al. 1987, Thompson et al. 2004).

Temperature requirements vary by species and life stage, so water temperature can have a wide range of effects on the biological assemblage. An increase in temperature will cause a shift in the biological assemblage structure towards species tolerant of higher temperatures, which may mean a loss of sensitive native species. Higher temperatures may increase metabolic rates, increase food demands, and increase the incidence of disease. It may cause changes in movement patterns organisms, and can influence fish spawning, incubation and emergence (Beschta et al. 1987, Thompson et al. 2004).

Due to their greater mobility, fish may be better able to adapt to temperature shifts than benthic macroinvertebrates since they can move into areas with more favorable temperatures.

Dissolved Oxygen Deficit

Oxygen is necessary for respiration in benthic macroinvertebrates and fish, though sensitivity to low dissolved oxygen varies by taxon (Haur and Lamberti 1996, Eriksen et al. 1996, Hilsenhoff 1987, Thompson et al. 2004). Dissolved oxygen can be depleted through biological respiration and decomposition of organic matter. Streams that have an excess of organic matter, high biological respiration (e.g., dark-phase photosynthetic activity), high temperatures, and slow (un-aerated) water are likely to have dissolved oxygen deficits (Hauer and Lamberti 1996). Total organic carbon and chemical oxygen demand indicate the capacity of the stream to consume oxygen and may be less variable over time than the direct DO measures.

Increased Ionic Strength

Specific conductance, total dissolved solids, and total chlorides in surface waters can increase as a result of runoff from disturbed land or land where agricultural additives (fertilizer, pesticides, and manure) have been applied. High conductivity is generally associated with increased alkalinity (see pH and ammonia effects above), and poorer biological conditions, though the mechanism for impairment is not well documented in the absence of ammonia effects (Imbert and Stanford 1996, Roy 2000). It may be that high conductivity (and the associated measures) is indicative of the intensity of human activities in the watershed and these activities may be generating other unmeasured stressors.

pH Imbalance

Extremely low or high pH can impair normal biological metabolism. Low pH is rare in agricultural areas, but excessively high pH can be common. High pH increases the toxicity of ammonia, by increasing the unionized ammonia concentration relative to ionized. The sources of elevated pH include increased conductivity and alkalinity from agricultural and urban runoff, and septic discharges. During daytime in the growing season, pH is further elevated by photosynthesis of algae, which removes carbon dioxide and bicarbonate, reducing bicarbonate buffering capacity. If there is excess algal production due to nutrient enrichment, this effect is exacerbated.

3.2.3. Correlation Analyses

3.2.3.1. Bennett Creek Watershed

In the Bennett Creek watershed, BIBI scores had strong negative correlations with total nitrogen (TN), nitrate+nitrite (NO3+NO2), nitrate (NO3), and sulfate (SO4) (Table 3-2). BIBI scores were also negatively correlated with specific conductivity and dissolved oxygen. FIBI scores from the Bennett Creek dataset were significantly correlated with dissolved oxygen and three of the habitat metrics (Velocity/Depth Diversity Score, Riffle Quality Score, Pool/Glide/Eddy Quality Score) (Table 3-3).

Table 3-1. Available measurements relevant to each candidate cause.

Candidate Cause	Relevant Measurements
Nutrient enrichment	Water chemistry variables: nitrate, nitrite, nitrate+nitrite (NO_3-NO_2), total nitrogen, total phosphorus, ortho-phosphate
Excess sediment/turbidity	%Embeddedness, extensive sand and/or silt/clay, turbidity
Habitat degradation	MBSS habitat metrics
Ammonia toxicity	Ammonia concentration in water
Thermal loading	Water temperature
Low dissolved oxygen	Dissolved oxygen
Ionic strength	Specific conductance
pH imbalance	pH

Table 3-2. Correlation coefficients (r-values) of BIBI (2005) scores with physical and chemical stressors in the Bennett Creek watershed. Correlations with p-levels <.05 are considered significant and are in bold type. r-values that are greater than 0.4 are italicized.

	Parameter	BIBI r-value	Sample Size	p
Habitat	Instream Habitat Score	0.19	56	0.16
	Epifaunal Substrate Score	0.05	56	0.70
	Velocity/Depth Diversity Score	-0.28	48	0.06
	Pool/Glide/Eddy Quality Score	-0.21	48	0.15
	Riffle Quality Score	-0.02	48	0.89
	Embeddedness	0.04	48	0.79
	Shading	0.26	48	0.12
Chemistry (spring)	pH (std units)	-0.14	57	0.29
	Specific conductance (log mS/cm)	**-0.34**	57	*0.01*
	DOC (log mg/l)	-0.09	41	0.57
	Nitrate - N03 (log mg/l)	***-0.53***	40	*0.00*
	Water Temperature (°C)	0.26	31	0.16
	Dissolved Oxygen (mg/l)	***-0.42***	27	*0.03*
	Total Nitrogen - TN (log mg/l)	***-0.59***	32	*0.00*
	Total Phosphorus - TP (log mg/l)	-0.31	32	0.08
	Ortho Phosphate (log mg/l)	-0.23	32	0.20
	Ammonia - NH3 (log m/l)	-0.18	29	0.34
	Turbidity (log NTU)	-0.13	19	0.60
	Sulfate - S04 (log mg/l)	***-0.43***	26	*0.03*
	Nitrate + Nitrite (log mg/l)	***-0.55***	22	*0.01*

Table 3-3. Correlation coefficients (r-values) of FIBI (2005) scores with physical and chemical stressors in the Bennett Creek watershed. Correlations with p-levels <.05 are considered significant and are in bold type. r-values that are greater than 0.4 are italicized.

	Parameter	FIBI r-value	Sample Size	p
Habitat	Instream Habitat Score	0.38	39	0.51
	Epifaunal Substrate Score	0.28	39	0.08
	Velocity/Depth Diversity Score	***0.50***	31	*0.01*
	Pool/Glide/Eddy Quality Score	**0.39**	31	*0.04*
	Riffle Quality Score	***0.42***	31	*0.02*
	Embeddedness	-0.15	31	0.42
	Shading	-0.34	31	0.06
Chemistry	Water Temperature (°C)	0.06	39	0.73
	Dissolved Oxygen (mg/l)	***0.46***	39	*0.00*
	pH (std units)	0.29	39	0.07
	Specific conductance (log mS/cm)	0.06	39	0.71
	Nitrate - N03 (log mg/l)	0.35	25	0.08
	Sulfate - S04 (log mg/l)	-0.16	25	0.45
	Total Nitrogen - TN (log mg/l)	0.09	16	0.74
	Total Phosphorus - TP (log mg/l)	0.11	16	0.69
	Ortho Phosphate (log mg/l)	-0.11	16	0.68
	Ammonia - NH3 (log m/l)	0.15	14	0.61

3.2.3.2. Northern Piedmont

BIBI scores had strong negative correlations with sulfate and specific conductivity, and weak but significant negative correlations with pH, DOC, nitrite, total phosphorus, and ammonia (r values ranged from -0.12 to -0.29) (Table 3-4). All of the habitat metrics except for pool/glide/eddy quality had weak but significant positive correlations with BIBI scores (r values ranged from 0.11 to 0.35). FIBI scores had strong positive correlations with velocity/depth diversity, pool/glide/eddy quality, instream habitat, and riffle quality, and weak but significant positive correlations with epifaunal substrate, pH, DO, temperature, DOC and nitrite (Table 3-5). FIBI scores had weak negative correlations with shading, embeddedness and specific conductivity.

Table 3-4. Correlation coefficients (r-values) of BIBI (2005) scores with physical and chemical stressors in the Northern Piedmont ecoregion. Correlations with p-levels <.05 are considered significant and are in bold type. r-values that are greater than 0.4 are italicized.

	Parameter	BIBI r-value	Sample Size	p
Habitat	Instream Habitat Score	**0.26**	832	0.00
	Epifaunal Substrate Score	**0.35**	832	0.00
	Velocity/Depth Diversity Score	**0.11**	832	0.00
	Pool/Glide/Eddy Quality Score	0.02	832	0.64
	Riffle Quality Score	**0.26**	832	0.00
	Shading	**0.15**	832	0.00
	Embeddedness	**-0.25**	831	0.00
Chemistry	Sulfate - S04 (log mg/l)	***-0.43***	849	0.00
	Specific conductance (log mS/cm)	***-0.41***	849	0.00
	Nitrate - N03 (log mg/l)	0.04	848	0.28
	pH (std units)	**-0.29**	847	0.00
	DOC (log mg/l)	**-0.24**	462	0.00
	Total Nitrogen - TN (log mg/l)	0.01	462	0.85
	Total Phosphorus - TP (log mg/l)	**-0.22**	462	0.00
	Ortho Phosphate (log mg/l)	-0.08	455	0.10
	Ammonia - NH3 (log m/l)	**-0.12**	445	0.01
	Nitrite - NO2 (log mg/l)	**-0.25**	426	0.00

Table 3-5. Correlation coefficients (r-values) of FIBI (2005) scores with physical and chemical stressors in the Northern Piedmont ecoregion. Correlations with p-levels <.05 are considered significant and are in bold type. r-values that are greater than 0.4 are italicized.

	Parameter	FIBI r-value	Sample Size	p
Habitat	Instream Habitat Score	***0.42***	805	0.00
	Epifaunal Substrate Score	**0.27**	805	0.00
	Velocity/Depth Diversity Score	***0.60***	805	0.00
	Pool/Glide/Eddy Quality Score	***0.58***	805	0.00
	Riffle Quality Score	***0.42***	805	0.00
	Shading	**-0.19**	805	0.00
	Embeddedness	**-0.10**	804	0.00
Chemistry	Sulfate - S04 (log mg/l)	-0.07	816	0.05
	Nitrate - N03 (log mg/l)	0.06	816	0.11
	pH (std units)	**0.14**	806	0.00
	Dissolved Oxygen (mg/l)	**0.20**	806	0.00
	Water Temperature (°C)	**0.20**	806	0.00
	Specific conductance (log mS/cm)	**-0.16**	804	0.00
	DOC (log mg/l)	**0.10**	446	0.03
	Total Nitrogen - TN (log mg/l)	-0.04	446	0.44
	Total Phosphorus - TP (log mg/l)	0.02	446	0.69
	Ortho Phosphate (log mg/l)	0.02	439	0.70
	Turbidity (log NTU)	0.04	432	0.40
	Ammonia - NH3 (log m/l)	0.03	430	0.52
	Nitrite - NO2 (log mg/l)	**0.10**	411	0.04

4 PLEASANT BRANCH – STRESSOR IDENTIFICATION

4.1. Description of Impairment: Pleasant Branch

FIBI scores at all of the sites in the Pleasant Branch subwatershed were greater than 3.00, so the fish assemblage is not considered to be impaired. Based on the BIBI scores, the benthic macroinvertebrate assemblages at two of the three sites are impaired (Figure 4-1).

4.2. Candidate Causes – Potential Stressor Sources: Pleasant Branch

The conceptual diagram (Figure 4-2) shows the stressor sources, the stressors they induce and the effects on the biological assemblage for the Pleasant Branch subwatershed. Sources in this subwatershed include agricultural practices (row crops and livestock), the Pleasant Branch waste-water treatment plant, low and medium density residential developments, commercial and institutional (Windsor Knolls Middle School) developments, atmospheric deposition, and (potentially failing) septic systems.

4.3. Analysis of Evidence – Associating candidate causes: Pleasant Branch

The three biological sampling sites located in the Pleasant Branch subwatershed are permanent, non-random sites that were established for restoration monitoring. One of the sites, BENN05P2007, is located at the mouth of Pleasant Branch and was sampled in 2006 and 2007. In 2006, it received a BIBI score of 3.00. In 2007, the BIBI score decreased to 2.75. The other two sites are located approximately 1.5 miles upstream, in the area near the Windsor Knolls Middle School. These two sites were sampled in 2004. One received a BIBI score of 4.00, and the other, BENN02-2004, had a BIBI score of 2.75.

In situ water quality measurements (water temperature, dissolved oxygen, pH and specific conductance) were taken at all three sites. Water temperature and dissolved oxygen values were comparable to reference at all but BENN05P2007, where the summer water temperature was greater than the 75th percentile of reference site values (Table 4-1). Spring and summer specific conductance values at BENN05P2007 were greater than the 75th percentile of reference site values in 2006 and 2007 (the 2007 value was greater than the 95th percentile of reference site values) and spring pH values at this site fluctuated from being greater than the 95th percentile of reference site values in 2006 (8.41) to being less than the 25th percentile of reference site values in 2007 (6.71). Specific conductance values at the other two sites were comparable to reference. pH values at these two sites were either comparable to reference or were only slightly outside the range of reference values.

Very limited water chemistry data are available for Pleasant Branch, but one of the 2003 nutrient synoptic sites (located at the BENN02-2004 biological sampling site) had an elevated NO_3-NO_2 concentration. Turbidity measurements at all three sites exceeded the 75th percentile of reference site values; the highest was a reading of 49 NTU at BENN05P2007 in 2006.

In 2006 and 2007, only one of the habitat metric values (pool/glide/eddy quality) at BENN05P2007 was comparable to reference (Table 4-2). In 2007, scores for four of the habitat metrics were less than the 5th percentile of reference site values. Percent embeddedness at BENN05P2007 exceeded the reference 75th percentile, and percent shading was less than the reference 5th percentile. At the

other two sites, three habitat metrics scores were comparable to reference; epifaunal substrate and pool/glide/eddy scores were less than the reference 25th percentile. Percent embeddedness and percent shading at these two sites were comparable to reference.

4.4. Characterization of Causes: Pleasant Branch

4.4.1. Elimination of candidate causes: Pleasant Branch

Dissolved oxygen values were comparable to reference at all three sites. No other candidate causes could be eliminated.

4.4.2. Strength of evidence: Pleasant Branch

The strength of evidence analysis was completed for eight candidate causes and twelve lines of logic. It is summarized in Tables 4-3a-d.

4.4.3. Identification of probable causes: Pleasant Branch

BENN05P2007. From the strength of evidence analysis it appears that habitat degradation and excessive sediment/turbidity are major factors that may be causing impairment of the benthic macroinvertebrate assemblage at this site. These factors may also be impacting the fish assemblage, since this site had the lowest FIBI score (3.67), and FIBI scores in the Northern Piedmont ecoregion were strongly correlated with several of the habitat metrics. Other candidate causes that may be affecting the biota at this site include nutrient enrichment and high ionic concentrations. Evidence regarding thermal loading and pH imbalance was inconsistent, and there is no evidence for or against ammonia toxicity because ammonia concentrations were not measured.

One of the sources of excess sedimentation and turbidity at BENN05P2007 is land disturbing activities (mainly upstream) that cause sediment runoff and bank erosion, such as uncontrolled access of livestock (horses and cattle) into streams and tributaries. Other potential sources of excess sediment and turbidity include runoff from impervious surfaces such as roads, naturally erodible soils, and instream sources.

Habitat degradation is another likely cause of biological impairment at this site. BENN05P2007 received low scores on all of its habitat metrics, and a nearby representative habitat evaluation site that was surveyed as part of the stream corridor assessment (SCA) was rated 'suboptimal' for macroinvertebrate substrate, embeddedness, bank condition and riparian vegetation. The habitat at this site appears to be influenced by development upstream. Approximately 60% of the upstream catchment area is urban (mostly low density residential), and 27% is agricultural (Figure 4-3). In areas of urban land use, there is more impervious surface. This increase in impervious cover results in increased surface runoff (i.e. reduced infiltration), increased storm flow, increased erosion, decreased channel stability, and decreased subsurface flow. Inadequate riparian buffer is another problem cited at and upstream of this site. Lack of riparian buffer may contribute to channel instability and reductions in habitat (i.e. less woody debris) and shading. Decreased shading can lead to increases in water temperature.

Although nutrient data are not available for this site, nutrient enrichment may be a contributing factor to impairment of the benthic macroinvertebrate assemblage. Elevated NO_3-NO_2

concentrations were recorded at an upstream site during the 2003 nutrient synoptic survey, and BIBI scores in the Bennett Creek watershed were negatively correlated with nitrogen concentrations (NO_3, NO_3-NO_2, TN). High nitrogen and phosphorus levels can lead to excessive algal production, which in turn has effects on food resources, trophic relationships, habitat quality, ammonia and dissolved oxygen. The pathway between the stressor and receptors are indirect (through algal production). Possible sources of nutrients in the upstream catchment area are the Pleasant Branch waste-water treatment facility, fertilizers that are applied to agricultural lands and residential lawns, animal waste from livestock, failing septic systems, and atmospheric deposition.

The elevated specific conductance values that were recorded at BENN05P2007 also indicate that upstream human activities may be affecting the benthic macroinvertebrate assemblage, although there is no plausible mechanism for conductivity to impact the biota. BIBI scores in the Bennett Creek watershed and the Northern Piedmont ecoregion were negatively correlated with specific conductance values.

BENN02-2004. From the strength of evidence analysis it appears that habitat degradation is a factor that may be causing impairment of the benthic macroinvertebrate assemblage at this site. Another candidate cause may be nutrient enrichment. Evidence regarding excessive sediment/turbidity, thermal loading, ionic strength and pH imbalance was inconsistent or implausible, and there is no evidence for or against ammonia toxicity because ammonia concentrations were not measured.

BENN02-2004 is located in the vicinity of the Windsor Knolls Middle School and areas of low density residential developments. It is just below the confluence of Pleasant Branch and an upper tributary. Habitat degradation appears to be a likely factor of biological impairment at this site. It received low habitat metric scores for epifaunal substrate and pool/glide/eddy quality. During the stream corridor assessment (SCA), this site and the areas immediately upstream of this site were cited as problem areas due to moderate erosion (Figure 4-4). The causes of the erosion were attributed to land use change upstream and morphology (a bend at a steep slope). About a tenth of a mile upstream from the site, problems with inadequate buffers were reported. These areas were also identified in the Lower Monocacy River Watershed Restoration Action Strategy (WRAS), which cited three areas of concern in the vicinity of BENN02-2004 due to inadequate buffers and erosion (Frederick County DPW 2004). Other problems at or upstream of this site that were identified during the SCA are stormwater pipe outflows, fish barriers and trash dumps with residential yard waste.

Although nutrient data were not collected during the 2004 biological sampling events, it was collected at BENN02-2004 during the 2003 nutrient synoptic survey. The site had elevated NO_3-NO_2 concentrations. Since BIBI scores in the Bennett Creek watershed were negatively correlated with nitrogen concentrations (NO_3, NO_3-NO_2, TN), nutrient enrichment may be a contributing factor to impairment of the benthic macroinvertebrate assemblage. The dominant land use upstream of this site is low density residential development. Possible sources of nutrients include failing septic systems, lawn fertilizers, atmospheric deposition, and fertilizers and animal waste from agricultural lands in the upper reaches of the catchment area.

It is worth noting that BENN01-2004, which is located approximately 0.3 miles downstream of BENN02-2004, had a BIBI score of 4.00. BENN01-2004 had slightly better habitat metric scores than BENN02-2004. During the stream corridor assessment, no problems areas (such as inadequate riparian buffer and erosion) were reported at the site or in the area immediately upstream of the site.

The surrounding land use at this site is forest, agriculture, and medium density residential development. The medium density residential developments are either areas served by community and multi-use water and sewerage systems which are either existing or under construction (S-1), or areas where improvements to, or construction of new community and multi-use water supply and sewerage systems will be given immediate priority, with construction scheduled to start within 3 years (S-3) (Figure 4-5).

4.5. Summary of Results – Pleasant Branch

A summary of the candidate causes associated with the two biologically impaired sites, along with their likely sources, is shown in Table 4-4. Nutrient enrichment and habitat degradation were the most prevalent and probable causes of impairment at the biologically impaired sites. The most probable sources of nutrient enrichment are agricultural lands, residential developments and atmospheric deposition. It would be helpful to obtain more water chemistry data for Pleasant Branch, since nutrient data were unavailable for the biological sampling sites. The most probable sources of habitat degradation are urban land use, inadequate riparian buffers and bank instability and erosion from upstream land use and natural factors.

Ten priority restoration sites on Pleasant Branch were identified in the Lower Monocacy Watershed Restoration Action Strategy (Frederick County DPW 2004). One of the sites, site #31, is located at a biological sampling site (BENN-02-2004), but the other sites lack biological data. Problem areas were identified using the SCA data. Commonly cited problems include inadequate buffers, erosion, and direct animal access to streams. Fish barriers and trash dumps were also documented. Descriptions of the problems at these priority sites and photos some of the problem areas are summarized in Table 4-5 and Figures 4-6a-h. Table 4-6 summarizes the results of the SCA survey for the Pleasant Branch subwatershed.

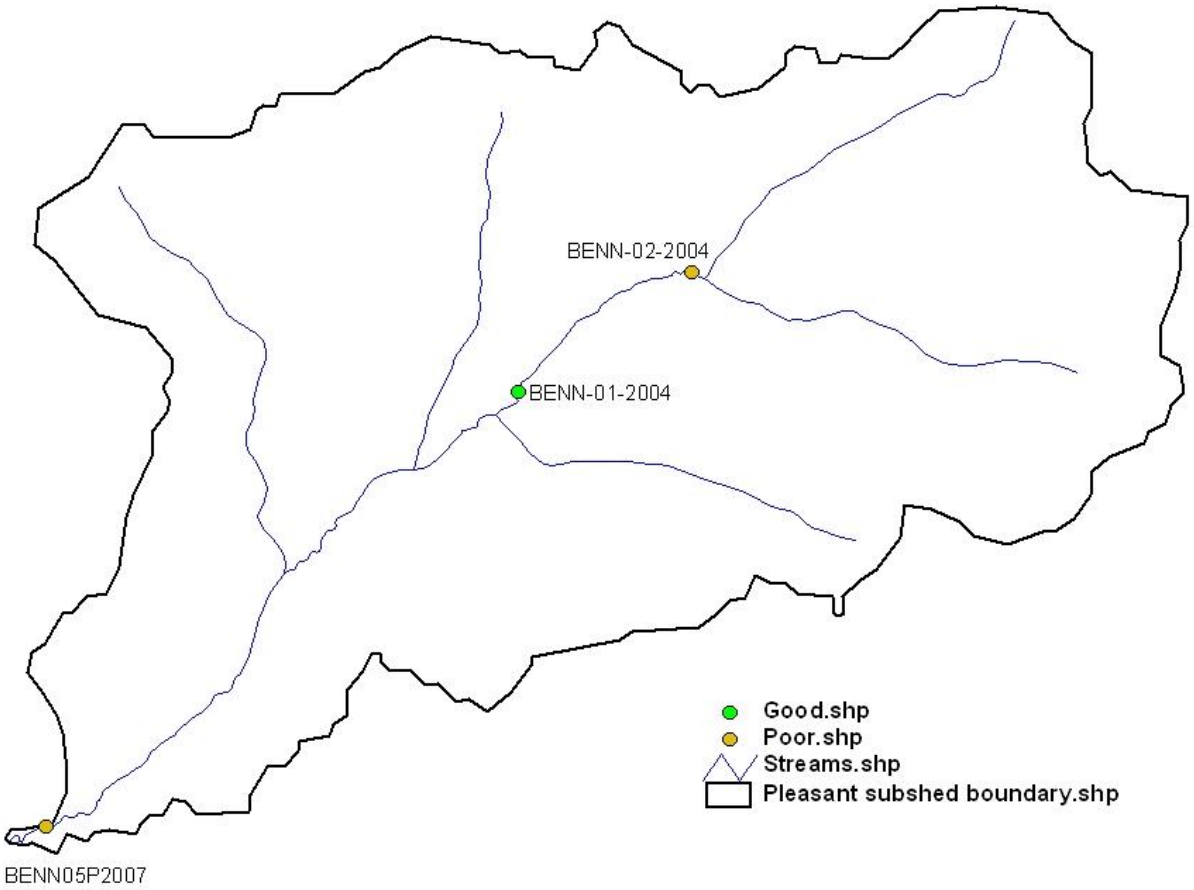

Figure 4-1. Locations of biological sampling sites in the Pleasant Branch subwatershed. Sites are color-coded based on their lowest IBI rating (i.e. if the BIBI score was lower than the FIBI score, the BIBI score was used).

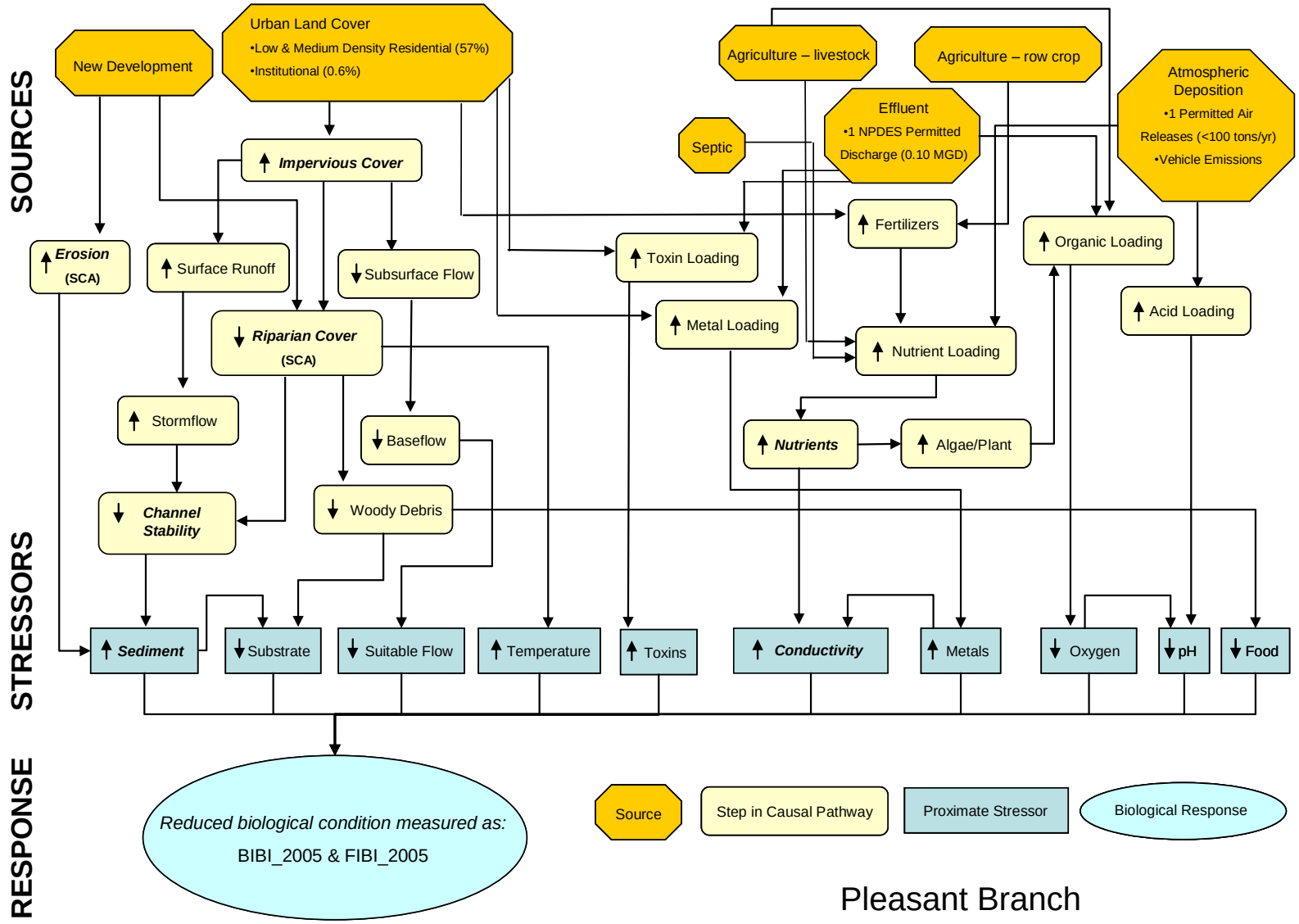

Figure 4-2. Conceptual Model for the Pleasant Branch subwatershed. Steps in the causal pathway and proximate stressors for which there are evidence are italicized.

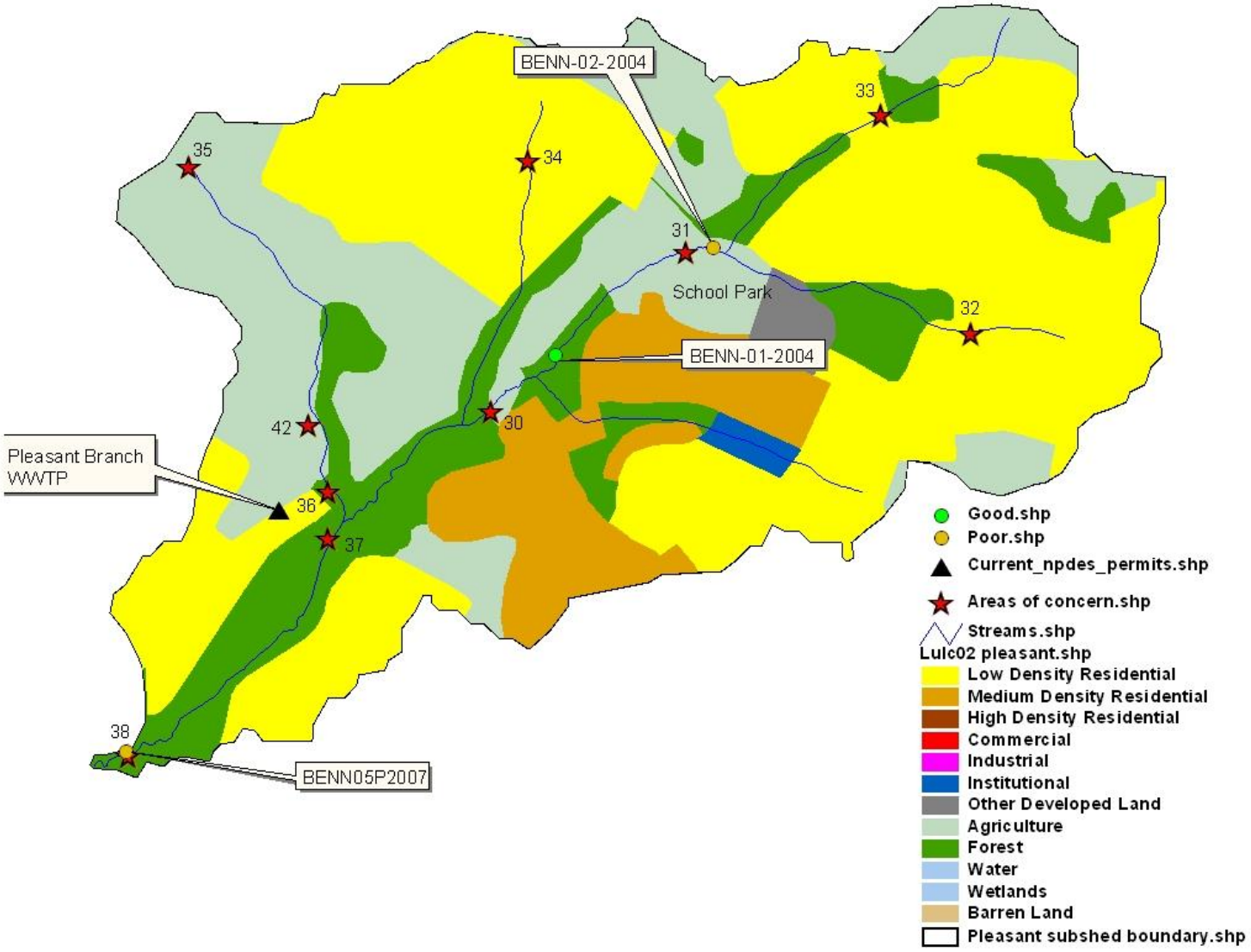

Figure 4-3. Land use land cover, biology, Envirofacts, nutrient synoptic survey and priority restoration site information for Pleasant Branch. Descriptions of the priority restoration sites can be found in Table 4-4.

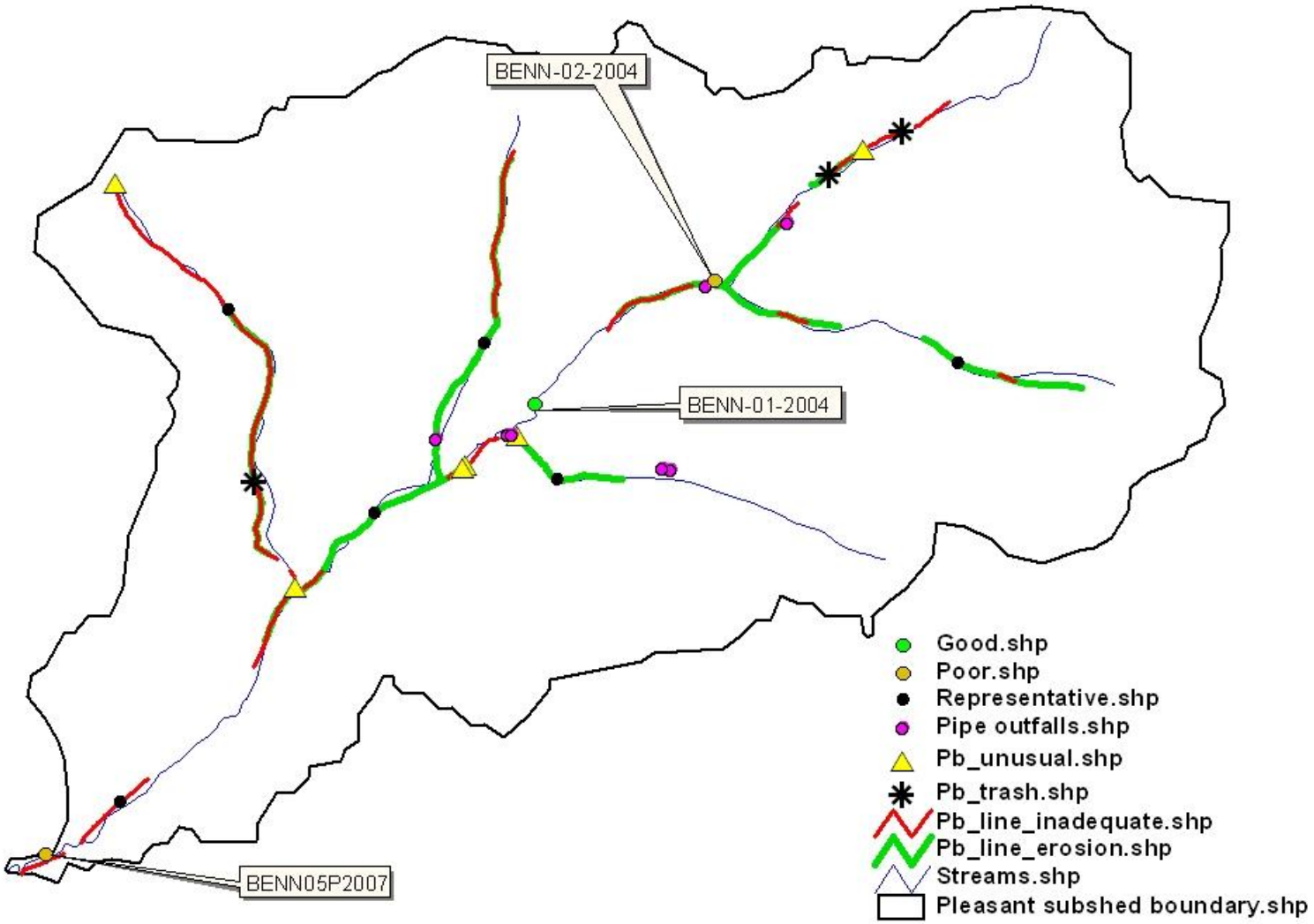

Figure 4-4. Stream corridor assessment results for Pleasant Branch.

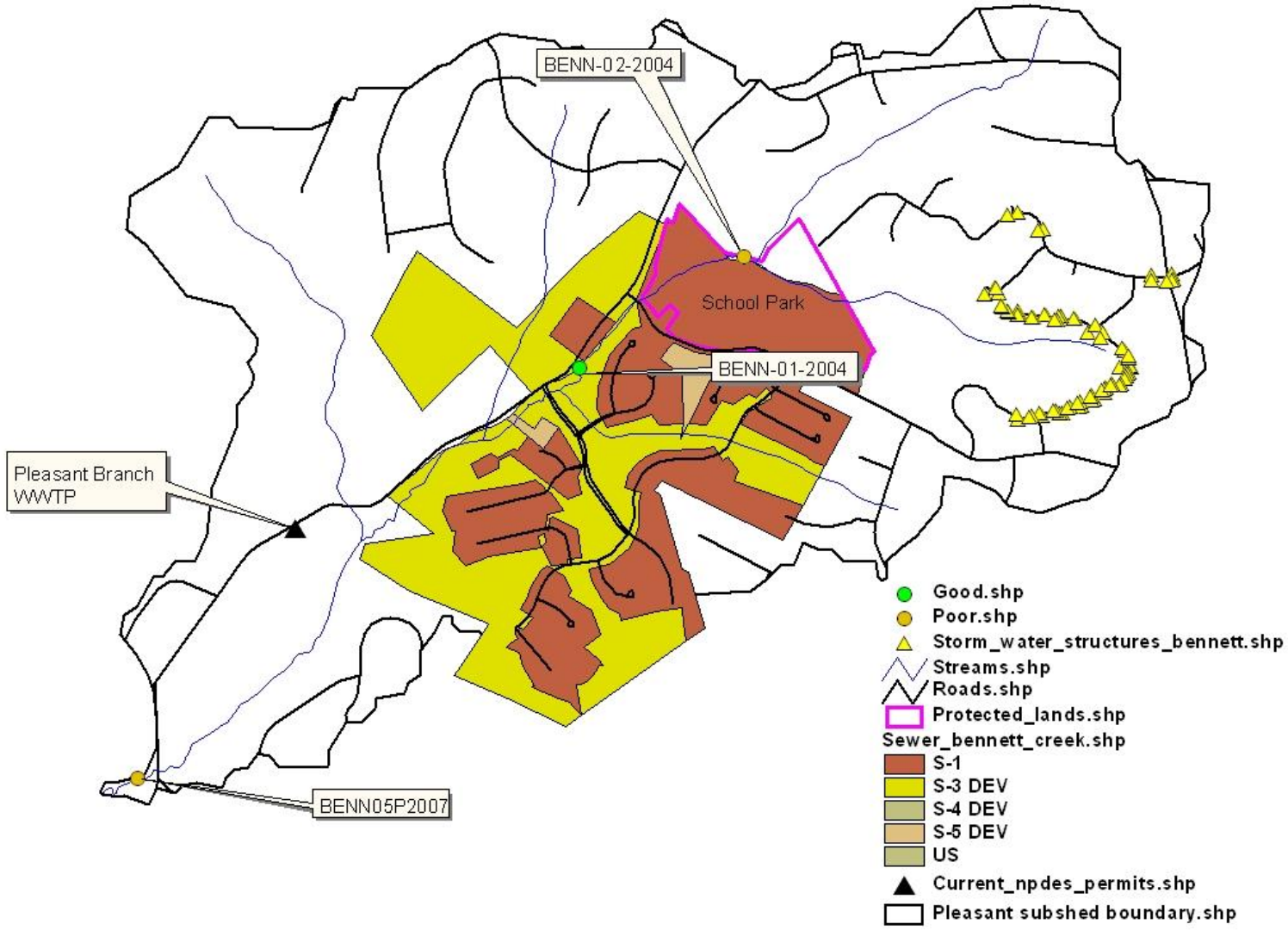

Figure 4-5. Roads, sewer and stormwater structure information for Pleasant Branch. Descriptions of the sewer codes can be found in Appendix C.

Figure 4-6a. Stormwater pipe outflow problem site identified during the stream corridor assessment. It is located near site BENN02-2004.

Figure 4-6b. Erosion problem site identified during the stream corridor assessment. It is located upstream of site BENN02-2004.

Figure 4-6c. Inadequate buffer problem site identified during the stream corridor assessment. It is located near site BENN05P2007.

Figure 4-6d. Trash dump (cars) at priority restoration site #42.

Figure 4-6e. Fish barrier at priority restoration site #30.

Figure 4-6f. Fish barrier at priority restoration site #36.

Figure 4-6g. Inadequate buffer at priority restoration site #34.

Figure 4-6h. Inadequate buffer at priority restoration site #36.

Table 4-1. BIBI & FIBI scores and water chemistry measurements taken in the Pleasant Branch subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of Pleasant Branch).

Parameter	**N Piedmont**	**BENN05P2007** 2006	2007	**BENN-01-2004**	**BENN-02-2004**	**NSS 95** (2003)
		RM 0.1		RM 1.3	RM 1.6	RM 1.6
Biological	**Ref Values[1]**	**Values**				
BIBI_05	**3.00**	3.00	*2.75*	4.00	*2.75*	
FIBI_05	**3.00**	3.67		4.67	4.33	
Chem_Spring						
pH (std units)	**7.06** - 7.61	***8.41***	*6.71*	*7.68*	*7.67*	7.23
Specific Conduct (mS/cm)	0.178	*0.247*	***0.505***	0.173	0.150	0.143
DOC (mg/L)	2.23					
SO4 (mg/L)	9.81					
NH3 (mg/L)	0.019					
NO3 (mg/L)	2.71					
NO2 (mg/L)	0.008					
NO2+NO3 (mg/L)						4.86
TN (mg/L)	2.82					
TKN (mg/L)						
TP (mg/L)	0.0260					
O_PHOS (mg/L)	0.005					0.003
Water Temp (°C)		14.4	10.4	14.7	13.8	17.6
DO (mg/L)		11.8	13.7			9.8
Turbidity (NTU)	3.5	***12.2***	*4.0*			
AcidSrc						
Chem_Summer						
Water Temp (°C)	20.5	16.5	*22.4*	16.5	16.5	
DO (mg/L)	**8.20**	9.8	10.9	9.5	10.2	
pH (std units)	**7.03** - 7.57	7.55	*7.83*	*6.96*	7.29	
Specific Conduct (mS/cm)	0.192	*0.288*	***0.303***	0.177	0.158	
Turbidity (NTU)	3.5	***49.0***	*8.4*	***19.8***	***11.7***	

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 4-2. BIBI & FIBI scores and physical habitat measurements taken in the Pleasant Branch subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of Pleasant Branch).

Parameter	**N Piedmont**	**BENN05P2007** 2006	2007	**BENN-01-2004**	**BENN-02-2004**	**NSS 95** (2003)
		RM 0.1		RM 1.3	RM 1.6	RM 1.6
Biological	**Ref Values[1]**	**Values**				
BIBI_05	**3.00**	3.00	*2.75*	4.00	*2.75*	
FIBI_05	**3.00**	3.67		4.67	4.33	
Habitat						
Instream Habitat	**14**	***11***	***10***	15	15	
Epifaunal Substrate	**14**	***7***	***7***	*13*	*12*	
Velocity/Depth Diversity	**10**	*9*	***7***	10	10	
Pool/Glide/Eddy Quality	**10**	10	***8***	*9*	***8***	
Ex_Pool		34	30	25	15	
Riffle Quality	**12**	*9*	*8*	14	13	
Ex_Riffle/Run		43	45	50	60	
Channel Alt	**10**					
Bank Stability	**8**					
Embeddedness	40	*50*	*50*	35	35	
Shading	**70**	***10***	***20***	70	80	

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 4-3a. **PLEASANT BRANCH**. Strength of evidence for candidate causes: Nutrient Enrichment and Excessive Sediment/Turbidity.

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
Co-occurrence				
Benthic Macroinvertebrates	No nutrient data were collected during the benthic sampling events.	NE	At the site where %embeddedness and turbidity were (slightly) higher than the reference 75th percentile and sand & silt/clay were categorized as 'extensive,' the BIBI score was 2.75 in 2007.	+
Fish	No nutrient data were collected during the fish sampling events.	NE	With FIBI scores greater than 3.00, the fish assemblage is not considered to be impaired. However, the lowest FIBI score (3.67) occurred at BENN05P2007, where %embeddedness and turbidity were (slightly) higher than the reference 75th percentile and sand & silt/clay were categorized as 'extensive' in 2007.	+
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	No nutrient data were collected during the benthic sampling events.	NE	Somewhat consistent. In 2007, the association is observed at the only site where %embeddedness is greater than the reference 75th percentile. At the same site in 2006, with the same %embeddedness and a very high turbidity measurement (49 NTU), the BIBI score was 3.00. This is considered fair; however it is on the threshold of being degraded.	0
FIBI	No nutrient data were collected during the fish sampling events.	NE	Somewhat consistent. With FIBI scores greater than 3.00, the fish assemblage is not considered to be impaired. The lowest FIBI score did occur at the site with the highest %embeddedness. %embeddedness was the same (35%) at the other 2 sites, yet FIBI scores differed slightly (4.33 & 4.67).	0
Biological gradient				
BIBI - within the Bennett Ck watershed	Strong significant negative correlations exist between BIBI scores and nitrate, total nitrogen,and nitrate+nitrite concentrations.	++	BIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0

Table 4-3a (continued). PLEASANT BRANCH

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
FIBI - within the Bennett Ck watershed	There are no significant correlations between FIBI scores and nutrient concentrations.	0	FIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0
BIBI- within the Northern Piedmont ecoregion	Weak significant negative correlations exist between BIBI scores and total phosphorus and nitrite concentrations.	+	A weak (r = -0.25) significant negative correlation exists between %embeddedness and BIBI scores. Too small a sample size for BIBI scores and turbidity measurements.	+
FIBI - within the Northern Piedmont ecoregion	A very weak (r=0.10) significant positive correlation exists between FIBI scores and nitrite concentrations. There are no other significant correlations between nutrient concentrations and FIBI scores.	0	A very weak (r = -0.10) significant negative correlation exists between FIBI scores and %embeddedness. FIBI scores were not significantly correlated with turbidity measurements.	0
Complete exposure pathway	Organisms are exposed directly to water column where nutrient enrichment is measured	+	Organisms are exposed directly to sediment and turbidity	+
Plausibility: stressor - response	Stressor-response thresholds have not been established for nutrient enrichment	NE	Stressor-response thresholds have not been established for sediment or turbidity	NE
Specificity of cause	Nutrient enrichment is one of many plausible and consistently associated stressors	NE	Excess sediment/turbidity is one of several plausible and consistently associated stressors	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE

Table 4-3a (continued). PLEASANT BRANCH

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
Consistency of evidence	Tough to determine in Pleasant Branch due to lack of data. The nitrate+nitrite concentration at the 2003 nutrient synoptic site on Pleasant Branch, which was taken at site BENN-02-2004, was elevated, and the 2004 BIBI score at this site was 2.75. The biological gradient shows that benthic macroinvertebrates in the Bennett Ck watershed are negatively correlated with nitrogen concentrations.	+	Evidence for the benthic macroinvertebrate assemblage is consistent at BENN05P2007 in 2007 (and somewhat consistent in 2006, since its BIBI score of 3.00 is on the threshold of being impaired). Evidence is not consistent at the other 2 sites.	0
Coherence of evidence	Nutrient enrichment may be a contributing factor to biological impairment	+	Excess sediment/turbidity may be a factor of biological impairment at BENN05P2007. It does not appear to be a factor at the other two sites on Pleasant Branch.	+

Table 4-3b. PLEASANT BRANCH. Strength of evidence for candidate causes: Habitat degradation and Excess Ammonia Toxicity.

