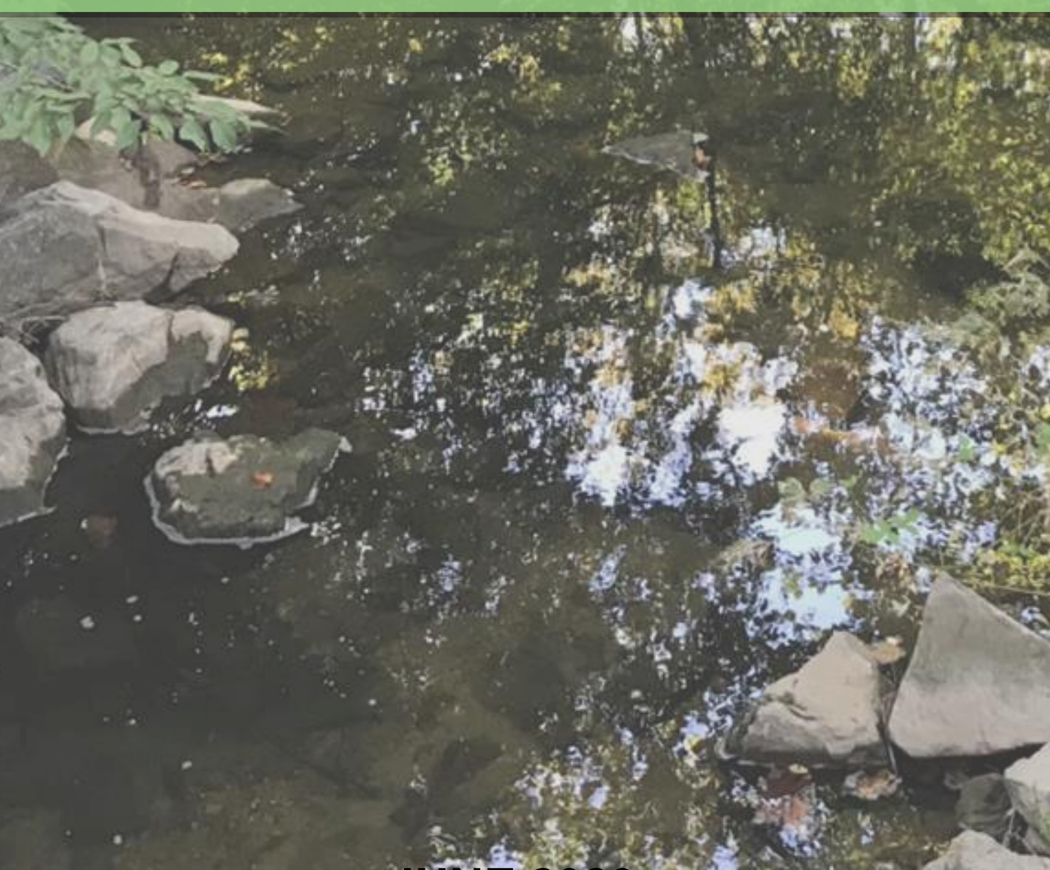
US Army Corps of Engineers

ANACOSTIA WATERSHED RESTORATION MONTGOMERY COUNTY, MARYLAND CONTINUING AUTHORITIES PROGRAM SECTION 206 AQUATIC ECOSYSTEM RESTORATION FEASIBILITY STUDY

DRAFT INTEGRATED FEASIBILITY REPORT AND ENVIRONMENTAL ASSESSMENT

APPENDIX B: PLAN FORMULATION



MARCH 2025

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TABLE OF CONTENTS

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MONTGOMERY COUNTY, MARYLAND
CONTINUING AUTHORITIES PROGRAM SECTION 206
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APPENDIX B1: 2015 ANACOSTIA WATERSHED RESTORATION: MONTGOMERY COUNTY AQUATIC ECOSYSTEM RESTORATION FEASIBILITY STUDY REPORT SYNOPSIS

Note: This Report Synopsis reflects planning analysis and formulation completed during the terminated study from 2015 and may no longer reflect site conditions as of the writing of this report (2025). The Report Synopsis is presented as is with no revisions to existing conditions or plan formulation actions.

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Report Synopsis for
Anacostia Watershed Restoration
Montgomery County, Maryland

1.0 Stage of Planning Process

The U.S. Army Corps of Engineers (USACE) Baltimore District is conducting the Anacostia Watershed Restoration, Montgomery County, Maryland Feasibility Study to develop and evaluate potential ecosystem restoration solutions to address degraded aquatic ecosystems in the Anacostia River Watershed in Montgomery County, Maryland. The Section 905(b) report *Anacostia River and Tributaries, Maryland and the District of Columbia, Comprehensive Watershed Plan* was completed in July 2005 and recommended that USACE conduct a comprehensive investigation of watershed problems (USACE 2005). The resulting Anacostia Restoration Plan (ARP) was completed in February 2010 and identified over 3,000 projects (candidate restoration projects (CRP)) for the restoration of the Anacostia River watershed, including projects that USACE could potentially implement as stream restoration, wetland restoration, and fish blockage removal/modification (USACE 2010). A Feasibility Cost Sharing Agreement (FCSA) was subsequently signed with Montgomery County and executed October 8, 2013. The Alternatives Milestone was completed on February 28, 2014. A tentatively selected plan (TSP) has been identified and the Tentatively Selected Plan Milestone is the next planning decision point.

2.0 Timeline

Feasibility Cost Sharing Agreement Signed*	08 OCT 2013
Alternatives Milestone*	28 FEB 2014
Tentatively Selected Plan Milestone	15 MAY 2015
Public Review Begins	29 JUL 2015
Agency Decision Milestone	30 OCT 2015
Division Engineer Transmittal	02 FEB 2016
Civil Works Review Board	06 MAY 2016
30-Day S&A Review start	17 MAY 2016
30-Day S&A Review end	28 JUN 2016

*Complete

3.0 Study Authority

The Anacostia Watershed Restoration, Montgomery County, Maryland Study is being conducted under the authority of a September 8, 1988 resolution of the House Committee on Public Works and Transportation. That resolution reads as follows:

> *"Resolved by the Committee on Public Works and Transportation of the United States House of Representatives, that the Board of Engineers for Rivers and Harbors is hereby requested to review the report of the Chief of Engineers on the Anacostia River and Tributaries, District of Columbia and Maryland, published as House Document No. 202, 81st Congress, 1st Session, with a view to determining if further improvements for flood control, navigation, erosion, sedimentation, water quality and other related water resources needs are advisable at this time."*

4.0 Non-Federal Sponsor

The Anacostia Watershed Restoration, Montgomery County, Maryland study is being conducted in partnership with Montgomery County, Maryland, which entered into a FCSA on October 8, 2013. The primary point of contact on behalf of the non-federal sponsor is the Montgomery County Department of Environmental Protection (MCDEP).

5.0 Purpose and Need

In February 2010, USACE in partnership with the Metropolitan Washington Council of Governments (MWCOG), along with other local jurisdictions and state and local resource agencies completed the ARP. The ARP identifies more than 3,000 restoration opportunities within each of the river's 14 primary subwatersheds and the tidal river reach. The candidate projects represent opportunities within the following restoration strategies: stormwater retrofits; stream restoration; wetland creation/restoration; fish blockage removal/modification; riparian reforestation; riparian meadow creation; street tree and riparian invasive management; trash reduction; and parkland acquisition. Of these projects, fish passage blockage removal/modification, riparian reforestation, invasive management, stream restoration, and wetland creation/restoration represent strategies that could be implemented by USACE under current policy directives. During a May 2012 meeting, MCDEP staff confirmed that stream restoration is a priority for Montgomery County. At that time, the decision was made to undertake an ecosystem restoration feasibility study to evaluate which of these candidate projects or other opportunities not previously identified in the ARP could be implemented by USACE under its Civil Works program.

5.1 Federal Interest

USACE has a long history in the Anacostia River watershed, dating back to the founding of Washington, D.C. Early USACE work included making the land habitable and suitable for construction of the city and navigation on the mainstem of the Anacostia River. Efforts to restore the Anacostia River watershed began nearly three decades ago. Since that time, local, state, and federal government agencies, as well as environmental organizations and dedicated private citizens have contributed significant resources toward watershed restoration. Formal cooperation between government agencies came with the 1987, signing of the Anacostia Watershed Agreement and the formation of the Anacostia Watershed Restoration Committee (AWRC).

Within the Anacostia River watershed, numerous federal commitments and actions have been made within the past 30 years, culminating in current federal efforts to restore urban streams in the watershed (Figure 1). In Fiscal Year 2014 the federal government committed to continuing feasibility studies on the Anacostia River watershed (Executive Order 13508 Combined Fiscal Year 2014 Action Plan Report and Fiscal Year 2013 Progress Report).
The Anacostia River drains to the Potomac River, ultimately emptying to the Chesapeake Bay. There are 150 major rivers and streams included in the 100,000 plus streams and rivers in the Chesapeake drainage basin. The Chesapeake supports greater than 3,600 species of plants, fish, and animals, including 348 species of finfish, 173 species of shellfish, and greater than 2,700 plant species. As home to 29 species of waterfowl and a major resting ground along the Atlantic

Migratory Bird Flyway, roughly 1,000,000 waterfowl winter in the Chesapeake Bay's basin each year. The Chesapeake Bay also provides recreational opportunities to more than 15,000,000 citizens living in the watershed and produces greater than 500 million pounds of seafood per year (CBP, 2014).

Executive Order 13508, Chesapeake Bay Protection and Restoration

On May 12, 2009, President Obama issued Executive Order (EO) 13508 to protect and restore the Chesapeake Bay and its watershed. The EO declared the Chesapeake Bay a "national treasure" and recognized that there are many nationally significant assets owned by the federal government in the Chesapeake Bay and its watershed such as public lands, facilities, military installations, parks, forests, wildlife refuges, monuments, and museums. The Executive Order directed the federal government to exercise a greater leadership role to restore this ecological, economic, and cultural resource. In November 2009, the Federal Leadership Committee (FLC) designated by EO 13508 issued a series of reports containing recommendations for addressing challenges facing the health of the Chesapeake Bay watershed including developing tools and actions to improve water quality; focusing on conserving resources; strengthening of stormwater management at federal facilities; consideration of climate change impacts; science and decision-making support for ecosystem management; and habitat and research activities. The FLC was convened to manage the development of strategies and program plans for the watershed and ecosystem of the Chesapeake Bay and oversee their implementation. The FLC for the Chesapeake Bay is composed of representatives from the U.S. Environmental Protection Agency (EPA) and the Departments of Agriculture, Commerce, Defense, Homeland Security, Interior, and Transportation.

Chesapeake Bay Program

Federal interest in the ecological health of the Chesapeake Bay can be traced to the late 1970s/early 1980s and to the Chesapeake Bay Program (CBP). The Chesapeake Bay was the first estuary targeted by Congress for restoration and protection (CBP 2012). The Chesapeake Bay Program (CBP) was established in 1983. The EPA is the federal lead agency that coordinates restoration efforts and implements strategies, but the CBP is a regional partnership of government agencies and organizations. There are 18 federal agencies listed as CBP partners (including USACE), as well as 26 academic institutions, 35 non-governmental organizations (NGOs), and at least 6 other partners.

There have been a number of agreements since 1983 for the purpose of guiding Chesapeake Bay restoration. These include the Chesapeake Bay Agreement of 1983, the 1987 Chesapeake Bay Agreement, Chesapeake 2000, and the recently signed 2014 Chesapeake Bay Agreement. Through the 2014 Chesapeake Bay Agreement, the partnership has recommitted its efforts to restoration of the Bay and its watershed.

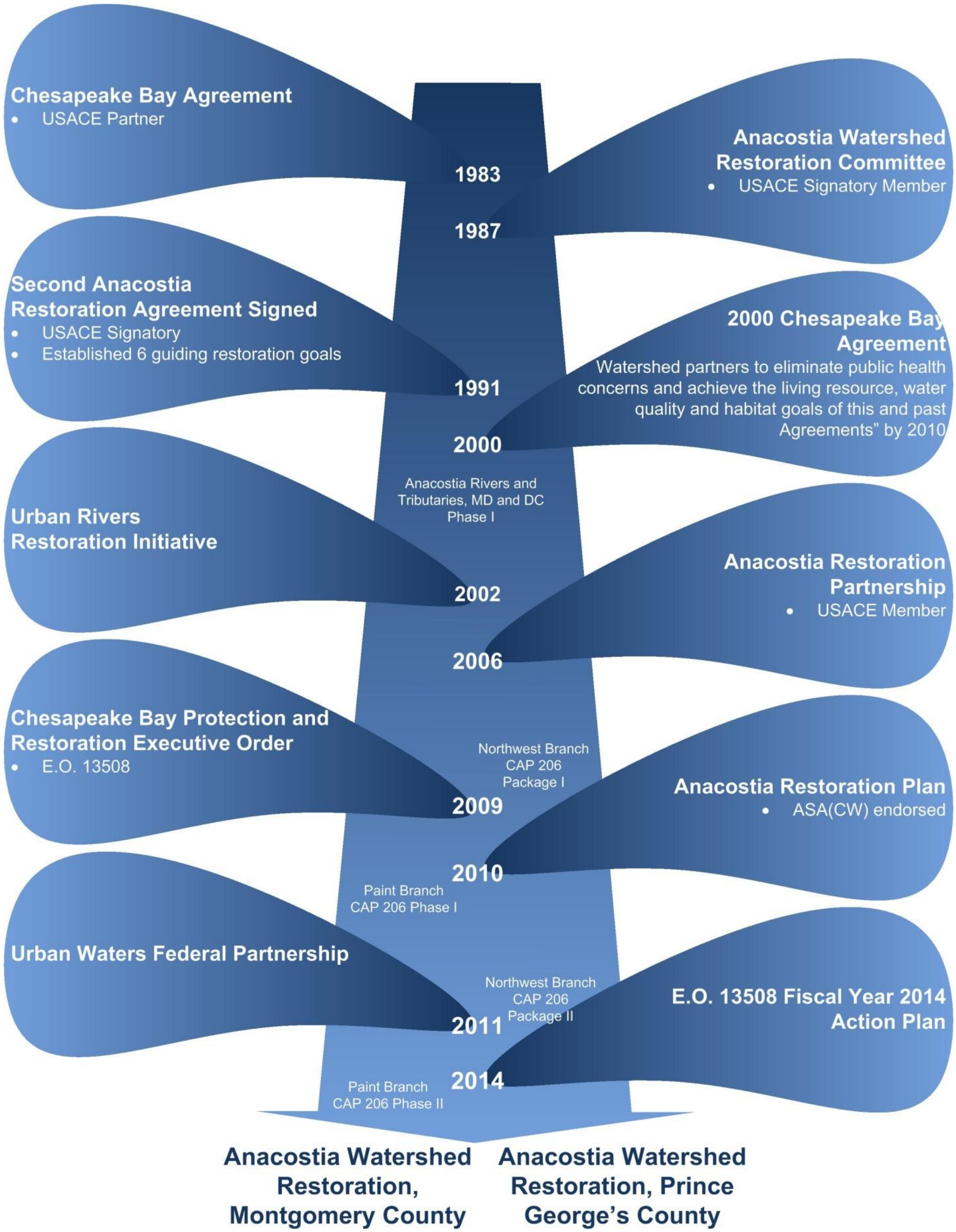

Figure 1. Federal Commitments within the Anacostia River Watershed

5.2 Institutional Significance

In 1987, after recognizing the need for environmental restoration in the Anacostia River watershed, local jurisdictions and the state of Maryland came together to sign the first Anacostia Watershed Restoration Agreement, which created the Anacostia Watershed Restoration Committee (AWRC). The signatory members of the AWRC included the District of Columbia, Montgomery and Prince George's Counties in Maryland, the State of Maryland, USACE, EPA, and the National Park Service (NPS). USACE was designated as the Federal liaison and MWCOG was the primary provider of administrative policy and technical support to the AWRC and its restoration efforts. In June 2006 MWCOG established the Anacostia Restoration Partnership (AWRP), which was essentially a reorganization of the AWRC, and the creation of the AWRP Steering Committee (MWCOG 2015).

Federal agencies have a long-standing interest in the restoration of the Anacostia River watershed. Over the past 25 years, the U.S. Fish and Wildlife Service (USFWS) Chesapeake Bay Field Office has conducted studies aimed at documenting the magnitude and effects of chemical contaminant impacts in the tidal river. Working with partners, USFWS biologists have also provided substantial support towards the restoration. This includes reviewing the ARP, commenting on monitoring protocols proposed by MWCOG, and serving on the Anacostia Watershed Toxics Alliance, and the Leadership Council for a Cleaner Anacostia. USFWS has also conducted stream restoration projects within the watershed, including the 1.8 mile Watt's Branch project (completed in 2011), which restored and stabilized a stream system that was eroding by an estimated 1500 tons per year (USFWS 2011). Following the tenets presented in the ARP to combine, or cluster, the synergistic benefits of aquatic ecosystem restoration projects, stream restoration, restoration of floodplain benches, and installation of upland green infrastructure and stormwater low impact development best management practices (BMPs) resulted in overall channel stability within Watts Branch and progress toward attaining the Chesapeake Bay Program designated use of protection and propagation of fish, shellfish, and wildlife (EPA 2013). Additionally, the combination of the projects result in about a one-third reduction in total suspended solids, along with other nutrient loading reductions, which supported improved water quality and correspondingly habitat quality (EPA 2013).

In addition to restoration opportunities, USFWS and other federal agencies have promoted efforts to increase recreation within the Anacostia River watershed. NPS has helped to obtain funding for a riverside trail along the Anacostia River, and more broadly, the Department of Interior has developed new Urban Initiatives and Urban Refuge Programs to encourage urban residents to enjoy the natural resources of the Anacostia River.

In 2011, 13 federal agencies partnered to work together to reconnect urban communities with their waterways by improving coordination and collaborating with community-led revitalization efforts. The Anacostia River watershed is one of seven locations selected to be part of The Urban Waters Federal Partnership. The Partnership now also includes 27 non-governmental organizations and helps to align resources, funding, and expertise with federal efforts to restore urban waters and parks, increase outdoor recreation, and engage residents and youth.

Additionally, the federal government is a substantial landowner in the watershed. Federal land holdings in the watershed account for approximately 15%, encompassing 16,000 acres (USACE 1994), which does not include federal holdings in the District of Columbia.

5.2 Public Significance

The local and regional public has recognized the significance of the Anacostia River watershed by forming and participating in numerous volunteer groups that support the restoration and protection of the Anacostia River Watershed. The Anacostia Watershed Society (AWS) was founded in 1989 with a vision to protect and restore the Anacostia River and its watershed communities. AWS conducts numerous educational events and undertakes projects such as stream restoration, stormwater best management practices (BMPs) and retrofits, and others throughout the watershed. In 2013, more than 8,000 people participated in AWS programs and projects (AWS 2014).

Other groups active in the watershed and Montgomery County include Eyes of Paint Branch, Friends of Little Paint Branch, Neighbors of Northwest Branch, and Friends of Sligo Creek, which was formally organized as a non-governmental organization. The public representatives residing in the sub-watersheds are also active participants and represented as part of the AWRP Citizens Advisory Committee. Additional information related to the AWRP Citizens Advisory Committee and the various sub-watershed groups within the Anacostia River watershed is available online at http://anacostia.net/Subwatershed/groups.html.

5.3 Technical Significance

Many species of wildlife occur within the Anacostia River watershed that could benefit from restoration and protection of stream and riparian habitats (including wetlands). Restoration of stream habitat will improve the availability and quality of refugia, spawning and nesting areas, nutrient cycling functions, and increased primary productivity. Additionally, restoration would decrease stream erosion, which introduces sediment to the stream system and results in smothering of benthic habitats. Species which would benefit include a variety of migratory, waterfowl, and predatory bird species. Bird species strongly affiliated with stream and riparian habitats include the Kentucky warbler (*Geothlypis formosa*), Acadian flycatcher (*Empidonax virescens*), willow flycatcher (*Empidonax traillii*), woodcock (*Scolopax minor*), prothonotary warbler (*Protonotaria citrea*), great blue heron (*Ardea Herodias*), green heron (*Butorides virescens*), wood duck (Aix sponsa), marsh wren (*Cistothorus palustris*), mallard (*Anas platyrhnchos*), and red-shouldered hawk (*Buteo lineatus*). Additional bird species affiliated with mature forests that could benefit include wood thrush (*Hylocichla mustelina*), red-eyed vireo (*Vireo olivaceus*), northern parula (*Setophaga americana*), yellow warbler (*Setophaga petechia*), Cooper's hawk (*Accipiter cooperii*), and barred owl (*Strix varia*).

The Montgomery County portion of the watershed provides habitat for migratory American eel, a fish species of conservation concern in the USFWS's Northeast Region. To this effect, USFWS supports efforts to remove eel blockages within the watershed.[1] Non-anadromous fish are listed in Table 1 and all would potentially benefit from stream restoration work. Other stream restoration work, such as bank stabilization and addition of in-stream habitat, benefit fish and wildlife resources directly by providing refugia and habitat for spawning and nesting, and also by enhancing habitat for benthic invertebrates—the base of the aquatic food chain.

American eel (*Anguilla rostrata*) is a catadromous fish living in the freshwaters of the watershed and spawning in the Sargasso sea of the Atlantic Ocean. The American eel stock is depleted in U.S. waters, at or near historic low levels due to overfishing, habitat loss, predation, turbine mortality, and other factors (ASMFC 2015). In 2010, USFWS was petitioned to list American eel under the Endangered Species Act. The proposed rule is to be published by September 30, 2015.

Table 1. Non-anadromous fish species in the Anacostia River Watershed, Montgomery County.

Sea lamprey *Petromyzon marinus*	Swallowtail shiner *Notropis procne*	Brown trout *Salmo trutta*
Least brook lamprey *Lampetra aepyptera*	Bluntnose minnow *Pimephales notatus*	Banded killifish *Fundulus diaphanus*
American eel *Anguilla rostrata*	Fathead minnow *Pimephales promelas*	Eastern mosquitofish *Gambusia holbrooki*
Eastern mudminnow *Umbra pygmaea*	Blacknose dace *Rhinichthys atratulus*	Potomac sculpin *Cottus girardi*
Goldfish *Carassius auratus*	Longnose dace *Rhinichthys cataractae*	Blue Ridge sculpin *Cottus caeruleomentum*
Central stoneroller *Campostoma anomalum*	Creek chub *Semotilus atromaculatus*	Redbreast sunfish *Lepomis auritus*
Rosyside dace *Clinostomus funduloides*	Fallfish *Semotilus corporalis*	Green sunfish *Lepomis cyanellus*
Satinfin shiner *Cyprinella analostana*	White sucker *Catostomus commersonii*	Pumpkinseed *Lepomis gibbosus*
Spotfin shiner *Cyprinella spiloptera*	Creek chubsucker *Erimyzon oblongus*	Bluegill *Lepomis macrochirus*
Silverjaw minnow *Notropis buccatus*	Northern hogsucker *Hypentelium nigricans*	Longear sunfish *Lepomis megalotis*
Cutlips minnow *Exoglossum maxillingua*	Golden redhorse *Moxostoma erythrurum*	Smallmouth bass *Micropterus dolomieu*
E. silvery minnow *Hybognathus regius*	Yellow bullhead *Ameiurus natalis*	Largemouth bass *Micropterus salmoides*
Common shiner *Luxilus cornutus*	Brown bullhead *Ameiurus nebulosus*	Greenside darter *Etheostoma blennioides*
Golden shiner *Notemigonus crysoleucas*	Channel catfish *Ictalurus punctatus*	Fantail darter *Etheostoma flabellare*
Comely shiner *Notropis amoenus*	Margined madtom *Noturus insignis*	Tessellated darter *Etheostoma olmstedi*
Spottail shiner *Notropis hudsonius*	Rainbow trout *Oncorhynchus mykiss*	

[1] Note that the watershed in Montgomery County is not generally utilized by other migratory fish species occurring in the Prince George's County portion of the watershed, such as herring, because of its position upstream and lack of habitat meeting requirements of these species.

6.0 Study Scope

The ARP identified 304 potential aquatic ecosystem restoration projects in Montgomery County that represented possible USACE-led projects. During a September 2011 scoping meeting with MCDEP, County staff expressed their concern that excess sediment contribution from incised headwater streams is impacting habitat conditions in the larger tributaries farther downstream including the Potomac River, which has been designated by EPA as an American Heritage River, as well as Chesapeake Bay. Previous stream geomorphic restoration projects in Montgomery County have shown better physical stability over time in headwaters than lower in stream systems. Consequently, the PDT has concentrated investigation on headwater streams. Potential restoration areas were also based on the location of ARP candidate projects that represent an ecosystem restoration opportunity as part of the USACE ARP watershed plan.

6.1 Study Area

The Anacostia River watershed encompasses approximately 176 square miles, located entirely within the metropolitan Washington, D.C. area. The drainage within Montgomery County is approximately 61 square miles, accounting for about one third of the total Anacostia River watershed. The Anacostia River flows through Maryland and then the District of Columbia into the Potomac River; the river ultimately drains to the Chesapeake Bay (Figure 2). Anacostia River sub-watersheds largely within Montgomery County include Sligo Creek, Northwest Branch, Paint Branch, and Little Paint Branch (Figure 3). The watershed in Montgomery County falls primarily within the Piedmont physiographic province. However, along the county's border with Prince George's County, small sections of the streams lie within the Coastal Plain province.

Northwest Branch

The Northwest Branch subwatershed of the Anacostia originates south and east of Olney, MD near the intersection of Route 108 and Georgia Avenue, and flows south approximately 15 miles before passing into Prince Georges County, where it is joined by several other major tributaries to form the Anacostia River. (The Northwest Branch mainstem and some tributaries are located within an extensive forested stream valley park system. Without this protection the stream conditions would likely be worse.) Above Ednor Road, there is low density development, and streams are undergoing a transition from widespread historic agricultural use to higher impervious land uses. Newer development in this area must provide stream buffers and modern stormwater management techniques. Below Ednor Road, the middle section of the subwatershed contains a mix of moderate to higher density housing interspersed with large areas of parkland. Altered hydrology is common in this section, and many of the tributaries have insufficient stream buffers. Below Bonifant Road, the downstream portion of Northwest Branch is an older urban subwatershed. It is highly developed and densely populated in many areas, with very little stream valley protection or stormwater management. As a result, stream conditions have been significantly altered.

Sligo Creek

The Sligo Creek headwaters are located in the Wheaton area, north of the intersection of Georgia Avenue and University Avenue. Sligo Creek flows southeast approximately eight miles before passing into Prince Georges County, where it joins the Northwest Branch of the

Anacostia River. It is one of the County's most urbanized areas, containing high density residential and commercial areas such as Wheaton Triangle, Wheaton Central Business District, parts of Silver Spring, and Takoma Park. This older development was established before today's modern stormwater structures and environmental buffers were required. There are many areas where tributaries were paved over and piped into storm drains and where the larger stream channels have been heavily armored to resist erosion. Although this does provide increased bank stability, it reduces available instream habitat. Areas that have not been armored suffer from varying degrees of erosion due to unmitigated stormflows.

This subwatershed was the first targeted for Anacostia watershed restoration efforts within Montgomery County. Since the early 1990s, these have included new runoff BMPs, improvements to the sanitary sewers, and stream channel restoration. This has lead to notable increases in stormwater management and improving instream habitat stability. Blockages downstream prevent natural re-colonization of Sligo from the Northwest Branch.

Paint Branch

The Paint Branch subwatershed begins near Spencerville, MD, just to the south and east of the intersection of Spencerville Road and New Hampshire Avenue. Paint Branch flows south for approximately nine miles before entering Prince Georges County, and then joins Little Paint and several other major tributaries to form the Northeast Branch of the Anacostia River. Paint Branch is unique in that it provides a coldwater fishery and wild brown trout population close to the Nation's capital. The Upper Paint Branch (above Fairland Road) is a county Special Protection Area (SPA)2 where new development is required to follow regulations for the protection of the coldwater resources here.

The Gum Springs and Good Hope tributaries of Paint Branch provide spawning/nursery areas and cold clean baseflow for young trout, while the Right Fork and the Left Fork provide cold clean baseflow. The mainstem supports adult trout populations as far downstream as I-495. Land use in the upper portion of Paint Branch is primarily made up of areas of low and medium density residential housing with open section road which has benefited the receiving streams as opposed to curb and gutter roadways, with some commercial and agricultural activities. Development in the lower portions of the watershed occurred primarily before requirements for stormwater BMPs were put in place and are reflected in degraded stream habitat. Among the historic development in the lower watershed is a quarry. There has been a continuing effort to improve the stream through restoration projects and the purchase of large areas of forested parkland to provide protection to the riparian areas.

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[2] A Special Protection Area (SPA) is an area designated by the Montgomery County Council within a watershed where streams, wetlands, and related natural features are of a very high quality and where special measures (over and above standard environmental laws, regulations, and guidelines) must be applied to land development and to certain land uses in order to protect the high quality conditions of these natural features. (http://www.montgomeryplanning.org/environment/spa/faq.shtm)

Little Paint Branch

Little Paint Branch is located in the easternmost portion of Montgomery County. It is unique in that it is a transition area between the Piedmont and the Coastal Plain physiographic regions. The headwaters originate south of Burtonsville, near the intersection of Routes 29 and 198, and the stream flows south for approximately three miles before entering Prince George's County, where it eventually joins Paint Branch. Little Paint Branch is transected by the Rt. 29 corridor, which contains many of the County's important industrial and commercial complexes. Many regional stormwater BMPs have been installed in the upper portions of Little Paint to mitigate the effects from high density residential and commercial land uses. The lower portions of the subwatershed were developed prior to requirements for stormwater BMPs, leading to degraded conditions. High densities in this part of the subwatershed and lack of available public land make retrofitting these areas difficult.

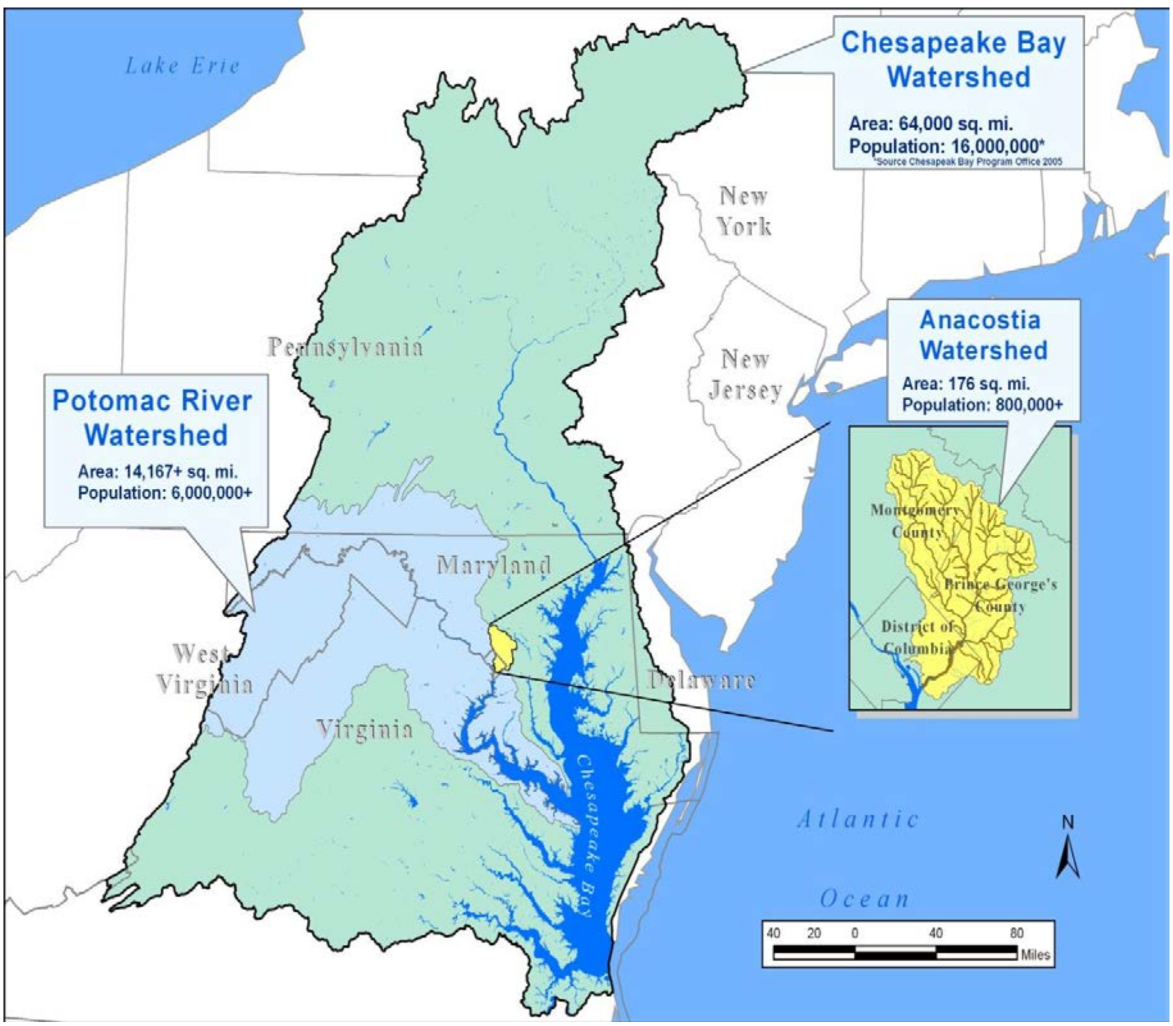

Figure 2. Anacostia River Watershed

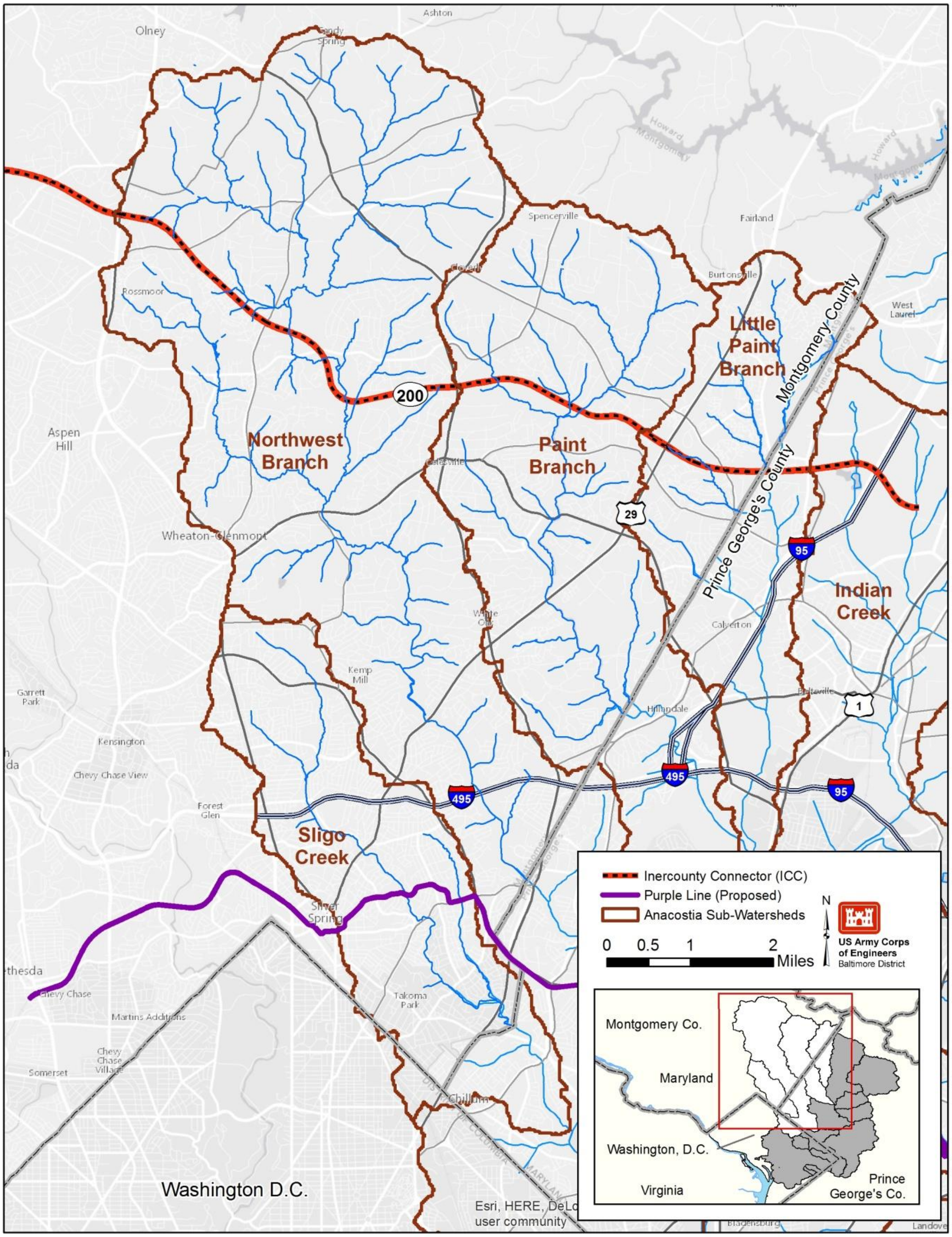

Figure 3. Anacostia River Watershed and Sub-watersheds in Montgomery County, MD.

