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Gregory Busch, Manager

# IMPACTS CAUSED BY GROUNDWATER WITHDRAWALS ON STREAMFLOW, FISHERIES COMMUNITIES AND AQUATIC HABITAT IN THE WESTERN PIEDMONT AND BLUE RIDGE PROVINCES OF MARYLAND

by

Patrick A. Hammond

**2022**

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## CONVERSION FACTORS AND SYMBOLS

| Multiply | by | to obtain |
| --- | --- | --- |
| *Length* | | |
| inch (in) | 2.54 | centimeter (cm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| *Area* | | |
| square foot ($ft^2$) | 0.0929 | square meter ($m^2$) |
| square mile ($mi^2$) | 2.59 | square kilometer ($km^2$) |
| *Volume* | | |
| gallon (gal) | 3.785 | liter (l) |
| *Discharge Rate* | | |
| gallon per minute (gpm) | 3.785 | liter per minute (l/min) |
| *Production Rate* | | |
| gallon per day (gpd) | $3.785 \times 10^{-3}$ | cubic meter per day ($m^3$/d) |
| *Transmissivity* | | |
| gallon per day per foot (gal/d-ft) | 0.0124 | square meter per day ($m^2$/d) |

Annual average use gallons per day = gallons per day average (gpd avg)
Use during the month of maximum use =-gallons per day maximum (gpd max)

Use of notation: As close as possible, the original scientific or mathematical notations of any papers discussed have been retained, in case a reader wishes to review those studies

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## KEY RESULTS

Much of the literature concerning the effects of water withdrawals on stream flow, fisheries communities and aquatic habitat are studies relating operational aspects of reservoirs and dams to impacts on downstream ecological flows.

Most of the evidence for impacts on aquatic resources due to groundwater withdrawals is based on studies of the High Plains aquifer, where demand for irrigation water in Kansas and Nebraska may vary from as low as twice the average annual recharge to as much as more than 100 times the recharge., and the withdrawal rate from the High Plains aquifer in Colorado and New Mexico during 1980 was nearly eight times the natural recharge to the aquifer. The Maryland water balance policy effectively limits withdrawals to about ½ of the available annual average effective recharge in a watershed and only a few headwater streams in the State have approached that level. The lower Flint River basin of southwest Georgia has also been extensively studied. One investigation indicated that withdrawals within the 1290 $mi^2$ basin were 197 Mgd avg during a drought year, with a long-term average of 94 Mgd avg. By comparison, the primary watershed in the present study (Monocacy River in Maryland) has a drainage area of about 960 $mi^2$, with water use permits of less than a total of 20 Mgd avg. This information suggests that the High Plains and Floridan aquifer analogies are not applicable to groundwater withdrawals in the fractured rock areas of Maryland.

Statistical studies in the Georgia Piedmont and glaciated Connecticut terrane are more analogous to the Maryland fractured rock areas. For withdrawals by simple intakes (no reservoir) or from groundwater in the Georgia Piedmont, there was no significant difference between fisheries communities and aquatic habitat relative to the reference streams. In terms of drought recovery, there was a rapid recolonization of new taxa following the onset of surface flow, stabilizing about 165 days after rewetting. The authors of the Connecticut study indicated that those streams had species-poor habitats due to highly altered landscapes, not water withdrawals.

The present study was initiated due to the relatively few detailed site-specific investigations in the literature. The sites chosen for case studies were based on combinations of conditions observed during the major drought of 1998-2002, extensive amounts of aquifer testing, water level monitoring, interference impacts to domestic wells, or biological assessments completed in the watersheds of interest.

During the drought of 2002, Hollow Creek at US Route 40 was “bone dry”. Immediately upstream, Middletown’s primarily water supply is groundwater taken from a well field. The amount withdrawn from the municipal wells was approximately equal to the calculated base flow in the stream. A MBSS survey conducted in 2010 indicated that the stream was unimpaired under the then dry, but non-drought conditions.

Only 10 gpm was flowing below the Myersville reservoir under dry conditions during August 1997. After installation of a low-flow maintenance device, the MBSS data collected under average conditions during 2012 in Little Catoctin Creek immediately downstream of the reservoir indicated that stream was not impaired. Although the Myersville WTP well had caused nearby domestic wells to go dry, it is unlikely that the town's groundwater withdrawals have impacted the watershed, since the average use of 0.2 cfs is small relative to the size of the drainage area (7.3 $mi^2$) and estimated average baseflow (6.1 cfs) in the basin. Although an investigation of the effects of withdrawals of Westminster's well 8 (Votech well) indicated that there were no impacts to the domestic wells in the Maplecrest Subdivision, the MBSS data sampling immediately downstream of the municipal well was reviewed for potential impacts. The FIBI/BIBI scores from those samples indicated that the condition of the fish community and aquatic habitat were fair to good; however, the survey was completed during the very wet year of 2003.

At the end of the 2002 drought about 20 gpm was flowing in Linganore Creek, just upstream of the confluence of Linganore Creek and Dollyhyde Creek. Just below the confluence the flow was 160 gpm, the increase in flow due to discharge from Dollyhyde Creek. By comparison, the flow out of the much smaller upstream Woodville Branch tributary was about 50 gpm. At that time, Mount Airy was pumping about 290 gpm out of the basin, indicating that the spring-fed Woodville Branch tributary was a major source of water to Linganore Creek during low flow periods.

The BIBI results in Linganore Creek indicate that 16 of the 27 sites were impaired. The most common feature within those watersheds was agricultural activity. The FIBI scores indicate that only 4 sites were impaired, all with D.A. < 0.5 $mi^2$. Also, sampling at 19 of 28 sites occurred during the very wet years of 1996 and 2003, only 2 sites were sampled during a dry year (2010), and none were sampled during a drought. This would indicate that flow was a primary factor in the overall fair to good FIBI scores and it appears to have had limited effect on the BIBI scores.

Sites X and Y, immediately downstream of the Mount Airy well field, were effectively unimpaired. The most downstream site (W) in the Woodville Branch basin did have an impaired BIBI of 1, but the flows (2.15 cfsm), FIBI (4.67) and PHI (95.9) indicate optimum physical conditions existed on the sample date. It is likely that the BIBI impairment at that site was due to elevated nitrate-nitrogen ($NO_3$-N) levels from nearby farming activity.

Horsepen Branch flows south of Poolesville. Erosion is present on large parts of the channel due to downcutting and a lack of an adequate buffer to provide bank stabilization. Much of the watershed tends to dry up almost completely in the summer, likely due to the drought-sensitive underlying consolidated sedimentary rock geology. Except for site A, in the upper portion of the basin, the effects of water withdrawals and urban development were likely not significant. It is possible that backwater from Potomac River flooding and the resulting erosion and sedimentation caused the degraded habitat in the lower portion of the watershed.

The Broad Run watershed begins west of the Town of Poolesville. Land use has historically been agricultural, and a forested stream buffer provides protection along many stretches of the creek. All biological stream samples indicate that the Broad Run aquatic habitat is largely unimpaired, and none made the case that runoff from urban areas or withdrawals for the Poolesville public water supply wells have impacted the watershed.

1997 and 2001 MBSS sampling of Dry Seneca Creek, on the east side of Poolesville, indicated that the stream was unimpaired both above and below the Poolesville WWTP, except at the most downstream site G, which was likely impaired by runoff from nearby cropland. Conversely, after sampling in 2000, MODEP indicated that the stream was impaired by runoff from urban areas and discharge from the WWTP. All the MSW sites sampled before 2010 upstream and downstream of the WWTP were unimpaired, except for the seventh most downstream one, site Q. Of the two MBSS samples taken in 2015, the first site (E) downstream of the WWTP was unimpaired, while the most downstream site (D) was slightly impaired (BIBI-2.5). After installation of an ENR treatment system in 2010, the Total Nitrogen (TN), Phosphorus (TP), $NO_2$, and $NO_3$ concentrations declined by amounts equal to or greater than 50%., indicating that the ENR system significantly improved the quality of the aquatic habitat downstream of the WWTP.

2001 MBSS sampling at site A in the Russell Branch tributary to Dry Seneca Creek indicated that the stream was impaired; however, the drainage area at that station was only 75 acres. Such small drainage areas may have low indices but not be impaired. Another factor to consider is that land use in the watershed is 47% urban, suggesting that runoff from impermeable surfaces may have degraded the aquatic habitat of the stream. There also was no flow in the stream, which was likely due to either the small drainage area or groundwater withdrawals from nearby town public supply wells.

MBSS surveys conducted in the Piney Creek watershed near Taneytown indicated that all sites were impaired, based on the single sample BIBI limit of 2.65. All are located outside of the capture zone of Taneytown wells 13 and 14, except for site E, indicating that groundwater withdrawals from the well were not the cause of the degraded aquatic habitat. The most likely cause of the impacts was farming activity, as all sites had high nitrogen levels (>3.0 mg/L), except for sites C and D. Based on the single sample FIBI limit of 2.50, none of the sites were impaired, except for site F. One possible explanation is that most of the samples were taken in 1996 during high flow periods. The one exception was the sample taken on 8/24/2004 at the site F, which had a low flow (0.01 cfs) and small drainage area (296 ac), and the best information indicates that there were no water withdrawals within the vicinity of that site. A perched water table may also have reduced the impacts of withdrawals on streamflow from the Taneytown supply wells.

Except for Hollow Creek and upper Linganore Creek during the drought of 2002, groundwater withdrawals by the public water supplies in the present study do not appear to have caused significant impacts to fish communities or aquatic habitat. In those two exceptional cases, biological sampling after the drought indicated both streams had recovered to the point that they were no longer impaired. The major factor affecting BIBI scores were land use practices, especially those associated with agricultural activity. Fish communities appear to be impacted mostly by low flows, especially in watersheds with small drainage areas. This was notable in Piney Creek, where the BIBI scores were low, but the FIBI scores were high, when most of the samples were taken during the high flow year of 1996. If refugia is available, fish populations appear to recover rapidly after droughts. The high surface runoff in watersheds underlain by the low permeability soils of the New Oxford Formation may produce naturally low BIBI scores that may be mistaken for the effects of urban runoff.

# Introduction

The State of Maryland is in the Mid-Atlantic region of the eastern United States and has a wide range of geology and aquifer types. The aquifers vary from high yielding (wells commonly producing more than 500 gpm) in confined and unconfined, unconsolidated sandstone layers on the eastern shore and southern Maryland to relatively, low yielding aquifers (wells generally producing less than 100 gpm) in the fractured rock areas of the Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateau provinces of central and western Maryland. The state includes much of the major Washington-Baltimore metropolitan complex, where about 5 million people live. Most of the metropolitan area is served by surface water from the Potomac River and the Baltimore City reservoir system. Some of the fastest growing suburban areas, however, are in the Piedmont and Blue Ridge areas, and are supplied by wells in fractured rock aquifers.

The slopes and dimensional characteristics of streams in the Piedmont and Blue Ridge areas are governed primarily by the underlying bedrock formations. Piedmont and Blue Ridge streams have characteristics and patterns that reflect their landscape and watershed settings. The basic differences in the streams are the result of the long-term geologic processes that created the underlying rocks and shaped the land surface. The topography of the stream valleys was created by varied geologic materials undergoing chemical reactions, weathering, uplifting, erosion, and deposition over thousands of years. The surrounding geology has a significant effect on how a stream looks and behaves. Regional geological characteristics govern the relief, size, and shape of the watersheds and determine the way that water is conveyed across the landscape and into stream channel networks. The geologic environment also influences the types of materials that are found along the banks and bottom of streams. These materials, in turn, affect channel appearance, the erosion rates, and the types of aquatic habitat communities found streams in different areas of the state.

The individual study sites are in the Middletown Valley of the Blue Ridge (BR) Province (Myersville and Middletown), the Mesozoic Lowland (ML) Province (Poolesville and Taneytown) and the western Piedmont Crystalline (PCR) Province (Votech/Maplecrest and Mount Airy). The watersheds of the Middletown Valley and the western Piedmont are underlain by crystalline rock formations. These include schist, quartzite, and gneiss metamorphic rocks, as well as granitic igneous rocks that are composed of crystals or crystal fragments and are not easily eroded. The Frederick and Wakefield Valleys are also in the western Piedmont and consist primarily of limestone and dolomite sedimentary rocks formed from carbonate materials that are highly susceptible to erosion; however, none of the study sites are in those areas. The broad Middletown Valley is floored by gneiss and volcanic rock lies in the trough between the Catoctin and South Mountains. Stream channels are characterized by steep slopes on the tow ridges, and moderate slopes in the interspersed valley areas. Sediments found within the valley streams are derived from gneiss and volcanic rocks, which create variety of gravel, cobble, and boulder-size materials. This western Piedmont Province is characterized by rolling terrain and low ridges. Streams generally flow within valleys that have cut into the landscape through many years of erosion. Most Piedmont streams have moderate slopes controlled by bedrock outcrops at the surface; however, steeply sloped areas and even small waterfalls exist. The Mesozoic Lowland (ML) HGMR is present in central and northeastern Frederick County, northwestern Carroll County, and western Montgomery County. The HGMR is characterized by its underlying geology of Triassic consolidated sedimentary rocks of the New Oxford Formation and Gettysburg Shale, with Jurassic intrusions.

There are certain watershed factors that influence runoff contributions to stream flow. The amount of rainfall that is absorbed into the ground is determined by the permeability of the soil and underlying geology. Clay soils have lower permeability than sandy soils; consequently, clay soils will promote greater amounts of surface runoff than sandy soils. On the two rock types at the study sites, the Triassic consolidated sedimentary rock formations have clay-rich soils, whereas the Piedmont crystalline rocks have more permeable silty and sandy soils. The shape of a watershed can influence the rate of discharge at the drainage network outlet because the distances from the watershed boundary to the outlet vary with shape, thereby governing the timing of flow concentration. Steeply sloped watersheds will convey water to streams more rapidly than watersheds with gentle slopes. Forested watersheds often have very little surface runoff from small to moderate precipitation events. Vegetation reduces runoff by intercepting rainfall, increasing roughness, and enhancing soil permeability. In urban areas, impervious land cover increases the amount of surface runoff, the velocity of overland flow, and time of runoff concentration during storm events.

The health of a stream's aquatic community depends, in part, on the physical features within a reach. The primary biological communities in a stream ecosystem are bacteria, algae/diatoms, macroinvertebrates, and fish. Bacteria are decomposers that break down the organic materials derived from plants and animals into nutrients that fuel the algal and diatom community. If a stream does not retain organic material and make it available to bacteria, the aquatic community will be very poor. To trap organic debris, a stream must have appropriate physical features that establish the hydraulic conditions necessary to retain materials imported into the channel. Algae and diatom communities tend to use the hard substrates found in streams. Cobble and gravel in riffles, bedrock in runs and pools, woody debris, and even stable sands are all suitable substrates for colonization. Algal and diatom community richness is vital to other components of the food web, such as the benthic macroinvertebrates. A large portion of the aquatic life in streams is composed of benthic macroinvertebrates, including clams, crayfish, worms, and aquatic insects. The more diverse the features of a stream, the more diverse the macroinvertebrate community. The physical habitat characteristics of a stream also influence the fish community. Like macroinvertebrates, fish species have adapted to specific habitats by using different feeding methods and other morphological characteristics. Refugia are features and factors that provide organisms or entire aquatic communities with mechanisms to withstand environmental stresses, such as drought. The types of refugia available for aquatic life in an area can change with the physiographic region because of the changes in the physical environment, including bottom substrate materials, floodplain width, and watershed slope.

## Location of Study Area

The study area is in the western Piedmont and Blue Ridge provinces of the fractured rock areas of Maryland, Figure 1. The investigation was conducted to determine if certain municipal groundwater withdrawals may have impacted streamflow, fisheries communities, and aquatic habitat, especially during the drought of 1998-2002. The individual sites chosen were the Little Catoctin Creek watershed, near Myersville and Hollow Creek, near Middletown, Linganore Creek/Woodville Branch, near Mount Airy, in Frederick County, Dry Seneca Creek, Horsepen Branch and Broad Run, near Poolesville, in Montgomery County, and Piney Creek, near Taneytown, and Middle Run, near Westminster, in Carroll County.

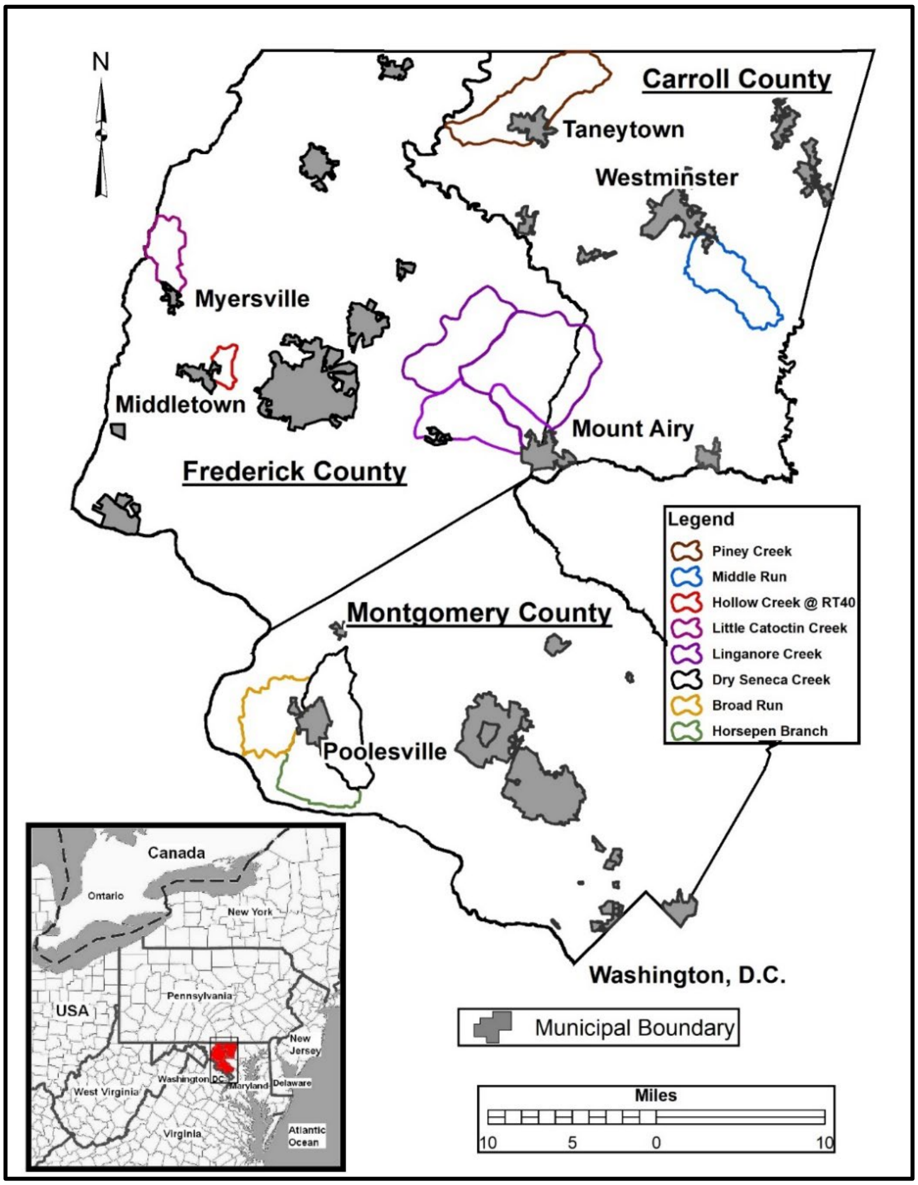


**Figure 1.** Location map of study area.

## The History of Water Appropriation or Use Regulations in Maryland

The Water Appropriations Act of 1933 created regulatory authority over the appropriation of surface and ground waters for any use (with significant exemptions, especially for subdivisions, and municipal and agricultural users). The Well Drillers Law was passed in 1945 and addressed the issue of licensing well drillers. It also required permits before and completion reports after drilling of any water well, providing a wealth of data on the ground waters of the state. The permitting system for well drillers and water appropriations was one of the earliest such programs in the nation. The 1933 law was largely ignored until about 1957, when the “Regulated Riparian” system for surface water was adopted. At that time, the “American Rule” or Reasonable Use Doctrine governed groundwater use, which states that a landowner has the right only to a reasonable and beneficial use of the waters upon his land. The reasonable use theory does not prevent the proper, non-wasteful consumption of such waters for the development of land for mining or other uses, allowing the underground waters of neighboring properties to be interfered with or diverted. In 1988, the water use regulations were modified based on elements of the Restatement (second) of Torts, Section 858, which requires replacement of impacted water supplies, with some restrictions. They also require consideration of the aggregate and cumulative changes of new and future appropriations, and their contributions to future degradation of the state’s waters, which are provisions used to protect the hydrologic balance of the state’s water resources, along with protection of fisheries communities and aquatic habitat.

# Background Discussion

Much of the literature concerning the effects of water withdrawals on stream flow, fisheries communities and aquatic habitat seems to be based on a relatively few, site-specific studies relating operational aspects of reservoirs and dams to impacts on downstream ecological flows. These investigations were primarily concentrated on the impacts caused by large reservoirs, which generally have the capacity to capture multi-year flows and substantially alter the flow regime, Collier et al. (1996), Magilligan and Nislow (2005) and Graf (2006). This is especially the case for hydro-electric dams, which tend to decrease the magnitude and frequency of high flows and produce more constant low flows. An exception is that flow may cease for extended periods when not generating power unless there is some method for maintaining a discharge other than by operating main turbines. Another problem is that a large dam tends to release oxygen-deficient, cold water downstream, unless there is some artificial method for increasing the $O_2$ content (DO) of the tailwaters below the dam.

There are only a few known investigations that have been conducted to show the effects on fisheries and aquatic habitat caused by withdrawals from small reservoirs, simple surface intakes, and groundwater sources. Simple intakes and groundwater withdrawals may cause similar potential impacts, since both only affect low flows (i.e., neither can capture high surface runoff).

Vogel et al. (2007) studied the relationship between reservoir storage, yield, and in-stream flow. They indicated that the impact of reservoirs on downstream flows depends on the ratios of storage capacity and annual yield to the mean annual inflow into a reservoir. By using various reservoir release rules, including drought management, they offered several potential trade-off scenarios for balancing adequate in-stream flows with water supply needs. For smaller reservoirs ($S/\mu$ or storage capacity/mean annual flow $< 0.4$) using a minimum release policy with or without augmentation, combined with drought augmentation, would best aid in decisions concerning reservoir operations.

Freeman and Marcinek (2006) studied the effects of 14 surface water withdrawals (simple intakes) and 14 reservoirs in the Georgia Piedmont. They plotted the number of fluvial specialist and habitat generalist fish species against a withdrawal index (WI = permitted maximum monthly use/7Q10), drainage area, and the presence of a reservoir. They found that fluvial specialists increased with drainage area and decreased downstream of a reservoir or with increase of the withdrawal index, while the number of generalists remained unchanged in all cases. For the simple intakes, and by analogy groundwater withdrawals, there was no significant difference between fluvial specialists and generalists relative to the reference streams. They noted that the water supply reservoirs in their study primarily released surface water. This led to higher temperatures downstream of the reservoirs than the simple intakes, which were expected to be detrimental to the fluvial specialists.

Lessard and Hayes (2003) studied the effects of 10 small, surface water release dams on Michigan streams during the summers of 1998 and 1999. They found that changes in the mean downstream temperature varied from a cooling of 1º C to more than an increase of 5º C (mean +2.7º). Increased temperatures downstream produced lower densities of certain cold water fish species while the overall species richness increased. They found that the presence of a dam alone did not negatively impact fluvial dependent species. They suggested that it was possible that colder, downstream tributaries provided thermal refugia under suboptimal conditions.

Churchel and Batzer (2006) studied six headwater streams in the Georgia Piedmont, five of which went dry (and one which retained some surface water) during the extreme drought of 1998-2002. In terms of drought recovery, there was a rapid recolonization period following the onset of surface flow and the number of new taxa colonizing the streams stabilized about 165 days after rewetting.

Meador and Carlisle (2011) used a national empirical predictive model to access streamflow variability at 97 sites in 28 major river basins within the eastern United States. They found that 49 of the 97 sites had reduced streamflow variability, with a 36% mean loss of native species, which was much more than the mean 5% loss at unaltered sites, and a median loss of 70% for fluvial specialist species. The anthropogenic factors having the most influence on streamflow variability were reservoir storage and wastewater discharge volumes. They also found that water withdrawals produced no significant difference between sites with reduced or unaltered streamflow variability.

The purpose of the Kanno and Vokoun (2010) study was to evaluate the ecological effects of water withdrawals and impoundments at 33 sites on 2nd to 4th order streams in Connecticut during the summers of 2007 and 2008. They studied water withdrawals associated with dams and reservoirs (16 impoundments), those taken from groundwater wells (11 intakes) near streams without impoundments, and 6 reference sites. They used the same withdrawal index (WI) as Freeman and Marcinek (2006). The WI values for the groundwater intakes were less than 10, which was similar for those for the simple surface water intakes in the Georgia study. No obvious trend could be detected in the Connecticut data to indicate that the groundwater withdrawals had caused significant ecological impacts. The mean species richness was 7.0, 9.7 and 7.8 species at the impoundment, groundwater intake and reference sites, respectively; as compared to the Georgia study, which had mean species richness of 17.5, 23.5 and 30.5 species, respectively. Kanno and Vokoun (2010) suggested that the Connecticut streams are species-poor habitats with highly altered landscapes, which might explain the much lower species richness relative to the Georgia study. Finally, the Connecticut study found that the presence of an impoundment only affected one fish assemblage metric.

Much of the evidence for impacts on aquatic resources due to groundwater withdrawals is based on the Falke et al (2010), Gido et al (2010), Wen and Chen (2006) and the Rugel et al (2010) investigations. The first three were studies of the High Plains aquifer, the principal geologic unit which is the Ogallala Formation. Miller and Appel (1997) suggested that in Kansas and Nebraska, where recharge rates to the aquifer are high, the demand for irrigation water could be as low as twice the average annual recharge, and where recharge rates are low, the demand could be more than 100 times the recharge. Robson and Banta (1995) indicated that the withdrawal rate from the High Plains aquifer during 1980 in Colorado and New Mexico was nearly eight times the natural recharge to the aquifer. The Maryland water balance policy effectively limits withdrawals to about ½ of the available annual average effective recharge in a watershed and only a few headwater streams in the State have approached that level.

The Rugel et al (2010) paper concerns the effects of irrigation withdrawals from the karstic, upper Floridan aquifer on streamflow in the lower Flint River basin of southwest Georgia. The lower Flint River watershed has a drainage area of 1290 $mi^2$. Wen and Zhang (2009) indicated that for the basin the estimated irrigation water use from groundwater in a drought year was 197 Mgd avg, while the long-term estimated average water use was 94 Mgd avg. The reported use for the entire Flint River basin was 89% of the estimated use during the drought year of 2007. By comparison, the primary watershed in the present study (Monocacy River in Maryland) has a drainage area of about 960 $mi^2$, with water use permits of less than a total of 20 Mgd avg, primarily for quarries and municipal water supplies.

