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RESEARCH ARTICLE

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Landscape changes and watershed erosion in Prince George's County, Maryland

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Abstract

This study evaluated erosion rates and sediment production in streams, and factors potentially influencing them throughout the Anacostia, Patuxent, and Potomac (non-Anacostia) River watersheds within Prince George's County, Maryland, US. As part of the County's watershed-scale biological monitoring program, from approx. 1999 to 2008, permanent monuments were established to allow measurement of stream channel cross-sectional (XS) area. The intent of this study was to characterize the intensity and spatial distribution of fluvial geomorphic instability across the county and use the results to target and plan stormwater management and stream restoration actions. For this study, 78 stream locations were re-surveyed in 2020, representing a time lapse of from 12 to 21 years. Data collected included XS dimensions, modified Wolman 100-particle pebble counts, and reach-specific soil bulk density. Land use/land cover data were compiled from the National Land Cover Dataset (NLCD), precipitation from the National Weather Service Center for Environmental Information (NCEI), and soils from the Natural Resources Conservation Service Web Soil Survey (NRCS/WSS). We calculated percent change in XS area, rates of erosion, sediment yield, and assigned geomorphic classifications, and interpreted them in the context of spatial positions relative to changes in land cover characteristics. Sediment yields among the 78 reaches exhibited a combination of those undergoing enlargement/erosion (67.9%), reduction/deposition (25.6%), and the remaining 6.4% with essentially no change over the period of record. Of the top 20 most geomorphically active reaches surveyed in the County, 12 are in the Anacostia River basin, with the other scattered among the Patuxent River and Potomac River basins.

KEYWORDS
erosion, fluvial geomorphology, physical habitat, prioritization, restoration, stormwater

1 | INTRODUCTION

The physical form of streams and rivers is widely understood to be a function of balance between flow and sediment (Lane, 1955; Simon & Darby, 1997; Soar et al., 2017). Lane (1955) stated that if a watercourse/flowpath has the energy to carry more sediment than is suspended in the moving water column, it will begin to pull it from the channel sides and bottom. This accelerated erosion is physically expressed as channel widening and deepening, and includes obliteration of physical habitat, shifting from enlargement to reduction

(Jayakaran et al., 2013; Simon & Darby, 1997). Thus, as land cover conversions alter surface flow paths during storm events, increases in both surface and in-channel erosion can potentially be substantial (Booth, 1990; Borrelli et al., 2020; Leh et al., 2011; Roy & Sahu, 2016). Further, the spatial relationship of these conversions coupled with other forms of human activities can have strong, cumulative, and cascading effects on ecological conditions in streams and rivers and other surface waters (Brierley et al., 2006; Chessman et al., 2006; Grabowski et al., 2014; James & Lecce, 2013; Nietch et al., 2005; Soar et al., 2017; USEPA, 2006; Walsh et al., 2005; Waters, 1995). Models of channel evolution demonstrate recovery patterns of streams and rivers following physical disturbance including instream sediment processes and riparian vegetation and contribute to fluvial restoration efforts (Cleur & Thorne, 2014; Hupp, 1992; Hupp & Simon, 1991; McCandless, 2003; Simon & Hupp, 2006; Simon & Rinaldi, 2006).

Prince George's County, Maryland (USA) is in the Mid-Atlantic Coastal Plain physiographic province (Figure 1) and is dominated by sandy soils and substrate (Cooke et al., 1952; Glaser, 1971) and an abundance of relatively unstable, geomorphically active channels. Fluvial models have suggested that lower gradient, sand-dominated streams are more prone to rapid adjustment than channels of more coarse bed and bank materials (Simon & Darby, 1997). This further suggests that small-scale local efforts at stream stabilization are likely to be ineffective and that a broader perspective is needed to manage elevated flows and sediment input at upstream sources in headwater regions of watersheds. Concepts of restoration and management of watersheds has evolved from the relatively straightforward approach of analysis and design for managing floods and stabilizing reaches to assessment of the key contemporary and historic physical, ecological, and social controls on river change (Beechie et al., 2010; Sear et al., 2009; Simon et al., 2007). Strict reliance on small numbers of variables in describing geomorphic conditions of watersheds is problematic; specific to this study is sediment yield.