6.2 Project Area

The proposed project area includes seven stream reaches in four sub-watersheds of the Anacostia River watershed (Table 2; Figure 4). The selection process for these reaches is described in Section 12. These stream reaches are generally on park land owned by Maryland-National Capital Parks and Planning Commission (M-NCPPC). This land is primarily bordered by forested, residential, institutional (schools), and transportation (roads) land uses. Roads cross several stream reaches via bridges, and there are walking/biking trails that also border some reaches.

Montgomery County is highly developed, being predominantly residential and commercial. Within the general study area there are approximately 164 public parks including athletic fields, playgrounds, public gardens, historic sites, picnic areas, and camp sites (M-NCPPC 2014b). Of particular note are the Best Natural Areas as designated by M-NCPPC. These areas contain the best examples of park natural resources in Montgomery County. There are two best natural areas in the Anacostia watershed located in Montgomery County: Northwest Branch Stream Valley Park and Upper Paint Branch Stream Valley Park. Both of these areas are dedicated as preservation parks and show little signs of encroachment by development. There are natural and hard surface trails for hiking, biking, rollerblading, and horseback riding as well as opportunities for fishing. The Upper Paint Branch Park supports natural brown trout populations while the Northwest Branch Park support bass and sunfish populations and is stocked with rainbow trout providing put-and-take fishing (M-NCPPC 2014a).

Table 2. Area and length of project area stream reaches.

Stream Segment	Drainage Area (mi^2)	Drainage Area (ac)	Length (mi)
Little Paint Branch			
Galway Tributary (1)	1.39	890	1.8
Green Castle Tributary (2)	1.48	950	1.2
Northwest Branch			
Bel Pre Tributary (3)	4.38	2800	3.1
Lamberton Tributary (5)	0.55	350	1.0
Quaint Acres Tributary (6)	0.73	470	0.5
Paint Branch			
Stewart/April Lane (14)	0.36	230	0.8
Sligo Creek			
Sligo Creek/Colt Terrace (12)	0.59	380	0.7

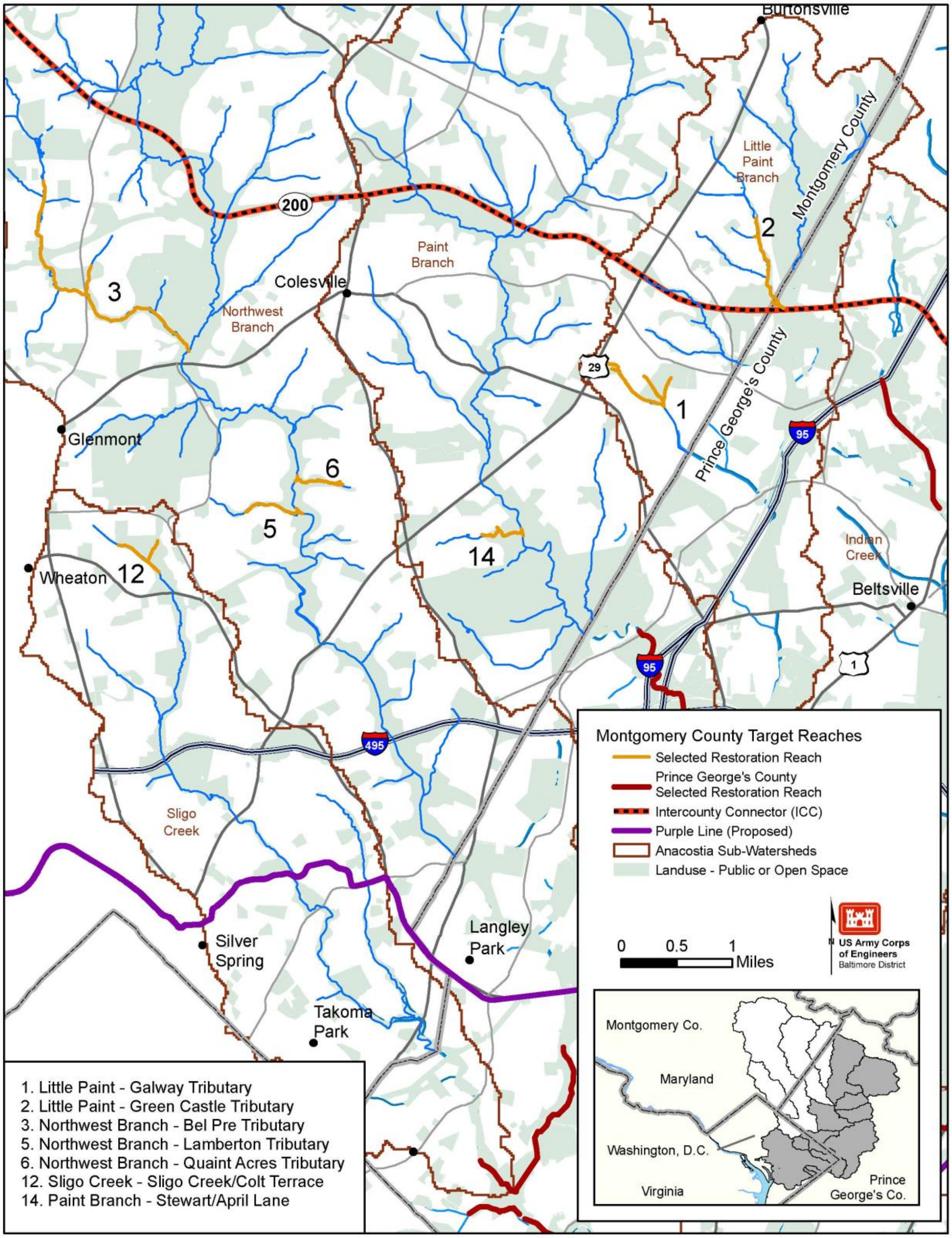

Figure 4. Project area in Montgomery County, Maryland.

7.0 Prior Reports and Existing Water Projects

Recent studies have included Anacostia River and Tributaries, Maryland and District of Columbia, Phase I and Phase II (Northwest Branch); Anacostia Federal Facilities Impact Assessment; the ARP; and Stormwater Pollution Prevention and Retrofit Planning Study in Prince George's County undertaken under Section 219. Recently constructed projects include the Northwest Branch and Paint Branch, Continuing Authorities Program Section 206 projects, Heritage Island restoration project, Continuing Authorities Program Section 1135, Kenilworth Marsh Restoration in the mainstem Anacostia River which beneficially used sediment from a federal navigation channel in the Anacostia River. Other projects currently in final designs for construction under the Section 510 Program include bioretention systems at two elementary schools (Cesar Chavez and Ridgecrest Elementary) in Prince George's County, Maryland, both of which were identified in the ARP.

MCDEP has undertaken several stream restoration projects in the Anacostia River watershed and vicinity, which inform this study, including the Lamberton and Northwood Stream Restoration projects, completed in 2003. The Lamberton project partially failed due to inadequate design; a different design procedure is being utilized for projects in this current effort.

Additionally, MCDEP conducts stream monitoring activities throughout the county, collecting data on stream habitat conditions and fish and benthic macro invertebrate species presence and abundance, which began in the watershed in 1994. As part of Montgomery County's National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) Permit, an implementation plan to meet watershed goals was prepared in 2012. The watershed implementation plan (WIP) outlines a comprehensive roadmap for watershed restoration that targets runoff management; bacteria, sediment, and nutrient reduction; and trash and litter management. The WIP addresses total maximum daily loads (TMDLs) established by MDE on behalf of EPA for bacteria, sediment, nutrients, and trash, and focuses on achieving the maximum practicable reductions. As discussed in section 10.0, the projects and actions outlined in the WIP for the Anacostia River watershed in Montgomery County is expected to reduce nutrient input to streams and reduce peak flows.

In July of 2005, the Washington Suburban Sanitary Commission (WSSC) entered into a consent decree to settle a lawsuit brought by the U.S. Department of Justice on behalf of the EPA regarding overflows in WSSC's wastewater collection system. The resulting comprehensive 12-year plan has augmented existing effort to identify and repair problems within the 5,400 mile sewer system in Montgomery and Prince George's Counties, Maryland. The Sewer Repair, Replacement, and Rehabilitation (SR3) program has improved the condition of the wastewater collection system and has included actions such as pipe lining, relocation, and replacement; manhole repairs; and other types of repairs. Work has occurred throughout the Anacostia River watershed and scheduled to be largely complete at the end of 2015. WSSC, in partnership with USACE Baltimore District, participated in a feasibility study under the Continuing Authorities Program, Section 14, though the projects were never completed due to lapses in program funding.

The SR3 program and the consent decree have resulted in fewer sanitary system overflows and increased stream health. As of 2013, WSSC's system is below the national average for sewer overflows. Given the extensive network of sewer lines that run immediately parallel to or under stream networks in the watershed, the enhancement conducted under the SR3 Program as a result of the Consent Decree is significantly improving water quality by reducing sanitary sewer overflows and leaks that can cause pathogens, bacteria, and nutrients to enter streams. The SR3 Program has also protected sewer lines and manholes exposed by stream erosion utilizing stream geomorphic and traditional engineering techniques.

Construction of the InterCounty Connector (ICC), a toll road in Montgomery and Prince George's Counties, necessitated numerous mitigation actions, some of which are ongoing. These mitigation actions include stream restoration projects on Paint Branch in an area designated as a Special Protection Area with a reproducing population of brown trout.

8.0 Problems/Opportunities

Stream ecosystems in the study area (Anacostia River watershed) have historically been indirectly degraded through human alteration of the natural landscape, and directly impacted by human activities in streams and floodplains. These changes generally led to loss of forested riparian corridors, alteration of stream habitat, and alteration of stream hydrology. From the colonial era through early 20th century, excess erosion from clearing/logging, agricultural, and to a limited extent mining land uses generated substantial quantities of sediment which were delivered to area streams by runoff. Mill dams in valleys trapped a substantial portion of this sediment, filling floodplain wetlands and transforming stream character. Many area streams were channelized or piped accompanying 20th century urbanization to increase development opportunities along streams. Urbanization up until the late 20th century generated stormwater runoff that caused excess stream erosion and degraded stream water quality. Modern environmental watershed management practices mitigate the effects of human land use on streams and a variety of watershed restoration activities are underway that are improving aquatic habitat condition.

About 95 percent of stream miles in the Anacostia River watershed were determined as having fish and/or benthic indices of biological integrity (IBI) in the very poor to poor categories (MDE 2012). Utilizing a biological stressor identification process, MDE determined that biological communities in the Anacostia River are strongly influenced by urban land use and associated effects: altered hydrology and elevated levels of chlorides, sulfates, and conductivity from impervious surface runoff. Degraded habitat conditions affecting aquatic life include channel alteration, channel erosion, and scouring and transport of suspended sediments. Biological communities are also degraded by alterations of riparian buffer zones (MDE 2012). Over 70 percent of forestland and 6,500 acres of wetlands have been lost within the watershed since colonial settlement (UWFP 2011); a substantial portion of these losses occurred within the Montgomery County study area.

Opportunities

1. Restore stream and riparian (including wetland) ecosystem habitat, function, and quality in and along the Anacostia River and tributaries.
2. Provide long-term targeted synergistic aquatic ecosystem restoration in the Anacostia River watershed by improving habitat connectivity with other restoration projects and stormwater retrofits.

Secondary Opportunities

3. Provide increased natural resource based recreation and educational opportunities along the Anacostia River.
4. Remove invasive vegetation in riparian areas of the Anacostia River and its tributaries.

9.0 Planning Goals/Objectives

The project goal is to provide a solution in the Anacostia River watershed in Montgomery County that will restore ecological function, structure, and health in selected stream reaches and riparian zones and those areas downstream affected by restoration actions. This feasibility study directly supports the habitat goals of the Chesapeake Bay Protection and Restoration Executive Order, E.O. 13508.

The study objectives are:

Primary

1. Restore stream ecosystem function in selected stream reaches within the Anacostia River Watershed. Through restoration, stream physical habitat quality is expected to be improved to “good” or better, as measured by Rapid Habitat Assessment (RHA), immediately following restoration activities. This objective is represented by improvement in stream habitat units and utilized in cost effective incremental cost analysis. Physical habitat data, biological data, water quality data, stream geomorphic data, land use data, and other data will be required to assess and inventory the present ecological condition of the aquatic habitat /streams to forecast their future condition and to identify the expected lift in ecological function and structure from restoration activities.
2. Restore the natural range of non-anadromous and migratory fish to the greatest extent practicable in the Anacostia River and its streams at stream restoration reaches. This objective is represented as linear feet of non-anadromous fish and eel habitat made available. Inventories of stream blockages, information on ongoing fish passage remediation efforts, fish community data, and other data will be required to assess the effects of proposed blockage removal. Maryland-National Capital Park and Planning Commission (M-NCPPC) generally considers fish blockages to be vertical drops of six inches or greater.

3. Restore non-tidal wetlands and re-establish hydrologic connection to the floodplain in the Anacostia River watershed to the maximum practicable area along stream restoration reaches immediately following restoration activities. This objective is represented by the acreage of non-tidal wetland and wetted areas with hydric soils restored. Because much of the riparian areas of potential restoration reaches are forested, opportunities for wetland restoration and floodplain reconnection are limited by the need to avoid habitat conversion. Where feasible, hydrologic reconnection with the floodplain may allow restoration of natural processes in the hyporheic zone. Additionally, areas along stream reaches that are able to connect with the floodplain more frequently could rewet floodplain soils from below, also restoring wetlands. Soils data, hydrologic data, and inventories of wetland plants and herpetofauna in the watershed will be required to assess the effectiveness of proposed wetland restoration.

Secondary

4. Increase riparian habitat structure and function through treatment of invasive plant species in riparian areas of the Anacostia River, and its tributaries over. To plan for removal activities and to assess their effectiveness, assessments of invasive plant species distribution, density, and control plans may be required.

9.1 Planning Constraints

The study team identified the following constraints:

1. Avoid conversion of high quality forest to other habitat types. This is of concern for upland high quality forests in riparian areas that could be detrimentally impacted by increased wetness.
2. Avoid conversion of stream order functions. This is of concern for headwater and first order streams that are intended to provide higher levels of primary productivity, nutrient cycling, and contributions of organic matter than downstream systems.
3. Avoid negative impacts to bedrock and natural features that provide excellent aquatic habitat.
4. Avoid work in the Special Protection Area (SPA).

9.2 Planning Considerations

The study team also identified the following considerations:

1. Prioritize restoration activities on public lands to the greatest extent possible.
2. To the extent possible, focus restoration activities on headwater streams.
3. Minimize impacts to forest[3] during construction because of high value of mature native woody vegetation.

[3] Deer browse on seedlings and saplings and competition from invasive exotic plants precludes ready natural reestablishment of healthy forest understory, creating heightened concern over resultant detrimental environmental

4. Minimize impacts to actively used recreational space, or compensate.
5. Minimize restoration work in the upper Paint Branch watershed.

Restoration activities must be formulated to help resolve known issues, and avoid creating new problems for aquatic communities such as new fish blockages.

10.0 Inventory and Forecast

Finfish - Montgomery County is historically home to more than 60 species of freshwater fish, representing nearly every family of freshwater fish known in Maryland. This includes trout, catfishes, sunfishes and bass, minnows, suckers, sculpins, darters and perch, killifishes, lampreys, American eel, Eastern mudminnow, and Eastern mosquitofish. Potential migrants historically present in the non-tidal Coastal Plain include sea lamprey, American eel, shortnose sturgeon, blueback herring, alewife herring, hickory shad, American shad. Potential migrants historically in the Piedmont include sea lamprey and American eel (Smith and Bean 1899).

It is estimated that historically (1898-1948) there were approximately 47 non-anadromous species of fish in Sligo Creek. As of 2015, there may be 12 to 17 species of fish in Sligo Creek, including blacknose dace, longnose dace, satinfin shiner, spottail shiner, northern creek chub, goldfish, tessellated darter, American eel, white sucker, northern hogsucker, bluegill, bluegill-green sunfish hybrid, rosyside dace, central stoneroller, brown bullhead, and swallowtail shiner. There have been multiple efforts to reintroduce native fish into the upper mainstem of Sligo Creek, to accompany improved stream habitat from restoration efforts. Blockages downstream prevent natural re-colonization of Sligo from the Northwest Branch. These reintroduction efforts have resulted in an increase in the number of native fish species from only two species in 1988 to 12 in 2009 (MCDEP 2012). The species present in other streams segments of interest in this study are similar to the generalist species found in Sligo Creek. Thus, in the absence of stream restoration efforts, coupled with improvements in water quality, these species are likely to persist in these streams over the 50-year period of analysis, but the species assemblage will likely not increase.

A biological stressor evaluation performed by MDE and Maryland Department of Natural Resources (DNR) (MDE 2012) identified that approximately 95% of stream miles in the Anacostia River basin are estimated as having fish and/or benthic indices of biological integrity (FIBI and BIBI) in the very poor to poor category. The biological impairment listing is based on the combined results of DNR Maryland Biological Stream Survey (MBSS) round one (1995-1997) and round two (2000-2004) data, which include 37 sites. Thirty-three of the 37 sites have BIBI or FIBI scores significantly lower than 3.0 out of 5.0 (i.e., poor to very poor). The evaluation identified hydrological, morphological, and chemical parameters with significant associations with poor to very poor biological condition. Degradation of biological communities in the Anacostia River is influenced by urban land use and consequent altered flows and elevated levels of chlorides, sulfates, and conductivity from impervious surface runoff. The sediment parameters associated with these degraded biological conditions include presence of bar

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trade-offs. (Native woody riparian vegetation can be reestablished if deer protection is provided, invasive species controlled, and replanting done).

formation, channel alteration, and poor to marginal epifaunal substrate. In-stream habitat parameters associated with poor stream biological condition includes channelization, poor to marginal in-stream habitat structure, poor to marginal riffle-run quality, and concrete/gabion presence (MDE 2012). These habitat conditions are expected to persist over the 50-year period of analysis in the absence of stream restoration actions.

Fish Blockages – The ARP and MCDEP have mapped numerous fish blockages within and adjacent to the candidate stream segments. Human-caused rather than natural, fish blockages are of interest in the study. Nearly all mapped blockages are relatively small partial blockages that block fish passage during low flow periods. There are larger blockages downstream of the stream segments, in Prince George's County, that limit anadromous fish movement to streams in Montgomery County during low flow periods. Three of these blockages are targeted for remediation by the Anacostia Watershed Restoration, Prince George's County project. Due to the remote headwater position of the stream proposed for restoration in Montgomery County, it is unexpected that anadromous fish will significantly utilize these streams with the removal of these partial blockages. These identified blockages are not a barrier to American eel, but blockages identified on the proposed streams do prevent American eel passage and utilization of habitat. Besides the Anacostia Watershed Restoration, Prince George's County project, fish blockage removal is not anticipated in the foreseeable future due to stakeholder's other restoration priorities. Benefits for the Montgomery County project are not predicated on the projects in Prince George's County. Within Montgomery County, the small fish passage blockages within the study stream segments are also expected to persist over the 50-year period of analysis without project action, as their remediation is a low restoration priority for area stakeholders. Through at least 2030 it is expected that most environmental work in the watershed will focus on implementation of watershed implementation plans (WIPs), which target water quality as mandated by the Chesapeake Bay TMDL. Stakeholders are focused on implementing stormwater BMPs, stormwater retrofits, and other projects targeting water quality and, to a lesser extent, stormwater quantity.

Water Quality - By 2030, Montgomery County plans to provide water quality treatment for 4,544 acres of impervious cover within the Anacostia River watershed with numerous SWM water quality control features, with continued improvement of the sanitary sewer system, and with other progressive environmental management actions. These actions are being implemented over time and water quality improves in neighboring streams as projects are implemented.Over 2000 stormwater projects have been completed in the watershed and another 50 projects are currently in construction or design. Stream sites from the tentatively selected plan will be prioritized for restoration utilizing scoring criteria based on current and planned stormwater and water quality improvement projects. The implementation of the WIP will subsequently result in 100% attainment of the waste load allocation for sediment, nutrient, and trash reduction. Thus, the magnitude of degraded water quality as a stressor to aquatic ecosystems is expected to diminish, and is decreasing as projects are implemented..

Sanitary Sewer – As a result of WSSC's SR3 program, in response to a consent decree entered in 2005, work on the sanitary sewer system has occurred throughout the Anacostia River watershed, including within and upstream of potential project sites. As of 2013, WSSC's sewer system is below the national average for sewer overflows. The enhancements conducted under the SR3 program is helping improve water quality by reducing sewer overflows and leaks. This work, and ongoing routine system maintenance, is expected to reduce the loads of pathogens, bacteria, and nutrients in Anacostia streams as compared to historic loads.

Stream geomorphic condition – MDE requires that urban stormwater runoff be managed through "… a unified approach for sizing stormwater BMPs in the State of Maryland to meet pollutant removal goals, maintain groundwater recharge, reduce channel erosion, prevent overbank flooding, and pass extreme floods" (MDE 2000).

While stream geomorphic conditions would be expected to eventually achieve a condition of dynamic equilibrium with stormwater runoff, based on the pattern evidenced in urban streams of the study area and elsewhere in Maryland, the streams reaching an equilibrium condition would likely take many decades to centuries and only after substantial quantities of sediment were eroded and trees lost to bank erosion. Accordingly, absent a geomorphic restoration project, future conditions without project in the streams were assumed to be equivalent to current conditions. Although the State of Maryland has embarked upon more stringent stormwater regulations related to channel protection volume, the unstable geomorphic conditions would not self-correct in a timely manner. The regulations apply to new developments and the watershed is largely built-out.

Wetlands – In the evaluated stream reaches, approximately 15 acres of wetlands are currently mapped by the National Wetlands Inventory. These forested wetlands are within parkland owned by M-NCPPC. Without restoration activities, these wetlands are expected to persist, but no additional wetland acreage or improvement to floodplain connection is expected.

Trees – Many of the tributaries in the Anacostia River watershed run through forested riparian buffers owned by M-NCPPC. There are 36 stream valley parks in Montgomery County, and M-NPPC owns or manages over 36,000 acres of parkland. The extent of forest along stream reaches is unlikely to change, as it is generally mature forest in public ownership and used as parkland. Additionally, forests in Montgomery County are protected by the Forest Conservation Law, which aims to save, maintain, and plant forested areas for the benefit of county residents and future generations. Due to deer browse pressure and competition from invasive exotic species, forest succession is problematic and the removal of trees for project construction or other activities is highly discouraged.

Climate Change – Simulations for the Chesapeake Bay watershed through the year 2100 predict increased precipitation amounts in winter and spring, as well as increased intensities of precipitation, northeasters (though their frequency may decrease), and tropical storms (Najjar et al. 2010). Precipitation volume and intensity has increased in the mid-Atlantic region of the Chesapeake watershed over the last century and these trends are projected to continue to the end of the 21st century (NOAA 2013; Najjar et al. 2010). By 2030, annual mean precipitation may increase by up to 4%, with increases of up to 15% by 2095 (Najjar 2010). The increased intensity of precipitation may cause higher peak flows and accelerate stream erosion within the watershed's streams absent restoration.

Human Population - Within the entirety of Montgomery County, human population is expected to increase for the foreseeable future, from about 940,000 people in 2010 to nearly 1.1 million people in 2030 (USACE 2014), which is a 17 percent increase. This percentage change is expected within the Anacostia River watershed in Montgomery County as well.

10.1 Fish and Wildlife Resources Considerations

USFWS and other Federal agencies have promoted efforts to increase recreation within the Anacostia River watershed. The NPS has helped obtain funding for a riverside trail along the Anacostia, and, more broadly, the Department of the Interior has developed new Urban Initiatives and Urban Refuge Programs to encourage urban residents to enjoy the natural resources of the Anacostia River. Additionally, the National Oceanic and Atmospheric Administration and the EPA have worked over the last 30 years to reduce the flow of pollutants into the watershed.

Efforts that restore the Montgomery County stream reaches are likely to benefit Department of Interior Trust Resources within the watershed. Ultimately, such efforts along with other programs to reduce pollutant inputs should result in a healthier and more diverse fish and wildlife community.

Finally, Montgomery County DEP has monitored and will continue to monitor benthic macroinvertebrate, fish, and other fauna and flora, and habitat at all proposed project locations. USFWS personnel are visiting all potential project locations to make their own assessment of stream functional performance, including provision of habitat.

USFWS contacted the natural resources specialist from the AWS, Jorge A. Bogantes Montero, to identify recreational fishing locations in Prince George's and Montgomery Counties, Maryland. As an expert in recreational fishing hotspots in the Anacostia River watershed, he pinpointed 10 locations in the two counties where recreational fishing currently occurs. However, none of these locations are in the reaches selected for restoration in Montgomery County. Despite the lack of known recreational fishing, the stream reaches do host game species, including American eel, various panfish, smallmouth bass, and brown bullhead.

11.0 Key Uncertainties

Issue: The location of habitat features in the stream reaches is uncertain at this time. Diverse and stable in-stream habitat, including riffle pool run complexes, woody material, and other habitat cover features are key to ensuring that habitat benefits are realized and are important features for MCDEP. Grading and stabilizing eroding streambanks, while also reducing flow energies may help to retain organic carbon which is especially important for headwater streams, where this study is predominantly focused.

Uncertainty: Habitat features will be included in more detailed designs, but their location and extent will not be known until further hydraulic modeling and detailed topography is included with design. Benefit calculations have assumed that these features are included at a scale and frequency to reasonably maximize habitat benefits.

Planning Decisions: To ensure acceptability of designs with the sponsor and stakeholders, habitat features will be included as specific features in detailed designs and their placement, frequency, and type will be coordinated with the sponsor and stakeholders.

Issue: Concept designs do not incorporate detailed limits of disturbance, access, easement requirements, or staging areas.

Potential Impacts: Limits of disturbance, access, and staging areas may change as designs are advanced.

Uncertainty: As the limits of disturbance, access, and staging areas are incorporated into designs, their impacts to trees, private property, neighborhoods, and other features must be considered and may necessitate changes from what is shown in concept designs. These changes may have cost implications as well.

Planning Decisions: The Environmental Assessment, 404(b)1, and cost estimates assume reasonably maximized limits of disturbance from construction activities, including site access and staging areas. Stakeholder input will be required to ensure acceptability and minimization of impacts. Other stream restoration projects (including the USACE Continuing Authorities Program, Section 206 Northwest Branch and Paint Branch projects) in the area have incorporated techniques such as "working in the wet" (no pump-arounds) and in-stream haul roads (which are removed as construction progresses) to minimize overall landscape impacts.

12.0 Formulating Alternative Plans

Figure 5 presents the plan formulation steps leading to the selection of the TSP. The Focused Array of Alternatives, and the selected stream reaches were presented at the Alternatives Milestone meeting and agreed upon by the Vertical Team. The process leading to their selection is summarized in this section.

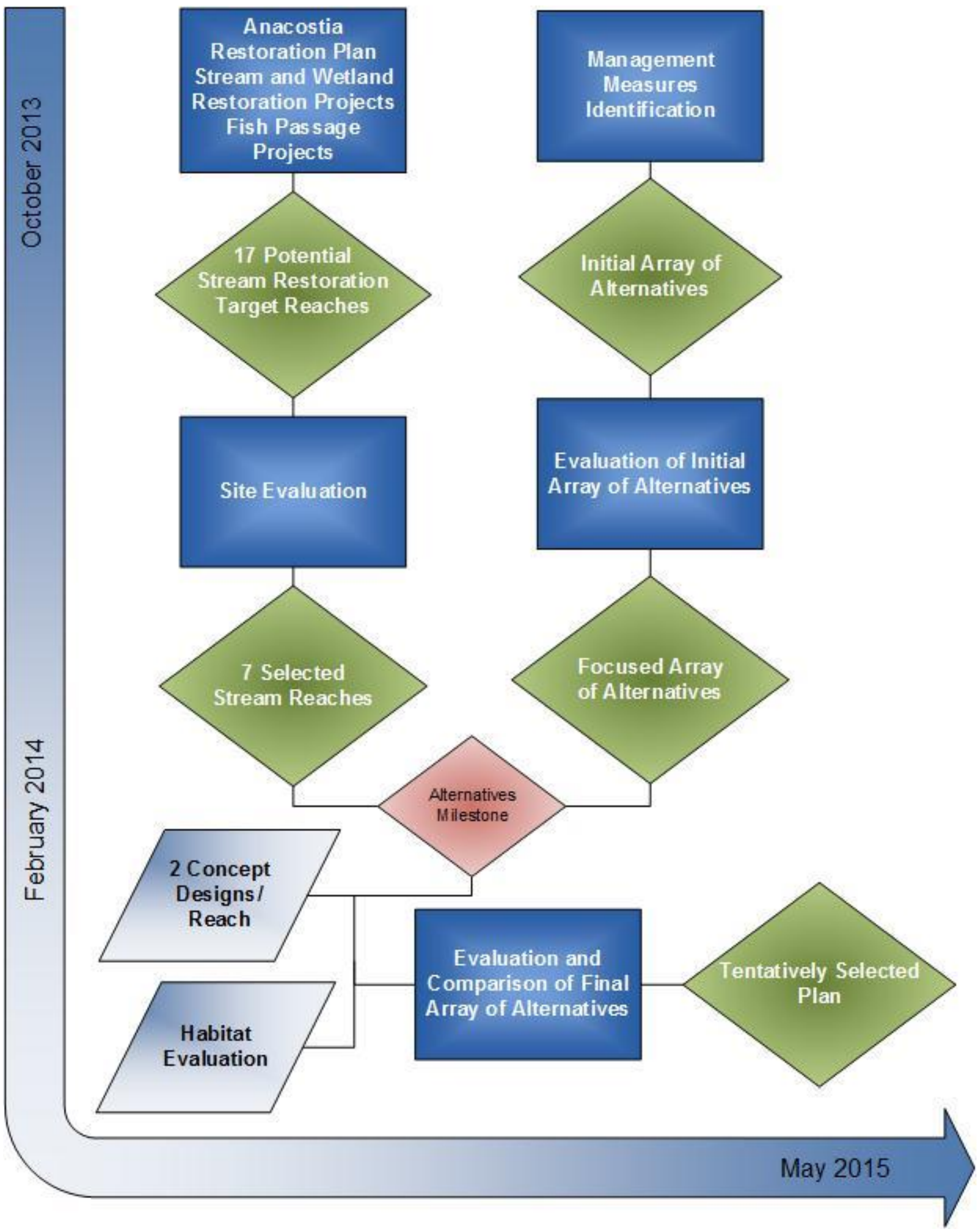

Figure 5. Plan Formulation for Anacostia Watershed Restoration, Montgomery County, Maryland.

12.1 Management Measures

Potential management measures were identified through a brainstorming process after the development of project problems, opportunities, objectives, and constraints. Additional management measures were identified during the development of the initial array of alternative plans. There are multiple types of stream restoration, wetland restoration, and fish passage measures that could potentially be implemented. Over the length of a stream segment of interest, different types of measures for different restoration objectives could be combined.

After conceptual plans for each potential restoration reach were developed, these measures were reexamined to determine whether additional alternatives could be generated. No additional measures were identified that met planning objectives and did not violate planning constraints. The potential project reaches were spatially constrained by adjacent private properties that preclude the use of some measures. Other measures are limited by the need to remove mature trees. While some measures may provide stream stability and prevention of bank erosion (such as concrete and gabion structures), they are not formulated for ecosystem benefits.

Table 3. Ecosystem Restoration Management Measures.

