Department of Public Works
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Watershed, Ecosystem, and Restoration Services

Assessment of the biological health of streams on the Patuxent Research Refuge within Anne Arundel County, Maryland

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Prepared by:
Anne Arundel County, Maryland
Department of Public Works
Bureau of Engineering
Watershed, Ecosystem, and Restoration Services Division
Annapolis, Maryland

Authors:
Christopher Victoria
Janis Markusic

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For more information about this report, please contact:

Christopher Victoria
Department of Public Works
Bureau of Engineering
Watershed, Ecosystem, and Restoration Services
Anne Arundel County
2662 Riva Road / MS 7301
Annapolis, Maryland 21401
410.222.4240
pwvict16@aacounty.org

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I. Introduction. Over the last 7 years, Anne Arundel County (County) has sought and received permission to perform biological sampling on the streams located within the North Track of the Patuxent Research Refuge (Refuge), located near Maryland City, Maryland. This permission was granted with a variety of conditions, including the need to share all data collected with Refuge personnel. The purpose of this brief report is to summarize our findings of the biological conditions within the Refuge.

In 2002, two targeted sites were sampled in the execution of a Watershed Restoration Action Strategy for the Upper Patuxent River done in conjunction with the Maryland Department of Natural Resources and Prince Georges County. In 2006, four targeted sites were sampled as part of the development of an ongoing Watershed Assessment of the Upper Patuxent River done in fulfillment of County obligations associated with compliance with our NPDES MS4 permit. Finally, in 2007, 10 randomly distributed sites were sampled as part of assessment work done through the Countywide Biological Monitoring and Assessment Program. More detailed information about biological, habitat, and geomorphologic conditions within the Anne Arundel County part of the Patuxent River watershed can be found in Anne Arundel County (2004), Stribling et al. (2008) and KCI (2006).

II. Methods. Field data collection was conducted in accordance with the methods described in the Sampling and Analysis Plan (SAP) for Anne Arundel County Biological Monitoring and Assessment Program (Tetra Tech 2005), which are summarized below. A combination of randomly chosen and targeted sites has been sampled within the Refuge. Figure 1 shows sample site locations.

A. Field and Laboratory Methods

1. <u>Site Identification</u>

Sites were located in the field using topographic maps and handheld GPS units for navigation to pre-selected coordinates, which mark the mid-point of each site. A 75-meter segment of stream was measured following the thalweg, and both upstream and downstream ends were flagged and labeled.

2. <u>Benthic Sampling and Processing</u>

At each site, benthic macroinvertebrates were collected from a 75-meter reach by sampling approximately 20 ft^2 of surface area with a D-frame net (595 µm mesh), with an emphasis on the most productive habitat types (e.g., riffles, snags, vegetated banks, sandy bottom) found within the reach. The most productive habitat types, in order of sampling preference include riffles, gravel/broken peat and/or clay lumps in a run area, snags/logs that create a partial dam or are in a run area, undercut banks and associated root mats in moving water, and detrital/sand areas in moving water. Kazyak (2001) also states that it is appropriate to move outside of the 75m reach if necessary to locate riffle habitat. Samples are primarily collected by jabbing the net into a habitat type (snags, root wads) to dislodge organisms or by disturbing the bottom substrate just upstream of the net allowing organisms to wash into the net. Larger surfaces such as logs or cobbles are often scrubbed by hand to further dislodge organisms. All sampled material (including leaf litter, small woody debris, and sediment) was composited in a 595 µm sieve bucket, placed in one or more one-liter sample containers and preserved in 70 - 80% ethanol.

Internal and external labels were completed for each container. Samples were tracked on chain-of-custody forms and transported to the laboratory for sorting.

All taxonomic identifications were completed by an outside expert laboratory. Prior to identification, the sample was subsampled down to the target number of bugs needed for a 100 insect assessment (80 to 120 insects, total). Subsamplng of the original sample involved spreading the entire sample on a Caton gridded tray (Caton 1991, Flotemersch et al. 2006) with 30 square grids (6-cm each), which allows isolation of physically defined amounts of sample material (leaf litter detritus, sticks, substrate particles) from the total sample and the separation/removal of the organisms from that material. A minimum of four grids were selected at random and sorted to completion until the target number of organisms (100 ± 20%) was reached. If more than 40 organisms are found in the first grid, the original four grids are re-spread on a separate Caton tray and another four grids are then randomly selected for sorting, and consecutive grids are selected until the target number is reached.

3. *Benthic Taxonomy*

Primary taxonomy on each sample (Boward and Friedman 2000) was performed by the contract laboratory and individual organisms were identified primarily to genus level. In some cases, (e.g., when individuals were early instars or had damaged or missing diagnostic morphological features), identification was left at genus-group, subfamily, or family level. Taxonomic data were received in Excel spreadsheets. Functional feeding group, habit, and tolerance value designations were assigned to each taxon according to Merritt and Cummins (1996), Barbour et al. (1999), and Stribling et al. (1998). The tolerance value assigned to each taxon is based on its ability to survive and reproduce in the presence of chemical pollution, hydrologic alteration, or habitat degradation (Stribling et al. 1998, Bressler et al. 2005, 2006, Flotemersch et al. 2006).

4. *Stream Physical Habitat Assessments Methods*

Physical habitat quality was visually assessed at each site using the USEPA Rapid Bioassessment Protocol (RBP; Barbour and Stribling 1994; Barbour et al. 1999) The RBP evaluates 10 parameters that describe instream physical characteristics, channel morphology, and riparian vegetation and stream bank structure. Each parameter was scored as either optimal, suboptimal, marginal, or poor and given a corresponding score based on a 20-point scale (20 = best, 0 = worst), or 10-point scale for individual bank parameters. The following 10 parameters were evaluated:

- pool substrate characterization
- epifaunal substrate/available cover
- pool variability
- sediment deposition
- channel flow status
- channel alteration
- channel sinuosity
- bank stability
- vegetative protection
- riparian vegetative zone width