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
Co-occurrence				
Benthic Macroinvertebrates	The site with the highest BIBI score (4.00) had the highest habitat metric scores. Habitat scores for instream habitat, epifaunal substrate, velocity/depth diversity, and pool quality were all below the 5th percentile of reference in 2007 at BENN05P2007, which had a BIBI score of 2.75.	+	Ammonia was not measured during the benthic macroinvertebrate sampling events.	NE
Fish	With FIBI scores greater than 3.00, the fish assemblage is not considered to be impaired. However, the lowest FIBI score (3.67) occurred at BENN05P2007, which had the lowest scores on the habitat metrics.	+	Ammonia was not measured during the fish sampling events.	NE
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Associations with some metrics are more consistent than with others. Overall they are mostly consistent.	+	Ammonia was not measured during the fish sampling events.	NE
FIBI	With FIBI scores greater than 3.00, the fish assemblage is not considered to be impaired. However, the sites with better habitat metric scores had better FIBI scores.	+	Ammonia was not measured during the benthic sampling events.	NE
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with MBSS habitat metrics.	0	BIBI scores were not significantly correlated with ammonia concentrations.	0
FIBI - within the Bennett Ck watershed	FIBI scores had positive significant correlations with 3 MBSS habitat metrics (velocity/depth diversity, pool/glide/eddy, riffle quality).	+	FIBI scores were not significantly correlated with ammonia concentrations.	0

Table 4-3b (continued). PLEASANT BRANCH.

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
BIBI- within the Northern Piedmont ecoregion	Weak (r = 0.11 to 0.35) significant positive correlations exist between BIBI scores and 4 of 5 MBBS habitat metrics.	+	A very weak (r = -0.12) significant negative correlation exists between BIBI scores and ammonia concentrations.	0
FIBI - within the Northern Piedmont ecoregion	Significant positive correlations exist between FIBI scores and the 5 MBSS habitat metrics (for 4 of these, r > 0.4).	++	FIBI scores were not significantly correlated with ammonia concentrations.	0
Complete exposure pathway	Organisms are exposed directly to instream morphological habitat features and indirectly to riparian habitat features	+	Organisms are exposed directly to water column where ammonia concentration is measured	+
Plausibility: stressor - response	Not established for this study	NE	Observed levels throughout the Bennett Ck watershed are generally below reference criteria levels.	−
Specificity of cause	Poor habitat quality is one of several plausible and consistently associated stressors	NE	Ammonica toxicity is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE

Table 4-3b (continued). PLEASANT BRANCH.

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
Consistency of evidence	Overall, consistent.	+	It is consistently not a factor at other sites in the Bennett Ck watershed. However it cannot be ruled out in Pleasant Branch due to lack of data.	NE
Coherence of evidence	Habitat impairment may be a contributing factor to biological impairment.	+	At sites in the Bennett Ck watershed where ammonia was measured, concentrations were generally below the 25th percentile of reference levels and it did not appear to be a factor of biological impairment. However it cannot be ruled out in Pleasant Branch due to lack of data.	NE

Table 4-3c. PLEASANT BRANCH. Strength of evidence for candidate causes: Thermal Loading and Dissolved Oxygen Deficit.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
Co-occurrence				
Benthic Macroinvertebrates	The site with the highest BIBI score (4.00) had the highest water temperature.	–	DO concentrations were high (>11.5 mg/l) at the one site at which it was measured. This site had a BIBI score of 3.00 in 2006 and 2.75 in 2007.	–
Fish	With FIBI scores greater than 3.00, the fish assemblage is not considered to be impaired. However, the lowest FIBI score (3.67) occurred at BENN05P2007, where water temperature was highest.	+	DO concentrations were higher than the 25th percentile of reference at all the sites (the lowest was 9.5 mg/l). All FIBI scores were greater than 3.00.	–
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Inconsistent - higher water temperatures are not observed at sites with lower BIBI scores.	–	Low DO concentrations were not observed at BENN05P2007, which had BIBI score of 3.00 in 2006 and 2.75 in 2007.	–
FIBI	The association between lower FIBI scores and higher temps occurred at 1 out of 3 sites.	0	Low DO concentrations were not observed at sites on Pleasant Branch. All FIBI scores were greater than 3.00.	–
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with water temperature.	0	BIBI scores were not significantly correlated with DO measurements.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with water temperature.	0	A strong (r = 0.48) significant positive correlation exists between FIBI scores and DO measurements.	++

Table 4-3c (continued). PLEASANT BRANCH.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
BIBI- within the Northern Piedmont ecoregion	Did not calculate - too small a sample size.	NE	Did not calculate - too small a sample size.	NE
FIBI - within the Northern Piedmont ecoregion	A weak (r = 0.20) significant positive correlation exists between FIBI scores and water temperature measurements. A weak (r = -0.19) significant negative correlation exists between FIBI scores and shading.	–	A weak (r = 0.2) significant positive correlation exists between FIBI scores and DO measurements.	+
Complete exposure pathway	Organisms are exposed directly to water temperature	+	Organisms are exposed directly to water column where DO is measured	+
Plausibility: stressor - response	Not established	NE	Oxygen is not commonly considered limiting until it is below 4-6 mg/L. Observed DO levels were all well above 6 mg/l.	–
Specificity of cause	Thermal loading may impact certain cold water species	NE	DO deficit is not consistently associated with biological impairment. Organic enrichment is one of many plausible and consistently associated stressors.	0
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE

Table 4-3c (continued). PLEASANT BRANCH.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
Consistency of evidence	Inconsistent	_	Inconsistent	_
Coherence of evidence	Water temperature can fluctuate greatly. The existing evidence for Pleasant Branch and for the Bennett Ck watershed as a whole does not indicate that thermal loading is a contributing factor to biological impairment.	_	DO deficit does not appear to be a factor of biological impairment, even in the summer, when DO stress would be greatest.	_

Table 4-3d. PLEASANT BRANCH. Strength of evidence for candidate causes: Ionic Strength and pH Imbalance.

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
Co-occurrence				
Benthic Macroinvertebrates	Conductivity was higher than the 75th percentile of reference at one site (and greater than the 95th percentile in 2007). This site had a BIBI score of 3.00 in 2006 and 2.75 in 2007.	+	pH was lower than the 25th percentile of reference at one site with a BIBI score of less than 3.00, and pH was (slightly) higher than the 75th percentile of reference at the other site that had a BIBI score of less than 3.00.	+
Fish	With FIBI scores greater than 3.00, the fish assemblage is not considered to be impaired. However, the lowest FIBI score (3.67) occurred at BENN05P2007, where conductivity was highest.	+	With FIBI scores greater than 3.00, the fish assemblage is not considered to be impaired. However, pH was higher than the 75th percentile of reference at the site that had the lowest FIBI score (3.67).	+
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Association is observed at the one site with elevated conductivity levels.	+	Inconsistent. In 2006 at BENN05P2007 the pH was higher than the 95th percentile of reference (8.41) and the BIBI score was 3.00 (fair). At BENN-01-2004 the pH was higher than the 75th percentile of reference and the BIBI score was 4.00.	–
FIBI	Association is observed at the one site with elevated conductivity levels.	+	Inconsistent. The site with a pH value in the reference range did not have the highest FIBI score.	–
Biological gradient				
BIBI - within the Bennett Ck watershed	There is a significant negative correlation between conductivity and BIBI scores (r=-0.34).	+	BIBI scores were not significantly correlated with pH.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with specific conductance.	0	FIBI scores were not significantly correlated with pH.	0

Table 4-3d (continued). PLEASANT BRANCH.

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
BIBI- within the Northern Piedmont ecoregion	A strong (r = -0.41) significant negative correlation exists between BIBI scores and specific conductance.	++	A weak (r = -0.29) significant negative correlation exists between BIBI scores and pH.	+
FIBI - within the Northern Piedmont ecoregion	A weak (r = -0.16) significant negative correlation exists between FIBI scores and specific conductance.	+	A very weak (r = 0.14) significant positive correlation exists between FIBI scores and pH.	0
Complete exposure pathway	Organisms are exposed directly to water column where conductivity and chloride are measured	+	Organisms are exposed directly to water column where pH is measured	+
Plausibility: stressor - response	Not established	NE	Not established	NE
Specificity of cause	Not applicable because ionic strength is not a plausible mechanism	NE	Not applicable because pH is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE

Table 4-3d (continued). PLEASANT BRANCH

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
Consistency of evidence	Consistent but not plausible	NE	Inconsistent	–
Coherence of evidence	This measure should be used as an indicator of sources at BENN05P2007 because there is no plausible mechanism for impact to benthic macroinvertebrates.	NE	pH imbalance may be a local or temporary issue but does not appear to have consistent effects	–

Table 4-4. A summary of the candidate causes associated with the biologically impaired sites in the Pleasant Branch subwatershed, and their possible sources. ☑ indicates that the source and/or step in the causal pathway are present or likely to be present in the upstream catchment area; ☑☑ indicates that the source and/or step in the causal pathway were documented at the site.

Candidate Cause	Pleasant Branch	
	BENN05 - P2007	BENN02-2004
Nutrient Enrichment		
Agricultural		
Fertilizer/Manure Application	☑	☑
Direct Animal Access to Streams	☑	
Residential Developments		
Failing Septic Systems	☑	☑
High Concentrations of Septic System Leach Fields	☑	☑
Application of Lawn Fertilizers	☑	☑
Pleasant Branch WWTP	☑	
Atmospheric Deposition		
Vehicle Emissions	☑	☑
Permitted Air Releases	☑	☑
Soil Disturbances		
Excess Sediment/Turbidity		
Land Disturbing Activities		
Direct Animal Access to Streams	☑ ☑	
Runoff from Impervious Surfaces	☑	
Row Crop Agriculture	☑	
Construction		
Natural Factors (i.e instream sources, naturally erodible soils)	☑	
Habitat Degradation		
Urban Land Use		
Impervious Surfaces	☑	☑
Stormwater Pipe Outflows	☑	☑ ☑
Inadequate Riparian Buffer	☑ ☑	☑ ☑
Bank Instability and Erosion		
Upstream Land Use	☑	☑ ☑
Direct Animal Access to Streams	☑ ☑	
Natural Factors (i.e instream sources, naturally erodible soils)	☑	☑ ☑
Channel Alteration		
Ionic Strength		
Human Activities	☑	

Table 4-5. Priority Restoration Sites on Pleasant Branch that were identified in the Lower Monocacy Watershed Restoration Action Strategy (Frederick County DPW 2004). Site locations are shown in Figure 4-3.

Site	Problem	Suggested Restoration
30	Dam and road crossing of unknown origin/purpose forming a fish barrier in the Pleasant Grove area	
31	Inadequate buffer through the Windsor Knolls School	Possible school yard habitat with Community Commons
32	Inadequate buffer and erosion through Meadow Brooke, Quail Run, and Freemont Hills subdivisions	Target with Backyard Buffer
33	Inadequate buffer and erosion through the Friendship, Freemont Court and Adgate Drive areas	Target with Backyard Buffer and possible storm water management structures
34	Inadequate buffer and erosion within subdivision	Target with Backyard Buffer
35	2500’ of 5’ high eroded stream bank and 1700’ of inadequate buffer with horses accessing stream	Target with CREP, Needs fencing
36	Fish barrier at road crossing of Route 75	Site for State Highway Administration Restoration assistance
37	Large estate lots with inadequate buffer with horses accessing the stream	Target with Backyard Buffer,
38	Inadequate buffer with livestock accessing the stream	Target with CREP, Needs fencing
42	Trash dumping site	

Table 4-6. Summary of the SCA results for the Pleasant Branch subwatershed (Czwartacki et al. 2004).

Potential Problems	Number	Estimated Length	Very Severe	Severe	Moderate	Low Severity	Minor
Channel Alterations	3	375 ft (0.07 miles)	0	0	0	0	3
Erosion Sites	9	14430 ft (2.73 miles)	3	2	2	2	0
Exposed Pipes	0	NA	0	0	0	0	0
Fish Barriers	9	NA	0	0	1	3	5
Inadequate Buffers	12	7500 ft (1.42 miles)	4	0	2	3	3
Pipe Outfalls	7	NA	0	0	1	1	5
Trash Dumpings	3	NA	0	3	0	0	0
Unusual Conditions	2	NA	0	0	0	2	0
Total	**45**		**7**	**5**	**6**	**11**	**16**
Comments	**4**						
Representative Sites	**6**						

5 BENNETT UPPER MAINSTEM - STRESSOR IDENTIFICATION

5.1. Description of Impairment: Bennett Upper Mainstem

FIBI scores at all of the sites in the Bennett Upper Mainstem subwatershed were equal to or greater than 3.00, so the fish assemblage is not considered to be impaired. Based on the BIBI scores, the benthic macroinvertebrate assemblages at two of the three sites within the Frederick County portion of the Bennett Upper Mainstem subwatershed are impaired. Both of these sites are located on Bennett Creek mainstem (Figure 5-1). In the Montgomery County portion of the subwatershed, the benthic macroinvertebrate assemblages at four of the nine sites are impaired. Two of these sites are located on tributaries and two are located on the Bennett Creek mainstem.

5.2. Candidate Causes – Potential Stressor Sources: Bennett Upper Mainstem

The conceptual diagram (Figure 5-2) shows the stressor sources, the stressors they induce and the effects on the biological assemblage for the Upper Bennett subwatershed. Sources in this subwatershed include agricultural practices (row crops and livestock), low and medium density residential developments, commercial and institutional developments, atmospheric deposition, and (potentially failing) septic systems.

5.3. Analysis of Evidence – Associating candidate causes: Bennett Upper Mainstem

Bennett Creek mainstem sites. Two randomly-selected biological sampling sites are located on the Bennett Creek mainstem in the Frederick County portion of the Bennett Creek Upper Mainstem subwatershed. One of the sites, BCBC314, was sampled for fish in 1997, 1999 and 2003 and for benthic macroinvertebrates in 2003. The site had a BIBI score of 2.75 in 2003; FIBI scores were all greater than 3.00. Sampling was performed by field crews from Montgomery County.
The other site, FR-P- 377-242-96, which is located approximately a half mile upstream of BCBC314, was sampled for fish and benthic macroinvertebrates in 1996 by MBSS crews. The BIBI score was 1.50 and the FIBI score was 4.00. The benthic macroinvertebrate assemblage was dominated by Orthocladiinae (Diptera: Chironomidae).

Limited data are available for BCBC314. *In situ* water quality measurements (water temperature, dissolved oxygen, pH and specific conductance) were taken during the spring and summer. All values except for the summer pH were comparable to reference, and the 2003 summer pH value was only slightly above the 75th percentile of reference site values (Tables 5-1a-c). Montgomery County performs rapid habitat assessments that include some but not all of the MBSS habitat metrics. The MBSS metrics that were assessed (epifaunal substrate, velocity/depth diversity and channel alteration) were comparable to reference (Table 5-2). Of the additional metrics assessed by Montgomery County, left bank stability received a marginal rating (moderately unstable). All of the other metrics received ratings of optimal or suboptimal.

More data are available for FR-P- 377-242-96. Two variables - nitrate concentration and summer pH - were greater than the 75th percentile of reference site values, but all other *in situ* and water chemistry values were comparable to reference. Three habitat metrics – epifaunal substrate, channel alteration and bank stability – had scores that were less than the 25th percentile of reference site values. Percent shading was also less than the 25th percentile of reference site values.

5.4. Characterization of Causes: Bennett Upper Mainstem

5.4.1. Elimination of candidate causes: Bennett Upper Mainstem

Ammonia concentrations and water temperatures were comparable to reference at all sites. No other candidate causes could be eliminated.

5.4.2. Strength of evidence: Bennett Upper Mainstem

The strength of evidence analysis was completed for eight candidate causes and twelve lines of logic. It is summarized in Tables 5-3a-d.

5.4.3. Identification of probable causes: Bennett Upper Mainstem

BCBC314. From the strength of evidence analysis it appears that nutrient enrichment may be a contributing factor to impairment of the benthic macroinvertebrate assemblage at this site. Habitat degradation due to marginal stability on the left bank may be another cause of biological impairment. Evidence regarding excessive sediment/turbidity, ionic strength and pH imbalance was inconsistent or implausible.

Although nutrient data are not available for this site, elevated nitrate concentrations were recorded at the upstream site, FR-P-377-242-96, during the 1996 biological sampling event, so it is likely that BCBC314 also had elevated nitrate concentrations. BIBI scores in the Bennett Creek watershed were negatively correlated with nitrogen concentrations (NO_3, NO_3- NO_2, TN). Possible sources of nutrients include fertilizers being applied to agricultural lands in the upstream catchment area, fertilizers being applied to lawns in the surrounding low density residential developments, failed septic systems and atmospheric deposition (Figure 5-3).

FR-P- 377-242-96. From the strength of evidence analysis it appears that nutrient enrichment and habitat degradation may be factors contributing to impairment of the benthic macroinvertebrate assemblage at this site. Although pH was elevated in the summer, it was comparable to reference in the spring and is not likely to be a consistent or widespread factor. The elevated summer pH value may be due to increased photosynthesis resulting from increased summer algal production. No periphyton data are available to confirm this. Evidence regarding excessive sediment/turbidity and ionic strength was inconsistent or implausible.

The elevated nitrate concentration and low BIBI score (1.50) is consistent with patterns seen throughout the Bennett Creek watershed, where BIBI scores were negatively correlated with nitrogen concentrations (NO_3, NO_3- NO_2, TN). Possible sources of nutrients include fertilizers being applied to agricultural lands in the upstream catchment area, fertilizers being applied to lawns in the surrounding low density residential developments, failed septic systems and atmospheric deposition.

Habitat degradation is another possible factor of biological impairment at this site. It received low scores for channel alteration and bank stability, and it received an epifaunal substrate score that was slightly less than the 25^{th} percentile of reference site values. Based on the bank stability score, 30-60% of banks have erosional scars and there is high potential for erosion during extreme high flow events. This may result in decreased organic bank habitat (i.e. woody debris and root wads) for the

benthic macroinvertebrates. It is worth noting that a low bank stability score and a low BIBI score also co-occurred at BCBC314.

Impaired sites in Montgomery County.

There were four biologically impaired sites located in the Montgomery County portion of the Upper Bennett subwatershed. BCBC401 is located on the Bennett Creek mainstem, approximately 1.5 miles upstream from FR-P- 377-242-96. It had a BIBI score of 1.75 and a FIBI score of 4.00. Nutrient data were not collected during the biological sampling events, but a nutrient synoptic site that was located 0.1 miles downstream from this site had an elevated NO_3- NO_2 concentration and an orthophosphate concentration greater than the 75th percentile of reference site values. Therefore nutrient enrichment may be a factor of impairment at this site. Possible nutrient sources in the upstream catchment area include fertilizers that are applied to agricultural lands and residential lawns, animal waste from livestock, failing septic systems, and atmospheric deposition. The site had instream habitat and epifaunal substrate scores that were less than the reference 25th percentile, so habitat degradation may also be a factor contributing to biological impairment. In addition, summer dissolved oxygen concentrations at this site were less than the reference 25th percentile, so dissolved oxygen deficit may be impacting the biota.

BCBC305 is the other impaired site located on the Bennett Creek mainstem. It had a BIBI score of 2.00 and a FIBI score of 4.16. It is approximately one mile upstream of BCBC401. Limited data are available for this site. Scores from the rapid habitat assessment and *in situ* water quality measurements were generally comparable to reference (pH was slightly below the 25th percentile of reference site values in the spring). Nutrient enrichment may be a factor, but there is no evidence for or against this because nutrients were not measured. Possible nutrient sources would include fertilizers that are applied to agricultural lands and residential lawns, animal waste from livestock, failing septic systems, and atmospheric deposition.

The two other impaired sites were located on tributaries. BCBC308 is located approximately 0.2 miles from the confluence of the tributary with Bennett Creek, near BCBC401. This site had a BIBI score of 2.00 and a FIBI score of 3.22. Possible factors of impairment include excessive sediment and low pH (the spring pH value was 6.39, the summer value was 6.72). The other site, BCBC210, is located on a tributary that flows into Bennett Creek between FR-P-377-242-96 and BCBC401. It had a BIBI score of 2.38 and a FIBI score of 3.84. The site was rated 'marginal' for bank stability and sediment deposition during the rapid habitat assessment, so habitat degradation may be a factor contributing to impairment. Nutrient enrichment may also be a factor at both of these sites (surrounding land use is forest, agriculture and low density residential), but there is no evidence for or against this because nutrients were not measured.

5.5. Summary of Results – Bennett Upper Mainstem

A summary of the candidate causes associated with the two biologically impaired sites (in the project area), along with their likely sources, is shown in Table 5-4. Nutrient enrichment and habitat degradation were the most prevalent and probable causes of impairment at the biologically impaired sites. The site with the lowest BIBI score (FR-P-377-242-96) was sampled in 1996, so it would be valuable to obtain more recent data for this area, along with more extensive nutrient data. The most probable sources of nutrient enrichment are agricultural lands, low density residential developments

and atmospheric deposition. The most probable sources of habitat degradation are erosion from upstream land use and natural factors.

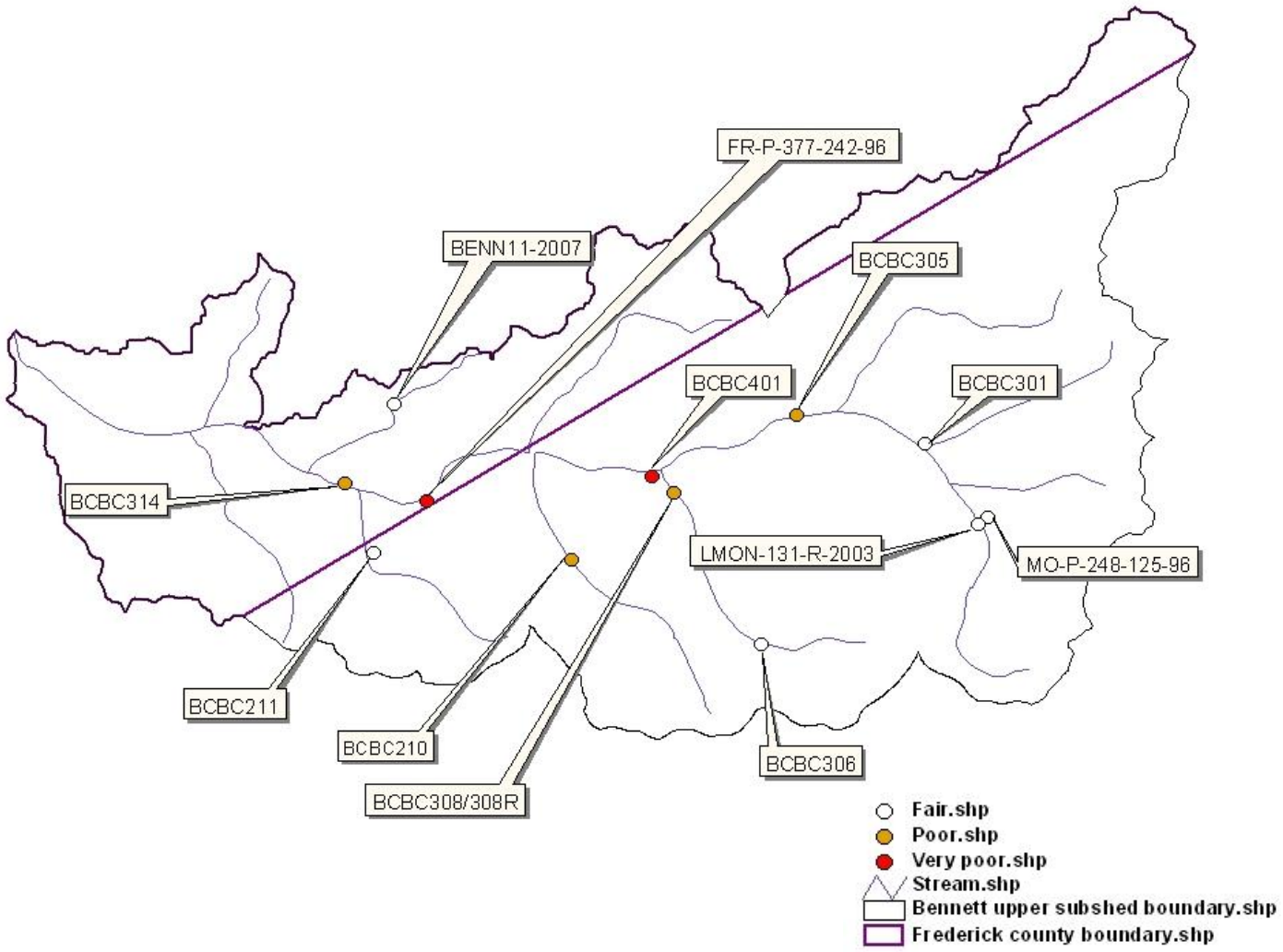

Figure 5-1. Locations of biological sampling sites in the Bennett Upper Mainstem subwatershed. Three sites are located in the project area. Sites are color-coded based on their lowest IBI rating (i.e. if the BIBI score was lower than the FIBI score, the BIBI score was used).

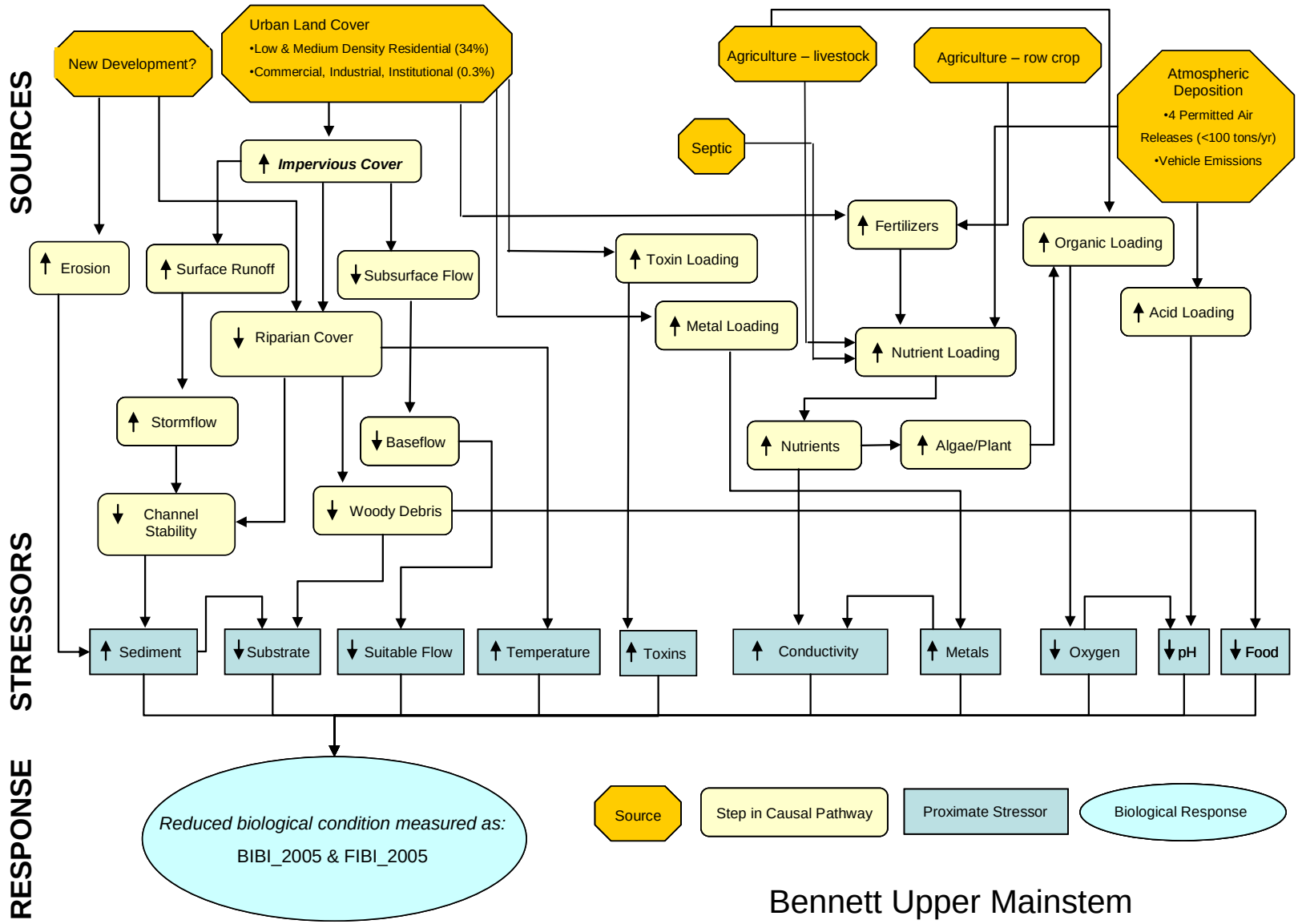

Figure 5-2. Conceptual Model for the Bennett Upper Mainstem subwatershed.

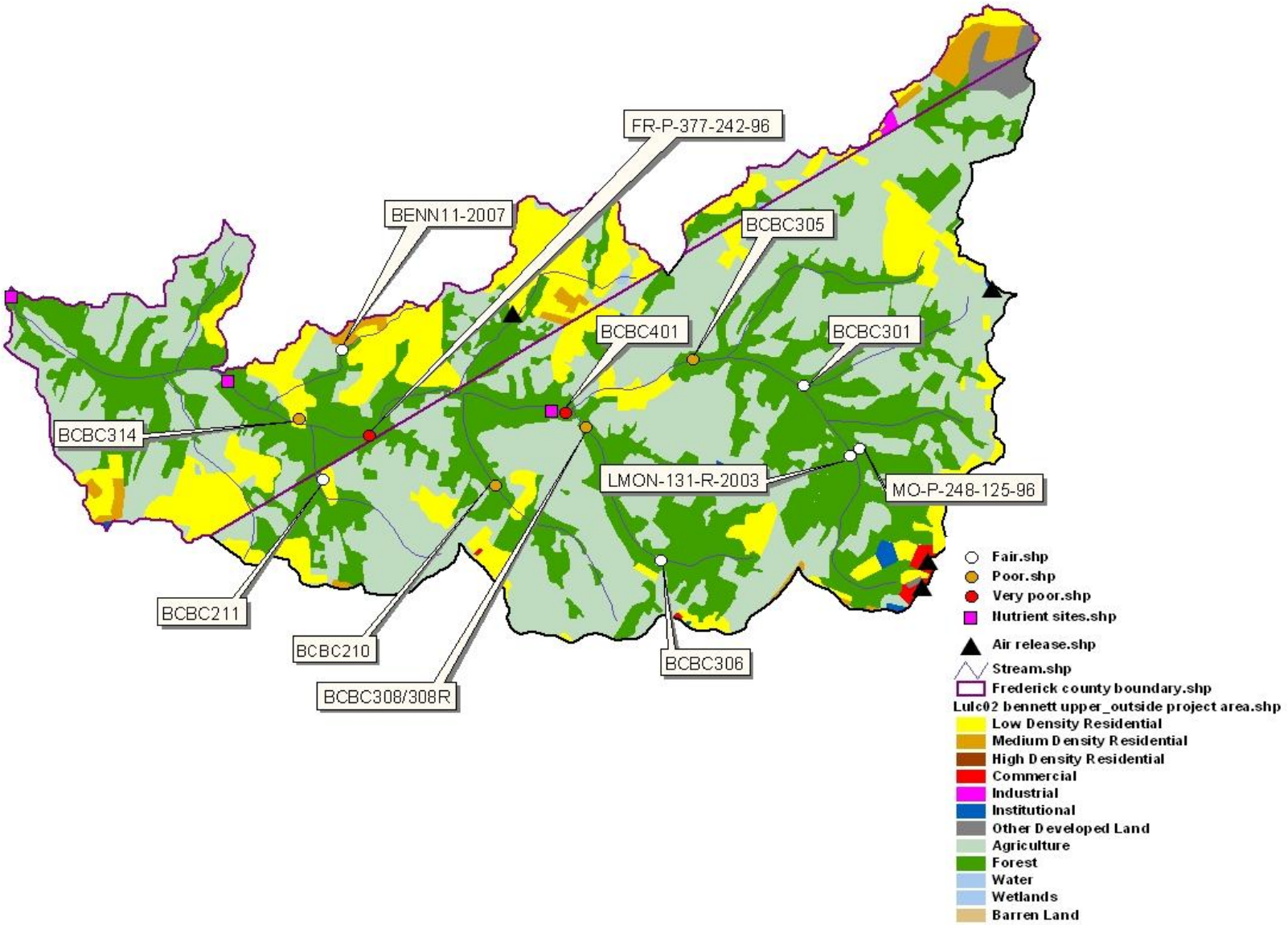

Figure 5-3. Land use land cover, biology, nutrient synoptic survey and Envirofacts information for the Bennett Upper Mainstem subwatershed.

Table 5-1a. BIBI and FIBI scores and spring water chemistry measurements taken at Bennett Upper Mainstem sites. The mean BIBI and FIBI scores were used for sites that were sampled multiple times. Parameter values are compared to the associated reference values, which are highlighted in gray (bold type = 25th percentile of the reference distribution; normal type = 75th percentile). Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. River Miles refer to the distance from the mouth of the Bennett Creek mainstem. Tributaries to the Bennett Creek mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem; the values in parentheses refer to the distance of the site from the mouth of the tributary.

Site Information		***Biological***		***Chemistry_Spring***							
Site ID	River Mile	BIBI_05	FIBI_05	DOC (mg/L)	SO4 (mg/L)	NH3 (mg/L)	NO3 (mg/L)	NO2+NO3 (mg/L)	TN (mg/L)	TP (mg/L)	O_PHOS (mg/L)
		3.00	**3.00**	2.23	9.81	0.019	2.71		2.82	0.026	0.005
NSS 73	RM 9.4							3.25			0.004
NSS 75	RM 11.3							3.20			0.003
BENN11-2007	RM 11.5	3.00		0.32		0.002	***6.31***	6.31	***7.59***	0.018	0.001
BCBC314	RM 11.7	*2.50*	4.11								
BCBC211	RM 11.8 (0.5)	3.63	3.00								
FR-P-377-242-96	RM 12.3	***1.25***	4.00	1.70	7.22		*3.03*				
BCBC210	RM 13.2 (0.7)	*2.38*	3.84								
NSS 76	RM 13.8							3.12			*0.007*
BCBC401	RM 13.9	***1.63***	4.00								
BCBC308	RM 14.0 (0.2)	*2.00*	3.22								
BCBC306	RM 14.0 (1.3)	3.50	3.17								
BCBC305	RM 14.8	*2.25*	4.16								
BCBC301	RM 15.6	3.83	3.78								
MO-P-248-125-96	RM 16.2	3.25	4.00	0.90	8.81		2.26				
LMON-131-R-2003	RM 16.2	3.25	3.00	0.87	8.94	0.003	2.43		2.62	0.005	0.001

Table 5-1b. BIBI and FIBI scores and spring *in situ* water chemistry measurements taken at Bennett Upper Mainstem. The mean BIBI and FIBI scores were used for sites that were sampled multiple times. Parameter values are compared to the associated reference values, which are highlighted in gray (bold type = 25th percentile of the reference distribution; normal type = 75th percentile). Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. River Miles refer to the distance from the mouth of the Bennett Creek mainstem. Tributaries to the Bennett Creek mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem; the values in parentheses refer to the distance of the site from the mouth of the tributary.

Site Information		***Biological***		***In situ_Spring***					
Site ID	River Mile	BIBI_05	FIBI_05	pH (std units)	Specific Conduct (mS/cm)	Water Temp (°C)	DO (mg/L)	Turbidity (NTU)	AcidSrc
		3.00	**3.00**	**7.06** - 7.61	0.178			3.5	
NSS 73	RM 9.4			7.47	0.153	14.8	10.8		
NSS 75	RM 11.3			7.35	0.135	19.1	9.8		
BENN11-2007	RM 11.5	3.00		7.15	*0.180*	11.8	10.2	***18.4***	
BCBC314	RM 11.7	*2.75*	4.11	7.37	0.140	11.0	11.9		
BCBC211	RM 11.8 (0.5)	3.63	3.00	*6.63*	0.094	11.0	12.2		
FR-P-377-242-96	RM 12.3	***1.25***	4.00	7.17	0.125				none
BCBC210	RM 13.2 (0.7)	*2.38*	3.84	7.55	0.165	9.0	11.4		
NSS 76	RM 13.8			7.45	0.147	19.3	9.8		
BCBC401	RM 13.9	***1.63***	4.00	7.23	0.150	8.0	12.5		
BCBC308	RM 14.0 (0.2)	*2.00*	3.22	***6.39***	*0.209*	15.0	11.9		
BCBC306	RM 14.0 (1.3)	3.50	3.17	*6.88*	0.133	13.6	10.5		
BCBC305	RM 14.8	*2.25*	4.16	*6.84*	0.130	13.3	10.8		
BCBC301	RM 15.6	3.83	3.78	*7.71*	0.130	9.0	13.3		
MO-P-248-125-96	RM 16.2	3.25	4.00	7.21	*0.218*				none
LMON-131-R-2003	RM 16.2	3.25	3.00	7.34	*0.226*				none

Table 5-1c. BIBI and FIBI scores and summer in situ water chemistry measurements taken at Bennett Upper Mainstem sites. The mean BIBI and FIBI scores were used for sites that were sampled multiple times. Parameter values are compared to the associated reference values, which are highlighted in gray (bold type = 25th percentile of the reference distribution; normal type = 75th percentile). Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. River Miles refer to the distance from the mouth of the Bennett Creek mainstem. Tributaries to the Bennett Creek mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem; the values in parentheses refer to the distance of the site from the mouth of the tributary.

Site Information		***Biological***		***In situ_Summer***				
Site ID	River Mile	BIBI_05	FIBI_05	Water Temp (°C)	DO (mg/L)	pH (std units)	Specific Conduct (mS/cm)	Turbidity (NTU)
		3.00	**3.00**	20.5	**8.2**	**7.03** - 7.57	0.192	3.5
BENN11-2007	RM 11.5	3.00						
BCBC314	RM 11.7	*2.75*	4.11	17.9	8.4	*7.90*	0.148	
BCBC211	RM 11.8 (0.5)	3.63	3.00	17.5	8.9	*6.78*	0.088	
FR-P-377-242-96	RM 12.3	***1.25***	4.00	14.3	9.2	*8.30*	0.130	
BCBC210	RM 13.2 (0.7)	*2.38*	3.84	19.4	8.7	*7.70*	0.162	
BCBC401	RM 13.9	***1.63***	4.00	19.9	***7.2***	*7.73*	0.160	
BCBC308	RM 14.0 (0.2)	*2.00*	3.22	18.4	8.7	*6.72*	0.146	
BCBC306	RM 14.0 (1.3)	3.50	3.17	17.1	*7.6*	7.26	0.140	
BCBC305	RM 14.8	*2.25*	4.16	17.3	9.2	7.09	0.114	
BCBC301	RM 15.6	3.83	3.78	18.9	8.3	7.30	0.141	
MO-P-248-125-96	RM 16.2	3.25	4.00	12.9	9.2	7.19	0.174	
LMON-131-R-2003	RM 16.2	3.25	3.00	17.2	8.7	7.17	*0.200*	0.4

Table 5-2. BIBI and FIBI scores and habitat measurements taken at Bennett Upper Mainstem sites. The mean BIBI and FIBI scores were used for sites that were sampled multiple times. Parameter values are compared to the associated reference values, which are highlighted in gray (bold type = 25th percentile of the reference distribution; normal type = 75th percentile). Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. River Miles refer to the distance from the mouth of the Bennett Creek mainstem. Tributaries to the Bennett Creek mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem; the values in parentheses refer to the distance of the site from the mouth of the tributary.

Site Information		***Biological***		***Habitat***								
Site ID	River Mile	BIBI_05	FIBI_05	Instream Habitat	Epifaunal Substrate	Velocity Depth	Pool Quality	Riffle Quality	Channel Alt	Bank Stability	Embed	Shading
		3.00	**3.00**	**14**	**14**	**10**	**10**	**12**	**10**	**8**	40	**70**
BENN11-2007	RM 11.5	3.00		***9***	*8*	*8*	***7***	*7*			***80***	*65*
BCBC314	RM 11.7	*2.75*	4.11		15	16				18		
BCBC211	RM 11.8 (0.5)	3.63	3.00		17	14				15		
FR-P-377-242-96	RM 12.3	***1.25***	4.00	14	*12*	16	15	13	*6*	6	31	*60*
BCBC210	RM 13.2 (0.7)	*2.38*	3.84	15	15				17			
BCBC401	RM 13.9	***1.63***	4.00	*13*	*13*				17			
BCBC308	RM 14.0 (0.2)	*2.00*	3.22	15	17				18			
BCBC306	RM 14.0 (1.3)	3.50	3.17	***9***	17				18			
BCBC305	RM 14.8	*2.25*	4.16	14	16				17			
BCBC301	RM 15.6	3.83	3.78	18	16				18			
MO-P-248-125-96	RM 16.2	3.25	4.00	*12*	14	12	12	14	10	7	35	78
LMON-131-R-2003	RM 16.2	3.25	3.00	***8***	*13*	10	***8***	15			35	96

Table 5-3a. BENNETT UPPER MAINSTEM SITES. Strength of evidence for candidate causes: Nutrient Enrichment and Excessive Sediment/Turbidity.

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
Co-occurrence				
Benthic Macroinvertebrates	Limited nutrient data. One site with a BIBI score of 1.50 had NO3 concentrations slightly greater than the 75th percentile of reference (1996 data). A nutrient synoptic site 0.1 miles downstream of a site that had a BIBI score of 1.75 had slightly elevated NO2+NO3 and O_Phos values.	+	Limited data. %embeddedness was less than the 75th percentile of reference at the site with the lowest BIBI score. At a trib site with a BIBI score of 3.00, %embeddedness and turbidity were greater than the 95th percentile of reference.	–
Fish	With FIBI scores greater than or equal to 3.00, the fish assemblage is not considered to be impaired. No nutrient data were collected at the sites with the lowest FIBI scores.	NE	With FIBI scores greater than or equal to 3.00, the fish assemblage is not considered to be impaired. %embeddedness was not recorded at the sites with the lowest FIBI scores.	NE
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Consistent at three mainstem sites - one with a BIBI score less than 3.00 had an elevated NO3 value, and two sites with normal NO3 values (2.26 and 2.43 mg/l) had BIBI scores greater than 3.00. Close to consistent at one trib - the site had a BIBI score of 3.00 and its NO3 and TN values were greater than the 95th percentile of reference.	+	Inconsistent at two sites (limited data)	–
FIBI	Inconsistent - the site with elevated NO3 concentrations had a high FIBI score (4.00).	–	No obvious or consistent associations at the 3 sites with data.	–
Biological gradient				
BIBI - within the Bennett Ck watershed	Strong significant negative correlations exist between BIBI scores and nitrate, total nitrogen,and nitrate+nitrite concentrations.	++	BIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0
FIBI - within the Bennett Ck watershed	There are no significant correlations between FIBI scores and nutrient concentrations.	0	FIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0

Table 5-3a (continued). BENNETT UPPER MAINSTEM SITES.

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
BIBI- within the Northern Piedmont ecoregion	Weak significant negative correlations exist between BIBI scores and total phosphorus and nitrite concentrations.	+	A weak (r = -0.25) significant correlation exists between %embeddedness and BIBI scores. Too small a sample size for BIBI scores and turbidity measurements.	+
FIBI - within the Northern Piedmont ecoregion	A very weak (r=0.10) significant positive correlation exists between FIBI scores and nitrite concentrations. There are no other significant correlations between nutrient concentrations and FIBI scores.	0	A very weak (r = -0.10) significant correlation exists between FIBI scores and %embeddedness. FIBI scores were not significantly correlated with turbidity measurements.	0
Complete exposure pathway	Organisms are exposed directly to water column where nutrient enrichment is measured	+	Organisms are exposed directly to sediment and turbidity	+
Plausibility: stressor - response	Stressor-response thresholds have not been established for nutrient enrichment	NE	Stressor-response thresholds have not been established for sediment or turbidity	NE
Specificity of cause	Nutrient enrichment is one of many plausible and consistently associated stressors	NE	Excess sediment/turbidity is one of several plausible and consistently associated stressors	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Evidence is limited due to a lack of nutrient data. The little that we have is mostly consistent for the benthic macroinvertebrate assemblage.	+	Evidence is limited. The little that we have is not consistent.	–
Coherence of evidence	Nutrient enrichment may be a contributing factor to biological impairment of the benthic macroinvertebrate assemblage.	+	Excess sediment/turbidity does not appear to be a factor in biological impairment. However this is based on very little evidence.	–

Table 5-3b. BENNETT UPPER MAINSTEM SITES. Strength of evidence for candidate causes: Habitat Degradation and Excess Ammonia Toxicity.

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
Co-occurrence				
Benthic Macroinvertebrates	Limited data. The site that had the lowest BIBI score had the lowest scores for channel alteration and bank stability. The site that received the lowest overall habitat metric scores had a BIBI score on the threshold of being degraded (3.00).	+	NH3 was only measured during two benthic macroinvertebrate sampling events. At both sites, concentrations were lower than the 25th percentile of reference, and BIBI scores were 3.00 or greater.	–
Fish	With FIBI scores greater than or equal to 3.00, the fish assemblage is not considered to be impaired. However, two of the sites with the lowest FIBI scores had low instream habitat metric scores.	+	At the one site with NH3 data, NH3 was less than the 25th percentile of reference and the FIBI score was 3.00.	–
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Consistent at one site for bank stability and channel alteration metrics. Consistent at two sites with low epifaunal substrate scores. Not consistent for these metrics at other sites with BIBI scores of less than 3.00.	0	No associations were observed at the two sites	–
FIBI	Overall, no consistent associations.	–	Need more data to determine consistency.	NE
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with MBSS habitat metrics.	0	BIBI scores were not significantly correlated with ammonia concentrations.	0
FIBI - within the Bennett Ck watershed	FIBI scores had positive significant correlations with 3 MBSS habitat metrics (velocity/depth diversity, pool/glide/eddy, riffle quality).	+	FIBI scores were not significantly correlated with ammonia concentrations.	0

Table 5-3b (continued). BENNETT UPPER MAINSTEM SITES.

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
BIBI- within the Northern Piedmont ecoregion	Weak (r = 0.11 to 0.35) significant positive correlations exist between BIBI scores and 4 of 5 MBBS habitat metrics.	+	A very weak (r = -0.12) significant negative correlation exists between BIBI scores and ammonia concentrations.	0
FIBI - within the Northern Piedmont ecoregion	Significant positive correlations exist between FIBI scores and the 5 MBSS habitat metrics (for 4 of these, r > 0.4).	++	FIBI scores were not significantly correlated with ammonia concentrations.	0
Complete exposure pathway	Organisms are exposed directly to instream morphological habitat features and indirectly to riparian habitat features	+	Organisms are exposed directly to water column where ammonia concentration is measured	+
Plausibility: stressor - response	Not established for this study	NE	Observed levels are below reference criteria levels.	–
Specificity of cause	Poor habitat quality is one of several plausible and consistently associated stressors	NE	Ammonica toxicity is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Evidence is limited. Certain habitat metrics have low scores at certain sites with lower BIBI and FIBI scores. Appears to be site-specific.	+	The limited evidence consistently shows ammonia toxicity not to be factor.	–
Coherence of evidence	Habitat impairment may be a contributing factor to biological impairment at certain sites.	+	Ammonia toxicity does not appear to be a factor.	–

Table 5-3c. BENNETT UPPER MAINSTEM SITES. Strength of evidence for candidate causes: Thermal Loading and Dissolved Oxygen Deficits.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
Co-occurrence				
Benthic Macroinvertebrates	The site with the highest spring-time water temperature (15°C) had a BIBI score of 2.00.	+	DO concentrations were high (>10.5 mg/l) at the benthic sampling sites at which it was measured. The site with the lowest DO had a BIBI score of 3.25.	–
Fish	All summer water temperatures were less than the 25th percentile of reference. The site with the highest water temperature had a high FIBI score (4.00).	–	2 of the 11 sites had DO concentrations that were less than the 25th percentile of reference. The site with the lowest DO (7.2 mg/l) had a FIBI score of 4.00. The other site (DO=7.6 mg/l) had a FIBI score of 3.17.	0
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Inconsistent at three of the four sites with water temperature data that had BIBI scores of 3.00 or less.	–	There was no consistent association between lower DO concentrations and lower BIBI scores.	–
FIBI	Inconsistent.	–	Overall, inconsistent.	–
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with water temperature.	0	BIBI scores were not significantly correlated with DO measurements.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with water temperature.	0	A strong (r = 0.48) significant positive correlation exists between FIBI scores and DO measurements.	++

Table 5-3c (continued). BENNETT UPPER MAINSTEM SITES.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
BIBI- within the Northern Piedmont ecoregion	Did not calculate - too small a sample size.	NE	Did not calculate - too small a sample size.	NE
FIBI - within the Northern Piedmont ecoregion	A weak (r = 0.2) significant positive correlation exists between FIBI scores and water temperature measurements.	–	A weak (r = 0.2) significant positive correlation exists between FIBI scores and DO measurements.	+
Complete exposure pathway	Organisms are exposed directly to water temperature	+	Organisms are exposed directly to water column where DO is measured	+
Plausibility: stressor - response	Not established	NE	Oxygen is not commonly considered limiting until it is below 4-6 mg/L. Observed DO levels were all above 6 mg/l.	–
Specificity of cause	Thermal loading may impact certain cold water species	NE	DO deficit is not consistently associated with biological impairment. Organic enrichment is one of many plausible and consistently associated stressors.	0
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Inconsistent	–	Inconsistent	–
Coherence of evidence	Water temperature can fluctuate greatly. The existing evidence does not indicate that thermal loading is a contributing factor to biological impairment.	–	DO deficit does not appear to be a factor of biological impairment, even in the summer, when DO stress would be greatest.	–

Table 5-3d. BENNETT UPPER MAINSTEM SITES. Strength of evidence for candidate causes: Ionic Strength and pH Imbalance.