Sediment yield is reduced or increasingly attenuated as watershed drainage area increases (Jayakaran et al., 2013; Prosser et al., 2001), an observation that highlights the necessity of understanding spatial setting and framework. Gregory (2006) emphasizes modeling to understand uncertainties and feedback processes associated with restoration designs, influences of climate change on geomorphic processes, and a better understanding of cultural, social, and political constraints. All of these fluvial processes at various stages of recovery are occurring due to current and historical land use and cover conditions, simultaneous with ongoing and predicted changes in climate and precipitation (Dupigny-Giroux et al., 2018). Recognizing the importance of spatial and temporal scale in considering watershed conditions is, in part, the impetus behind this study. The purpose of this project is to compare and analyze geomorphic changes in streams and watersheds and resulting sediment yields, and to associate them with historic changes in land use/land cover activities.

Prince George's County has been monitoring ecological conditions of its streams and watersheds in a consistent and routine manner for nearly 25 years, beginning in 1999. The biological monitoring and assessment program uses a probability-based, rotating basin design through which it has assessed more than 1000 stream sites through four complete rounds (Round 1: 1999–2003; Round 2: 2010–2013; Round 3: 2015–2017; Round 4: 2018–2020). Sampling and analysis of biological and physical habitat conditions have resulted in assessments of biological degradation from 0% to 100%, with most of the watersheds in the 40%–50% range. During Round 1, monumented cross sections (XS) were set for measuring channel form, with intermittent surveys periodically between 1999 and 2010.

2 | SITES

There were 92 reaches with monumented XS randomly selected from the historical database for the 2020 re-survey. Fourteen reaches were removed from the study due to insufficient historical data because the XS location was on private property where permission to access was denied, or the stream channel had been converted to a lake, pond, wetland, or marsh with no discernible channel due to anthropogenic influences, natural channel adjustments, or beaver activity. The remaining 78 reaches (Table 1, Figure 2) were resurveyed and documented for continued future monitoring. Changes to bankfull and full cross-sectional area were evaluated to determine the change in Rosgen Level 2 classification (Rosgen, 1994) and to predict annual sediment loads from each surveyed reach.

3 | DATA SOURCES

The principal sources of data and information used in this project include recent (2020) and historical (1999–2004) stream channel geomorphology data (including pebble counts) housed in the County biological monitoring and assessment database. The temporal interval of these stream channel field data ranges from 15 to 21 years. Land use and land cover data (LULC) were downloaded from the National Land Cover Dataset (NLCD) for 7 years: 2001, 2004, 2006, 2008, 2011, 2013, and 2016; and rainfall records covering a 29-year period (1990–2019) were acquired from the National Center for Environmental Information (NCEI) of the National Oceanographic and Atmospheric Administration (NOAA).

4 | FIELD METHODS AND DATA ANALYSIS PROCEDURES

Historical data were organized for each XS including field datasheets, Excel spreadsheets, global positioning system (GPS) coordinates, and site photographs. Field crews used the information to determine original locations from GPS coordinates or manmade monuments such as bridges, underpasses, roads, buildings, and utilities captured by site photos. Permission to access reaches located on private property was received prior to fieldwork either by phone, email, the receipt of a permission letter mailed to the property owner recorded in state

