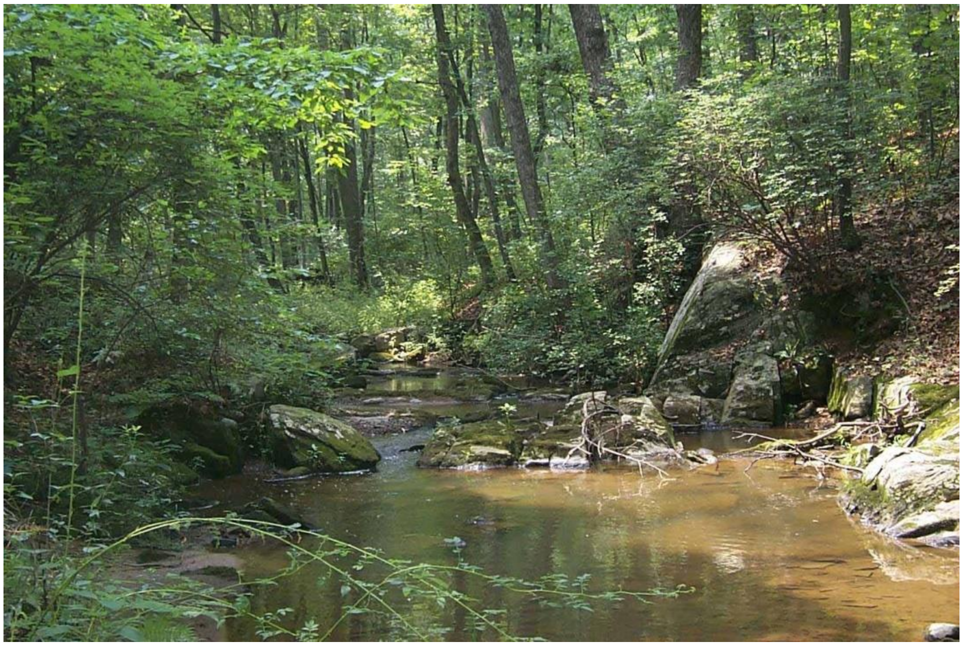
Biological Condition Gradient:

A Headwater Steam Catchment in the Northern Piedmont Region, Montgomery County, Maryland



Technical Expert Workshop

Preliminary Report (first draft for review), April 3, 2013

Executive Summary

To be added

Note: This is a preliminary draft based on an expert panel evaluation (March 27, 2013) of a small data set. The results and conclusions will be reviewed by the expert panel before this report is finalized. Additional sections to be incorporated into this report include a table of contents, literature references, graphics and analysis depicting the relationship between the expert panel analysis (a preliminary biological condition gradient for Northern Piedmont Region streams) and Montgomery County biological indices for fish and macroinvertebrates, and a draft Biological Condition Gradient Table has been developed and is included in an appendix (appendix B). The latter two sections are currently draft and are included with this report as separate files.

Preliminary Report: Northern Piedmont Biological Condition Gradient for Montgomery County, Maryland

Why Is Measuring Biological Condition Important?

People care about the biota that live in their waters. For streams in the Northern Piedmont region of Montgomery County, Maryland, fish, mollusks, insects, amphibians and birds rely on a quality stream environment for at least one part of their life if not all. Additionally, a healthy aquatic community and a surrounding, intact watershed provide many social and economic benefits such as food, recreation and flood control. The Clean Water Act of 1972 reflects this public priority by establishing the national goal to restore and maintain the chemical, physical and ***biological integrity*** of the Nation's waters.

Biological assessments can be used to directly measure the overall biological integrity of an aquatic community and the synergistic effects of stressors on the aquatic biota residing in a waterbody (Figure 1-1) (USEPA 2003). Biological assessments are an evaluation of the biological condition of a waterbody using surveys of the structure and function of resident biota. The biota functions as continual monitors of environmental quality, increasing the sensitivity of our assessments by providing a continuous measure of exposure to stressors and access to responses from species that cannot be reared in the laboratory. This increases the likelihood of detecting the effects of episodic events (e.g., spills, dumping, treatment plant malfunctions), toxic nonpoint source (NPS) pollution (e.g., agricultural pesticides), cumulative pollution (i.e., multiple impacts over time or continuous low-level stress), nontoxic mechanisms of impact (e.g., trophic structure changes due to nutrient enrichment), or other impacts that periodic chemical sampling might not detect. Biotic response to impacts on the physical habitat such as sedimentation from stormwater runoff and physical habitat alterations from dredging, filling, and channelization can also be detected using biological assessments.

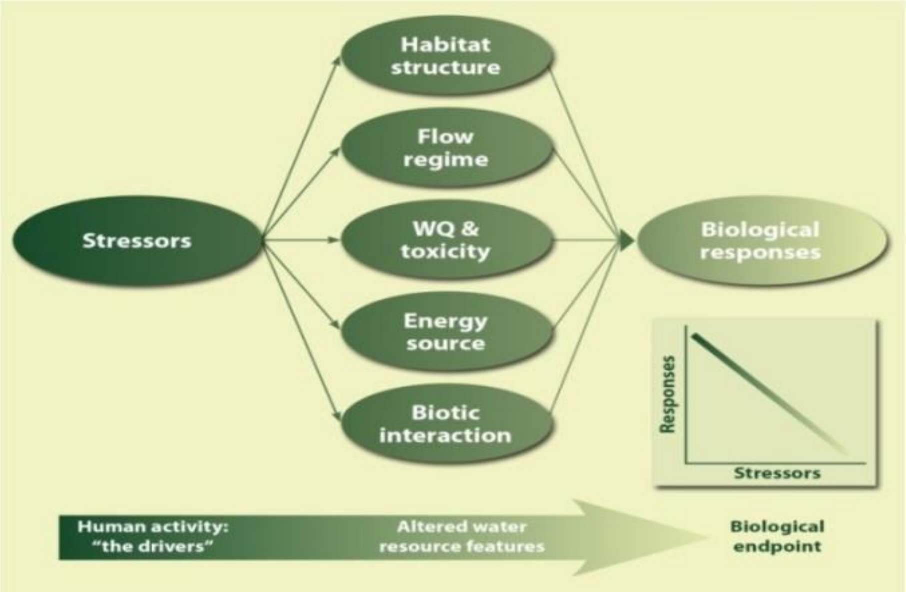


Figure 1-1. Biological assessments provide information on the cumulative effects on aquatic communities from multiple stressors. Figure courtesy of David Allen, University of Michigan.

The Biological Condition Gradient

The Biological Condition Gradient (BCG) is a conceptual, narrative model that describes how biological attributes of aquatic ecosystems change along a gradient of increasing anthropogenic stress. It provides a framework for understanding current conditions relative to natural, undisturbed conditions. Some states, such as Maine and Ohio, have used a BCG framework to more precisely define their designated aquatic life uses, monitor status and trends, and track progress in restoration and protection (USEPA 810-R-11). These two states and many others have used biological assessments and BCG-like models to support water quality managements over several decades. Based on these efforts, USEPA worked with biologists from across the United States to develop the BCG conceptual model (Davies and Jackson 2006.) The BCG shows an ecologically based relationship between the stressors affecting a waterbody (the physical, chemical, biological impacts) and the response of the aquatic community, manifested as the biological condition. The model can be adapted or calibrated to reflect specific geographic regions and waterbody type (e.g., streams, rivers, wetlands, estuaries, lakes). Approaches to calibrate the BCG to region-, state-, or tribe-specific conditions have been applied in several ecological regions by multiple states and tribes.

In practice, the BCG is used to first identify the critical attributes of an aquatic community and then describe how each attribute changes in response to stress. Practitioners can use the BCG to interpret biological condition along a standardized gradient regardless of assessment method and apply that information to different state or tribal programs. For example, Pennsylvania is using a BCG calibrated to its streams to identify exceptional and high-quality waters based on biological condition (exceptional waters may also be identified with other criteria, say, scenic or recreational value) (USEPA 810-R-11)

The BCG is divided into six levels of biological conditions along the stressor-response curve, ranging from observable biological conditions found at no or low levels of stress (level 1) to those found at high levels of stress (level 6) (Figure 1-2):

Level 1. Native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within range of natural variability. Level 1 describes waterbodies that are pristine, or biologically indistinguishable from pristine condition.

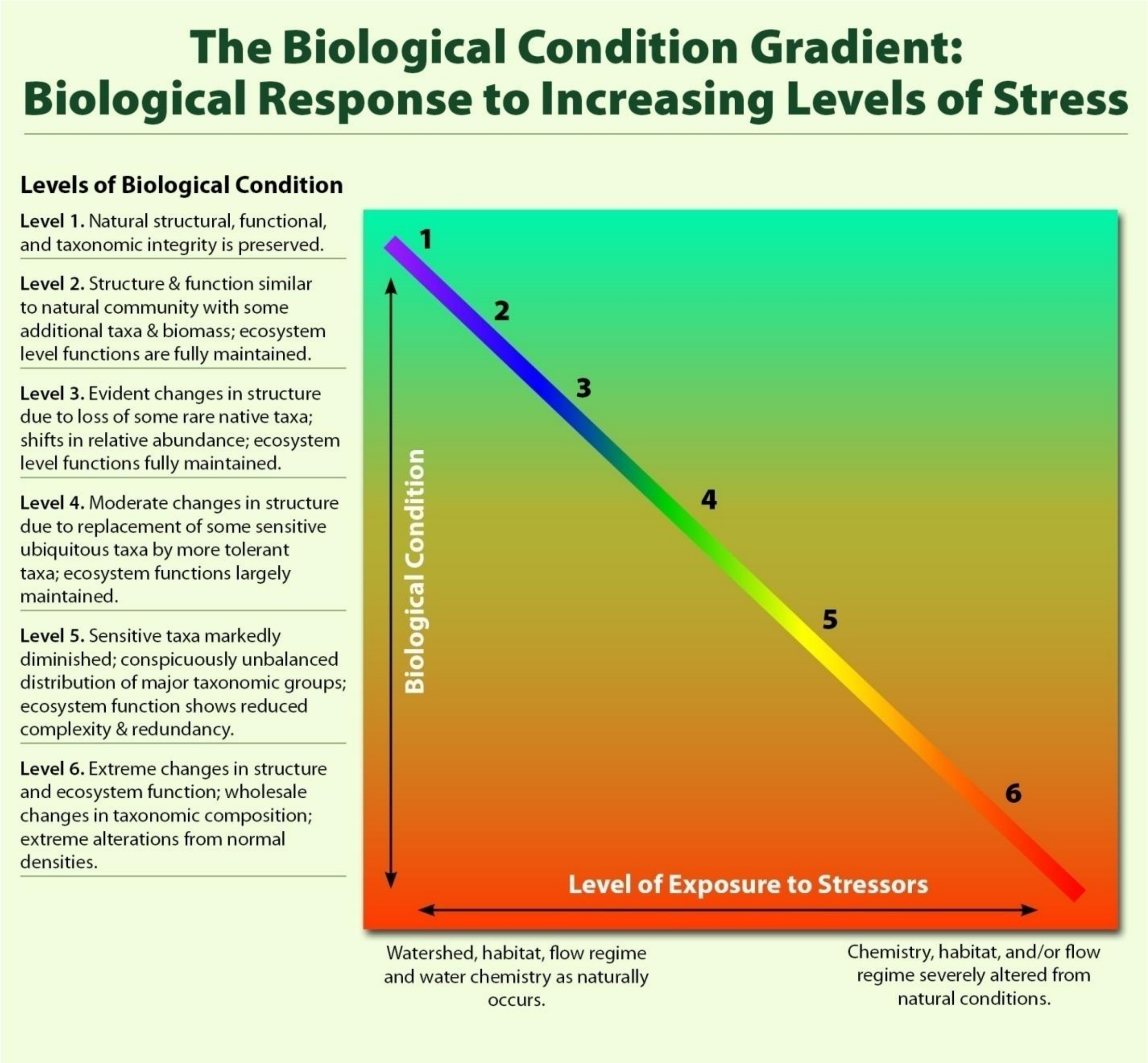
Level 2. Virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability.

Level 3. Some changes in structure due to loss of some highly sensitive native taxa; shifts in relative abundance of taxa but sensitive–ubiquitous taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system, but may differ quantitatively.

Level 4. Moderate changes in structure due to replacement of sensitive–ubiquitous taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes.

Level 5. Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased buildup or export of unused organic materials.

Level 6. Extreme changes in structure; wholesale changes in taxonomic composition; extreme alterations from normal densities and distributions; organism condition is often poor (e.g. diseased individuals may be prevalent); ecosystem functions are severely altered.



The Biological Condition Gradient: Biological Response to Increasing Levels of Stress

Levels of Biological Condition

Level 1. Natural structural, functional, and taxonomic integrity is preserved.

Level 2. Structure & function similar to natural community with some additional taxa & biomass; ecosystem level functions are fully maintained.

Level 3. Evident changes in structure due to loss of some rare native taxa; shifts in relative abundance; ecosystem level functions fully maintained.

Level 4. Moderate changes in structure due to replacement of some sensitive ubiquitous taxa by more tolerant taxa; ecosystem functions largely maintained.

Level 5. Sensitive taxa markedly diminished; conspicuously unbalanced distribution of major taxonomic groups; ecosystem function shows reduced complexity & redundancy.

Level 6. Extreme changes in structure and ecosystem function; wholesale changes in taxonomic composition; extreme alterations from normal densities.

Watershed, habitat, flow regime and water chemistry as naturally occurs.

Chemistry, habitat, and/or flow regime severely altered from natural conditions.

Source: Modified from Davies and Jackson 2006

Figure 1-2. The Biological Condition gradient (BCG).

The scientific panels that developed the BCG conceptual model identified 10 attributes of aquatic ecosystems that change in response to increasing levels of stressors along the gradient, from level 1 to 6 (see Table 1). The attributes include several aspects of community structure, organism condition, ecosystem function, spatial and temporal attributes of stream size, and connectivity.

Each attribute provides some information about the biological condition of a waterbody. Combined into a model like the BCG, the attributes can offer a more complete picture about current waterbody conditions and also provide a basis for comparison with naturally expected waterbody conditions. All states and tribes that have applied a BCG used the first seven attributes that describe the composition and structure of biotic community on the basis of the tolerance of species to stressors and, where available, included information on the presence or absence of native and nonnative species and, for fish and amphibians, observations on overall condition (e.g., size, weight, abnormalities, tumors).

Table 1. Biological and other ecological attributes used to characterize the BCG.

Attribute	Description
I. Historically documented, sensitive, long-lived, or regionally endemic taxa	Taxa known to have been supported according to historical, museum, or archeological records, or taxa with restricted distribution (occurring only in a locale as opposed to a region), often due to unique life history requirements (e.g., sturgeon, American eel, pupfish, unionid mussel species).
II. Highly sensitive (typically uncommon) taxa	Taxa that are highly sensitive to pollution or anthropogenic disturbance. Tend to occur in low numbers, and many taxa are specialists for habitats and food type. These are the first to disappear with disturbance or pollution (e.g., most stoneflies, brook trout [in the east], brook lamprey).
III. Intermediate sensitive and common taxa	Common taxa that are ubiquitous and abundant in relatively undisturbed conditions but are sensitive to anthropogenic disturbance/pollution. They have a broader range of tolerance than Attribute II taxa and can be found at reduced density and richness in moderately disturbed sites (e.g., many mayflies, many darter fish species).
IV. Taxa of intermediate tolerance	Ubiquitous and common taxa that can be found under almost any conditions, from undisturbed to highly stressed sites. They are broadly tolerant but often decline under extreme conditions (e.g., filter-feeding caddisflies, many midges, many minnow species).
V. Highly tolerant taxa	Taxa that typically are uncommon and of low abundance in undisturbed conditions but that increase in abundance in disturbed sites. Opportunistic species able to exploit resources in disturbed sites. These are the last survivors (e.g., tubificid worms, black bullhead).
VI. Nonnative or intentionally introduced species	Any species not native to the ecosystem (e.g., Asiatic clam, zebra mussel, carp, European brown trout). Additionally, there are many fish native to one part of North America that have been introduced elsewhere.
VII. Organism condition	Anomalies of the organisms; indicators of individual health (e.g., deformities, lesions, tumors).
VIII. Ecosystem function	Processes performed by ecosystems, including primary and secondary production; respiration; nutrient cycling; decomposition; their proportion/dominance; and what components of the system carry the dominant functions. For example, shift of lakes and estuaries to phytoplankton production and microbial decomposition under disturbance and eutrophication.
IX. Spatial and temporal extent of detrimental effects	The spatial and temporal extent of cumulative adverse effects of stressors; for example, groundwater pumping in Kansas resulting in change in fish composition from fluvial dependent to sunfish.
X. Ecosystem connectance	Access or linkage (in space/time) to materials, locations, and conditions required for maintenance of interacting populations of aquatic life; the opposite of fragmentation. For example, levees restrict connections between flowing water and floodplain nutrient sinks (disrupt function); dams impede fish migration, spawning. Extensive burial of headwater streams leads to cumulative downstream impacts to biota through energy input disruption, habitat modification, and loss of refugia and dispersing colonists

Source: Modified from Davies and Jackson 2006.

The last three BCG attributes of ecosystem function, connectance, and spatial and temporal extent of detrimental effects can provide valuable information when evaluating the potential for a waterbody to be protected or restored. For example, a manager can choose to target resources and restoration activities to a stream where there is limited spatial extent of stressors or there are adjacent intact wetlands and stream buffers or intact hydrology versus a stream with comparable biological condition but where adjacent wetlands have been recently eliminated, hydrology is being altered, and stressor input is predicted to increase.

The BCG model provides a framework to help water quality managers do the following:

Decide what environmental conditions are desired (goal-setting)—The BCG can provide a framework for organizing data and information and for setting achievable goals for waterbodies relative to "natural" conditions, e.g., condition comparable or close to undisturbed or minimally disturbed condition.

Interpret the environmental conditions that exist (monitoring and assessment)—managers can get a more accurate picture of current waterbody conditions.

Plan for how to achieve the desired conditions and measure effectiveness of restoration—The BCG framework offers water program managers a way to help evaluate the effects of stressors on a waterbody, select management measures by which to alleviate those stresses, and measure the effectiveness of management actions.

Communicate with stakeholders—When biological and stress information is presented in this framework, it is easier for the public to understand the status of the aquatic resources relative to what high-quality places exist and what might have been lost.

Specifically, biological assessment information has been used by federal, state, tribal and local governments to:

- ***Define goals for a waterbody***—Information on the composition of a naturally occurring aquatic community can provide a description of the expected biological condition for other similar waterbodies and a benchmark against which to measure the biological integrity of surface waters. Many states and tribes have used such information to more precisely define their designated aquatic life uses, develop biological criteria, and measure the effectiveness of controls and management actions to achieve those uses.
- ***Report status and trends***—Depending on level of effort and detail, biological assessments can provide information on the status of the condition of the expected aquatic biota in a waterbody and, over time with continued monitoring, provide information on long-term trends.
- ***Identify high-quality waters and watersheds***—Biological assessments can be used to identify high-quality waters and watersheds and support implementation of antidegradation policies.
- ***Document biological response to stressors***—Biological assessments can provide information to help develop biological response signatures (e.g., a measurable, repeatable response of specific species to a stressor or category of stressors). Examples include sensitivity of mayfly species (pollution-sensitive aquatic insects) to metal toxicity or temperature-specific preferences of fish species. Such information can provide an additional line of evidence to support stressor identification and causal analysis (USEPA 2000a), as well as to inform numeric criteria development (USEPA 2010a).

For further information and examples of implementation, see *A Primer on Using Biological Assessments to Support Water Quality Management*, EPA 810-R-11-01. Calibrating the Conceptual Model to Local Conditions

Calibrating the Conceptual BCG Model to Local Conditions

The BCG can serve as a starting point for defining the response of aquatic biota to increasing levels of stress in a specific region. The model can be applied to any region or waterbody by calibrating it to local conditions using specific expertise and local data. To date, most states and tribes are calibrating the BCG using the first seven attributes that characterize the biotic community primarily on the basis of tolerance to stressors, presence/absence of native and nonnative species, and organism condition.

A multistep process is followed to calibrate a BCG to local conditions (Figure 1-3); to describe the native aquatic assemblages under natural conditions; to identify the predominant regional stressors; and to describe the BCG, including the theoretical foundation and observed assemblage response to stressors. Calibration begins with the assembly and analysis of biological monitoring data. Next, a calibration workshop is held in which experts familiar with local conditions use the data to define the ecological attributes and set narrative statements; for example, narrative decision rules for assigning sites to a BCG level on the basis of the biological information collected at sites. Documentation of expert opinion in assigning sites to tiers is a critical part of the process. A decision model can then be developed that encompasses those rules and is tested with independent data sets. A decision model based on the tested decision rules is a transparent, formal, and testable method for documenting and validating expert knowledge. A quantitative data analysis program can then be developed using those rules.

BCG Development for Montgomery County

Montgomery County convened a panel of 17 technical experts consisting of stream and fisheries biologists and aquatic ecologists to develop a BCG conceptual model for the Piedmont region of Maryland (see list of panel members). The panel participated in several webinars/ conference calls, and an all-day panel meeting on March 27, 2013. The objective was to develop a BCG narrative model, including narrative descriptions of the BCG levels as they are manifested in the Piedmont region of Maryland, and using data collected by Montgomery County.

The County developed a Benthic Index of Biotic Integrity (B-IBI) and a Fish Index of Biotic Integrity (F-IBI) in 1998 as a way to rate and compare local streams. Narrative categories of ‘ excellent’, ‘good’, ‘fair’ and ‘poor’ were used. These stream categories were used in the Countywide Stream Protection Strategy, County Master Plans, and in the annual SPA Reports. Local officials and the public understood and accepted this concept. Soon, however, people began to describe streams as ‘high’ good or ‘low’ excellent and began to ask what would be needed to improve streams from ‘poor’ to ‘good’. In order to try and answer this question, the individual metrics and other information on the biological community structure and function of the biotic community had to be taken from the IBI’s. A better tool was sought that would provide more refined and detailed information on streams and their response to land use change. The BCG appeared to be that tool and a pilot evaluation was sought to see how the BCG would rate streams representing a wide range of conditions.

Identifying BCG Attributes

Biologists have long observed that taxa differ in their sensitivity to pollution and disturbance. While biologists largely agree on the relative sensitivity of taxa, there may be subtle differences among stream types (high vs. low gradient) or among geographic regions. The workgroup participants used their collective experience and judgment to assign sensitivities of the organisms to the disturbance gradient. Participants discussed the fish and benthic macroinvertebrates that occur in Montgomery County and in Maryland’s Piedmont, and developed a consensus assignment prior to the workshop. Examples are shown in Tables 2 and 3, and Figure 3.

Table 2. Examples of Northern Piedmont fish and salamanders by attribute group.

Ecological Attribute	Number of species	Example Species
I Endemic, rare	5	Brook trout, bridle shiner, Chesapeake log perch, Maryland darter, trout perch
II Highly Sensitive	7	Yellow perch, northern hog sucker, margined mad tom, dusky salamander, longtailed salamander
III Intermediate Sensitive	11	Fallfish, fantail darter, Potomac sculpin, Blue Ridge sculpin
IV Intermediate Tolerant	14	Channel catfish, least brook lamprey, pumpkinseed, tessellated darter
V Tolerant	13	American eel, mummichog, white sucker, sea lamprey, northern two-lined salamander
VI-i Sensitive Nonnative	2	brown trout, rainbow trout
VI-m Intermediate nonnative	6	Black crappie, golden redhorse, smallmouth bass
VI-t Tolerant nonnative	6	common carp, goldfish, green sunfish, largemouth bass, snakehead
x unassigned		Unidentified fish, hybrids

Table 3. Examples of Northern Piedmont benthic macroinvertebrates by attribute group.

Ecological Attribute	Number of taxa	Example Species
I Endemic, rare		None attributed
II Highly Sensitive	~50	Mayflies: *Habrophlebia, Epeorus, Ephemera, Leucrocuta, Habrophlebiodes, Paraleptophlebia,* Stoneflies*: Sweltsa, Talloperla, Eccoptura,* Caddisflies: *Wormaldia, Diplectrona, Rhyacophila, Dolophilodes,* Flies: *Dixa,* Prodiamesinae
III Intermediate Sensitive	~60	Mayflies: *Diphetor, Ephemerella, Ameletus, Serratella,* Stoneflies: *Amphinemura, Acroneuria, Leuctra, Isoperla,* Dragonflies: *Cordulegaster, Lanthus,* Caddisflies: *Neophylax, Rhyacophila, Pycnopsyche, Glossosoma,* Beetles*: Oulimnius, Anchytarsus,* Flies: Diamesinae, *Hexatoma, Prosimulium*
IV Intermediate Tolerant	>100	Mayflies: *Baetis, Stenonema,* Damsel and Dragonflies: *Calopteryx, Boyeria,* Caddisflies: *Hydropsyche, Polycentropus,* Beetles: *Helichus, Optioservus,* Fishflies: *Nigronia,* Other*: Chelifera,* Tanytarsini, *Tipula, Tabanidae, Crangonyx,* Enchytraeidae
V Tolerant	>50	Beetles*:* Hydrophilidae, Dytiscidae, Flies: *Hemerodromia,* most Chironomini and Orthocladiinae, Stratiomyiidae, Other: Isopoda, Physidae, Hirudinae, Tubificidae
V Nonnative	2	Asian Clam: *Corbicula,* Snails: *Bithnya*
x Unassigned		Ambiguous family-level or order-level identifications, unknown tolerance

Figure 3. Important aquatic species in Maryland's Piedmont headwater streams. Salamanders (Long-tailed, Dusky, and Red); fishes (Potomac Sculpin, Rosyside Dace, American Eel); Insects (Sweltsa, *Paraleptophlebia*, *Ephemerella*).

Expert Solicitation: Determining BCG Levels

Panelists examined biological data from individual sites and assigned those samples to Levels 1 to 6 of the BCG. The intent was to achieve consensus and, in the process, to document the scientific rationale that experts were using to make their assignments. Expert solicitation is the first step in a rigorous, transparent process to develop quantifiable rules for decision making and model development. The end result is the refinement of existing , or development of new, biological indices. Though the first step in a longer process, expert evaluation of changes in taxa, in-stream and riparian habitat, and watershed condition can yield immediate detail and insight on the response of local and regional biota to increasing stress. This information can be used to identify high quality waters that maybe threatened and require additional protection and waters that show early signs of degradation but where protection or restoration efforts could be most efficient and successful.

The data that the experts examined when making BCG level assignments were provided in worksheets. The worksheets contained lists of taxa, taxa abundances, BCG attribute levels assigned to the taxa, BCG attribute metrics and limited site information (e.g., such as watershed area), size class (i.e., headwater), and stream gradient. Participants were not allowed to view Station IDs or waterbody names when making BCG level assignments, as this might bias their assignments. Fish and macroinvertebrate worksheets can be found in Appendix C.

The workgroup examined macroinvertebrate data from 16 samples, and fish data from 17 samples. The group was able to reach a consensus opinion on the BCG level assignments for all sites reviewed. The panels were able to distinguish 4 separate BCG levels (BCG Levels 3-6), although Level 6 (extreme degradation) was rare. The experts also identified significant changes in assemblages the indicated shifts either up or down along the gradient. For example, the fish group identified a sample that was borderline between Levels 2 and 3, that is, half of the experts assessed the samples at Level 2 - and half at Level 3+ . All agreed that these sites were borderline between the two levels because of excellent habitat and water quality conditions and potential for these sites to support native or other sensitive species that were currently missing e.g. brook trout. The macroinvertebrate group identified three samples that they considered borderline Level 2-3 because the expected sensitive and native taxa were either absent or present in low numbers and the in-stream habitat and water quality were judged sufficient or close to sufficient to support these taxa. Additionally, the level of disturbance in the immediate watershed area was low and restoration potential for these sites judged excellent.

The experts discussed the transitions between levels; that is, what is changed or lost between a higher level to a lower level. The expert's rationale on what constituted a significant change or loss of the biotic community was recorded. The descriptions of the transitions become the basis for the next step in development of a quantitative BCG model, the development of narrative decision criteria for assigning sites to BCG levels.

Level 1 – Level 2 Natural Conditions (undisturbed to minimally disturbed). The panel felt that Level 1 sites, which are indistinguishable from pristine or undisturbed, would have strictly native taxa for all assemblages evaluated (fish, salamander, benthic macroinvertebrates) with no (non-natives present, some endemic species, and evidence of connectivity in the form of migratory fish. The presence of non-native species and loss of endemic species would move a site to the next level down on the gradient, Level 2. However, there are no sites within the piedmont that do not have some degree of disturbance, including legacy effects from agriculture and forestry from 100 to 200 years ago. This is typical situation for most of the North American continent. For practical reasons, Level 1 and highly rated level 2 (e.g. 2+) have been combined. These sites have excellent water quality and support habitat critical for native taxa. For macroinvertebrates, Level 2+ sites would have many highly sensitive taxa and relatively high richness and abundance of intermediate sensitive-ubiquitous taxa. Many of these taxa are characterized by having limited dispersal capabilities or are habitat specialists. Tolerant taxa are present but have low abundance. Presence of sensitive-rare, cold water indicator taxa such as the mayfly *Epeorus*, and stoneflies *Sweltsa* and *Talloperla* would be expected to occur.

Level 2 Near Natural (minimally disturbed). For fish, the panel decided that non-native species may be present, but they cannot exclude native species. A site that would be assigned to Level 2 must also maintain connectivity between the mainstem, associated wetlands and headwater streams so that migratory fish and amphibians (e.g., eel, lamprey, salamanders) are present or known to access the site. Native top predators (e.g. brook trout) are present. The best fish site (upper Patuxent River) lacked brook trout, but reintroduction of reproducing native brook trout and access for migratory fish would raise this site to Level 2 status. Several sites rated as BCG level 3 supported habitat and water quality that would support a reproducing native brook population. These sites would then be rated as a level 2. The Long-tailed and Dusky salamanders were noted as two amphibians that panelists agreed would also help indicate Level 2 Piedmont streams given a complimentary fish community. Macroinvertebrate panelists believed that presence of several key taxa would help indicate Level 2 streams, especially coldwater indicator mayflies, stoneflies, and caddisflies (e.g, *Epeorus*, *Paraleptophlebia*, *Sweltsa*, and *Wormaldia*).

Level 3 Near Natural Habitat (loss of native taxa). Level 3 condition was generally considered a good quality condition by the panel. For macroinvertebrates, Level 3 sites should have several highly sensitive taxa and relatively high richness and abundance of intermediate sensitive-ubiquitous taxa. Taxa with intermediate tolerance may increase in richness and abundance. Tolerant taxa are somewhat more common but still have low abundance. Key sensitive taxa include the caddisfly *Diplectrona*, the mayfly *Ephemerella* and the stonefly *Amphinemura*. Panelists expected other key taxa to indicate Level 2 streams, especially coldwater indicator mayflies, stoneflies, and caddisflies (e.g, *Epeorus*, *Sweltsa*, and *Wormaldia*).

Level 3 – Level 4. For fish, the transition from Level 3 to Level 4 is characterized by increasing loss of sensitive species, and by increased abundance of tolerant species indicating nutrient enrichment and/or excess sedimentation. Salamander taxa would include the more generalist or tolerant Red Salamander and Two-lined Salamander, but sensitive Dusky may also occur. For macroinvertebrates, panelists agreed that as sites slipped toward Level 4, that highly sensitive macroinvertebrate taxa were more poorly represented but some intermediate sensitive-ubiquitous taxa populations were maintained. Although cool and coldwater indicator taxa such as *Dolophilodes*, *Diplectrona* and *Leuctra* are usually present, obvious increases in intermediate-tolerance and tolerant individuals were noted when compared to Level 2-3, driven primarily by increases in specific chironomid midgefly subfamilies.

Level 4 Significant Alteration in Aquatic Biota (Moderately Disturbed). Sensitive species and individuals are still present but in reduced numbers (e.g., approximately 10 – 30% of the community rather than 50% found in Level 3 streams). The experts generally agree that the persistence of some sensitive species indicates that their original ecosystem function is still maintained albeit at a reduced level. For example, Level 4 streams may have sculpins, but non-native species occur more frequently. Similarly, macroinvertebrate taxa such as *Diplectrona* and *Dolophilodes* may occur, but other key taxa such as *Ephemerella* and *Neophylax* are absent. These streams may harbor 2 to 3 salamander species (Dusky, Red, and Two-lined).

Level 4 – Level 5. The panel considered sites rated towards the lower end of Level 4 (e.g. approximately 10 - 15% of the sensitive species present) to be trending towards a markedly diminished aquatic community characteristic of the next level down, Level 5. Tolerant taxa predominant and sensitive species are either absent or present in very low numbers. Though not part of this evaluation, there can be increased evidence of physiological stress. Most notably in fish and amphibian communities, lesions, tumors, and other abnormalities are increasingly observed.

Level 5 Major Alteration in Aquatic Biota (Major level of disturbance). In Level 5, sensitive species and individuals may be present but their functional role is negligible within the system. Those sensitive taxa remaining are highly ubiquitous ones within the region having very good dispersal capabilities. Tolerant Two-lined salamanders might be the only salamander present. For macroinvertebrates, streams trending toward Level 5 revealed that highly sensitive macroinvertebrate taxa were usually absent and

Chironomid midges (mostly tolerant Orthocladiinae and Chironomini) often comprised >50% of the community in Level 5 streams. Level 5 typically has abundant organisms that are mostly tolerant or intermediate tolerance, both native and introduced, and may have relatively high diversity within the tolerant organisms. Macroinvertebrate communities could have high or low overall diversity, but most representatives are opportunistic or pollution tolerant species.

Level 5 – Level 6. Transition from level 5 to level 6 is characterized by loss of remaining diversity to a depauperate community. Some highly tolerant organisms such as fathead minnows, brown bullhead, various maggot genera, tubificid and naidid worms, or physid snails may be very abundant, indicating extreme organic enrichment and hypoxia; or extreme low abundance and low richness of all organisms may indicate toxic conditions. Under hypoxic conditions, only those tolerant invertebrates adapted to living in low dissolved oxygen or can breathe atmospheric air may be present.

Level 6 Severe Alteration in Aquatic Biota (Extreme level of disturbance). In the Piedmont, these streams are heavily degraded from urbanization and/or industrialization and can range from having no aquatic life at all or harbor a severely depauperate community composed entirely of highly tolerant or tolerant invasive species adapted to hypoxia, extreme sedimentation and temperatures, or other toxic chemical conditions. In our exercise, panelist ratings were mixed for a couple of sites where some indicated a 6 while others indicated 5-. Experts who did not rate the site as a 6 indicated that the stream could get even worse.

Results

A preliminary BCG based on benthic macroinvertebrates, fish and salamander assemblages has been developed (Appendix B and see Table 4 at end of this section for an abbreviated version). The BCG is based on macroinvertebrate, fish and salamander assemblages in 1st to 3rd order streams (1:24,000 scale) with catchment areas ranging from 0.5 to 5 mi^2. The panelists working with the fish and salamander assemblages rated the 17 selected sites from BCG Level 3+ to 6. The 16 macroinvertebrate sites were rated roughly from 2- to 6+. Where both sets of sites overlapped (sites with both assemblages), there was relatively good agreement. For example, at Samp002 the fish experts rated the site a 4 while the macroinvertebrate experts rated it as a 3-. Similarly, Samp012 was rated a 6+ by fish panelists and a 5- by macroinvertebrate specialists. At Samp004, both groups of panelists rated the site a solid Level 3. The rationale for assignment of each sample was documented and among the assemblage groups, there was consistent agreement on basis for the assignments. The rationale for the assignments becomes the basis for development of narrative decision rules to BCG level assignment. In turn, with further testing and peer review, these narrative statements then become the basis for quantification and development of numeric biological indices or models.

Ten Mile Creek sites ratings ranged between the high end of BCG level 3 (e.g. a 3+) to BCG level 4. For most BCG level development done to date, sites that are comparable to BCG level 4 are often judged as attaining their designated aquatic life use. Several of the Ten Mile Creek sites, particularly the primary head water streams, were judged as very good quality, receiving a low BCG level 2 rating (e.g. 2-) or high BCG level 3 rating (e.g. 3+). The experts felt that these streams have excellent potential for improvement to BCG level 2 if protected with options for additional protection considered.

The information provided by each of the assemblages was complementary, each providing additional insight into the current condition as well as potential for restoration. For example, for several sites there were cool and cold water sensitive benthic macroinvertebrate taxa present as well as sensitive salamander species. The native brook trout were not present at these sites but because of the presence of these other assemblages indicative of good water quality and habitat, these streams c may be able to support a self-sustaining native brook trout population and be a candidate for an upgrade from their current use class, class # 1, to class # 3. These sites are approaching and may achieve conditions comparable to Northern Piedmont Sentinel sites that, as of this date, occur only outside of the county.

Three of the sites were split into “before and after” sets that were rated by both groups (this information was not provided to the panelists).

1.) Clarksburg Tributary was sampled twice, 14 years apart (1998 and 2012); panelists rated the macroinvertebrate community as a 3 to 3- before residential development and a 4- after development. The abundance of sensitive taxa declined from 86% to 28% while tolerant taxa increased from 5% to 64%. However, the panelists believed that the stream had retained some sensitive taxa and thus did not rate the site a 5.

2.) Right Fork was also initially sampled in 1998 prior to extensive urbanization and was re-sampled in 2012. Macroinvertebrates changed from a Level 2+ stream to a 4-; some highly sensitive, cool and coldwater invertebrate taxa (*Diplectrona, Dolophilodes, Eccoptura*) and some intermediate sensitive taxa (e.g., *Ephemerella*)were eradicated following urbanization. For fish, this site changed from a 3 to a 3- having similar species composition but had experienced large increases in abundance of the tolerant Blacknose Dace.

3.) Piney Branch fishes were sampled 15 yrs apart (before and after extensive urbanization). Experts rated the “before” data as a 3- (3s and 4s) and the “after” data as a 4- (4s and 5s). Here, sensitive taxa dropped from 52% to 9% (mostly loss of sculpins) while tolerants (both native and non-native) increased from 44% to 89%.

Comparison of BCG level assignments and IBI scores

See attachment: BCG and IBI Correspondence, to be incorporated into report this week. Under review and needs formatting assistance!

Table 4.

Biological Condition Gradient: description of biological communities in Northern Piedmont streams (Montgomery County, Maryland)

1

Natural or native condition

Native structural, functional and taxonomic integrity is preserved; ecosystem function is preserved within the range of natural variability

I *Historically documented, sensitive, long-lived, or regionally endemic taxa:* Depending on size of stream, one or more of the following are present: Vertebrates: Bridle Shiner, Brook Trout, Chesapeake Logperch, Maryland Darter, Trout Perch. May be absent in very small headwaters.

II *Highly Sensitive taxa:* Depending on size of stream, one or more of the following are present: Vertebrates: Comely Shiner, Margined Madtom, Northern Hogsucker, River Chub, Shield Darter, Warmouth, Yellow Perch, Dusky Salamander, Long-Tailed Salamander. River chub, warmouth, yellow perch only in larger streams. In very small headwaters fish may be absent, but salamander species are present. Invertebrates: Ephemeroptera: *Habrophlebia; Epeorus; Ephemera; Leucrocuta; Habrophlebiodes,;Paraleptophlebia, Drunella* Plecoptera: *Sweltsa*; *Talloperla; Eccoptura; Pteronarcys* Trichoptera: *Wormaldia Diplectrona*, *Rhyacophila*, *Dolophilodes*, *Psilotreta; Goera; Lepidostoma* Diptera: *Dixa,* Prodiamesinae

III *Intermediate Sensitive taxa* : Densities of Intermediate Sensitive taxa are as naturally occur: Vertebrates (examples): Fallfish, Rosyside Dace, Potomac Sculpin, Blue Ridge Sculpin, Common Shiner, Fantail Darter, Central Stoneroller. All sensitive vertebrates combined are well more than half of the vertebrate fauna in richness and abundance. Invertebrates (examples): Plecoptera: *Amphinemura, Acroneuria*; *Leuctra; Isoperla*; *Clioperla; Prostoia*, *Allocapnia,* Ephemeroptera: *Diphetor*, *Acentrella; Ephemerella, Ameletus; Serratella/Teloganopsis*; *Odonata: Cordulegaster; Lanthus* Trichoptera: *Neophylax*; *Rhyacophila*; *Pycnopsyche; Glossosoma* Coleoptera: *Oulimnius; Anchytarsus; Psephenus; Promoresia* Diptera: Diamesinae*; Hexatoma*; *Prosimulium;*

IV *Taxa of Intermediate tolerance:* Densities of intermediate tolerant taxa are as naturally occur: Vertebrates (examples): Channel Catfish, Tessellated Darter, Pumpkinseed, Least Brook Lamprey Invertebrates (examples): Ephemeroptera: *Baetis; Stenonema*; *Caenis* Odonata: *Argia; Calopteryx; Boyeria* Trichoptera: *Chimarra*, *Cheumatopsyche, Hydropsyche*, *Polycentropus; Ironoquia* Coleoptera: *Helichus*; *Optioservus; Stenelmis;* Megaloptera: *Nigronia;* Diptera: *Chelifera, Clinocera;* Tanytarsini, *Tipula, Simulium;* Non-Insects: *Crangonyx;* Enchytraeidae;

V *Tolerant taxa* : Occurrence and densities of tolerant taxa are at low density, as naturally occur: Vertebrates (examples): American Eel, Blacknose Dace, Creek Chub, Golden Shiner, Mummichog, White Sucker, Northern Two-Lined Salamander. Invertebrates (examples): Coleoptera: Most Hydrophilidae and Dytiscidae genera; Diptera: most Chironomini and Orthocladiinae*;* Tabanidae, Stratiomyiidae; Non-Insects: Isopoda, Physidae, Hirudinae*;* Tubificidae

VI-i *Intolerant Non-native, intentionally introduced taxa* : Non native taxa such as Brown Trout or Rainbow Trout, are absent or, if they occur, their presence does not displace native trout or alter structure and function.

VI-m *Intermediate Non-native taxa* : Do not occur. Vertebrates (examples): Smallmouth Bass, Black Crappie, Longear Sunfish, Golden Redhorse. Invertebrates: Asian clam *(Corbicula)*

VI-m *Tolerant Non-native taxa* : Do not occur. Vertebrates (examples): Common Carp, Goldfish, Fathead Minnow, Green Sunfish, Largemouth Bass

VII *Physiological condition of long-lived organisms:* Anomalies are absent or rare; any that occur are consistent with naturally occurring incidence and characteristics

VIII *Ecosystem Function:* Rates and characteristics of life history *(e.g., reproduction, immigration, mortality, etc.)*, and materials exchange processes *(e.g., production, respiration, nutrient exchange, decomposition, etc.)* are comparable to that of "natural" systems; the system is predominantly heterotrophic, sustained by leaf litter inputs from intact riparian areas, with low algal biomass; P/R<1 (Photosynthesis: Respiration ratio)

IX *Spatial and temporal extent of detrimental effects:* Not applicable- disturbance is limited to natural events such as storms, droughts, fire, earth-flows. A natural flow regime is maintained.

X *Ecosystem connectance:* Depending on size of stream, migratory fish such as American eel or sea lamprey occur (absent in smallest headwaters). Depending on local geology, reach is highly connected with groundwater, its floodplain, and riparian zone, and other reaches in the basin. Many Piedmont streams are coolwater due to natural groundwater input. Allows for access to habitats and maintenance of seasonal cycles that are necessary for life history requirements, colonization sources and refugia for extreme events.

2 **Minimal changes in structure of the biotic community and minimal changes in ecosystem function** *Virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability*	***Whole assemblage and sample*** • Overall taxa richness and density is as naturally occurs (species names are not repeated – see description of BCG Level 1 for names) **I** ***Historically documented, sensitive, long-lived, regionally endemic taxa*** • Depending on size of stream, one or more of Attribute I fish are present. Brook trout as top predator **II** ***Highly Sensitive taxa*** • Richness of rare and/or specialist invertebrate taxa is low to moderate though densities may be low. • At least some taxa are present; **vertebrates** occur at densities higher than single accidental individual. **Invertebrates:** Several taxa present.(comprising nearly 1/5th of all taxa) **III** ***Intermediate Sensitive taxa*** • Richness and abundance of intermediate sensitive taxa is high. • **Vertebrates and Invertebrates**: All sensitive taxa (highly sensitive + intermediate sensitive): comprise half or more of all taxa and individuals **IV** ***Taxa of Intermediate tolerance*** • Present but generally comprise less than half of species and abundance **V** ***Tolerant taxa*** • Occurrence and densities of Tolerant taxa are as naturally occur. Typically present but a very small fraction of organisms. • Migratory fish species present. **VI-i** ***Intolerant Non-native, intentionally introduced taxa*** • Reproducing populations of brown trout or rainbow trout may be present indicating good water quality; cannot displace brook trout **VI-m, VI-t** ***Intermediate and Tolerant Non-native taxa*** • Do not occur. ***Physiological condition; Ecosystem Function; Spatial and temporal extent*** • Not addressed **X** ***Ecosystem connectance*** • Connectance on a local scale (floodplain, tributaries) remains good; dams and other flow obstructions downstream do not impede migration of eels and lamprey.

3 **Evident changes in structure of the biotic community and minimal changes in ecosystem function** *Some changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa but sensitive-ubiquitous taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system*	***Whole assemblage and sample*** • Overall taxa richness is as naturally occurs but density may be higher due to enrichment or other subsidy-stress effect. (species names are not repeated – see description of BCG Level 1 for names) **I** ***Historically documented, sensitive, long-lived, regionally endemic taxa*** • Typically absent **II** ***Highly Sensitive taxa*** • Highly sensitive vertebrates may be absent but 2-3 highly sensitive invertebrate taxa observed. **III** ***Intermediate Sensitive taxa*** • Richness and abundance of intermediate sensitive taxa is high. • **Vertebrates**: All sensitive taxa (highly sensitive + intermediate sensitive): comprise nearly half or more of all taxa and individuals; may be less than half in smaller streams (< 1.5 sq mi); **Invertebrates**: all sensitive taxa combined make up >50% of taxa and abundance. **IV** ***Taxa of Intermediate tolerance*** • Vertebrates: Present but makeup less than half of species and abundance ; • **Invertebrates**: overall increase in richness and elevated abundance but comprising <40% of taxa and <25% abundance **V** ***Tolerant taxa*** • Occurrence and densities of tolerant taxa higher than in Level 2; may be greater than half of community in smaller streams • Tolerant individuals less than half of all individuals in larger streams; **Invertebrates**: make up only 10% of richness and <25% of individuals. **VI-i** ***Intolerant Non-native, intentionally introduced taxa:*** May be absent **VI-m** ***Intermediate Non-native taxa:*** May occur **VI-t** ***Tolerant Non-native taxa*** • May occur at low densities • Tolerant nonnative individuals comprise small fraction of all vertebrates ***Physiological condition; Ecosystem Function; Spatial and temporal extent*:** Not addressed **X** ***Ecosystem connectance*** • Connectance on a local scale (floodplain, tributaries) remains good; eels and lamprey may be absent due to dams and other flow obstructions. Non-native sunfish (centrachidae) may occur due to ponds and dams.

4 **Moderate changes in structure of the biotic community and minimal changes in ecosystem function** *Moderate changes in structure due to replacement of some Sensitive-ubiquitous taxa by more tolerant taxa, but reproducing populations of some Sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes*	***Whole assemblage and sample*** • Overall taxa richness is slightly reduced, and density may be high. (species names are not repeated – see description of BCG Level 1 for names) **I *Historically documented, sensitive, long-lived, regionally endemic taxa:*** Absent **II *Highly Sensitive taxa*** • Typically absent but could occur in low numbers depending on proximity to cleaner tributaries **III *Intermediate Sensitive taxa*** • Richness and abundance of intermediate sensitive taxa is reduced, but at least some species remain at viable densities as functioning part of community. Coldwater invertebrate taxa are limited. • Vertebrates: Two or three sensitive taxa occur; at more than a small fraction of total individuals. Sensitive fish may be absent in very small headwaters (< 1 sq mi) if sensitive salamanders are present. Invertebrates: Several taxa possible but comprise less than 40% of richness and <30% abundance. **IV *Taxa of Intermediate tolerance*** • Present and may be diverse and abundant showing increases from Level 3. **V *Tolerant taxa*** • Occurrence and densities of tolerant taxa higher; may be accompanied by high dominance of one or two species **VI-i *Intolerant Non-native, intentionally introduced taxa*** • Typically absent **VI-m *Intermediate Non-native taxa*** • May occur **VI-t *Tolerant Non-native taxa*** • May occur at higher densities; may be dominant ***Physiological condition; Ecosystem Function; Spatial and temporal extent:*** Not addressed **X *Ecosystem connectance*** Connectance disrupted; eels and lamprey typically absent due to dams and other flow obstructions. Non-native sunfish (centrachidae) occur due to ponds and dams. Filling of interstitial spaces obstructs access to hyporheic zone for early instar mayfly/stonefly nymphs, eliminating nursery areas and *refugia* for storm-events and low flows. Adult stoneflies from upstream reaches continue to oviposit but reproductive success is limited; stonefly/mayfly nymphs continue to colonize by drift, with limited success.

5 **Major changes in *structure* of the biotic community and moderate changes in *ecosystem function*** *Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased build-up or export of unused materials*	***Whole Assemblage And Sample*** • Overall Taxa richness is reduced, but density may be high. (species names are not repeated – see description of BCG level 1 for names) **I *Historically Documented, Sensitive, Long-Lived, Regionally Endemic Taxa*** • Absent **II *Highly Sensitive Taxa*** • Absent **III *Intermediate Sensitive Taxa*** • Richness and abundance of intermediate sensitive taxa is greatly reduced, may be absent. **IV *Taxa Of Intermediate Tolerance*** • Present and may be diverse and abundant **V *Tolerant Taxa*** • Occurrence and densities of tolerant taxa high; accompanied by high dominance of one or two species **VI-I *Intolerant Non-Native, Intentionally Introduced Taxa* :** Typically absent **VI-M *Intermediate Non-Native Taxa:*** May occur **VI-T *Tolerant Non-Native Taxa*** • Occurrence and densities of tolerant taxa high; accompanied by high dominance of one or two species ***Physiological Condition; Ecosystem Function; Spatial And Temporal Extent*** • Not Addressed **X *Ecosystem Connectance*** • Connectance disrupted; eels and lamprey typically absent due to dams and other flow obstructions. non-native sunfish (Centrachidae) occur due to ponds and dams. Filling of interstitial spaces obstructs access to hyporheic zone for early instar mayfly/stonefly nymphs, eliminating nursery areas and *refugia* for storm-events and low flows. Adult stoneflies from upstream reaches may continue to oviposit but reproductive success is limited; mayfly/stonefly nymphs may colonize by drift unless headwater tributaries are impacted.

6 **Severe changes in structure of the biotic community and major loss of ecosystem function** *Extreme changes in structure; wholesale changes in taxonomic composition; extreme alterations from normal densities and distributions; organism condition is often poor; ecosystem functions are severely altered*	***Whole Assemblage And Sample*** • Overall Taxa richness is greatly reduced, but density may be high (extreme enrichment), or very low (indicating toxicity). (species names are not repeated – see description of BCG Level 1 for names) **I *Historically Documented, Sensitive, Long-Lived, Regionally Endemic Taxa*** • Absent **II *Highly Sensitive Taxa*** • Absent **III *Intermediate Sensitive Taxa*** • Typically absent **IV *Taxa Of Intermediate Tolerance*** • May be present but typically reduced diverse and abundance **V *Tolerant Taxa*** • High dominance of one or two species **VI-I *Intolerant Non-Native, Intentionally Introduced Taxa*** • Absent **VI-M *Intermediate Non-Native Taxa*** • May be absent **VI-T *Tolerant Non-Native Taxa*** • May have high dominance of one or two species (e.g., Fathead Minnow, Common Carp) ***Physiological Condition; Ecosystem Function; Spatial And Temporal Extent*** • Not Addressed **X *Ecosystem Connectance*** Connectance disrupted; eels and lamprey typically absent due to dams and other flow obstructions. non-native tolerant fish occur. Sources of colonists from headwater tributaries are missing with increased burial and piping of headwaters.

Conclusion

The results of this pilot showed a remarkable level of agreement among the experts (Montgomery County, MDE, MDNR, USEPA, and University of Maryland) and across assemblages (benthic macroinvertebrates, fish and salamander). Further refinement and analysis are planned this spring and summer, including evaluation of independent data sets but the preliminary findings show that:

1) The individual expert judgments of the biological condition of the Ten Mile Creek sites ranged between high to fair quality (BCG levels 2- to level 4). The highest quality Ten Mile Creek site was the King Spring Tributary where the primary headwater stream supported cold and cool water sensitive, native benthic macroinvertebrate taxa. The experts predicted that these sites were excellent candidates for protection. A cursory evaluation of watershed condition indicate the area immediate to these streams have no or low road density and impervious surface. However, the fish community is potentially impacted by influences from novel, non-native taxa swimming upstream from the reservoir in Ten Mile Creek.

2) Three of the sites were sampled before and after land use disturbance and changes in the assemblages were consistently identified by the experts and results in lower BCG level assignments. For instance, Samp006 (Right Fork) macroinvertebrates changed from a Level 2+ stream to a 4-between 1998 and 2012; some highly sensitive, cool and coldwater invertebrate taxa (Diplectrona, Dolophilodes, Eccoptura) and some intermediate sensitive taxa (e.g., Ephemerella)were eradicated following urbanization. All three sites came from County Special Protection Areas (SPA) – one in the Upper Paint Branch, one in the Piney Branch and one in the Clarksburg Master Plan. The land use disturbance resulted from the conversion of rolling piedmont fields and forests to residential development of different levels of imperviousness.

3) High quality Northern Piedmont sites such as Ten Mile Creek and Sopers Branch showed potential for supporting native brook trout populations. These streams may be candidates for a use upgrade from class 1 to class 3. MDE and MDNR experts participating in the expert panel offered to work with Montgomery County to further evaluate this possibility.

4) The information from the three different assemblages (*benthic macroinvertebrates, fish, salamanders*) were complementary and provided strong evidence for identifying high quality conditions and detecting early response to stress in sensitive, threatened streams. In particular, the presence of sufficient numbers of sensitive, cold and cool water benthic invertebrates and sensitive salamander are robust indicators of high quality conditions, including sites that could support the return of native brook trout. Additionally, certain fish taxa such as eels, herring, or sea lamprey are indicative of streams that are not disconnected from the Mainstem River and the Chesapeake Bay. These fish species migrate from coastal waters up through the rivers and into the streams.

5) Because of the high quality nature of Ten Mile Creek headwaters (e.g., Kings Spring Tributary and similar 1st order streams); coldwater indicators and the potential for Brook Trout re-introduction in Ten Mile Creek; and the documented decline in biological quality from “before and after” studies as in the Clarksburg Tributary example, caution should be applied for planned urban developments within upland and headwaters in order to protect these high quality, sensitive streams and the watershed.

6) The experts discussed the use of the Northern Piedmont BCG as a framework for communicating to the public and their officials detailed information on the condition of the aquatic biota and potential for restoration and for protection; predicted biological gains from management actions; and progress once actions taken. This framework will help develop a BCG using quantitatively robust data from the Northern Piedmont of Maryland that could materially assist local efforts to describe risk in different development and land use options as well as restoration opportunities. Based on a very preliminary analysis of the relationship between the BCG level site assignments by the experts and the site’s ibi scores, the BCG analysis provided additional precision in detecting early or more subtle shifts in the biota indicative of either degradation or improvements depending on the direction of change. This result indicates the potential for using a BCG to supplement the existing IBIs and enhance the county’s biological assessment approach to detect high quality conditions and track progress in restoration.

7) Numeric decision rules can be developed and the narrative model quantified with further refinement of the narrative BCG (e.g., analysis of a larger data set, continued expert solicitation, and independent peer review). A numeric BCG can then be used to refine and improve existing biological indices or become basis for new biological indices.

APPENDIX A

SELECTED CASE EXAMPLES FROM:

A PRIMER ON USING BIOLOGICAL ASSESSMENTS TO SUPPORT WATER QUALITY MANAGEMENT

EPA 810-R-11-01

These case studies show use of a biological condition gradient framework to support state water quality management programs.

3.1 Protecting Water Quality Improvements and High Quality Conditions in Maine

Abstract

Maine has used biological, habitat, and other ecological information to designate aquatic life uses that reflect the highest achievable conditions of its waterbodies and has used antidegradation policy to maintain and protect high existing conditions. Maine uses a Biological Condition Gradient to designate levels of protection for its waterbodies (e.g., designated aquatic life uses) and to assign numeric biological criteria to protect those uses. Maine describes the system as a *tiered use classification*. For Maine, tiered aquatic life uses highlight the relationship between biology, water quality, and watershed condition in determining the need for waterbody protection to maintain existing high quality conditions or the potential for water quality improvement to attain water quality standards. Maine's integrated, data-driven approach has resulted in documented improvement in water quality throughout the state, including upgrades of designated uses of more than 1,300 stream miles, from Class C to Class B, and from Class B to Class A or AA waters (Outstanding National Resource Waters).

In 1983 the Maine Department of Environmental Protection (ME DEP) initiated a statewide biological monitoring and assessment program and revised water quality standards (WQS) by 1986 to recognize high levels of water quality condition. Maine established four classes for freshwater rivers and streams (see Table 3-1). All four classes meet or exceed the Clean Water Act (CWA) section 101(a)(2) goal for aquatic life protection. Every waterbody is assigned to one of four tiers by considering its existing biological condition, its highest achievable condition on the basis of biological potential, aquatic habitat, watershed condition, levels of dissolved oxygen, and numbers of bacteria (Table 3-1). Agency biologists developed a linear discriminant model to measure the biological attainment of each class, establish numeric biological criteria, and assign corresponding antidegradation tiers for purposes of statewide planning (see Table 3-1, column 6). Part of Maine's antidegradation policy requires that where any actual measured water quality criterion exceeds that of a higher class, that quality must be maintained and protected [Maine Revised Statutes Title 38, §464.4(F)]. In effect, by having multiple levels of aquatic life use standards in law, Maine has established a means of improving water quality in incremental steps, and of using antidegradation reviews and reclassification upgrades to maintain and protect water quality and aquatic life conditions that exceed existing or designated aquatic life uses.

The following case study offers an example of how Maine has used tiered use classifications and antidegradation policy cooperatively in its water quality management program. In conjunction with habitat and other chemical and physical parameters, Maine assigns waters to designated use classes (AA, A, B, or C; Table 3-1) on the basis of the *potential* for water quality improvement. In the 1980s, monitoring on the Piscataquis River near the towns of Guilford and Sangerville found aquatic life conditions insufficient to meet even the minimum Class C conditions at which the river was classified. The segment of the river in the Guilford-Sangerville area had a history of poor water quality, including recurrent fish kills from poorly treated industrial and municipal wastes. However, the state determined that this segment of the river could attain at least Class C. The state determined that sewage treatment plant and industrial discharges were the only significant source of stressors to the river, with very good quality upstream conditions and good salmonid production elsewhere. Additionally, the river's habitat structure and hydrologic regime were very good.

Table 3-1. Criteria for Maine River and stream classifications and relationship to antidegradation policy.

Class	Dissolved oxygen criteria	Bacteria criteria	Habitat narrative criteria	Aquatic life narrative criteria*** and management limitations/restrictions	Corresponding federal antidegradation policy tiers
AA	As naturally occurs	As naturally occurs	Free-flowing and natural	As naturally occurs**; no direct discharge of pollutants; no dams or other flow obstructions.	3 (Outstanding National Resource Water [ONRW])
A	7 ppm; 75% saturation	As naturally occurs	Natural**	Discharges permitted only if the discharged effluent is of equal to or better quality than the existing quality of the receiving water; before issuing a discharge permit the Department shall require the applicant to objectively demonstrate to the department's satisfaction that the discharge is necessary and that there are no reasonable alternatives available. Discharges into waters of this class licensed before 1/1/1986 are allowed to continue only until practical alternatives exist.	2 1/2
B	7 ppm; 75% saturation	64/100 mg (g.m.) or 236/100 ml (inst.)*	Unimpaired**	Discharges shall not cause adverse impact to aquatic life** in that the receiving waters shall be of sufficient quality to support all aquatic species indigenous** to the receiving water without detrimental changes to the resident biological community.**	2 to 2 1/2
C	5 ppm; 60% saturation; and 6.5 ppm (monthly avg.) when temperature is </= 24 °C	125/100 mg (g.m.) or 236/100 (inst.)*	Habitat for fish and other aquatic life	Discharges may cause some changes to aquatic life**, provided that the receiving waters shall be of sufficient quality to support all species of fish indigenous** to the receiving waters and maintain the structure** and function** of the resident biological community. **	1 to 2

Source: Maine DEP (modified). http://www.maine.gov/dep/blwq/docmonitoring/classification/reclass/appa.htm.

Notes:

* g.m. = geometric mean; inst. = instantaneous level.

** Terms are defined by statute (Maine Revised Statutes Title 38, §466).

*** Numeric biological criteria in Maine regulation Chapter 579, Classification Attainment Evaluation Using Biological Criteria for Rivers and Streams.

Four years after issuance of new National Pollutant Discharge Elimination System (NPDES) permits requiring better industrial pretreatment and improved wastewater treatment at the Guilford-Sangerville treatment facility, follow-up monitoring found water quality improvements that exceeded Class C and attained Class B aquatic life conditions. The achievement of higher water quality conditions was preserved through a classification upgrade process (supported by the industry and the two towns). The river was upgraded to Class B and now attains those higher aquatic life use goals. The redesignation process requires the state legislature to enact a statutory change of a waterbody's classification and can take considerable time to complete. However, during the reclassification process the improved water quality conditions existing in the Piscataquis River were protected through implementation of the state's Tier II antidegradation policy. The value secured by maintaining the higher quality condition was demonstrated in 2009 when the Piscataquis River was designated as critical habitat for the restoration of the endangered Atlantic salmon.

The management actions based on documented improvements in the biological condition in this example demonstrate the complementary application of the state's tiered aquatic life use classification and the Tier 2 and 2½ antidegradation policy. Using that approach, water quality upgrades from Class C to B and from B to A or AA have been repeated in many parts of the state, and subsequently maintained and protected. Overall, Maine has redesignated more than 1,300 miles of streams to a higher class on the basis of biological information (e.g., biological improvements due to point source controls, nonpoint source practices, dam operational modifications or removal) and societal values (e.g., water quality and habitat protection for wild trout populations; critical species protection, especially Atlantic salmon habitat and tribal petitions).

3.3 Protection of Antidegradation Tier II Waters in Maryland

Abstract

Maryland is identifying high-quality waters for antidegradation purposes on a waterbody-by-waterbody basis. Maryland has designated Tier II waters on the basis of two indices of biotic integrity—fish and benthic invertebrates—and provides additional protection so that those waters are not degraded. New or increased point source dischargers and local sewer planning activities that have the potential to affect Tier II waters are required to examine alternatives to eliminate or reduce discharges or impacts. The state has developed requirements that must be met for projects that do not implement a no-discharge alternative. To help local planners to determine whether a planned activity has the potential to affect a Tier II water, the state has developed geographic information system shapefiles that identify such waters. Those files are provided to local jurisdictions to improve their knowledge of where Tier II waters occur. Biological assessments, in conjunction with chemical and physical assessments, are then conducted to determine the status of those waters and detect trends in condition.

In its state water quality standards (WQS), Maryland adopted an antidegradation policy for protecting all waters for existing and designated uses. High-quality (Tier II) waters receive additional attention and regulatory protections. Identification of Tier II waters, in this case streams, is based on a waterbody-by-waterbody approach using biological survey data, from which two indices of biotic integrity (IBIs) are developed—one for benthic invertebrates and one for fish. Those with both scores above 4 are designated Tier II waters. The state has identified more than 230 high-quality water segments. To protect downstream high-quality waters, a watershed approach to protection is applied. Tier II waters must be protected so that water quality does not degrade to minimum standards, and that requirement has implications for potential discharges and local planning activities.

Application of Tier II Protection

The Maryland Department of the Environment (MDE) requires that applicants for amendments to county plans (i.e., water and sewer plans) or permits for new or expanding point source discharges evaluate alternatives to eliminate or reduce discharges or impacts [COMAR 26.08.02.04-1(B)]. Applicants for permits must consider whether the receiving waterbody is Tier II (or whether a Tier II determination is pending); MDE reviews proposed amendments to county plans discharging to Tier II waters. In both cases, discharges to Tier II waters require a Tier II review [2.26.08.02.04-1(F)].

MDE has developed a cooperative approach to protecting Tier II waters. Monitoring and WQS programs work with the National Pollutant Discharge Elimination System (NPDES) permitting program to help screen for potential effects from new or expanded discharges and to develop permit conditions to minimize those effects and maintain existing high-quality waters. Outreach materials are available to educate county planners about Tier II waters, and geographic information system (GIS) shapefiles that planners can use to help locate Tier II waters within their jurisdictions have been developed.[1] That information provides Maryland county planners a way to determine early on whether their projects could affect Tier II waters.

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[1] More information about GIS is at http://www.gis.com/content/what-gis.

A list of recommendations for land-disturbing projects that are not able to implement a no-discharge alternative provides the following initial guidance:

1. Implementation of environmental site design (also known as low-impact development)—Design elements and practices must be approved for Tier II waters with opportunity provided for exploration of appropriate alternatives and justification for structural elements in the proposed designs.
2. Expanded riparian buffers—Buffers must be at a minimum of 100 feet; wider buffers may be required depending on slope and soil type.
3. Biological, chemical, and flow monitoring in the Tier II watershed—Applicants may be required to conduct biological assessments in conjunction with chemical, physical, and flow assessments to help determine the remaining assimilative capacity and cumulative impacts of current and future development. Depending on project specifics, additional monitoring may be required, such as the completion of a hydrogeologic study for a major mining project or additional pH monitoring because of impacts associated with instream grout applications seen in many common transportation projects.
4. Additional practices—Depending on the potential for project-specific effects on water quality, applicants may be required to implement other practices, such as enhanced sediment and erosion control practices or implementation of more environmentally protective alternatives.

If those general requirements cannot be implemented, applicants must submit a detailed hydrologic study and alternatives analysis to demonstrate that the assimilative capacity of a waterbody will be maintained. The assimilative capacity of a waterbody is typically site-specific and determined through studies of the waterbody. In terms of WQS, assimilative capacity is a measure of the capacity of a receiving water to assimilate additional pollutant(s) but still meet the applicable water quality criteria and designated uses.

3.4 Using Complementary Methods to Describe and Assess Biological Condition of Streams in Pennsylvania

Abstract

The Pennsylvania Department of Environmental Protection (PA DEP) has developed a new benthic macroinvertebrate index of biotic integrity (IBI) to assess the health of wadeable, freestone (e.g., high gradient, soft water) streams. Additionally, PA DEP calibrated a benthic macroinvertebrate Biological Condition Gradient (BCG) and is exploring using the BCG to more precisely describe biological characteristics in Pennsylvania streams. Potentially, the BCG can be used in conjunction with the IBI to identify aquatic life impairments and to describe the biological characteristics of waters assigned special protection. PA DEP is also exploring using a discriminant analysis model with additional taxonomic, habitat, and landscape parameters to describe exceptional value waters.

Describing Waters along a Gradient of Condition

Pennsylvania Department of Environmental Protection (PA DEP) has developed a new benthic macroinvertebrate index of biotic integrity (IBI) for the wadeable, freestone (high-gradient, soft-water) streams in Pennsylvania using the reference condition approach (PA DEP 2009). PA DEP has alternative assessment methods in place for other stream types (i.e., low-gradient pool-gliders, karst [limestone]-dominated). The IBI provides an integrated measure of the overall condition of a benthic macroinvertebrate community by combining multiple metrics into a single index value. PA DEP uses the IBI to assess attainment of aquatic life uses.

A **metric** is a measurable aspect of a biological community that responds in a consistent, predictable manner to increasing anthropogenic stress. Examples of metrics include **taxa richness**, which is a measure of the number of different kinds of organisms (taxa) in a sample collection, and **% dominance**, which is a measure of which species compose the majority of organisms present in a sample collection.

To gain a more comprehensive view of an aquatic community, multiple types of metrics are combined into a **biological, or biotic, index**. The typical biological index may include information from 7 to 12 different metrics. The metric values are typically scored on a unitless scale of 0 to 100 and averaged to obtain a single value.