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
Co-occurrence				
Benthic Macroinvertebrates	Conductivity was higher than the 75th percentile of reference at three sites. One of these sites had a BIBI score of less than 3.00.	+	pH was lower than the 25th percentile of reference at two sites (one on a trib, one on the mainstem) with BIBI scores of less than 3.00.	+
Fish	The two sites with the lowest FIBI scores (3.00) had the highest and lowest conductivities.	0	With FIBI scores greater than or equal to 3.00, the fish assemblage is not considered to be impaired. However, at one of the sites with a lower FIBI score (3.00), pH was lower than the 25th percentile of reference.	+
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Association is observed at only one of the three sites with conductivity values greater than the 75th percentile of reference.	–	Association is consistent at one trib and one mainstem site, but not at the majority of sites.	–
FIBI	Inconsistent.	–	Overall, inconsistent.	–
Biological gradient				
BIBI - within the Bennett Ck watershed	There is a significant negative correlation between conductivity and BIBI scores (r=-0.34).	+	BIBI scores were not significantly correlated with pH.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with specific conductance.	0	FIBI scores were not significantly correlated with pH.	0

Table 5-3d (continued). BENNETT UPPER MAINSTEM SITES.

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
BIBI- within the Northern Piedmont ecoregion	A strong (r = -0.41) significant negative correlation exists between BIBI scores and specific conductance.	++	A weak (r = -0.29) significant negative correlation exists between BIBI scores and pH.	+
FIBI - within the Northern Piedmont ecoregion	A weak (r = -0.16) significant negative correlation exists between FIBI scores and specific conductance.	+	A very weak (r = 0.14) significant positive correlation exists between FIBI scores and pH.	0
Complete exposure pathway	Organisms are exposed directly to water column where conductivity and chloride are measured	+	Organisms are exposed directly to water column where pH is measured	+
Plausibility: stressor - response	Not established	NE	Not established	NE
Specificity of cause	Not applicable because ionic strength is not a plausible mechanism	NE	Not applicable because pH is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Inconsistent	NE	Overall, inconsistent. However, low pH may be an issue at certain trib sites.	0
Coherence of evidence	There is no plausible mechanism for impact to benthic macroinvertebrates. It may be an indicator of sources at sites with elevated conductivities.	NE	pH may be a local or temporary issue (i.e at BCBC308 and BCBC305) but does not appear to have consistent effects throughout this area.	0

Table 5-4. A summary of the candidate causes associated with the biologically impaired sites in the Bennett Upper Mainstem project area, and their possible sources. ☑ indicates that the source and/or step in the causal pathway are present or likely to be present in the upstream catchment area; ☑☑ indicates that the source and/or step in the causal pathway were documented at the site.

Candidate Cause	Bennett Ck Mainstem	
	BCBC-314	FR-P-377-242-96
Nutrient Enrichment		
Agricultural		
Fertilizer/Manure Application	☑	☑
Direct Animal Access to Streams		
Residential Developments		
Failing Septic Systems	☑	☑
High Concentrations of Septic System Leach Fields		
Application of Lawn Fertilizers	☑	☑
Pleasant Branch WWTP		
Atmospheric Deposition		
Vehicle Emissions	☑	☑
Permitted Air Releases	☑	☑
Soil Disturbances		
Excess Sediment/Turbidity		
Land Disturbing Activities		
Direct Animal Access to Streams		
Runoff from Impervious Surfaces		
Row Crop Agriculture		
Construction		
Natural Factors (i.e instream sources, naturally erodible soils)		
Habitat Degradation		
Urban Land Use		
Impervious Surfaces		
Stormwater Pipe Outflows		
Inadequate Riparian Buffer		
Bank Instability and Erosion		
Upstream Land Use	☑	☑
Direct Animal Access to Streams		
Natural Factors (i.e instream sources, naturally erodible soils)	☑	☑
Channel Alteration		☑
Ionic Strength		
Human Activities		

6 FAHRNEY BRANCH – STRESSOR IDENTIFICATION

6.1. Description of Impairment: Fahrney Branch

FIBI scores at all of the sites in the Fahrney Branch subwatershed were greater than 3.00, so the fish assemblage is not considered to be impaired. Based on the BIBI scores, the benthic macroinvertebrate assemblages at five of the seven sites are impaired. Three of these sites are located in the eastern portion of subwatershed and two of the sites are located in the western portion (Figure 6-1). Based on the locations of these impaired sites, two problem areas were identified: Fahrney (east) and Fahrney (west) (Figure 6-2).

6.2.1. Candidate Causes – Potential Stressor Sources: Fahrney Branch

The conceptual diagram (Figure 6-3) shows the stressor sources, the stressors they induce and the effects on the biological assemblage for the Fahrney Branch subwatershed. Sources in this subwatershed include agricultural practices (row crops and livestock), low and medium density residential developments, commercial, industrial and institutional (Kemptown Elementary School) developments, facilities with (expired) permits to make NPDES discharges (<0.005 MGD), atmospheric deposition, and failing septic systems.

6.3. Analysis of Evidence – Associating candidate causes: Fahrney Branch (east)

Three of the biologically impaired sites are located in the eastern portion of the subwatershed. One of the sites (BENN-03-2005) is a permanent, non-random site that was established for restoration monitoring, and the remaining two sites, BENN25-2007 and BENN03-2007, were selected randomly. BENN25-2007 is the furthest site upstream along the mainstem. It had a BIBI score of 1.75. BENN-03-2005 is located about a half mile downstream of BENN25-2007, near the Kemptown Elementary School, at the confluence of the Fahrney mainstem with a tributary. It had a BIBI score of 2.75 and a FIBI score of 3.67. BENN03-2007 is located about a mile downstream of BENN-03-2005, on a tributary. It had a BIBI score of 2.50.

In situ water quality measurements (water temperature, dissolved oxygen, pH and specific conductance) were taken in the spring at all three sites[4]. Few values were comparable to the reference distribution. Turbidity and spring pH values were all greater than the 75th percentile of reference site values (Table 6-1a). Specific conductance values at BENN25-2007 and BENN03-2007 were greater than the 75th percentile of reference site values. At BENN-03-2005, the summer water temperature was slightly greater than the 75th percentile of reference site values, and the summer pH value was slightly less than the 25th percentile of reference site values. The summer dissolved oxygen value at BENN-03-2005 was comparable to reference (Table 6-1b).

Nutrient data are available for BENN03-2007 and BENN25-2007. Nitrogen concentrations were very elevated at both sites. Nitrate (NO_3), nitrate-nitrite (NO_3-NO_2) and total nitrogen (TN) concentrations were greater than the 95th percentile of the reference distribution at both sites, and the nitrite (NO_2) concentration at BENN03-2007 was greater than the 95th percentile of the reference

[4] The dissolved oxygen measurement at BENN25-2007 was questionable (it was entered as 1 mg/l), so it was not included.

distribution. At BENN03-2007, phosphorus concentrations were also elevated, with total phosphorus and ortho-phosphate values equal to or slightly greater than the 75th percentile of reference site values. Ammonia concentrations at both sites were comparable to reference.

BENN-03-2005, which had a higher BIBI score than the other two sites, had the best overall habitat scores. Its epifaunal substrate metric had a score that was slightly less than the 25th percentile of reference site values, but all of the other metric values were comparable to reference (Table 6-2). BENN03-2007 had very low metric scores for velocity/depth diversity and pool/glide/eddy quality (less than the 5th percentile of reference site values). Its epifaunal substrate score was slightly less than the 25th percentile of reference site values, and its percent shading value (40) was less than the 5th percentile of reference site values. BENN25-2007 had the worst habitat scores. All were less than the 5th percentile of reference site values, and it had the highest percent embeddness (100). Percent embeddedness at the other two sites was equal to or greater than the 75th percentile of reference site values.

6.4. Characterization of Causes: Fahrney Branch (east)

6.4.1. Elimination of candidate causes: Fahrney Branch (east)

Dissolved oxygen and ammonia concentrations were comparable to reference. No other candidate causes could be eliminated.

6.4.2. Strength of evidence: Fahrney Branch (east)

The strength of evidence analysis was completed for eight candidate causes and twelve lines of logic. It is summarized in Tables 6-3a-d.

6.4.3. Identification of probable causes: Fahrney Branch (east)

BENN25-2007. From the strength of evidence analysis it appears that habitat degradation, excessive sediment/turbidity and nutrient enrichment are major factors that may be causing impairment of the benthic macroinvertebrate assemblage at this site. Other candidate causes that may be affecting the biota at this site include high ionic concentrations and pH imbalance. Evidence regarding thermal loading was inconsistent.

Habitat degradation is a likely cause of biological impairment at this site. BENN25-2007 received very low scores on all of its habitat metrics, in particular on epifaunal substrate and pool/glide/eddy quality. The habitat at this site is influenced by the surrounding land use and also by land use in the upstream catchment area. The land use in the area adjacent to the site is primarily forest and low density residential (Figure 6-4). About a quarter of a mile upstream of this site, the SCA reported a 1200 foot stretch of inadequate buffer along fallow agricultural land (Figure 6-5). Lack of riparian buffer may contribute to channel instability and reductions in habitat (i.e. less woody debris) and shading. The Kemptown Church Road crosses the stream in this area of inadequate buffer. Roads and other paved areas in the residential developments are likely contributing to increased surface

runoff (i.e. reduced infiltration), increased storm flow, increased erosion, decreased channel stability, and decreased subsurface flow.

Excess sedimentation and turbidity is another likely factor contributing to impairment of the benthic macroinvertebrate assemblage at BENN25-2007. Land disturbing activities that cause sediment runoff and bank erosion, such as row crop agriculture and uncontrolled access of livestock (horses and cattle) into streams and tributaries, are likely sources. Other potential sources include runoff from impervious surfaces such as roads, naturally erodible soils, and instream sources.

Nutrient enrichment appears to be another factor contributing to impairment of the benthic macroinvertebrate assemblage. Nitrate, nitrate-nitrite and total nitrogen (NO_3, NO_3-NO_2, TN) concentrations were very elevated at this site, and the BIBI score was low. This is consistent with the negative correlations that occurred between BIBI scores and nitrogen concentrations in the Bennett Creek dataset. High nitrogen levels can lead to excessive algal production, which in turn has effects on food resources, trophic relationships, habitat quality, ammonia and dissolved oxygen. The pathway between the stressor and receptors are indirect (through algal production). Possible sources of nitrogen include high concentrations of septic system leach fields, failed septic systems, fertilizers being applied to agricultural lands and residential lawns, animal waste from livestock, and atmospheric deposition.

The elevated specific conductance value that was recorded at BENN25-2007 also indicates that human activities may be affecting the benthic macroinvertebrate assemblage, although there is no plausible mechanism for conductivity to impact the biota. BIBI scores in the Bennett Creek watershed and the Northern Piedmont ecoregion were negatively correlated with specific conductance values. pH imbalance may also be affecting the benthic macroinvertebrate assemblage at this site. Increased conductivity and alkalinity from agricultural and urban runoff, septic discharges and photosynthesis of algae are possible contributing factors to the high pH value.

BENN-03-2005. From the strength of evidence analysis it appears that excessive sediment/turbidity and habitat degradation are factors that may be causing impairment of the benthic macroinvertebrate assemblage at this site. Another candidate cause that may be affecting the biota is nutrient enrichment. Evidence regarding thermal loading, high ionic concentrations and pH imbalance was inconsistent or implausible.

Excess sedimentation and turbidity may be contributing to impairment of the benthic macroinvertebrate assemblage at BENN-03-2005. The SCA survey identified this site and the corridor stretching approximately a half mile upstream of this site as a problem area for erosion. The field crews cited ‘bend at steep slope’ as the cause of the erosion problem at this site. The SCA survey also documented the presence of three pipe outflows located about a third of a mile upstream from this site. Two were stormwater outflow pipes and one was discharging runoff from the road. The discharge from the road runoff pipe was an orange color and had a musky smell. Runoff from these pipes and from impervious surfaces in the surrounding area may be contributing to sediment runoff and bank erosion. The erosion problems and pipe outflows may also be contributing to habitat degradation of the epifaunal substrate.

Although nutrient data are not available for this site, nitrogen concentrations at the upstream site, BENN25-2007, were high, so it is likely that nitrogen concentrations are also elevated at this site. Nutrient enrichment may be a contributing factor to impairment of the benthic macroinvertebrate assemblage, which would be consistent with the negative correlation between the BIBI scores and nitrogen concentrations in the Bennett Creek dataset. Possible sources of nitrogen include the NPDES permitted discharge from the Kemptown Elementary School[5], high concentrations of septic system leach fields, failed septic systems, fertilizers being applied to residential lawns, and atmospheric deposition. There is an S-1 sewer area to the east of the site (Figure 6-6). These areas are served by community and multi-use water and sewerage systems which are either existing or under construction.

BENN03-2007. From the strength of evidence analysis it appears that nutrient enrichment and habitat degradation are major factors that may be causing impairment of the benthic macroinvertebrate assemblage at this site. Other candidate causes that may be affecting the biota at this site include excessive sediment/turbidity, high ionic concentrations, and pH imbalance. Evidence regarding thermal loading was inconsistent.

Nutrient enrichment appears to be major factor contributing to impairment of the benthic macroinvertebrate assemblage. This site had the highest nitrogen and phosphorus concentrations and a low BIBI score. This is consistent with the negative correlations that occurred between BIBI scores and nitrogen concentrations in the Bennett Creek dataset. High nitrogen levels can lead to excessive algal production, which in turn has effects on food resources, trophic relationships, habitat quality, ammonia and dissolved oxygen. The most likely source of nitrogen is manure and fertilizers being applied to the surrounding and upstream agricultural lands. Disturbance of phosphorus-rich soils from row crop agriculture may be a possible source of the elevated orth-phosphate concentration. Other possible nutrient sources include atmospheric deposition and animal waste from livestock in the upstream catchment area.

Habitat degradation is another likely cause of biological impairment at this site. BENN30-2007 received low scores on several of its habitat metrics, in particular on velocity/depth diversity and pool/glide/eddy quality. The surrounding land use at this site is primarily agricultural. About a quarter of a mile upstream of this site, the SCA reported a 1000 foot stretch of inadequate buffer. Lack of riparian buffer may contribute to channel instability and reductions in habitat (i.e. less woody debris) and shading. Apparently this land has been enrolled in the conservation reserve program (CREP), which encourages landowners to convert highly erodible cropland and other environmentally sensitive areas to permanent cover, such as introduced or native grasses, trees, filter strips, riparian forest buffers, wetlands, and shallow water habitats.

Although excess sedimentation and turbidity is a possible factor of biological impairment at this site, the turbidity measurement and embeddedness value were only slightly elevated. Possible sources include land disturbing activities such row crop agriculture, naturally erodible soils and instream sources.

[5] In the June 2007 query of the Envirofacts database, the NPDES discharge permit for Kemptown Elementary was listed as 'expired,' so I am not sure if they are currently discharging into the stream.

The elevated specific conductance value that was recorded at BENN03-2007 also indicates that human activities may be affecting the benthic macroinvertebrate assemblage, although there is no plausible mechanism for conductivity to impact the biota. BIBI scores in the Bennett Creek watershed and the Northern Piedmont ecoregion were negatively correlated with specific conductance values. pH imbalance may also be affecting the benthic macroinvertebrate assemblage at this site, although the pH value of 8.18 is not likely high enough to impact the biota. Increased conductivity and alkalinity from agricultural runoff, septic discharges and photosynthesis of algae are possible contributing factors to the higher pH value.

6.5. Analysis of Evidence – Associating candidate causes: Fahrney Branch (west)

Two of the biologically impaired sites are located in the western portion of the subwatershed. One of the sites (BENN06P2007) is a permanent, non-random site that was established for restoration monitoring, and the other site, FR-P-101-233-96, was selected randomly. FR-P-101-233-96 is located approximately 1.1 miles upstream from the mouth of Fahrney Branch. It was sampled by MBSS crews in 1996 and had a BIBI score of 1.75 and a FIBI score of 4.00. BENN06P2007 is located about a half mile upstream of FR-P-101-233-96. It was sampled by crews from Versar, Inc. in 2006 and 2007. In 2006, it had a BIBI score of 2.75 and a FIBI score of 4.00. When it was sampled in 2007, it had a BIBI score of 3.00.

In situ water quality measurements (water temperature, dissolved oxygen, pH and specific conductance) were taken at both sites. Most values were comparable to the reference distribution. The summer water temperature at FR-P-101-233-96 was slightly higher than the 75th percentile of the reference site values. Spring and summer turbidity measurements at BENN06P2007 were higher than the 75th percentile of reference site values. The spring specific conductance value and the summer pH value at BENN06P2007 were slightly elevated. Additional water chemistry data are available for FR-P-101-233-96. Nitrate (NO_3), sulfate (SO_4) and DOC concentrations were higher than the 75th percentile of reference site values. Ammonia concentrations were not measured at either site.

Aside from one or two low habitat metric scores, the overall habitat assessment scores at both sites were comparable to reference. FR-P-101-233-96 had a very low bank stability score, and its instream habitat metric score was slightly lower than the 25th percentile of the reference site values. BENN06P2007 had a pool/glide/eddy quality score that was slightly lower than the 25th percentile of the reference site values. Percent embeddedness at BENN06P2007 was slightly elevated (equal to the 75th percentile of the reference distribution), and percent shading at both sites was lower than the 25th percentile of the reference site values.

6.6. Characterization of Causes: Fahrney Branch (west)

6.6.1. Elimination of candidate causes: Fahrney Branch (west)

Dissolved oxygen concentrations were comparable to reference. No other candidate causes could be eliminated.

6.6.2. Strength of evidence: Fahrney Branch (west)

The strength of evidence analysis was completed for eight candidate causes and twelve lines of logic. It is summarized in Tables 6-4a-d.

6.6.3. Identification of probable causes: Fahrney Branch (west)

FR-P-101-233-96. From the strength of evidence analysis it appears that nutrient enrichment and habitat degradation are factors that may be causing impairment of the benthic macroinvertebrate assemblage at this site. Evidence regarding excessive sediment/turbidity, thermal loading, high ionic concentrations and pH imbalance was inconsistent, and there is no evidence for or against ammonia toxicity because ammonia concentrations were not measured.

Nutrient enrichment appears to be a factor contributing to impairment of the benthic macroinvertebrate assemblage. The NO_3 concentration was higher than the 95^{th} percentile of the reference distribution and the site had a very poor BIBI score (1.75). This is consistent with the negative correlations that occurred between BIBI scores and nitrogen concentrations in the Bennett Creek dataset. High nitrogen levels can lead to excessive algal production, which in turn has effects on food resources, trophic relationships, habitat quality, ammonia and dissolved oxygen. The most likely source of nitrogen is manure and fertilizers being applied to the surrounding and upstream agricultural lands (Figure 28). Other possible nutrient sources include atmospheric deposition and animal waste from livestock in the upstream catchment area. There is one residential dwelling near the site, so there is a slight chance that a failing septic system is also a contributing factor.

Habitat degradation is another possible factor of biological impairment at this site. It received a low score for bank stability, and it received an instream habitat score that was slightly less than the 25^{th} percentile of reference site values. During the SCA survey, a 5000 foot stretch of inadequate buffer was documented at and upstream of this site. The inadequate riparian buffer is likely contributing to the poor bank stability at this site. Lack of riparian buffer may also be contributing to reductions in instream habitat (i.e. less woody debris) and shading, which can result in increased water temperatures. An elevated summer water temperature was recorded at this site in 1996.

BENN06P2007. This site, which received a poor BIBI score (2.75) in 2006 and a fair BIBI score (3.00) in 2007, is on the threshold of being impaired. From the strength of evidence analysis it appears that nutrient enrichment and habitat degradation are factors that may be impacting the benthic macroinvertebrate assemblage at this site. Other candidate causes that may be affecting the biota include excessive sediment/turbidity, high ionic concentrations, and pH imbalance. Evidence regarding thermal loading was inconsistent and there is no evidence for or against ammonia toxicity because ammonia concentrations were not measured.

Although nutrient data are not available for this site, nitrogen concentrations at all of the sites (including the site 0.5 miles downstream) in this subwatershed were elevated, so it is likely that nitrogen concentrations are also elevated at this site. This may be affecting the benthic macroinvertebrate assemblage, which would be consistent with the negative correlation between the BIBI scores and nitrogen concentrations in the Bennett Creek dataset. The most likely sources of

nitrogen are manure and fertilizers being applied to the surrounding and upstream agricultural lands, and direct animal access to streams. Other possible nutrient sources include atmospheric deposition.

Habitat degradation may also be impacting the benthic macroinvertebrate assemblage at this site. Its pool/glide/eddy quality score was slightly low, and the SCA crew documented an inadequate buffer at this site. Lack of riparian buffer may contribute to reductions in habitat (i.e. less woody debris) and shading and bank instability. Excessive sediment/turbidity may also be affecting the biota. Land disturbing activities such row crop agriculture and direct animal access to streams are likely factors contributing to the elevated turbidity and percent embeddedness values that were recorded at this site. Other possible sources include naturally erodible soils and instream sources.

The slightly elevated specific conductance value that was recorded at BENN06P2007 also indicates that human activities may be affecting the benthic macroinvertebrate assemblage, although there is no plausible mechanism for conductivity to impact the biota. BIBI scores in the Bennett Creek watershed and the Northern Piedmont ecoregion were negatively correlated with specific conductance values. The summer pH value at this site was slightly higher than the 75th percentile of the reference distribution, so pH imbalance may also be affecting the benthic macroinvertebrate assemblage at this site. However, with a neutral pH value of 7.74, pH imbalance is not a likely factor. Increased conductivity from agricultural runoff and photosynthesis of algae are possible contributing factors to the higher summer pH value.

6.7. Summary of Results: Fahrney Branch

A summary of the candidate causes associated with the five biologically impaired sites, along with their likely sources, is shown in Table 6-5. Nutrient enrichment, habitat degradation and excess sediment and turbidity were the most prevalent and probable causes of impairment at the biologically impaired sites. The most probable sources of nutrient enrichment are agricultural lands, residential developments and atmospheric deposition. The most probable sources of habitat degradation are inadequate riparian buffers, bank instability and erosion from upstream land use and natural factors. Urban land use also appears to be having a negative impact on the habitat at certain sites.

WRAS Priority Restoration Sites. Six priority restoration sites in the Fahrney Branch subwatershed were identified in the Lower Monocacy Watershed Restoration Action Strategy (Frederick County DPW 2004). Inadequate buffer, erosion and direct animal access to stream were commonly cited problems. Several of these areas of concern were located at or near biological sampling sites. Site 29 is located at BENN06P2007, where there is a 1.5 mile stretch of inadequate buffer and erosion with animal access to part of the stream. Other parts have been fenced and are now part of the CREP program. Another problem site is located at BENN-03-2005, where there is a stretch of inadequate buffer at the Kemptown School. Two of the other priority restoration sites are located near the remaining biological sampling sites. One site, which is located upstream of BENN-04-2005, has an erosion problem due to an unknown cause, and another site, which is located upstream of FR-351-112-96, has a 2000 foot stretch of inadequate buffer with crop land on both sides. Descriptions of the six priority restoration sites and photos of some of the problem areas can be found in Table 6-6 and Figure 6-7a-g (Frederick County DPW 2004).

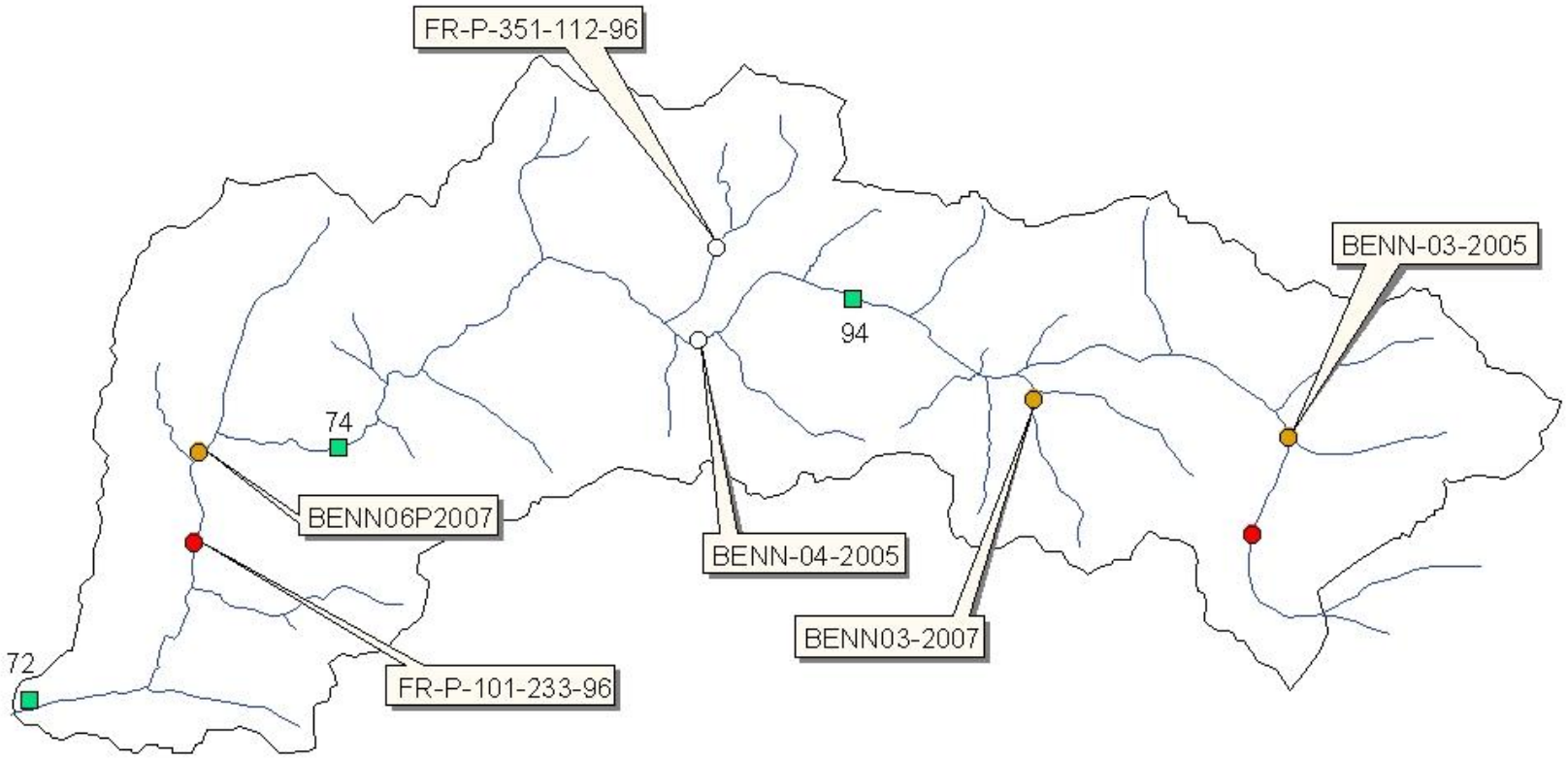

Figure 6-1. Locations of biological sampling sites and nutrient survey sites (2003) in the Fahrney subwatershed.

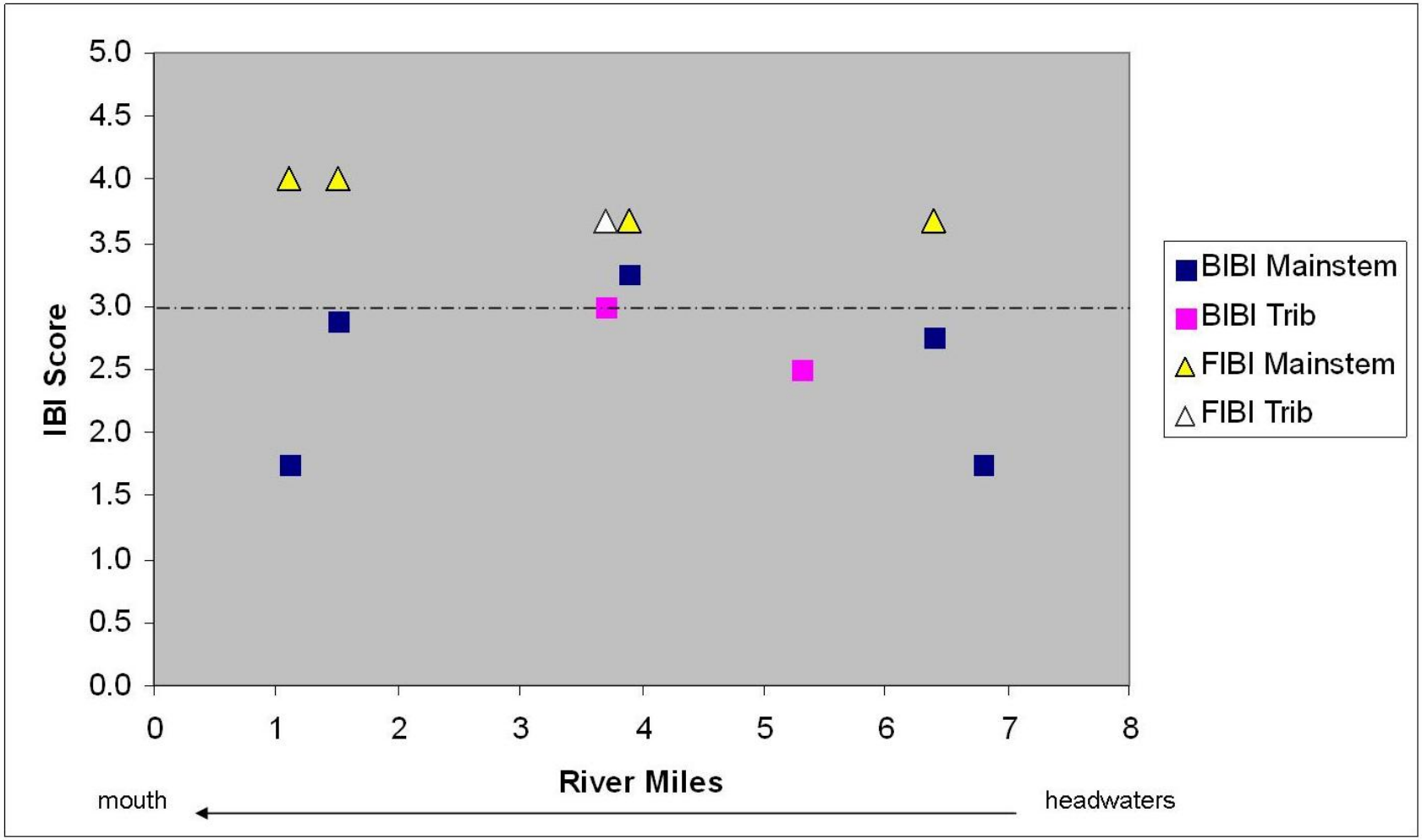

Figure 6-2. Problem areas were identified where sites had IBI scores of less than 3.00.

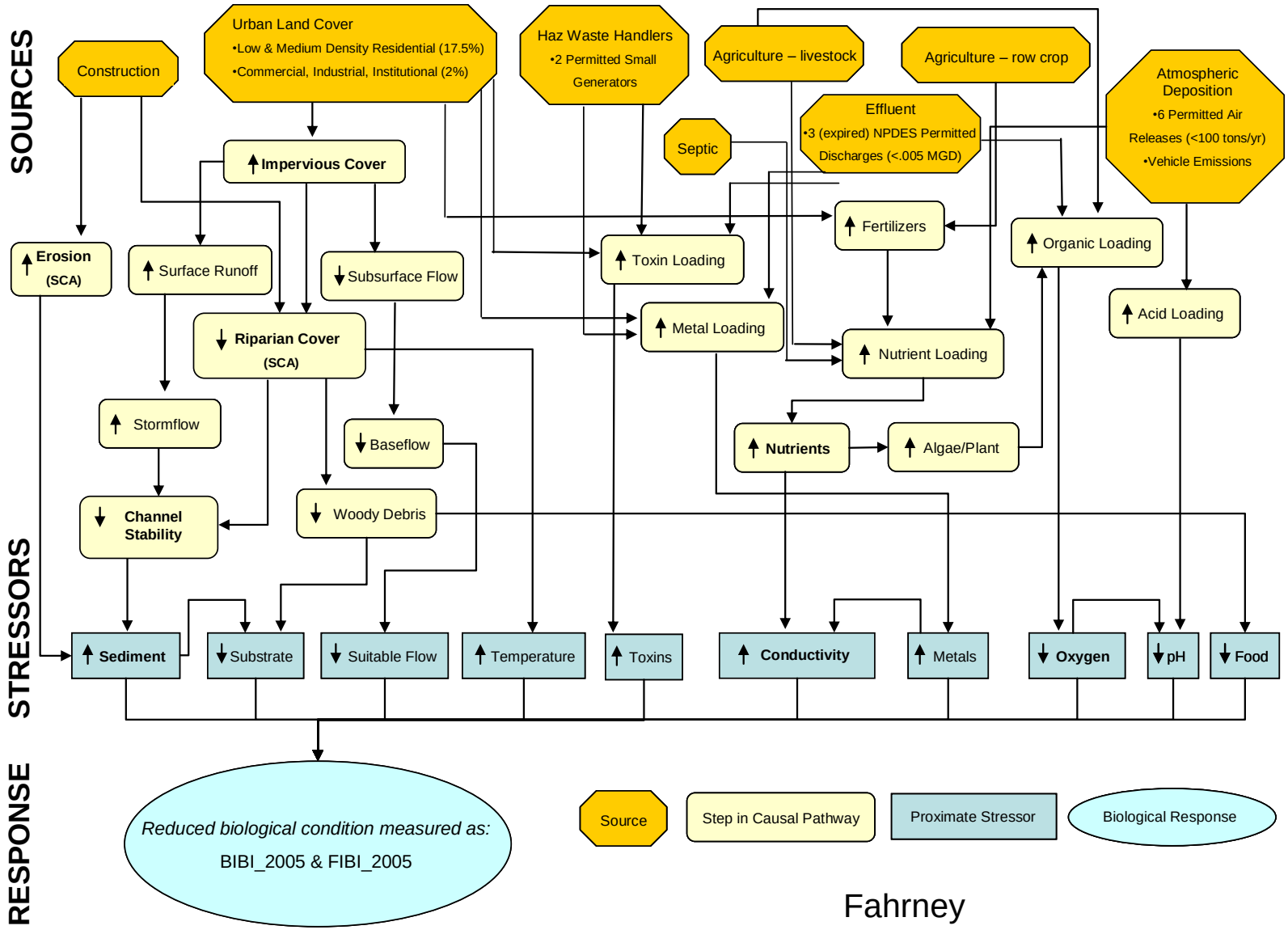

Figure 6-3. Conceptual Model for the Fahrney subwatershed.

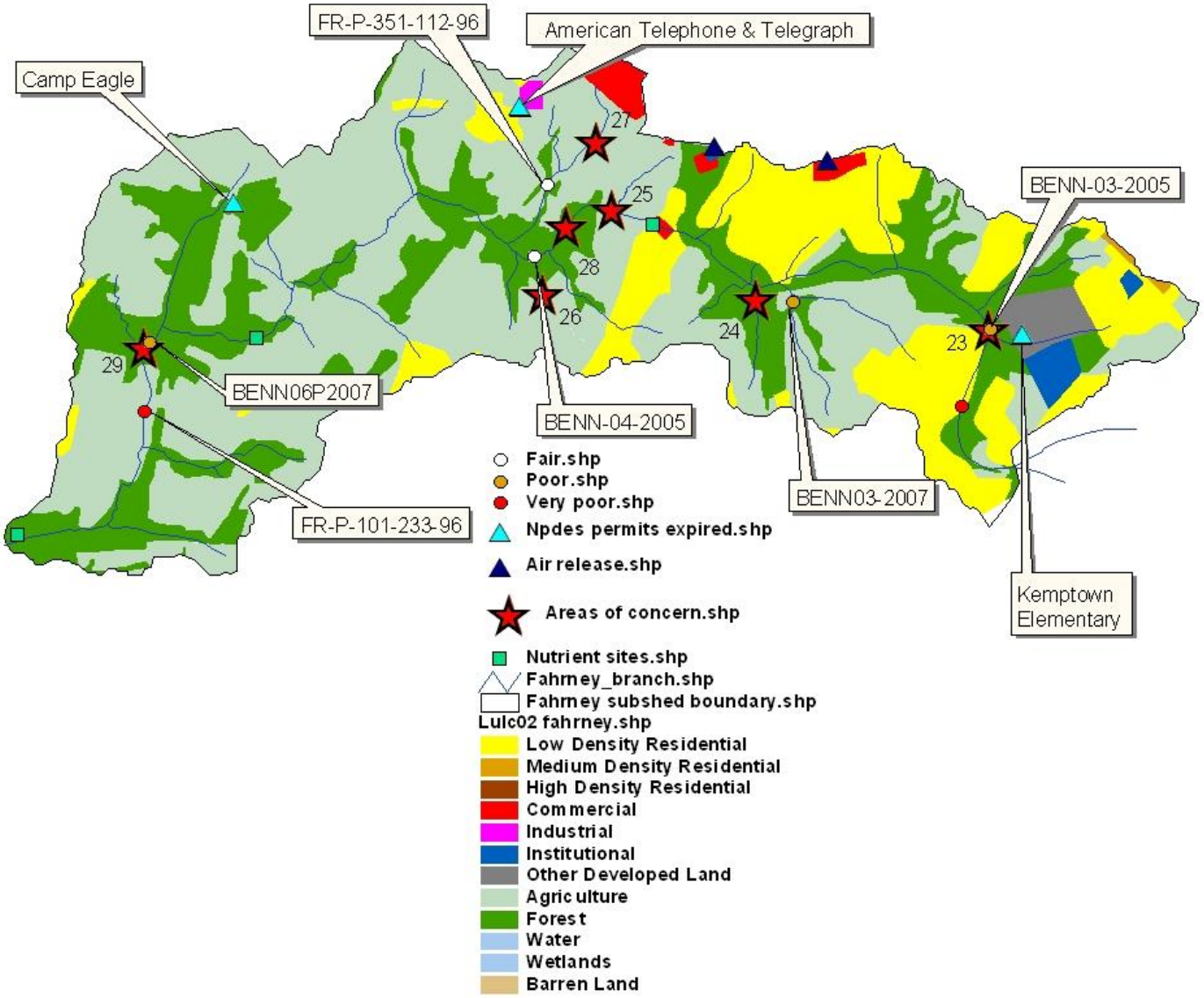

Figure 6-4. Land use land cover, biology, nutrient synoptic survey and Envirofacts information for the Fahrney Branch subwatershed.

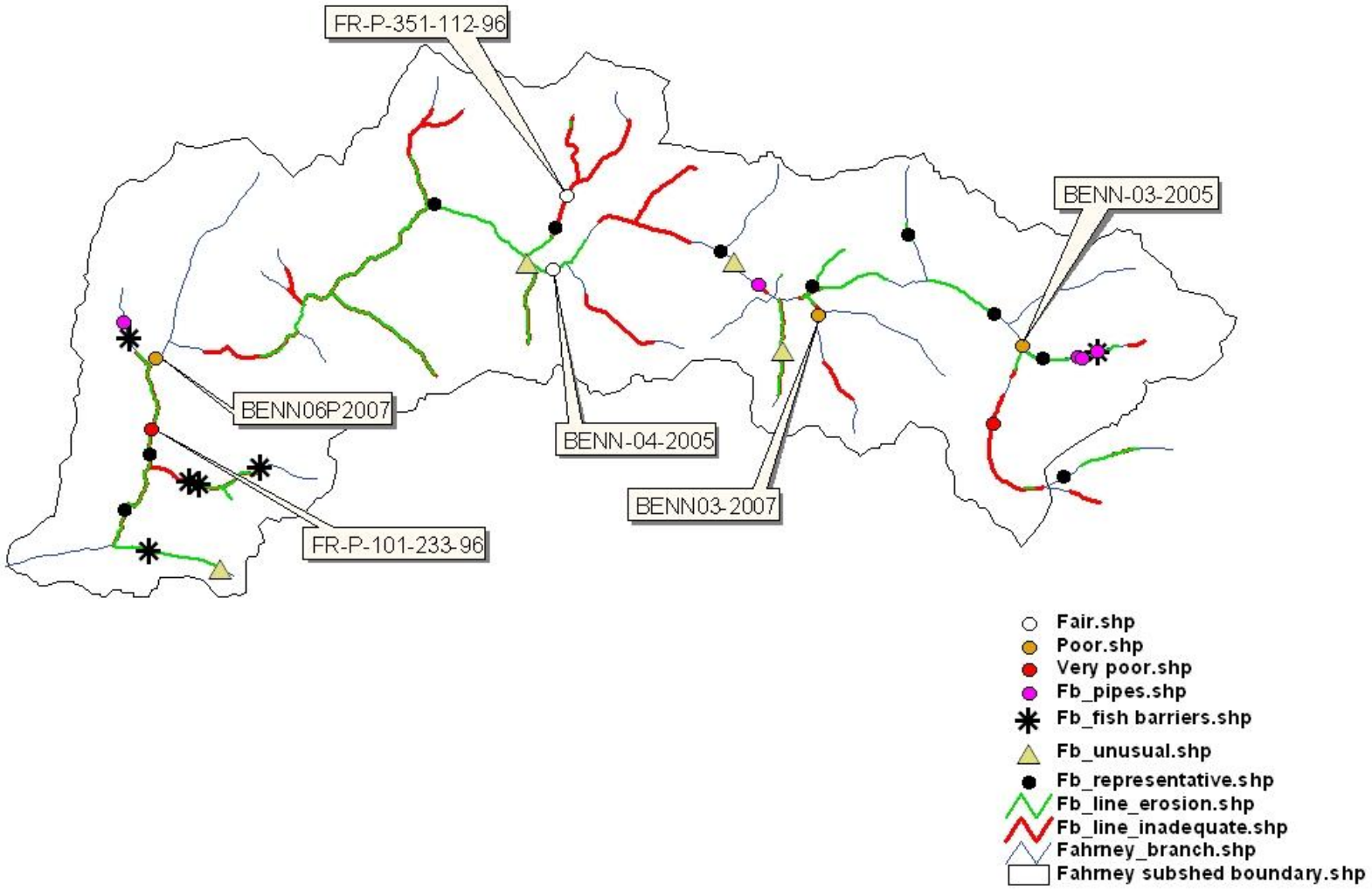

Figure 6-5. Stream corridor assessment results for Fahrney Branch.

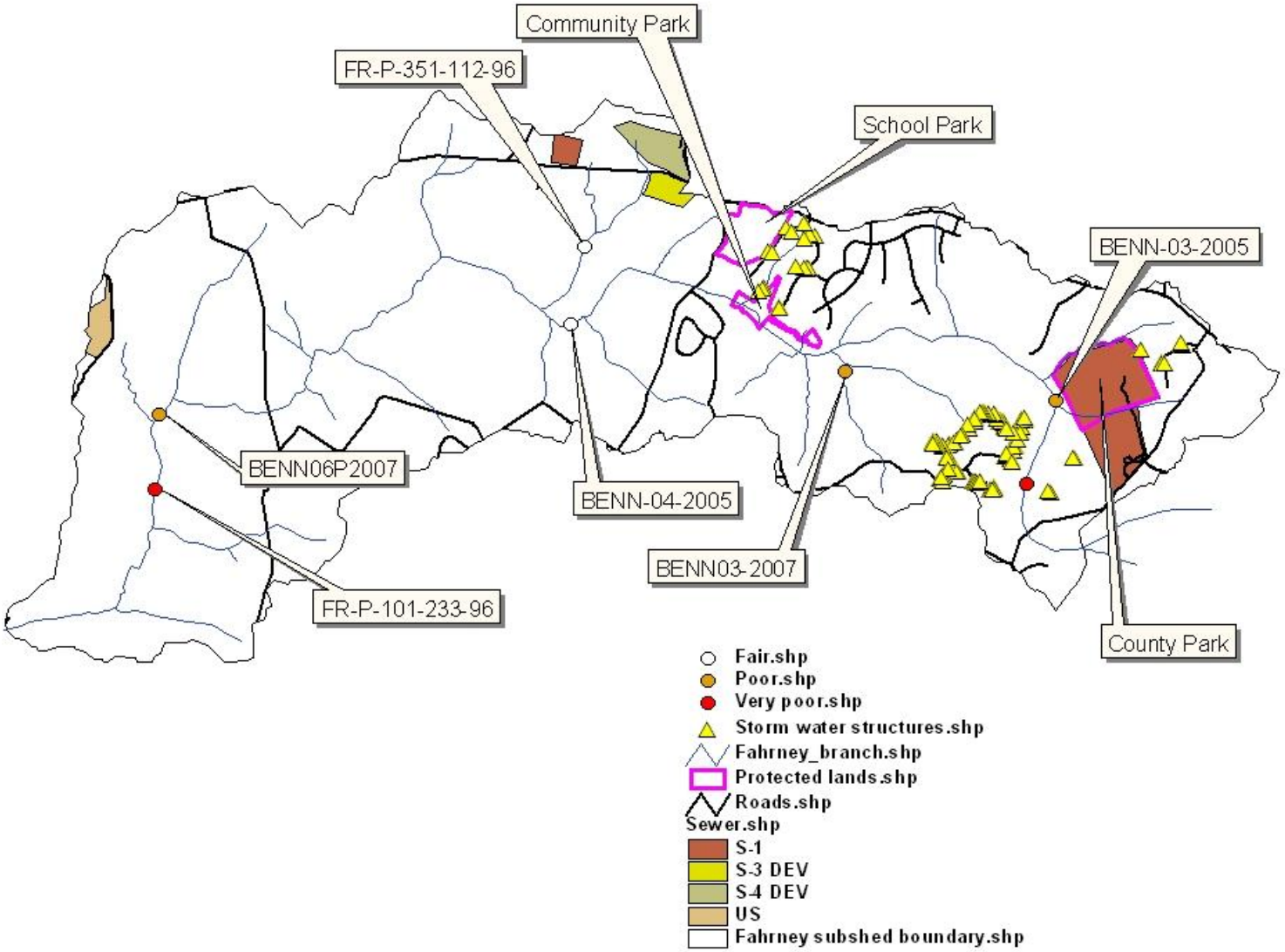

Figure 6-6. Roads, sewer and stormwater structure information for Fahney Branch. Descriptions of the sewer codes can be found in Appendix C.