These data indicate that the effects of groundwater withdrawals in Maryland could be on the order of a magnitude less than the impacts noted for irrigation uses from the High Plains aquifers and the upper Floridan aquifer in Georgia. This does not include the facts that irrigation withdrawals are highly consumptive and are highest when recharge is low, while the withdrawals in the Maryland study area are largely non-consumptive and have much less effect on streamflow during drought than irrigation uses. This information would suggest that the High Plains and Floridan aquifer analogies are not applicable to groundwater withdrawals in the fractured rock areas of Maryland.

# Methods of Investigation

Stream survey/biological assessments conducted in basins associated with the water withdrawals in the study area were reviewed and the analysis of the data obtained were used to determine the effects of the withdrawals upon the natural resources of the State. The investigations were conducted using the protocols contained in the Maryland Biological Stream Survey (MBSS) Sampling Manual (Kazyak, 1996). Sampling of water quality and benthic macroinvertebrates were completed during the Spring Index Period (March 1 to May 1). Sampling of fish and herpetofauna and evaluation of the physical habitat, including stream flow measurements, were conducted during the Summer Index Period (June 1 to September 30). After collection of the sampling data was complete, it was analyzed to determine any loss of certain fish species and develop an Index of Biotic Integrity (IBI) score that was then compared to control sites and/or available regional data.

The Maryland Department of Natural Resources (MD DNR) has performed biological assessments at more about 3700 sites in the State, primarily on a random basis. If multiple samples (at least three) have been taken at a site, it would be considered impaired, if either the FIBI (Fish Index of Biotic Integrity) or the BIBI (Benthic Index of Biotic Integrity) score was less than 3.0 (1.0–1.9 very poor, 2.0–2.9 poor, 3.0–3.9 fair and 4.0–5.0 good). If only one or two samples were taken, then the limits are 2.5 and 2.65 for the FIBI and BIBI scores, respectively. To date, watersheds seem to be mostly impaired by urbanization (impermeable surfaces) and agricultural activities (cropland). Evidence of this relationship is that there was no significant change in the average FIBI scores during the 2001-02 drought at the MBSS sentinel sites in the four regions of the State (Coastal Plain, eastern and western shores, eastern Piedmont, and the highlands), while there were significant declines in the scores on the western shore of the Coastal Plain and the eastern Piedmont during high runoff periods (entire year of 2003 and the growing season of 2008), Figure 2.

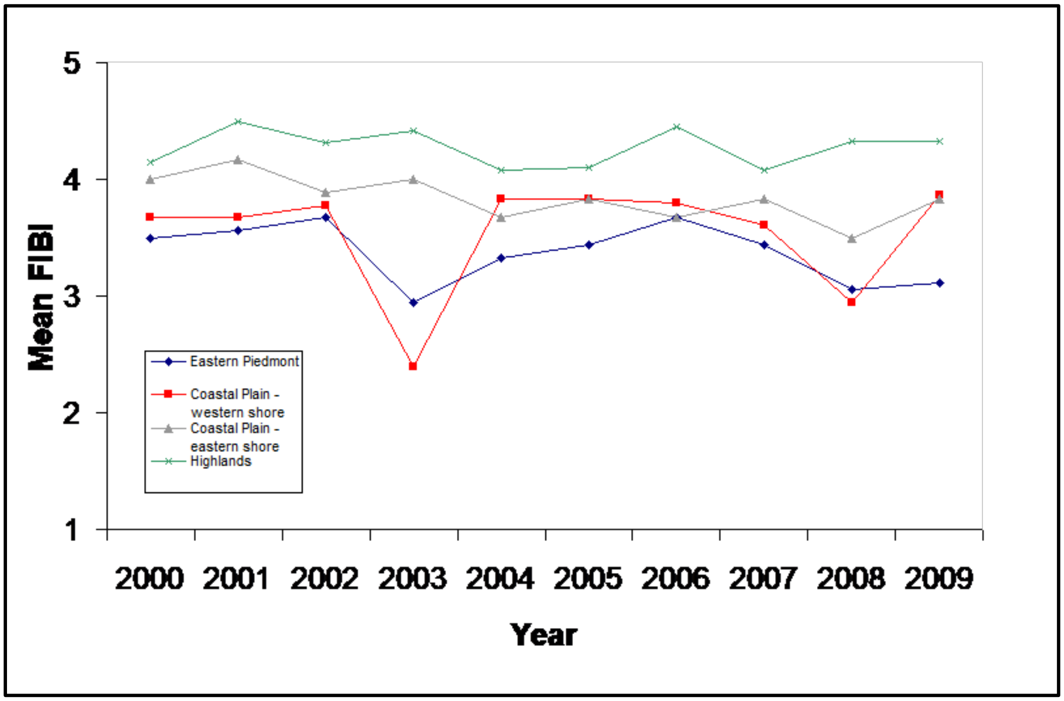


**Figure 2.** Mean FIBI scores at MBSS sentinel sites during the period 2000-2009.

The State funded biological assessments at six sites in 2010, including four in watersheds with heavy groundwater use and one to determine the effectiveness of operating rules designed to protect trout habitat downstream of the Hunting Creek reservoir. The earlier MD DNR random sampling included watersheds for many of the other reservoirs in the State and several other basins with heavy groundwater withdrawals. These studies found that the only impairments that could be related to withdrawals had been due to mining activity at the Medford Quarry and the Mettiki Coalmine.

Most ecological flow recommendations do not appear to consider the effects of reservoir and groundwater storage, the potential for controlled cold-water releases from reservoirs (with adequate DO levels), or the frequency distribution of individual uses or classes of withdrawals. This may prove to be important, since most of the present groundwater and reservoir withdrawals in Maryland are from small 1$^{st}$ to 3$^{rd}$ order streams (headwaters & creeks) and are used by public purveyors which are dependent on a continuing source of water. The high number of withdrawals in these basins is simply because more than 90% of all non-tidal stream miles in the State fall in these classes. It is noted, however, that most of the water used in the fractured rock areas of the State, by volume, is surface water taken from 4$^{th}$ or higher order streams (small to large rivers), which are generally thought to need less protection than lower order streams.

## Acknowledgements

This study fulfills one of the objectives of a cooperative regional study, Fleming et al., 2012, (USGS Publication SIR 2012-5160) of the fractured rock areas of Maryland that involved the Maryland Department of the Environment, the Maryland Geological Survey, the U.S. Geological Survey and the Monitoring and Non-Tidal Assessment (MANTA) Division of the Maryland Department of Natural Resources.

# Case Studies

## Hollow Creek/Middletown Case Study

Figure 3 is a map of upper Hollow Creek and Cone Branch, with those watersheds outlined, in Middletown, Frederick County. On August 20 of the 2002 drought, the author made a visit to observe the flows in the various streams in the town, especially to see the effects of groundwater withdrawals on baseflow in Hollow Creek. It was noted that Hollow Creek at US Route 40 was "bone dry" on that day, while other, smaller, nearby basins were still flowing. A later discussion with a local biologist indicated that the stream may have been dry for about a year during the drought. The estimated flow observed in Hollow Creek below US Route 40 was 100 gpm, which was equal to the reported wastewater treatment plant discharge rate. A second visit was made to Hollow Creek at US Route 40 during another dry period on August 14, 2007, where it was noted that the stream was wet, but had no flow, indicating that it had likely just gone dry.

The natural flows in Hollow Creek were estimated using the approximate flows observed in Cone Branch at US Route 40 (5-10 gpm), where groundwater withdrawals were nil, and data from the USGS Catoctin Creek gage, Figure 4. The flows using the Cone Branch data (18-36 gpm) were much higher than those calculated from the Catoctin Creek data (9 gpm). This was also the case on August 14, 2007, when the estimated unimpacted flow in Hollow Creek was 285 gpm, using the Cone Branch estimated flow (50+ gpm, plus 30 gpm for groundwater withdrawals) and 34 gpm using the USGS gage data.

Since the Cone Branch flows were affected by pond storage and discharge factors, the previous analysis is only considered to be an approximation. However, on June 14, 2010, the flows in Hollow Creek were measured as part of a MBSS survey at the US Route 40 site. The unit flow in Hollow Creek on that date was 0.336 cfsm (0.76 cfs). This was nearly the same as at the USGS gage (0.359 cfsm or 24 cfs); however, when you add in the equivalent flow for municipal withdrawals, the unit flow is then 0.698 cfsm (1.58 cfs). These data suggest that Hollow Creek, which is spring-fed, and Cone Branch are significant sources of water for Catoctin Creek during low flow periods.

From analyses conducted using the Catoctin Creek streamflow data, it was estimated that the baseflow during 2002 in the Hollow Creek WHPA (Drainage area = 3.14 $mi^2$) would have been 623,000 gpd avg, or 4.2 in/yr, while withdrawals in the WHPA were 85% of that value, or 536,000 gpd avg. In 2007, the estimated baseflow (8.2 in/yr) was 1,234,000 gpd avg, while the withdrawals of 489,000 gpd avg were 40% of that value. The baseflow in 2010 was 8.6 in/yr and municipal withdrawals were 483,600 gpd avg, indicating that withdrawals were 38% of the effective recharge in the WHPA. The baseflows in 2007 and 2010 indicate that those were dry years, between average year baseflow (10.9 in/yr) and the 1-in-10-year baseflow (5.7 in/yr). These data suggest that the substantial, potential, sustained natural drought flows in the Hollow Creek are likely due to both high recharge and ground water storage in the basin.

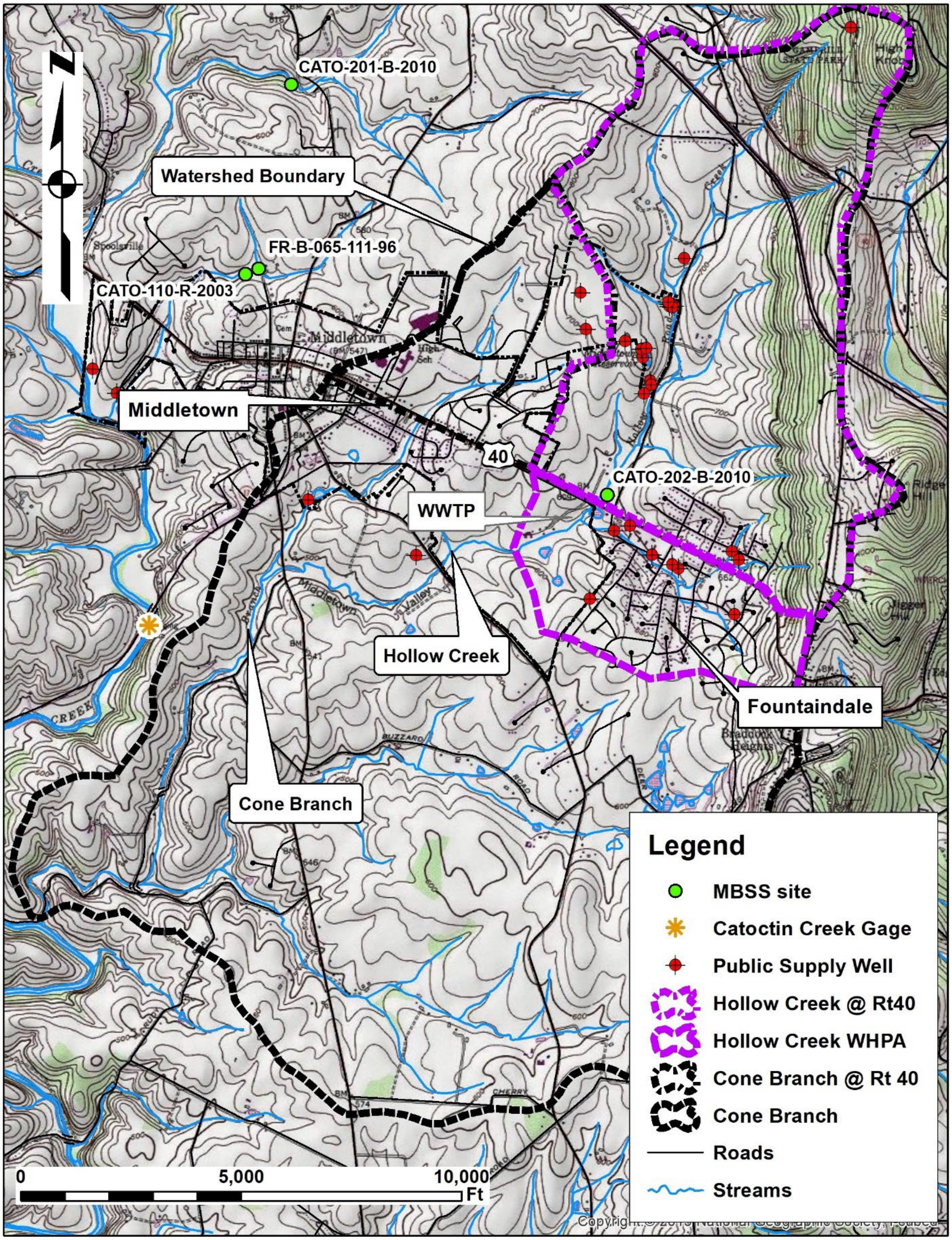


**Figure 3.** Topographic map of Hollow Creek and Cone Branch used to show impacts of the Middletown public water supply well withdrawals on streamflow and aquatic habitat in Hollow Creek.

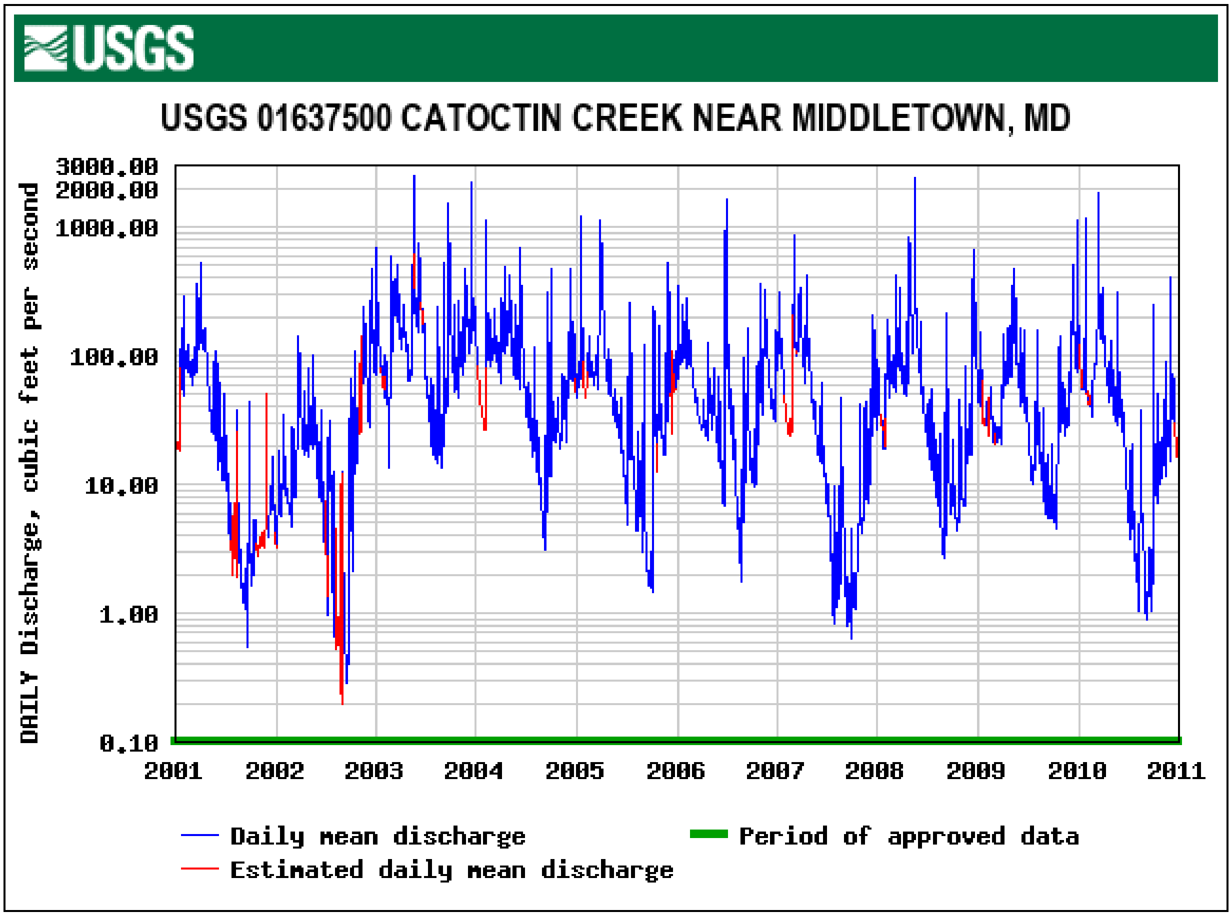


**Figure 4.** Streamflow records from USGS gaging station 01637500 in Catoctin Creek near Middletown during the period 2001 to 2010.

**Table 1.** MBSS data collected in Little Catoctin Creek, Hollow Creek and Cone Branch, with flow data from the Catoctin Creek stream gage.

| Stream | ID No | D (ac) | D ($mi^2$) | Flow (cfs) | Flow (cfsm) | Date | BIBI | FIBI | CIBI | PHI98 | PHI05 | %Urban | %AG | %Forest | $NO_3$ (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Little Catoctin Creek | FR-B-065-111-96 | 279 | 0.44 | 0.3 | 0.682 | 6/13/1996 | 2 | 1 | 1.5 | 11.8 | N/R | 8.2 | 87.5 | 4.7 | 10.3 |
| | | | | | | | | | | | | | | | |
| | CATO-110-R-2003 | 391 | 0.61 | 0.29 | 0.475 | 7/22/2003 | 3 | 1.3 | 2.2 | 73.1 | N/R | 8 | 90 | 0 | 3.9 |
| | | | | | | | | | | | | | | | |
| | CATO-201-B-2010 | 1026.8 | 1.60 | 1.13 | 0.704 | 6/10/2010 | 4.25 | 3.67 | 4.0 | 92.2 | N/R | 8.8 | 86.9 | 4.0 | 3.2 |
| | | | | | | | | | | | | | | | |
| Hollow Creek | CATO-202-B-2010 | 1448.4 | 2.26 | 0.76 | 0.336 | 6/14/2010 | 3 | 3 | 3.0 | 68.0 | N/R | 13.0 | 53.2 | 32.6 | 2.0 |
| | | Est. withdrawals added | | 1.58 | 0.698 | 6/14/2010 | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Cone Branch | CATO-203-B-2010 | 355 | 0.55 | 0.169 | 0.305 | 6/10/2010 | N/R | N/R | | | | | | | |
| | | Est. Withdrawals added | | 0.20 | 0.361 | 6/10/2010 | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Catoctin Creek Gage | 1637500 | 43,485 | 66.9 | 100 (85%) | 1.495 | 6/13/1996 | 700cfs 6/11/96 | | | | | | | | |
| | | | | 235 (95%) | 3.510 | 7/22/2003 | 2520 cfs 7/16/2003 | | | | | | | | |
| | | | | 45 (50%) | 0.673 | 6/10/2010 | Possible Storm | | | | | | | | |
| | | | | 24 (25%) | 0.359 | 6/14/2010 | Probable baseflow | | | | | | | | |

Note: Possible storm event Catoctin Creek 6/10/2010 (6/9 - 32 cfs, 6/10 - 45 cfs, 6/11 - 25 cfs)
Note: Cone Branch flow may be affected by pond discharge/storage
Note: Except for FR-B-065-111-96, PHI-98 and PHI-05 not rated as of this date
Note: 2010 was a dry, but not drought year (about 3-4 - yr return)

Table 1 is a summary of the results of a MBSS survey of Hollow Creek (CATO-202-B-2010) at the US Route 40 crossing conducted in 2010, drainage area (D.A.) of 2.3 $mi^2$. The BIBI and FIBI both were equal to 3 and the PHI was 68.0, indicating the existence of sub-optimal, but not degraded, conditions during a dry year under low flow conditions (25$^{th}$ percentile of average daily flows). A survey of Little Catoctin Creek (CATO-201-B-2010) was also completed in 2010 to provide data from a control watershed not influenced by groundwater withdrawals. The BIBI was 4.25, the FIBI was 3.67 and the PHI was 92.2, which indicated optimal conditions existed at that 1.6 $mi^2$ site. Previous surveys completed in 1996 and 2003 and conducted in smaller drainage areas (0.4 and 0.6 $mi^2$) in Wiles Branch (FR-B-065-11-96 and CATO-110-R-2003) indicated those portions of that watershed were degraded. Stream flow was not a factor since those were the two wettest years on record. While it is likely that agricultural practices had greater impacts on aquatic habitat than stream flow in the smaller areas of the Wiles Branch watershed, the $NO_3$ concentrations, using the of >3.0 mg/L (moderately elevated) standard, Roth et al. (1999), are not consistent with the BIBI scores. The one site (FR-B-065-111-97) with the highest nitrates (10.9 mg/L) does have a low BIBI, as well as a low FIBI, while the two other sites in the Little catoctin Creek watershed have high nitrate levels, but fair to good BIBI scores. The Hollow Creek site has both low $NO_3$ concentrations and BIBI scores.

## Little Catoctin Creek, Myersville/Middle Run, Votech-Maplecrest Case Studies

The few crystalline rock aquifer interference impacts known to have occurred in Maryland included withdrawals from the Myersville Water Treatment Plant well that caused four domestic wells to either go dry or have reduced yields. An investigation of reports of declining yields or increased turbidity in domestic wells at the Maplecrest community indicated that those problems were not related to withdrawals from the nearby Westminster Votech well. No investigation has been conducted to determine if there were impacts to streamflow or aquatic habitats due to withdrawals from those wells. Table 2 contains the MBSS data collected at Myersville and near the Westminster Votech (well 8) site.

Site CATO-191-A-2012, Figure 5, located in Little Catoctin Creek, just below Myersville's reservoir and a nearby low yielding public supply well, was surveyed during the spring of 2012, resulting in a BIBI score of 4.5. Previously, on August 28, 1997, the only flow below the reservoir was 10 gpm leaking from a closed overflow valve. A flow-by device was installed to maintain a minimum flow of 0.15 cfs. The subsequent good instream biological habitat was probably due to a large portion (65%) of forest in the watershed, the small storage of the reservoir, low elevation of the dam, limited withdrawals (0.06 cfs average for 2012) above the MBSS site, the minimum flow-by, and the low yield of the well. At site CATO-301-R-2017 in Catoctin Creek, the BIBI source was 3.5 and the FIBI score was 4. This also was probably due to a large forest area (62%) and limited withdrawals (0.18 cfs in July 2017) within a moderately large (34.4 $mi^2$) watershed.

**Table 2.** MBSS data collected in Little Catoctin Creek and Catoctin Creek, near Myersville, and Middle Run, near Westminster (Votech site).

| Site ID | Name | BIBI | FIBI | CBI | PHI | | Flow | D.A. | Flow | USGS 6375/58621 | | Date | Land Use % | | | $NO_3$ | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1998 | 2005 | cfs | $mi^2$ | cfsm | cfs | cfsm | | Urban | AG | Forest | mg/L | |
| Myersville | CATO-191-A-2012 | 4.5 | N/R | N/A | N/R | N/R | N/R | 5.0 | N/A | N/A | N/A | N/R | 3.6 | 30.8 | 65.4 | NR | N/R |
| | CATO-301-R-2017 | 3.5 | 4 | 3.75 | N/R | N/R | N/R | 34.4 | 0.19 (est.) | 13 (50%) | 0.19 | 7/27/2017 | 7.3 | 30.2 | 62.3 | 1.1 | N/R |
| | | | | | | | | | | | | | | | | | |
| Votech | LIBE-105-R-2003 | 3.7 | 4 | 3.85 | 93.3 | 91.7 | 3.76 | 1.14 | 3.3 | 35 (90%) | 2.52 | 6/23/2003 | 16 | 63 | 20 | 4.9 | Bank erosion |

Using the $NO_3$ concentration limit of >3.0 mg/L, the high BIBI score and low $NO_3$ concentration in Little Catoctin Creek indicates that agricultural activity likely had not impaired the stream.

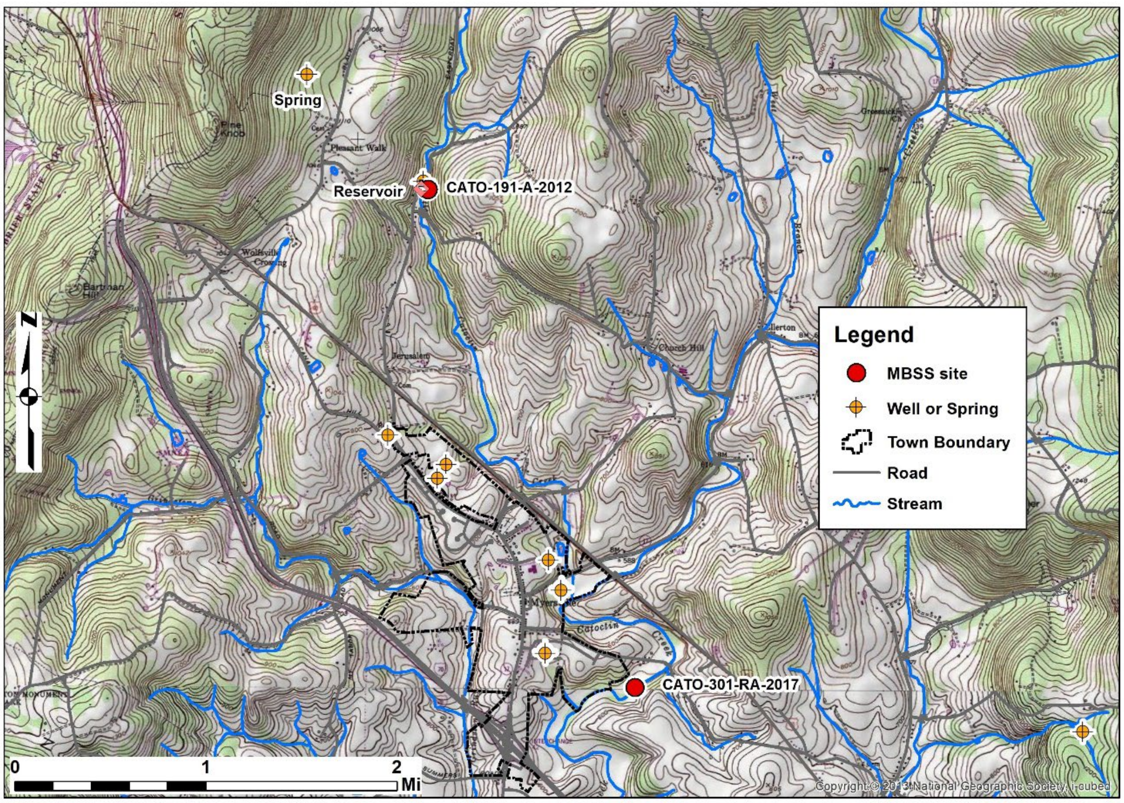


**Figure 5.** Topographic map of the Myersville area, showing public water supplies and MBSS sites.

Site LIBE-105-R-2003 is located downstream of the Westminster Votech well in the Middle Run watershed, Figure 6. The BIBI score was 3.75 and the FIBI score was 4. The drainage area (D.A.) of the Votech well (148 acres) is 20% of the D.A. at the MBSS site; however, the withdrawals from the well (0.18 cfs) in June 2003 were a small fraction (4.8%) of the measured flow at the MBSS site (3.76 cfs on 6/23/2003). By comparison, in the case of the Hammond (2022) study on the effects of dewatering of the Mettiki Coalmine, reductions in flows of about 20% did not appear to impair the aquatic habitat in streams overlying the mine. Although the $NO_3$ was high (4.9 mg/L) at the Middle Run site, the BIBI score (3.75) indicates that the stream at the sampling point was not impaired.