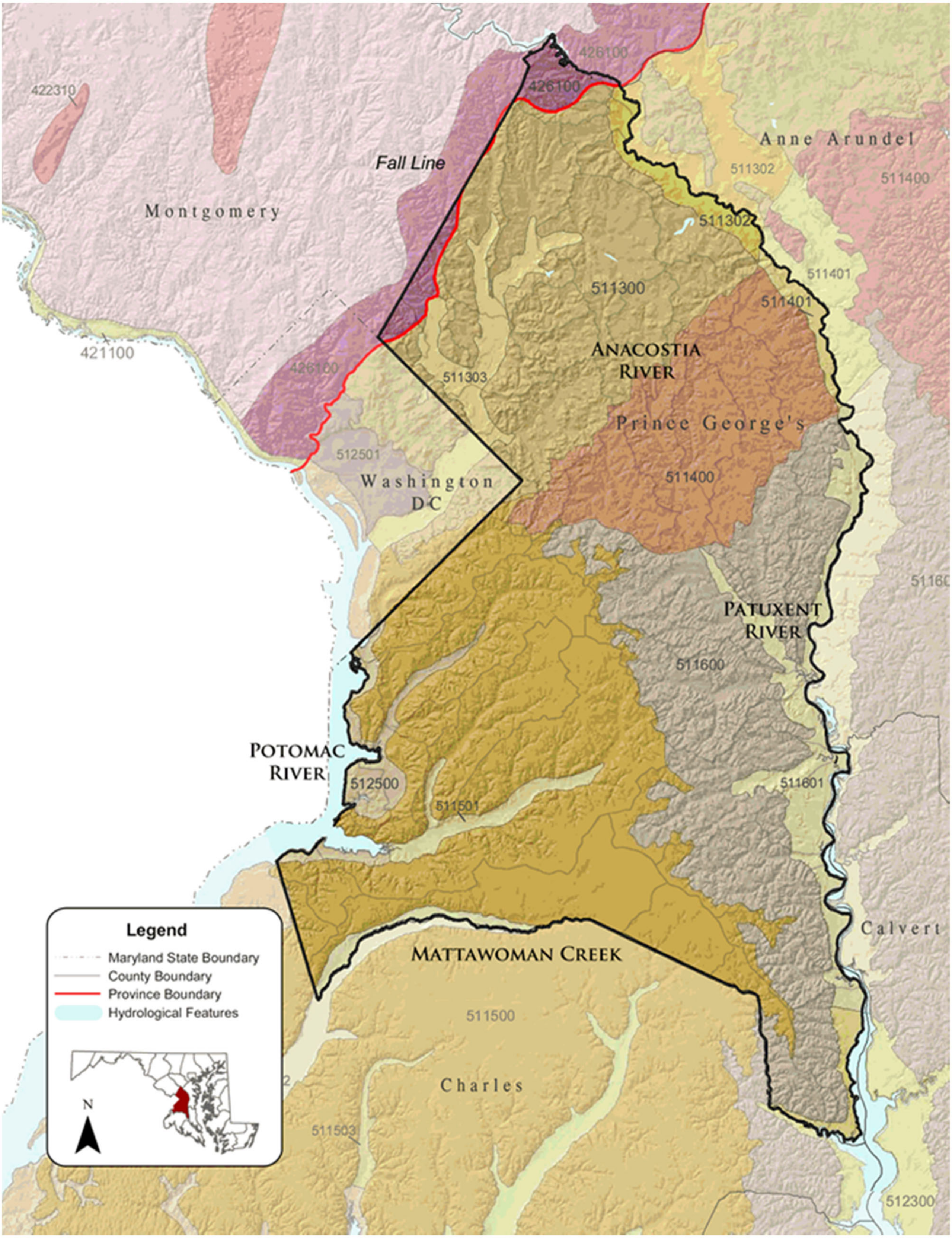

FIGURE 1 Prince George's County is located in Maryland's Coastal Plain, politically bounded by Anne Arundel and Calvert counties on the east, Montgomery and Howard on the north and northwest, and the District of Columbia on the west. Hydrologic and physiographic boundaries are the Patuxent River, Mattawoman Creek, Potomac River, and, roughly, the Fall Line (red line). Physiographic map adapted from Reger and Cleaves (2003). [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Stream sites throughout Prince George's County (Maryland) for which channel cross-section (XS) surveys were repeated.