Measure	Objective 1 (Stream Restoration)	Objective 2 (Wetland Restoration)	Objective 3 (Fish Passage)	Objective 4 (Riparian Habitat)
Natural Channel Design				
Floodplain				
Create New	●	●		●
Reconnect by lowering bank	●	●		●
Reconnect by raising stream	●	●		
Vegetation (riparian and in-stream)	●	●		●
Legacy Sediment Removal	●			
Habitat				
Root wads	●			
Boulders	●			
Riffles/Pools	●			
Lunkers and "man-made objects"	●			●
Coarse Woody Debris	●	●		
Grade Control Structure				
Step Pools	●	●	●	●
Weirs	●	●		
Vanes	●	●		
J-Hooks	●	●		
Connection				
Fish Ladder			●	
Step Pools	●		●	
"Hard Design"				
Blanketing				
Rip-Rap	●			
Gabion Basket				
Other Measures				
Streambank Stabilization (ERDC)				
Concrete channel excavation (mid-channel)	●		●	●
Concrete channel modification (baffles)	●			●
Regenerative stream restoration/ stormwater conveyance	●	●		
Imbricated Rip-Rap	●			
Pipe Daylighting	●			
Stream Relocation	●	●	●	●
Infrastructure Relocation	●	●	●	●
Riparian Invasive Species Removal		●		●

Habitat measures, such as root wads and boulders, were not included in conceptual plans, but they will be included at higher levels of design resolution as the designs are optimized.

12.2 Final Array of Alternative Plans

Alternative 1: Future Without Project (FWOP: No Action)

Alternative 2a: Natural Channel Design

- Natural Channel Design – in-stream habitat improvement at all segments
- Wetland restoration in concert with stream restoration, opportunities are likely to include Quaint Acres Tributary, Bel Pre Tributary, and Sligo Tributary
- Floodplain reconnection where appropriate
- Stream relocation, where appropriate
- Partial removal of concrete in channelized stream reaches or addition of in-stream structures within concrete channels
- Daylight pipes where appropriate
- Fish passage provision at blockages within segments
- Invasive plant species removal where appropriate

Alternative 2b: Natural Channel Design with Major Infrastructure Modification

- This alternative includes all the measures included in Alternative 2a
- Relocation or movement of existing major infrastructure such as bridges and roads to provide habitat improvement (riparian reforestation, improved stream geometry)
- Removing concrete completely from channelized stream reaches

Alternative 2c: Natural Channel Design Without Concrete Channels

- This alternative includes all the measures included in Alternative 2a
- Concrete channels are not altered

Alternative 3: Hard Design

- Use of rip-rap, gabion baskets, and concrete matting
- Wetland restoration in concert with stream restoration, opportunities are likely to include Quaint Acres Tributary, Bel Pre Tributary
- Stream relocation, where appropriate
- Fish passage improvement: step pools or fish ladder
- Invasive plant species removal where appropriate

Alternative 4: Streambank Stabilization

- Use of ERDC Streambank Stabilization techniques for stream restoration
- Wetland restoration in concert with stream restoration, opportunities are likely to include Quaint Acres Tributary, Bel Pre Tributary
- Stream relocation, where appropriate

- Partial removal of concrete in channelized stream reaches or addition of in-stream structures within concrete channels
- Daylight pipes where appropriate
- Fish passage improvement: step pools or fish ladder
- Invasive plant species removal where appropriate

13.0 Evaluation and Comparison of Array of Alternative Plans

Specific criteria and metrics were developed for evaluation and comparison of the initial alternative plans developed from the identified measures (Table 4).

Table 4. Criteria and metrics used for evaluation and comparison of initial array of alternatives.

Criteria	Metric	Notes
Ecosystem Benefit	Yes/Neutral	
Ecosystem Impact	High/Low	Long-term impact within project area (i.e. tree removal)
Community Impacts (Surrounding Built Environment)	High/Low	Potential flooding; recreation facilities; trails
Cost	$ / $$ / $$$	General “low” ($100s/lf), “medium” ($200s/lf), “high” ($300s/lf)
Implementability	+ 0 -	Implemented in a reasonable timeframe with reasonable technology
Durability/Sustainability	High/Med/Low	Measure of OMRR&R sustainability and practicality.

Alternative 2b: Natural Channel Design with Major Infrastructure Modification was not evaluated further due to challenges in implementation based on past experience in the Anacostia River watershed and the high cost that would accompany road and bridge relocation.

The array of alternative plans carried forward to be compared was:

- Alternative 1: FWOP (No-Action)
- Alternative 2a: Natural Channel Design
- Alternative 2c: Natural Channel Design Without Concrete Channels
- Alternative 3: Hard Design
- Alternative 4: Streambank Stabilization

The array of alternative plans was evaluated as shown in Table 5.

Table 5. Comparison of alternatives.

Criteria	Alt 1 No Action	Alt 2a Natural Channel Design	Alt 2c NCD w/o Concrete Channels	Alt 3 Hard Design	Alt 4 Streambank Stabilization
Environmental Benefit	Neutral	Yes	Yes	Neutral	Neutral
Environmental Impact	High	Low	Low	Low	Low
Community Impacts (Surrounding Built Environment)	Low	Low	Low	Low	Low
Cost	_	$$$	$$	$$	$
Implementability	+	+	+	+	+
Durability/Sustainability	Low	High	High	Med	High

Based on this comparison array, the following alternatives will be carried forward because they best meet the project objectives for ecosystem restoration. The natural channel design alternatives offer environmental benefits with low environmental impact while being implementable and sustainable.

- FWOP (No-Action)
- Natural Channel Design without concrete channels

14.0 Identifying the Tentatively Selected Plan and Recommended Plan

The array of alternatives has undergone additional analysis including development of conceptual designs, development of parametric cost estimates, and evaluation of ecosystem outputs (ecosystem outputs model was approved for one-time use on February 24, 2015).

Two concept designs based on natural channel design were developed for each stream segment and ecosystem outputs as measured by the Montgomery County Rapid Habitat Assessment were determined. Each conceptual stream restoration site was treated as a measure and combined in IWR Planning Suite to generate plans. Eight best buy plans were generated and evaluated.

The TSP is represented by the concept plans for each stream presented in section 14.1.

Table 6 presents the criteria used to evaluate the TSP and form the basis for recommendation.

Table 6. Criteria For Evaluation of the Tentatively Selected Plan

Evaluation Criteria	Description
Cost (Total $)	Total Project Cost
Cost (Average Annual)	Average Annual Project Cost
Total AASHU	Average Annual Stream Habitat Units
Wetted Acres Restored	Area of floodplain that would be reconnect with stream (inclusive of wetland creation)
Non-anadromous Fish Passage Opened (feet)	Feet of fish passage that would be opened and available for utilization by non-anadromous fish
American Eel Passage Opened (feet)	Feet of fish passage that would be opened and available for utilization by eels
Anacostia Restoration Plan (ARP) Candidate Restoration Projects (CRP)	Number of ARP candidate restoration projects (CRP) incorporated
Environmental Impact/Tree Impacts	Estimation of scale of project impacts to surrounding environment, particularly potential for tree removal

14.1 Conceptual Designs

For the selected alternative, two concept-level designs were developed for the stream miles proposed for restoration. These designs are briefly described in the appendix. The general difference is one design uses less structure or onsite trees (uprooting or falling trees) to construct the structures. Other types of in-stream structure such as riffle grade control or retaining wall may be used locally due to lack of space or infrastructure conflicts.

Whether stream grade can be raised to increase stream-floodplain interaction or raise floodplain groundwater levels would require additional analyses to verify that these would not pose unacceptable flood risks to properties or structures. These opportunities are tentative until these analyses are completed. As designs progress for all sites, additional wetlands and vernal pools will be incorporated along the stream banks to the furthest extent practical, in order to maximize habitat benefit. Benches will be integrated wherever possible to reconnect the streams with their floodplains. The number and type of in-stream features may change as selected designs move forward and modeling is performed. Conceptual plans were prepared for all streams.

Parametric cost estimates were prepared for the 10% level concept designs. These costs included advanced design, construction, and construction management. Parametric costs were estimated by linear foot based on concept cost estimates contained in 2012 bid data for Northwest Branch Package 2. The 2012 estimate was escalated to 2014 costs using the Civil Works Construction Cost Index System. Economy of scale cost savings that could accrue for constructing projects at multiple segments (four percent) were applied to Bel Pre and Poplar Run Tributary. This was based on previous investigation of cost-savings for the nearby Great Seneca Muddy Branch Watershed Study.

14.2 Rapid Habitat Assessment

Because of the screening criteria utilized in the study, the candidate segments generally possess wooded riparian corridors with pervasive conditions of erosion. In-stream habitat conditions within any segment vary longitudinally. In-stream habitat conditions can vary along a gradual gradient in response to changes in the relative importance of watershed versus local hydrologic influences accompanying an increase in drainage area proceeding downstream. Conditions may also show pronounced changes at major points of substrate change. Additionally, there are often localized erosional and depositional areas that extend for only short lengths along the stream. These often occur in the vicinity of woody debris jams, coarse sediment deposits (particularly cobble and gravel), bedrock outcrops, and built environment features such as stormwater outfall pipes, concrete structures, and boulder stabilization works.

MCDEP (2013, 1997) procedures were chosen to assess habitat conditions because they have been utilized by MCDEP since the 1990s and thus allowed for ready comparison of previous to current conditions. MCDEP has utilized the protocols to assess existing conditions as well as conditions of streams following geomorphic restoration work. The MCDEP RHA procedures are founded on protocols developed by the EPA in the 1980s and 1990s, and are similar to procedures also utilized by Maryland Biological Stream Survey (MBSS) of the MD DNR. Use of these procedures was coordinated with USACE EcoPCX and approved for one time use on February 24, 2015.

Habitat quality in stream reaches is characterized using MCDEP (2013, 1997) rapid habitat assessment (RHA) procedures. Following the RHA procedures and guidance, 10 habitat parameters are scored in the field. Each individual parameter can score from 0 to 20 or 0 to 10 for left bank or right bank specific metrics. The worst possible habitat score is 0, and the best possible score is 20. The RHA procedures divide the total score into distinct narrative classes ranging from excellent to poor. The data is entered into spreadsheets in the office, and these 10 parameters are then summed to produce a total habitat score for the reach. Habitat conditions are not expected to improve in stream reaches without intervention, nor are they expected to worsen as the watersheds are generally built out. Future actions by others including stabilization of infrastructure along the stream and stormwater management retrofits will address some causes of stream degradation by reducing sediment deposition and increasing bank stability scores showing an overall improvement in RHA in the future without project condition from the existing condition. Average future without project and future with project RHA results are presented in Table 7.

Table 7. Future Without Project (FWOP) and With Project Habitat Assessment.

Segment #	Stream	FWOP RHA	With Project RHA
1	Galway Tributary	Good (116)	Excellent/Good (162)
2	Green Castle Tributary	Good (124)	Excellent/Good (159)
3	Bel Pre Tributary	Fair (98)	Excellent/Good (155)
5	Lamberton Tributary	Fair (90)	Excellent/Good (155)
6	Quaint Acres Tributary	Good/Fair (106)	Excellent/Good (164)
12	Sligo Creek/Colt Terrace	Fair (75)	Excellent/Good (157)
14	Stewart/April Lane	Good/Fair (110)	Excellent/Good (161)

Additionally, any new development would be required to incorporate effective stormwater BMPs reducing sedimentation and pollutants in the stream coming from upland areas. With concomitant expected improvement in water quality through MCDEP's WIP implementation it is expected that BIBI and FIBI scores, measures of the aquatic communities' health, will also improve.

Quantifying stream habitat requires consideration of habitat quantity and quality. Physical habitat quantity is determined using stream length and stream order (Strahler 1957). Stream order shows a close correlation to stream width, depth, wetted perimeter, and volume, and is simpler to determine/measure. The total habitat available within a reach is represented by the simple equation:

Habitat Quantity x Habitat Quality Score = Stream Habitat Units (SHU)

SHUs are expected to accrue upon project completion and have been annualized over the project life (AASHU). The average improvement in RHA is expected to be about 56.5. This means that one SHU is equivalent to 3.54 miles of first order stream restored or about 1.77 miles of second order stream restored to "excellent/good" habitat conditions. Excellent/good habitat conditions could support "excellent" or "good" aquatic communities. Excellent communites are "comparable to the biological community found in reference streams. Exceptional assemblage of species with a balanced community composition." Good communities have a "decreased number of sensitive species, and a decreased number of specialized feeding groups with some intolerant species present (MCDEP 2013)."

With improved water quality, stream restoration resulting in improved RHA scores will equate to improved fish and benthic macroinvertebrate Index of Biotic Integrity scores, a key metric for Chesapeake Bay recovery.

14.3 Analysis

A cost effective/incremental cost analysis (CE/ICA) was completed utilizing IWR Planning Suite software (version 2.0) to help evaluate and quantify significant contributions or effects of individual plans. Plans are combinations of stream sites and design alternatives for those stream sites.

A total of 6,561 possible plan combinations were evaluated in CE/ICA analysis. Of these 29 plans (including the No-Action Alternative) were identified as being cost effective and 8 were identified as best buys.

Based on the CE/ICA best buy plans for in-stream habitat benefits and the criteria for the evaluation of other benefits presented in Table 9, the PDT recommends the selection of Plan 4 as the TSP. This plan includes stream restoration of three of the study segments investigated in Montgomery County, with associated wetted area restoration and fish blockage removal. Analysis of these plans for the TSP selection is discussed in the following subsections. The conceptual design for each stream are presented in the Appendix. The final array of alternative plans is described below and identified in Figure 6 and Table 8.

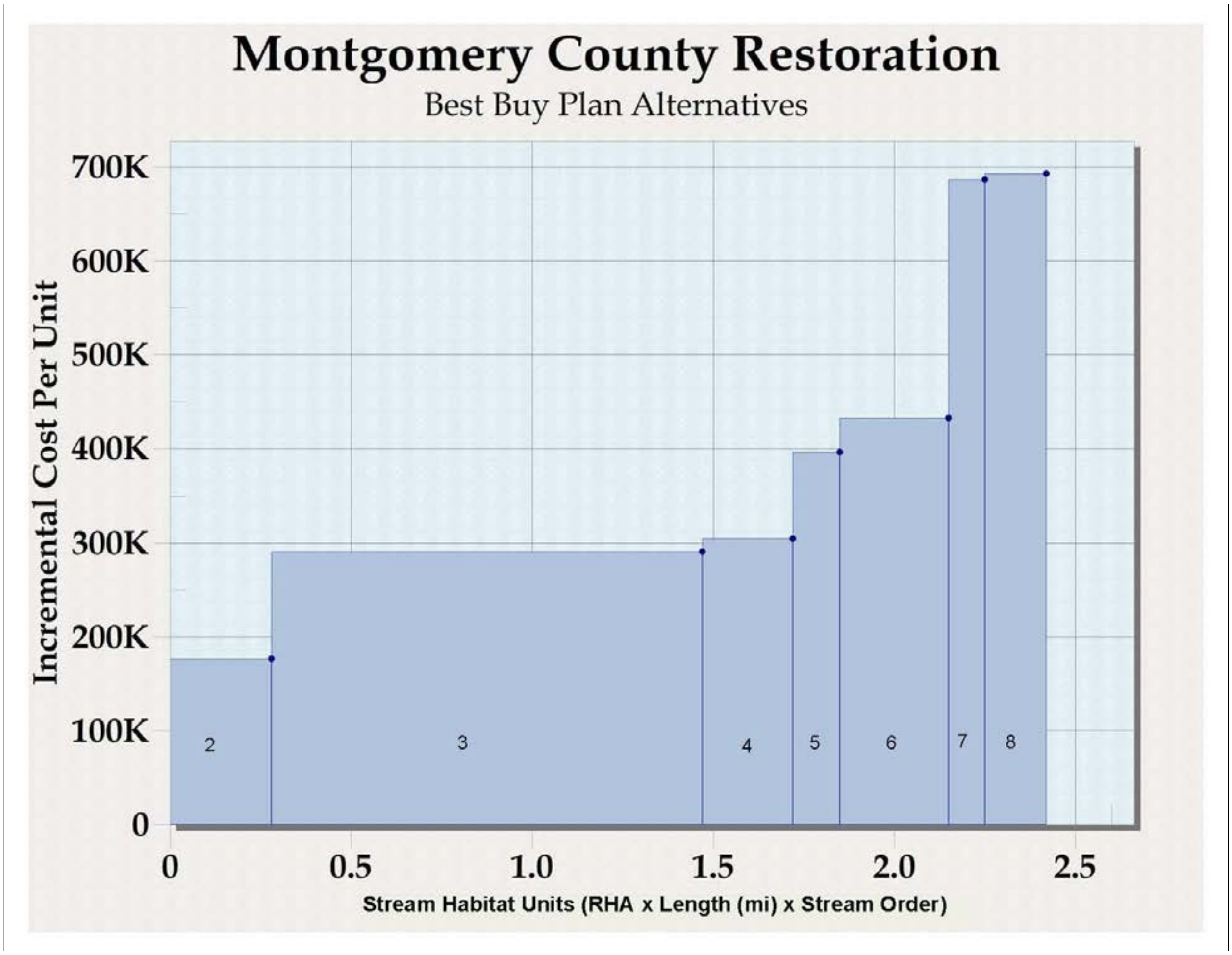

Figure 6. CE/ICA Results

Table 8. CE/ICA Results

Site	#5	#3	#12	#6	#1	#14	#2
Plan							
1	No Action						
2	Lamberton						
3	Lamberton	Bel Pre					
4	Lamberton	Bel Pre	Sligo Creek				
5	Lamberton	Bel Pre	Sligo Creek	Quaint Acres			
6	Lamberton	Bel Pre	Sligo Creek	Quaint Acres	Galway		
7	Lamberton	Bel Pre	Sligo Creek	Quaint Acres	Galway	Stewart/April Lane	
8	Lamberton	Bel Pre	Sligo Creek	Quaint Acres	Galway	Stewart/April Lane	Green Castle

The evaluation of alternative plans is conducted by assessing or measuring the differences between each with- and without plan condition and by appraising or weighting those differences. Evaluation consists of four general tasks: 1) forecast the most likely with-project conditions expected under each alternative plan; 2) compare each with-project condition to the without-project condition and document differences between the two; 3) characterize the beneficial and adverse effects by magnitude, location, timing and duration; and 4) qualify plans for further consideration.

Plans were evaluated based on the following criteria: outputs and plan effects, contributions to the Federal objective (NER), the study goals and objectives, the Planning Guidance Notebook's four evaluation criteria (completeness, effectiveness, efficiency, and acceptability), and other criteria deemed significant by participating stakeholders.

Table 9. Evaluation and Comparison Leading to the Tentatively Selected Plan. Plan 4, which is shaded, is the recommended TSP.

Plan	Total Cost	Stream Habitat Units	Eel Passage (ft)	Non-anadromous Fish Passage (ft)	Wetted Area (ac)	ARP Candidate Projects
1	0	0	0	0	0	0
2	$1,186,234	0.28	2006	1494	0	0
3	$9,487,150	1.47	2632	2120	106	4
4	$11,315,952	1.72	2632	3240	135	11
5	$12,551,637	1.85	2632	4348	135	12
6	$15,665,576	2.15	2632	7178	135	19
7	$17,312,689	2.25	2632	9464	135	19
8	$20,140,030	2.42	2632	9464	149	20

14.4 Selecting a Recommended Plan

Plan four (restoration of selected stream sites utilizing natural channel design techniques) is recommended as the TSP and the NER plan as determined by all of the evaluation criteria. Plan four incorporates restoration at Lamberton Tributary, Bel Pre tributary, and Sligo Creek. Selecting the NER plan requires careful consideration of planning goals, objectives, and constraints. The NER plan reasonably maximizes ecosystem benefits as measured by stream habitat units (SHU), restoration of wetted acreage, and American eel and non-anadromous fish passage, while considering cost effectiveness and incremental cost analyses, significance of outputs, completeness, efficiency, effectiveness, and acceptability. Restoring the stream reaches in Plan 4 also addresses 11 candidate restoration projects identified in the Anacostia Restoration Plan, reinforcing federal commitments to the Anacostia River Watershed as described in the following section.

The following steps describe the sequential evaluations of the Plans:

Step 1: Based on the CE/ICA analysis (Figure 6), two plans (7 and 8) were rejected as they provide relatively little in-stream restoration benefit for the added cost. Plan 7 could add over 2,000 feet of additional accessible habitat to non-anadromous fish, but the relatively small increase in stream habitat units does not justify the added expense. Plan 8 adds approximately 14 additional acres for floodplain reconnection and wetland restoration, and over 0.25 additional stream habitat units. The incremental costs are not justified.

Step 2: The CE/ICA analysis represents the cost effective analysis for the in-stream physical habitat benefits (Objective 1). Until reaching plan 7, there is no significant change in slope of the graph, which would indicate a marked increase in incremental costs per stream habitat unit. However, it is clear that Plan 3 provides significant in-stream benefits per unit of cost. This plan also incorporates all of the eel passage opportunities available, and the majority of wetted area available for restoration. However, it only incorporates 4 potential projects identified in the Anacostia Restoration Project. Plan 3 is used as a baseline for comparison of the remaining plans (plans 4 through 6).

Step 3: Plan 4 provides nearly 30 additional acres of floodplain reconnection and wetland restoration in the highly altered and urban Sligo Creek. The plan would address seven additional projects identified in the Anacostia Restoration Plan, the majority of which are wetland restoration. The increase in incremental costs for additional stream habitat units is negligible in comparison to Plan 3.

In comparison to Plan 4, Plan 6 addresses an additional 8 projects identified in the Anacostia Restoration Plan, seven of which are on the Galway Tributary. Stream restoration on the Galway Tributary would address a highly incised stream channel that borders a local public park. It would also allow the only opportunity for stream daylighting of all the stream segments investigated. This currently piped section of stream portion also flows through the public park. Finally, restoration of Galway Tributary would likely reduce sediment inputs to completed and planned restoration efforts downstream in the Little Paint Branch and Paint Branch subwatersheds. A mile-long stream section has been restored about one-mile downstream of the Galway Tributary site. Downstream of that point, restoration of Little Paint Branch and Paint Branch is planned or has been completed to its confluence with Indian Creek.

Compared to Plan 3 (Lamberton Tributary and Bel Pre Tributary) Plan 6 provides an additional 5,058 feet of passage for non-anadromous fish, which includes nearly 3,000 additional feet opened on Galway Tributary. This plan provides an additional 1.3 miles of restored second order urban stream habitat.

While there is benefit in restoring the additional streams compared to Plan 4, the increase in incremental costs for Plans 5 and 6 is not justified for Federal participation. Restoration of the proposed stream reaches in Plan 4 will provide habitat diversity within the stream channels as well as diversity of habitat adjacent to the streams. Riffles and pools, created through the use of natural channel design, will form a diversity of aquatic habitats that provide the foundation for many of the biological and water quality functions that natural streams provide. Macroinvertebrates find habitat around rocks and coarse substrate, filtering food from the water column. Fish utilize the pools and the overhead cover provided for protection and cooler water temperatures. The hyporheic zone — areas of the streambed and near stream aquifers through which stream water flows – has been identified as critically important in stream nutrient cycling, in moderating stream temperature regimes, and in creating unique habitats within streams.

Maximizing the creation of wetlands and wetted area will enable the greatest amount of nutrient cycling and water retention possible with the project, providing a great benefit to downstream aquatic communities. Ultimately, this goal enhances surface water storage processes, supports soil moisture regulation, provides pathways for aquatic organism movement, and augments contact time for biogeochemical processes. Increasing fish passage potential will expand available habitat for non-anadromous fish and American eels while also enhancing the resilience of fish communities to perturbations.

In a watershed context, the recommended plan helps to achieve levels 1 through 3 of the stream functions pyramid (Figure 7), leading to a functioning biological community (Harman et al. 2012). Together, restoration at all proposed stream reaches helps to ensure that a complete solution, with other stakeholder actions, can be achieved for restoration of the Anacostia River Watershed.

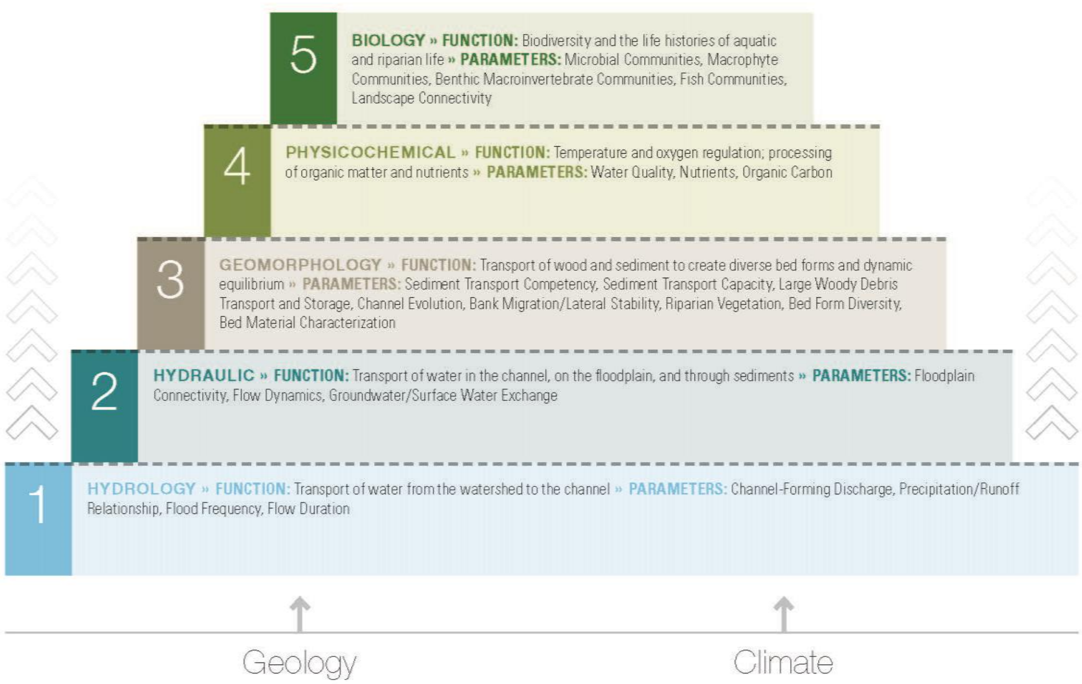

Figure 7. Stream Functions Pyramid (Harman et al. 2012)

14.4.1 Systems / Watershed Context

Since 1987, restoration of the Anacostia River Watershed has been conducted under the umbrella of the AWRC (now the AWRP), which is made up of numerous federal, state, local, non-governmental, and industry organizations. The ARP, completed in 2010 by USACE, is the latest of most complete plan for watershed restoration and outlined actions by the AWRP. The TSP builds upon the actions outlined for USACE participation in the AWRP and ARP, and complements many other ongoing activities in the watershed, including implementation of stormwater BMPs implemented by others, stream restoration projects by other agencies, and changes in permitting for new development. The TSP will also benefit from projects that will be proposed to be undertaken in Prince George's County through the Anacostia Watershed Restoration, Prince George's County, Maryland project. Those projects will address several partial fish barriers that limit movement of non-anadromous and migratory fish to Montgomery County. Those projects in Prince George's County will be proposed to be undertaken in about the same time period as the TSP in Montgomery County, though benefits for Montgomery County are not predicated on the projects in Prince George's County.

Other agencies participating in restoration projects throughout the Anacostia River watershed include: MCDEP, Prince George's County Department of Environmental Resources, District of Columbia Department of the Environment, MDE, MWCOG, University of Maryland, EPA, NPS, the National Oceanographic and Atmospheric Administration, and the USFWS. The U.S. Department of Agriculture, Beltsville Agricultural Center recently completed a stream restoration project in the lower reaches of Little Paint Branch. Other agencies and entities participating in the restoration effort include General Services Administration, AWS, subwatershed groups, Audubon Society, and others.

14.4.2 Environmental Operating Principles

The USACE Environmental Operating Principles (EOP) were developed to ensure that USACE missions include totally integrated sustainable environmental practices. The EOP relate to the human environment and apply to all aspects of business and operations. The principles were designed to provide direction on how to better achieve stewardship of air, water, and land resources, and to demonstrate a positive relationship between management of these resources and the protection and improvement of a sustainable environment. The seven principles are:

- Foster sustainability as a way of life throughout the organization.
- Proactively consider environmental consequences of all USACE activities and act accordingly.
- Create mutually supporting economic and environmentally sustainable solutions.
- Continue to meet our corporate responsibility and accountability under the law for activities undertaken by USACE, which may impact human and natural environments.
- Consider the environment in employing a risk management and systems approach throughout the life cycles of projects and programs.
- Leverage scientific, economic and social knowledge to understand the environmental context and effects of Corps actions in a collaborative manner.

- Employ an open, transparent process that respects views of individuals and groups interested in USACE activities.

Through collaboration with stakeholders, residents, and agencies, this project employing environmentally sustainable solutions to ecological degradation. This project fully embraces the EOP.

15.0 Key Social and Environmental Factors

15.1 Stakeholder Perspectives and Differences.

MCDEP is very supportive of efforts to restore streams and open fish passage. The sponsor expects that during the design process, the stream concept designs will be refined and explicit habitat features incorporated at a scale at which those features can be discerned. In particular, MCDEP wants to ensure creation of stable riffle-pool-run complexes, the placement of coarse woody debris in the form of rootwads, and fish passage blockages remediated on Stewart/April Lane where appropriate and feasible.

M-NCPPC wants to ensure that impacts from construction are minimized. The agency requires coordination and approval of designs on their land. Trees should be preserved to the greatest extent possible and early coordination on tree conservation is required.

MWCOG has been briefed on the Anacostia Watershed Restoration Montgomery County, Maryland study, and is supportive of their proposed actions.

AWRP has been briefed on the Anacostia Watershed Restoration projects, and the members are generally supportive of their actions.

USFWS has stated that efforts that restore the Montgomery County stream reaches are likely to benefit Department of Interior Trust Resources within the watershed. Ultimately, such efforts, along with other programs to reduce pollutant inputs should result in a healthier and more diverse fish community.

The report will be made available to stream neighbors and local watershed groups, after approval to release the draft report to the public.

15.2 Environmental Compliance.

An integrated environmental assessment is being prepared and will be available with the draft document, along with a draft finding of no significant impact. No issues have been raised to date. The project will be in compliance with all applicable laws and regulations in accordance with the national environmental protection act.

16.0 References

Anacostia Watershed Society (AWS). 2014. 2014 State of the Anacostia River Report Card. Retrieved September 9, 2014 from http://www.anacostiaws.org/programs/publicaffairs/state-of-the-river.

Atlantic States Marine Fisheries Commission (ASMC). 2015. American eel. Retrieved April 3, 2015 from http://www.asmfc.org/species/american-eel.

Chesapeake Bay Program (CBP). 2012. Facts and Figures. Available online at http://www.chesapeakebay.net/discover/bay101/facts. Accessed 27 May 2014.

CBF. 2014. Economic Impacts of the Chesapeake Bay. Available online at http://www.cbf.org/document.doc?id=1924. Accessed 3 June 2014.

Harman, W., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K. Suggs, C. Miller. 2012. A Function-Based Framework for Stream Assessment and Restoration Projects. US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC. EPA 843-K-12-006

Maryland Department of the Environment (MDE). 2012. Watershed Report for Biological Impairment of the Non-Tidal Anacostia River Watershed, Prince Georges and Montgomery Counties, Maryland and Washington D.C. Biological Stressor Identification Analysis Results and Interpretation. U.S. Environmental Protection Agency, Region III, Water Protection Division. Accessed May 21, 2014 from http://www.mde.state.md.us/programs/Water/TMDL/Documents/BSID_Reports/Anacostia_River_BSID_Report_020112_final.pdf.

Maryland-National Capital Park and Planning Commission (M-NCPPC). 2014a. Best Natural Areas. Montgomery County Department of Parks. Accessed July 16, 2014 from http://www.montgomeryparks.org/wildmontgomery/best_natural_areas/bna-index.shtm.

M-NCPPC. 2014b. Parks Directory. Montgomery County Department of Parks. Accessed July 15, 2014 from http://www.montgomeryparks.org/search/parks-search.php.

Metropolitan Washington Council of Governments. (MWCOG). 2010. Anacostia Watershed Environmental Baseline Conditions and Restoration Report. Washington, D.C.

MWCOG. 2010. Anacostia Watershed Restoration Partnership. Accessed March 10, 2015 from http://www.anacostia.net/about.html.

Montgomery County Department of Environmental Protection (MCDEP). 1997. Montgomery County Water Quality Monitoring Program: Stream Monitoring Protocols.

MCDEP. 2012. Anacostia Watershed Implementation Plan. Accessed May 15, 2014 from http://www.montgomerycountymd.gov/DEP/Resources/Files/ReportsandPublications/Water/Watershed percent20studies/Anacostia/AnacostiaRiverWIP_FINAL.pdf.

MCDEP. 2013. Anacostia I Restoration Project Monitoring Report. Watershed Management Division. Pagination by Chapter plus Appendices.

Najjar, R., C. Pyke, M.B. Adams, D. Breitburg, C. Hershner, M. Kemp, R. Howarth, M. Mullholand, M. Paolisso, D. Secor, K. Sellner, D. Wardrop, and R. Wood. 2010. Potential climate-change impacts on the Chesapeake Bay. *Estuarine Coastal and Shelf Science* 86:1-20.

National Oceanic and Atmospheric Administration (NOAA). 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 1. Climate of the Northeast U.S. January 2013.

Rice, K.C. and J.D. Jastram. 2015. Rising air and stream-water temperatures in Chesapeake Bay region, USA. *Climatic Change* 128:127-138.

Smith, H.M., and B.A. Bean. 1899. List of fishes known to inhabit the waters of the District of Columbia and vicinity. U.S. Government Printing Office.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Transactions, American Geophysical Union, Vol. 38, No. 6

United States Army Corps of Engineers (USACE). 2005. Anacostia River and Tributaries, Maryland and the District of Columbia, Comprehensive Watershed Plan Section 905(b) Report. July 2005.

USACE. 2010. Anacostia River Watershed Restoration Plan and Report.

U.S. Army Corps of Engineers, The Nature Conservancy, and Interstate Commission on the Potomac River Basin. 2014. Middle Potomac River Watershed Assessment: Potomac River Sustainable Flow and Water Resources Analysis. Final Report. 107 pp. and 11 appendices.

U.S. Environmental Protection Agency (EPA). 2013. District of Columbia Section 319 Non-Point Source Program Success Story: Restoration Efforts Stabilize Watts Branch and Reduce Sediment Loading. EPA 841-F-13-001H. Washington, D.C. February 2013. Retrieved March 11, 2015 from http://water.epa.gov/polwaste/nps/success319/upload/dc_watts.pdf.

U.S. Fish and Wildlife Service (USFWS). 2011. Kenk's Amphipod (Stygobromus kenki) Spotlight Species Action Plan. Annapolis, MD.