Additionally, PA DEP is exploring use of a Biological Condition Gradient (BCG) to describe the biological characteristics of freestone streams along a gradient of condition. PA DEP conducted a series of three expert workshops in 2006, 2007, and 2008 to calibrate a BCG along a gradient from minimally to heavily stressed conditions (PA DEP 2009). The BCG is a narrative model based on measurable attributes, or characteristics, of aquatic biological communities expected in natural conditions (e.g., presence of native taxa, some pollution tolerant taxa present but typically not dominant, absence of invasive species). Additionally, the BCG model includes attributes that describe interactions among biotic communities (e.g., food web dynamics), the spatial and temporal extent of stress, and the presence of naturally occurring habitats and landscape condition (for more information, see Tool # 2, *The Biological Condition Gradient*). To date, states and tribes that have applied the BCG have used the BCG attributes that describe the taxonomic composition of the resident aquatic biota and, where available, information on fish condition, for example lesions and abnormalities (BCG attributes I–VII) (see Table 2-2). Some states are exploring the application of additional attributes on food web dynamics, extent of stress, and landscape condition (BCG attributes VIII–X). These efforts are providing valuable information that will aid the U.S. Environmental Protection Agency (EPA) in further refining the BCG.

To develop the BCG for its streams, biologists from PA DEP, in conjunction with external taxonomic experts and scientists, e.g., the Delaware River Basin Commission, Western Pennsylvania Conservancy, and EPA, used the BCG attributes that characterize specific changes in community taxonomic composition (PA DEP 2009). For example, in the highest tiers of the BCG, locally endemic, native, and sensitive taxa are well represented (attributes I and II) and the relative abundances of pollution-tolerant organisms (attribute V) are typically lower. With increasing stress, more pollution-tolerant species may be found with concurrent loss of pollution-sensitive species (attribute VI). At the beginning of the expert workshops, the biologists first assigned or adjusted BCG attributes to each macroinvertebrate taxon (e.g., pollutant-sensitive or tolerant) and then reviewed taxa lists from samples representing minimally disturbed to severely disturbed site conditions (Figure 3-2). The evaluated samples included sites judged as either reference quality (e.g., at or close to minimally disturbed conditions) or heavily stressed based on specific selection criteria (PA DEP 2009). To further test the robustness of the BCG process, additional sites that were not part of the reference or heavily stressed sample groups were evaluated. Those sites represented a range of site conditions, including moderately to heavily stressed site conditions (non-reference and moderately stressed; see Figure 3-2). Using the BCG tier descriptions of predicted changes in the attributes as a guide, they assigned each site to one of the six BCG tiers.

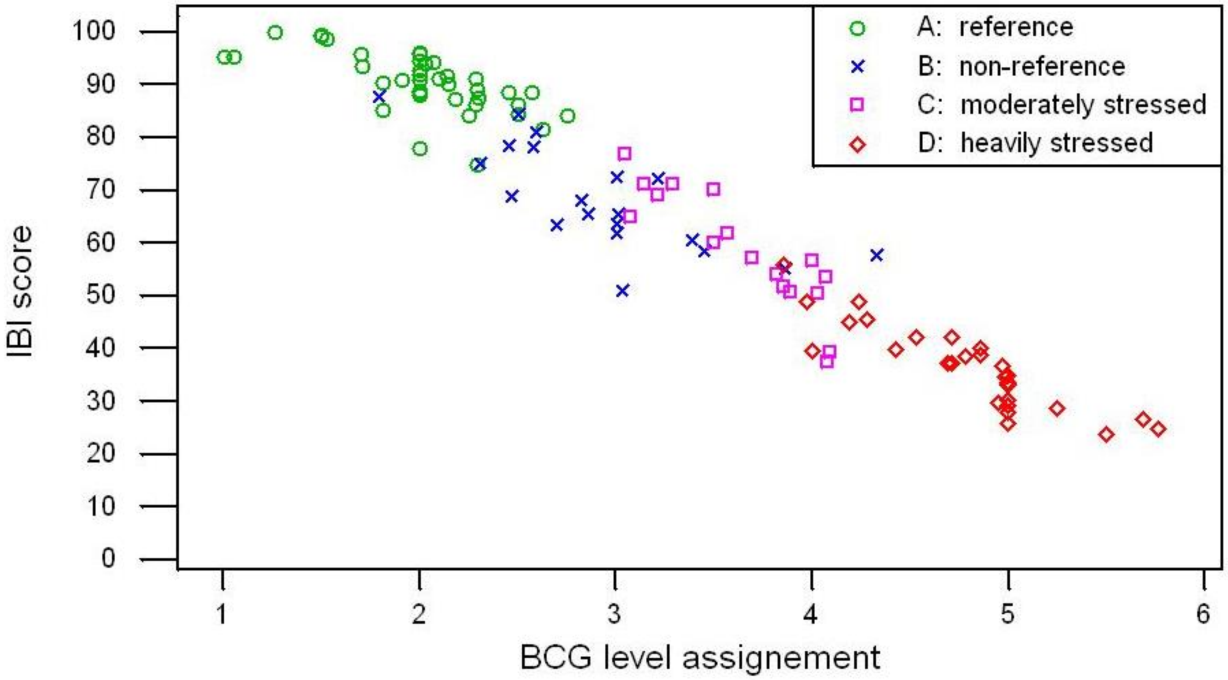


Figure 3-2. Comparison of calibrated BCG tier assignments (mean value) and IBI scores for freestone streams representing range of conditions from minimal to severely stressed.

For all the evaluated samples, PA DEP biologists analyzed the relationship between a sample's BCG tier assignment with its corresponding IBI score (PA DEP 2009). A strong correlation existed between the calibrated BCG tier assignments and the IBI scores (Figure 3-2). Based on these results, PA DEP is evaluating using the BCG to describe the biological characteristics of streams along a gradient of condition; for example, the reference sites clustered at IBI scores near 80 and above. Based on taxonomic information and without knowledge of the IBI scores, the experts assigned these sites to BCG tiers 1.5 to 2.5. BCG tier 2 represents close to natural conditions (e.g., minimal changes in structure and function relative to natural, or pristine, conditions; supports reproducing populations of native species of fish and benthic macroinvertebrates). This information can meaningfully convey to the public the biological characteristics of waters in the context of the Clean Water Act and the goal to protect aquatic life. Using both the IBI and BCG, PA DEP might be able to develop a cost-effective, publicly transparent approach to routinely monitor and assess the condition of its freestone streams and to help identify potential high-quality (HQ) or exceptional value (EV) streams.

Describing Exceptional Value Waters

Pennsylvania's regulations define waters of EV that are of unique ecological or geological significance. EV streams are given the highest level of protection and constitute a valuable subset of Pennsylvania's aquatic resources. To support protection of these waters, PA DEP is considering the use of a discriminant analysis model to evaluate the relationship between condition of the watershed, a stream, and its aquatic biota (e.g., the connection of riparian areas with a stream and the floodplain or the spatial extent of stressors and their sources in the watershed). PA DEP is evaluating the use of a discriminant model that incorporates measures of land use and physical habitat along with IBI scores and indicator taxa richness to make distinctions between EV and HQ waters. The abiotic measures PA DEP is using address habitat fragmentation and spatial and temporal extent of stress and are comparable to the national BCG model attributes IX (extent of stress) and X (ecosystem connectance). The results of this effort could potentially support decisions on where to target resources for sustainable, cost-effective protection of EV waters and healthy watersheds. Through this work, PA DEP is providing EPA valuable feedback on the technical development and potential program application for BCG attributes IX and X.

Potential Application to Support Protection of Waters of Highest Quality

PA DEP is exploring new approaches to help identify streams that are of the highest quality and might require special protection. For example, a stream might be found to meet the expected biological condition of an HQ or EV water based on its IBI score and BCG tier assignment. This information could be used to support further study to determine whether its designation should be as an HQ water or if it meets the additional criteria for designation as an EV water. When biological information is presented in context of a BCG framework, it is easier for the public to understand the status of the aquatic resources, including waters that are in excellent condition and require additional protection.

3.5 Use of Biological Assessments to Support Use Attainability Analysis in Ohio

Abstract

Ohio uses biological assessment information in conjunction with physical habitat assessments to strengthen use attainability analyses (UAAs) in the state. The technical and programmatic underpinnings for Ohio's use attainability determinations is the state's aquatic life use classification approach, which is based on the relationship between biology, habitat, and the potential for water quality improvement. Ohio's biological monitoring and assessment program provides timely, statewide information on the status of waterbodies and the data to support a UAA if needed, including when biological conditions improve and an upgrade of a designated use is warranted. Typically, in situations where the habitat needed to meet aquatic life uses is present, Ohio has taken management actions to address water quality issues and restore impairments.

In 1990 Ohio used biological assessment information to specify levels of biological condition for specific streams and rivers based on ecoregional reference sites. As a result, the state refined definitions of some aquatic life uses, adopted new ones, and assigned biological criteria to key uses to support a tiered approach to water quality management within the Ohio water quality standards (Table 3-3).

Table 3-3. Summary of Ohio's beneficial use designations for the protection of aquatic life in streams.

Beneficial use designation	Key attributes
Coldwater habitat (CWH)	Native cold water or cool water species; put and take trout stocking.
Exceptional warmwater habitat (EWH)	Unique, unusual, and highly diverse assemblage of fish and invertebrates.
Seasonal salmonid habitat (SSH)	Supports lake run steelhead trout fisheries.
Warmwater habitat (WWH)	Typical assemblages of fish and invertebrates, similar to least impacted reference conditions.
Limited warmwater habitat (LWH)	Temporary designations based on 1978 WQS. Predate Ohio tiered aquatic life use classification and were not subjected to UAA; being phased out as UAA are conducted for each LWH waterbody or segment. Most of the LWH waterbodies or segments have been redesignated as WWH or higher with the exception of some mine-drainage-affected segments that were designated LRW.
Modified warmwater habitat (MWH)	More tolerant assemblages of fish and macroinvertebrates are present relative to a WWH assemblage, but otherwise generally similar species to WWH present; irretrievable modifications of habitat preclude complete recovery to least impacted reference condition.
Limited resource water (LRW)	Fish and macroinvertebrates severely limited by physical habitat or other irretrievable condition; minimum protection afforded by the CWA.

Source: Ohio EPA, April 2004. http://www.epa.ohio.gov/portals/35/wqs/designation_summary.pdf.

When designating aquatic life uses, the quality of habitat is a major factor in a use attainability analysis (UAA) process to determine the potential for restoration and expected biological condition for streams and rivers in Ohio. If sufficient good habitat attributes are not present, such as higher quality substrates and sufficient instream cover, a determination about restorability is made. If habitat is sufficient or could be restored, it is assumed that any observed biological impairments are due to the effects of other stressors (e.g., metals, nutrients) that could be remediated through readily available water quality management options (e.g., permit conditions and/or best management practices [BMPs]) and the biological assemblage restored. The aquatic life use classifications are based on ecological conditions, and in 1990 biological criteria were developed to protect each use. Ohio's biological criteria include two indices based on stream fish assemblages (Index of Biological Integrity [IBI] and Modified Index of Well-Being [MIwb]) and one index based on stream macroinvertebrate assemblages (Invertebrate Community Index [ICI]). The biological criteria were developed based on regional reference conditions and are stratified by each of the state's five level 3 ecoregions and three site types (headwater, wadeable, and boatable sites).

Using these aquatic life use classifications, Ohio has been able to determine attainable levels of condition for streams and rivers. For example, in the mid-1980s biological surveys of Hurford Run, a small stream located in an urban/industrial area of Canton, Ohio, showed that the stream was severely impaired by toxic chemical pollutants and that some sites had no fish at all. Hurford Run is channelized for nearly its entire length. Because of the severity of the biological impairment, a UAA was conducted to determine if the warmwater habitat (WWH) aquatic life use was attainable and, if not, to determine the most appropriate designated use for the stream. Based on biological and habitat assessments, the most appropriate aquatic life uses for the different segments of Hurford Run could be determined. For example, very poor habitat quality from historical channelization in the *upper reach of Hurford Run* and the associated hydrological modifications (e.g., ephemeral flows) resulted in a limited warmwater habitat (LWH) designation for this upper reach.

The *middle reach of Hurford Run* has been subject to extensive, maintained channel modifications that also resulted in degraded habitat features, though water is always present. Channel maintenance practices resulting in poor-quality substrates, poorly developed pools and riffles, and a lack of instream cover preclude biological recovery to assemblages consistent with the WWH use, which indicated that the middle reach should be designated a modified warmwater habitat (MWH), reflecting the attainable biological potential for a channel-modified stream determined by scientific studies. The *lower reach of Hurford Run* was previously relocated and channelized, but over time the reach has naturally recovered sufficient good-quality habitat attributes, such as coarse substrates and better developed riffle and pool features associated with the WWH use for this ecoregion. Biological assessments confirmed the presence of aquatic assemblages typical of WWH. Based on this information, this segment was designated as WWH. The designated aquatic life uses reflect the current best possible condition in each segment of Hurford Run and provide a basis for management actions to ensure that the associated criteria are met and the use is protected. Numeric biological criteria have been established for key designated aquatic life uses, and a segment is listed on the 303(d) list if it is in nonattainment of the biological criteria. Additionally, the different segments are routinely monitored by the state and the condition reevaluated on a regular basis. If there is any information indicating that a higher use is being attained or could be attained, that water is considered for redesignation to the higher use.

Ohio has also used biological assessment data to refine its water quality criteria in some cases. For instance, when Ohio's aquatic life use classifications were established in 1978, Ohio established dissolved oxygen criteria to protect each designated use. Initially, a dissolved oxygen criterion of 6 mg/L as a minimum was established for exceptional warmwater habitat (EWH) waters to protect highly sensitive species supported by this use. However, analyses of ambient biological and chemical data suggested that the 6 mg/L minimum criterion was over-protective for EWH waters. Data showed a relationship between stressors and biological measures, with dissolved oxygen concentrations less than 5.0 mg/L being associated with IBI scores not in attainment of EWH biological criteria. And, in general, data showed that with dissolved oxygen greater than 5.0 mg/L, IBI scores are much more likely to attain EWH. These results were used to justify refining the EWH criteria to the current 6 mg/L average, 5 mg/L minimum (Ohio EPA 1996). The criterion revision also supported the redesignation of some rivers and streams from WWH to EWH.

APPENDIX B

NORTHERN PIEDMONT REGION BIOLOGICAL CONDITION GRADIENT

Currently a separate file 4/2/13

APPENDIX C

Expert Solicitation Workshop: List of Experts, Data Spread Sheets

currently a separate file 4/2/13

MEMORANDUM – DRAFT

Date: April 3, 2013

To: Mary Dolan and Valdis Lazdins, Montgomery County Planning Department

From: Biohabitats and Brown and Caldwell, a Joint Venture

RE: Ten Mile Creek Watershed Environmental Analysis
in Support of the Clarksburg Master Plan Limited Amendment
SUBJ: Summary of the 1994 Master Plan Scenario Analysis

Introduction

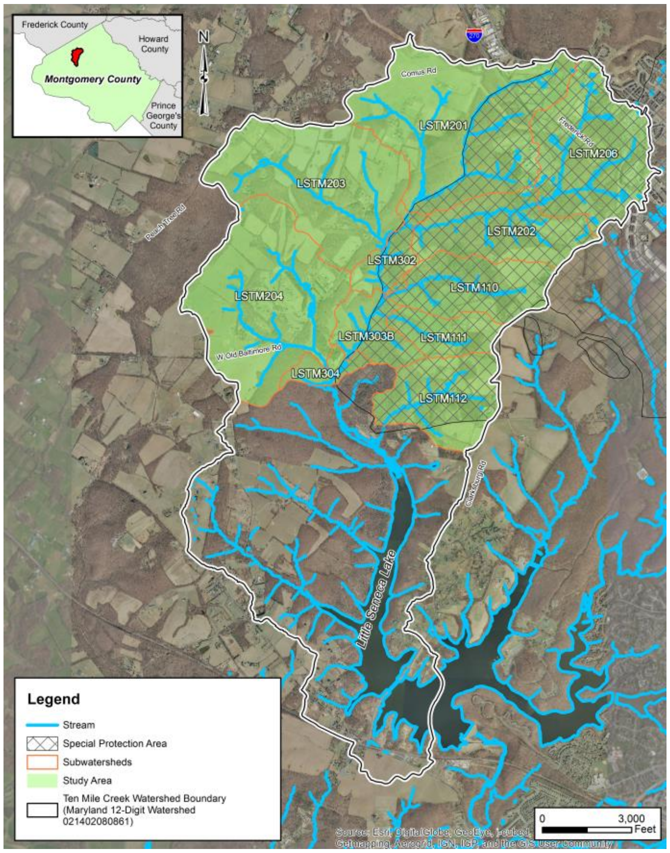
The Ten Mile Creek watershed in northwestern Montgomery County is the focus of an environmental analysis study in support of the Limited Amendment to the Clarksburg Master Plan, being undertaken by the Maryland-National Capital Park and Planning Commission (M-NCPPC) Montgomery County Planning Department. This environmental analysis is being conducted for the Planning Department by Biohabitats and Brown and Caldwell, a Joint Venture, with support from the Center for Watershed Protection. It is being done in collaboration with Montgomery County Department of Environmental Protection (DEP) and Montgomery County Department of Permitting Services (DPS).

As the purpose of this study is to determine the baseline environmental conditions in order to evaluate potential watershed response to development within the Ten Mile Creek watershed, analyses have focused only on subwatersheds upstream of the existing USGS gage station and those that have the potential to be directly affected by development (Figure 1). These subwatersheds are referred to as the Ten Mile Creek "study area." The Ten Mile Creek study area drains approximately 4.8 square miles of primarily rural and forested lands in Montgomery County, flowing from its headwaters just north of Frederick Road to Little Seneca Lake. A basic profile of the study area is provided in Table 1.

NOTE: Planimetric information shown in this document is based on copyrighted GIS Data from M-NCPPC, and may not be copied or reproduced without express written permission from M-NCPPC.

Table 1. Profile of the Current Ten Mile Creek Study Area

Area	• 3,046 acres (4.8 square miles)
Stream Length	• Approximately 22 miles (including Ten Mile Creek and its tributaries)
Land Use	• 46% Forest • 38% Rural • 7% Low Density Residential
Land Cover	• 4% Impervious Cover • 46% Forest Cover • Remaining land cover predominantly a mix of non-forested pervious area, including pasture, cropland, and turf
Water Quality	• Use I-P Stream
Major Transportation Routes	• Dwight D. Eisenhower Memorial Highway (I-270) • Frederick Road (MD 355)
Significant Natural and Historical Features	• Rustic roads • Old Baltimore Road stream ford • Cemeteries • 1994 Clarksburg Master Plan Individual Sites (Clarksburg School, Moneysworth Farm, and Cephas Summers House) • 1994 Clarksburg Master Plan Historical District (Clarksburg Historical District)



Source: Esri, DigitalGlobe, GeoEye, i-cubed, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure 1. Ten Mile Creek Watershed and Subwatersheds

The Consultant Team conducted an environmental study to document existing conditions and to evaluate potential watershed response to development proposed by the 1994 Master Plan. The assessment was conducted through a series of analyses and consisted of two primary phases:

1. **Existing Conditions** – This phase included several tasks to compile available information and document the baseline environmental conditions to be used as the basis for evaluating potential watershed response to development within the Ten Mile Creek watershed. Specific tasks included:
    - **Data Discovery** - This task included collection and review of existing data and reports provided by the Planning Department and Montgomery County Department DEP;
    - **Data Collection** – This task included limited field investigations to supplement existing data and to verify watershed conditions;
    - **Summary** – Existing conditions were summarized in a series of maps to illustrate watershed features and described in an Existing Conditions summary report. Powerpoint slides were also prepared for use in presentations to the Montgomery County Planning Board and the public.
2. **Environmental Analyses** – This phase consisted of several analyses to estimate the impact of development on multiple watershed characteristics which may be predictors of post-development stream conditions. The analyses conducted by the Consultant Team included existing conditions and build-out of the development in Ten Mile Creek proposed by 1994 Master Plan. Proposed development was assumed to be controlled by new stormwater management practices referred to as Environmental Site Design (ESD), as described in more detail in later sections. The analyses included:
    - **Spatial Watershed Analysis** to define attribute characteristics that have the potential to either influence the landscape's ability to recover from disturbance, or that are critical to long term ecological stability and integrity of Ten Mile Creek. The analysis included overlays of anticipated development disturbance areas to quantify the impacts on individual watershed attributes, and to identify development areas impacting the highest versus lower quantities of combined watershed resources, i.e., to determine the relative extent of impacts between development areas.
    - **ESD Research Summary** to document current knowledge regarding watershed responses to development, including the ability of Environmental Site Design (ESD) practices [1] to replicate natural hydrology and mitigate the impacts of development on stream morphology, habitat, water quality and overall stream conditions.
    - **Pollutant Load Analysis** to assess the impacts of development on annual estimated nutrient and sediment loads and changes in predicted runoff volume to Ten Mile Creek.
    - **Hydrologic and Hydraulic (H&H) Analysis** to assess the impacts of development on hydrologic conditions resulting in changes in streamflow volume, peak streamflow and velocity. Estimated changes in hydrology can be used to predict areas with the greatest potential for stream channel and habitat degradation which provide important predictors of impacts to the overall health of Ten Mile Creek.

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[1] Environmental Site Design (ESD) is a term used primarily in Maryland, and encompasses numerous stormwater design practices described in the Maryland Stormwater Design Manual.

Documents previously produced for this study include:

- Report – Existing Conditions in the Ten Mile Creek Study Area
- Memorandum – Spatial Watershed Analysis
- Memorandum – Environmental Site Design Literature Review
- Memorandum – Pollutant Load Modeling Assumptions
- Memorandum – Pollutant Load Modeling Results
- Memorandum – Preliminary Results of the Hydrology and Hydraulics Analysis

Each document provides details on analyses conducted. This memorandum contains a summary of results.

Approach to Analyses of Existing Conditions and the 1994 Master Plan Scenario

There is no single model or analytical tool that can be used to predict the impacts of development on watershed conditions or the resulting changes in the biological communities which provide indicators of overall stream conditions. Therefore, the Consultant Team used several analytical methods to provide data that can inform qualitative predictions of watershed-wide and subwatershed-specific impacts. Figure 2 illustrates the conceptual framework used for selection of the analyses described in the following sections. The graphic illustrates a relationship between development (including changes to grading, soil conditions, imperviousness and other land cover attributes) and the watershed characteristics which influence the biological conditions used to characterize overall stream quality.

Development can have direct impacts on several watershed characteristics:

- **Geomorphology** (i.e., form) of a stream channel. In undeveloped watersheds, streams are typically stable and pristine, provide a variety of habitats in bed forms created by natural wood and sediment transport, maintain a diverse aquatic population, and have good tree coverage. After development, streams change in response to increased sediment supply, and increased discharges or stream flow along with loss of bank vegetation leads to erosion and loss of biological habitat.
- **Water quality**. Development has a direct impact on water quality because impervious surfaces collect many harmful pollutants, including nutrients, sediment, oils, chlorides, metals, pesticides and other pollutants. When it rains, these pollutants are washed away with the stormwater runoff and directed into stream through the storm drain system. Stream water temperatures can also be impacted due to warming caused by impervious surfaces and due to loss of forest cover. Changes in water quality and temperature affect processing of organic matter and nutrients, as well as oxygen regulation. While some pollutants are not effectively treated by ESD or other stormwater management practices, ESD practices are expected to reduce the post-development loads of some pollutants (i.e., sediments and nutrients) and mitigate temperature changes more effectively than traditional stormwater practices.
- **Hydrology**. Development and its subsequent increase in impervious cover disrupt the natural water balance by increasing the amount of stormwater runoff. Curbs and gutters, storm drain

pipes, catch basins and other drainage systems quickly speed the runoff through pipes to a stormwater facility or directly into receiving waters, which results in streams receiving high volumes of runoff in a short period of time, leading to the erosion and changes in geomorphology described above. ESD practices are intended to control these high volumes of stormwater runoff and replicate runoff conditions similar to runoff from "woods in good condition".

- **Habitat**. Development has direct impacts to terrestrial habitat through the conversion of forests and other undeveloped lands to land uses predominated by a mix of impervious surfaces and open space (i.e., turf), thereby eliminating natural habitat and some existing soil-stabilizing vegetation. In addition, development has a direct impact to aquatic habitat where it directly impacts existing streams, such as in the case of stream crossings from new roads or other infrastructure.
- **Biology**. Each of the watershed attributes described above has a direct impact on aquatic habitat conditions. Changes to any or all of these attributes are expected to result in changes to the abundance and diversity of aquatic biological communities, which in turn will result in changes to stream condition scores.

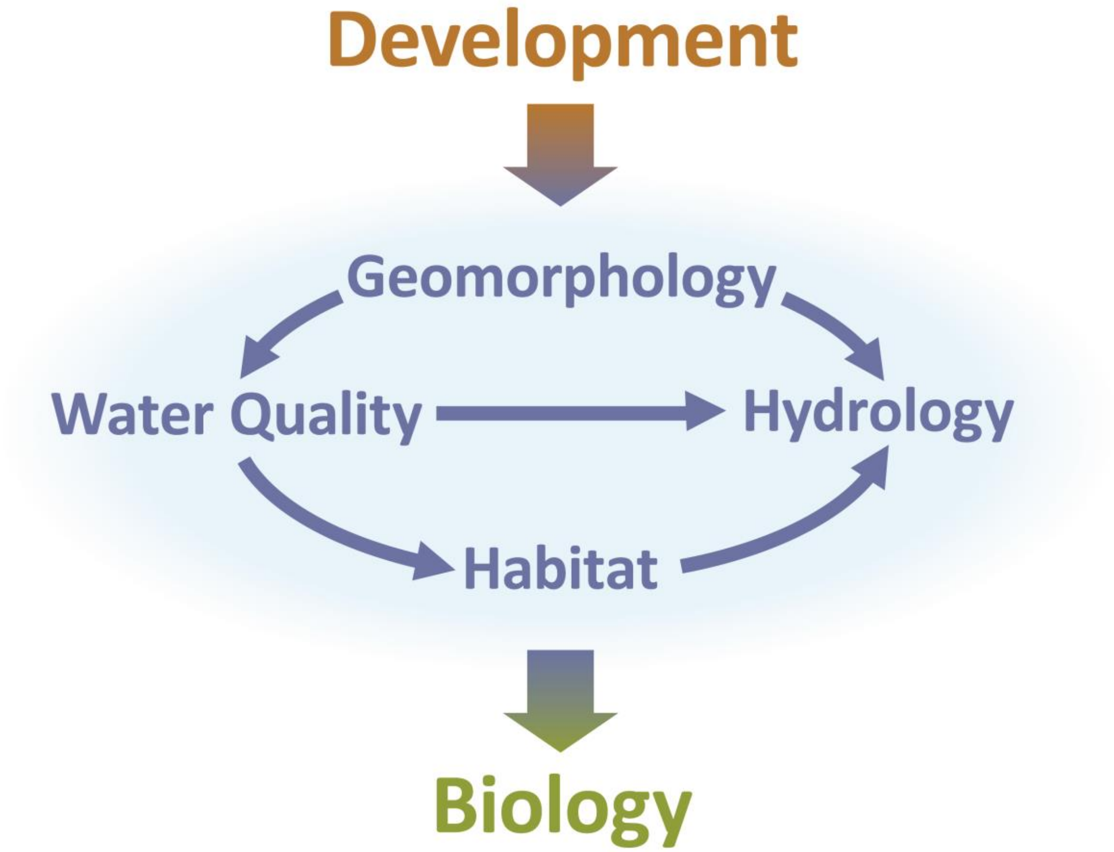

Figure 2. Relationship between Development and Watershed Characteristics Affecting Aquatic Biota

Models and other analytical tools cannot quantitatively estimate changes to all of the above watershed characteristics. Most importantly, although there are scientific studies which document direct correlations between increased imperviousness and lowered biological quality, predictive tools are not readily available to comprehensively estimate the post-development habitat conditions in Ten Mile Creek.

The analyses of multiple watershed characteristics are appropriate as part of any effort to predict changes in watershed health and stream quality, and the approach to the Ten Mile Creek environmental analysis was to select a series of tools to gain perspective on multiple aspects of development impacts. Potential changes to streamflow volume, peak streamflow, and streamflow velocity were estimated by modeling post-development compared to existing conditions using a Hydrologic and Hydraulic (H&H) model. This information was used to project potential impacts to stream geomorphology. In addition, pollutant load modeling was conducted in order to assess changes in pollutant loads as a result of development. In addition, although changes in geomorphology can't be directly modeled, impacts to stream channel stability might be predicted based on

While it's well established that hydrologic impacts are related to in-stream habitat and water quality, these factors are also directly impacted by land cover, which would change significantly in directly disturbed areas. A Spatial Analysis was conducted to quantify the changes to natural resource attributes throughout the watershed (e.g., forest cover, wetlands, springs, seeps, etc.). The Spatial Analysis was also used to develop a relative scoring system which helped identify features and portions of the watershed providing the greatest ecological values in support of the overall health of the Ten Mile Creek.

Summary – Existing Conditions

Existing conditions in the Ten Mile Creek were evaluated through review of GIS data and numerous reports and studies of the watershed. Key watershed characteristics are described below:

- Ten Mile Creek feeds into Little Seneca Lake, which serves as a reservoir providing additional flow to the Potomac River, a public raw water supply, during drought periods (Montgomery County Department of Park and Planning, 1994). The aquifer in the study area is designated as a Sole Source Aquifer per the United States Environmental Protection Agency's (U.S. EPA) Sole Source Aquifer Program (Greenhorne & O'Mara, Inc., 1992).

- Base flows are low in the summer months and the creek is susceptible to low flows from lack of rain. However, even in the driest years tributaries have continued to flow and to provide cool, clean water as refuge for the stream biotic community. Montgomery County DEP located seeps and springs throughout the Ten Mile Creek study area, the majority are in headwaters of tributaries to Ten Mile Creek. Both are necessary to maintain base flows in headwater streams (Montgomery County Department of Environmental Protection, 2013).

- Wetlands are concentrated along Ten Mile Creek mainstem. These are predominantly palustrine forested wetlands and are groundwater-dominated.

- Beaver have developed a series of dams in the upper reaches of Ten Mile Creek which provide pools that act as refuge for fish, amphibians and reptiles during the drier summer months and habitat for wintering waterfowl and wildlife in the winter months (Montgomery County Planning Department, 2009). In addition, “bird surveys in 2009 observed or heard 12 migratory nesting forest interior bird species in Stage 4 forest interior areas of Ten Mile Creek” (Montgomery County Planning Department, 2009).

- Development in the overall watershed is low, and roughly half of the study area is forested. Imperviousness is approximately 4%, and the remaining land cover in the study area is predominantly a mix of non-forested pervious area, including pasture, cropland, and turf. Ten Mile Creek subwatersheds labeled LSTM206 and LSTM201 have the highest impervious cover and urban land uses.

- Subwatersheds LSTM202 and LSTM201, as well as, subwatersheds along the mainstem have the highest forested land cover. The forested cover along the mainstem and through LSTM202 and LSTM201 is a major contiguous hub linking hubs in Black Hill and Little Bennett Regional Parks by corridors. MDNR (2003) defines hubs as areas that consist of large contiguous tracts of forest land that are integral to the ecological health of the state and corridors as linear remnants of these vital habitats that form linkages among the hubs. The largest gap in forest cover occurs in northeast LSTM201, north of I-270 which bisects the corridor to Little Bennett Regional Park. Forested areas within the study area are characterized as upland or bottomland hardwood forest. Upland hardwood forest is particularly prevalent in the western portion of study area. Bottomland hardwood forests are located along stream, floodplains and wetland areas within the watershed.

- Soils within the study area were formed from weathered phyllite, a metamorphic rock, and are generally rocky with a shallow to moderate depth to bedrock and steep slopes. Based on soil survey mapping, 45 percent slopes are the steepest slopes found along the upland stream valley. The upland summits range from 3 to 8 percent slopes (Soil Survey Staff, 2013). Erodible soils were prevalent in subwatersheds LSTM203, LSTM204, LSTM202, and LSTM112. The shallow bedrock, slopes, and erodible soils could pose general siting restrictions for foundations, septic systems, roads, basements, etc., as well as a challenge for erosion and sediment control during construction activities, and post-construction stormwater management. In addition, disturbance to the shallow soils, as a result of grading associated with development, could also create negative impacts to local stream habitat and biology.

- Long-term and spatially comprehensive geomorphic monitoring data are not available for Ten Mile Creek. The limited available datasets and field observations suggest that the streams are very dynamic (i.e. streams frequently move and deposit material and adjust their shape). Evidence of widespread and significant channel degradation (i.e. chronic lowering of the channel bed with time), which is often observed in highly disturbed watersheds, is not evident in the Ten Mile Creek watershed. Flood flows along many reaches of Ten Mile Creek still access the floodplain, sustaining important geomorphic and ecological processes. Streams in the region have been subjected to an extended history of changes in sediment supply and hydrology due to land use changes. Like many streams in the region, Ten Mile Creek has adjusted in response to these historic changes, and continues to adjust to existing inputs of water and sediment.

- Long-term monitoring of the stream habitat within the Ten Mile Creek watershed by DEP, including measurement of the physical habitat and sampling of biological communities (fish, benthic macroinvertebrates, and herptofauna), indicates that the overall biological condition is in the good range (63-87) with an average score for all stations of 77. Two subwatersheds (LSTM110 and LSTM110) scored in the excellent range (>87) and two subwatersheds (LSTM112 and LSTM206) scored fair (41-63).

- In-stream physical habitat conditions (such as stream bed and bank conditions) show signs of decline since 2007. While the change is subtle over time, these conditions are indicative of a watershed that is sensitive and is responding to various stressors. Evidence of declining habitat conditions include increased embeddedness (the degree to which coarse bed material is choked by fine sediments), sedimentation, and decreased streambank vegetation. However a proportional response in the overall biological condition has not been observed. Long-term monitoring data collected by DEP does generally indicate that the proportion of sensitive taxa, both fish and benthic macroinvertebrate, present within the watershed are declining while the tolerant individuals are increasing in both number and richness.

Summary – Spatial Watershed Analysis

The intent of the Spatial Watershed Analysis is to identify areas that have high resource value and support watershed health. Natural resource attributes, such as forest, wetlands and streams, were mapped and assigned a metric value. These attribute maps were overlaid on each other and analyzed to help identify, define the areal extent of, and measure and describe areas that contribute to watershed health.

The composite natural resource attribute scores for the Ten Mile Creek study area are summarized in Figure 3, which utilizes a different shade of green to represent the total number of attributes that occur at a point on the landscape in the analysis. The darker green areas have higher numbers of attributes present and are generally associated with the presence of the stream system and its buffer areas, forested areas, and wetlands.

After preparing the composite map shown in Figure 3, GIS algorithms were used to create statistical categories, which were then used to create two additional composite maps. The purpose of consolidating the data into fewer groups created by the statistical categories is to delineate areas of somewhat similar score values and to presents a different view of the data. The final composite map produced through this method is shown in Figure 4, which more clearly illustrates the location of the higher attribute scores.

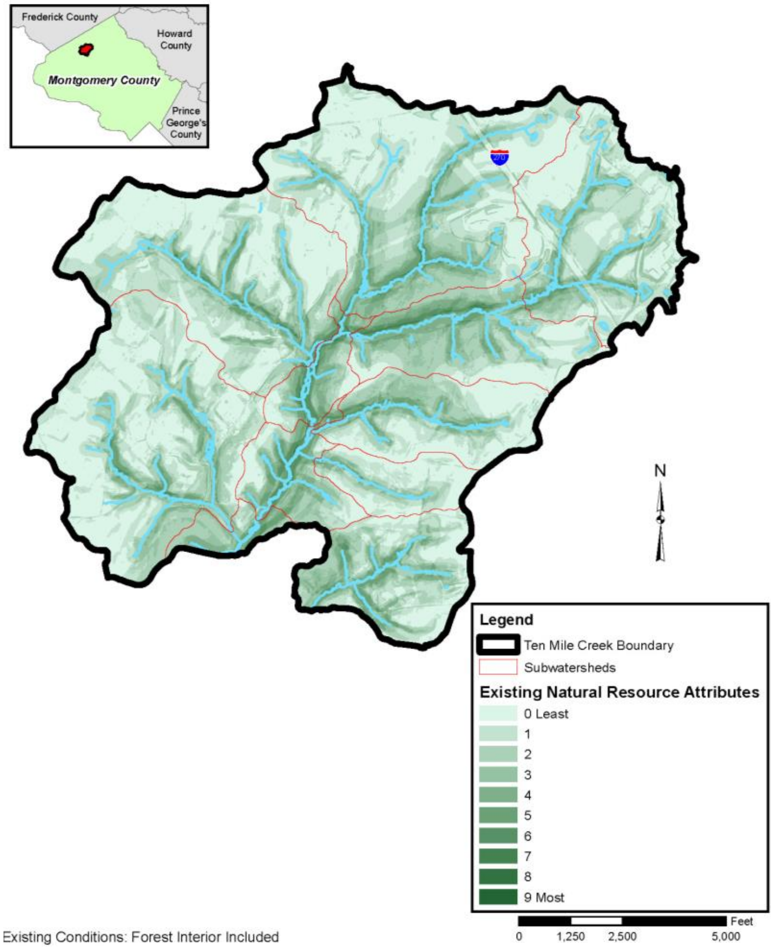

Figure 3. Composite Map of Natural Resources Attribute Scores

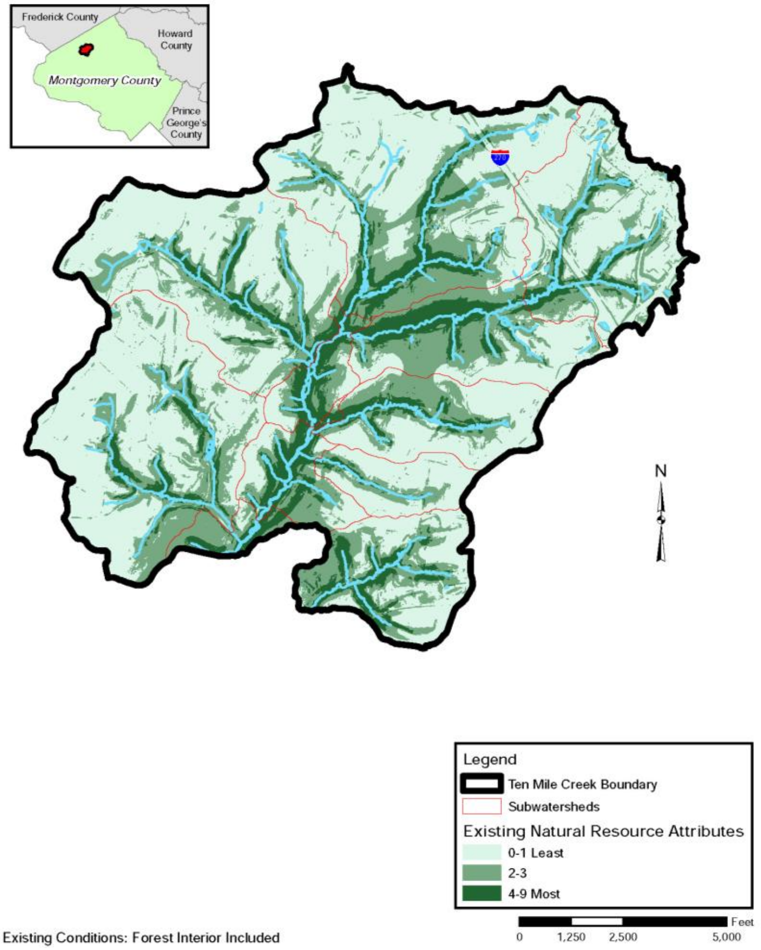

Figure 4. Map of Natural Resources Attribute Scores Grouped into Three Categories

Projected limits of disturbance associated with development of the 1994 Master Plan, as delineated by Planning, were overlaid on the existing conditions Spatial Watershed Analysis composite maps to identify the extent of potential impacts to natural resources as a result of the development proposed in the Master Plan. No more than eight natural resource attributes were identified at any location within the projected limits of disturbance. Figure 5 illustrates the impacts to the three category analysis shown in Figure 4.

The projected limits of disturbance are approximately 407 acres, or 13% of the Ten Mile Creek study area. Natural resources impacts associated with development regulated by the County (e.g., SPA buffer requirements) were limited to forest, slope and soil impacts whereas other features, such as streams, wetlands, springs, seeps, and floodplains, are protected. However, public infrastructure in support of development, including the proposed 355 Bypass and the sanitary sewer extension, may result in impacts to a variety of natural resources. The most significant impacts occur in Subwatershed 206, and are largely associated with the proposed 355 Bypass.

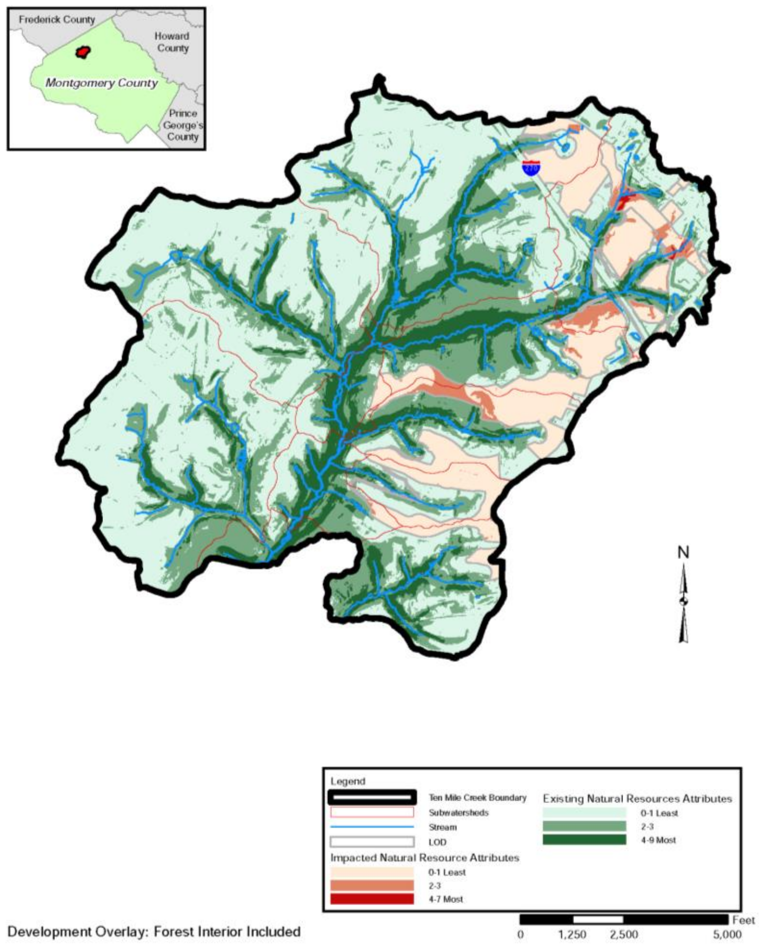

Figure 5. Attribute Category (Three) Areas Impacted by 1994 Master Plan Scenario

Summary – Environmental Site Design Review

A detailed review of development, Environmental Site Design, and erosion and sediment control was conducted. The conclusions of the review are summarized below.

Impacts of Stormwater Runoff and Land Development

- In addition to thresholds identified by the Impervious Cover Model (e.g., 10%), available data suggest that degradation in stream biology begins to happen at much lower levels of impervious cover.
- Riparian corridor preservation is a very useful tool for protecting in-stream habitat and biology, but appears to be the most effective when coupled with watershed impervious cover of 15 to 20% or less.
- Zero order streams are extremely important, particularly given the high quality nature of Ten Mile Creek, and presence of important amphibian species.

- The B-IBI is currently used to classify streams in Montgomery County and while this is an excellent indicator of general stream health, other metrics should be considered for tracking subtle changes in the quality of stream biology in Ten Mile Creek.
- The relationship between hydrology and in-stream aquatic biota has been documented, but no model has been calibrated to Montgomery County's data. An analysis of specific flow characteristics and measures of in-stream biology would be very helpful in understanding future development in Ten Mile Creek and elsewhere in Montgomery County.
- Ongoing maintenance is a challenge for any stormwater management practice, and analyses should consider loss of function and storage in stormwater BMPs over time.
- Hydrologic assumptions inherent in MDE's stormwater regulations should be modeled at a site level to ensure consistency, and account for soil compaction.
- Although MDE requirements allow for the combination of ESD techniques and traditional stormwater detention, detention practices should be avoided if possible due to potential stream warming effects.

Impacts of Construction and Erosion and Sediment Control (ESC)

- A decrease in stream habitat and biology during construction has been documented in several studies. Biological monitoring should be conducted immediately downstream of construction sites to detect initial indications of stream degradation.
- ESC regulations should be strictly enforced, with special emphasis on proposed clearing and grading limits.

Summary – Pollutant Load Analysis

Watershed-wide, pollutant loads for nutrients (Nitrogen and Phosphorus) increase during construction, and decrease to slightly above pre-developed rates in the post-developed condition (Figure 6). Annual runoff volume increases during construction and continues to have a significant increase in the post-developed condition. This result at first seems counterintuitive, since the goal of ESD generate hydrology equivalent to "woods in good condition," which should result in less annual runoff volume than the cropland currently present in much of the land to be developed. However, sizing using the Short Cut Method defined in the Stormwater Manual, combined with the impacts of soil compaction, may lead to practices sized below the necessary volume needed to achieve the goal of producing hydrology equivalent to woods in good condition. In addition, many of the practices that qualify as "ESD Practices" in the Manual do not actually achieve 100% runoff reduction, and the practice selected for this modeling exercise typically reduces runoff by 40%.

The apparent decrease in TSS can be explained by the agricultural uses dominant in much of the watershed. This TSS calculation may under represent TSS, however, since TSS calculations do not include channel erosion, which may increase as the watershed urbanizes, both due to increased runoff volume and decrease in sediment sources to the stream channel (by converting cropland) in the watershed.

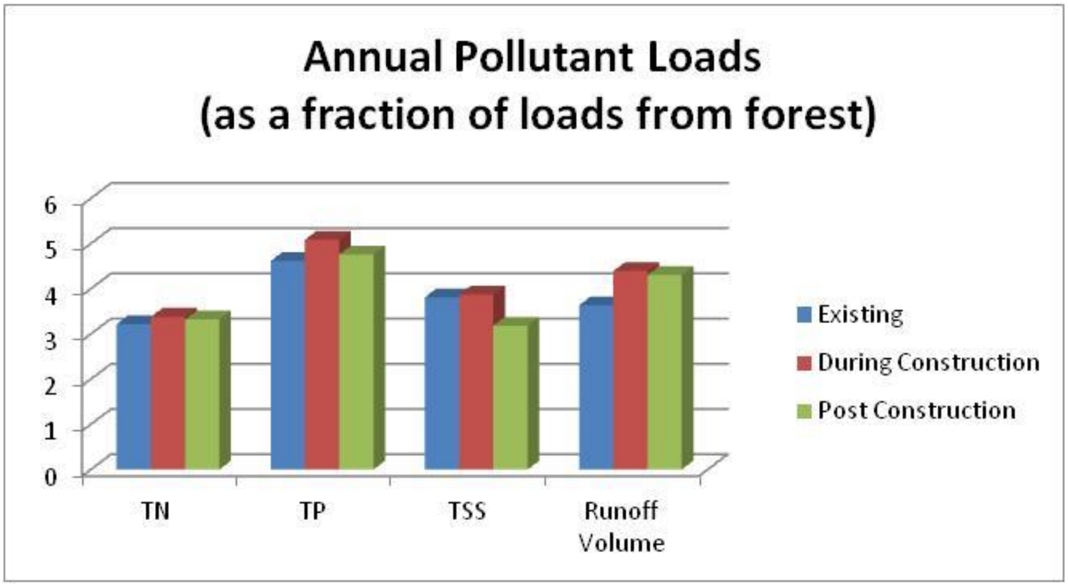

Figure 6. Comparative Pollutant Loads Throughout the Development Process

Response to development is not uniform across the watershed, and is also pollutant-specific. For example, subwatershed LSTM 206 has the largest increase in TSS during construction (76%), but only a modest (7%) increase in total phosphorus. In addition, subwatersheds that are highly impacted during construction can have relatively low post-construction loads. For example, even though LSTM 206 showed an increase in sediment loads during construction, the sediment loads from this subwatershed in the post-developed condition are actually 35% lower than existing conditions.

Total nitrogen increases moderately throughout the construction process in the watershed as a whole, with different results by subwatershed. LSTM 202 shows a decline in TN, while LSTM 206, 302 and 302B have increases of greater than 10%. This difference is primarily explained by the fact that land conversion in LSTM 202 is primarily from cropland to urban land, and cropland has a very high nitrogen loading rate. In contrast, land in LSTM 206, 302 and 303B is converted primarily from forest and pasture land. During construction, the loads are slightly higher than post-construction loads in all subwatersheds.

While the magnitude of the loads and the percent change are slightly different for phosphorus than for nitrogen, the patterns are generally the same (i.e., the subwatersheds with increases or decreases in nitrogen tend to have similar changes for phosphorus), with one exception. In LSTM 303B, the increase in phosphorus (3%), is lower than the 14% increase in nitrogen in the same subwatershed. In this subwatershed, development is located primarily on pasture land which has a very low nitrogen load, but a phosphorus load similar to cropland. Loads for phosphorus are higher during construction.

Sediment loads decrease uniformly after construction, except in undisturbed watersheds. This is because sediment loads from urban land are much lower than those from most pre-developed land uses, with the exception of forest. Sediment loads are much higher during construction, with the sediment load increasing, on average, about 2% during the construction period. Some subwatersheds experience an increase during construction, and decrease after construction. For example, subwatershed LSTM 206 has a 76% increase during construction, but a 35% decrease after construction. This result occurs because sediment loads from construction are much higher than any rural land, while loads from developed land are much lower. Consequently, subwatersheds with a large area of disturbance will experience an increase during construction, followed by a much lower post-construction load.

In summary, pollutant load modeling results for implementing Stage 4 of 1994 Master Plan Land Use with Full ESD indicate that there would be a slight increase in nutrient loads both during and following construction. Sediment loads, excluding stream bank erosion, would increase slightly during the construction phase, and then decrease in the post-developed condition.

Summary – Hydrologic and Hydraulic (H&H) Analysis

Hydrology is an important driver in determining stream health, and has a direct influence on water quality, stream morphology/habitat and biology. Since one of the primary goals of stormwater management, and ESD in particular, is to restore natural hydrology, it is important to understand how hydrology is related to stream health.

Background – Hydrology as a Stream Health Indicator

Impacts from development cause shifts in the natural hydrologic cycle, which typically results in a modified hydrograph including higher runoff volumes, "flashier" hydrology, and decreased baseflow, as illustrated in Figure 7. As discussed earlier, these hydrologic impacts can then in turn cause degradation in stream habitat and morphology, and well as in-stream biology.

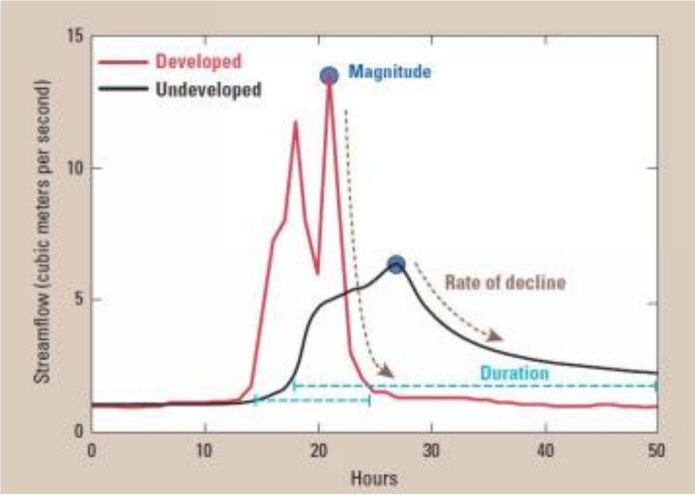

Figure 7. Hydrograph Illustrating Typical Stream "Flashiness" after Development

In addition to direct water quality impacts that can be caused by the greater volume of runoff and associated loads of pollutants such as nutrients, metals, fertilizers, salts, hydrocarbons and other urban pollutants, stream morphology can also be impacted by altered hydrology caused by increased impervious cover and loss of natural soils and forests. As illustrated above, the change in hydrology increases stream power, and consequently results in erosion and enlargement of stream channels. At impervious covers as low as 7 to 10% in a watershed, an “unraveling” of streams can be seen, as evidenced by an enlarged cross-sectional profile, including both stream widening and downcutting. This phenomenon has been documented in Tributary 104 of Seneca Creek in Montgomery County (MCDEP, 2012), with data showing a decrease in stream cross-sectional area following sediment deposition from construction, followed by channel enlargement, for a net 15% increase in channel area from 2002 to 2010. The channel depth also increased by over 50% during this time period.

The combination of this active channel erosion and direct impacts to the riparian corridor and stream bed result in degraded stream habitat. While these results are not universal, typical impacts of increased imperviousness include stream straightening (i.e., decrease in sinuosity), as was also documented in Tributary 104 of Seneca Creek (MCDEP, 2012), increase in “embeddedness” of channel sediment, and decrease in depth diversity. Often, these and other measures are integrated into combination stream health indicator metrics such as fish habitat.

Background – Environmental Site Design

Although the impacts described above are well documented in Montgomery County and elsewhere, many of the available scientific studies that have established correlations between development and changes in stream channel geometry were based on data from areas developed without stormwater controls, or developed using “traditional” stormwater design practices (i.e., ponds), which are no longer the design standard for development in Maryland. If approved, development in the Ten Mile Creek Area will be required to be controlled through the use of ESD practices to the Maximum Extent Practicable (MEP). Maryland stage law defines ESD as “using small-scale stormwater management practices, non-structural techniques, and better site planning to mimic natural hydrologic runoff characteristics and minimize the impact of land development on water resources”. If this stormwater management technique is successful, it is possible that some of the impacts typically associated with land development can be mitigated.

Although ESD practices have been in use in Maryland for over a decade, new regulations requiring MEP implementation have only been in effect since 2010. Therefore, there are very few large-scale applications of ESD, and the Consultant Team could find no direct evidence documenting the impacts of ESD on in-stream biota.

In order to reproduce a natural hydrograph, a stormwater practice needs to first reduce the volume of runoff, which is very different from traditional stormwater practices. As shown in the example hydrograph in Figure 8, traditional stormwater management practices can be effective at reducing the peak runoff produced by storm events, but those practices do not reduce the increased runoff volume quantities produced by urbanization.

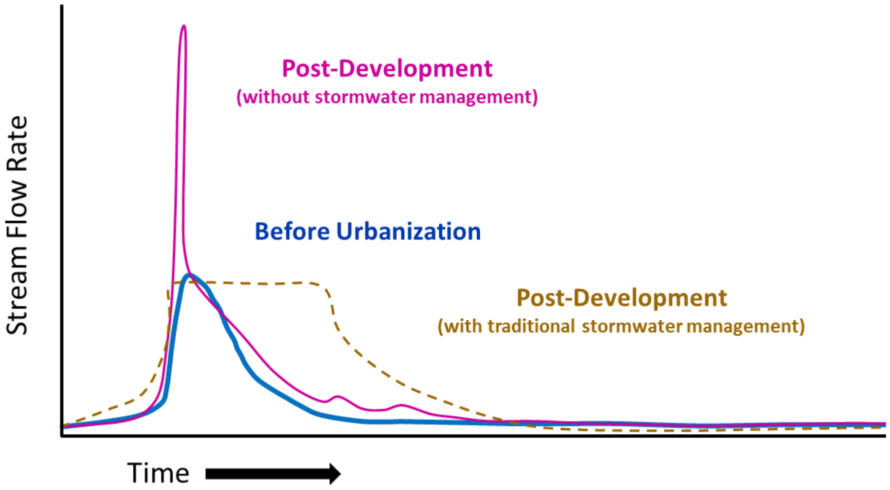

Figure 8. Example of Post-Development Hydrograph with Traditional Stormwater Management

A review of stormwater BMP effectiveness literature determined that ESD practices are much more effective than most traditional practices at reducing the volume of stormwater runoff produced from developed land. Figure 9 provides a hydrograph that illustrates the conceptual runoff reduction which ESD practices are intended to achieve in order to replicate natural hydrology. However, literature sources report differing results, with a recent Maryland study demonstrating that a bioretention practice did achieve the intended volumetric goals but did not reproduce the shape of the natural hydrograph due to differing flow duration (Olszewski and Davis, 2013).

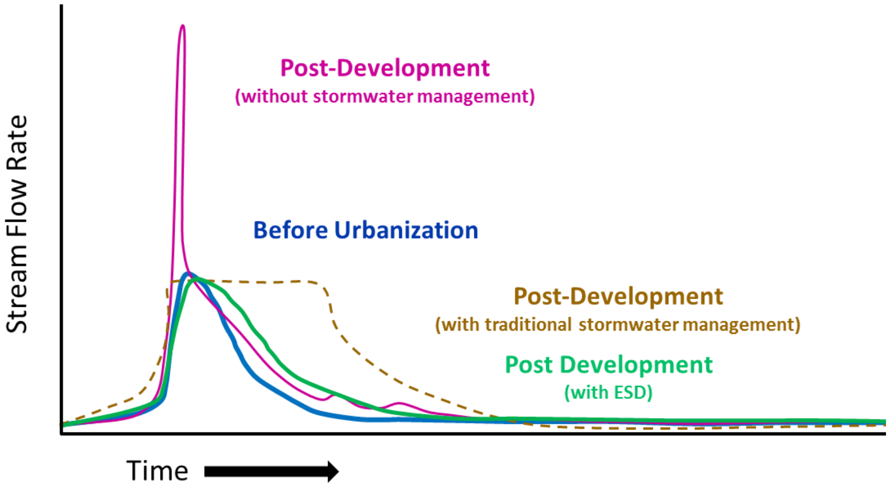

Figure 9. Conceptual Hydrograph comparing ESD with Traditional Stormwater Management

H&H Modeling Methods

The Consultant Team developed a model to predict H&H impacts to Ten Mile Creek that would result from the completion of the Clarksburg Master Plan implemented with ESD in accordance with State and County regulations. The model used for this analysis was XP-SWMM 2012, a commercial modeling package developed by XP Solutions. XP-SWMM is a dynamic rainfall-runoff model that was originally developed as a graphical user interface to the USEPA Stormwater Water Management Model (EPA SWMM).

The model was set up to simulate a 1-year, 24-hour storm (2.6 inches) and a 2-year, 24-hour storm (3.2 inches) and assuming an SCS Type II distribution. The 1-yr and 2-yr storm events were chosen to analyze the effects of development on the existing stream condition due to the ability of these storm events to influence the shape and form of natural channels.

A “base conditions” model scenario was created to represent the Ten Mile Creek watershed under existing conditions, prior to development described in the Master Plan. To characterize the runoff characteristics of each subwatershed, each runoff node was assigned acreages of pervious and impervious land based on available GIS data which were analyzed prior to beginning this modeling effort. Infiltration on pervious land covers was modeled using the SCS Curve Number method. Composite curve numbers were calculated for each runoff nodes based on land use and hydrologic soil group (HSG) information. Additional details regarding model setup are described in Attachment B-4.

To represent the Master Plan Scenario, the base conditions model was altered in two manners. First, the runoff nodes were parameterized to represent the land use and land cover conditions proposed in the 1994 Master Plan. This step required GIS-based analysis and additional calculations to quantify how the proposed development (including a new utility easement and highway interchange) would change the existing impervious cover and alter the existing composite curve numbers. To account for construction impacts on soil, it was conservatively assumed that the hydrologic soil groups (HSGs) of disturbed areas would be reduced by one category (e.g., B soils became C soils; C soils became D soils).

The Maryland Stormwater Design Manual describes use of the 1-yr rainfall as a target storm event for achieving ESD, and requires that ESD practices be used as first choice to capture enough of this rainfall so that the curve number from the developed site will be equivalent to the curve number from woods in good condition. The manual also addresses soil compaction within ESD practices, however, it does not account for changes in the storage and infiltration rates of landscape soils that occur due to disturbance and alteration during construction. Although Montgomery County’s sub-tilling requirements may partially mitigate these impacts, the HSG adjustments described above were used to provide a safety factor that may help account for increased runoff that could be generated from pervious areas compacted during development.

Secondly, the base scenario model was altered to conceptually direct runoff from the new development to ESD practices. For the purposes of this screening-level analysis, micro-bioretention was used as the representative ESD practice. The required area and storage volume of micro-bioretention was calculated based on the new impervious surface of each subwatershed, using the procedures of the Maryland Stormwater Design Manual and guidelines provided by Montgomery County DEP. Each micro-bioretention filter was modeled with 6” of storage above the filter media, and was conservatively assumed to have a saturated condition within the soil media. The assumed infiltration rate of 0.25 in/hr would allow the ponded volume to drain within 24 hours. The micro-bioretention filters were also assumed to have a 3-inch thick stone reservoir at the base, and underdrains that would be placed above the level of the stone reservoir and discharge to surface water.

The ESD sizing parameters described above were chosen to provide an additional safety factor appropriate for this planning-level study. Although design guidelines allow designers to assume faster media infiltration rates and larger deeper ponding above the media, it would be impractical to assume that all ESD practices installed for the proposed Master Plan development would operate at optimal design capacity during all storm events. Instead, the assumptions described above were used to evaluate stream impacts that may occur as a result of varying degrees of performance from practices installed throughout the development areas proposed in the Ten Mile Creek study area.

H&H Model Results

As described in more detail in Attachment B-3, the H&H model predicted that the response to development will not be uniform across the Ten Mile Creek study area, and similar to the WTM model predictions described previously, estimated much larger changes in stream flow metrics in subwatershed LSTM 110 and LSTM 111 than in some of the other subwatersheds proposed for development.

Overall, the H&H modeling results indicated that the proposed Master Plan development constructed with ESD may have the potential to cause increased total streamflow volume in the majority of subwatersheds within the Ten Mile Creek study area. In most subwatersheds, the increased volume was predicted to be conveyed in the stream at low to moderate velocities during the latter part of the storm hydrograph.

When analyzing the metric of peak flow, the Master Plan development with ESD scenario was predicted to reduce peak flows for the majority of the sub-watersheds with the exception of reaches associated with LSTM 110 and LSTM 111 and at the model domain outlet. The predictions of increase peak streamflows in LSTM 110 and LSTM 111 may be the result of large proportional increases in impervious cover. Figure 10 provides a hydrograph generated for LSTM 111 to illustrate the stream response in this specific subwatershed.

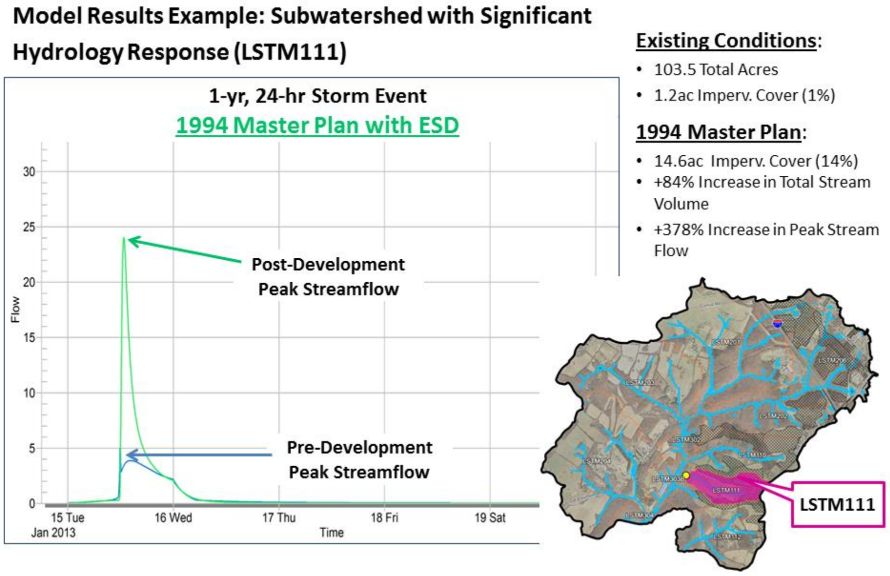

Figure 10. Representative Hydrograph Illustrating Predicted Stream Response for LSTM 110

A sensitivity analysis was conducted to determine the range of response that may be predicted by modeling another Master Plan scenario using ESD with more moderate sizing parameters and this analysis is summarized in an amendment to the report in Appendix B-3. This analysis indicated that although total streamflow volumes were relatively unchanged, more moderate ESD modeling assumptions appeared to lower the peakflow rates from some subwatersheds when compared to the more conservative ESD assumptions used in the first Master Plan modeling run. Although lowered peak streamflows were seen in LSTM 110 and LSTM 111, the hydrographs still differed significantly from pre-development hydrographs.

Summary

The results of the H&H model indicated that ESD practices can help control the elevated peak stream flows caused by development. However, the post-development H&H model hydrographs do not replicate the pre-development hydrographs, which was consistent with some of the evidence documented in the literature reviewed for this study. In general, the H&H modeling results indicate that the development proposed for the Ten Mile Creek study area may increase total streamflow volumes in the majority of subwatersheds, and the increased runoff volumes may be conveyed to the stream at low to moderate velocities during the latter part of the storm hydrographs.

The change in post-development hydrology response was not uniform across the subwatersheds, and significant increases in post-development peak flows were predicted in two subwatersheds. Although modeling for Ten Mile Creek predicts changes to flows, it does not provided information about changes to sediment supply, which are a necessary part of predicting channel response. A clear threshold for geomorphic change is uncertain, however, if it were possible to hold other factors constant (e.g., bed slope and substrate), changes to the stream channel would be expected to be relative to the magnitude of change in flows. For the locations included in the modeling, this perspective would suggest that the channel at LSTM111 would be the most vulnerable to geomorphic changes (e.g, enlargement). In contrast, the channels at LSTM112, LSTM201, LSTM202, and LSTM206 would be predicted to undergo relatively less geomorphic change, and the channel at LSTM110 would be predicted to undergo an intermediate response.

Another important consideration is that the results of the modeling do not provide information at a finer spatial scale than the relatively large subwatershed areas upstream of the few model node locations. It is likely that portions of the channel network extending upstream from each of these model points would experience geomorphic change differently, and that the spatial variability in geomorphic responses would be dependent on local changes to the supply of water and sediment, as well as to existing, interdependent channel properties such as slope, substrate, shape, vegetation, and other factors that were beyond the scope of this evaluation.

In summary, the H&H modeling predicted that although ESD may help mitigate increased in peak streamflows in some locations, development will result in changes to stream hydrology which, when combined with other changes to watershed characteristics, may contribute to changes in overall stream condition. A comprehensive evaluation of each of the predicted changes is needed in order to understand the stream system as a whole.

Summary and Conclusion

The results of each analysis were reviewed by the Consultant Team and the relative change, or impact, within each subwatershed was assigned a narrative rating, as summarized in the Table 2, below. The rationale for these narrative ratings is provided below.

Table 2. Summary of 1994 Master Plan Scenario Analysis

Subwatershed	Watershed Indicator				
	Hydrology	Geomorphology (inferred from H&H Analysis)	Pollutant Loading	Natural Resource Disturbance (per Spatial Analysis)	OVERALL
LSTM110	Significant	Significant	Low	Moderate	Significant
LSTM111	Significant	Significant	N/A	Low to Moderate	Significant to Moderate
LSTM112	Low	Low	N/A	Low	Low
LSTM201	Low	Low	Low	Low to Moderate	Low to Moderate
LSTM202	Moderate	Moderate	N/A	Low to Moderate	Moderate
LSTM203	N/A	N/A	N/A	N/A	N/A
LSTM204	N/A	N/A	N/A	N/A	N/A
LSTM206	Low to Moderate	Low to Moderate	Significant	Significant	Moderate
LSTM302	Low	Low	Moderate to Significant	Low	Moderate
LSTM303B	Moderate	Moderate	Low to Moderate	Low	Moderate
LSTM304	Low to Moderate	Low to Moderate	N/A	N/A	Low to Moderate

Key findings include:

- The projected limits of disturbance associated with the 1994 Master Plan are approximately 407 acres, or 13% of the Ten Mile Creek study area (Table 3). Most development would occur in Subwatershed 206, followed by Subwatershed 110, 202, 111 and 201. However, the extent of development is greatest across Subwatersheds 111 and 110. No development would occur in Subwatersheds 203, 204, and 304.