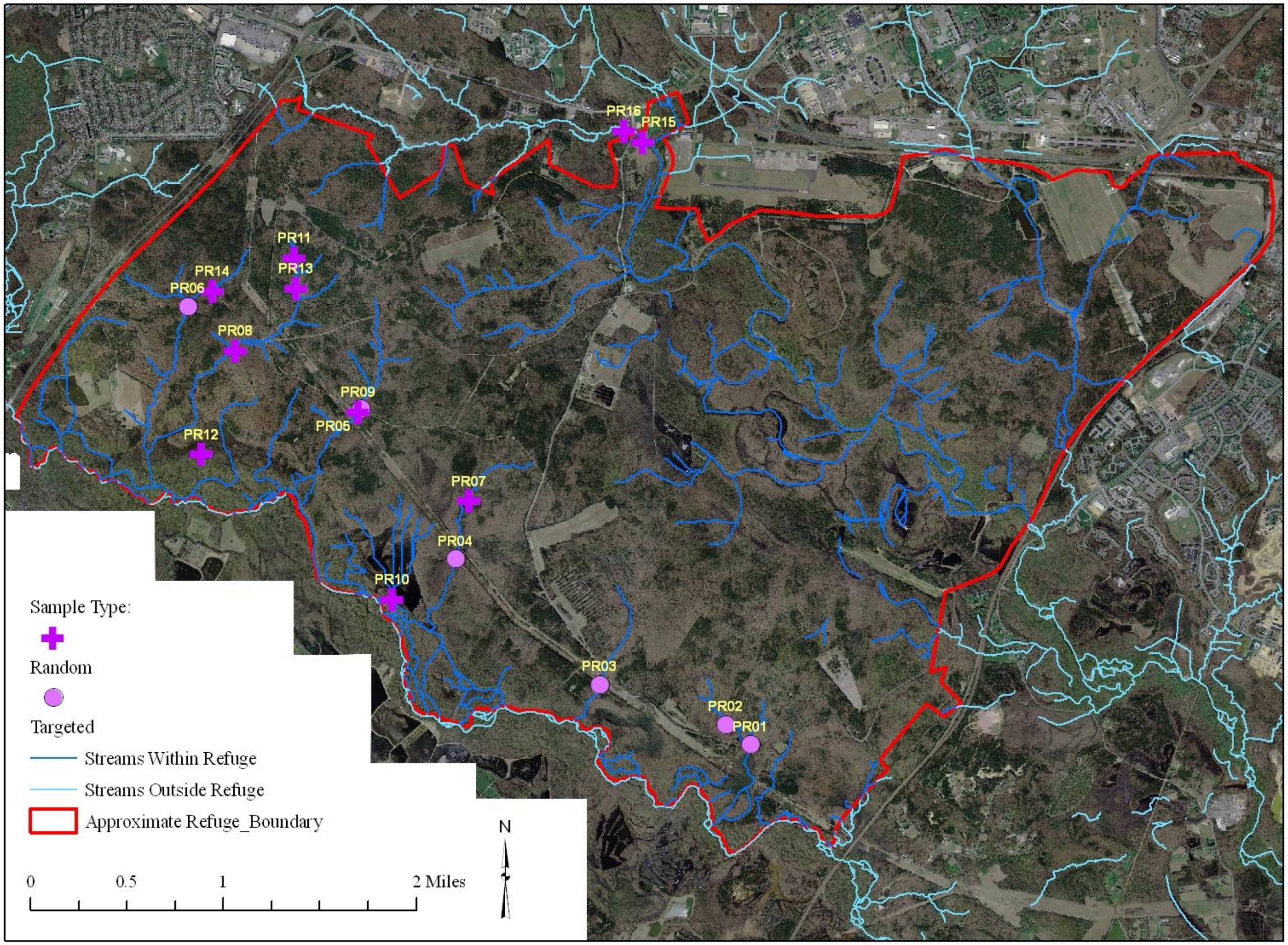

Figure 1. Location of County biological sample stations within the Patuxent Research Refuge.

5. *Water Quality*

Conductivity, dissolved oxygen, pH, and temperature were measured at each site using a multiple parameter water quality meter, which was calibrated according to the specifications provided by the manufacturer. All calibrations were recorded on a calibration log sheet.

6. *Geomorphic Assessment*

Geomorphic surveys were conducted within the 75-meter segments at targeted site in the Refuge. Geomorphic assessment measurements included a simplified longitudinal profile survey, a cross section survey, and pebble counts. Data from these measurements were recorded on field forms and used to determine the stream type of each reach as categorized by the Rosgen Stream Classification (Rosgen 1996). Using basic geomorphic parameters described in greater detail below, stream reaches were classified into one of 42 basic stream types. Details on each of the types can be found in Rosgen (1996) and are briefly described in the Data Analysis section of this report.

The simplified longitudinal profile was performed throughout the 75-meter reach length of each site. The purpose of the longitudinal profile was to identify indicators and elevations of the bankfull discharge (bankfull indicators) and to determine the bankfull water surface slope throughout the reach. Once the bankfull indicators were identified, elevation data on the channel thalweg, water surface, and bankfull indicator were collected, at a minimum, at the upstream and downstream ends of the representative reach on the same bed feature.

The cross section surveys were performed at channel transects that were installed in riffles as close to the midpoint of the 75-meter reach as possible. If no riffles existed within the reach, cross sections were installed in a nearby run or glide within a straight transitional reach (i.e., not in the pool of a meander). Typically, cross section monuments, consisting of iron reinforcement bars hammered to within six inches of the ground surface and topped with yellow caps, are installed at each location. However, due the potential dangers associated with unexploded ordinance that exist throughout this part of the PRR, no monuments were installed at any of the study sites. The photos at each cross section were located using the GPS.

Each cross section survey consisted of measuring the topographic variability of the associated stream bed, floodplains, and terraces, including:

- changes in topography,
- top of each channel bank,
- elevations of bankfull indicators,
- edge of water during time of survey,
- thalweg or deepest elevation along active channel, and
- depositional and erosional features within the channel.

During the cross section survey, the following measurements and calculations of the bankfull channel that are critical for determining the stream type of each reach also were collected:

- Bankfull Width (Wbkf): the width of the channel at the elevation of bankfull discharge or at the stage that defines the bankfull channel.
- Mean Depth (Dbkf): the mean depth of the bankfull channel.
- Bankfull Cross Sectional Area (Abkf): the area of the bankfull channel, estimated as the product of bankfull width and mean depth.
- Width Depth Ratio (Wbkf/Dbkf): the ratio of the bankfull width divided by the mean depth.
- Maximum Depth (Dmbkf): the maximum depth of the bankfull channel, or the difference between the thalweg elevation and the bankfull discharge elevation.
- Width of Floodprone Area (Wfpa): the width of the channel at a stage of twice the maximum depth. If the width of the floodprone area was far outside of the channel, its value was visually estimated or paced off.
- Entrenchment Ratio (ER): the ratio of the width of the floodprone area divided by bankfull width.
- Sinuosity (K): ratio of the stream length divided by the valley length or the valley slope divided by the channel slope. Sinuosity was visually estimated or the valley length was paced off so that an estimate could be calculated. In some cases, this parameter was estimated using GIS digital maps.