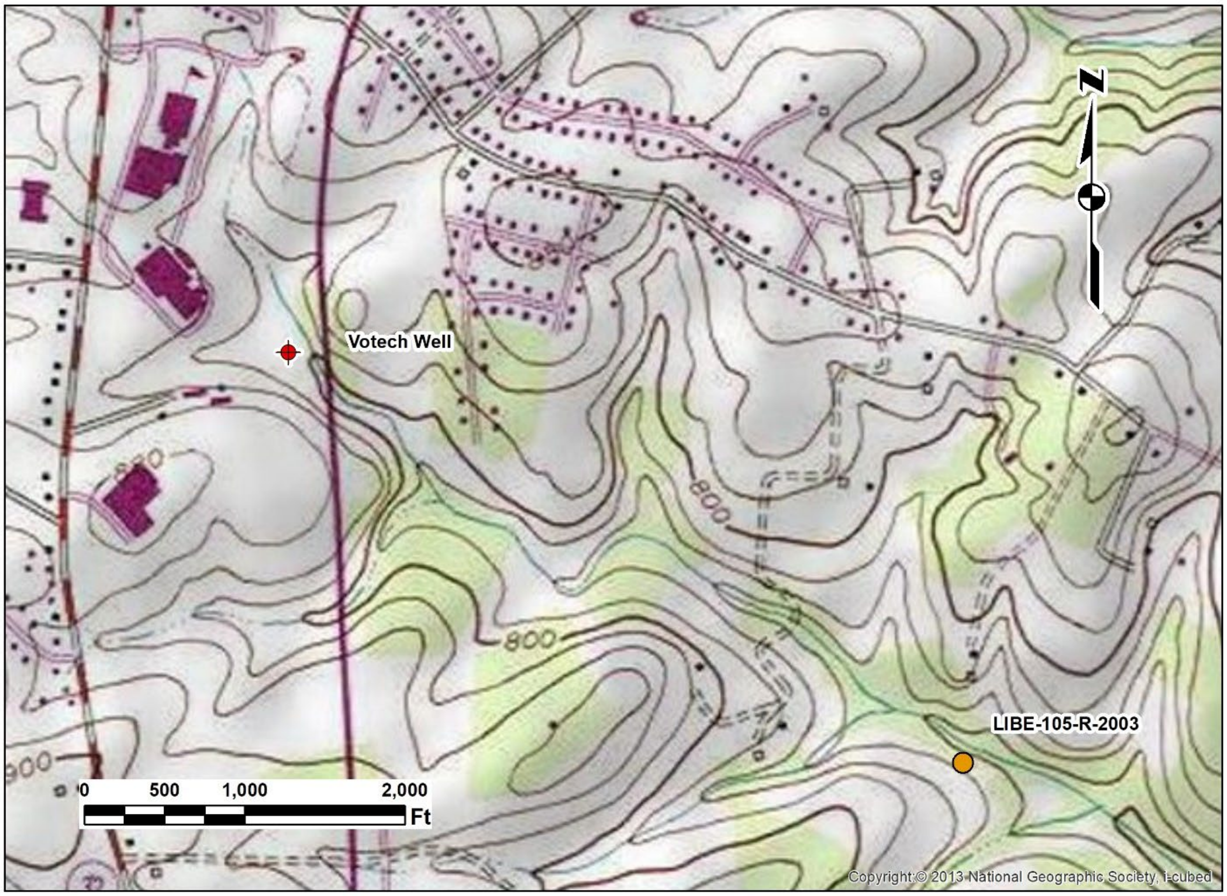


**Figure 6.** Topographic map near the Maplecrest Subdivision, showing the locations of Westminster well 8 (Votech well) and a MBSS site in Middle Run.

# Linganore Creek-Woodville Branch, Mount Airy Case Study

On August 20, 2002, the author observed about 20 gpm flowing in Linganore Creek, just upstream of the confluence of Linganore Creek and Dollyhyde Creek at the MD RT 75 stream crossing (D.A.= 40.7 $mi^2$ or 0.0011 cfsm), Figure 7. On the same day, the Frederick County Department of Utilities and Solid Waste Management (DUSWM) also measured a flow of 160 gpm (0.230 mgd or 0.006 cfsm) in Linganore Creek at Gashouse Pike (D.A. = 59.5 $mi^2$), indicating that the increase in flow was due to discharge from Dollyhyde Creek. By comparison, the flow out of the upstream tributary Woodville Branch (D.A. 6.6 $mi^2$), from which Mount Airy withdraws its primary groundwater supply, was about 50 gpm (0.017 cfsm). The FC DUSWM also measured flow on the same date in the Bens Branch tributary (D.A.= 15.9 $mi^2$) of 66 gpm (0.095 mgd or 0.009 cfsm).

On August 20, 2002, the flows at the nearby Bennett Creek gage (D.A. = 63 $mi^2$) were 0.6 mgd (0.014 cfsm). Adding in the groundwater withdrawal (414,000 gpd) from Woodville Branch by Mount Airy would increase the unit flows in Woodville Branch, Linganore Creek at MD RT 75, and Linganore Creek at Gashouse Pike to 0.114 cfsm, 0.017 cfsm and 0.017 cfsm, respectively. This would indicate that the natural flows in the spring-fed Woodville Branch watershed are enhanced by increased recharge and aquifer storage capacity, and it is a major source of water for the Linganore Creek basin during low flow periods. In addition, since there is close agreement between the Bennett Creek and the two Linganore Creek sites, this indicates that the reduced flows in Linganore Creek were due to the withdrawals by the Town of Mount Airy. Also, when groundwater withdrawals are added to the flow measured in Bens Branch, the combined unit flow is 0.019 cfsm, again indicating groundwater withdrawals were the source of reduced flows in that stream.

Table 3 is a summary of the results of MBSS surveys conducted in the Linganore Creek watershed between 1996 and 2012 and Figure 7 shows the locations of the sample sites. Highlighted in yellow in Table 3 and shown on Figures 8 and 9 are those sites which were impaired, based on the limits of 2.5 for the FIBI and 2.65 for the BIBI for streams where single samples are taken. The site AB data is not considered in this analysis since that site is immediately below Lake Linganore and likely was affected by reservoir operations. The BIBI results indicate that 16 of the 27 sites were impaired, while the FIBI scores indicate that only 4 sites were impaired, all which had a D.A.< 0.5 $mi^2$. Of note is that the 5 sites with a CIBI less than 2.58, Table 3 and Figure 10, neglecting site AB, all had a D.A.< 0.5 $mi^2$, 4 of which had unit flows from 7% to 57% of the Bennett Creek reference gage. Two other sites (M and Q) had small drainage areas, one which (Q) had an impaired BIBI. The 8 sites (highlighted in purple) with samples collected during the lowest regional flow periods (0.13 to 0.78 cfsm @ gage 6435) had suboptimal to optimal CIBI scores exceeding 3.09. Included are sites X and Y, immediately downstream of the Mount Airy well field. The most downstream site (W) in the Woodville Branch basin did have an impaired BIBI of 1, but the flows (2.15 cfsm), FIBI (4.67) and PHI (95.9) indicate optimum physical conditions existed on the sample date. One possibility is the BIBI impairment at that site was due to elevated nitrate-nitrogen ($NO_3$-N) levels from nearby farming activity. The five sites with impaired CIBI results had PHI values (highlighted in grey) less than 65. Three others (F, T and Y) had impaired BIBI scores, but there are no comments in the MBSS reports that might indicate reasons for the impacts. One site was not impaired (AA) and the last one (AB) was affected by reservoir operations. The greatest percentage of land use upstream of the 16 impaired sites with low BIBI scores is for agricultural activity, except for sites A (forest) and B (urban); however, this is also the case for the 11 unimpaired sites, except for sites L and Z (both forest).

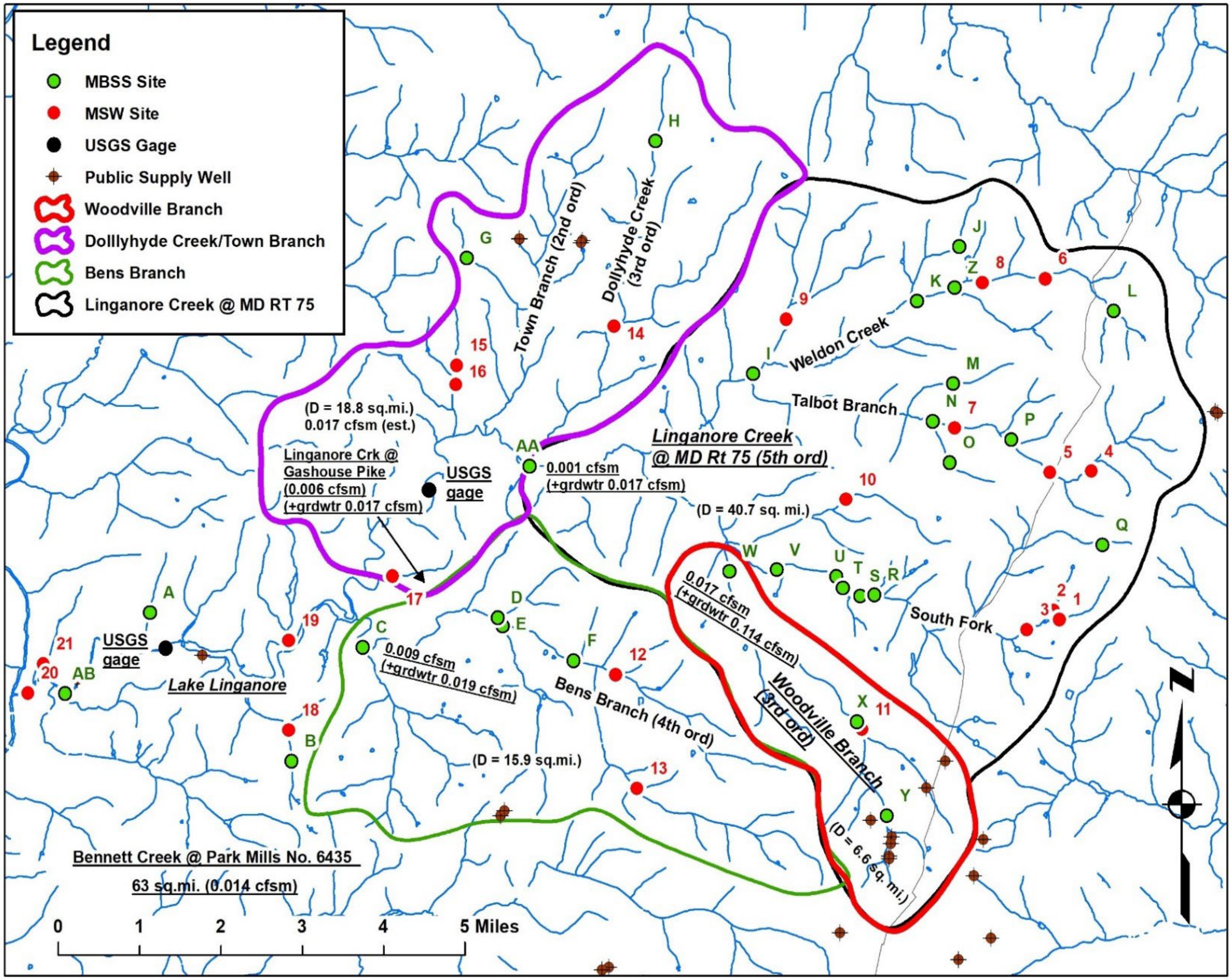


**Figure 7.** Linganore Creek streamflow measurements/estimates on August 20, 2002, and MBSS/MSW sites 1996-2012.

**Table 3.** Data from Linganore Creek watershed MBSS surveys 1996-2012.

| Site ID | Name | BIBI | FIBI | CIBI | PHI | | Flow | D.A | unit flow | Flow Gage 6435 | | | Date | Land Use % | | | $NO_3$ | Comments Impaired sites |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1998 | 2005 | cfs | $mi^2$ | cfsm | cfs | Daily % | cfsm | | Urban | AG | Forest | mg/L | |
| A | LMON-142-R-2003 | 2.5 | 1.0 | 1.75 | 64.8 | | 0.04 | 0.38 | 0.11 | 94.4 | 90 | 1.50 | 7/2/2003 | 2 | 23 | 74 | 0.1 | Shallow, little cover, 2 ATV trails cross stream |
| B | LMON-118-R-2003 | 2 | 3 | 2.50 | | 50.7 | 0.1 | 0.19 | 0.53 | 92 | 90 | 1.46 | 7/1/2003 | 39 | 52 | 9 | 2.2 | Heavy silt, new housing development upstream |
| C | LMON-337-R-2003 | 2.3 | 4.7 | 3.50 | | 76.8 | 8.73 | 15.5 | 0.56 | 48.9 | 75 | 0.78 | 8/21/2003 | 6 | 70 | 22 | 2.8 | High point bar, deep pool head of site |
| D | FR-P-411-305-96 | 3.25 | 5 | 4.13 | | 78 | 10.84 | 10 | 1.08 | 77 | 90 | 1.23 | 8/9/1996 | 0.8 | 67.8 | 30.7 | 3.7 | No comments |
| E | LMON-107-R-2003 | 2.5 | 3.67 | 3.09 | | 70.2 | 4.72 | 2.15 | 2.20 | 169 | 95 | 2.69 | 6/16/2003 | 5 | 81 | 13 | 4.9 | Deep channel, eroded banks |
| F | FR-P-461-251-96 | 2.5 | 4.67 | 3.59 | 34 | | 10.39 | 6.6 | 1.57 | 63 | 90 | 1.00 | 8/28/1996 | 1 | 61.1 | 37.3 | 2.5 | No comments |
| G | LMON-123-R-2003 | 2 | 2 | 2.00 | | 58 | 0.5 | 0.31 | 1.61 | 179 | 90 | 2.85 | 6/24/2003 | 2 | 57 | 39 | 2.2 | Cow access to stream |
| H | LMON-147-T-2000 | 1.3 | 1 | 1.15 | 4.8 | 25.4 | 0.08 | 0.41 | 0.20 | 32 | 50 | 0.51 | 6/27/2000 | 0 | 96.5 | 3.4 | 3.6 | Pasture-Ag influence multifloral rose |
| I | LMON-328-R-2003 | 2 | 4.3 | 3.15 | | 77.6 | 3.12 | 9.75 | 0.32 | 48.9 | 75 | 0.78 | 8/21/2003 | 1 | 73 | 23 | 3.6 | Heavy deposits of silt |
| J | FR-P-399-126-96 | 1.5 | 1.3 | 1.40 | 17.6 | | 0.37 | 0.36 | 1.03 | 64 | 75 | 1.02 | 6/3/1996 | 0 | 73.3 | 26.3 | 7.1 | $NO_3$-N elevated |
| K | LMON-209-T-2000 | 4 | 4 | 4.00 | 97.2 | 73.3 | 2.71 | 3.98 | 0.68 | 29 | 50 | 0.46 | 6/28/2000 | 0.1 | 51.5 | 48 | 2.0 | |
| L | LMON-108-R-2003 | 3.25 | 3.33 | 3.29 | | 76.3 | 1.79 | 0.76 | 2.36 | 152 | 95 | 2.42 | 6/17/2003 | 3 | 39 | 58 | 1.1 | |
| M | LMON-119-T-2000 | 4.3 | 4.3 | 4.30 | 81 | 78.7 | 0.21 | 0.35 | 0.60 | 110 | 80 | 1.75 | 6/22/2000 | 0.7 | 80.4 | 18.9 | 3.0 | |
| N | FR-P-388-208-96 | 1.8 | 4.7 | 3.25 | N/R | N/R | 4.76 | 4.74 | 1.00 | 109 | 80 | 1.74 | 6/13/1996 | 1.1 | 57.7 | 40.5 | 2.8 | $NO_3$-N elevated |
| O | LMON-109-R-2003 | 2.3 | 4 | 3.15 | | 78.7 | 1.28 | 0.62 | 2.06 | 152 | 95 | 2.42 | 6/17/2003 | 0 | 57 | 40 | 1.6 | Extremely thick vegetation (multifloral rose) |
| P | FR-P-388-246-96 | 2.3 | 4.7 | 3.50 | N/R | N/R | 7.87 | 4.28 | 1.84 | 1100 | 95 | 17.52 | 6/18/1996 | 1.2 | 57.1 | 41.1 | 3.1 | $NO_3$-N elevated |
| Q | LMON-113-R-2003 | 2.25 | 3.67 | 2.96 | | 72.4 | 0.5 | 0.22 | 2.27 | 169 | 95 | 2.69 | 6/16/2003 | 2 | 85 | 12 | 3.4 | Pasture along right bank |
| R | LMON-204-B-2010 | 3 | 4.67 | 3.84 | N/R | N/R | 1.53 | 6.73 | 0.23 | 15 | 25 | 0.24 | 7/12/2010 | 0.9 | 74.4 | 23.6 | 3.2 | |
| S | FR-P-156-252-96 | 2.75 | 5 | 3.88 | 81.3 | | 15.05 | 6.42 | 2.34 | 102 | 80 | 1.62 | 6/26/1996 | 0.2 | 65.5 | 33.2 | 2.6 | |
| T | FR-P-156-217-96 | 2 | 4 | 3.00 | 64.8 | | 15.43 | 6.83 | 2.26 | 135 | 80 | 2.15 | 6/24/1996 | 0.3 | 65 | 33.8 | 3.1 | No comments |
| U | FR-P-156-231-96 | 3.75 | 5 | 4.38 | 86.3 | | 16.94 | 7.15 | 2.37 | 135 | 80 | 2.15 | 6/24/1996 | 0.2 | 63.8 | 34.9 | 3.0 | |
| V | FR-P-156-234-96 | 3 | 5 | 4.00 | 94.8 | | 12.55 | 7.6 | 1.65 | 77 | 90 | 1.23 | 8/9/1996 | 0.2 | 63 | 35.9 | 3.0 | |
| W | FR-P-321-214-96 | 1 | 4.67 | 2.84 | | 95.9 | 12.9 | 6.92 | 1.86 | 135 | 95 | 2.15 | 9/24/1996 | 2.4 | 70.3 | 26.5 | 4.1 | $NO_3$-N elevated |
| X | LMON-205-B-2010 | 3.75 | 4.33 | 4.04 | N/R | N/R | 1.64 | 3.56 | 0.46 | 36 | 50 | 0.57 | 6/14/2010 | 18 | 72.3 | 9.4 | 4.6 | Watershed drains Mount Airy |
| Y | LMON-104-T-2000 | 2.5 | 3.67 | 3.09 | 45.8 | 61.6 | 0.53 | 1.13 | 0.47 | 21 | 25 | 0.33 | 7/5/2000 | 14.7 | 67.1 | 18.2 | 3.5 | |
| Z | LMON-209-A-2011 | 2.8 | 4.3 | 3.55 | N/R | N/R | 1.16 | 0.99 | 1.17 | 8.3 | 20 | 0.13 | 8/2/2011 | 3.7 | 37.9 | 58 | 2.6 | |
| AA | LMON-495-B-2012 | 2.75 | 5 | 3.88 | 55 | | 11.9 | 41.7 | 0.29 | 20 | 75 | 0.32 | 8/9/2012 | 9.1 | 56.9 | 32.9 | 3.5 | |
| AB | LMON-494-B-2012 | 1.25 | 2.7 | 1.98 | 55 | | 16.8 | 83.5 | 0.20 | 20 | 75 | 0.32 | 8/9/2012 | 10.8 | 56.9 | 28.6 | 2.7 | Affected by reservoir operations |

| Site ID | Flow Gage 642438 | | | Date |
|---|---|---|---|---|
| | cfs | | cfsm | |
| X | 26.4 | 50 | 0.47 | 6/14/2010 |
| R | 14 | 25 | 0.25 | 7/12/2000 |

**Table 4.** Data from Linganore Creek watershed MSW surveys 2007-2011.

| Map Id | Site No. | BIBI | Location | Watershed |
|---|---|---|---|---|
| 1 | 0235-02-2008 | 3.0 | West Falls Rd. | South Fork UT |
| 2 | 0235-03-2008 | 3.0 | West Falls Rd. | South Fork UT |
| 3 | 0235-01-2008 | 3.57 | Atleen Dr. | South Fork UT |
| 4 | 0238-03-2008 | 1.57 | Roop Rd./Candle Dr. | Talbot Br. UT |
| 5 | 0238-02-2008 | 2.43 | Buffalo/Black Anklr Rds. | Talbot Br. |
| 6 | 0238-02-2007 | 3.29 | Barnes Rd. | Weldon Ck. |
| 7 | 0238-01-2011 | 3.29 | Blank Ankle Rd. | Talbot Br. |
| 8 | 0238-03-2011 | 3.57 | Barnes Rd. | Weldon Ck. |
| 9 | 0238-02-2011 | 1.86 | Woodville Rd. | Linganore Ck. UT |
| 10 | 0235-02-2003 | 2.43 | Harrisville/West Veleor Rds. | South Fork UT |
| 11 | 0235-01-2003 | 1.57 | Woodville/Old Bohn Rds. | Woodville Br. |
| 12 | 0234-02-2011 | 3.86 | Lime Plant/Detrick Rds. | Bens Br. |
| 13 | 0234-01-2011 | 4.43 | J. Smith/Hope Valley GC Rds. | Bens Br. |
| 14 | 0236-03-2008 | 3.29 | Dollyhyde Rd. | Dollyhyde Ck. |
| 15 | 0236-02-2008 | 3.29 | Alton Rd. | Town Br. UT |
| 16 | 0236-01-2008 | 2.71 | Alton Rd. | Town Br. UT |
| 17 | 0234-03-2011 | 3.86 | Gas House Pike | Linganore Ck. UT |
| 18 | 0232-01-2008 | 2.14 | Yeagerstown Rd. | Lake Linganore UT |
| 19 | 0232-03-2003 | 1.57 | Boyers Mill Rd. | Indian Cave Ck. |
| 20 | 0232-02-2008 | 2.43 | Linganore Rd./MD RT 70 | Linganore Ck. |
| 21 | 0232-03-2008 | 1.29 | Linganore Rd./MD RT 70 | Linganore Ck. UT |

Using the $NO_3$ concentration limit of >3.0 mg/L, 9 of 17 sites with impaired BIBI had elevated $NO_3$ concentrations (highlighted in blue, Table 3), while the remaining 8 (highlighted in grey) had low levels of $NO_3$. Four sites (highlighted in orange) had high $NO_3$ levels but were unimpaired. Only the remaining 7 sites (highlighted in white) were both unimpaired and had low $NO_3$ concentrations. This would suggest that care should be taken when trying to relate impaired BIBI scores to high $NO_3$ concentrations.

Table 4 and Figure 11 provide the results of samples collected by the Maryland Stream Waders (MSW) program. There were 9 sites with impaired BIBI scores. Sites 10, 18 and 21 had small drainage areas and site 20 was downstream of the Lake Linganore reservoir. There was residential development immediately upstream of site 9, but a large majority of the watershed is in cropland. Sites 4 and 5 have watersheds primarily affected by agricultural activity, while site 19 had a highly urbanized watershed. Site 11 was in Woodville Branch, but the low BIBI (1.6) is inconsistent with the more rigorous MBSS sampling at the site (X) which produced a BIBI score of 3.8. Other than Woodville Branch sites MSW 11 and MBSS X, there was fairly good agreement between the MBSS and MSW BIBI scores in the Linganore Creek basin, Figure 12.

While withdrawals of groundwater for the Mount Airy public water supply likely caused the reduced flows in Linganore Creek above the confluence with Dollyhyde Creek and may have impaired the biological habitat, conditions likely improved rapidly after the 2002 drought and the follow-on record or near record wet year of 2003. The most impaired streams within the Linganore Creek watershed had drainage areas less than 0.5 $mi^2$ and unit flows substantially less than the regional average calculated from the Bennett Creek gage (6435) data and had no significant groundwater withdrawals within the sample site drainage areas. A likely reason of the low flows is that small headwaters streams are usually within aquifer recharge areas, so much of the runoff infiltrates into the ground before it reaches the stream. Much of the data were collected during the extremely wet years of 1996 and 2003; however, the FIBI surveys were conducted in the summer and early fall periods, when seasonal flows are declining. The CIBI scores for the 8 surveys, including the 2 in the upstream portion of Woodville Branch, conducted during the lowest flow periods, indicated that those streams were not impaired. The downstream site (W) in Woodville Branch did have a low BIBI score, but that may have been due to high concentrations of $NO_3$-N caused by runoff from a nearby farm. Overall, the data in Table 3 indicate that there is a poor correlation between the BIBI scores and $NO_3$ concentrations.