Table 3. Extent of Limit of Disturbance (LOD) Across the Subwatersheds

Subwatershed	**Subwatershed Area (acres)**	**LOD within Subwatershed (acres)**	**% of Subwatershed**	**% of Total LOD**
110	211.0	88.1	42%	22%
111	103.5	47.5	46%	12%
112	228.2	21.7	10%	5%
201	610.5	40.8	7%	10%
202	242.9	61.7	25%	15%
203	493.2	-	0%	0%
204	543.6	-	0%	0%
206	370.0	135.9	37%	33%
302	77.3	5.1	7%	1%
303B	117.0	6.6	6%	2%
304	49.0	-	0%	0%
TOTAL	**3,046.2**	**407.4**		**100%**

- Natural resources impacts associated with development regulated by the County (e.g., SPA buffer requirements) were limited to forest, slope and soil impacts whereas other features, such as streams, wetlands, springs, seeps, and floodplains, are protected. However, public infrastructure in support of development, including the proposed 355 Bypass and the sanitary sewer extension, will result in impacts to a variety of natural resources. The most significant impacts occur in Subwatershed 206, and are largely associated with the proposed 355 Bypass. Development within Subwatershed 110 will result in loss of forested areas, including interior forest.

- Watershed-wide, pollutant loads for nutrients (Nitrogen and Phosphorus) increase during construction, and decrease to slightly above pre-developed rates in the post-developed condition. Sediment loads decrease uniformly after construction, except in undisturbed watersheds. This is because sediment loads from urban land are much lower than those from most pre-developed land uses, with the exception of forest.

- Sediment loads are much higher during construction, with the sediment load increasing, on average, about 2% during the construction period. Some subwatersheds experience an increase during construction, and decrease after construction. For example, subwatershed LSTM 206 has a 76% increase during construction, but a 35% decrease after construction. This result occurs because sediment loads from construction are much higher than any rural land, while loads from developed land are much lower. Consequently, subwatersheds with a large area of disturbance will experience an increase during construction, followed by a much lower post-construction load.

- The results of the H&H model indicated that ESD practices can help control the elevated peak stream flows caused by development. However, the post-development H&H model hydrographs do not replicate the pre-development hydrographs, which was consistent with some of the evidence documented in the literature reviewed for this study. In general, the H&H modeling results indicate that the development proposed for the Ten Mile Creek study area may increase total streamflow volumes in the majority of subwatersheds, and the increased runoff volumes may be conveyed to the stream at low to moderate velocities during the latter part of the storm hydrographs.

- The change in post-development hydrology response was not uniform across the subwatersheds, and significant increases in post-development peak flows were predicted in two subwatersheds.

- Although modeling for Ten Mile Creek predicts changes to flows, it does not provided information about changes to sediment supply, which are a necessary part of predicting channel response. A clear threshold for geomorphic change is uncertain, however, if it were possible to hold other factors constant (e.g., bed slope and substrate), changes to the stream channel would be expected to be relative to the magnitude of change in flows. For the locations included in the modeling, this perspective would suggest that the channel at LSTM111 would be the most vulnerable to geomorphic changes (e.g, enlargement). In contrast, the channels at LSTM112, LSTM201, LSTM202, and LSTM206 would be predicted to undergo relatively less geomorphic change, and the channel at LSTM110 would be predicted to undergo an intermediate response.

- In summary, the H&H modeling predicted that although ESD may help mitigate increased in peak streamflows in some locations, development will result in changes to stream hydrology which, when combined with other changes to watershed characteristics, may contribute to changes in overall stream condition.

- Despite potential natural resource impacts and pollutant loading identified within Subwatershed 206, it is important to note that this subwatershed already has the highest level of development and the lowest stream quality within the watershed. Changes associated with development may not be as notable within this subwatershed as they will be in other subwatersheds that are currently predominantly forest.

Hydrology

For each subwatershed, the estimated change in streamflow volume and peak streamflow after construction was compared to estimated pre-development flows. A narrative rating was assigned based this percent change for any parameter:

≥ 25% increase	Significant
15% to 25% increase	Moderate
10% to 15% increase	Low to Moderate
5% to 10% increase	Low
< 5% increase	No Change (N/A)

The overall H&H rating for each subwatershed takes into account the modeled changes in total streamflow volume and peak streamflow at each model location. The Master Plan development scenario was modeled with a range of ESD sizing assumptions to reflect a range of potential responses, and both the moderate and more conservative ESD assumptions were compared to predicted Existing Condition flows in establishing the ratings shown below.

Subwatershed	**Predicted H&H Impacts**
LSTM110	Significant
LSTM111	Significant
LSTM112	Low
LSTM201	Low
LSTM202	Moderate
LSTM203	N/A
LSTM204	N/A
LSTM206	Low to Moderate
LSTM302	Low
LSTM303B	Moderate
LSTM304	Low to Moderate

Geomorphology

Potential impacts to stream geomorphology (channel form) were inferred from the results of the Hydrologic & Hydraulic analysis.

Pollutant Loading

For each subwatershed, the estimated change in pollutant loading (nutrients and sediment) during construction and after construction was reviewed. A narrative rating was assigned based on this percent change:

≥ 25% increase	Significant
20% to 25% increase	Moderate to Significant
15% to 20% increase	Moderate
10% to 15% increase	Low to Moderate
5% to 10% increase	Low
< 5% increase	No Change (N/A)

The overall Pollutant Load rating for each subwatershed takes into account the potential load change of each pollutant during and after construction.

Subwatershed	TP - During Construction	TP - After Construction	TN - During Construction	TN - After Construction	TSS - During Construction	Overall Pollutant Loads
LSTM110	Significant	Low	Moderate	Low	N/A	**Low**
LSTM111	Significant	N/A	Low to Moderate	N/A	N/A	**N/A**
LSTM112	Low	N/A	N/A	N/A	N/A	**N/A**
LSTM201	Low to Moderate	N/A	Low	Low	Low	**Low**
LSTM202	N/A	N/A	N/A	N/A	N/A	**N/A**
LSTM203	N/A	N/A	N/A	N/A	N/A	**N/A**
LSTM204	N/A	N/A	N/A	N/A	N/A	**N/A**
LSTM206	Significant	Moderate	Significant	Significant	Significant	**Significant**
LSTM302	Significant	Significant	Moderate to Significant	Moderate	Low	**Moderate to Significant**
LSTM303B	Significant	Low	Moderate	Low to Moderate	Low to Moderate	**Low to Moderate**
LSTM304	N/A	N/A	N/A	N/A	N/A	**N/A**

Spatial Analysis

The narrative rating for the Spatial Analysis was determined by reviewing both the overall watershed loss and subwatershed of natural resources due to disturbance within each subwatershed. This is based on the Spatial Analysis that does not include Forest Interior as a metric (Note – including Forest Interior would shift Subwatershed 202 to "Moderate"). The narrative rating for each subwatershed is based on the following areas of impacts to land that has two to nine natural resource attributes present:

Greater than 15 acres	Significant
15 to 25 acres	Moderate to Significant
5 to 15 acres	Moderate
1 to 5 acres acres	Low to Moderate
Less than 1 acre acres	Low
No impacts	N/A)

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Technical Memorandum

Prepared for: Montgomery County Planning Department

Project Title: Clarksburg Master Plan Limited Amendment for the Ten Mile Creek Watershed

Project No.: 143717

Technical Memorandum No. 1

Subject: Preliminary Results of the Hydrology and Hydraulics Analysis

Date: Revised April 2, 2013

To: Mary Dolan and Valdis Lazdins, Montgomery County Planning Department

From: Biohabitats and Brown and Caldwell, a Joint Venture

Limitations:

This is a draft memorandum and is not intended to be a final representation of the work done or recommendations made by Brown and Caldwell. It should not be relied upon; consult the final report.

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Section 1: Introduction

One of the chief means by which development can impact a stream is by hydrologic alteration. In the absence of stormwater controls, an increase in impervious cover can lead to higher peak streamflows and current velocities. This in turn can lead to increased erosion and sedimentation both on the land surface and within the stream system, and subsequent impacts to biota. One of the major goals of environmental site design (ESD) is to maintain natural hydrology and prevent adverse hydrologic and hydraulic (H&H) impacts. This technical memorandum presents the methods and preliminary results of a planning-level modeling analysis to evaluate the potential H&H effects of the Clarksburg Master Plan on Ten Mile Creek.

Section 2: Methods

The primary tool used for the analysis was XP-SWMM 2012, a commercial modeling package developed by XP Solutions. XP-SWMM is a dynamic rainfall-runoff model that was originally developed as a graphical user interface to the USEPA Stormwater Water Management Model (EPA SWMM). For this project, the model is being used to predict H&H impacts to Ten Mile Creek that would result from the completion of the Clarksburg Master Plan implemented with full ESD in accordance with State and County regulations.

2.1 Model Set-Up and Base Conditions Scenario

XP-SWMM offers several options for the simulation of rainfall-runoff. For this project, the SWMM Runoff Non-Linear Reservoir method was selected because it provides the most flexibility for simulating ESD practices. The model was set up to simulate a 1-year, 24-hour storm (2.6 inches) and a 2-year, 24-hour storm (3.2 inches) and assuming an SCS Type II distribution. The 1-yr and 2-yr storm events were chosen to analyze the effects of development on the existing stream condition due to the ability of these storm events to influence the shape and form of natural channels. The model domain consists of the Ten Mile Creek watershed upstream of Little Seneca Lake. The watershed was conceptually divided into 11 runoff nodes that represent areas draining to Ten Mile Creek. The runoff nodes are listed in ascending order starting from the most downstream node. The main Ten Mile Creek itself was represented in the model as 17 hydraulic links, parameterized as natural channels using cross-sectional survey data provided by the County. Links are labeled according to their upstream node and have the prefix 'LN', for example link LN102 conveys flows from node 102 to node 101. A link node diagram of the study area is provided in Appendix A, located at the end of this memorandum. A "base conditions" model scenario was created to represent the Ten Mile Creek watershed under existing conditions, prior to development described in the Master Plan. To characterize the runoff characteristics of each subwatershed, each runoff node was assigned acreages of pervious and impervious land based on available GIS data. Infiltration on pervious land covers was modeled using the SCS Curve Number method. Composite curve numbers were calculated for each runoff nodes based on land use and hydrologic soil group (HSG).

2.2 Master Plan Scenario

To represent the Master Plan Scenario, the base conditions model was altered in two manners. First, the runoff nodes were parameterized to represent the land use and land cover conditions proposed in the 1994 Master Plan. This step required GIS-based analysis and additional calculations to quantify how the proposed development (including a new utility easement and highway interchange) would change the existing impervious cover and alter the existing composite curve numbers. To account for construction impacts on soil, it was conservatively assumed that the hydrologic soil groups (HSGs) of disturbed areas would be reduced by one category (e.g., B soils became C soils; C soils became D soils). Secondly, the base scenario model was altered to conceptually direct runoff from the new development to ESD practices. For the purposes of this screening-level analysis, micro-bioretention was used as the representative ESD practice. The required area and storage volume of micro-bioretention was calculated based on the new impervious surface of each subwatershed, using the procedures of the Maryland Stormwater Design Manual and guidelines provided by Montgomery County DEP[1]. Each micro-bioretention filter was modeled with 6" of storage above the filter media, and was conservatively assumed to have a saturated condition within the soil media. The assumed infiltration rate of 0.25 in/hour would allow the ponded volume to drain within 24 hours. The micro-bioretention filters were also assumed to have a 3-inch thick stone reservoir at the base, and underdrains that would be placed above the level of the stone reservoir, and discharge to surface water.

2.3 Method of Interpretation

The key metrics that will be used to compare the base conditions and Master Plan scenario are total runoff volume, peak streamflow, and the peak stream velocity in Ten Mile Creek. It is also useful to compare the hydrographs to determine whether the post-development condition is expected to produce a longer duration of elevated stream velocity, regardless of impacts on peak streamflow.

In this planning-level model, the result of interest is the difference in these parameters between existing development and the post-development scenario, rather than the absolute value of the parameters in either scenario. The locations of primary interest are the outlets of subbasins where the majority of the development will take place (i.e., subwatersheds LSTM202, LTSM206, LSTM 111, AND LSTM 112), in addition to the model domain outlet. If the model predicts that the Master Plan would cause significant increases in total runoff volume, streamflow, or stream velocity—or extend the period of elevated streamflow—it would be concluded that the development has the potential to cause adverse hydrologic impacts to Ten Mile Creek, and additional ESD or other protective practices might be considered. Conversely, it might be concluded that ESD practices designed according the Maryland manual have the potential to adequately prevent or mitigate such impacts.

Section 3: Preliminary Results

Stable model runs were obtained for the different modeling scenarios, with overall continuity errors well within the acceptable range of < ± 2%. Table 1 provides a comparison summary of the total stream volume from basins where development is proposed. The table provides a comparison of the total stream volume from the existing conditions and the master plan scenario for the 1-yr and 2-yr 24-hour storm event. As shown in Table 1, the model predicted that the total stream flow volume for the master plan scenario would increase for a majority of the subwatersheds for the 1-yr and 2-yr storm event.

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[1] Note that the manual does not require consideration of construction impacts to soil, so the HSG adjustments discussed above were not used for ESD sizing.

Table 1- Summary of Total Streamflow Volume Results

		1-yr 24-hr Storm Volume (Ac-ft)		2-yr 24-hr Storm Volume (Ac-ft)	
Model Link #	Corresponding Watershed #	Existing Conditions	1994 Master Plan*	Existing Conditions	1994 Master Plan*
LN 071	LSTM 110	8.7	15.0	13.6	21.7
LN 061	LSTM 111	4.3	7.9	6.8	11.4
LN 021	LSTM 112	10.0	9.6	15.6	14.6
LN 110	LSTM 201	25.4	22.4	36.2	35.1
LN 101	LSTM 202	39.5	44.1	56.7	62.1
LN 102	LSTM 206	27.9	29.6	38.7	40.6
LN 080	LSTM 302	83.9	88.7	126.8	132.2
LN 050	LSTM 303	101.2	116.4	154.0	172.9
LN 030	Outlet	126.2	141.5	193.4	212.3

* Master Plan model scenario assumed treatment with ESD, and soil compaction from construction activities

Table 2 provides a comparison summary of the peak stream flow from basins where development is proposed. The table provides a comparison of the peak stream flow from the existing conditions and the master plan scenario for the 1-yr and 2-yr 24-hour storm event. The model predicted that the peak stream flow increased in some subwatersheds while decreasing in others. It is important to note that the change in peak flow rate from the existing conditions to the master plan scenario for the particular watersheds of interest, LSTM 202, LSTM 206, LSTM 110, and LSTM 111. The model predicted an increase in peak streamflow for subwatersheds LSTM 110 and LSTM 111; however, a decrease in peak streamflow was predicted for subwatersheds LSTM 202 and LSTM 206. An increase in peak flow is attributed to the sensitivity of the watershed to the change in land use over the existing conditions and ESD storage volumes being exceeded in those particular subwatersheds.

Table 3 provides a summary of the impervious cover percentages for the existing and proposed conditions. Sub-watersheds LSTM 110 and LSTM 111 show the most significant change in land use from their existing condition. A more thorough study of subwatersheds LSTM 110 and LSTM 111 is warranted for a more comprehensive understanding of how these particular watersheds impact Ten Mile Creek and what additional protective measures are needed for these particular watersheds to attenuate the peak flow associated with an increase in impervious area.

Table 2 - Summary of Peak Streamflow Results

		1-yr 24-hr Storm Peak Streamflow (cfs)		2-yr 24-hr Storm Peak Streamflow (cfs)	
Model Link #	Corresponding Watershed #	Existing Conditions	1994 Master Plan*	Existing Conditions	1994 Master Plan*
LN 071	LSTM 110	16.2	29.2	33.2	52.0
LN 061	LSTM 111	5.0	24.0	8.2	43.2
LN 021	LSTM 112	19.9	21.1	33.3	37.4
LN 110	LSTM 201	88.1	74.9	118.0	95.4
LN 101	LSTM 202	175.7	134.5	246.9	198.2
LN 102	LSTM 206	158.8	128.3	219.4	182.9
LN 080	LSTM 302	216.5	184.3	320.5	278.5
LN 050	LSTM 303	215.5	212.8	354.8	365.3
LN 030	Outlet	213.7	219.2	384.4	399.4

* Master Plan model scenario assumed treatment with ESD, and soil compaction from construction activities

Table 3 Summary of Impervious Cover Changes

Watershed ID	Existing Cumulative Imperviousness (%)	Master Plan Scenario Cumulative Imperviousness (%)	Change in Impervious Area %
LSTM 110	1.6%	15.1%	13.5%
LSTM 111	1.2%	14.0%	12.8%
LSTM 112	2.5%	5.7%	3.2%
LSTM 201	3.8%	6.7%	2.9%
LSTM 202	10.6%	22.7%	12.1%
LSTM 206	16.1%	30.0%	13.9%
LSTM 302	5.4%	10.7%	5.3%
LSTM 303B	5.7%	10.8%	5.1%

Table 4 provides a comparison summary of the peak stream velocity in the reaches that drain basins where development is proposed. The table provides a comparison of the peak stream velocity from the existing conditions to the master plan scenario for the 1-yr and 2-yr 24-hour storm event. The model predicted that the peak stream velocity remained relatively unchanged from the existing conditions to the Master Plan scenario. Again, it is important to note the sub-watersheds that had the greatest response in terms of change in peak stream velocity were LSTM 110 and LSTM 111.

Table 4 Summary of Peak Stream Velocity					
		1-yr 24-hr storm Peak Stream Velocity (ft/s)		2-yr 24-hr storm Peak Stream Velocity (ft/s)	
Link #	Corresponding Watershed #	Existing Conditions	1994 Master Plan*	Existing Conditions	1994 Master Plan*
LN 071	LSTM 110	1.8	2.2	2.3	2.5
LN 061	LSTM 111	1.3	2.3	1.6	2.8
LN 021	LSTM 112	2.0	2.0	2.2	2.3
LN 110	LSTM 201	2.0	1.9	2.3	2.1
LN 101	LSTM 202	2.9	2.7	3.3	3.0
LN 102	LSTM 206	2.8	2.7	3.2	2.9
LN 080	LSTM 302	1.9	1.8	2.0	2.1
LN 050	LSTM 303	2.3	2.3	2.8	2.8
LN 030	Outlet	2.7	2.7	3.2	3.3

* Master Plan model scenario assumed treatment with ESD, and soil compaction from construction activities

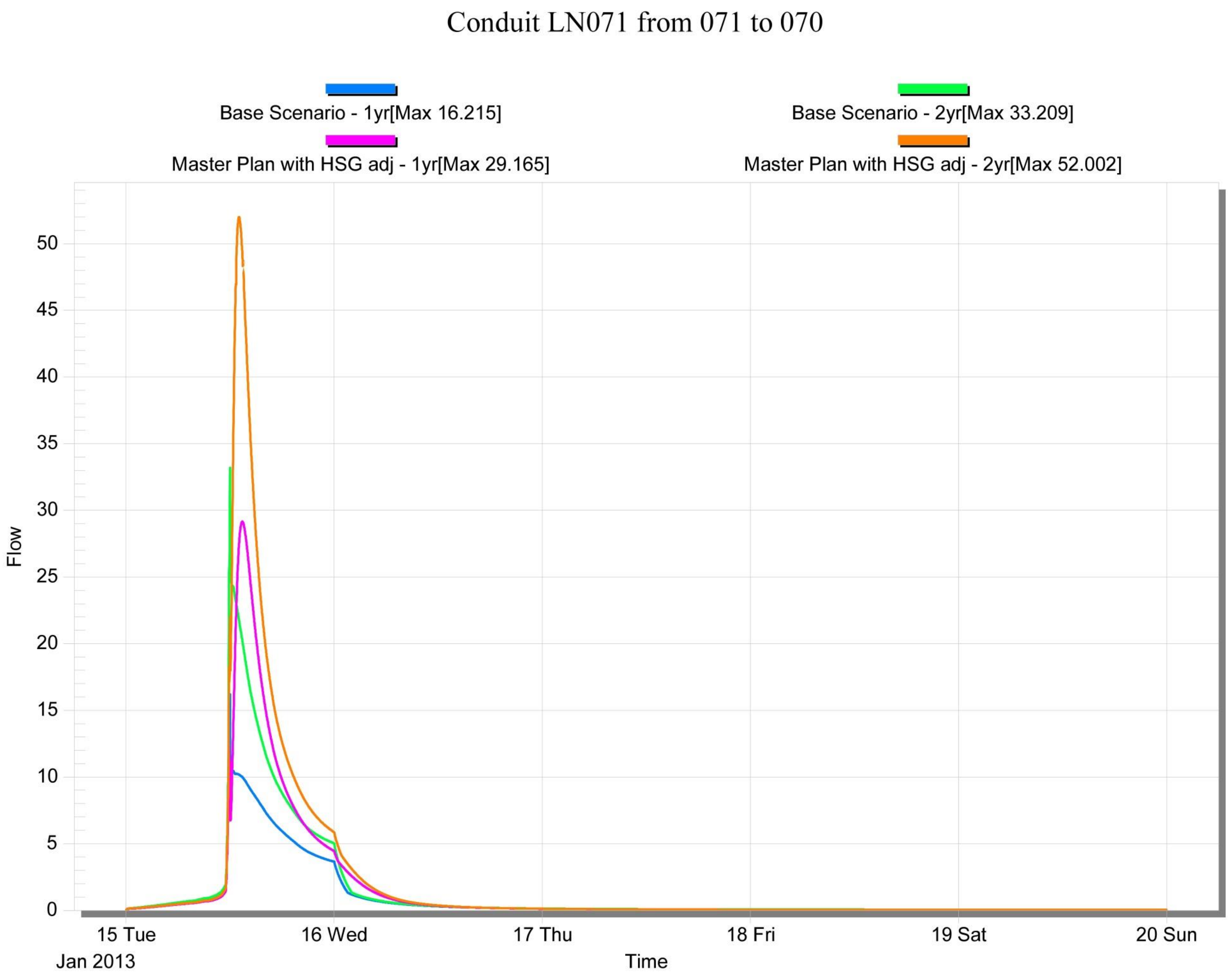
In conclusion, these preliminary results indicate that the proposed Master Plan development constructed with full ESD appears to have the potential to cause increased total streamflow volume in the majority of subwatersheds within the Ten Mile Creek study area. The increased stormwater volume would be caused by the greater runoff volume from increased impervious cover. In most subwatersheds, the increased volume was predicted to be conveyed in the stream at low to moderate velocities during the latter part of the storm hydrograph.

When analyzing the metric of peak flow, the Master Plan development with ESD scenario was predicted to reduce peak flows for the majority of the sub-watersheds with the exception of reaches associated with LSTM 110 and LSTM 111 as well as the model domain outlet. The predictions of increase peak streamflows in LSTM 110 and LSTM 111 were driven by the large proportional increases in impervious cover and the conservative nature of the model scenarios, which included an assumption of relatively low infiltration rates in ESD practices due to saturated media. Relaxation of this assumption would be expected to effect the model prediction.

The metric of peak stream velocity was predicted to remain relatively unchanged when compared to the existing conditions, but was predicted to experience small increases in LSTM 100 and LSTM 111.

APPENDIX A

Hydrographs
and
Link Node Diagram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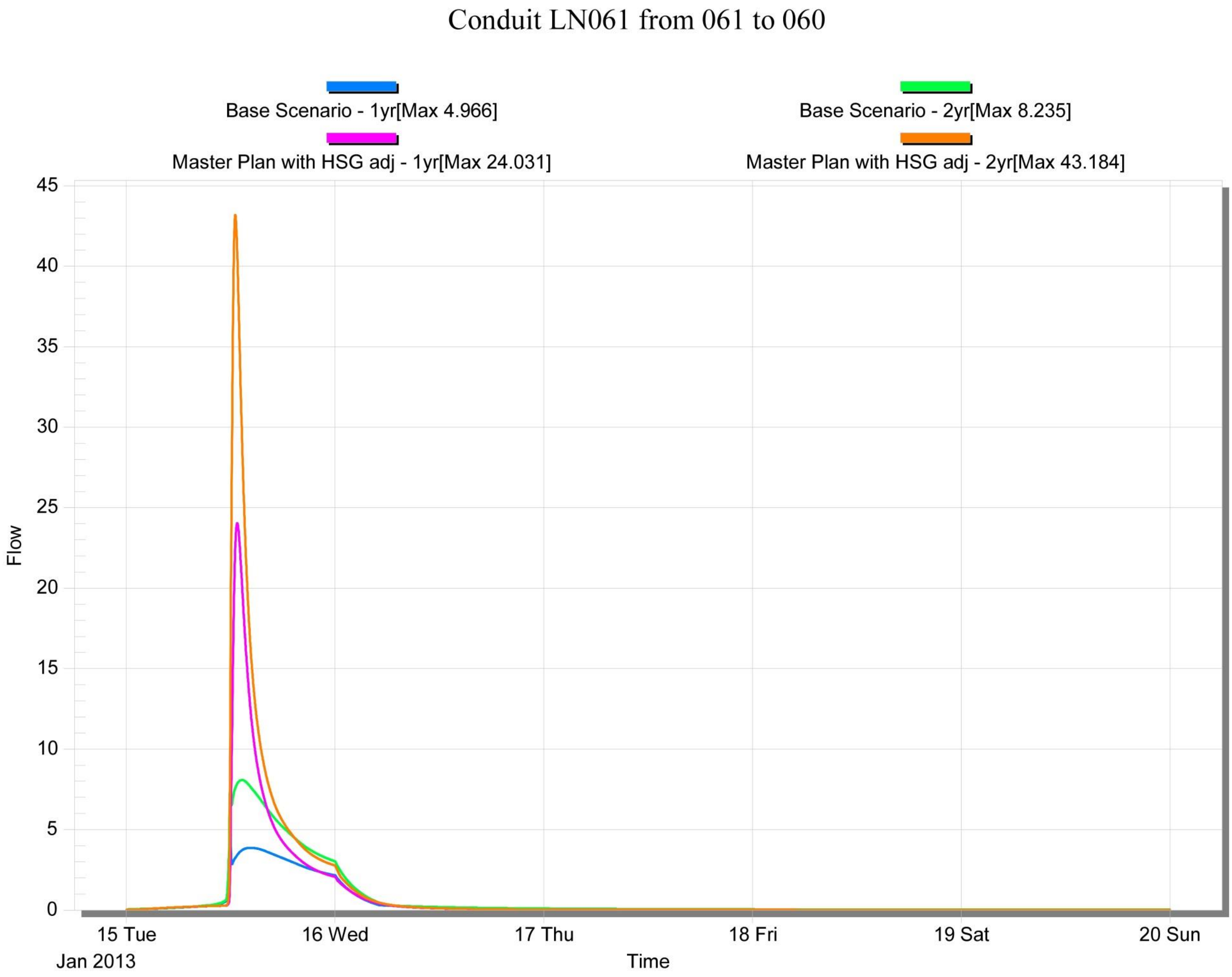
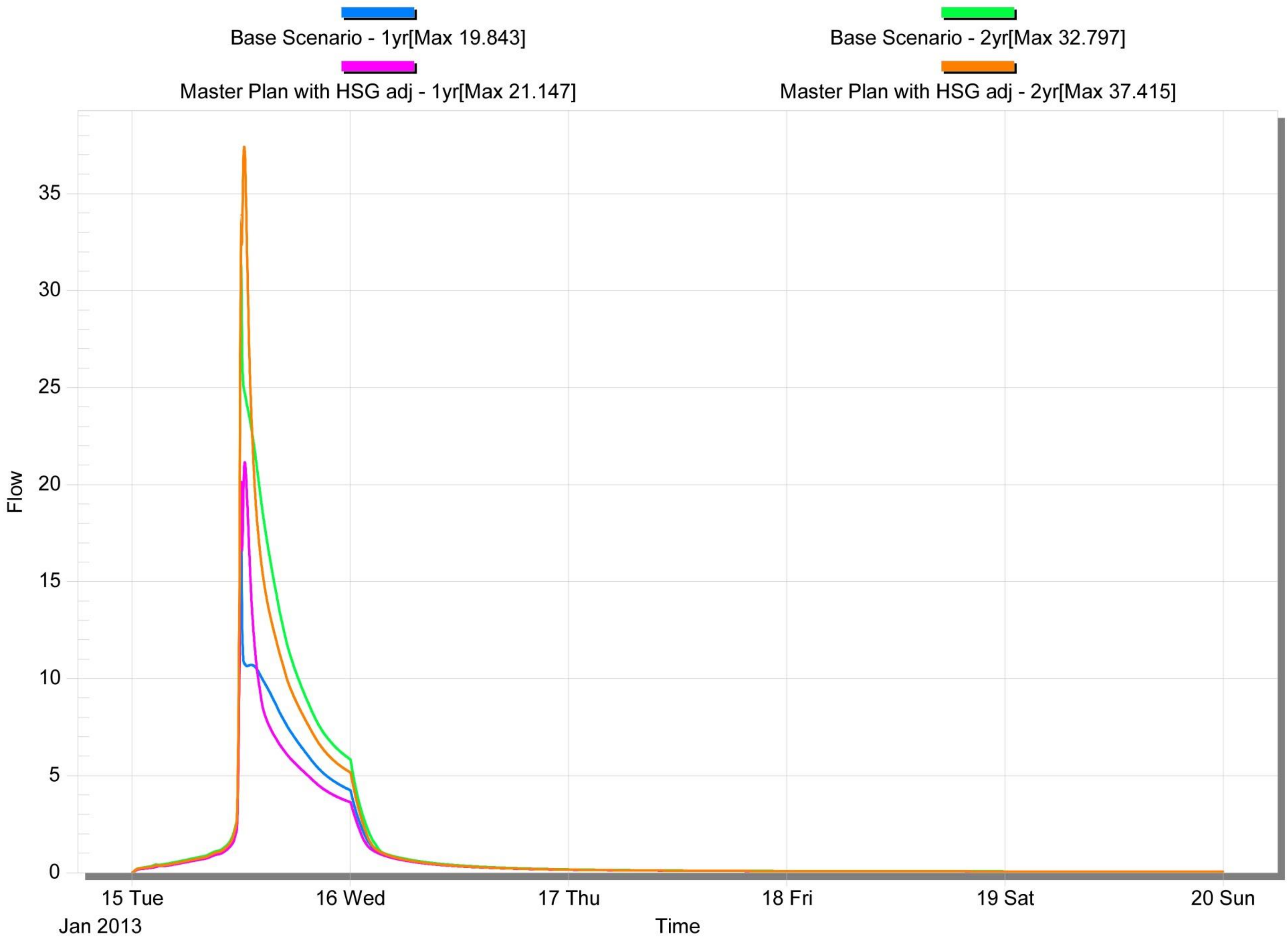
Base Scenario - 1yr[Max 16.215]
Base Scenario - 2yr[Max 33.209]
Master Plan with HSG adj - 1yr[Max 29.165]
Master Plan with HSG adj - 2yr[Max 52.002]
Flow
50
45
40
35
30
25
20
15
10
5
0
15 Tue
Jan 2013
16 Wed
17 Thu
18 Fri
19 Sat
20 Sun
Time


Conduit LN061 from 061 to 060
Base Scenario - 1yr[Max 4.966]
Base Scenario - 2yr[Max 8.235]
Master Plan with HSG adj - 1yr[Max 24.031]
Master Plan with HSG adj - 2yr[Max 43.184]
45
40
35
30
25
20
15
10
5
0
Flow
15 Tue
Jan 2013
16 Wed
17 Thu
18 Fri
19 Sat
20 Sun
Time

Conduit LN021 from 021 to 020



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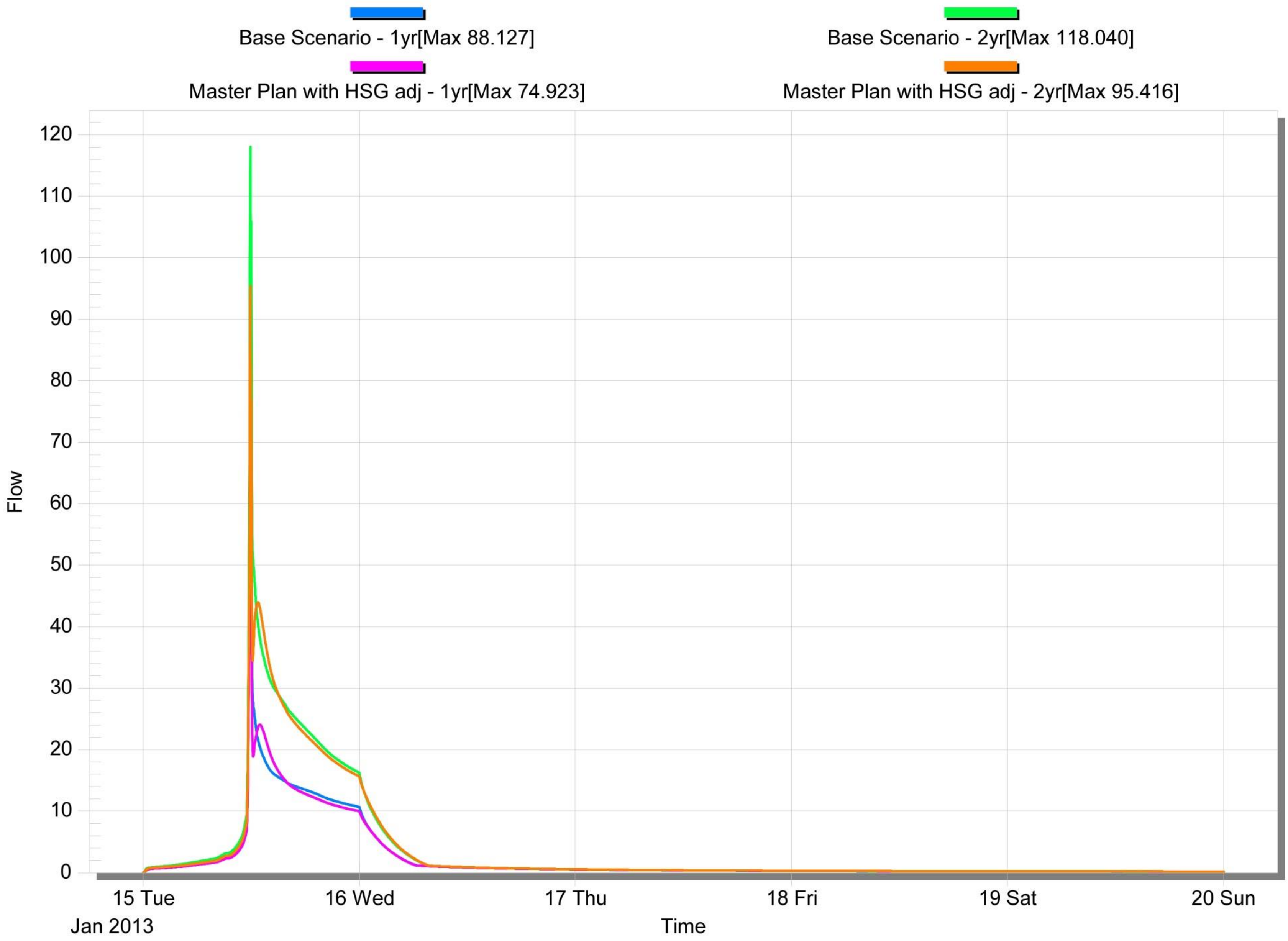

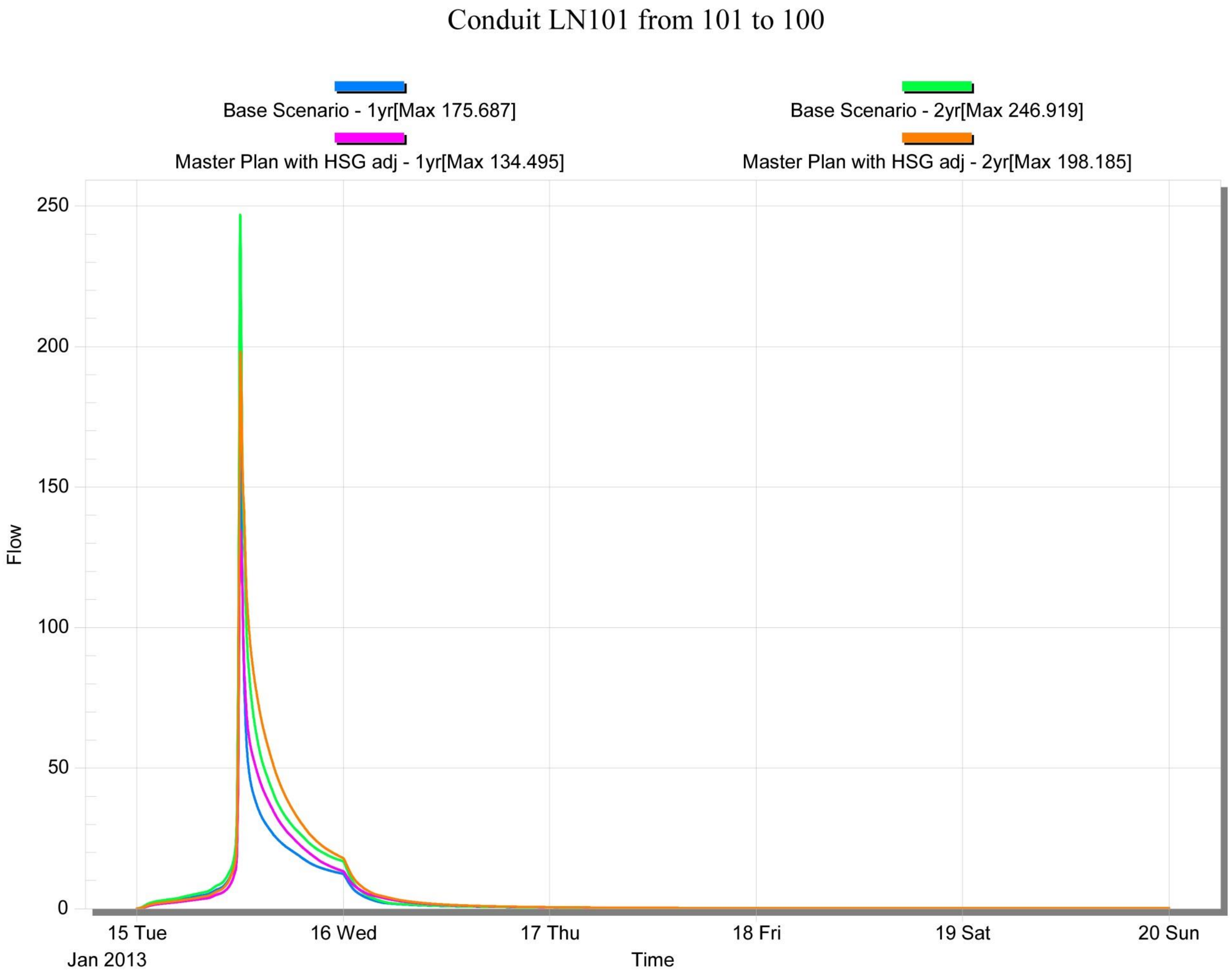
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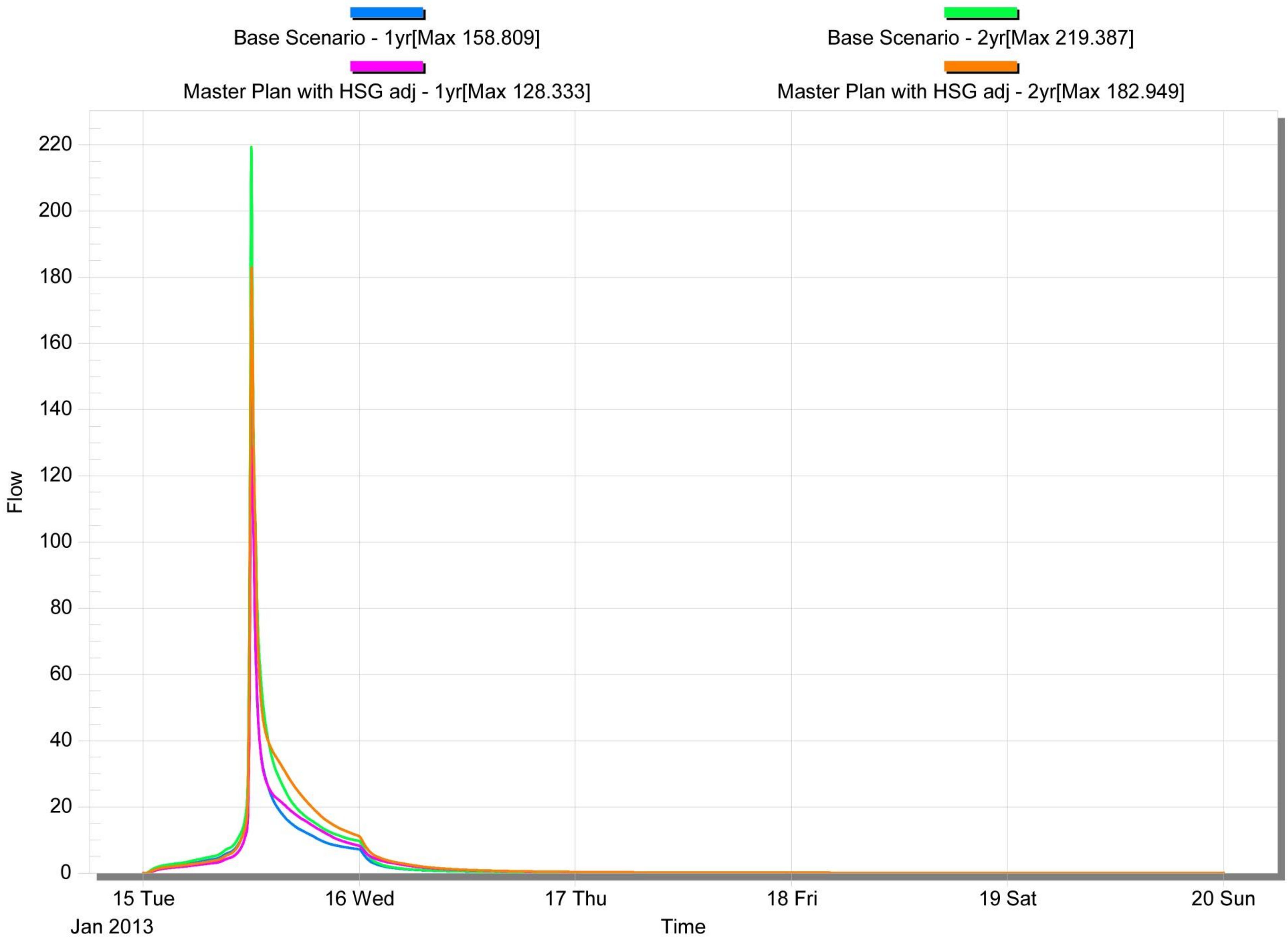
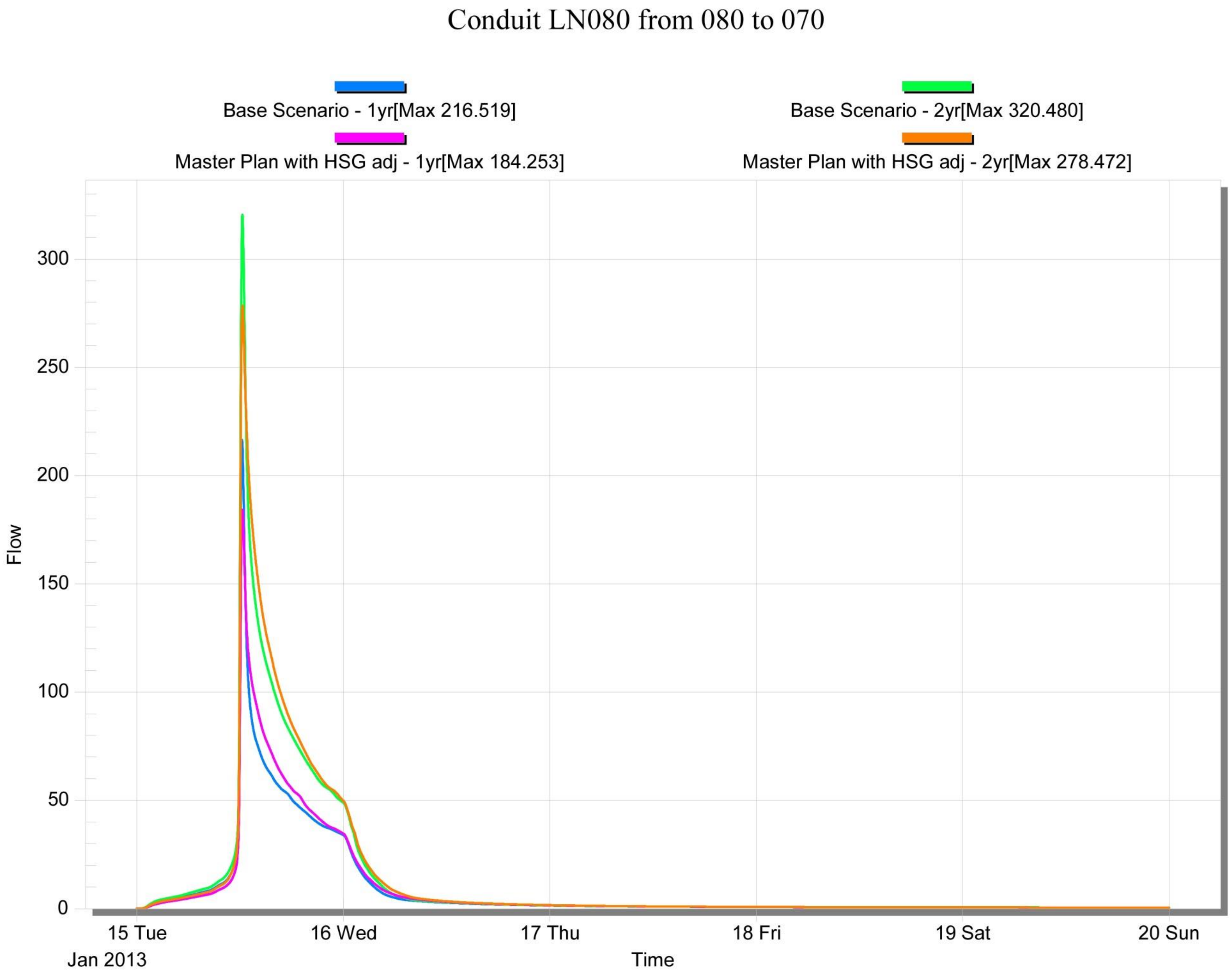
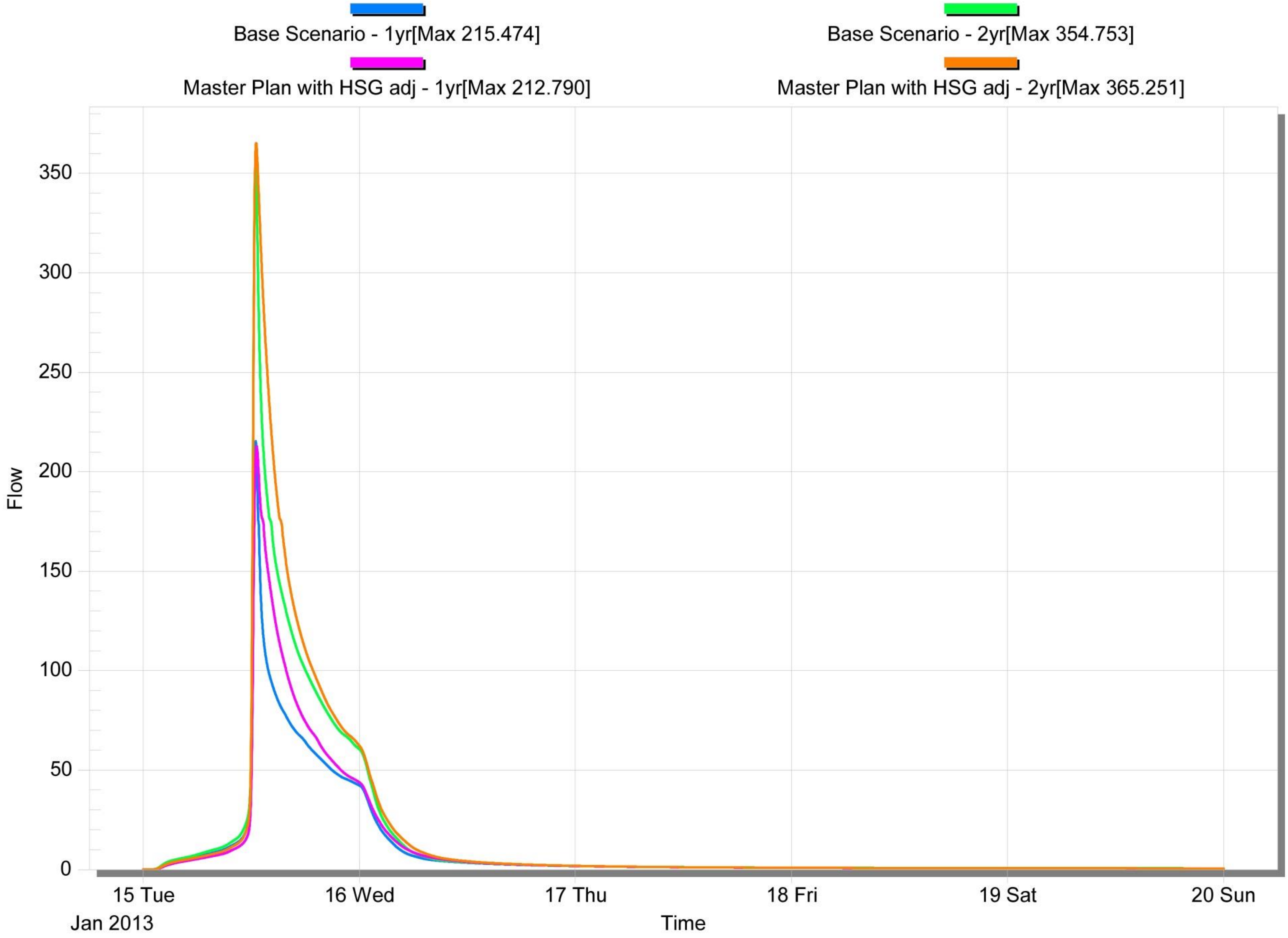
Base Scenario - 1yr[Max 175.687]
Base Scenario - 2yr[Max 246.919]
Master Plan with HSG adj - 1yr[Max 134.495]
Master Plan with HSG adj - 2yr[Max 198.185]
Flow
250
200
150
100
50
0
15 Tue
Jan 2013
16 Wed
17 Thu
18 Fri
19 Sat
20 Sun
Time

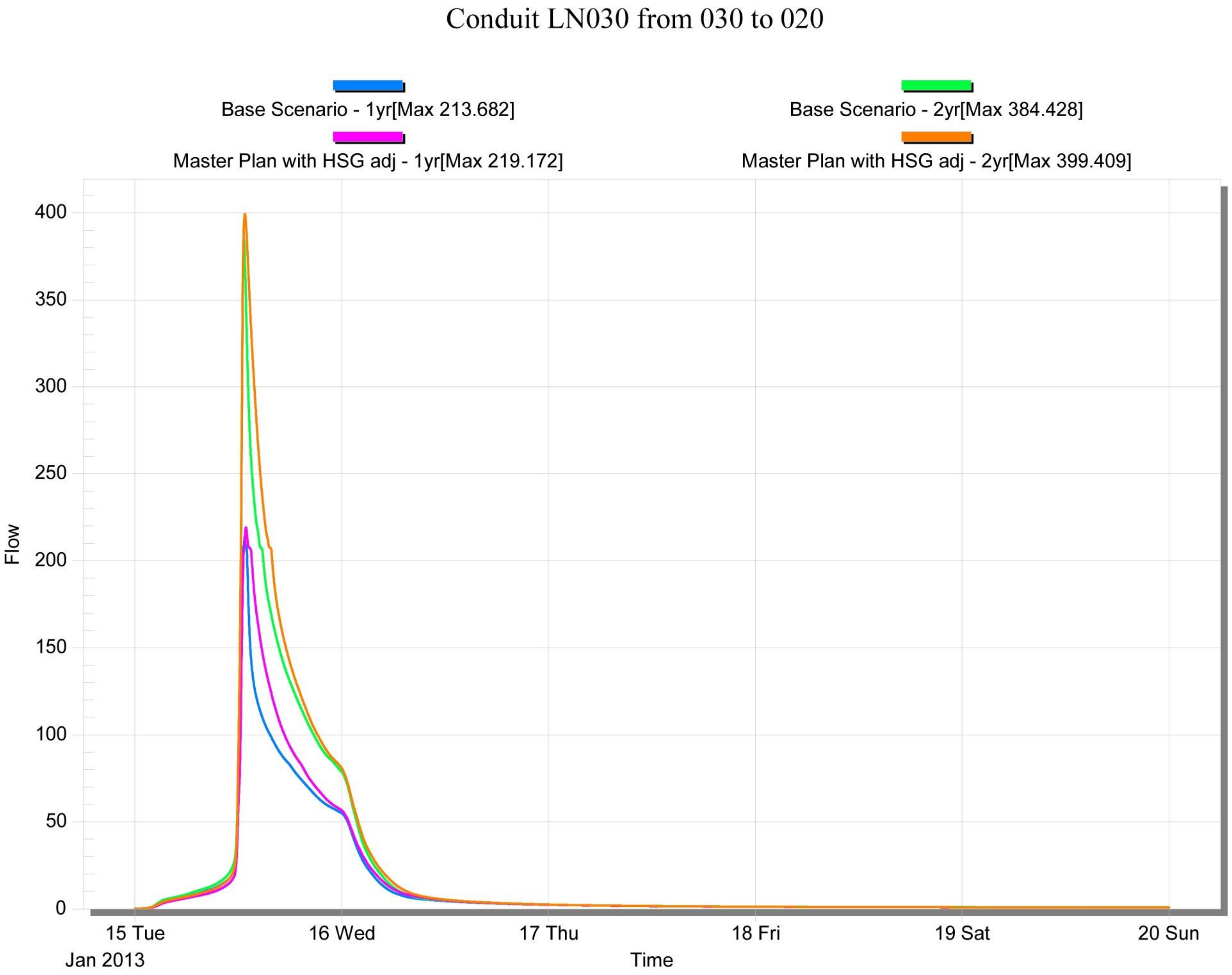
Conduit LN102 from 102 to 101




Conduit LN080 from 080 to 070
Base Scenario - 1yr[Max 216.519]
Base Scenario - 2yr[Max 320.480]
Master Plan with HSG adj - 1yr[Max 184.253]
Master Plan with HSG adj - 2yr[Max 278.472]
Flow
300
250
200
150
100
50
0
15 Tue
Jan 2013
16 Wed
17 Thu
18 Fri
19 Sat
20 Sun
Time

Conduit LN050 from 050 to 040





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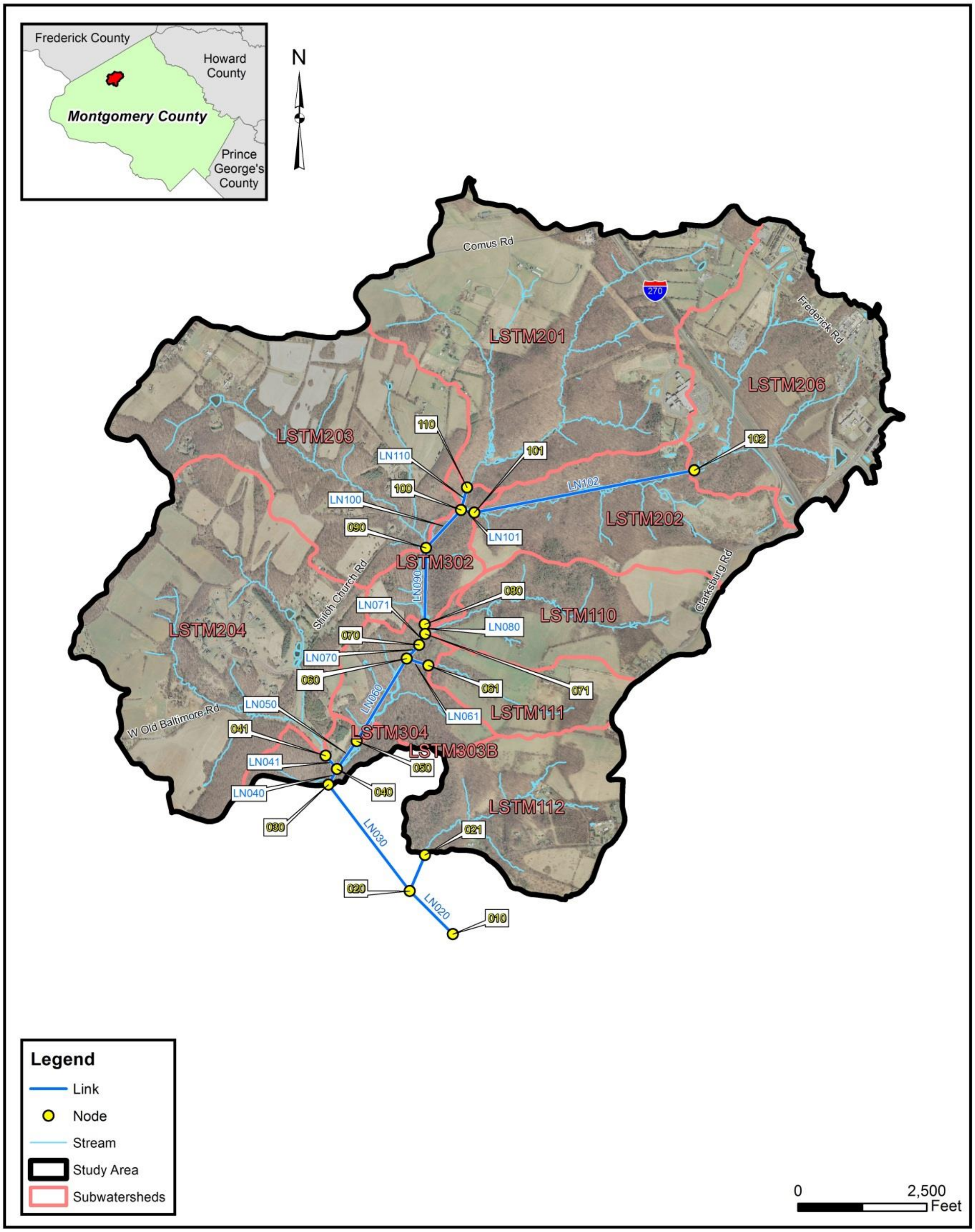

Ten Mile Creek

Clarksburg Master Plan Limited Amendment

SWMM Model Features

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Amendment A

Prepared for: Montgomery County Planning Department
Project Title: Clarksburg Master Plan Limited Amendment for the Ten Mile Creek Watershed
Project No.: 143717

Amendment A to Technical Memorandum No. 1

Subject: Revised Environmental Site Design Modeling scenario
Date: April 3, 2013
To: Mary Dolan and Valdis Lazdins, Montgomery County Planning Department
From: Biohabitats and Brown and Caldwell, a Joint Venture

Limitations:

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Section 1: Introduction

The purpose of this document is to serve as an amendment to Technical Memorandum No. 1: *Preliminary Results of the Hydrology and Hydraulics Analysis,* dated April 2, 2013. An additional Hydrologic and Hydraulic (H&H) analysis was performed to supplement the analysis described in Technical Memorandum No. 1. The purpose of the additional analysis was to examine a range of modeling assumptions associated with Environmental Site Design (ESD) practices, and this amendment summarizes the assumptions and findings of the additional analysis. For a description of model setup and discussion of the results from the previous model scenarios, please refer to Technical Memorandum No. 1.

Section 2: Methods

In the original Master Plan model scenario described in Technical Memorandum No. 1, the ESD practices were modeled with 6” of storage above the filter media, and were conservatively assumed to have a saturated condition within the soil media. The assumed infiltration rate of 0.25 in/hour would allow the ponded volume to drain within 24 hours. The micro-bioretention filters were also assumed to have a 3-inch thick stone reservoir at the base, and underdrains that would be placed above the level of the stone reservoir and discharge to surface water.

The additional ESD model scenario described in this amendment utilized more moderate ESD model assumptions, including deeper ponding area above the soil media and allowance for more storage within the soil media of the ESD practices. The assumption of a 3-inch thick stone reservoir at the base and underdrains that discharge to surface water remained the same for this additional ESD model scenario.

The revised ESD model assumptions included 8” of storage above the soil media, with a decaying infiltration rate and modeling the available storage within the soil media as if it were initially dry with a constant infiltration rate. The Horton method was utilized in XP-SWMM to represent both the decaying infiltration of the ponded area and the constant infiltration from the soil media. A maximum infiltration rate of 2 in/hour and a minimum (asymptotic) infiltration rate of 0.25 in/hour with a decaying rate of 0.0015/sec were utilized in the model to represent the decaying infiltration rate. A constant infiltration rate of 0.025 in/hour was used to represent the infiltration from the soil media.

The available storage within the soil media was computed by assuming that the soil media cross section would be 3-ft deep with a 40% void ratio. This depth of storage was combined with the assumed 3-inch thick stone reservoir, also with a 40% void ratio, to arrive at the total storage available within the conceptualized micro-bioretention cross section. It is important to note that no other model parameters were adjusted from the Master Plan scenario described in Technical Memorandum No. 1 other than the ESD practice modifications described above.

By modeling the ESD parameters described above, the results of this additional modeling run can be used in conjunction with the original results to represent an expected range of response to the Master Plan development scenario with treatment from ESD. Although design standards allow larger storage volumes than those used for in the H&H modeling analyses, constructed practices cannot be assumed to function at maximum design performance at all locations throughout the development, or at all times through a range of storm events. Therefore, the parameters selected for modeling represent a more moderate level of performance which allows for a margin of safety which is appropriate for this planning-level analysis.

2.1 Method of Interpretation

As stated in the original Technical Memorandum No. 1, the key metrics used to compare the revised ESD modeling assumptions with those of the base conditions and Master Plan scenarios are total runoff volume, peak streamflow, and peak stream velocity. It is also useful to compare the hydrographs to determine whether the post-development condition is expected to produce a longer duration of elevated stream velocity, regardless of impacts on peak streamflow.

The locations of primary interest for this analysis were the outlets of subwatersheds where the majority of the Master Plan development is proposed (i.e., subwatersheds LSTM202, LTSM206, LSTM 111, AND LSTM 110), in addition to the model domain outlet.

Section 3: Preliminary Results

Stable model runs were obtained for the revised ESD modeling scenario, with overall continuity errors well within the acceptable range of < ± 2%. Table 1 provides a comparison summary of the total streamflow volume for the outlets of the primary subbasins for the 1-yr storm event and 2-yr storm event. As also shown in Technical Memorandum No. 1 and below, total streamflow volume is generally expected to increase after development, and the revised ESD assumptions modeled in this additional analysis had minimal impacts on the total streamflow volume as compared with the ESD assumptions originally modeled for the Master Plan scenario[1].

Table 1 Summary of Total Streamflow Volume

		1-yr 24-hr storm Volume (ac-ft)			2-yr 24-hr storm Volume (ac-ft)		
Model Link #	Corresponding Watershed #	Existing Conditions	1994 Master Plan*	Master Plan* with revised ESD	Existing Conditions	1994 Master Plan*	Master Plan* with revised ESD
LN 071	LSTM 110	8.7	15.0	15.9	13.6	21.7	22.6
LN 061	LSTM 111	4.3	7.9	8.4	6.8	11.4	11.9
LN 101	LSTM 202	39.5	44.1	46.0	56.7	62.1	64.0
LN 102	LSTM 206	27.9	29.6	30.7	38.7	40.6	41.7
LN 030	Outlet	126.2	141.5	145.3	193.4	212.3	216.3

* Master Plan model scenarios assumed treatment with ESD, and soil compaction from construction activities

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[1] The small differences in streamflow volume between these two analyses are more likely attributable to model response to the changes in the ESD parameters and modeling method, rather than being indicators of changes in stream response.

Table 2 provides a summary of the model results for the peak streamflow for the same subbasins for the 1-yr and 2-yr storm event. It is interesting to note that the revised ESD modeling scenario remained relatively unchanged for subwatersheds LSTM 206 and LSTM 202. However, when comparing the revised ESD scenario with the original modeled Master Plan ESD scenario for subwatersheds LSTM 110, LSTM 111, and the model outlet, the model predicted a decrease in peak flow rate.

Table 2 Summary of Peak Stream Flow

		1-yr 24-hr storm Peak Stream Flow (cfs)			2-yr 24-hr storm Peak Stream Flow (cfs)		
Model Link #	Corresponding Watershed #	Existing Conditions	1994 Master Plan*	Master Plan* with ESD, additional storage	Existing Conditions	1994 Master Plan*	Master Plan* with ESD, additional storage
LN 071	LSTM 110	16.2	29.2	15.3	33.2	52.0	26.2
LN 061	LSTM 111	5.0	24.0	12.9	8.2	43.2	22.6
LN 101	LSTM 202	175.7	134.5	134.5	246.9	198.2	195.5
LN 102	LSTM 206	158.8	128.3	128.6	219.4	182.9	182.7
LN 030	Outlet	213.7	219.2	197.0	384.4	399.4	341.0

* Master Plan model scenarios assumed treatment with ESD, and soil compaction from construction activities

Table 3 provides a comparison summary of the peak stream velocity between the Existing Conditions scenario, the Master Plan scenario modeled with original ESD assumptions, and the Master Plan scenario modeled with revised ESD assumptions. The model predicted that the peak stream velocity remained relatively unchanged between the three scenarios when analyzing subwatersheds LSTM 202, LSTM 206, and the outlet. For the reaches draining subwatersheds LSTM 110 and LSTM 111, the model predicted that under the revised ESD scenario, the peak stream velocities would remain close to those of the existing conditions. It is important to remember that for this planning-level model, the result of interest is the difference in the parameters between the modeling scenarios rather than the absolute value of the parameters for any one scenario.