			Year							Year			
Stream name	No.	Site ID	1	2	3	MB	Stream name	No.	Site ID	1	2	3	MB
Paint Branch	3	05-001	2001	2020		AN	Horsepen Br	31	10-009	2002	2020		PX
Paint Branch	4	05-001A	2004	2020		AN	Horsepen Br	32	10-011	2002	2020		PX
Little Paint Br	5	05-019B	2001	2020		AN	Western Br	42	21-005	2003	2020		PX
Little Paint Br	6	05-019C	2001	2004	2020	AN	Western Br	43	21-011	2003	2020		PX
Little Paint Br	7	05-019D	2004	2020		AN	Spice Cr	60	32-003	2001	2020		PX
Little Paint Br	8	05-027	2001	2020		AN	Rock Cr	61	32-028	2001	2020		PX
Little Paint Br	9	05-027A	2004	2020		AN	Piscataway Cr	62	33-007	2000	2020		PX
Indian Creek	10	07-011	2005	2020		AN	County Line Cr	63	37-007B	2001	2020		PX
Indian Creek	11	07-015A	2004	2020		AN	County Line Cr	64	37-011B	2001	2020		PX
Indian Creek	12	07-028	2003	2020		AN	Mataponi Cr	65	38-023	2002	2020		PX
Indian Creek	13	07-035	2003	2004	2020	AN	Mataponi Cr	66	38-027	2002	2020		PX
Indian Creek	14	07-038	2003	2020		AN	Swan Point Cr	67	39-042A	2002	2020		PX
U. Beaverdam Cr	15	08-001	2000	2020		AN	Honey Branch	68	39-075	2002	2020		PX
U. Beaverdam Cr	16	08-001B	2004	2020		AN	Mt. Nebo Br	69	39-080	2002	2020		PX
U. Beaverdam Cr	17	08-003	2004	2020		AN	Mill Branch	70	39-084	2002	2020		PX
U. Beaverdam Cr	18	08-014	2000	2004	2020	AN	Green Br	71	39-092	2002	2020		PX
U. Beaverdam Cr	19	08-016	2004	2020		AN	Collington Br	72	40-013	2003	2020		PX
U. Beaverdam Cr	20	08-018	2000	2020		AN	Black Branch	73	40-016	2000	2005	2020	PX
Beck Branch	21	08-022	2000	2020		AN	Collington Br	74	40-031	2003	2020		PX
U. Beaverdam Cr	22	08-035A	2000	2020		AN	Collington Br	75	40-035	2003	2020		PX
U. Beaverdam Cr	23	08-035B	2004	2020		AN	Collington Br	76	40-037	2003	2020		PX
U. Beaverdam Cr	24	08-039	2000	2020		AN	Collington Br	77	40-047	2003	2020		PX
U. Beaverdam Cr	25	08-044	2000	2020		AN	Federal Spring Br	78	41-009	2001	2020		PX
U. Beaverdam Cr	26	08-046A	2004	2020		AN	Carey Branch	44	24-002	2000	2020		PM
Beck Branch	27	08-065A	2004	2020		AN	Henson Creek	45	24-007	2000	2020		PM
Northwest Br	28	09-005	2004	2020		AN	Henson Creek	46	24-009	2000	2020		PM
Northwest Br	29	09-009	2004	2020		AN	Henson Creek	47	24-019	2000	2020		PM
UT to NE Br	33	12-011	2004	2020		AN	Henson Creek	48	24-020	2000	2020		PM
UT to NE Br	34	15-003A	1999	2004	2020	AN	Henson Creek	49	24-039	2000	2020		PM
Brier Mill Run	35	16-001	2004	2010	2020	AN	Henson Creek	50	24-041	2000	2020		PM
L. Beaverdam Cr	36	19-003	2000	2005	2020	AN	Tinkers Creek	51	25-005	2001	2020		PM
L. Beaverdam Cr	37	19-005	2002	2020		AN	Tinkers Creek	52	25-020A	2001	2020		PM

TABLE 1 (Continued)

Stream name	No.	Site ID	Year 1	Year 2	Year 3	MB	Stream name	No.	Site ID	Year 1	Year 2	Year 3	MB
L. Beaverdam Cr	38	19-006	2002	2020		AN	Tinkers Creek	53	25-020B	2001	2020		PM
L. Beaverdam Cr	39	19-023A	2001	2020		AN	Tinkers Creek	54	25-020C	2001	2020		PM
L. Beaverdam Cr	40	19-025	2002	2020		AN	Broad Creek	55	28-003	2000	2020		PM
L. Beaverdam Cr	41	19-036	2002	2020		AN	UT to Broad Cr	56	28-007	2000	2020		PM
Walker Br	1	03-001	2000	2020		PX	Hunters Mill Br	57	29-003	2000	2020		PM
Bear Branch	2	04-005	2000	2020		PX	Mattawoman Cr	58	31-004B	2003	2020		PM
Horsepen Branch	30	10-001	2002	2020		PX	UT/Mattawoman Cr	59	31-025	2003	2020		PM

Note: There is a total of 78 reaches with 1 or 2 revisits and with time intervals ranging from 15 to 21 years. Major basins (MB) are the Anacostia River (AN), the Patuxent River (PX), and the Potomac River (PM). Map numbers (No.) are used in Figure 2.

Abbreviation: UT, unnamed tributary.

taxation records, or by direct field contact. When the original monuments were located, a survey was completed using them. If the original monuments were not located, new XS monuments were placed on the terrace or floodplain at the top of each bank in line with a riffle occurring in the 100-meter reach; original GPS coordinates were always used as the midpoint mark (the 50 m mark of the 100 m tape). Old and new XS monuments were spray painted orange, marked with orange flagging tape and rebar caps, documented with photos, and the GPS coordinates recorded for future monitoring.