USFWS. 2011. Restoring an Urban Watershed. Accessed March 10, 2015 from http://www.fws.gov/chesapeakebay//Newsletter/Fall11/urban/Restoring.html

USFWS. 2014. U.S. Fish and Wildlife Service Species Assessment and Listing Priority Assignment Form: Kenk's amphipod. http://ecos.fws.gov/docs/candidate/assessments/2014/r5/K04P_I01.pdf

Urban Waters Federal Partnership (UWFP). 2011. New Life For The Anacostia River Watershed.

APPENDIX – Conceptual Design Descriptions

Galway

Approximately 19 structures (cross-vanes and J-hooks) are proposed for restoring the left and right fork of Galway tributary (Figure 6). The concept design includes realigning the stream just upstream of a concrete channel. The in-stream structures would increase connection to the surrounding forested floodplain. The stream is entrenched and disconnected from the floodplain. The stream bed would be raised utilizing the in-stream structures to reconnect to the floodplain. Outfall protection at the end of stream, leading into the concrete channel, would be constructed to eliminate/reduce storm runoff erosion. Initial designs include wetland cells near the downstream terminus. However, tree species there include mature upland species.

Figure 6. Galway Tributary Conceptual Design.

Green Castle

Approximately 29 structures are proposed to maintain stability in Green Castle tributary. Green Castle experiences frequent strong currents from storm outfalls (Figure 7). The stream is very entrenched to the extent that a few utilities are exposed. Due to the lack of a wide floodplain, a Rosgen Bc designed channel cross section would be most suitable for this reach. In-stream structures would provide grade control to eliminate bed scour, helping to protect exposed utilities. Access to this site would be challenging and some trees would be cut, which is why log-structures are used for many features.

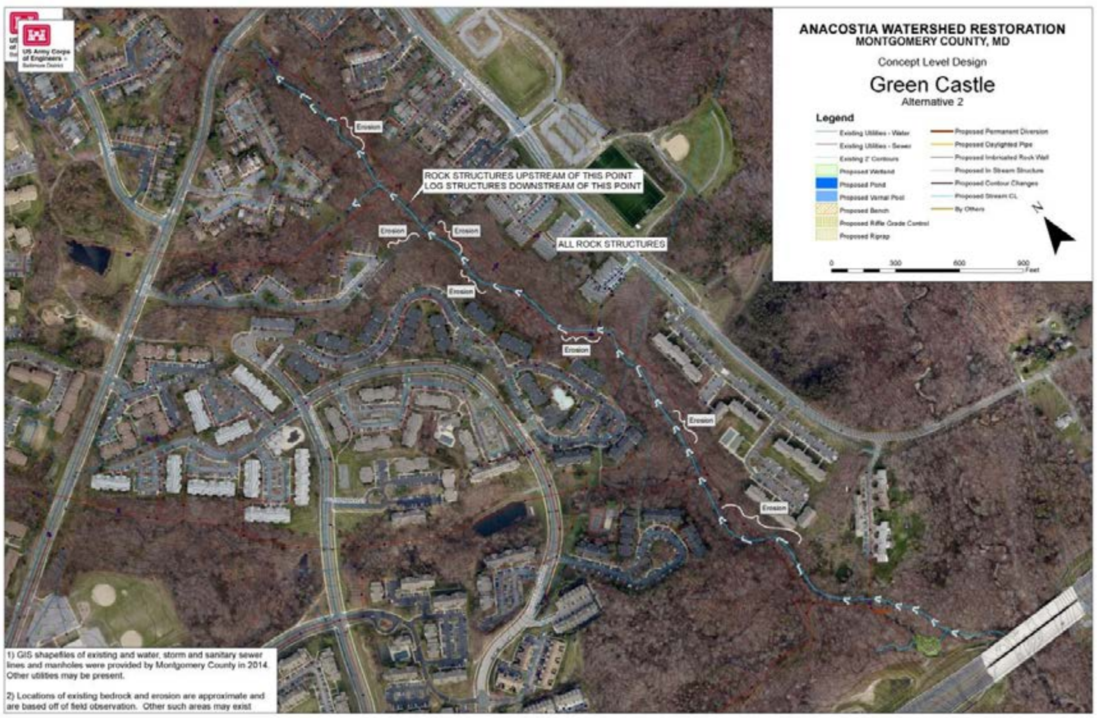

Figure 7. Green Castle Tributary Conceptual Design.

Bel Pre

Bel Pre tributary is roughly 3.1 miles long and requires different restoration methodologies for different segments (Figures 8-10). A total of 79 structures (cross-vanes, J-logs, J-hooks) have been proposed to maintain long term stability for the stream system. Some channel re-alignment is proposed to better convey the flow and reduce erosion to stream banks adjacent to private residential property. This realignment also would increase floodplain connectivity, which would capture the suspended sediment. Raising the stream water level could potentially raise floodplain groundwater levels as part of efforts to restore forested wetlands of floodplain degraded by excess drainage from stream incision. In the lower reach of this system there is a potential for wetland cells and vernal pools. In the vicinity of Layhill Road (Maryland Route 182), the stream has an unfavorable angle of approach to the roadway that is causing sediment loading and erosion downstream of the stream crossing. Riffle grade control would likely eliminate this problem and reduce scouring of sewer lines crossing the stream. Log structures are recommended in the center of the reach. Based on initial observations, it is likely that log structures would not be feasible elsewhere along the reach due to the geomorphic and hydraulic conditions.

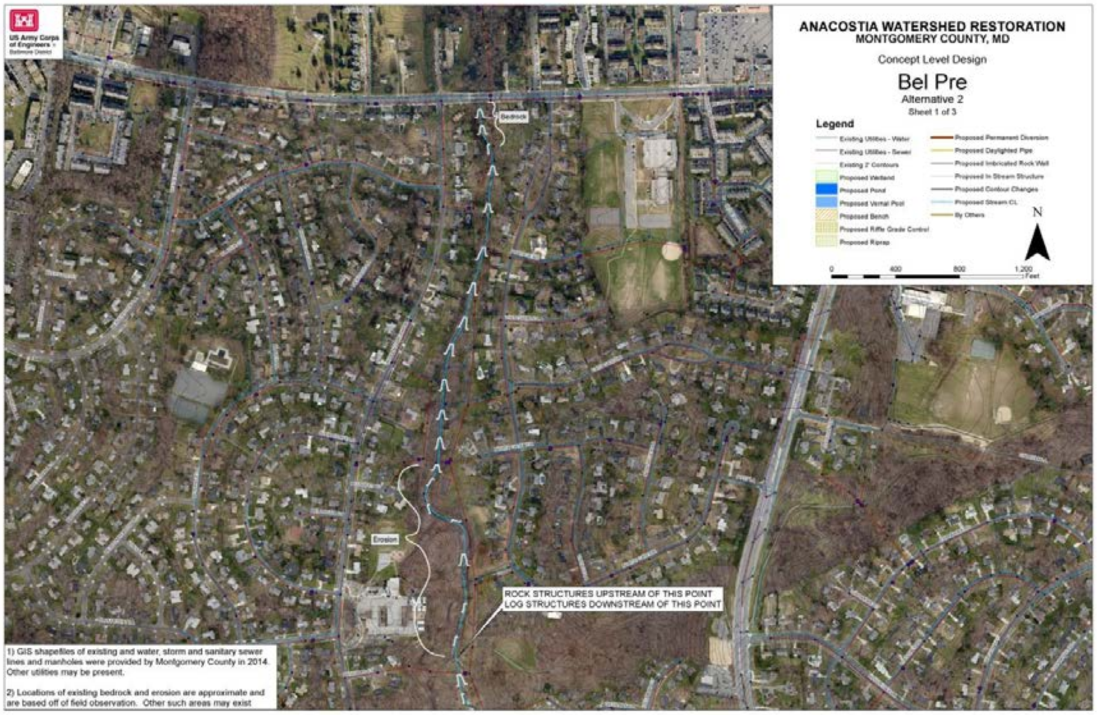

Figure 8. Bel Pre Tributary Conceptual Design, sheet 1.

Figure 9. Bel Pre Tributary Conceptual Design, sheet 2.

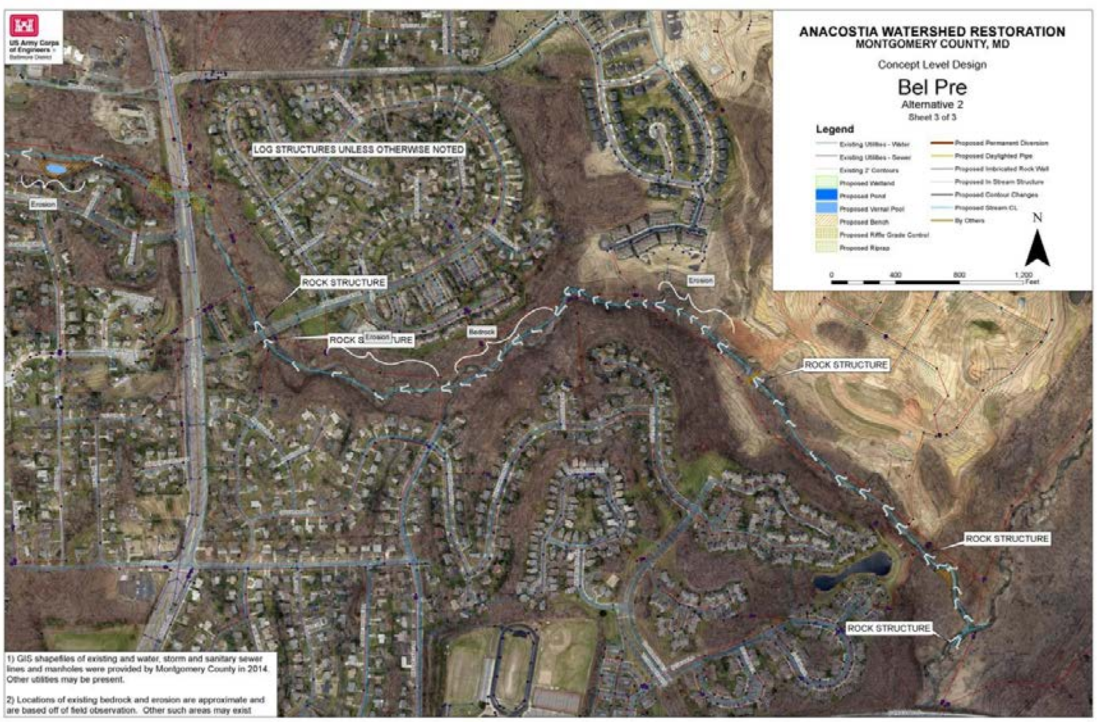

Figure 10. Bel Pre Tributary Conceptual Design, sheet 3.

Lamberton

To correct the lateral movement and erosion problems in Lamberton tributary, about 19 structures are proposed for placement in the channel (Figure 11). The alignment would not change much, and a Rosgen B channel could be created. Downstream of Lovejoy Street, the proposed design would provide fish passage through an existing culvert. This is a very high energy system and rock structures with geotextile on the upper portion of this project are essential. An imbricated retaining wall was incorporated in the downstream portion where. A riffle grade control at the lower portion is proposed.

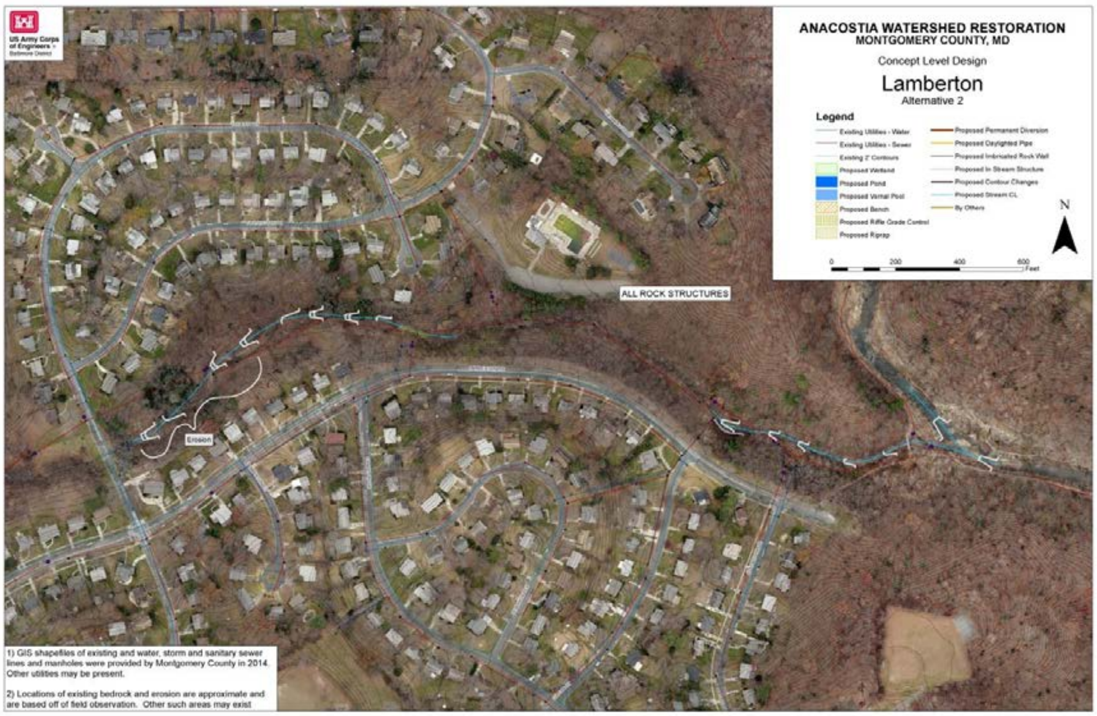

Figure 11. Lamberton Tributary Conceptual Design.

Quaint Acres

The restoration plan for Quaint Acres tributary (Figure 12) was based on the setting of the stream valley which has the lowest impervious cover of all the sites considered. Approximately 28 structures are proposed to restore the stream and eliminate two fish blockages. Most of the structures would be log-structures to blend in with the stream valley. The geomorphic and soil conditions present an opportunity for shallow vernal pools and wetland cells in this area, though this would need to be coordinated with WSSC and tree impacts evaluated. Shallow marsh cells are propsed (a stable D channel with shrubs) to slow the water and provide a functional system.

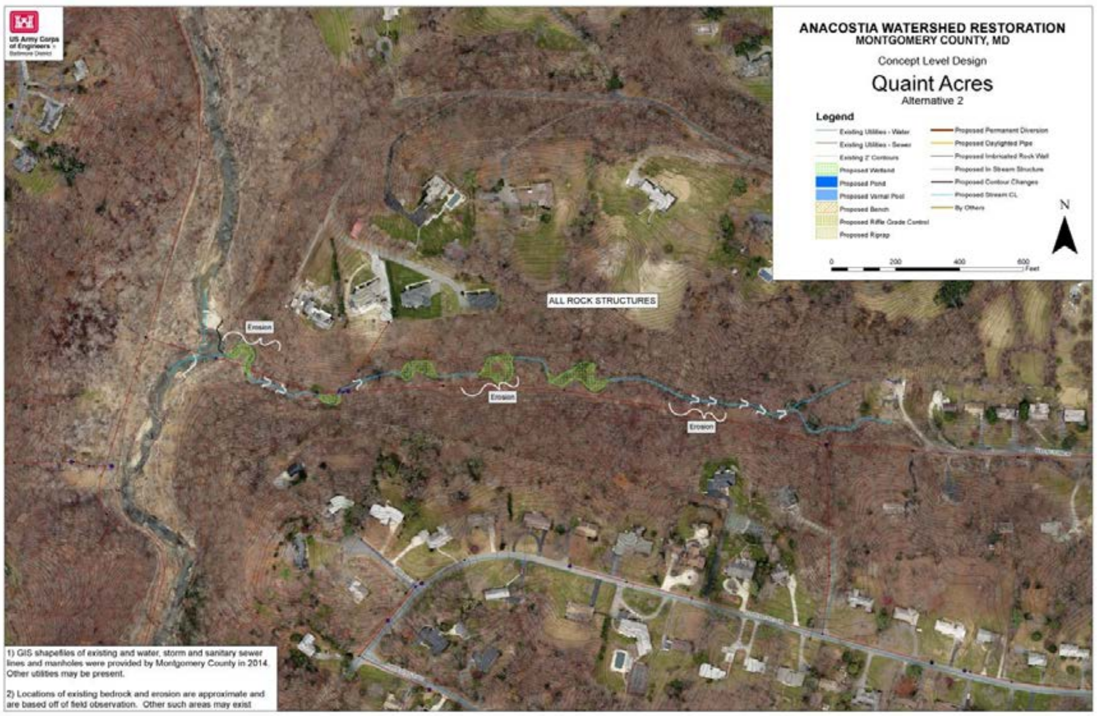

Figure 12. Quaint Acres Tributary Conceptual Design.

Stewart/April Lane

Due to the flashy nature of the Stewart/April Lane tributary and the presence of bedrock along much of the reach, 21 in-stream structures and two imbricated stone retaining walls are proposed to maintain stability (Figure 13). Removal of the excess boulders in the active channel would reduce stress, and the proposed structures would improve stability. A riffle grade control at two different locations would guide the water away from eroding embankments and provide more stability within the channel bed at sewer line crossings. A downstream fish blockage has been tentatively identified and it would be remediated through the placement of in-stream structures.

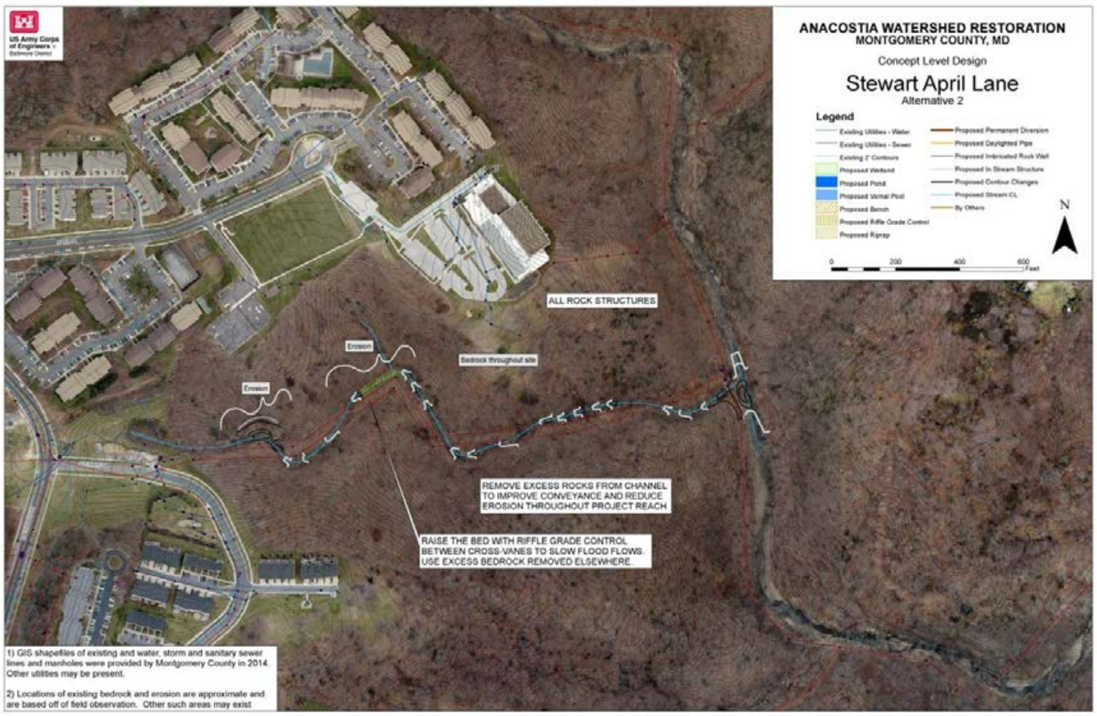

Figure 13. Stewart/April Lane Tributary Conceptual Design.

Sligo Creek/Colt Terrace

Colt Terrace tributary flows along residential homes on the right stream bank and forest on the left bank (Figure 14). This system ends at an existing storm water management/BMP facility. The other headwater stream starts from neighborhood pavement and joins Colt Terrace via a very entrenched gulley.

The main stem of Sligo Creek requires approximately 15 in-stream structures to elevate the streambed and reconnect it with its floodplain. These structures would provide stability and improve potential floodplain and physical aquatic habitat. There are some open areas where the proposed design would enhance their hydrologic connectivity, creating suitable wetland habitats. Most of the mature trees present in the reach are of species that tolerate temporary submergence or inundation.

The system from Colt Terrace requires two culvert replacements due to size and poor condition. No in-stream structures are proposed for this area. A shallow and wide system with planting is suitable because of the wide floodplain and presence of wetland soils. Additionally, relocation of the stream about 200 feet downstream of the first culvert would likely result in a more sustainable design. This area has large trees with ample room to create a system meandering between the trees without damaging the root system.

Figure 14. Sligo Creek/Colt Terrace Tributary Conceptual Design.

ANACOSTIA WATERSHED RESTORATION
MONTGOMERY COUNTY, MARYLAND
CONTINUING AUTHORITIES PROGRAM SECTION 206
AQUATIC ECOSYSTEM RESTORATION FEASIBILITY STUDY

DRAFT INTEGRATED FEASIBILITY REPORT AND ENVIRONMENTAL ASSESSMENT

APPENDIX B2: ANACOSTIA WATERSHED RESTORATION MODEL DOCUMENTATION AND APPROVAL

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Anacostia Watershed Assessment
Model Procedures January 2015

Table of Contents

INTRODUCTION

In fall 2013, Baltimore District, U.S. Army Corps of Engineers (USACE) began documenting biological benefit models for approval by USACEHQ. The proposed models utilize existing methods of Montgomery County Department of Environmental Protection (MCDEP) and Maryland Biological Stream Survey (MBSS data) and are applicable within the Anacostia Watershed. These methods characterize changes in aquatic habitat conditions that could be produced by stream geomorphic restoration projects. MCDEP and MBSS have published habitat and biological condition assessment procedures, and have collected data in the study area since the 1990s using these methods.

The methodology and metrics in MCDEP and MBSS are similar but are applicable in two domains. Both are based on USEPA rapid bioassessment methodology (Barbour et al. 1999). MCDEP developed and utilizes a Rapid Habitat Assessment (RHA) procedure that is applicable within Montgomery County, Maryland. MCDEP has collected habitat data for many years utilizing this procedure and will continue to use RHA in the foreseeable future; therefore the use of RHA in Montgomery County is efficient and ensures data continuity.

MBSS developed its Physical Habitat Index (PHI) for three geographic regions in Maryland: Piedmont, Coastal Plain, and Highlands. For this study, Piedmont and Coastal Plain models are utilized and are applicable within the Anacostia Watershed (in appropriate geomorphic areas) in both Montgomery County and Prince George's County. PHI will be utilized in Prince George's County because MBSS protocols and metrics are also utilized by Prince Georges County in their biological monitoring programs. Furthermore, statewide MBSS datasets include both Montgomery and Prince George's Counties, but the data network is less dense than county datasets.

PROCEDURES

Rapid Habitat Assessment

Rapid habitat assessment (RHA) is applicable in the Anacostia Watershed within Montgomery County, Maryland.

Because of the screening criteria utilized in the study, the candidate segments generally possess wooded riparian corridors with pervasive conditions of erosion. Instream habitat conditions within any segment vary longitudinally. Instream habitat conditions can vary along a gradual gradient in response to changes in relative importance of watershed versus local hydrologic influences accompanying increase in drainage area proceeding downstream, or show pronounced changes at major points of substrate change. Additionally, there are often localized erosional and depositional areas that extend for only short lengths of stream. These often occur in the vicinity of woody debris jams, coarse sediment deposits (particularly cobble and gravel), bedrock outcrops, and built environment features such as stormwater outfall pipes, concrete structures, and boulder stabilization works.

Stream habitat assessment progressed through a sequence of steps (Table 1). MCDEP (2013, 1997) procedures were chosen to assess habitat conditions because they have been utilized by MCDEP since the 1990s and thus allowed for ready comparison of previous to current conditions. MCDEP has utilized the protocols to assess existing conditions as well as conditions of streams following geomorphic restoration work. The MCDEP RHA procedures are founded on protocols developed by the USEPA in the 1980s and 1990s, and are similar to procedures also utilized by Maryland Biological Stream Survey (MBSS) of the MD DNR. Use of these procedures was coordinated with USACE EcoPCX.

Table 1: Rapid Habitat Assessment Steps.

Step	Location	Assessment Step
1	Office & Field	Subdivide stream segments into reaches based on habitat conditions
2	Field	Assess stream reach habitat condition
3	Office	Quantify existing stream habitat
4	Office	Forecast future stream habitat with and without geomorphic project
5	Office	Quantify total future habitat quantity change with geomorphic project

1. Segment Subdivision Into Reaches

Streams often have the presence/absence of several natural and built environment features and conditions that have major controlling effect on habitat conditions within segments (Tables 2 and 3). Segments can contain reaches with any combination of these features and conditions. Segments which possess a range of varying habitat conditions along their length can be divided into reaches at break points based on presence/absence of these features/conditions. Reaches are sampled rather than the entire segment because this is cost and time efficient. RHA is performed within each reach.

Table 2: Channel physical materials affecting/controlling habitat conditions.

Stream Substrate
Piped or in culvert
Concrete channel
Natural meander (not channelized)
Channelized (earthen)
Stabilized discontinuously but systematically
Stabilized continuously
Earth (alluvium, colluvium, in-place soil)
Bedrock channel/banks

Table 3: Flows affecting habitat

Flow
Intermittent flow (such as via loss into substrate)
Frequent backwater from downstream
Ponded (lentic rather than lotic)
Receiving flow from joining stream and stormwater outfalls

2. Reach Habitat Condition Assessment

Within each reach, a representative 75 m length measured along the channel thalweg capturing the range of conditions in that reach is field-identified and sampled as per MCDEP procedures (2013, 1997; Appendix A). Assess stream reach as per MCDEP summer qualitative habitat procedures and record data onto MCDEP data sheets ("Habitat Assessment Field Data Sheet for Riffle/Run Prevalent Streams" and "MCDEP Summer Habitat Data Sheet"; Appendix B). The two assessment forms are very similar. MCDEP collects data on the second form to ensure consistency with MBSS collected data. The final habitat score is determined from the first data sheet. When using the first data sheet, follow additional guidance in Table 4, which is a summary of Appendix A, Table 7.

While all data should be recorded as per MCDEP protocols to ensure consistency with past and future monitoring efforts, not all data collected on the "MCDEP Summer Habitat Data Sheet" will be utilized in determining a final RHA score because much of its data is used in other monitoring protocols or models.

Habitat quality in stream reaches is characterized using MCDEP (2013, 1997) rapid habitat assessment (RHA) procedures. Following the RHA procedures and guidance, 10 habitat parameters are scored in the field (Table 4). Each individual parameter can score from 0 to 20 (explanations of scores are provided with the "Habitat Assessment Field Data Sheet for Riffle/Run Prevalent Streams", Appendix B). The worst possible habitat score is 0, and the best possible score is 20. The RHA procedures divide the total score into distinct narrative classes ranging from excellent to poor (Table 5). The data is entered into spreadsheets in the office, and these 10 parameters are then summed to produce a total habitat score for the reach.

Table 4: Habitat assessment parameters (from MCDEP 1997).

Habitat Parameter	Spreadsheet Abbreviation	Biological Relationships
Instream Cover (fish)	INS_COV	Includes the relative quantity and variety of natural structures in the stream, such as fallen trees, logs, and branches, large rocks, and undercut banks, that are available as refugia, feeding, or laying eggs.
Epifaunal Substrate (macroinvertebrates)	EPI_SUB	Is essentially the microhabitat diversity or hard substrates (rocks, snags) available for insects and snails. As with fish, the greater the variety and number of available microhabitats or attachment sites, the greater the variety of insects.
Embeddedness	EMBEDD	Refers to the extent to which rocks (gravel, cobble, and boulders) are covered or sunken into the silt, sand, or mud of the stream bottom. (>0.5")
Channel Alteration	CH_ALTER	A measure of large-scale changes in the shape of the stream channel.
Sediment Deposition	SED_DEP	Measures the amount of sediment that has accumulated and the changes that have occurred to the stream bottom as a result of the deposition.
Riffle Frequency	RIFF_FREQ	A measure of the sequence of riffles and thus the heterogeneity occurring in a stream.
Channel Flow Status	CHAN_FLOW	The degree to which the channel is filled with water.
Bank Vegetative Protection (left and right banks scored separately (0-10) and summed)	LB+RB_VEG	Measures the amount of the stream bank that is covered by vegetation.
Bank Stability (left and right banks scored separately (0-10) and summed)	LB+RB_STAB	Measures whether the stream banks are eroded (or the potential for erosion).
Riparian Buffer Zone Width (left and right banks scored separately (0-10) and summed)	LB+RB_BUFFER	Measures the width of natural vegetation from the edge of the stream bank out through the floodplain.

Table 5: RHA Ranks (MCDEP, 2013)

RHAB Score (out of 200)	Percentage	Narrative Ranking
200-166	100%-83%	Excellent
165-154	82%-77%	Excellent/Good
153-113	76%-57%	Good
112-101	56%-51%	Good/Fair
100-60	50%-30%	Fair
59-54	29%-24%	Fair/Poor
53-0	23%-0%	Poor

Sensitivity

All habitat scores, with the exception of riparian buffer width, may be affected by a stream geomorphic restoration project. In theory, a site with a "poor" RHAB score of 0 could be improved to 180 which is "excellent". The score, generally, cannot be improved to 200 because the riparian buffer width will likely be unchanged by a project. In practice, it is highly unlikely that a stream with a score of 0 would be encountered and also unlikely that all variables could be increased to a top score of 20. The best attainable condition (BAC) for restored streams would not exceed the conditions of the most natural streams in the watershed (Stoddard et al. 2006). All streams and stream conditions in Montgomery County can be characterized by RHA. Streams that have scores of Poor or Fair could be improved to receive scores of good or excellent, depending on expected changes to cover, stream complexity, and water movement through a reach. For example, a stream receives a score of 8 (medium marginal score) under existing conditions for channel flow status. This indicates that water fills 25-75% of the available channel and/or riffle substrates are mostly exposed. With project conditions through realignment of streambanks, raising the streambed, and other measures, may produce a score of 18 for channel flow status. This means that water reaches the base of both lower banks and has a minimal amount of channel substrate exposed. Concurrently, we can expect other metrics to improve similarly. A stream that has an RHAB score of 98, "fair", under current conditions may receive a with project score of 164, "excellent/good". Under this scenario, no score is improved to its maximum value, and some scores may only improve by 3 points or remain unchanged. However, BAC is achievable.

Rescaling

In order to compare Stream Habitat Units (next section) between projects in Montgomery and Prince George's Counties, the RHA will be rescaled from 0 to 1. The RHA score will be divided by 200 to rescale between 0 and 1.

3. Quantifying Existing Stream Habitat

Quantifying stream habitat requires consideration of habitat quantity and quality:

<u>Habitat Quantity</u>

Physical habitat quantity is determined using stream length and stream order (Strahler 1957). Stream order shows a close correlation to stream width, depth, wetted perimeter, and volume, and is simpler to determine/measure. Candidate stream segment reach lengths are determined from field GPS data and GIS data. Stream order for reaches is interpreted from maps and aerial photographs.

To quantify stream habitat present within reaches of each segment, stream reach length (feet) per stream order is determined. Then, stream length is multiplied by stream order to generate a single number combining these metrics that represented habitat quantity.
Detailed future with project stream widths will not be determined until detailed restoration designs are drafted. Therefore, decision making to determine a tentatively selected plan will depend upon comparison of habitat quantity based on stream order, as that is the most comparable measure between alternatives and conditions.

In cases where stream reaches are piped or contained within a dewatered concrete channel, that reach is considered as having zero habitat quantity under existing conditions.

Total Habitat Availability

Habitat available within a stream reach is a function of habitat quantity and habitat quality. The total habitat available within a reach is represented by the simple equation:

Habitat Quantity x Habitat Quality Score = Stream Habitat Units

For a segment, total habitat availability is the simple sum of HUs for all the reaches within the segment.

4. Forecast of Future Stream Habitat Condition

Without Project

Stream water quality is expected to improve over the 50-year evaluation period. As part of Montgomery County's National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) Permit, an implementation plan to meet watershed goals was prepared in 2012. The watershed implementation plan (WIP) outlines a comprehensive roadmap for watershed restoration that targets runoff management; bacteria, sediment, and nutrient reduction; and trash and litter management. Montgomery County's MS4 Permit area covers 70% of the total Anacostia watershed area within the County and the WIP focuses on restoration efforts within the MS4 Permit area. The MS4 Permit area has approximately 21% impervious cover within the Anacostia watershed. The WIP addresses total maximum daily loads (TMDLs) established by Maryland Department of the Environment (MDE) for bacteria, sediment, nutrients, and trash, and focuses on achieving the maximum practicable reductions.

By 2030, Montgomery County will provide water quality treatment for 4,544 acres of impervious cover within the Anacostia Watershed with numerous SWM water quality control features, with continued improvement of the sanitary sewer system, and with other progressive environmental management actions. The implementation of the WIP will result in 100% attainment of the waste load allocation for sediment, nutrient, and trash reduction. Thus, the magnitude of degraded water quality as a stressor to aquatic ecosystems is expected to diminish as water quality impairment will be below levels experienced in 2009.

MDE requires that urban stormwater runoff be managed through "… a unified approach for sizing stormwater BMPs in the State of Maryland to meet pollutant removal goals, maintain groundwater recharge, reduce channel erosion, prevent overbank flooding, and pass extreme floods." Design features required by MDE for MS4 stormwater permits include the use of pre-treatment vegetation, wetland pockets and pools, flow reduction techniques, native plants, measdows, trees, permeable soils, and the creation of sinuous flow paths.

The 2000 Maryland Stormwater Design Manual requires all extended detention facilities to have wet pool storage and management of the one-year 24 hour storm, which helps attenuate peak flows and reduce stormwater quantity. In general, stormwater controls are designed to control the "first flush" (first ½ inch) of runoff from impervious surfaces.

While stormwater retrofits and upgrades will help address stormwater quantity, it is expected that stormwater runoff quantity control will remain less than needed for decades. While stream geomorphic conditions would be expected to eventually achieve a condition of dynamic equilibrium with stormwater runoff, based on the pattern evidenced in urban streams of the study area and elsewhere in Maryland, the streams reaching an equilibrium condition would likely take many decades to centuries and only after substantial quantities of sediment were eroded and trees lost to bank erosion. Accordingly, absent a geomorphic restoration project, future conditions without project in the streams are assumed to be equivalent to current conditions.