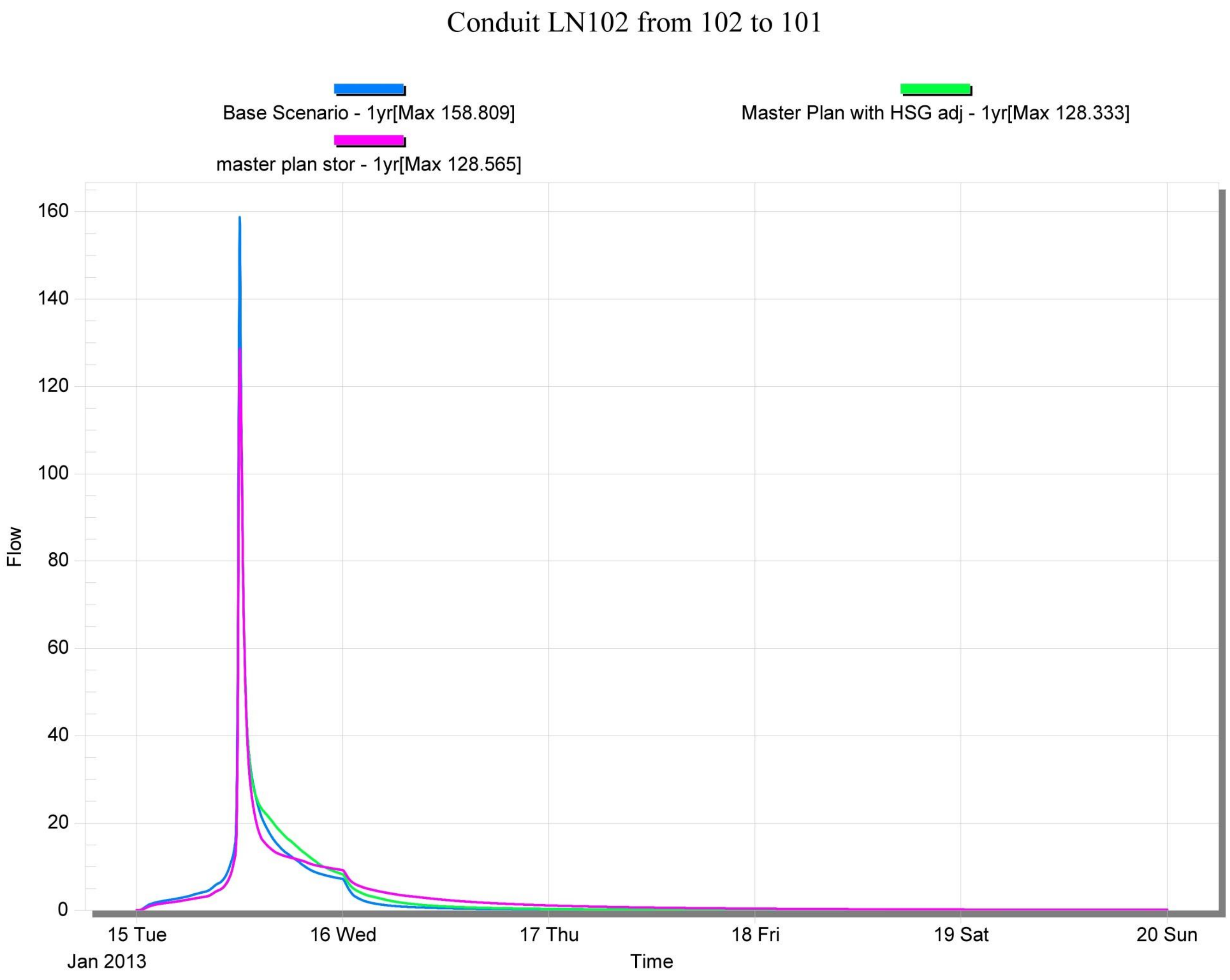
Table 3 Summary of Peak Stream Velocity							
		1-yr 24-hr storm Peak Stream Flow (cfs)			2-yr 24-hr storm Peak Stream Flow (cfs)		
Model Link #	Corresponding Watershed #	Existing Conditions	1994 Master Plan*	Master Plan* with ESD, additional storage	Existing Conditions	1994 Master Plan*	Master Plan* with ESD, additional storage
LN 071	LSTM 110	1.8	2.2	1.8	2.3	2.5	2.1
LN 061	LSTM 111	1.3	2.3	1.9	1.6	2.8	2.2
LN 101	LSTM 202	2.9	2.7	2.8	3.3	3.0	3.0
LN 102	LSTM 206	2.8	2.7	2.6	3.2	2.9	2.9
LN 030	Outlet	2.7	2.7	2.7	3.2	3.3	3.1

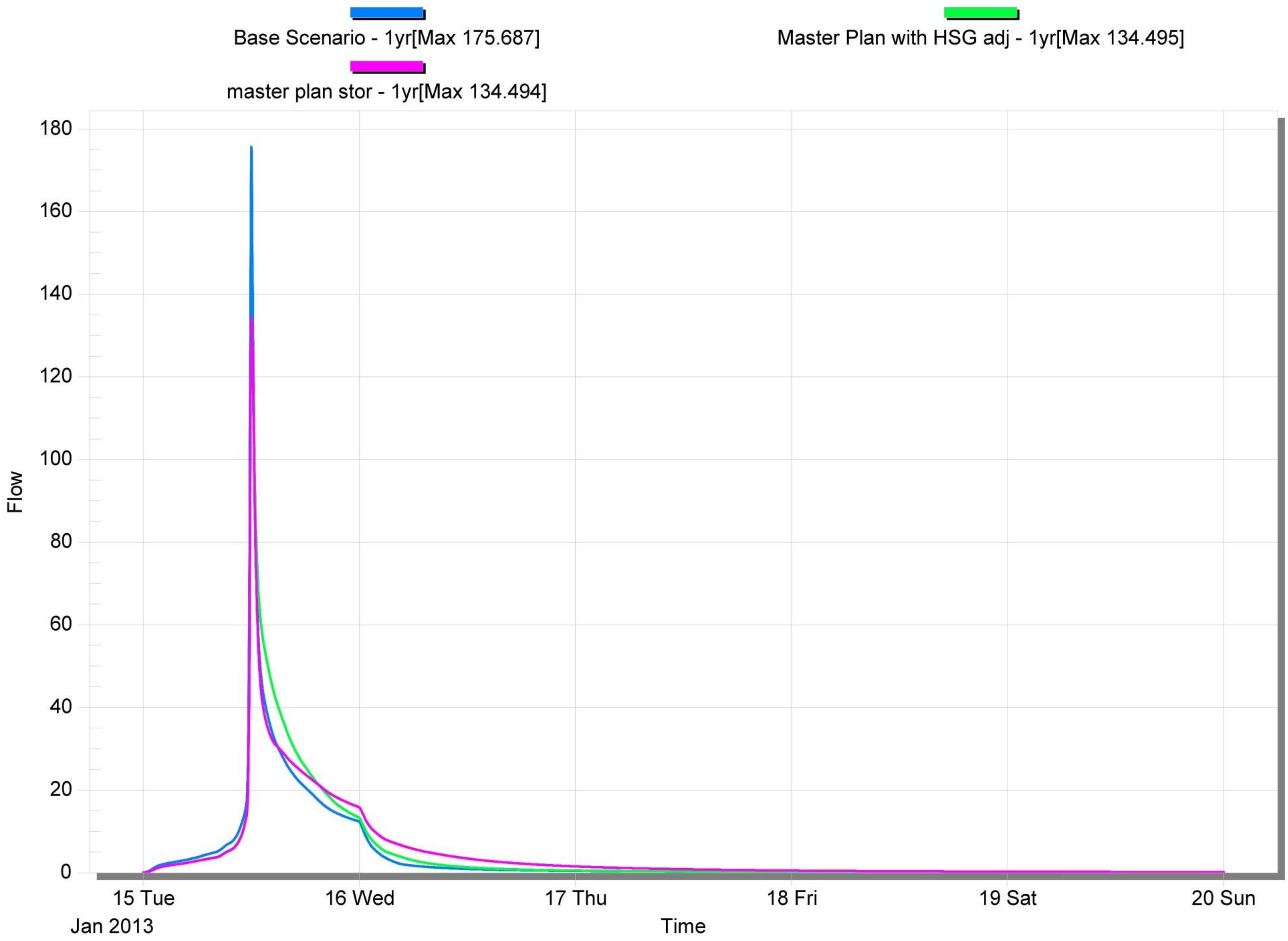
* Master Plan model scenarios assumed treatment with ESD, and soil compaction from construction activities

In conclusion, when comparing the revised ESD model scenario with the previous Master Plan scenario the results indicate that for subwatersheds LSTM 202, LSTM 206, and the model outlet the metrics of total streamflow volume, peak stream flow, and peak stream velocity remain relatively unchanged. The greatest response from the revised ESD model scenario was observed in subwatersheds LSTM 110 and LSTM 111. The model predicted a decrease in peak stream flow when compared to the original Master Plan model scenario outlined in Technical Memorandum No. 1, however, an increase in peak stream flow over the existing conditions model scenario is predicted. When comparing the metrics of total streamflow volume the model predicted little difference between the original master plan scenario to that of the revised ESD scenario. A slight decrease was observed in subwatersheds LSTM 110 and LSTM 111 when analyzing the metric of peak stream velocity for the revised ESD scenario compared to the original master plan model.

APPENDIX A

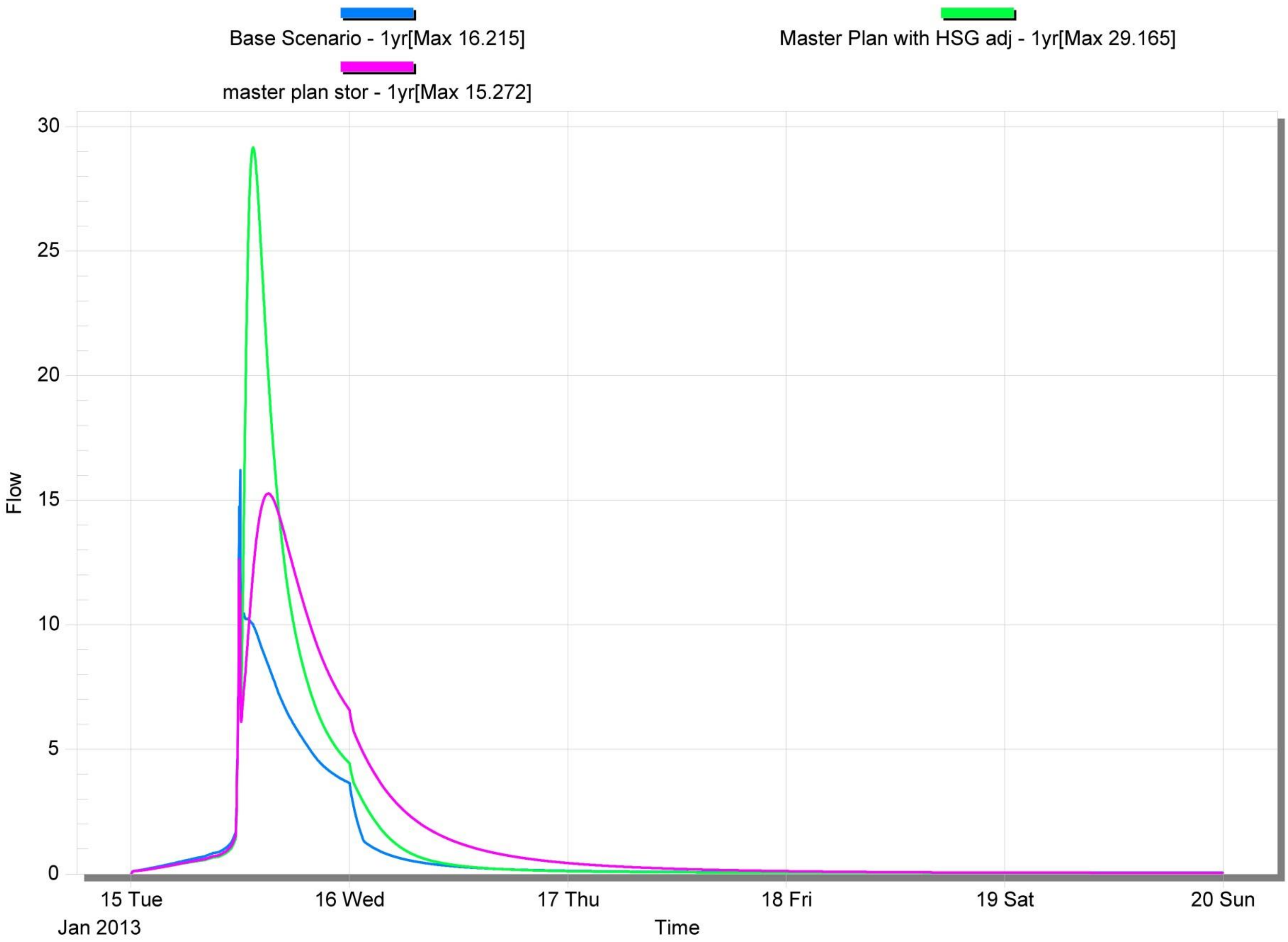
Hydrographs

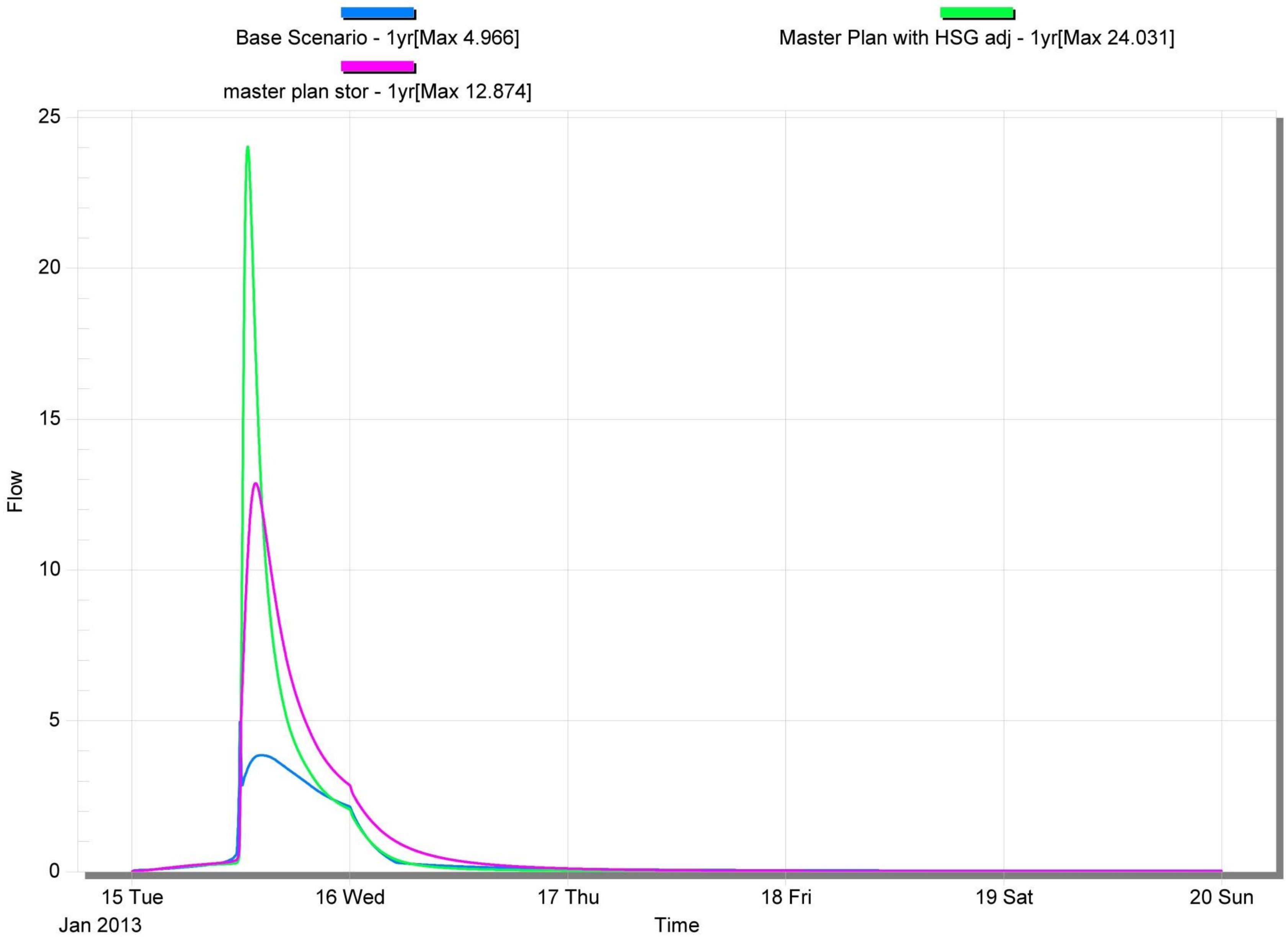

Conduit LN102 from 102 to 101
Base Scenario - 1yr[Max 158.809]
Master Plan with HSG adj - 1yr[Max 128.333]
master plan stor - 1yr[Max 128.565]
Flow
160
140
120
100
80
60
40
20
0
15 Tue
Jan 2013
16 Wed
17 Thu
18 Fri
19 Sat
20 Sun
Time



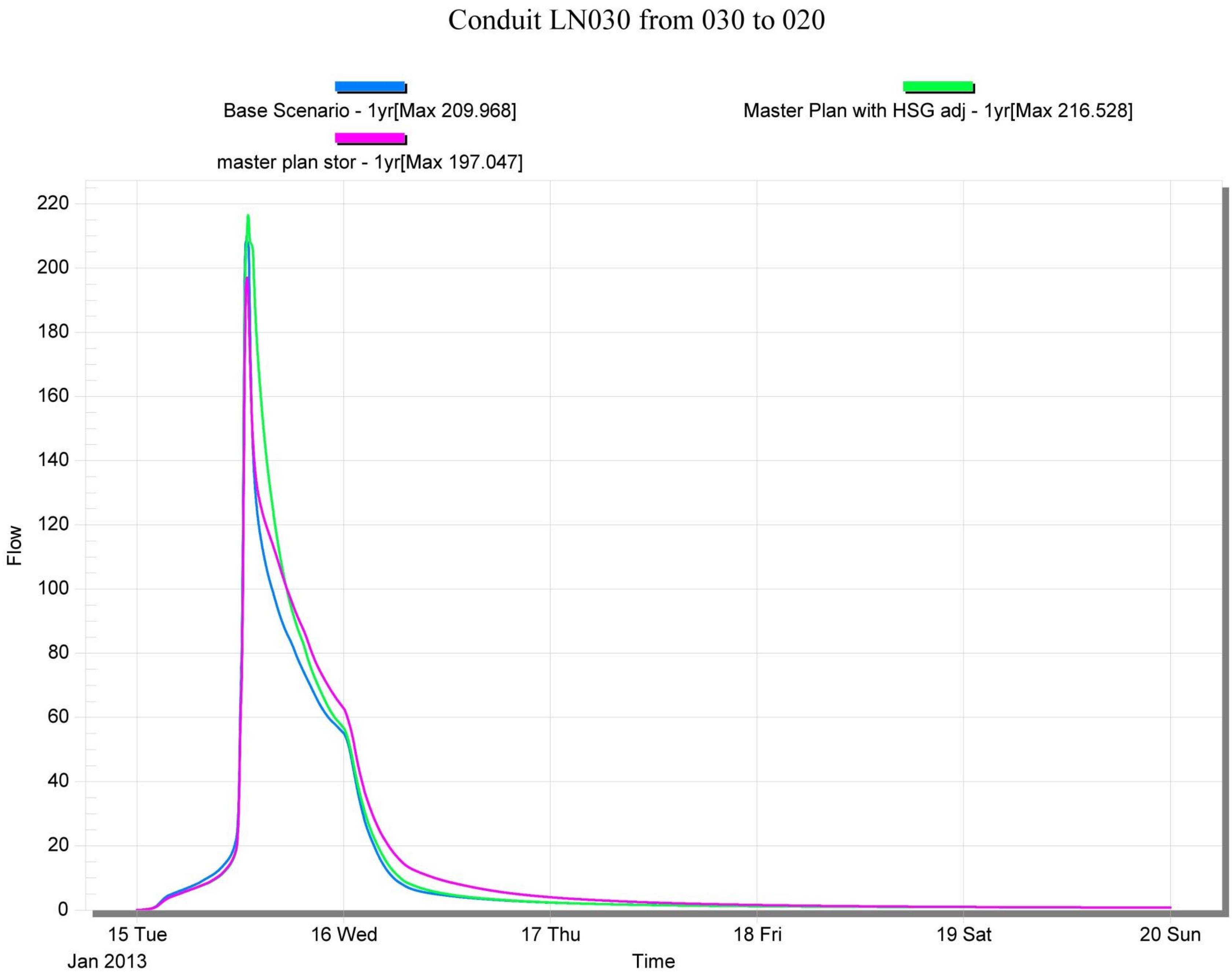
Conduit LN101 from 101 to 100

Conduit LN071 from 071 to 070





Conduit LN061 from 061 to 060


Conduit LN030 from 030 to 020
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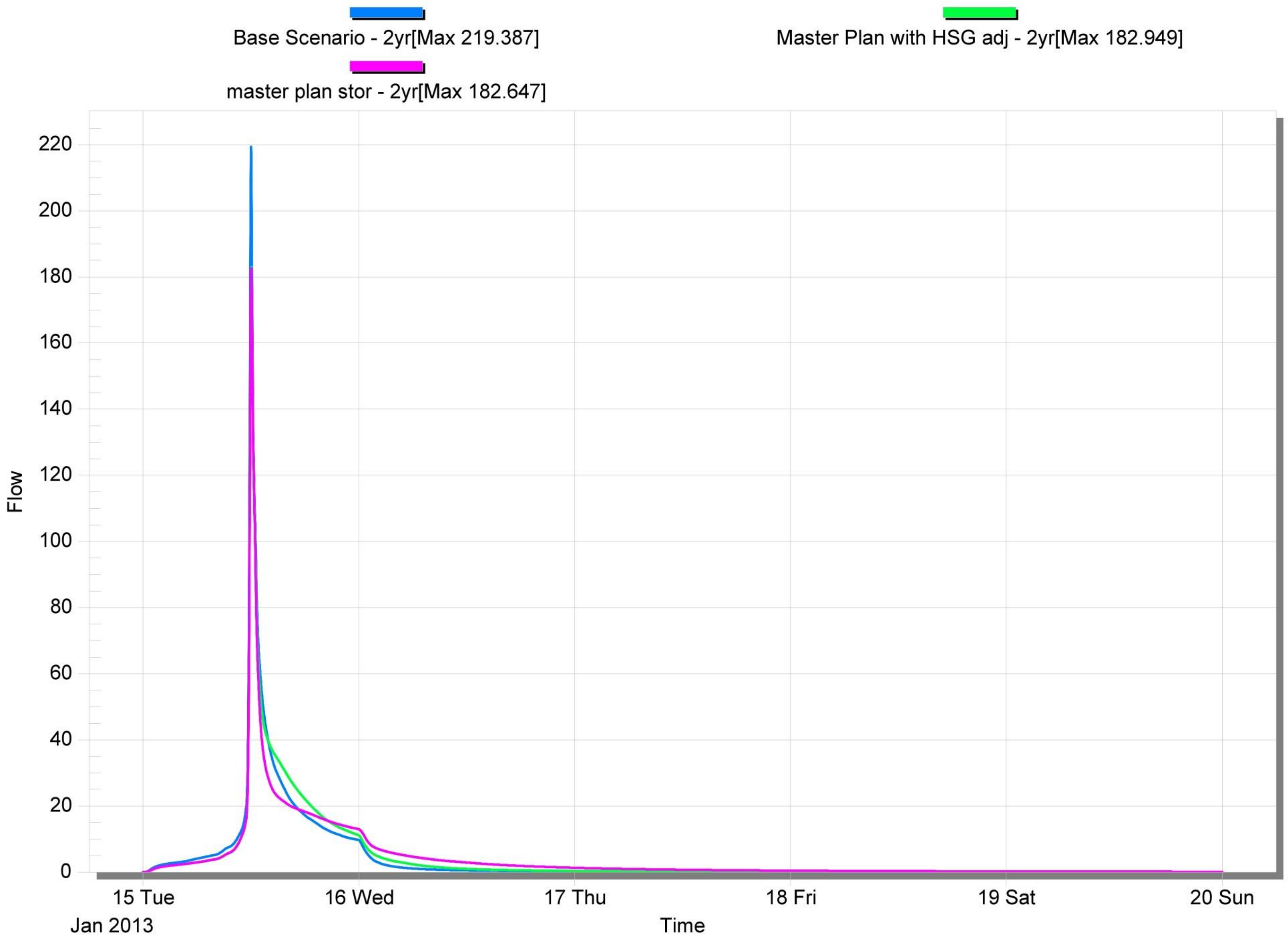
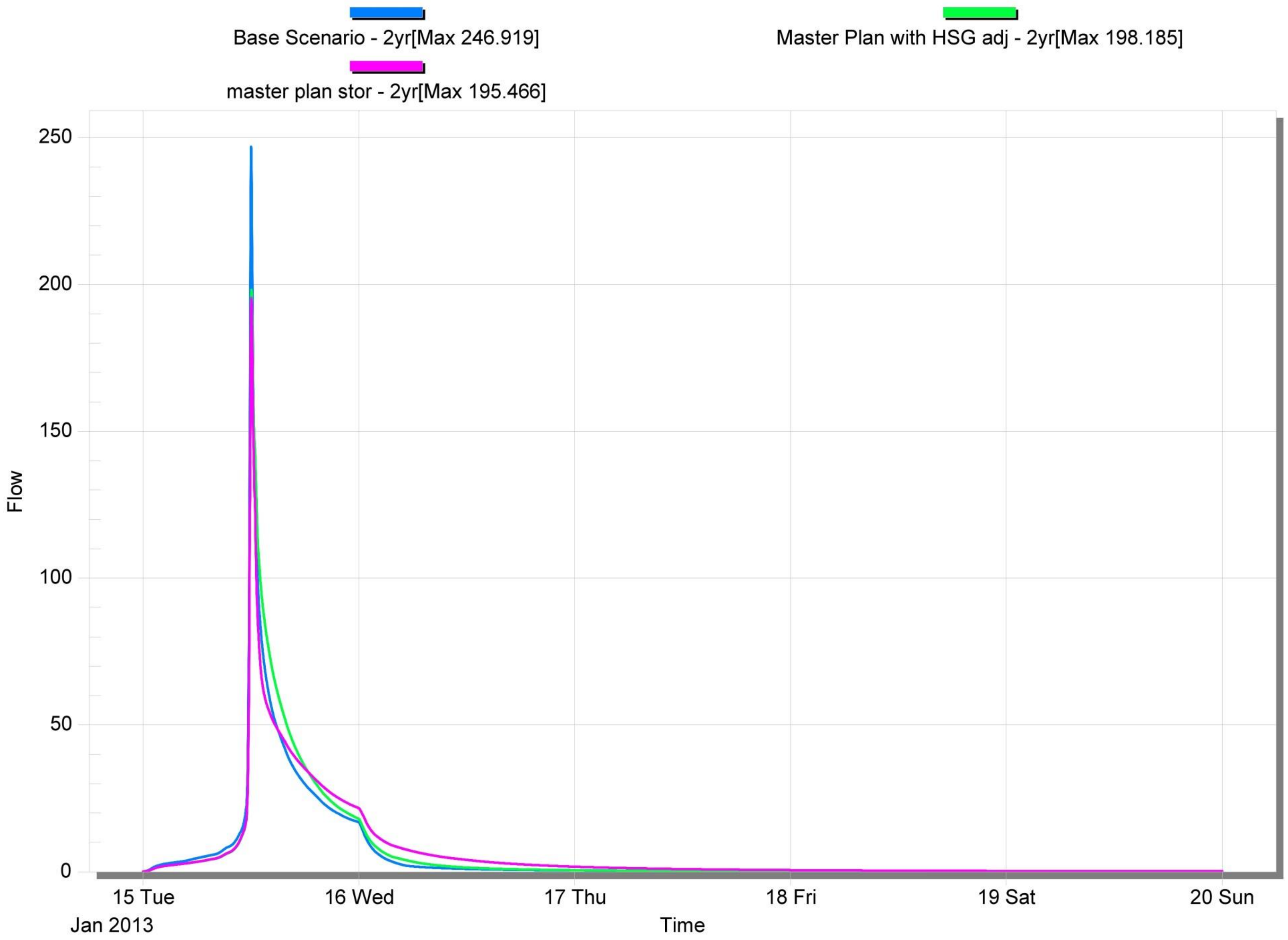
Master Plan with HSG adj - 1yr[Max 216.528]
master plan stor - 1yr[Max 197.047]
Flow
220
200
180
160
140
120
100
80
60
40
20
0
15 Tue
Jan 2013
16 Wed
17 Thu
18 Fri
19 Sat
20 Sun
Time

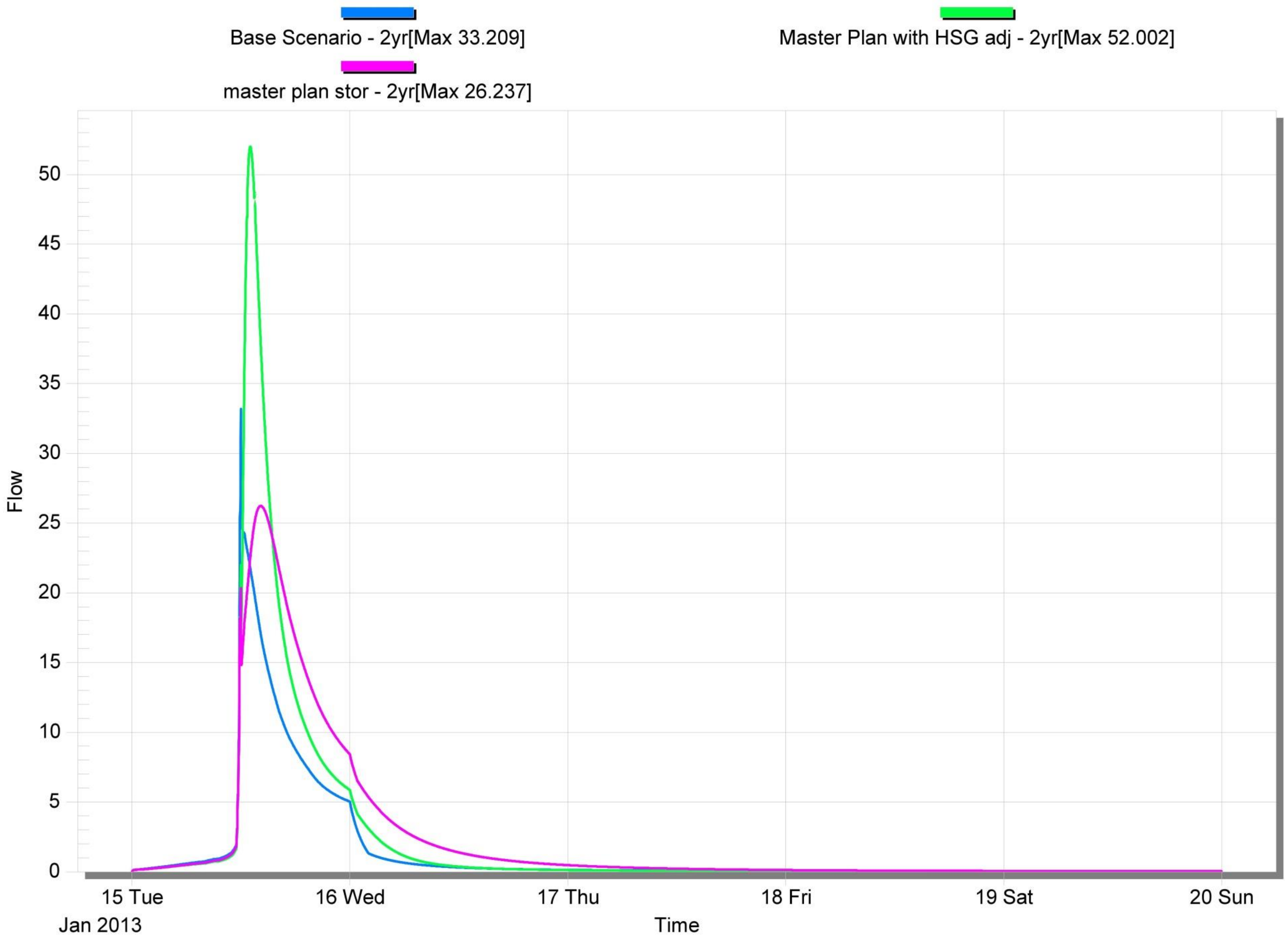
Conduit LN102 from 102 to 101



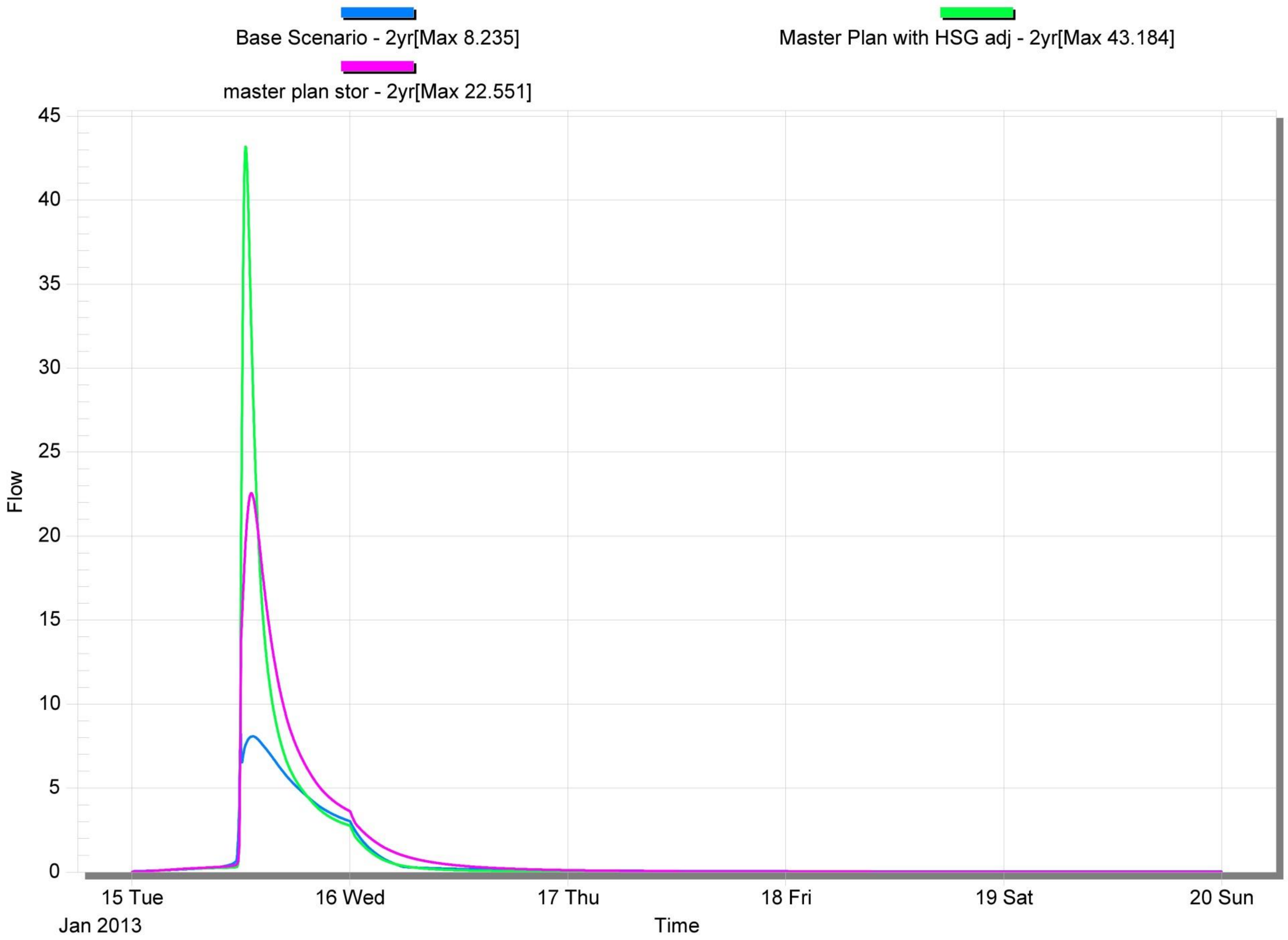
Conduit LN101 from 101 to 100



Conduit LN071 from 071 to 070



Conduit LN061 from 061 to 060



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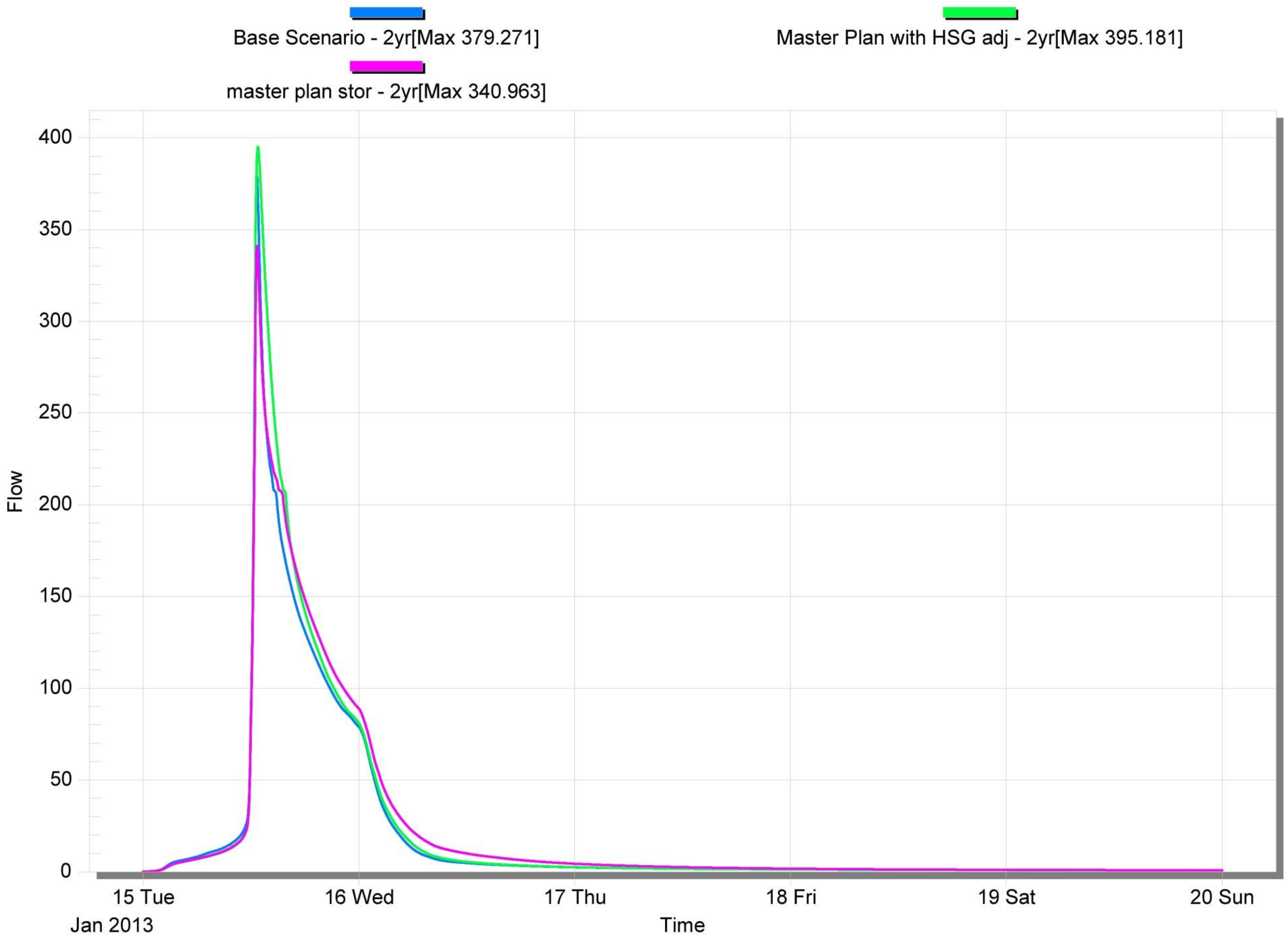

Biohabitats
Brown AND Caldwell
A Joint Venture

MEMORANDUM – DRAFT

Date: April 3, 2013

To: Mary Dolan and Valdis Lazdins, Montgomery County Planning Department

From: Biohabitats and Brown and Caldwell, a Joint Venture

RE: Ten Mile Creek Watershed Environmental Analysis
in Support of the Clarksburg Master Plan Limited Amendment
SUBJ: Spatial Watershed Analysis

The Ten Mile Creek watershed in northwestern Montgomery County is the focus of an environmental analysis study in support of the Limited Amendment to the Clarksburg Master Plan, being undertaken by the Maryland-National Capital Park and Planning Commission (M-NCPPC) Montgomery County Planning Department. This environmental analysis is being conducted for the Planning Department by Biohabitats and Brown and Caldwell, a Joint Venture, with support from the Center for Watershed Protection. It is being done in collaboration with Montgomery County Department of Environmental Protection (DEP) and Montgomery County Department of Permitting Services (DPS).

As the purpose of this study is to determine the baseline environmental conditions in order to evaluate potential watershed response to development within the Ten Mile Creek watershed, this analysis focuses on subwatersheds upstream of the USGS gage station and those that have the potential to be directly affected by development. These subwatersheds are referred to as the “study area.”

The 1994 Clarksburg Master Plan allows for development in the eastern portion of the watershed. This memorandum presents a Spatial Watershed Analysis of both existing conditions and implementation of the 1994 Master Plan. The intent of this analysis is to identify areas that have high resource value and support watershed health. This memorandum is intended to provide a description of that analysis, the methods used, supporting maps, and a description of the results.

NOTE: Planimetric information shown in this document is based on copyrighted GIS Data from M-NCPPC, and may not be copied or reproduced without express written permission from M-NCPPC.

METHODS

The conceptual basis of this analysis is centered on Geographical Information System (GIS) information that can be used to map important watershed health characteristics or attributes such as forested areas, wetlands, streams, and green infrastructure, etc. The areas (or in GIS terminology "polygons") in the watershed where these important attributes occur were assigned a value of 1 point, and the areas where they did not occur were assigned a value of 0. These attribute maps were overlaid on each other and analyzed to help identify, define the areal extent of, and measure and describe areas that contribute to watershed health.

Attribute Data

Available existing GIS data pertaining to natural resource attributes that are important for water quality and ecological health were collected. These data were provided by the Montgomery County Planning Department and DEP. Mapping summarizing these attributes is included in the report "Existing Conditions in the Ten Mile Creek Study Area, in support of the Limited Amendment to the Clarksburg Master Plan" prepared for the Planning Department by the Joint Venture.

The attribute data used in this analysis includes:

- Steep Slopes, >15%
- Steep Slopes, >25%
- Erodible Soils
- Hydric Soils
- Forest
- Interior Forest
- 100-Year Floodplain
- Perennial/Intermittent Streams with associated 175' Buffer
- Ephemeral Channels with associated 25' Buffer
- Wetlands and associated 25' Buffer
- Springs, Seeps & Seasonal Ponds with associated 25' Buffer

The attributes selected for the spatial analysis align with Montgomery County's Environmental Guidelines and DEP's definition of environmentally sensitive areas (Montgomery County Department of Park and Planning, 2000). To provide for growth while protecting Montgomery County's natural resources, all proposals for development in Montgomery County are reviewed in terms of environmental impact and protection before being approved by the planning Board. The Guidelines for Environmental Management of Development in Montgomery County provides guidance "regarding appropriate techniques to protect natural resources during the development process" (Montgomery County Department of Park and Planning, 2000). These guidelines are "applied to protect sensitive environmental features on development plans" (Montgomery County Department of Park and Planning, 2000). Sensitive areas include streams and their buffers, 100-year floodplains, habitat of threatened and endangered species, erodible soils and steep slopes (Montgomery County Department of Park and Planning, 2000).

In addition, any development activity within a Special Protection Area (SPA), unless exempted, must go through a water quality review process by completing monitoring and reporting according to the approved Water Quality Plan and county regulations. An element of the Water Quality Plan includes the preservation of environmentally sensitive areas and priority forest conservation areas. Environmentally sensitive areas “refers to areas having beneficial features to the natural environment, including but not limited to: steep slopes; habitat for Federal and/or State rare, threatened, and endangered species; 100-year ultimate floodplains; streams; seeps; springs; wetlands, and their buffers: priority forest stands; and other natural features in need of protection” (Montgomery County Department of Environmental Protection, 2012).

Data Layers Created in GIS Information Inventory

For each attribute included in this analysis, a data layer was created in GIS to display conditions within the study area. All attribute layers were then overlaid and combined for use in one map to contain all available baseline data and ensure that all data would be compatible in the analysis (e.g., interior forest and buffer boundaries). That map represents an inventory of information available for this analysis.

Below is a description of each attribute used in this analysis.

- **Steep Slopes >15% and >25%:** Steep slopes are a sensitive environmental feature addressed in the Guidelines for Environmental Management of Development in Montgomery County and can influence buffer widths of other sensitive environmental features and/or can prohibit certain development activities. Steep slopes are defined as having a gradient equal to or greater than 25 percent. However, in SPAs, steep slopes are slopes greater than 15 percent. The guidelines recommend that steep slopes should be incorporated into open space and/or remain undisturbed (Montgomery County Department of Park and Planning, 2000).

- **Erodible Soils:** Erodible soils are soil classified as having “severe hazard of erosion by the NRCS” in the 1995 Soil Survey of Montgomery County (Montgomery County Department of Park and Planning, 2000). As mentioned in the Guidelines for Environmental Management of Development in Montgomery County, erodible soils should be incorporated into open space when possible and managed appropriately during construction. Erodible soils in conjunction with steep slopes can influence the buffer width around natural resources (i.e. streams and wetlands) (Montgomery County Department of Park and Planning, 2000).

- **Hydric Soils:** Hydric soils are “soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part” (Soil Survey, 2013). The hydric soil category rating of a soil map unit indicates the proportion of a map unit that meets the hydric soil definition (Soil Survey, 2013). The presence of hydric soils indicates a potential condition for a wetland resource and a potential limitation with respect to development (i.e. depth to saturated zone and slow water movement) (Soil Survey, 2013).

- **Forest:** A forest, as defined by the County’s Forest Conservation Law (1992 L.M.C., ch. 4, § 1), is a “biological community dominated by trees and other woody plants (including plant communities, the understory, and forest floor) covering a land area which is 10,000 square feet or greater and at least 50 feet wide. Among the numerous ecosystem services forests provide are food and cover for wildlife, temperature regulation, carbon sequestration and nutrient cycling. All forest polygons were included in the spatial analysis.

- **Interior Forest:** Montgomery County designates interior forest as 1) contiguous forest tracts consisting of a minimum of 50 acres in size with 10 or more acres of forest more than 300 feet from the nearest forest edge, or 2) a riparian forest with an average minimum width of 300 feet and at least 50 acres in size. These forest interiors that can support forest interior dwelling birds that require large forest areas to breed and maintain viable populations (Jones, McCann, & McConville, 2000).

- **FEMA 100-year Floodplain:** The 100-year floodplain is the land area within the limits of the 100-year storm flow water elevation which have a 1 percent annual chance of occurring. Floodplain guidelines in the Guidelines for Environmental Management of Development in Montgomery County "are based on existing State and County regulations that govern development activities in these areas" (Montgomery County Department of Park and Planning, 2000). The guidelines restrict or even prohibit new development within the 100-year floodplain to prevent flood hazards and conserve habitats (Montgomery County Department of Park and Planning, 2000).

- **Perennial/Intermittent Streams:** Streams consist of either perennial (continually flowing) or intermittent (seasonally flowing) channels that convey concentrations of groundwater and stormwater runoff along with various dissolved and suspended materials across the landscape. Streams and their riparian corridor (terrestrial area transitioning from a water body to an upland) perform various biophysical and biogeochemical processes, including uptake of nutrients and pollutants and provide other ecosystem services, such as freshwater and habitat for wildlife. The importance of streams and their associated riparian corridor is recognized in stream buffer requirements described in the County's Environmental Guidelines (Montgomery County Department of Park and Planning, 2000), and is represented in the spatial analysis the DEP stream layer and associated 175-foot buffer along each side of the stream.

- **Ephemeral Channels:** Ephemeral channels are defined channels that are above the groundwater table and convey flow only during and shortly after a rain event. These channels are situated at the top of a watershed where water first concentrates and typically have direct connections to a stream channel. As a conduit into perennial/intermittent streams, protection of the quality of these channels is an important component of stream health. Ephemeral channels are regulated by the U.S. Army Corps under the authority of the Clean Water Act (1972) and are represented in the spatial analysis as the regulated stream channel and include an unregulated 25-foot buffer strip to account for their role in stream health. The basis for the 25-foot buffer is consistent with the minimum buffer around non-tidal wetlands regulated by Maryland Department of Environment (MDE) and U.S. Army Corps guidance on maintaining buffer strips for water quality considerations (Fischer and Fischenich, 2000 and Fischer, 2002).

- **Wetlands:** A wetland is an area "inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (Environmental Laboratory, 1987). Some environmental benefits that wetlands provide include water purification, flood protection, groundwater recharge and streamflow maintenance, and wildlife habitat. Wetlands are also a natural resource that may be subject to regulatory jurisdiction under Section 404 of the Clean Water Act or Section 10 of the Rivers and Harbors Act (Environmental Laboratory, 1987). From a regulatory perspective, environmental protection and permitting requirements are in place at the federal and state level for construction related activities within or adjacent to wetland resources. In the GIS analysis, a buffer of 25 feet was assigned around mapped wetlands. The 25-foot buffer is regulated by MDE under the authority of the Maryland Non-tidal Wetlands Protection Act (1989).

- **Springs, Seeps, and Seasonal Pools:** A seep is defined as a water feature exclusively fed by groundwater and does not typically flow, whereas a spring is a water feature fed by groundwater that flows intermittently or constantly (Montgomery County Department of Environmental Protection, 2012). Seeps and springs in the headwaters of tributaries to Ten Mile Creek are necessary to maintain base flows in headwater streams and to provide habitat for trout and other sensitive aquatic species that rely on cool, clean water (Montgomery County Planning Department & Montgomery County Department of Environmental Protection, 2013).

  A seasonal pool or vernal pool is a small, temporary body of water not directly connected to a flowing stream. Seasonal pools are important because they support unique habitat for amphibians and aquatic invertebrates (Stanko, et. al., 2010).

  Springs seeps and seasonal pools are regulated by MDE under the authority of Maryland Non-tidal Wetlands Protection Act and were buffered by 25 feet as discussed for the wetlands. In the GIS analysis, a buffer of 25 feet was assigned around mapped springs, seeps, and seasonal pools.

Attribute Conversion to Metrics-Scoring Methodology

Each attribute included in this analysis has associated with it a benefit to **watershed health**. In order to allow the GIS software to help identify areas with important watershed health characteristics, numerical values are assigned to different attribute areas, using a simple presence/absence approach (Table 1). If an attribute has a positive effect, then the areas in which that attribute are present are assigned a value of one. Areas where the attribute does not occur are assigned a value of zero.

For instance, research has shown that forested areas enhance the rate of runoff infiltration, filter and cleanse pollutants from stormwater, and provide habitat for many species of plants and animals. These characteristics are beneficial to watershed health. Therefore, forested areas (and the mapped polygons or areas associated with them in GIS) are assigned a numerical value of one in the forest attribute GIS layer. Areas that are not mapped as forested are assigned a value of zero.

The strategy of using the same numerical value of one for the presence of each one of the beneficial attributes is intentional. This analysis is intended to identify areas that are important to watershed health, without necessarily weighting one attribute's value more than another's. Using the zero/one ranking strategy assigns the same value of benefit to each attribute. Ranking watershed attributes and documenting their relative values in the scientific literature is beyond the scope of this analysis.

Table 1. Attribute Summary and Metric Scores

Attribute	Score	
	Present	**Absent**
Steep Slopes, >15% – presence/absence	1	0
Steep Slopes, >25% – presence/absence	1	0
Erodible Soils – presence/absence	1	0
Hydric Soils– presence/absence	1	0
Forest – presence/absence	1	0
Interior Forest – presence/absence	1	0
FEMA 100-Year Floodplain – presence/absence	1	0
Perennial/Intermittent Streams – presence/absence	1	0
Ephemeral Channels – presence/absence	1	0
Wetlands – presence/absence	1	0
Springs, Seeps, and Pools – presence/absence	1	0
Maximum Possible Score	**11**	

Composite Map

Using GIS, attribute layers can be overlain to display on top of one another, and also combined and summed such that attribute values are “stacked up” in each area of the map. When the layers are overlain, all the values associated with each attribute layer are assigned their corresponding point on the ground in the watershed. The resulting composite map will have all the boundaries of every attribute, which creates numerous intersecting boundaries and creates many areas where multiple attributes may overlap. The polygons created when all the attributes are overlain contain all of the values for all the attributes that pertain to that particular area in the watershed. GIS sums all the values of the attributes for each point on the ground and the attribute sum is assigned to each polygon created.

The result is a map with many polygons or areas. Each polygon has an attribute total score associated with it. The lowest possible score for a mapped area is zero (no attributes present) The highest possible score for a mapped area is equal to the number of attributes used in the analysis is 13, if each attribute is present and the subwatershed receives an “excellent” rating for stream condition.

An algorithm in ArcGIS software (Natural Breaks-Jenks Classification) was used to create statistical categories for the range of possible values. The algorithm combines two methods. The first is Natural Breaks, where the data is partitioned into categories based on natural groups in distribution (low points in the data histogram). The second is the Jenks Classification, a method of statistical data classification that partitions data into classes using an algorithm that calculates groupings of data values based on the data distribution. Jenks optimization seeks to reduce variance within groups and maximize variance between groups.

The number of categories that the Natural Breaks-Jenks Classification algorithm computes is determined by the user. For this analysis, the data was additionally analyzed using three and five categories. GIS was then used to create a map with different color shades for each three- and five-category analysis.

Alternative Analysis- Forest Interior Not Included

An alternative analysis using the methodology described above was conducted with the forest interior layer removed. This alternative analysis had a maximum potential score of 10 versus 11. The reasoning behind this alternative analysis was to more directly evaluate **stream quality** as opposed to overall watershed health.

RESULTS

Existing Conditions

The composite natural resource attribute scores for the Ten Mile Creek study area are summarized in Figure 1, Figure 1a and Table 2. Figures 1 and 1a utilize a different shade of green to represent the total number of attributes that occur at a point on the landscape in the analysis. The darker green areas have higher numbers of attributes present and are generally associated with the presence of the stream system and its buffer areas, forested areas, and wetlands.

When including forest interior, 11 natural resource attributes were analyzed and the maximum number of attributes present at any location in the study area is nine. Without forest interior the maximum number of natural resource attributes present at any location is eight. The total land area occupied by natural resource attributes is summarized in Table 2.

Table 2. Summary of Land Area and Natural Resources Attribute Scores (without Forest Interior Attribute)

Attribute/Natural Resources Score	With Forest Interior		Without Forest Interior	
	Area (Acres)	% of Total Area	Area (Acres)	% of Total Area
0	1116.2	37%	1116.2	37%
1	708.8	23%	847.2	28%
2	520.5	17%	480.3	16%
3	325.7	11%	310.6	10%
4	216.8	7%	181.7	6%
5	106.2	3%	93.6	3%
6	44.8	1%	14.7	<1%
7	6.5	<1%	1.8	<1%
8	0.7	<1%	<0.1	<1%
9	<0.5	<1%	N/A	N/A

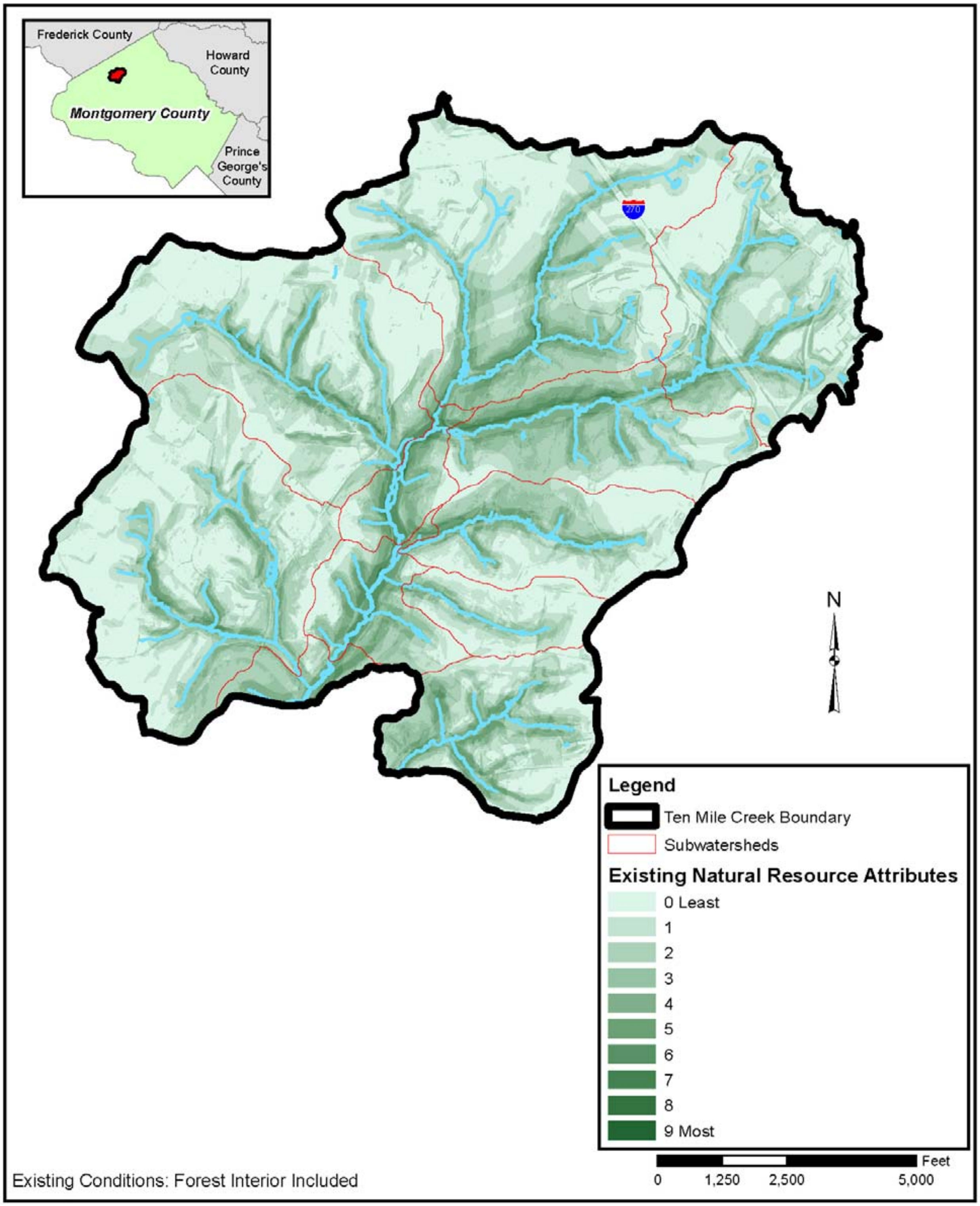

Figure 1. Composite Map of Natural Resources Attribute Scores, Forest Interior Included

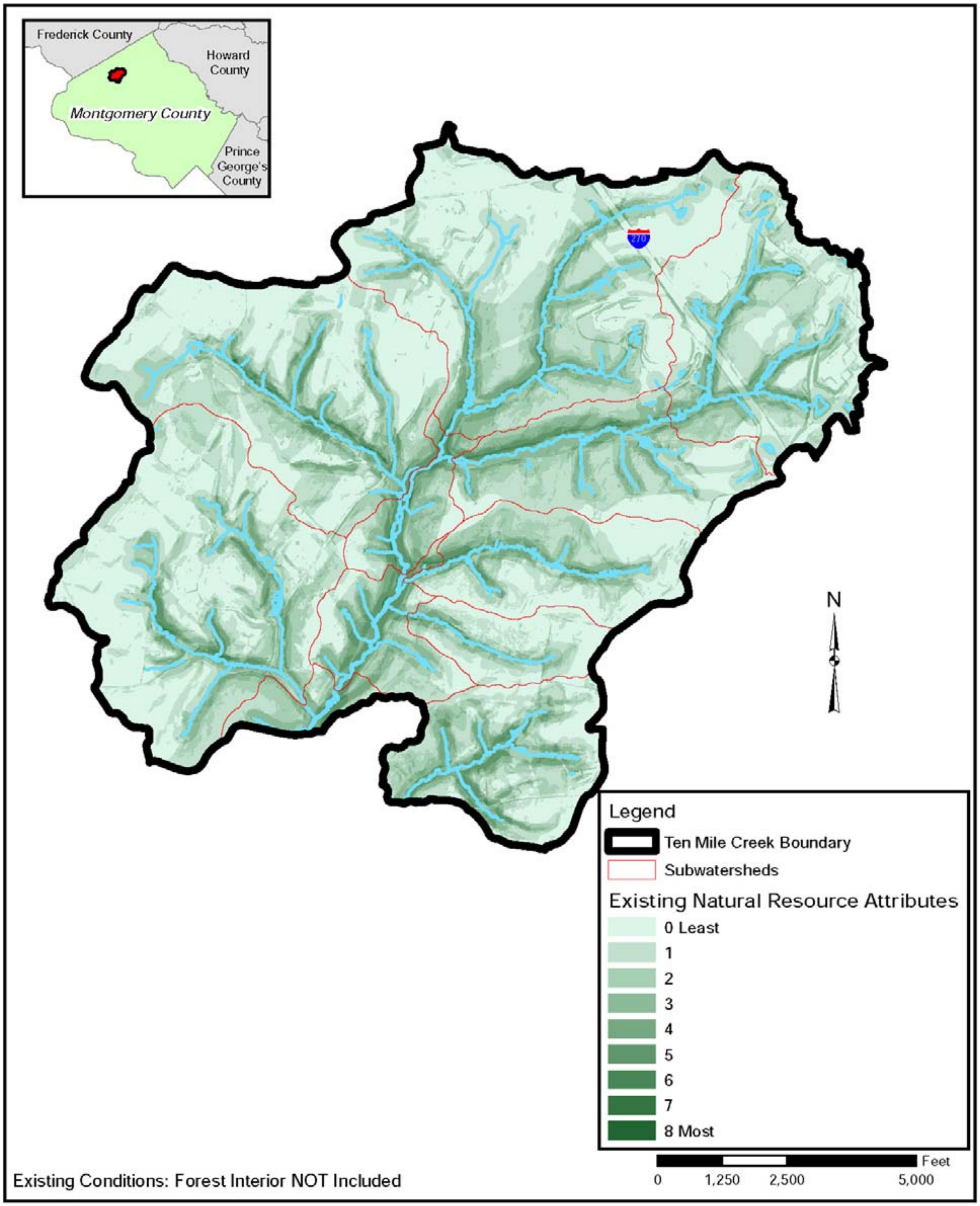

Figure 1a. Composite Map of Natural Resources Attribute Scores, Forest Interior Not Included

Figure 2 (with forest interior) and Figure 2a (without forest interior) are composite maps that use the Natural Breaks/Jenks Classification to create five statistical categories; the baseline attribute data is grouped accordingly, and illustrated using five different shades of green. The consolidation of the data into fewer groups may be helpful in differentiating areas of somewhat similar score values. The total land area occupied by natural resource attributes is summarized Table 3.

Table 3. Natural Resources Attribute Scores, Grouped into Five Categories, and their Corresponding Areas

Attribute Scores/Categories	With Forest Interior		Without Forest Interior	
	Area (Acres)	% of Total Area	Area (Acres)	% of Total Area
0 to 1	1825	60%	1963.4	64%
2	520.5	17%	480.3	16%
3	326.7	11%	310.6	10%
4 to 5	323	11%	275.3	9%
6 to 9	52	2%	16.6	1%

Figure 3 (with forest interior) and Figure 3a (without forest interior) are the third composite maps produced for this analysis, using the Natural Breaks/Jenks Classification algorithm to statistically create three categories. The further consolidation of the data into fewer categories differentiates the watershed into fewer discrete areas than Figures 1 and 2, and presents a different view of the data. The total land area occupied by natural resource attributes is summarized Table 4.