To determine the size of channel substrate within the 75-meter reach segments, a Wolman Pebble Count (Wolman 1954) was performed, which consists of stratifying the reach based on its frequency of pools, riffles, runs, and glides. The goal of the pebble count is to measure the intermediate axis of 100 particles across ten transects, or ten particles in each of ten transects across the bankfull width and calculate the median particle size, the D50, of the reach. This value was then used for categorizing the sites into the Rosgen Stream Classification (Rosgen 1996). The number of transects performed in each bed feature was determined by measuring or visually estimating the percentage of reach length for each type of bed feature. For example, if riffles covered 20 percent of the reach length, then 20 percent of the pebble count, or two transects, were performed in riffles. If a channel was clearly a sand or silt bed channel with no distinct variation in material size, the pebble count was not performed, and the D50 was visually estimated. However, if the channel did have changes in bed material size from feature to feature, a full pebble count was performed.

B. Data Analysis

1. <u>Data Structure</u>

Benthic macroinvertebrate, physical habitat, and water quality data were entered into EDAS, Version 3.2 (Tetra Tech 1999). This relational database allows for the management of location and other metadata, taxonomic and count data, raw physical habitat scores, the calculation of metric values, physical habitat and water quality rankings, and B-IBI values.

2. <u>Physical Habitat</u>

The 10 RBP metric scores are summed to obtain a final habitat score, which is then compared to a reference condition score. However, since there was no RBP data for reference sites within Anne Arundel, a reference condition based on similar studies from Prince George’s County, Maryland (Stribling et al. 1999) was used. The values were compared to the maximum possible score (168) for overall percent comparability for each site.

Table 1 provides narrative ratings that correspond to physical habitat quality scores. These scores express the potential of a stream or watershed to support a healthy biological community. Percentages and their narrative ratings were adapted from Plafkin et al. (1989).

Table 1. EPA RBP Scoring

Score	**Narrative**
151 +	Comparable
126 – 150	Supporting
97 – 125	Partially Supporting
0 – 96	Non-supporting

Source: Stribling et al. 1999

3. *Benthic Index of Biotic Integrity (BIBI)*

The biological indicator is based on the Index of Biological Integrity (IBI; Karr et al. 1986), which uses characteristics of the benthic macroinvertebrate assemblage structure and function to assess the overall water resource condition. Benthic IBI (B-IBI) were developed by the MBSS and calibrated for different geographic areas of Maryland (Stribling et al. 1998). In 2005, MBSS revised the B-IBI (Southerland et al. 2005). The revised benthic metrics calculated in this report were those selected and calibrated specifically for Maryland Coastal Plain streams. The seven metrics calculated for each of the benthic macroinvertebrate samples were:

- **Total number of taxa.** The taxa richness of a community is commonly used as a qualitative measure of stream water and habitat quality. Stream degradation generally causes a decrease in the total number of taxa.
- **Number of EPT taxa.** Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) are generally sensitive to degraded stream conditions. A low number of taxa representing these orders is indicative of stream degradation.
- **Number of Ephemeroptera.** Mayflies are generally sensitive to pollution and the number of mayfly genera represented by individuals in a sample can be an indicator of stream conditions, generally decreasing with increasing stress.
- **Percent Intolerant to Urban.** This is the percentage of the benthic sample that is intolerant to urban stressors. This metric decreases with increased stream degradation.
- **Percent Ephemeroptera**. The degree to which mayflies dominate the community can indicate the relative success of these generally pollution intolerant individuals in sustaining reproduction. The presence of stresses will reduce the abundance of mayflies relative to other, more tolerant individuals; although, some mayfly groups, such as several genera of the family Baetidae, are known to increase in numbers in cases of nutrient enrichment.
- **Number of Scrapers.** Specialized feeders such as scrapers tend to be more sensitive species and are thought to be well represented in healthy streams, and tend to decrease with increasing stressors.

- **Percent Climbers.** This is the percentage of the benthic sample living primarily on stem type surfaces. Climbers tend to decrease with increasing stressors.

Table 2. MBSS BIBI Metrics

Metric	Threshold		
	1	3	5
Number of Taxa	< 14	14-21	>= 22
Number of EPT Taxa	< 2	2-4	>= 5
Number of Ephemeroptera Taxa	< 1	1	>= 2
Percent Intolerant to Urban	<10	10-27	>= 28
Percent Ephemeroptera	< 0.8	0.8-10.9	>= 11
Number of Scraper Taxa	< 1	1	>= 2
Percent Climbers	< 0.9	0.9-7.9	>= 8

Source: Southerland et al. (2005)

Each metric was scored on a 5, 3, 1 basis (5 being the best, 1 being the worst) according to stream health. Metric scoring criteria are listed in Table 2. Overall biological index scores are obtained by summing of the seven metric scores for each site, and dividing by the number of metrics (7). For sites PR01 and PR02, the original BIBIs were calculated using older metrics replaced by Southerland et al. (2005). To be directly comparable to the other samples, these scores were recalculated using the current metrics. Using the format established by MBSS, the resulting value is then compared to the index scoring criteria for translation into narrative categories (Table 3). An average score for all data collected on the Refuge is presented in the next section.

Table 3. MBSS BIBI Scoring

BIBI Score	Narrative Ranking	Characteristics
4.0 – 5.0	Good	Comparable to reference streams considered to be minimally impacted, biological metrics fall within the upper 50 % of reference site conditions.
3.0 – 3.9	Fair	Comparable to reference conditions, but some aspects of biological integrity may not resemble the qualities of minimally impacted streams.
2.0 – 2.9	Poor	Significant deviation from reference conditions, indicating some degradation. On average, biological metrics fall below the 10th percentile of reference site values.
1.0 - 1.9	Very Poor	Strong deviation from reference conditions, with most aspects of biological integrity not resembling the qualities of minimally impacted streams, indicating severe degradation. On average, most or all metrics fall below the 10th percentile of reference site values.

4. *Water Quality*

Water quality data were compared to Maryland water quality standards for Use I streams. Use I streams have designated uses for water contact recreation and protection of nontidal warm water aquatic life. Table 4 lists the water quality standards for these streams.