With Restoration Project

With a geomorphic restoration project, future stream conditions would differ from without project conditions. Forecast change in condition from existing to future provides benefits input for cost-effectiveness analyses. This information would also be utilized for NEPA compliance purposes.

i Reach Habitat Quantity

If segment reaches contain piped streams that would be daylighted or dry concrete channel streams that would have flow and natural substrate restored, there would be an increase in stream habitat quantity equal to that reach length. In cases where a surface stream does exist but its length or order were changed with-project, then stream habitat quantity would also change. Possible change in stream length could occur via either increasing or decreasing stream sinuosity.

Changes in other physical metric changes of width, depth, wetted perimeter, and volume could change. However, accurately determining these over a segment length is challenging. Changes in stream width will be determined when detailed feasibility level project designs are drafted. Total restoration acreage will be determined as outlined in Table II-2-4 in EC 11-2-199 when detailed designs are available. In early decision making, stream order is used as a proxy to represent these stream attributes and therefore these changes are not determined.

ii Reach Habitat Quality Change

Based on findings of habitat assessments of other previously restored reaches in the Anacostia Watershed (Table 6; MCDEP, 2013), it is expected that instream habitat quality of existing erosion surface streams could be improved up to excellent/good condition, as per Table 5. Many streams in the Anacostia Watershed lie in wooded settings; therefore there is minimal opportunity for improvement in riparian buffer zone score because the buffer is already vegetated. While the habitat quality of the buffer may be improved through plantings, invasive species control, or similar measures, these efforts would not appreciably change the buffer zone score. Change in individual parameters could theoretically be as great as 20. However, all candidate stream segments already having some water and habitat would have potential to produce actual changes somewhat less than 20.

Table 6. MCDEP Stream Restoration Projects: RHA Monitoring (MCDEP 2013)

Stream/Project	Seasons	Pre Project Score Range	Pre-Project Sampling Years	Project Completed	Post-Project Score Range	Post Project Sampling
Paint Branch	Spring and Summer Average	Good to Excellent/Good	1995, 2000	2001	Good to Excellent/ Good	2001, 2002, 2003, 2004, 2005, 2007, 2009
Northwest Branch South of Randolph Rd	Spring and Summer Average	Good/Fair	1999	2001	Fair to Good	2003, 2005, 2007, 2009
Lockridge Drive	Spring Only	Good	1995, 2001	2001	Good/Fair to Excellent/ Good	2002, 2004, 2005, 2007, 2009
Sligo Creek Wayne to Piney	Spring and Summer Average	Good/Fair	1992, 1999	2003	Fair to Good	2005, 2006, 2007, 2008, 2009, 2011

iii Segment Total Habitat Availability Change

As with existing conditions, total habitat availability under forecast future conditions would be the sum of all the reach habitat quantities for a given segment.

5. Total Habitat Quantity Availability Change (Benefits)

For each segment, the difference between with-project total habitat quantity and existing conditions total habitat quantity is determined by simple subtraction. That difference constitutes the project benefits that are compared to alternatives to inform plan formulation.

Benefits of constructing multiple segments which are physically separate from each other are the simple sum of habitat units that would be produced by restoring the individual segments. No interactive benefits between restored segments or other portions of the stream system, such as would be produced by reduced downstream sedimentation, are captured.

Physical Habitat Index

The physical habitat index (PHI) is applicable in the Anacostia Watershed in both Montgomery and Prince George's Counties by physiographic province. However, PHI will be utilized in Prince George's County, Maryland for the Anacostia Watershed Restoration, Prince George's County Project.

Because of the screening criteria utilized in the study, the candidate segments generally possess wooded riparian corridors with pervasive conditions of erosion. Instream habitat conditions within any segment vary longitudinally. Instream habitat conditions can vary along a gradual gradient in response to changes in relative importance of watershed versus local hydrologic influences accompanying increase in drainage area proceeding downstream, or show pronounced changes at major points of substrate change. Additionally, there are often localized erosional and depositional areas that extend for only short lengths of stream. These often occur in the vicinity of woody debris jams, coarse sediment deposits (particularly cobble and gravel), bedrock outcrops, and built environment features such as stormwater outfall pipes, concrete structures, and boulder stabilization works.

Stream habitat assessment progressed through a sequence of steps (Table 7). MBSS (2003) procedures were chosen to assess habitat conditions because they have been utilized by PGDER since the 1990s and thus allowed for ready comparison of previous to current conditions. PGDER has utilized the protocols to assess existing conditions recently through contracts with TetraTech. MBSS has also sampled extensively throughout Prince George's County during several rounds of stream surveys. Use of these procedures was coordinated with USACE EcoPCX.

Table 7. Physical Habitat Index Steps.

Step	Field or Office	Habitat Assessment Step Details
1	Office & Field	Subdivide stream segments into reaches based on habitat conditions.
2	Field	Assess stream reach habitat condition.
3	Office	Compute PHI
4	Office	Quantify Existing Stream Habitat
5	Office	Forecast future stream habitat with and without project
6	Office	Quantify total future habitat quantity change with geomorphic project

1. Segment Subdivision Into Reaches

Streams often have the presence/absence of several natural and built environment features and conditions that have major controlling effect on habitat conditions within segments (Tables 8 and 9). Segments can contain reaches with any combination of these features and conditions. Segments which possess a range of varying habitat conditions along their length can be divided into reaches at break points based on presence/absence of these features/conditions. Reaches are sampled rather than the entire segment because this is cost and time efficient. PHI is calculated for each reach.

Table 8: Channel physical materials affecting/controlling habitat conditions.

Stream Substrate
Piped or in culvert
Concrete channel
Natural meander (not channelized)
Channelized (earthen)
Stabilized discontinuously but systematically
Stabilized continuously
Earth (alluvium, colluvium, in-place soil)
Bedrock channel/banks

Table 9: Flows affecting habitat

Flow
Intermittent flow (such as via loss into substrate)
Frequent backwater from downstream
Ponded (lentic rather than lotic)
Receiving flow from joining stream and stormwater outfalls

2. Reach Habitat Condition Assessment

Within each reach, a representative 75 m length measured along the channel thalweg capturing the range of conditions in that reach is field-identified and sampled as per MBSS procedures (MDDNR 2013; Appendix C). Assess stream reach as per MBSS field protocols and record data onto MBSS data sheets ("MBSS Summer Habitat Data Sheet"; Appendix E). Not all metrics collected on the data sheet will be used to calculate PHI but should be collected for consistency with past and future monitoring efforts. Additionally, the remoteness score is based on the "MBSS Spring Habitat Data Sheet" (Appendix E) in which the distance from the stream to the nearest road is recorded in meters. This distance has been measured utilizing GIS and aerial photography for the Anacostia Watershed Restoration project. Information on the metrics used to calculate PHI are reproduced in Tables 10-11.

Table 10. Habitat assessment parameters utilized for PHI (from MDDNR 2013).

Metric	Units	Value Range*	Notes
Watershed Area	Acres	19.95-93,325.4 acres (Coastal Plain) 28.84-38,904.5 acres (Piedmont)	
Remoteness	Meters	0-700 m	Based on measured distance (in meters) from stream to nearest road. If road were greater than 700 m from stream, a remoteness score of 20 is assigned (see section 3).
Percent Shading	Percentage	5.2-99 (Coastal Plain) 4-100 (Piedmont)	Rated based on estimates of the degree and duration of shading at a site during summer, including any effects of shading caused by landforms.
Embeddedness	Percentage	0-100	Not used in Coastal Plain PHI. Rated as a percentage based on the fraction of surface area of larger particles* that is surrounded by fine sediments on the stream bottom. In low gradient streams with substantial natural deposition, the correlation between embeddedness and fishability or ecological health may be weak or non-existent, but this metric is rated in all streams to provide similar information from all sites statewide. (*> 0.5")
Epibenthic Substrate	Unitless	0-20	Rated based on the amount and variety of hard, stable substrates usable by benthic macroinvertebrates. Because they inhibit colonization, floculent materials or fine sediments surrounding otherwise good substrates are assigned low scores. Scores are also reduced when substrates are less stable.

Instream Habitat	Unitless	0-20	Rated based on perceived value of habitat to the fish community. Within each category, higher scores should be assigned to sites with a variety of habitat types and particle sizes. In addition, higher scores should be assigned to sites with a high degree of hypsographic complexity (uneven bottom). In streams where ferric hydroxide is present, instream habitat scores are not lowered unless the precipitate has changed the gross physical nature of the substrate. In streams where substrate types are favorable but flows are so low that fish are essentially precluded from using the habitat, low scores are assigned. If none of the habitat within a segment is useable by fish, a score of zero is assigned.
Total number instream woody debris and rootwads	Enumerated	0-32	
Erosion Extent	Meters	0-75**	Based on procedures in MDDNR 2013.
Severity	Unitless	0 = none; 1=min; 2=mod; 3=severe	
Riffle Quality	Unitless	0-20	Not used in Coastal Plain PHI Rated based on the depth, complexity, and functional importance of riffle/run habitat in the segment, with highest scores assigned to segments dominated by deeper riffle/run areas, stable substrates, and a variety of current velocities.

*Value Range: Watershed Area, Percent Shading, and Total Number of Instream Woody Debris and Rootwads based on data reported in MDDNR 2003. These values informed the development of the PHI.

**Bank erosion may exceed 75m in braided streams.

Table 11. Selected Metrics from MBSS Stream Habitat Assessment Guidance Sheet MDDNR 2013)

Habitat Parameter	Optimal 16-20	Sub-Optimal 11-15	Marginal 6-10	Poor 0-5
Instream Habitat	Greater than 50% of a variety of cobble, boulder, submerged logs, undercut banks, snags, root wads, aquatic plants, or other stable habitat	30-50% of stable habitat. Adequate habitat	10-30% mix of stable habitat. Habitat availability less than desirable	Less than 10% stable habitat. Lack of habitat is obvious
Epifaunal Substrate	Preferred substrate abundant, stable, and at full colonization potential (riffles well developed and dominated by cobble; and/or woody debris prevalent, not new, and not transient)	Abund. of cobble with gravel &/or boulders common; or woody debris, aquatic veg., undercut banks, or other productive surfaces common but not prevalent /suited for full colonization	Large boulders and/or bedrock prevalent; cobble, woody debris, or other preferred surfaces uncommon	Stable substrate lacking; or particles are over 75% surrounded by fine sediment or flocculent material
Riffle/Run Quality	Riffle/run depth generally >10 cm, with maximum depth greater than 50 cm (maximum score); substrate stable (e.g. cobble, boulder) & variety of current velocities	Riffle/run depth generally 5-10 cm, variety of current velocities	Riffle/run depth generally 1-5 cm; primarily a single current velocity	Riffle/run depth < 1 cm; or riffle/run substrates concreted
Embeddedness[a]	Percentage that gravel, cobble, and boulder particles are surrounded by fine sediment or flocculent material. Based on approximated observation and compared to MBSS representative conditions.			
Shading[b]	Percentage of segment that is shaded by overhanging vegetation or other structures (duration is considered in scoring). 0% = fully exposed to sunlight all day in summer; 100% = fully and densely shaded all day in summer. Percentage is approximated based on a visual assessment.			

a) Embeddedness Rated as a percentage based on the fraction of surface area of larger particles that is surrounded by fine sediments on the stream bottom. Based on riffle substrates – area with the fastes flow within riffle or run habitats. Several substrates should be examined within the riffle to determine the approximate average condition within the fast part of the riffle. In low gradient streams with substantial natural deposition, the correlation between embeddedness and fishability or ecological health may be weak or non-existent, but this metric is rated in all streams to provide similar information from all sites statewide. See MDDNR 2013 page 26 for more information on methodology.

b) Shading Rated based on estimates of the degree and duration of shading at a site during summer, including any effects of shading caused by landforms (MDDNR 2013, page 26).

Sensitivity
Most PHI metrics may be influenced by a stream geomorphic restoration project. However, watershed area and remoteness score will not be affected by a project. Similarly, percent shading is unlikely to affected appreciably by a project. Theoretical sites with all scores at the extremes of the metric value range can produce final PHI scores that are greater than 100 and less than 0. This occurs because the PHI computations are based on observed streams in Maryland and those extreme conditions have not been sampled and thus are not reflected in the PHI equations. If a final PHI score is outside of the acceptable range of 0-100 the scoring for the stream must be reviewed and if the scores are representative of stream conditions, Maryland DNR should be contacted for further consultation as these would constitute novel conditions. The best attainable condition (BAC) for restored streams would not exceed the conditions of the most natural streams in the watershed (Stoddard et al. 2006). A representative piedmont stream sampled by MBSS in 1997, HO-P-195-130-97, received a PHI score of 36, "severely degraded". Most metrics were low and its erosion extent was relatively great. Its watershed area is small, 102.3 acres, with a remoteness score of 3, indicating that a road is immediately adjacent to the stream. If we assume that a geomorphic restoration project can improve stream conditions from one level to the next best level at the same relative condition, PHI can improve to 58, "degraded". If we assume that conditions can further be improved, with more instream woody debris, less erosion, and relatively modest improvements in other scores, we can reach a score of at least 66, "moderately degraded". Other streams with different combinations of metric scores demonstrate similar results and sensitivity to metric changes. However, in all cases BAC is achievable.

3. Compute PHI

The metrics collected in the field are entered into a spreadsheet (PhysicalHabitatIndexModel.xlsx) which calculates PHI utilizing the equations listed below. Utilize separate worksheets for Coastal Plain or Piedmont stream reaches as appropriate.

PHI was developed by MBSS for Maryland streams, thus its calculations are based on data collected in Maryland streams and it is not valid for use outside of Maryland.

a. Metrics are first transformed:

<u>Coastal Plain</u>

REMOTE = Remoteness Score

Remoteness Score = 0.615 + (0.733*(√distance in meters from road))

TSHADING = arcsine(square root(percent shading/100))

RESEPISUB = epibenthic substrate score - (3.5233+2.5821(Log(Watershed Area in acres))

RESINSTRHAB = instream habitat score - (0.5505 + 4.2475(Log(Watershed Area in acres))

RESWOOD = total # of instream woody debris and rootwads - (-12.24+8.8120(Log(Watershed Area in acres))

TBANKSTAB = square root of the final value calculated

BANKSTAB = if bank stability on 0-20 score = 0-20 score

BANKSTAB = if erosion extent is used = [((erosion extent)/-15) x severity] for each bank + 20

Note: severity is altered so that original severity 0 = 0, 1 = 1, 2 = 1.5, and 3 = 2.0

Piedmont

EMBEDDED = percent embeddedness
REMOTE = Remoteness Score
  Remoteness Score = 0.615 + (0.733*(√distance in meters from road))
RESTSHADING = arcsine(square root(percent shading/100)) - (1.7528 - 0.1990(Log(Watershed Area in acres))
EPISUB = epibenthic substrate score
RESINSTRHAB = instream habitat score - (9.9876 + 1.5476(Log(Watershed Area in acres))
WOOD = total number of instream woody debris and rootwads
TBANKSTAB = square root of the final value calculated
  BANKSTAB = if bank stability on 0-20 score = 0-20 score
  BANKSTAB = if erosion extent is used = [((erosion extent)/-15) x severity] for each bank + 20
    Note: severity is altered so that original severity 0 = 0, 1 = 1, 2 = 1.5, and 3 = 2.0
RESRIFFQUAL = riffle quality score - (5.8467 + 2.4075(Log(Watershed Area in acres))

b. The transformed metrics are then scaled:

Coastal Plain

REMOTE = (value)/(18.570)
TSHADING = (value - 0.226)/(1.120)
RESEPISUB = (value + 13.199)/(17.213)
RESINSTRHAB = (value + 15.094)/(18.023)
RESWOOD = (value + 28.903)/(33.803)
TBANKSTAB = (value)/(4.472)

Piedmont

EMBEDDED = (100 - value)/(90)
REMOTE = (value)/(16)
RESTSHADING = (value + 1.142)/(1.405)
EPISUB = (value - 1)/(17)
RESINSTRHAB = (value + 12.805)/(15.745)
WOOD = (value)/(12)
TBANKSTAB = (value - 1)/(3.243)
RESRIFFQUAL = (value + 16.252)/(19.637)

c. Final scores are calculated:

Coastal Plain

Coastal Plain PHI = (sum of metric scores)/6

Piedmont

Piedmont PHI = (sum of metric scores)/8

The resulting PHI score is multiplied by 100. The score corresponds to one of four narrative classes: minimally degraded; partially degraded; degraded; severely degraded (Table 12).

Table 12. Description of PHI Scoring Classes (MDDNR, 2011)

Narrative Class	Score
Minimally Degraded	81-100
Partially Degraded	66-80
Degraded	51-65
Severely Degraded	0-50

MDDNR. 2011. Results from Round 3 of the Maryland Biological Stream Survey (2007-2009). Prepared by: Versar, Inc. 77 pages. http://www.dnr.maryland.gov/streams/R3ReportIntro.asp

Normalize
The range of possible values for individual metrics can result in final PHI scores that are over or under the acceptable 0 to 100 range. While it is highly unlikely that streams with such scores will be encountered, scores will be normalized so that all possible scores are within 0-100, and then rescaled from 0-1. If a final PHI score is outside of the acceptable range of 0-100 the scoring for the stream must be reviewed and if the scores are representative of stream conditions, Maryland DNR should be contacted for further consultation as these would constitute novel conditions. Coastal Plain streams have a possible PHI range from -9.82 to 135.88 while Piedmont streams have a possible range from -3.44 to 134.77.

4. Quantify Existing Stream Habitat

Quantifying stream habitat requires consideration of habitat quantity and quality:

Habitat Quantity
Physical habitat quantity is determined using stream length and stream order. Stream order shows a close correlation to stream width, depth, wetted perimeter, and volume, and is simpler to determine/measure. Candidate stream segment reach lengths are determined from field GPS data and GIS data. Stream order for reaches is interpreted from maps and aerial photographs.

To quantify stream habitat present within reaches of each segment, stream reach length per stream order is determined. Then, stream length is multiplied by stream order to generate a single number combining these metrics that represented habitat quantity.

In cases where stream reaches are piped or contained within a dewatered concrete channel, that reach is considered as having zero habitat quantity under existing conditions.

Total Habitat Availability
Habitat available within a stream reach is a function of habitat quantity and habitat quality. The total habitat available within a reach is represented by the simple equation:

Habitat Quantity x PHI = Stream Habitat Units

For a segment, total habitat availability is the simple sum of HUs for all the reaches within the segment.

5. Forecast future stream habitat with and without project

Without Project

Stream water quality is expected to improve over the 50-year evaluation period. In 2011 Prince George's County initiated development of its local strategies to fulfill Phase II Watershed Implementation Plan (WIP) requirements to meet Chesapeake Bay Watershed TMDLs. Unlike Montgomery County, Prince George's County has developed its WIP at the county scale, rather than at the watershed scale. By 2025 non-federal (not originating from federally owned lands) nutrient loads delivered to the Chesapeake Bay from Prince George's County will be reduced from 2009 loads by 9.32 percent for total nitrogen and 3.61 percent for total phosphorus. These reductions will be accomplished through implementation of stormwater BMPs and retrofits, impervious surface reduction and disconnection, agriculture BMPs, and other methods and account for projected population growth in the county. Prince George's County will retrofit water quality treatment for 7,109 acres of untreated impervious area throughout the county by 2017, which does not include treatment of state or federal area.

Maryland Department of the Environment (MDE) requires that urban stormwater runoff be managed through "… a unified approach for sizing stormwater BMPs in the State of Maryland to meet pollutant removal goals, maintain groundwater recharge, reduce channel erosion, prevent overbank flooding, and pass extreme floods." Design features required by MDE for MS4 stormwater permits include the use of pre-treatment vegetation, wetland pockets and pools, flow reduction techniques, native plants, meadows, trees, permeable soils, and the creation of sinuous flow paths.

The 2000 Maryland Stormwater Design Manual requires all extended detention facilities to have wet pool storage and management of the one-year 24 hour storm, which helps attenuate peak flows and reduce stormwater quantity. In general, stormwater controls are designed to control the "first flush" (first ½ inch) of runoff from impervious surfaces.

While stormwater retrofits and upgrades will help address stormwater quantity, it is expected that stormwater runoff quantity control will remain less than needed for decades. While stream geomorphic conditions would be expected to eventually achieve a condition of dynamic equilibrium with stormwater runoff, based on the pattern evidenced in urban streams of the study area and elsewhere in Maryland, the streams reaching an equilibrium condition would likely take many decades to centuries and only after substantial quantities of sediment were eroded and trees lost to bank erosion. Accordingly, absent a geomorphic restoration project, future conditions without project in the streams are assumed to be equivalent to current conditions.

With Restoration Project

With a geomorphic restoration project, future stream conditions would differ from without project conditions. Forecast change in condition from existing to future provides benefits input for cost-effectiveness analyses. This information would also be utilized for NEPA compliance purposes.

i Reach Habitat Quantity

If segment reaches contain piped streams that would be daylighted or dry concrete channel streams that would have flow and natural substrate restored, there would be an increase in stream habitat quantity equal to that reach length. In cases where a surface stream does exist but its length or order were changed with-project, then stream habitat quantity would also change. Possible change in stream length could occur via either increasing or decreasing stream sinuosity.

Changes in other physical metric changes of width, depth, wetted perimeter, and volume could change. However, accurately determining these over a segment length is challenging. Because stream order is used as a proxy to represent these stream attributes these changes are not determined.

ii Reach Habitat Quality Change

Based on findings of habitat assessments of other previously restored reaches in the Anacostia Watershed (MCDEP, 2013), it is expected that instream habitat quality of existing erosion surface streams could be improved up to excellent/good condition, as per Table 12. Many streams in the Anacostia Watershed lie in wooded settings; therefore there is minimal opportunity for improvement in the percent shading score. While the habitat quality of the buffer area may be improved through plantings, invasive species control, or similar measures, these efforts would not appreciably change the shading. However, trees will be planted where opportunities exist. Change in individual parameters could theoretically be as great as 20. However, all candidate stream segments already having some water and habitat would have potential to produce actual changes somewhat less than 20.

iii Segment Total Habitat Availability Change

As with existing conditions, total habitat availability under forecast future conditions would be the sum of all the reach habitat quantities for a given segment.

6. Quantify total future habitat quantity change

For each segment, the difference between with-project total habitat quantity and existing conditions total habitat quantity is determined by simple subtraction. That difference constitutes the project benefits that are compared to alternatives to inform plan formulation.

Benefits of constructing multiple segments which are physically separate from each other are the simple sum of habitat units that would be produced by restoring the individual segments. No interactive benefits between restored segments or other portions of the stream system, such as would be produced by reduced downstream sedimentation, are captured.

REFERENCES

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Maryland Department of Natural Resources. 2003. A Physical Habitat Index for Freshwater Wadeable Streams in Maryland. Final Report. Chesapeake Bay and Watershed Programs. Monitoring and Non-tidal Assessment. CBWP-MANTA-EA-03-4. Pagination by chapter.

Maryland Department of Natural Resources. 2005. Maryland Biological Stream Survey 2000-2004, Volume XIV: Stressors Affecting Maryland Streams.

Maryland Department of Natural Resources. 2013. Sampling Manual: Field Protocols. Rev. Jan. 2013. Maryland Biological Stream Survey. Chesapeake Bay and Watershed Programs. Monitoring and Non-tidal Assessment. CBWP-MANTA-EA-07-01. 63 pages.

Montgomery County Department of Environmental Protection. 1997. Montgomery County Water Quality Monitoring Program: Stream Monitoring Protocols.

Montgomery County Department of Environmental Protection. 2013. Anacostia I Restoration Project Monitoring Report. Watershed Management Division. Pagination by Chapter plus Appendices.

Montgomery County Department of Environmental Protection. 2013. Habitat Monitoring. Website: http://www6.montgomerycountymd.gov/dectmpl.asp?url=/content/dep/water/monHabitat.asp#assess

Stoddard, J.L., D.P. Larsen, C.P. Hawkins, R.K. Johnson, and R.H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications, 16(4):1267

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Transactions, American Geophysical Union, Vol. 38, No. 6

Appendix A

Rapid Habitat Assessment

Montgomery County Department of Environmental Protection

Water Quality Monitoring Program Stream Monitoring Protocols
February 20, 1997

Section G. Monitoring Procedures for Habitat (in part)

G. Monitoring Procedures for Habitat

1. Objectives

The objective of the habitat inventory procedures is to describe the structure of the physical features that characterize the condition of the stream resource and influence the existing aquatic community (Barbour and Stribling 1994). The quantification of aquatic habitat is as important as measuring instream biological communities in order to document nonpoint source impact. Habitat inventory supports an understanding of the relationship between habitat quality and the present biological conditions (Barbour and Stribling 1991). The habitat assessment protocol consists of two procedures:

- o Rapid Habitat Assessment
- o Quantitative Habitat Assessment

The collection of habitat data from reference streams allows for the development of habitat conditions from the least impaired streams in a region (Barbour and Stribling 1991). Subsequent quantification of habitat at a study site and a comparison of that habitat to the reference conditions allows the determination of whether poor habitat is the cause of impairment. Assuming that water quality remains constant, there is a predictable relationship between habitat quality and biological condition, (Figure 2), (Plafkin et al. 1989). The attainable biological potential of a

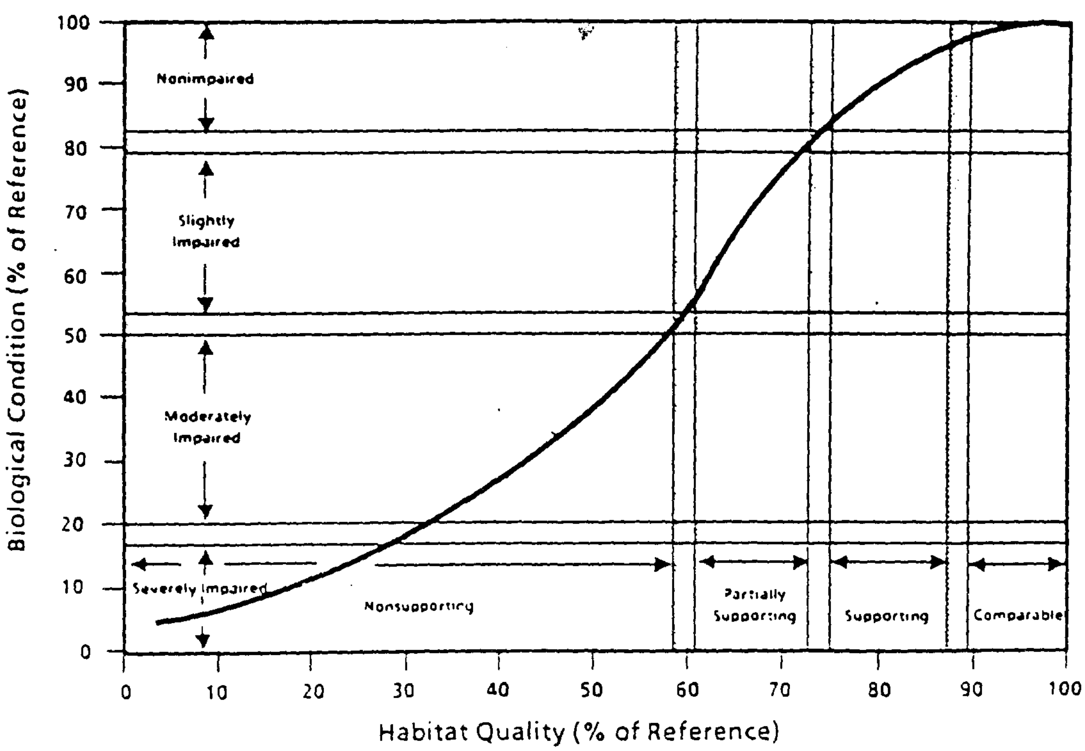

Figure 2. The Relationship Between Habitat And Biological Condition (Plafkin et al. 1989).

site is primarily determined by the quality of the habitat at that site (Plafkin et al. 1989). Streams with high biological integrity should have optimal habitat conditions (as compared to the reference conditions). However, water quality rarely remains a constant, and water quality impacts above those caused by habitat constraints are likely. Four causes of biological impairment are possible (Barbour and Stribling 1991):

a. Observed biological effects are due to habitat impairment.

b. Biological effects are due to water quality impairment.

c. There is an elevation of the perceived condition of the biological community beyond the expected habitat relationship because of nutrient enrichment effects.

d. It is not possible to separate habitat/water quality (

The base flow conditions occurring during the low fl through September) are the main limiting factors to the ca (Gougeon pers. comm. 1993). This is the time of most stres flow is at a yearly low, available riffle and run habitat is limitin wetted width, water temperature is at the highest levels, an levels. Quantitative measurements of the habitat conditio information needed to understand the structure and composit is monitored at other times of year within the same stream se

2. Field Methods

The habitat assessment protocol includes a series of vi taken within the 75 meter stream segment. This assessment p and quantitatively, the quality of the stream habitat so that po can be determined for follow up remedial monitoring.

A rapid habitat assessment should be done every time In addition, a detailed habitat assessment, conducted during of year, will provide needed information on site habitat lim community.

The objective of these field measurements is to descri stream segment. Field measurements will be recorded on the meter stream segment will be located and measured using a wa along the 75 meter segment at 0, 37.5 and 75 meter distance completed.

A. Before or after visiting the stream segment

1. Record the dominant upstream land use fr photography or from a drive by survey.

2. Record the drainage area upstream of the

3. Record an estimate of drainage area imperv use.

Table 7. Habitat Assessment Parameters and Selected Literature on Biologica. Effects, Geomorphic Effects, or Measurement techniques. (Barbour and Stribling, 1994)

	Parameter	Biological Relationships	Selected Pertinent References
1.	Instream Cover (fish)	Includes the relative quantity and variety of natural structures in the stream, such as fallen trees, logs, and branches, large rocks, and undercut banks, that are available as refugia, feeding, or laying eggs. A wide variety and/or abundance of submerged structures in the stream provides the fish with a large number of niches, thus increasing the diversity. As variety and abundance of cover decreases, habitat structure becomes monotonous, fish diversity decreases, and the potential for recovery following disturbance decreases.	Wesche and others 1985; Pearsons and others 1992; Gorman 1988; Rankin 1991; Barbour and Stribling 1991; Plafkin and others 1989; Platts and others 1983; Osborne and others 1991.
2.	Epifaunal Substrate (macro-invertebrates)	Is essentially the microhabitat diversity or hard substrates (rocks, snags) available for insects sand snails. Numerous types of insect larvae attach themselves to rocks, logs branches, or other submerged substrates. As with fish, the greater the variety and number of available microhabitats or attachment sites, the greater the variety of insects in the stream. Rocky-bottom areas are critical for maintaining a healthy variety of insects in most high gradient streams. Snags and submerged logs are among the most productive habitat structure in low gradient streams.	Ball 1982; Osborne and others 1991; Barbour and Stribling 1991; Platts and others 1983; MacDonald and others 1991; Rankin 1991; Reice 1980; Clements 1987; Suedel and Rodgers 1991; Benke and others 1984; Hawkins and others 1982.
3.	Embeddedness	Refers to the extent to which rocks (gravel, cobble, and boulders) are covered or sunken into the silt, sand, or mud of the stream bottom. Generally, as rocks become embedded, the surface area available to macroinvertebrates and fish (shelter, spawning, and egg incubation) is decreased. Embeddedness is a result of large-scale sediment movement and deposition, and is a parameter evaluated in the riffles and runs of high gradient streams.	Ball 1982; Osborne and others 1991; Rankin 1991; MacDonald and others 1991; Barbour and Stribling 1991; Burton and Harvey 1990; Beschta and Platts 1986; Berkman and others 1986.

Table 7. Continued

	Parameter	Biological Relationships	Selected Pertinent References
4.	Velocity/Depth Regimes	Examines the availability of each of the four primary current/depth combinations: (1) slow-deep, (2) slow-shallow, (3) fast-deep, and (4) fast-shallow. The best streams in high gradient regions will have all four habitat types present. The presence or availability of these four habitats relates to the stream's ability to provide and maintain a stable aquatic environment. The general guidelines are 0.5 m depth to separate shallow from deep, and 0.3 m/sec to separate fast from slow.	Ball 1982; Osborne and Hendricks 1983; Rankin 1991; Hughes and Omernik 1983; Platts and others 1983; Cushman 1985; Gore and Judy 1981; Bain and Boltz 1989; Gislason 1985; Hawkins and others 1982; Oswood and Barber 1982; Statzner and others 1988.
5.	Channel Alteration	A measure of large-scale changes in the shape of the stream channel. Many streams in urban and agricultural areas have been straightened, deepened, or diverted into concrete channels, often for flood control purposes. Such streams have far fewer natural habitats for fish, macroinvertebrates, and plants than do naturally meandering streams. Channel alteration is present when artificial embankments, riprap, and other forms of artificial bank stabilization or structures are present; when the stream is very straight for significant distance;s when dams and bridges are present; and when other such changes have occurred. Scouring is often associated with channel alteration.	Barbour and Stribling 1991; Simon 1989a, b; Simon and Hupp 1987; Hupp and Simon 1986; Hupp 1992; Rosgen 1985; Rankin 1991; MacDonald and others 1991.
6.	Sediment Deposition	Measures the amount of sediment that has accumulated and the changes that have occurred to the stream bottom as a result of the deposition. Deposition occurs from large-scale movement of sediment caused by watershed erosion. Sediment deposition may cause the formation of islands, point bars (areas of increased deposition usually at the beginning of a meander that increase in size as the channel is diverted toward the outer bank) or shoals, or result in the filling of pools. Increased sedimentation also results in increased deposition. Usually this is evident in areas that are obstructed by natural or manmade debris and areas where the stream flow decreases, such as bends. High levels of sediment deposition create an unstable and continually changing environment that becomes unsuitable for many organisms.	MacDonald and others 1991; Platts and others 1983; Ball 1982; Armour and others 1991; Barbour and Stribling 1991; Rosgen 1985.