Table 4. Natural Resources Attribute Scores, Grouped into Three Categories, and their Corresponding Areas

Attribute Scores/Categories	With Forest Interior		Without Forest Interior	
	Area (Acres)	% of Total Area	Area (Acres)	% of Total Area
0 to 1	1825	60%	1963.4	64%
2 to 3	846.2	28%	790.9	26%
4 to 9	375	12%	291.9	10%

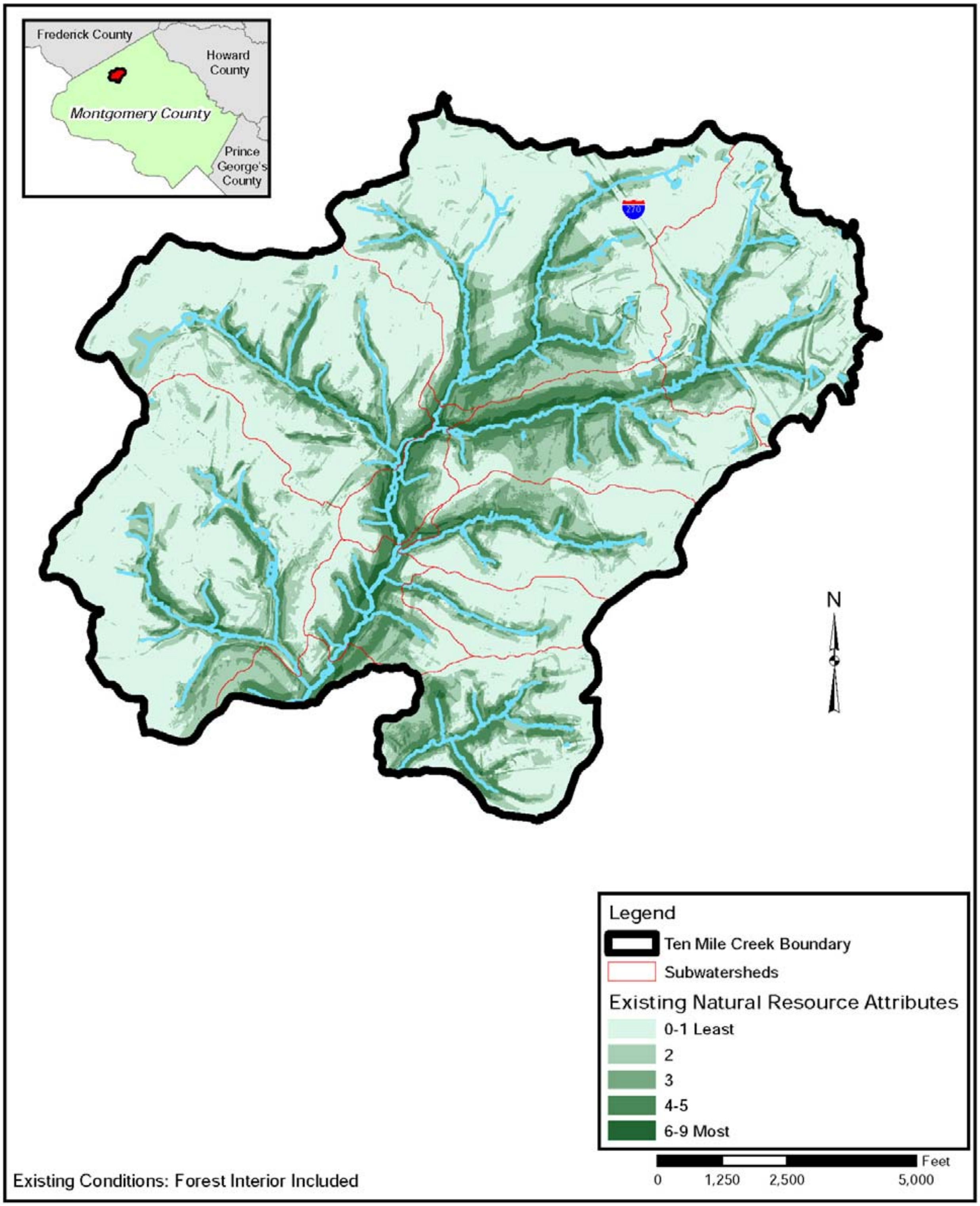

Figure 2. Map of Natural Resources Attribute Scores Grouped into Five Categories, Forest Interior Included

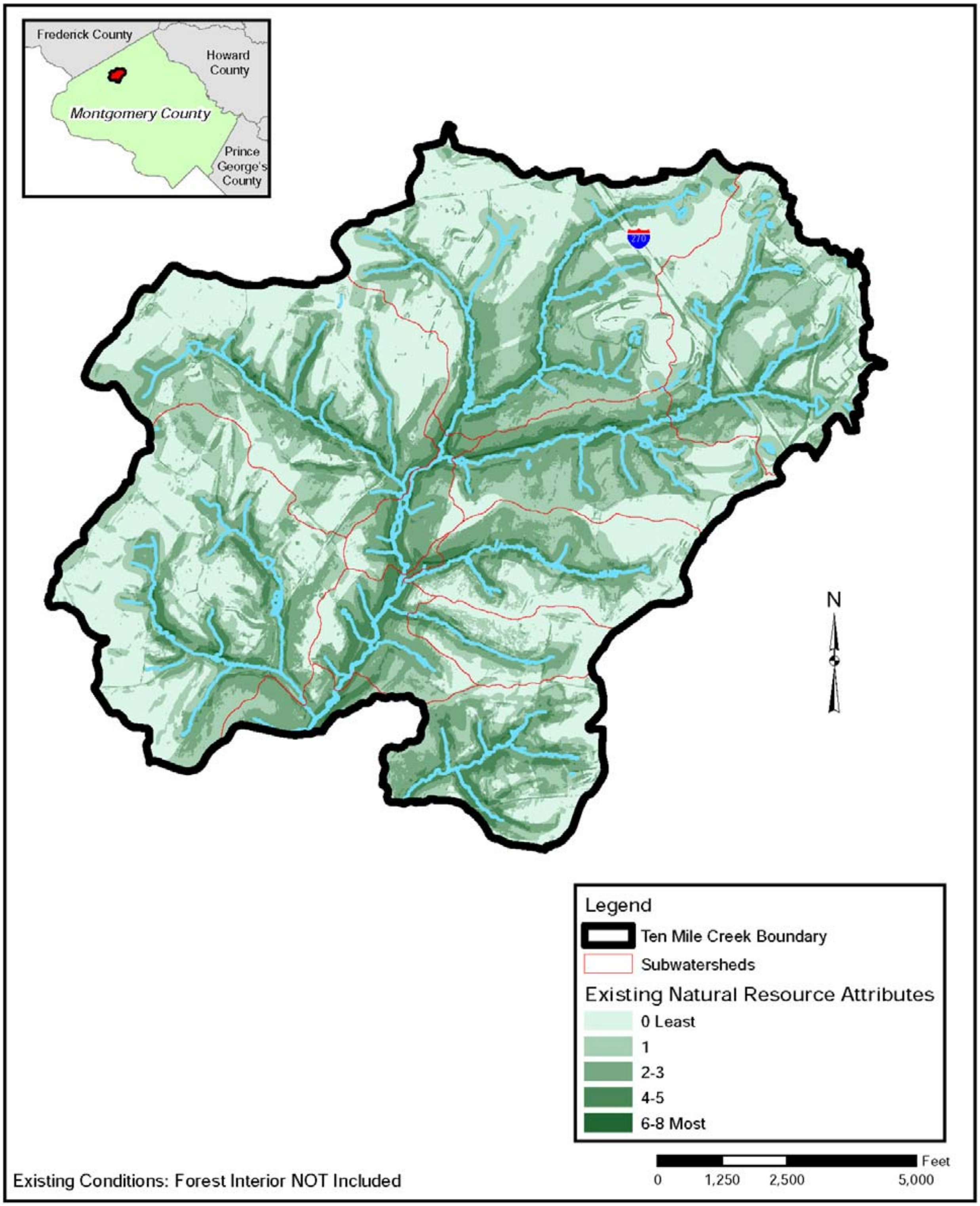

Figure 2a. Map of Natural Resources Attribute Scores Grouped into Five Categories, Forest Interior Not Included

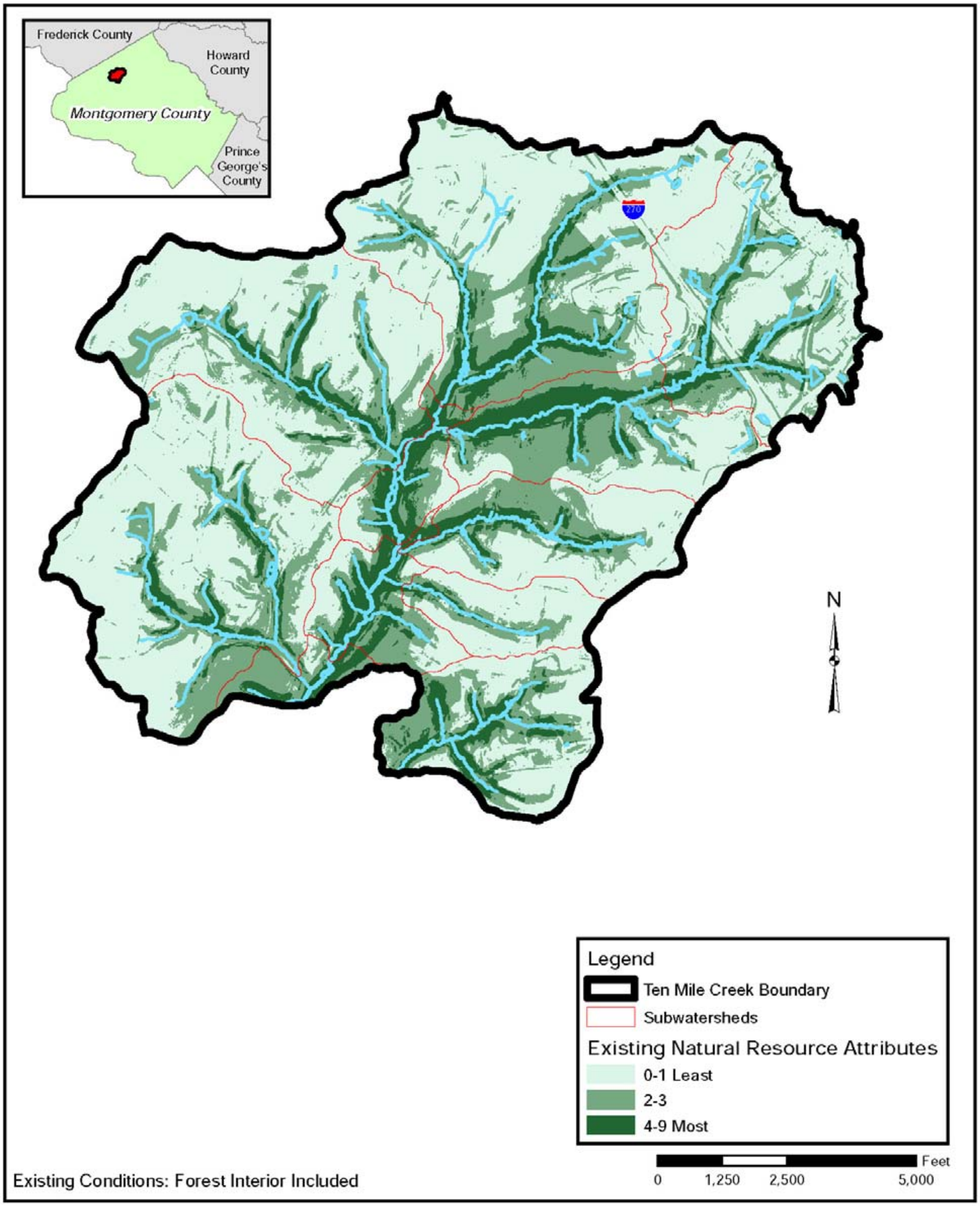

Figure 3. Map of Natural Resources Attribute Scores Grouped into Three Categories, Forest Interior Included

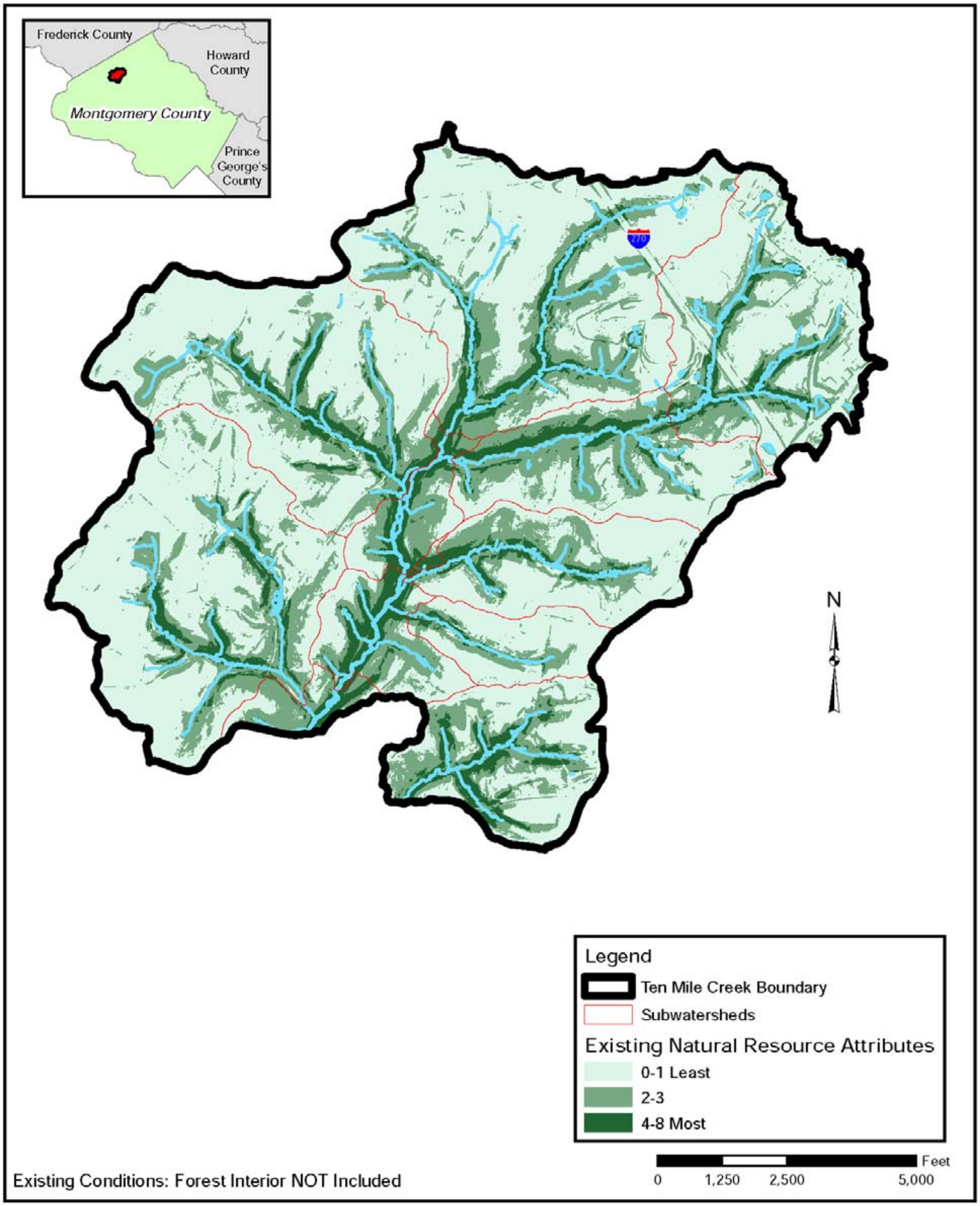

Figure 3a. Map of Natural Resources Attribute Scores Grouped into Three Categories, Forest Interior Not Included

1994 Master Plan Scenario

The Planning Department developed projected limits of disturbance associated with build-out of the 1994 Master Plan. The projected limits of disturbance are approximately 407 acres, or 13% of the Ten Mile Creek study area. These limits of disturbance were overlaid on the existing conditions Spatial Watershed Analysis, with and without the interior forest attribute, to identify extent of potential impacts to natural resources.

No more than seven natural resource attributes were identified at any location within the projected limits of disturbance. Figure 4 through 6 and Tables 5 through 7 display the results of this analysis. As with existing conditions, the composite scores, five categories, and three categories are presented. The darker red areas in the figures have the high numbers of natural resource attributes present that would be impacted by implementation of this 1994 Master Plan scenario.

Table 5. Attribute Areas that will be Impacted by this 1994 Master Plan Scenario

Attribute/Natural Resources Score	With Forest Cover		Without Forest Cover	
	Area (acres)	% of Disturbed Area	Area (acres)	% of Disturbed Area
0	246.3	60%	246.3	60%
1	100.6	25%	111.6	27%
2	41.5	10%	35.2	9%
3	13.3	3%	9.5	2%
4	4.3	1%	3.6	1%
5	11.3	<1%	1.1	<1%
6	0.1	<1%	0.1	<1%
7	<0.1	<1%	<0.1	<1%

Table 6. Attribute Category (Five) Areas that will be Impacted by this 1994 Master Plan Scenario

Attribute Scores/Categories	With Forest Cover		Without Forest Cover	
	Area (acres)	% of Disturbed Area	Area (acres)	% of Disturbed Area
0 to 1	346.9	85%	357.9	88%
2	41.5	10%	35.2	9%
3	13.3	3%	9.5	2%
4	4.3	1%	3.6	1%
5 to 7	1.4	<1%	1.2	<1%

Table 7. Attribute Category (Three) Areas that will be Impacted by this 1994 Master Plan Scenario

Attribute Scores/Categories	With Forest Cover		Without Forest Cover	
	Area (acres)	% of Disturbed Area	Area (acres)	% of Disturbed Area
0 to 1	346.9	85%	357.9	88%
2 to 3	54.8	14%	44.8	11%
4 to 7	5.8	1%	4.8	1%

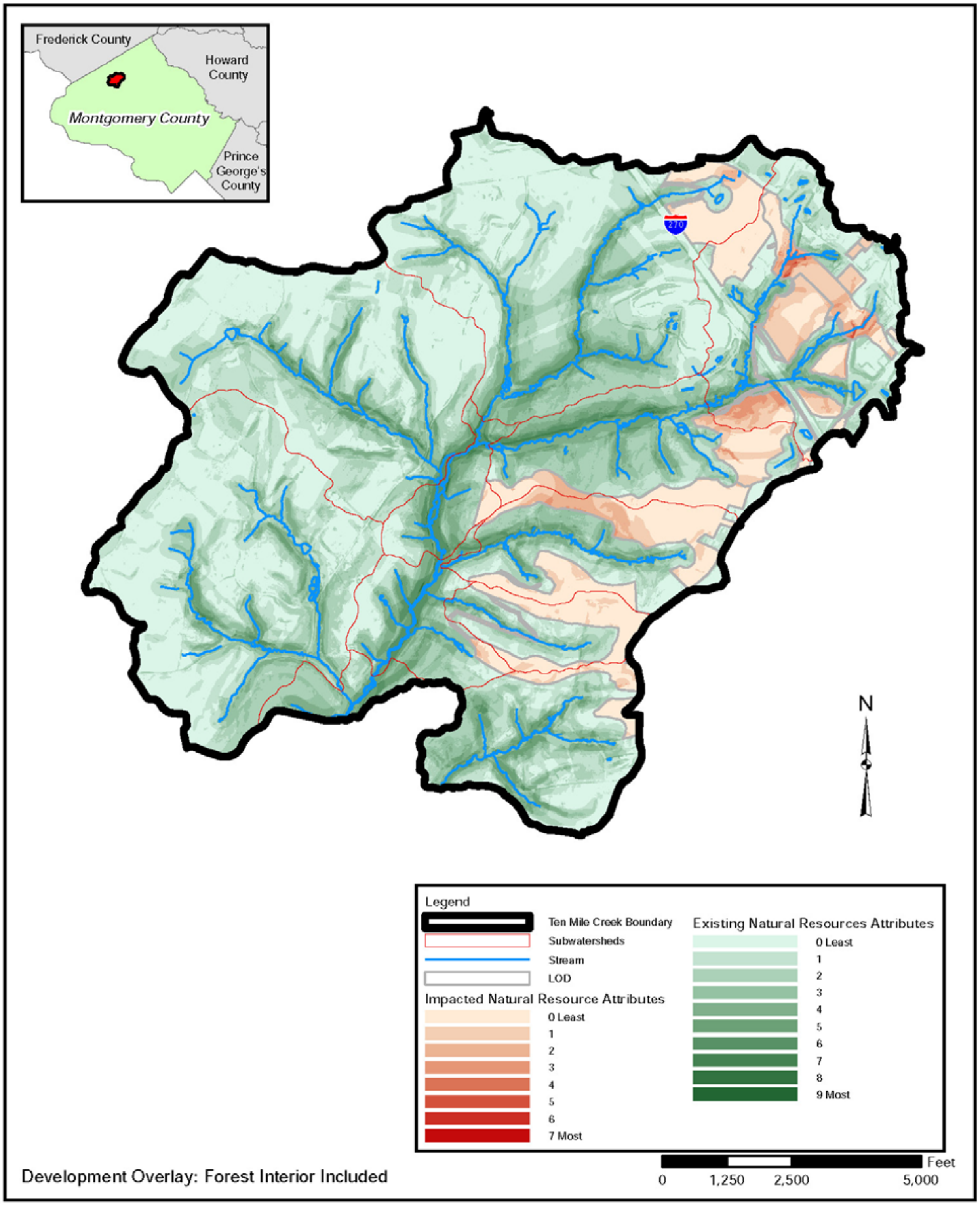

Figure 4. Attribute Areas that will be Impacted by this 1994 Master Plan Scenario, Forest Interior Included

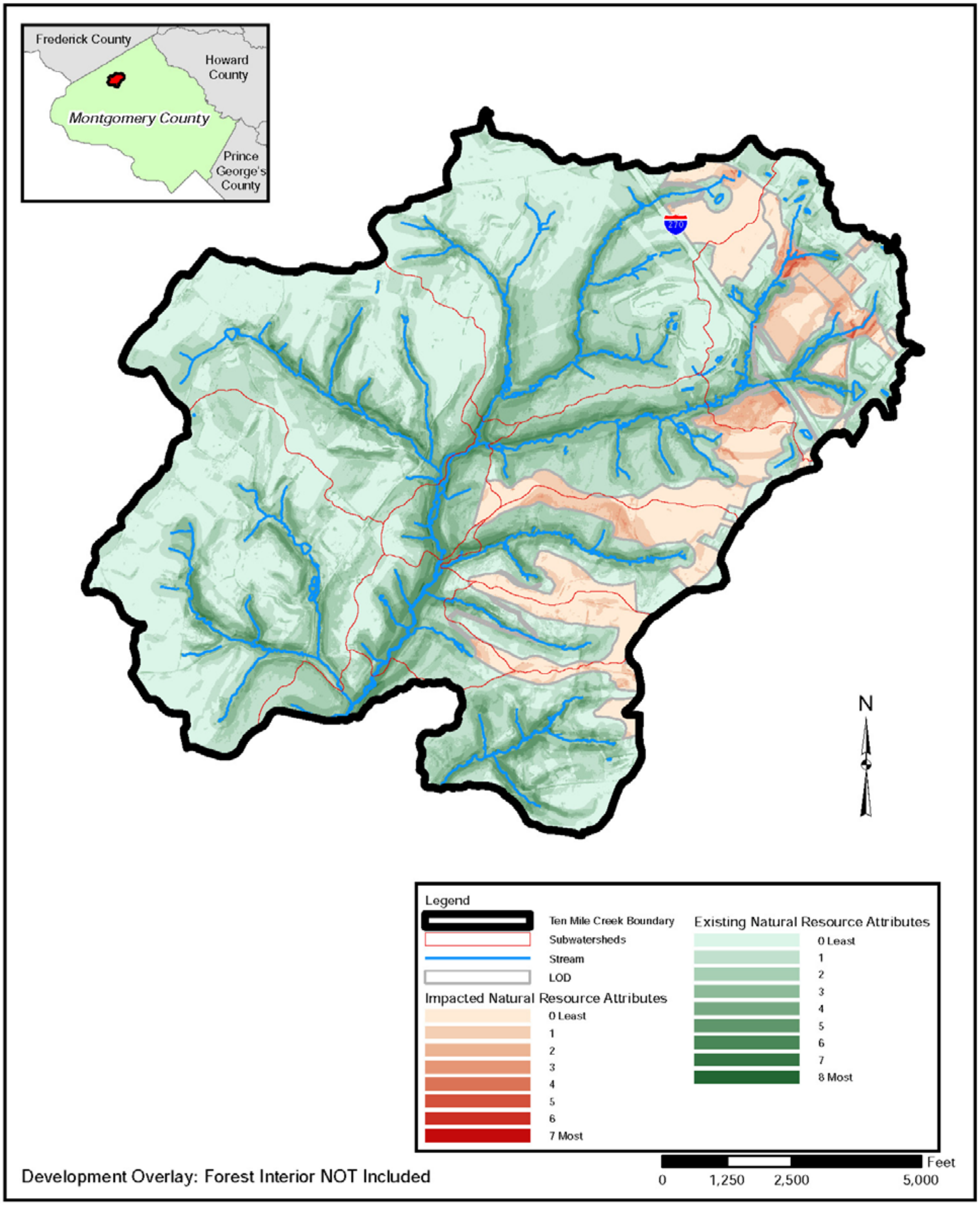

Figure 4b. Attribute Areas that will be Impacted by this 1994 Master Plan Scenario, Forest Interior Not Included

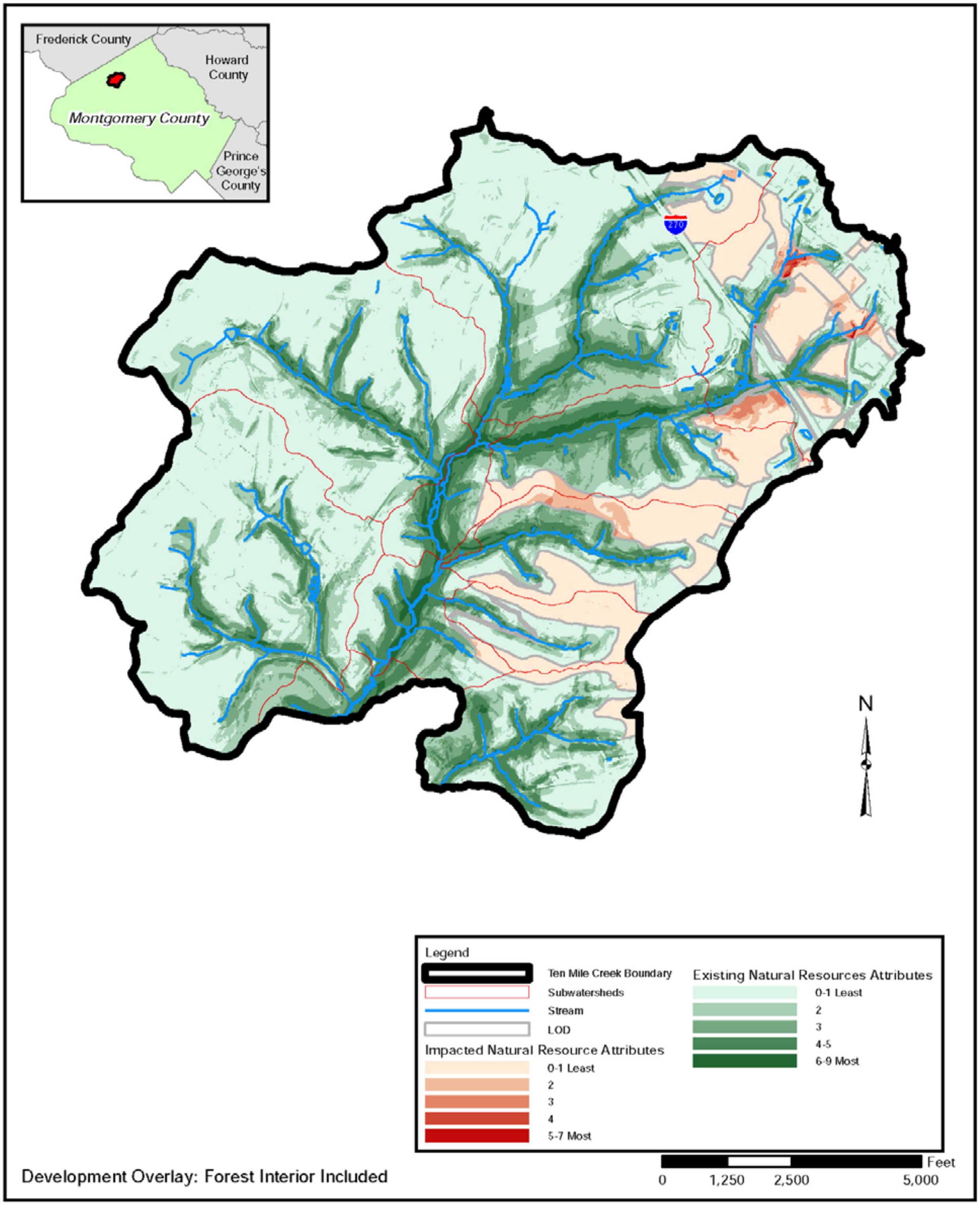

Figure 5. Attribute Category (Five) Areas that will be Impacted by this 1994 Master Plan Scenario, Forest Interior Included

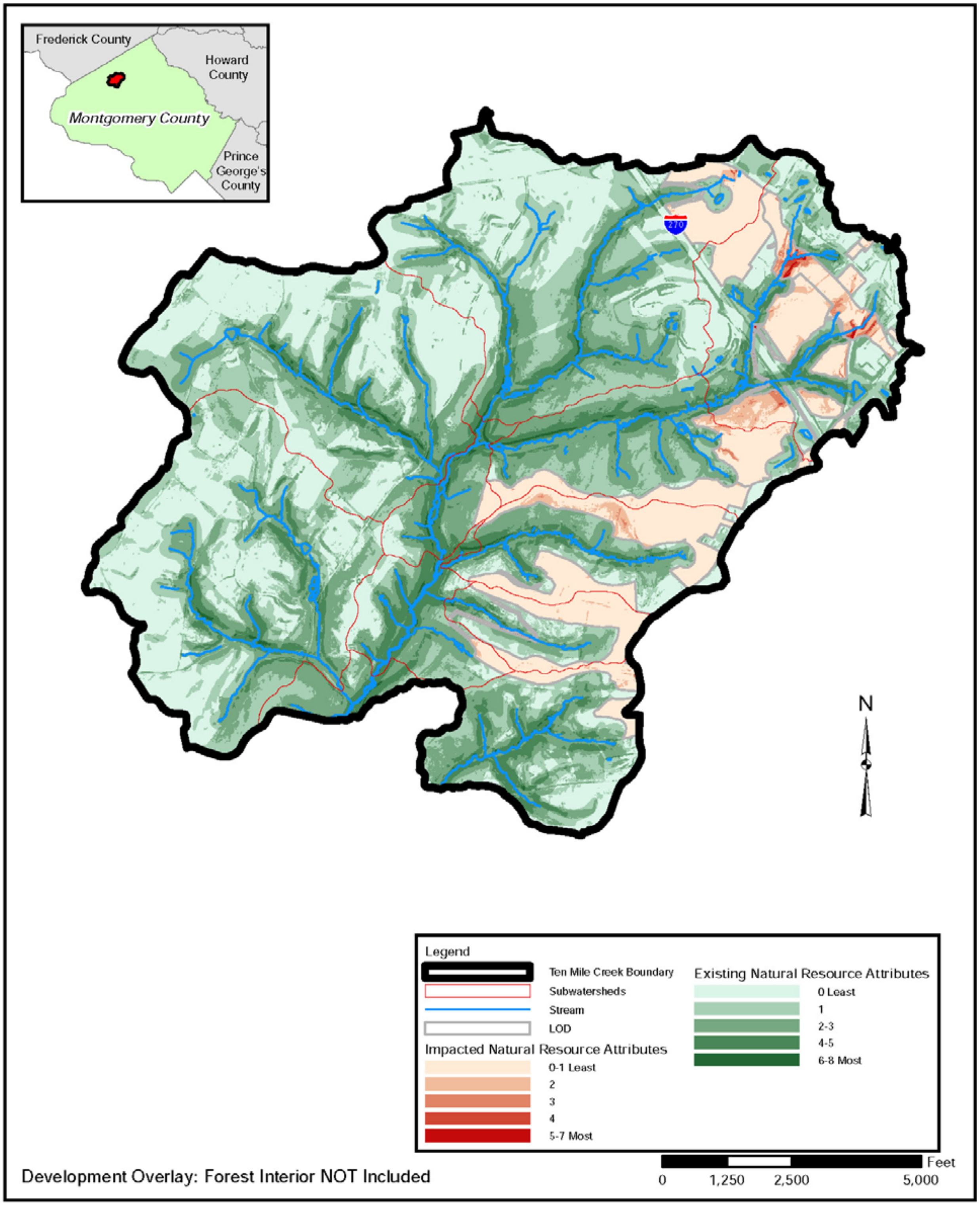

Figure 5b. Attribute Category (Five) Areas that will be Impacted by this 1994 Master Plan Scenario, Forest Interior Not Included

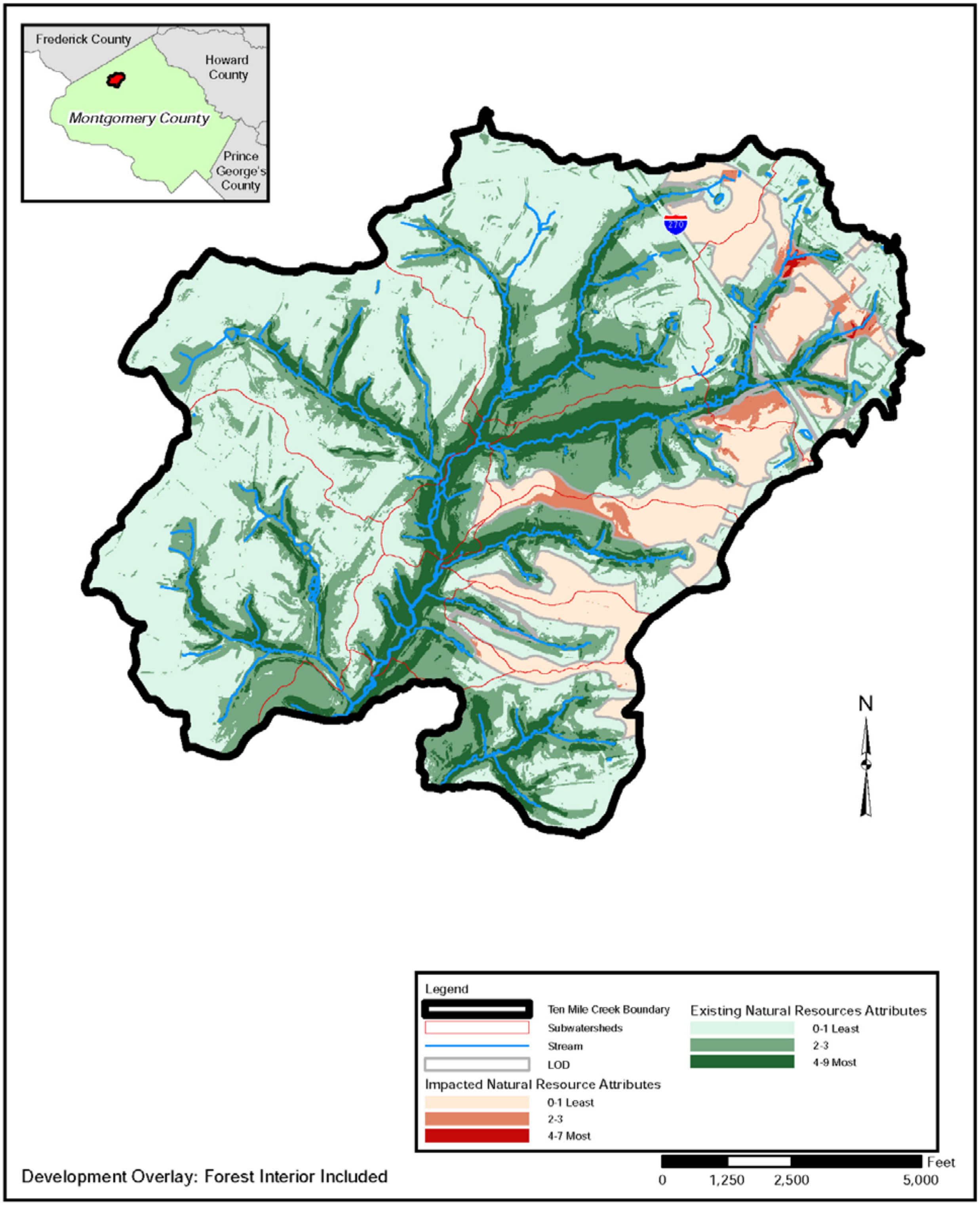

Figure 6. Attribute Category (Three) Areas that will be Impacted by this 1994 Master Plan Scenario, Forest Interior Included

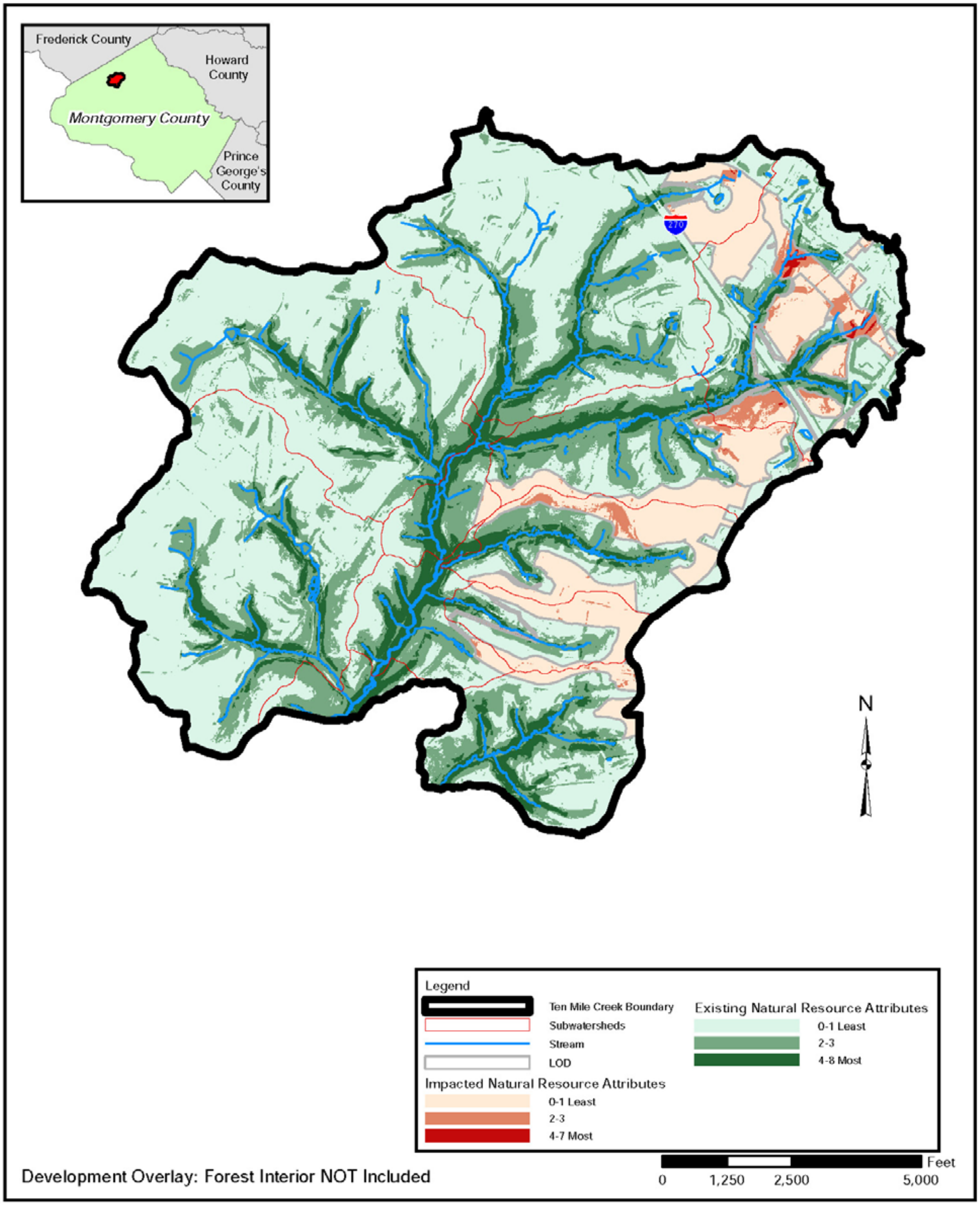

Figure 6b. Attribute Category (Three) Areas that will be Impacted by this 1994 Master Plan Scenario, Forest Interior Not Included

DISCUSSION

Forest Interior Included

From Figure 1 and Table 2 over75% of the total land area in the watershed is located in areas designated as Category 0 (37%), 1 (23%) or 2 (17%). Twenty percent of the total area of the watershed is located in areas designated as Category 3 (11%), Category 4 (7%) or Category 5 (3%). Less than 2% of the watershed is located in areas designated as Category 6-9. Most of that 2% is located in areas designated as Category 6 with the remaining areas designated as Category 7-9 with less than 1% of the total watershed area. More than half the land area is located in Categories 0-1 and more than 75% is located in Categories 0-2. The darker areas corresponding to higher attribute values are concentrated near the streams, reflecting both the importance of streams and their buffer areas to watershed health, and to the abundance of stream-related GIS data used in the analyses relative to the other non-stream attribute data.

Figure 2 condenses the GIS information into 5 categories and the watershed areas of low versus high attribute scores become more distinct from one another. The locations of the areas with attribute scores of 6 or higher become somewhat more clear.

Figure 3 condenses the GIS information into 3 categories. The category with the highest attribute scores, 4-9, is more plainly visible in this figure. This category occupies only 12% of the total watershed, and the location of the higher attribute scores near the stream channels becomes more apparent in this analysis.

The proposed development areas are approximately 407 acres or 13% of the total watershed area (Figures 4-6 and Tables 5-7). The range of attribute scores for the proposed development areas is 0-7. Approximately 60% of the proposed development areas have an attribute score of 0 (60.5%). Approximately 85% of the proposed development areas have an attribute score of 0-1. Approximately 14% of the proposed development areas have an attribute score of 2-3, and just over 1% of the area has an attribute score of 4 or greater.

Alternative Analysis- Forest Interior Not Included

Removing interior forest from the analysis shifts approximately 2% of the land area from Categories 2-3 into Category 1. From Figure 1a and Table 2 over 80% of the total land area in the watershed is located in areas designated as Category 0 (37%), 1 (28%) or 2 (16%). Almost twenty percent of the total area of the watershed is located in areas designated as Category 3 (10%), Category 4 (6%) or Category 5 (3%). Less than 1% of the watershed is located in areas designated as Category 6-7. More than half the land area is located in Categories 0-1 and more than 80% is located in Categories 0-2. The darker areas corresponding to higher attribute values are concentrated near the streams, reflecting both the importance of streams and their buffer areas to watershed health, and to the abundance of stream-related GIS data used in the analyses relative to the other non-stream attribute data.

Figure 2a condenses the GIS information into 5 categories and the watershed areas of low versus high attribute scores become more distinct from one another. The locations of the areas with attribute scores of 6 or higher become somewhat more clear.

Figure 3a condenses the GIS information into 3 categories. The category with the highest attribute scores, 4-8, is more plainly visible in this figure. This category occupies only 10% of the total watershed, and the location of the higher attribute scores near the stream channels becomes more apparent in this analysis.

The proposed development areas are approximately 407 acres or 13% of the total watershed area (Figures 4a-6a and Tables 5-7). The range of attribute scores for the proposed development areas is 0-7. Approximately 60% of the proposed development areas have an attribute score of 0. Approximately 88% of the proposed development areas have an attribute score of 0-1. Approximately 11% of the proposed development areas have an attribute score of 2-4, and only 1% of the area has an attribute score of 4.

The distribution of proposed disturbance within each subwatershed is displayed in Figures 7 and 8.

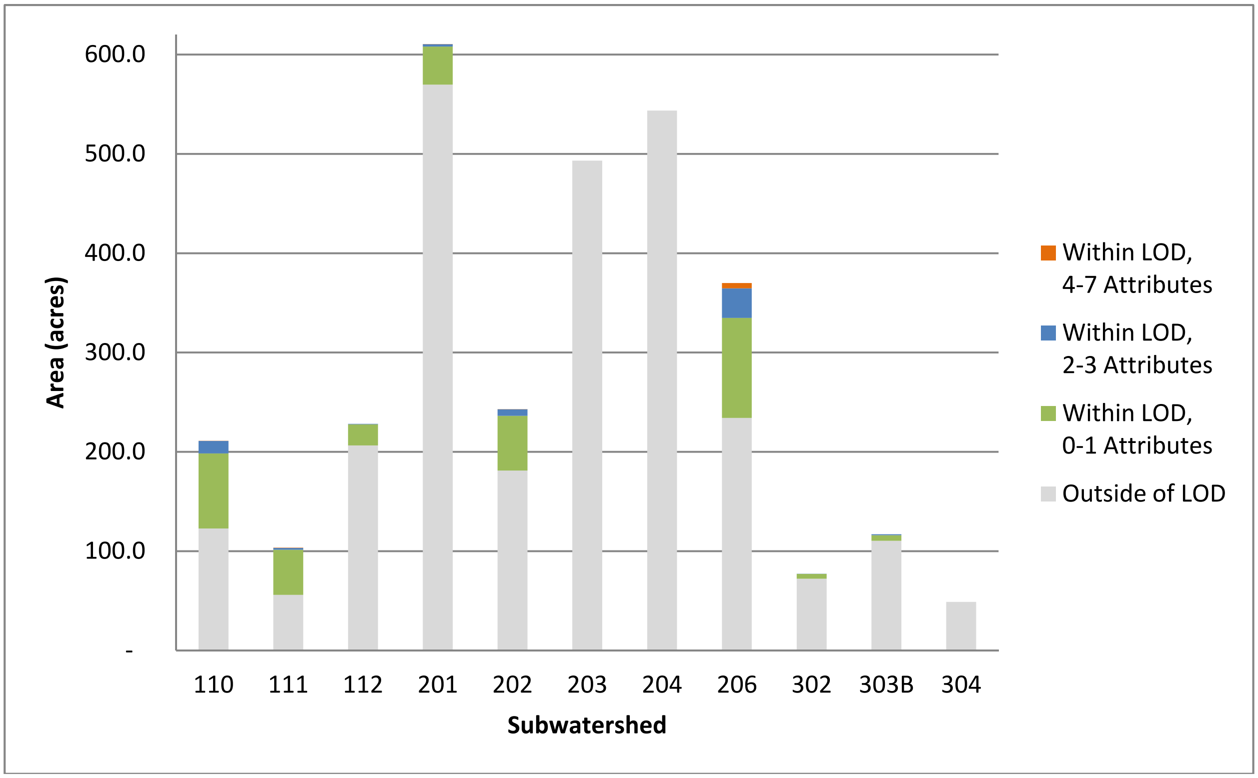

Figure 7. Distribution of Disturbance Across Subwatershed Area, Forest Interior Included

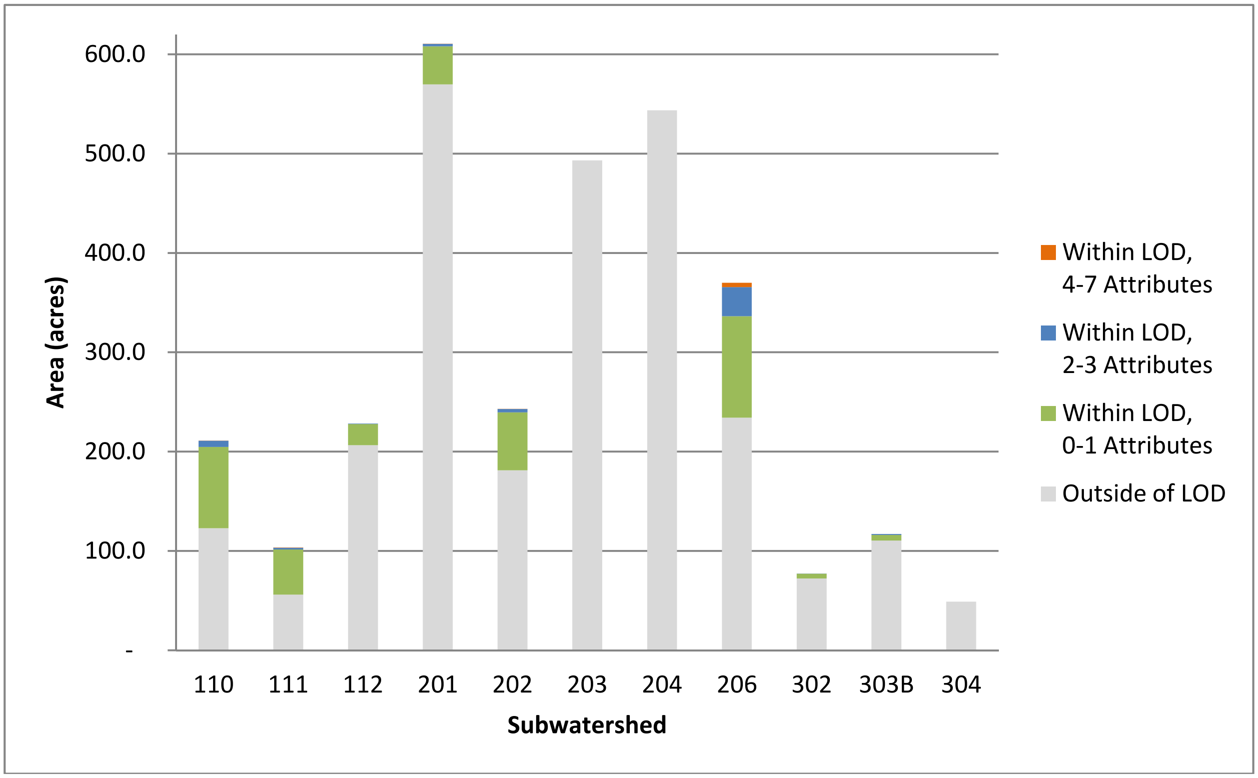

Figure 8. Distribution of Disturbance Across Subwatershed Area, Forest Interior Not Included

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MEMORANDUM – DRAFT

Date: March 15, 2013

To: Mary Dolan and Valdis Lazdins,
Montgomery County Planning Department

From: Center for Watershed Protection

RE: Ten Mile Creek Watershed Environmental Analysis
in Support of the Clarksburg Master Plan Limited Amendment
SUBJ: Pollutant Load Modeling Assumptions

Overview

Pollutant load modeling of Total Nitrogen (TN), Total Phosphorus (TN) and Total Suspended Solids (TSS) and annual runoff volume (in acre-ft) was conducted using the Watershed Treatment Model (WTM; CWP, 2010), a simple spreadsheet model developed by the Center for Watershed Protection. This memo outlines the key assumptions and modifications to the model used to simulate existing and post-developed conditions in the Ten Mile Creek watershed. The WTM use several spreadsheet tabs to summarize loads and practices, and the following tabs were used for this modeling exercise:

- Primary Sources: Summarizes pollutant loads from stormwater runoff that can be described by land characteristics alone.
- Secondary Sources: Describes other sources of pollution, such as septic system loads and channel erosion.
- Existing Management Practices: Describes both the structural, non-structural and programmatic practices in place within the watershed.
- Retrofit Worksheet: A worksheet used to enter individual stormwater management practices. This was originally intended to model stormwater retrofit practices, but is used to simulate all stormwater management practices for the modeling in Ten Mile Run.
- Loads to Groundwater: This is not a separate section of the WTM, but was calculated separately for this project.

Primary Sources

Key inputs for this tab include annual rainfall, runoff coefficients, stormwater pollutant concentrations and annual pollutant loading rates.

Annual Rainfall

Annual rainfall was assumed to be 40.4 inches per year (source: http://www.weather.com/weather/wxclimatology/monthly/USMD0093).

Soils

In the WTM, soils are aggregated on a subwatershed basis, by Hydrologic Soil Group (HSG), as determined from GIS data available from the Montgomery County Department of Planning.

Land Use Categories

Land uses provided by the Montgomery County Planning Department were grouped into broader land use classifications for some of the analyses described here. These are summarized in Table 1.

Table 1. Land Use Classification

Classification	Land Use Categories Included
Residential	Low-Density Residential Medium-Density Residential High-Density Residential
Commercial	Commercial Industrial
Transportation	Transportation
Municipal	Open Urban Land Institutional
Rural	Cropland Pasture Large-Lot Subdivision – Agriculture Large-Lot Subdivision - Forest
Forest	Deciduous Forest Evergreen Forest Wetlands – Forested Wetlands - Nonforested Mixed Forest Brush
Bare Ground	Bare Ground

Runoff Coefficients

Runoff coefficients for turf, forest, and impervious cover used WTM defaults, and it was assumed that cropland had the same runoff coefficients as turf and pasture has the same runoff coefficients as forest. The resulting runoff coefficients are presented in Table 2.

Table 2. Runoff Coefficients for Land Cover Types

Hydrologic Soil Group	Impervious	Turf	Forest	Pasture	Bare Ground	Cropland	Large Lot Subdivision - Agriculture	Large Lot Subdivision - Forest
A	.95	.15	.02	.02	.5	.15	.02	.02
B	.95	.20	.03	.03	.5	.20	.03	.03
C	.95	.22	.04	.04	.5	.22	.04	.04
D	.95	.25	.05	.05	.5	.25	.05	.05

The runoff coefficient for each land use category was determined by intersecting land cover, impervious cover and forest cover layers. In urban land use categories, all land cover that was not classified as forest or impervious cover was assumed to be turf.

Pollutant Concentrations

For urban land uses, pollutant loads are calculated by multiplying a runoff concentration by an annual runoff volume. Concentrations were taken from Pitt et al. (2004), which summarized NPDES monitoring data in the northeastern United States. Concentrations are included in Table 3.

Table 3. Urban Runoff Pollutant Concentrations (mg/l)

	TN	TP	TSS
Residential	2	0.3	59
Commercial	2.1	0.26	73
Transportation	2.3	0.3	53
Municipal	1.8	0.22	18

Annual Loading Rates

Pollutant loading from non-urban land is estimated as an annual load in pounds per acre. Loads for TN and TP were taken from the Chesapeake Bay Program Phase 5.3 Model Documemntation (US EPA, 2010; Table 4). For TSS, the edge of field loads from this documentation (also Table 5.3) were multiplied by a delivery ratio based on watershed size, also used in the Bay Model, as defined by the following equation:

$$DR = .417762 \bullet A^{-0.134958} - 0.127097$$

Where:

DR = Sediment Delivery Ratio
A = Watershed Area (square miles)

Loads from Large Lot Subdivision (both Large Lot Subdivision – Agriculture and Large Lot Subdivision – Forest), were calculated as an area-weighted average of Pasture and Forest loads, depending on the forest cover in that land use category, such that:

$$LR_{LLS} = (f)(LR_F) + (1-f)(LR_P)$$

Where:

$LR_{LLS,F,P}$ = Loading Rates from Large Lot Subdivision, Forest, and Pasture, respectively
f = Fraction of LLS land use in forest cover

Table4. Annual Pollutant Loading from Rural Land

	TN (lb/year)	TP (lb/year)	Erosion (tons/acre/year)
Cropland	23.4	1.02	4.7
Pasture	7.3	0.94	1.2
Forest	3.6	0.14	0.36
Bare Ground	29.5	9.7	24.4

Notes:
1: Cropland is an average of values for "Hay with Nutrient Management" and "Conservation Tillage with Nutrient Management"
2: Pasture is the value for "Pasture with Nutrient Management"

Secondary Sources

In the WTM, Secondary Sources include point sources or other pollutant loads that cannot be determined solely based on land use. In this phase of modeling, septic systems were the only secondary sources accounted for. Illicit discharges and SSOs may be significant sources of nutrients, but insufficient data were available to adequately model these sources at this time.

Septic Systems (On-Site Sewage Disposal Systems)

Septic systems were modeled using WTM defaults, and with the following assumptions:

1) Septic system efficiency is equivalent to conventional septic systems.

2) Depth to ground water is greater than 5 feet.

3) Septic system density is less than one system per acre

4) Septic systems are applied on clay or mixed texture soils (i.e., not sandy soils)

5) Maintenance is average

Existing Management Practices

In this model run, turf management was the only management practice modeled. The WTM estimates loads from turf based on nutrient application rates and fertilizer mixture. It was assumed that fertilizer was applied 1.1 times per year, at 150 lbs of N per acre, and that the fertilizer was a phosphorus-free product. The WTM adjusts turf runoff coefficient and loading rates based on other characteristics of urban land. In the future conditions, it is assumed that turf on all new properties is compacted and "on homes <5 years old."

Stormwater Retrofit Worksheet

Although this sheet of the WTM was originally intended for implementing individual retrofit practices, it is used, and slightly customized) in this modeling exercise as it allows for flexibility in accounting for design variations of individual practices. The following modifications were made to the default WTM spreadsheet:

Loads to the Practice

In the WTM, loads to each practice are estimated using an average concentration for urban land. For this modeling effort, the loads were instead determined using concentrations specific to the land use on which the practice is applied. For example, the load to a practice applied on residential land will be calculated using the concentrations for residential land.

In the existing (but not future) condition, the impervious cover draining to the practice was unknown. As a result, the average impervious cover for the land use that the practice treated was typically applied. There were three exceptions to this rule, including the following: 1) Dry wells applied on residential land were assumed to treat rooftop (100% impervious); 2) Practices that are note to treat "Roadway" or "Parking Lot" are assigned 100% impervious cover, regardless of the land use. 3) One large pond was designed to treat "Clarksburg Detention Facility." For this practice, the impervious cover was estimated from aerial photography at 40%.

For future conditions, the impervious cover within each land parcel is provided, and assumed to be consistent across subwatersheds.

Practice Efficiencies

To be consistent with previous work completed for Montgomery County, practice efficiencies were determined from values reported in Schueler and Lane (2012) and Hirschman et al. (2008), as follows:

Table 5. Efficiencies for Urban BMPs (%)
(Schueler and Lane, 2012 and Runoff Reduction from Hirschman et al., 2008)

	TN	TP	TSS	Runoff Reduction
Dry Water Quantity Pond	5%	10%	10%	0%
Dry Extended Detention Pond	20%	20%	60%	15% (A/B Soils only)
Wet Pond or Wetland	20%	45%	60%	0%
Filters	40%	60%	80%	0%
Infiltration Practices	80%	85%	95%	90% (A/B soils) 50% (C/D Soils)
Bioretention A/B Soils	80%	85%	95%	80%
Bioretention C/D Soils	25%	45%	55%	40%

In this iteration, Environmental Site Design (ESD) is modeled as Bioretention, applied on the entire site.

Dominant Soil Types

In the WTM, a dominant soil type is assigned to each stormwater BMP's drainage area. In the existing conditions, all stormwater BMPs were in watersheds dominated by B soils, so B soils were assigned to each practice. In the future conditions, it was assumed that soil compaction during the initial phases of development. As a result, the dominant soil type for most properties was C soils. One exception was the New Pulte (4) property which was dominated by D soils.

Capture Discount

Since practices do not capture the volume of stormwater runoff for all runoff events, enlarging or undersizing a practice affects its overall pollutant capture. The data presented in Table 5 are based on capture of the runoff from a 1" storm event, with undersized practices providing less annual pollutant removal, and larger practices providing improved removal rates. The Capture discount is multiplied by the efficiencies presented in Table 5 to determine actual pollutant removals.

$$CC = 10^{\wedge 0.277*\mathrm{Log}(P_{\mathrm{Capture}})}$$

Where:

CC = Capture Discount
P_{capture} = Rainfall event captured by the stormwater BMP (inches)

Existing Conditions

In the existing conditions, practice sizing data were unavailable, so it was assumed that practices were sized to treat the 1" storm event (i.e., 1 CC value of 1.0)

Future Conditions

In the future condition, practices are sized using tables provided in the Maryland Department of the Environment's (MDE's) Stormwater Management Design Manual , using the tables in Chapter 5. Practice sizing was based on the soil type within each property/watershed intersection (in the current condition) as well as the impervious cover forecast for the property. Resulting practice sizing is presented in Table 6.

Table 6. Sizing for Proposed Development Sites

Property/ Development Scenario	Impervious Cover	Soil Types (existing)	Target Precipitation Event (inches)
Egan Mattlyn Load	50%	B/C	1.8
Fire Station	37%	B	1.8
Hammer Hill	30%	B	1.6
MD 355 Load	100%	B/C	2.6
MD121 Interchange	30%	B/C	1.6
Miles Coppola Alone	60%	B/C	2
NewPulte_Load	33%	B/C	1.8
NewPulte_Load 4	42%	B/C	1.8

Subsurface Loads

The WTM is not a groundwater model, but does model supplemental loads to groundwater from three sources: 1) septic systems; 2) leaching urban lawns; and 3) infiltration from stormwater management practices. While the loads from rural land are assumed to include all pathways to the stream (i.e., they represent an in-stream load), loads from urban land in the base calculations only include surface runoff. The loads calculated by the WTM assume some filtration by underlying soils, so that subsurface phosphorus and sediment loads are modeled as 0 lbs/year. However, nitrogen is more mobile. It is assumed that 40% of all loads to groundwater reach the stream. This is the same assumption made for Edge of Stream loads in the Chesapeake Phase 5.3 model (US EPA, 2010).

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MEMORANDUM – DRAFT

Date: March 15, 2013

To: Mary Dolan and Valdis Lazdins,
Montgomery County Planning Department

From: Center for Watershed Protection

RE: Ten Mile Creek Watershed Environmental Analysis
in Support of the Clarksburg Master Plan Limited Amendment
SUBJ: Pollutant Load Modeling Results

Modeling Scenarios

Water quality can be impacted by land development, both during the development process, and in the post-developed condition. Annual pollutant loading was assessed using the Watershed Treatment Model (CWP, 2010- a simple spreadsheet model that calculates annual runoff volume as well as pollutant loads for Nitrogen (TN), Phosphorus (TP) and Sediment (TSS). Three scenarios were analyzed. The "base conditions" scenario represents conditions as they are before implementation of the Master Plan. The "post construction" scenario models the 1994 Master Plan with the implementation of Environmental Site Design (ESD) ESD. Finally, the "during construction" scenario is similar to the post construction scenario, but assumes that construction occurs over ten construction seasons, so that 10% of the developable land is in active construction, and additional fertilizer is applied to establish new lawns. The water quality modeling also reflects conversion of 36 septic systems to sewer. Results include annual runoff volume, as well as annual runoff loads for TN, TP and TSS.

A detailed description of the modeling assumptions are provided under separate cover (See "WTM Model Assumptions"). However, a few of these assumptions, especially those regarding ESD implementation, are useful for understanding the modeling results. Environmental Site Design (ESD) has the goal of achieving the hydrology of "Woods in Good Condition" for the one year storm event in Maryland. In the Maryland Stormwater Design Manual (The Stormwater Manual), this is goal is presumed to be achieved by assigning a "Target Rainfall" event depending on the post-construction condition and requiring that the runoff from this rainfall event be captured in an ESD practice. For this modeling exercise, it is assumed that ESD implementation includes the following:

1) Designers select a target rainfall event from look-up tables in the Maryland Stormwater Design Manual (Stormwater Manual; MDE, 2010). (This target event ranges between 1.0" and 2.6" for the sites modeled).
2) The volume captured by stormwater practices is calculated using the "Short Cut Sizing" methodology described in the Stormwater Manual, which sizes stormwater practices based solely on the impervious cover in the area draining to the practice.
3) During construction, soils are compacted so that the runoff from urban soils is slightly elevated.
4) ESD practices are represented by bioretention with an underdrain. This practice reduces the annual runoff volume by 40%.

Stream channel erosion is not modeled, since insufficient data were available to adequately model this source. It is important to note, however, that channel erosion can be a significant source of sediment in urban streams, representing up to 2/3 of the sediment load (Cronin and Langland, 2003).

Watershed-Wide Pollutant Load

Watershed-wide, pollutant loads for nutrients (Nitrogen and Phosphorus) increase during construction, and decrease to slightly above pre-developed rates in the post-developed condition (Figure 1). Annual runoff volume increases during construction and continues to have a significant increase in the post-developed condition. This result at first seems counterintuitive, since the goal of ESD generate hydrology equivalent to “woods in good condition,” which should result in less annual runoff volume than the cropland currently present in much of the land to be developed. However, sizing using the Short Cut Method defined in the Stormwater Manual, combined with the impacts of soil compaction, may lead to practices sized below the necessary volume needed to achieve the goal of producing hydrology equivalent to woods in good condition. In addition, many of the practices that qualify as “ESD Practices” in the Manual do not actually achieve 100% runoff reduction, and the practice selected for this modeling exercise typically reduces runoff by 40%.

As described in the next section of this memorandum, the apparent decrease in TSS can be explained by the agricultural uses dominant in much of the watershed. This TSS calculation may under represent TSS, however, since TSS calculations do not include channel erosion, which may increase as the watershed urbanizes, both due to increased runoff volume and decrease in sediment sources to the stream channel (by converting cropland) in the watershed.

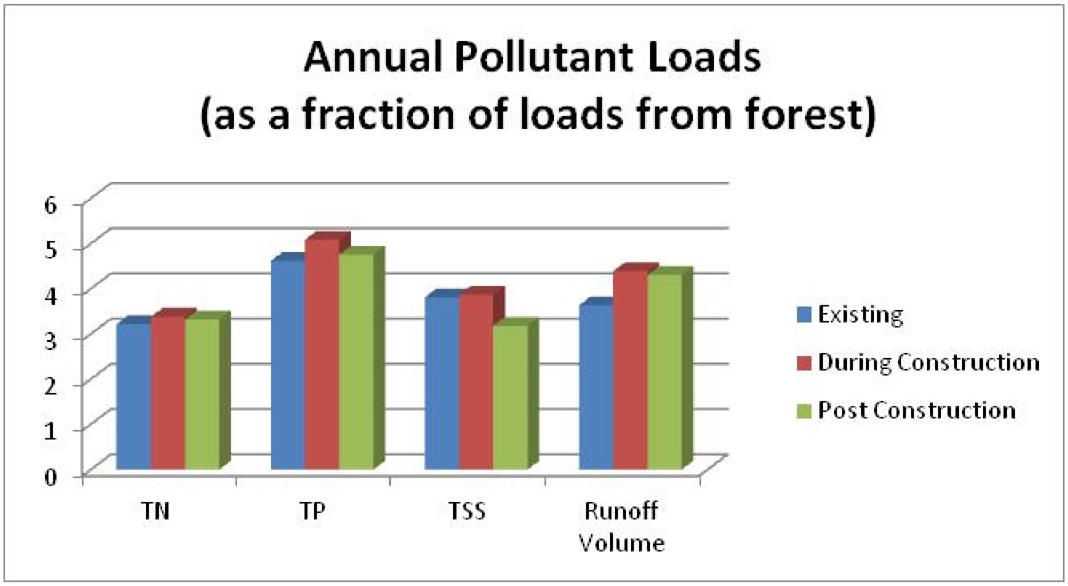


Figure 1. Comparative Pollutant Loads Throughout the Development Process

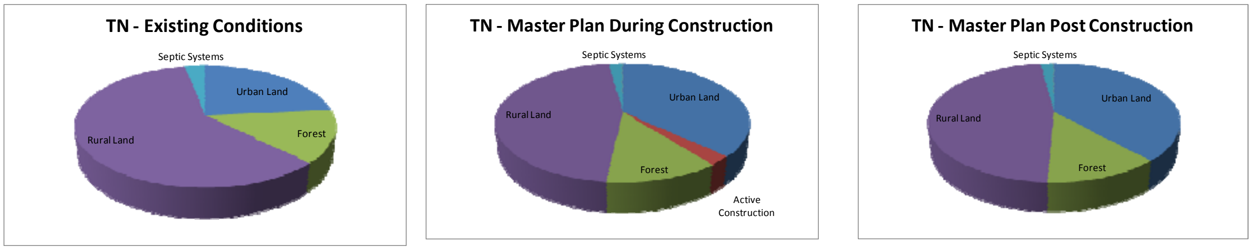
Sources of Pollutants

In the current conditions, the watershed is dominated by rural land and forest cover, with urban land comprising 15% of the total watershed area, increasing to 25% in the post-construction conditions (Figure 2). This increase in urban land is achieved be converting both rural and forested land, so that these land uses decrease by 7% and 3%, respectively.

Each of the land uses represented in Figure 2 generates pollutants and runoff at different relative rates (Figures 2-6). For example, forested land results in the lowest pollutant export of all land uses, comprising 45% of the land cover but no more than 15% of any pollutant in the existing conditions (Figures 2-6). Rural land, urban land, and active construction, on the other hand, generate relatively high pollutant loads or runoff volumes, depending on the pollutant. Rural land generates disproportionate amounts of all pollutants, as well as runoff volume, in all phases of development with one exception. In the post-developed condition, rural land generates runoff almost exactly equal to its land cover in the watershed (i.e., 33% urban land generating 34% of total runoff volume). Urban land produces disproportionate amounts of pollutants with the exception of TSS, which is dominated by rural land in all phases of development. Active construction is only present in a small fraction of the watershed (2.5%), but disproportionately contributes to runoff volume (5%), and pollutant loads of TP (13%) and TSS (18%).

In general, pollutants with the greatest increase are those where urban land is a relatively high pollutant source. For example, runoff is generated primarily by urban land, and runoff volume shows a significant increase. By contrast, TSS (excluding loads from channel erosion) actually decreases as development proceeds, and rural land is the dominant sediment source in all phases of development.

Figure 2. Land Use: Current, During Construction and Post Construction

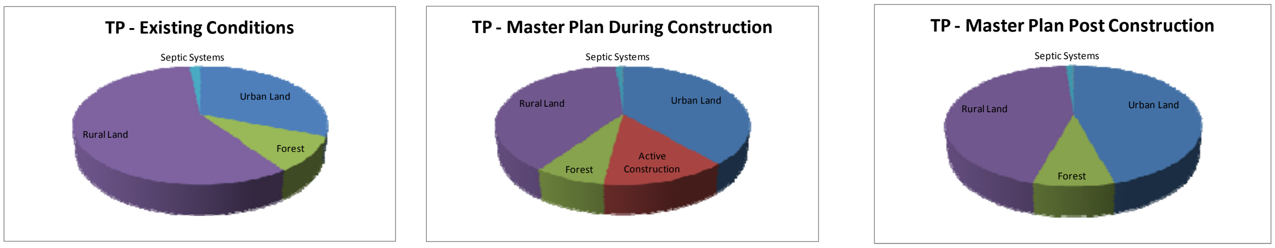


TN - Existing Conditions

TN - Master Plan During Construction

TN - Master Plan Post Construction

Figure 3. TN Sources: Current, During Construction and Post Construction

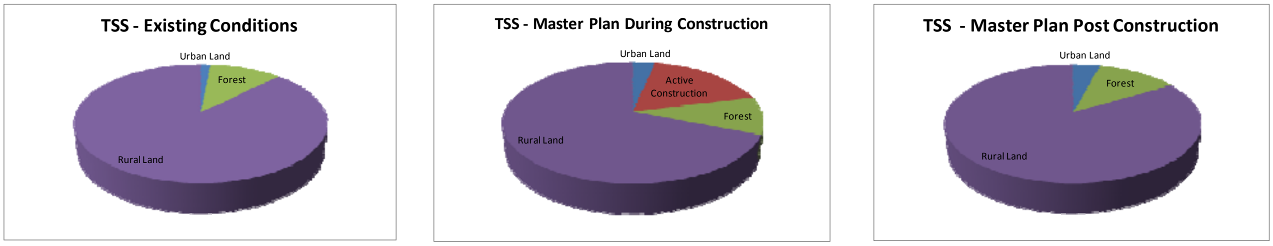


TP - Existing Conditions

TP - Master Plan During Construction

TP - Master Plan Post Construction

Figure 4. TP Sources: Current, During Construction and Post Construction

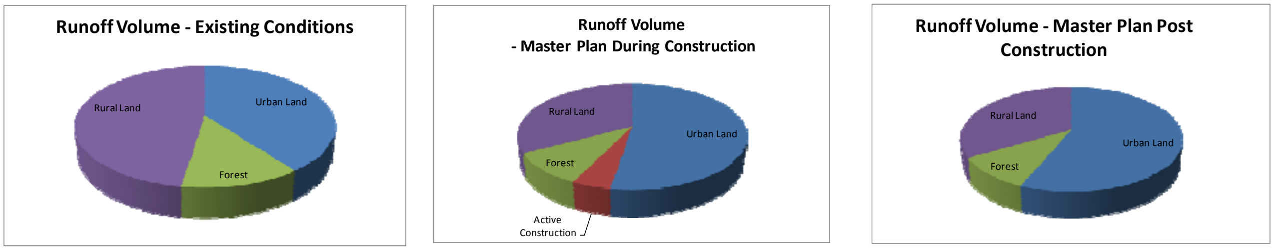


TSS - Existing Conditions

TSS - Master Plan During Construction

TSS - Master Plan Post Construction

Figure 5. Sediment Sources: Current, During Construction and Post Construction



Runoff Volume - Existing Conditions

Runoff Volume - Master Plan During Construction

Runoff Volume - Master Plan Post Construction

Figure 6. Sources of Runoff Volume: Current, During Construction and Post Construction

Pollutant Load by Subwatershed

Response to development is not uniform across the watershed (Tables 1-4), and is also pollutant-specific. For example, subwatershed LSTM 206 has the largest increase in TSS during construction (76%), but only a modest (7%) increase in total phosphorus. In addition, subwatersheds that are highly impacted during construction can have relatively low post-construction loads. For example, even though LSTM 206 showed a tremendous increase in sediment loads during construction, the sediment loads from this subwatershed in the post-developed condition are actually 35% lower than existing conditions.

Total Nitrogen

Total nitrogen increases moderately throughout the construction process in the watershed as a whole, with dramatically different results by subwatershed. LSTM 202 shows a significant decline in TN, while LSTM 206, 302 and 302B have increases of greater than 10%. This difference is primarily explained by the fact that land conversion in LSTM 202 is primarily from cropland to urban land, and cropland has a very high nitrogen loading rate. In contrast, land in LSTM 206, 302 and 303B is converted primarily from forest and pasture land. During construction, the loads are slightly higher than post-construction loads in all subwatersheds.

Table 1. Annual Load - Total Nitrogen (lb/year)

Subwatershed	Existing Conditions	1994 Masterplan (during construction)	Change (%)	1994 Masterplan (After Construction)	Change (%)
LSTM 110	2,406	2,786	16%	2,516	5%
LSTM 111	1,327	1,469	11%	1,322	0%
LSTM 112	2,902	2,862	-1%	2,866	-1%
LSTM 201	6,955	7,443	7%	7,301	5%
LSTM 202	2,370	1,941	-18%	1,820	-23%
LSTM 203	6,083	6,083	0%	6,083	0%
LSTM 204	7,928	7,928	0%	7,928	0%
LSTM 206	4,079	5,160	27%	5,159	26%
LSTM 302	364	436	20%	426	17%
LSTM 303B	637	732	15%	725	14%
LSTM 304	179	179	0%	179	0%
Watershed	**35,229**	**37,019**	**5%**	**36,326**	**3%**

Total Phosphorus

While the magnitude of the loads and the percent change are slightly different for phosphorus than for nitrogen, the patterns are generally the same (i.e., the subwatersheds with significant increases or decreases in nitrogen tend to have similar changes for phosphorus), with one exception. In LSTM 303B, the increase in phosphorus (3%), is much lower than the 14% increase in nitrogen in the same subwatershed. In this subwatershed, development is located primarily on pasture land which has a very low nitrogen load, but a phosphorus load similar to cropland. Loads for phosphorus are much higher during construction.