5. *Geomorphic Assessment*

Geomorphic field data were compared to regional relationships of bankfull channel geometry developed by the USFWS for streams in the Maryland Coastal Plain (McCandless 2003). This comparison is a crucial step in verifying whether field determined bankfull estimates are appropriate or within a range of known values for drainage basins of similar size. Determination of bankfull indicators can be difficult in potentially impacted streams like those assessed for this report. To be cautious, field staff would typically identify two or more possible topographic features within the cross section as possible bankfull indicators. Occasionally, changes to the field-called bankfull indicator were made in the office if, based upon an inspection of the plotted cross section and photographs, another identified indicator or obvious slope break or other observable feature gave better agreement with the regional relationships that have been well established in this physiographic region. However, no changes to the field-derived call were made if there was no obvious other potential indicator observable in the cross section and only one bankfull indicator was called in the field or if there was reasonable (±15% of the expected value for the drainage area upstream of the sample point) agreement between the original call and the Coastal Plain regional relationships.

Table 4. Maryland COMAR Standards

Parameter	Standard
pH	6.5 to 8.5
Dissolved Oxygen (mg/L)	Minimum of 5 mg/L
Conductivity (mS/cm)	No state standard
Turbidity (NTU)	Maximum of 150 NTU and maximum monthly average of 50 NTU
Temperature (°C)	Maximum of 32°C (90°F) or ambient temperature, whichever is greater

Source: COMAR 26.08.02.03-3

After field data were compared to the regional relationships and determined to be accurate estimates of the bankfull channel parameters, the longitudinal profile survey, the cross section survey, and the pebble count data were analyzed for each assessment site. These data were then used to identify each stream reach as one of the stream types categorized by the Rosgen Stream Classification (Rosgen 1996). In this classification methodology, streams are categorized based on their measured field values of entrenchment ratio, width/depth ratio, sinuosity, water surface slope, and channel materials according to the table in Appendix B: Rosgen Stream Classification. As described in Rosgen (1996), the classification system categorizes streams into broad stream types, which are identified by the letters, A, G, F, B, E, C, D, and DA. Additionally, when a numeric code for dominant bed material is added, a total of 41 unique types exist in this scheme.

The most entrenched streams are the A, G, and F channels. In these streams, flood flows are confined to their channels with little relief provided by a floodplain. Type A streams generally occur in narrow high relief valleys and are generally narrow, deep, confined, and entrenched streams with cascading step-pools and low sinuosity. These streams can be very stable if the bed material consists mainly of bedrock or boulders. Type G streams occur in moderate gradient valleys and also are generally narrow and deep. These streams also have step-pool systems, but are generally more sinuous and gully-like than A streams. G streams are considered unstable and commonly have grade control problems and high bank erosion rates. Type F streams occur in more gentle gradients and have higher width/depth ratios than A and G streams. F streams are generally entrenched in highly weathered materials that make these streams laterally unstable. These streams usually have riffle-pool morphologies, greater sinuosity than A and G streams, and high bank erosion rates (Rosgen 1994; Rosgen 1996).

Type B streams are moderately entrenched. These streams have better floodplain connectivity than the entrenched A, G, and F streams. B streams are found in narrow valleys of moderate relief and generally have very stable planforms, profiles, and banks. Riffles and rapids dominate these channels with intermittent pools (Rosgen 1994; Rosgen 1996).

The least entrenched single thread channels are the type E and C streams. Type E streams are commonly narrow and deep but have very wide and well-developed floodplains. These streams are highly sinuous with well-vegetated banks, a riffle-pool morphology, and low gradients; occurring in broad valleys and meadows. E streams are generally very stable, efficiently conveying flood flows and transporting sediment. Type C streams have wider and shallower channels with well-developed floodplains and very broad valleys. These streams have riffle-pool morphology, point bar depositional features, and well-defined meandering channels (Rosgen 1994; Rosgen 1996).

Type D and DA streams are multi-thread streams (Rosgen 1994; Rosgen 1996). These stream types are very uncommon in the mid-Atlantic and are very rare in Anne Arundel County. None were observed during this assessment and so are not discussed further.

To facilitate the data analysis and classification work, an Excel spreadsheet developed by the Ohio Department of Fish and Game's Division of Soil and Water Conservation specifically designed for Rosgen stream classification was used to analyze the channel data collected and help classify the stream reaches.

Because the goal of the geomorphic assessment component of this study is to support the biological assessments, a full set of geomorphic parameters was not collected. Additionally, not all sites were assessed and classified due to serious violations of this scheme's requirements associated with a particular site's attributes. Therefore, the data have certain limitations that should be noted:

- An assessment reach length of between 10 and 20 bankfull channel widths is typically required for classification purposes. Depending upon the location of random biological site, some reaches met this criterion while others did not. Consequently, while it is unlikely that a change in stream type would occur using a properly sized assessment reach, any classifications reported here should be considered subject to refinement during future reassessment work.
- Typically, stream classification using the Rosgen methodology (Rosgen 1996) is best performed on riffle or step cross sections. Many of the 75-meter reaches assessed in this study did not contain riffles, although transition reaches between meanders were frequently identified and used for cross section placement.
- Pebble count data were collected for stream classification purposes only and are not appropriate for use in hydraulic calculations of bankfull velocity and discharge. This is particularly the case for the many sand bed channels in the study area, where data on the dune height would be used instead of the 84th percentile particle size, or D84, in hydraulic calculations. Dune height data were not collected for this study.
- No detailed analyses of stream stability were performed for this study. Statements referring to stream stability are based on observations and assumptions, which were founded on fundamental geomorphic principles. Conclusive evidence of the stability of

the sampling units assessed could only be obtained after detailed watershed and stream stability assessments were performed.

A summary of the stream types identified for the streams in this study is included in Appendix B: Geomorphic Assessment Results.

III. Result. Conditions within the Refuge are summarized in Table 5 and Figure 2. Overall, benthic macroinvertebrate populations indicate poor biological health. Seventy five percent of sites (12 of 16) had "Poor" or" Very Poor" biological scores. BIBIs ranged from a low of 1.86 at sites PR01 and PR02 to a high of 4.10 at site PR06.

Table 5. Summary of biological, habitat and geomorphic conditions observed in the Patuxent Research Refuge.