New XS monuments were established by driving 36″ × 0.5″ (=91.4 × 1.3 cm) round rebar into the ground at the top of the left and right bank to an elevation of approximately 0.5″ (1.3 cm) and placing a cap on the exposed rebar to minimize the potential of injury or other hazard. In locations where rebar was placed in maintenance areas with a higher probability of human or animal contact, the capped rebar was driven into the ground so that the top of the cap was level with the surface of the ground. Care was taken to access the location of the XS from the downstream side of the cross-section transect to avoid disturbance to bank and bed material. A 100 m measuring tape was stretched across the XS from left to right so that the rebar monuments were positioned between the ends and directly under the measuring tape. The measuring tape was held taut by Silvey stakes which utilize a locking pliers-clamp attached to a tension spring.

Each monumented XS was surveyed using a laser level positioned on the highest bank. Tree branches and bushes were trimmed as needed to create a clear line of sight through the cross section. Sight recordings were taken with a LS-80 L receiver positioned at the top of an AdirPro 711–45 SK oval-shaped fiberglass surveyor leveling rod graduated to feet/tenths. Surveys started at the left bank (facing downstream) rebar monument and ended at the right bank rebar monument. Rod level was recorded at breaks in elevations across the cross section and at the geomorphic features of top of bank, bankfull elevation, and edge of water for each bank. Additional recordings were taken at the lowest elevation of the stream bed (identified as the thalweg) and water depths were recorded between left and right edge of water.

Channel cross-sectional area (XSa) was calculated by multiplying the channel width at the elevation of the lowest bank by the mean depth at the elevation of the lowest bank. A key assumption in this analysis is that because only a single XS profile was taken at each site, one linear foot (=30.5 cm) is used to calculate sediment volume. Thus, values produced are potentially substantial underestimates of true sediment loss and/or gain but still provide an effective comparison among reaches. Reach-specific bulk density values were obtained by taking three 350 cm^3 sediment cores from representative bank face locations, returning them to the laboratory, drying and weighing them to the nearest 0.1 gram, and calculating the mean value (Appendix A). For 11 sites that did not have cores taken, 0.0625[i] is used as the conversion factor to translate one cubic foot (1 ft^3 [$=0.028\text{m}^3$]) of soil to tons (Schueler & Stack, 2014). Annual sediment yield is calculated as:

$$\frac{\Delta \text{XSa} * 1 * B}{T},$$

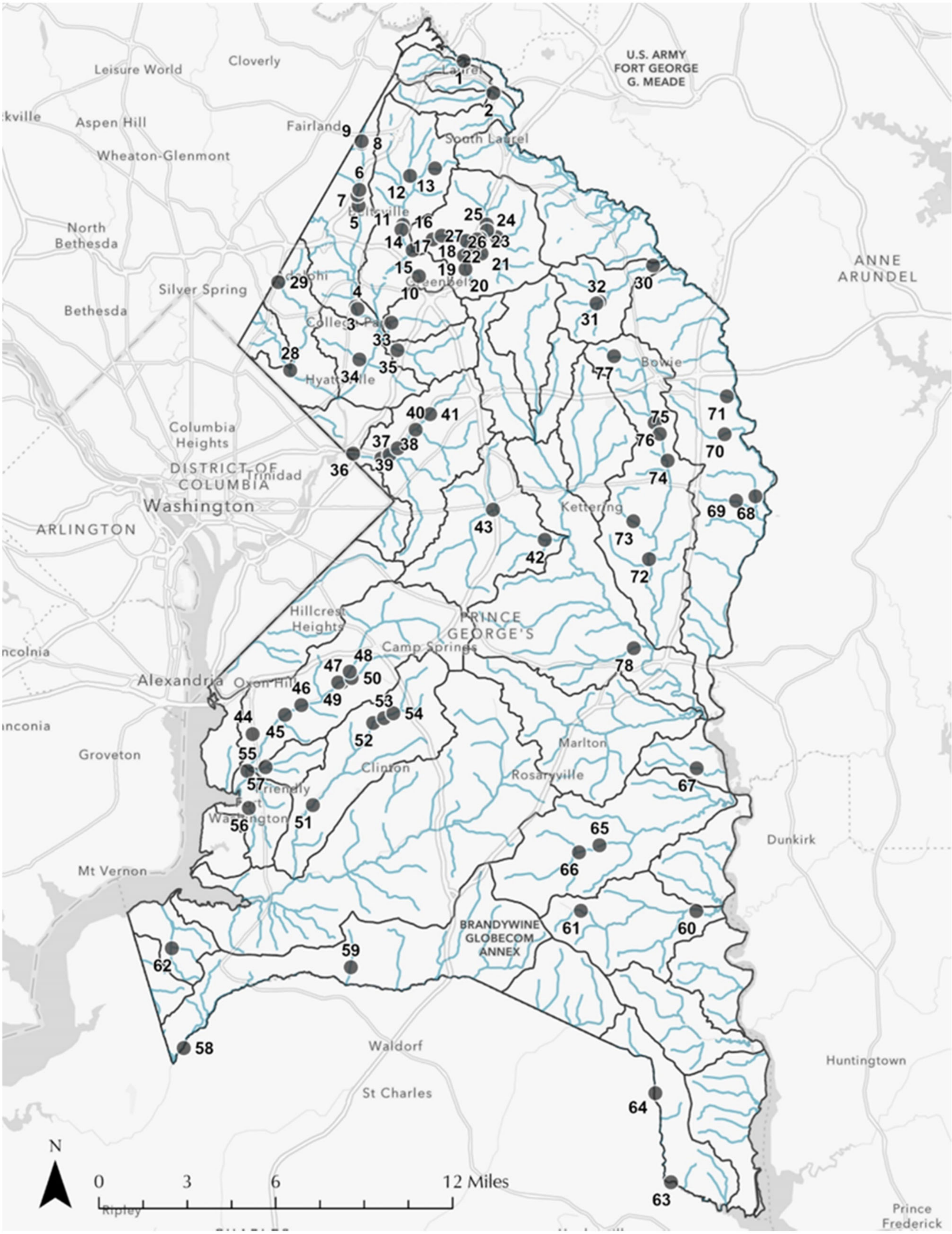

FIGURE 2 Spatial distribution of stream sites ($n = 78$) throughout Prince George's County (Maryland) evaluated. Site numbers are cross-reference to Site identification numbers and stream names in Table 2. [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Uncertainty ratings (UR) of sites for which the field teams were able to locate the original XS monument are 0 (high uncertainty—original monument not found), 1 (moderate uncertainty), and 2 (low uncertainty—original monument found).

No.	Station ID	Stream name	UR	No.	Station ID	Stream name	UR
1	03-001	Walker Branch	2	40	19-025	L. Beaverdam Creek	2
2	04-005	Bear Branch	2	41	19-036	L. Beaverdam Creek	2
3	05-001	Paint Branch	2	42	21-005	Southwest Branch	0
4	05-001A	Paint Branch	2	43	21-011	Southwest Branch	2
5	05-019B	Little Paint Branch	2	44	24-002	Carey Branch	2
6	05-019C	Little Paint Branch	2	45	24-007	Henson Creek	0
7	05-019D	Little Paint Branch	2	46	24-009	Henson Creek	0
8	05-027	Little Paint Branch	0	47	24-019	Henson Creek	1
9	05-027A	Little Paint Branch	0	48	24-020	Henson Creek	2
10	07-011	UT to Indian Creek	2	49	24-039	UT/Henson Creek	0
11	07-015A	Indian Creek	0	50	24-041	UT/Henson Creek	0
12	07-028	UT to Indian Creek	1	51	25-005	Tinkers Creek	1
13	07-035	UT to Indian Creek	2	52	25-020A	Tinkers Creek	2
14	07-038	Indian Creek	0	53	25-020B	Tinkers Creek	2
15	08-001	U. Beaverdam Creek	2	54	25-020C	Tinkers Creek	1
16	08-001B	U. Beaverdam Creek	0	55	28-003	Broad Creek	2
17	08-003	U. Beaverdam Creek	0	56	28-007	UT to Broad Creek	2
18	08-014	UT/U. Beaverdam Ck.	0	57	29-003	Hunters Mill Branch	0
19	08-016	UT/U. Beaverdam Ck.	1	58	31-004B	Mattawoman Creek	1
20	08-018	UT/U. Beaverdam Ck.	1	59	31-025	UT/Mattawoman Ck.	2
21	08-022	Beck Branch	0	60	32-003	Spice Branch	1
22	08-035A	U. Beaverdam Creek	0	61	32-028	Rock Creek	0
23	08-035B	U. Beaverdam Creek	0	62	33-007	Piscataway Creek	1
24	08-039	U. Beaverdam Creek	0	63	37-007B	County Line Creek	0
25	08-044	UT/U. Beaverdam Ck.	0	64	37-011B	County Line Creek	0
26	08-046A	UT/U. Beaverdam Ck.	0	65	38-023	Mataponi Creek	2
27	08-065A	Beck Branch	0	66	38-027	Mataponi Creek	2
28	09-005	Northwest Branch	0	67	39-042A	Swan Point Creek	0
29	09-009	Northwest Branch	2	68	39-075	Honey Branch	2
30	10-001	Horsepen Branch	0	69	39-080	Mount Nebo Branch	2
31	10-009	Horsepen Branch	1	70	39-084	Mill Branch	1
32	10-011	Horsepen Branch	1	71	39-092	Green Branch	1
33	12-011	UT/Northeast Br.	1	72	40-013	Collington Branch	2
34	15-003A	UT to Northeast Br.	0	73	40-016	Black Branch	1
35	16-001	Brier Ditch	2	74	40-031	Collington Branch	1
36	19-003	L. Beaverdam Creek	0	75	40-035	Collington Branch	1
37	19-005	L. Beaverdam Creek	0	76	40-037	Collington Branch	1
38	19-006	Cabin Branch	0	77	40-047	Collington Branch	1
39	19-023A	L. Beaverdam Creek	1	78	41-009	Federal Spring Br	0