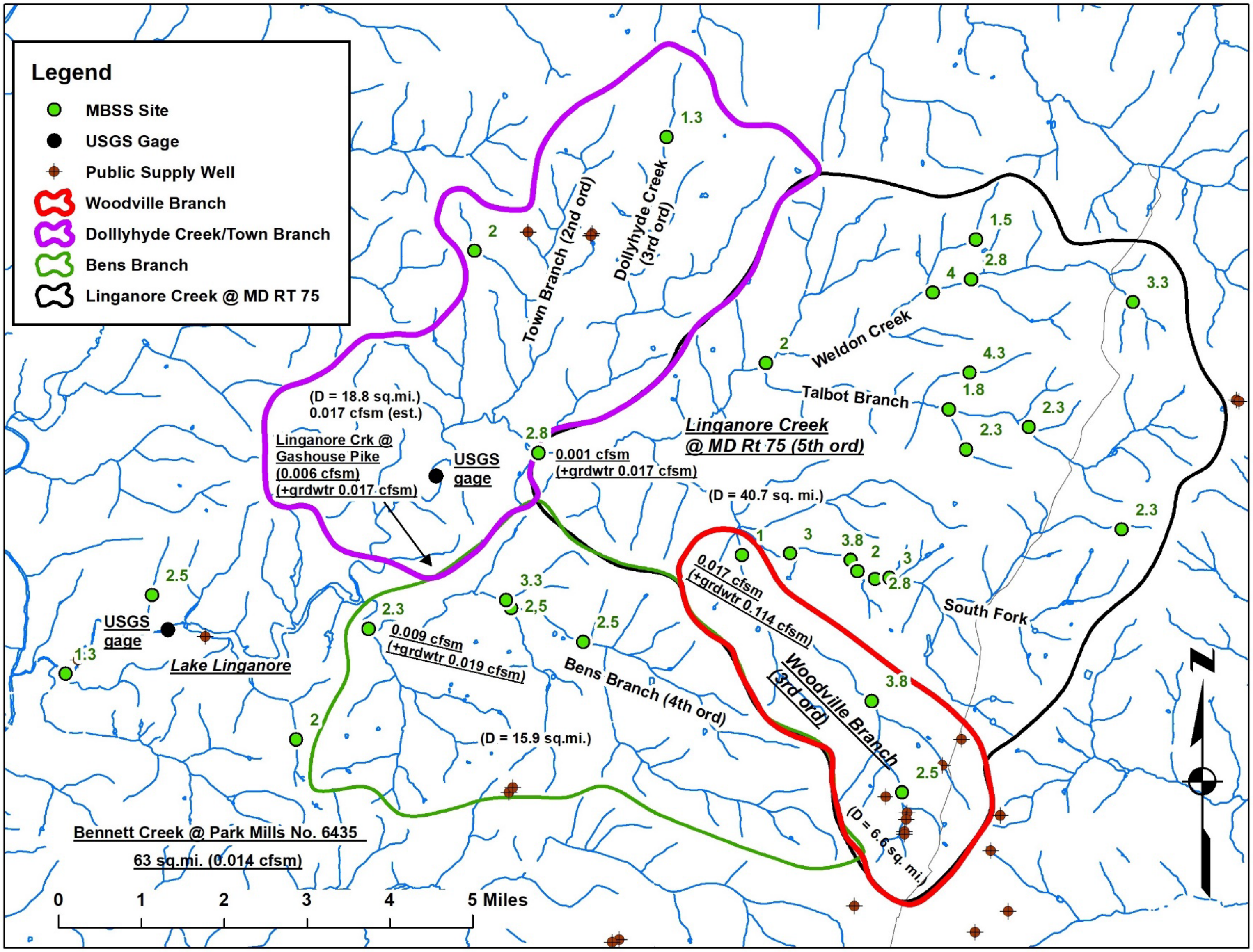


**Figure 8**. Linganore Creek MBSS sites with BIBI scores and streamflow measurements 1996-2012.

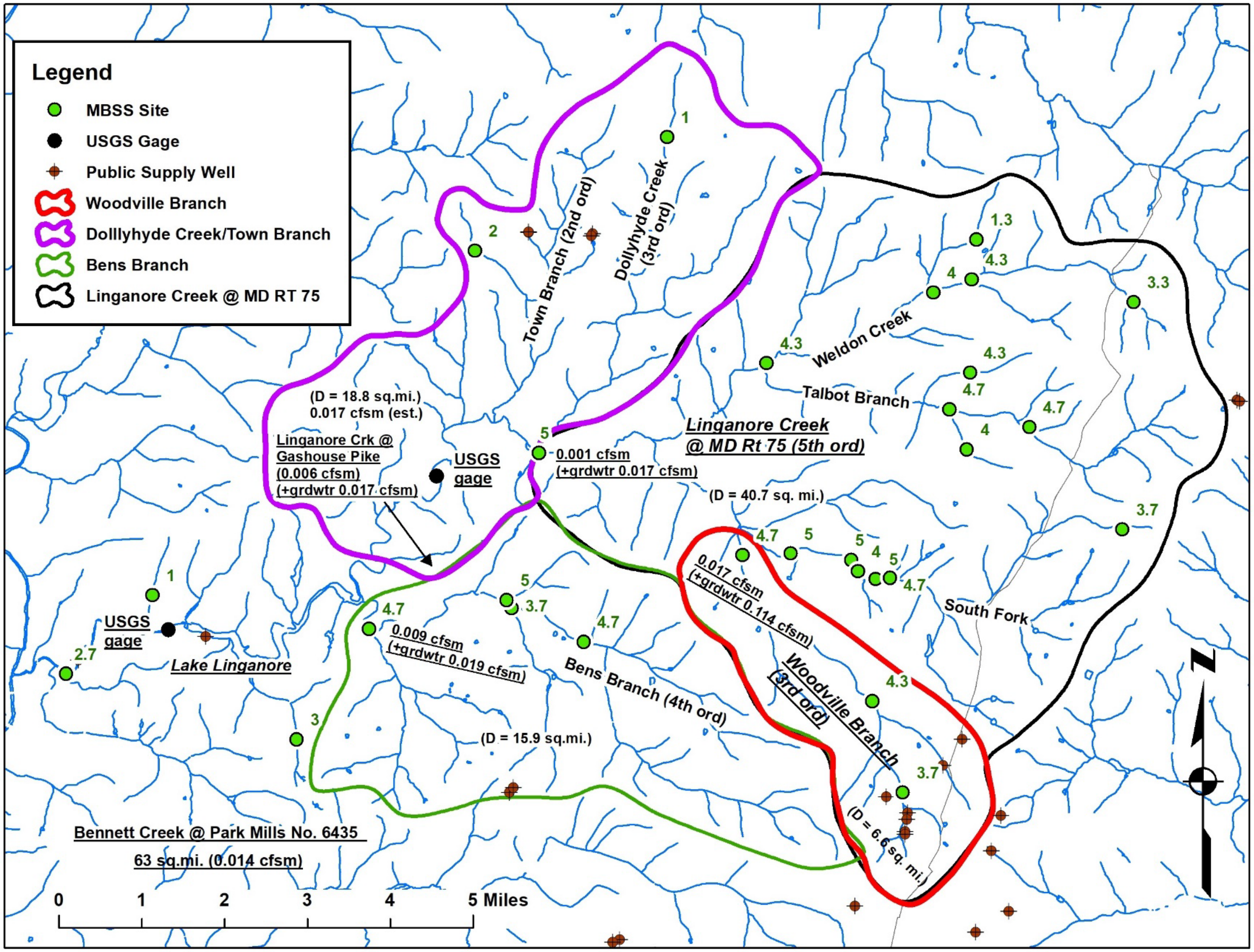


**Figure 9.** Linganore Creek MBSS sites with FIBI scores and streamflow measurements 1996-2012.

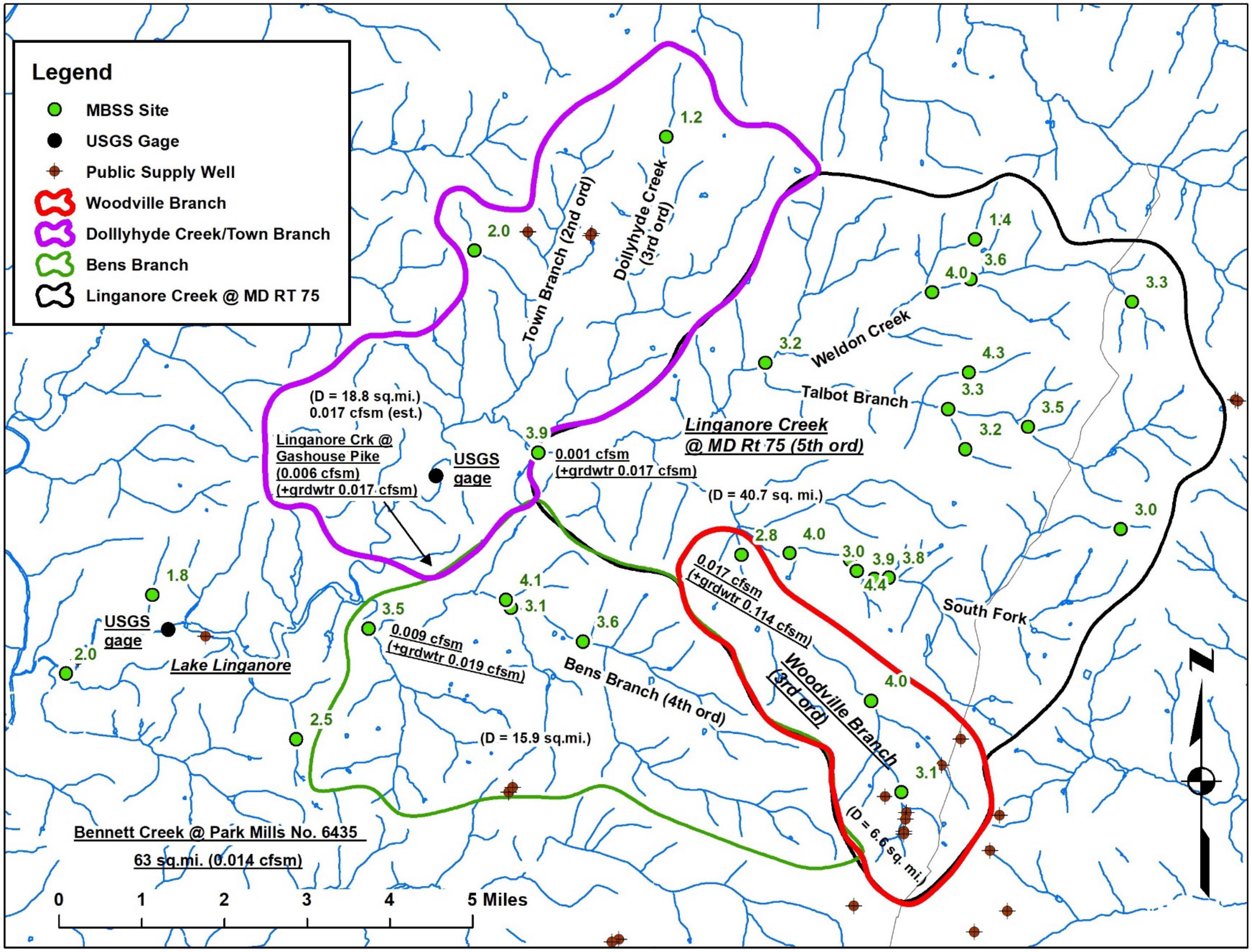


**Figure 10.** Linganore Creek MBSS sites with CIBI scores and streamflow measurements 1996-2012.

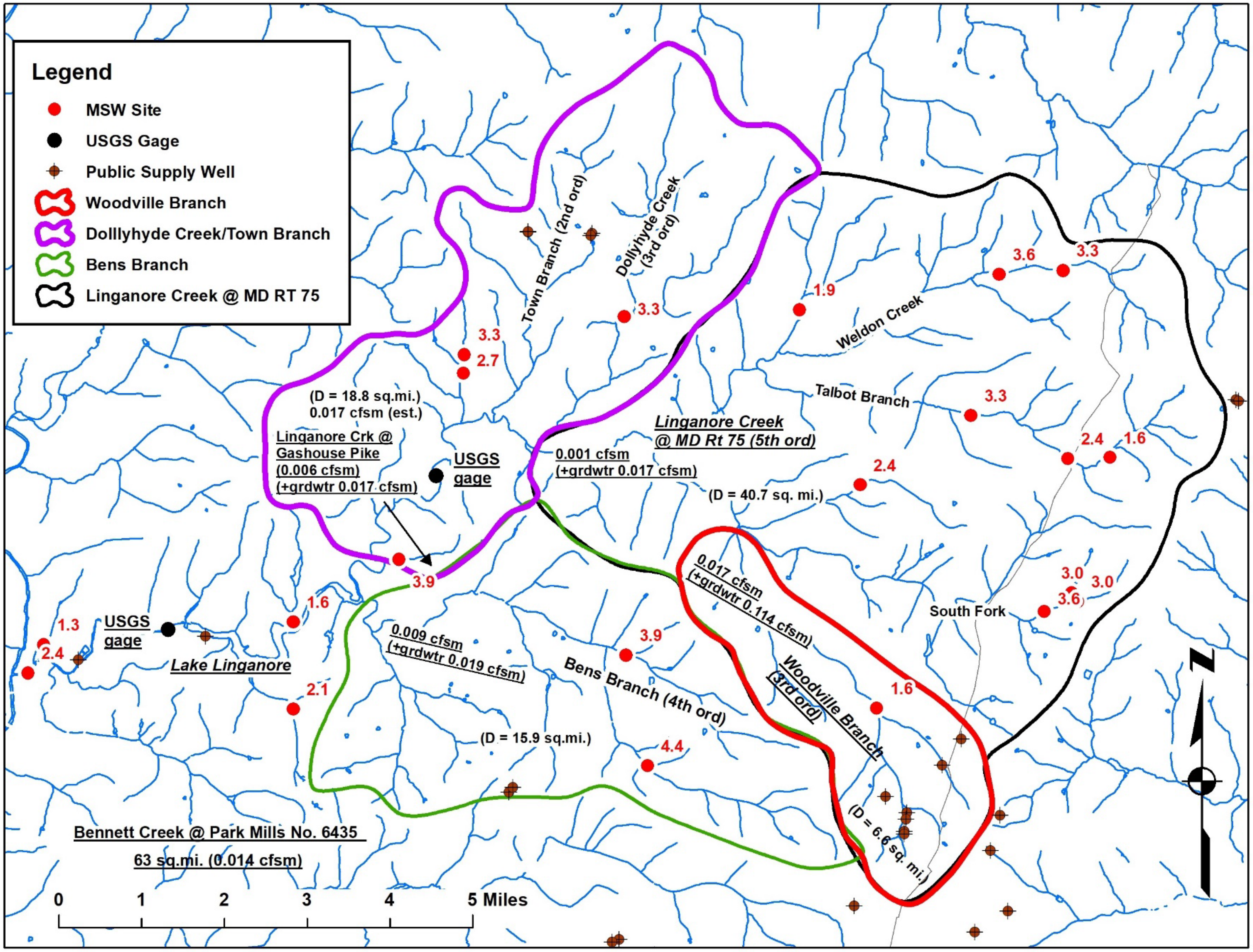


**Figure 11.** Linganore Creek MSW sites with BIBI scores and streamflow measurements 1996-2012.

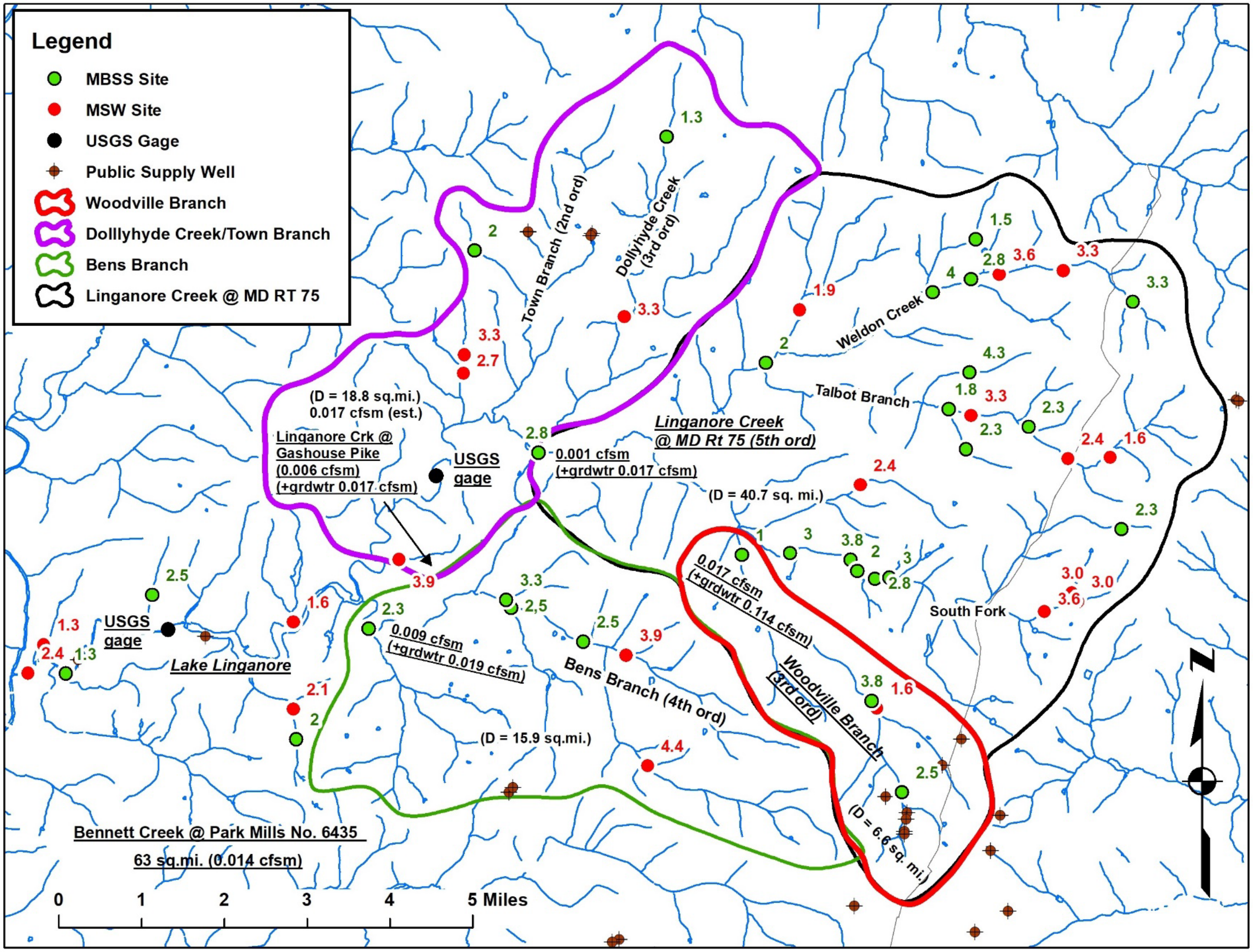


**Figure 12.** Linganore Creek MBSS and MSW sites with BIBI scores and streamflow measurements 1996-2012.

# Dry Seneca Creek-Horsepen Branch-Broad Run, Poolesville Case Study

In the 1980s acid rain from electric power plants was recognized as one of the most important environmental problems in Maryland. What data that were available on the adverse biological effects of low pH could not be used to compare conditions across regions or watersheds, because of the different methods used and spatial coverage limitations. This led to the creation of the MBSS program in 1989 to provide information on the status of biological resources in Maryland streams and the cumulative effects of acidic deposition and other anthropogenic stresses. In addition, the Clean Water Act requires each state to determine if water quality standards related to aquatic life were being attained and to submit a biennial list of impaired waters to the United States Environmental Protection Agency (USEPA). Other organizations such as county and municipal governments, regional water management authorities, and volunteer watershed groups also gather valuable stream monitoring data. In Montgomery County, the Department of the Environment (MODEP) and the volunteer Maryland Stream Waders (MSW) organization collect other such data that can be used to augment the MBSS program. Tributaries and the main stem of each stream in the Poolesville area were sampled in 1997 during the initial MBSS (1994-97) study, Figure 13 and Table 5. Where less than three years of data is available, acceptable scores are 2.65 for BIBI and 2.50 for FIBI.

Horsepen Branch flows south of Poolesville. Near Tom Fox and Hughes Road, the channel is stormwater-dominated, with dry upstream areas. Erosion is present on large parts of the channel due to downcutting and a lack of adequate buffer to provide bank stabilization. One branch flows through a large impoundment located on the Poolesville Public Golf Course. Further downstream, there is an abrupt transition in geology from the sandstone-based upland areas to the alluvial sediments of the Potomac River floodplain. The lower portion of the watershed is subject to backwater flow from the Potomac River during flooding, resulting in sedimentation and bank erosion. Much of the watershed tends to dry up almost completely in the summer likely due to the drought-sensitive underlying geology of the New Oxford Formation. Horsepen Branch UT2 UT1, site D, was impaired (BIBI-1.25, FIBI-1.33) and is a shallow stream in a wildlife management area that had many problems. It had an elevated sulfate concentration and a poor physical habitat score due primarily to instream habitat, pool/glide/eddy quality, and channel alteration, had no riparian buffer, and was directly adjacent to a gravel road. Site A is the most upstream site (D.A., 774 ac) and was impaired (BIBI-1.50, FIBI-1.0). Flows appear the have been reduced by more than 50% due to Poolesville's withdrawals on the sample date and the stream was reported dry at other times. Runoff could also have cause problems as 20% of the subwatershed was in urban development. Sites B, C and E were all in the alluvial plain. Each had low flows relative to the applicable USGS stream gage data. It is possible the stream flow slows due to the change in hydraulic gradient upon entering the alluvial plain and is affected by the presence of several large upstream impoundments. Each site had poor BIBI scores, but fair to good FIBI scores. It is unclear why the BIBI scores were so low. MBSS notes indicate that site B had a deep and narrow channel, with heavy siltation, at site C beavers were present and sampling was difficult, while site E had a deep channel with slow flow. Except for site A, the effects of water withdrawals and urban development were likely not significant. It is possible that backwater from Potomac River flooding and the resulting erosion and sedimentation caused the degraded habitat.

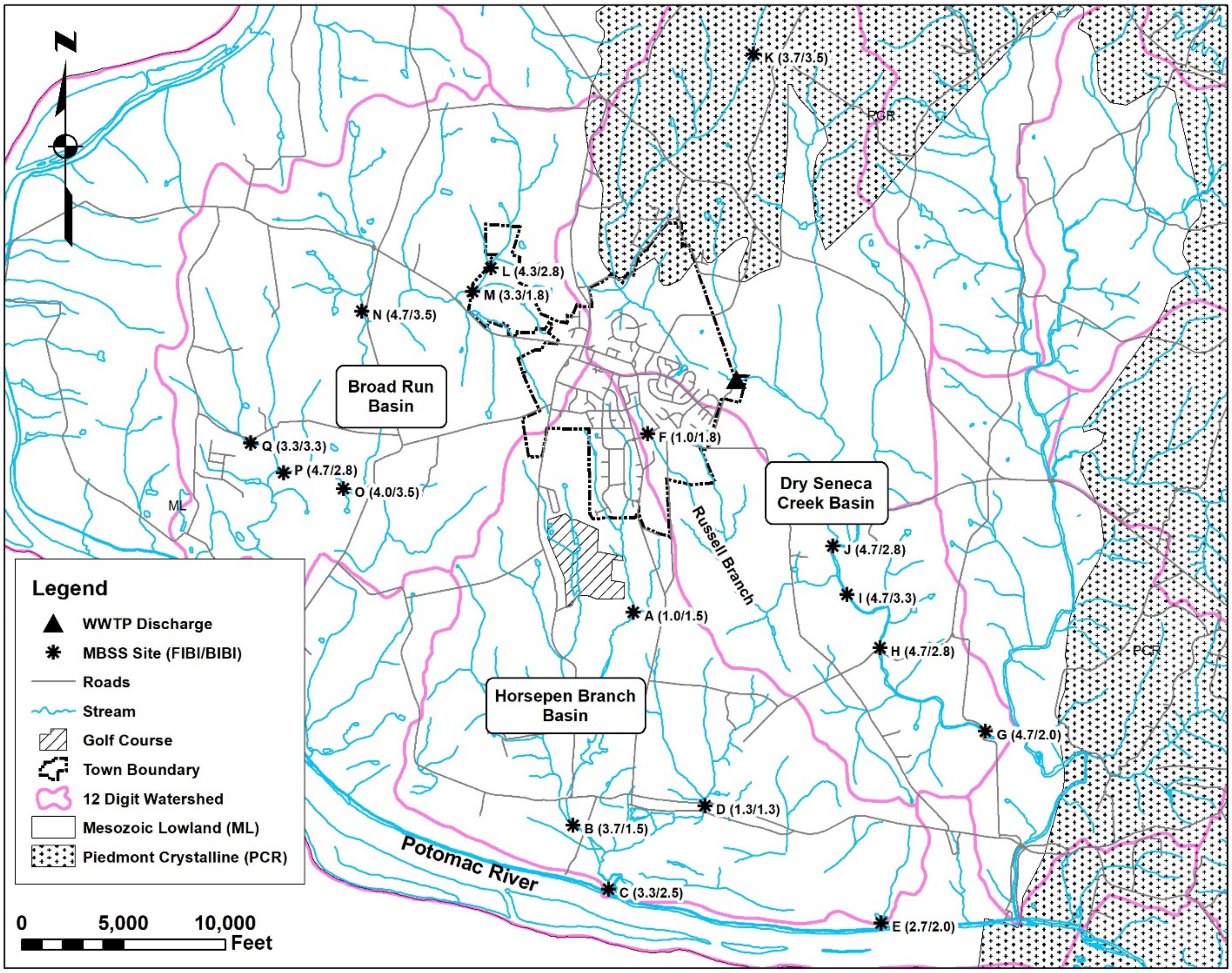


**Figure 13.** Map of the Dry Seneca Creek, Horsepen Branch and Broad Run watersheds in the vicinity of Poolesville, including MBSS sites with FIBI and BIBI scores.

The headwaters of Broad Run begin west of the Town of Poolesville. Land use has historically been agricultural in this area and that has little changed in over 100 years. A forested stream buffer provides protection along many stretches of Broad Run. From samples taken in Broad Run during 1997, sites L (UT1), P (main stem) and Q (UT2 UT1) were unimpaired. Site M (UT1) was impaired (BIBI-1.75); however, there was a beaver pond present. Sites N and O were unimpaired when sampled in 2001.