Station	BIBI	BIBI Condition	RBP	RBP Habitat Condition	Sample Type	Year Sampled	Rosgen Stream Type
PR01	1.57	Very Poor	120	Partially Supporting	Targeted	2002	*ND*
PR02	1.86	Very Poor	123	Partially Supporting	Targeted	2002	*ND*
PR03	2.40	Poor	158	Comparable to Reference	Targeted	2006	*ND*
PR04	2.70	Poor	152	Comparable to Reference	Targeted	2006	*ND*
PR05	3.00	Fair	167	Comparable to Reference	Targeted	2006	*ND*
PR06	4.10	Good	147	Supporting	Targeted	2006	*ND*
PR07	2.71	Poor	119	Partially Supporting	Random	2007	E5
PR08	2.14	Poor	122	Partially Supporting	Random	2007	E5
PR09	2.71	Poor	123	Partially Supporting	Random	2007	B5c
PR10	2.14	Poor	113	Partially Supporting	Random	2007	*ND*
PR11	3.00	Fair	126	Supporting	Random	2007	G5
PR12	1.73	Very Poor	135	Supporting	Random	2007	*ND*
PR13	2.43	Poor	134	Supporting	Random	2007	E4
PR14	2.43	Poor	112	Partially Supporting	Random	2007	G4c
PR15	2.71	Poor	87	Non-supporting	Random	2007	B4c
PR16	3.29	Fair	117	Partially Supporting	Random	2007	F4
Averages	**2.56**	**Poor**	**128**	**Supporting**			

ND = no data

Habitat scores show good quality habitat throughout the Refuge. Approximately 44% were judged as having "Comparable to Reference" or "Supporting" habitat conditions. Only one site was judged "Non-supporting," the lowest category in the ranking scheme.

Of the sites assessed in the Refuge, Rosgen classification was performed at eight locations. Three of eight were classified as E type streams, two of eight were classified as either G or B types streams, while the remaining site was classified as an F type stream. The assessment reaches had mostly sand-dominated bottoms. Three of the eight reaches classified had a gravel substrate. The average D50 of the classified reaches was 3.7 mm, which is in the gravel particle class. Slopes ranged from a high of just over 2 % to a low of 0.42%, with an average of 1.1% across all sites.

Water chemistry conditions are summarized in Table 6. The sites showed no serious impairments in dissolved oxygen, temperature, or conductivity. Dissolved oxygen values were above 5 mg/L at for all samples except those collected at PR02 and PR04, where observed values were 3.95 and 4.95 mg/L, respectively. No temperature values exceeded the acceptable maximum value of 32° C. While there is no state standard for this parameter, conductivity values were also in an acceptable range for streams in the Coastal Plain based upon the best professional judgment of the authors, although measurement trended toward the lower range (~100µS/cm) of acceptable values (12 of 16 <100µS/cm).

For pH, nearly all values were much lower than the minimum of 6.5. A total of 13 of 15 (one value discarded due to QA/QC problems) were below 6.5. A total of around 47% were below 5.5, a value typically associated with stress in fish populations. One very high value (9.78 at PR06) was not included in the summary presented in Table 6.

Table 6. Summary of water quality observations at biological sample stations.

Parameter (units)	**Average (SD)**	**Minimum-Maximum**	**% Observations Exceeding COMAR Standards**
Dissolved Oxygen (mg/L)	8.91 (2.19)	3.6-11.58	13
Conductivity (µS/cm)	73.6 (50.2)	34.3-201.0	Not Applicable
Temperature (deg, C)	11.2 (4.98)	5.1-21.8	0
pH (units)	5.40 (1.53)	3.94-7.26	87

IV. Conclusions. Overall, biological conditions within Refuge streams, as measured by the BIBI, appear moderately to severely impaired. Overall, the sites were dominated by tolerant invertebrates like amphipods and midges. Some stoneflies and blackflies were also observed at these sample points. See Appendix A for details on the specific invertebrates found during this work.

Generally, habitat and biological community conditions tend to be related. The quality of reach habitat conditions dictates the level of potential biological health that a particular site can achieve, all other factors being equal. In essence, this means that sites with "Good" BIBI scores tend to be associated with "Comparable" habitat, those with "Fair" BIBIs scores tend to have "Supporting" habitat, and so on. When biological community health and habitat conditions do not correlate well, it is a possible indicator of human impacts, which tend to manifest themselves in two basic ways.

First, when biological conditions are better than expected for the habitat quality observed (i.e. - a BIBI of "Good" and a habitat rating of "Partially Supporting" or "Non-supporting"), nutrient enrichment from agricultural activities or other sources is often suspected. Conversely, when biological conditions are worse than expected for the observed habitat quality (i.e.- a BIBI of "Poor" and a habitat rating of "Comparable to Reference" or "Supporting"), then pollutant impacts, excessive high flow conditions, geomorphic instability, or some other stressor might be the causative agent.