Table 7. Continued

	Parameter	Biological Relationships	Selected Pertinent References
7.	Channel Sinuosity/ Heterogeneity	Is a way to measure the sequence of riffles anc thus the heterogeneity occurring in a stream. Riffles are a source of high-quality habitat and diverse fauna, therefore, an increased frequency of occurrence greatly enhances the diversity of the stream community. For areas where riffles are uncommon, a run/bend ratio can be used as a measure of meandering or sinuosity. A high degree of sinuosity provides for diverse habitat and fauna, and the stream is better able to handle surges when the stream fluctuates as a result of storms. The absorption of this energy by bends protects the stream from excessive erosion and flooding. In "oxbow" streams of coastal areas and deltas, meanders are highly exaggerated and transient. Natural conditions are shifting channels and bends. Alteration of these streams is usually in the form of flow regulation and diversion. A stable channel is one that does not exhibit progressive changes in slope, shape, or dimensions, although short-term variations may occur during floods (Gordon and others 1992).	Hupp and Simon 1991; Ball 1982; Brown and Brussock 1991; Brussock and Brown 1991; Platts and others 1983; Rankin 1991; Rosgen 1985.
8.	Channel Flow Status	Is the degree to which the channel is filled with water. The flow status will change as the channel enlarges or as flow decreases as result of dams and other obstructions, diversions for irrigation, drought, aggrading stream bottoms with actively widening channels. When water does not cover much of the streambed, the amount of viable substrate for aquatic organisms is limited. In high gradient streams, riffles and cobble substrate are exposed; and, in muddy bottom streams, the decrease in water level will expose logs and snags, there reducing the areas with good habitat. Channel flow status is usually a seasonal parameter and is useful for interpreting biological condition in abnormal or degraded flow conditions.	Rankin 1991; Rosgen 1985; Hupp and Simon 1986; MacDonald and others 1991; Ball 1982; Hicks and others 1991.
9.	Bank Stability (condition of banks)	Measures whether the stream banks are eroded (or the potential for erosion). Steep banks are more likely to collapse and suffer from erosion than are gently sloping banks and are therefore considered to be unstable. Signs of erosion include crumbling, unvegetated banks, exposed tree roots, and exposed soil. Eroded banks indicate a problem of sediment movement and deposition, and suggest a scarcity of cover and allochthonous input to streams.	Ball 1982; MacDonald and others 1991; Armour and others 1991; Barbour and Stribling 1991; Hupp and Simon 1986, 1991; Simon 1989a; Hupp 1992; Hicks and others 1991; Osborne and others 1991.

Table 7. Continued

	Parameter	Biological Relationships	Selected Pertinent References
10.	Bank Vegetative Protection	Measures the amount of the stream bank that is covered by vegetation. The root systems of plants growing on stream banks help hold soil in place, thereby reducing the amount of erosion that is likely to occur. This parameter supplies information on the ability of the bank to resist erosion as well as some additional information on the uptake of nutrients by the plants, the control of instream scouring, and stream shading. Banks that have full, natural plant growth are better for fish and macroinvertebrates than are banks without vegetative protection or those shored up with concrete or riprap. This parameter is made more effective by defining the natural vegetation for the region and stream type (i.e., shrubs, trees, etc.).	Hupp and Simon 1986, 1991; Simon and Hupp 1987; Ball 1982; Osborne and others 1991; Rankin 1991; Barbour and Stribling 1991.
11.	Grazing or Other Disruptive Pressure	Is a measure of disruptive changes to the riparian zone because of grazing or human interference (e.g., mowing). In areas of high grazing pressure from livestock or where residential and urban development activities disrupt the riparian zone, the growth of a natural plant community is impeded. This parameter relates to the standing crop biomass expected in a given season. Residential developments, urban centers, golf courses, and rangeland are the common causes of anthropogenic pressure on the riparian zone.	MacDonald and others 1991; Platts and others 1983; Armour and others 1991; Myers and Swanson 1991; Osborne and others 1991; Barbour and Stribling 1991.
12.	Riparian Vegetative Zone Width	Measures the width of natural vegetation from the edge of the stream bank out through the floodplain. The riparian vegetative zone serves as a buffer zone to pollutants entering a stream from runoff, controls erosion, and provides stream habitat and nutrient input into the stream. A relatively undisturbed riparian zone reflects a healthy stream system; narrow, far less useful riparian zones occur when roads, parking lots, fields, lawns, bare soil, rocks, or buildings are near the stream bank. The presence of "old field" (i.e., a previously developed fields in continuous or periodic use), paths, and walkways in an otherwise undisturbed riparian zone may be judged to be inconsequential to destruction of the riparian zone.	Barton and others 1985; Naiman and others 1993; Hupp 1992; Gregory and others 1991; Platts and others 1987; Rankin 1991; Barbour and Stribling 1991.

Table 7. Continued

	Parameter	Biological Relationships	Selected Pertinent References
13.	Pool Substrate Characterization	Evaluates the type and condition of bottom substrates found in pools. Firmer sediment types (e.g., gravel, sand) and rooted aquatic plants support a wider variety of organisms than a pool substrate dominated by mud or bedrock and no plants. In addition, a stream that has a uniform substrate in its pools will support far fewer types of organisms than a stream that has a variety of substrate types.	Beschta and Platts 1986; USEPA 1983.
14.	Pool Variability	Rates the overall mixture of pool types found instreams, according to size and depth. The four basic types of pools are large-shallow, large-deep, small-shallow, and small-deep. A stream with many pool types will support a wide variety of aquatic species. Rivers with low sinuosity (fe bends) and monotonous pool characteristics do not have sufficient quantities and types of habitat to support a diverse aquatic community. General guidelines are any pool dimension (i.e., length, width, oblique) greater than half the cross-section of the stream for separating large from small and 1 m depth separating shallow and deep.	Beschta and Platts 1986; USEPA 1983.

numbered water level marked on the gauge with the adjoining water level and associated flow measured with a flow meter. The gauge height is plotted on the Y axis and discharge on the X axis. A line fitted to the data points will provide a predictive tool to determine future stream flows using the height observed on the staff height gauge. The more flow and gauge readings plotted, the more precise and accurate the rating curve will be.

b. Habitat Assessment Data Sheets.

The parameters on the data sheets are summed and compared to the EPA RBP habitat assessment rating table (Table 8).

; for the Habitat Assessment Field Data Sheet for Riffle/Run Prevalent 1994).

Category	Range
Optimal	166-200
Sub-Optimal	113-153
Marginal	60-100
Poor	0-47

Appendix B

Rapid Habitat Assessment

Montgomery County Department of Environmental Protection

Data Sheets

A. Habitat Assessment Field Data Sheet for Riffle/Run Prevalent Streams
B. MCDEP Summer Habitat Data Sheet

HABITAT ASSESSMENT FIELD DATA SHEET *RIFFLE/RUN PREVALENT STREAMS*

STREAM ______________________ DATE ______________________

SITE ______________________ INVESTIGATOR ______________________

Riffle/Run Prevalent Streams are those in moderate to high gradient landscapes that sustain water velocities of approximately 1 ft/sec or greater. Natural streams have substrates primarily composed of coarse sediment particles (i.e., gravel or larger) or frequent coarse particulate aggregations along stream reaches.

Habitat Parameter	Category			
	Optimal	Suboptimal	Marginal	Poor
1. Instream Cover (Fish)	Greater than 50% mix of snags, submerged logs, undercut banks, or other stable habitat.	30-50% mix of stable habitat; adequate habitat for maintenance of populations.	10-30% mix of stable habitat; habitat availability less than desirable.	Less than 10% mix of stable habitat; lack of habitat is obvious.
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Epifaunal Substrate	Well-developed riffle and run; riffle is as wide as stream and length extends two times the width of stream; abundance of cobble.	Riffle is as wide as stream but length is less than two times width; abundance of cobble; boulders and gravel common.	Run area may be lacking; riffle not as wide as stream and its length is less than 2 times the stream width; gravel or large boulders and bedrock prevalent; some cobble present.	Riffles or run virtually nonexistent; large boulders and bedrock prevalent; cobble lacking.
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Embeddedness	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Channel Alteration	Channelization or dredging absent or minimal; stream with normal, sinuous pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	New embankments present on both banks; and 40 to 80% of stream reach channel-ized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted.
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from coarse gravel; 5-30% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, coarse sand on old and new bars; 30-50% of the bottom affected; sediment deposits at obstruction, constriction, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Habitat Parameter	Category			
	Optimal	Suboptimal	Marginal	Poor
6. Frequency of Riffles	Occurrence of riffles relatively frequent; distance between riffles divided by the width of the stream equals 5 to 7; variety of habitat.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream equals 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is between ratio >25.
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
7. Channel Flow Status	Water reaches base of both lower banks and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
SCORE ____	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank Vegetative Protection (score each bank) Note: determine left or right side by facing downstream.	More than 90% of the streambank surfaces covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption, through grazing or mowing, minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 2 inches or less in average stubble height.
SCORE ____ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ____ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
9. Bank Stability (score each bank)	Banks stable; no evidence of erosion or bank failure; little potential for future problems.	Moderately stable; infrequent, small areas of erosion mostly healed over.	Moderately unstable; up to 60% of banks in reach have areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
SCORE ____ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ____ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
10. Riparian Vegetative Zone Width (score each bank riparian zone)	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
SCORE ____ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ____ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

Total Score ____

MCDEP SUMMER HABITAT DATA SHEET

Page ☐ Of ☐

STATION ID Watershed Code ☐☐☐☐ Segment ID ☐☐☐☐

DATE Year ☐☐☐☐ Month ☐☐ Day ☐☐

Reviewed By: ____________

2nd Reviewer: ____________

Office Use Only **MBSS SITE ID** Watershed Code ☐☐☐☐ Segment ☐☐☐ Type ☐

BANK EROSION
(Facing Downstream)

	Left Bank	Right Bank
Extent (m)	☐☐	☐☐
Severity 1=min 2=mod 3=severe	☐	☐
Mean Eroded Height (m)	☐☐.☐	☐☐.☐
Eroded Area (Extent/mean ht./10)	☐☐☐	☐☐☐

STREAM CHARACTER

A = Absent
P = Present
E = Extensive

- ☐ Braided
- ☐ Riffle
- ☐ Run/Glide
- ☐ Deep Pool(>= 0.5m)
- ☐ Shallow Pool(< 0.5m)
- ☐ Boulder (>2m)
- ☐ Boulder (0.25 - 2m)
- ☐ Cobble (5 cm - 25 cm)
- ☐ Bedrock
- ☐ Gravel (0.1cm - 5cm)
- ☐ Sand
- ☐ Overhead Cover
- ☐ Silt/Clay
- ☐ Undercut Bank
- ☐ Beaver Pond

BAR FORMATION & SUBSTRATE

(Check One)
- ☐ None
- ☐ Minor
- ☐ Moderate
- ☐ Extensive

(Check that apply)
- ☐ Cobble
- ☐ Gravel
- ☐ Sand
- ☐ Silt/Clay

EXOTIC PLANTS
Relative Abundance
(A, P, E)

A = Absent
P = Present
E = Extensive

- ☐ Multiflora Rose
- ☐ Mile-a-Minute
- ☐ Japanese Honeysuckle
- ☐ Japanese Silt Grass
- ☐ Thistle
- ☐ Garlic Mustard
- ☐ Periwinkle
- ☐ Kudzu
- ☐ English Ivy
- ☐ ____________

☐☐ No. of Instream Woody Debris (1.5m x 0.1m diameter)

☐☐ No. of Dewatered Woody Debris (debris out of water)

☐☐ No. of Instream Rootwads

☐☐ No. of Dewatered Rootwads

COMMENTS: ____________

s:\wmd\wrp\data\dataform\mcdeps additions to forms\field data sheets\fish\habitat-1

MCDEP SUMMER HABITAT DATA SHEET

HABITAT ASSESSMENT

Notes:

1. Instream Habitat (0-20) .... [ ][ ]
2. Epifaunal Substrate (0-20) .... [ ][ ]
3. Velocity/Depth Diversity (0-20) .... [ ][ ]
4. Pool/Glide/Eddy Quality (0-20) .... [ ][ ]
   Extent (m) .... [ ][ ]
5. Riffle/Run Quality (0-20) .... [ ][ ]
   Extent (m) .... [ ][ ]
6. Embeddedness (%) .... [ ][ ][ ]
7. Shading (%) .... [ ][ ][ ]

MBSS Stream Habitat Assessment Guidance Sheet

Habitat Parameter	Optimal 20 19 18 17 16	Sub-Optimal 15 14 13 12 11	Marginal 10 9 8 7 6	Poor 5 4 3 2 1 0
1. Instream Habitat	Greater Than 50% of a Variety of cobble, boulder, Submerged logs, undercut banks, snags, rootwads, aquatic plants, or other stable habitat	30-50% mix of stable habitat. Adequate habitat	10-30% mix of stable habitat. Habitat availability less than desirable	Less Than 10% stable habitat. Lack of habitat is obvious
2. Epifaunal Substrate	Preferred substrate abundant, stable, and at full colonization potential (riffles well developed and dominated by cobble; and/or woody debris prevalent, not new, and not transient)	Abund. Of cobble with gravel &/or boulders common; or woody debris, aquatic veg., undercut banks, or other productive surfaces common but not prevalent/suited for full colonization.	Large boulders and/or bedrock prevalent; cobble, woody debris, or other preferred surfaces uncommon	Stable substrate lacking; or particles are over 75% surrounded by fine sediment or flocculent material
3. Velocity/Depth Diversity	Slow (<0.3 m/s), deep (>0.5 m/s); slow, shallow (<0.5m/s); fast (>0.3 m/s), deep; fast, shallow habitats all present	Only 3 of the 4 habitat categories present	Only 2 of the 4 habitat categories present	Dominated by 1 velocity/depth category (usually pools)
4. Pool/Glide/Eddy Quality	Complex cover/&/or depth >1.5 m; both deep (>0.5m)/ shallows (<0.2 m) present	Deep (>0.5m) areas present; but only moderate cover	Shallows(<0.2m) prevalent in pool/ glide/ eddy habitat; little cover	Max depth <0.2m in pool/glide/eddy habitat; or absent completely
5. Riffle/Run Quality	Riffle/run depth generally >10 cm, with maximum depth greater than 50 cm (Maximum score); substrate stable (e.g. Cobble, boulder) & variety of current velocities	Riffle/run depth generally 5-10 cm, variety of current velocities	Riffle/run depth generally 1-5 cm; primarily a single current velocity	Riffle/run depth <1 cm; or riffle/run substrates concreted
6. Embeddedness	Percentage that gravel, cobble, and boulder particles are surrounded by line sediment or flocculent material			
7. Shading	Percentage of segment that is shaded (duration is considered in scoring). 0% = fully exposed to sunlight all day in summer; 100% = fully densely shaded all day in summer			

Appendix C

Physical Habitat Assessment
Sampling Manual: Field Protocols
Revision January 2013

Maryland Department of Natural Resources
Maryland Biological Stream Survey

Selected Document Sections

A. Section 3.5.9 Physical Habitat (in part)

3.5.9 Physical Habitat

Physical habitat assessments conducted by MBSS are intended to represent the habitat conditions available to the organisms living in the streams and to report on the extent to which certain anthropogenic factors may be affecting Maryland's streams. MBSS Habitat assessment protocols are based on a combination of metrics modified and adapted from USEPA's Rapid Bioassessment Protocols (RBP) and Ohio EPA's Qualitative Habitat Evaluation Index (QHEI). Although EPA's RBP habitat assessment protocols differentiate between riffle-run and pool-glide stream types, all metrics selected for the MBSS are scored at all MBSS sample sites to allow direct comparisons across physiographic regions and summaries of conditions on a statewide basis.

Certain MBSS physical habitat variables are recorded based on counts, measurements, or estimates made in the field. These variables include distance from nearest road to site, width of riparian buffer, stream gradient, width, depth, velocity, culvert width and length, extent and height of eroded bank, numbers of woody debris and root wads, extent of channelization, percent embeddedness, and percent shading. The quality of five habitat assessment metric variables along with the severity of bank erosion, buffer breaks, and bar formation are rated using standardized MBSS rating methods. The collection of data on certain other habitat variables are based on the observation (or not) of certain conditions such as buffer breaks, land use types, and evidence of channelization. Based on observations at sites, the absence, presence or extensive presence of stream character and bar substrate is recorded. The type and relative size of riparian vegetation and the type of land cover adjacent to the buffer are reported using standard MBSS codes. The method used for collecting data in the field for each variable differs based on the expected use of each variable as well as optimizing the time required to collect useable information.

Data sheet entries for all physical habitat variables are based on observations within or from the 75 m site only, unless otherwise stated below.

In all cases where it is necessary to differentiate the left bank of the stream from the right bank, the left and right are determined while facing upstream.

Only persons who have attended MBSS training and have demonstrated proficiency with performing MBSS physical habitat assessments should conduct MBSS physical habitat assessments.

Most MBSS physical habitat assessment information is collected during the Summer Index Period.

3.5.9.2 Summer Index Period Physical Habitat Assessment

The physical habitat assessment variables recorded during the Summer Index Period can be found on the MBSS Summer Habitat Data Sheet and should be recorded on this sheet. The methods used to determine exactly what should be recorded for each variable are described, by variable, below. Data sheet entries for all Summer Index Period physical habitat variables are based on observations within or from the 75 m site only, unless otherwise specified.

In all cases where it is necessary to differentiate the left bank of the stream from the right bank, the left and right are determined while facing upstream.

Many of the summer physical habitat assessment measures require sufficiently clear water to observe the stream bottom throughout the majority of the 75 m site. If conditions do not allow sufficient visibility to see all of the features that must be observed, or if conditions are unsafe for wading, the site should be considered unsampleable for physical habitat. In many cases, the stream may be sampleable during a return visit when the water level is lower. However, if the stream cannot be sampled for summer physical habitat assessment, this should be noted on the Summer Index Period Data Sheet. Codes designating reasons that a stream could not be sampled are provided on page 43.

1. **Habitat Assessment Metrics.** Five metrics: instream habitat, epifaunal substrate, pool quality, riffle quality, and velocity depth diversity are rated on a scale of 0-20 using criteria provided on the Habitat Assessment Guidance Sheet (pages 44 and 45). The scores for each of these metrics are meant to characterize a distinct aspect of stream habitat. The instream habitat metric primarily addresses habitat for fishes and epifaunal substrate is meant to rate the suitability of habitat for benthic macroinvertebrates. The general quality of riffle and pool habitats are rated based primarily on the prevalence of sufficient depth and extent of these habitats. Velocity/depth/diversity provides a measure of the how well fast, slow, deep, and shallow areas are represented in the stream.

2. **Embeddedness.** The percent of riffle substrates surrounded by fine substrates, such as sand and silt, is recorded based on visual observation. Riffle substrates that are examined should include the area with the fastest flow within riffle or run habitats. If no riffle is present within the 75 m site, embeddedness can be rated based on the closest available riffle located in the same reach as the site (but should not be more than 75 m away from the upstream or downstream end of the site). Several substrates should be examined within the riffle to determine the approximate average condition within the fast part of the riffle. Substrates should be examined for embeddedness prior to disturbances (such as walking or netting) that are likely to dislodge fine materials from around larger substrate.

3. **Shading.** The percent of the wetted area of the 75 m site that is shaded by overhanging vegetation or other structures is approximated based on a visual assessment. If clearing of vegetation was conducted to facilitate electrofishing, or for any other reason, shading should be rated based on the condition prior to clearing.

4. **Woody Debris.** For the MBSS, large woody debris are defined as any natural woody structures (e.g. logs, snags, dead tree trunks), with the exception of live trees that are at least 10 cm in diameter and more than 1.5 m long. The number of large woody debris, located in the wetted portion of the 75 m stream site (instream woody debris), is counted. The number of large woody debris in the stream channel or immediate riparian area, but not in the wetted portion of the stream (dewatered woody debris) are counted separately from instream woody

debris. Only those dewatered woody debris from the immediate riparian area that (in the opinion of the evaluator) are likely to become wetted during high flows, or fall into the stream channel should be counted.

5. **Root Wads.** For the MBSS, root wads that are on live trees with a chest high trunk diameter (DBH) of at least 15 cm should be counted. These should be counted along both banks of the stream within the 75 m site. Those root wads that are in the water (instream) are counted separately from those not in the stream (dewatered). However, only those dewatered root wads that provide stability to the stream bank or that are likely to become wetted during high flows should be counted.

6. **Stream Character.** The Stream Character portion of the MBSS Summer Habitat Data Sheet lists 15 stream features. For each feature, an A, P, or E should be recorded in the box next to the feature indicating whether the feature is absent, present, or extensive respectively in the 75 m stream site.

7. **Maximum Depth.** The maximum depth of the MBSS site is considered the deepest area found anywhere within the 75 m. Maximum depth is recorded to the nearest cm.

8. **Wetted Width, Thalweg Depth, and Thalweg Velocity.** The wetted width, thalweg depth and thalweg velocity are measured at four transects within the 75 m MBSS site. The four transects are located at the 0 m, 25 m, 50 m, and 75 m portions of the MBSS site (beginning with 0m at the downstream-most end of the site). Wetted width is measured from bank to bank (perpendicular to the direction of the stream flow) to the nearest 0.1 m and includes only the wetted portion of the stream. Islands or other large features in the stream that would not be covered by water during higher base-flow should not be included in the measurement of wetted width. Features that would be covered by water (during higher base-flow should be included in the wetted width measurement. Thalweg depth is the depth (in cm) of the deepest part of the stream at each transect. Thalweg velocity is the stream current velocity (in m/sec) in the deepest part of the stream at each transect.

9. **Flow.** Measurements that can be used to calculate flow (often referred to as discharge) are recorded on the MBSS Summer Habitat Data Sheet. A transect that is suitable for taking these measurements should be located. A suitable transect approximates a "U" shaped channel to the extent possible. The most useful measurements are acquired by avoiding transects with boulders or other irregularities that create backflows and cross flows. The stream channel can be modified to more closely approximate a "U" shaped channel and provide laminar flow with adequate depth for taking velocity measurements. Unless the stream is very small (less than 0.5 m wide), a minimum of 10 measurements should be taken. As many as 25 measurements can be recorded on the MBSS Summer Habitat Data Sheet. In general, more measurements are required in larger streams. The measurements consist of depth (to the nearest 0.5 cm) and velocity (to the nearest 0.001 m/sec) and should be recorded at regular intervals. Velocity measurements should be taken at 0.6 of the distance from the water surface to the bottom (measured from the surface), making sure to orient the sensor to face upstream and taking care to stand well downstream to avoid deflection of flows. Depth and velocity measurements should be taken at the exact same locations. The Lat Loc on the MBSS Summer Habitat Data Sheet refers to the distance from one stream bank (either left or right) where each depth and velocity measurement is taken.

10. **Alternative Flow**. If flows are so low that they can not be measured with a flow meter,

the stream should be constricted as much as possible in a 1 meter section of uniform width and depth. The speed of a floated object should be recorded three times as a substitute for velocity measured with the flow meter. Record on the data sheet the depth, width, and time (3 trials) for the floated object.

11. **Bank Erosion.** The length and average height of erosion on both banks of the stream, within the 75 m site should be recorded along with the severity of erosion, on the MBSS Summer Habitat Data Sheet. In braided streams it is possible to have the total extent of eroded bank add up to more than 75 m. Since the objective of this measure is to determine the total area of erosion present at the site, this is acceptable.

12. **Bar Formation and Substrate**. Boxes in this portion of the MBSS Summer Habitat Data Sheet should be filled in completely to indicate if the bar formation is absent (fill in the box next to "None"), minor, moderate, or extensive; and the dominant substrate type(s) that make up the bars in the site. More than one substrate can be selected. However substrates comprising only a minor part of the substrate should not be selected.

Appendix D

A Physical Habitat Index For Freshwater Wadeable Streams in Maryland

Maryland Department of Natural Resources

May 2003

Selected Document Sections

A. **Methods: Sections 2.1 and 2.3**
B. **Results and Discussion: Sections 3.1, 3-1 to 3-20**
C. **Appendix B: 7-1 to 7-3**

2 METHODS

2.1 Physical Habitat Index Revision

Revising the PHI consisted of classifying streams in the state, developing a new set of reference criteria that did not include any biological variables, analyzing the physical habitat metrics statistically for normality and transforming as necessary, selecting discriminatory habitat metrics that were free of watershed area effects, assembling the metrics into a new multimetric physical habitat index, testing the new index for discrimination efficiency and association with biological indices, and comparing it to the provisional PHI. Physical habitat data were collected by the MBSS from 1994-2000 and methods for the collection of these data have been extensively described elsewhere (Roth et al. 1999). A list of the physical habitat data collected for each site by sampling periods is shown in Table 1. Habitat variables are shown along with the nature of the data (character or numeric) and what aspect of habitat is reflected by each variable.

We used general level III ecoregions as the main classification of streams, consistent with the MBSS program (Omernik 1987, Roth et al. 1999). We used the Piedmont and Coastal Plain regions and combined all other ecoregions in the state into a Highlands class.

After streams were classified, we developed new reference criteria for establishing reference habitat characteristics. We relied on land use/land cover values to develop reference and degraded stream criteria for selecting reference streams. Land use/land cover analysis and data are described in Roth et al. (1999).

Table 1 – Habitat variables collected during the three MBSS study periods. The types of data as well as the habitat feature represented by each measure are also indicated. (LCLU = land cover/land use, Data Types: Char = character, Num = numeric)

Variable	Feature	1994	1995-1997	2000	Data Type
1	Site Info	SITE	SITE	SITEYR	Char
2	Site Info	LAT	LAT	LAT_DD	Num
3	Site Info	LONG	LONG	LONG_DD	Num
4	Site Info	NORTHING	NORTHING	NORTHING	Num
5	Site Info	EASTING	EASTING	EASTING	Num
6	Catchment Size	ACREAGE	ACREAGE	ACRES	Num
7	LCLU-Catchment	URBAN	URBAN	URBAN	Num
8	LCLU-Catchment	AGRI	AGRI	AGRI	Num
9	LCLU-Catchment	FOREST	FOREST	FOREST	Num
10	LCLU-Catchment		WETLANDS	WETLANDS	Num
11	LCLU-Catchment		BARREN	BARREN	Num
12	LCLU-Catchment		WATER	WATER	Num
13	LCLU-Catchment		HIGHURB		Num
14	LCLU-Catchment		LOWURB	LOW_URB	Num
15	LCLU-Catchment		PASTUR	HAYPAST	Num
16	LCLU-Catchment		PROBCROP		Num
17	LCLU-Catchment		ROWCROP	ROWCROP	Num
18	LCLU-Catchment		CONIFER	CONIFOR	Num
19	LCLU-Catchment		DECIDFOR	DECIDFOR	Num
20	LCLU-Catchment		MIXEDFOR	MIXEDFOR	Num
21	LCLU-Catchment		EMERGWET	EMERWET	Num
22	LCLU-Catchment		WOODYWET	WOODWET	Num
23	LCLU-Catchment		COALMINE		Num
24	LCLU-Catchment		TRANS	TRANS	Num
25	LCLU-Catchment			OTHGRASS	Num
26	LCLU-Catchment			HIGH_RES	Num
27	LCLU-Catchment			HIGH_COM	Num
28	LCLU-Catchment			BAREROCK	Num
29	LCLU-Catchment			QUARRY	Num
30	LCLU-Reach	OLD_FLD	OLD_FLD	OLD_FLD	Char
31	LCLU-Reach	DEC_FOR	DEC_FOR	DEC_FOR	Char
32	LCLU-Reach	CONI_FOR	CONI_FOR	CONI_FOR	Char
33	LCLU-Reach	WETLAND	WETLAND	WETLAND	Char
34	LCLU-Reach	SURFMINE	SURFMINE	SURFMINE	Char
35	LCLU-Reach	LANDFILL	LANDFILL	LANDFILL	Char
36	LCLU-Reach	RESIDENT	RESIDENT	RESIDENT	Char
37	LCLU-Reach	COMM_IND	COMM_IND	COMM_IND	Char
38	LCLU-Reach	CROPLAND	CROPLAND	CROPLAND	Char
39	LCLU-Reach	PASTURE	PASTURE	PASTURE	Char
40	LCLU-Reach	ORCH_VIN	ORCH_VIN	ORCH_VIN	Char
41	LCLU-Reach			GOLF	Char
42	Hydrology		THAVEL0	THALVE0	Num

Table 1 (continued).

Variable	Feature	1994	1995-1997	2000	Data Type
43	Hydrology		THAVEL25	THALVE25	Num
44	Hydrology		THAVEL50	THALVE50	Num
45	Hydrology		THAVEL75	THALVE75	Num
46	Hydrology		DISCHARG	DISC_CFS	Num
47	Geomorphology			GRAD	Num
48	Geomorphology	SEG_LEN		SEG_LEN	Num
49	Geomorphology	MAXDEPTH	MAXDEPTH	MAXDEPTH	Num
50	Geomorphology			STWID_0	Num
51	Geomorphology			STWID_75	Num
52	Geomorphology	WETWID0	WETWID0	WETWID0	Num
53	Geomorphology	WETWID25	WETWID25	WETWID25	Num
54	Geomorphology	WETWID50	WETWID50	WETWID50	Num
55	Geomorphology	WETWID75	WETWID75	WETWID75	Num
56	Geomorphology	THADEP0	THADEP0	THALDE0	Num
57	Geomorphology	THADEP25	THADEP25	THALDE25	Num
58	Geomorphology	THADEP50	THADEP50	THALDE50	Num
59	Geomorphology	THADEP75	THADEP75	THALDE75	Num
60	Geomorphology	FLOODHT			Num
61	Geomorphology			TURB_FLD	Num
62	Geomorphology	VEL_DPTH	VEL_DPTH	VEL_DEPT	Num
63	Geomorphology	POOLQUAL	POOLQUAL		Num
64	Geomorphology			POOLGLID	Num
65	Geomorphology			EXPOOL	Num
66	Geomorphology	RIFFQUAL	RIFFQUAL		Num
67	Geomorphology			RIFFLRUN	Num
68	Geomorphology			EXRIFRUN	Num
69	Geomorphology	EMBEDDED	EMBEDDED	EMBED	Num
70	Geomorphology			CONCR_L	Num
71	Geomorphology			CONCR_B	Num
72	Geomorphology			CONCR_R	Num
73	Geomorphology			GABIO_L	Num
74	Geomorphology			GABIO_B	Num
75	Geomorphology			GABIO_R	Num
76	Geomorphology			RIPRP_L	Num
77	Geomorphology			RIPRP_B	Num
78	Geomorphology			RIPRP_R	Num
79	Geomorphology			BERM_L	Num
80	Geomorphology			BERM_B	Num
81	Geomorphology			BERM_R	Num
82	Geomorphology			DREG_L	Num
83	Geomorphology			DREG_B	Num
84	Geomorphology			DREG_R	Num
85	Geomorphology			PIPE_L	Num
86	Geomorphology			PIPE_B	Num

Table 1 (continued).

Variable	Feature	1994	1995-1997	2000	Data Type
87	Geomorphology			PIPE_R	Num
88	Geomorphology			CULVPRES	Num
89	Geomorphology			CULVSAMP	Num
90	Geomorphology			CULVWID	Num
91	Geomorphology	CHAN_ALT	CHAN_ALT		Num
92	Geomorphology	CH_FLOW	CH_FLOW		Num
93	Geomorphology	BANKSTAB	BANKSTAB		Num
94	Geomorphology		BANKHTFH		Num
95	Geomorphology		BANKANGL		Num
96	Geomorphology		BANKROOT		Num
97	Geomorphology		BANKSOIL		Num
98	Geomorphology		PARTSIZE		Num
99	Geomorphology		ERODIND5		Num
100	Geomorphology		ERODIND3		Num
101	Geomorphology			ERODEXLT	Num
102	Geomorphology			ERODEXRT	Num
103	Geomorphology			ERODSVLT	Num
104	Geomorphology			ERODSVRT	Num
105	Geomorphology			ERODARLT	Num
106	Geomorphology			ERODARRT	Num
107	Geomorphology			BAR_NONE	Num
108	Geomorphology			BAR_MIN	Num
109	Geomorphology			BAR_MOD	Num
110	Geomorphology			BAR_EXT	Num
111	Geomorphology			COB_BAR	Num
112	Geomorphology			GRAV_BAR	Num
113	Geomorphology			SAND_BAR	Num
114	Geomorphology			SC_BAR	Num
115	Wood	WOOD_DEB	WOOD_DEB	WOODINST	Num
116	Wood			WOODDEWA	Num
117	Wood		NUMROOT	ROOTINST	Num
118	Wood			ROOTDEWA	Num
119	Visual Habitat	INSTRHAB	INSTRHAB	INSTRHAB	Num
120	Visual Habitat	EPI_SUB	EPI_SUB	EPI_SUB	Num
121	Stream Character	MEANDER	MEANDER		Char
122	Stream Character	BRAIDED	BRAIDED	BRAIDED	Char
123	Stream Character	CHANNEL	CHANNEL	CHAN_YN	Char
124	Stream Character	STRAIGHT	STRAIGHT		Char
125	Stream Character	RIFFLE	RIFFLE	RIFFLE	Char
126	Stream Character	RUN_GLID	RUN_GLID	RUNGLIDE	Char
127	Stream Character	DEEPPOOL	DEEPPOOL	DEEPOOL	Char
128	Stream Character	SHALPOOL	SHALPOOL	SHALPOOL	Char
129	Stream Character	BOULDGT2	BOULDGT2	LRGBOULD	Char
130	Stream Character	BOULDLT2	BOULDLT2	SMLBOULD	Char

Table 1 (continued).

Variable	Feature	1994	1995-1997	2000	Data Type
131	Stream Character	COBBLE	COBBLE	COBBLE	Char
132	Stream Character	BEDROCK	BEDROCK	BEDROCK	Char
133	Stream Character	GRAVEL	GRAVEL	GRAVEL	Char
134	Stream Character	SAND	SAND	SAND	Char
135	Stream Character	SILTCLAY	SILTCLAY	SILTCLAY	Char
136	Stream Character	CONCRETE	CONCRETE		Char
137	Stream Character	ROOTWAD	ROOTWAD		Char
138	Stream Character	UNDCTBNK	UNDCTBNK	UNDERCUT	Char
139	Stream Character	OH_COVER	OH_COVER	OH_COVER	Char
140	Stream Character	H_REFUSE	H_REFUSE		Char
141	Stream Character	EMER_VEG	EMER_VEG	EMRPLANT	Char
142	Stream Character	SUBM_VEG	SUBM_VEG		Char
143	Stream Character	FLOATVEG	FLOATVEG	FLTPLANT	Char
144	Stream Character	STORMDRN	STORMDRN		Char
145	Stream Character	EFF_DIS	EFF_DIS		Char
146	Stream Character	BEAVPOND	BEAVPOND	BEAVPND	Char
147	Stream Blockage	ST_BLKHT	ST_BLKHT	ST_BLKHT	Num
148	Stream Blockage	ST_BLKTP	ST_BLKTP	ST_BLKTP	Char
149	Riparian Condition	SHADING	SHADING	SHADING	Num
150	Riparian Condition	RIP_WID	RIP_WID	RV_WID_L	Num
151	Riparian Condition			RV_WID_R	Num
152	Riparian Condition	BUFF_TYP	BUFF_TYP		Char
153	Riparian Condition	ADJ_COVR	ADJ_COVR	ADJ_CV_L	Char
154	Riparian Condition			ADJ_CV_R	Char
155	Riparian Condition			RV_BU_BL	Char
156	Riparian Condition			RV_BU_BR	Char
157	Riparian Condition			VEG_T_1L	Char
158	Riparian Condition			VEG_T_2L	Char
159	Riparian Condition			VEG_T_3L	Char
160	Riparian Condition			VEG_T_4L	Char
161	Riparian Condition			VEG_T_1R	Char
162	Riparian Condition			VEG_T_2R	Char
163	Riparian Condition			VEG_T_3R	Char
164	Riparian Condition			VEG_T_4R	Char
165	Riparian Condition			BRKTYPE	Char
166	Riparian Condition			BRK_SIDE	Char
167	Riparian Condition			BRK_SEV	Char
168	Riparian Condition			MULTFLOR	Char
169	Riparian Condition			MILEMIN	Char
170	Riparian Condition			JHONEY	Char
171	Riparian Condition			RCANGRAS	Char
172	Riparian Condition			THISTLE	Char
173	Riparian Condition			EXO_OTHE	Char
174	Remoteness	REMOTE	REMOTE		Num

Table 1 (continued).