Table 2. Annual Load - Total Phosphorus (lb/year)

Subwatershed	Existing Conditions	1994 Masterplan (during construction)	Change (%)	1994 Masterplan (After Construction)	Change (%)
LSTM 110	137	220	60%	144	5%
LSTM 111	88	128	45%	87	-1%
LSTM 112	147	158	8%	147	1%
LSTM 201	351	390	11%	354	1%
LSTM 202	128	129	1%	100	-22%
LSTM 203	346	346	0%	346	0%
LSTM 204	427	427	0%	427	0%
LSTM 206	308	428	39%	368	19%
LSTM 302	16	28	75%	21	27%
LSTM 303B	137	220	60%	144	5%
LSTM 304	8	8	0%	8	0%
Watershed	**1,991**	**2,304**	**16%**	**2,038**	**2%**

Total Sediment

Sediment loads decrease uniformly after construction, except in undisturbed watersheds. This is because sediment loads from urban land are much lower than those from most pre-developed land uses, with the exception of forest. Sediment loads are much higher during construction, with the sediment load increasing, on average, about 2% during the construction period. Some subwatersheds experience a dramatic increase during construction, and at the same time have an extreme decrease after construction. For example, subwatershed LSTM 206 has a 76% increase during construction, but a 35% decrease after construction. This result occurs because sediment loads from construction are much higher than any rural land, while loads from developed land are much lower. Consequently, subwatersheds with a large area of disturbance will experience a dramatic increase during construction, followed by a much lower post-construction load. It is important to note that these modeled loads do not include channel erosion.

Table 3. Annual Load - Total Sediment (lb/year)

Subwatershed	Existing Conditions	1994 Masterplan (during construction)	Change (%)	1994 Masterplan (After Construction)	Change (%)
LSTM 110	258,706	258,850	0%	106,872	-59%
LSTM 111	198,599	170,314	-14%	76,908	-61%
LSTM 112	327,212	286,048	-13%	264,780	-19%
LSTM 201	545,924	580,117	6%	522,271	-4%
LSTM 202	154,454	139,261	-10%	78,496	-49%
LSTM 203	570,708	570,708	0%	570,708	0%
LSTM 204	700,426	700,426	0%	700,426	0%
LSTM 206	109,852	193,819	76%	71,488	-35%
LSTM 302	39,981	42,664	7%	23,788	-40%
LSTM 303B	70,061	78,948	13%	66,209	-5%
LSTM 304	15,820	15,820	0%	15,820	0%
Watershed	**2,991,740**	**3,036,972**	**2%**	**2,497,765**	**-17%**

Annual Runoff Volume

Annual runoff volume increases in every subwatershed except those that are not disturbed (LSTM 203, LSTM 204 and LSTM 304). Subwatersheds with the greatest increase were almost the inverse of results for sediment loading, with the greatest increases in LSTM 110 and 111, which would have the highest fraction of land disturbed for land development. Runoff increases are slightly higher during the construction phase, since bare ground has a high runoff coefficient, but no controls that reduce runoff volume.

Table 4. Annual Runoff Volume (acre-ft/year)

Subwatershed	Existing Conditions	1994 Masterplan (during construction)	Change (%)	1994 Masterplan (After Construction)	Change (%)
LSTM 110	63	107	69%	101	59%
LSTM 111	31	51	67%	48	55%
LSTM 112	77	86	12%	84	9%
LSTM 201	212	252	19%	250	18%
LSTM 202	72	90	25%	86	19%
LSTM 203	161	161	0%	161	0%
LSTM 204	226	226	0%	226	0%
LSTM 206	230	319	39%	311	35%
LSTM 302	11	16	46%	15	40%
LSTM 303B	17	22	31%	21	28%
LSTM 304	7	7	0%	7	0%
Watershed	**1,106**	**1,337**	**21%**	**1,310**	**18%**

Summary

Water quality modeling results for implementing Stage 4 of 1994 Master Plan Land Use with Full ESD indicate that there would be a slight increase in nutrient loads both during and following construction, a significant increase in flow volumes. Sediment loads, excluding stream bank erosion, would increase slightly during the construction phase, and then decrease in the post-developed condition. The potential for the increase in annual runoff volume is the most significant result, as it could potentially lead to greater channel erosion or directly impact in-stream biota.

Some techniques for decreasing these impacts include the following:

1) Size stormwater practices to capture runoff from both impervious and pervious surfaces.
2) Design the site to minimize disturbance, preserve or add forest cover, and reduce impervious cover.
3) Decrease disturbance, and selectively disturb the least permeable soils. Use these areas to promote infiltration.
4) Decompact disturbed soils to reduce runoff generated by urban pervious surfaces.

References

Center for Watershed Protection (CWP), 2010. The Watershed Treatment Model 2010. Ellicott City, MD

Langland, M.J., and Cronin, T.M., eds., 2003, A summary report of sediment processes in Chesapeake Bay and watershed: U.S. Geological Survey Water-Resources Investigations Report 03–4123, 109 pp.

Maryland Department of the Environment (MDE), 2009. Maryland Stormwater Design Manual. Available at: http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/MarylandStormwaterDesignManual/Pages/programs/waterprograms/sedimentandstormwater/stormwater_design/index.aspx

Biohabitats
Brown AND Caldwell
A Joint Venture

MEMORANDUM – DRAFT

Date: April 3, 2013

To: Mary Dolan and Valdis Lazdins, Montgomery County Planning Department

From: Biohabitats and Brown and Caldwell, a Joint Venture

RE: Ten Mile Creek Watershed Environmental Analysis
in Support of the Clarksburg Master Plan Limited Amendment
SUBJ: Trend Analysis of Little Seneca Creek Benthic and Habitat Assessment Data

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The use of analog or reference sites is a common tool used by biologists to extrapolate stressor response relationships to a test site. In the case of this study, the goal is to extrapolate the likely impacts to the habitats and benthic macroinvertebrate communities of the Ten Mile Creek Watershed (LSTM) using an adjacent Special Protection Area as an analog. The Little Seneca Creek Watershed (LSLS) within the Clarksburg Special Protection area was selected as an analog due to its proximity to the study site and similarities among the hydrology, physiography and historic land use. In addition, pre-development benthic macroinvertebrate index of biotic integrity (BIBI) and habitat scores for the LSLS watershed generally scored in the good range similar to the LSTM watershed. Biological and habitat sampling has been performed consistently in both watersheds since 1994 to document baseline and post-development conditions.

The biological and habitat sampling data within the LSLS watershed represents three distinct time periods (DEP 2010):

- *Pre-development*. This period spanned from 1994 to 2000 when the dominant land use within the watershed was agricultural.
- *Construction*. This period spanned from 2001-2007 when most of the land clearing and grading activities occurred. During this time period only sediment control Best Management Practices (BMPs) were in place and no water quality or quantity BMPs were functional.
- *Stabilization*. This period encompasses 2008 to present when the decline in the housing market significantly slowed construction and the first sites were permanently stabilized and stormwater BMPs were brought online. It should be noted that the during this period, the decline in the housing market prevented build-out in a timely manner and delayed the conversion of sediment BMPs to functional stormwater BMPs.

Existing Biological and Habitat Conditions

The biological and habitat conditions as determined by the County BIBI and habitat assessment metrics are discussed for the full period of record and relative to these three distinct time periods. A graphical summary of the available data is presented in Attachment A and the raw data are presented in tabular format in Attachment B and C. Microsoft Excel was used to develop standard correlation calculations that quantify the strength of relationships between metrics. Results from these correlation analyses are presented in tabular form in Attachment D.

Note: References to data provided in the text correspond to the attachment letter and figure/table number. For example, A1 references Attachment A, Figure 1.

Overall Trends

The biological condition of the Little Seneca Creek Watershed, as represented by the BIBI scores, is highly variable. Overall the BIBI scores fluctuated between good and fair with no strong upward or downward tendency (A1). The variability in BIBI scores among years and sampling stations does, however, increase after construction started. This increase in variability may reflect a stressor response at some specific sample stations, such as LSLS103B and 103C, and may relate to the specific construction activities occurring in a given sample year (A1). The two individual metrics that demonstrate an overall declining trend over time are the biotic index (B1) and proportion of EPT individuals (B3). Declines in both of these metrics reflect an increase in the proportion of tolerant individuals within the watershed.

In contrast to the BIBI scores, the habitat scores do show an overall declining trend over time and 6 of the 14 individual stations also show a decline (A6). The individual metrics showing decline include sediment deposits (C5), channel flow diversity (C7), bank vegetation (C8 and C9), and bank stability (C10 and C11). The declines in bank vegetation and bank stability likely lead to bank erosion, which increases the sediment supply. This increase in sediment supply coupled with an increase of fine sediments associated with construction activities could be influencing the scores for sediment deposits and flow diversity as the excess sediment is stored within the channel boundaries and fills pools.

The correlation analysis shows that the average annual BIBI and habitat metrics are positively correlated. Specifically the bank stability, bank vegetation and buffer condition have relatively greater influences on average annual BIBI score than other metrics (D1).

Pre-development

During the pre-development period both the BIBI and habitat scores experienced relatively low variability and scored in the good and good to excellent/good range respectively (A3 and B9). Indications of a good quality system include slight increasing trends in the raw metrics for the Proportion of Shredders (B5), and Ratio of Scrapers (B6) combined with slight declining trends in the Proportion of Hydropsyche & Cheumatopsyche (B4). In contrast, slight declining trends in the raw Number of EPT Taxa (B8) and increases in the Proportion of Dominant Taxa (B2) over time are indicative of a degrading system. Overall the habitat values did not show much variability (A8), but the scores for instream cover showed slight increases during the pre-development period (C1). The correlation analysis indicates that habitat parameters influencing the BIBI score are bank vegetation, channel alteration, epibenthic substrate and riffle frequency (D2).

Construction

During the construction phase, the average of the BIBI showed no strong overall trend; however, the average BIBI score was 4 points lower than the pre-development period (A4 and B9). Increasing trends in the raw Biotic Index (B1), Proportion of Dominant Taxa (B2), Proportion of Hydropsyche & Cheumatopsyche (B4) combined with declining trends in the Proportion of EPT individuals (B3), and Ratio of Scrapers (B6) contribute to the decline in the average BIBI score (B9). The average of the habitat scores showed no overall trend, but LSLS102 and 413 showed declining trends while LSLS103C and 206 show improving trends (A9 and C14). Correlation analysis indicates that bank stability, buffer condition, instream cover and sediment deposits emerge as the important factors influencing the BIBI score (D3).

Stabilization

During the Stabilization Phase, the overall BIBI showed no strong overall trend (A5 and B9). While the average BIBI score was similar to the construction phase, the stabilization phase shows the widest year to year variability (A5 and B9). The one observed trend of note was a slight decrease in the Taxa Richness (B7), which corresponds to a decrease in diversity and could lead to a more fragile system in the future. The overall habitat scores show declining trends at 5 of the stations (LSTM 102, 103C, 104, 109, and 110) and increasing trends at LSLS202, 203 and 206 (A10 and C14). Both Instream Cover (C1) and Bank Vegetation (C8 and C9) show very slight signs of decline over the periods and Embeddedness (C3) and Riffle Frequency (C6) show very slight improvements over the period. Correlation analysis indicates that the same factors habitat parameters are influencing the average annual BIBI scores; however, the buffer conditions and channel alteration parameters are negatively correlated indicating that as these parameters improve, the BIBI still declines (D4).

Data Extrapolation

While the data sets represent a reasonable account of biological conditions for the pre-construction, construction, and stabilization time periods, several confounding issues prevent these findings from being extrapolated quantitatively to the Ten Mile Creek Watershed. These confounding issues include:

1. The SPA reports do not contain adequate quantitative data to ascertain the extent of development activities occurring in a given subwatershed at a given time. Based on personal communications between DEP staff and Biohabitats, it may be possible to develop a more detailed spatial chronology of development, but the associated effort is beyond the scope of this study.
2. The state of the economy prolonged the period from initial disturbance to final stabilization, but current regulations now will limit the amount of land disturbance that can occur before site stabilization.
3. The Clarksburg development was designed according to the MD 2000 SWM regulations, whereas the new regulations are designed to better match existing hydrology using LID.

Conclusion

While the data do not indicate that the Little Seneca Watershed is showing strong signs of decline in biological condition as evidenced by the BIBI score, the variability from year to year and site to site suggests that some degree of stressor response is occurring within the system. The data do suggest that the overall habitat conditions are declining slightly over time. Some correlation between these habitat parameters and the BIBI score was observed and if the habitat continues to decline, the BIBI scores are expected to ultimately respond accordingly. Based on the rates of change and the continuing construction within the watershed, it may take some time before the system stabilizes and a new baseline is established such that the true impact of the development in the watershed can be determined. Given the changes in land development regulations and changes in economic condition since the development plans in the Little Seneca Watershed were approved, these data do not provide a perfect analog to describe the magnitude of change in biological condition associated with development in the Ten Mile Creek Watershed. These data, however, do generally agree with other studies that suggest that biological condition degrades above a certain threshold of impervious cover (*e.g.*, Paul and Meyer 2001). The results of the Little Seneca Creek data review indicate that development does negatively influence the biological condition in the short term despite the application of the “best available technologies” at the time of plan approval. The long-term influence on biological condition is uncertain at the present time.

References

Montgomery County Department of Environmental Protection (DEP). (2012). Special protection area program annual report 2010. Montgomery County Department of Environmental Protection, Department of Permitting Services, and Maryland-National Capital Park and Planning Commission.

Paul, M.J., and Meyer, J.L., 2001, Streams in the urban landscape: Annual Review of Ecology and Systems, v. 32, p. 333–365.

Attachments

Attachment A: Graphical Data Summaries
Attachment B: Montgomery County Benthic Index of Biotic Integrity (BIBI) Data Summary
Attachment C: Montgomery County Habitat Assessment Data Summary
Attachment D: Montgomery County BIBI and Habitat Assessment Correlation Analysis

Attachment A

Graphical Data Summaries

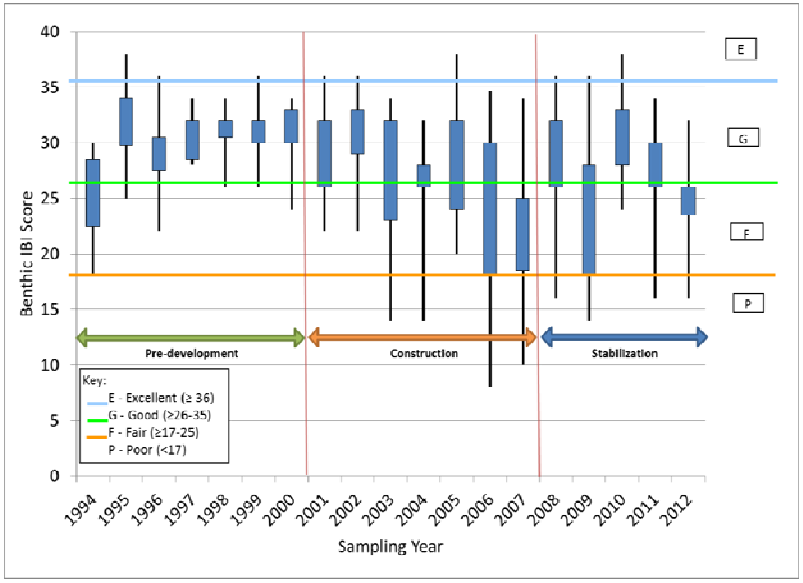

Figure A1. Variability among BIBI scores at all sampling stations over time.

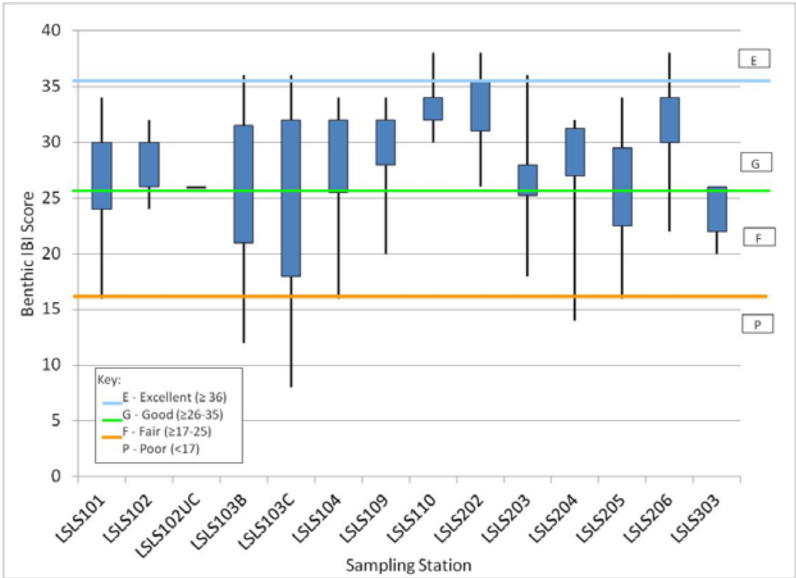

Figure A2. Variability among BIBI scores at all sampling stations over time (1994-2012).

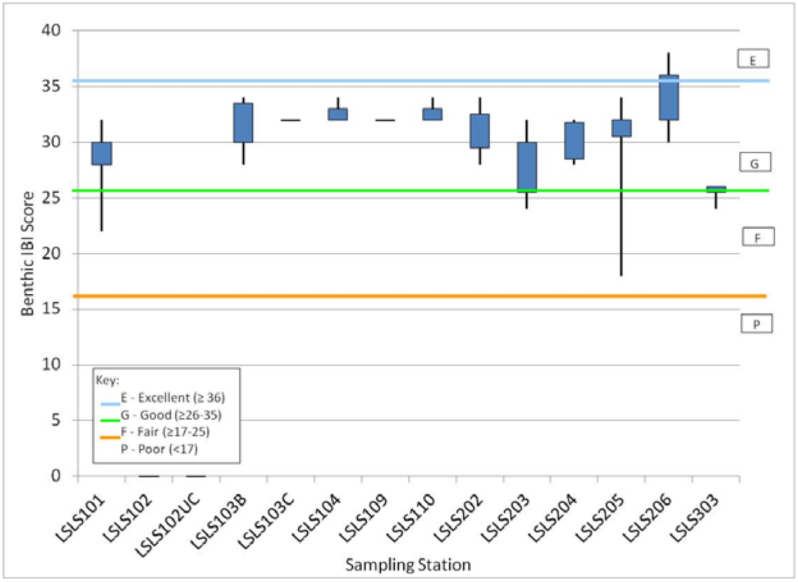

Figure A3. Variability among pre-development period BIBI scores

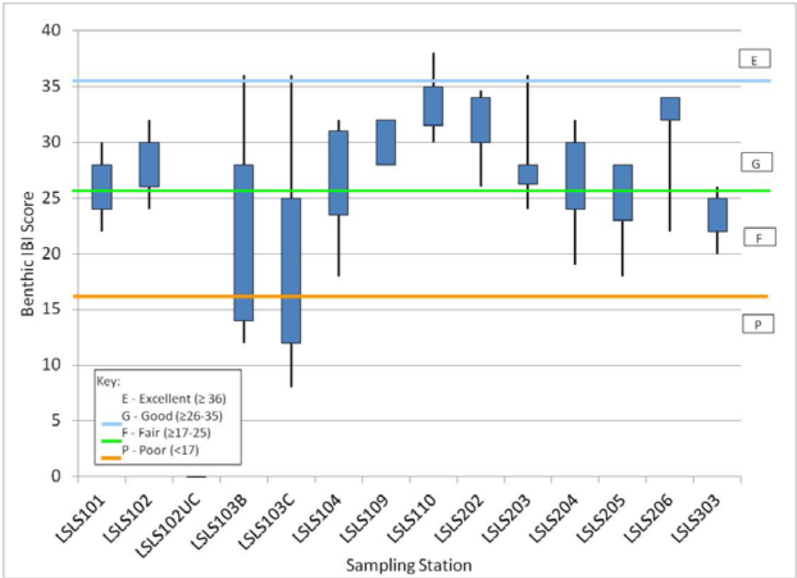

Figure A4. Variability among construction period BIBI scores

Attachment A

Graphical Data Summaries

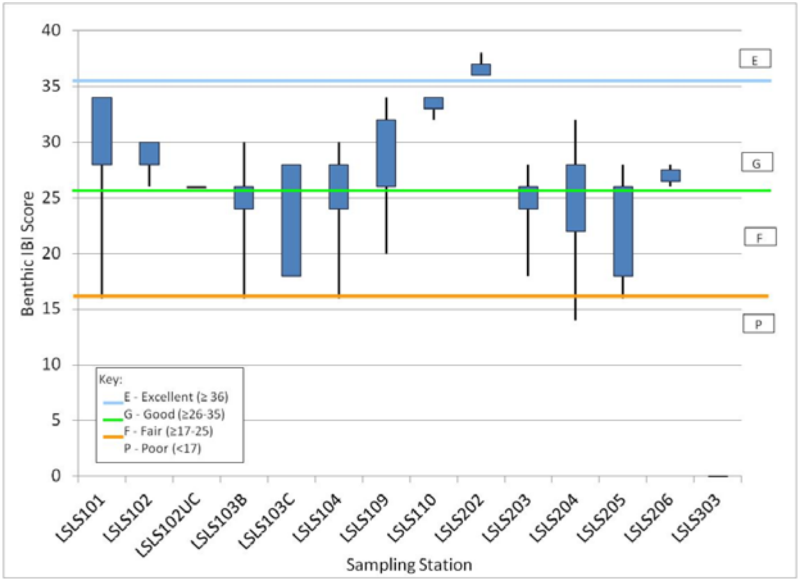

Figure A5. Variability among stabilization period phase BIBI scores

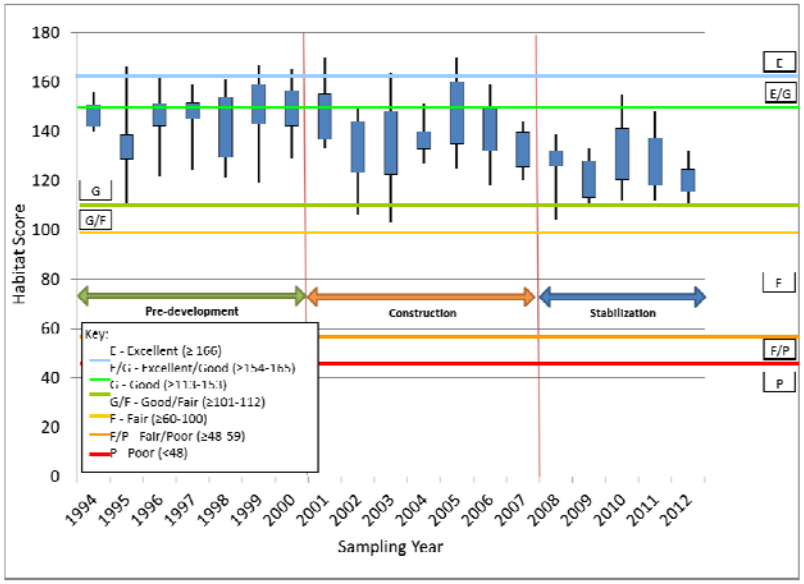

Figure A6. Variability among habitat scores at all sampling stations over time (1994-2012).

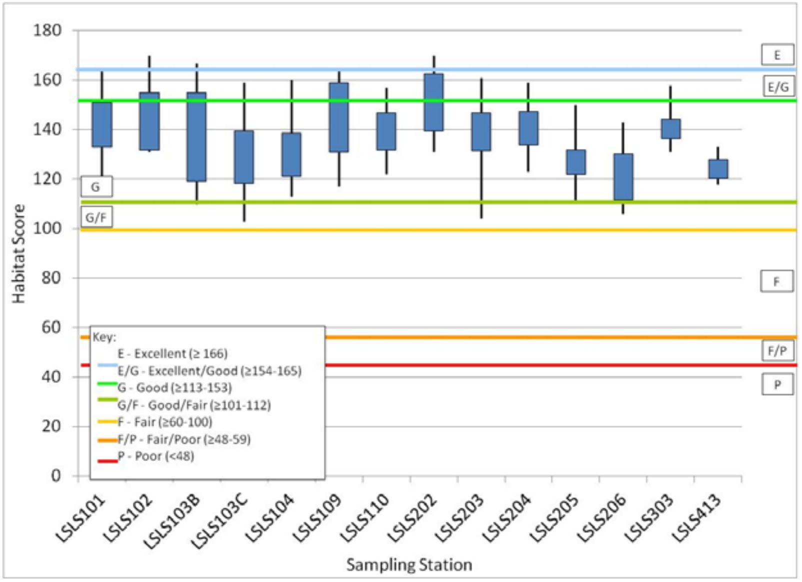

Figure A7. Ranges of composite habitat scores among the permanent sampling stations

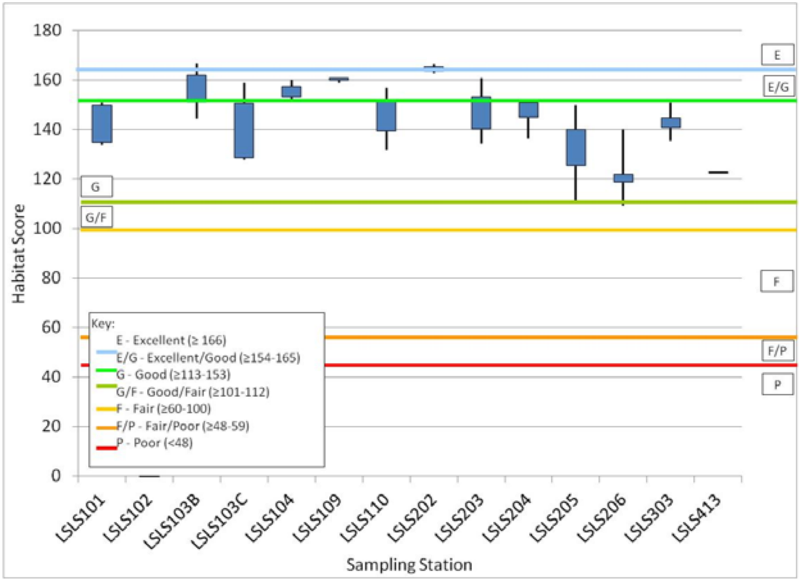

Figure A8. Variability among pre-development period habitat scores

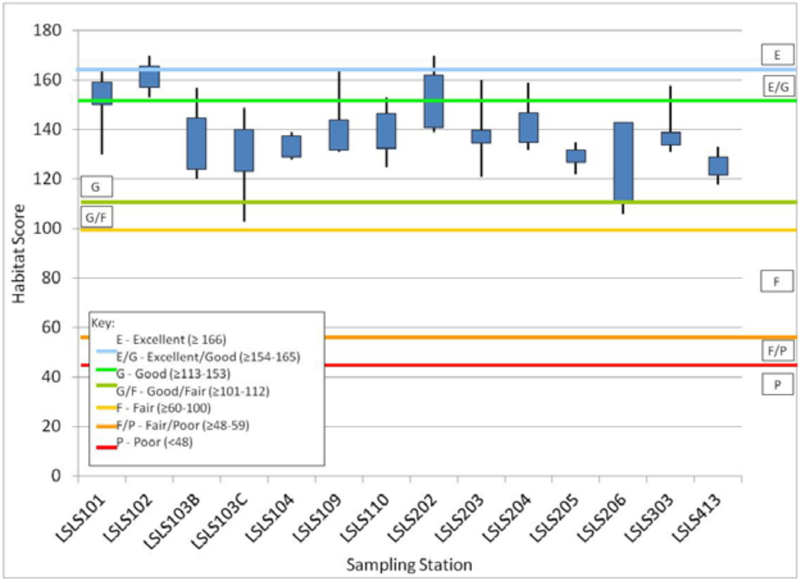

Figure A9. Variability among construction habitat scores

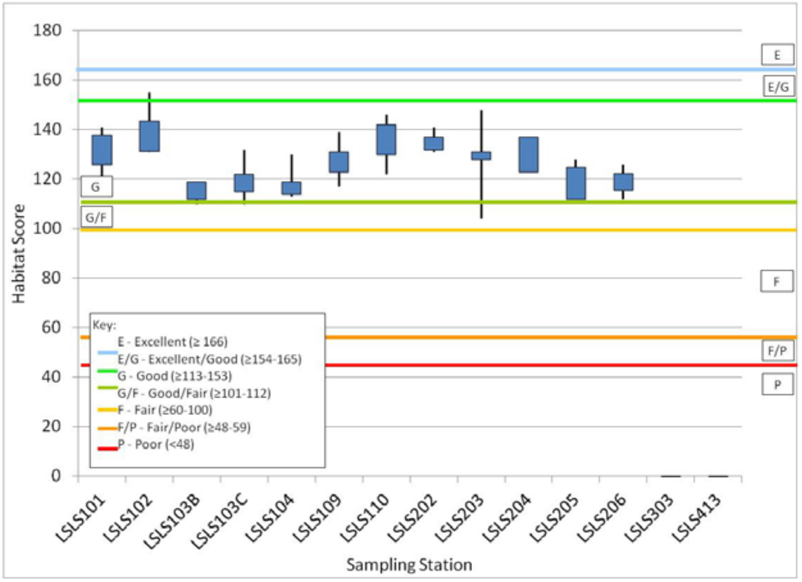

Figure A10. Variability among stabilization period habitat scores

Attachment B

Montgomery County Benthic Index of Biotic Inegrity (BIBI)

Data Summary

Table B1. Biotic Index

Time Period	Sample Year	LSLS101	LSLS102	LSLS102UC	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	Average
Pre-development	1994										4.31	4.34	4.67	3.82		4.29
	1995	4.9			3.18					4	4.315	3.36	2.89	3.05	5.48	3.90
	1996	6.23			4.29					4.51	4.53	3.88	4.94	3.9	6.05	4.79
	1997	4.48			3.77	4.16					4.85	4.56	4.21			4.34
	1998				3.14	3.8	3.22	4.04	3.86		3.63	3.21	3.07	4.61	5.71	3.83
	1999	4.4			3.16	4.22	3.41		4.58		4.67	3.82	3.9	3.87		4.00
	2000	4.46			3.26	4.42	3.27		4.81		4.33				6.39	4.42
Construction	2001	5.61			3.08	4.88	3.87	4.05	4.93	5.92	3.79	4.24	4.67	5.67	6.4	4.76
	2002	2.88			4.62	4.82	4.22						4.35	3.96	6.05	4.41
	2003	6			6.78	6.705	3.61	3.27	4.42		5.15	4.42	5.62	3.9	5.99	5.08
	2004	4.13			5.42	6.66	4.785	3.94		3.56	5.37	4.35	5.08	3.68	6.52	4.86
	2005	3.45	3.79		5.5	5.72	4.05	4.39	4.12	3.53	4.7	5.68	5.07	4.14	5.44	4.58
	2006	5.39	3.68		6.77	6.8	6.81	5.29	3.85	4.36	6.08	6.155	6.56	4.27	6.3	5.56
	2007	5.7			6.61	6.85	6.44	5.52		5.08	5.92		5.84			6.00
Stabilization	2008	4.08			4.84	6.14	5.94	4.9		4.61	5.39	4.92	5.08			5.10
	2009	5.74			5.24	6.18	5.45	4.34		4.47	5.54	6.08	5.92			5.44
	2010	2.8	3.57		5.88	4.08	5.31	3.55	4.79	3.66	5.03	4.57	5.12			4.40
	2011	4.71	4.95		6.26	5.77	5.35	5.51	4.27		5.15	5.93	6.18	5.67		5.43
	2012	6.24	5.9	5.52	5.62	4.31	5.53	6.39	5.22		5.86	5.98	6.34	5.26		5.68

Pre-development	Average	4.89	#DIV/0!	#DIV/0!	3.47	4.15	3.30	4.04	4.42	4.26	4.38	3.86	3.95	3.85	5.91	4.22
	RSQ	0.32	#DIV/0!	#DIV/0!	0.17	0.36	0.06	#DIV/0!	**0.92**	**1.00**	0.00	0.06	0.07	0.28	**0.55**	0.01
	Slope	-0.21	#DIV/0!	#DIV/0!	-0.10	0.12	0.02	#DIV/0!	0.48	0.51	0.00	-0.07	-0.12	0.14	0.13	-0.01
Construction	Average	4.74	3.74	#DIV/0!	5.54	6.06	4.83	4.41	4.33	4.49	5.17	4.97	5.31	4.27	6.12	5.04
	RSQ	0.03	**1.00**	#DIV/0!	**0.60**	**0.56**	**0.64**	**0.62**	**0.99**	0.16	**0.73**	**0.73**	**0.58**	0.25	0.06	**0.57**
	Slope	0.10	-0.11	#DIV/0!	0.49	0.32	0.48	0.31	-0.21	-0.18	0.33	0.39	0.26	-0.19	-0.05	0.20
Stabilization	Average	4.71	4.81	5.52	5.57	5.30	5.52	4.94	4.76	4.25	5.39	5.50	5.73	5.47	#DIV/0!	5.21
	RSQ	0.15	**0.99**	#DIV/0!	**0.55**	0.40	0.33	0.36	0.20	**0.86**	0.07	0.20	**0.55**	**1.00**	#DIV/0!	0.13
	Slope	0.33	1.17	#DIV/0!	0.26	-0.41	-0.09	0.42	0.22	-0.48	0.06	0.20	0.28	-0.41	#DIV/0!	0.12
Composite	Average	4.78	4.38	5.52	4.86	5.34	4.75	4.60	4.49	4.37	4.92	4.72	4.97	4.29	6.03	4.78
	RSQ	0.00	**0.55**	#DIV/0!	**0.54**	0.14	**0.60**	0.33	0.06	0.01	**0.51**	**0.60**	**0.58**	0.38	0.10	**0.53**
	Slope	-0.01	0.24	#DIV/0!	0.19	0.09	0.20	0.13	0.02	-0.02	0.09	0.13	0.14	0.09	0.03	0.08

Table B2. Proportion of Dominant Taxa

Time Period	Sample Year	LSLS101	LSLS102	LSLS102UC	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	Average
Pre-development	1994										39	31	50	21		35.25
	1995	43			15					31	41.5	38.5	36	33	55	36.63
	1996	68			48					40	24	48	39	30	64	45.13
	1997	36			47	38					38	29	24			35.33
	1998				59	68	71	59	53		49	77	73	32	47	58.80
	1999	41			84	53	61		25		34	55	42	31		47.33
	2000	46			60	55	52		23		34				76	49.43
Construction	2001	60			35	47	27	32	37	68	28	35	42	71	69	45.92
	2002	41			34	27	36						42	33	58	38.71
	2003	68			90	66	64	79	20		45	31	57	27	45	53.82
	2004	43			60	89	51	35		30	60	46	59	40	77	53.64
	2005	41	54		48	43	22	39	26	53	31	53	38	41	38	40.54
	2006	59	70		92	93	93	53	36	51.25	55.5	72.5	80	37	62	65.71
	2007	63			86	91	68	61		40	57		59			65.63
Stabilization	2008	45			43	79	73	44		37	41	40	26			47.56
	2009	65			43	70	58	38		37	41	62	47			51.22
	2010	36	33		62	49	59	28	36	19	31	36	33			38.36
	2011	35	49		68	60	55	60	29		35	49	64	62		51.45
	2012	71	65	56	60	40	71	78	47		59	70	50	58		60.42

Pre-development	Average	46.80	#DIV/0!	#DIV/0!	52.17	53.50	61.33	59.00	33.67	35.50	37.07	46.42	44.00	29.40	60.50	43.99
	RSQ	0.07	#DIV/0!	#DIV/0!	**0.67**	0.14	**1.00**	#DIV/0!	**0.80**	**1.00**	0.00	**0.41**	0.03	0.34	0.24	**0.46**
	Slope	-1.60	#DIV/0!	#DIV/0!	9.86	3.60	-9.50	#DIV/0!	-15.00	9.00	-0.18	6.19	1.60	1.35	2.75	2.77
Construction	Average	53.57	62.00	#DIV/0!	63.57	65.14	51.57	49.83	29.75	48.45	46.08	47.50	53.86	41.50	58.17	51.99
	RSQ	0.01	**1.00**	#DIV/0!	**0.47**	**0.48**	0.35	0.07	0.00	0.31	0.38	**0.75**	0.33	0.21	0.05	**0.49**
	Slope	0.64	16.00	#DIV/0!	8.11	8.61	6.96	2.29	-0.22	-3.48	3.94	7.40	3.86	-3.80	-1.80	3.57
Stabilization	Average	50.40	49.00	56.00	55.20	59.60	63.20	49.60	37.33	31.00	41.40	51.40	44.00	60.00	#DIV/0!	49.80
	RSQ	0.04	**1.00**	#DIV/0!	**0.66**	**0.79**	0.02	**0.52**	0.37	**0.75**	0.20	0.27	**0.47**	**1.00**	#DIV/0!	0.27
	Slope	2.20	16.00	#DIV/0!	5.90	-8.80	-0.70	9.00	5.50	-9.00	3.00	4.70	6.50	-4.00	#DIV/0!	2.60
Composite	Average	50.65	54.20	56.00	57.44	60.50	57.40	50.50	33.20	40.63	41.28	48.31	47.83	39.69	59.10	48.47
	RSQ	0.01	0.06	#DIV/0!	0.10	0.04	0.06	0.01	0.02	0.03	0.10	0.10	0.03	**0.41**	0.00	0.22
	Slope	0.29	-1.18	#DIV/0!	1.23	0.88	1.01	0.33	0.26	-0.49	0.59	0.82	0.46	1.67	-0.21	0.81

Table B3. Proportion of EPT Individuals

Time Period	Sample Year	LSLS101	LSLS102	LSLS102UC	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	Average
Pre-development	1994										80	77	79	71		76.75
	1995	35			40					67.5	80	86	86	84	22	62.56
	1996	11			59					58	64	71	43	61	20	48.38
	1997	47			61	64					52	54	61			56.50
	1998				82	77	86	72	72		88	90	93	39	21	72.00
	1999	46			93	79	84		71		58	73	68	52		69.33
	2000	53			69	60	78		54		63				6	54.71
Construction	2001	29			72	35	58	60	52	22	74	57	46	22	6	44.42
	2002	62			50	67	56						53	59	10	51.00
	2003	13			2	24.5	81	89	74		42	61	20	62	2	42.77
	2004	45			7	2	39	56		64	31	46	23	36	9	32.55
	2005	49	74		34	49	46	51	64	83	64	18	33	34	28	48.23
	2006	32	77		4	6	1	37	66	67.75	20	16	13	43	19	30.90
	2007	32			6	3	7	29		48	32		29			23.25
Stabilization	2008	59			40	12	15	39		51	47	49	58			41.11
	2009	18			50	23	32	61		58	47	27	45			40.11
	2010	68	61		27	65	19	53	56	66	59	53	47			52.18
	2011	54	45		20	30	34	31	62		60	33	23	28		38.18
	2012	4	26	29	34	58	25	7	44		25	25	24	38		28.25

Pre-development	Average	38.40	#DIV/0!	#DIV/0!	67.33	70.00	82.67	72.00	65.67	62.75	69.29	75.17	71.67	61.40	17.25	62.89
	RSQ	**0.46**	#DIV/0!	#DIV/0!	**0.59**	0.02	**0.92**	#DIV/0!	**0.79**	**1.00**	0.17	0.01	0.00	**0.64**	**0.71**	0.05
	Slope	5.42	#DIV/0!	#DIV/0!	7.66	-1.00	-4.00	#DIV/0!	-9.00	-9.50	-2.54	-0.71	-0.46	-6.67	-2.86	-1.03
Construction	Average	37.43	75.50	#DIV/0!	25.00	26.64	41.14	53.67	64.00	56.95	43.83	39.60	31.00	42.67	12.33	39.02
	RSQ	0.01	**1.00**	#DIV/0!	**0.52**	0.35	**0.65**	**0.53**	0.25	0.35	**0.45**	**0.75**	**0.41**	0.00	**0.50**	**0.55**
	Slope	-0.54	3.00	#DIV/0!	-9.21	-6.91	-10.64	-7.04	2.03	5.93	-6.50	-9.62	-4.21	0.11	3.60	-3.51
Stabilization	Average	40.60	44.00	29.00	34.20	37.60	25.00	38.20	54.00	58.33	47.60	37.40	39.40	33.00	#DIV/0!	39.97
	RSQ	0.18	**1.00**	#DIV/0!	0.33	**0.47**	0.18	**0.50**	**0.43**	**1.00**	0.12	0.27	**0.86**	**1.00**	#DIV/0!	0.26
	Slope	-7.40	-17.50	#DIV/0!	-4.20	9.90	2.20	-9.40	-6.00	7.50	-3.10	-4.20	-9.00	10.00	#DIV/0!	-2.77
Composite	Average	38.65	56.60	29.00	41.67	40.91	44.07	48.75	61.50	58.53	54.78	52.25	46.89	48.38	14.30	48.06
	RSQ	0.00	**0.83**	#DIV/0!	0.31	0.19	**0.64**	**0.49**	0.24	0.01	0.39	**0.61**	**0.45**	**0.44**	0.03	**0.56**
	Slope	0.16	-6.22	#DIV/0!	-2.87	-2.47	-5.13	-3.64	-0.93	0.23	-2.11	-3.05	-2.78	-2.11	-0.42	-1.97

KEY:

1. **Bold Green** numbers indicate an R-square value in excess of 0.4. This would be considered a moderate to strong trend.

Attachment B

Montgomery County Benthic Index of Biotic Inegrity (BIBI)

Data Summary

Table B4. Proportion of Hydropsyche & Cheumatopsyche

Time Period	Sample Year	LSLS101	LSLS102	LSLS102UC	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	Average
Pre-development	1994										80	70	96	45		72.75
	1995	5			19					31.5	69.5	28.5	13	5	20	23.94
	1996	50			2					9	44	17	14	6	8	18.75
	1997	7			0	2					34	23	22			14.67
	1998				0	0	0	0	1		30	1	1	0	66	9.90
	1999	4			0	0	0		11		22	2	3	0		4.67
	2000	0			1	0	0		0		22				21	6.29
Construction	2001	0			0	0	0	2	0	13	21	2	11	3	38	7.50
	2002	0			2	1	2						6	0	15	3.71
	2003	7			0	1	0	0	0		19	11	18	0	50	9.64
	2004	5			0	33	1.5	1		2	13	0	0	0	14	6.32
	2005	0	0		59	94	42	2	1	6	59	29	49	6	91	33.69
	2006	1	0		43	89	0	0	1	2.75	34.5	29	43	1	30	21.10
	2007	9			33	25	17	0		17	43		59			25.38
Stabilization	2008	0			4	0	10	0		1	45	20	43			13.67
	2009	5			26	30	3	2		5	57	72	82			31.33
	2010	2	2		38	9	0	1	5	5	52	13	54			16.45
	2011	6	8		61	17	4	6	4		60	37	65	9		25.18
	2012	17	0	0	20	7	2	18	7		43	32	48	10		17.00

Pre-development	Average	13.20	#DIV/0!	#DIV/0!	3.67	0.50	0.00	0.00	4.00	20.25	43.07	23.58	24.83	11.20	28.75	21.57
	RSQ	0.21	#DIV/0!	#DIV/0!	**0.46**	**0.60**	#DIV/0!	#DIV/0!	0.01	**1.00**	**0.89**	**0.77**	**0.54**	**0.55**	0.09	**0.65**
	Slope	-4.56	#DIV/0!	#DIV/0!	-2.74	-0.60	0.00	#DIV/0!	-0.50	-22.50	-10.11	-11.90	-14.09	-6.83	3.54	-8.81
Construction	Average	3.14	0.00	#DIV/0!	19.57	34.71	8.93	0.83	0.50	8.15	31.58	14.20	26.57	1.67	39.67	15.33
	RSQ	0.20	#DIV/0!	#DIV/0!	**0.55**	**0.42**	0.19	0.28	**0.83**	0.00	0.36	**0.60**	**0.68**	0.03	0.08	**0.58**
	Slope	0.79	0.00	#DIV/0!	8.57	12.29	3.18	-0.24	0.24	-0.04	4.79	5.69	8.89	0.23	4.34	4.02
Stabilization	Average	6.00	3.33	0.00	29.80	12.60	3.80	5.40	5.33	3.67	51.40	34.80	58.40	9.50	#DIV/0!	20.73
	RSQ	**0.70**	0.06	#DIV/0!	0.25	0.00	0.40	**0.73**	**0.43**	**0.75**	0.00	0.01	0.01	**1.00**	#DIV/0!	0.00
	Slope	3.50	-1.00	#DIV/0!	6.70	0.10	-1.50	4.00	1.00	2.00	-0.10	-1.10	-0.70	1.00	#DIV/0!	0.05
Composite	Average	6.94	2.00	0.00	17.11	19.25	5.43	2.67	3.00	9.23	41.56	24.16	34.83	6.54	35.30	19.05
	RSQ	0.06	0.21	#DIV/0!	0.36	0.07	0.02	0.30	0.06	**0.42**	0.00	0.01	0.16	0.08	0.11	0.02
	Slope	-0.57	0.52	#DIV/0!	2.40	1.63	0.38	0.66	0.17	-1.15	0.05	0.40	2.06	-0.60	2.32	-0.36

Table B5. Proportion of Shredders

Time Period	Sample Year	LSLS101	LSLS102	LSLS102UC	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	Average
Pre-development	1994										2.02	5.41	0.53	2.31		2.57
	1995	21.81			14.92					31.93	11.285	42.32	31.41	32.86	3.45	23.75
	1996	8.2			48.54					40.49	27.64	48.84	26.75	30.87	11.15	30.31
	1997	38.24			48.45	39.1					21.99	27.74	24.84			33.39
	1998				62.71	68.03	72.97	58.66	53.23		50.27	76.71	73.49	22.22	5.96	54.43
	1999	16.52			85.4	53.48	61.19		25.21		31.8	55.78	42.68	18.66		43.41
	2000	47.62			61.69	56.41	52.57		16.6		36.45				0	38.76
Construction	2001	4.85			36.7	7.27	26.67	32.18	22.73	9.17	28.96	27.75	21.05	9.4	1.48	19.02
	2002	14.95			26	29.03	18.56						14.41	12.4	0	16.48
	2003	6.73			1.77	1.39	64.44	79.47	9.52		18.92	32.43	3.67	10.68	2.04	21.01
	2004	20.69			3.17	0	18.86	32.16		26.01	18.03	22.47	7.38	9.49	2.45	14.61
	2005	8.11	59.84		4.59	13.76	8.94	25.22	28.03	54.89	11.65	3.48	5.36	12.26	3.45	18.43
	2006	27.31	70.97		1.53	0	1.01	17.6	36.87	51.9325	6.15	2.905	2.7	19.81	0	18.37
	2007	24.46			1.02	0.71	3.33	21.01		24.6	2.97		4.44			10.32
Stabilization	2008	46.15			5.56	5.62	0.99	36.8		39.44	1.47	13.33	3.75			17.01
	2009	6.67			5.88	2.62	23.94	38.82		42.71	0.57	1.88	0.88			13.77
	2010	64.78	47.59		7.03	53.61	13.45	30.52	28.41	35.66	11.43	19.83	10.78			29.37
	2011	36.15	21.62		2.6	6.74	28.97	18.83	14.29		3.01	5.42	0.54	15.66		13.98
	2012	1.81	19.26	17.65	16.44	42.16	10	2.65	10.37		7.14	11.11	3.88	5.84		12.36

Pre-development	Average	26.48	#DIV/0!	#DIV/0!	53.62	54.26	62.24	58.66	31.68	36.21	25.92	42.80	33.28	21.38	5.14	32.37
	RSQ	0.28	#DIV/0!	#DIV/0!	**0.68**	0.16	**0.99**	#DIV/0!	**0.91**	**1.00**	**0.65**	**0.53**	**0.55**	0.04	0.30	**0.65**
	Slope	4.14	#DIV/0!	#DIV/0!	10.25	3.74	-10.20	#DIV/0!	-18.32	8.56	5.96	9.54	9.57	1.17	-1.17	6.14
Construction	Average	15.30	65.41	#DIV/0!	10.68	7.45	20.26	34.61	24.29	33.32	14.45	17.81	8.43	12.34	1.57	16.89
	RSQ	**0.52**	**1.00**	#DIV/0!	**0.66**	0.22	0.33	0.25	**0.40**	0.34	**0.98**	**0.70**	**0.66**	**0.48**	0.02	0.30
	Slope	3.03	11.13	#DIV/0!	-5.47	-2.33	-5.74	-5.22	3.28	4.96	-4.36	-5.99	-2.56	1.44	0.10	-0.89
Stabilization	Average	31.11	29.49	17.65	7.50	22.15	15.47	25.52	17.69	39.27	4.72	10.31	3.97	10.75	#DIV/0!	17.30
	RSQ	0.12	**0.81**	#DIV/0!	0.31	0.26	0.11	**0.87**	**0.90**	0.29	0.23	0.00	0.00	**1.00**	#DIV/0!	0.04
	Slope	-5.92	-14.17	#DIV/0!	1.85	7.72	2.31	-8.83	-9.02	-1.89	1.38	-0.09	-0.01	-9.82	#DIV/0!	-0.91
Composite	Average	23.24	43.86	17.65	24.11	23.75	27.06	32.83	24.53	35.68	16.21	24.84	15.47	15.57	3.00	22.70
	RSQ	0.02	**0.83**	#DIV/0!	**0.44**	0.15	**0.47**	0.39	0.17	0.05	0.29	0.34	0.32	0.15	0.36	0.15
	Slope	0.50	-6.70	#DIV/0!	-3.31	-2.03	-3.69	-3.00	-1.08	0.59	-1.31	-2.13	-1.87	-0.63	-0.55	-0.87

Table B6. Ratio of Scrapers

Time Period	Sample Year	LSLS101	LSLS102	LSLS102UC	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	Average
Pre-development	1994										22	13	12	42		22.25
	1995	68			23					37	9.5	15	14	63	79	38.56
	1996	36			24					33	11	9	24	73	68	34.75
	1997	11			0	8					11	31	31			15.33
	1998				46	57	39	73	97		13	55	38	68	52	53.80
	1999	22			92	68	63		71		18	42	53	78		56.33
	2000	47			12	63	44		93		38				79	53.71
Construction	2001	77			58	57	30	30	100	47	49	30	28	12	84	50.17
	2002	14			83	87	46						29	100	93	64.57
	2003	36			40	87.5	60	20	89		56	43	76	80	96	62.14
	2004	21			83	27	28.5	15		4	29	38	78	97	73	44.86
	2005	7	55		11	2	20	95	58	44	24	42	49	94	47	42.15
	2006	48	0		20	0	80	64	14	61.25	58	33	25	94	73	43.87
	2007	17			11	0	42	38		49	18		23			24.75
Stabilization	2008	75			36	13	8	22		60	36	33	29			34.67
	2009	88			17	10	33	75		71	18	13	16			37.89
	2010	22	0		32	7	50	50	42	64	20	30	28			31.36
	2011	66	50		12	48	50	54	78		18	21	20	42		41.73
	2012	2	38	0	18	3	0	75	83		36	17	27	53		29.33

Pre-development	Average	36.80	#DIV/0!	#DIV/0!	32.83	49.00	48.67	73.00	87.00	35.00	17.50	27.50	28.67	64.80	69.50	39.25
	RSQ	0.11	#DIV/0!	#DIV/0!	0.10	**0.67**	0.04	#DIV/0!	0.02	**1.00**	0.26	**0.70**	**0.96**	**0.65**	0.01	**0.50**
	Slope	-3.52	#DIV/0!	#DIV/0!	5.57	17.60	2.50	#DIV/0!	-2.00	-4.00	2.39	8.20	8.11	5.43	-0.44	5.32
Construction	Average	31.43	27.50	#DIV/0!	43.71	37.21	43.79	43.67	65.25	41.05	39.00	37.20	44.00	79.50	77.67	47.50
	RSQ	0.20	**1.00**	#DIV/0!	**0.52**	**0.70**	0.06	0.18	**0.86**	0.06	0.21	0.08	0.03	**0.42**	**0.42**	**0.63**
	Slope	-5.04	-55.00	#DIV/0!	-10.57	-15.38	2.29	5.99	-16.12	2.33	-3.73	0.82	-1.79	11.69	-6.17	-4.92
Stabilization	Average	50.60	29.33	0.00	23.00	16.20	28.20	55.20	67.67	65.00	25.60	22.80	24.00	47.50	#DIV/0!	35.00
	RSQ	**0.52**	**0.53**	#DIV/0!	0.39	0.02	0.00	0.38	**0.84**	0.13	0.00	0.20	0.00	**1.00**	#DIV/0!	0.05
	Slope	-16.80	19.00	#DIV/0!	-4.10	1.80	0.10	8.50	20.50	2.00	0.00	-2.40	0.00	11.00	#DIV/0!	-0.68
Composite	Average	38.65	28.60	0.00	34.33	33.59	39.57	50.92	72.50	47.03	26.92	29.06	33.33	68.92	74.40	41.17
	RSQ	0.00	0.00	#DIV/0!	0.04	0.26	0.10	0.03	0.16	0.31	0.08	0.00	0.00	0.00	0.00	0.00
	Slope	0.11	0.58	#DIV/0!	-1.08	-3.49	-1.46	1.06	-2.15	2.07	0.75	0.01	0.04	0.28	0.06	-0.15

KEY:

1. **Bold Green** numbers indicate an R-square value in excess of 0.4. This would be considered a moderate to strong trend.

Attachment B
Montgomery County Benthic Index of Biotic Inegrity (BIBI)
Data Summary

Table B7. Taxa Richness

Time Period	Sample Year	LSLS101	LSLS102	LSLS102UC	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	Average
Pre-development	1994										17	23	14	26		20.00
	1995	25			31					25	18	21.5	23	26	23	24.06
	1996	15			19					18	29	25	29	27	20	22.75
	1997	22			20	26					23	28	27			24.33
	1998				22	13	22	17	17		16	14	17	18	18	17.40
	1999	18			14	15	12		16		19	18	21	24		17.44
	2000	16			22	15	19		33		23				15	20.43
Construction	2001	13			15	18	13	20	16	12	23	20	17	11	18	16.33
	2002	13			15	18	14						17	13	11	14.43
	2003	14			9	9.5	17	11	14		19	18	20	18	10	14.50
	2004	17			13	10	12	15		21	18	17	14	19	18	15.82
	2005	15	20		21	12	29	13	23	20	20	26	17	23	15	19.54
	2006	12	9		12	6	11	24	17	24.75	25	15	14	22	15	15.90
	2007	10			12	9	19	16		26	27		20			17.38
Stabilization	2008	15			31	13	18	13		23	30	32	16			21.22
	2009	19			25	21	18	16		28	22	15	15			19.89
	2010	21	20		18	18	19	20	25	23	22	16	18			20.00
	2011	23	19		16	19	21	19	21		20	28	19	25		20.91
	2012	13	15	21	21	18	13	18	22		24	15	25	14		18.25

Pre-development	Average	19.20	#DIV/0!	#DIV/0!	21.33	17.25	17.67	17.00	22.00	21.50	20.71	21.58	21.83	24.20	19.00	20.92
	RSQ	0.31	#DIV/0!	#DIV/0!	0.31	**0.46**	0.09	#DIV/0!	**0.70**	**1.00**	0.01	0.23	0.02	0.37	**0.97**	0.21
	Slope	-1.13	#DIV/0!	#DIV/0!	-1.66	-3.10	-1.50	#DIV/0!	8.00	-7.00	0.25	-1.27	0.43	-1.07	-1.49	-0.62
Construction	Average	13.43	14.50	#DIV/0!	13.86	11.79	16.43	16.50	17.50	20.75	22.00	19.20	17.00	17.67	14.50	16.27
	RSQ	0.12	**1.00**	#DIV/0!	0.00	**0.66**	0.09	0.01	0.24	**0.95**	0.24	0.01	0.00	**0.92**	0.01	0.24
	Slope	-0.36	-11.00	#DIV/0!	-0.11	-1.73	0.86	0.21	0.85	2.32	0.81	-0.19	0.00	2.46	0.14	0.40
Stabilization	Average	18.20	18.00	21.00	22.20	17.80	17.80	17.20	22.67	24.67	23.60	21.20	18.60	19.50	#DIV/0!	20.05
	RSQ	0.00	**0.89**	#DIV/0!	**0.59**	0.18	0.14	**0.55**	**0.52**	0.00	0.33	0.17	**0.79**	**1.00**	#DIV/0!	**0.45**
	Slope	0.00	-2.50	#DIV/0!	-2.90	0.80	-0.70	1.30	-1.50	0.00	-1.40	-2.10	2.20	-11.00	#DIV/0!	-0.49
Composite	Average	16.53	16.60	21.00	18.67	15.03	17.13	16.83	20.40	22.08	21.94	20.72	19.06	20.46	16.30	18.98
	RSQ	0.04	0.05	#DIV/0!	0.01	0.00	0.01	0.03	0.04	0.17	0.10	0.02	0.06	0.12	**0.43**	0.06
	Slope	-0.15	0.32	#DIV/0!	-0.12	-0.06	0.09	0.14	0.22	0.37	0.21	-0.13	-0.19	-0.33	-0.69	-0.13

Table B8. Number EPT Taxa

Time Period	Sample Year	LSLS101	LSLS102	LSLS102UC	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	Average
Pre-development	1994										12	14	4	16		11.50
	1995	12			16					14	8.5	13	12	11	10	12.06
	1996	4			9					11	12	12	14	11	7	10.00
	1997	12			9	12					15	14	15			12.83
	1998				12	9	9	10	9		10	7	12	8	6	9.20
	1999	9			10	8	7		9		10	8	11	13		9.44
	2000	7			11	7	10		11		9				7	8.86
Construction	2001	7			6	9	9	12	8	9	15	11	9	5	6	8.83
	2002	9			8	13	9						11	9	4	9.00
	2003	5			2	4.5	12	8	9		11	11	6	10	2	7.32
	2004	9			4	3	5.5	7		12	10	10	8	10	9	7.95
	2005	3	12		9	4	14	10	14	13	10	11	8	14	4	9.69
	2006	4	5		5	3	1	10	11	14.5	11	6.5	7	12	5	7.31
	2007	6			4	4	5	9		16	15		11			8.75
Stabilization	2008	6			16	4	7	5		14	18	17	9			10.67
	2009	10			15	9	8	11		13	12	5	7			10.00
	2010	11	10		10	8	6	9	13	16	11	11	11			10.55
	2011	8	11		8	9	10	10	12		11	14	8	17		10.73
	2012	3	6	9	13	10	7	7	14		10	9	11	9		9.00

Pre-development	Average	8.80	#DIV/0!	#DIV/0!	11.17	9.00	8.67	10.00	9.67	12.50	10.93	11.33	11.33	11.80	7.50	10.56
	RSQ	0.05	#DIV/0!	#DIV/0!	0.15	**0.91**	0.11	#DIV/0!	**0.75**	**1.00**	0.08	**0.64**	0.25	0.22	**0.42**	**0.48**
	Slope	-0.38	#DIV/0!	#DIV/0!	-0.54	-1.60	0.50	#DIV/0!	1.00	-3.00	-0.29	-1.31	1.03	-0.67	-0.51	-0.50
Construction	Average	6.14	8.50	#DIV/0!	5.43	5.79	7.93	9.33	10.50	12.90	12.00	9.90	8.57	10.00	5.00	8.41
	RSQ	0.24	**1.00**	#DIV/0!	0.03	**0.52**	0.20	0.09	**0.59**	**0.99**	0.01	**0.45**	0.00	**0.78**	0.00	0.01
	Slope	-0.54	-7.00	#DIV/0!	-0.18	-1.27	-0.93	-0.24	0.92	1.15	-0.13	-0.68	0.00	1.43	0.06	-0.05
Stabilization	Average	7.60	9.00	9.00	12.40	8.00	7.60	8.40	13.00	14.33	12.40	11.20	9.20	13.00	#DIV/0!	10.19
	RSQ	0.16	**0.57**	#DIV/0!	0.37	**0.65**	0.04	0.04	0.25	**0.43**	**0.70**	0.06	0.20	**1.00**	#DIV/0!	0.32
	Slope	-0.80	-2.00	#DIV/0!	-1.30	1.20	0.20	0.30	0.50	1.00	-1.70	-0.70	0.50	-8.00	#DIV/0!	-0.26
Composite	Average	7.35	8.80	9.00	9.28	7.28	7.97	9.00	11.00	13.25	11.69	10.84	9.67	11.15	6.00	9.67
	RSQ	0.08	0.01	#DIV/0!	0.00	0.04	0.05	0.08	**0.59**	0.27	0.02	0.03	0.06	0.01	0.30	0.09
	Slope	-0.15	-0.11	#DIV/0!	-0.02	-0.14	-0.16	-0.13	0.33	0.22	0.06	-0.09	-0.12	0.04	-0.35	-0.08

Table B9. BIBI Score

Time Period	Sample Year	LSLS101	LSLS102	LSLS102UC	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	Average
Pre-development	1994										32.04	29.72	32.53	28.39		30.67
	1995	26.84			20.26					30.24	30.33	31.02	27.29	32.24	27.24	28.18
	1996	24.80			26.73					26.75	27.02	29.34	24.34	30.35	25.53	26.86
	1997	22.22			23.65	24.16					24.98	26.41	26.13			24.59
	1998				35.86	36.98	37.90	36.71	38.26		32.49	40.49	38.82	23.98	27.71	34.92
	1999	20.12			47.70	35.09	36.45		29.10		24.68	32.20	30.57	27.57		31.50
	2000	27.64			29.99	32.60	32.36		29.43		28.72				26.30	29.58
Construction	2001	24.56			28.22	22.27	20.94	24.03	30.08	23.26	30.34	23.37	22.34	17.38	28.61	24.62
	2002	19.60			27.83	30.86	23.22						22.10	28.80	24.63	25.29
	2003	19.47			18.94	25.14	37.76	36.22	27.49		27.01	26.48	25.79	26.45	26.63	27.03
	2004	20.60			21.95	21.33	20.14	20.64		20.32	23.05	22.98	24.31	26.90	26.12	22.58
	2005	15.82	34.83		24.01	27.94	23.25	29.95	27.27	34.68	28.04	23.52	25.55	28.55	28.99	27.11
	2006	23.59	29.46		23.04	25.48	24.23	26.36	23.22	34.82	27.03	22.63	23.91	29.14	26.29	26.09
	2007	20.90			19.95	17.45	20.97	22.44		28.21	25.11		26.41			22.68
Stabilization	2008	31.28			22.55	16.60	17.24	20.59		28.76	27.98	26.16	23.73			23.88
	2009	27.18			23.39	21.48	22.67	30.77		32.40	25.39	25.25	27.35			26.21
	2010	28.45	22.15		24.99	26.71	21.47	24.38	26.28	29.04	26.43	22.93	25.86			25.33
	2011	29.11	26.07		24.23	24.44	26.04	25.54	28.07		26.52	24.17	25.72	25.54		25.95
	2012	14.76	21.90	17.27	23.51	22.81	16.69	26.51	29.07		26.25	23.14	24.40	24.14		22.54

Pre-development	Average	24.32	#DIV/0!	#DIV/0!	30.70	32.21	35.57	36.71	32.26	28.50	28.61	31.53	29.95	28.50	26.69	29.47
	RSQ	0.02	#DIV/0!	#DIV/0!	**0.45**	0.29	**0.93**	#DIV/0!	**0.72**	**1.00**	0.15	0.18	0.07	0.35	0.00	0.07
	Slope	-0.23	#DIV/0!	#DIV/0!	3.54	2.34	-2.77	#DIV/0!	-4.42	-3.49	-0.56	1.08	0.76	-0.89	-0.01	0.41
Construction	Average	20.65	32.14	#DIV/0!	23.42	24.35	24.36	26.61	27.01	28.26	26.76	23.80	24.34	26.20	26.88	25.06
	RSQ	0.03	**1.00**	#DIV/0!	0.40	0.15	0.02	0.03	**0.81**	0.32	0.28	0.12	**0.51**	**0.49**	0.00	0.03
	Slope	-0.24	-5.37	#DIV/0!	-1.05	-0.80	-0.44	-0.49	-1.15	1.62	-0.61	-0.27	0.56	1.67	0.03	-0.15
Stabilization	Average	26.15	23.37	17.27	23.73	22.41	20.82	25.56	27.81	30.06	26.51	24.33	25.41	24.84	#DIV/0!	24.78
	RSQ	**0.57**	0.00	#DIV/0!	0.22	**0.41**	0.01	0.08	**0.97**	0.00	0.16	**0.67**	0.00	**1.00**	#DIV/0!	0.09
	Slope	-3.11	-0.12	#DIV/0!	0.28	1.54	0.23	0.66	1.40	0.14	-0.23	-0.71	-0.03	-1.40	#DIV/0!	-0.29
Composite	Average	23.35	26.88	17.27	25.93	25.71	25.42	27.01	28.83	28.85	27.41	26.86	26.51	26.88	26.80	26.61
	RSQ	0.00	**0.81**	#DIV/0!	0.12	0.33	**0.46**	0.18	0.28	0.06	0.22	**0.41**	0.16	0.09	0.00	0.34
	Slope	0.02	-1.57	#DIV/0!	-0.45	-0.70	-1.09	-0.56	-0.40	0.23	-0.21	-0.51	-0.28	-0.20	0.02	-0.33

KEY:
1. **Bold Green** numbers indicate an R-square value in excess of 0.4. This would be considered a moderate to strong trend.