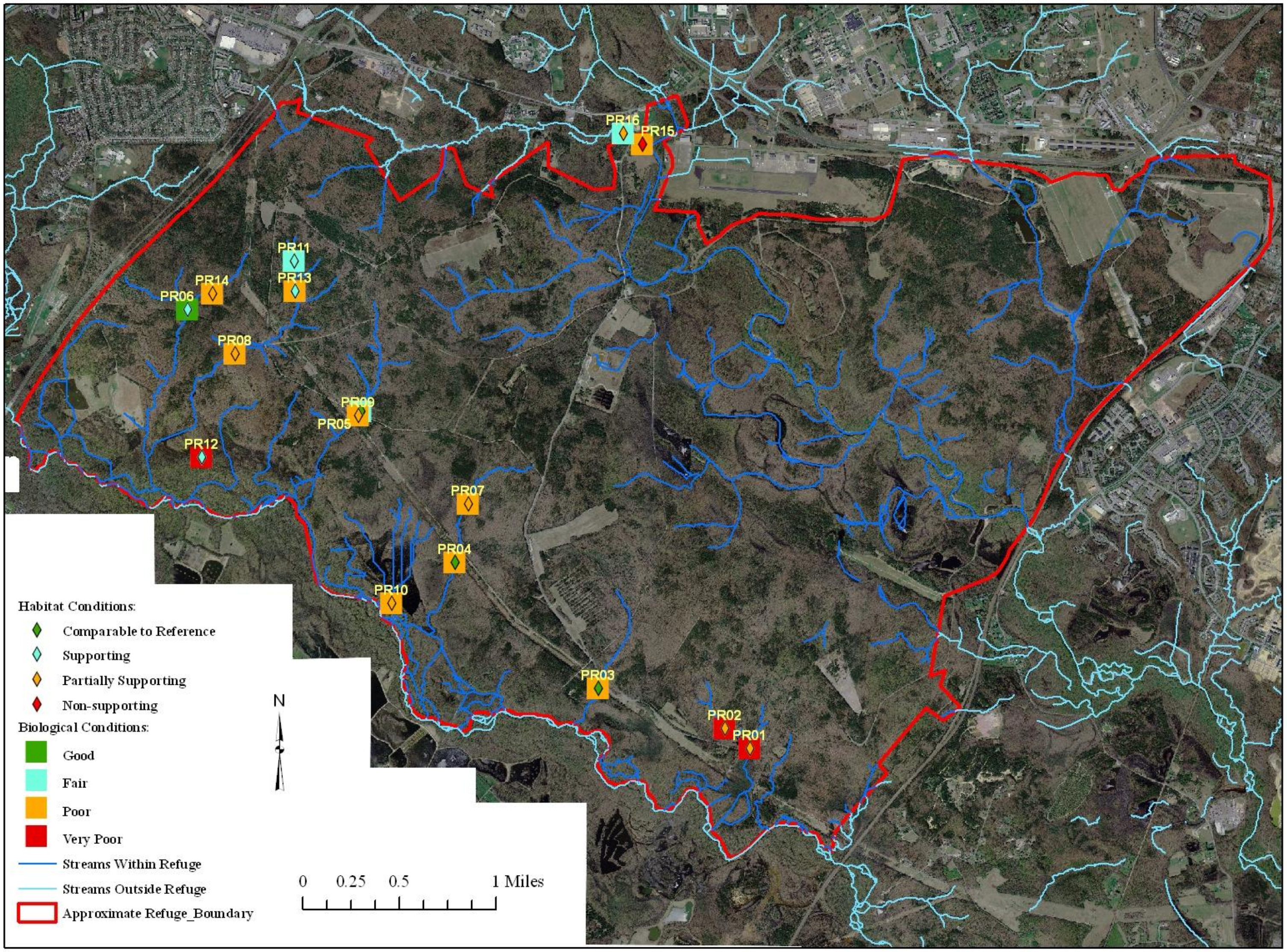

Figure 2. Biological and habitat conditions observed within the Refuge.

This relationship is explored in Table 7. Sites PR01-05 and PR12-13 show more impairment in their biological communities than would be expected from the available habitat characterized during this assessment. Specific impacts to water quality within the upstream drainage areas, such as contaminant inputs from any agricultural or landscaping activities, should be investigated. It should be noted that all these sites showed some pH depression, with all values measured below 6.5, with sites PR01, 03, and 12, all below pH 6, and sites PR02 and PR13 with pH values below 4. The reason for level of pH depression is unclear, but further investigation at these sites should be undertaken.

Table 7. Comparison of sample site biological scores to EPA RBP habitat condition.

EPA RBP Habitat Scores	**BIBI Score**			
	Good	**Fair**	**Poor**	**Very Poor**
Comparable to Reference			PR03 PR04 PR05	
Supporting	PR06	PR11	PR13	PR12
Partially Supporting		PR16	PR07 PR08 PR09 PR10 PR14	PR01 PR02
Non-Supporting			PR15	

Green cells contain stations where the biological community was less impaired than the habitat scores would predict.
Orange cells contain stations where biological community matched available habitat.
Pink cells contain stations where the biological community was more impaired than the habitat scores would predict.

Sites PR06, 15, and 16 showed moderately enriched benthic communities in comparison to expectations associated with available habitat. However, unlike the degraded sites described above, all of these enriched sites were very close to being in their appropriate habitat category, with observed point deficiencies of 9 points or less keeping them from the correct habitat category. In contrast, the RBP scores of the impaired sites would require point reductions of 9 to 42 points to shift these sites to the appropriate orange cells of Table 7.

Land use and land cover conditions, discussed only briefly here, are thoroughly characterized in Anne Arundel County (2004) and Stribling et al. (2008). Current dominant land uses and relatively low impervious surface amounts in the Refuge lead to a logical expectation of high quality biological communities at these sites. Nearly every site had much less than 10 percent impervious surface contributing to the upstream drainage areas and most were nearly 100 percent forested and have been for many years. However, it is possible that biological communities in these streams have not reestablished themselves and are still recovering from past impacts associated with this area's use as a military installation or from harmful agricultural practices that may have occurred on this land. The impacts of historical land uses have been shown to have severe impacts on current populations of benthic macroinvertebrates (Harding et al. 1998).

Benthic community composition did not track well with geomorphic characteristics in the Refuge. In fact, the least impaired communities observed in the Refuge were found in stream types typically associated with instability conditions. Sites PR11 and PR16 both rated as in “Fair” health and yet had the G5 and F4 Rosgen stream type present, respectively. As described previously, these types typically have high channel shear stress and generate excessive sediment relative to other stream types. Regardless of the impact on benthic community health, about 38% of sites sampled had stream types considered unstable in this classification system. As this stability assessment work was done at probability-based sites only, it is possible that significant instability exists in the stream systems draining the Refuge. However, additional geomorphic assessment work would need to be performed to ultimately determine the amount of potentially unstable stream reaches present.

Based upon the information presented here, the following recommendations are made:

Investigate Potential Water Quality Impacts. As mentioned above, sites PR01-05, 12, and 13 have biological communities depressed relative to available habitat quality. Investigations should be conducted upstream of these sites to determine if on-going impairments exist associated with known or unknown activities occurring in the contributing drainage areas. Additionally, there was some apparent pH depression at these sites, with all values measured below 6.5. Sites PR01, 03, and 12, all were below pH 6, and sites PR02 and PR13 had pH values below 4. One outlier, PR06, had a pH value of 9.78. These pH values should be confirmed and, if still present, the cause should be determined and corrected, if possible.

Evaluate Stream Stability Throughout Refuge. Over one third of sites where geomorphic work was performed had apparent stability problems associated with their determined stream type. Additional geomorphic assessment is recommended for Refuge streams so that corrective action, as necessary, can be taken to enhance overall stability and sediment delivery to the Patuxent River watershed. The Service’s Chesapeake Bay Field Office Stream Assessment Program has the capability to assist the Refuge in performing such an assessment of its streams.