**Table 5.** MBSS data for Horsepen Branch, Russell Branch, Dry Seneca Creek, and Broad Run, including stream gage data and water withdrawals.

| Map ID | SITE_YR | Stream_Name | DATE_SUM | D.A. (acres) | Disch CFS | Use CFS | Disch cfsm | Use cfsm | Disch+Use cfsm | Stream Gages | Gage Disch cfsm | 7Q10 cfsm | bibi_05 | FIBI_05 | CIBI | PHI_98 | PHI_05 | Urban% | AG% | Forest% | $NO_3$ mg/L | Significant Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | PRMO-209-R-2008 | Horsepen Branch | 7/9/2008 | 774 | 0.12 | 0.17 | 0.10 | 0.14 | 0.24 | 6390/6440/6450 | *0.11/0.18/0.74 | | 1.50 | 1.00 | 1.25 | - | - | 20.3 | 55.8 | 20.7 | 2.9 | |
| B | PRMO-313-R-2002 | Horsepen Branch | 6/11/2002 | 3,803 | 0.12 | 0.25 | 0.02 | 0.04 | 0.06 | 6390/6440/6450 | *0.12/0.18/0.34 | 0.0004/ 0.0007/ 0.067 | 1.50 | 3.67 | 2.58 | 30.5 | 75.3 | 3.0 | 57.7 | 37.8 | 0.6 | Heavy silt, channel deep&narrow |
| C | COCA-307-N-2003 | Horsepen Branch | 8/7/2003 | 8,296 | 0.37 | 0.22 | 0.03 | 0.02 | 0.05 | 6390/6440/6450 | *0.16/**1.0/**0.8 | | 2.50 | 3.33 | 2.92 | - | 57.3 | 1.4 | 46.5 | 50.1 | 0.3 | Beavers present, hard to sample |
| | | | | | | Wells 2(1/4),4(1/2),6(2/3),8(1) | | | | | | Average | 1.83 | 2.67 | 2.25 | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| D | MO-P-436-226-97 | Horsepen Branch UT2 UT1 | 6/5/1997 | 1,127 | 0.02 | 0 | 0.01 | 0 | 0.01 | 6390/6440/6450 | **0.7/**0.6/**0.9 | | 1.25 | 1.33 | 1.29 | 6.0 | - | 0.1 | 51.6 | 48.3 | 1.5 | Many problems, see remarks*** |
| E | COCA-205-N-2003 | Horsepen Branch UT2 | 8/7/2003 | 1,252 | 0.4 | 0 | 0.20 | 0 | 0.20 | 6390/6440/6450 | *0.16/**1.0/**0.8 | | 2.00 | 2.67 | 2.33 | - | 60.1 | 0.0 | 28.8 | 70.1 | 0.0 | Deep, slow flow |
| | | | | | | | No wells | | | | | 0.0004/ 0.0007/ 0.067 | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| F | SENE-112-R-2001 | Russell Branch | 7/9/2001 | 76 | 0 | 0.2 | 0 | 1.7 | 1.7 | 6390/6440/6450 | *0.10/**0.6/**2.1 | | 1.75 | 1.00 | 1.38 | 16.2 | 47.6 | 46.9 | 44.0 | 9.1 | 1.5 | Near zero flow |
| | | | | | | Wells 2(1/4) 3(1/3),6(1/3),7(1) | | | | | | | | | | | | | | | | |
| | | Stream (WWTP Discharge) | | | (-WWTP) | | | | | | | | | | | | | | | | | |
| G | MO-P-102-308-97 | Dry Seneca Creek (0.68 cfs) | 7/7/1997 | 12,253 | 0.46* | 0.17 | 0.02 | 0.01 | 0.07** | 6390/6440/6450 | *0.08/0.13/0.45 | | 2.00 | 4.67 | 3.34 | 59.0 | - | 1.9 | 67.0 | 30.3 | 2.5 | NO-NO3 elevated, large cropland |
| H | MO-P-190-302-97 | Dry Seneca Creek (0.59E cfs) | 6/25/1997 | 10,962 | 1.49* | 0.17 | 0.09 | 0.01 | 0.13** | 6390/6440/6450 | *0.09/0.20/0.50 | | 2.75 | 4.67 | 3.71 | 55.0 | - | 2.6 | 67.4 | 29.4 | 2.4 | |
| I | SENE-210-R-2001 | Dry Seneca Creek (0.72 cfs) | 8/7/2001 | 10,214 | 0.73* | 0.15 | 0.05 | 0.01 | 0.10** | 6390/6440/6450 | *0.01/0.12/0.34 | | 3.25 | 4.67 | 3.96 | 31.8 | 67.8 | 1.8 | 65.2 | 31.5 | 2.3 | Wooded corridor between farms |
| J | SENE-211-R-2001 | Dry Seneca Creek (0.72 cfs) | 8/8/2001 | 8,127 | 0.33* | 0.15 | 0.03 | 0.01 | 0.09** | 6390/6440/6450 | *0.01/0.10/0.32 | | 2.75 | 4.67 | 3.71 | 87.6 | 76.5 | 1.6 | 65.8 | 31.0 | 2.4 | |
| K | MO-P-311-112-97 | Dry Seneca Creek | 7/1/1997 | 759 | 0.2 | 0 | 0.17 | 0.00 | 0.17 | 6390/6440/6450 | *0.06/0.15/0.55 | | 3.50 | 3.70 | 3.60 | 58.0 | - | 0.1 | 86.3 | 11.9 | 1.6 | |
| | | | *Streamflow - WWTP discharge | | | Wells 2(1/4),3(2/3),5(1/2) | | | *includes WWTP discharge | | | Average | 2.85 | 4.48 | 3.66 | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| L | MO-P-514-116-97 | Broad Run ut1 | 7/15/1997 | 1,086 | 0.02 | 0.02 | 0.01 | 0.01 | 0.02 | 6390/6440/6450 | *0.04/0.06/0.38 | | 2.75 | 4.33 | 3.54 | 12.9 | - | 0.0 | 78.0 | 20.7 | 1.8 | |
| M | MO-P-016-227-97 | Broad Run ut1 | 6/19/1997 | 1,396 | 0.26 | 0.08 | 0.12 | 0.04 | 0.16 | 6390/6440/6450 | *0.21/**1.5/0.88 | | 1.75 | 3.33 | 2.54 | 22.2 | - | 1.3 | 75.0 | 22.3 | 1.8 | Beaver pond present |
| | | | | | | | Well 5-K(1/10), L(1/2) | | | | | Average | 2.25 | 3.83 | 3.04 | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| N | PRMO-110-R-2002 | Broad Run | 6/10/2002 | 1,576 | 0.41 | 0 | 0.17 | 0 | 0.17 | 6390/6440/6450 | *0.15/0.20/0.41 | | 3.50 | 4.67 | 4.09 | 63.3 | 77.6 | 0.0 | 68.8 | 27.6 | 0.7 | |
| O | PRMO-202-R-2002 | Broad Run | 6/24/2002 | 6,456 | 1.21 | 0.11 | 0.12 | 0.01 | 0.13 | 6390/6440/6450 | *0.09/0.23/0.36 | | 3.50 | 4.00 | 3.75 | 94.8 | 79.0 | 0.5 | 72.2 | 25.7 | 1.9 | |
| P | MO-P-206-311-97 | Broad Run | 6/17/1997 | 6,818 | 0.99 | 0.13 | 0.09 | 0.01 | 0.11 | 6390/6440/6450 | *0.19/0.24/0.63 | | 2.75 | 4.67 | 3.71 | 39.8 | - | 0.5 | 70.5 | 27.4 | 2.5 | |
| | | | | | | N&O-Wells 2(1/4),4(1/2),5(1/2) | | | | | | Average | 3.25 | 4.45 | 3.85 | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| Q | MO-P-496-215-97 | Broad Run ut2 ut1 | 6/17/1997 | 807 | 0.11 | 0 | 0.09 | 0 | 0.09 | 6390/6440/6450 | *0.19/0.24/0.63 | | 3.25 | 3.33 | 3.29 | 27.1 | - | 1.2 | 69.2 | 28.9 | 2.6 | Near road, NO-NO3 Hi, ANC low |

| Stream Gages | |
|---|---|
| | 6390 - Monocacy River @ Bridgeport - ML; distance 40 mi |
| | 6440 - Goose Creek near Leesburg (VA) - PCR/ML; distance 10 mi |
| | 6450 - Seneca Creek @ Dawsonville - PCR; distance 4 mi |

| PHI Scoring | |
|---|---|
| Score | Narrative Rating |
| 81-100 | Minimally Degraded |
| 66.0-80.9 | Partially Degraded |
| 51.0-65.9 | Degraded |
| 0-50.9 | Severely Degraded |

| BIBI/FIBI/CIBI(IBI) Scoring | |
|---|---|
| Score | Narrative Rating |
| 5.00-4.00 | Good |
| 3.99-3.00 | Fair |
| 2.99-2.00 | Poor |
| 1.00-1.99 | Very Poor |
| Less than 3 years of data Minimum acceptable scores BIBI=2.65 and FIBI=2.50 | |

* - flows reflect baseflow, except where indicated otherwise

** - flows affected by storm

***Shallow stream in a Wildlife Management Area. Sulfate concentration elevated. Poor physical habitat score due primarily to instream habitat, pool/glide/eddy quality, and channel alteration. No riparian buffer, directly adjacent to a gravel road.

Discharge + Use matches fairly well either 6390 or 6440 data, but not 6450; difference is probably due to higher storage capacity in the crystalline rock Seneca Creek watershed

WWTP discharges to Dry Seneca Creek above all MBSS sites in that basin

About 10-15% reduction in flow due to withdrawals in Broad Run; except site K, which had 44% reduction in flow (IBI = 3.54), but error in estimating withdrawal could be substantial

Horsepen Branch - Site A, no apparent reduction in flow, possible perched basin; sites B & C, discharge + use substantially less than flows at gages

Russell Branch - very small watershed in center of Town's well field, probable exceptional reduction in flow due to withdrawals

MODEP (Dorsey, 2001) monitored seven stations in Broad Run for benthic macroinvertebrates (collected in March -April 2000) and fish (surveyed in June-July 2000), Table 6 and Figure 14. Most of the stations had ratings for both fish and habitat conditions as fair to good. Overall, there appeared to be no water quality parameters causing impairment of the stream. Physical chemistry samples were within COMAR's parameters derived by MDE. The temperatures recorded from the beginning of June through the end of September 2000 also did not reveal any hot or cold peaks that may affect the overall biological community. One station, BR201, was evaluated during the fall for quantitative habitat analysis. It was a low flow station and may not have been able to sustain an adequate fish habitat for a wide diversity of fish species. That station was moderately entrenched and had confined fast floodwater, allowing for the likelihood that pioneering species would be found within the active channel. At site BRBR302 both the fish and benthos scored lower than expected but showed no physical signs for impairment. The station was located on a farm, with a small riparian buffer, where there could have been a fish blockage downstream, or chemicals released upstream. MODEP recommended that agricultural management plans be reviewed to ensure the least amount of impairment by runoff. Sites BR201 and BR 302 were located 2-3 miles west of the trough of depression formed by the Poolesville well field and outside of the influence of runoff from the town's impermeable surfaces, factors which could not be causes for impairment to the aquatic habitat of Broad Run. In general, there is relatively good agreement between the results of the various sampling programs (MBSS, MODEP and MSW). All indicate that the Broad Run aquatic habitat is largely unimpaired, and none made the case that runoff from urban areas or withdrawals for the Poolesville public water supply wells have impacted the watershed.

**Table 6.** MODEP biological assessment data for Broad Run.

| MODEP 2000 Broad Run Biological Assessment Survey | | | | | | |
|---|---|---|---|---|---|---|
| Benthic Macroinvertebrates | | | | Fish | | |
| Site | | | | Site | | |
| BR # | Habitat (%) | Biological (%) | | BR # | Habitat (%) | Biological (%) |
| BR 106 | 72 | 80 | | BR 106 | 71 | 74 |
| BR 201 | 67 | 86 | | BR 201 | 69 | 24 |
| BR 302 | 67 | 45 | | BR 302 | 71 | 38 |
| BR 401 | 59 | 85 | | BR 401 | 65 | 68 |
| BR 403 | 75 | 54 | | BR 403 | 69 | 74 |
| BR 406 | 71 | 65 | | BR 406 | 68 | 74 |
| BR 409 | 74 | 60 | | BR 409 | 84 | 74 |

| Habitat Upper Limits (%) | | | |
|---|---|---|---|
| Poor | Fair | Good | Excellent |
| 25-30 | 50-57 | 77-83 | 100 |
| | | | |
| **Biological Upper Limits (%)** | | | |
| Poor | Fair | Good | Excellent |
| 42-44 | 66-68 | 88-90 | 100 |

In Dry Seneca Creek during a 1997 survey, the upstream MBSS site K (BIBI-3.50, FIBI-3.70) and intermediate site J (BIBI-2.75, FIBI-4.67) were unimpaired. The downstream site (G) was impaired (BIBI-2.00), but this was likely due to elevated NO-$NO_3$ concentrations from a large cropland area in the vicinity of the sampled site. Downstream flows include WWTP discharge, which when deducted indicate that the unit flows decrease downstream. This could reflect changes in lithology, since site K is upstream in a crystalline rock aquifer, which would tend to have more storage and higher permeability than the downstream consolidated sedimentary rock New Oxford Formation. However, the flows are not synoptic measurements, which would make it difficult to determine absolute differences. Follow on samples were collected downstream of the WWTP at sites I and J during the early part of the 2001-2002 drought. The results indicate that the stream was unimpaired (BIBI-3.25 and 2.75, FIBI-4.67 and 4.67). Conversely, sampling in 2000 by MODEP indicates that Dry Seneca Creek immediately below the WWTP discharge was impaired at site 307, Figure 15 and Table 7. MODEP indicated that the low scores are most likely due to impacts of runoff from the town of Poolesville, and the Poolesville WWTP outfall about 100 meters upstream of the sample site. Possible sanitary overflow from the WWTP outfall was observed by MODEP staff during the spring sampling period. However, Dry Seneca Creek was unimpaired further downstream at site 313.

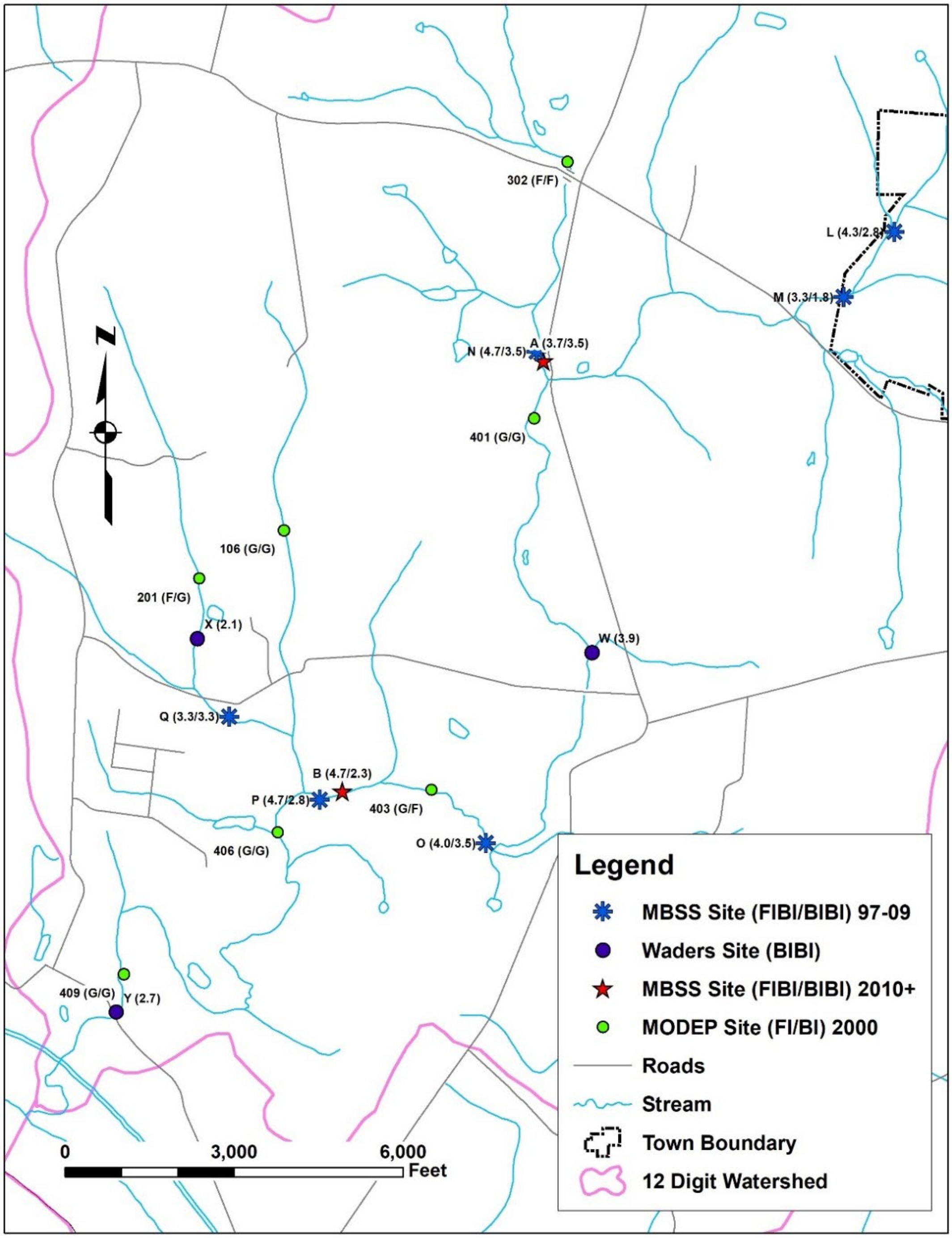


**Figure 14.** Broad Run MBSS sites with FIBI/BIBI scores, MSW (Waders) sites with BIBI scores, and MODEP sites with ratings (G-good, F-fair).

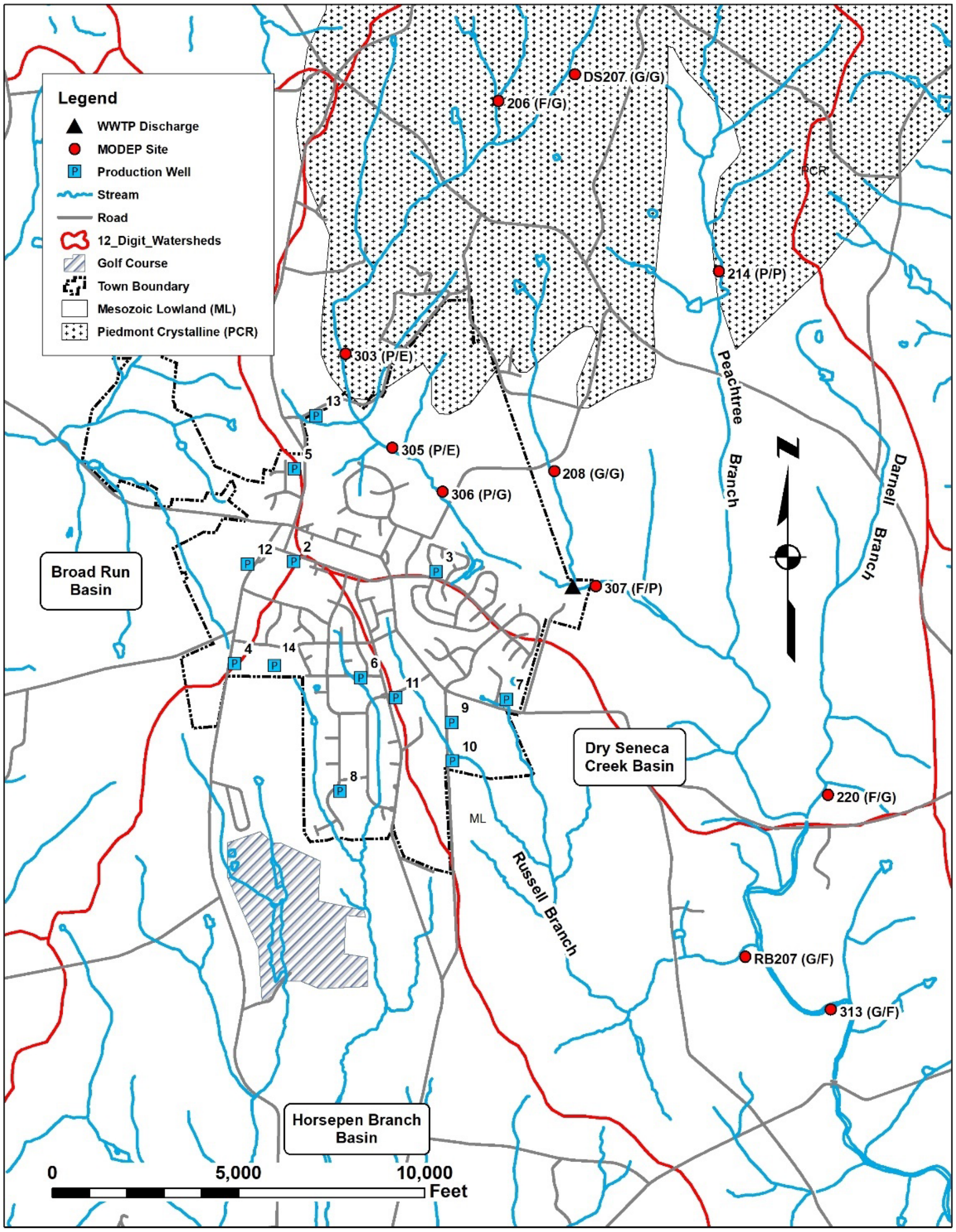


**Figure 15.** Dry Seneca Creek MODEP sites with ratings (E-excellent, G-good, F-fair, P-poor).

**Table 7.** MODEP biological assessment data for Dry Seneca Creek.

| MODEP Dry Seneca Creek Biological Assessment Survey | | | | | | |
|---|---|---|---|---|---|---|
| Benthic Macroinvertebrates | | | | Fish | | |
| Site | | | | Site | | |
| DS# | Habitat % | Biological % | | DS# | Habitat % | Biological % |
| DS 206 | 68 | 81 | | DS 206 | 75 | 56 |
| DS 207 | 72.5 | 85.5 | | DS 207 | 73 | 79 |
| DS 208 | 83.5 | 85.5 | | DS 208 | 77 | 69.5 |
| DS 214 | 63 | 25 | | DS 214 | 69.5 | 42.5 |
| DS 303 | 71 | 95 | | DS 303 | 61 | 34 |
| DS 305 | 71 | 90.5 | | DS 305 | 75 | 39 |
| DS 306 | 80 | 75 | | DS 306 | 67.5 | 34 |
| DS 307 | 66 | 40 | | DS 307 | 69.5 | 52 |
| RB 207 | 68 | 60 | | RB 207 | 69 | 79 |
| DS 220 | 71 | 75 | | DS 220 | 82 | 46 |
| DS 313 | 65 | 55 | | DS 313 | 69 | 81.5 |

| Habitat (%) Upper Limits | | | |
|---|---|---|---|
| Poor | Fair | Good | Excellent |
| 25-30 | 50-57 | 77-83 | 100 |

| Biological (%) Upper Limits | | | |
|---|---|---|---|
| Poor | Fair | Good | Excellent |
| 42-44 | 66-68 | 88-90 | 100 |

The Poolesville sequence batch reactor type WWTP was upgraded in 2010 to a biologically enhanced nutrient removal (ENR) system, Poolesville (2011). In addition, the WWTP utilizes multimedia pressure filters and ultraviolet disinfection prior to discharge into Dry Seneca Creek.

All the MSW sites sampled before 2010 upstream and downstream of the WWTP were unimpaired, Figures 16 and 17, and Table 8, except for the seventh most downstream one, site Q (BIBI - 1.3). Site G was closest site to the WWTP and was impaired (BIBI-1.3), but it was upstream of the plant and the sample was taken in 2013. There were two MBSS samples taken in 2015, Figure 18 and Table 9. The first site (E) downstream of the WWTP was unimpaired (BIBI-3.0), while the most downstream site (D) was slightly impaired (BIBI-2.5). Table 10 provides water chemistry, physical habitat, and stream flow data in Dry Seneca Creek before and after the 2010 construction of the ENR system. They indicate that the Total Nitrogen (TN), Phosphorus (TP), $NO_2$, and $NO_3$ concentrations declined by amounts equal to or greater than 50% after 2010. Prior to 2010, the lowest $NO_3$ concentration (1.63 mg/L) was at site K; upstream of the WWTP; however, it was greater than the post-2010 concentrations downstream of the WWTP. This was likely due to farming activity since the major land use (86.3%) was agriculture in the watershed above the sampling point. These data indicate that the addition of the ENR treatment system had significantly improved the quality of the aquatic habitat downstream of the WWTP. It is also noted that none of the stream samples exceeded the $NO_3$ concentration limit of >3.0 mg/L