Note: Label identification numbers (No.) are shown in Figure 2, where they identify the station ID and stream names for which cross sections were evaluated.
Abbreviation: UT, unnamed tributary.

where, ΔXSa is change in XSa in ft^2, 1 is channel length in feet, B is the conversion factor (bulk density), and T is the number of years elapsed between two separate XS surveys.

Note that a fraction of each of the soil cores was also analyzed for nutrient content, although not evaluated in this paper. Results are given in Appendix A for Total Nitrogen (TN [mg/L]), Total Kjeldahl

Nitrogen (TKN [mg/L]), Nitrate-Nitrite (NOx, as N [mg/L]), and Total Phosphorus (TP, as P [mg/L]).

A pebble count was conducted at each cross section reach to determine the D50 of bed material for the 100 m stream assessment reach, and to contribute to channel classification. A 100 m tape was laid along the edge of the water of the stream reach following the meander pattern of the stream centerline with the monumented cross section positioned at the 50 m mark. A pebble count was recorded every 10 m within the 100 m stream reach which included the monumented cross section at the 50 m midpoint. The modified Wolman 100-particle pebble count was measured at each transect, where the intermediate axis of 10 random pebbles was measured.

5 | RATING CROSS SECTIONS BASED ON DISCOVERY (UNCERTAINTY OF VISIT LOCATIONS)

A rating system was applied to each XS representing the confidence of the field crew in locating the original monumented cross sections. The rating system uses the numbers 0, 1, and 2. A rating of 0 (high uncertainty) means that the field crew was unable to verify the location of the original cross section based on historic data. This may be because photographed landmarks are no longer present or visible, bank erosion has eliminated the original location of monuments, or the error of equipment utilized to record the GPS coordinates of the original cross section monuments made it difficult to determine the exact location. In these instances, the XS profile was taken at the approximate reach midpoint, near the 50 m mark. A rating of 1 (moderate uncertainty) indicates that the original cross section was not located but indicators were present to suggest that the location of a new cross section is near the original location. A rating of 2 (low uncertainty) indicates that the field crew found the original location through discovery of the original cross-section monuments or photographed landmarks identified in the field. Overlays of the historic and current cross-sectional surveys were analyzed to verify the rating of 2. Use and application of this rating system (Table 2) resulted in 39.7% of the XS site locations ($n = 31$, 0) being rated as high uncertainty; 25.6% ($n = 20$, 1) rated as moderate, and 34.6% ($n = 27$, 2) as low.

6 | PRECIPITATION

Rainfall data were downloaded for a 29-year period (1990–2019) from the weather station at Thurgood Marshall/Baltimore-Washington International Airport (BWI) (NCEI, 2021). Data are housed and managed by the National Center for Environmental Information (NCEI) of the National Oceanographic and Atmospheric Administration (NOAA). The network and station identification are GHCND: USW00093721 (39.1733°, −76.684°). Note that there were insufficient metadata for the 1990–1995 records, so we used data from 1996 to 2020, 24 years. We combined daily records to monthly totals for graphic displays with monthly medians to allow for inter- and intra-annual comparisons, and to serve as a baseline for subsequent geomorphic surveys that may seek to relate increases in magnitude and frequency of storm events to changes in channel dimensions (Dupigny-Giroux et al., 2018).