Figure 6-7a. Erosion problem site at and upstream of stream of BENN-03-2005.

Figure 6-7b. Erosion problem site at and upstream of stream of BENN-03-2005.

Figure 6-7c. Stormwater outflow pipes upstream of BENN03-2005.

Figure 6-7d. Road runoff outflow pipe upstream of BENN03-2005.

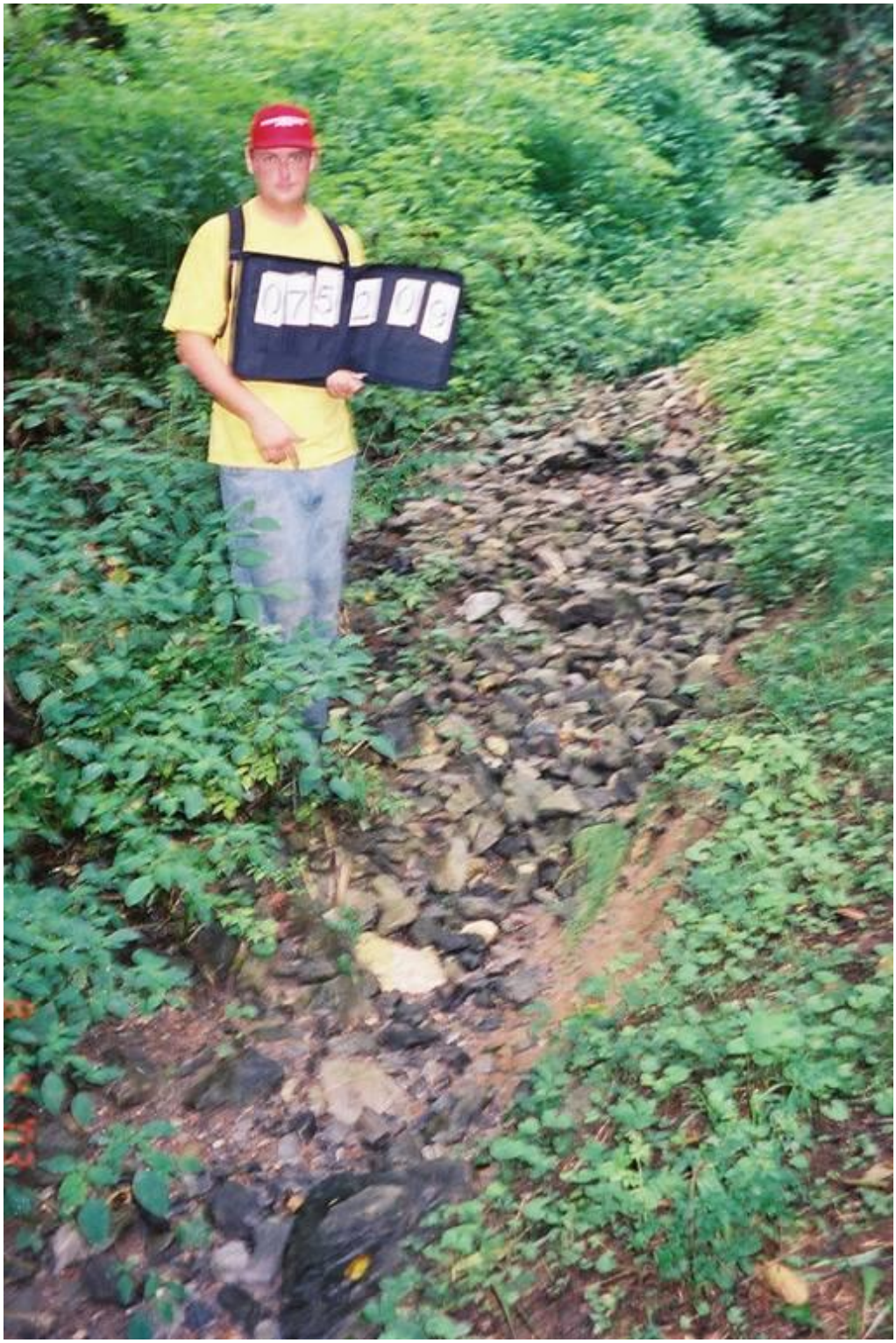

Figure 6-7e. Stormwater outflow upstream of BENN-03-2005.

Figure 6-7f. Inadequate buffer at BENN25-2007.

Figure 6-7g. Inadequate buffer at the priority restoration site near FR-351-112-96.

Table 6-1a. BIBI & FIBI scores and spring water chemistry measurements taken in the Fahrney Branch subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of Fahrney Branch). Tributaries to the Fahrney mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem.

Parameter	**N Piedmont**		**NSS 72** (2003)	**FR-P-101-233-96**	**BENN06P2007** (2006&2007)	**NSS 74** (2003)	**FR-P-351-112-96**	**BENN-04-2005**	**NSS 94** (2003)	**BENN03-2007**	**BENN-03-2005**	**BENN25-2007**
			RM 0.1	RM 1.1	RM 1.5	RM 2.1	RM 3.7	RM 3.9	RM 4.6	RM 5.3	RM 6.4	RM 6.8
Biological	**Ref Values**[1]	**N**					**Values**					
BIBI_05	**3.00**	54		***1.75***	*2.75* 3.00		3.00	3.25		*2.50*	*2.75*	***1.75***
FIBI_05	**3.00**	53		4.00	4.00		3.67	3.67			3.67	
Chem_Spring												
pH (std units)	**7.06** - 7.61	51	7.40	7.37	7.60	7.59	*7.05*	*7.96*	7.43	*8.18*	*7.97*	***8.70***
Specific Conduct (mg/L)	0.178	51	0.171	0.168	*0.180*	0.158	0.145	0.164	0.144	*0.258*	0.154	*0.198*
DOC (mg/L)	2.23	51		*2.80*			1.90			1.39		1.65
SO4 (mg/L)	9.81	51		*10.72*			8.62					
NH3 (mg/L)	0.019	25								0.010		0.012
NO3 (mg/L)	2.71	51		***4.28***			***3.54***			***8.95***		***8.00***
NO2 (mg/L)	0.008	25								***0.018***		0.004
NO2+NO3 (mg/L)			4.22			4.40			4.75	8.97		8.00
TN (mg/L)	2.82	25								***10.87***		***9.84***
TKN (mg/L)										1.90		1.84
TP (mg/L)	0.0260	25								0.0259		0.0116
O_PHOS (mg/L)	0.005	25	*0.006*			*0.011*			0.005	*0.006*		0.001
Water Temp (°C)			15.1		11.8	20.8		15.2	19.1	12.5	12.0	11.6
DO (mg/L)			9.88		11.40	9.44		8.30	9.90	10.40	10.40	--
Turbidity (NTU)	3.5	25			*7.0*			*9.5*		*5.5*	*8.2*	*9.3*
AcidSrc				none			none					

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 6-1b. BIBI & FIBI scores and summer water chemistry measurements taken in the Fahrney Branch subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of Fahrney Branch). Tributaries to the Fahrney mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem.

Parameter	**N Piedmont**		**NSS 72** (2003)	**FR-P-101-233-96**	**BENN06P2007** (2006&2007)	**NSS 74** (2003)	**FR-P-351-112-96**	**BENN-04-2005**	**NSS 94** (2003)	**BENN03-2007**	**BENN-03-2005**	**BENN25-2007**
			RM 0.1	RM 1.1	RM 1.5	RM 2.1	RM 3.7	RM 3.9	RM 4.6	RM 5.3	RM 6.4	RM 6.8
Biological	**Ref Values**[1]	**N**					**Values**					
BIBI_05	**3.00**	54		***1.75***	*2.75*	3.00	3.00	3.25		*2.50*	*2.75*	***1.75***
FIBI_05	**3.00**	53		4.00	4.00		3.67	3.67			3.67	
Chem_Summer												
Water Temp (°C)	20.5	51		*21.3*	15.1		18.2	*21.2*			*20.8*	
DO (mg/L)	**8.20**	51		9.9	11.1		***7.5***	***7.3***			9.4	
pH (std units)	**7.03** - 7.57	51		7.34	*7.74*		*6.91*	7.4			*6.94*	
Specific Conduct (mg/L)	0.192	51		0.152	0.183		0.162	0.178			0.178	
Turbidity (NTU)	3.5	25			***15.4***			***13.2***				

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 6-2. BIBI & FIBI scores and physical habitat measurements taken in the Fahrney Branch subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of Fahrney Branch). Tributaries to the Fahrney mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem.

Parameter	**N Piedmont**		**NSS 72** (2003)	**FR-P-101-233-96**	**BENN06P2007** (2006&2007)	**NSS 74** (2003)	**FR-P-351-112-96**	**BENN-04-2005**	**NSS 94** (2003)	**BENN03-2007**	**BENN-03-2005**	**BENN25-2007**
			RM 0.1	RM 1.1	RM 1.5	RM 2.1	RM 3.7	RM 3.9	RM 4.6	RM 5.3	RM 6.4	RM 6.8
Biological	**Ref Values[1]**	**N**					**Values**					
BIBI_05	**3.00**	54		***1.75***	*2.75*	3.00	3.00	3.25		*2.50*	*2.75*	***1.75***
FIBI_05	**3.00**	53		4.00	4.00		3.67	3.67			3.67	
Habitat												
Instream Habitat	**14**	51		*13*	18		15	15		16	14	***7***
Epifaunal Substrate	**14**	51		15	16		*13*	***8***		*13*	*13*	***2***
Velocity/Depth Diversity	**10**	51		14	10		11	17		***7***	14	***6***
Pool/Glide/Eddy Quality	**10**	51		11	*9*		17	17		***7***	13	***2***
Ex_Pool					22			29		13	30	5
Riffle Quality	**12**	51		18	14		***6***	18		12	15	***6***
Ex_Riffle/Run					53			46		62	45	70
Channel Alt	**10**	26		10			10					
Bank Stability	**8**	26		***3***			13					
Embeddedness	40	51		30	40		***80***	*70*		40	*60*	***100***
Shading	**70**	51		***35***	*60*		75	***35***		***40***	85	85
Remoteness	**14**	26		***9***			16					

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 6-3a. FAHRNEY (EAST). Strength of evidence for candidate causes: Nutrient Enrichment and Excessive Sediment/Turbidity.

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
Co-occurrence				
Benthic Macroinvertebrates	Nutrient data is available for 2 of the 3 sites in this area. All 3 sites have BIBI scores of less than 3.00 and the 2 sites with nutrient data have very high NO3 and TN values (greater than the 95th percentile of reference).	++	The lowest BIBI score (1.75) occurred at the site that had the highest %embeddedness (100%), the highest turbidity and extensive silt/clay. The other 2 sites, which both had BIBI scores of less than 3.00, had %embeddedness and turbidity values equal to or greater than the 75th percentile of reference, and extensive sand or silt/clay.	+
Fish	Only 1 of the 3 sites in this area was sampled for fish. This site lacked nutrient data.	NE	With a FIBI score of 3.67, the fish community at the 1 site is not considered to be impaired.	0
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Low BIBI scores and high NO3 & TN concentrations are consistent at the 2 sites with nutrient data.	+	There is a consistent association between low BIBI scores and elevated %embeddedness and turbidity.	+
FIBI	Lack evidence.	NE	Need more data to determine consistency.	0
Biological gradient				
BIBI - within the Bennett Ck watershed	Strong significant negative correlations exist between BIBI scores and nitrate, total nitrogen,and nitrate+nitrite concentrations.	++	BIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0
FIBI - within the Bennett Ck watershed	There are no significant correlations between FIBI scores and nutrient concentrations.	0	FIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0
BIBI- within the Northern Piedmont ecoregion	Weak significant negative correlations exist between BIBI scores and total phosphorus and nitrite concentrations.	+	A weak (r = -0.25) significant correlation exists between %embeddedness and BIBI scores. Too small a sample size for BIBI scores and turbidity measurements.	+

Table 6-3a (continued). FAHRNEY (EAST).

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
FIBI - within the Northern Piedmont ecoregion	A very weak (r=0.10) significant positive correlation exists between FIBI scores and nitrite concentrations. There are no other significant correlations between nutrient concentrations and FIBI scores.	0	A very weak (r = -0.10) significant correlation exists between FIBI scores and %embeddedness. FIBI scores were not significantly correlated with turbidity measurements.	0
Complete exposure pathway	Organisms are exposed directly to water column where nutrient enrichment is measured	+	Organisms are exposed directly to sediment and turbidity	+
Plausibility: stressor - response	Stressor-response thresholds have not been established for nutrient enrichment	NE	Stressor-response thresholds have not been established for sediment or turbidity	NE
Specificity of cause	Nutrient enrichment is one of many plausible and consistently associated stressors	NE	Excess sediment/turbidity is one of several plausible and consistently associated stressors	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Consistent for the benthic macroinvertebrate community at the 2 sites with data and consistent in the Bennett Creek watershed as a whole.	++	Consistent for the benthic macroinvertebrate community at the 3 sites and consistent with the negative correlation between %embeddedness and BIBI scores in the Northern Piedmont ecoregion.	+
Coherence of evidence	Nutrient enrichment may be a contributing factor to biological impairment of the benthic macroinvertebrate community.	++	Excess sediment/turbidity may be a factor of biological impairment, especially at site BENN25-07.	+

Table 6-3b. FAHRNEY (EAST). Strength of evidence for candidate causes: Habitat Degradation and Excess Ammonia Toxicity.

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
Co-occurrence				
Benthic Macroinvertebrates	The lowest BIBI score occurred at the site that had the lowest habitat metric scores (scores ranged from 2 to 7, out of 20). The highest of the 3 BIBI scores (2.75) occurred at the site with the highest habitat metric scores.	+	NH3 was measured during 2 of the 3 benthic macroinvertebrate sampling events. At both sites, concentrations were lower than the 25th percentile of reference. The site with the higher NH3 concentration had a lower BIBI score.	+
Fish	With a FIBI score of 3.67, the fish community at the 1 site is not considered to be impaired.	0	NH3 was not measured at the 1 site that was sampled for fish.	NE
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Associations with some metrics are more consistent than with others. Overall they are mostly consistent.	+	The 2 sites had low NH3 concentrations and low BIBI scores.	–
FIBI	Need more data to determine consistency.	0	Lack evidence.	NE
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with MBSS habitat metrics.	0	BIBI scores were not significantly correlated with ammonia concentrations.	0
FIBI - within the Bennett Ck watershed	FIBI scores had positive significant correlations with 3 MBSS habitat metrics (velocity/depth diversity, pool/glide/eddy, riffle quality).	+	FIBI scores were not significantly correlated with ammonia concentrations.	0
BIBI- within the Northern Piedmont ecoregion	Weak (r = 0.11 to 0.35) significant positive correlations exist between BIBI scores and 4 of 5 MBBS habitat metrics.	+	A very weak (r = -0.12) significant negative correlation exists between BIBI scores and ammonia concentrations.	0

Table 6-3b (continued). FAHRNEY (EAST).

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
FIBI - within the Northern Piedmont ecoregion	Significant positive correlations exist between FIBI scores and the 5 MBSS habitat metrics (for 4 of these, r > 0.4).	++	FIBI scores were not significantly correlated with ammonia concentrations.	0
Complete exposure pathway	Organisms are exposed directly to instream morphological habitat features and indirectly to riparian habitat features	+	Organisms are exposed directly to water column where ammonia concentration is measured	+
Plausibility: stressor - response	Not established for this study	NE	Observed levels are below reference criteria levels.	–
Specificity of cause	Poor habitat quality is one of several plausible and consistently associated stressors	NE	Ammonica toxicity is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Mostly consistent for the benthic macroinvertebrate community.	+	NH3 values are consistently lower than the 25th percentile of reference.	–
Coherence of evidence	Habitat impairment may be a contributing factor to biological impairment.	+	Ammonia toxicity does not appear to be a factor.	–

Table 6-3c. FAHRNEY (EAST). Strength of evidence for candidate causes: Thermal Loading and Dissolved Oxygen Deficits.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
Co-occurrence				
Benthic Macroinvertebrates	Spring water temperatures were low compared to other sites in the subwatershed. The BIBI scores at these sites were less than 3.00. The site with the lowest BIBI score had the lowest water temperature.	–	Spring DO measurements were available for 2 sites. Values were high (10.4 mg/l). BIBI scores were 2.75 & 2.50.	–
Fish	Summer water temperature was only measured at one site. The value was slightly higher than the 75th percentile of reference. The FIBI score at this site was 3.67.	–	Summer DO was only measured at one site. The value was greater than the 25th percentile of reference. The FIBI score was 3.67.	–
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Inconsistent.	–	Inconsistent.	–
FIBI	Need more evidence to determine consistency.	NE	Need more evidence to determine consistency.	NE
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with water temperature.	0	BIBI scores were not significantly correlated with DO measurements.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with water temperature.	0	A strong (r = 0.48) significant positive correlation exists between FIBI scores and DO measurements.	++
BIBI- within the Northern Piedmont ecoregion	Did not calculate - too small a sample size.	NE	Did not calculate - too small a sample size.	NE

Table 6-3c (continued). FAHRNEY (EAST).

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
FIBI - within the Northern Piedmont ecoregion	A weak (r = 0.2) significant positive correlation exists between FIBI scores and water temperature measurements.	–	A weak (r = 0.2) significant positive correlation exists between FIBI scores and DO measurements.	+
Complete exposure pathway	Organisms are exposed directly to water temperature	+	Organisms are exposed directly to water column where DO is measured	+
Plausibility: stressor - response	Not established	NE	Oxygen is not commonly considered limiting until it is below 4-6 mg/L. The observed DO levels are well above 6 mg/l.	–
Specificity of cause	Thermal loading may impact certain cold water species	NE	DO deficit is not consistently associated with biological impairment. Organic enrichment is one of many plausible and consistently associated stressors.	0
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Inconsistent.	–	Inconsistent.	–
Coherence of evidence	Water temperature can fluctuate greatly. The existing evidence for this area and for the Bennett Ck watershed as a whole does not indicate that thermal loading is a contributing factor to biological impairment.	–	DO deficit does not appear to be a factor of biological impairment, even in the summer, when DO stress would be greatest.	–

Table 6-3d. FAHRNEY (EAST). Strength of evidence for candidate causes: Ionic Strength and pH Imbalance.

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
Co-occurrence				
Benthic Macroinvertebrates	Spring conductivity values were greater than the 75th percentile of reference at 2 of the 3 sites. BIBI scores were less than 3.00 at all 3 sites.	+	pH was higher than the 75th percentile (but lower than the 95th) of reference at all 3 sites. The BIBI scores were less than 3.00.	+
Fish	Summer conductivity was only measured at one site. The value was less than the 75th percentile of reference. The FIBI score was 3.67.	_	pH was only measured at one site. The value was less than the 25th percentile (but greater than the 5th) of reference. The FIBI score was 3.67.	_
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Consistent at 2 out of 3 sites.	0	The sites with higher pH values consistently had lower BIBI scores.	+
FIBI	Need more evidence to determine consistency.	NE	Need more evidence to determine consistency.	NE
Biological gradient				
BIBI - within the Bennett Ck watershed	There is a significant negative correlation between conductivity and BIBI scores (r=-0.34).	+	BIBI scores were not significantly correlated with pH.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with specific conductance.	0	FIBI scores were not significantly correlated with pH.	0
BIBI- within the Northern Piedmont ecoregion	A strong (r = -0.41) significant negative correlation exists between BIBI scores and specific conductance.	++	A weak (r = -0.29) significant negative correlation exists between BIBI scores and pH.	+

Table 6-3d (continued). FAHRNEY (EAST).

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
FIBI - within the Northern Piedmont ecoregion	A weak (r = -0.16) significant negative correlation exists between FIBI scores and specific conductance.	+	A very weak (r = 0.14) significant positive correlation exists between FIBI scores and pH.	0
Complete exposure pathway	Organisms are exposed directly to water column where conductivity and chloride are measured	+	Organisms are exposed directly to water column where pH is measured	+
Plausibility: stressor - response	Not established	NE	Not established	NE
Specificity of cause	Not applicable because ionic strength is not a plausible mechanism	NE	Not applicable because pH is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Mostly consistent for the benthic macroinvertebrate community. But not plausible.	NE	Although spring pH values were higher than reference and the summer pH value was less than reference, values were not low enough to be considered acidic (less than 5) or high enough to be considered alkaline (greater than 9). However they may somehow be impacting the benthic macroinvertebrate community.	+
Coherence of evidence	This measure should be used as an indicator of sources because there is no plausible mechanism for impact to the biological community. 2 of the sites had elevated conductivity values.	NE	pH may be a local or temporary issue that is affecting the benthic macroinvertebrate community.	+

Table 6-4a. FAHRNEY (WEST). Strength of evidence for candidate causes: Nutrient Enrichment and Excessive Sediment/Turbidity.

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
Co-occurrence				
Benthic Macroinvertebrates	6 of the 7 sites in the subwatershed had BIBI scores of 3.00 or less. 4 of these sites had NO3 data, and all NO3 values were greater than the 95th percentile of reference. NO3+NO2 and TN values in the subwatershed are elevated. A few sites have elevated O_Phos values.	++	% embeddedness values at 6 of the 7 sites were equal to or greater than the 75th percentile of reference, turbidity values at the 5 sites with data were greater than the 75th percentile of reference and the 5 sites with substrate size class data had extensive sand or silt/clay. %embeddedness was elevated (>40%) at 5 sites with BIBI scores less than or equal to 3.00.	+
Fish	With FIBI scores greater than 3.00, the fish community is not considered to be impaired. The site with the higher NO3 concentration had a higher FIBI score.	–	All FIBI scores are 3.00 or greater, so the fish community is not considered to be impaired. However, sites with elevated %embeddedness values had lower FIBI scores.	+
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Nitrogen values are consistently high in this subwatershed and BIBI scores are consistently low.	+	Consistent at some sites but not others (i.e. the 2 sites with the lowest BIBI scores (1.75) had the highest and lowest %embeddedness values (100% & 30%).	0
FIBI	Inconsistent at the 2 sites with fish and nutrient data.	–	The lowest FIBI scores did consistently occur at the sites with the higher %embeddedness values.	+
Biological gradient				
BIBI - within the Bennett Ck watershed	Strong significant negative correlations exist between BIBI scores and nitrate, total nitrogen,and nitrate+nitrite concentrations.	++	BIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0
FIBI - within the Bennett Ck watershed	There are no significant correlations between FIBI scores and nutrient concentrations.	0	FIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0

Table 6-4a (continued). FAHRNEY (WEST).

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
BIBI- within the Northern Piedmont ecoregion	Weak significant negative correlations exist between BIBI scores and total phosphorus and nitrite concentrations.	+	A weak (r = -0.25) significant correlation exists between %embeddedness and BIBI scores. Too small a sample size for BIBI scores and turbidity measurements.	+
FIBI - within the Northern Piedmont ecoregion	A very weak (r=0.10) significant positive correlation exists between FIBI scores and nitrite concentrations. There are no other significant correlations between nutrient concentrations and FIBI scores.	0	A very weak (r = -0.10) significant correlation exists between FIBI scores and %embeddedness. FIBI scores were not significantly correlated with turbidity measurements.	0
Complete exposure pathway	Organisms are exposed directly to water column where nutrient enrichment is measured	+	Organisms are exposed directly to sediment and turbidity	+
Plausibility: stressor - response	Stressor-response thresholds have not been established for nutrient enrichment	NE	Stressor-response thresholds have not been established for sediment or turbidity	NE
Specificity of cause	Nutrient enrichment is one of many plausible and consistently associated stressors	NE	Excess sediment/turbidity is one of several plausible and consistently associated stressors	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Not all sites have nutrient data, but those that do consistently have elevated nitrogen values and low BIBI scores. This is also consistent in the Bennett Creek watershed as a whole.	+	The majority of sites in this subwatershed have elevated embeddedness and turbidity values and low BIBI scores. Lower FIBI scores consistently occurred at sites with higher %embeddedness values.	+
Coherence of evidence	Nutrient enrichment may be a contributing factor to biological impairment of the benthic macroinvertebrate community.	+	Excess sediment/turbidity may be a factor of biological impairment. It appears to be impacting some sites more than others.	+

Table 6-4b. FAHRNEY (WEST). Strength of evidence for candidate causes: Habitat Degradation and Excessive Ammonia Toxicity.

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
Co-occurrence				
Benthic Macroinvertebrates	One of the sites with the lowest BIBI score (1.75) had very low habitat metric scores. All of the other sites (even those with BIBI scores greater than or equal to 3.00) had at least one habitat metric that was less than the 25th percentile of reference.	+	Very limited data. At the 2 sites with data NH3 values were below the 25th percentile of reference. BIBI scores at these 2 sites were less than 3.00.	–
Fish	All FIBI scores are 3.00 or greater, so the fish community is not considered to be impaired. Each site had at least one habitat metric that was less than the 25th percentile of reference.	0	NH3 was not measured at any of the sites sampled for fish.	NE
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Consistent for certain metrics at certain sites.	+	No associations were observed at the two sites	–
FIBI	Each site had at least one habitat metric that was less than the 25th percentile of reference.	0	Lack evidence.	NE
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with MBSS habitat metrics.	0	BIBI scores were not significantly correlated with ammonia concentrations.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with MBSS habitat metrics.	0	FIBI scores were not significantly correlated with ammonia concentrations.	0

Table 6-4b(continued). FAHRNEY (WEST).

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
BIBI- within the Northern Piedmont ecoregion	Weak (r = 0.11 to 0.35) significant positive correlations exist between BIBI scores and 4 of 5 MBBS habitat metrics.	+	A very weak (r = -0.12) significant negative correlation exists between BIBI scores and ammonia concentrations.	0
FIBI - within the Northern Piedmont ecoregion	Significant positive correlations exist between FIBI scores and the 5 MBSS habitat metrics (for 4 of these, r > 0.4).	++	FIBI scores were not significantly correlated with ammonia concentrations.	0
Complete exposure pathway	Organisms are exposed directly to instream morphological habitat features and indirectly to riparian habitat features	+	Organisms are exposed directly to water column where ammonia concentration is measured	+
Plausibility: stressor - response	Not established for this study	NE	Observed levels are below reference criteria levels.	–
Specificity of cause	Poor habitat quality is one of several plausible and consistently associated stressors	NE	Ammonica toxicity is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Certain habitat metrics have low scores at certain sites with lower BIBI & FIBI scores. Certain sites appear to be impacted by habitat degradation more than others.	+	NH3 values are consistently lower than the 25th percentile of reference.	–
Coherence of evidence	Habitat impairment may be a contributing factor to biological impairment at certain sites.	+	Ammonia toxicity does not appear to be a factor.	–

Table 6-4c. FAHRNEY (WEST). Strength of evidence for candidate causes: Thermal Loading and Dissolved Oxygen Deficit.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
Co-occurrence				
Benthic Macroinvertebrates	The site with the highest BIBI score (3.25) had the highest spring temperature.	−	The site with the highest BIBI score (3.25) had the lowest DO (8.3 mg/l).	−
Fish	3 of 5 sites had summer temperatures (slightly) greater than the 75th percentile of reference. One of the highest FIBI scores (4.00) occurred at the site with the highest temperature.	−	2 of the sites with the lowest FIBI scores (3.67) had the lowest DO's (7.5 & 7.3 mg/l).	+
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	There are not obvious or consistent associations between BIBI scores and spring temperatures.	−	There are no obvious or consistent associations between BIBI scores and DO.	−
FIBI	There are no consistent associations between FIBI scores and summer temperatures.	−	The 3 sites with lowest FIBI scores (3.67) have the lowest DO values.	+
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with water temperature.	0	BIBI scores were not significantly correlated with DO measurements.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with water temperature.	0	A strong (r = 0.48) significant positive correlation exists between FIBI scores and DO measurements.	++

Table 6-4c (continued). FAHRNEY (WEST).

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
BIBI- within the Northern Piedmont ecoregion	Did not calculate - too small a sample size.	NE	Did not calculate - too small a sample size.	NE
FIBI - within the Northern Piedmont ecoregion	A weak (r = 0.2) significant positive correlation exists between FIBI scores and water temperature measurements.	–	A weak (r = 0.2) significant positive correlation exists between FIBI scores and DO measurements.	+
Complete exposure pathway	Organisms are exposed directly to water temperature	+	Organisms are exposed directly to water column where DO is measured	+
Plausibility: stressor - response	Not established	NE	Oxygen is not commonly considered limiting until it is below 4-6 mg/L. The observed DO levels are above 6 mg/l.	−
Specificity of cause	Thermal loading may impact certain cold water species	NE	DO deficit is not consistently associated with biological impairment. Organic enrichment is one of many plausible and consistently associated stressors.	0
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Inconsistent	–	Lower FIBI scores consistently occur at sites with lower DO values. However, all DO values are greater than 6 mg/l and all FIBI scores are greater than 3.00.	0
Coherence of evidence	Water temperature can fluctuate greatly. The existing evidence for this subwatershed and for the Bennett Ck watershed as a whole does not indicate that thermal loading is a contributing factor to biological impairment.	–	Lower DO values may be affecting the fish community but these sites are not considered to be impaired.	0

Table 6-4d. FAHRNEY (WEST). Strength of evidence for candidate causes: Ionic Strength and pH Imbalance.

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
Co-occurrence				
Benthic Macroinvertebrates	There are 5 sites with benthic macroinvertebrate and conductivity data. Conductivities at all but 1 site are less than the 75th percentile of reference. The one that is over is only slightly above and does not occur at the site with the lowest BIBI score.	–	4 sites have pH values that are greater than the 75th percentile of reference. 3 of these sites have BIBI scores of less than 3.00.	+
Fish	All summer conductivities are less than the 75th percentile of reference. The site with the highest conductivity had a FIBI score of 4.00.	–	All FIBI scores are 3.00 or greater, so the fish community is not considered to be impaired. However, 2 of the sites with lower FIBI scores have summer pH values less than the 25th percentile of reference.	+
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	There are no obvious or consistent associations between BIBI scores and conductivity.	–	Overall, inconsistent.	–
FIBI	Sites with higher conducitivity values do not consistently have lower FIBI scores.	–	Consistent at 2 out of 3 sites with FIBI scores of 3.67.	0
Biological gradient				
BIBI - within the Bennett Ck watershed	There is a significant negative correlation between conductivity and BIBI scores (r=-0.34).	+	BIBI scores were not significantly correlated with pH.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with specific conductance.	0	FIBI scores were not significantly correlated with pH.	0

Table 6-4d (continued). FAHRNEY (WEST).

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
BIBI- within the Northern Piedmont ecoregion	A strong (r = -0.41) significant negative correlation exists between BIBI scores and specific conductance.	++	A weak (r = -0.29) significant negative correlation exists between BIBI scores and pH.	+
FIBI - within the Northern Piedmont ecoregion	A weak (r = -0.16) significant negative correlation exists between FIBI scores and specific conductance.	+	A very weak (r = 0.14) significant positive correlation exists between FIBI scores and pH.	0
Complete exposure pathway	Organisms are exposed directly to water column where conductivity and chloride are measured	+	Organisms are exposed directly to water column where pH is measured	+
Plausibility: stressor - response	Not established	NE	Not established	NE
Specificity of cause	Not applicable because ionic strength is not a plausible mechanism	NE	Not applicable because pH is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Inconsistent and not plausible	NE	A somewhat consistent association between pH imbalance (values not in the normal reference range) and lower BIBI and/or FIBI scores seemed to occur at certain sites but not at others.	0
Coherence of evidence	This measure should be used as an indicator of sources because there is no plausible mechanism for impact to the biological community.	NE	pH may be a local or temporary issue at certain sites but does not appear to have a consistent effect throughout the subwatershed.	0

Table 6-5. A summary of the candidate causes associated with the biologically impaired sites in the Fahrney project area, and their possible sources. ☑ indicates that the source and/or step in the causal pathway are present or likely to be present in the upstream catchment area; ☑☑ indicates that the source and/or step in the causal pathway were documented at the site.

Candidate Cause	WEST		EAST		
	FR-P-101-233-96	BENN06P-2007	BENN03-2007	BENN-03-2005	BENN25-2007
Nutrient Enrichment					
Agricultural					
Fertilizer/Manure Application	☑	☑	☑	☑	☑
Direct Animal Access to Streams	☑	☑☑			
Residential Developments					
Failing Septic Systems	☑			☑	☑
High Concentrations of Septic System Leach Fields				☑	☑
Application of Lawn Fertilizers	☑			☑	☑
Kemptown School NPDES Discharge				☑	
Atmospheric Deposition					
Vehicle Emissions	☑	☑	☑	☑	☑
Permitted Air Releases	☑	☑	☑	☑	☑
Soil Disturbances					
Excess Sediment/Turbidity					
Land Disturbing Activities					
Direct Animal Access to Streams		☑☑			
Runoff from Impervious Surfaces				☑	☑
Row Crop Agriculture		☑	☑		☑
Construction					
Natural Factors (i.e instream sources, naturally erodible soils)			☑	☑	☑
Habitat Degradation					
Urban Land Use					
Impervious Surfaces				☑	☑
Stormwater Pipe Outflows				☑	
Inadequate Riparian Buffer	☑ ☑	☑ ☑	☑ ☑		☑ ☑
Bank Instability and Erosion					
Upstream Land Use	☑	☑	☑		☑
Direct Animal Access to Streams		☑			
Natural Factors (i.e instream sources, naturally erodible soils)	☑	☑	☑	☑	☑
Channel Alteration					
Ionic Strength					
Human Activities			☑		☑

Table 6-6. Priority Restoration Sites in the Fahrney subwatershed that were identified in the Lower Monocacy Watershed Restoration Action Strategy (Frederick County DPW 2004). Site locations are shown in Figure 6-4.

Site	Problem	Suggested Restoration
22	East of Route 75 is slated for future development	Possible area for low impact development at the time of rezoning and development
23	Area with an inadequate buffer at Kemptown School	Possible school yard habitat project with Community Commons
24	Inadequate buffer with cases of horses accessing the stream	Target with CREP and/or Backyard Buffer, Needs fencing
25	3800 feet of inadequate buffer with cattle accessing the stream	Target with CREP and/or Backyard Buffer, Needs fencing
28	One mile of inadequate buffer and erosion with cattle accessing the stream	Target with CREP and/or Backyard Buffer, Needs fencing
29	One a one half miles of inadequate buffer and erosion with animal access to streampart of the area has already been CREPed and there is no access to the stream (possible monitoring site)	Target with CREP and/or Backyard Buffer, Needs fencing

Table 6-7. Summary of the SCA results for the Fahrney Branch subwatershed (Czwartacki et al. 2004).

Potential Problems	Number	Estimated Length	Very Severe	Severe	Moderate	Low Severity	Minor
Channel Alterations	0	NA	0	0	0	0	0
Erosion Sites	24	41515 ft (7.86 miles)	9	6	0	7	2
Exposed Pipes	0	NA	0	0	0	0	0
Fish Barriers	6	NA	0	0	0	1	5
Inadequate Buffers	29	42250 ft (8 miles)	13	6	5	3	2
Pipe Outfalls	5	NA	0	1	1	0	3
Trash Dumpings	0	NA	0	0	0	0	0
Unusual Conditions	4	NA	0	2	0	2	0
Total	**68**		**22**	**15**	**6**	**13**	**12**
Comments							
Representative Sites	**10**						

7 MONOCACY DIRECT- NORTH – STRESSOR IDENTIFICATION

7.1. Description of Impairment: Monocacy Direct-North

All seven of the biological sampling sites in the Monocacy Direct-North subwatershed are located on the same tributary (Figure 7-1). Based on the BIBI scores, the benthic macroinvertebrate assemblages at three of these sites are impaired. The fish assemblage was sampled at two sites; one had a very poor FIBI score (1.67) and the other had a poor FIBI score of 2.67. The impaired sites are located within approximately a half mile of one another; two are on the mainstem, and one is on a tributary.

7.2. Candidate Causes – Potential Stressor Sources: Monocacy Direct-North

The conceptual diagram (Figure 7-2) shows the stressor sources, the stressors they induce and the effects on the biological assemblage for the Monocacy Direct-North subwatershed. Sources in this subwatershed include agricultural practices (row crops and livestock), low density residential and institutional (Monocacy National Battlefield) developments, atmospheric deposition, and failing septic systems. Fifty percent of the land use land cover in the Monocacy Direct-North subwatershed consists of agriculture (Figure 7-3).

7.3. Analysis of Evidence – Associating candidate causes: Monocacy Direct-North

The three biologically impaired sites are located in the Monocacy National Battlefield National Park, from approximately river mile 0.5 to river mile 1.1. Two of the sites, NCRW-115-N-2004 and MONY-102-N-2004, are targeted, non-random sites that were sampled by MBSS crews in 2004. NCRW-115-N-2004 had a poor BIBI score (2.00) and a poor FIBI score (2.67). MONY-102-N-2004 had a poor BIBI score (2.50) and a very poor FIBI score (1.67). The other site, BENN30-2007, was selected randomly. It was sampled by a crew from Versar, Inc. in 2007 and had a very poor BIBI score (1.50).

In situ water quality measurements (water temperature, dissolved oxygen, pH and specific conductance) were taken at BENN30-2007 in the spring. Turbidity, pH and specific conductance values were all greater than the 75th percentile of reference site values (Table 7-1a-b). Limited *in situ* water quality measurements were taken in the spring at NCRW-115-N-2004 and MONY-102-N-2004. The spring specific conductance values at both sites were greater than the 75th percentile of reference site values, and the spring pH value at MONY-102-N-2004 was slightly elevated. Summer *in situ* water quality measurements at NCRW-115-N-2004 and MONY-102-N-2004 were taken during the fish sampling events. Dissolved oxygen concentrations were less than the 25th percentile of the reference distribution (the DO value of 7.5 mg/l at NCRW-115-N-2004 was less than the 5th percentile of the reference distribution), and specific conductance values were greater than the 75th percentile of the reference distribution.

Additional water chemistry data are available for all three sites. Nitrogen and phosphorus concentrations were elevated at all sites. Nitrate (NO_3), total nitrogen (TN), total phosphorus (TP) and ortho-phosphate (O_PHOS) concentrations were greater than the 75th percentile of the reference distribution at all of the sites, and the nitrite (NO_2) concentration at BENN30-2007 was greater than

the 75th percentile of the reference distribution. Sulfate (SO_4) values measured at NCRW-115-N-2004 and MONY-102-N-2004 were greater than the 75th percentile of reference site values. Ammonia concentrations at all the sites were comparable to reference.

All of the habitat metric scores at MONY-102-N-2004 and BENN30-2007 were less than the 25th percentile of reference site values (Table 7-2). At NCRW-115-N-2004, two of the habitat metrics – epifaunal substrate and riffle quality – had scores that were less than the 25th percentile of the reference distribution. Percent embeddedness was equal to or greater than the 75th percentile of the reference site values at all of the sites, and percent shading was less than the 5th percentile of the reference distribution at BENN30-2007.

7.4. Characterization of Causes: Monocacy Direct-North

7.4.1. Elimination of candidate causes: Monocacy Direct-North

Water temperatures were comparable to reference, so thermal loading does not appear to be a factor of impairment. No other candidate causes could be eliminated.

7.4.2. Strength of evidence: Monocacy Direct-North

The strength of evidence analysis was completed for eight candidate causes and twelve lines of logic. It is summarized in Tables 7-3a-d.

7.4.3. Identification of probable causes: Monocacy Direct-North

NCRW-115-N-2004. From the strength of evidence analysis it appears that nutrient enrichment and habitat degradation are factors that may be causing impairment of the benthic macroinvertebrate and fish assemblages at this site. Other candidate causes that may be affecting the biota include excessive sediment/turbidity and high ionic concentrations. Evidence regarding ammonia toxicity and pH imbalance was inconsistent.

Nutrient enrichment appears to be a factor contributing to impairment of the benthic macroinvertebrate assemblage. Nitrogen and phosphorus concentrations were elevated and the site had a poor BIBI score (2.00). This is consistent with the negative correlations that occurred between BIBI scores and nitrogen concentrations in the Bennett Creek dataset. High nutrient levels can lead to excessive algal production, which in turn has effects on food resources, trophic relationships, habitat quality, ammonia and dissolved oxygen. A low summer dissolved oxygen concentration was recorded at this site, which likely had a negative impact on the fish assemblage. This is consistent with the strong positive correlation that occurred between FIBI scores and dissolved oxygen values in the Bennett Creek dataset. A likely source of nitrogen is manure and fertilizers being applied to the surrounding and upstream agricultural lands. Other possible nutrient sources include atmospheric deposition and runoff from nearby roads. Soil disturbances in the surrounding agricultural lands are a possible source of phosphorus.

Habitat degradation is another possible factor of biological impairment at this site, which had low metric scores for epifaunal substrate and riffle quality. This is consistent with the strong positive

correlation that occurred between FIBI scores and riffle quality scores in the Bennett Creek dataset. The most likely sources contributing to the degradation are surrounding and upstream land use (which consists primarily of forest, agricultural lands, and a major road, I-270) and natural instream factors. With a slightly elevated percent embeddedness, excessive sediment/turbidity may also be affecting the biota. Land disturbing activities in the upstream agricultural lands and runoff from impervious surfaces like I-270, which is located about 0.3 miles upstream of the site, are likely contributing factors (Figure 7-4). Other possible sources include naturally erodible soils and instream sources.

The elevated specific conductance value that was recorded at NCRW-115-N-2004 also indicates that human activities may be affecting the benthic macroinvertebrate assemblage, although there is no plausible mechanism for conductivity to impact the biota. BIBI scores in the Bennett Creek watershed and the Northern Piedmont ecoregion were negatively correlated with specific conductance values.

MONY-102-N-2004. From the strength of evidence analysis it appears that nutrient enrichment and habitat degradation are factors that may be causing impairment of the benthic macroinvertebrate and fish assemblages at this site. Other candidate causes that may be affecting the biota include excessive sediment/turbidity, high ionic concentrations and pH imbalance. Evidence regarding ammonia toxicity was inconsistent.

As with NCRW-115-N-2004, nutrient enrichment appears to be a factor contributing to impairment of the biota. Nitrogen and phosphorus concentrations were elevated and the site had a poor BIBI score (2.50). This is consistent with the negative correlations that occurred between BIBI scores and nitrogen concentrations in the Bennett Creek dataset. High nutrient levels can lead to excessive algal production, which in turn has effects on food resources, trophic relationships, habitat quality, ammonia and dissolved oxygen. A low summer dissolved oxygen concentration was recorded at this site, and there is a strong positive correlation between dissolved oxygen concentration and FIBI scores in the Bennett Creek dataset. The most likely source of nitrogen is manure and fertilizers being applied to the surrounding and upstream agricultural lands. Other possible nutrient sources include atmospheric deposition and runoff from nearby roads. Soil disturbances in the surrounding agricultural lands are a possible source of phosphorus.

Habitat degradation is a likely factor of biological impairment at this site, which received very low scores on all of its habitat metrics. The most likely sources contributing to the degradation are surrounding and upstream land use. This site is located less than 0.1 miles from Monocacy Battlefield Road and I-270, and it has an inadequate riparian buffer bordered by pasture and crop land. With a slightly elevated percent embeddedness, excessive sediment/turbidity may also be affecting the biota. Land disturbing activities in the upstream agricultural lands and runoff from the nearby roads are likely contributing factors. Other possible sources include naturally erodible soils and instream sources.

The elevated specific conductance value that was recorded at MONY-102-N-2004 also indicates that human activities may be affecting the biota, although there is no plausible mechanism for conductivity to impact the biota. BIBI scores in the Bennett Creek watershed and the Northern Piedmont ecoregion were negatively correlated with specific conductance values. The spring pH

value was slightly elevated, so pH imbalance may also be affecting the biota at this site. However, with a neutral pH value of 7.65, pH imbalance is not a likely factor. Increased conductivity from agricultural and road runoff are possible contributing factors to the slightly elevated spring pH value.

BENN30-2007. From the strength of evidence analysis it appears that nutrient enrichment and habitat degradation are factors that may be causing impairment of the benthic macroinvertebrate assemblage at this site. Other candidate causes that may be affecting the biota include excessive sediment/turbidity, high ionic concentrations and pH imbalance. Evidence regarding ammonia toxicity was inconsistent.

As with the other two impaired sites, nutrient enrichment appears to be a factor contributing to impairment of the benthic macroinvertebrate assemblage. Nitrogen and phosphorus concentrations were more elevated than the other two sites and the site had the lowest BIBI score (1.50). This is consistent with the negative correlations that occurred between BIBI scores and nitrogen concentrations in the Bennett Creek dataset. High nutrient levels can lead to excessive algal production, which in turn has effects on food resources, trophic relationships, habitat quality, ammonia and dissolved oxygen. The most likely sources of nitrogen are manure and fertilizers being applied to the surrounding and upstream agricultural lands, atmospheric deposition and runoff from nearby major roads. Soil disturbances in the surrounding agricultural lands are a possible source of phosphorus.

Habitat degradation is a likely factor of biological impairment at this site, which received very low scores on all of its habitat metrics. The most likely sources contributing to the degradation are surrounding and upstream land use. The adjacent land use consists primarily of roads (Monocacy Battlefield Road and I-270) and row crop agriculture. Excessive sediment/turbidity may also be affecting the biota. Percent embeddedness and turbidity values were very elevated at this site and shading was only 20%. Land disturbing activities in the upstream agricultural lands and runoff from the nearby roads are likely contributing factors. Other possible sources include naturally erodible soils and instream sources.

The elevated specific conductance value that was recorded at this site also indicates that human activities may be affecting the biota, although there is no plausible mechanism for conductivity to impact the biota. BIBI scores in the Bennett Creek watershed and the Northern Piedmont ecoregion were negatively correlated with specific conductance values. The spring pH value was elevated, so pH imbalance may also be affecting the biota at this site. Increased conductivity from agricultural and road runoff are possible contributing factors to the elevated spring pH value.

7.5. Summary of Results: Monocacy Direct-North

A summary of the candidate causes associated with the three biologically impaired sites, along with their likely sources, is shown in Table 7-4. Nutrient enrichment, habitat degradation, and excess sediment and turbidity were the most prevalent and probable causes of impairment at the biologically impaired sites. High ionic concentrations were also detected at all of the sites. The most probable sources of nutrient enrichment are agricultural lands and atmospheric deposition. Runoff from I-270 may also be contributing to the elevated nutrient concentrations and the high conductivites. The most probable sources of habitat degradation are roads (I-270 in particular),

inadequate riparian buffers and bank instability and erosion from upstream land use and natural factors. Stream corridor assessments were not conducted in this subwatershed.