Attachment C

Montgomery County Habitat Assessment

Data Summary

Table C1. Average of Instream Cover

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			12						8	11	14	12	16		12.17
	1995	11		13					15	10	12.5	13.5	10	13		12.25
	1996	15		16					16	10	14	16	11	18		14.50
	1997	12		17	14					13	16	13				14.17
	1998			18	15	14	16	16		15	15	12	14	14	15	14.91
	1999	15		17	15	15	16	13		8	14	12	10			13.50
	2000	13		16	14	14	16	13		13				15		14.25
Construction	2001								16	8					14	12.67
	2002	17		15	13	10						14	13	15		13.86
	2003	17		15	12	9	17	15		13	14	12	15	13		13.82
	2004	14		14	16	10.5	11		14	11	12	15	15	15		13.41
	2005	17	16	15	13	12	12	11	17	15	15	13	16	16		14.46
	2006	15	14	16	15	7	10	13	15.7	14.5	15	14	16	15	12	13.73
	2007	9		17	15	9	15		14	9		13				12.63
Stabilization	2008	12		12	15	9	11		17	12	10	15				12.56
	2009	15		15	15	12	17		14	11	14	8				13.44
	2010	16	9	13	15	9	12	11	13	11	9	12				11.82
	2011	13	9	14	14	7	14	9		13	15	13	14			12.27
	2012	8	9	12	14	10	13	12		10	10	11	15			11.27

Pre-development	Average	13.20	#DIV/0!	15.57	14.50	14.33	16.00	14.00	15.50	11.00	13.75	13.42	11.40	15.20	15.00	13.68
	RSQ	0.14	#DIV/0!	**0.58**	0.00	0.00	#DIV/0!	**0.75**	**1.00**	0.21	**0.54**	0.39	0.01	0.02	#DIV/0!	**0.42**
	Slope	0.33	#DIV/0!	0.79	0.00	0.00	0.00	-1.50	1.00	0.57	0.70	-0.50	0.07	-0.11	#DIV/0!	0.33
Construction	Average	14.83	15.00	15.33	14.00	9.58	13.00	13.00	15.34	11.75	14.00	13.50	15.00	14.80	13.00	13.51
	RSQ	**0.54**	**1.00**	**0.53**	0.30	0.09	0.07	**0.43**	0.09	0.11	0.30	0.00	**0.82**	0.19	**1.00**	0.00
	Slope	-1.23	-2.00	0.40	0.46	-0.27	-0.50	-0.86	-0.17	0.45	0.60	-0.03	0.70	0.30	-0.40	0.01
Stabilization	Average	12.80	9.00	13.20	14.60	9.40	13.40	10.67	14.67	11.40	11.60	11.80	14.50	#DIV/0!	#DIV/0!	12.27
	RSQ	0.26	#DIV/0!	0.01	**0.75**	0.07	0.00	0.11	**0.92**	0.08	0.00	0.03	**1.00**	#DIV/0!	#DIV/0!	**0.53**
	Slope	-1.00	0.00	-0.10	-0.30	-0.30	0.10	0.50	-2.00	-0.20	0.10	-0.30	1.00	#DIV/0!	#DIV/0!	-0.37
Composite	Average	13.69	11.40	14.83	14.33	10.54	13.85	12.56	15.17	11.36	13.10	12.97	13.42	15.00	13.67	13.25
	RSQ	0.02	**0.94**	0.09	0.01	**0.47**	0.16	**0.54**	0.09	0.04	0.09	0.15	**0.51**	0.01	**1.00**	0.18
	Slope	-0.07	-1.05	-0.10	0.03	-0.39	-0.21	-0.30	-0.08	0.08	-0.10	-0.12	0.26	-0.04	-0.38	-0.08

Table C2. Average of Epibenthic Substrate

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			15						16	11	16	12	13		13.83
	1995	16		13					16.5	16	13	9	14.5	13.5		13.94
	1996	18		13					17	17	17	13	10	13		14.75
	1997	16		17	13					18	15	12				15.17
	1998			17	14	14	18	11		18	17	10	12	11	9	13.73
	1999	11		16	16	16	16	14		16	13	13	16			14.70
	2000	12		15	13	16	15	12		18				10		13.88
Construction	2001								16	19					16	17.00
	2002	14		12	12	11						9	10	14		11.71
	2003	16		12	10	14	16	13		14	11	12	8	8		12.18
	2004	14		11	13	13.5	14		10	15	15	13	13	15		13.32
	2005	15	15	11	13	13	17	9	16	16	16	12	12	16		13.92
	2006	12	13	13	13	16	15	16	16.3	13.5	13	15	12	11	9	13.41
	2007	17		10	17	17	17		17	17		13				15.63
Stabilization	2008	15		11	16	16	15		16	16	15	14				14.89
	2009	13		8	12	11	15		15	14	15	13				12.89
	2010	17	17	11	17	12	14	15	14	13	13	12				14.09
	2011	17	17	12	15	16	16	15		17	15	13	11			14.91
	2012	10	14	9	10	12	14	13		17	14	15	16			13.09

Pre-development	Average	14.60	#DIV/0!	15.14	14.00	15.33	16.33	12.33	16.75	17.00	14.33	12.17	12.90	12.10	9.00	14.28
	RSQ	**0.74**	#DIV/0!	0.21	0.03	**0.75**	**0.96**	0.11	**1.00**	0.29	0.19	0.08	0.16	**0.89**	#DIV/0!	0.01
	Slope	-1.23	#DIV/0!	0.36	0.20	1.00	-1.50	0.50	0.50	0.25	0.57	-0.37	0.45	-0.59	#DIV/0!	0.02
Construction	Average	14.67	14.00	11.50	13.00	14.08	15.80	12.67	15.06	15.75	13.75	12.33	11.00	12.80	12.50	13.88
	RSQ	0.01	**1.00**	0.13	**0.64**	**0.78**	0.13	0.06	0.06	0.15	0.17	**0.58**	**0.40**	0.01	**1.00**	0.00
	Slope	0.11	-2.00	-0.20	0.97	1.01	0.30	0.57	0.30	-0.36	0.70	0.80	0.80	0.20	-1.40	0.04
Stabilization	Average	14.40	16.00	10.20	14.00	13.40	14.80	14.33	15.00	15.40	14.40	13.40	13.50	#DIV/0!	#DIV/0!	13.97
	RSQ	0.10	**0.75**	0.00	0.24	0.04	0.04	**0.75**	**1.00**	0.19	0.13	0.08	**1.00**	#DIV/0!	#DIV/0!	0.07
	Slope	-0.60	-1.50	0.00	-0.90	-0.30	-0.10	-1.00	-1.00	0.50	-0.20	0.20	5.00	#DIV/0!	#DIV/0!	-0.16
Composite	Average	14.56	15.20	12.56	13.60	14.11	15.54	13.11	15.38	16.14	14.20	12.59	12.21	12.45	11.33	14.05
	RSQ	0.03	0.17	**0.58**	0.00	0.04	0.24	0.17	0.07	0.14	0.00	0.08	0.01	0.00	0.02	0.01
	Slope	-0.07	0.24	-0.34	0.03	-0.09	-0.13	0.17	-0.10	-0.11	0.02	0.09	0.03	0.01	-0.14	-0.02

Table C3. Average of Embeddedness

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			14						14	16	13	15	8		13.33
	1995	9.5		10					14.5	10.5	10.5	5.5	9	10		9.94
	1996	14		16					15	10	14	13	12	11		13.13
	1997	16		15	13					13	12	11				13.33
	1998			13	14	14	16	10		15	10	13	13	12	9	12.64
	1999	16		16	14	15	14	14		9	15	13	12			13.80
	2000	16		17	13	14	16	12		14				15		14.63
Construction	2001								17	12					11	13.33
	2002	18		16	8	16						14	8	11		13.00
	2003	16		10	5	14	16	14		13	15	14	8	8		12.09
	2004	14		7	9	12.5	16		9	15	15	14	16	14		12.86
	2005	16	15	13	14	13	12	8	15	16	16	14	13	15		13.85
	2006	16	13	15	10	12	12	10	14.7	13	6	13	14	14	9	12.26
	2007	9		12	16	9	12		10	8		12				11.00
Stabilization	2008	13		2	10	10	12		9	6	12	8				9.11
	2009	12		6	7	6	7		11	12	12	11				9.33
	2010	13	13	6	8	7	12	9	10	10	10	4				9.27
	2011	12	15	8	9	10	12	13		12	9	8	6			10.36
	2012	10	16	10	8	10	11	9		10	14	7	10			10.45

Pre-development	Average	14.30	#DIV/0!	14.43	13.50	14.33	15.33	12.00	14.75	12.21	12.92	11.42	12.20	11.20	9.00	12.97
	RSQ	**0.62**	#DIV/0!	0.34	0.00	0.00	0.00	0.25	**1.00**	0.00	0.03	0.13	0.01	**0.96**	#DIV/0!	0.34
	Slope	1.07	#DIV/0!	0.64	0.00	0.00	0.00	1.00	0.50	0.07	-0.24	0.59	-0.08	1.05	#DIV/0!	0.40
Construction	Average	14.83	14.00	12.17	10.33	12.75	13.60	10.67	13.14	12.83	13.00	13.50	11.80	12.40	10.00	12.63
	RSQ	**0.54**	**1.00**	0.00	**0.63**	**0.87**	**0.75**	**0.62**	0.25	0.08	**0.51**	**0.69**	**0.55**	**0.51**	**1.00**	0.31
	Slope	-1.23	-2.00	0.03	1.71	-1.16	-1.20	-1.57	-0.76	-0.37	-2.60	-0.37	1.70	1.30	-0.40	-0.24
Stabilization	Average	12.00	14.67	6.40	8.40	8.60	10.80	10.33	10.00	10.00	11.40	7.60	8.00	#DIV/0!	#DIV/0!	9.71
	RSQ	**0.60**	**0.96**	**0.92**	0.08	0.11	0.05	0.00	0.25	0.27	0.01	0.10	**1.00**	#DIV/0!	#DIV/0!	**0.83**
	Slope	-0.60	1.50	1.80	-0.20	0.40	0.30	0.00	0.50	0.80	0.10	-0.50	4.00	#DIV/0!	#DIV/0!	0.37
Composite	Average	13.78	14.40	11.44	10.53	11.61	12.92	11.00	12.52	11.81	12.43	11.03	11.33	11.80	9.67	11.99
	RSQ	0.12	0.15	0.37	0.22	**0.67**	**0.53**	0.13	0.40	0.07	0.07	0.14	0.10	0.33	0.02	0.37
	Slope	-0.17	0.16	-0.46	-0.31	-0.55	-0.42	-0.16	-0.36	-0.12	-0.13	-0.21	-0.17	0.35	-0.04	-0.19

KEY:

1. **Bold Green** numbers indicate an R-square value in excess of 0.4. This would be considered a moderate to strong trend.

Attachment C
Montgomery County Habitat Assessment
Data Summary

Table C4. Average of Channel Alteration

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			18						16	17	17	17	13		16.33
	1995	18.5		17					18.5	16	16.5	17	15.5	18		17.13
	1996	18		19					19	16	18	18	18	17		17.88
	1997	19		19	19					18	19	17				18.50
	1998			19	19	19	18	19		17	19	17	14	18	16	17.73
	1999	18		18	18	18	17	18		16	18	18	14			17.30
	2000	19		19	17	18	18	19		17				17		18.00
Construction	2001								19	19					17	18.33
	2002	19		18	16	18						18	15	19		17.57
	2003	18		16	15	16	16	19		18	16	15	14	16		16.27
	2004	18		15	18	17	16		18	17	15	18	18	19		17.18
	2005	18	18	18	19	18	18	15	18	18	18	15	13	18		17.23
	2006	18	18	18	18	18	16	18	18	18	18	17	17	18	16	17.57
	2007	19		13	16	17	18		16	17		19				16.88
Stabilization	2008	19		18	18	17	16		16	14	18	19				17.22
	2009	17		16	17	17	16		18	16	17	18				16.89
	2010	18	17	18	17	17	15	19	20	10	17	19				17.00
	2011	18	18	17	15	18	18	18		17	15	19	18			17.36
	2012	19	17	15	17	17	18	19		16	17	19	17			17.36

Pre-development	Average	18.50	#DIV/0!	18.43	18.25	18.33	17.67	18.67	18.75	16.57	17.92	17.33	15.70	16.60	16.00	17.55
	RSQ	0.06	#DIV/0!	0.24	**0.89**	**0.75**	0.00	0.00	**1.00**	0.15	**0.50**	0.17	**0.54**	0.26	#DIV/0!	0.33
	Slope	0.06	#DIV/0!	0.18	-0.70	-0.50	0.00	0.00	0.50	0.14	0.39	0.11	-0.63	0.44	#DIV/0!	0.19
Construction	Average	18.33	18.00	16.33	17.00	17.33	16.80	17.33	17.80	17.83	16.75	17.00	15.40	18.00	16.50	17.29
	RSQ	0.00	#DIV/0!	0.17	0.12	0.02	0.33	0.18	**0.69**	**0.49**	**0.60**	0.07	0.05	0.00	**1.00**	0.17
	Slope	0.00	0.00	-0.46	0.29	0.06	0.40	-0.57	-0.40	-0.24	0.90	0.23	0.30	0.00	-0.20	-0.12
Stabilization	Average	18.20	17.33	16.80	16.80	17.20	16.60	18.67	18.00	14.60	16.80	18.80	17.50	#DIV/0!	#DIV/0!	17.17
	RSQ	0.04	0.00	0.37	0.33	0.13	**0.50**	0.00	**1.00**	0.08	0.33	0.13	**1.00**	#DIV/0!	#DIV/0!	0.31
	Slope	0.10	0.00	-0.50	-0.40	0.10	0.60	0.00	2.00	0.50	-0.40	0.10	-1.00	#DIV/0!	#DIV/0!	0.08
Composite	Average	18.34	17.60	17.28	17.27	17.50	16.92	18.22	18.05	16.44	17.23	17.65	15.88	17.30	16.33	17.35
	RSQ	0.02	**0.42**	0.25	0.19	0.22	0.04	0.00	0.09	0.08	0.12	0.20	0.04	0.27	0.02	0.05
	Slope	-0.02	-0.11	-0.14	-0.12	-0.08	-0.05	-0.01	-0.07	-0.10	-0.07	0.10	0.06	0.21	-0.02	-0.02

Table C5. Average of Sediment Deposit

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			12						15	11	12	14	12		12.67
	1995	8		10.5					14	11	12.5	7.5	6.5	9.5		9.94
	1996	11		8					13	9	14	15	10	10		11.25
	1997	15		14	12					10	11	9				11.83
	1998			12	10	13	14	9		16	10	13	9	12	12	11.82
	1999	14		15	14	14	14	12		6	11	10	8			11.80
	2000	14		15	9	16	16	11		14				14		13.63
Construction	2001								15	8					9	10.67
	2002	13		15	9	17						12	9	11		12.29
	2003	15		5	6	15	16	13		13	14	14	9	13		12.09
	2004	13		11	7	14.5	9		14	13	14	10	13	9		11.59
	2005	15	15	3	12	9	8	15	14	16	12	10	11	15		11.92
	2006	15	12	15	11	9	10	8	12.7	11.5	4	10	15	14	12	11.37
	2007	9		14	8	8	11		7	11		10				9.75
Stabilization	2008	9		6	6	8	12		7	8	11	7				8.22
	2009	8		7	10	9	10		7	11	9	7				8.67
	2010	11	15	9	7	8	13	11	6	11	11	6				9.82
	2011	9	12	11	7	8	6	6		13	9	9	6			8.73
	2012	8	10	10	6	8	5	6		14	9	8	9			8.45

Pre-development	Average	12.40	#DIV/0!	12.36	11.25	14.33	14.67	10.67	13.50	11.57	11.58	11.08	9.50	11.50	12.00	11.85
	RSQ	**0.58**	#DIV/0!	**0.44**	0.08	**0.96**	**0.75**	**0.43**	**1.00**	0.02	0.15	0.00	0.24	**0.48**	#DIV/0!	0.23
	Slope	1.06	#DIV/0!	0.79	-0.50	1.50	1.00	1.00	-1.00	-0.21	-0.30	0.01	-0.67	0.52	#DIV/0!	0.26
Construction	Average	13.33	13.50	10.50	8.83	12.08	10.80	12.00	12.54	12.08	11.00	11.00	11.40	12.40	10.50	11.38
	RSQ	0.17	**1.00**	0.03	0.12	**0.90**	0.21	0.30	**0.57**	0.14	**0.75**	**0.49**	**0.72**	0.28	**1.00**	0.17
	Slope	-0.51	-3.00	0.49	0.43	-1.96	-0.90	-1.29	-1.05	0.46	-3.20	-0.63	1.40	0.80	0.60	-0.17
Stabilization	Average	9.00	12.33	8.60	7.20	8.20	9.20	7.67	6.67	11.40	9.80	7.40	7.50	#DIV/0!	#DIV/0!	8.78
	RSQ	0.02	**0.99**	**0.84**	0.08	0.13	**0.64**	**0.75**	**0.75**	**0.92**	0.33	0.31	**1.00**	#DIV/0!	#DIV/0!	0.02
	Slope	-0.10	-2.50	1.20	-0.30	-0.10	-1.80	-2.50	-0.50	1.40	-0.40	0.40	3.00	#DIV/0!	#DIV/0!	0.05
Composite	Average	11.69	12.80	10.69	8.93	11.18	11.08	10.11	10.97	11.69	10.83	9.97	9.96	11.95	11.00	10.87
	RSQ	0.15	0.28	0.08	0.35	**0.66**	**0.50**	0.24	**0.53**	0.00	0.16	0.30	0.01	0.21	0.02	**0.46**
	Slope	-0.20	-0.37	-0.18	-0.31	-0.63	-0.54	-0.29	-0.52	0.03	-0.17	-0.24	-0.04	0.22	0.06	-0.19

Table C6. Average of Riffle Frequency

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			13						17	19	16	15	16		16.00
	1995	17		15.5					19	16.5	16.5	10.5	13.5	13.5		15.25
	1996	17		19					18	17	17	16	15	15		16.75
	1997	18		18	17					19	19	16				17.83
	1998			17	16	18	19	12		18	17	14	15	13	6	15.00
	1999	16		17	18	17	16	16		17	16	14	13			16.00
	2000	16		17	13	19	19	15		19				14		16.50
Construction	2001								19	19					9	15.67
	2002	18		17	15	17						14	14	16		15.86
	2003	19		13	14	16	19	16		16	14	8	15	13		14.82
	2004	15		14	16	17.5	18		14	15	14	16	15	13		15.23
	2005	17	18	12	18	17	17	10	17	18	17	13	13	17		15.69
	2006	17	17	16	16	18	19	18	17.3	16	14	14	15	12	8	15.52
	2007	18		4	15	17	17		17	14		13				14.38
Stabilization	2008	12		17	17	17	17		16	11	16	8				14.56
	2009	16		14	8	17	19		14	13	13	12				14.00
	2010	17	18	13	17	17	17	19	16	14	17	16				16.45
	2011	17	18	14	17	18	17	18		18	16	16	14			16.64
	2012	18	15	18	18	16	14	14		14	18	16	17			16.18

Pre-development	Average	16.80	#DIV/0!	16.64	16.00	18.00	18.00	14.33	18.50	17.64	17.42	14.42	14.30	14.30	6.00	16.19
	RSQ	**0.44**	#DIV/0!	0.27	0.36	0.25	0.00	**0.52**	**1.00**	0.36	0.23	0.00	0.15	0.30	#DIV/0!	0.01
	Slope	-0.27	#DIV/0!	0.46	-1.00	0.50	0.00	1.50	-1.00	0.29	-0.33	0.01	-0.18	-0.28	#DIV/0!	0.04
Construction	Average	17.33	17.50	12.67	15.67	17.08	18.00	14.67	16.86	16.33	14.75	13.00	14.40	14.20	8.50	15.31
	RSQ	0.02	**1.00**	**0.45**	0.10	0.20	0.23	0.00	0.09	**0.46**	0.07	0.04	0.00	0.09	**1.00**	0.28
	Slope	-0.11	-1.00	-1.66	0.23	0.16	-0.30	0.14	-0.23	-0.59	0.30	0.29	0.00	-0.40	-0.20	-0.13
Stabilization	Average	16.00	17.00	15.20	15.40	17.00	16.80	17.00	15.33	14.00	16.00	13.60	15.50	#DIV/0!	#DIV/0!	15.57
	RSQ	**0.77**	**0.75**	0.02	0.17	0.05	**0.50**	**0.89**	0.00	**0.47**	0.35	**0.78**	**1.00**	#DIV/0!	#DIV/0!	**0.60**
	Slope	1.30	-1.50	0.20	1.10	-0.10	-0.80	-2.50	0.00	1.10	0.70	2.00	3.00	#DIV/0!	#DIV/0!	0.59
Composite	Average	16.75	17.20	14.92	15.67	17.25	17.54	15.33	16.73	16.19	16.23	13.68	14.54	14.25	7.67	15.70
	RSQ	0.01	0.18	0.08	0.00	0.12	0.21	0.14	**0.45**	0.34	0.15	0.00	0.09	0.04	0.29	0.07
	Slope	-0.04	-0.18	-0.17	-0.02	-0.06	-0.15	0.21	-0.23	-0.23	-0.11	-0.02	0.06	-0.07	0.20	-0.04

KEY:

1. **Bold Green** numbers indicate an R-square value in excess of 0.4. This would be considered a moderate to strong trend.

Attachment C

Montgomery County Habitat Assessment

Data Summary

Table C7. Average of Channel Flow

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			16						19	14	16	17	15		16.17
	1995	10		15.5					15	17	11.5	15	13.5	11.5		13.63
	1996	10		15					16	17	17	16	14	15		15.00
	1997	14		15	13					17	16	17				15.33
	1998			15	10	11	14	11		18	15	16	15	17	17	14.45
	1999	13		15	15	15	15	17		18	15	17	15			15.50
	2000	14		16	13	14	15	16		18				14		15.00
Construction	2001								15	19					17	17.00
	2002	11		12	12	10						15	11	12		11.86
	2003	15		14	12	12	17	15		19	15	13	14	13		14.45
	2004	15		13	14	14	14		14	15	14	16	14	12		14.09
	2005	14	17	13	17	15	14	11	15	17	16	14	13	15		14.69
	2006	10	14	14	14	14	14	14	15.3	15	17	16	15	16	17	14.66
	2007	14		11	15	13	14		12	17		17				14.13
Stabilization	2008	10		16	15	15	15		9	12	15	17				13.78
	2009	11		9	9	12	10		13	14	9	14				11.22
	2010	11	15	9	9	14	9	16	9	18	14	13				12.45
	2011	9	11	9	10	12	9	12		19	15	18	16			12.73
	2012	8	15	11	9	10	9	12		13	9	15	16			11.55

Pre-development	Average	12.20	#DIV/0!	15.36	12.75	13.33	14.67	14.67	15.50	17.71	14.75	16.17	14.90	14.50	17.00	15.01
	RSQ	**0.64**	#DIV/0!	0.03	0.10	**0.52**	**0.75**	**0.60**	**1.00**	0.00	0.17	**0.41**	0.04	0.07	#DIV/0!	0.00
	Slope	0.79	#DIV/0!	-0.04	0.50	1.50	0.50	2.50	1.00	0.00	0.41	0.26	-0.13	0.22	#DIV/0!	-0.01
Construction	Average	13.17	15.50	12.83	14.00	13.00	14.60	13.33	14.26	17.00	15.50	15.17	13.40	13.60	17.00	14.41
	RSQ	0.00	**1.00**	0.05	**0.46**	**0.43**	**0.50**	0.18	0.25	0.39	**0.64**	0.38	**0.53**	**0.76**	#DIV/0!	0.02
	Slope	-0.03	-3.00	-0.14	0.69	0.63	-0.60	-0.57	-0.29	-0.51	0.80	0.49	0.70	1.00	0.00	-0.10
Stabilization	Average	9.80	13.67	10.80	10.40	12.60	10.40	13.33	10.33	15.20	12.40	15.40	16.00	#DIV/0!	#DIV/0!	12.35
	RSQ	**0.53**	0.00	0.27	**0.44**	**0.66**	**0.62**	**0.75**	0.00	0.13	0.09	0.00	#DIV/0!	#DIV/0!	#DIV/0!	0.21
	Slope	-0.60	0.00	-1.00	-1.10	-1.00	-1.30	-2.00	0.00	0.70	-0.60	0.00	0.00	#DIV/0!	#DIV/0!	-0.30
Composite	Average	11.81	14.40	13.25	12.47	12.93	13.00	13.78	13.33	16.78	14.17	15.59	14.46	14.05	17.00	14.09
	RSQ	0.11	0.25	**0.61**	0.12	0.01	**0.56**	0.06	**0.50**	0.22	0.11	0.02	0.01	0.00	#DIV/0!	**0.43**
	Slope	-0.14	-0.35	-0.34	-0.18	-0.04	-0.45	-0.11	-0.35	-0.17	-0.13	-0.04	0.03	-0.01	0.00	-0.18

Table C8. Average of Bank Vegetation

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			9						8	7	7.5	7.5	8.5		7.92
	1995	7		8					8.5	7	7	6	5.25	8		7.09
	1996	7		7					7	6.5	5.5	5.5	7	9		6.81
	1997	5.5		6	8					5	8	4				6.08
	1998			8	3	7	9	7		8	8	7	6	8	6.5	7.05
	1999	8		8.5	8.5	9	9	9		8	8	6	6.5			8.05
	2000	3		8	5	6	8	8		7				8		6.63
Construction	2001								8	8					6.5	7.50
	2002	7		7	5	5						5.5	5	4		5.50
	2003	8		5	4	4	8	8		5.5	7	5	6	8		6.23
	2004	7		6	7	5	5		8	5	5	5	8	7		6.18
	2005	8	9	8	8	6.5	7.5	8	8	8	8	6	7	9		7.77
	2006	8	8	8	6	5.5	7	6	7.8	5.5	6.5	5.5	6	7	4.5	6.52
	2007	6.5		7	7	6.5	6.5		6	4		3.5				5.88
Stabilization	2008	6		5	5	6.5	6.5		5	3.5	5	6				5.39
	2009	6.5		5	5.5	3.5	8		6	5.5	5.5	4				5.50
	2010	5	7.5	4.5	4	5.5	5	7	8	7	4.5	4				5.64
	2011	7.5	3	5	4	4	5.5	6		5	5	5	4			4.91
	2012	5	4.5	2.5	3.5	4.5	6	5.5		5	3.5	2	4			4.18

Pre-development	Average	6.10	#DIV/0!	7.79	6.13	7.33	8.67	8.00	7.75	7.07	7.25	6.00	6.45	8.30	6.50	7.09
	RSQ	0.26	#DIV/0!	0.01	0.03	0.11	**0.75**	0.25	**1.00**	0.00	0.32	0.07	0.05	0.19	#DIV/0!	0.04
	Slope	-0.48	#DIV/0!	-0.04	-0.35	-0.50	-0.50	0.50	-1.50	0.02	0.30	-0.17	-0.10	-0.08	#DIV/0!	-0.06
Construction	Average	7.42	8.50	6.83	6.17	5.42	6.80	7.33	7.56	6.00	6.63	5.08	6.40	7.00	5.50	6.51
	RSQ	0.01	**1.00**	0.25	0.38	**0.55**	0.02	**0.57**	0.40	0.35	0.02	0.22	0.17	0.35	**1.00**	0.01
	Slope	-0.04	-1.00	0.31	0.49	0.39	-0.10	-0.57	-0.24	-0.45	0.15	-0.21	0.30	0.70	-0.40	-0.05
Stabilization	Average	6.00	5.00	4.40	4.40	4.80	6.20	6.17	6.33	5.20	4.70	4.20	4.00	#DIV/0!	#DIV/0!	5.12
	RSQ	0.02	**0.43**	**0.53**	**0.75**	0.21	0.23	**0.96**	**0.96**	0.10	**0.53**	**0.56**	#DIV/0!	#DIV/0!	#DIV/0!	**0.64**
	Slope	-0.10	-1.50	-0.50	-0.45	-0.35	-0.35	-0.75	1.50	0.25	-0.35	-0.70	0.00	#DIV/0!	#DIV/0!	-0.30
Composite	Average	6.56	6.40	6.53	5.57	5.61	7.00	7.17	7.23	6.19	6.23	5.15	6.02	7.65	5.83	6.36
	RSQ	0.01	**0.71**	**0.53**	0.13	0.32	**0.53**	**0.53**	0.19	0.30	**0.48**	**0.41**	0.29	0.11	**0.86**	**0.55**
	Slope	-0.02	-0.69	-0.22	-0.13	-0.18	-0.22	-0.16	-0.10	-0.14	-0.16	-0.15	-0.12	-0.11	-0.27	-0.14

Table C9. Minimum of Bank Vegetation

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			9						8	6	7	7	8		7.50
	1995	7		8					8.5	6.5	6.5	6	5	7.5		6.88
	1996	7		7					7	6	5	5	5	9		6.38
	1997	5		6	8					5	8	3				5.83
	1998			8	3	7	9	7		8	8	7	6	8	6	7.00
	1999	8		8	8	9	9	9		8	8	6	6			7.90
	2000	3		8	5	5	8	8		7				8		6.50
Construction	2001								8	8					6	7.33
	2002	7		7	4	5						5	5	4		5.29
	2003	8		5	4	4	8	8		5	7	5	6	8		6.18
	2004	7		6	7	5	5		8	5	5	5	8	7		6.18
	2005	8	9	8	8	6	7	8	8	8	8	6	7	9		7.69
	2006	8	8	8	6	5	7	6	7.7	5.5	6	5	6	7	4	6.37
	2007	6		7	7	6	6		5	4		3				5.50
Stabilization	2008	5		5	5	6	6		5	3	5	5				5.00
	2009	6		4	5	3	8		6	5	5	4				5.11
	2010	4	7	4	4	5	5	7	8	7	4	4				5.36
	2011	7	3	5	3	4	5	6		5	5	5	4			4.73
	2012	5	4	2	3	4	6	5		5	3	2	4			3.91

Pre-development	Average	6.00	#DIV/0!	7.71	6.00	7.00	8.67	8.00	7.75	6.93	6.92	5.67	5.80	8.10	6.00	6.85
	RSQ	0.23	#DIV/0!	0.03	0.04	0.25	**0.75**	0.25	**1.00**	0.02	**0.53**	0.02	0.01	0.00	#DIV/0!	0.00
	Slope	-0.47	#DIV/0!	-0.07	-0.40	-1.00	-0.50	0.50	-1.50	0.07	0.50	-0.11	-0.03	0.01	#DIV/0!	-0.01
Construction	Average	7.33	8.50	6.83	6.00	5.17	6.60	7.33	7.34	5.92	6.50	4.83	6.40	7.00	5.00	6.36
	RSQ	0.07	**1.00**	0.25	**0.49**	**0.41**	0.08	**0.57**	0.40	0.29	0.00	0.24	0.17	0.35	**1.00**	0.03
	Slope	-0.11	-1.00	0.31	0.63	0.26	-0.20	-0.57	-0.36	-0.42	0.00	-0.26	0.30	0.70	-0.40	-0.06
Stabilization	Average	5.40	4.67	4.00	4.00	4.40	6.00	6.00	6.33	5.00	4.40	4.00	4.00	#DIV/0!	#DIV/0!	4.82
	RSQ	0.02	**0.52**	**0.42**	**0.90**	0.17	0.15	**1.00**	**0.96**	0.20	**0.50**	**0.42**	#DIV/0!	#DIV/0!	#DIV/0!	**0.53**
	Slope	0.10	-1.50	-0.50	-0.60	-0.30	-0.30	-1.00	1.50	0.40	-0.40	-0.50	0.00	#DIV/0!	#DIV/0!	-0.26
Composite	Average	6.31	6.20	6.39	5.33	5.29	6.85	7.11	7.12	6.06	5.97	4.88	5.75	7.55	5.33	6.14
	RSQ	0.03	**0.80**	**0.55**	0.15	0.37	**0.56**	**0.55**	0.19	0.26	0.37	0.33	0.11	0.06	**0.86**	**0.51**
	Slope	-0.05	-0.74	-0.24	-0.15	-0.20	-0.24	-0.18	-0.11	-0.14	-0.16	-0.13	-0.07	-0.08	-0.27	-0.14

KEY:

1. **Bold Green** numbers indicate an R-square value in excess of 0.4. This would be considered a moderate to strong trend.

Table C10. Average of Bank Stability

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			6.5						8.5	7	7	8	6.5		7.25
	1995	6.5		7.25					9	8.5	6.75	6	5.75	6.5		7.03
	1996	5		6					9	7	5	6	5	8		6.38
	1997	5.5		6	6					6	6	5				5.75
	1998			6	3	7.5	6	6		8	7	4	5	7	5.5	5.91
	1999	5.5		8	6	6	8	8		9	6	5.5	6.5			6.85
	2000	3		8	5	6	7	7.5		7				7		6.31
Construction	2001								9	4.5					6	6.50
	2002	4.5		6	4.5	5						5	5	3.5		4.79
	2003	6		6	4	4	7	7		5	7	4	5	7		5.64
	2004	7		6	7	5.25	5		7	4	4	4	7	5		5.57
	2005	7	9	7	5	5.5	6	7	8	7	7	7	6	7		6.81
	2006	6	8	8	4	5	5	6	8.8	5.5	7	4	7.5	5.5	5.5	6.13
	2007	5.5		7	4	6	7		8	5.5		3.5				5.81
Stabilization	2008	6.5		4.5	5	6	7		7	4	7	5				5.78
	2009	4.5		5.5	5	3	3.5		6	6	3.5	3.5				4.50
	2010	5.5	8	6	4	5.5	5	7	8.5	6.5	5	3.5				5.86
	2011	5.5	3.5	6	3.5	4	6	8		7	8	3	5			5.41
	2012	6	4.5	3.5	3.5	4	4	4.5		5.5	3.5	3	3			4.09

Pre-development	Average	5.10	#DIV/0!	6.82	5.00	6.50	7.00	7.17	9.00	7.71	6.29	5.58	6.05	7.00	5.50	6.50
	RSQ	**0.58**	#DIV/0!	0.25	0.00	**0.75**	0.25	**0.52**	#DIV/0!	0.03	0.05	**0.58**	0.17	0.06	#DIV/0!	0.25
	Slope	-0.48	#DIV/0!	0.21	0.00	-0.75	0.50	0.75	0.00	-0.09	-0.09	-0.41	-0.25	0.06	#DIV/0!	-0.13
Construction	Average	6.00	8.50	6.67	4.75	5.13	6.00	6.67	8.16	5.25	6.25	4.58	6.10	5.60	5.75	5.89
	RSQ	0.08	**1.00**	**0.62**	0.04	**0.44**	0.00	**0.57**	0.07	0.24	0.07	0.04	**0.69**	0.18	**1.00**	0.04
	Slope	0.14	-1.00	0.34	-0.13	0.24	0.00	-0.29	-0.09	0.24	0.30	-0.13	0.60	0.40	-0.10	0.06
Stabilization	Average	5.60	5.33	5.10	4.20	4.50	5.10	6.50	7.17	5.80	5.40	3.60	4.00	#DIV/0!	#DIV/0!	5.13
	RSQ	0.00	**0.55**	0.05	**0.88**	0.15	0.15	**0.48**	0.36	0.30	0.04	**0.75**	**1.00**	#DIV/0!	#DIV/0!	0.24
	Slope	0.00	-1.75	-0.15	-0.45	-0.30	-0.35	-1.25	0.75	0.40	-0.25	-0.45	-2.00	#DIV/0!	#DIV/0!	-0.25
Composite	Average	5.59	6.60	6.29	4.63	5.20	5.88	6.78	8.03	6.36	5.98	4.65	5.73	6.30	5.67	5.91
	RSQ	0.02	**0.67**	0.19	0.14	0.37	0.34	0.09	0.36	0.27	0.07	**0.52**	0.18	0.16	0.02	**0.44**
	Slope	0.03	-0.64	-0.09	-0.08	-0.16	-0.17	-0.06	-0.12	-0.14	-0.06	-0.16	-0.10	-0.12	-0.01	-0.10

Table C11. Minimum of Bank Stability

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			6						8	6	7	8	6		6.83
	1995	6.5		7					9	8.5	6.5	6	5.5	6		6.88
	1996	5		6					9	6	5	6	4	8		6.13
	1997	5		6	6					6	6	4				5.50
	1998			6	3	7	6	6		8	7	4	5	7	5	5.82
	1999	5		8	6	6	8	8		9	6	5	6			6.70
	2000	3		8	5	5	7	7		7				7		6.13
Construction	2001								9	4					5	6.00
	2002	4		6	3	5						5	5	3		4.43
	2003	6		6	4	4	7	7		5	7	4	5	7		5.64
	2004	7		6	7	5	5		7	4	4	4	7	5		5.55
	2005	7	9	7	5	5	5	7	8	7	7	7	6	7		6.69
	2006	6	8	8	4	5	4	6	8.7	5.5	6	4	7	5	5	5.87
	2007	5		6	4	5	6		8	4		3				5.13
Stabilization	2008	6		4	5	5	6		7	4	6	5				5.33
	2009	4		4	4	2	2		5	5	3	3				3.56
	2010	4	8	5	4	4	5	7	8	6	4	3				5.27
	2011	5	3	6	3	4	5	8		6	8	2	4			4.91
	2012	5	4	3	3	3	3	4		5	3	3	3			3.55

Pre-development	Average	4.90	#DIV/0!	6.71	5.00	6.00	7.00	7.00	9.00	7.50	6.08	5.33	5.70	6.80	5.00	6.28
	RSQ	**0.73**	#DIV/0!	**0.42**	0.00	**1.00**	0.25	0.25	#DIV/0!	0.00	0.04	**0.63**	0.16	0.20	#DIV/0!	0.16
	Slope	-0.51	#DIV/0!	0.29	0.00	-1.00	0.50	0.50	0.00	0.00	0.07	-0.51	-0.28	0.16	#DIV/0!	-0.10
Construction	Average	5.83	8.50	6.50	4.50	4.83	5.40	6.67	8.14	4.92	6.00	4.50	6.00	5.40	5.00	5.61
	RSQ	0.05	**1.00**	0.20	0.01	0.15	0.17	**0.57**	0.08	0.06	0.00	0.07	**0.63**	0.14	#DIV/0!	0.02
	Slope	0.14	-1.00	0.20	0.09	0.09	-0.30	-0.29	-0.10	0.14	0.00	-0.20	0.50	0.40	0.00	0.05
Stabilization	Average	4.80	5.00	4.40	3.80	3.60	4.20	6.33	6.67	5.20	4.80	3.20	3.50	#DIV/0!	#DIV/0!	4.52
	RSQ	0.04	**0.57**	0.00	**0.89**	0.08	0.08	**0.52**	0.11	0.32	0.01	**0.52**	**1.00**	#DIV/0!	#DIV/0!	0.15
	Slope	-0.10	-2.00	0.00	-0.50	-0.20	-0.30	-1.50	0.50	0.30	-0.10	-0.50	-1.00	#DIV/0!	#DIV/0!	-0.22
Composite	Average	5.22	6.40	6.00	4.40	4.64	5.31	6.67	7.87	6.00	5.63	4.41	5.46	6.10	5.00	5.57
	RSQ	0.01	**0.67**	0.27	0.17	**0.57**	**0.48**	0.09	**0.40**	0.35	0.11	**0.48**	0.17	0.10	#DIV/0!	**0.50**
	Slope	-0.02	-0.71	-0.12	-0.11	-0.20	-0.25	-0.07	-0.15	-0.16	-0.08	-0.17	-0.10	-0.11	0.00	-0.12

Table C12. Minimum of Buffer

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			10						9	8	8	2	9		7.67
	1995	9		9.5					9.5	3	7	4.5	2	8		6.56
	1996	7		10					8	8	6	6	3	9		7.13
	1997	9		10	9					7	7	4				7.67
	1998			8	9	10	6	8		6	9	6	3	5	7	7.00
	1999	10		10	10	10	7	9		8	9	5	1			7.90
	2000	9		8	8	10	6	8		5				6		7.50
Construction	2001								9	5					6	6.67
	2002	8		8	7	10						3	3	9		6.86
	2003	10		8	5	8	7	8		6	7	8	1	10		7.09
	2004	10		9	8	7	4		9	5	9	5	2	9		7.00
	2005	10	10	8	8	8	4	8	9	5	9	9	2	5		7.31
	2006	10	10	8	7	7	4	9	7.7	5.5	8	6	4	5	6	6.94
	2007	4		5	8	6	4		9	3		8				5.88
Stabilization	2008	5		9	6	5	5		8	5	7	9				6.56
	2009	5		6	7	8	5		8	6	7	7				6.56
	2010	8	10	6	8	6	3	8	10	7	7	7				7.27
	2011	8	9	5	6	6	3	9		7	8	6	2			6.27
	2012	8	9	7	6	6	5	8		8	9	9	3			7.09

Pre-development	Average	8.80	#DIV/0!	9.36	9.00	10.00	6.33	8.33	8.75	6.57	7.67	5.58	2.20	7.40	7.00	7.35
	RSQ	0.23	#DIV/0!	0.33	0.10	#DIV/0!	0.00	0.00	**1.00**	0.02	0.28	0.22	0.04	**0.66**	#DIV/0!	0.11
	Slope	0.26	#DIV/0!	-0.25	-0.20	0.00	0.00	0.00	-1.50	-0.14	0.34	-0.36	-0.08	-0.61	#DIV/0!	0.07
Construction	Average	8.67	10.00	7.67	7.17	7.67	4.60	8.33	8.74	4.92	8.25	6.50	2.40	7.60	6.00	6.82
	RSQ	0.19	#DIV/0!	0.39	0.25	**0.74**	**0.50**	**0.57**	0.12	0.28	0.16	0.30	0.17	**0.73**	#DIV/0!	0.11
	Slope	-0.57	0.00	-0.46	0.31	-0.63	-0.60	0.29	-0.09	-0.25	0.30	0.66	0.30	-1.30	0.00	-0.07
Stabilization	Average	6.80	9.33	6.60	6.60	6.20	4.20	8.33	8.67	6.60	7.60	7.60	2.50	#DIV/0!	#DIV/0!	6.75
	RSQ	**0.75**	**0.75**	0.27	0.03	0.00	0.08	0.00	**0.75**	**0.94**	**0.78**	0.01	**1.00**	#DIV/0!	#DIV/0!	0.09
	Slope	0.90	-0.50	-0.50	-0.10	0.00	-0.20	0.00	1.00	0.70	0.50	-0.10	1.00	#DIV/0!	#DIV/0!	0.08
Composite	Average	8.13	9.60	8.03	7.47	7.64	4.85	8.33	8.72	6.03	7.80	6.50	2.33	7.50	6.33	7.00
	RSQ	0.13	**0.63**	**0.62**	0.39	**0.74**	**0.48**	0.00	0.00	0.01	0.02	0.21	0.03	0.09	**0.62**	0.21
	Slope	-0.13	-0.14	-0.23	-0.17	-0.34	-0.20	0.01	-0.01	-0.03	0.02	0.14	0.03	-0.14	-0.11	-0.04

KEY:
1. **Bold Green** numbers indicate an R-square value in excess of 0.4. This would be considered a moderate to strong trend.

Table C13. Average of Buffer

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			10						9	9	8.5	3.5	9		*8.17*
	1995	9		9.75					9.5	3.25	8	4.5	2.5	8.75		*6.91*
	1996	8		10					8.5	8.5	7	6.5	4	9		*7.69*
	1997	9.5		10	9.5					7	8	5.5				*8.25*
	1998			8.5	9	10	8	9		6	9.5	7	3.5	7.5	7.5	*7.77*
	1999	10		10	10	10	8.5	9.5		8.5	9.5	5.5	2.5			*8.40*
	2000	9		9	8.5	10	8	9		5				8		*8.31*
Construction	2001								9.5	5.5					7.5	*7.50*
	2002	8.5		9	8	10						5	3	9		*7.50*
	2003	10		8	6.5	8	8.5	9		6	8	8	3	10		*7.73*
	2004	10		9	8.5	8	6.5		9	7.5	9.5	6	4.5	9		*7.95*
	2005	10	10	9	8.5	8.5	6	8	9	7	9.5	9	5	7		*8.19*
	2006	10	10	9	8	7.5	6	9.5	8	7	9	7	6	7	7.5	*7.96*
	2007	5.5		5.5	8.5	7	6.5		9	4.5		8				*6.81*
Stabilization	2008	5.5		9	7.5	6.5	7		8.5	5	8	9				*7.33*
	2009	7		7	8	8	7		8.5	7	8	7				*7.50*
	2010	8.5	10	7	8	6.5	5.5	9	10	8	8	7.5				*8.00*
	2011	8.5	9	6	7.5	6	6	9.5		7.5	8.5	6.5	4.5			*7.23*
	2012	8.5	9	7.5	7	7	6.5	8.5		8	9	9	6			*7.82*

Pre-development	Average	9.10	#DIV/0!	9.61	9.25	10.00	8.17	9.17	9.00	6.75	8.50	6.25	3.20	8.45	7.50	*7.93*
	RSQ	0.21	#DIV/0!	0.26	0.16	#DIV/0!	0.00	0.00	**1.00**	0.02	0.18	0.10	0.06	**0.62**	#DIV/0!	*0.27*
	Slope	0.16	#DIV/0!	-0.14	-0.20	0.00	0.00	0.00	-1.00	-0.14	0.23	-0.24	-0.08	-0.22	#DIV/0!	*0.13*
Construction	*Average*	*9.00*	*10.00*	*8.25*	*8.00*	*8.17*	*6.70*	*8.83*	*8.90*	*6.25*	*9.00*	*7.17*	*4.30*	*8.40*	*7.50*	*7.66*
	RSQ	0.19	#DIV/0!	0.30	0.23	**0.69**	**0.47**	0.02	**0.40**	0.00	0.30	0.30	**0.94**	**0.68**	#DIV/0!	*0.01*
	Slope	-0.43	0.00	-0.41	0.20	-0.46	-0.45	0.07	-0.15	-0.02	0.30	0.43	0.80	-0.70	0.00	*-0.02*
Stabilization	*Average*	*7.60*	*9.33*	*7.30*	*7.60*	*6.80*	*6.40*	*9.00*	*9.00*	*7.10*	*8.30*	*7.80*	*5.25*	*#DIV/0!*	*#DIV/0!*	*7.58*
	RSQ	**0.78**	**0.75**	0.33	0.32	0.04	0.24	0.25	**0.75**	**0.68**	**0.78**	0.00	**1.00**	#DIV/0!	#DIV/0!	*0.11*
	Slope	0.75	-0.50	-0.40	-0.15	-0.10	-0.20	-0.25	0.75	0.65	0.25	-0.05	1.50	#DIV/0!	#DIV/0!	*0.07*
Composite	Average	8.59	9.60	8.51	8.20	8.07	6.92	9.00	8.95	6.68	8.57	7.03	4.00	8.43	7.50	*7.74*
	RSQ	0.12	**0.63**	**0.60**	**0.44**	**0.81**	**0.56**	0.02	0.01	0.00	0.00	0.21	**0.50**	0.11	#DIV/0!	*0.05*
	Slope	-0.10	-0.14	-0.19	-0.12	-0.29	-0.17	-0.01	-0.01	0.02	0.01	0.11	0.15	-0.08	0.00	*-0.02*

Table C14. Composite Habitat Score

Time Period	Sample Year	LSLS101	LSLS102	LSLS103B	LSLS103C	LSLS104	LSLS109	LSLS110	LSLS202	LSLS203	LSLS204	LSLS205	LSLS206	LSLS303	LSLS413	Average
Pre-development	1994			151						156	145	150	140	141		*147.17*
	1995	135		144.5					166.5	134.5	136.5	111	109.5	135.5		*134.13*
	1996	143		152					163	140	146	143	122	151		*145.00*
	1997	151		159	148					144	152	124				*146.33*
	1998			156	128	152	161	132		161	152	131	121	142	123	*141.73*
	1999	150		167	159	160	159	157		141	149	131	119			*149.20*
	2000	134		165	129	155	161	147		151				145		*148.38*
Construction	2001								170	140					133	*147.67*
	2002	150		149	120	139						127	106	131		*131.71*
	2003	164		123	103	128	164	153		139	143	122	111	134		*134.91*
	2004	151		127	138	136	131		141	134	136	132	143	139		*137.09*
	2005	162	170	133	149	138	137	125	162	160	159	135	127	158		*147.31*
	2006	151	153	157	133	130	132	140	159.2	137.5	132	132	143	139	118	*139.76*
	2007	130		120	141	129	144		139	121		127				*131.38*
Stabilization	2008	126		119	132	130	139		131	104	137	128				*127.33*
	2009	128		110	115	113	131		133	128	123	112				*121.44*
	2010	141	155	114	122	119	123	146	141	130	126	112				*129.91*
	2011	138	131	119	117	117	127	138		148	137	125	112			*128.09*
	2012	120	132	112	110	114	117	122		131	123	119	126			*120.55*

Pre-development	Average	142.60	#DIV/0!	156.36	141.00	155.67	160.33	145.33	164.75	146.79	146.75	131.67	122.30	142.90	123.00	*144.56*
	RSQ	0.00	#DIV/0!	**0.77**	0.05	0.14	0.00	0.36	**1.00**	0.02	**0.44**	0.04	0.15	0.11	#DIV/0!	*0.20*
	Slope	0.22	#DIV/0!	3.25	-2.60	1.50	0.00	7.50	-3.50	0.68	2.07	-1.54	-2.04	0.77	#DIV/0!	*1.09*
Construction	*Average*	*151.33*	*161.50*	*134.83*	*130.67*	*133.33*	*141.60*	*139.33*	*154.24*	*138.58*	*142.50*	*129.17*	*126.00*	*140.20*	*125.50*	138.55
	RSQ	0.32	**1.00**	0.02	**0.44**	0.21	0.21	0.39	0.36	0.08	0.01	0.14	**0.67**	0.36	**1.00**	*0.05*
	Slope	-3.66	-17.00	-1.06	5.89	-1.20	-3.90	-5.71	-3.55	-1.64	-1.00	0.94	9.00	4.00	-3.00	*-0.73*
Stabilization	*Average*	*130.60*	*139.33*	*114.80*	*119.20*	*118.60*	*127.40*	*135.33*	*135.00*	*128.20*	*129.20*	*119.20*	*119.00*	*#DIV/0!*	*#DIV/0!*	*125.46*
	RSQ	0.00	**0.72**	0.04	**0.63**	**0.42**	**0.84**	**0.96**	**0.89**	**0.55**	0.09	0.01	**1.00**	#DIV/0!	#DIV/0!	*0.07*
	Slope	-0.20	-11.50	-0.50	-4.20	-2.80	-4.80	-12.00	5.00	7.40	-1.40	-0.50	14.00	#DIV/0!	#DIV/0!	*-0.69*
Composite	Average	142.13	148.20	137.64	129.60	132.86	140.46	140.00	150.57	138.89	139.77	127.12	123.29	141.55	124.67	*137.32*
	RSQ	0.14	**0.74**	**0.63**	0.23	**0.87**	**0.77**	0.18	**0.58**	0.23	**0.41**	0.21	0.00	0.00	0.21	**0.55**
	Slope	-0.89	-4.58	-2.73	-1.56	-3.10	-3.07	-0.96	-2.17	-1.15	-1.13	-0.81	0.09	0.05	-0.87	*-1.24*

KEY:
1. **Bold Green** numbers indicate an R-square value in excess of 0.4. This would be considered a moderate to strong trend.

Attachment D

Montgomery County BIBI and Habitat

Correlation Analysis

Table D1. Overall (1994-2012) Correlation Table

	Bank Stability	*Bank Stability (min)*	*Bank Vegetation*	*Bank Vegetation (min)*	*Buffer*	*Buffer (min)*	*Channel Alteration*	*Channel Flow*	*Composite Habitat Score*	*Embeddedness*	*Epibenthic Substrate*	*Instream Cover*	*Riffle Frequency*	*Sediment Deposit*	*xBIBI Score*	*xBiotic Index*	*xNumber EPT Taxa*	*xProportion of Dominant Taxa*	*xProportion of EPT Individuals*	*xProportion of Hydropsyche & Cheumatopsyche*	*xProportion of Shredders*	*xRatio of Scrapers*	*xTaxa Richness*
Bank Stability	**1.00**																						
Bank Stability (min)	**0.97**	**1.00**																					
Bank Vegetation	**0.88**	**0.88**	**1.00**																				
Bank Vegetation (min)	**0.86**	**0.88**	**0.99**	**1.00**																			
Buffer	0.22	0.29	0.37	0.39	**1.00**																		
Buffer (min)	0.34	**0.41**	**0.46**	**0.47**	**0.93**	**1.00**																	
Channel Alteration	0.00	0.03	0.04	0.06	0.18	0.13	**1.00**																
Channel Flow	**0.79**	**0.80**	**0.79**	**0.79**	0.35	0.38	0.27	**1.00**															
Composite Habitat Score	**0.78**	**0.82**	**0.86**	**0.86**	**0.57**	**0.61**	0.39	**0.89**	**1.00**														
Embeddedness	**0.44**	**0.53**	**0.64**	**0.67**	**0.62**	**0.60**	0.39	**0.68**	**0.87**	**1.00**													
Epibenthic Substrate	**0.42**	0.31	0.26	0.23	-0.16	-0.17	**0.44**	**0.56**	0.35	0.06	**1.00**												
Instream Cover	0.16	0.27	0.40	**0.43**	0.36	0.30	0.37	0.31	**0.54**	**0.63**	-0.17	**1.00**											
Riffle Frequency	0.15	0.18	0.03	0.03	**0.50**	**0.57**	**0.54**	0.23	**0.41**	**0.40**	0.21	0.05	**1.00**										
Sediment Deposit	**0.47**	**0.58**	**0.63**	**0.67**	**0.62**	**0.64**	0.16	**0.58**	**0.80**	**0.89**	-0.21	**0.64**	0.31	**1.00**									
BIBI Score	**0.50**	**0.53**	**0.63**	**0.64**	0.34	**0.45**	-0.04	0.34	**0.51**	0.38	-0.12	**0.43**	0.03	**0.50**	**1.00**								
Biotic Index	**-0.55**	**-0.61**	**-0.62**	**-0.63**	-0.39	**-0.60**	-0.21	-0.35	**-0.58**	**-0.41**	0.03	-0.32	-0.32	**-0.55**	**-0.68**	**1.00**							
Number EPT Taxa	0.24	0.16	0.05	-0.01	-0.06	0.14	0.12	0.00	0.03	-0.23	0.31	-0.23	**0.41**	-0.21	0.10	**-0.40**	**1.00**						
Proportion of Dominant Taxa	-0.39	-0.36	-0.32	-0.29	-0.22	**-0.43**	-0.08	-0.15	-0.31	-0.14	-0.06	0.02	**-0.45**	-0.24	-0.14	**0.67**	**-0.71**	**1.00**					
Proportion of EPT Individuals	**0.58**	**0.59**	**0.64**	**0.63**	0.40	**0.61**	0.04	0.39	**0.56**	0.37	-0.01	0.24	0.28	**0.51**	**0.83**	**-0.91**	**0.49**	**-0.62**	**1.00**				
Proportion of Hydropsyche & Cheumatopsyche	0.31	0.19	0.23	0.16	0.00	0.04	**-0.50**	0.10	0.03	-0.10	0.01	-0.30	-0.05	-0.04	0.15	0.07	**0.41**	-0.24	0.22	**1.00**			
Proportion of Shredders	0.22	0.31	0.32	0.35	0.37	**0.42**	**0.48**	0.24	**0.44**	0.32	0.10	**0.56**	0.26	0.37	**0.63**	**-0.62**	0.03	-0.03	**0.52**	**-0.54**	**1.00**		
Ratio of Scrapers	-0.03	0.09	0.19	0.26	0.07	0.04	0.03	0.00	0.14	0.32	-0.38	**0.42**	-0.24	0.38	0.35	-0.24	**-0.62**	0.15	0.11	**-0.56**	0.33	**1.00**	
Taxa Richness	0.26	0.19	0.01	-0.05	-0.05	0.09	0.23	0.02	0.06	-0.22	0.35	-0.10	**0.42**	-0.23	0.06	-0.24	**0.86**	**-0.50**	0.29	0.31	0.13	**-0.63**	**1.00**

KEY:

1. **Bold Green** numbers indicate an R value in excess of 0.4. This would be considered a moderate to strong trend.

Attachment D

Montgomery County BIBI and Habitat

Correlation Analysis

Table D2. Pre-development Period Correlation Table

	Bank Stability	*Bank Stability (min)*	*Bank Vegetation*	*Bank Vegetation (min)*	*Buffer*	*Buffer (min)*	*Channel Alteration*	*Channel Flow*	*Composite Habitat Score*	*Embeddedness*	*Epibenthic Substrate*	*Instream Cover*	*Riffle Frequency*	*Sediment Deposit*	*xBIBI Score*	*xBiotic Index*	*xNumber EPT Taxa*	*xProportion of Dominant Taxa*	*xProportion of EPT Individuals*	*xProportion of Hydropsyche & Cheumatopsyche*	*xProportion of Shredders*	*xRatio of Scrapers*	*xTaxa Richness*
Bank Stability	**1.00**																						
Bank Stability (min)	**0.98**	**1.00**																					
Bank Vegetation	**0.78**	**0.80**	**1.00**																				
Bank Vegetation (min)	**0.70**	**0.75**	**0.98**	**1.00**																			
Buffer	-0.22	-0.29	0.10	0.12	**1.00**																		
Buffer (min)	-0.01	-0.09	0.24	0.23	**0.95**	**1.00**																	
Channel Alteration	**-0.91**	**-0.88**	**-0.85**	**-0.79**	0.18	0.02	**1.00**																
Channel Flow	0.14	0.01	0.33	0.24	**0.83**	**0.89**	-0.22	**1.00**															
Composite Habitat Score	-0.13	-0.21	0.14	0.12	**0.96**	**0.93**	0.14	**0.87**	**1.00**														
Embeddedness	-0.29	-0.35	-0.01	-0.01	**0.94**	**0.82**	0.28	**0.74**	**0.96**	**1.00**													
Epibenthic Substrate	-0.35	-0.39	-0.32	-0.38	0.30	**0.41**	**0.54**	0.27	0.34	0.22	**1.00**												
Instream Cover	**-0.88**	**-0.84**	**-0.54**	**-0.46**	0.29	0.06	**0.81**	-0.08	0.30	**0.46**	0.27	**1.00**											
Riffle Frequency	**-0.42**	**-0.53**	**-0.56**	**-0.64**	**0.51**	**0.53**	**0.58**	**0.47**	**0.54**	**0.50**	**0.78**	0.26	**1.00**										
Sediment Deposit	-0.17	-0.24	0.00	0.02	**0.82**	**0.67**	0.09	**0.64**	**0.79**	**0.88**	-0.19	0.27	0.29	**1.00**									
xBIBI Score	0.15	0.23	**0.59**	**0.70**	0.08	-0.04	**-0.42**	-0.03	0.01	0.07	**-0.68**	0.09	**-0.80**	0.22	**1.00**								
xBiotic Index	-0.14	-0.26	-0.36	**-0.50**	0.26	0.24	0.30	**0.40**	**0.46**	**0.47**	**0.43**	0.25	**0.71**	0.30	**-0.60**	**1.00**							
xNumber EPT Taxa	0.11	0.03	-0.24	-0.33	-0.29	-0.10	-0.08	0.00	-0.35	**-0.49**	0.33	**-0.53**	0.35	**-0.44**	**-0.65**	-0.01	**1.00**						
xProportion of Dominant Taxa	**-0.42**	-0.32	0.03	0.17	0.13	-0.10	0.27	-0.22	0.12	0.30	-0.32	**0.71**	**-0.43**	0.25	**0.71**	-0.22	**-0.88**	**1.00**					
xProportion of EPT Individuals	**0.44**	**0.44**	**0.73**	**0.77**	0.11	0.17	**-0.72**	0.26	-0.02	-0.11	**-0.50**	**-0.45**	**-0.60**	0.08	**0.71**	**-0.70**	0.01	0.06	**1.00**				
xProportion of Hydropsyche & Cheumatopsyche	**0.61**	**0.48**	**0.42**	0.28	-0.05	0.08	**-0.76**	**0.46**	-0.01	-0.13	-0.32	**-0.69**	-0.09	0.08	0.00	0.11	**0.45**	**-0.58**	**0.48**	**1.00**			
xProportion of Shredders	**-0.68**	**-0.55**	-0.27	-0.10	0.13	-0.06	**0.64**	-0.37	0.05	0.19	0.11	**0.79**	-0.13	0.03	0.36	-0.30	**-0.59**	**0.82**	-0.16	**-0.90**	**1.00**		
xRatio of Scrapers	0.00	0.15	0.30	**0.45**	0.03	-0.11	0.02	-0.33	0.02	0.14	-0.40	0.32	**-0.58**	0.13	**0.68**	-0.39	**-0.87**	**0.82**	0.11	**-0.60**	**0.68**	**1.00**	
xTaxa Richness	-0.09	-0.14	**-0.63**	**-0.73**	**-0.44**	-0.35	0.30	-0.29	**-0.40**	**-0.42**	0.39	-0.21	**0.51**	**-0.43**	**-0.91**	**0.41**	**0.74**	**-0.71**	**-0.63**	0.10	**-0.42**	**-0.68**	**1.00**

KEY:

1. **Bold Green** numbers indicate an R value in excess of 0.4. This would be considered a moderate to strong trend.

Attachment D

Montgomery County BIBI and Habitat

Correlation Analysis

Table D3. Construction Period Correlation Table

	Bank Stability	Bank Stability (min)	Bank Vegetation	Bank Vegetation (min)	Buffer	Buffer (min)	Channel Alteration	Channel Flow	Composite Habitat Score	Embeddedness	Epibenthic Substrate	Instream Cover	Riffle Frequency	Sediment Deposit	xBIBI Score	xBiotic Index	xNumber EPT Taxa	xProportion of Dominant Taxa	xProportion of EPT Individuals	xProportion of Hydropsyche & Cheumatopsyche	xProportion of Shredders	xRatio of Scrapers	xTaxa Richness
Bank Stability	**1.00**																						
Bank Stability (min)	**0.93**	**1.00**																					
Bank Vegetation	**0.93**	**0.92**	**1.00**																				
Bank Vegetation (min)	**0.90**	**0.93**	**0.99**	**1.00**																			
Buffer	0.33	**0.61**	**0.48**	**0.58**	**1.00**																		
Buffer (min)	0.16	**0.46**	0.39	**0.49**	**0.95**	**1.00**																	
Channel Alteration	0.26	0.10	0.39	0.35	0.05	-0.03	**1.00**																
Channel Flow	**0.80**	**0.71**	**0.77**	**0.75**	0.09	-0.02	0.37	**1.00**															
Composite Habitat Score	**0.86**	**0.86**	**0.97**	**0.98**	**0.55**	**0.44**	**0.55**	**0.76**	**1.00**														
Embeddedness	0.33	**0.46**	**0.63**	**0.68**	**0.70**	**0.73**	**0.52**	0.18	**0.72**	**1.00**													
Epibenthic Substrate	**0.63**	0.36	**0.52**	**0.44**	-0.40	**-0.54**	**0.50**	**0.78**	**0.50**	-0.04	**1.00**												
Instream Cover	0.02	0.28	0.16	0.23	**0.77**	**0.83**	-0.28	**-0.41**	0.14	**0.50**	**-0.73**	**1.00**											
Riffle Frequency	0.11	0.18	0.39	**0.41**	**0.59**	**0.61**	**0.70**	-0.01	**0.54**	**0.86**	-0.15	**0.46**	**1.00**										
Sediment Deposit	-0.30	0.01	-0.04	0.06	**0.71**	**0.88**	-0.17	**-0.44**	0.02	**0.56**	**-0.83**	**0.85**	**0.55**	**1.00**									
xBIBI Score	0.28	**0.43**	0.39	**0.42**	**0.56**	**0.68**	-0.14	0.04	0.35	0.39	-0.40	**0.74**	0.40	**0.63**	**1.00**								
xBiotic Index	0.09	-0.07	-0.28	-0.34	**-0.52**	**-0.68**	-0.33	0.13	-0.37	**-0.89**	0.30	**-0.50**	**-0.77**	**-0.72**	-0.34	**1.00**							
xNumber EPT Taxa	0.25	0.10	0.37	0.30	-0.13	-0.10	0.36	-0.04	0.32	**0.47**	0.33	0.07	0.34	-0.10	-0.04	**-0.42**	**1.00**						
xProportion of Dominant Taxa	0.04	-0.05	-0.30	-0.33	-0.33	**-0.51**	-0.31	0.14	-0.35	**-0.83**	0.18	**-0.43**	**-0.70**	**-0.58**	-0.34	**0.95**	**-0.64**	**1.00**					
xProportion of EPT Individuals	-0.03	0.09	0.31	0.34	**0.41**	**0.63**	0.24	-0.10	0.35	**0.78**	-0.31	**0.55**	**0.72**	**0.71**	**0.62**	**-0.90**	**0.43**	**-0.93**	**1.00**				
xProportion of Hydropsyche & Cheumatopsyche	**0.65**	**0.57**	**0.44**	0.39	0.10	-0.07	-0.19	0.15	0.30	-0.08	0.24	0.25	-0.18	-0.28	0.25	0.39	0.34	0.24	-0.26	**1.00**			
xProportion of Shredders	0.26	**0.45**	**0.47**	**0.53**	**0.64**	**0.77**	0.09	0.32	**0.51**	**0.54**	-0.26	**0.51**	**0.50**	**0.64**	**0.83**	**-0.50**	-0.25	-0.39	**0.66**	-0.18	**1.00**		
xRatio of Scrapers	**-0.45**	-0.25	-0.15	-0.08	0.34	**0.60**	0.03	-0.26	-0.05	**0.42**	**-0.60**	**0.42**	**0.50**	**0.80**	**0.51**	**-0.70**	-0.19	**-0.59**	**0.77**	**-0.68**	**0.71**	**1.00**	
xTaxa Richness	**0.78**	**0.68**	**0.68**	**0.62**	0.15	-0.03	0.09	0.34	**0.56**	0.25	**0.49**	0.12	0.01	-0.32	0.04	0.09	**0.63**	-0.06	-0.09	**0.86**	-0.22	**-0.68**	**1.00**

KEY:

1. **Bold Green** numbers indicate an R value in excess of 0.4. This would be considered a moderate to strong trend.

R:\BIO\PROJECT\12036.01 Ten Mile Creek\C. Analysis\LSLS Analysis\Data\LSLS_CorrelationSummary

Attachment D

Montgomery County BIBI and Habitat

Correlation Analysis

Table D4. Stabilization Period Correlation Table

	Bank Stability	Bank Stability (min)	Bank Vegetation	Bank Vegetation (min)	Buffer	Buffer (min)	Channel Alteration	Channel Flow	Composite Habitat Score	Embeddedness	Epibenthic Substrate	Instream Cover	Riffle Frequency	Sediment Deposit	xBIBI Score	xBiotic Index	xNumber EPT Taxa	xProportion of Dominant Taxa	xProportion of EPT Individuals	xProportion of Hydropsyche & Cheumatopsyche	xProportion of Shredders	xRatio of Scrapers	xTaxa Richness
Bank Stability	**1.00**																						
Bank Stability (min)	**0.98**	**1.00**																					
Bank Vegetation	**0.65**	**0.50**	**1.00**																				
Bank Vegetation (min)	**0.71**	**0.56**	**0.99**	**1.00**																			
Buffer	-0.14	-0.15	-0.04	-0.03	**1.00**																		
Buffer (min)	-0.08	-0.06	-0.08	-0.08	**0.98**	**1.00**																	
Channel Alteration	-0.09	0.09	**-0.79**	**-0.75**	-0.30	-0.20	**1.00**																
Channel Flow	**0.83**	**0.89**	0.28	0.30	**-0.41**	-0.27	0.33	**1.00**															
Composite Habitat Score	**0.97**	**0.96**	**0.54**	**0.62**	-0.07	-0.03	0.01	**0.74**	**1.00**														
Embeddedness	**-0.52**	-0.40	**-0.89**	**-0.83**	-0.07	-0.09	**0.75**	-0.32	-0.32	**1.00**													
Epibenthic Substrate	**0.84**	**0.90**	0.23	0.29	**-0.50**	**-0.41**	**0.41**	**0.93**	**0.83**	-0.10	**1.00**												
Instream Cover	0.06	-0.09	**0.63**	**0.58**	**-0.56**	**-0.63**	**-0.61**	-0.05	-0.09	**-0.55**	-0.06	**1.00**											
Riffle Frequency	0.17	0.27	**-0.42**	-0.30	0.33	0.33	**0.54**	0.07	**0.40**	**0.63**	0.29	**-0.80**	**1.00**										
Sediment Deposit	**0.41**	0.33	**0.45**	**0.53**	**0.65**	**0.57**	**-0.47**	-0.13	**0.53**	-0.22	-0.01	-0.22	**0.48**	**1.00**									
xBIBI Score	0.32	0.17	**0.67**	**0.72**	-0.30	**-0.44**	**-0.56**	-0.10	0.35	-0.29	0.13	**0.68**	-0.13	**0.42**	**1.00**								
xBiotic Index	**-0.78**	**-0.72**	**-0.72**	**-0.76**	**-0.46**	**-0.47**	**0.47**	-0.39	**-0.77**	**0.64**	-0.34	0.08	-0.19	**-0.79**	-0.27	**1.00**							
xNumber EPT Taxa	**0.90**	**0.84**	**0.72**	**0.78**	**-0.45**	**-0.44**	-0.17	**0.71**	**0.86**	**-0.48**	**0.81**	0.40	-0.01	0.27	**0.62**	**-0.57**	**1.00**						
xProportion of Dominant Taxa	**-0.84**	**-0.75**	**-0.86**	**-0.90**	-0.23	-0.23	**0.55**	**-0.43**	**-0.81**	**0.72**	**-0.42**	-0.17	-0.05	**-0.73**	**-0.49**	**0.96**	**-0.74**	**1.00**					
xProportion of EPT Individuals	**0.79**	**0.67**	**0.89**	**0.93**	0.24	0.21	**-0.64**	0.33	**0.76**	**-0.72**	0.34	0.24	0.01	**0.76**	**0.57**	**-0.94**	**0.72**	**-0.99**	**1.00**				
xProportion of Hydropsyche & Cheumatopsyche	-0.40	**-0.52**	0.14	0.15	-0.35	**-0.52**	-0.39	**-0.60**	-0.36	0.12	-0.39	**0.67**	-0.31	-0.04	**0.72**	**0.41**	0.00	0.20	-0.09	**1.00**			
xProportion of Shredders	**0.68**	**0.63**	**0.61**	**0.66**	**0.60**	**0.60**	**-0.45**	0.27	**0.71**	**-0.53**	0.23	-0.21	0.30	**0.87**	0.21	**-0.98**	**0.44**	**-0.90**	**0.89**	**-0.41**	**1.00**		
xRatio of Scrapers	0.19	0.13	0.26	0.30	**-0.83**	**-0.91**	0.00	0.15	0.21	0.07	0.39	**0.65**	-0.15	-0.20	**0.75**	0.25	**0.58**	-0.02	0.06	**0.68**	-0.35	**1.00**	
xTaxa Richness	**0.80**	**0.75**	**0.63**	**0.65**	**-0.68**	**-0.65**	-0.07	**0.77**	**0.70**	**-0.47**	**0.82**	**0.52**	-0.21	-0.05	**0.52**	-0.34	**0.95**	**-0.54**	**0.51**	0.02	0.18	**0.66**	**1.00**

KEY:

1. **Bold Green** numbers indicate an R value in excess of 0.4. This would be considered a moderate to strong trend.