Variable	Feature	1994	1995-1997	2000	Data Type
175	Remoteness			DIST_RD	Num
176	Aesthetics	AESTHET	AESTHET	AESTHET	Num

Once streams were classified and new reference criteria developed, we examined and transformed the physical habitat metrics for use in the multimetric habitat index. The databases from the three sampling periods (1994, 1995-1997, and 2000) were merged and numerically and visually examined for statistical distributions (central tendency and variance) and adherence to assumptions of normality and equal error variance. Several metrics required transformations to meet those assumptions (Table 2). In addition, there were some differences in the way habitat metrics were measured among the 3 collection periods. We calibrated two metrics (erosion index and remoteness) to make them comparable among sampling periods. Lastly, some riparian land use, habitat, and substrate data consisted of discrete presence/absence values. These were difficult to model using a parametric statistical approach and were combined into a percentage of the different land use, habitat, and substrate types present at a site to approximate more continuous variable behavior (Table 2).

We looked at the spatial dependence of metrics using standard pearson correlation analysis of each metric with watershed area. Watershed areas had been calculated by the MBSS (e.g. Roth et al. 1999) and areas were plotted against each metric for reference sites. For metrics exhibiting spatial dependence, a regression model was built to predict the metric value for each site based on watershed area. The residuals from this prediction were then used as the value for that metric. Conceptually, degraded sites would have larger or smaller residuals than reference sites, whose mean residuals should be equal to zero. Table 2 lists metrics requiring spatial modeling. Metrics not showing spatial dependence were not modeled this way.

Once reference sites for each stream class were identified, the data prepared, transformed, and corrected for spatial dependence, individual metrics were rescaled from 0 to 100 (Barbour et al. 1999). For metrics decreasing with degradation, we calculated the scaled metric value using the formula:

$$\text{Metric}_{\text{scale}} = \frac{(\text{value}) - (\text{min})}{(95^{\text{th}}\ \text{Percentile}) - (\text{min})} \times 100$$

where min = minimum value for that metric and the 95th percentile is the 95th percentile of the metric values. For metrics that increased in value with degradation, we used the formula:

$$\text{Metric}_{\text{scaled}} = \frac{(\text{max}) - (\text{value})}{(\text{max}) - (5^{\text{th}}\ \text{percentile})} \times 100$$

where max = maximum value for that metric and 5th percentile is the 5th percentile of metric values.

Once the metrics were properly scored, we evaluated their ability to discriminate between reference and degraded sites in each stream class. We used box and whisker plots to analyze the distributions of scores in reference and degraded streams and calculated discrimination efficiencies for each metric (discrimination efficiency = percent of degraded site scores below the 25th percentile of reference site scores)(Barbour et al. 1999).

Table 2 - Variables used for building metrics. The variables listed are the ones that could be normalized. Transformations used for transformed variables are shown, along with the formulae for calculating new variables and variables transformed for comparability among years.

Variable	Description (Transformation)
TACRE	Watershed area (common log)
FORLU	Adjacent forested land use
SINUOUS	Sinuosity
MAXDEPTH	Maximum depth
WETWID	Wetted width
THADEP	Thalweg depth
WIDDEP	Wetted width/Thalweg depth
VELDEP	Velocity/depth quality
POOLQUAL	Pool quality
RIFFQUAL	Riffle quality
EMBEDDED	Embeddedness
TBANKSTAB	Transformed bank stability (square root)
WOOD	Instream Wood
INSTRHAB	Instream Habitat
EPISUB	Epibenthic substrate
SUBSTR	Substrate
HAB	Habitat
TSHAD	Transformed percent shading (arc-sine square-root)
RIPWID	Riparian width
REMOTE	Remoteness
AESTHET	Aesthetics

FORLU = percent of adjacent forest types present (old field, deciduous forest, coniferous forest, wetland).
SINUOUS = Straight line distance of upstream to downstream ÷ 75m.
BANKSTAB = MBSS 2000 erosion extent was converted to 0-20 score bank stability using the formula:

$$= \left[\frac{(\text{Erosion Extent})}{-15} \times (\text{Severity}) \right]_{\text{left bank}} + \left[\frac{(\text{Erosion Extent})}{-15} \times (\text{Severity}) \right]_{\text{right bank}} + 20$$

SUBSTR = Percent of substrate types present in Coastal Plain (cobble, gravel, sand, and silt/clay), Piedmont (small boulder, cobble, gravel, sand, silt/clay), and Highland (bedrock, large boulders, small boulders, cobble, gravel, sand, and silt/clay) streams.
HAB = percent of habitat types present (riffle, run/glide, deep pools, shallow pools, undercut banks, overhanging cover).
REMOTE = MBSS 2000 distance to road was converted to a 0-20 remoteness score using the equation:

$$= 0.615 + 0.733\sqrt{\text{meters from road}}$$

Of the most discriminating metrics, we selected the set that was least redundant (avoiding an abundance of highly correlated metrics) and reflected the largest diversity of habitat characteristics. The scores for these metrics were averaged to calculate a final physical habitat index (PHI) score for each site within each stream class.

Once the final PHI was calculated for each site, we looked for watershed area effects in final scores among the reference sites by measuring correlation between watershed area and the final PHI scores. Variables exhibiting watershed area effects were corrected using regression analysis. After investigating for area effects, we looked at the discrimination efficiency of the overall PHI scores by looking at both box and whisker distribution plots of scores in reference and degraded sites and calculating the percent discrimination efficiency as the percentage of degraded sites scoring below the 25^{th} percentile of the reference scores.

We investigated the relationship between the new PHI developed here and the provisional PHI (Hall et al. 2000) using regression analysis. We developed and equation for converting between the different PHI values as well and we measured the root mean square error of the regression to estimate the error involved in predicting the provisional PHI value from the revised value. We also compared correlations between each of the habitat indices and the fish and benthic indices to compare the indices.

We looked at the relationship between the PHI and the fish index of biological integrity (FIBI, Roth et al. 1997, 1998, 2000) and the benthic index of biological integrity (BIBI, Stribling et al. 1998) using correlation analysis. We looked at these relationships statewide, within each stream class, and then by major river basin. Finally, we constructed multiple regression models to predict FIBI and BIBI scores using a variety of chemical measures (pH, acid neutralizing capacity, nitrate and sulfate concentration, conductivity, dissolved oxygen, and mean temperature) and the PHI. Chemistry data were collected by MBSS (Roth et al. 1999). We used the forward-stepwise selection method, and limited the models to 4 final variables.

2.3 Statistical Analysis

Statistical analyses were made using standard visual and numeric analysis techniques along with correlation analysis, simple linear regression, and multiple linear regression with Statistica 5.0 software (Statsoft 1995, Zar 1999).

3 RESULTS AND DISCUSSION

3.1 Physical Habitat Index Revision

We investigated a number of different stream classifications for the state. We originally split study sites into Coastal Plain and Non-Coastal Plain sites, consistent with the original PHI approach. Non-Coastal Plain sites consisted of the Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateau (Figure 1). Seeing as the Piedmont represents nearly a third of the state and has markedly different soils and land use history, we added the Piedmont region as a third class of streams and combined the remaining non-Coastal Plain sites into a Highlands class in our final classification. An additional reason for distinguishing the Piedmont class was that original reference criteria for the non-Coastal Plain sites led to a predominance of Highland streams serving as reference sites for the whole non-Coastal Plain class. Because Piedmont streams were so underrepresented, we were concerned that the two class approach would be biased against Piedmont streams.

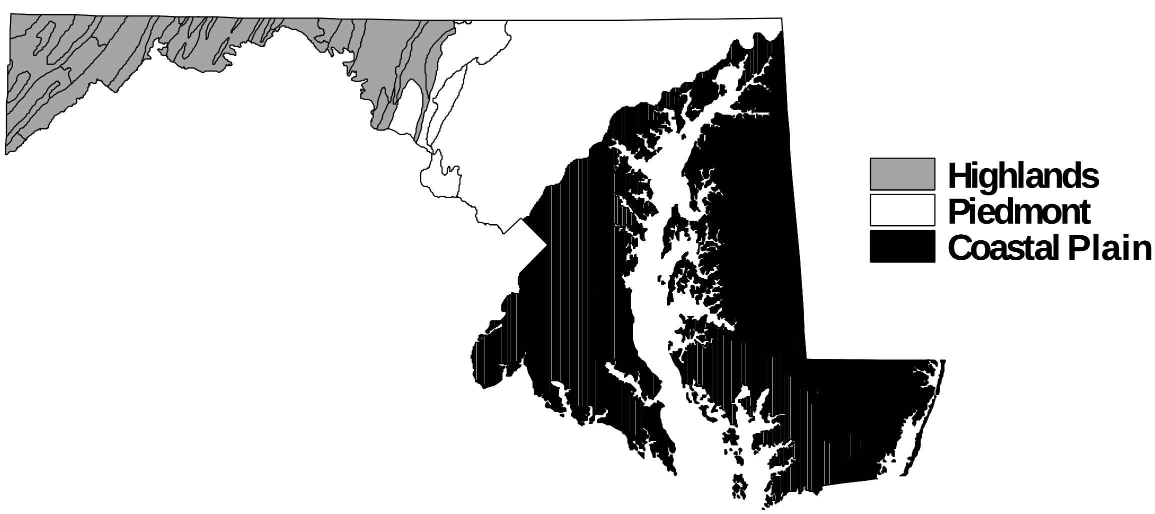

Figure 1 – Map of Maryland indicating ecoregions of the state. The Highland stream class was formed by joining the Blue Ridge, Valley and Ridge, and Appalachian Plateau ecoregions.

Once we had classified the streams of the state, we proceeded to define reference criteria. Our objective while selecting reference and degraded criteria was to refrain from using biological or chemical variables. We wanted to avoid the circularity affecting the original PHI reference criteria, which included FIBI scores. In addition, we wanted to avoid using chemical variables because one function of the PHI is to be used to diagnose biological stream degradation separately from chemical degradation. By keeping the criteria separate, we hoped to isolate their effects. For this reason, we selected land use/land cover values as our reference criteria, with the implicit assumption that greater landscape disturbance alters channel morphology, the template upon which physical habitat is based. Relationships between agricultural and urban transformations of the landscape and stream condition are well established (see Wiley et al. 1990, Roth et al. 1996, Wang et al. 1997, Paul and Meyer 2002). We excluded any channelized streams from consideration as reference sites.

We used different criteria for each of the three stream classes. We sought criteria that maximized the contrast in land cover between reference and degraded conditions (reflecting the least disturbed reference and most degraded land use conditions possible), while at the same time providing enough sites for statistical comparison (Table 3). For Coastal Plain areas, reference criteria were greater than 70% forest and less than 3% urban land cover, while degraded sites were less than 15% forest and/or greater than 85% agriculture and/or greater than 50% urban. This resulted in 40 reference sites and 49 degraded sites in the Coastal Plain class (7 and 9 % of the sites in the class respectively). For the Piedmont class, reference criteria were set lower to provide enough sites for adequate comparison. We set reference criteria at greater than 55% forest and less than

2% urban. Due to the amount of disturbed landscape, however, we were able to set stricter criteria for degraded sites: less than 10% forest, and/or greater than 85% agriculture and/or 70% urban. These criteria resulted in 30 reference sites and 66 degraded sites (5 and 12% of Piedmont sites respectively). The Highlands class contained the most forested watersheds. For this reason, criteria could be set much higher. Reference criteria were set at greater than 95% forest and less than 0.5% urban. Degraded criteria were set at less than 25% forest and/or greater than 75% agriculture and/or greater than 30% urban. This gave 36 reference sites and 28 degraded sites (11 and 8% of Highland sites respectively).

Table 3 – Reference and degraded stream criteria for each of the three stream classes used for constructing physical habitat indices for Maryland. Below this is shown the number of sites in each stream class and the distribution of those sites in reference, degraded, and non-categorized groups. (F=forest, A=agriculture, U=urban).

Stream Class	*Reference Criteria*	*Degraded Criteria*
Coastal Plain	F>70% and U<3%	F<15% and/or A>85% and/or U>50%
Piedmont	F>55% and U<2%	F<10% and/or A>85% and/or U>70%
Highlands	F>95% and U<0.5%	F<25% and/or A>75% and/or U>30%

	Reference	*Non-categorized*	*Degraded*
Coastal Plain (544)	40 (7%)	455 (84%)	49 (9%)
Piedmont (561)	30 (5%)	465 (83%)	66 (12%)
Highlands (343)	36 (10%)	279 (82%)	28 (8%)

There was equal representation of reference sites across the state and no east to west bias (Figure 2). This was a result, in part, of relaxing the reference criteria for Piedmont streams as compared to other areas so we could identify ample reference sites within the Piedmont. This needs to be considered when comparing results from

Piedmont sites with the two other regions as the Piedmont criteria set a lower reference standard, resulting in greater habitat degradation in reference sites. As a result, there are lower expectations for the reference condition within this class and the calculation of impairment thresholds for physical habitat in the Piedmont may have to be different from the other two stream classes. For example, the 25th percentile of reference PHI could be used for Coastal Plain and Highland streams, while the 75th percentile of reference PHI is used for Piedmont streams.

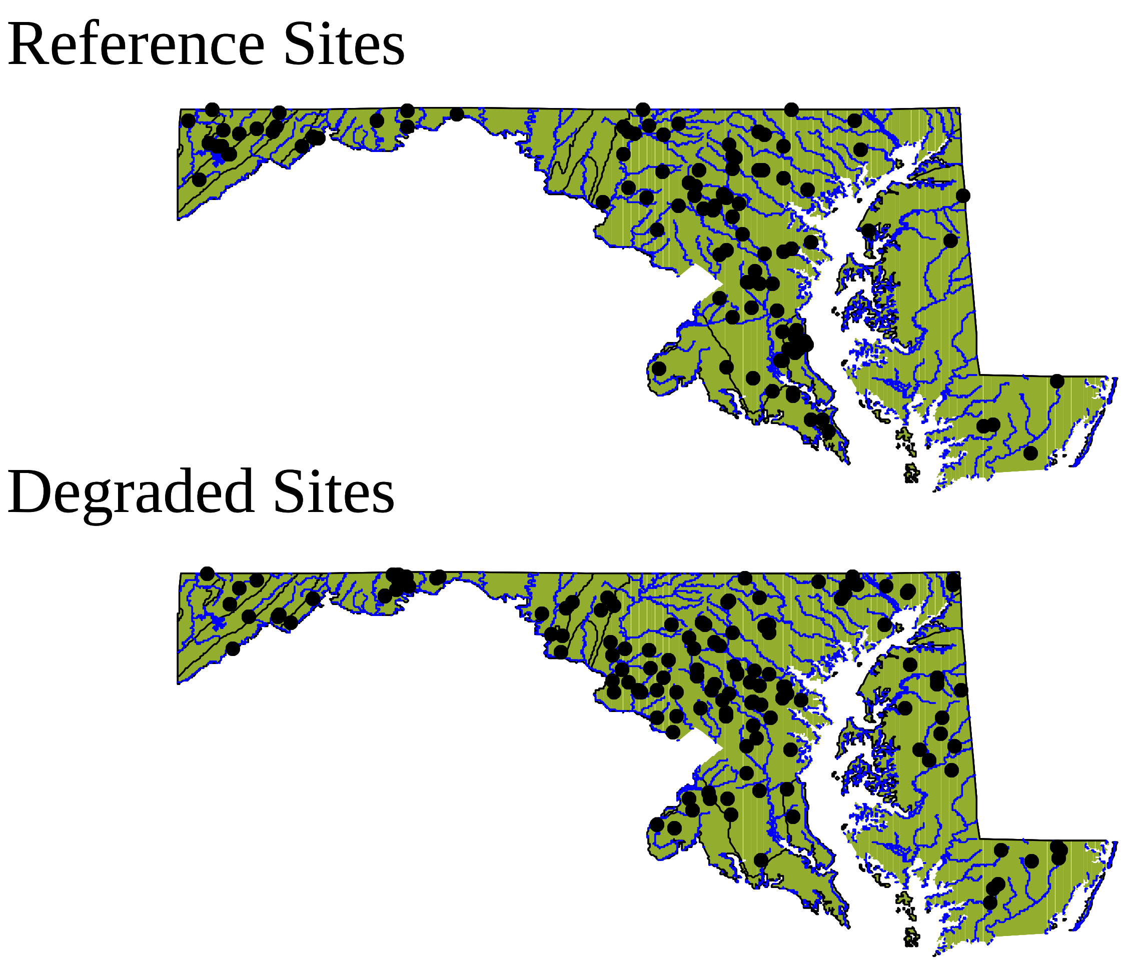

Figure 2 – Map of the location of physical habitat reference and degraded sites across the state.

Reference streams did tend to be smaller than degraded streams in the Coastal Plain and Highland stream classes, but were actually larger, on average, than degraded streams in the Piedmont region (Figure 3). It is generally difficult to find large sized reference streams, because the patchy nature of land use disturbance tends to disrupt large contiguous patches of forested land. While this situation may affect this analysis, the box-and-whisker plots clearly indicate overlap in stream sizes among the reference and degraded conditions in each stream class. In addition, we corrected for area effects to isolate the effects of area on several potential metrics (see below).

Once we established stream classes and reference and degraded criteria, we began to analyze potential metrics. Metrics were transformed as necessary (Table 2). We also had to modify a few variables. Adjacent forested land use was constructed from the percent of four land use types (old field, deciduous forest, coniferous forest, and wetland) observed adjacent to the study reach. The substrate variables were constructed from the percent of sediment types present at a site, with the assumption that a variety of sediment types is preferable to more homogeneous substrate conditions. We determined which sediment classes to consider by considering only those present in at least 50% of the reference sites (Table 4). For Coastal Plain streams, we calculated the percent in cobble, gravel, sand, and silt/clay; for Piedmont streams, the percent of small boulder, cobble, gravel, sand, and silt/clay; and, lastly, for Highland streams, the percent bedrock, large and small boulders, cobble, gravel, sand, and silt/clay.

We modified the habitat metric in a similar way. We calculated the percent of habitat types present at each site, again assuming that a variety of habitat types was preferable to only a few types. In this case, all three classes used the same set of habitat

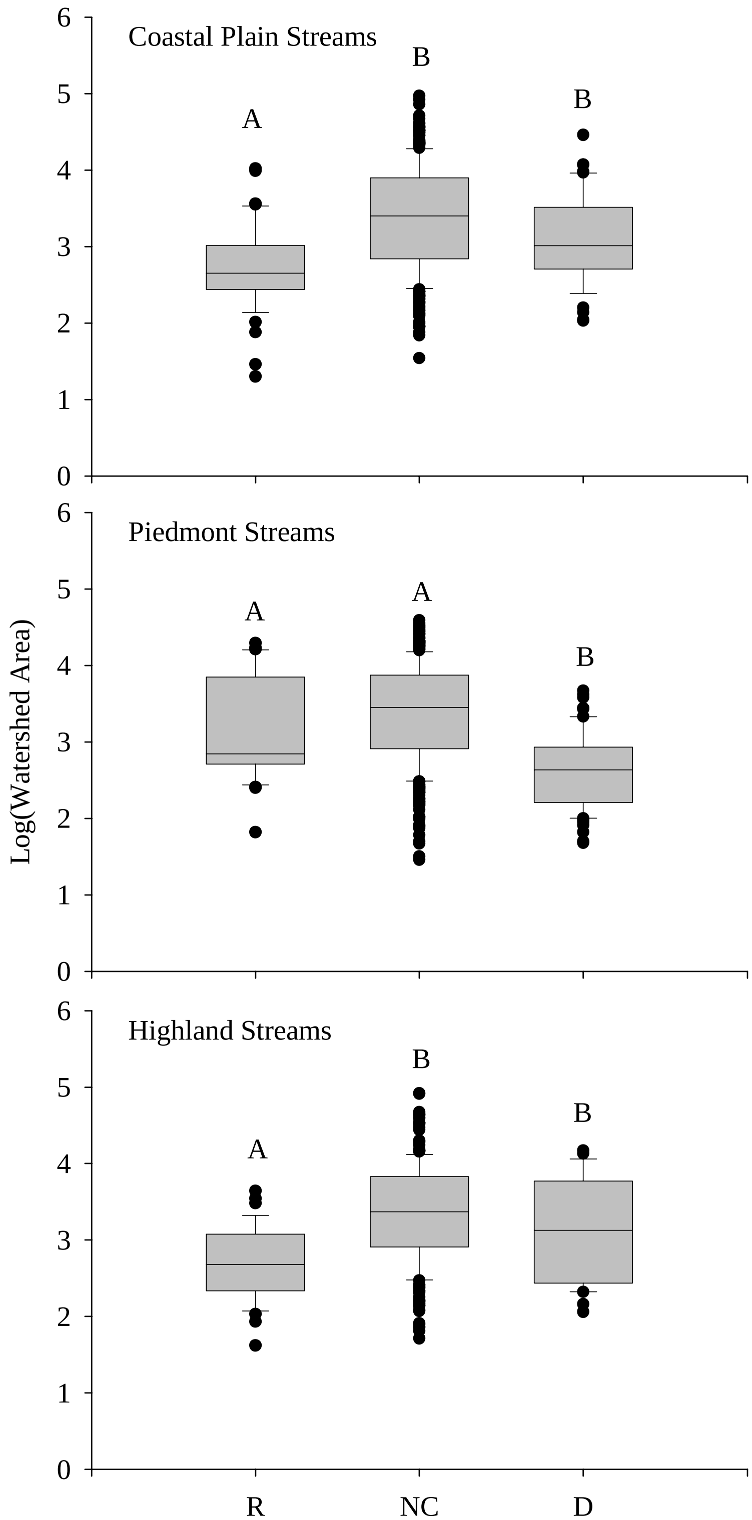

Figure 3 – Box and whisker plots of watershed area by reference category (R=reference, NC=non-categorized, D=degraded) and by stream class. Boxes indicate the median, 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles. Within a stream class, categories with different letters above the boxes are significantly different ($p<0.05$, one-way ANOVA, Tukey's HSD multiple comparisons test).

types, which were present in at least 50% of the reference sites in each class. These habitat types were riffle, run/glide, deep pools, shallow pools, undercut banks, and overhanging cover. Emergent and floating vegetation were excluded, as they were only present in, at most, 30% of the reference sites.

Table 4 – The percent of reference sites having each substrate types in each of the three stream classes. Substrate types in bold were used in calculating the SUBSTR metric for each stream class (>50% reference sites).

	Stream Class		
Substrate Type	*Coastal Plain*	*Piedmont*	*Highlands*
Large Boulder	7.1	40.0	**54.5**
Small Boulder	28.6	**93.1**	**93.9**
Cobble	**51.5**	**97.2**	**94.3**
Bedrock	3.6	28.6	**56.5**
Gravel	**78.9**	**97.3**	**97.1**
Sand	**91.5**	**100.0**	**100.0**
Silt/clay	**97.9**	**100.0**	**96.8**

Two other new variables were considered. The width:depth ratio was calculated as the ratio of wetted width to average stream thalweg depth calculated for each site. Bankfull or channel widths would have been more comparable than wetted widths, which are subject to flow conditions, but these data were not available for the MBSS sites. Sinuosity was also estimated as the ratio of the straight line distance between the upstream and downstream segment endpoints and 75 m, the stream reach length assessed and measured along the thalweg.

Two other variables were collected in each period, but using different approaches. For each, we derived equations to make the measurements comparable among years. Bank stability was measured on a 0-20 scale from 1994-1997. During the 2000 sampling, the MBSS estimated bank stability as the linear extent of erosion along both banks (maximum of 75 m each bank) and also noted the severity of the erosion (from 0=minimal to 3=severe). We converted the year 2000 data to a 0-20 scale using the following formula:

$$= \left[\frac{\text{(Erosion Extent)}}{-15} \times \text{(Severity)} \right]_{\text{left bank}} + \left[\frac{\text{(Erosion Extent)}}{-15} \times \text{(Severity)} \right]_{\text{right bank}} + 20$$

and we used severity values of 0,1,1.5, and 2. Thus, if all 75 m of stream were eroded severely on each bank, each bank would score –10, for a sum total of –20. Adding 20 to this score would result in a score of 0 for bank stability. Likewise, if there was no erosion, a site would get a score of 20.

The second variable we converted was remoteness, which had been scored on a scale of 0-20 from 1994-1997, wheras, during the 2000 sampling, instead of using this scale, the actual distance to a road was estimated. Because of this discrepancy, we converted the 1994-1997 values to make the measures comparable. The original method stated distance criteria for each scoring range: 0-5 scores had roads adjacent to the stream, 6-10 were where roads were within 0.25 miles of the stream but accessible by trail, scores of 11-15 for streams within 0.25 miles but not accessible by trail, and scores of 16-20 for sites more than 0.25 miles. We converted the miles to meters and created a gradient of distances corresponding to each metric score. We then regressed the 0-20 based scores for each site against the distance in meters to calculate new remoteness scores for the 2000 data. The formula for this conversion was

$$= 0.615 + 0.733\sqrt{\text{meters from road}}\ .$$

These values can be found in Appendix A where all the physical habitat data are shown for each site.

We found relationships between watershed area and several variables in reference sites in each of the three regions (Coastal Plain: pool quality, instream wood, instream habitat quality, and epibenthic substrate quality; Piedmont: velocity-depth quality, pool quality, riffle quality, instream habitat quality, and percent shading; Highlands: velocity-depth quality and percent of habitat present)(Table 5). The likely reason is the description of the different habitat metrics and their dependence on depth criteria for scoring. Since stream depth, like most channel dimensions, increases with stream size, it is not surprising that we found these relationships (e.g. Figure 4). We corrected these variables by regressing reference site values against the $\log_{10}$ of their watershed area. We used the regression formula, based on reference sites, to predict the metric value for any given site based on its watershed area. We took the residual of this value and used it as our metric score. We assumed increasing negative residuals were correlated with physical disturbance, which is demonstrated by the mean residual riffle quality in degraded Piedmont streams (Figure 5).

Once we finished the area corrections, we analyzed all the metrics for their ability to discriminate between reference and degraded sites. We calculated discrimination efficiencies for each metric and examined correlation coefficients among the metrics (Table 6). In general, we sought to combine metrics that exhibited some discrimination (>0.25) and we attempted to avoid having too many highly correlated variables together. Ultimately, it was the performance of the final multimetric that was our focus, rather than any one metric alone. Based on our analyses, we selected a set of discriminatory metrics for each of the three stream classes and these were combined into a final multimetric PHI (Table 7). In the Coastal Plain region, we found that bank stability, wood, instream

Table 5 – Regression equations used to correct spatial dependence for different variables in each of the three stream classes. The equations were derived from reference site catchment area versus metric value regressions. Watershed area values (acres) were then entered for each site and the residuals from the predicted values used as the response variable. (Abbreviations are explained in Table 2).

Stream Classes		
Coastal Plain	*Piedmont*	*Highlands*
POOLQUAL = -1.170+4.3125 (TACRE)	VELDEP = 1.2083+3.3096 (TACRE)	VELDEP = 1.4974+2.4473 (TACRE)
WOOD = -12.24+8.8120 (TACRE)	POOLQUAL = -1.751+4.4219 (TACRE)	HAB = -0.1591+0.28704 (TACRE)
INSTRHAB = 0.5505+4.2475 (TACRE)	RIFFQUAL = 5.8467+2.4075 (TACRE)	
EPISUB = 3.5233+2.5821 (TACRE)	INSTRHAB = 9.9876+1.5476 (TACRE)	
	TSHAD = 1.7528-0.1990 (TACRE)	

habitat, epibenthic substrate, shading, and remoteness were the best combination of metrics for discriminating degraded sites from reference. In Piedmont streams, riffle quality, bank stability, wood, instream habitat, epibenthic substrate, shading, remoteness, and embeddedness were the best metrics. Finally, in the Highlands streams, bank stability, epibenthic substrate, shading, riparian width, and remoteness were used. All the multimetrics originally had aesthetics included as a metric. This was a very discriminating metric but it was felt to reflect stressors that may be independent of instream habitat, so it was left out of the multimetric indicator. Detailed equations and procedures for calculating the final multimetric PHI in each region are given in Appendix B.

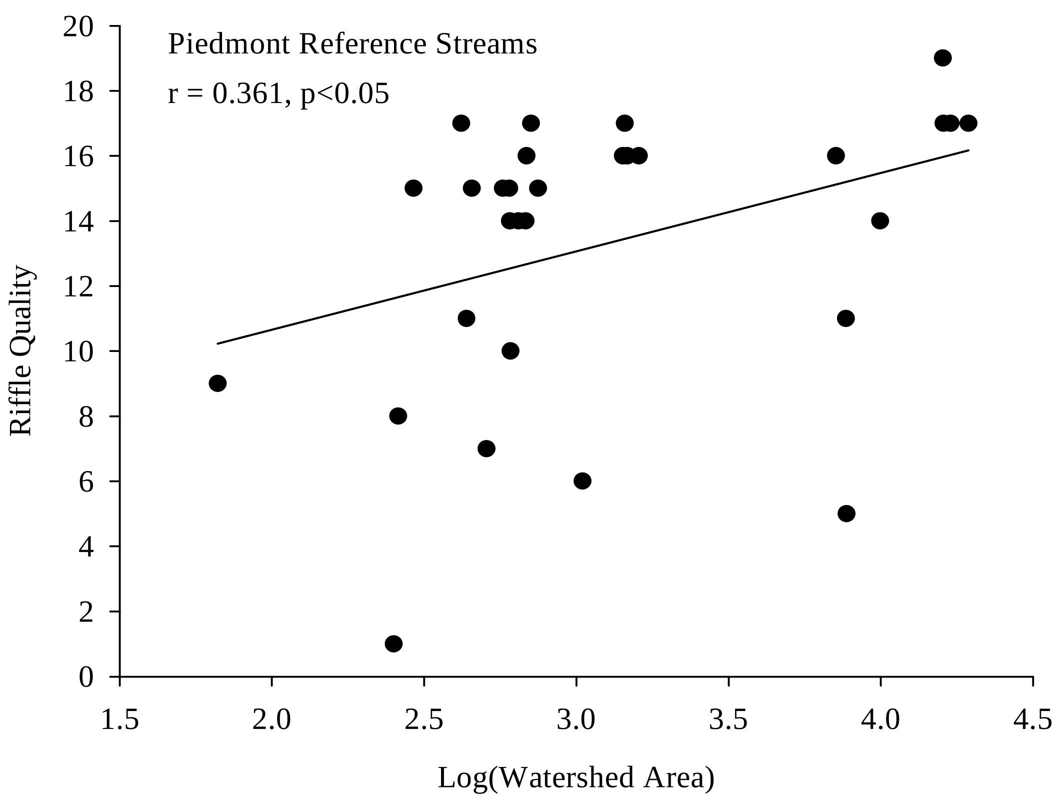

Figure 4 – Plot of watershed area against riffle quality scores in Piedmont reference streams. The pearson correlation coefficient is shown. Similar analyses were run for all metrics to check for watershed area effects.

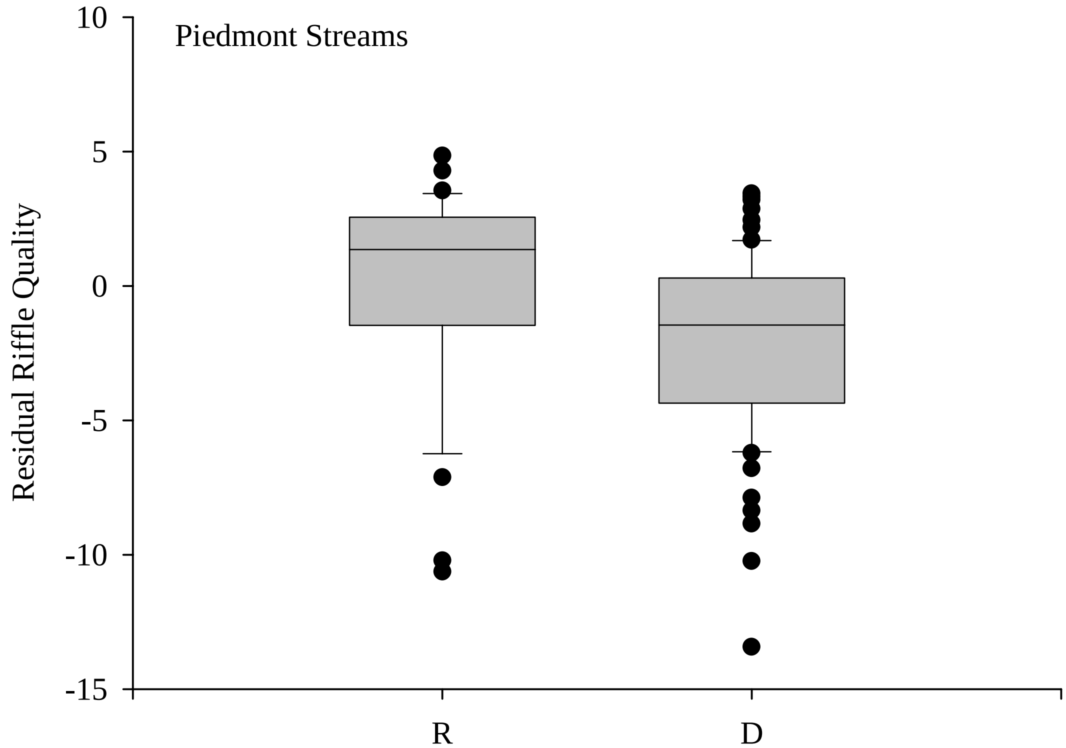

Figure 5 – Box and whisker plot of residual riffle quality in reference (R) and degraded (D) sites in Piedmont streams. Residual riffle quality was calculated by subtracting the riffle quality of a test site predicted based on the area of that watershed (estimated from the regression of area versus riffle quality in reference sites) from the observed riffle quality. Negative residuals indicate sites having worse riffle quality than that predicted for reference sites of similar watershed area. Boxes indicate the median, 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles.