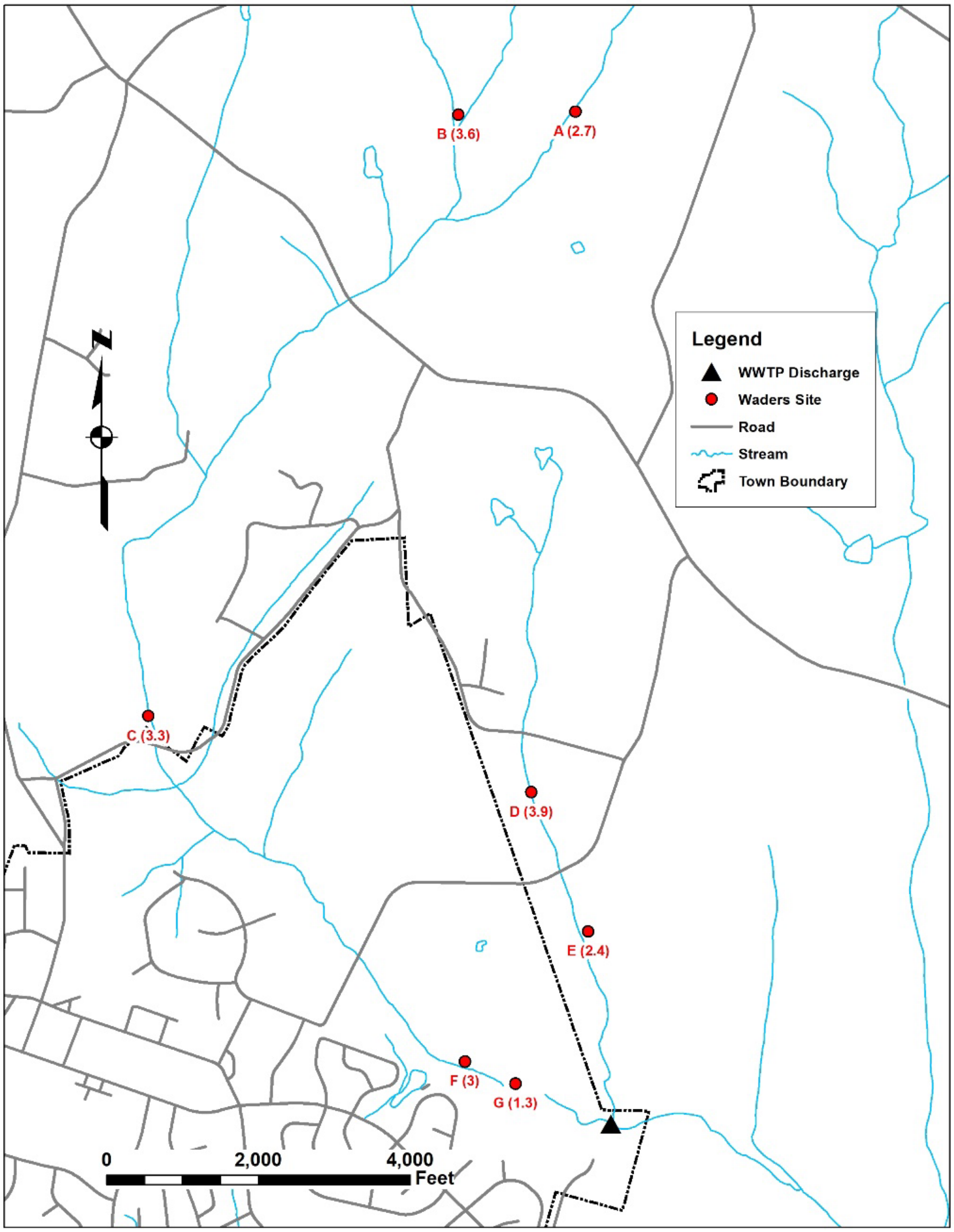


**Figure 16.** Map of MSW (Waders) sites above the Poolesville WWTP with BIBI scores.

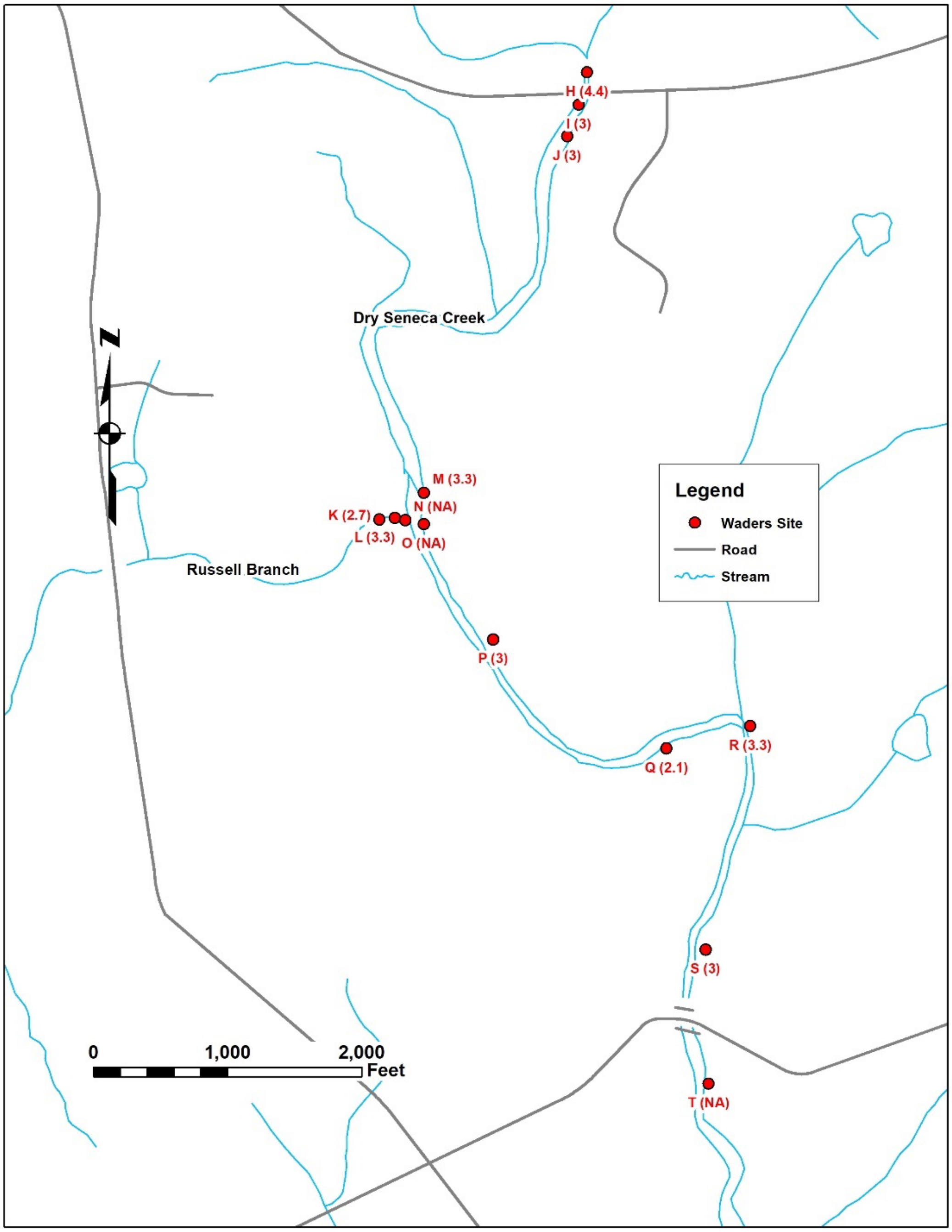


**Figure 17.** Map of MSW (Waders) sites below the Poolesville WWTP with BIBI scores.

**Table 8.** MSW (Waders) BIBI data for Broad Run, Horsepen Branch, Russell Branch, and Dry Seneca Creek.

| Map ID | Watershed | BIBI | Location |
|---|---|---|---|
| | *Broad Run* | | |
| Y | 0851-01-2010 | 2.71 | River Rd-South |
| W | 0851-03-2010 | 3.86 | Club Hollow Rd |
| | *Broad Run UT* | | |
| X | 0851-02-2010 | 2.14 | Club Hollow Rd |
| | | | |
| | *Horsepen Branch* | | |
| U | 0850-01-2010 | 3 | Sycamore Landing Rd |
| | Horsepen Branch UT | | |
| V | 0850-02-2010 | 1.86 | Koteen Way & Hillary St |
| | | | |
| | *Russell Branch* | | |
| K | 0855-02-2009 | 2.71 | Partnership Rd |
| N | 0855-01-2012 | N/A | Partnership Rd |
| L | 855-4-2001 | 3.29 | Sugarland Rd |
| | | | |
| | *Dry Seneca Creek* | | |
| S | 0855-01-2009 | 3 | Sugarland Rd |
| O | 0855-02-2012 | N/A | Partnership Rd |
| M | 0855-03-2009 | 3.29 | Partnership Rd |
| T | 0855-03-2012 | N/A | Sugarland Rd |
| R | 855-1-2001 | 3.29 | Sugarland Rd |
| Q | 855-2-2001 | 2.14 | Sugarland Road |
| P | 855-3-2001 | 3 | Sugarland Rd |
| J | 855-5-2001 | 3 | Whites Ferry Rd |
| F | 0856-01-2009 | 3 | Seneca Chase Park Rd |
| B | 0856-01-2013 | 3.57 | Rt 28 & RT 109 |
| D | 0856-02-2009 | 3.86 | Cattail Lane/Road |
| G | 0856-03-2013 | 1.29 | Wooton Ave/Spates Hill Rd |
| I | 856-1-2001 | 3 | Whites Ferry Rd |
| H | 856-2-2001 | 4.43 | Whites Ferry Rd |
| C | 856-3-2001 | 3.29 | Jerusalem Rd |
| A | 856-5-2001 | 2.71 | Peach Tree Rd |
| | *Dry Seneca Creek UT* | | |
| E | 856-4-2001 | 2.43 | Cattail Rd |

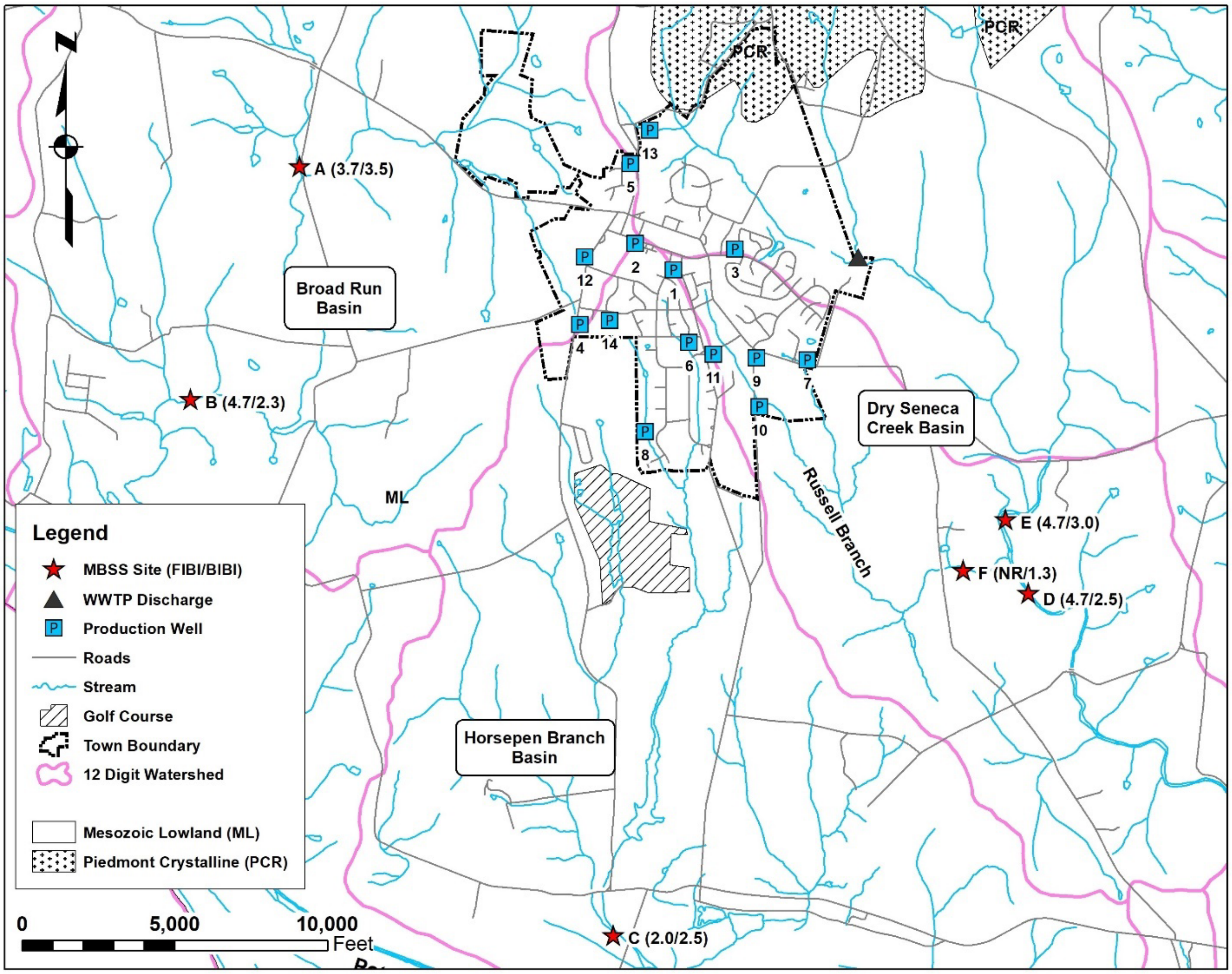


**Figure 18.** Map of MBSS data sampled in 2015-2017, with FIBI/BIBI scores.

**Table 9.** MBSS data sampled in 2015-2017 from Broad Run, Horsepen Branch, Russell Branch and Dry Seneca Creek.

| Site | Map ID | FIBI | BIBI | D.A. | Urban | AG | Forest | $NO_3$ | Spring | Summer |
|---|---|---|---|---|---|---|---|---|---|---|
| **Broad Run** | | | | | | | | | | |
| PRMO-311-R-2017 | B | 3.7 | 3.5 | 6,819 | 6.3 | 65.8 | 25.2 | 1.2 | 3/13/2017 | 7/13/2017 |
| PRMO-110-R-2016 | A | 4.7 | 2.3 | 1,572 | 5.4 | 64.1 | 19.5 | 1.1 | 3/8/2016 | 6/24/2016 |
| **Horsepen Branch** | | | | | | | | | | |
| PRMO-313-R-2016 | C | 2 | 2.5 | 3,803 | 15.4 | 44.2 | 33 | 0.8 | 3/8/2016 | 6/16/2016 |
| **Russell Branch** | | | | | | | | | | |
| SENE-198-B-2012 | F | N/R | 1.3 | 1,942 | 11.8 | 54.4 | 31.3 | 1.4 | 3/8/2012 | N/R |
| **Dry Seneca Creek** | | | | | | | | | | |
| SENE-210-R-2015 | D | 4.7 | 2.5 | 10,214 | 11.2 | 57.9 | 28.8 | 2.3 | 4/15/2015 | 8/5/2015 |
| SENE-211-R-2015 | E | 4.7 | 3 | 8,127 | 11.5 | 58.1 | 28.3 | 1.3 | 4/16/2015 | 8/5/2015 |

**Table 10.** Water chemistry, physical habitat, and streamflow data in Dry Seneca Creek before and after the construction of the Poolesville WWTP ENR system.

| Site | FIBI | BIBI | D.A. | PHI-98/05 | Urban | AG | Forest | NO2 | NO3 | TN | TP | Flow | wwtp | Flow-wwtp | Unit Flow | Stream Gages | Gage Disch Unit Flow | Date |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number | | | Acres | | % | % | % | mg/L | mg/L | mg/L | mg/L | cfs | cfs | cfs | cfsm | Number | cfsm | |
| Pre-2010 | | | | | | | | | | | | | | | | | | |
| MO-P-102-308-97 | 4.67 | 2 | 12,253 | 59/- | 1.9 | 67 | 30.3 | N/R | 2.47 | N/R | N/R | 1.14 | 0.68 | 0.46 | 0.024 | 6390/6440/6450 | *0.08/0.13/0.45 | 7/7/1997 |
| MO-P-190-302-97 | 4.67 | 2.75 | 10,962 | 55/- | 2.6 | 67.4 | 29.4 | N/R | 2.37 | N/R | N/R | 2.08 | 0.59E | 1.49 | 0.087 | 6390/6440/6450 | *0.09/0.20/0.50 | 6/25/1997 |
| MO-P-311-112-97 | 3.7 | 3.5 | 759 | 58/- | 0.1 | 86.3 | 11.9 | N/R | 1.63 | N/R | N/R | 0.2 | N/A | 0.20 | 0.169 | 6390/6440/6450 | *0.06/0.15/0.55 | 7/1/1997 |
| SENE-210-R-2001 | 4.67 | 3.25 | 10,214 | 32/68 | 1.8 | 65.2 | 31.5 | 0.071 | 2.26 | 2.72 | 0.07 | 1.45 | 0.72 | 0.73 | 0.046 | 6390/6440/6450 | *0.01/0.12/0.34 | 8/7/2001 |
| SENE-211-R-2001 | 4.67 | 2.75 | 8,127 | 88/77 | 1.6 | 65.8 | 31 | 0.077 | 2.37 | 3.04 | 0.095 | 1.05 | 0.72 | 0.33 | 0.026 | 6390/6440/6450 | *0.01/0.10/0.32 | 8/8/2001 |
| Post-2010 | | | | | | | | | | | | | | | | | | |
| SENE-210-R-2015 | 4.7 | 2.5 | 10,214 | N/R | 11.2 | 57.9 | 28.8 | 0.026 | 1.11 | 1.43 | 0.022 | 1.65 | 0.55 | 1.10 | 0.069 | 6390/6440/6450 | *0.11/0.12/0.58 | 8/5/2015 |
| SENE-211-R-2015 | 4.7 | 3 | 8,127 | N/R | 11.5 | 58.1 | 28.3 | 0.039 | 1.22 | 1.62 | 0.018 | 1.5 | 0.55 | 0.95 | 0.075 | 6390/6440/6450 | *0.11/0.12/0.58 | 8/5/2015 |

Immediately upstream of the WWTP, MODEP sites 303, 305 and 306 had poor fish scores, but good to excellent benthic macroinvertebrate results. MODEP attributed this to the recovery from the 1999 drought. This may have been possible since the Churchel and Batzer (2006) study indicated rapid recolonization of invertebrates occurred which stabilized after 165 days in the Georgia Piedmont streams to near pre-drought levels. It could have taken the fish some additional time to migrate from downstream refugia and repopulate the area above the Poolesville WWTP. Further upstream, at sites 206 and DS207 the fish scores were fair to good. Those sites were in a crystalline rock area, where the aquifer is expected to have higher sustained flows than the downstream consolidated sedimentary rock formation, which is characterized by low baseflow. The most upstream area may have been isolated from the effects of the drought providing adequate habitat for maintenance of the fish population. The one exception is site 303, but it is located near the boundary of the two formations, where a thin crystalline rock aquifer may overlie the consolidated sedimentary rock formation, which may have led to low flows during the drought.

The tributary Russell Branch enters Dry Seneca Creek downstream of the WWTP discharge. MBSS Sampling in 2001 produced a FIBI score of 1.0 and a BIBI score of 1.75 at site F, Figure 13, Table 5. This would indicate that the stream was impaired; however, the drainage area at the station was only 75 acres. Various State biologists have indicated that basins with such small drainage areas may have low indices but not be impaired. Another factor to consider is that land use in the watershed is 47% urban, 44% agricultural land and 9% forest, suggesting that runoff from impermeable surfaces may have degraded the aquatic habitat of the stream. There was no flow in the stream, which was likely due to either the small drainage area or groundwater withdrawals from nearby town public supply wells. A benthic study was completed in the watershed in the spring of 2012. The calculated BIBI, at a downstream station with a relatively large drainage area (1942 acres or 3.0 $mi^2$), was 1.25. Within the larger watershed the land use was: 11.8% urban, of which 7.5% was open space and 4.2% low density urban area. Due to budget constraints, the fall sampling could not be completed, and no flow measurements are available. MODEP data indicates Russell Branch (site RB207) was unimpaired during sampling in 2000 (FI-Good, BI-fair), Figure 15, Table 7. Samples collected by the MSW program in 2001 (site L, BIBI-3.29) and 2009 (site K-BIBI- 2.71), Figure 17, Table 8, also indicate that the stream was unimpaired. It is not likely that runoff from impermeable surfaces or decreased flow due to Poolesville withdrawals caused the impairment at the downstream MBSS site in Russell Branch. These inconsistencies in the benthic samples cannot be resolved without additional study.

Figure 19 is a map of the drawdowns in 4-5 May 2005, Yoxtheimer (2006) and Transmissivity (T) values, Hammond (2022), related to the testing and pumping of the Poolesville public water supply wells. Most of the water pumped comes from the areas with the greatest drawdown, such that most of it was taken from the upper reaches of Russell Branch and Horsepen Branch. There is a limited withdrawal from Dry Seneca Creek, even if Russell Branch is included. There is little water taken from the Broad Run watershed. It is unlikely that there would be any significant impacts to Dry Seneca Creek or Broad Run or that any changes in flow would be outside the margin of error for the typical devices used for streamflow measurements.

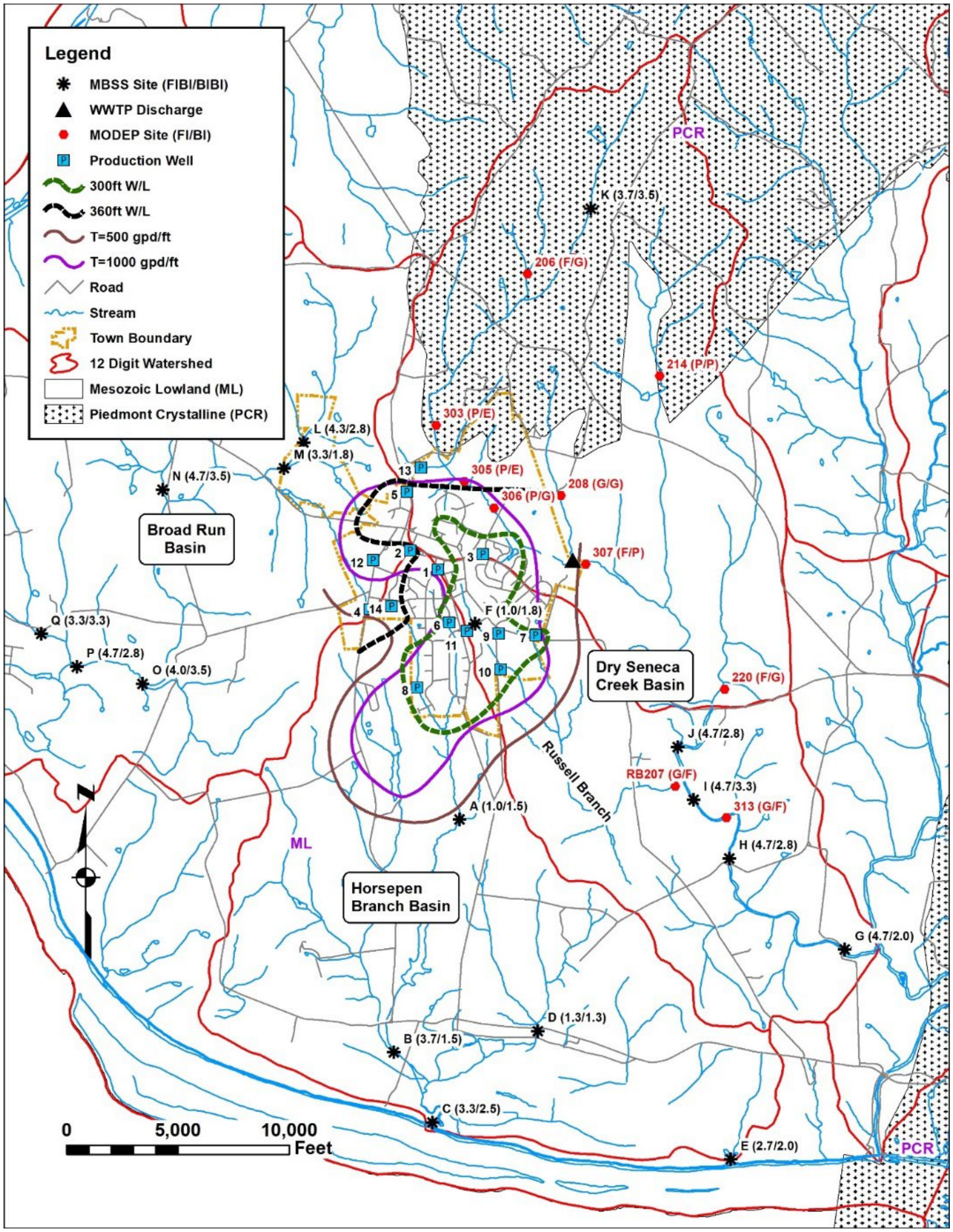


**Figure 19.** Map of MBSS sites, with FIBI/BIBI scores, MODEP sites, with FI/BI scores, and contours of water level drawdowns and transmissivity values resulting from withdrawals by Poolesville's public water supply wells.

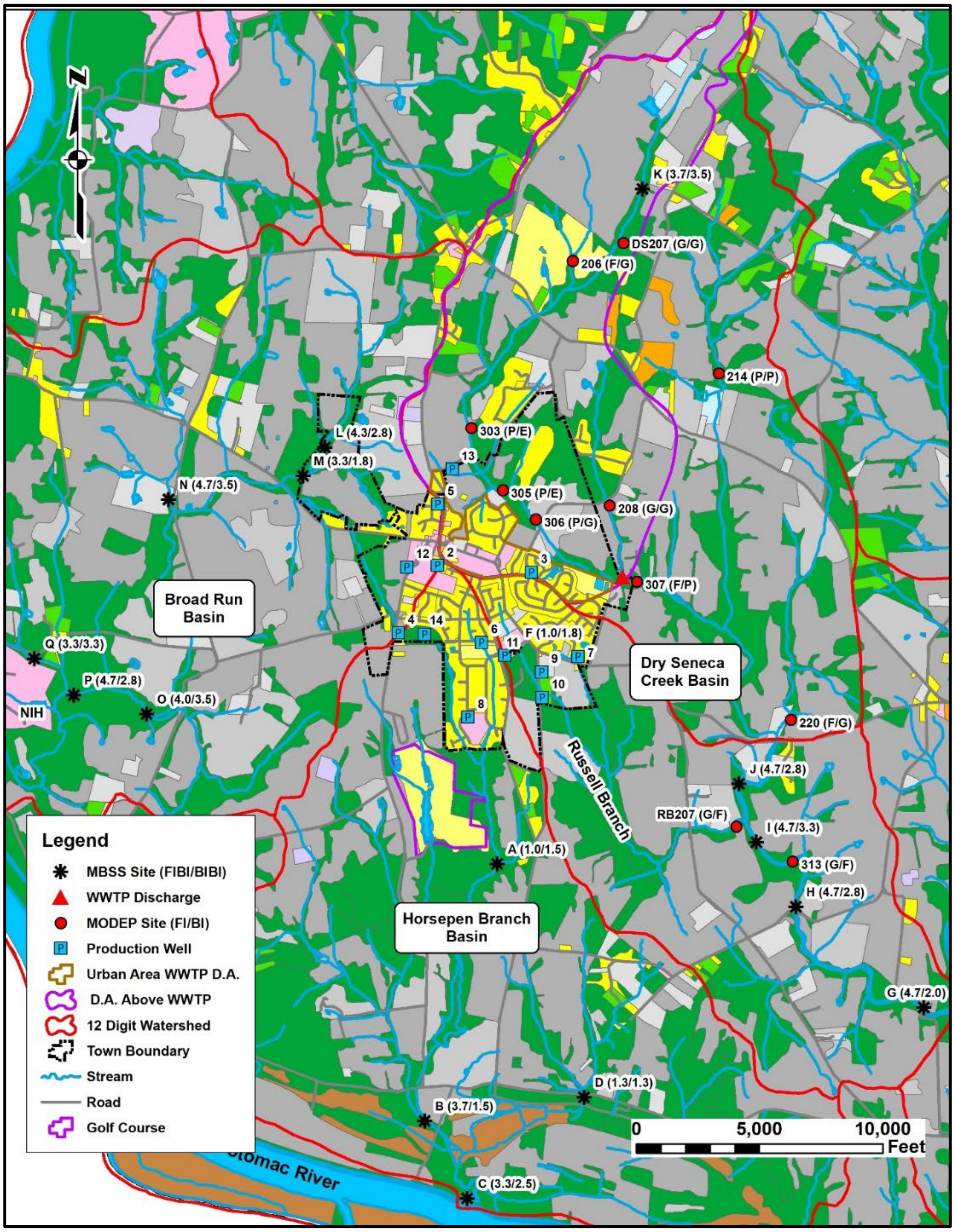


**Figure 20.** Map of the land use patterns in the Dry Seneca Creek, Horsepen Branch and Broad Run watersheds, with MBSS and MODEP sites, Poolesville's public supply wells, the drainage area above the WWTP and the urban land within that drainage area.

It was proposed that the urbanized areas of Poolesville and the WWTP discharge caused the degraded habitat below the WWTP. Figure 20 is a map of the land use patterns in the Dry Seneca Creek, Horsepen Branch and Broad Run watersheds. The drainage area in Dry Seneca Creek above the WWTP consists of 3848 acres of which, at present, 282 acres are in urban areas. However, only 130 acres of the drainage area at site J (above the confluence with Russell Branch) was in urban areas in 2001. As 9% of the town acreage consists of impervious surfaces, Poolesville (2011), that indicates that 0.3 % of the drainage area above the WWTP consists of impervious surfaces. It is unlikely that runoff from impervious surfaces is a significant factor causing degradation of Dry Seneca. Creek.

There are presently 165 acres of the town's urban area in the Broad Run basin. However, only about 1.2% (18 ac) of the drainage area above site M was in urban areas during sampling in in 1997. Also, 1.2% of the drainage area of site Q is urbanized, but that is at the National Institutes of Health property. Urban areas within the watersheds of the remaining sites (L, N, O and P) were 0-0.5%. These data also indicate that it is unlikely that runoff from impervious surfaces cause any degradation of aquatic habitat in the Broad Run basin.

In the case the upper reaches of Russell Branch and Horsepen Branch (MBSS sites A and F) there is significant urbanization, which in conjunction with the Poolesville water withdrawals may have led to the degradation at those locations.

## Piney Creek, Taneytown Case Study

Table 11 is a summary of the results of MBSS surveys conducted in the Piney Creek watershed near Taneytown in 1996 (6 samples), 2000 (1 sample) and 2004 (1 sample), while Figures 21, 22 and 23 show the locations and results of the sampling. Based on the single sample BIBI limit of 2.65, all sites were impaired. All are located outside of the capture zone of Taneytown well 14, except for site E, indicating that groundwater withdrawals from the well were not the cause of the degraded aquatic habitat. The most likely cause of the impacts was farming activity, as all sites had high $NO_3$ levels (>3.0 mg/L), except for sites C (2.1 mg/L) and D (3.0 mg/L). Based on the single sample FIBI limit of 2.50, none of the sites were impaired, except for site F. One possible explanation is that most of the samples were taken in 1996 during high flow periods. The one exception (FIBI-2.0) was the sample taken on 8/24/2004 at the site F, which had a low flow (0.01 cfs) and small drainage area (296 acres).

Table 12 and Figures 21 and 24 provide the locations and results of samples collected by the Maryland Stream Waders (MSW) program. At 8 of the 15 sites BIBI scores indicated that the stream was impaired. Sites 1 and 2 (impaired), and 8 and 9 (unimpaired) were effectively duplicate samples. The average BIBI score (2.0) of the 6 upstream MSW sites was like those of the 4 upstream MBSS sites (2.15), Figure 25. The 3 downstream MSW sites had an average score of 2.7 that was significantly higher than the 2 downstream MBSS sites (1.65). Near the capture zone of well 14, the 3 MSW samples had an average score of 3.5 that was much higher than the 1 MBSS sample (1.5).