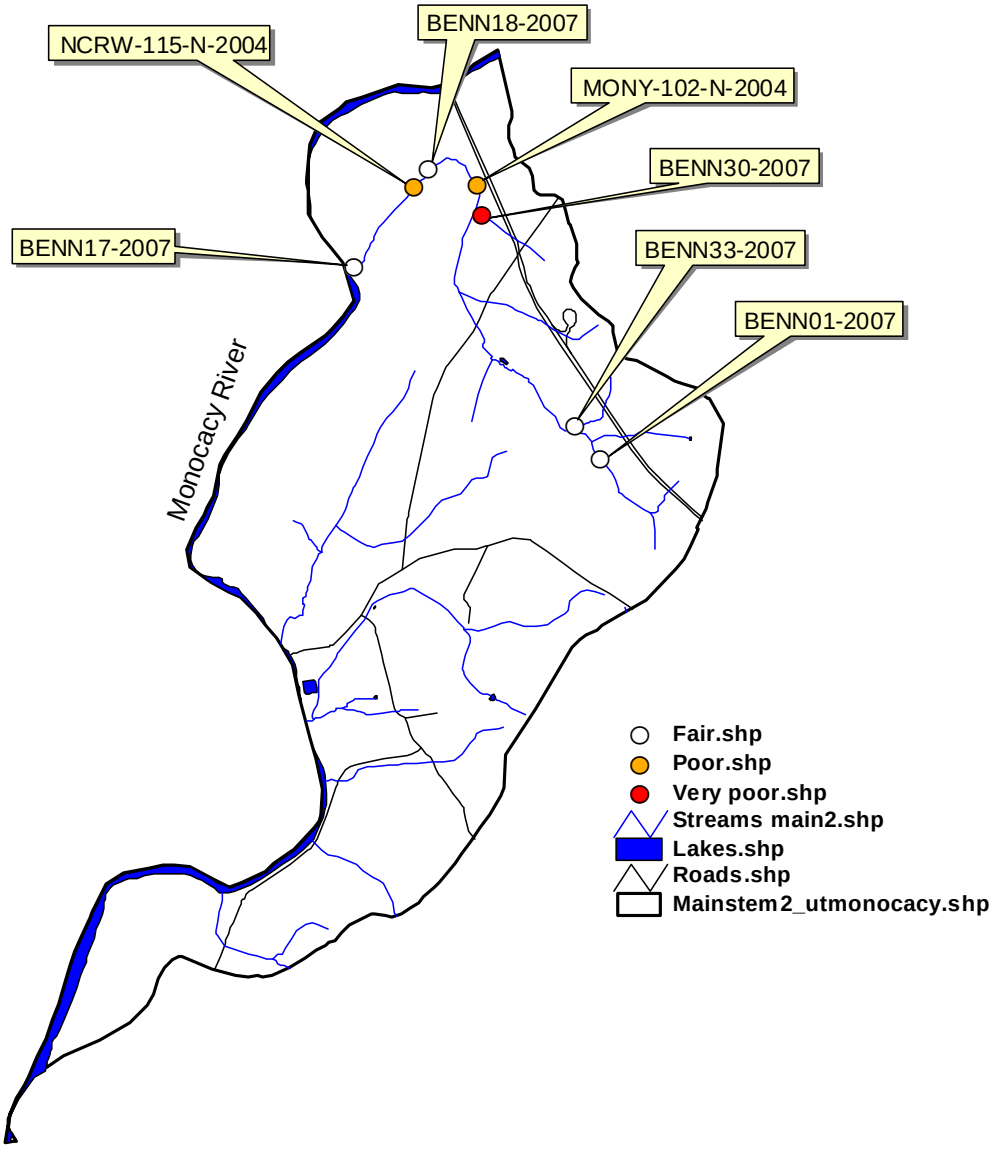

Figure 7-1. Locations of biological sampling sites in the Monocacy Direct-North subwatershed.

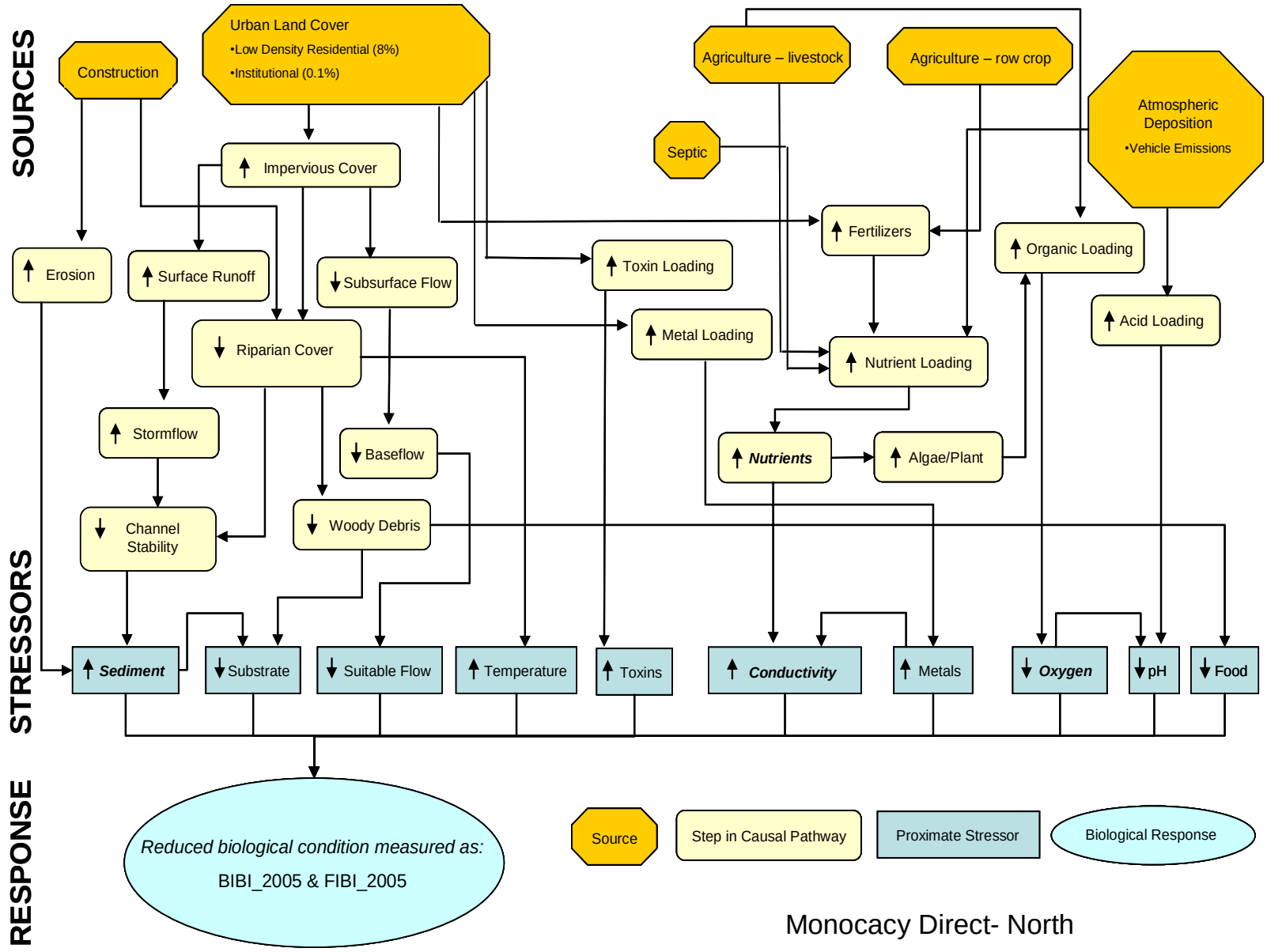

Figure 7-2. Conceptual Model for the Monocacy Direct-North subwatershed.

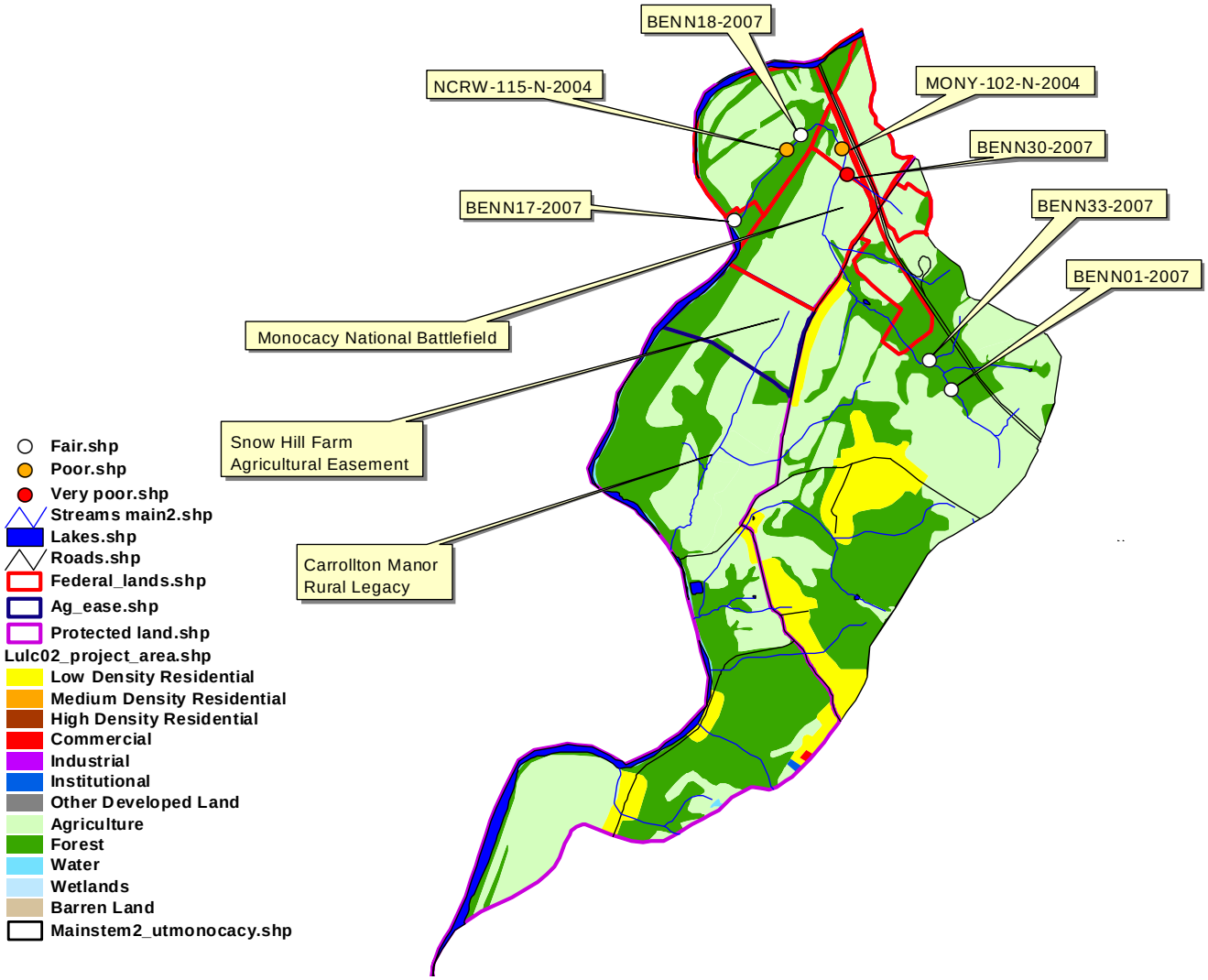

Figure 7-3. Land use land cover and biological information for Monocacy Direct-North.

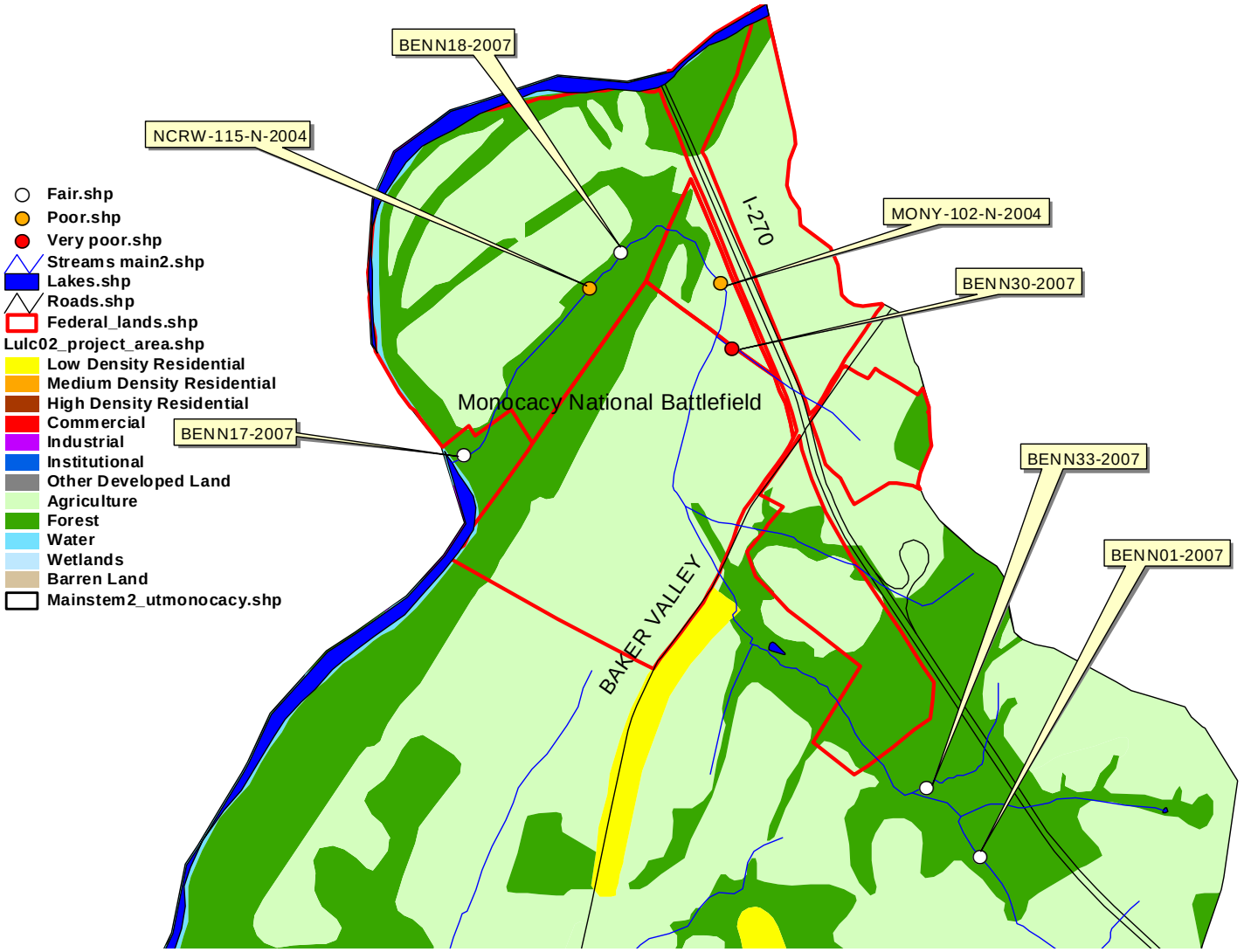

Figure 7-4. Land use land cover and biological information for the unnamed tributary to the Monocacy River.

Table 7-1a. BIBI & FIBI scores and spring water chemistry measurements taken in the Monocacy Direct-North subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of the Monocacy River). Tributaries to the unnamed stream are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem.

Parameter	**N Piedmont**		**BENN17-2007**	**NCRW-115-N-2004**	**BENN18-2007**	**MONY-102-N-2004**	**BENN30-2007**	**BENN33-2007**	**BENN01-2007**
			RM 0.1	RM 0.5	0.6	RM 0.9	RM 1.1	RM 2.3	RM 2.6
Biological	**Ref Values[1]**	**N**				**Values**			
BIBI_05	**3.00**	54	3.00	*2.00*	3.25	*2.50*	***1.50***	3.75	3.25
FIBI_05	**3.00**	53		*2.67*		***1.67***			
Chem_Spring									
pH (std units)	**7.06** - 7.61	51	8.34	7.56	7.59	7.65	8.02	7.30	7.24
Specific Conduct (mS/cm)	0.178	51	*0.278*	*0.311*	*0.270*	*0.306*	*0.306*	*0.281*	*0.229*
DOC (mg/L)	2.23	51	2.04	1.45	1.77	1.43	1.74	1.34	1.79
SO4 (mg/L)	9.81	51		*12.61*		*12.60*			
NH3 (mg/L)	0.019	25	*0.020*	0.011	0.012	0.011	0.013	0.006	0.010
NO3 (mg/L)	2.71	51	*3.12*	***3.61***	***3.32***	***3.58***	***4.61***	***4.11***	***3.94***
NO2 (mg/L)	0.008	25	*0.012*	0.006	*0.010*	0.006	*0.009*	0.004	*0.011*
NO2+NO3 (mg/L)			3.13		3.33		4.62	4.11	3.95
TN (mg/L)	2.82	25	*3.47*	*3.70*	*3.56*	*3.70*	***4.85***	***4.38***	***4.21***
TKN (mg/L)			0.339		0.230		0.236	0.273	0.263
TP (mg/L)	0.026	25	*0.033*	*0.031*	0.022	*0.028*	*0.034*	0.013	0.015
O_PHOS (mg/L)	0.005	25	0.013	0.020	0.011	0.021	0.025	0.006	0.004
Water Temp (°C)			13.8		13.7		13.5	13.0	13.0
DO (mg/L)			10.8		9.9		9.7	11.1	10.7
Turbidity (NTU)	3.5	25	***18.6***		*4.1*		***18.5***	*4.2*	*4.1*
AcidSrc				none		none			

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 7-1b. BIBI & FIBI scores and summer water chemistry measurements taken in the Monocacy Direct-North subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of the Monocacy River). Tributaries to the unnamed stream are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem.

Parameter	**N Piedmont**		**BENN17-2007**	**NCRW-115-N-2004**	**BENN18-2007**	**MONY-102-N-2004**	**BENN30-2007**	**BENN33-2007**	**BENN01-2007**
			RM 0.1	RM 0.5	0.6	RM 0.9	RM 1.1	RM 2.3	RM 2.6
Biological	**Ref Values[1]**	**N**				**Values**			
BIBI_05	**3.00**	54	3.00	*2.00*	3.25	*2.50*	***1.50***	3.75	3.25
FIBI_05	**3.00**	53		*2.67*		***1.67***			
Chem_Summer									
Water Temp (°C)	20.5	51		19.3		19.3			
DO (mg/L)	**8.20**	51		***7.5***		*7.8*			
pH (std units)	**7.03** - 7.57	51		7.51		7.55			
Specific Conduct (mS/cm)	0.192	51		*0.280*		*0.270*			
Turbidity (NTU)	3.5	25		*6.4*		2.6			

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 7-2. BIBI & FIBI scores and physical habitat measurements taken in the Monocacy Direct-North subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of the Monocacy River). Tributaries to the unnamed stream are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem.

Parameter	**N Piedmont**		**BENN17-2007**	**NCRW-115-N-2004**	**BENN18-2007**	**MONY-102-N-2004**	**BENN30-2007**	**BENN33-2007**	**BENN01-2007**
			RM 0.1	RM 0.5	0.6	RM 0.9	RM 1.1	RM 2.3	RM 2.6
Biological	**Ref Values[1]**	**N**				**Values**			
BIBI_05	**3.00**	54	3.00	*2.00*	3.25	*2.50*	***1.50***	3.75	3.25
FIBI_05	**3.00**	53		*2.67*		***1.67***			
Habitat									
Instream Habitat	**14**	51	***7***	14	*12*	***9***	***7***	17	*12*
Epifaunal Substrate	**14**	51	***7***	*8*	*13*	*10*	***5***	14	*10*
Velocity/Depth Diversity	**10**	51	13	11	13	***7***	***7***	14	*8*
Pool/Glide/Eddy Quality	**10**	51	11	15	11	***8***	***5***	14	***8***
Ex_Pool			48	49	41	48	10	41	29
Riffle Quality	**12**	51	*9*	*9*	12	*7*	*7*	14	*10*
Ex_Riffle/Run			27	31	38	48	65	36	46
Channel Alt	**10**	26							
Bank Stability	**8**	26							
Embeddedness	40	51	*50*	40	*45*	*41*	***75***	*50*	*50*
Shading	**70**	51	***40***	90	*60*	88	***20***	80	70

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 7-3a. MONOCACY DIRECT-NORTH. Strength of evidence for candidate causes: Nutrient Enrichment and Excessive Sediment/Turbidity.

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
Co-occurrence				
Benthic Macroinvertebrates	NO3 & TN values were greater than the 75th percentile of reference (and 95th at several sites) at all sites. TP and O_Phos values were greater than the 75th percentile of reference at most sites. BIBI scores at 3 sites were less than 3.00. The site with the worst BIBI score (1.50) had the highest NO3, TN, TP and O_Phos concentrations.	+	%embeddedness and turbidity at all sites are equal to or greater than the 75th percentile of reference, and silt/clay and sand are present or extensive at all sites. BIBI scores at 3 sites were less than 3.00. The site with the lowest BIBI score (1.50) had the highest %embeddedness (75), high turbidity (18.5 NTU) and extensive sand & silt/clay.	+
Fish	2 sites were sampled for fish. Both had elevated NO3, TN, TP and O_Phos concentrations. Both sites had FIBI scores of less than 3.00.	+	Both sites had %embeddedness values of 40% (equal to the 75th percentile of reference). Sand & silt/clay were present but not extensive at either site. One site had a FIBI of 1.67, the other 2.67. Turbidity was elevated (6.4 NTU) at the site with the higher FIBI score.	0
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Associations between elevated nutrient concentrations and low BIBI scores are consistent at some sites but not others.	0	Associations between elevated %embeddedness and turbidity and low BIBI scores are consistent at some sites but not others.	0
FIBI	Consistent at one site. Inconsistent at the other, yet close (with a FIBI score of 3.00, the site is on the threshold of being impaired).	0	Not consistent - the site with higher turbidity had a higher FIBI score. Both sites had equal embeddedness values yet one had a better FIBI score than the other.	_

Table 7-3a (continued). MONOCACY DIRECT-NORTH.

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
Biological gradient				
BIBI - within the Bennett Ck watershed	Strong significant negative correlations exist between BIBI scores and nitrate, total nitrogen,and nitrate+nitrite concentrations.	++	BIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0
FIBI - within the Bennett Ck watershed	There are no significant correlations between FIBI scores and nutrient concentrations.	0	FIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0
BIBI- within the Northern Piedmont ecoregion	Weak significant negative correlations exist between BIBI scores and total phosphorus and nitrite concentrations.	+	A weak (r = -0.25) significant correlation exists between %embeddedness and BIBI scores. Too small a sample size for BIBI scores and turbidity measurements.	+
FIBI - within the Northern Piedmont ecoregion	A very weak (r=0.10) significant positive correlation exists between FIBI scores and nitrite concentrations. There are no other significant correlations between nutrient concentrations and FIBI scores.	0	A very weak (r = -0.10) significant correlation exists between FIBI scores and %embeddedness. FIBI scores were not significantly correlated with turbidity measurements.	0
Complete exposure pathway	Organisms are exposed directly to water column where nutrient enrichment is measured	+	Organisms are exposed directly to sediment and turbidity	+
Plausibility: stressor - response	Stressor-response thresholds have not been established for nutrient enrichment	NE	Stressor-response thresholds have not been established for sediment or turbidity	NE

Table 7-3a (continued). MONOCACY DIRECT-NORTH.

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
Specificity of cause	Nutrient enrichment is one of many plausible and consistently associated stressors	NE	Excess sediment/turbidity is one of several plausible and consistently associated stressors	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Nutrient concentrations are consistently elevated. Some sites are biologically impaired, others are not.	0	Consistent for the benthic macroinvertebrate community at one site (BENN30-2007) but not at others. Inconsistent for the fish community.	0
Coherence of evidence	Nutrient enrichment may be a contributing factor to biological impairment. It appears to be impacting certain sites (i.e.BENN30-2007) more than others.	+	Excess sediment may be a factor of biological impairment at certain sites, in particular on the benthic macroinvertebrate community at BENN30-2007.	+

Table 7-3b. MONOCACY DIRECT-NORTH. Strength of evidence for candidate causes: Habitat Degradation and Excess Ammonia Toxicity.

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
Co-occurrence				
Benthic Macroinvertebrates	The site with the lowest BIBI score (1.50) had very low habitat metric scores. The site with the best BIBI score (3.75) had the best habitat metric scores.	+	1 site had a NH3 value that was slightly greater than the 75th percentile of reference. It had a BIBI score of 3.00. The site with the best BIBI score (3.75) had the lowest NH3 concentration.	0
Fish	The habitat metric scores at the site with the lowest FIBI score (1.67) were all less than the 25th percentile of reference. The site that had the better FIBI score (2.67) had better scores on all but the epifaunal substrate metric.	+	NH3 concentrations were less than the 75th percentile of reference at both sites. FIBI scores were 1.67 and 3.00.	–
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Mostly consistent.	+	There are no obvious or consistent associations between BIBI scores and NH3 concentrations.	–
FIBI	Mostly consistent.	+	There are no obvious or consistent associations between FIBI scores and NH3 concentrations.	–
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with MBSS habitat metrics.	0	BIBI scores were not significantly correlated with ammonia concentrations.	0
FIBI - within the Bennett Ck watershed	FIBI scores had positive significant correlations with 3 MBSS habitat metrics (velocity/depth diversity, pool/glide/eddy, riffle quality).	+	FIBI scores were not significantly correlated with ammonia concentrations.	0

Table 7-3b (continued). MONOCACY DIRECT-NORTH.

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
BIBI- within the Northern Piedmont ecoregion	Weak (r = 0.11 to 0.35) significant positive correlations exist between BIBI scores and 4 of 5 MBBS habitat metrics.	+	A very weak (r = -0.12) significant negative correlation exists between BIBI scores and ammonia concentrations.	0
FIBI - within the Northern Piedmont ecoregion	Significant positive correlations exist between FIBI scores and the 5 MBSS habitat metrics (for 4 of these, r > 0.4).	++	FIBI scores were not significantly correlated with ammonia concentrations.	0
Complete exposure pathway	Organisms are exposed directly to instream morphological habitat features and indirectly to riparian habitat features	+	Organisms are exposed directly to water column where ammonia concentration is measured	+
Plausibility: stressor - response	Not established for this study	NE	Observed levels are below reference criteria levels.	–
Specificity of cause	Poor habitat quality is one of several plausible and consistently associated stressors	NE	Ammonica toxicity is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Mostly consistent - sites with better habitat scores generally have better FIBI and BIBI scores. Certain sites appear to be more impacted by habitat degradation (i.e. BENN30-07) than others.	+	NH3 values are consistently lower than the 25th percentile of reference. BIBI & FIBI scores and NH3 concentrations do not follow a consistent pattern.	–
Coherence of evidence	Habitat impairment may be a contributing factor to biological impairment at certain sites.	+	Ammonia toxicity does not appear to be a factor of biological impairment.	–

Table 7-3c. MONOCACY DIRECT-NORTH. Strength of evidence for candidate causes: Thermal Loading and Dissolved Oxygen Deficits.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
Co-occurrence				
Benthic Macroinvertebrates	Water temperature was measured at 5 sites. It ranged from 13.0-13.8°C. BIBI scores ranged from 1.50 to 3.75. The site with the highest temperature had a BIBI score of 3.00.	–	DO was measured at 5 sites. It ranged from 9.7-11.1 mg/l. BIBI scores ranged from 1.50 to 3.75. The site with the highest DO value had the highest BIBI score (3.75) and the site with the lowest DO had the lowest BIBI score (1.50).	+
Fish	Water temperature values were equal at both sites, and were both below the 75th percentile of reference. FIBI scores at the 2 sites were 2.67 & 1.67.	–	DO values were below the 25th percentile of reference (7.5 and 7.8 mg/l). One site had a FIBI score of 1.67. The other was on the threshold of impairment (3.00).	+
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	There are no obvious or consistent associations between BIBI scores and water temperatures.	–	Mostly consistent. Sites with higher DO values generally had better BIBI scores.	+
FIBI	There are no obvious or consistent associations between FIBI scores and water temperatures.	–	Consistent at one site, somewhat consistent at the other (since 3.00 is on the threshold of impairment)	0
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with water temperature.	0	BIBI scores were not significantly correlated with DO measurements.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with water temperature.	0	A strong (r = 0.48) significant positive correlation exists between FIBI scores and DO measurements.	++

Table 7-3c (continued). MONOCACY DIRECT-NORTH.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
BIBI- within the Northern Piedmont	Did not calculate - too small a sample size.	NE	Did not calculate - too small a sample size.	NE
FIBI - within the Northern Piedmont ecoregion	A weak (r = 0.2) significant positive correlation exists between FIBI scores and water temperature measurements.	–	A weak (r = 0.2) significant positive correlation exists between FIBI scores and DO measurements.	+
Complete exposure pathway	Organisms are exposed directly to water temperature	+	Organisms are exposed directly to water column where DO is measured	+
Plausibility: stressor - response	Not established	NE	Oxygen is not commonly considered limiting until it is below 4-6 mg/L. The observed DO levels are above 6 mg/l.	–
Specificity of cause	Thermal loading may impact certain cold water species	NE	DO deficit is not consistently associated with biological impairment. Organic enrichment is one of many plausible and consistently associated stressors.	0
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Inconsistent	–	Somewhat consistent. Low DO may be impacting the biota at certain sites. However, all DO values are above 6 mg/l.	0
Coherence of evidence	Water temperature can fluctuate greatly. The existing evidence for this subwatershed and for the Bennett Ck watershed as a whole does not indicate that thermal loading is a contributing factor to biological impairment.	–	DO deficit may be a factor of biological impairment at certain sites.	0

Table 7-3d. MONOCACY DIRECT-NORTH. Strength of evidence for candidate causes: Ionic Strength and pH Imbalance.

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
Co-occurrence				
Benthic Macroinvertebrates	Conductivities at all 7 sites were greater than the 75th (but less than the 95th) percentile of reference. The 3 sites with BIBI scores less than 3.00 had the highest conductivities (>0.300).	+	3 of the 7 sites have pH values that are greater than the 75th percentile of reference. BIBI scores at 2 of these sites are less than 3.00.	+
Fish	Conductivities at the 2 sites are 0.280 and 0.270. Both are greater than the 75th percentile of reference. FIBI scores are 2.67 and 1.67.	+	pH values are within the normal range (7.51 and 7.55). FIBI scores are 3.00 & 1.67.	–
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	The association between higher conductivities and lower BIBI scores is mostly consistent.	+	Overall, inconsistent.	–
FIBI	Consistent at one site, somewhat consistent at the other (since 3.00 is on the threshold of impairment)	0	No consistent associations.	–
Biological gradient				
BIBI - within the Bennett Ck watershed	There is a significant negative correlation between conductivity and BIBI scores (r=-0.34).	+	BIBI scores were not significantly correlated with pH.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with specific conductance.	0	FIBI scores were not significantly correlated with pH.	0

Table 7-3d (continued). MONOCACY DIRECT-NORTH

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
BIBI- within the Northern Piedmont ecoregion	A strong (r = -0.41) significant negative correlation exists between BIBI scores and specific conductance.	++	A weak (r = -0.29) significant negative correlation exists between BIBI scores and pH.	+
FIBI - within the Northern Piedmont ecoregion	A weak (r = -0.16) significant negative correlation exists between FIBI scores and specific conductance.	+	A very weak (r = 0.14) significant positive correlation exists between FIBI scores and pH.	0
Complete exposure pathway	Organisms are exposed directly to water column where conductivity and chloride are measured	+	Organisms are exposed directly to water column where pH is measured	+
Plausibility: stressor - response	Not established	NE	Not established	NE
Specificity of cause	Not applicable because ionic strength is not a plausible mechanism	NE	Not applicable because pH is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Mostly consistent but not plausible.	NE	No clear patterns or consistencies.	_
Coherence of evidence	This measure should be used as an indicator of sources because there is no plausible mechanism for impact to the biological community.	NE	pH may be a local or temporary issue but does not appear to have consistent effects throughout the subwatershed.	_

Table 7-4. A summary of the candidate causes associated with the biologically impaired sites in the Monocacy Direct-North subwatershed, and their possible sources. ☑ indicates that the source and/or step in the causal pathway are present or likely to be present in the upstream catchment area; ☑☑ indicates that the source and/or step in the causal pathway were documented at the site.

Candidate Cause	NCRW-115-N-2004	MONY-102-N-2004	BENN30-2007
Nutrient Enrichment			
Agricultural			
Fertilizer/Manure Application	☑	☑	☑
Direct Animal Access to Streams			
Residential Developments			
Failing Septic Systems			
High Concentrations of Septic System Leach Fields			
Application of Lawn Fertilizers			
Atmospheric Deposition			
Vehicle Emissions	☑	☑	☑
Permitted Air Releases	☑	☑	☑
Soil Disturbances	☑	☑	☑
Excess Sediment/Turbidity			
Land Disturbing Activities			
Direct Animal Access to Streams			
Runoff from Impervious Surfaces	☑	☑	☑
Row Crop Agriculture	☑	☑	☑
Construction			
Natural Factors (i.e instream sources, naturally erodible soils)	☑	☑	☑
Habitat Degradation			
Urban Land Use			
Impervious Surfaces	☑	☑	☑
Stormwater Pipe Outflows			
Inadequate Riparian Buffer		☑	☑
Bank Instability and Erosion			
Upstream Land Use	☑	☑	☑
Direct Animal Access to Streams			
Natural Factors (i.e instream sources, naturally erodible soils)	☑	☑	☑
Channel Alteration			
Ionic Strength			
Human Activities	☑	☑	☑

8 LITTLE BENNETT – STRESSOR IDENTIFICATION

8.1. Description of Impairment: Impaired Sites, Little Bennett subwatershed

The majority of the Little Bennett subwatershed lies within Montgomery County (Figure 8-1). Although no biological sampling sites are located in the project area, Little Bennett Creek is a major tributary to Bennett Creek, and performing stressor identifications at impaired sites in this subwatershed may provide valuable information about possible sources of impairment that are entering the project area. MBSS field crews sampled six biological sampling sites in this subwatershed for both fish and benthic macroinvertebrates. The benthic macroinvertebrate assemblages were impaired at three of the sites, and the fish assemblages received ratings of poor at two sites.

8.2. Candidate Causes – Potential Stressor Sources: Little Bennett subwatershed

The conceptual diagram (Figure 8-2) shows the stressor sources, the stressors they induce and the effects on the biological assemblage for the Little Bennett subwatershed. Sources in this subwatershed include agricultural practices (row crops and livestock), urban land cover that includes low and medium density residential, commercial, industrial and institutional developments, the Hyattstown wastewater treatment plant, failing septic systems, and atmospheric deposition. There is a small commercial park located in the Frederick County portion of the subwatershed (Figure 8-3).

8.3. Analysis of Evidence – Associating candidate causes: Impaired Sites, Little Bennett subwatershed

The biological sampling sites in this subwatershed are located in the Little Bennett Regional Park, which consists primarily of forested land. One of the biologically impaired sites, MO-P-495-312-96, is located on the Little Bennett Creek mainstem. It had a poor BIBI score (2.25) and a good FIBI score (4.67). Two of the other impaired sites, MO-P-111-136-96 and LMON-119-R-2003, are located on the same tributary. MO-P-111-136-96 had a poor BIBI score (2.75) and a poor FIBI score (2.00). LMON-119-R-2003 had a fair BIBI score (3.00) and a very poor FIBI score (1.33). Site LMON-215-R-2003, which is located on a tributary to the Bennett Creek mainstem, had a poor BIBI score (2.75). Site locations were selected randomly for all of these sites.

In situ water quality measurements are available for the impaired sites. The spring pH values at the two tributary sites, MO-P-111-136-96 and LMON-119-R-2003, were low (6.7 and 6.6, respectively), as were the summer pH values at LMON-119-R-2003 (6.45) (Tables 8-1a & 8-1b). The acid source at these sites was identified as acid deposition. and LMON-205-R-2003 had a spring pH value (8.39) that was greater than the 75th percentile of the reference site values and a summer pH value (6.91) that was less than the 25th percentile of reference site values. The spring specific conductance value at MO-P-111-136-96 was greater than the 95th percentile of reference site values (0.767 mS/cm) and the spring conductance value at LMON-215-R-2003 was slightly greater than the 75th percentile of reference site values (0.202 mS/cm). It is interesting to note that the

specific conductance at LMON-119-R-2003, which is located approximately 0.4 miles upstream of MO-P-111-136-96, was very low (0.071 mS/cm, which is less than the 5th percentile of reference site values) and that the summer conductance value at MO-P-111-136-96 was also low (0.082 mS/cm). The summer dissolved oxygen values at both of these sites were less than the 25th percentile of the reference site values. *In situ* water quality measurements at MO-P-495-312-96, the impaired mainstem site, were comparable to the reference distribution.

Additional water chemistry data are available for all sites. Nutrient values at all but LMON-215-R-2003 were comparable to the reference distribution, as were all of the other water chemistry parameters that were measured. LMON-215-R-2003 had nitrate and total nitrogen values that were greater than the 75th percentile of the reference site values (3.18 mg/L and 3.41 mg/L, respectively).

Aside from a slightly low habitat metric score for instream habitat, the remaining habitat metric scores at MO-P-495-312-96 were comparable to reference, and percent embeddedness was low (5) and percent shading was high (90) (Table 8-2). MO-P-111-136-96 had low habitat metric scores for instream habitat, riffle quality, channel alteration and bank stability, but percent embeddedness and percent shading were comparable to reference. LMON-119-R-2003 had a slightly low habitat metric score for epifaunal substrate, but its other habitat metric scores were comparable to reference, as were percent embeddedness and percent shading. LMON-215-R-2003 scored well on all habitat metrics.

8.4. Characterization of Causes: Impaired Sites, Little Bennett subwatershed

8.4.1. Elimination of candidate causes: Impaired Sites, Little Bennett subwatershed

Water temperature values, ammonia concentrations, nutrient concentrations and embeddedness values were comparable to reference at the impaired sites, so thermal loading, ammonia toxicity, nutrient enrichment and excessive sediment do not appear to be a factors of impairment.

8.4.2. Strength of evidence: Little Bennett subwatershed

The strength of evidence analysis was completed for eight candidate causes and twelve lines of logic. It is summarized in Tables 8-3a-d.

8.4.3. Identification of probable causes: Impaired Sites, Little Bennett subwatershed

MO-P-111-136-96 and LMON-119-R-2003. From the strength of evidence analysis it appears that pH imbalance and habitat degradation may be factors contributing to biological impairment at these sites. Other candidate causes that may be affecting the biota include high ionic concentrations.

Both of these sites had low pH values, and acidic deposition was identified as the source. These acidic conditions appear to be impacting the biota at these sites. At both sites, two of the most abundant benthic macroinvertebrate taxa were Plecoptera:Leuctridae and Plecoptera: Amphinemura, which are known to be tolerant of low pH conditions. Low dissolved oxygen concentrations may also be affecting the biota at these sites, although oxygen is not commonly considered limiting until it is below 4-6 mg/L, and the lowest summer DO value was 7.73 mg/l.

Habitat degradation may be another factor contributing to biological impairment at these sites. Channel alteration and bank stability received low scores at MO-P-111-136-96, as did one or two additional metrics (instream habitat and epifaunal substrate). FIBI scores in the Northern Piedmont ecoregion were positively correlated with the habitat metrics, so habitat degradation may be affecting the fish assemblage in particular at these sites. Surrounding land use is primarily forest, so natural factors such as instream sources and naturally erodible soils appear to be the most likely sources of habitat degradation.

Although the spring specific conductance value at MO-P-111-136-96 was very elevated, the summer conductivity value was much lower (below the 5th percentile of the reference distribution), so high ionic concentrations are not likely factors contributing to impairment at MO-P-111-136-96.

MO-P-495-312-96. From the strength of evidence analysis it is not clear what factors may be contributing to impairment of the benthic macroinvertebrate assemblage. The instream habitat metric had a slightly low score, so habitat degradation is a possible factor. The land use surrounding and upstream of this site is primarily forest, although the site is close to a road a single dwelling.

LMON-205-R-2003. From the strength of evidence analysis it appears that nutrient enrichment may be contributing to impairment of the benthic macroinvertebrate assemblage. Nitrate and total nitrogen values were elevated, and the correlation analyses of BIBI scores versus nutrient values in the Bennett Creek dataset showed that nitrogen concentrations and BIBI scores were negatively correlated. Possible sources of nitrogen include manure and fertilizers being applied to the surrounding and upstream agricultural lands and atmospheric deposition.

8.5. Summary of Results: Little Bennett

A summary table was not prepared because the majority of this subwatershed (and all of the biological sampling sites) are located outside the project area. Two of the impaired sites appear to be impacted by low pH conditions due to acidic deposition. Habitat degradation may also be a factor of impairment at three of the sites. Nutrient enrichment may be impacting the benthic macroinvertebrate assemblage at one of the sites.

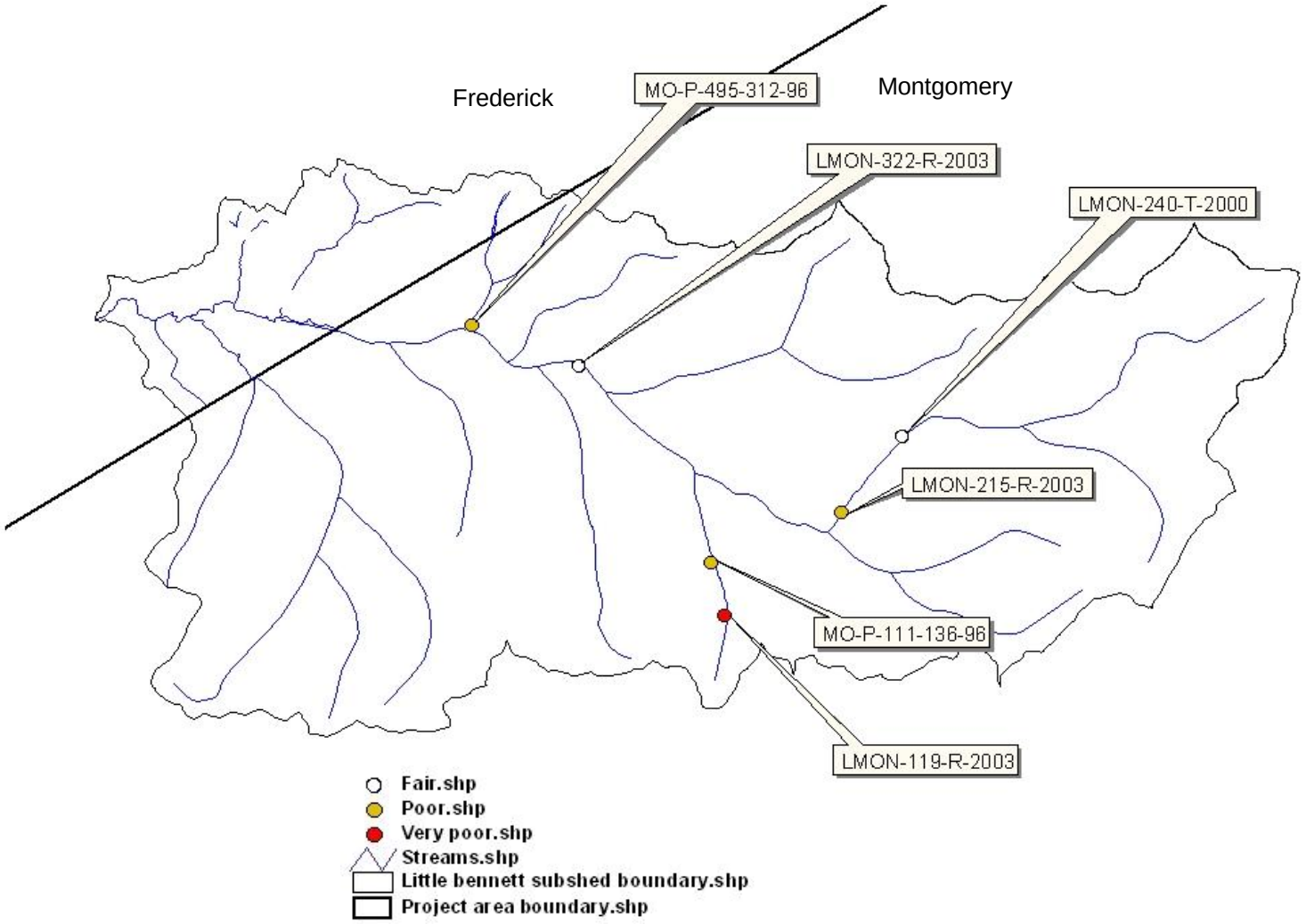

Figure 8-1. Locations of biological sampling sites in the Little Bennett subwatershed.

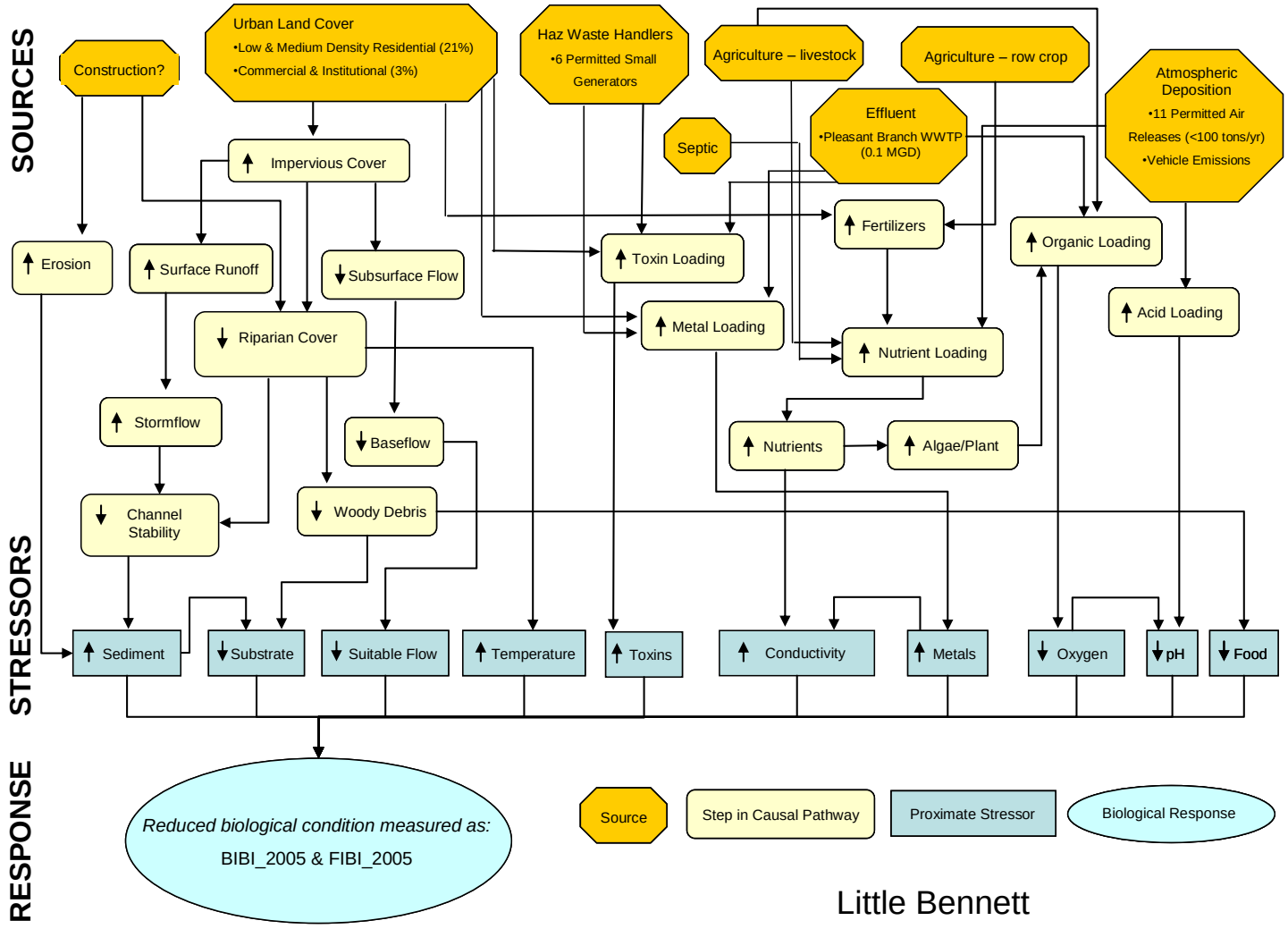

Figure 8-2. Conceptual Model for the Little Bennett subwatershed.