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Appendix A: Taxa List by Organism Prevalence and by Sample Station

Organism ID	Total	% Total
Caecidotea (amphipod)	189	10.77
Stegopterna (black fly)	161	9.17
Leuctra (stone fly)	124	7.07
Simulium (black fly)	71	4.05
Tanytarsus (midge)	71	4.05
Hydrobaenus (midge)	61	3.48
Thienemannimyia (midge)	61	3.48
Polypedilum (midge)	58	3.30
Enchytraeidae (worm)	57	3.25
Crangonyx (amphipod)	55	3.13
Tribelos	52	2.96
Pseudorthocladius	51	2.91
Limnophyes	41	2.34
Leuctra	39	2.22
Lumbriculidae	32	1.82
Parametriocnemus	31	1.77
Pisidium	30	1.71
Zavrelimyia	28	1.60
Psectrocladius	24	1.37
Orthocladius/Cricotopus	21	1.20
Rheocricotopus	21	1.20
Alotanypus	18	1.03
Spirosperma	18	1.03
Ablabesmyia	16	0.91
Enchytraeidae	16	0.91
Amphinemura	15	0.85
Bezzia/Palpomyia	15	0.85
Natarsia	14	0.80
Ironoquia	13	0.74
Thienemanniella	13	0.74
Corynoneura	12	0.68
Micropsectra	12	0.68
Tipula	11	0.63
Nais	10	0.57
Apsectrotanypus	9	0.51
Ceratopogonidae	9	0.51
Culicoides	9	0.51
Cyphon	9	0.51
Larsia	9	0.51
Tubificinae	9	0.51
Phaenopsectra	8	0.46
Rheosmittia	8	0.46

Organism ID	**Total**	**% Total**
Ormosia	7	0.40
Ancyronyx	6	0.34
Calopteryx	6	0.34
Centroptilum	6	0.34
Omisus	6	0.34
Synurella	6	0.34
Chaetocladius	5	0.28
Hydroporinae	5	0.28
Nemoura	5	0.28
Rheotanytarsus	5	0.28
Tanypodinae	5	0.28
Ceratopogon	4	0.23
Cordulegaster	4	0.23
Eukiefferiella	4	0.23
Eurylophella	4	0.23
Libellula	4	0.23
Libellulidae	4	0.23
Limnephilidae	4	0.23
Limnodrilus	4	0.23
Polycentropus	4	0.23
Tvetenia	4	0.23
Brillia	3	0.17
Collembola	3	0.17
Crangonyctidae	3	0.17
Cryptochironomus	3	0.17
Diplocladius	3	0.17
Dixella	3	0.17
Hexatoma	3	0.17
Lepidoptera	3	0.17
Nigronia	3	0.17
Parachaetocladius	3	0.17
Paramerina	3	0.17
Paratendipes	3	0.17
Pseudolimnophila	3	0.17
Stenelmis	3	0.17
Stygobromus	3	0.17
Wormaldia	3	0.17
Zavrelia	3	0.17
Alluaudomyia	2	0.11
Anopheles	2	0.11
Aulodrilus	2	0.11
Bezzia	2	0.11
Capniidae	2	0.11
Cernotina	2	0.11

Organism ID	Total	% Total
Chrysops	2	0.11
Conchapelopia	2	0.11
Corethrella	2	0.11
Diplectrona	2	0.11
Diptera	2	0.11
Heterotrissocladius	2	0.11
Lumbricidae	2	0.11
Nematoda	2	0.11
Neoporus	2	0.11
Ptilostomis	2	0.11
Pycnopsyche	2	0.11
Stenochironomus	2	0.11
Baetidae	1	0.06
Boyeria	1	0.06
Capniidae/Leuctridae	1	0.06
Chaetogaster	1	0.06
Chauliodes	1	0.06
Cheumatopsyche	1	0.06
Chironomidae	1	0.06
Chironomini	1	0.06
Clinotanypus	1	0.06
Corduliidae/Libellulidae	1	0.06
Cryptolabis	1	0.06
Dero	1	0.06
Gonomyia	1	0.06
Guttipelopia guttipennis	1	0.06
Gymnometriocnemus	1	0.06
Helichus	1	0.06
Hemerodromia	1	0.06
Hydrobius	1	0.06
Ischnura	1	0.06
Limnophila	1	0.06
Lioporeus	1	0.06
Matus	1	0.06
Menetus	1	0.06
Naididae	1	0.06
Orthocladiinae	1	0.06
Paraphaenocladius	1	0.06
Prosimulium	1	0.06
Prostoma	1	0.06
Pseudosmittia	1	0.06
Sialis	1	0.06
Somatochlora	1	0.06
Sperchopsis	1	0.06

Organism ID	Total	% Total
Stempellinella	1	0.06
Sublettea	1	0.06
Tipulidae	1	0.06
	1755	100.00

Final ID	PR01	PR02	PR03	PR04	PR05	PR06	PR07	PR08	PR09	PR10	PR11	PR12	PR13	PR14	PR15	PR16	Grand Totals
Ablabesmyia						8		3						3		2	16
Alluaudomyia								1		1							2
Alotanypus		18															18
Amphinemura						15											15
Ancyronyx																6	6
Anopheles				2													2
Apsectrotanypus				1	4		1		3								9
Aulodrilus										2							2
Baetidae																1	1
Bezzia	2																2
Bezzia/Palpomyia									3	2	2		6	2			15
Boyeria														1			1
Brillia				3													3
Caecidotea	11	41		27		5	37			17		50				1	189
Calopteryx					1	1								1		3	6
Capniidae			2														2
Capniidae/Leuctridae															1		1
Centroptilum															3	3	6
Ceratopogon									2				1	1			4
Ceratopogonidae				8						1							9
Cernotina					2												2
Chaetocladius		1		3		1											5
Chaetogaster												1					1
Chauliodes			1														1
Cheumatopsyche																1	1

Final ID	PR01	PR02	PR03	PR04	PR05	PR06	PR07	PR08	PR09	PR10	PR11	PR12	PR13	PR14	PR15	PR16	Grand Totals
Chironomidae				1													1
Chironomini				1													1
Chrysops					1						1						2
Clinotanypus										1							1
Collembola				3													3
Conchapelopia				2													2
Cordulegaster						2								2			4
Corduliidae/Libellulidae		1															1
Corethrella				2													2
Corynoneura	5		1		1	2	1	1					1				12
Crangonyctidae		3															3
Crangonyx	2		2	6	23	1			4	14		1		2			55
Cryptochironomus	1														2		3
Cryptolabis			1														1
Culicoides								1		6	2						9
Cyphon							8				1						9
Dero							1										1
Diplectrona						1								1			2
Diplocladius						1									1	1	3
Diptera				2													2
Dixella														3			3
Enchytraeidae	2	2					18	5	9	1	16	2	9	1	7	1	73
Eukiefferiella															4		4
Eurylophella						1										3	4
Gonomyia				1													1
Guttipelopia guttipennis							1										1
Gymnometriocnemus				1													1