In the immediate vicinity of well 13, the average of the 3 MSW sites (1.7) was lower than the 1 MBSS score (2.3). All sites had drainage areas less than 300 acres. Sites 11 and 12 had large majorities of the watersheds in cropland and were primarily affected by agricultural activity. Site 10 was in a highly urbanized watershed where runoff might have been a factor in the degraded watershed. Site F is in a forested watershed. While no records could be found for site G, it had a very small drainage area (65 acres) and, as a result, may have been impacted by a lack of streamflow.

The possibility that withdrawals from well 13 and the three ESAB (Elektrisha Svetsnings-Aktiebolaget or Electric Welding Limited Company) recovery wells may have impacted the aquatic habitat at the four MSW/MBSS nearby sites was investigated. The ESAB wells were not in service on any of the sampling dates of those sites. Well 10 was completed in 1967 in the consolidated sedimentary rock Triassic New Oxford Formation with a static water level (SWL) of 39 ft (12 m). The well was online from the 1960s to the early 1990s and was then taken out of service due to declining yields related to interference with well 13, located about ½ mile southwest of well 10. In 1999, the SWL in well 10 was 149 ft (45 m) or about 100 ft (30 m) below regional water levels, providing clear evidence of interference with well 13. Well 13 was completed in 1985 with a SWL level of 84 ft (25.6 m) during an aquifer test that was about 50 ft (15 m) below regional water levels, which was additional proof of interference with well 10.

Tetrachloroethylene (PCE) contamination was discovered in well 13 in 1987; however, the concentrations were below the Maximum Contaminant Level (MCL) of 5 μg/L until 2003. ESAB installed a treatment system and withdrawals from the recovery wells reduced the PCE levels of raw water samples taken from well 13 from an average of 12.1 μg/L (2003−2004) to an average of 4.7 μg/L (2005−2008). The remainder of the PCE was removed by a granulated activated charcoal treatment system. Well 13 has been out of service since 2009, due to radiological contamination (adjusted gross alpha radiation). Water levels in monitoring wells collected in the upper zone (depth ≤ 50 ft), Figure 26, indicated that the water table had a gradual hydraulic gradient, while the water levels in the deeper aquifer (depth >50ft), Figure 27, formed a steeper hydraulic gradient in the direction of well 13. The PCE concentration isopleths, Figures 28 and 29, show similar patterns. In the upper zone, the PCE contamination is drawn slightly to north direction, while the PCE in the lower zone is drawn west/southwest toward well 13, with a secondary direction to the north. One explanation is that from the spill site, the contaminant flowed initially to the north based on the hydraulic characteristics of the vadose (unsaturated) zone. Upon reaching the water table, it then moved in the direction of groundwater flow, while leaking slowly to the lower zone and then migrating to well 13. MW-D (depth of 30 ft) has highly variable PCE readings, with high values measured in 1999 (39.2 ppb) and 2001 (31.2 ppb) relative to AW-87-2 (depth 97 ft, dry and PCE not detectable). The upper zone appears to have a relatively low permeability, with residual PCE contamination, which is likely flushed into MW-D during recharge events. MW-C was a 51-ft well with PCE concentrations >500 ppb and the adjacent well MW-B was a 100-ft dry well. At both nested well sites, the upper zone appeared to be a perched water table, largely less affected by pumping of well 13 than the two dry wells in the lower zone. The decline in PCB levels in AW-87-2, from 18-23 ppb in 1987 to 3.4 ppb in 2003 probably reflects a change in hydraulic gradient due the pumping of well 13.

In 2010, well 10R was drilled as a replacement for well 10 (10 ft or 3 m away), primarily because there was a hole is the well 10 riser pipe that could not be repaired. The SWL was 29 ft (9 m) and had recovered about 120 ft (37 m) relative to the 1999 SWL in well 10, since well 13 was no longer interfering because it was out of service due to the radiological contamination. During a 72-hr aquifer test of well 10R, observation water levels were measured in Taneytown wells 9, 10, 11, 12 and 13, plus PCE monitoring wells AW-87-1 and MW-04-G, Figure 30. The drawdowns were 0-2 ft in wells 9, 11 and 12. In the pumping well 10R and well 10 the drawdowns were 180 ft and 130 ft, respectively. Significant drawdowns of 38 ft, 26 ft and 25 ft were observed in well 13, AW-87-1 and MW-04-G, respectively.

All the water level data indicate that there is a highly anisotropic aquifer connecting wells 10/10R and 13 along an approximate strike direction. Water supply wells 9, 11 and 12, and MSW sites 10 and 11 appear to have been outside or at the edge of the capture zone formed by withdrawals from supply wells 10, 10R and 13. Site F may be within the trough of depression; however, in October 2003, well 13 was taken off-line and was out of service until after May 2004, while the BIBI samples at site F were taken on 4/27/2004, so all of the wells that might have caused impacts to the site were off line when the sample was collected. In addition, the BIBI score at site F (2.25) was higher than the scores (1.6-1.9) outside of the capture zone of wells 10 and 13, while pumping from the ESAB wells did not start until January 2005. The ESAB recovery system also includes a 180-ft injection well and a shallow pond for the injection of the treated water.

Overall, stream impairment was indicated by the many low BIBI scores in the Piney Creek watershed, whether the sample sites were within or outside of the potential capture zones of wells 10, 10R, 13 and 14, and the ESAB recovery wells. A potential perched water table may also have reduced the impacts of withdrawals on streamflow from the Taneytown supply wells. The most common impairment factor was the elevated nitrogen levels at the sample sites due to agricultural activity. All FIBI scores were satisfactory (>2.50), except site F, which had a score of 2.0, but that site had a small drainage area, and the best information indicates that there were no water withdrawals within the vicinity of that site.

**Table 11.** MBSS data for Piney Creek, including stream gage data and water withdrawals.

| Map ID | SITEYR | StreamName | DATESUM | D.A. (acres) | Disch CFS | Use CFS | Disch cfsm | Use cfsm | Disch+Use cfsm | Gage | Gage cfsm | 7Q10 cfsm | BIBI 05 | FIBI 05 | CIBI | PHI 98 | PHI 05 | $SO_4$ mg/L | $NO_3$ mg/L | Urban % | AG % | Forest % | Sampler's Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | CR-P-156-361-96 | Piney Creek | 8/20/1996 | 6,919 | 9.56 | 0 | 0.88 | 0 | 0.88 | 6390 | *0.46 | | 2.50 | 5.00 | 3.75 | 92.20 | | 17.9 | 4.6 | 3.2 | 83 | 13.2 | Heavy agricutural activity, high nitrogen levels and cows have direct access to stream |
| B | CR-P-156-314-96 | Piney Creek | 8/20/1996 | 6,949 | 9.53 | 0 | 0.88 | 0.00 | 0.88 | 6390 | *0.46 | | 2.00 | 5.00 | 3.50 | 92.20 | - | 17.8 | 4.6 | 3.2 | 83 | 13.2 | |
| C | UMON-310-R-2000 | Piney Creek | 9/7/2000 | 11,531 | 0.92 | 0 | 0.05 | 0.00 | 0.05 | 6390 | *0.10 | | 1.75 | 4.00 | 2.88 | 31.30 | 69.8 | 14.7 | 2.1 | 2 | 81 | 15.8 | |
| D | CR-P-142-324-96 | Piney Creek | 8/6/1996 | 11,930 | 15.2 | 0 | 0.82 | 0.00 | 0.82 | 6390 | **0.55 | | 2.25 | 4.00 | 3.13 | 31.30 | - | 19.1 | 3.0 | 1.9 | 81 | 15.4 | |
| E | CR-P-406-102-96 | Piney Creek UT1 | 6/13/1996 | 422 | 0.3 | 0.61 | 0.45 | 0.93 | 1.38 | 6390 | **2.17 | 0.0004 | 1.50 | 3.33 | 2.42 | 27.90 | - | 28.5 | 5.5 | 0 | 91 | 9.5 | AG Use Hi. N-NO3 & SO4 Hi |
| F | UMON-197-E-2004 | Piney Creek UT | 8/24/2004 | 296 | 0.01 | 0.25 | 0.02 | 0.55 | 0.57 | 6390 | **0.41 | | 2.25 | 2.00 | 2.13 | NRF | 69.3 | 22.0 | 3.9 | 3.3 | 0.1 | 96.7 | |
| G | CR-P-042-101-96 | Piney Creek UT | NRF | 63 | NRF | NA | NA | NA | NA | NA | NA | | NRF | NRF | NRF | NRF | NRF | NRF | NRF | NRF | NRF | NRF | |
| H | CR-P-116-316-96 | Piney Creek | 8/7/1996 | 20,936 | 20.6 | 0.61 | 0.63 | 0.02 | 0.65 | 6390 | **0.90 | | 1.75 | 3.33 | 2.54 | 70.10 | - | 20.5 | 4.0 | 2.6 | 82 | 14.7 | High AG activity. Stong sewage smells (WWTP) |
| I | CR-P-116-327-96 | Piney Creek | 8/8/1996 | 20,988 | 16.3 | 0.61 | 0.50 | 0.02 | 0.52 | 6390 | **0.51 | | 1.50 | 4.00 | 2.75 | 79.70 | - | 20.4 | 4.0 | 2.5 | 82 | 14.8 | |

NRF - No Record Found; NA - Not Applicable

*Flows appear to reflect baseflow

**Flows affected by storms

$NO_3$ >2.8 mg/L poor; 1.8-2.8 mg/L fair to poor

$SO_4$ No national standard could be found, but a limit of 25 mg/L might be possible

**Table 12.** MSW BIBI data for Piney Creek.

| Map Id | Site No. | BIBI | Location | Watershed |
|---|---|---|---|---|
| 1 | 0266-02-2011 | 1.29 | 5200 FSK HWY | Piney Creek |
| 2 | 0266-03-2011 | 1.29 | 5200 FSK HWY | Piney Creek |
| 3 | 0257-01-2000 | 2.71 | FSK HWY | Piney Creek |
| 4 | 0257-03-2000 | 1.57 | FSK HWY | Piney Creek UT |
| 5 | 0257-04-2000 | 3 | Teeter Rd. | Piney Creek |
| 6 | 0257-05-2000 | 2.14 | Teeter Rd. | Piney Creek UT |
| 7 | 0255-04-2000 | 3.57 | Fringer Road | Piney Creek |
| 8 | 0255-03-2000 | 3.57 | Harney Road | Piney Creek |
| 9 | 0255-02-2000 | 3.29 | Harney/Walnut Grove Rds. | Piney Creek UT |
| 10 | 0255-01-2000 | 1.86 | Trevanian Rd. | Piney Creek UT |
| 11 | 0256-81-2004 | 1.57 | FSK HWY/Allendale Rd. | Piney Creek UT |
| 12 | 0254-04-2000 | 1.57 | FSK HWY | Piney Creek UT |
| 13 | 0254-02-2000 | 2.71 | Roop Rd. | Piney Creek UT |
| 14 | 0254-03-2000 | 2.43 | Roop Rd. | Piney Creek |
| 15 | 0254-03-2012 | 3.0 | Baumgartner Rd. | Piney Creek |