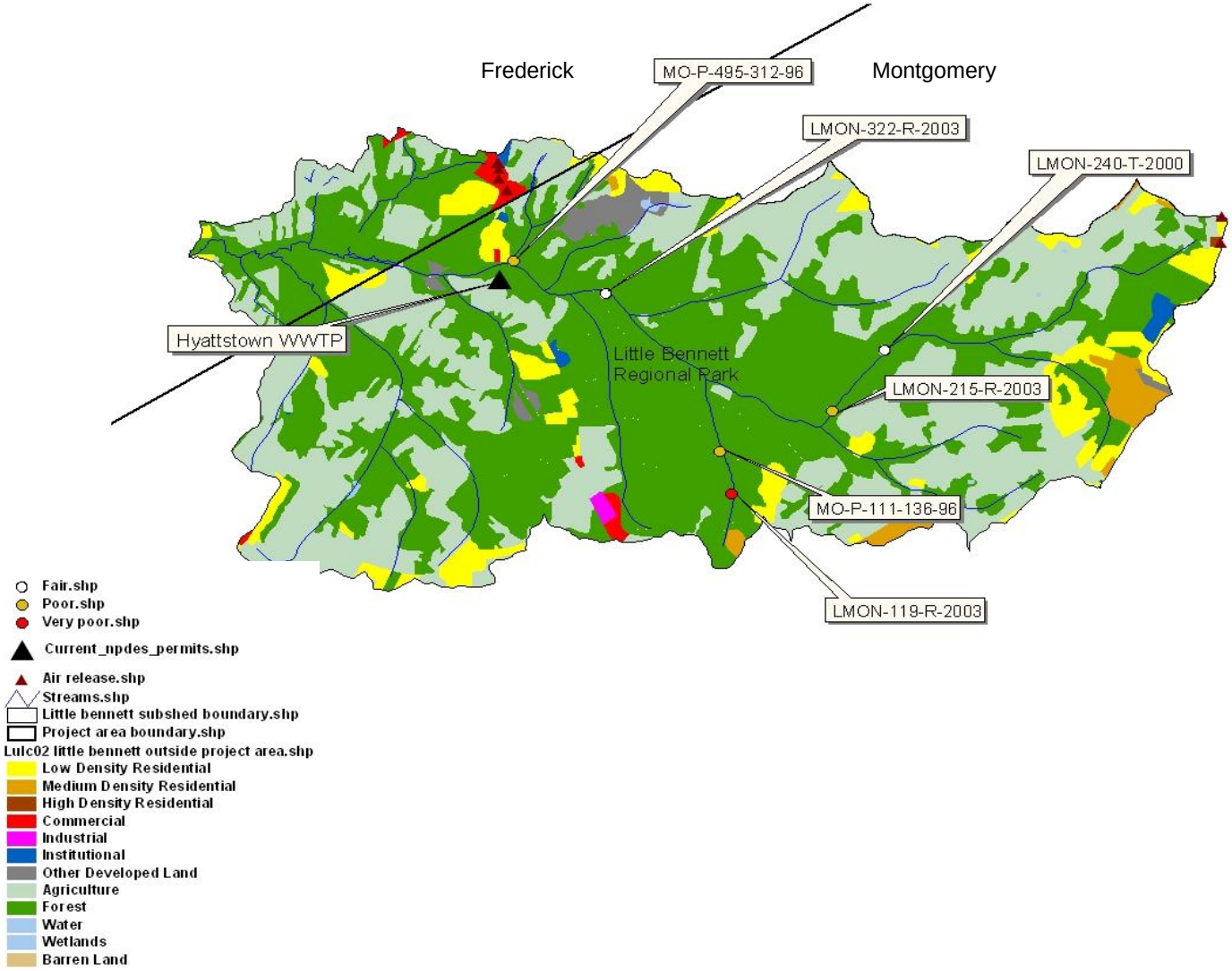

Figure 8-3. Land use land cover and biological information for the Little Bennett subwatershed.

Table 8-1a. BIBI & FIBI scores and spring water chemistry measurements taken in the Little Bennett subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of Little Bennett Creek). Tributaries to the Little Bennett mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem.

Parameter	**N Piedmont**		**NSS 77**	**MO-P-495-312-96**	**LMON-322-R-2003**	**MO-P-111-136-96**	**LMON-119-R-2003**	**LMON-215-R-2003**	**LMON-240-T-2000**
			RM 1.0	3.6	RM 4.5	RM 5.5	RM 5.5	RM 6.7	RM 7.3
Biological	**Ref Values**[1]	**N**				**Values**			
BIBI_05	**3.00**	54		*2.25*	3.25	*2.75*	3.00	*2.75*	3.50
FIBI_05	**3.00**	53		4.67	4.00	*2.00*	***1.33***	3.00	3.00
Chem_Spring									
pH (std units)	**7.06** - 7.61	51	7.52	7.35	*8.27*	*6.7*	***6.61***	*8.39*	7.53
Specific Conduct (mS/cm)	0.178	51	0.173	0.140	0.162	***0.767***	0.071	*0.202*	*0.180*
DOC (mg/L)	2.23	51		1.20	1.10	1.20	0.92	1.06	1.74
SO4 (mg/L)	9.81	51		7.18	7.79	8.27	7.48	7.56	7.08
NH3 (mg/L)	0.019	25			0.002		0.003	0.002	0.000
NO3 (mg/L)	2.71	51		2.61	2.56	0.85	0.82	*3.18*	3.21
NO2 (mg/L)	0.008	25			0.005		0.000	0.004	0.000
NO2+NO3 (mg/L)			1.87						
TN (mg/L)	2.82	25			2.79		0.93	*3.41*	3.46
TKN (mg/L)									
TP (mg/L)	0.026	25			0.010		0.005	0.008	0.009
O_PHOS (mg/L)	0.005	25	0.003		0.004		0.001	0.003	0.003
Water Temp (°C)			15.2						
DO (mg/L)			10.23						
Turbidity (NTU)	3.5	25							
AcidSrc				none	none	AD	AD	none	none

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 8-1b. BIBI & FIBI scores and summer water chemistry measurements taken in the Little Bennett subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of Little Bennett Creek). Tributaries to the Little Bennett mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem.

Parameter	**N Piedmont**		**NSS 77**	**MO-P-495-312-96**	**LMON-322-R-2003**	**MO-P-111-136-96**	**LMON-119-R-2003**	**LMON-215-R-2003**	**LMON-240-T-2000**
			RM 1.0	3.6	RM 4.5	RM 5.5	RM 5.5	RM 6.7	RM 7.3
Biological	**Ref Values[1]**	**N**				**Values**			
BIBI_05	**3.00**	54		*2.25*	3.25	*2.75*	3.00	*2.75*	3.50
FIBI_05	**3.00**	53		4.67	4.00	*2.00*	***1.33***	3.00	3.00
Chem_Summer									
Water Temp (°C)	20.5	51		18.5	20.6	16.8	15.9	18.6	20.0
DO (mg/L)	**8.20**	51		9.70	8.80	7.73	8.00	8.80	8.60
pH (std units)	**7.03** - 7.57	51		7.12	7.41	7.23	*6.45*	*6.91*	*7.62*
Specific Conduct (mS/cm)	0.192	51		0.130	0.163	0.082	0.078	0.188	*0.222*
Turbidity (NTU)	3.5	25			0.9		2.8	1.6	*5.5*

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 8-2. BIBI & FIBI scores and physical habitat measurements taken in the Little Bennett subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of Little Bennett Creek). Tributaries to the Little Bennett mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem.

Parameter	**N Piedmont**		**NSS 77**	**MO-P-495-312-96**	**LMON-322-R-2003**	**MO-P-111-136-96**	**LMON-119-R-2003**	**LMON-215-R-2003**	**LMON-240-T-2000**
			RM 1.0	3.6	RM 4.5	RM 5.5	RM 5.5	RM 6.7	RM 7.3
	Ref Values[1]	**N**	**Values**						
Biological									
BIBI_05	**3.00**	54		*2.25*	3.25	*2.75*	3.00	*2.75*	3.50
FIBI_05	**3.00**	53		4.67	4.00	*2.00*	***1.33***	3.00	3.00
Habitat									
Instream Habitat	**14**	51		*13*	16	*12*	14	17	***9***
Epifaunal Substrate	**14**	51		18	16	14	*12*	17	*8*
Velocity/Depth Diversity	**10**	51		18	17	12	10	17	11
Pool/Glide/Eddy Quality	**10**	51		15	17	11	10	18	12
Ex_Pool					45		33	40	57
Riffle Quality	**12**	51		17	16	*8*	13	18	12
Ex_Riffle/Run					44		46	62	30
Channel Alt	**10**	26		10		*8*			
Bank Stability	**8**	26		8		*7*			
Embeddedness	40	51		5	20	35	40	20	25
Shading	**70**	51		90	90	80	95	80	***45***

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 8-3a. Little Bennett. Strength of evidence for candidate causes: Nutrient Enrichment and Excessive Sediment/Turbidity.

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment	Score
Co-occurrence				
Benthic Macroinvertebrates	NO3 & TN concentrations at 2 of the 7 sites were greater than the 75th percentile of reference. The benthic macroinvertebrate community was impaired at one of these sites (BIBI scores of 2.75 & 3.50).	0	The site with the lowest BIBI score (2.50) had the lowest %embeddedness (5).	–
Fish	The 2 sites with the highest NO3 and TN concentrations had FIBI scores of 3.00. The 2 sites with the lowest FIBI scores had the lowest NO3 and TN concentrations.	–	Of the 6 sites sampled for fish, the site with the highest %embeddedness (40) had the lowest FIBI score (1.33). The site with the lowest %embeddedness (5) had the highest FIBI score (4.67).	+
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Inconsistent.	–	Inconsistent. Sites with higher %embeddedness did not consistently have lower BIBI scores.	–
FIBI	Inconsistent.	–	Consistent. Sites with higher %embeddedness values had lower FIBI scores.	+
Biological gradient				
BIBI - within the Bennett Ck watershed	Strong significant negative correlations exist between BIBI scores and nitrate, total nitrogen,and nitrate+nitrite concentrations.	++	BIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0
FIBI - within the Bennett Ck watershed	There are no significant correlations between FIBI scores and nutrient concentrations.	0	FIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0
BIBI- within the Northern Piedmont ecoregion	Weak significant negative correlations exist between BIBI scores and total phosphorus and nitrite concentrations.	+	A weak (r = -0.25) significant correlation exists between %embeddedness and BIBI scores. Too small a sample size for BIBI scores and turbidity measurements.	+

Table 8-3a (continued). Little Bennett.

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
FIBI - within the Northern Piedmont ecoregion	A very weak (r=0.10) significant positive correlation exists between FIBI scores and nitrite concentrations. There are no other significant correlations between nutrient concentrations and FIBI scores.	0	A very weak (r = -0.10) significant correlation exists between FIBI scores and %embeddedness. FIBI scores were not significantly correlated with turbidity measurements.	0
Complete exposure pathway	Organisms are exposed directly to water column where nutrient enrichment is measured	+	Organisms are exposed directly to sediment and turbidity	+
Plausibility: stressor - response	Stressor-response thresholds have not been established for nutrient enrichment	NE	Stressor-response thresholds have not been established for sediment or turbidity	NE
Specificity of cause	Nutrient enrichment is one of many plausible and consistently associated stressors	NE	Excess sediment/turbidity is one of several plausible and consistently associated stressors	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Nutrient concentrations are consistently low in this subwatershed. There is one site with a low BIBI score and elevated nitrogen concentrations and low BIBI and FIBI scores.	0	Consistent for the fish community.	+
Coherence of evidence	Nutrient enrichment may be a contributing factor to biological impairment at site LMON-215-R-2003	+	Excess sediment may be a factor of biological impairment on the fish community.	+

Table 8-3b. Little Bennett. Strength of evidence for candidate causes: Habitat Degradation and Excess Ammonia Toxicity.

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
Co-occurrence				
Benthic Macroinvertebrates	Sites with BIBI scores of less than 3.00 have instream habitat scores that are (slightly) less than the 25th percentile of reference. Sites with the highest BIBI scores have some of the lowest individual metric scores.	0	NH3 concentrations are very low (<.007). The site with the highest BIBI score (4.00) had the highest NH3 value.	–
Fish	Certain metrics are less than the 25th percentile of reference at the 2 sites with FIBI scores of less than 3.00. The site with the best FIBI score (4.67) generally had high metric scores.	+	NH3 concentrations are very low (<.007). The highest NH3 concentration (.003) occurred at the site with the lowest FIBI score (1.33).	+
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Somewhat consistent. Depends on the metric and depends on the site.	0	Inconsistent. Sites with higher NH3 concentrations did not consistently have lower BIBI scores.	–
FIBI	Mostly consistent. Depends on the metric and depends on the site.	+	Inconsistent. Sites with higher NH3 concentrations did not consistently have lower FIBI scores.	–
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with MBSS habitat metrics.	0	BIBI scores were not significantly correlated with ammonia concentrations.	0
FIBI - within the Bennett Ck watershed	FIBI scores had positive significant correlations with 3 MBSS habitat metrics (velocity/depth diversity, pool/glide/eddy, riffle quality).	+	FIBI scores were not significantly correlated with ammonia concentrations.	0
BIBI- within the Northern Piedmont ecoregion	Weak (r = 0.11 to 0.35) significant positive correlations exist between BIBI scores and 4 of 5 MBBS habitat metrics.	+	A very weak (r = -0.12) significant negative correlation exists between BIBI scores and ammonia concentrations.	0

Table 8-3b (continued). Little Bennett

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
FIBI - within the Northern Piedmont ecoregion	Significant positive correlations exist between FIBI scores and the 5 MBSS habitat metrics (for 4 of these, r > 0.4).	++	FIBI scores were not significantly correlated with ammonia concentrations.	0
Complete exposure pathway	Organisms are exposed directly to instream morphological habitat features and indirectly to riparian habitat features	+	Organisms are exposed directly to water column where ammonia concentration is measured	+
Plausibility: stressor - response	Not established for this study	NE	Observed levels are below reference criteria levels.	–
Specificity of cause	Poor habitat quality is one of several plausible and consistently associated stressors	NE	Ammonica toxicity is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Mostly consistent for the fish community. Somewhat consistent for the benthic macroinvertebrates. There is variation among the individual metrics and sites.	+	NH3 values are consistently lower than the 25th percentile of reference. There are no clear and consistent associations between NH3 concentrations and FIBI and BIBI scores.	–
Coherence of evidence	Habitat impairment may be a contributing factor to biological impairment at certain sites. Some sites appear to be impacted by habitat degradation more than others.	+	Ammonia toxicity does not appear to be a factor.	–

Table 8-3c. Little Bennett. Strength of evidence for candidate causes: Thermal Loading and Dissolved Oxygen Deficits.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
Co-occurrence				
Benthic Macroinvertebrates	Limited data (1 site). Temperature was 12°C and BIBI score was 4.00.	–	Limited data (1 site). DO was 9.6 mg/l and BIBI score was 4.00.	–
Fish	Summer water temperatures are at or below the 75th percentile of reference. The site with the lowest temperature had the lowest FIBI score.	–	Summer DO values ranged from 7.73 to 9.70 mg/l. The sites with the lowest FIBI scores had the lowest DO values. The site with the highest FIBI score had the highest DO value.	+
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Need more data to evaluate consistency.	NE	Need more data to evaluate consistency.	NE
FIBI	There are no consistent associations between FIBI scores and summer water temperature values.	–	Mostly consistent. The sites with higher DO values generally had better FIBI scores.	+
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with water temperature.	0	BIBI scores were not significantly correlated with DO measurements.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with water temperature.	0	A strong (r = 0.48) significant positive correlation exists between FIBI scores and DO measurements.	++
BIBI- within the Northern Piedmont ecoregion	Did not calculate - too small a sample size.	NE	Did not calculate - too small a sample size.	NE

Table 8-3c (continued). Little Bennett.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
FIBI - within the Northern Piedmont ecoregion	A weak (r = 0.2) significant positive correlation exists between FIBI scores and water temperature measurements.	–	A weak (r = 0.2) significant positive correlation exists between FIBI scores and DO measurements.	+
Complete exposure pathway	Organisms are exposed directly to water temperature	+	Organisms are exposed directly to water column where DO is measured	+
Plausibility: stressor - response	Not established	NE	Oxygen is not commonly considered limiting until it is below 4-6 mg/L. All observed DO values are above 6 mg/l.	–
Specificity of cause	Thermal loading may impact certain cold water species	NE	DO deficit is not consistently associated with biological impairment. Organic enrichment is one of many plausible and consistently associated stressors.	0
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Inconsistent	–	Mostly consistent - sites with higher DO values generally had better FIBI scores. Sites consistently had DO values greater than 6 mg/l.	0
Coherence of evidence	Water temperature can fluctuate greatly. The existing evidence for this subwatershed and for the Bennett Ck watershed as a whole does not indicate that thermal loading is a contributing factor to biological impairment.	–	DO deficit may be a factor of biological impairment on the fish community, which was sampled in the summer when DO stress was greatest. There appears to be an association between higher DO values and better FIBI scores. However all DO values were greater than 7 mg/l, which makes DO seem an unlikely factor of impairment.	0

Table 8-3d. Little Bennett. Strength of evidence for candidate causes: Ionic Strength and pH Imbalance.

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
Co-occurrence				
Benthic Macroinvertebrates	3 sites had conductivity values greater than the 75th percentile of reference (1 value was greater than the 95th). 2 of these sites had BIBI scores of less than 3.00.	+	2 sites with lower BIBI scores (2.75 & 3.00) were located on the trib with low spring pH values (6.7 & 6.61) and acid deposition. Leuctridae was the most abundant taxon at both sites; Amphinemura was third most abundant. These taxa are commonly found in low pH conditions.	+
Fish	The 1 site that had a conductivity value greater than the 75th percentile of reference had a FIBI score of 3.00. The 2 sites with the lowest FIBI scores (1.33 & 2.00) had the lowest sumer conductivities.	–	The 2 sites with the lowest FIBI scores (1.33 & 2.00) were located on the trib with the low pH conditions in the spring (1 of these sites had a pH value of 6.45 in the summer).	+
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Mostly inconsistent.	–	There are consistent associations at the trib with low pH conditions. At other sites there are no clear or consistent associations.	0
FIBI	Inconsistent. If anything, low conductivities are consistently associated with low FIBI scores.	–	There are consistent associations at the trib with low pH conditions. At other sites there are no clear or consistent associations.	0
Biological gradient				
BIBI - within the Bennett Ck watershed	There is a significant negative correlation between conductivity and BIBI scores (r=-0.34).	+	BIBI scores were not significantly correlated with pH.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with specific conductance.	0	FIBI scores were not significantly correlated with pH.	0
BIBI- within the Northern Piedmont ecoregion	A strong (r = -0.41) significant negative correlation exists between BIBI scores and specific conductance.	++	A weak (r = -0.29) significant negative correlation exists between BIBI scores and pH.	+

Table 8-3d (continued). Little Bennett.

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
FIBI - within the Northern Piedmont ecoregion	A weak (r = -0.16) significant negative correlation exists between FIBI scores and specific conductance.	+	A very weak (r = 0.14) significant positive correlation exists between FIBI scores and pH.	0
Complete exposure pathway	Organisms are exposed directly to water column where conductivity and chloride are measured	+	Organisms are exposed directly to water column where pH is measured	+
Plausibility: stressor - response	Not established	NE	Not established	NE
Specificity of cause	Not applicable because ionic strength is not a plausible mechanism	NE	Not applicable because pH is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Mostly inconsistent. Also not plausible.	NE	Low pH does appear to be affecting the fish and benthic macroinvertebrate community on one of the tribs. There are no clear patterns or consistencies at other sites throughout the watershed.	+
Coherence of evidence	This measure should be used as an indicator of sources because there is no plausible mechanism for impact to the biological community. The extreme fluctuation in spring and summer conductivity values at MO-P-111-136-96 is of interest, along with the low conductivity values at LMON-119-R-2003 (both are biologically impaired sites).	NE	pH appears to be a local or temporary issue that is affecting the biota on one of the tribs.	+

9 BENNETT MIDDLE MAINSTEM– STRESSOR IDENTIFICATION

9.1. Description of Impairment: Bennett Middle Mainstem

Only one biological sampling site is located in the Bennett Middle Mainstem subwatershed. It is located at approximately River Mile 9 on the Bennett Creek mainstem (Figure 9-1). MBSS sampled the fish and macroinvertebrate assemblages at this site (FR-P-015-304-96) in 1996. With a BIBI score of 2.25, the benthic macroinvertebrate assemblage at this site is impaired. The fish assemblage rated 'good,' receiving a FIBI score of 4.33. Data from this site and from upstream sites were used to perform the stressor identification.

9.2. Candidate Causes – Potential Stressor Sources: Bennett Middle Mainstem

The conceptual diagram (Figure 9-2) shows the stressor sources, the stressors they induce and the effects on the biological assemblage for the Bennett Middle Mainstem subwatershed. Sources in this subwatershed include agricultural practices (row crops and livestock), low and medium density residential developments, commercial, industrial and institutional developments, atmospheric deposition, and failing septic systems.

9.3. Analysis of Evidence – Associating candidate causes: Bennett Middle Mainstem

Aside from a summer water temperature that was slightly higher than the 75th percentile of reference site values, *in situ* water quality measurements (water temperature, dissolved oxygen, pH and specific conductance) were comparable to the reference distribution (Table 9-1). Limited nutrient data are available for FR-P-015-304-96. The nitrate (NO_3) concentration was higher than the 75th percentile of reference site values. Nutrient synoptic and biological sampling sites located upstream on the Bennett Creek mainstem generally had elevated nitrogen concentrations too. The ammonia concentration was not measured at this site.

Except for a low bank stability score, the habitat metric scores and percent embeddedness at FR-P-015-304-96 were comparable to the reference distribution. Percent shading (45) was less than the 5th percentile of reference site values, and an inadequate riparian buffer was documented by MBSS crews during the habitat assessment.

9.4. Characterization of Causes: Bennett Middle Mainstem

9.4.1. Elimination of candidate causes: Bennett Middle Mainstem

Dissolved oxygen, percent embeddedness, pH and specific conductance measurements were comparable to reference at FR-P-015-304-96, so dissolved oxygen deficit, excess sediment (turbidity was not measured at this site), pH imbalance and high ionic concentrations do not appear to be factors of impairment.

9.4.2. Strength of evidence: Bennett Middle Mainstem

The strength of evidence analysis was completed for eight candidate causes and twelve lines of logic. It is summarized in Tables 9-2a-d.

9.4.3. Identification of probable causes: Bennett Middle Mainstem

FR-P-015-304-96. From the strength of evidence analysis it appears that nutrient enrichment and habitat degradation are factors that may be causing impairment of the benthic macroinvertebrate assemblage at this site. There is no evidence for or against ammonia toxicity because ammonia concentrations were not measured.

Nutrient enrichment appears to be a factor contributing to impairment of the benthic macroinvertebrate assemblage. The nitrate (NO_3) concentration was elevated at this site, and the BIBI score was low. This is consistent with the negative correlations that occurred between BIBI scores and nitrogen concentrations in the Bennett Creek dataset, and with co-occurrences of low BIBI scores and elevated nitrogen concentrations at upstream sites in the Upper Bennett and Fahrney subwatersheds. High nitrogen levels can lead to excessive algal production, which in turn has effects on food resources, trophic relationships, habitat quality, ammonia and dissolved oxygen. Likely nitrogen sources include fertilizers and manure being applied to upstream agricultural lands and atmospheric deposition. Surrounding land use is primarily forest and agricultural lands, but there is a nearby dwelling, so a failed septic system and fertilizers being applied to residential lawns are other possible sources (Figures 43 & 44).

Habitat degradation due to bank instability is another possible cause of biological impairment at this site. An inadequate riparian buffer may be contributing to the bank instability, and unstable banks and lack of buffer may result in decreased organic bank habitat (i.e. woody debris and root wads) for the benthic macroinvertebrates. Inadequate riparian buffer and low percent shading can cause increased water temperatures. An elevated summer water temperature was recorded at this site. It is worth noting that low bank stability scores and low BIBI scores also co-occurred at BCBC314 and FR-377-242-96, which are two sites located upstream on the Bennett Creek mainstem in the Upper Bennett subwatershed.

9.5. Summary of Results: Bennett Middle Mainstem

A summary of the candidate causes associated with the biologically impaired site, along with the likely sources, is shown in Table 9-3. The most probable causes of impairment are nutrient enrichment and habitat degradation. The most likely sources of nutrient enrichment are agricultural lands, residential developments and atmospheric deposition. The most probable sources of habitat degradation are inadequate riparian buffers and bank instability and erosion from upstream land use (agricultural and urban) and natural factors.

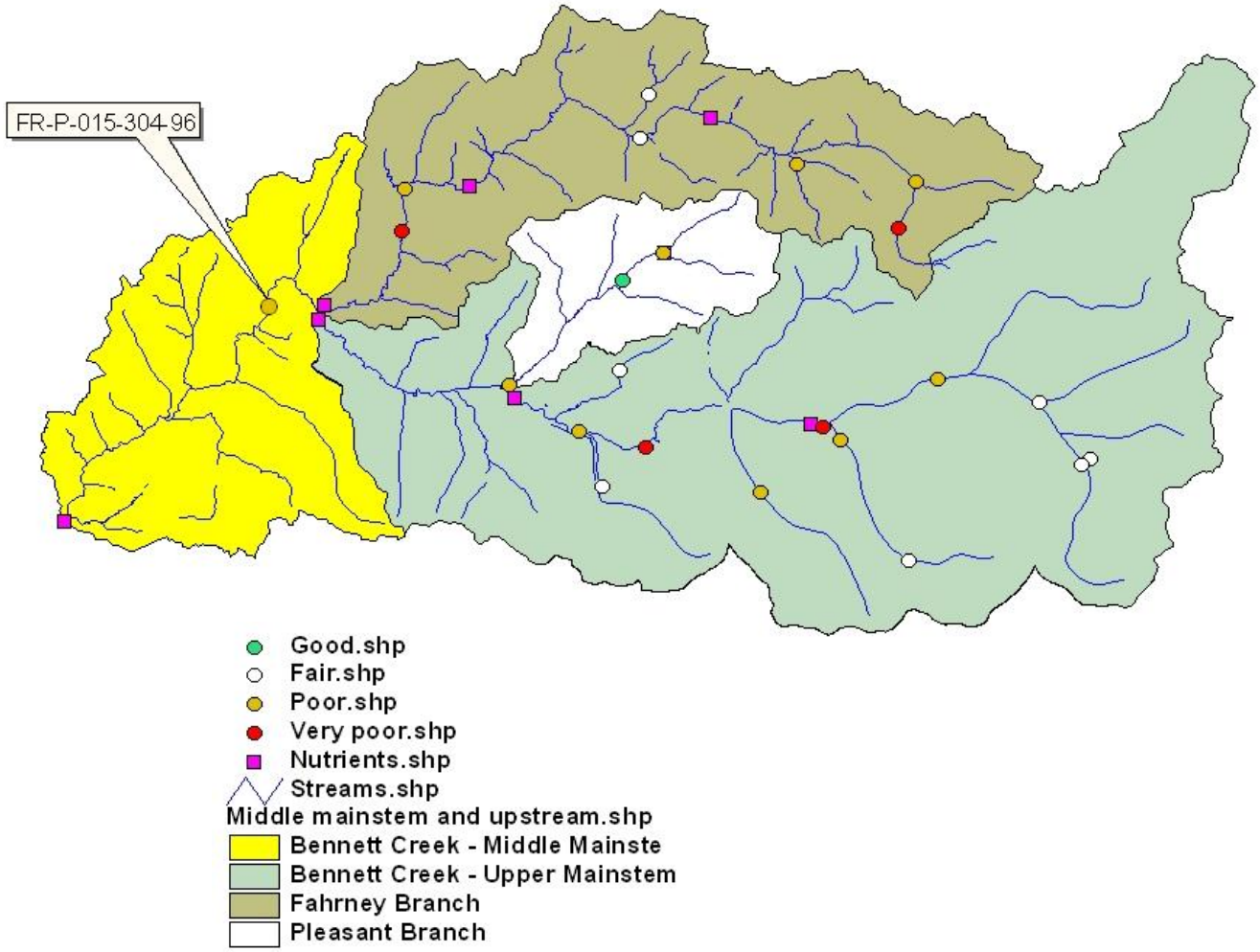

Figure 9-1. Locations of biological sampling sites and nutrient synoptic sites in the Bennett Middle Mainstem subwatershed.

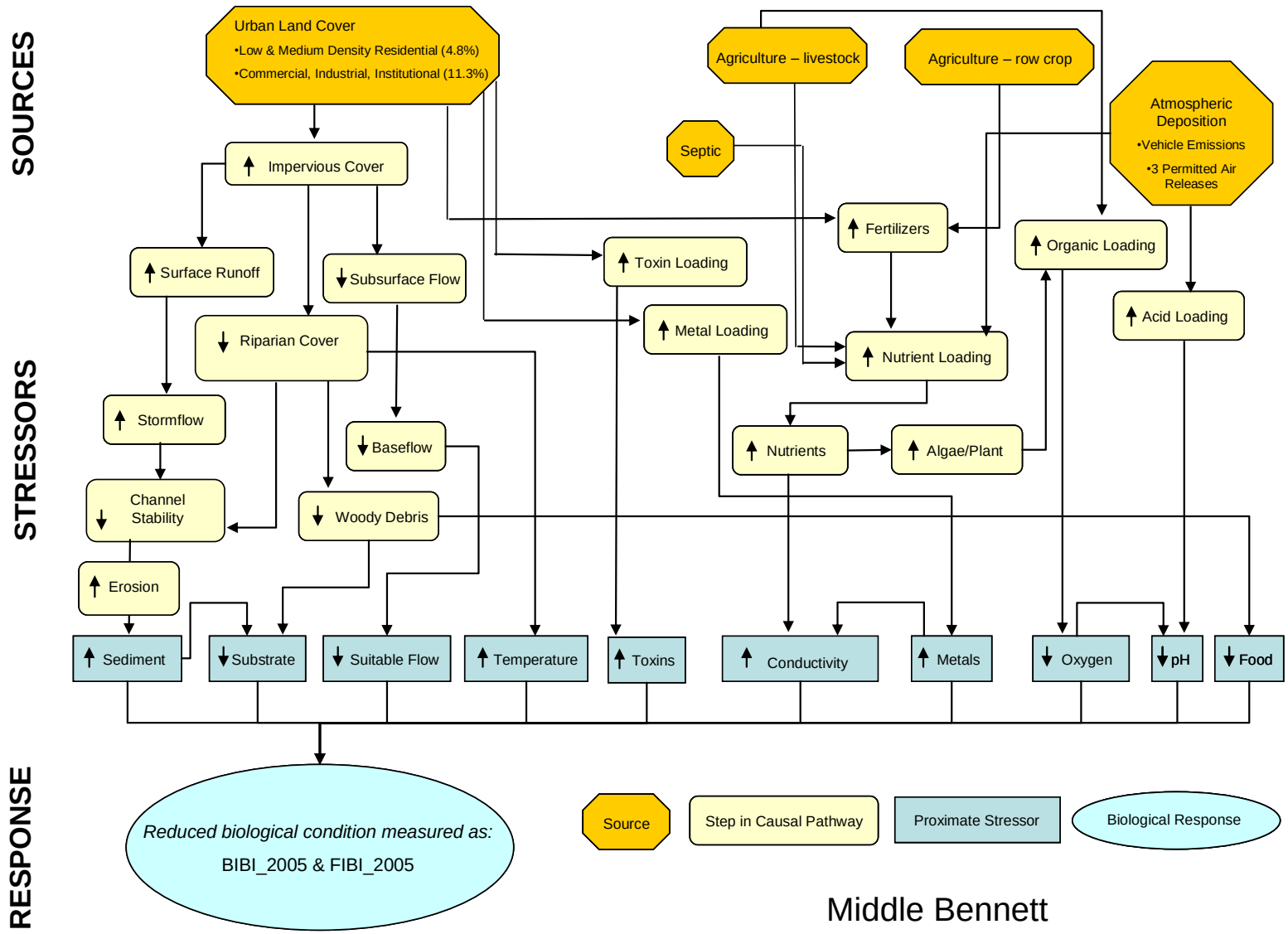

Figure 9-2. Conceptual Model for the Bennett Middle Mainstem subwatershed.

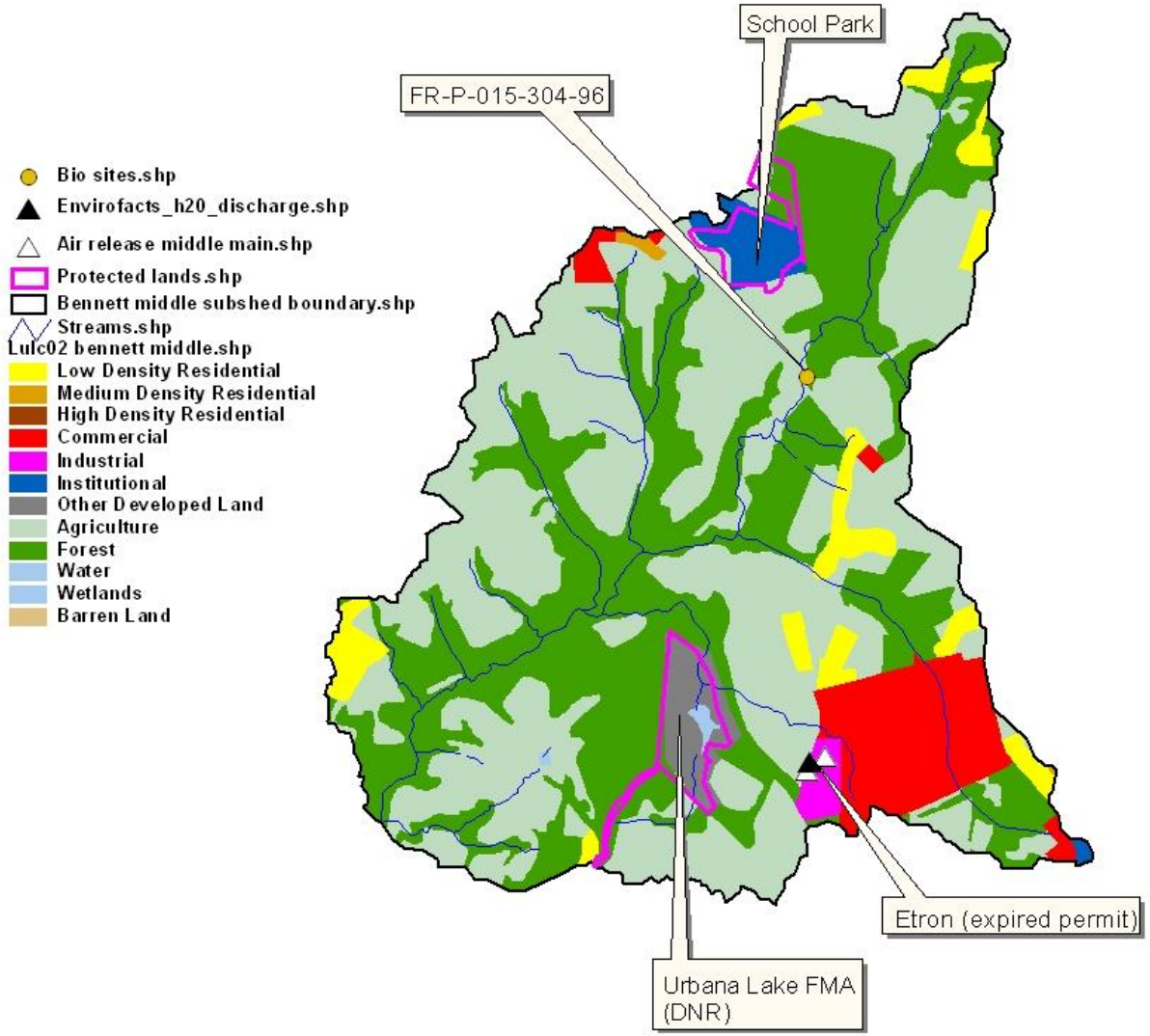

Figure 9-3. Land use land cover, biological and Envirofacts information for the Bennett Middle Mainstem subwatershed.

Table 9-1. BIBI & FIBI scores, water chemistry and habitat measurements taken in the Bennett Middle Mainstem subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'RM' refers to River Mile (distance from the mouth of Bennett Creek).

Parameter	**N Piedmont**		**FR-P-015-304-96**
			RM 9
Biological	**Ref Values[1]**	**N**	
BIBI_05	**3.00**	54	*2.25*
FIBI_05	**3.00**	53	4.33
Chem_Spring			
pH (std units)	**7.06** - 7.61	51	7.13
Specific Conduct (mg/L)	0.178	51	0.153
DOC (mg/L)	2.23	51	1.4
SO4 (mg/L)	9.81	51	7.49
NH3 (mg/L)	0.019	25	
NO3 (mg/L)	2.71	51	***3.71***
NO2 (mg/L)	0.008	25	
NO2+NO3 (mg/L)			
TN (mg/L)	2.82	25	
TKN (mg/L)			
TP (mg/L)	0.026	25	
O_PHOS (mg/L)	0.005	25	
Water Temp (°C)			
DO (mg/L)			
Turbidity (NTU)	3.5	25	
AcidSrc			none
Chem_Summer			
Water Temp (°C)	20.5	51	*22.3*
DO (mg/L)	**8.2**	51	9.3
pH (std units)	**7.03** - 7.57	51	7.35
Specific Conduct (mg/L)	0.192	51	0.144
Turbidity (NTU)	3.5	25	
Habitat			
Instream Habitat	**14**	51	15
Epifaunal Substrate	**14**	51	15
Velocity/Depth Diversity	**10**	51	18
Pool/Glide/Eddy Quality	**10**	51	19
Ex_Pool			
Riffle Quality	**12**	51	14
Ex_Riffle/Run			
Channel Alt	**10**	26	10
Bank Stability	**8**	26	*5*
Embeddedness	40	51	20
Shading	**70**	51	***45***

Table 9-2a. BENNETT MIDDLE MAINSTEM. Strength of evidence for candidate causes: Nutrient Enrichment and Excessive Sediment/Turbidity.

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
Co-occurrence				
Benthic Macroinvertebrates	This site had a NO3 concentration greater than the 75th percentile of reference and had the lowest BIBI score (2.25). Many of the upstream nutrient synoptic sites and biological sampling sites in Upper Bennett and Fahrney had elevated NO3 and NO3+NO2 concentrations.	+	%embeddedness at this site is lower than the 75th percentile of reference and is the lowest in this subwatershed (20%). This site has the lowest BIBI score (2.25). Turbidity and substrate size class data are not available for this site.	–
Fish	This site had the highest NO3 concentration (which was greater than the 75th percentile of reference) and the highest FIBI score (4.33).	–	%embeddedness at this site is the lowest in the subwatershed (20%). This site has the highest FIBI score (4.33).	–
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Limited evidence in this subwatershed. Consistent for the 1 site and for several sites upstream in Upper Bennett and Fahrney.	+	Limited evidence. This site had a low %embeddedness and low BIBI score. %embeddedness at upstream sites on the Bennett mainstem are generally low.	–
FIBI	Limited evidence in this subwatershed. FIBI scores are not consistently lower at sites with elevated nutrient concentrations.	–	Limited evidence. At this site a high FIBI score occurred at a site with low %embeddedness. Upstream mainstem sites generally had low %embeddedness values. FIBI scores varied.	0
Biological gradient				
BIBI - within the Bennett Ck watershed	Strong significant negative correlations exist between BIBI scores and nitrate, total nitrogen,and nitrate+nitrite concentrations.	++	BIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0
FIBI - within the Bennett Ck watershed	There are no significant correlations between FIBI scores and nutrient concentrations.	0	FIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0

Table 9-2a (continued). BENNETT MIDDLE MAINSTEM.

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
BIBI- within the Northern Piedmont ecoregion	Weak significant negative correlations exist between BIBI scores and total phosphorus and nitrite concentrations.	+	A weak (r = -0.25) significant correlation exists between %embeddedness and BIBI scores. Too small a sample size for BIBI scores and turbidity measurements.	+
FIBI - within the Northern Piedmont ecoregion	A very weak (r=0.10) significant positive correlation exists between FIBI scores and nitrite concentrations. There are no other significant correlations between nutrient concentrations and FIBI scores.	0	A very weak (r = -0.10) significant correlation exists between FIBI scores and %embeddedness. FIBI scores were not significantly correlated with turbidity measurements.	0
Complete exposure pathway	Organisms are exposed directly to water column where nutrient enrichment is measured	+	Organisms are exposed directly to sediment and turbidity	+
Plausibility: stressor - response	Stressor-response thresholds have not been established for nutrient enrichment	NE	Stressor-response thresholds have not been established for sediment or turbidity	NE
Specificity of cause	Nutrient enrichment is one of many plausible and consistently associated stressors	NE	Excess sediment/turbidity is one of several plausible and consistently associated stressors	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Consistent for the benthic macroinvertebrate community at this site and consistent in the Bennett Creek watershed as a whole.	+	Limited evidence. %embeddedness is consistently low at this site and on upstream mainstem sites.	–
Coherence of evidence	Nutrient enrichment may be a contributing factor to biological impairment of the benthic macroinvertebrate community.	+	Excess sediment/turbidity does not appear to be a factor of biological impairment at this site.	–

Table 9-2b. BENNETT MIDDLE MAINSTEM. Strength of evidence for candidate causes: Habitat Degradation and Excess Ammonia Toxicity.

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
Co-occurrence				
Benthic Macroinvertebrates	Bank stability had a low score at this site (5), and the BIBI score was low (2.25). All of the other habitat metrics had scores that were greater than the 25th percentile of reference. Another upstream site (on the Bennett mainstem) had a low bank stability score and a low BIBI score.	+	NH3 was not measured at this site.	NE
Fish	The FIBI score at this site was high (4.33). All of the habitat metrics except for bank stability had high scores.	–	NH3 was not measured at this site.	NE
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Mostly consistent. BIBI scores of less than 3.00 occurred at 2 out of 3 sites with bank stability scores 7 or less.	+	Lack evidence.	NE
FIBI	Limited evidence. Aside from a few sites with poor bank stability, habitat metrics generally have high scores and FIBI scores are equal to or greater than 3.00.	–	Lack evidence.	NE
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with MBSS habitat metrics.	0	BIBI scores were not significantly correlated with ammonia concentrations.	0
FIBI - within the Bennett Ck watershed	FIBI scores had positive significant correlations with 3 MBSS habitat metrics (velocity/depth diversity, pool/glide/eddy, riffle quality).	+	FIBI scores were not significantly correlated with ammonia concentrations.	0

Table 9-2b (continued). BENNETT MIDDLE MAINSTEM.

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
BIBI- within the Northern Piedmont ecoregion	Weak (r = 0.11 to 0.35) significant positive correlations exist between BIBI scores and 4 of 5 MBBS habitat metrics.	+	A very weak (r = -0.12) significant negative correlation exists between BIBI scores and ammonia concentrations.	0
FIBI - within the Northern Piedmont ecoregion	Significant positive correlations exist between FIBI scores and the 5 MBSS habitat metrics (for 4 of these, r > 0.4).	++	FIBI scores were not significantly correlated with ammonia concentrations.	0
Complete exposure pathway	Organisms are exposed directly to instream morphological habitat features and indirectly to riparian habitat features	+	Organisms are exposed directly to water column where ammonia concentration is measured	+
Plausibility: stressor - response	Not established for this study	NE	Observed levels are below reference criteria levels.	–
Specificity of cause	Poor habitat quality is one of several plausible and consistently associated stressors	NE	Ammonica toxicity is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	A poor bank stability score and a low BIBI score occurred at this site, along with at another upstream mainstem site.	+	Lack site-specific evidence.	NE
Coherence of evidence	Poor bank stability may be a contributing factor to biological impairment of the benthic macroinvertebrate community at this site.	+	Upstream NH3 concentrations are below the 75th percentile of reference. Ammonia toxicity is an unlikely factor of biological impairment.	–

Table 9-2c. BENNETT MIDDLE MAINSTEM. Strength of evidence for candidate causes: Thermal Loading and Dissolved Oxygen Deficits.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
Co-occurrence				
Benthic Macroinvertebrates	Spring water temperature was not measured at this site.	NE	Spring DO was not measured at this site.	NE
Fish	Summer water temperature was higher than the 75th percentile of reference and the FIBI score was high (4.33).	_	The summer DO value at this site was 9.3 mg/l, which is above the 25th percentile of reference. The FIBI score was high (4.33).	_
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Lack evidence.	NE	Lack evidence.	NE
FIBI	At this site a high FIBI score occurred at a site with a temperature that was higher than the 75th percentile of reference. There are no consistent associations between temperature and FIBI scores at upstream mainstem sites.	_	At this site a high FIBI score occurred at a site with a DO value that was higher than the 25th percentile of reference. DO values at upstream sites are all greater than 7 mg/l and FIBI scores do not consistently vary with fluctuations in DO values.	_
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with water temperature.	0	BIBI scores were not significantly correlated with DO measurements.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with water temperature.	0	A strong (r = 0.48) significant positive correlation exists between FIBI scores and DO measurements.	++
BIBI- within the Northern Piedmont ecoregion	Did not calculate - too small a sample size.	NE	Did not calculate - too small a sample size.	NE

Table 9-2c (continued). BENNETT MIDDLE MAINSTEM.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
FIBI - within the Northern Piedmont ecoregion	A weak (r = 0.2) significant positive correlation exists between FIBI scores and water temperature measurements.	–	A weak (r = 0.2) significant positive correlation exists between FIBI scores and DO measurements.	+
Complete exposure pathway	Organisms are exposed directly to water temperature	+	Organisms are exposed directly to water column where DO is measured	+
Plausibility: stressor - response	Not established	NE	Oxygen is not commonly considered limiting until it is below 4-6 mg/L. The observed DO levels are above 6 mg/l.	–
Specificity of cause	Thermal loading may impact certain cold water species	NE	DO deficit is not consistently associated with biological impairment. Organic enrichment is one of many plausible and consistently associated stressors.	0
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	The site with the highest water temperature had the highest FIBI score. Overall there are no obvious or consistent associations between water temperature and FIBI scores.	–	DO values are all greater than 7 mg/l. There are no obvious or consistent patterns between DO levels and FIBI scores.	–
Coherence of evidence	Water temperature can fluctuate greatly. The existing evidence for this site and for upstream sites does not indicate that thermal loading is a contributing factor to biological impairment of the fish community.	–	DO deficit does not appear to be a factor of biological impairment on the fish community at this site.	–

Table 9-2d. BENNETT MIDDLE MAINSTEM. Strength of evidence for candidate causes: Ionic Strength and pH Imbalance.

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
Co-occurrence				
Benthic Macroinvertebrates	The spring conductivity value at this site is less than the 75th percentile of reference. The BIBI score is 2.25.	–	The spring pH value at this site is within the range of reference values. The BIBI score is 2.25.	–
Fish	The summer conductivity value at this site is less than the 75th percentile of reference. The FIBI score is 4.33.	–	The summer pH value at this site is within the range of reference values. The FIBI score is 4.33.	–
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	This site had a low BIBI score and a relatively low conductivity. Conductivities at upstream sites on the Bennett mainstem are generally low and there are no obvious or consistent patterns between BIBI scores and conductivity values.	–	This site had a low BIBI score and a normal pH value. pH values at upstream sites on the Bennett mainstem are generally within the reference range. There are no obvious or consistent patterns between BIBI scores and pH values at upstream mainstem sites.	–
FIBI	This site had a high FIBI score and a relatively low conductivity. Conductivities at upstream sites on the Bennett mainstem are generally low and there are no obvious or consistent patterns between FIBI scores and conductivity values.	–	This site had a high FIBI score and a normal pH value. pH values at upstream sites on the Bennett mainstem are generally within the reference range. There are no obvious or consistent patterns between FIBI scores and pH values at upstream mainstem sites.	–
Biological gradient				
BIBI - within the Bennett Ck watershed	There is a significant negative correlation between conductivity and BIBI scores (r=-0.34).	+	BIBI scores were not significantly correlated with pH.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with specific conductance.	0	FIBI scores were not significantly correlated with pH.	0
BIBI- within the Northern Piedmont ecoregion	A strong (r = -0.41) significant negative correlation exists between BIBI scores and specific conductance.	++	A weak (r = -0.29) significant negative correlation exists between BIBI scores and pH.	+

Table 9-2d (continued). BENNETT MIDDLE MAINSTEM.