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MEMORANDUM

Date: April 3, 2013

To: Mary Dolan and Valdis Lazdins,
Montgomery County Planning Department

From: Center for Watershed Protection

RE: **Ten Mile Creek Watershed Environmental Analysis in Support of the Clarksburg Master Plan Limited Amendment**
SUBJ: Environmental Site Design Literature Review

---

1. Introduction and Background

Stage 4 of the Clarksburg Master Plan is planned to occur in the headwaters of Ten Mile Creek, a very sensitive and high quality tributary of Little Seneca Creek located in Montgomery County, Maryland. Although the previous three stages of development were developed with relatively stringent stormwater criteria of the Special Protection Area, there was some degradation in the hydrology, stream morphology/habitat, water quality and biology in the tributaries of Little Seneca Creek that these projects impacted, particularly during the construction phase (MCDEP, 2012). In anticipation of Stage 4, it is critical to understand the potential for stream degradation in Ten Mile Creek, as well as the ability of current stormwater management technologies to mitigate these impacts.

The memo summarizes the hydrologic, water quality, habitat/geomorphic and biological impacts of development and the effectiveness of sediment and stormwater control practices in following four sections:

- *Post Construction Impacts* summarizes the impacts of stormwater runoff and the built environment on water resources. The impacts described in this section focus on development without stormwater controls in place.
- *Stormwater Management* identifies the benefits of stormwater management controls, with a focus on differences between traditional stormwater management and Environmental Site Design.
- *Construction Impacts* describes impacts occurring during the construction process, *and*
- *Erosion and Sediment Control (ESC)* reviews the effectiveness of ESC practices in mitigating these impacts.

2. Post Construction Impacts

The impacts of land use change on water resources have long been documented. While many different land cover parameters have been linked to stream degradation, impervious cover has been used as a measure in many studies due to its ease of measurement and its reliability as a predictor of the health of water resources. The model was originally presented by Schueler (1994), as a management tool and as a linear relationship between stream quality and watershed impervious cover. Over the years, this model has been tested and, while it has been supported by many studies, "Reformulated Impervious Cover Model" (Schueler et al., 2009; Figure 1) was proposed in 2009 based on newer studies. In this model, impervious cover represents a range of stream quality. This is particularly true at lower levels of impervious cover, where pervious land cover, location of land development, and other issues exert a stronger influence.

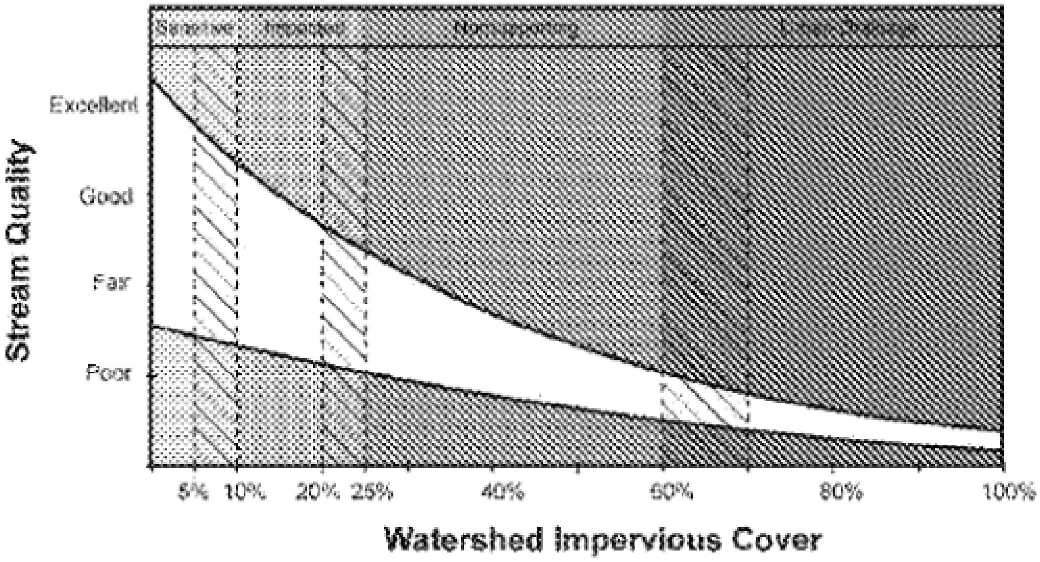

Figure 1. Reformulated Impervious Cover Model (Schueler et al., 2009)

In Montgomery County as a whole, data have been supportive of this model of stream health (Figure 2). While there is a wide range of variability at low levels of impervious cover, no "Excellent" streams are found above ~12% impervious cover, no "Good" streams are found above ~20% impervious cover, and no "Fair" streams are found above ~37% impervious cover. These data suggest that impervious cover is an important driver in Montgomery County, but also that stream health must be influenced by other factors, particularly at low levels of impervious cover.

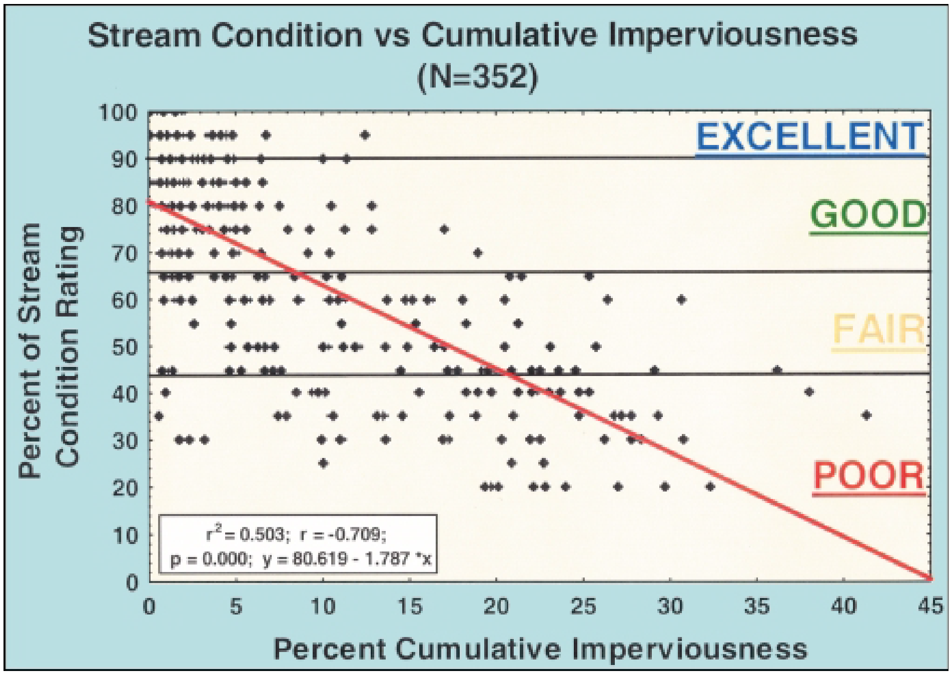

Figure 2. Relationship Between Stream Condition and Impervious Cover in Montgomery County Streams (MCDEP, 2003)

Hydrologic Impacts

While impervious cover is a useful tool, other measures of watershed development, some of which are strongly correlated with impervious cover, have also been evaluated as predictors of stream condition (Table 1). Some of these measures are highly specific, and may be important to our understanding of development in Ten Mile Creek. For example, GIS metrics such as the "clumpiness," (a representation of how contiguous each land use is) or "patchiness" (which indicates fragmented land use) of different classes of land cover can help understand the importance of the *location* of land disturbance. Forest cover may be important, particularly at low levels of development, where the presence of agricultural land may result in stream degradation. For example, an evaluation of Montgomery County streams (Goetz et al., 2003) demonstrated correlations between impervious cover, watershed tree cover, and riparian tree cover on stream health (Figure 3). Based on these results, the authors of this study suggested that guidelines for excellent stream health rating were no more than 6% impervious with at least 65% forested buffers, and no more than 10% impervious with at least 60% buffered for a rating of good.

Table 1. Measures of Land Development Other than Impervious Cover

Soil Disturbance or compaction
Effective Impervious Cover
Forest Cover
Developed Land or Urban Land
Population Density
Road Density
Number of stream crossings
Forest/Disturbed/Impervious cover in riparian buffer
“Patchiness” or “Clumpiness” of forest or urban land cover
Agricultural or cropland cover
Population Density
Land Cover Class
Land Use Category

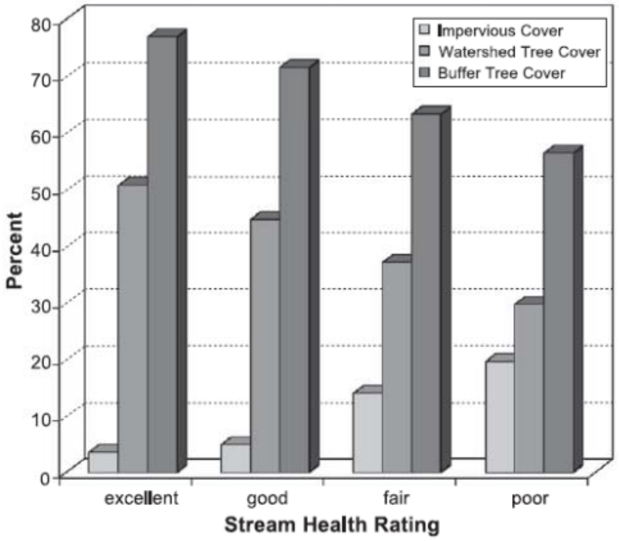

Figure 3. Relationship of Land Cover to Stream Health (Goetz et al., 2003)

While these data support the notion that land cover other than imperviousness is important, researchers have come to different conclusions regarding the relative importance of each component of land cover. One challenge of interpreting these data is that these land use measures are often correlated with one another. For example, further study in Montgomery County found a *negative* correlation between riparian buffer forest cover and watershed impervious cover, and a positive correlation between riparian forest cover and watershed-wide forest cover (Snyder et al., 2005). As a result, researchers have attempted to "tease out" the importance of each land cover in determining water quality. Of particular interest to the watershed manager is the influence of the riparian corridor in mitigating development impacts.

Riparian Corridor

Stream buffers are an integral part of watershed planning, and provide direct benefits to stream habitat. However, the benefit of stream buffers appears to be overwhelmed by watershed factors such as intense development. While some researchers finding benefits of riparian corridor at all levels of development (e.g., Moore and Palmer, 2005), others find that a forested buffer is most effective in combination with watershed-wide forest cover or limited impervious cover. This particularly true in the steep Piedmont region, where channelized flows can bypass the buffer. For example, Roy et al. (2007), in a study of Georgia streams, found that riparian buffers are most effective at improving fish diversity at impervious cover of 15% or less. Others, such as Snyder et al. (2005), found a relationship between riparian corridor composition (e.g., forested versus urban), but found that *watershed* variables such as impervious cover or forested cover in the entire drainage area are a more powerful predictor of stream health. Fitzpatrick (2005) found no relationship between riparian cover and habitat or hydrologic characteristics, citing possible channelization and point source discharges as a possible confounding factor. Other studies have reached similar conclusions, citing riparian corridor as a "co-predictor," along with urban land use of in-stream quality or a "necessary element" but not a guarantee of good quality (e.g., Urban et al., 2006, Booth, 2002, Kratzer et al., 2006, Ourso, 2003).

2.1 Hydrologic Impacts

Hydrologic impacts originate from a shift in the hydrologic cycle that occurs with land development (Figure 4). This shift typically results in a modified hydrograph including higher runoff volumes, “flashier” hydrology, and decreased baseflow. In addition quantifying these impacts, recent research has focused on understanding how these hydrologic impacts in turn cause degradation in stream habitat and morphology, as well as in-stream biology.

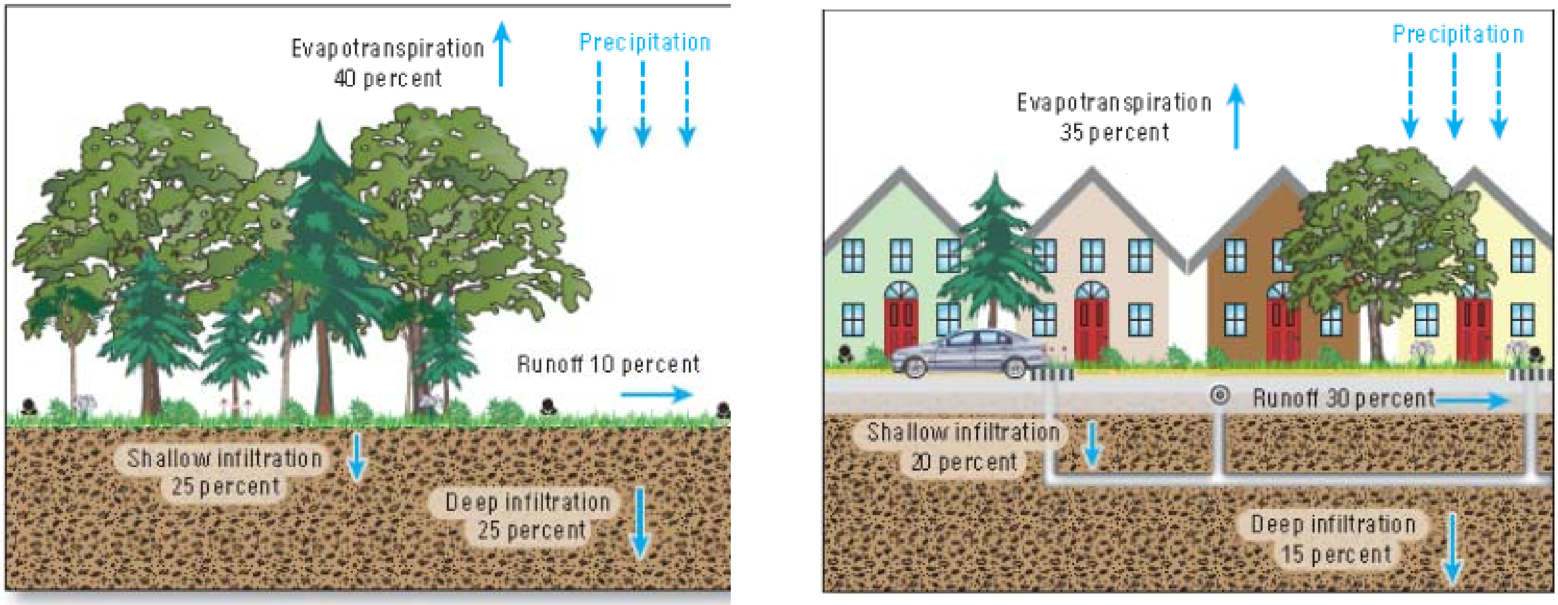

Figure 4. Change in Water Balance with Development (Coles et al., 2012)

Increased Runoff Volume

Several studies have documented increased stormwater runoff volumes resulting from land development. This increase in runoff volume is a result of the introduction of impervious cover to the landscape, compaction during and after construction, and loss of forest cover. Hydrologic models (e.g., NRCS, 1986) have documented the influence of land cover and soil type. In the first three stages of the Clarksburg development plan, the runoff coefficient increased (Figure 5), and in the amount of infiltration and evaporation decreased (Figure 6), as impervious cover and land clearing occurred in the watershed. In the corresponding years, a corresponding undisturbed stream, Soper’s Branch, did not experience these changes in hydrology.

The effects of impervious cover and changing land cover on runoff volume appear to be most pronounced at the very small catchment scale. For instance, Dietz and Clausen (2008) measured an increase in annual runoff volume from 0.1 cm/year to 50 cm/year when a 4.2-acre suburban development increased from 0% to 30% impervious cover, with a logarithmic increase in runoff coefficient. At the larger watershed scale, these effects are somewhat dampened. The “Simple Method” (Schueler, 1987), based on data at the catchment scale, finds a linear rather than logarithmic relationship between stormwater runoff and watershed impervious cover at the catchment scale.

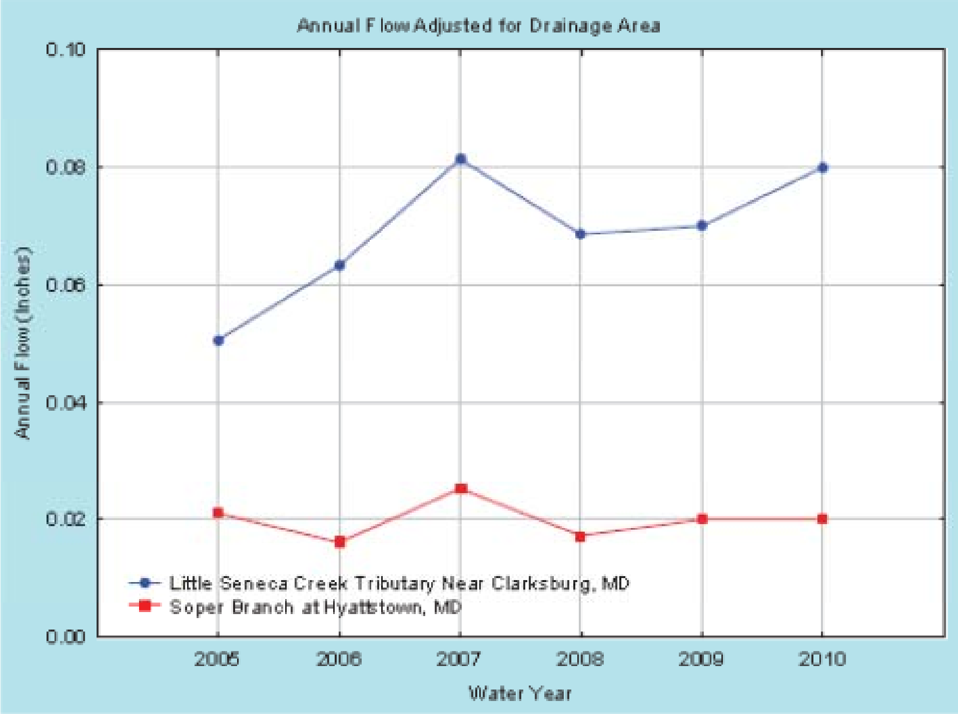

Figure 5. Comparison of runoff coefficient in a developing tributary of Little Seneca Creek (Clarksburg) versus a control stream Soper Branch (MCDEP, 2012)

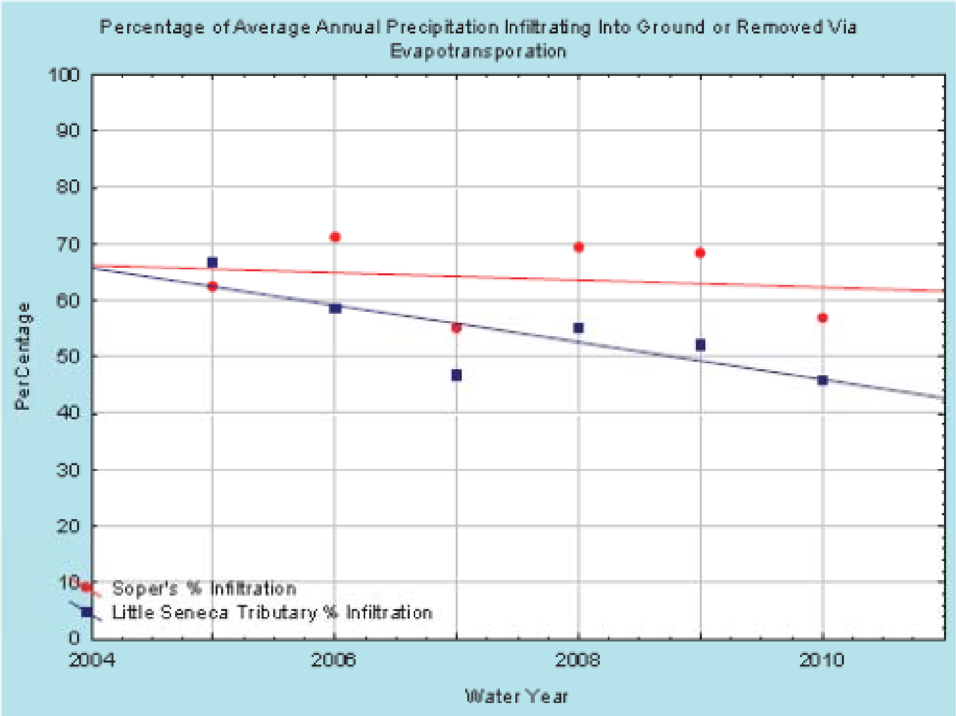

Figure 6. "Runoff Reduction" volume in a developing Little Seneca tributary (Clarksburg)

Another physical change that may compound the impact of development on hydrology is the compaction and disturbance of soils during and after the construction process. The impacts of soil compaction are well documented (Table 2), yet the specific response to soil compaction is dependent on a number of factors such as soil texture and organic matter (Saxton and Rawls, 2006), and depth of the soil profile (Hursch, 1944). These studies point to the need to better understand soil compaction when sizing stormwater management practices (see Section 3 of this report).

Table 2. Studies Documenting the Impacts of Soil Compaction

Finding	Study
Finds that lawns constructed earlier than 2000 had lower curve number than those built post 2000, and that both had lower curve numbers than disturbed soils.	Woltemade, 2010
Disturbed soils have infiltration rates <2.0 cm/hr, compared to 32 cm/hr for forested lands.	Kays et al., 1980
Storage in the agricultural soil profile is about 1/3 as much in disturbed forest due to stripping of upper soil layers	Hursch, 1944
Construction activity or compaction treatments reduced infiltration rates 70 to 99 percent.	Gregory et al., 2006
Infiltration rate is inversely related to soil compaction in sandy soils. In clayey soils, soil moisture is also an important parameter.	Pitt al., 2005

Flashiness

Flashiness (Figure 7) is an important hydrologic metric because of its influence on stream habitat and biology. It occurs as a result of the increased runoff volume, combined with increased runoff velocity, or shorter time of concentration. While there are many specific metrics used to describe flashiness, the resulting stream hydrology has four basic characteristics (Coles et al., 2012): 1) Increased magnitude of the peak discharge; 2) decreased duration of peak flows; 3) increased rate of decline or recession, and 4) increased frequency of high flow events. Flashiness has been documented at varying degrees of urbanization (Table 3). In the early stages of development in the Clarksburg SPA, MCDEP (2012) documented a decrease in stream flashiness, as well as time of concentration, or the time required for a drop of water to travel from the most hydrologically remote point in the subcatchment to the point of collection (Figure 8).

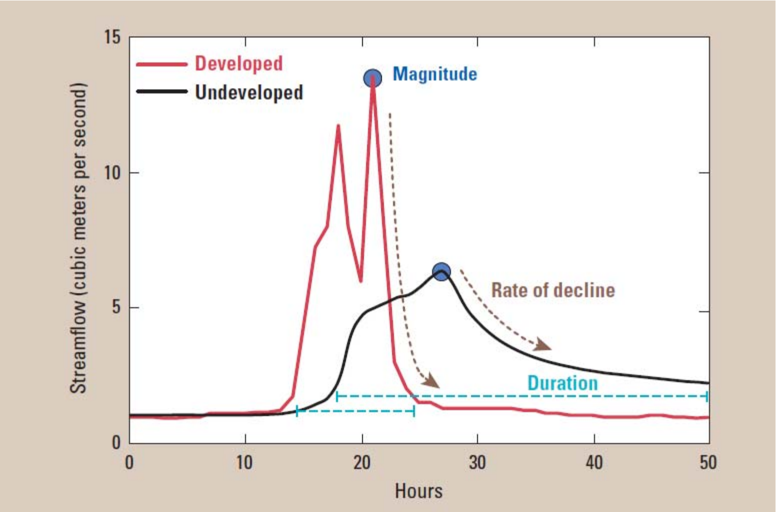

Figure 7. Stream Flashiness (Coles et al., 2012)

Table 3. Selected Studies of Stream Flashiness

Measure of Flashiness	Source	Result
2-year peak	Fitzpatrick, 2005	At less than 30% IC, 2-year peak increased linearly. At greater than 30% IC, results were dependent on other watershed characteristics.
Flashiness	Jarnagin, 2007	Watersheds with less than 20% 'urban' development displayed background levels of stream flashiness and mean flashiness increased with urban development density thereafter
Flashiness	Roy et al., 2005	Increased imperviousness was positively correlated with the frequency of storm events and rates of the rising and falling limb of the hydrograph (i.e., storm ‘‘flashiness’’) during most seasons.
Peak Flows	Moglen et al. (2004)[1]	A study in the Maryland Piedmont: ~65% urban catchments had 3–4 times greater 2 yr peak flows than in forested catchment.

1: As reported in O’Driscoll (2010)
IC: Impervious Cover

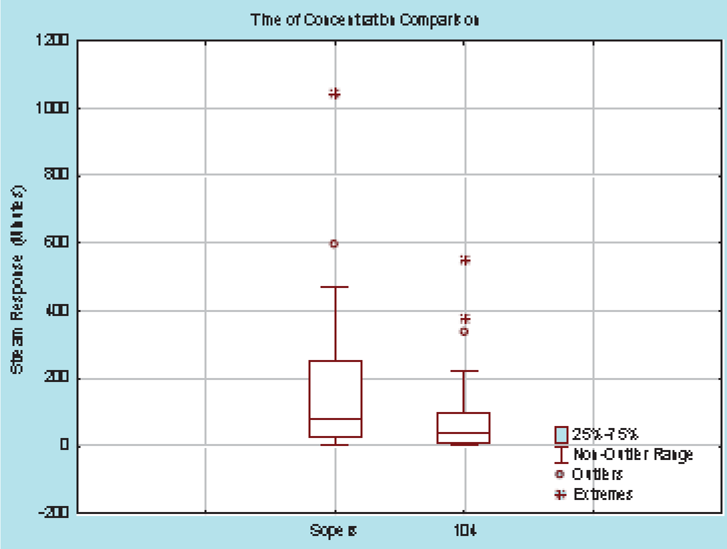

Figure 8. Time of Concentration is lower in the developed "Tributary 104" versus undeveloped Sopers Branch

Decrease in baseflow

Natural baseflows are typically correlated with healthy macroinvertebrate and fish communities. Most studies indicate that stream baseflow decreases with increased land development (e.g., Moglen, 2004), although some studies contradict this claim (e.g., Coles et al., 2004). Because this impact is somewhat less well documented, ongoing monitoring in Ten Mile Creek should document changes in baseflow over time. Ten Mile Creek appears to be losing some upstream baseflow through infiltration back into groundwater in the lower reaches closer to Little Seneca Lake. (Van Ness, 2013) The baseflow in Ten Mile Creek is, however, remarkably reliable, with baseflow typically continuing in most drought events. The biological communities in Ten Mile Creek appear to be well adapted to current baseflow conditions, and any alteration of those conditions would be expected to have negative impacts on stream health.

2.2 Impacts on Water Quality

Concentrations of pollutants in urban runoff concentrations are significantly higher for many pollutants compared to typical concentrations in non-urban land uses. This typically results in higher in-stream pollutant concentrations in urban areas as well. Urban streams typically have higher concentrations of nutrients, metals, hydrocarbons, and bacteria than the equivalent size agricultural or forested watershed (CWP, 2003). Sources of these pollutants include vehicles, sewage (in the form of illicit discharges), fertilizers, and even atmospheric deposition onto paved surfaces.

Urbanizing watersheds often contribute to higher in-stream temperatures. For example, Urban (2006), found a significant correlation between urban land development and in-stream temperatures in a study of Connecticut streams. At the site level, Jones and Hunt (2010) documented high runoff temperatures on urban parking lots. Early monitoring in the SPAs of Montgomery County reflects little thermal impact on the majority of sites monitored. This may reflect the effectiveness of installed practices at these sites at reducing downstream temperatures (MCDEP, 2012), which include a significant amount of infiltration practices.

2.3 Impacts on Habitat and Stream Morphology

Stream morphology and habitat quality are also impacted by the changes in stream hydrology that result from land development, combined with the direct impacts to the stream corridor. The primary driver for changes in stream morphology is the altered hydrology resulting from increased impervious cover and loss of natural soils and forest. The resulting change in hydrology increases stream power, and consequently results in erosion and enlargement of stream channels. At as low as 7-10% impervious cover, we start to see destabilization and accelerated erosion of streams, as evidenced by an enlarged cross-sectional profile, including both stream widening and downcutting. This phenomenon has been documented in Tributary 104 of Seneca Creek (MCDEP, 2012), with data showing a decrease in stream cross sectional area following sediment deposition from construction, followed by channel enlargement, for a net 15% increase in channel area from 2002 to 2010. The channel depth increased by over 50% during this time period.

The combination of this active channel erosion and direct impacts to the riparian corridor and stream bed result in degraded stream habitat. While these results are not universal, typical impacts of impervious cover include stream straightening (i.e., decrease in sinuosity), as was also documented in Tributary 104 of Seneca Creek (MCDEP, 2012), increase in "embeddedness" of channel sediment, and decrease in depth diversity. Often, these and other measures are integrated into a combination metric such as "fish habitat." While the relationship between urban development and channel geometry are fairly consistent, habitat factors are less reliably influenced by watershed urbanization. One reason for this result is that highly localized effects, such as riparian vegetation (Cianfrani, 2006), past stream alteration (Fitzpatrick, 2005), or geologic features such as stream slope (Fitzpatrick, 2005) can strongly influence these habitat metrics.

Table 4. Some Studies of Geomorphology and Habitat Impacts

Study	Measure of Habitat Quality	Finding (s)
Coleman et al., 2006	Channel enlargement	Channel enlargement ratio is related to IC by a logarithmic relationship. In eastern streams, impacts begin IC at about 7-10%
Cianfrani et al., 2006	bankfull geometry, sediment grain size, large woody debris	These variables were positively correlated with IC. Study concludes that local factors (e.g., riparian vegetation) also influence habitat metrics. Streams with IC <13% and >24% responded differently to urbanization.
Booth, 2000	Fish habitat	At greater than 10% IC, most observed fish habitat is "degraded."An intact riparian corridor is necessary, but not sufficient to preserve fish habitat
Moglen et al., 2004	Channel Enlargement/ Channel Erosion	At 20% IC, channel erosion accounts for 40% of annual sediment loads.
Booth, 2000	Channel Stability	At greater than 10% impervious, most stream channels are unstable.
Coles et al., 2004	89 Habitat metrics	Only 11 of the 89 individual metrics responded to urbanization. However integrated habitat scores showed decline with urbanization.
Ourso, 2006	Range of metrics	Sinuosity, embeddedness, and % bank erosion correlated with IC
Fitzpatrick, 2005	Several habitat metrics	No significant relationship, possibly due to past disturbance.

IC: Impervious Cover

Impacts to and Loss of Headwater and Zero Order Streams

Another impact of land development is the loss of headwater and zero order streams. Headwater streams are typically first order, intermittent to perennial streams that originate in upland areas. Zero order streams are ephemeral channels that serve to convey concentrated surface runoff during storm events to the headwater streams. In Ten Mile Creek many of the headwater streams are fed by cool water springs and seeps, which help to maintain flow and support healthy and diverse stream communities. This is particularly important for Stage 4 of the Clarksburg Master Plan, which occurs primarily in the headwaters of a sensitive stream system. These streams are crucial to stream hydrology, chemistry, and biology, and are often channelized or otherwise eliminated during the development process. In addition, these streams are the most vulnerable to the impacts of channel erosion, since hydrologic "flashiness" is most pronounced at the small catchment scale. Headwater streams are important to the hydrologic and nutrient balances in stream systems. They comprise 70% of water volume and 65% of nitrogen to 2nd order streams, and 55% of water volume and 40% of nitrogen to 4th and higher-order streams (Alexander et al., 2007). In addition, they support diverse aquatic biota. For example, in a study by Meyer et al. (2007), three unmapped (i.e., zero order) streams supported over 290 macroinvertebrate taxa. Headwater streams provide benefits downstream by offering a refuge from temperature and flow extremes, competitors, predators, and introduced species; serving as a source of colonists; providing spawning sites and rearing areas; being a rich source of food; and creating migration corridors throughout the landscape (Meyer et al., 2007).

2.4 Biology

Of all stream indicators, biological indicators are most reliably predicted by changes in urban development (Table 5), largely because they integrate impacts to hydrology, habitat and chemistry. One underlying source of these changes is the shift in food source. Since urban land typically has higher nutrient loads than forested land, and can result in less forest cover in the watershed and riparian corridor, we see a shift from particulate to dissolved organic carbon as a food source, resulting in a shift in the macroinvertebrate community. Of the five functional feeding groups used to describe macroinvertebrates in Montgomery County (shredders, scrapers, predators, collectors and filterers), shredders represent highly sensitive taxa that rely on intact plants (usually in the form of leaves) to survive. As development occurs, the food sources switches from particulate to dissolved organic carbon, and shedders are replaced by collectors, filterers and predators.

The modified flow regime of the urban environment also results in direct impacts to fish and macroinvertebrate through the sheer energy of the modified flow regime. This, coupled with channel degradation and sediment loads that “smother” in-stream habitats, combine to reduce diversity of both macroinvertebrate and fish populations. The reduced sinuosity and depth diversity resulting from modifications to stream hydrology are damaging to fish in particular. Finally, fish, amphibians and aquatic are impacted by direct impacts to the stream system such as road crossings, and loss of headwater streams and small wetlands.

As urbanization occurs, the most sensitive taxa begin to disappear first (Coles et al., 2012). In Ten Mile Creek, it will be important to understand how the community changes over time with development. Biological monitoring in Montgomery County has been ongoing for decades, and includes a suite of fish and macroinvertebrate metrics. These metrics are assembled into an Index of Biotic Integrity (IBI), which integrates several individual scores (e.g., richness or diversity). Another approach that may be valid in the county is to develop a “Biological Condition Gradient,” which integrates several location-specific metrics to develop a six tier gradient of streams from “Native Condition” to “Severe Alteration of Structure and Function.” This approach may be helpful in future monitoring of SPAs to detect or report small changes in community structure as sensitive species begin to disappear.

Table 5. Impacts to Stream Biology

Study	Measure of Biological Condition	Findings
Alberti et al., 2007	B-IBI	In a study of 42 streams, the number of road crossings and patch size were better predictors of IBI than IC alone.
Belucci, 2007	Macroinvertebrate % of community[1]	At greater than 12% IC, no streams met Connecticut's criteria for stream biology.
Booth, 2000	B-IBI	At upper levels of IC, there is steady decline in IBI, but degradation can occur at lower levels of IC.
Coles et al., 2004	126 macroinvertebrate metrics, 92 fish, 164 algae	Of these, metrics, about 20% were strongly correlated with an "urban land index"
DeGasperi, 2009	B-IBI	Correlated with urban land and IC, and negatively correlated with forest cover
Fitzpatrick, 2005	Fish IBI	Strongly correlated with urban land
Houlahan, 2003	Amphibian Species Richness	Correlated with land use w/in 3000 feet of a wetland.
Kennen, 2010	Macroinvertebrates	Urban land, road density, a measure of forest contiguousness and percent urban land in the buffer are all predictive of an integrated measure of macroinvertebrate health.
Ourso, 2006	Measures of macroinvertebrate richness, abundance, and shredder abundance	Significant correlation for these parameters. Taxa richness begins to decline at IC as low as 1.2%.
MDNR, ND	Salamanders/ brook trout	At as low as 0.3% IC can lose some very sensitive species. About half of the salamander species remaining at 2% IC. Brook trout affected above 4% IC
Morgan and Cushman, 2005	Fish IBI	Relates fish IBI scores to urban development in coastal plain and Eastern Piedmont MD streams. In Eastern Piedmont, we see breakpoints at 10% and 25% urbanized areas. Some difference between 1st-3rd order streams, but see a decline in all.
Miltner et al., 2003	B-IBI	Significant decline at 13.8% urban land use, and second inability to meet aquatic life criteria at 27% urban land
Roy et al., 2007	Measures of fish assemblage	Some metrics best predicted by % urban land, but % forest cover in the stream reach important for some metrics at <15% IC
Moore and Palmer, 2005	Macroinvertebrate: EPT Richness, Total Richness, FFG Richness	Biodiversity declined directly with increases in urban (versus agricultural) land use. Riparian buffer lead to higher levels of diversity at all sites
Urban et al., 2006	Macroinvertebrate: EPT and species richness	Half of the taxa disappeared at a density of 10 houses/ha, and sensitive species (EPT) declined from 34% to 11% of total population.
Robbo and Kiesecker, 2004	Amphibian Larvae Richness	Number of amphibians in upland wetlands decreased as % forest (w/in 1km) decreased. Also influenced by wetland hydroperiod

IC: Impervious Cover

2.5 Relationship between Hydrology and Habitat/ Biology

As indicated in Figure 1, hydrology is an important driver in determining stream health, and has a direct influence on water quality, stream morphology/habitat and biology. Since one of the primary goals of stormwater management, and Environmental Site Design in particular, is to restore natural hydrology, we need to understand how hydrology is related to stream health. That is to say, if we manage hydrology correctly, will we in turn minimize degradation in the downstream channel?

While this review focuses on discrete types of impacts (e.g., impacts to biology versus impacts to hydrology), it is important to understand that these impacts act collectively so that, while mitigating one impact will influence in-stream condition, a comprehensive approach is needed to understand the stream system as a whole. Recent work by the USGS (Kashuba, 2012) presents an informative framework for understanding these impacts (Figure 9). The model was developed with data from New England streams, and is helpful in predicting the relative certainty of attaining a given in-stream result by managing impacts such as hydrology and water quality. Unfortunately, the model does not account for ESD practices, and only looked at very large watersheds (around 200 square kilometers and up). While the specific data in this model cannot be directly used to predict in-stream response to development in Ten Mile Creek, the result serves as a framework for understanding watershed response. For example, while hydrologic impacts are related to in-stream habitat and water quality, these factors are also directly impacted by land cover.

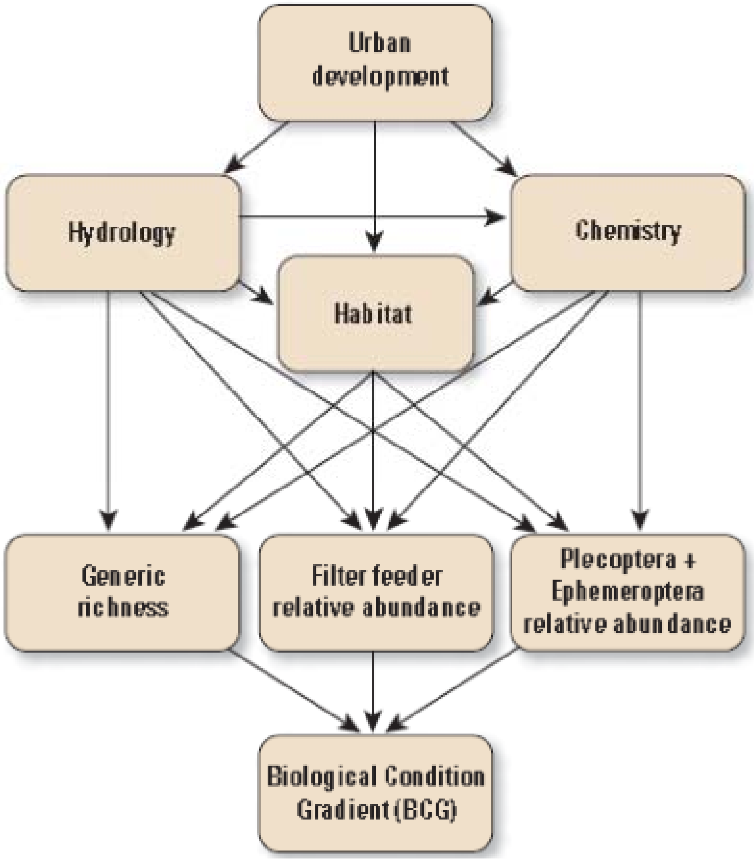

Figure 9. Network Describing Northeast Stream Conditions (Kashuba, 2012; figure from Coles et al., 2012).

Several studies, particularly in recent years, have attempted to the impacts of impervious cover from the impacts of the *responses* to impervious cover (Table 6). For example, several studies have separated hydrology as an independent variable to determine its impacts. In Kashuba's (2012) model, the output is the probability of achieving a given condition (e.g., probability of achieving a given BCG score). This model could be used to predict, for example, how controlling hydrology from development would increase the likelihood of a good outcome in terms of biological diversity. While no such specific model has been developed for streams outside of New England, the concept can be applied elsewhere. To do so, however, would require modifying the New England model to account for ESD, and to recalibrate it to account for local watershed sizes and conditions. Taken as a whole, it appears that hydrology plays a very strong role on instream habitat, but does not account for all of the impacts to instream biology that occur with urbanization.

Table 6. Studies relating Hydrology, Water Quality, Habitat and Biology

Study	Relationships Identified
King et al., 2011	Riparian cover, acidity, conductivity and woody debris (a combination of habitat and water quality variables) predicted macroinvertebrate community, but measures of urban land explained some variability not predicted by these variables alone.
Roy et al., 2007	Specific metrics of fish diversity were impacted by hydrologic variables including: altered storm flows in summer and autumn, % fine bed sediment in riffles. Overall, hydrologic variables explained 22 to 66% of the variation in fish assemblage richness and abundance.
Kennen et al., 2010	Study of 67 northeastern streams developed models to predict macroinvertebrate assemblage, as well as presence of specific taxa based on hydrologic variables. The most important variables are mean April flow, duration of high flows, and seasonal low flows.
DeGasperi et al., 2009	In King County, WA, analyzed 15 hydrologic variables to find those that are successful in predicting in-stream biology. Selected variables included High Pulse Count and High Pulse Duration
Fitzpatrick (2005)	Developed relationships between Fish IBI and several hydrologic or habitat variables, but found that urban land was a better predictor than any of these derivative variables.
Coleman et al., 2005	Study reports a relationship between flow and channel geometry

3. Stormwater Management and Environmental Site Design

Development in Stage 4 of the Clarksburg Master Plan will be required to use Environmental Site Design (ESD). If this stormwater management technique is successful, it is likely that some of the impacts typically associated with land development can be reduced. There are very few large-scale applications of ESD and consequently we could find no direct evidence of the impacts of ESD on in-stream biota. However, several studies have evaluated ESD, as well as individual practices, for benefits to hydrology and water quality.

3.1 What does ESD Mean in Maryland?

Maryland state law defines Environmental Site Design (ESD) as "using small-scale stormwater management practices, non-structural techniques, and better site planning to mimic natural hydrologic runoff characteristics and minimize the impact of land development on water resources."

In practice, the Maryland Stormwater Design Manual has laid out a process for achieving this goal that uses the 1-year rainfall (about 2.6"), as a target storm event. In the standards, ESD practices such as rain gardens, permeable pavement and green roofs, are the first choice to capture enough of this event so that the "curve number" from the site is equivalent to the curve number from woods in good condition. This means that a site with very little impervious cover would have a smaller design storm than a paved site. If it is impossible to meet these requirements with a list of ESD practices defined in the manual, then traditional stormwater management can be used to detain the remaining storm volume. So, although the goal is to reduce the runoff from the 2.6" storm event to the equivalent runoff of woods in good condition, this can be accomplished by capturing as little as the runoff from the 1" storm.

In addition to site planning that minimizes disturbance and conserves natural areas, the Maryland Stormwater Manual (MDE, 2009) identifies a list of ESD Practices (Table 7) that include three major categories: Alternative Surfaces, Nonstructural Practices and Micro-Scale Practices. All of these practices share two characteristics that make them different from most traditional stormwater practices: treating stormwater closer to its source, and reducing the volume (rather than only the peak) of stormwater runoff.

While the Maryland Stormwater Manual does address soil compaction for *practices*, it does not introduce a factor of safety or account for changes in the storage and infiltration rates of soils in the *landscape* due to disturbance and alteration during construction. Analysis conducted as a part of this study should consider soil compaction, and soil restoration measures should perhaps be required as a part of the stormwater plan. For an example, consult New York State's Stormwater Regulations (NYSDEC, 2010), which explicitly require soil restoration or oversizing of stormwater practices to account for runoff from compacted soils. Going beyond the requirements of the Maryland Stormwater management Manual, such as providing deep (24 inch) soil decompaction with organic matter amendment, is a potential strategy to provide extra protection for high-quality or sensitive watersheds.

Table 7. ESD Practices (MDE, 2012)

Alternative Surfaces

- A-1. Green Roofs
- A-2. Permeable Pavements
- A-3. Reinforced Turf

Non-Structural Practices

- N-1. Disconnection of Rooftop Runoff
- N-2. Disconnection of Non-Rooftop Runoff
- N-3. Sheetflow to Conservation Areas

Micro-Scale Practices

- M-1. Rainwater Harvesting
- M-2. Submerged Gravel Wetlands
- M-3. Landscape Infiltration
- M-4. Infiltration Berms
- M-5. Dry Wells
- M-6. Micro-Bioretention
- M-7. Rain Gardens
- M-8. Swales
- M-9. Enhanced Filters

3.2 Can Individual “ESD Practices” Theoretically Reproduce a Natural Hydrograph?

In order to reproduce a natural hydrograph, a stormwater practice needs to first reduce the volume of runoff. This is a stark difference from traditional stormwater management, which focuses on reproducing the peak runoff for a range of storm events rather than the runoff volume. A review of stormwater BMP effectiveness literature evaluated the “runoff reduction” capability of a range of practices. The results, as indicated in Table 8, indicate that the ESD practices are much more effective than most traditional stormwater practices at reducing the volume of stormwater runoff from a given storm event.

The data in Table 8 represent average effectiveness at “runoff reduction” based on a literature review of available BMP studies. These data represent average values from available individual practice studies. In these data, “runoff reduction” includes evaporation, infiltration and “extended filtration,” which would be exemplified by very slow release, perhaps from an underdrain below a filtering practice such as bioretention.

It is unclear, however, if reducing runoff volume alone is enough to reproduce a natural hydrograph. Two recent studies of bioretention practices came to different conclusions regarding this question. In North Carolina, Debusk et al. (2011) found no significant difference between outflow from a bioretention cell and the hydrograph of a nearby natural stream system. In Maryland, on the other hand, Olszewski and Davis (2013) performed virtually the same experiment and found that the bioretention cell did meet *volumetric* goals, but failed to reproduce the natural hydrograph’s shape due to differing flow *duration*. This paper proposes using flow-duration curves from natural streams as a design tool for ESD practices.

Table 8. Runoff Reduction of Stormwater Practices (Hirschman et al., 2008)

Practice	Runoff Reduction (RR) (%)
Green Roof	*45 to 60*
Rooftop Disconnection	*25 to 50*
Raintanks and Cisterns	40
Permeable Pavement	*45 to 75*
Grass Channel	*10 to 20*
Bioretention	*40 to 80*
Dry Swale	*40 to 60*
Wet Swale	*0*
Infiltration	*50 to 90*
ED Pond	*0 to 15*
Soil Amendments	*50 to 75*
Sheetflow to Open Space	*50 to 75*
Filtering Practice	*0*
Wetland/ Wet Pond	*0*

3.3 Can ESD Practices Remove Pollutants?

Recently, the Chesapeake Bay Program convened a panel of experts to estimate pollutant removal effectiveness of “Runoff Reduction” versus “Stormwater Treatment” practices. The results indicate that practices that reduce the volume of runoff are typically more effective at removing pollutants as well. Although ESD can incorporate both Stormwater Treatment and Runoff Reduction practices, one distinction of ESD is that its approach incorporates practices that reduce runoff volume on the site. The curve in Figure 10 represents the presumed phosphorus reduction based on the storm captured by these practices. It is important to note that, while Maryland’s standard targets about a 2.7” storm, the actual capture in ESD practices may be lower, so that a “mixed” efficiency might better characterize the site. The “bump” achieved by ESD practices is somewhat less impressive for sediment, which is effectively removed by traditional stormwater practices, and for nitrogen, which is mobile in ground water, and thus presumed to be less effectively removed by infiltration practices. Other pollutants that are mobile in groundwater, such as deicing salt, will move unimpeded into shallow groundwater, and could pose long-term problems for local streams.

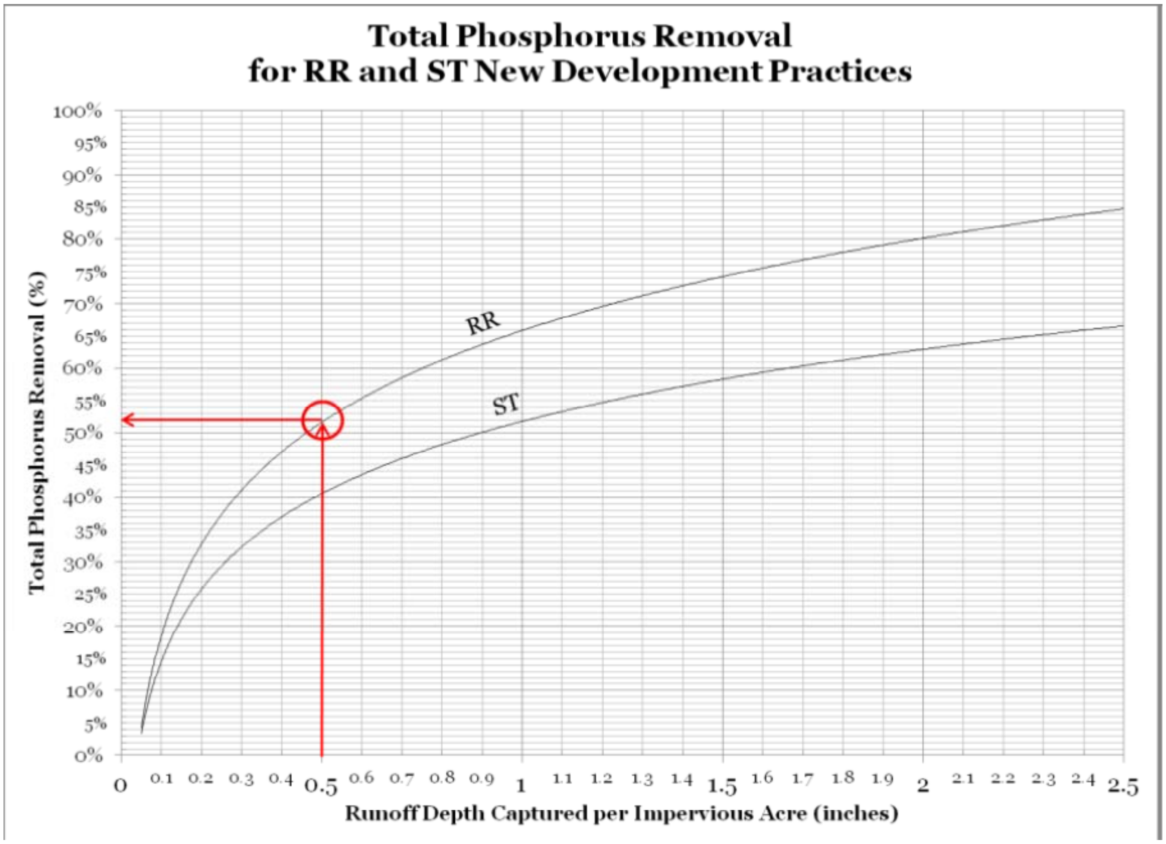

Figure 10. Phosphorus Removal Curve for "Runoff Reduction" (i.e., ESD) versus traditional stormwater management (Schueler and Lane, 2012)

When compared with traditional stormwater practices, ESD practices are in general superior at reducing downstream temperature increases. For example, according to Galli (1990) and Jones and Hunt (2010), stormwater ponds increase runoff temperatures. Results for ESD are more encouraging. Jones and Hunt (2008) showed that bioretention cells, and especially small cells, were able to reduce runoff temperatures. According to Winston et al. (2011), filter strips can also reduce runoff temperatures. Finally, Jones and Hunt (2012) found that landscape measures such as tree canopy, using light colored or less pavement, and use of underground conveyances can reduce runoff temperatures.

3.4 What are Important Program Components for Implementing Maryland's ESD Regulations in Ten Mile Creek?

There are two potential issues that need to be addressed to effectively implement ESD in Ten Mile Creek. First, the site infiltration and runoff calculations should consider soil compaction and, second, maintenance, or lack thereof, should be accounted for.

Site runoff volume computations in the MDE stormwater manual (MDE, 2010) are derived from a combination of soil type and impervious cover calculations. These calculations do not account for soil compaction and, although the manual does discuss infiltration testing and soil restoration for *practices*, there is no required method to effectively address soil compaction in the *landscape* (e.g., open fields that are compacted by construction. The State Stormwater Manual requires only a few inches of surface scarification of compacted soils. Montgomery County, however, requires about 6 inches of tilling for compacted soils, with 4 inches of topsoil added. This provides greater benefits than the State Manual requirements, but still falls short of the benefits provided by deep (24 inches) soil decompaction with organic matter amendment. The analysis conducted as a part of this study should consider soil compaction, and a possible regulatory tool would be to require soil restoration as a condition of site development. (See New York State's Stormwater Management Design Manual (NYSDEC, 2010) as an example. In addition, the "Equivalent Curve Number" methodology used at the state level should be modeled for this study to ensure that hydrologic assumptions are consistent.

Maintenance is a challenge for any stormwater practice. For example, Hirschman et al. (2009), in a field survey of BMPs in the James River Basin found that at least 50% of all stormwater BMPs were in need of maintenance. With the advent of ESD, more and more small practices will be implemented at the site level. Analyses should assume that some fraction of BMP storage is lost over time, with the potential consideration of oversizing practices to account for this lost storage. Programmatically, assurances should be made to ensure that practices are made through chain of custody agreements, inspections, and strong legal agreements for small practices on private property.

3.5 When Entire Sites or Catchments Implement ESD, What Is the Result?

While it is useful to understand the impact of individual practices, ESD should really be implemented the whole site or catchment level, and include a mix of site planning techniques and small micro-scale stormwater practices. A combination of modeling and monitoring studies provide some insight into the hydrological and water quality performance of ESD as a "whole site" practice (Table 9). Most of these studies are model-based, but both the model-based studies and monitoring studies point to some of the same trends. ESD is in general far superior to traditional stormwater management at reproducing natural stream flows. However, ESD has some limitations. For example, "tight" soils or soil compaction appears to be a major limitation for infiltration practices in the modeling studies. In addition, both modeling and monitoring studies point to the fact that ESD is most effective for small storm events. In Selbig and Bannerman (2008), a couple of small storms accounted for a much higher pollutant load in the ESD system. Further, it appears from several of the studies that, while infiltration practices can be very effective, these should be combined with land cover controls that reduce disturbance and impervious cover. Although these studies show hydrology-related ESD benefits, as indicated earlier, stream health depends on more than good hydrology. As a result, the findings of these studies cannot be used to estimate the effects of ESD on receiving stream biological communities and ecosystems. Similarly, while these studies show improvements in water quality using ESD, only a few of the pollutants that come from developed land are typically modeled or monitored. As with the results of the hydrology studies, the water quality results cannot be used to estimate ESD impacts to biological and overall stream ecosystem health.

Table 9. Results of ESD Development or Catchment Scale Studies

Study	Study Characteristics	Findings
Brander et al., 2004	Modeling Study: Evaluates four site layouts, including a cluster development a grid pattern, and two others. Compares runoff volumes for design storms	• Cluster designs that preserve open space create the least runoff. • Strategic placement of infiltration practices can reduce runoff for any development type. • Soil compaction during construction can hamper efforts to achieve runoff reductions. • Infiltration practices most effective for small storm events.
Burns et al., 2012	Study compares hydrographs of a forested and an adjacent urban (28% IC) watershed. Follows this with modeling of the urban watershed with traditional or on-lot stormwater practices.	• The uncontrolled runoff from the urban watershed had three times as much annual runoff and summer and winter baseflow. • Modeling the urban watershed with the use of a wetland system was ineffective at reproducing the natural hydrograph. • Models of the use of on-site practices showed more promise for producing the natural hydrograph.
Dietz and Clausen, 2008.	Jordan Cove: Monitored two side-by-side developments. The ESD development utilized distributed runoff controls throughout and had 20% (versus 45%) IC.	• As the conventional development was implemented, there was an exponential rise in runoff volume, while there was no relationship between runoff volume and IC in the ESD subdivision. • The same patterns held for nutrient export.
Holman-Dobbs et al., 2003	Models stream flow and annual runoff volume for various storm events comparing a pre-developed, “high impact” (50% IC, no stormwater management) and “low impact” development (50% IC, infiltration practices)	• Infiltration practices are most effective for small storm events and on soils with high infiltration rates.
Selbig and Bannerman, 2008	Monitoring study of two side-by-side developments. The ESD site has similar IC, but utilizes infiltration, including swales and an infiltration basin.	• Average annual runoff was significantly lower for the ESD site, and infiltration was most effective for smaller storm events. • While the ESD site typically better at pollutant removal, there were two years where pollutant loading from the ESD site was higher due to one or two very large storm events that were not captured by on-site practices. • Temperature from the LID site was somewhat elevated, but it is unclear if the reduced volumes combined with this temperature result in lower thermal loadings.
Zimmerman et al., 2010	Monitors runoff from a neighborhood retrofit with rain gardens, and a green roof.	• For both applications, significant runoff reduction can be achieved for small storm events. • Results for water quality were mixed, with loads from both the green roof and the retrofit neighborhood having higher loads than conventional land use for some pollutants.

IC: Impervious Cover

3.6 In-Stream Effects from an ESD Development: North Creek, City of Surrey, BC, Canada

There are very few examples documenting the in-stream impacts resulting from ESD development. However, North Creek, in the City of Surrey, BC, Canada offers some valuable insights (Page and Lilley, 2010). The East Clayton neighborhood was transformed from very low density rural land to high density residential over the period from 1999 to 2009, incorporating a full suite of ESD practices, as well as traditional detention. The neighborhood drains to North Creek, which was intensively monitored throughout the development period.

Results: Hydrology

The hydrologic results indicate that ESD practices have reduced storm flows, but increased mean annual flow. This implies that the innovative stormwater practices were effective at increasing baseflow, and in fact increased baseflow beyond pre-developed conditions.

Results: Chemistry and Biology

- Specific conductivity increased significantly over the monitoring period. The study authors conclude that this measure may be a surrogate for other urban pollutants.

- Temperature increased over the study period, probably due to the presence of a large stormwater pond at the outlet of the development.
- Turbidity was relatively constant but increased during the initial clearing and grading phase.
- Loss of sensitive taxa over the 10 year period.
- B-IBI (Benthic Index of Biological Integrity) increased, but this increase was largely driven by abundance of Turbellarian flatworms. This effect on the B-IBI masks an overall decline in biological health, as indicated by the loss of sensitive taxa. As a result, documenting the effects of ESD on stream biology may require the use of more specific indices of biological integrity, such as functional feeding group, or individual taxa metrics.
- The study is currently at the halfway point, and further monitoring will be needed to determine if the decline in stream biological health observed so far will continue, or whether recovery will occur over a longer period of time.

4. Construction Impacts

In addition to the soil compaction discussed in Section 2 of this report, construction impacts stream systems through increased soil disturbance and resulting sediment loads and turbidity. Concentrations of sediment in construction site runoff are significantly higher than in runoff from urban or forested lands. In the study by page and Lilley (2010) described above, in-stream turbidity increased during construction even though the City of Surrey was implementing innovative stormwater controls. Some studies have documented in-stream responses to development. For example, Gage et al. (2004) reported changes in alkalinity, dissolved oxygen, and macroinvertebrate community in response to “disturbance” in urbanizing watersheds in North Carolina. Miltner et al. (2003) reported a similar result, with a decrease in macroinvertebrate IBI at as low as 4% impervious cover during the land development process. This decline was attributed to land disturbance during the construction process.

A similar trend was found in the early stages of the Clarksburg Plan. During the peak construction period (2003-2007), IBI scores declined and began to recover again (Figure 11). At the same time, functional feeding groups were affected during the construction period, with a loss of almost all shredder species, and a dramatic increase in collectors and substantial increase in predators. After construction, there has been some recovery in shredder populations, with a corresponding decline in shredders. It is unclear if either the IBI or the species composition will return to predevelopment levels.

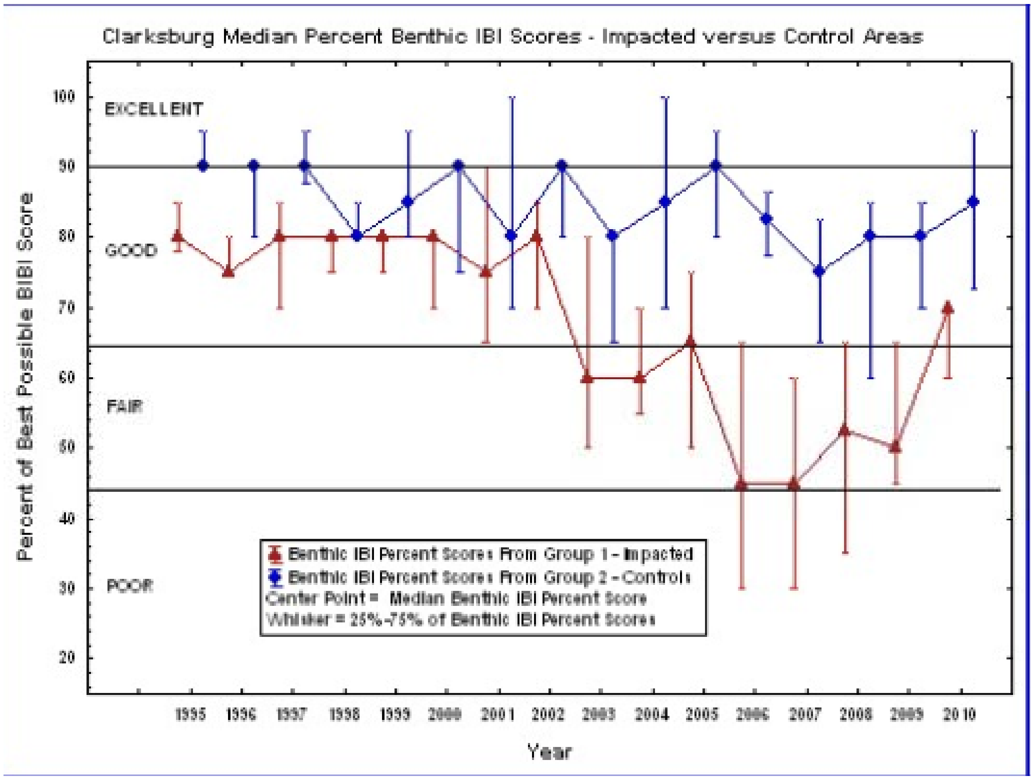

Figure 11. Benthic IBI Scores decline during the peak construction period in Clarksburg, and begin to recover (MCDEP, 2010).

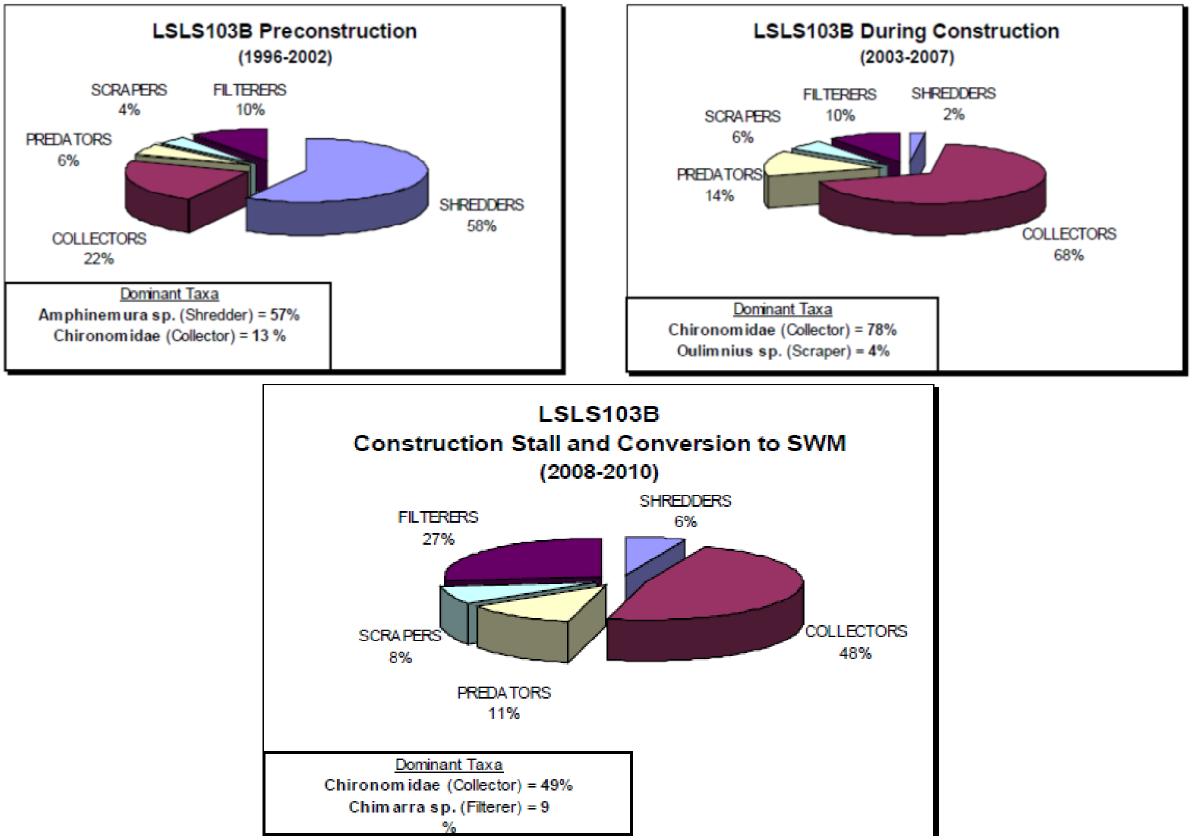

Figure 12. Functional Feeding Groups switched during construction, with a dramatic loss in shredder species, and significant increases in collectors and predators (MCDEP, 2010).

5. Erosion and Sediment Control (ESC) Practices

Currently, the Chesapeake Bay Program estimates that ESC practices remove 25% of TN, and 40% of TSS and TP (Baldwin, 2007). On the surface, these estimates of sediment removal, in particular, seem low compared to published values, particularly for “Enhanced” ESC practices. For example, recent research on the use of polyacrylamide in combination with sediment traps (McLaughlin, 2009) and Filter Socks (Faucette, 2008) are very encouraging, suggesting greater than 90% reduction in turbidity for sediment traps, and better than 90% sediment reduction for filter socks. Initial monitoring from construction sites in the SPAs of Montgomery County also demonstrated high removal efficiencies, with an average removal rate of approximately 70% TSS.

Although these practices can be effective individually, the greatest challenges to implementing effective ESC practices are related to site compliance. In an interesting study by Reice and Carmin (2000) in North Carolina, in-stream macroinvertebrates (EPT) were measured upstream, at the site, and downstream of construction sites in three counties, with varying strictness of ESC regulations. While EPT values were lower at the construction site than upstream in all cases, the decline was significantly lower in highly regulated counties.

Another challenge of implementing effective ESC practices is the uncertainty surrounding rainfall patterns. The rate of erosion is dramatically increased during large storm events, and intense summer storms can account a significant amount of annual sediment load, and can overwhelm stormwater practices installed on site. Grading limits that are proposed to be in effect during the construction of Stage 4 of the Clarksburg Plan will help to minimize the risk associated with large areas of exposed soil, and should be strictly enforced during the construction of Stage 4.

6. Conclusions and Recommendations

Impacts of Stormwater Runoff and Land Development

- In addition to thresholds identified by the Impervious Cover Model (e.g., 10%), available data suggest that degradation in stream biology begins to happen at much lower levels of impervious cover.
- Riparian corridor preservation is a very useful tool for protecting in-stream habitat and biology, but appears to be the most effective when coupled with watershed impervious cover of 15 to 20% or less.
- Headwater and zero order streams are extremely important, particularly given the high quality nature of Ten Mile Creek, and presence of important amphibian species.
- The B-IBI is currently used to classify streams in Montgomery County and while this is an excellent indicator of general stream health, other metrics should be considered for tracking subtle changes in the quality of stream biology in Ten Mile Creek.
- The relationship between hydrology and in-stream aquatic biota has been documented, but no model has been calibrated to Montgomery County's data. An analysis of specific flow characteristics and measures of in stream biology would be very helpful in understanding future development in Ten Mile Creek and elsewhere in Montgomery County.
- Ongoing maintenance is a challenge for any stormwater management practice, and analyses should consider loss of function and storage in stormwater BMPs over time.
- Hydrologic assumptions inherent in MDE's stormwater regulations should be modeled at a site level to ensure consistency, and account for soil compaction.
- Although MDE requirements allow for the combination of ESD techniques and traditional stormwater detention, detention practices should be avoided if possible due to potential stream warming effects.

Impacts of Construction and ESC

- A decrease in stream habitat and biology during construction has been documented in several studies. Biological monitoring should be conducted immediately downstream of construction sites to detect initial indications of stream degradation.
- ESC regulations should be strictly enforced, with special emphasis on proposed clearing and grading limits.
- The scientific literature indicates that ESD should perform better than traditional stormwater management, but will still not be sufficient to mitigate all of the negative environmental impacts from development.
- ESD can be supplemented with more stringent site design criteria, and/or combined with land use-based measures that reduce development footprint and impervious surfaces, to provide additional protection for high-quality or sensitive watersheds.

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