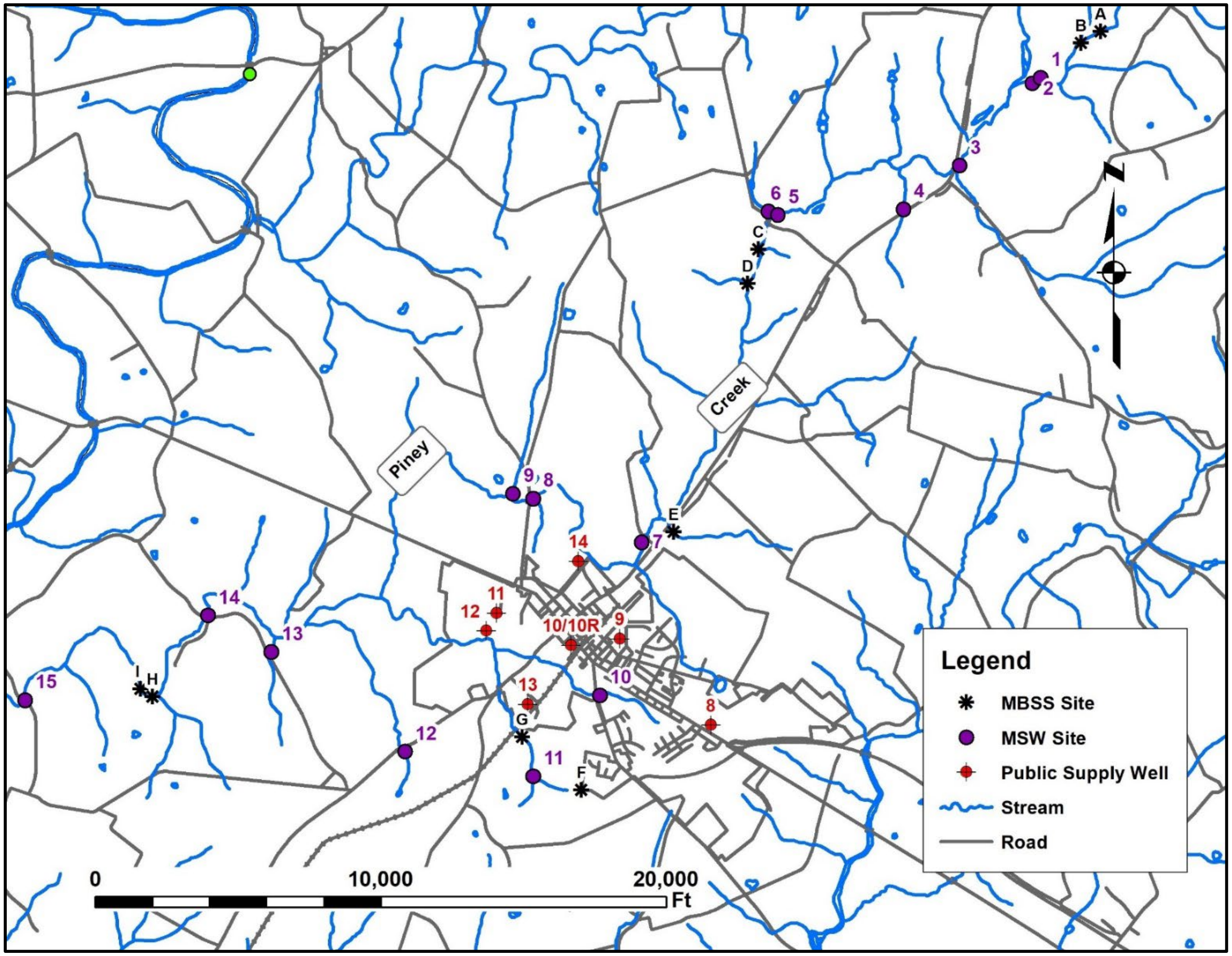


**Figure 21.** Locations of MBSS and MSW sample sites in Piney Creek watershed near Taneytown.

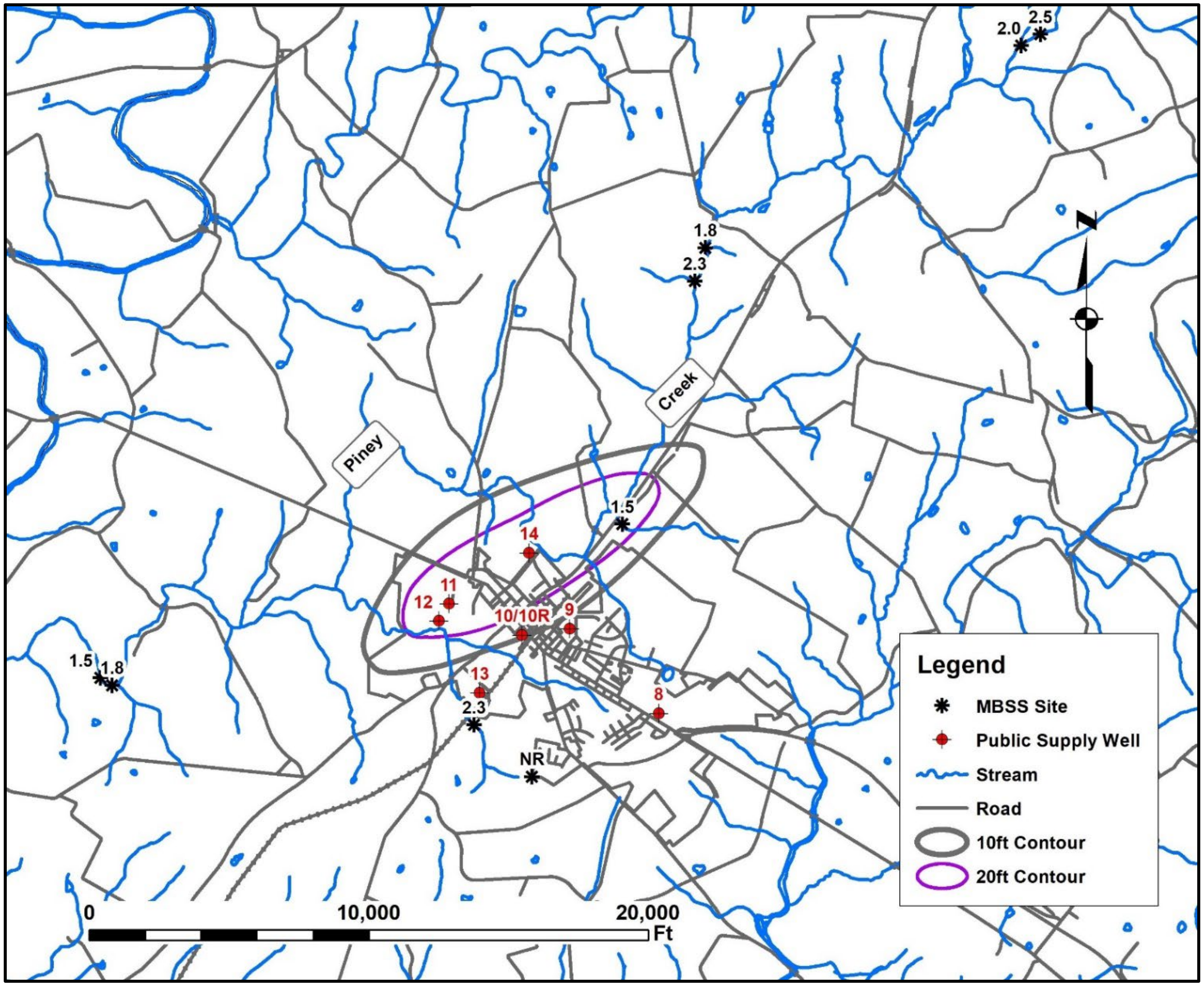


**Figure 22.** MBSS sample sites, with BIBI scores, in the Piney Creek watershed, near Taneytown.

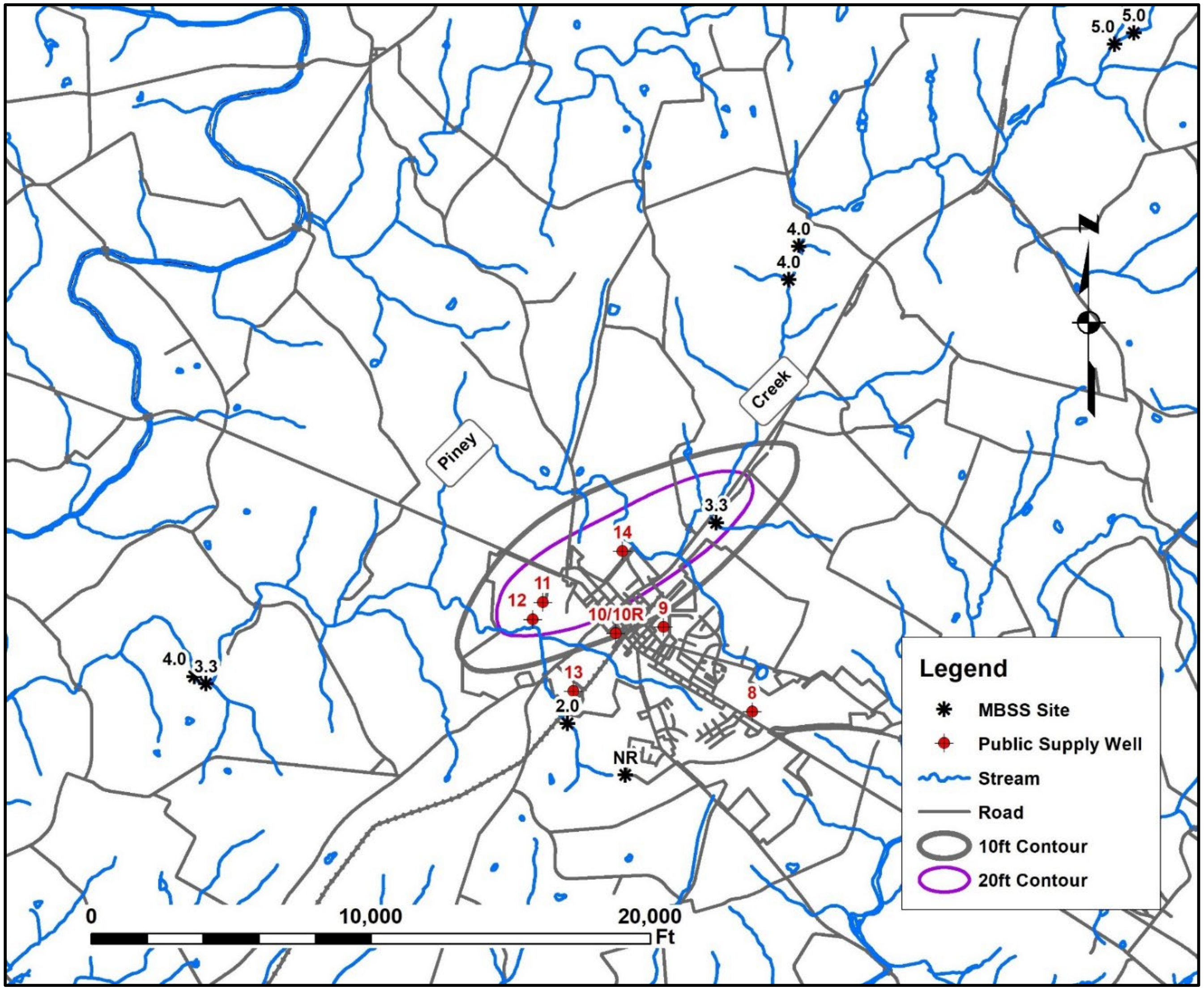


**Figure 23.** MBSS sample sites, with FIBI scores, in the Piney Creek watershed, near Taneytown.

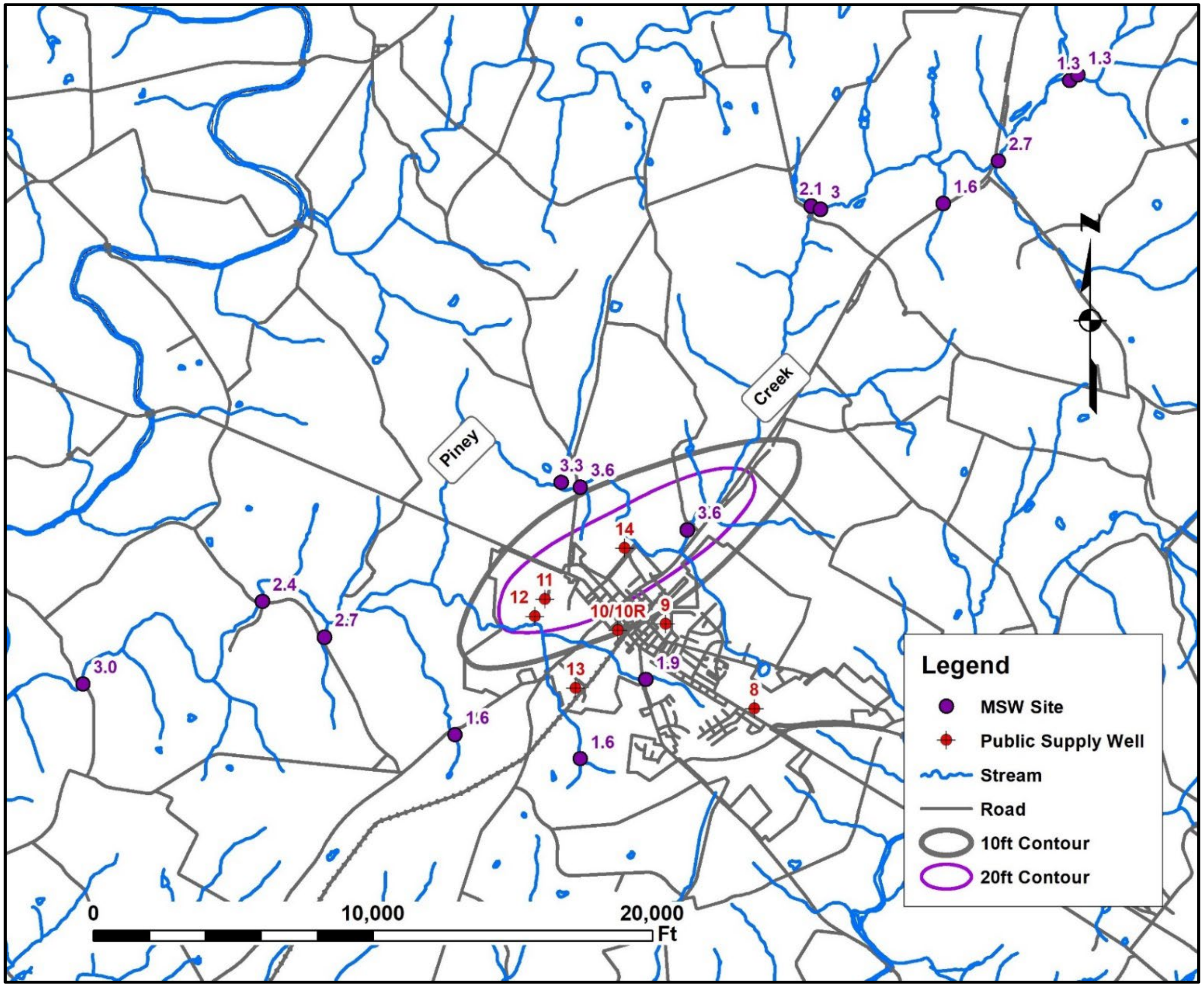


**Figure 24.** MSW sample sites, with BIBI scores, in the Piney Creek watershed, near Taneytown

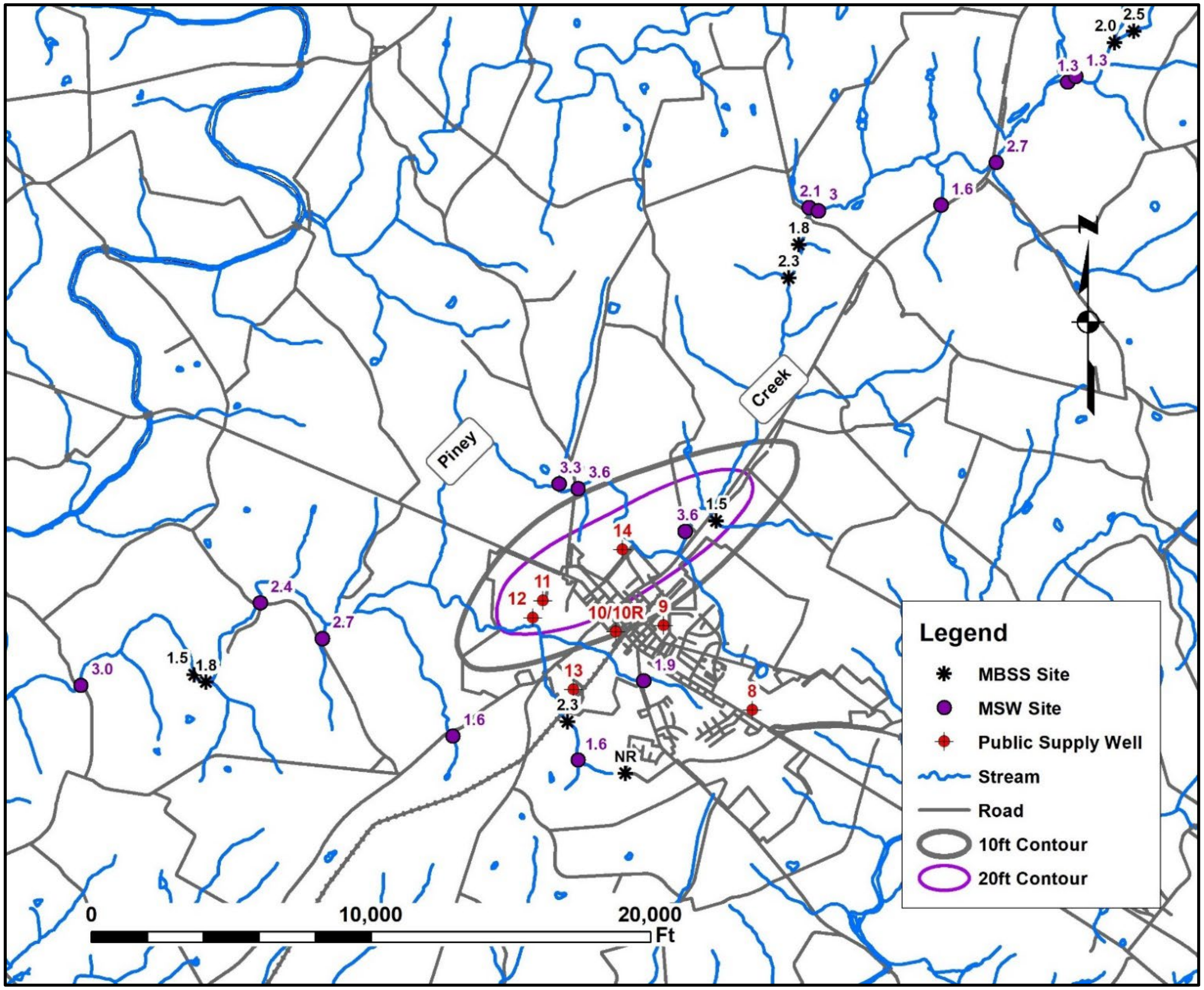


**Figure 25.** MBSS and MSW sample sites, with BIBI scores, in the Piney Creek watershed, near Taneytown

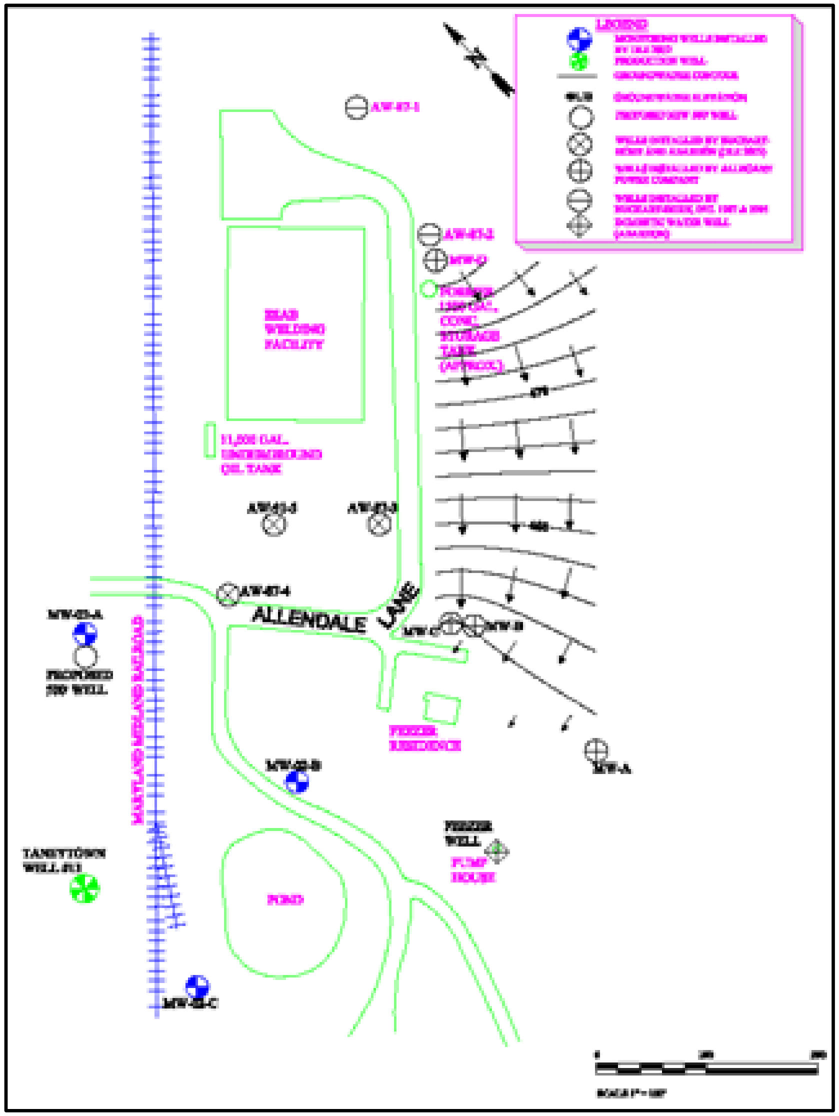

Figure 26. Shallow groundwater flow at the ESAB study site

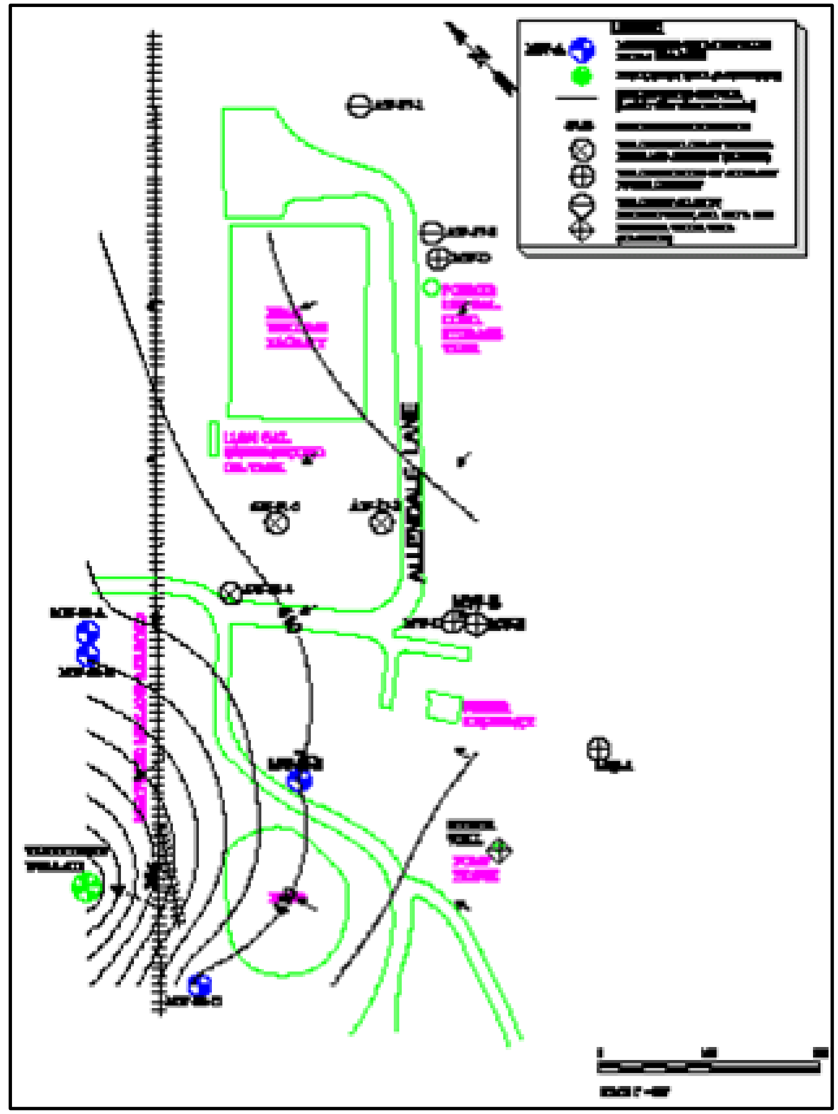

Figure 27. Deep groundwater flow at the ESAB study site.

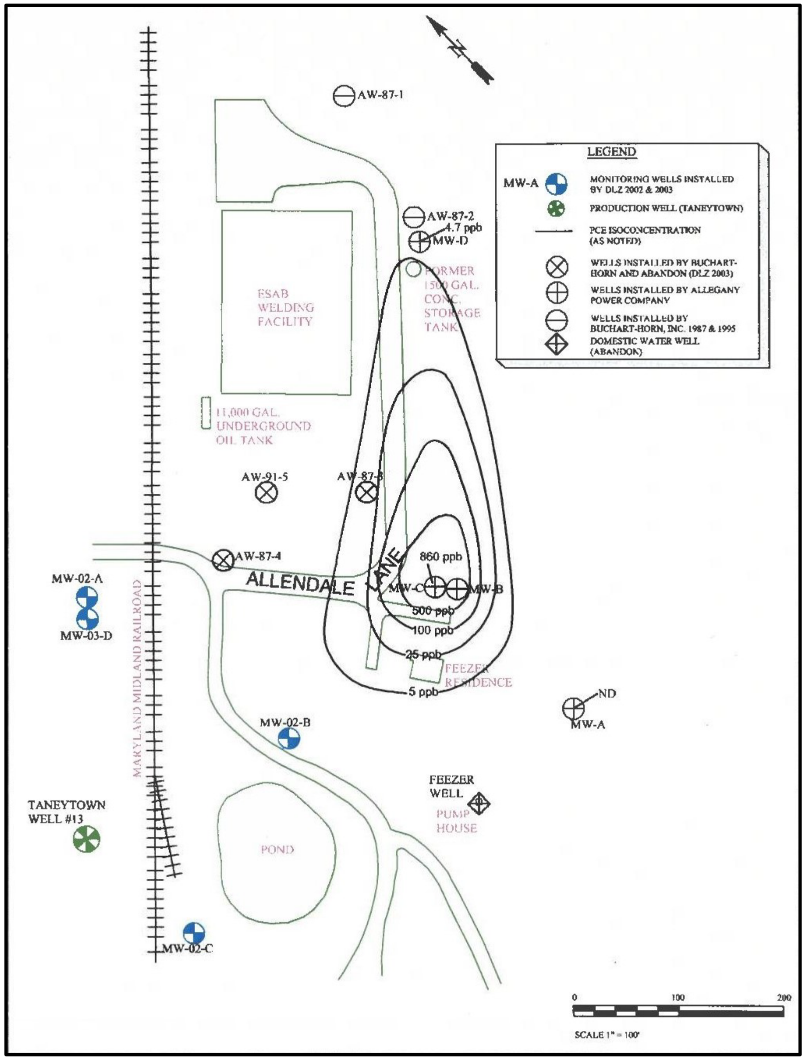


**Figure 28.** PCE concentrations upper zone at the ESAB study site.

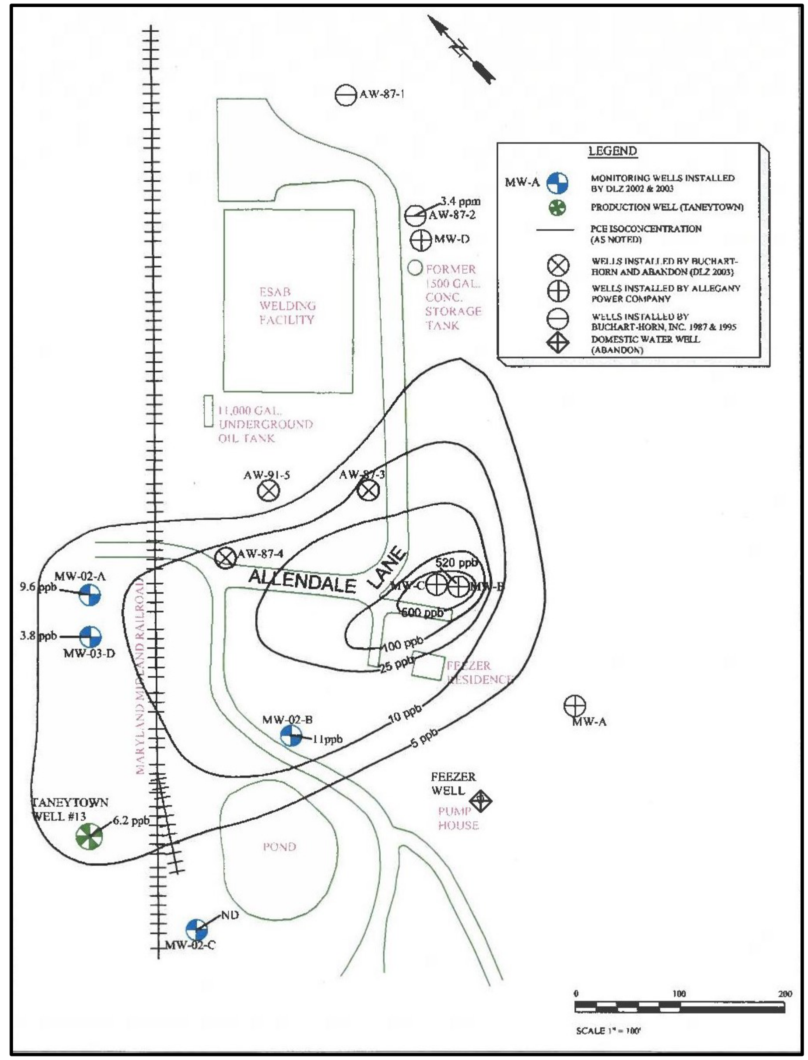


**Figure 29.** PCE concentrations lower zone at the ESAB study site.

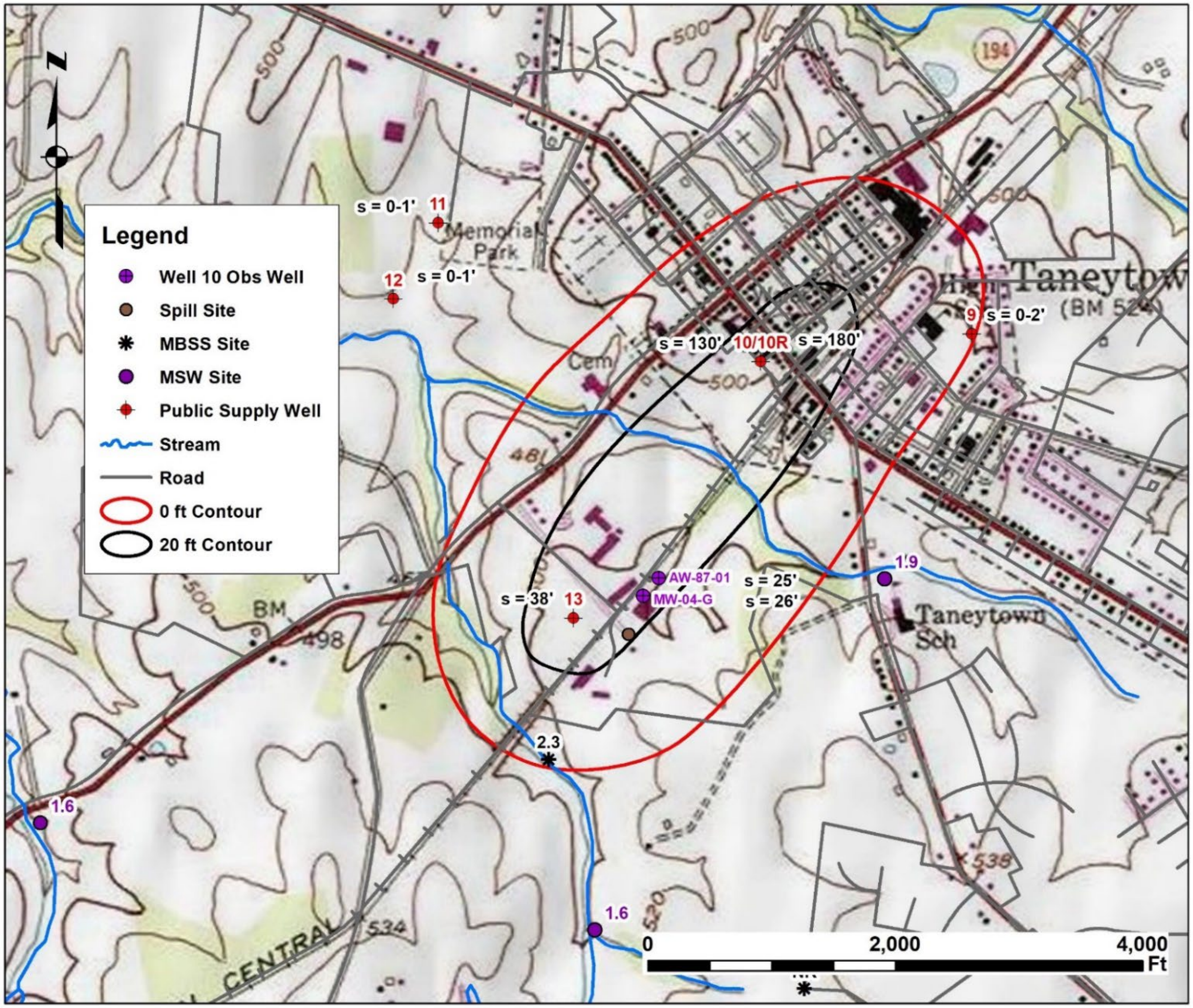


**Figure 30.** Topographic map on southwest side of Taneytown, with BIBI scores at MBSS/MSW sample sites and drawdown contours derived from a 72-hr aquifer test of Taneytown well 10R

# Watershed Baseflow Characteristics

**Table 13** Baseflow characteristics of watersheds near the study sites in the present investigation.

| Number | Gage Name | HGMR | Basin Area (sq.mi.) | Ratio Bflow / Tflow | Average (in) | Drought 1-in-10 yr Mean (in) | ≈Yr | Ratio Drought to Avg | Drought of Record Mean (in) | Yr | 1966 (in) | 1931 (in) | 2002 (in) | 120Q10 (in) | 60Q10 (in) | 7Q10 (in) | Period of Record | Prec. (in) | Elev. ft msl | Chnl. Slope ft/mi |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5875 | S. Br. Patapsco R. | PCR | 64.4 | 0.73 | 11.5 | 6.1 | 63 | 0.53 | 5.4 | 66 | 5.4 | - | - | 3.6 | 3.5 | 1.1 | 49-79 | 43 | 642 | 26.2 |
| 5860 | N. Br. Patapsco R. | PCR | 56.6 | 0.72 | 11.2 | 6.5 | 69 | 0.58 | 5.1 | 66 | 5.1 | - | - | 4.2 | 3.1 | 2.1 | 46-98 | NR | NR | NR |
| 6375 | Catoctin Creek | BR | 66.9 | 0.69 | 10.9 | 5.7 | 66 | 0.52 | 4.2 | 02 | 5.8 | - | 4.2 | 1.2 | 0.6 | 0.2 | 48-02 | 42.5 | 1110 | 47.5 |
| 6390 | Monocacy R Bridgeport | ML | 173 | 0.38 | 6.1 | 4.0 | 66 | 0.66 | 3.0 | 54 | 4.0 | - | 4.2 | 0.7 | 0.3 | 0.1 | 43-02 | 43.5 | 597 | 18.9 |
| 6435 | Bennett Creek | PCR | 62.8 | 0.68 | 10.1 | 5.9 | 85 | 0.58 | 4.3 | 02 | - | - | 4.3 | 3.5 | 2.6 | 1.5 | 49-02 | 41 | 468 | 23.8 |
| 6425 | Linganore Creek | PCR | 82.3 | 0.69 | 9.0 | 5.2 | 54 | 0.58 | 4.6 | 59 | 5.6 | - | - | 2.6 | 1.8 | 1.1 | 35-71 | 42.5 | 576 | 19.2 |

Table 13 includes the results of baseflow analyses, low flow calculations, and basin characteristics for the watersheds near or including the study area sites. Most notable is that while the precipitation in all watersheds is approximately the same, the baseflow to total flow ratio of the Monocacy River @ Bridgeport gage site (0.38) is much lower than the other sites (0.7). This would indicate that the surface flow of the Monocacy River @ Bridgeport is much higher than the other watersheds. This likely reflects the low permeability surface clay soil of the consolidated sedimentary rock New Oxford Formation (ML) underlying the watershed above that gage site. It is unknown what the MBSS reference stream is for the ML HGMR, but if it is a Piedmont stream, then the high natural runoff might produce results like that of runoff from an urban area. This could produce low BIBI scores like those which occurred in Poolesville (Horsepen Branch and Russell Branch) and Taneytown (Piney Creek) that reflect natural conditions unrelated to anthropogenic urban runoff. Also noted is the greater elevation and channel slope in the Catoctin Creek watershed. This may account for the similar average and drought year baseflows relative to the other PCR HGMR basins, but the lesser low flow characteristics of Catoctin Creek.

## REFERENCES

**Churchel, M.A. and Batzer, D.P.**, 2006, Recovery of aquatic macroinvertebrate communities from drought in Georgia piedmont headwater streams. American Midland Naturalist 156(2):259-272. https://doi.org/10.1674/0003-0031(2006)156[259:roamcf]2.0.co;2

**Collier M., Webb, R.H. and Schmidt, J.C.**, 1996, Dams and rivers. A primer on the downstream effects of dams. U.S. Geological Survey Circular 1126, 94 p. https://doi.org/10.3133/cir1126

**Dorsey, D.**, 2001, Broad Run watershed study. Montgomery County Department of Environmental Protection (MODEP), Watershed Management Division, Rockville, MD.

**Falke, J.E., Fausch, K.D., Magelky, R., Aldred, A., Durnford, D.S., Riley, L.D. and Oad, R.**, 2010, The role of groundwater pumping and drought on shaping ecological futures for stream fishes in a dryland river basin of the western Great Plains, USA. Ecohydrology 4:682-697. https://doi.org/10.1002/eco.158

**Fleming, B.J., Hammond, P.A., Stranko, S.A., Duigon, M.T., and Kasraei, S.**, 2012, A science plan for a comprehensive assessment of water supply in the region underlain by fractured rock in Maryland: U.S. Geological Survey Scientific Investigations Report 2012–5160, 29 p. https://doi.org/10.3133/sir20125160

**Freeman, M.C. and Marcinek P.A.**, 2006, Fish assemblage responses to water withdrawals and water supply reservoirs in Piedmont streams. Environmental Management 38(3):435-450. https://doi.org/10.1007/s00267-005-0169-3

**Gido, K.B., Dodds, W.K. and Eberle, M.E.**, 2010, Retrospective analysis of fish community change during a half-century of landuse and streamflow change. Journal of the North American Benthological Society 29:970-987. https://doi.org/10.1899/09-116.1

**Graf, W.L.**, 2006, Downstream hydrologic and geomorphic effects of large dams on American rivers. Geomorphology 29:336-360. https://doi.org/10.1016/j.geomorph.2006.06.022

**Hammond, P.A.**, 2022, Hydrological impacts caused by dewatering of the Mettiki D-mine, Garrett County, Maryland. Maryland Department of the Environment, Water Supply Program, Baltimore, MD.

**Hammond, P.A.**, 2022, Interference impacts caused by groundwater withdrawals from public water supply wells in the consolidated sedimentary rock aquifers of central Maryland. Maryland Department of the Environment, Water Supply Program, Baltimore, MD.

**Kanno, Y. and Vokoun, J.C.** 2010, Evaluating effects of water withdrawals and impoundments on fish assemblages in southern New England streams, USA. Fisheries Management and Ecology 17:272-283. https://doi.org/10.1111/j.1365-2400.2009.00724.x

**Kazyak, P.F.**, 1996, Maryland Biological Stream Survey sampling manual. Maryland Department of Natural Resources, Monitoring and Non-tidal Assessment Division, Annapolis, MD

**Lessard, J.L. and Hayes, D.B.,** 2003, Effects of elevated water temperature on fish and macroinvertebrate communities below small dams. River Research and Applications 19: 721-732. https://doi.org/10.1002/rra.713

**Magilligan, F.L. and Nislow, K.H.,** 2005, Changes in hydrologic regime by dams. Geomorphology 71:61-78. https://doi.org/10.1016/j.geomorph.2004.08.017

**Meador, M.R. and Carlisle, D.M.,** 2011, Relations between altered streamflow variability and fish assemblages in eastern USA streams. River Research and Applications 28(9):1359-1368. https://doi.org/10.1002/rra.1534

**Miller, J.A. and Appel, C.L.,** 1997, Ground water atlas of the United States: Kansas, Missouri, and Nebraska, HA 703-D, U.S. Geological Survey, Reston, VA. https://doi.org/10.3133/ha730d

**Poolesville,** 2011, Town of Poolesville Comprehensive Master Plan, Montgomery County, MD.

**Randall, S.,** 2001, Dry Seneca Creek watershed study. Montgomery County Department of Environmental Protection (MODEP), Watershed Management Division, Rockville, MD.

**Robson, S.G. and Banta, E.R.,** 1995, Ground water atlas of the United States: Arizona, Colorado, New Mexico, Utah, HA 703-C, U.S. Geological Survey, Reston VA. https://doi.org/10.3133/ha730c

**Roth, N.E., Southerland, M.T., Mercurio, G., Chaillou, J.C., Kazyak, P.F., Stranko, S.S., Prochaska, A.P., Heimbuch, D.G. and Seibel, J.C.**, 1999, State of the streams: 1995-1997 Maryland biological stream survey results. Maryland Department of Natural Resources, Annapolis. MD.

**Rugel, K., Jackson, C.R., Romeis, J.J., Golloday, S.W., Hicks, D.W. and Dowd, J.F.,** 2012, Effects of irrigation withdrawals on streamflows in a karst environment: lower Flint River basins, Georgia, USA. Hydrological Processes 26:523-534. https://doi.org/10.1002/hyp.8149

**Vogel, R.M., Sieber, J., Archfield, S.A., Smith, M.P., Apse, C.D., and Huber-Lee, A.,** 2007, Relations among storage, yield, and instream flow. Water Resources Research vol. 43, WO5402, 12 p. https://doi.org/10.1029/2006wr005226

**Wen, F. and Chen, X.,** 2006, Evaluation of the impact of groundwater irrigation on streamflow in Nebraska. Journal of Hydrology 327:603-617. https://doi.org/10.1016/j.jhydrol.2005.12.016

**Wen, M. and Zhang, Y.,** 2009, Agricultural water use estimation for the Flint River Basin Regional Water Development and Conservation Plan. Proceedings of the 2009 Georgia Water Resources Conference held April 27-29, 2009, at the University of Georgia:622-625.