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
FIBI - within the Northern Piedmont ecoregion	A weak (r = -0.16) significant negative correlation exists between FIBI scores and specific conductance.	+	A very weak (r = 0.14) significant positive correlation exists between FIBI scores and pH.	0
Complete exposure pathway	Organisms are exposed directly to water column where conductivity and chloride are measured	+	Organisms are exposed directly to water column where pH is measured	+
Plausibility: stressor - response	Not established	NE	Not established	NE
Specificity of cause	Not applicable because ionic strength is not a plausible mechanism	NE	Not applicable because pH is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Conductivities are consistently less than the 75th percentile of reference. Conductivity is not a plausible stressor on the biological community.	NE	There is not a consistent association between pH values and FIBI and BIBI scores at this site and upstream mainstem sites.	–
Coherence of evidence	This measure should be used as an indicator of sources because there is no plausible mechanism for impact to the biological community. Conductivity values were less than the 75th percentile of reference where measured in this area.	NE	pH may be a local or temporary issue but does not appear to have consistent effects at this site.	–

Table 9-3. A summary of the candidate causes associated with the biologically impaired site in the Bennett Middle Mainstem subwatershed, and their possible sources. ☑ indicates that the source and/or step in the causal pathway are present or likely to be present in the upstream catchment area; ☑☑ indicates that the source and/or step in the causal pathway were documented at the site.

Candidate Cause	FR-P-015-304-96
Nutrient Enrichment	
Agricultural	
Fertilizer/Manure Application	☑
Direct Animal Access to Streams	
Residential Developments	
Failing Septic Systems	☑
High Concentrations of Septic System Leach Fields	
Application of Lawn Fertilizers	☑
Atmospheric Deposition	
Vehicle Emissions	☑
Permitted Air Releases	☑
Soil Disturbances	
Excess Sediment/Turbidity	
Land Disturbing Activities	
Direct Animal Access to Streams	
Runoff from Impervious Surfaces	
Row Crop Agriculture	
Construction	
Natural Factors (i.e instream sources, naturally erodible soils)	
Drainage from pond	
Habitat Degradation	
Urban Land Use	
Impervious Surfaces	
Stormwater Structures	
Inadequate Riparian Buffer	☑
Bank Instability and Erosion	
Upstream Land Use	☑
Direct Animal Access to Streams	
Natural Factors (i.e instream sources, naturally erodible soils)	☑
Channel Alteration	
Ionic Strength	
Human Activities	

10 BEAR BRANCH

The Bear Branch subwatershed is of special interest because it contains the only tributary in the Lower Bennett subwatershed that is considered to be a pristine trout-bearing stream (MDNR 2003a). The three biological sampling sites in the Bear Branch subwatershed are located within the Stronghold Preserve. MBSS sampled the fish and macroinvertebrate assemblages at a targeted site, LMON-130-T-2000, in 2000. The site had a BIBI score of 3.75, and no fish were collected. The site is located in the upper headwaters and has a drainage area of 0.19 km^2 (Figure 10-1). The other two sites are randomly selected sites that were sampled by Versar in 2007. One is located approximately 0.2 miles downstream of site LMON-130-T-2000. This site received a BIBI score of 4.00. The other site, which had a BIBI score of 3.00, is located on a tributary to Bear Branch.

Because the benthic macroinvertebrate assemblages at the three sites within this subwatershed received BIBI scores greater than or equal to 3.00 and are not considered to be impaired, a stressor identification was not performed for this subwatershed. However, due to the special interest associated with this trout-bearing stream, and due to the fact that fish were not present at site LMON-130-T-2000, the water chemistry, habitat and SCA data were examined. Low pH conditions may be one contributing factor to the absence of fish from LMON-130-T-2000. The site had spring and summer pH values that were less than the 5^{th} percentile of the reference site values (5.87 and 5.55, respectively) and the acid source was identified as acid deposition (Table 10-1). The spring specific conductance value at this site was higher than the 75^{th} percentile of reference site values, but the summer pH value was extremely low (less than the 5^{th} percentile of the reference distribution). This is similar to the pattern seen at MO-P-111-136-96, the impaired site in the Little Bennett subwatershed. Dissolved oxygen deficit may be another factor. With a value of 5.1 mg/l, the dissolved oxygen concentration at LMON-130-T-2000 was lower than the 5^{th} percentile of reference, and below the 6 mg/l threshold which is commonly considered to be limiting.

Site LMON-130-T-2000 also had low scores on all of its habitat metrics, even though it is surrounded by relatively undisturbed forest (Figure 10-2 & Table 10-2). This may be largely due to the fact that it is an upper headwater site with a small drainage area and limited pool and riffle habitat. Also, fish barriers that were documented during the SCA survey may also be impacting the fish assemblage in this portion of the subwatershed (Figure 10-3 & Table 10-3). These fish barriers were identified as priority restoration sites in the Lower Monocacy Watershed Restoration Action Strategy (Frederick County DPW 2004). A few stretches of stream corridor were also documented as problem areas due to inadequate riparian buffers and erosion (Table 10-4).

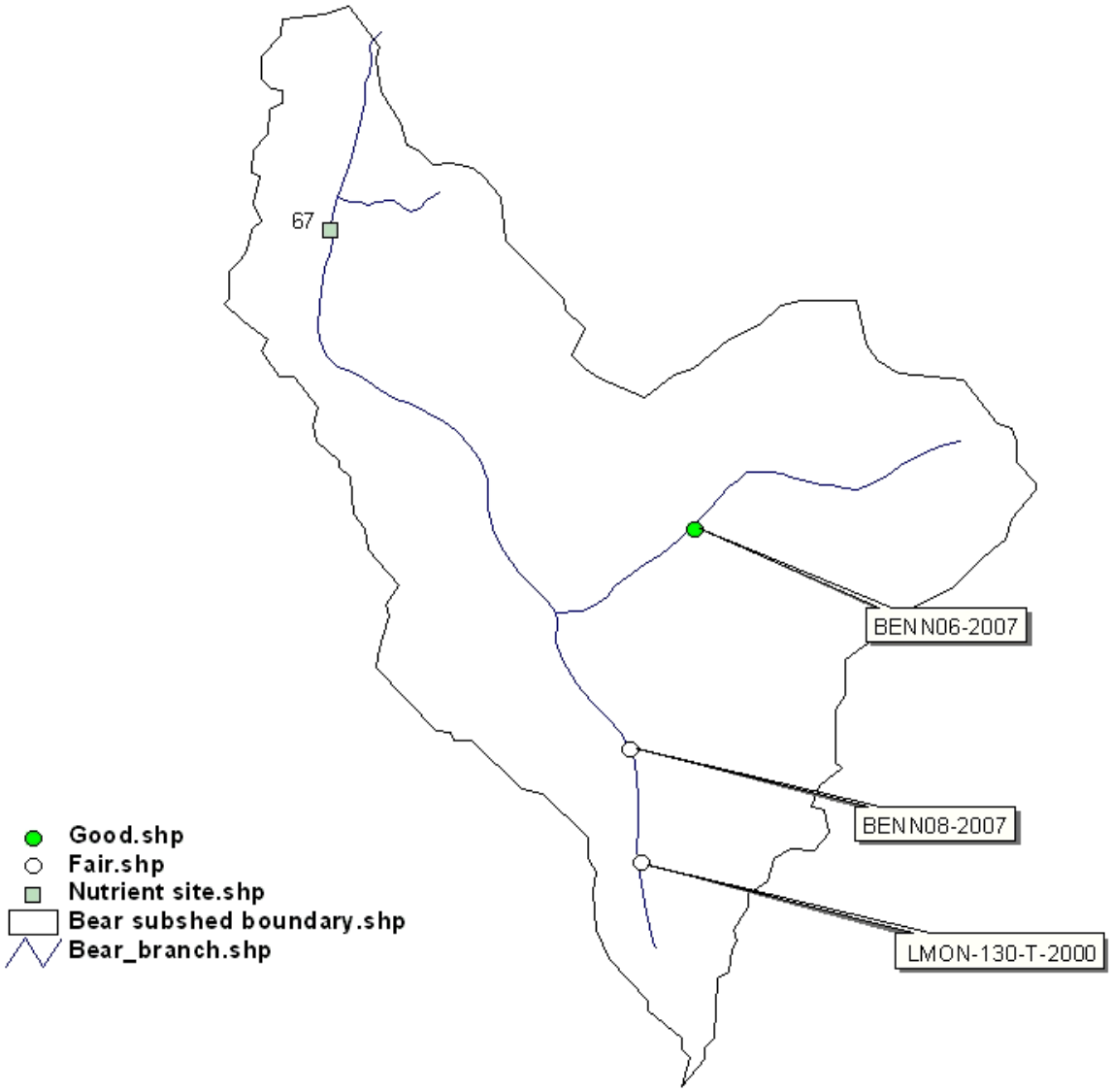

Figure 10-1. Locations of biological sampling and nutrient synoptic sites in the Bear Branch subwatershed.

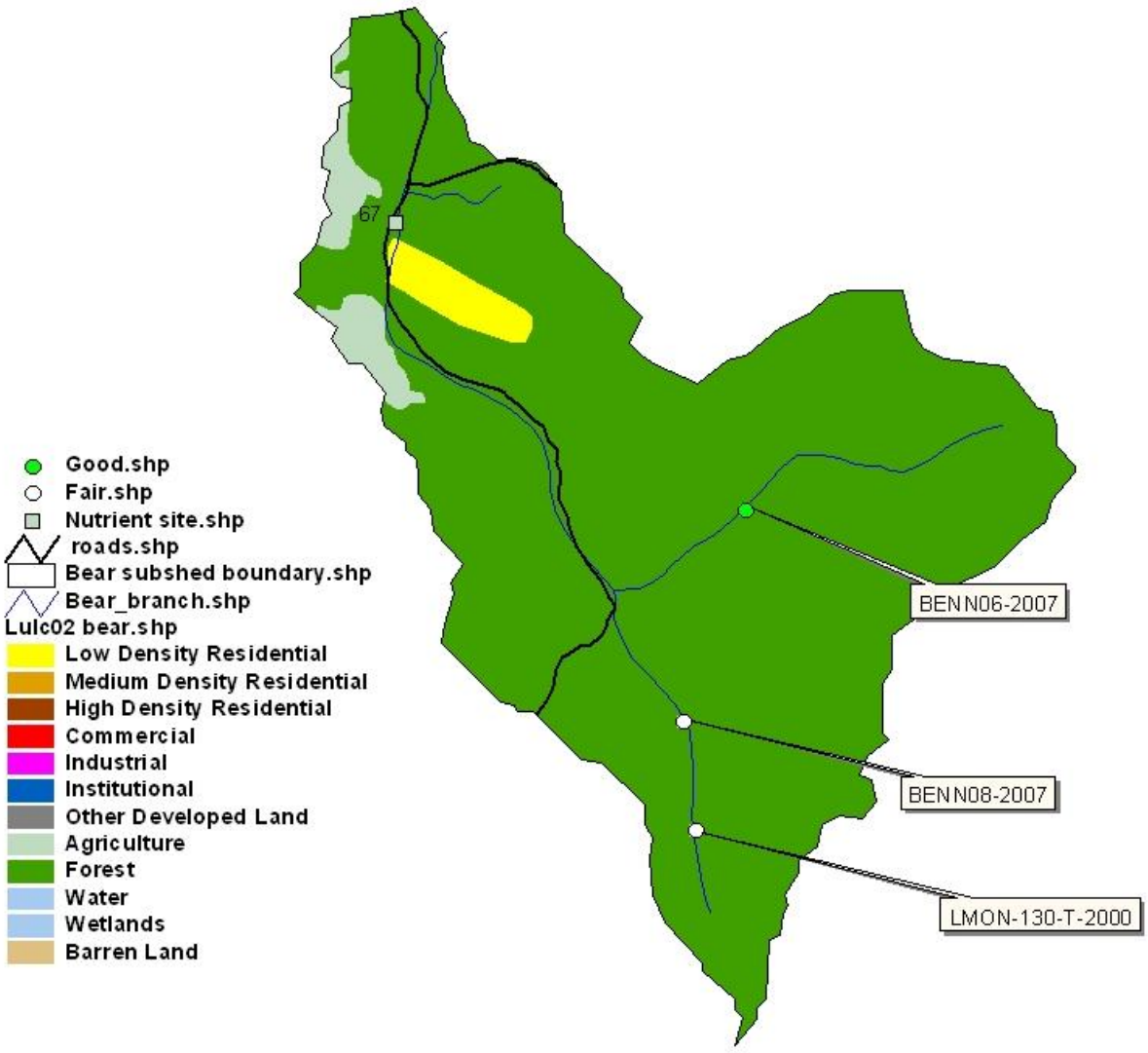

Figure 10-2. Land use land cover and biological information for the Bear Branch subwatershed.

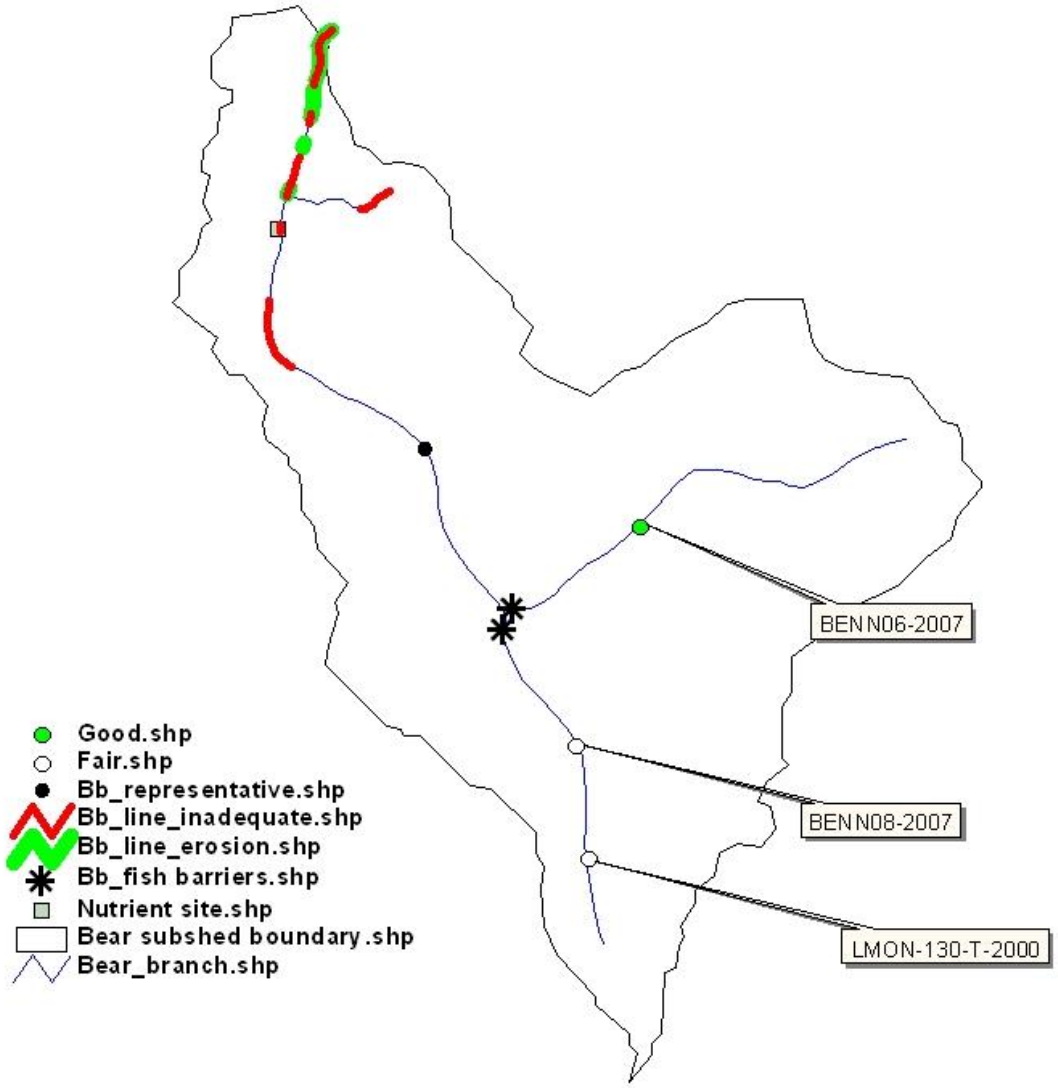

Figure 10-3. Results of the SCA assessments for the Bear Branch subwatershed.

Table 10-1. BIBI & FIBI scores and water chemistry measurements taken in Bear Branch. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of Bear Branch). Tributaries to the Bear Branch mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem; the value in parentheses refers to the distance of the site from the mouth of the tributary.

Parameter	**N Piedmont**		**NSS 67**	**BENN06-2007**	**BENN08-2007**	**LMON-130-T-2000**
			RM 0.5	RM 1.6 (0.4)	RM 1.9	RM 2.1
					Values	
Biological	**Ref Values**[1]	**N**				
BIBI_05	**3.00**	54		4.00	3.00	3.75
FIBI_05	**3.00**	53				no fish
Chem_Spring						
pH (std units)	**7.06** - 7.61	51	*7.89*	*6.45*	*8.69*	***5.87***
Specific Conduct (mS/cm)	0.178	51	0.086	0.063	0.057	*0.223*
DOC (mg/L)	2.23	51		0.24	1.82	2.10
SO4 (mg/L)	9.81	51				3.03
NH3 (mg/L)	0.019	25		0.003	0.004	0.000
NO3 (mg/L)	2.71	51		0.005	0.037	0.000
NO2 (mg/L)	0.008	25		0.002	0.002	0.000
NO2+NO3 (mg/L)			0.140	0.007	0.039	
TN (mg/L)	2.82	25		0.13	0.12	0.09
TKN (mg/L)				0.123	0.085	
TP (mg/L)	0.026	25		*0.031*	0.006	0.004
O_PHOS (mg/L)	0.005	25	0.006	0.003	0.001	0.000
Water Temp (°C)			17.9	11.6	12.6	
DO (mg/L)			9.5	9.6	11.0	
Turbidity (NTU)	3.5	25		***16.1***	1.8	
AcidSrc						AD
Chem_Summer						
Water Temp (°C)	20.5	51				17.8
DO (mg/L)	**8.20**	51				***5.1***
pH (std units)	**7.03** - 7.57	51				***5.55***
Specific Conduct (mS/cm)	0.192	51				0.026
Turbidity (NTU)	3.5	25				3.5

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 10-2. BIBI & FIBI scores and physical habitat measurements taken in Bear Branch. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of Bear Branch). Tributaries to the Bear Branch mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem; the value in parentheses refers to the distance of the site from the mouth of the tributary.

Parameter	**N Piedmont**		**NSS 67** RM 0.5	**BENN06-2007** RM 1.6 (0.4)	**BENN08-2007** RM 1.9	**LMON-130-T-2000** RM 2.1
				Values		
Biological	**Ref Values**[1]	**N**				
BIBI_05	**3.00**	54		4.00	3.00	3.75
FIBI_05	**3.00**	53				no fish
Habitat						
Instream Habitat	**14**	51		***9***	18	***8***
Epifaunal Substrate	**14**	51		***4***	*13*	*13*
Velocity/Depth Diversity	**10**	51		***6***	*9*	***7***
Pool/Glide/Eddy Quality	**10**	51		***4***	*9*	***3***
Ex_Pool				10	18	29
Riffle Quality	**12**	51		*9*	14	***6***
Ex_Riffle/Run				70	63	41
Channel Alt	**10**	26				
Bank Stability	**8**	26				
Embeddedness	40	51		85	40	40
Shading	**70**	51		75	85	95

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 10-3. Priority Restoration Sites in the Bear Branch subwatershed that were identified in the Lower Monocacy Watershed Restoration Action Strategy (Frederick County DPW 2004).

Tributary	Site	Problem	Suggested Restoration
Bear Branch	41	Two fish barriers on a naturally reproducing trout stream	

Table 10-4. Summary of the SCA results for the Bear Branch subwatershed (Czwartacki et al. 2004).

Potential Problems	Number	Estimated Length	Very Severe	Severe	Moderate	Low Severity	Minor
Channel Alterations	0	NA	0	0	0	0	0
Erosion Sites	3	1025 ft (0.19 miles)	0	0	3	0	0
Exposed Pipes	0	NA	0	0	0	0	0
Fish Barriers	2	NA	0	0	0	1	1
Inadequate Buffers	3	2250 ft (0.43 miles)	0	1	0	1	1
Pipe Outfalls	0	NA	0	0	0	0	0
Trash Dumpings	0	NA	0	0	0	0	0
Unusual Conditions	0	NA	0	0	0	0	0
Total	**8**		**0**	**1**	**3**	**2**	**2**
Comments	**0**						
Representative Sites	**1**						

11 BENNETT LOWER MAINSTEM– STRESSOR IDENTIFICATION

11.1. Description of Impairment: Bennett Lower Mainstem

Five biological sampling sites are located in the Bennett Lower Mainstem subwatershed (Figure 9-1). Four of these were randomly selected sites on tributaries to the Bennett Creek mainstem that were sampled by Versar in 2007. Only the benthic macroinvertebrate assemblages were assessed at these sites, and they all received BIBI scores greater than 3.00. The other site, LMON-421-T-2000, was a targeted MBSS site on the Bennett Creek mainstem. It is located approximately 0.2 miles from the confluence with the Monocacy River. This site had a BIBI score of 2.75, so the benthic macroinvertebrate assemblage is considered to be impaired. The FIBI score at this site was 3.67. Data from these sites and from upstream sites were used to perform the stressor identification.

11.2. Candidate Causes – Potential Stressor Sources: Bennett Lower Mainstem

The conceptual diagram (Figure 9-2) shows the stressor sources, the stressors they induce and the effects on the biological assemblage for the Bennett Lower Mainstem subwatershed. The land use land cover within this subwatershed is dominated by forest and agriculture (Figure 9-3). Sources in this subwatershed include agricultural practices (row crops and livestock), low density residential developments, atmospheric deposition, (potentially failing) septic systems, and land disturbing activities.

11.3. Analysis of Evidence – Associating candidate causes: Bennett Lower Mainstem

The spring pH value and the summer specific conductance and turbidity values at LMON-421-T-2000 were higher than the 75th percentile of the reference site values, but the other *in situ* water quality measurements were comparable to the reference distribution (Tables 11-1a & 11-1b). Additional water chemistry parameters, such as ammonia, nitrogen and phosphorus concentrations, were measured in the spring and were comparable to the reference distribution.

Bennett Creek is a deep and almost non-wadeable fourth order stream (Strahler 1957) at LMON-421-T-2000, and the stream reach that was sampled did not have any riffle habitat. Therefore the riffle quality metric received the lowest possible score (0) and the pool/glide/eddy quality metric received the highest possible score (20) (Table 11-2). The instream habitat and epifaunal substrate metric scores were lower than the 25th percentile of the reference site values. Percent embeddedness was comparable to the reference distribution, and percent shading (65) was lower than the 25th percentile of the reference distribution.

11.4. Characterization of Causes: Bennett Lower Mainstem

11.4.1. Elimination of candidate causes: Bennett Lower Mainstem

The water temperature, dissolved oxygen value and nutrient concentrations were comparable to reference at LMON-421-T-2000, so dissolved oxygen deficit, thermal loading and nutrient enrichment do not appear to be factors of impairment.

11.4.2. Strength of evidence: Bennett Lower Mainstem

The strength of evidence analysis was completed for eight candidate causes and twelve lines of logic. It is summarized in Tables 11-3a-d.

11.4.3 Identification of probable causes: Bennett Lower Mainstem

LMON-421-T-2000. From the strength of evidence analysis it appears that habitat degradation and excessive sediment and turbidity are factors that may be causing impairment of the benthic macroinvertebrate assemblage at this site. Other possible factors include pH imbalance and high ionic concentrations.

The natural lack of riffle habitat is likely a major factor affecting the benthic assemblage at this site, and is likely part of the reason why the site received low habitat metric scores for instream habitat and epifaunal substrate. Other contributing factors may be a narrow riparian buffer, agricultural lands (row crop) located approximately 0.1 miles north of the site, and outflows draining nearby ponds. The Lily Pons Water Gardens are located in the extensive wetland area immediately south of the sampling site. MBSS crews noted the presence of a culvert that drained a lot of silt and fine sediment from a nearby pond. This may account for the slightly elevated summer turbidity measurement.

Although pH was elevated in the spring, it was comparable to reference in the summer and pH imbalance is not likely to be a consistent or widespread factor. The elevated spring pH value may be due to runoff from nearby agricultural lands or from the Lily Pons Water Gardens. The slightly elevated summer specific conductance value that was recorded at this site also indicates that human activities may be affecting the biota, although there is no plausible mechanism for conductivity to impact the biota. BIBI scores in the Bennett Creek watershed and the Northern Piedmont ecoregion were negatively correlated with specific conductance values.

11.5. Summary of Results: Bennett Lower Mainstem

A summary of the candidate causes associated with the biologically impaired site, along with the likely sources, is shown in Table 11-4. The habitat at LMON-421-T-2000 is naturally limiting because it is a deep fourth order stream with no riffles. Excess sediment and turbidity from a nearby pond drainage and from natural instream factors also appear to be impacting the benthic macroinvertebrate assemblage at this site. Inadequate riparian buffers may also be contributing to habitat degradation.

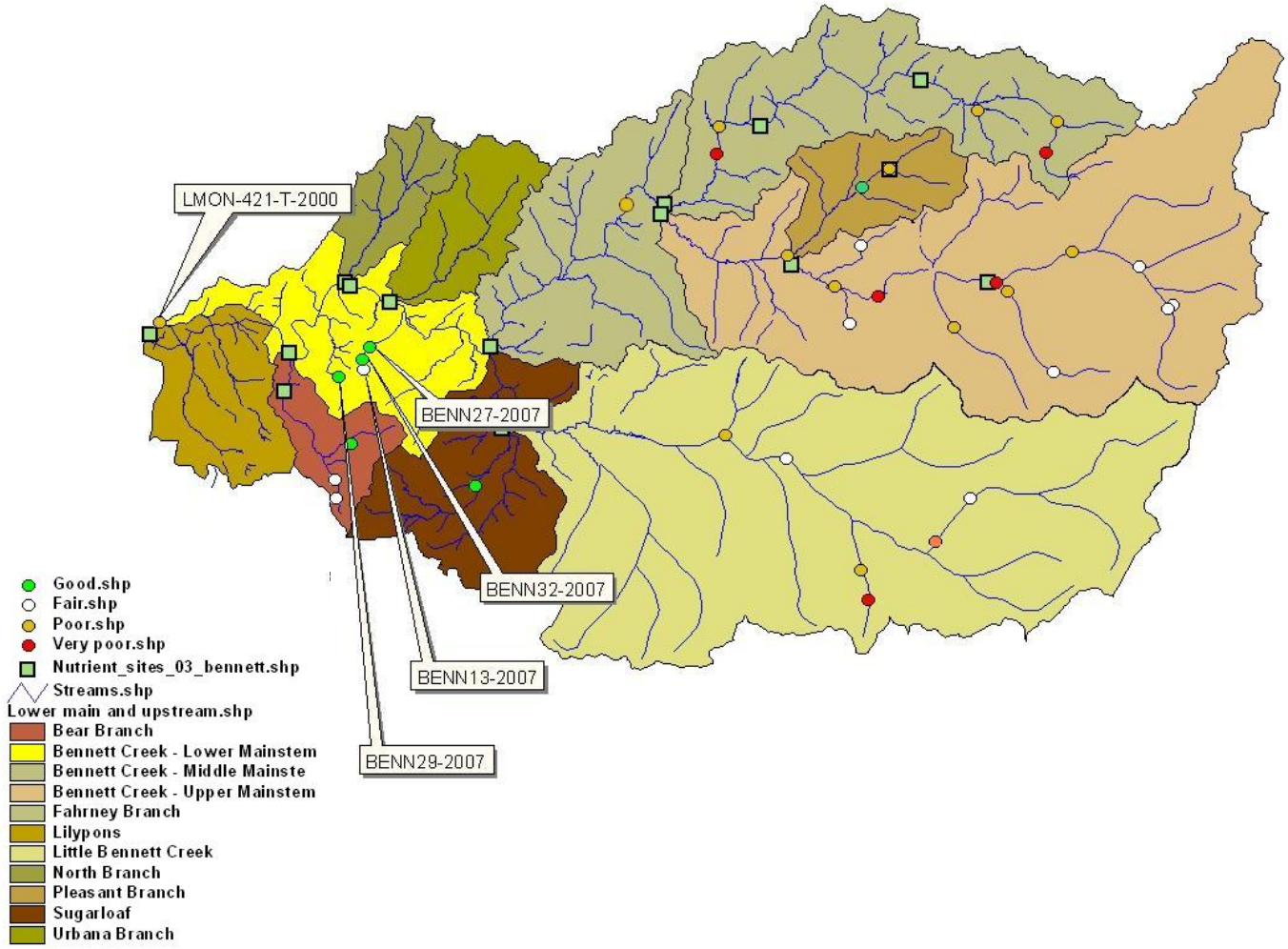

Figure 11-1. Locations of biological sampling and nutrient synoptic sites in the Bennett Lower Mainstem subwatershed and in upstream subwatersheds.

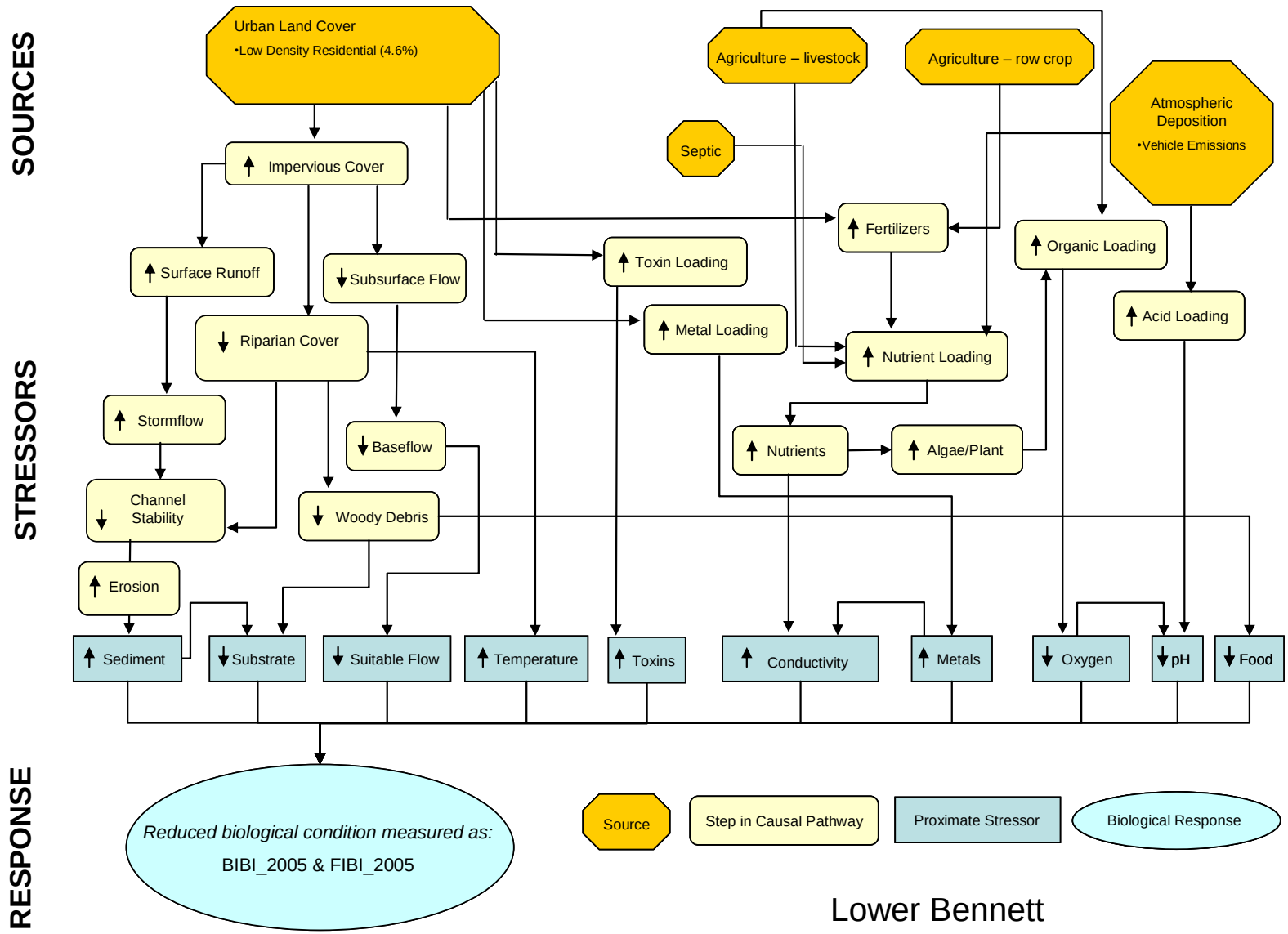

Figure 11-2. Conceptual Model for the Bennett Lower Mainstem subwatershed.

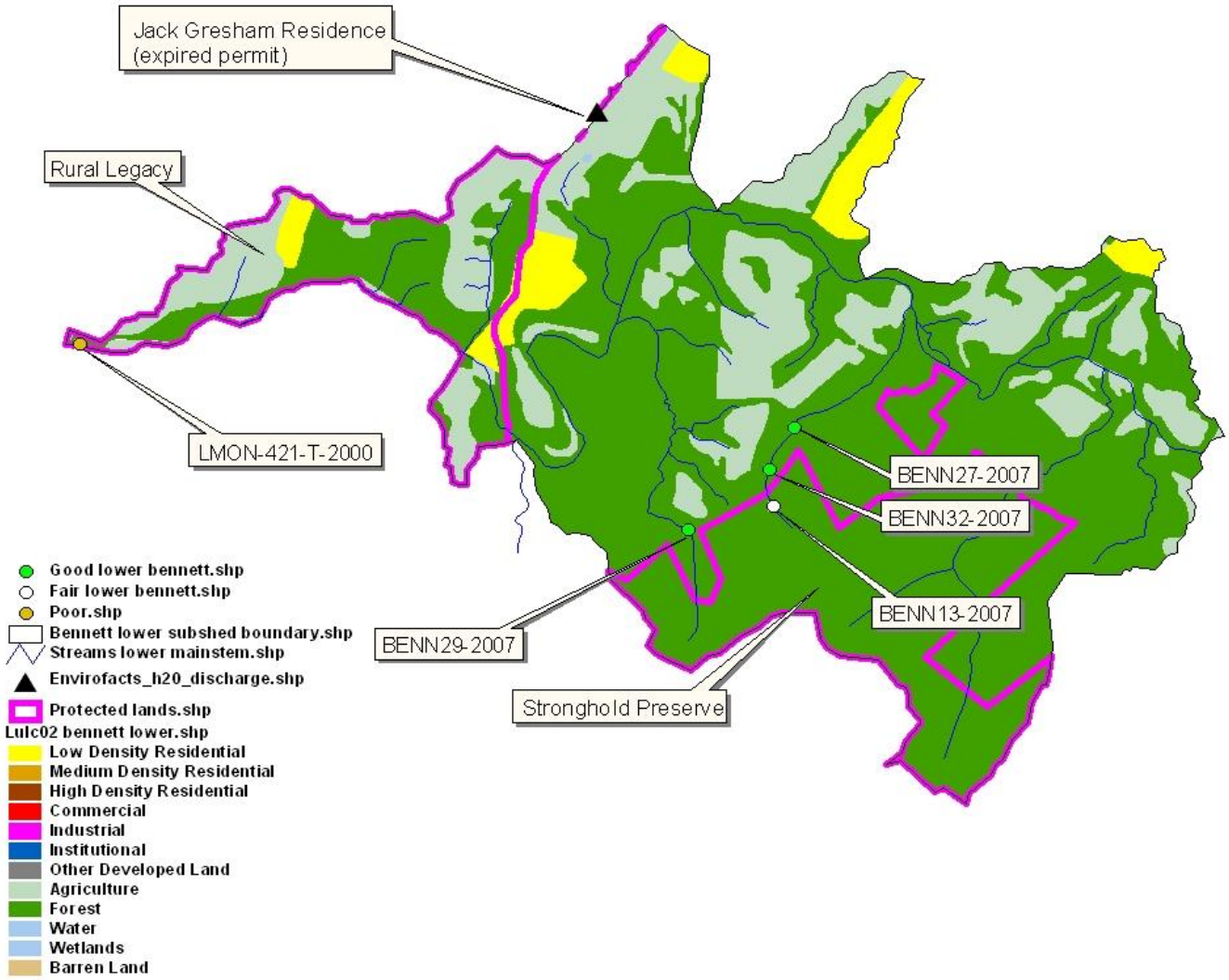

Figure 11-3. Land use land cover, Envirofacts, protected lands and biological sampling information for the Bennett Lower Mainstem.

Table 11-1a. BIBI & FIBI scores and spring water chemistry measurements taken in the Bennett Lower Mainstem subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of Bennett Creek). Tributaries to the Bennett Creek mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem; the value in parentheses refers to the distance of the site from the mouth of the tributary.

Parameter	**N Piedmont**		**NSS 65**	**LMON-421-T-2000**	**NSS 66**	**BENN29-2007**	**NSS 68**	**NSS 69**	**NSS 70**	**BENN27-2007**	**BENN32-2007**	**BENN13-2007**	**NSS 71**
			RM 0.1	RM 0.2	RM 2.1	RM 3.2	RM 3.8	RM 3.9	RM 4.5	RM 4.7 (0.6)	RM 4.7 (0.8)	RM 4.7 (0.9)	RM 6.2
									Values				
Biological	**Ref Values**[1]	**N**											
BIBI_05	**3.00**	54		*2.75*		4.25				4.25	4.00	3.25	
FIBI_05	**3.00**	53		3.67									
Chem_Spring													
pH (std units)	**7.06** - 7.61	51	*7.82*	*8.12*	*7.98*	*6.78*	*8.15*	*8.03*	*8.22*	*8.33*	7.12	*8.02*	*7.77*
Specific Conduct (mg/L)	0.178	51	0.174	0.171	0.158	0.067	*0.226*	0.172	*0.279*	0.072	0.053	0.042	0.170
DOC (mg/L)	2.23	51		1.27		*2.56*				2.08	*2.45*	*2.83*	
SO4 (mg/L)	9.81	51		8.66									
NH3 (mg/L)	0.019	25		0.000		0.004				0.007	0.008	0.008	
NO3 (mg/L)	2.71	51		1.82		0.07				0.09	0.08	0.05	
NO2 (mg/L)	0.008	25		0.000		0.002				0.002	0.002	0.002	
NO2+NO3 (mg/L)			2.28		1.96	0.07	1.99	2.43	1.89	0.09	0.08	0.05	3.26
TN (mg/L)	2.82	25		2.15		0.22				0.21	0.25	0.47	
TKN (mg/L)						0.152				0.125	0.172	0.415	
TP (mg/L)	0.026	25		0.009		0.011				0.017	0.017	*0.029*	
O_PHOS (mg/L)	0.005	25	0.003	0.001	0.003	0.003	0.002	0.002	0.003	*0.009*	0.003	0.002	0.003
Water Temp (°C)			16.2		18.0	12.0	16.9	17.9	18.1	16.2	14.9	14.4	16.0
DO (mg/L)			10.3		10.8	9.2	11.2	10.9	10.5	9.7	9.4	8.4	11.0
Turbidity (NTU)	3.5	25				*5.6*				*8.6*	***13.5***	***36.0***	
AcidSrc				none									

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 11-1b.BIBI & FIBI scores and summer water chemistry measurements taken in the Bennett Lower Mainstem subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of Bennett Creek). Tributaries to the Bennett Creek mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem; the value in parentheses refers to the distance of the site from the mouth of the tributary.

Parameter	**N Piedmont**		**NSS 65**	**LMON-421-T-2000**	**NSS 66**	**BENN29-2007**	**NSS 68**	**NSS 69**	**NSS 70**	**BENN27-2007**	**BENN32-2007**	**BENN13-2007**	**NSS 71**
			RM 0.1	RM 0.2	RM 2.1	RM 3.2	RM 3.8	RM 3.9	RM 4.5	RM 4.7 (0.6)	RM 4.7 (0.8)	RM 4.7 (0.9)	RM 6.2
									Values				
Biological	**Ref Values**[1]	**N**											
BIBI_05	**3.00**	54		*2.75*		4.25				4.25	4.00	3.25	
FIBI_05	**3.00**	53		3.67									
Chem_Summer													
Water Temp (°C)	20.5	51		13.8									
DO (mg/L)	**8.20**	51		9.5									
pH (std units)	**7.03** - 7.57	51		7.06									
Specific Conduct (mg/L)	0.192	51		*0.196*									
Turbidity (NTU)	3.5	25		*4.7*									

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 11-2. BIBI & FIBI scores and physical habitat measurements taken in the Bennett Lower Mainstem subwatershed. Parameter values are compared to the associated reference values. Values that are outside the reference range are italicized; values that are less than the 5th percentile or greater than the 95th percentile of the reference distribution are in boldface and italicized. 'NSS' refers to nutrient synoptic site. 'RM' refers to River Mile (distance from the mouth of Bennett Creek). Tributaries to the Bennett Creek mainstem are in red print. River Miles of tributaries refer to the river mile at which they flow into the mainstem; the value in parentheses refers to the distance of the site from the mouth of the tributary.

Parameter	**N Piedmont**		**LMON-421-T-2000**	**BENN29-2007**	**BENN27-2007**	**BENN32-2007**	**BENN13-2007**
Biological	**Ref Values[1]**	**N**	RM 0.2	RM 3.2	RM 4.7 (0.6)	RM 4.7 (0.8)	RM 4.7 (0.9)
BIBI_05	**3.00**	54	*2.75*	4.25	4.25	4.00	3.25
FIBI_05	**3.00**	53	3.67				
Habitat							
Instream Habitat	**14**	51	*13*	17	17	17	***11***
Epifaunal Substrate	**14**	51	*11*	14	*12*	*13*	*8*
Velocity/Depth Diversity	**10**	51	10	*8*	***7***	***7***	***6***
Pool/Glide/Eddy Quality	**10**	51	20	***8***	***7***	***5***	***3***
Ex_Pool			75	10	9	8	13
Riffle Quality	**12**	51	***0***	13	*10*	*8*	***6***
Ex_Riffle/Run			0	65	66	67	62
Channel Alt	**10**	26					
Bank Stability	**8**	26					
Embeddedness	40	51	30	*50*	40	*50*	*50*
Shading	**70**	51	*65*	*60*	80	90	80

[1] Reference values in bold type are the 25th percentile of the reference distribution; those in normal type are the 75th percentile.

Table 11-3a. BENNETT LOWER MAINSTEM. Strength of evidence for candidate causes: Nutrient Enrichment and Excessive Sediment/Turbidity.

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
Co-occurrence				
Benthic Macroinvertebrates	Nutrient values are less than the 75th percentile of reference at this site. The BIBI score is 2.75.	–	Sand and silt/clay are extensive at this site. Field crews commented on the presence of a culvert that was draining a pond with a lot of silt and fine sediment. %embeddedness is less than the 75th percentile of reference (30%). The BIBI score is 2.75.	+
Fish	Nutrient values are less than the 75th percentile of reference at this site. The FIBI score is 3.67.	–	Sand and silt/clay are extensive at this site. %embeddedness is less than the 75th percentile of reference (30%). The FIBI score is 3.67.	–
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Nutrient values at this site and at the 2 closest nutrient synoptic survey sites upstream on the Bennett mainstem are low, and the BIBI score at this site is 2.75. The other mainstem biological site in this subwatershed has an elevated NO3 concentration and a BIBI score of 2.25.	0	Although %embeddedness is less than the 75th percentile of reference, sand and fine sediment are extensive at this site, and the BIBI score is less than 3.00. The other mainstem biological site in this subwatershed has a lower %embeddedness and a BIBI score of 2.25.	0
FIBI	FIBI scores at both mainstem sites are greater than 3.00. The lower FIBI score (3.67) occurs at the site with the lower nutrient values.	–	FIBI scores at both mainstem sites are greater than 3.00. The lower FIBI score (3.67) occurs at the site with the (slightly) higher %embeddedness.	0
Biological gradient				
BIBI - within the Bennett Ck watershed	Strong significant negative correlations exist between BIBI scores and nitrate, total nitrogen,and nitrate+nitrite concentrations.	++	BIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0
FIBI - within the Bennett Ck watershed	There are no significant correlations between FIBI scores and nutrient concentrations.	0	FIBI scores were not significantly correlated with %embeddedness and turbidity measurements.	0

Table 11-3a (continued). BENNETT LOWER MAINSTEM

Causal Consideration	Nutrient Enrichment	Score	Excess Sediment/Turbidity	Score
BIBI- within the Northern Piedmont ecoregion	Weak significant negative correlations exist between BIBI scores and total phosphorus and nitrite concentrations.	+	A weak (r = -0.25) significant correlation exists between %embeddedness and BIBI scores. Too small a sample size for BIBI scores and turbidity measurements.	+
FIBI - within the Northern Piedmont ecoregion	A very weak (r=0.10) significant positive correlation exists between FIBI scores and nitrite concentrations. There are no other significant correlations between nutrient concentrations and FIBI scores.	0	A very weak (r = -0.10) significant correlation exists between FIBI scores and %embeddedness. FIBI scores were not significantly correlated with turbidity measurements.	0
Complete exposure pathway	Organisms are exposed directly to water column where nutrient enrichment is measured	+	Organisms are exposed directly to sediment and turbidity	+
Plausibility: stressor - response	Stressor-response thresholds have not been established for nutrient enrichment	NE	Stressor-response thresholds have not been established for sediment or turbidity	NE
Specificity of cause	Nutrient enrichment is one of many plausible and consistently associated stressors	NE	Excess sediment/turbidity is one of several plausible and consistently associated stressors	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Nutrient values at this site and in this area of the subwatershed are low.	–	Field crews noted extensive amounts of sand and silt/clay at this site. The BIBI score is less than 3.00.	+
Coherence of evidence	Nutrient enrichment does not appear to be a contributing factor to biological impairment at this site.	_	Excess sediment may be a contributing factor to impairment of the benthic macroinvertebrate community at this site.	+

Table 11-3b. BENNETT LOWER MAINSTEM. Strength of evidence for candidate causes: Habitat Degradation and Excess Ammonia Toxicity.