Final ID	PR01	PR02	PR03	PR04	PR05	PR06	PR07	PR08	PR09	PR10	PR11	PR12	PR13	PR14	PR15	PR16	Grand Totals
Helichus															1		1
Hemerodromia															1		1
Heterotrissocladius						1								1			2
Hexatoma	1						1					1					3
Hydrobaenus					1	2						2			20	36	61
Hydrobius											1						1
Hydroporinae						4							1				5
Ironoquia			1		2	1								1	1	7	13
Ischnura				1													1
Larsia				6			3										9
Lepidoptera					2	1											3
Leuctra			72		14	25	2		10		13		13	13		1	163
Libellula				4													4
Libellulidae				1	1	2											4
Limnephilidae						2			1				1				4
Limnodrilus								1		2				1			4
Limnophila													1				1
Limnophyes			1	20	5	2		2	2	1	6		1			1	41
Lioporeus																1	1
Lumbricidae											1					1	2
Lumbriculidae								2		21		5		3		1	32
Matus										1							1
Menetus												1					1
Micropsectra		3	1		1		1		4		2						12
Naididae	1																1
Nais										2					5	3	10
Natarsia					1					3		7		3			14

Final ID	PR01	PR02	PR03	PR04	PR05	PR06	PR07	PR08	PR09	PR10	PR11	PR12	PR13	PR14	PR15	PR16	Grand Totals
Nematoda										1		1					2
Nemoura									1				4				5
Neoporus											2						2
Nigronia			1								1				1		3
Omisus												6					6
Ormosia				2						2	2					1	7
Orthocladiinae						1											1
Orthocladius/Cricotopus											1	5	1		4	10	21
Parachaetocladius			1						2								3
Paramerina	3																3
Parametriocnemus	6										1			22	2		31
Paraphaenocladius										1							1
Paratendipes								1		1				1			3
Phaenopsectra	3				3									1	1		8
Pisidium										9		20		1			30
Polycentropus			1						3								4
Polypedilum	1		3	10	11	2		1	9		7	2	2	5	5		58
Prosimulium														1			1
Prostoma																1	1
Psectrocladius		1			1		22										24
Pseudolimnophila				2	1												3
Pseudorthocladius				4						8			5	1	33		51
Pseudosmittia										1							1
Ptilostomis							1				1						2
Pycnopsyche							1							1			2
Rheocricotopus						11		3					2	5			21
Rheosmittia								8									8

Final ID	PR01	PR02	PR03	PR04	PR05	PR06	PR07	PR08	PR09	PR10	PR11	PR12	PR13	PR14	PR15	PR16	Grand Totals
Rheotanytarsus															5		5
Sialis					1												1
Simulium	9		12	2	22	12	1	1	2				2	3		5	71
Somatochlora						1											1
Sperchopsis																1	1
Spirosperma										5		7			1	5	18
Stegopterna							1	43	23		39		44	11			161
Stempellinella									1								1
Stenelmis											1				2		3
Stenochironomus	1							1									2
Stygobromus			2													1	3
Sublettea					1												1
Synurella		6															6
Tanypodinae						2										3	5
Tanytarsus	51	6				3		2		2		6			1		71
Thienemanniella			2		9	2											13
Thienemannimyia		1	1	3	3	1	16	1			7		3	11	6	8	61
Tipula					3	2		1	1		1		1	2			11
Tipulidae										1							1
Tribelos		22						1	24	5							52
Tubificinae								3		3	1			1		1	9
Tvetenia				2											2		4
Wormaldia													3				3
Zavrelia							3										3
Zavrelimyia		3			6	2		3	3		4		3	3		1	28
Grand Totals	**99**	**108**	**105**	**120**	**120**	**117**	**119**	**85**	**107**	**114**	**113**	**117**	**104**	**108**	**109**	**110**	**1755**

Appendix B: Geomorphic Assessment Results

Station	(mi.^{2}) DA	(ft/ft) ER	(ft.) Wbf	(ft.) Dbf	(ft/ft) W/D	(ft.^{2}) Abf	(%) Slope	(ft/ft) Sinuosity	(ft.) Wfp	(mm) D50	Adj?	Rosgen LI Stream Type	Rosgen LII Stream Type
PR07	0.33	23*	12	1.1	11.3	12.7	0.69	1	276*	0.25	Sin	E	E5
PR08	0.40	17*	9	1.3	9	14.2	0.47	1.5	193*	0.47	None	E	E5
PR09	0.35	1.7	8.9	0.9	10.1	7.8	0.42	1.1	15.4	0.3	W/D, Sin	B	B5c
PR11	0.07	1.3	5.7	0.7	7.9	4.1	2.2	1.1*	7.6	0.36	Sin	G	G5
PR13	0.13	5.3	8.4	0.8	10.7	6.6	1.4	1.4	44.3	8.4	Sin	E	E4
PR14	0.10	1.8	4.9	0.9	5.6	4.3	1.7	1.2	8.9	0.42	ER	G	G5c
PR15	1.62	1.7	20.1	1.2	17	23.6	0.82	1.00	33.7	9.7	Sin	B	B4c
PR16	1.58	1.3	14.4	1.1	13	15.9	0.98	1.5	18.6	13	None	F	F4
Average	**0.57**	**6.64**	**10.43**	**1.00**	**10.58**	**11.15**	**1.09**	**1.23**	**75**	**4.11**			
SD	**0.65**	**8.50**	**4.97**	**0.21**	**3.43**	**6.74**	**0.63**	**0.21**	**102**	**5.33**			
Var	**0.42**	**72.29**	**24.74**	**0.04**	**11.76**	**45.40**	**0.40**	**0.04**	**10374**	**28.43**			

* Estimated using GIS mapping data.
See Rosgen (1996) for any additional explanation needed concerning these data.
DA = Drainage area.
ER = Entrenchment Ratio.
Wbf = width of the bankfull channel.
Dbf = Depth of the bankfull channel.
W/D = width to depth ratio of the bankfull channel.
Abf = cross sectional area of the bankfull channel.
Slope = water surface slope of the assessment reach.
Sinuosity = stream channel distance divided by the valley distance.
Wfp = width of the floodprone area.
D50 = median particle size determined in pebble count.
Adj? = notes any parameters that required allowed adjustment for classification purposes.
Rosgen LI Stream Type = the basic stream type classification.
Rosgen LII Stream Type = adds particle size to LI classification.

Appendix C: Representative Photos

Photo Not Available	Photo Not Available
PR01	PR02
	
PR03	PR04
	
PR05	PR06

	
PR07	PR08
	
PR09	PR10
	Photo Not Available
PR11	PR12

	
PR13	PR14
	
PR15	PR16