The final metrics selected reflected a mix of different habitat characteristics (e.g. reach land cover, geomorphology, wood, visual habitat, riparian condition, etc.), but we do not consider these to be the only metrics of importance in stream habitat assessment. Land use changes will continue to affect stream habitat and it may be that other metrics currently collected will need to be used in the future to better assess and diagnose habitat problems. While the current PHI can be used to assess habitat and calculate the number of habitat impaired streams across the state, variables not used likely will be important in diagnosing specific habitat problems at sites indicated as generally degraded by the PHI. In addition, it may be that future insights and modifications to the habitat assessment will result in revisions to the PHI. The program will be most flexible in terms of meeting any future changes by keeping the full suite of variables.

Table 6 – Discrimination efficiencies of each metric in each of the three stream classes in Maryland. Values in bold represent metrics selected for the PHI of each class. (Abbreviations are explained in Table 2).

Variable	**Discrimination Efficiency**		
	Coastal Plain	*Piedmont*	*Highlands*
FORLU	0.27	0.23	0.18
SINUOUS	0.08	0.23	0.21
MAXDEPTH	0.16	0.30	0.07
WETWID	0.10	0.59	0.18
THADEP	0.16	0.36	0.04
WIDDEP	0.16	0.52	0.46
VEL_DPTH	0.10	0.26	0.29
POOLQUAL	0.37	0.29	0.07
RIFFQUAL	0.18	**0.50**	0.14
EMBEDDED	0.22	**0.29**	0.00
TBANKSTAB	**0.53**	**0.32**	**0.57**
WOOD	**0.82**	**0.36**	0.25
INSTRHAB	**0.45**	**0.64**	0.25
EPI_SUB	**0.53**	**0.35**	**0.43**
SUBSTR	0.12	0.14	0.32
HABITAT	0.16	0.20	0.29
TSHADING	**0.51**	**0.70**	**0.46**
RIPWID	0.86	0.41	**0.75**
REMOTE	**0.71**	**0.36**	**0.64**
AESTHET	0.80	0.36	0.89

After assembling the multimetrics, we checked to see if there were any watershed area effects in the final multimetric by plotting watershed area versus the PHI for each region. There was no significant relationship between area and PHI score (Figure 6). This means there was no apparent dependence on area. This is not surprising, given the careful attention to controlling for stream size in the construction of the individual metrics. The lack of bias against small streams also means that habitat quality can be equally compared in streams of any size.

Table 7 – Metrics used in the PHI for each stream class, the direction of change with degradation, and the habitat feature reflected by each metric. Metrics denoted with an asterisk were watershed area corrected. (Abbreviations are explained in Table 2)

Region	Direction of Change	Feature
Coastal Plain		
TBANKSTAB	Decreases	Geomorphology
WOOD*	Decreases	Wood
INSTRHAB*	Decreases	Visual Habitat
EPISUB*	Decreases	Visual Habitat
TSHAD	Decreases	Riparian Condition
REMOTE	Decreases	Remoteness
Piedmont		
RIFFQUAL *	Decreases	Geomorphology
TBANKSTAB	Decreases	Geomorphology
WOOD	Decreases	Wood
INSTRHAB*	Decreases	Visual Habitat
EPISUB	Decreases	Visual Habitat
TSHAD*	Decreases	Riparian Condition
REMOTE	Decreases	Remoteness
EMBEDDED	Increases	Geomorphology
Highlands		
TBANKSTAB	Decreases	Geomorphology
EPISUB	Decreases	Visual Habitat
TSHAD	Decreases	Riparian Condition
RIPWID	Decreases	Riparian Condition
REMOTE	Decreases	Remoteness

After checking for watershed size dependence, we examined the ability of the overall multimetric indices to discriminate between reference and degraded streams in each stream class. Discrimination efficiency for the final PHI was highest for Highland streams (89%) and this was similar to the discrimination efficiency observed in the Coastal Plain region (84%). The discrimination in the Piedmont region was much lower

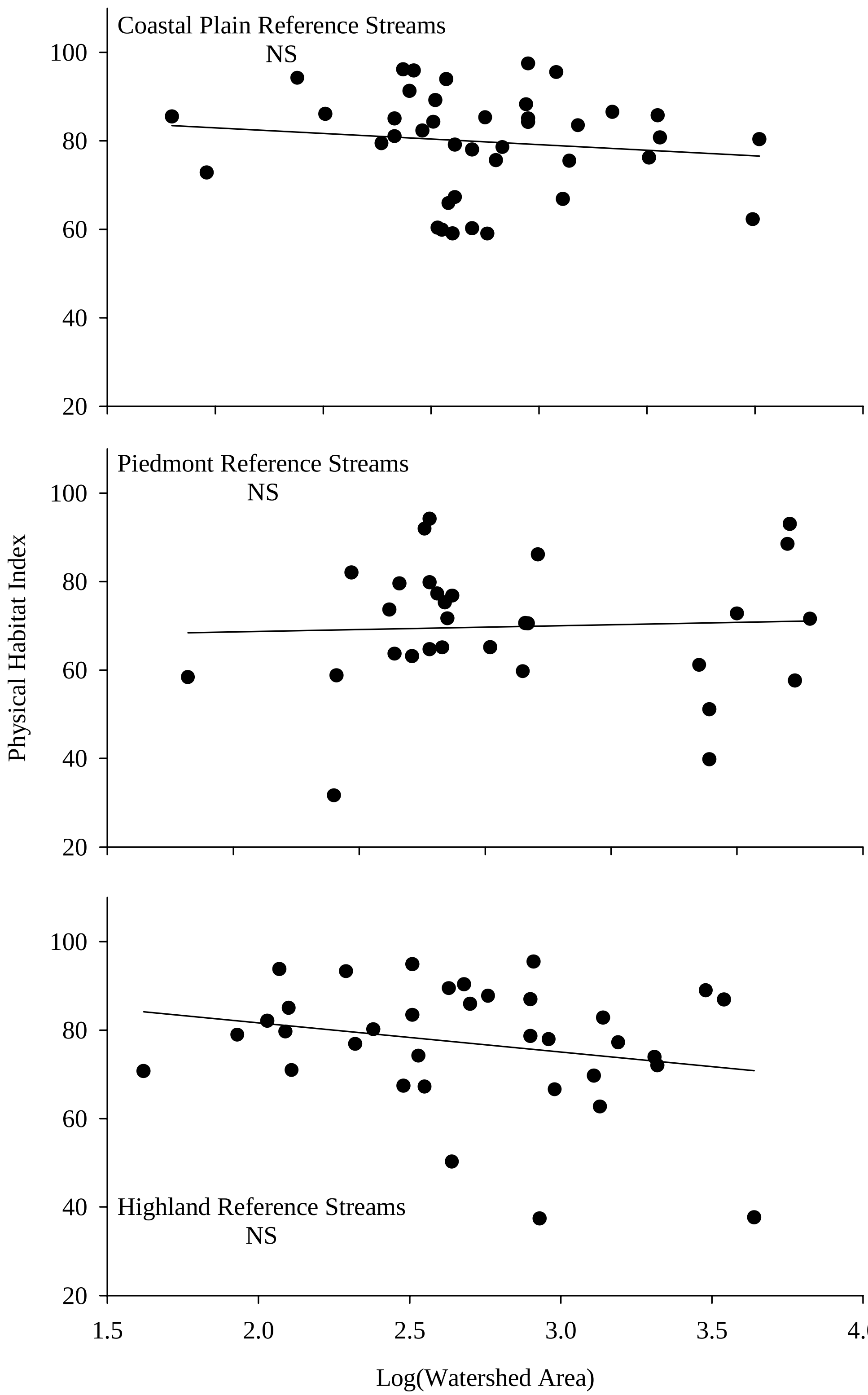

Figure 6 – Plots of watershed area versus the final PHI for reference streams in each stream class. None of the classes showed a significant correlation between area and PHI, indicating no watershed area effects. (NS = not significant).

(55%). This is likely a result of the lowered reference criteria used in the Piedmont region. We used streams with more land use disturbance in our reference set for this region to get a sufficient number of reference sites for identifying and scoring metrics. Scores are scaled to the reference distribution, which resulted in higher values for degraded sites in this region and the decreased observed discrimination efficiency. As mentioned above, any conclusions about the habitat quality in Piedmont streams must be tempered by these facts. Any threshold value should be based on the confidence with which the reference set reflects truly minimally disturbed conditions. For the Piedmont region, we are less confident reference sites reflect as minimally impacted a condition as in the other two regions and the impairment thresholds should reflect that uncertainty. In setting thresholds for establishing habitat impairment criteria, it may be necessary to use more conservative values (e.g., the 75th percentile of reference scores) for this region as opposed to others (which might use, for example, the 25th percentile of reference).

Having compiled new PHI scores, we related them to the FIBI and BIBI multimetric scores calculated for the same sites from the same study periods. We calculated correlation coefficients between the PHI and IBIs for each individual region (Table 8). We ran separate correlations between the PHI and IBIs for sites where the low pH (<5) and DO (<2 mg/L) sites had been removed in order to remove the potential interference of acid precipitation and low oxygen stressed sites (Table 8). These correlations are generally higher, largely because sites with these obvious chemical disturbances have been removed. Even without the low DO and low pH sites, the correlation coefficients are still quite low, but they are comparable to correlations observed with the provisional PHI (0.15 for the B-IBI and 0.46 with the FIBI)(Hall et al.

1999). The previous PHI was more strongly correlated with the FIBI, but FIBI scores were used for defining the reference condition, so that result is not surprising.

Table 8 – Results of correlation analyses among PHI and IBI values for each stream class. Values are Pearson product-moment correlation coefficients and significant coefficients ($p<0.05$) are indicated with an asterisk.

Stream Class	**All Sites**			**Low pH and DO Sites Removed**		
Coastal Plain	N	BIBI	FIBI	N	BIBI	FIBI
PHI versus	349	+0.300*	+0.070	331	+0.330*	+0.100
Piedmont						
PHI versus	415	+0.290*	+0.380*	414	+0.280*	+0.360*
Highlands						
PHI versus	263	+0.250*	+0.120*	254	+0.280*	+0.150*
Overall						
PHI versus	1027	+0.250*	+0.200*	999	+0.260*	+0.220*

Some studies have observed stronger relationships between physical habitat scores and multimetric biotic scores, while others show similar correlations to the ones we observed (Rankin 1995, Gerritsen et al. 1996, Dyer et al. 1998, Rankin et al. 1999, Rockdale County 2001). Habitat clearly constrains the biological integrity of streams. The degree to which it is statistically associated with biotic integrity will depend on the extent and nature of different stressors. Areas with numerous effluents would be expected to show stronger relationships between IBI scores and stream chemistry, those with extensive channelization and hydrologic modification may show stronger relationships with habitat, those with a mixture of stresses (e.g. urban land use) would likely show relationships with both chemistry and habitat.

Due to spatial differences in land use and therefore potential spatial differences in the types of habitat impacts, we expected to find various degrees of correlation between habitat and biological integrity in Maryland streams across the state. When we examined these relationships by river basin, we observed clear differences (Table 9). The BIBI was significantly correlated with the PHI in 12 of the 17 basins studied, most highly correlated with the habitat index in the North Branch Potomac, Chester, and Patapsco basins, but not correlated with the PHI in the Bush, Elk, Lower Potomac, Susquehanna, and Youghiogheny basins. The FIBI was significantly correlated with the PHI in fewer basins, 10 of 17, most highly correlated with the PHI in the Pocomoke, Nanticoke-Wicomico, and Middle Potomac basins, but not related to the PHI in the Choptank, Chester, Lower Potomac, Patuxent, Susquehanna, Upper Potomac, and West Chesapeake basins.

To examine the relative contribution of chemical and habitat variables in predicting biological integrity, we constructed very simple forward stepwise multiple linear regression models using a mixture of water chemistry variables (pH, acid neutralizing capacity, nitrate and sulfate concentration, conductivity, dissolved oxygen, and mean temperature) and the PHI. There were differences in the variables chosen in each region and between the BIBI and FIBI (Table 10). The PHI is a significant predictor in 5 of the 6 models, and is the first or second variable selected in 3 of those 5. The most common chemical predictors were conductivity and dissolved oxygen. These preliminary models predicted from 10 to 26 percent of the variance in IBI scores. The remaining variance may be due to other stressors, interactions among chemical and physical stressors, non-linear responses in biological responses to these stressors, and/or natural variability and sampling error. Because the PHI appears so frequently in the regression models, clearly the physical habitat index presents an important and significant predictor of biological integrity in Maryland streams.

Table 9 – Basin specific correlations between PHI and IBI values. For this analysis, all sites with pH<5 and dissolved oxygen < 2mg/L have been removed. Values are Pearson product-moment correlation coefficients and significant coefficients ($p<0.05$) are indicated with an asterisk.

	PHI versus		
Basin	**BIBI**	**FIBI**	**N**
Bush	-0.170	+0.380*	24
Choptank	+0.360*	-0.140	44
Chester	+0.510*	+0.150	41
Elk	+0.190	+0.440*	19
Gunpowder	+0.280*	+0.270*	48
Lower Potomac	-0.050	-0.010	65
Middle Potomac	+0.190*	+0.430*	125
North Branch Potomac	+0.500*	+0.310*	59
Nanticoke-Wicomico	+0.500*	+0.500*	22
Pocomoke	+0.400*	+0.590*	27
Patapsco	+0.420*	+0.330*	152
Potomac-Washington Metro	+0.230*	+0.250*	65
Patuxent	+0.230*	+0.060	92
Susquehanna	-0.150	+0.030	33
Upper Potomac	+0.260*	-0.140	74
West Chesapeake	+0.390*	-0.240	24
Youghiogheny	+0.130	+0.250*	85
Number Significant	**12 of 17**	**10 of 17**	

We compared our revised PHI to the provisional PHI (Hall et al. 1999)(Figure 7). The two were significantly correlated ($r^2=0.23$) and the regression equation between them is represented by the equation:

$$\text{Revised PHI} = 0.2368(\text{Provisional PHI}) + 53.331.$$

Using this score, previous values can be converted and compared with new PHI values, however, this will introduce error associated with the regression equation. The root mean square error of this regression was 12.9, which represents 20% of the mean revised PHI score, which is a fairly inaccurate estimate of the revised PHI. A much better approach is to calculate the revised PHI directly from the data. Appendix A contains revised PHI values calculated for each site using the habitat data directly, along with the provisional PHI values from the 1999 analysis.

Table 10 – Multiple linear regression model results. Models were built to predict BIBI and FIBI from a suite of chemical variables (pH, acid neutralizing capacity, nitrate and sulfate concentration, conductivity, dissolved oxygen, and mean temperature) and the PHI. Variables are shown in the order with which they entered the forward stepwise models. The signs in front of each variable represent the response of each IBI to that particular predictor. (DO=dissolved oxygen, Temp=temperature, NO_3=nitrate, ANC=acid neutralizing capacity).

	Response Variables			
Site Class	**BIBI**	**R^2**	**FIBI**	**R^2**
Coastal Plain	-Conductivity, +DO, +PHI, +Temp	0.20	+DO, -ANC, +Temp, +PHI	0.09
Piedmont	-Conductivity, +PHI, -NO_3, -Temp	0.19	+PHI, -Conductivity, +Temp, +DO	0.26
Highlands	+PHI, +pH, -Conductivity, -NO_3	0.16	+pH, -Conductivity, +DO, +PHI	0.12
Overall	-Conductivity, +DO, +PHI, +pH	0.15	+PHI, +DO, +Temp, -Conductivity	0.10

This revised PHI was not validated with an independent set of data. We recommend validation with data collected since 2000. The variables collected since 2000 can be entered into the models and PHI scores calculated. The reference and degraded criteria can be applied based on land use and the number of sites scoring in the correct category can be evaluated. Ideally, high percent classification rates are sought.

Appendix E

Physical Habitat Index

Maryland Biological Stream Survey

Data Sheets and Assessment Guidance

v. 2012

MBSS SUMMER HABITAT DATA SHEET

Page ___ Of ___

SITE — Watershed Code | Segment | Type | Year

Reviewer: First / Second

BANK EROSION

	Left Bank	Right Bank
Extent (m)		
Severity (0=none, 1=min, 2=mod, 3=severe)		
Average Height (m)		

BAR FORMATION & SUBSTRATE

Severity
0=none
1=min
2=mod
3=extensive

- Cobble
- Gravel
- Sand
- Silt/Clay

HABITAT ASSESSMENT

1. Instream Habitat (0-20)
2. Epifaunal Substrate (0-20)
3. Velocity/Depth Diversity (0-20)
4. Pool/Glide/Eddy Quality (0-20)
   Extent (m)
5. Riffle/Run Quality (0-20)
   Extent (m)
6. Embeddedness (%)
7. Shading (%)

FLOW

Lat Loc (m)	Depth (cm)	Velocity (m/s)
0 0 . 0 0	0 0 . 0	0 . 0 0

STREAM CHARACTER

Braided	Gravel	Boulder >2m
Riffle	Sand	Boulder <2m
Run/Glide	Silt/Clay	Beaver Pond
Deep Pool(>= .5m)	Cobble	Overhead Cover
Shallow Pool(< .5m)	Bedrock	Undercut Bank

A = Absent P = Present E = Extensive

- No. of Instream Woody Debris
- No. of Dewatered Woody Debris
- No. of Instream Rootwads
- No. of Dewatered Rootwads

Maximum Depth (cm)

	Wetted Width (m)	Thalweg Depth (cm)	Thalweg Velocity (m/s)
0 m			
25 m			
50 m			
75 m			

Alternative Flow Measurements

Distance (cm)

Depth (cm)

Width (cm)

Time (sec)
1.
2.
3.

COMMENTS

MBSS Stream Habitat Assessment Guidance Sheet

Habitat Parameter	Optimal 16-20	Sub-Optimal 11-15	Marginal 6-10	Poor 0-5
1. Instream Habitat[(a)]	Greater than 50% of a variety of cobble, boulder, submerged logs, undercut banks, snags, root wads, aquatic plants, or other stable habitat	30-50% of stable habitat. Adequate habitat	10-30% mix of stable habitat. Habitat availability less than desirable	Less than 10% stable habitat. Lack of habitat is obvious
2. Epifaunal Substrate[(b)]	Preferred substrate abundant, stable, and at full colonization potential (riffles well developed and dominated by cobble; and/or woody debris prevalent, not new, and not transient)	Abund. of cobble with gravel &/or boulders common; or woody debris, aquatic veg., undercut banks, or other productive surfaces common but not prevalent /suited for full colonization	Large boulders and/or bedrock prevalent; cobble, woody debris, or other preferred surfaces uncommon	Stable substrate lacking; or particles are over 75% surrounded by fine sediment or flocculent material
3. Velocity/Depth Diversity[(c)]	Slow (<0.3 m/s), deep (>0.5 m); slow, shallow (<0.5 m); fast (>0.3 m/s), deep; fast, shallow habitats all present	Only 3 of the 4 habitat categories present	Only 2 of the 4 habitat categories present	Dominated by 1 velocity/depth category (usually pools)
4. Pool/Glide/Eddy Quality[(d)]	Complex cover/&/or depth > 1.5 m; both deep (> .5 m)/shallows (< .2 m) present	Deep (>0.5 m) areas present; but only moderate cover	Shallows (<0.2 m) prevalent in pool/glide/eddy habitat; little cover	Max depth <0.2 m in pool/glide/eddy habitat; or absent completely
5. Riffle/Run Quality[(e)]	Riffle/run depth generally >10 cm, with maximum depth greater than 50 cm (maximum score); substrate stable (e.g. cobble, boulder) & variety of current velocities	Riffle/run depth generally 5-10 cm, variety of current velocities	Riffle/run depth generally 1-5 cm; primarily a single current velocity	Riffle/run depth < 1 cm; or riffle/run substrates concreted
6. Embeddedness[(f)]	Percentage that gravel, cobble, and boulder particles are surrounded by line sediment or flocculent material.			
7. Shading[(g)]	Percentage of segment that is shaded (duration is considered in scoring). 0% = fully exposed to sunlight all day in summer; 100% = fully and densely shaded all day in summer			
8. Trash Rating[(h)]	Little or no human refuse visible from stream channel or riparian zone	Refuse present in minor amounts	Refuse present in moderate amounts	Refuse abundant and unsightly

a) <u>Instream Habitat</u> Rated based on perceived value of habitat to the fish community. Within each category, higher scores should be assigned to sites with a variety of habitat types and particle sizes. In addition, higher scores should be assigned to sites with a high degree of hypsographic complexity (uneven bottom). In streams where ferric hydroxide is present, instream habitat scores are not lowered unless the precipitate has changed the gross physical nature of the substrate. In streams where substrate types are favorable but flows are so low that fish are essentially precluded from using the habitat, low scores are assigned. If none of the habitat within a segment is useable by fish, a score of zero is assigned.

b) <u>Epifaunal Substrate</u> Rated based on the amount and variety of hard, stable substrates usable by benthic macroinvertebrates. Because they inhibit colonization, floculent materials or fine sediments surrounding otherwise good substrates are assigned low scores. Scores are also reduced when substrates are less stable.

c) <u>Velocity/Depth Diversity</u> Rated based on the variety of velocity/depth regimes present at a site (slow-shallow, slow-deep, fast-shallow, and fast-deep). As with embeddedness, this metric may result in lower scores in low-gradient streams but will provide a statewide information on the physical habitat found in Maryland streams.

d) <u>Pool/Glide/Eddy Quality</u> Rated based on the variety and spatial complexity of slow- or still-water habitat within the sample segment. It should be noted that even in high-gradient segments, functionally important slow-water habitat may exist in the form of larger eddies. Within a category, higher scores are assigned to segments which have undercut banks, woody debris or other types of cover for fish.

e) <u>Riffle/Run Quality</u> Rated based on the depth, complexity, and functional importance of riffle/run habitat in the segment, with

highest scores assigned to segments dominated by deeper riffle/run areas, stable substrates, and a variety of current velocities.

f) Embeddedness Rated as a percentage based on the fraction of surface area of larger particles that is surrounded by fine sediments on the stream bottom. In low gradient streams with substantial natural deposition, the correlation between embeddedness and fishability or ecological health may be weak or non-existent, but this metric is rated in all streams to provide similar information from all sites statewide.

g) Shading Rated based on estimates of the degree and duration of shading at a site during summer, including any effects of shading caused by landforms.

h) Trash Rating The scoring of this metric is based on the amount of human refuse in the stream and along the banks of the sample segment.

ANACOSTIA WATERSHED RESTORATION
MONTGOMERY COUNTY, MARYLAND
CONTINUING AUTHORITIES PROGRAM SECTION 206
AQUATIC ECOSYSTEM RESTORATION FEASIBILITY STUDY

DRAFT INTEGRATED FEASIBILITY REPORT AND ENVIRONMENTAL ASSESSMENT

APPENDIX B3: COST-EFFECTIVENESS INCREMENTAL COST ANALYSIS OUTPUTS (2025)

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Montgomery County, MD CAP 206 Cost Effective Incremental Cost Analysis

Table of Contents

Metadata:

Basic Information

Software & Version: IWR Planning Suite, Version 2.0.9.36

Module: IWR-Plan CE/ICA Analyzer

Date: 3/28/2025

Planning Study Name: Montgomery County CAP 206

Planning Study Description: CAP 206

Planning Set Name: Montgomery County CAP 206 2025 CEICA

Planning Set Description: Planning set generated by Cost Effective/Incremental Cost Analysis

Parent Set Name: Montgomery County CAP 206 2025

Parent Set Type: Generated

CE/ICA Analysis Variables:

Output Variable = Output

Cost Variable = Cost

The following section presents a summary of benefit-cost analyses performed during development of the Montgomery County CAP 206. The Institute for Water Resources Planning Suite version 2.0.9.36 October 2024 was used to produce information summarized in the following pages. Likewise, the following are metadata for the file(s) from which the information presented in the following pages was produced:

File Name	File Date	Module	Module Version
MontgomeryCountyCAP206.sqlite	3/28/2025	Generated Planning Sets	2.0.9.36

Historical Information

Solutions

Solution	Code	# Scales
BelPre	BP	1
Lamberton	LB	1

Scales

Code	Scale	Name	Cost	Output
BP	0	No Action	0	0
BP	1	BelPre	14,684.00	1.13
LB	0	No Action	0	0
LB	1	Lamberton	4,214.00	0.26

Plan Generation Rules - Combinability, Dependence

No Relationships are defined.

Variable Relationships - Automated Edits

There were no automated edits defined between relationships.

Plan Generator

Planning Set Name: Montgomery County CAP 206 2025

Description: New Generated Set

Inefficient plans were NOT removed during generation.

No solutions were excluded.

References:

- Rogers, C., Robinson, M., Skaggs, L., & Heisey, S. (2006, November). IWR Planning Suite User's Guide. Alexandria, VA, United States of America: United States Army Corps of Engineers.

- Brandreth, B., & Skaggs, L. (2002, October). Lessons Learned from Cost Effectiveness and Incremental Cost Analyses. *IWR Report 02-R-5* .Alexandria, Virginia, United States of America: U.S. Army Corps of Engineers.

- Orth, K. (1994, October). Cost Effectiveness Analysis for Environmental Planning: Nine EASY Steps. *IWR Report 94-PS-2* . Alexandria, Virginia, United States of America: U.S. Army Corps of Engineers.

- Robinson, R., Hansen, W., Orth, K., & Franco, S. (1995, May). Evaluation of Environmental Investments Procedures Manual. *IWR Report 95-R-1* . Alexandria, Virginia, United States of America: U.S. Army Corps of Engineers.

Benefit-Cost Analysis Variable Definitions:

The following table provides a summary of the variables used during development of benefit-cost analyses performed during development of the Montgomery County CAP 206. The table provides a summary of variables, units, definitions, and any formulas/computations (where relevant) associated with individual variables that are dependent on values of multiple user-provided values costs or benefits.

Planning Study Variable Properties					
Name	**Units**	**Description**	**Type**	**Derived Function (if applicable)**	**Allowable Range**
Cost	$1000	Average Annual Cost in $1s	Currency		Any
Output	AAHUs	Output in Average Annual Habitat Units	Decimal		Any

Total and Average Cost

3/28/2025 1:43:46PM

All Plan Alternatives

Planning Set: Remove Sligo (Modified) CEICA 7-RevCost

Count	Name	Action Alternatives	Output (AAHUs)	Cost ($1000)	Average Cost
1	No Action Plan		0.00	0.00	0.00
2	BP0LB1	LB1	0.26	165.11	635.04
3	BP1LB0	BP1	1.13	579.28	512.64
4	BP1LB1	BP1LB1	1.39	759.46	546.37

Incremental Cost of Plan Combinations (Ordered By Output)

3/28/2025 1:44:30PM

Planning Set: Remove Sligo (Modified) CEICA 7-RevCost

Counter	Plan Alternative	Output (AAHUs)	Cost ($1000)	Average Cost ($1000/AAHUs)	Incremental Cost ($1000)	Inc. Output (AAHUs)	Inc. Cost Per Output
1	No Action Plan	0.000	0.000	0.000	0.000	0.000	0.000
2	BP0LB1	0.260	165.110	635.038	165.110	0.260	635.038
3	BP1LB0	1.130	579.280	512.637	414.170	0.870	476.057
4	BP1LB1	1.390	759.460	546.374	180.180	0.260	693.000

Chart of Alternatives:

This chart provides an illustration of costs and benefits associated with alternatives generated during development of the Montgomery County CAP 206. Alternatives are charted based on their benefit (x-axis) and cost (y-axis) coordinates.

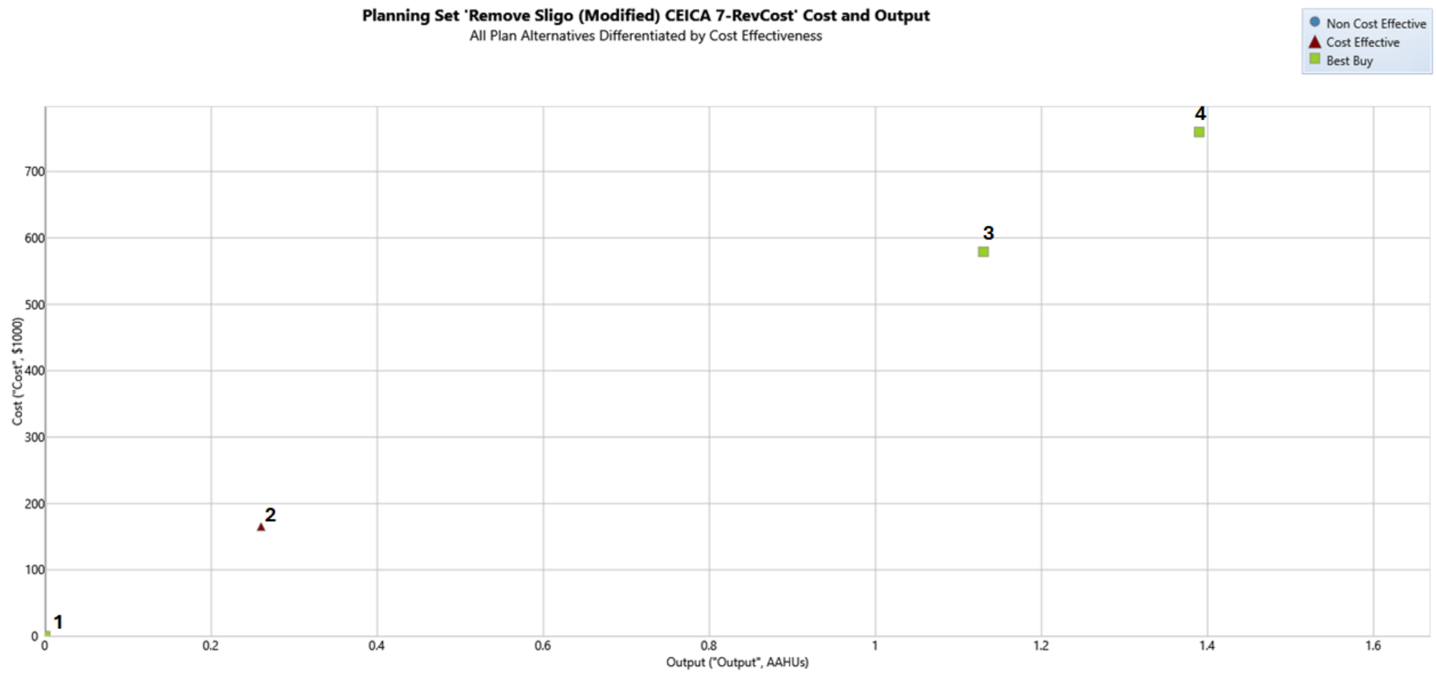

Chart of Cost-Effective Alternatives:

This chart provides an illustration of costs and benefits associated with cost-effective alternatives considered during development of the Montgomery County CAP 206. Alternatives are charted based on their benefit (x-axis) and cost (y-axis) coordinates. The depicted alternatives have been identified among the most cost-effective of the alternatives considered during development of the Montgomery County CAP 206.

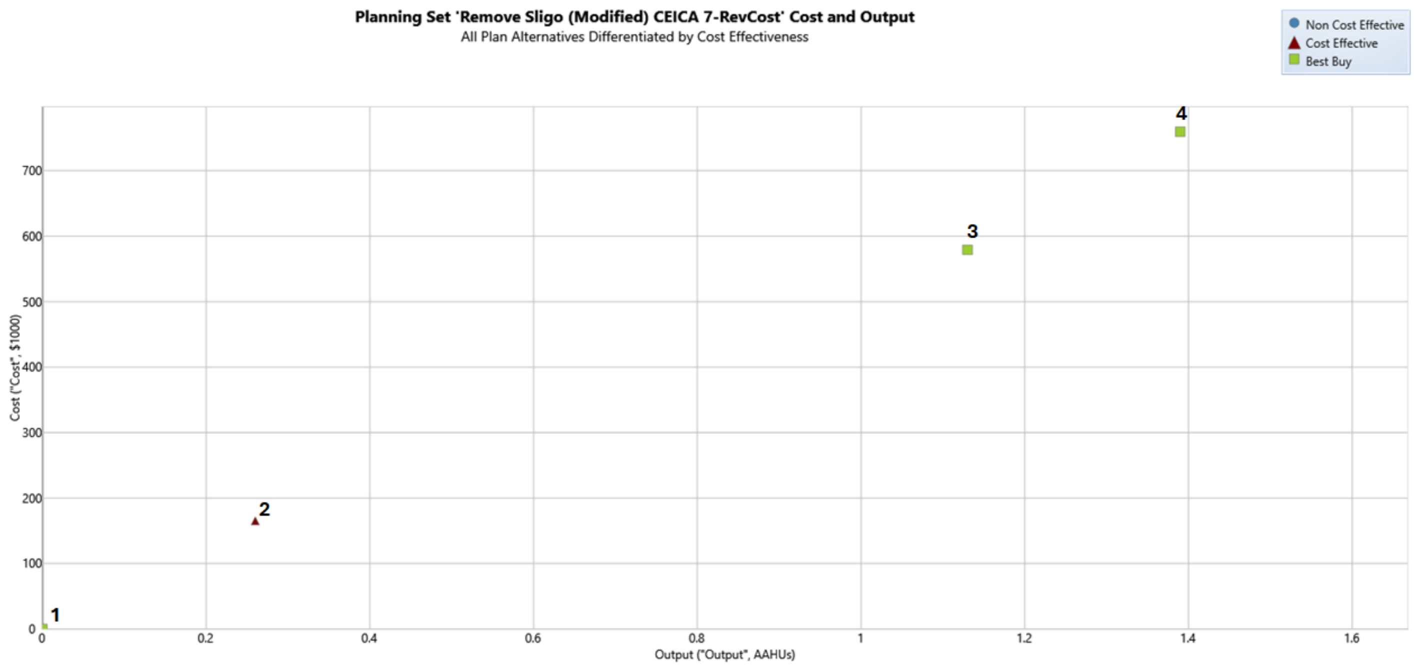

Chart of Incremental Costs and Benefits of Alternatives:

This chart provides an illustration of costs and benefits associated with alternatives considered during development of the Montgomery County CAP 206. The magnitudes of incremental benefits (width of rectangle) and incremental costs (height of rectangle) are represented to illustrate the relative magnitudes of each alternative's "added" costs associated with benefits exceeding the "next-best" cost-effective alternative.