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
Co-occurrence				
Benthic Macroinvertebrates	This is a 4th order stream that received a score of 0 for riffle quality. Instream habitat and epifaunal substrate metrics also had scores that were less than the 25th percentile of reference. The BIBI score is 2.75.	+	The NH3 concentration at this site is 0.000. The BIBI score is 2.75.	–
Fish	This is a 4th order stream that received a score of 0 for riffle quality. Instream habitat and epifaunal substrate metrics also had scores that were less than the 25th percentile of reference. The FIBI score is 3.67.	0	The NH3 concentration at this site is 0.000. The FIBI score is 3.67.	–
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Both mainstem sites in this subwatershed had at least one habitat metric that received a very low score. Both BIBI scores were less than 3.00.	+	NH3 concentrations in this subwatershed are less than the 75th percentile of reference. The sites with NH3 concentrations >0.00 had better BIBI scores.	–
FIBI	Both mainstem sites had FIBI scores greater than 3.00. The site with the better FIBI score had better scores on the habitat metrics.	+	NH3 concentrations in the Bennett Ck watershed are consistently less than the 75th percentile of reference. There are no consistent associations between NH3 concentrations and FIBI scores.	–
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with MBSS habitat metrics.	0	BIBI scores were not significantly correlated with ammonia concentrations.	0
FIBI - within the Bennett Ck watershed	FIBI scores had positive significant correlations with 3 MBSS habitat metrics (velocity/depth diversity, pool/glide/eddy, riffle quality).	+	FIBI scores were not significantly correlated with ammonia concentrations.	0

Table 11-3b (continued). BENNETT LOWER MAINSTEM

Causal Consideration	Habitat Degradation	Score	Excess Ammonia Toxicity	Score
BIBI- within the Northern Piedmont ecoregion	Weak (r = 0.11 to 0.35) significant positive correlations exist between BIBI scores and 4 of 5 MBBS habitat metrics.	+	A very weak (r = -0.12) significant negative correlation exists between BIBI scores and ammonia concentrations.	0
FIBI - within the Northern Piedmont ecoregion	Significant positive correlations exist between FIBI scores and the 5 MBSS habitat metrics (for 4 of these, r > 0.4).	++	FIBI scores were not significantly correlated with ammonia concentrations.	0
Complete exposure pathway	Organisms are exposed directly to instream morphological habitat features and indirectly to riparian habitat features	+	Organisms are exposed directly to water column where ammonia concentration is measured	+
Plausibility: stressor - response	Not established for this study	NE	Observed levels are below reference criteria levels.	–
Specificity of cause	Poor habitat quality is one of several plausible and consistently associated stressors	NE	Ammonica toxicity is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	This site received a score of 0 for riffle quality, had low scores on 2 other metrics and had a BIBI score of less than 3.00.	+	The NH3 concentration at this site is 0.00. NH3 is consistently not a factor at sites in the Bennett Ck watershed.	–
Coherence of evidence	Habitat degradation is likely a contributing factor to impairment of the biota at this site, and appears to have a greater impact on the benthic macroinvertebrate community than on the fish community.	+	Ammonia toxicity is not a contributing factor to biological impairment at this site.	–

Table 11-3c. BENNETT LOWER MAINSTEM. Strength of evidence for candidate causes: Thermal Loading and Dissolved Oxygen Deficits.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
Co-occurrence				
Benthic Macroinvertebrates	Spring water temperature was not measured at this site.	NE	Spring DO was not measured at this site.	NE
Fish	Summer water temperature was well below the 75th percentile of reference. The FIBI score was 3.67.	–	The summer DO value was above the 25th percentile of reference (9.5 mg/l). The FIBI score was 3.67.	–
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	Lack evidence.	NE	Lack evidence.	NE
FIBI	Both mainstem sites had FIBI scores greater than 3.00. The site with the better FIBI score had a higher water temperature (greater than the 75th percentile of reference).	+	Both mainstem sites had FIBI scores greater than 3.00. Both sites had about the same DO values (9.3 & 9.5 mg/l), which are greater than the 25th percentile of reference.	–
Biological gradient				
BIBI - within the Bennett Ck watershed	BIBI scores were not significantly correlated with water temperature.	0	BIBI scores were not significantly correlated with DO measurements.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with water temperature.	0	A strong (r = 0.48) significant positive correlation exists between FIBI scores and DO measurements.	++
BIBI- within the Northern Piedmont ecoregion	Did not calculate - too small a sample size.	NE	Did not calculate - too small a sample size.	NE

Table 11-3c (continued). BENNETT LOWER MAINSTEM.

Causal Consideration	Thermal Loading	Score	Dissolved Oxygen Deficit	Score
FIBI - within the Northern Piedmont ecoregion	A weak (r = 0.2) significant positive correlation exists between FIBI scores and water temperature measurements.	–	A weak (r = 0.2) significant positive correlation exists between FIBI scores and DO measurements.	+
Complete exposure pathway	Organisms are exposed directly to water temperature	+	Organisms are exposed directly to water column where DO is measured	+
Plausibility: stressor - response	Not established	NE	Oxygen is not commonly considered limiting until it is below 4-6 mg/L. Observed values are well above 6 mg/l.	–
Specificity of cause	Thermal loading may impact certain cold water species	NE	DO deficit is not consistently associated with biological impairment. Organic enrichment is one of many plausible and consistently associated stressors.	0
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	This site had a low water temperature and a FIBI score greater than 3.00. There are no obvious or consistent associations between water temperature and FIBI scores in the Bennett Ck watershed as a whole.	–	This site has a high summer DO value and a FIBI score greater than 3.00.	–
Coherence of evidence	Water temperature can fluctuate greatly. The existing evidence for this site and for upstream sites does not indicate that thermal loading is a contributing factor to biological impairment of the fish community.	–	DO deficit does not appear to be a factor of biological impairment at this site.	–

Table 11-3d. BENNETT LOWER MAINSTEM. Strength of evidence for candidate causes: Ionic Strength and pH Imbalance.

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
Co-occurrence				
Benthic Macroinvertebrates	The spring conductivity value at this site is less than the 75th percentile of reference. The BIBI score is 2.75.	–	The spring pH value at this site is greater than the 75th percentile of reference (8.12). The BIBI score is 2.75.	+
Fish	The summer conductivity value at this site is slightly greater than the 75th percentile of reference. The FIBI score is 3.67.	–	The summer pH value at this site is within the range of reference values. The FIBI score is 3.67.	–
Temporality	No evidence	NE	No evidence	NE
Consistency of association				
BIBI	The conductivity values at this site and at the 2 closest nutrient synoptic survey sites upstream on the Bennett mainstem are less than the 75th percentile of reference, and the BIBI score at this site is 2.75. The other mainstem biological site in this subwatershed has a lower conductivity value and a lower BIBI score.	–	The pH values at this site and at the 2 closest nutrient synoptic survey sites upstream on the Bennett mainstem are greater than the 75th percentile of reference, and the BIBI score is 2.75. The other mainstem biological site in this subwatershed has a pH value within the range of the reference values and has a lower BIBI score (2.25).	–
FIBI	The conductivity value at this site is slightly greater than the 75th percentile of reference and the FIBI score is 3.67. The other mainstem site has a lower conductivity value (the lowest in the subwatershed) and a higher FIBI score (4.33).	0	pH values at this site and the other mainstem site are within the range of reference values. Both sites have FIBI scores greater than 3.00.	–
Biological gradient				
BIBI - within the Bennett Ck watershed	There is a significant negative correlation between conductivity and BIBI scores (r=-0.34).	+	BIBI scores were not significantly correlated with pH.	0
FIBI - within the Bennett Ck watershed	FIBI scores were not significantly correlated with specific conductance.	0	FIBI scores were not significantly correlated with pH.	0
BIBI- within the Northern Piedmont ecoregion	A strong (r = -0.41) significant negative correlation exists between BIBI scores and specific conductance.	++	A weak (r = -0.29) significant negative correlation exists between BIBI scores and pH.	+

Table 11-3d (continued). BENNETT LOWER MAINSTEM.

Causal Consideration	Ionic Strength	Score	pH Imbalance	Score
FIBI - within the Northern Piedmont ecoregion	A weak (r = -0.16) significant negative correlation exists between FIBI scores and specific conductance.	+	A very weak (r = 0.14) significant positive correlation exists between FIBI scores and pH.	0
Complete exposure pathway	Organisms are exposed directly to water column where conductivity and chloride are measured	+	Organisms are exposed directly to water column where pH is measured	+
Plausibility: stressor - response	Not established	NE	Not established	NE
Specificity of cause	Not applicable because ionic strength is not a plausible mechanism	NE	Not applicable because pH is not consistently associated with biological impairment	NE
Analogy	No evidence	NE	No evidence	NE
Experiment	No evidence	NE	No evidence	NE
Predictive performance	No evidence	NE	No evidence	NE
Consistency of evidence	Not very consistent and not plausible.	NE	This site had a high pH value and a BIBI score less than 3.00. Other sites with higher pH values have better BIBI scores. No consistent patterns.	–
Coherence of evidence	This measure should be used as an indicator of sources because there is no plausible mechanism for impact to the biological community.	NE	pH may be a local or temporary issue but does not appear to have consistent effects.	–

Table 11-4. A summary of the candidate causes associated with the biologically impaired sites in the Lower Bennett subwatershed, and their possible sources. ☑ indicates that the source and/or step in the causal pathway are present or likely to be present in the upstream catchment area; ☑☑ indicates that the source and/or step in the causal pathway were documented at the site.

Candidate Cause	LMON-421-T-2000
Nutrient Enrichment	
Agricultural	
Fertilizer/Manure Application	
Direct Animal Access to Streams	
Residential Developments	
Failing Septic Systems	
High Concentrations of Septic System Leach Fields	
Application of Lawn Fertilizers	
Atmospheric Deposition	
Vehicle Emissions	
Permitted Air Releases	
Soil Disturbances	
Excess Sediment/Turbidity	
Land Disturbing Activities	
Direct Animal Access to Streams	
Runoff from Impervious Surfaces	
Row Crop Agriculture	
Construction	
Natural Factors (i.e instream sources, naturally erodible soils)	☑
Drainage from pond	☑
Habitat Degradation	
Urban Land Use	
Impervious Surfaces	
Stormwater Structures	
Inadequate Riparian Buffer	☑
Bank Instability and Erosion	
Upstream Land Use	
Direct Animal Access to Streams	
Natural Factors (i.e instream sources, naturally erodible soils)	
Channel Alteration	
Ionic Strength	
Human Activities	

12 PRIORITIZATION OF SUBWATERSHEDS

12.1 Methods

Data from the stressor source inventory and the stressor identification process were used to rank subwatersheds according to restoration needs. The first step in the prioritization process was to divide the subwatersheds into different groups based on available data[6] (Table 12-1). Subwatersheds were categoried into four 'tiers.' Tier 1 subwatersheds have more than one randomly-selected biological sampling site; Tier 2 subwatersheds have only a single such biological sampling site; Tier 3, none, but do have SCA and nutrient synoptic data; Tier 4 subwatersheds have no biological, SCA or nutrient synoptic data. Non-point source pollutant loading estimates for biological oxygen demand (BOD), total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) were available for all of the subwatersheds[7].

The prioritization process was made difficult by the fact that different amounts and types of data were available for each subwatershed. Because of this, different scoring schemes had to be developed for each of the different tiers of subwatersheds. Biological data were considered to have the greatest value, so BIBI and FIBI scores were considered in addition to pollutant loading data when ranking Tier 1 and Tier 2 subwatersheds. SCA, nutrient synoptic and land use land cover data were used with pollutant loading data to rank the Tier 3 subwatersheds, and Tier 4 subwatersheds were ranked using only pollutant loading data. In one situation, best professional judgment was also used when finalizing the rankings. This was for the Little Monocacy watershed. It was moved to the lowest priority position because very few of its stream miles are located in Frederick County. Results of the ranking process can be found in Table 12-2. In addition, detailed descriptions of the steps that were followed when calculating the scores can be found in Appendix D.

[6] It should be noted that sites in Montgomery County were not considered. Targeted sites were also excluded because their site selection tends to be biased towards impaired or reference conditions.

[7] Tetra Tech developed non-point source pollutant loading estimates for Bennett Creek watershed. The USEPA Spreadsheet Tool for the Estimation of Pollutant Load (STEPL) was used to predict the pollutant load from the non-point sources. The STEPL model was used to model four pollutants: biological oxygen demand (BOD), total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS).

Table 12-1. Summary of the data available for each tier of subwatersheds (this only includes sites within the project area).

Tier	Subwatershed	# of Biological Sampling Sites		# of nutrient survey sites	SCA data	# of priority restoration sites
		Random	Targeted			
1	Monocacy Direct-North	5	2	0	no	0
	Fahrney	4	3	3	yes	6
	Bennett Ck - Lower Mainstem	4	1	3	no	0
	Bennett Ck - Upper Mainstem	3	0	3	no	0
	Bear	2	1	1	yes	1
2	Bennett Ck - Middle Mainstem	1	0	0	no	0
	Monocacy Direct-South	1	0	1	no	0
	Sugarloaf	1	0	1	no	0
3	Pleasant Branch	0	3	1	yes	10
	Urbana	0	0	1	yes	3
	North	0	0	1	yes	3
4	Furnace Branch	0	0	0	no	0
	Lilypons	0	0	1	no	0
	Little Bennett	0	0	0	no	0
	Little Monocacy River	0	0	0	no	0

12.2 Results

It is recommended that the following three subwatersheds receive the highest priority for restoration efforts: Fahrney, Bennett Creek – Upper Mainstem and Bennett Creek - Middle Mainstem (Table 12-2). These subwatersheds are located in the north, central and eastern portions of the Bennett Creek subwatershed, where there tends to be greater amounts of development and higher percent urban land use. These high priority subwatersheds also generally had higher estimated pollutant loadings. It is recommended that subwatersheds that received scores greater than 70 receive lower priority (Furnace, Bear, Little Monocacy, Lilypons, Bennett Creek – Lower Mainstem, Sugarloaf). These subwatersheds generally have lower percent urban land use and lower estimated STEPL pollutant loads. Because only a very small portion of the Little Monocacy subwatershed is located in Frederick County, it is recommended that this subwatershed receive the lowest priority of all. The six remaining subwatersheds received scores between 40 and 70. It is recommended that they receive medium priority.

Although these scores are based on actual data, the fact that there are different amounts and types of data for each subwatershed made the scoring and prioritization process difficult. If additional data can be gathered over the next several years (as resources permit) so that each subwatershed has at least some biological sampling data, then it would be easier to make comparisons across subwatersheds and there would be greater confidence in the scores. Until more data can be gathered, however, it is recommended that the current scoring scheme be used as guidance for prioritization of future restoration efforts.

Table 12-2. Subwatershed rankings, on a scale of 1 (most in need of action) to 15 (least in need to action).

Rank	Subwatershed	Score	Tier
1	Fahrney	20.9	1
2	Bennett-Upper	29.8	1
3	Bennett-Middle	30.4	2
5	Mono-South	42.0	2
4	Mono-North	42.3	1
6	Pleasant	53.2	3
8	North	63.0	3
7	Little Bennett	63.6	4
9	Urbana	67.8	3
10	Sugarloaf	71.8	2
11	Bennett-Lower	74.8	1
12	Lilypons	79.9	4
15	Little Monocacy*	81.2	4
13	Bear	81.3	1
14	Furnace	95.6	4

* Little Monocacy was moved to last using best professional judgment because it has very few stream miles in Frederick County.

13 OVERALL SUMMARY & RECOMMENDATIONS

Based on the results of the subwatershed prioritization process, it is recommended that the Fahrney, Bennett Upper and Bennett Middle subwatersheds receive the highest priority for restoration. These subwatersheds are located in areas that tend to have greater amounts of development and higher percent urban land use. Conditions of biological impairment were prevalent in the problems areas identified in these subwatersheds, as well as in the Pleasant Branch and Monocacy Direct-North subwatersheds. Agricultural lands and residential developments are the most likely stressor sources in these subwatersheds. Habitat degradation and excess sediment and turbidity were other probable causes of impairment at many of the impaired sites in these subwatersheds. Commonly cited problems identified during the SCA survey in the Fahrney and Pleasant Branch subwatersheds include inadequate buffers, erosion and direct animal access to streams. Sixteen sites within these subwatersheds were identified as priority restoration sites in the Lower Monocacy River WRAS (Frederick County DPW 2004)

Large portions of the Little Bennett, Bear Branch, Monocacy Direct-South and Furnace Branch subwatersheds are protected lands. Much of the Monocacy Direct-South and Furnace Branch subwatersheds are managed by DNR and have protections through the rural legacy program. In Montgomery County, much of the Little Bennett subwatershed is protected by the Little Bennett Regional Park. Most of the Bear Branch subwatershed and parts of the Bennett Lower Mainstem and Sugarloaf subwatersheds are located in the Stronghold Preserve.

The Sugarloaf, Bennett Middle Mainstem and Monocacy Direct-South subwatersheds each had only one biological sampling site in the project area. The Monocacy Direct-North subwatershed had the largest number of biological sampling sites in the project area, but they were unevenly distributed. Sites were also clumped in an area in the Bennett Lower Mainstem subwatershed. There is a lack of biological data in the Urbana and North subwatersheds, which is unfortunate because this area is being subjected to increased rates of land cover conversions, with agricultural and forest lands undergoing suburbanization to residential and commercial areas. In the future, it would be valuable to obtain a more even distribution of biological sampling sites in several of the subwatersheds and to establish biological sampling sites in the subwatersheds that currently lack data or have dated information (pre-2000). Perhaps this can be achieved by stratifying the probabilistic sampling design by subwatershed, and through the prioritization of subwatersheds as recommended in this report.

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Appendix A. Summary statistics for water chemistry and habitat variables taken from reference sites in the Northern Piedmont ecoregion. Reference sites were derived from the list used by Versar, Inc. during the 2005 IBI re-development (Southerland et al. 2005). If a site was sampled multiple times, only the most recent data was used. Parameter values were compared to the reference condition values designated in bold type.

Chem_Spring	Valid N	Mean	Median	Min	Max	Lower Quartile	Upper Quartile	5th Percentile	95th Percentile	Std.Dev.
pH (std units)	51	7.41	7.34	6.37	8.75	**7.06**	**7.61**	6.63	8.39	0.49
Specific Conduct (mS/cm)	51	0.183	0.146	0.082	1.159	0.124	**0.178**	0.090	0.403	0.156
DOC (mg/L)	51	1.80	1.60	0.44	5.92	1.10	**2.23**	0.69	4.00	1.03
SO4 (mg/L)	51	8.47	7.17	2.86	23.07	5.68	**9.81**	3.85	16.14	4.17
NH3 (mg/L)	25	0.018	0.009	0.000	0.107	0.005	**0.019**	0.002	0.063	0.023
NO3 (mg/L)	51	2.06	2.11	0.80	3.71	1.36	**2.71**	0.94	3.28	0.80
NO2 (mg/L)	25	0.005	0.004	0.000	0.017	0.001	**0.008**	0.000	0.013	0.004
TN (mg/L)	25	2.24	2.15	1.06	3.90	1.34	**2.82**	1.14	3.80	0.87
TP (mg/L)	25	0.020	0.014	0.006	0.066	0.009	**0.026**	0.006	0.049	0.015
O_PHOS (mg/L)	25	0.006	0.003	0.000	0.044	0.001	**0.005**	0.001	0.015	0.009
Chem_Summer										
Water Temp (°C)	51	18.70	19.00	12.90	23.30	16.60	**20.50**	13.40	22.90	2.64
DO (mg/L)	51	8.82	8.80	5.30	12.60	**8.20**	9.30	7.60	10.60	1.15
pH (std units)	51	7.36	7.37	5.97	8.63	**7.03**	**7.57**	6.52	8.47	0.56
Specific Conduct (mS/cm)	51	0.179	0.150	0.071	0.851	0.122	**0.192**	0.099	0.302	0.122
Turbidity (NTU)	25	2.84	1.70	0.20	13.00	1.10	**3.50**	0.80	9.80	2.91
Habitat										
Instream Habitat	51	15.6	16.0	11.0	19.0	**14.0**	17.0	12.0	19.0	2.1
Epifaunal Substrate	51	14.9	16.0	4.0	19.0	**14.0**	17.0	8.0	18.0	3.3
Velocity/Depth Diversity	51	12.7	13.0	7.0	18.0	**10.0**	16.0	8.0	18.0	3.3
Pool/Glide/Eddy Quality	51	13.7	14.0	6.0	20.0	**10.0**	16.0	9.0	19.0	3.4
Riffle Quality	51	13.5	15.0	0.0	19.0	**12.0**	16.0	7.0	19.0	4.1
Embeddedness	51	30.9	25.0	10.0	90.0	20.0	**40.0**	10.0	70.0	19.0
Shading	51	81.4	80.0	50.0	99.0	**70.0**	94.0	60.0	95.0	12.6
Channel Alt	26	11.8	12.0	4.0	18.0	**10.0**	15.0	6.0	17.0	3.7
Bank Stability	26	10.8	10.0	4.0	18.0	**8.0**	15.0	5.0	17.0	3.9

Appendix B. Data set used for the Bennett Creek correlation analysis (BIBI and water chemistry)

Site	BIBI_05	pH	Conduct	ANC	DOC	SO4	NH3	NO3	NO2	NO2+ NO3	TN	TKN	TP	O_Phos	Chlor	Temp	DO	Turb
FR-P-101-233-96	1.75	7.37	0.168	516.4	2.8	10.72		4.280										
BENN-06-2006	2.75	7.6	0.180													11.8	11.4	7.0
BENN06P2007	3.00	5.8	0.484													9.0	13.5	8.0
FR-P-351-112-96	3.00	7.05	0.145	467.5	1.9	8.62		3.540										
BENN-04-2005	3.25	7.96	0.164													15.2	8.3	9.5
BENN03-2007	2.50	8.18	0.258		1.3853		0.010	8.950	0.018	8.968	10.866	1.897	0.026	0.006		12.5	10.4	
BENN-03-2005	2.75	7.97	0.154													12.0	10.4	8.2
BENN25-2007	1.75	8.7	0.198		1.6475		0.012	7.997	0.004	8.001	9.840	1.839	0.012	0.001		11.6		
LMON-421-T-2000	2.75	8.12	0.171	705.3	1.265	8.661	0.000	1.815	0.000		2.149		0.009	0.001	21.04			
BENN06-2007	4.00	6.45	0.063		0.2410		0.003	0.005	0.002	0.007	0.129	0.123	0.031	0.003		11.6	9.6	16.1
BENN08-2007	3.00	8.69	0.057		1.8207		0.004	0.037	0.002	0.039	0.124	0.085	0.006	0.001		12.6	11	1.8
LMON-130-T-2000	3.75	5.87	0.223	43.9	2.097	3.027	0.000	0.000	0.000		0.086		0.004	0.000	1.62			
BENN29-2007	4.25	6.78	0.067		2.5641		0.004	0.066	0.002	0.068	0.220	0.152	0.011	0.003		12.0	9.2	5.6
BENN27-2007	4.25	8.3	0.072		2.08		0.007	0.088	0.002	0.089	0.215	0.125	0.017	0.009		16.2	9.7	8.6
BENN32-2007	4.00	7.12	0.053		2.45		0.008	0.075	0.002	0.077	0.249	0.172	0.017	0.003		14.9	9.4	13.5
BENN13-2007	3.25	8.02	0.042		2.83		0.008	0.050	0.002	0.052	0.468	0.415	0.029	0.002		14.4	8.4	36.0
FR-P-015-304-96	2.25	7.13	0.153	445.8	1.40	7.49		3.710										
BENN17-2007	3.00	8.34	0.278		2.04		0.020	3.120	0.012	3.132	3.471	0.339	0.033	0.013		13.8	10.8	18.6
NCRW-115-N-2004	2.00	7.56	0.311	648.2	1.45	12.61	0.011	3.610	0.006		3.698		0.031	0.020	45.83			
BENN18-2007	3.25	7.59	0.270		1.77		0.012	3.323	0.010	3.333	3.563	0.230	0.022	0.011		13.7	9.9	4.1
MONY-102-N-2004	2.50	7.65	0.306	644.8	1.43	12.60	0.011	3.582	0.006		3.696		0.028	0.021	46.66			
BENN30-2007	1.50	8.02	0.306		1.74		0.013	4.609	0.009	4.618	4.853	0.236	0.034	0.025		13.5	9.7	18.5
BENN33-2007	3.75	7.3	0.281		1.34		0.006	4.106	0.004	4.110	4.382	0.273	0.013	0.006		13.0	11.1	4.2
BENN01-2007	3.25	7.24	0.229		1.79		0.010	3.938	0.011	3.948	4.212	0.263	0.015	0.004		13.0	10.7	4.1
LMON-210-R-2003	2.25	7.49	0.086	356.9	1.84	7.88	0.002	2.068	0.003		2.153		0.014	0.005	5.81			
BENN15-2007	4.00	6.95	0.088		0.68		0.007	1.684	0.002	1.685	1.794	0.108	0.019	0.013		12.0	9.6	11.2
MO-P-495-312-96	2.25	7.35	0.140	454.9	1.20	7.18		2.610										
LMON-322-R-2003	3.25	8.27	0.162	357.7	1.10	7.79	0.002	2.560	0.005		2.789		0.010	0.004	25.56			
MO-P-111-136-96	2.75	6.7	0.767	100.2	1.20	8.27		0.850										
LMON-119-R-2003	3.00	6.61	0.071	85.1	0.92	7.48	0.003	0.823	0.000		0.930		0.005	0.001	10.79			

(continued… BIBI and water chemistry)

Site	BIBI_05	pH	Conduct	ANC	DOC	SO4	NH3	NO3	NO2	NO2+NO3	TN	TKN	TP	O_PHOS	Chloride	Temp	DO	Turb
LMON-215-R-2003	2.75	8.39	0.202	396.4	1.06	7.56	0.002	3.181	0.004		3.412		0.008	0.003	35.73			
LMON-240-T-2000	3.50	7.53	0.180	486.4	1.74	7.08	0.000	3.207	0.000		3.464		0.009	0.003	25.59			
BENN05-2006	3.00	8.41	0.247													14.4	11.8	12.2
BENN05P2007	2.75	6.71	0.505													10.4	13.7	4.0
BENN-01-2004	4.00	7.68	0.173													14.7		
BENN-02-2004	2.75	7.67	0.150													13.8		
BENN11-2007	3.00	7.15	0.180		0.32		0.002	6.311	0.002	6.314	7.591	1.278	0.018	0.001		11.8	10.2	18.4
BCBC314	2.50	7.37	0.140													11.0		
FR-P-377-242-96	1.25	7.17	0.125	264.3	1.70	7.22		3.030									12.18	
BCBC211	3.75	6.63	0.094													11.0	11.4	
BCBC210	2.00	7.55	0.165													9.0	12.52	
BCBC401	1.25	7.23	0.150													8.0	11.86	
BCBC308	1.25	6.39	0.209													15.0	10.48	
BCBC306	3.50	6.88	0.133													13.6	10.79	
BCBC305	2.25	6.84	0.130													13.3	13.29	
BCBC301	3.75	7.71	0.130													9.0		
MO-P-248-125-96	3.25	7.21	0.218	293.2	0.90	8.81		2.260										
LMON-131-R-2003	3.25	7.34	0.226	297.2	0.87	8.94	0.003	2.431	0.000		2.620		0.005	0.001	46.38			
PRMO-114-R-2002	3.25	6.72	0.084	258.4	1.60	6.02	0.007	0.687	0.001	0.688	0.736		0.009	0.004	8.18			
PRMO-115-R-2002	4.25	6.91	0.082	265.2	1.56	5.89	0.006	0.695	0.002	0.697	0.725		0.006	0.004	8.12			
PRMO-120-R-2002	2.25	7.61	0.430	1322.5	3.38	50.76	0.009	1.601	0.003	1.604	1.662		0.051	0.035	45.53			
PRMO-304-R-2002	3.75	7.51	0.147	636.7	1.88	7.33	0.014	1.836	0.006	1.842	1.923		0.014	0.004	13.96			
PRMO-307-R-2002	3.25	7.6	0.177	650.5	3.59	10.12	0.015	1.948	0.012	1.960	1.990		0.022	0.004	18.99			
PRMO-311-R-2002	3.00	7.78	0.175	669.4	3.19	11.02	0.010	1.907	0.012	1.919	1.963		0.023	0.004	19.10			
PRMO-323-R-2002	2.75	7.44	0.156	628.2	1.85	7.32	0.012	1.818	0.005	1.823	1.891		0.015	0.003	13.89			
MO-P-064-328-97	2.00	7.28	0.1422	608.8	4	9.81		1.83										
MO-P-251-115-97	3.75	6.93	0.092	385.7	3.1	5.61		1.51										

Data set used for the Bennett Creek correlation analysis (FIBI and water chemistry).

Site	FIBI_05	pH	Cond	Temp	DO	ANC	DOC	SO4	NH3	NO3	NO2	NO2+ NO3	TN	TP	O_Phos	Chlor
FR-P-101-233-96	4.00	7.34	0.152	21.3	9.9	516.4	2.80	10.72		4.280						
BENN-06-2006	4.00	7.74	0.183	15.1	11.1											
FR-P-351-112-96	3.67	6.91	0.162	18.2	7.5	467.5	1.90	8.62		3.540						
BENN-04-2005	3.67	7.40	0.178	21.2	7.3											
BENN-03-2005	3.67	6.94	0.178	20.8	9.4											
LMON-421-T-2000	3.67	7.06	0.196	13.8	9.5	705.3	1.27	8.66	0.000	1.815	0.000		2.149	0.009	0.001	21.04
FR-P-015-304-96	4.33	7.35	0.144	22.3	9.3	445.8	1.40	7.49		3.710						
NCRW-115-N-2004	2.67	7.51	0.280	19.3	7.5	648.2	1.45	12.61	0.011	3.610	0.006		3.698	0.031	0.020	45.83
MONY-102-N-2004	1.67	7.55	0.270	19.3	7.8	644.8	1.43	12.60	0.011	3.582	0.006		3.696	0.028	0.021	46.66
LMON-210-R-2003	4.33	6.95	0.093	17.2	9.1	356.9	1.84	7.88	0.002	2.068	0.003		2.153	0.014	0.005	5.81
MO-P-495-312-96	4.67	7.12	0.130	18.5	9.7	454.9	1.20	7.18		2.610						
LMON-322-R-2003	4.00	7.41	0.163	20.6	8.8	357.7	1.10	7.79	0.002	2.560	0.005		2.789	0.010	0.004	25.56
MO-P-111-136-96	2.00	7.23	0.082	16.8	7.7	100.2	1.20	8.27		0.850						
LMON-119-R-2003	1.33	6.45	0.078	15.9	8.0	85.1	0.92	7.48	0.003	0.823	0.000		0.930	0.005	0.001	10.79
LMON-215-R-2003	3.00	6.91	0.188	18.6	8.8	396.4	1.06	7.56	0.002	3.181	0.004		3.412	0.008	0.003	35.73
LMON-240-T-2000	3.00	7.62	0.222	20.0	8.6	486.4	1.74	7.08	0.000	3.207	0.000		3.464	0.009	0.003	25.59
BENN05-2006	3.67	7.83	0.303	22.4	10.9											
BENN-01-2004	4.67	6.96	0.177	16.5	9.5											
BENN-02-2004	4.33	7.29	0.158	16.5	10.2											
BCBC314	4.33	7.90	0.148	17.9	8.4											
FR-P-377-242-96	4.00	8.30	0.130	14.3	9.2	264.3	1.70	7.22		3.030						
BCBC211	3.33	6.78	0.088	17.5	8.9											
BCBC210	4.00	7.70	0.162	19.4	8.7											
BCBC401	3.67	7.73	0.160	19.9	7.2											
BCBC308	3.00	6.72	0.146	18.4	8.7											
BCBC306	3.00	7.30	0.140	17.1	7.6											
BCBC305	4.00	7.10	0.114	17.3	9.2											
BCBC301	3.67	7.30	0.141	18.9	8.3											
MO-P-248-125-96	4.00	7.19	0.174	12.9	9.2	293.2	0.90	8.81		2.260						
LMON-131-R-2003	3.00	7.17	0.200	17.2	8.7	297.2	0.87	8.94	0.003	2.431	0.000		2.620	0.005	0.001	46.38
PRMO-114-R-2002	3.00	6.76	0.077	20.4	8.5	258.4	1.60	6.02	0.007	0.687	0.001	0.688	0.736	0.009	0.004	8.18
PRMO-115-R-2002	3.00	6.76	0.077	20.4	8.5	265.2	1.56	5.89	0.006	0.695	0.002	0.697	0.725	0.006	0.004	8.12
PRMO-120-R-2002	2.67	7.43	0.404	19.5	8.8	1322.5	3.38	50.76	0.009	1.601	0.003	1.604	1.662	0.051	0.035	45.53
PRMO-304-R-2002	4.00	7.12	0.132	20.9	7.1	636.7	1.88	7.33	0.014	1.836	0.006	1.842	1.923	0.014	0.004	13.96
PRMO-307-R-2002	4.00	7.11	0.173	20.5	8.4	650.5	3.59	10.12	0.015	1.948	0.012	1.960	1.990	0.022	0.004	18.99
PRMO-311-R-2002	4.33	7.25	0.175	19.2	8.4	669.4	3.19	11.02	0.010	1.907	0.012	1.919	1.963	0.023	0.004	19.10

(continued… FIBI and water chemistry)

Site	FIBI_05	pH	Cond	Temp	DO	ANC	DOC	SO4	NH3	NO3	NO2	NO2+ NO3	TN	TP	O_Phos	Chlor
PRMO-323-R-2002	4.33	7.67	0.138	20.0	9.9	628.2	1.85	7.32	0.012	1.818	0.005	1.823	1.891	0.015	0.003	13.89
MO-P-064-328-97	4.33	7.3	0.125	20	8.9	608.8	4	9.81		1.83						
MO-P-251-115-97	2.67	6.7	0.07	18	7.9	385.7	3.1	5.61		1.51						

Data set used for the Bennett Creek correlation analysis (BIBI and FIBI and habitat).

Site	BIBI_05	FIBI_05	InstrHab	EpiSub	Velocity	PoolQual	RiffleQual	Embed	Shading	Wood Inst	Wood Dewa	RootInst	RootDewa	ErodEX
FR-P-101-233-96	1.75	4.00	13	15	14	11	18	30	35					
BENN-06-2006	2.75	4.00	18	16	10	9	14	40	60					
BENN06P2007	3.00													
FR-P-351-112-96	3.00	3.67	15	13	11	17	6	80	75					
BENN-04-2005	3.25	3.67	15	8	17	17	18	70	35	4	1	0	3	36.5
BENN03-2007	2.50		16	13	7	7	12	40	40	3	6	3	4	29
BENN-03-2005	2.75	3.67	14	13	14	13	15	60	85	3	5	6	1	32
BENN25-2007	1.75		7	2	6	2	6	100	85	3	10	0	4	0
LMON-421-T-2000	2.75	3.67	13	11	10	20	0	30	65	4	2	5	7	70
BENN06-2007	4.00		9	4	6	4	9	85	75	9	10	6	7	0
BENN08-2007	3.00		18	13	9	9	14	40	85	4	22	8	8	
LMON-130-T-2000	3.75		8	13	7	3	6	40	95	3	12	2	3	0
BENN29-2007	4.25		17	14	8	8	13	50	60	2	6	4	6	13
BENN27-2007	4.25		17	12	7	7	10	40	80	2	8	0	13	23.5
BENN32-2007	4.00		17	13	7	5	8	50	90	5	24	0	6	29.5
BENN13-2007	3.25		11	8	6	3	6	50	80	3	14	0	4	24.5
FR-P-015-304-96	2.25	4.33	15	15	18	19	14	20	45					
BENN17-2007	3.00		7	7	13	11	9	50	40	1	6	1	12	73.5
NCRW-115-N-2004	2.00	2.67	14	8	11	15	9	40	90	1	3	4	3	63
BENN18-2007	3.25		12	13	13	11	12	45	60	7	13	7	12	63.5
MONY-102-N-2004	2.50	1.67	9	10	7	8	7	41	88	2	8	7	4	20.5
BENN30-2007	1.50		7	5	7	5	7	75	20	1	4	1	6	51
BENN33-2007	3.75		17	14	14	14	14	50	80	0	4	3	9	40.5
BENN01-2007	3.25		12	10	8	8	10	50	70	0	10	2	9	45
LMON-210-R-2003	2.25	4.33	12	10	11	11	16	35	95	0	4	2	7	7.5
BENN15-2007	4.00		14	13	8	9	11	75	50	4	3	4	6	23.5

(continued… BIBI and FIBI and habitat)

Site	BIBI_05	FIBI_05	InstrHab	EpiSub	Velocity	PoolQual	RiffleQual	Embed	Shading	Wood Inst	Wood Dewa	RootInst	RootDewa	ErodEX
MO-P-495-312-96	2.25	4.67	13	18	18	15	17	5	90					
LMON-322-R-2003	3.25	4.00	16	16	17	17	16	20	90	1	0	5	3	41.5
MO-P-111-136-96	2.75	2.00	12	14	12	11	8	35	80					
LMON-119-R-2003	3.00	1.33	14	12	10	10	13	40	95	4	7	2	8	11
LMON-215-R-2003	2.75	3.00	17	17	17	18	18	20	80	10	5	2	4	22
LMON-240-T-2000	3.50	3.00	9	8	11	12	12	25	45	5	17	2	1	49
BENN05-2006	3.00	3.67	11	7	9	10	9	50	10	2	14	1	0	
BENN05P2007	2.75		10	7	7	8	8	50	20	7	16	1	0	
BENN-01-2004	4.00	4.67	15	13	10	9	14	35	70	1	1	2	3	26
BENN-02-2004	2.75	4.33	15	12	10	8	13	35	80	0	2	1	3	32
BENN11-2007	3.00		9	8	8	7	7	80	65	3	3	2	8	45.5
BCBC314	2.50	4.33	15	16										
FR-P-377-242-96	1.25	4.00	14	12	16	15	13	31	60					
BCBC211	3.75	3.33	17	14										
BCBC210	2.00	4.00	15	15										
BCBC401	1.25	3.67	13	13										
BCBC308	1.25	3.00	15	17										
BCBC306	3.50	3.00	9	17										
BCBC305	2.25	4.00	14	16										
BCBC301	3.75	3.67	18	16										
MO-P-248-125-96	3.25	4.00	12	14	12	12	14	35	78					
LMON-131-R-2003	3.25	3.00	8	13	10	8	15	35	96	0	3	1	10	34.5
PRMO-114-R-2002	3.25	3.00	16	15	8	10	12	20	90	3	2	2	4	16
PRMO-115-R-2002	4.25	3.00	16	16	7	10	12	25	98	1	2	0	3	23
PRMO-120-R-2002	2.25	2.67	10	11	8	8	7	35	92	0	4	0	11	17.5
PRMO-304-R-2002	3.75	4.00	16	13	14	17	13	25	85	8	3	1	5	29
PRMO-307-R-2002	3.25	4.00	14	16	13	13	15	20	70	1	6	1	7	30
PRMO-311-R-2002	3.00	4.33	17	16	15	15	15	30	84	2	12	3	8	11
PRMO-323-R-2002	2.75	4.33	16	14	14	15	15	40	35	2	0	1	4	10
MO-P-064-328-97	2.00	4.33	14	16	12	16	12	25	70					
MO-P-251-115-97	3.75	2.67	12	12	7	5	7	35	95					

Appendix C. Descriptions of sewer codes.

Type	Description
US	Service beyond 20 years
S-1	Areas served by community and multi-use water and sewerage systems which are either existing or under construction
S-1 DEV	Areas served by community and multi-use water and sewerage systems which are either existing or under construction. Developer responsible for providing service.
S-3	Areas where improvements to, or construction of new community and multi-use water supply and sewerage systems will be given immediate priority. Construction scheduled to start within 3 years
S-3 DEV	Areas where improvements to, or construction of new community and multi-use water supply and sewerage systems will be given immediate priority. Construction scheduled to start within 3 years. Developer responsible for providing service.
S-4	Areas where improvements to, or construction of new community and multi-use water supply and sewerage systems will be programmed for 4 to 6 years.
S-4 DEV	Areas where improvements to, or construction of new community and multi-use water supply and sewerage systems will be programmed for 4 to 6 years. Developer responsible for providing service.
S-5	Areas where service by community systems is desirable, but implementation is expected to be at least 7 to 20 years.
S-5 DEV	Areas where service by community systems is desirable, but implementation is expected to be at least 7 to 20 years. Developer responsible for providing service.
NPS	No Planned Service

Appendix D. Summary of the process that was used to prioritize subwatersheds.

Calculation of pollutant loading scores. Avg_Score equals the average of the BOD, TN, TP and TSS scores. Scores were calculated for BOD, TN, TP and TSS loadings (lb/ac/yr) using the following formula: 100*(max-value)/(max-min).With this scoring scale, scores range from 0 (worst=highest TN concentration) to 100 (best=lowest TN concentration).

Catchment	Avg_Score	BOD	BOD_Score	TN	TN_Score	TP	TP_Score	TSS	TSS_Score
Fahrney	***0.0***	200.9	***0.0***	103.0	***0.0***	18.2	***0.0***	13972.3	***0.0***
Bennett-Upper	***26.7***	155.5	***23.1***	82.1	***20.8***	13.1	***28.9***	9338.4	***33.9***
Mono-North	***29.4***	116.0	***43.2***	73.7	***29.1***	13.1	***28.7***	11699.5	***16.6***
Bennett-Middle	***29.6***	137.7	***32.2***	73.7	***29.1***	12.2	***33.8***	10779.8	***23.4***
Mono-South	***52.7***	87.1	***57.9***	45.8	***56.8***	9.4	***49.9***	7659.9	***46.2***
Little Bennett	***63.6***	80.9	***61.0***	41.3	***61.3***	6.7	***65.3***	4834.1	***66.9***
Sugarloaf	***68.6***	63.9	***69.7***	35.9	***66.7***	5.7	***70.9***	4771.6	***67.3***
North	***75.1***	59.5	***72.0***	28.3	***74.3***	4.6	***77.0***	3406.5	***77.3***
Bennett-Lower	***77.4***	53.5	***75.0***	25.1	***77.4***	4.4	***78.2***	3163.2	***79.1***
Lilypons	***79.9***	47.7	***78.0***	22.7	***79.8***	3.9	***80.8***	2891.0	***81.1***
Urbana	***80.0***	47.2	***78.2***	23.4	***79.1***	3.9	***80.8***	2796.4	***81.8***
Little Monocacy	***81.2***	41.0	***81.3***	22.9	***79.6***	3.5	***83.2***	2957.5	***80.6***
Pleasant	***84.6***	46.4	***78.6***	19.3	***83.2***	3.0	***86.1***	1605.8	***90.5***
Furnace	***95.6***	11.4	***96.4***	6.8	***95.7***	1.3	***95.6***	1003.2	***94.9***
Bear	***100.0***	4.3	***100.0***	2.4	***100.0***	0.5	***100.0***	301.5	***100.0***
MAX		**200.9**		**103.0**		**18.2**		**13972.3**	
MIN		**4.3**		**2.4**		**0.5**		**301.5**	

Tier 1. Rankings for Tier 1 subwatersheds were calculated by:

1. Averaging the IBI scores from the randomly-selected biological sampling sites and converting them to a scale of 0 (worst) to 100 (best). If both BIBI and FIBI scores were available, the lowest score was used. The formula for converting to a scale of 0 to 100 = **(IBI score – 1) * 25.**

Subwatershed	Score	BIBI					FIBI				
		N	Mean	St Dev	Min	Max	N	Mean	St Dev	Min	Max
Fahrney	31.25	4	**2.25**	0.61	1.75	3	2	3.84	0.23	3.67	4
Bennett Ck - Upper	31.25	3	**2.25**	0.9	1.25	3	2	4.17	0.23	4	4.33
Monocacy Direct-North	48.75	5	**2.95**	0.86	1.5	3.75	0				
Bear	62.5	2	**3.5**	0.71	3	4	0				
Bennett Ck - Lower	73.5	4	**3.94**	0.47	3.25	4.25	0				

2. Since we feel that the biological data provides the most valuable information, we gave biological scores twice the weight in subwatersheds that had more than 2 randomly-selected biological sampling sites (note that Bear Branch only has 2 randomly selected biological sampling sites; therefore its biological scores were not given twice the weight). See the table below for the final Tier 1 scores.

Subwatershed	Bio Score	Bio Score	Pollutant Score	Final (=average) Score
Fahrney	31.3	31.3	0	**20.9**
Bennett Ck - Upper	31.3	31.3	26.7	**29.8**
Monocacy Direct-North	48.8	48.8	29.4	**42.3**
Bear	62.5		100	**81.3**
Bennett Ck - Lower	73.5	73.5	77.4	**74.8**

Tier 2. Rankings for Tier 2 subwatersheds were calculated by:

1. Converting the IBI score from the single randomly-selected biological sampling site to a scale of 0 (worst) to 100 (best). If both BIBI and FIBI scores were available, the lowest score was used. The formula for converting to a scale of 0 to 100 **= (IBI score – 1) * 25.**

Subwatershed	Score	BIBI	FIBI
Bennett Ck - Middle Mainstem	31.25	**2.25**	4.33
Monocacy Direct-South	31.25	**2.25**	4.33
Sugarloaf	75	**4**	

2. Averaging the biological score with the pollutant loading score. Results are shown in the table below.

Subwatershed	Bio Score	Pollutant Score	Final (=average) Score
Bennett Ck - Middle Mainstem	31.25	29.6	**30.4**
Monocacy Direct-South	31.25	52.7	**42.0**
Sugarloaf	75	68.6	**71.8**

Tier 3. Tier 3 rankings were calculated as follows:

1. The first score was calculated based on four criteria: 1) percent stream miles walked with erosion problems; 2) percent stream miles walked with inadequate buffers; 3) nutrient synoptic concentrations for nitrogen (NO2 + NO3); and 4) % forested. Calculations for these four criteria are shown below.

1. Percent stream miles walked with erosion problems (SCA)

Subwatershed	**Stream miles walked**	**Estimated length (miles) erosion sites**	**% Eroded**
Pleasant	5.76	2.73	47.40
Urbana	4.49	2.88	64.14
North	3.76	1.65	43.88

2. Percent stream miles walked with inadequate buffers (SCA)

Subwatershed	**Stream miles walked**	**Estimated length (miles) inadequate buffers**	**% Inadequate buffers**
Pleasant	5.76	1.42	24.65
Urbana	4.49	1.24	27.62
North	3.76	1.50	39.89

3. Nutrient synoptic concentrations for nitrogen (NO2 + NO3)

Subwatershed	**NO2 + NO3 (mg/L)**		
	Value (mg/L)	Log	Score
Pleasant	4.86	0.6866	0.00
Urbana	1.89	0.2765	100.00
North	1.99	0.2989	94.54
MIN	**1.89**	**0.2765**	
MAX	**4.86**	**0.6866**	

Formula for ranking = 100*(MAX-LogValue)/(MAX-MIN)

This scores the values on a scale from 0 (worst=highest nitrogen concentration) to 100 (best=lowest nitrogen concentration).

4. % Forested (based on 2002 LULC GIS file)

Subwatershed	% Forested
Pleasant	15
North	25
Urbana	31

Formula for final score =
(% Eroded + % Inadequate buffers + NO2+NO3 score + % forested)/4

FIRST RANKING SCORE FOR TIER 3 SUBWATERSHEDS:

Rank	Subwatershed	% Eroded	% Inad buffer	NO2-NO3 Score	% Forested	Mean Score
1	Pleasant	47.4	24.6	0.0	15	**21.76**
2	North	43.9	39.9	94.5	25	**50.83**
3	Urbana	64.1	27.6	100.0	31	**55.69**

2. Averaging the SCA/nutrient synoptic/land use score with the pollutant loading score. Results are shown in the table below.

Subwatershed	First Score	Pollutant Score	Final (=average) Score
Pleasant	21.8	84.6	53.2
North	50.8	75.1	63.0
Urbana	55.7	80.0	67.8

Tier 4. Tier 4 rankings were based only on pollutant loading scores:

Subwatershed	Pollutant Score
Furnace Branch	95.6
Lilypons	79.9
Little Bennett	63.6
Little Monocacy River	81.2