7 | LAND USE, LAND COVER, AND SOILS

We developed a geodatabase containing land use/land cover (LULC) data and soils information by watershed. The drainage area for each location was delineated, and the LULC and soils information spatially-associated with each surveyed reach, providing a set of descriptors of conditions contributing to in-channel characteristics. LULC data were downloaded and processed for 7 years, including 2001, 2004, 2006, 2008, 2011, 2013, and 2016. Soils data were extracted from the National Hydrography Dataset[ii] (NHD) for each watershed using a 25 m buffer around all 2019 NHDplus flowlines, linked with the Natural Resources Conservation Service Web Soil Survey[iii] (NRCS, 2021, WSS). There are no soils data for PG32_003 because data were constrained by a 25 m buffer around the NHD and there is no NHD feature in that watershed. The geodatabase provides the area of (1) each soil type with slope characteristics in each watershed, and (2) each watershed based on hydrologic soil group dominant condition.

The project geodatabase contains the following:

1. PG_County_Cross_Section_Watersheds_20210119: polygon of the initial watersheds file.
2. AOI: polygon of the total project boundary (area of interest) used to clip the land use prior to projecting in the appropriate coordinate system.
3. NLCD rasters: one for each year clipped to the AOI extent and projected in the watersheds coordinate system (NAD_1983_Contiguous_USA_Albers).
4. Land Use tables: one for each year containing the land use areas by watershed.
5. NLCD polygons: one for each year of land use where the land use tables were joined to the watersheds polygon.
6. Soils_All: polygon file with the soils clipped to the entire watershed project boundary.
7. Soils_clip_hydrgp: polygon file with soils data clipped to the 25-meter NHD buffer and dissolved by hydrological group classification.
8. Soilhydgrp_Watershed: table containing the hydrological group calculations by watershed within the clipped buffer area.
9. Soils_clip_NameSlope: polygon file with soils data clipped to the 25 m NHD buffer and dissolved by soil name classification with slope characteristics.
10. SoilName_Watershed: table containing the calculations by the watershed of soil name classification with slope characteristics within the clipped buffer area.
11. NHDplus_Flowline_2019: line file of merged NHD flowlines for the entire AOI.

TABLE 3 Stream channel cross-sectional area (XSa) measured in square feet (ft^2) at bankfull (BF) and full transects.

Stream name	SiteID	Year	BF Xsa	BF Xsa_delta	Full Xsa	Full Xsa_delta	Sed. Yield (tons/yr.)
Walker Branch	03-001	2000	31.7		105.8		
Walker Branch	03-001	2020	25.3	−6.4	69.2	−36.6	−0.06
Bear Branch	04-005	2000	61.2		80.8		
Bear Branch	04-005	2020	66.2	5	128.5	47.7	0.004[a]
Paint Branch	05-001	2001	225.2		225.2		
Paint Branch	05-001	2020	276.5	51.3	460.6	235.4	0.32
Paint Branch	05-001A	2004	160		313.6		
Paint Branch	05-001A	2020	209.5	49.5	433.7	120.1	0.17
Little Paint Branch	05-019B	2001	73		138		
Little Paint Branch	05-019B	2020	87.8	14.8	304.2	144.1	0.22
Little Paint Branch	05-019C	2001	115.8		257.4		
Little Paint Branch	05-019C	2004	121.8	6	121.8	−135.6	−1.3
Little Paint Branch	05-019C	2020	88.6	−27.2	141.1	−116.3	−0.2
Little Paint Branch	05-019D	2004	84.6		116.6		
Little Paint Branch	05-019D	2020	87.4	2.8	139.3	22.7	0.04
Little Paint Branch	05-027	2001	68		84.2		
Little Paint Branch	05-027	2020	87.8	19.8	171.9	87.7	0.15
Little Paint Branch	05-027A	2004	62.8		96.7		
Little Paint Branch	05-027A	2020	88.3	25.5	245.6	148.9	0.30
Indian Creek	07-011	2005	35.1		43.9		
Indian Creek	07-011	2020	21.3	−13.8	44.7	0.08	0.0001
Indian Creek	07-015A	2004	68.8		84.5		
Indian Creek	07-015A	2020	50.9	−17.9	53.1	−31.4	−0.003[a]
Indian Creek	07-028	2003	5.7		5.7		
Indian Creek	07-028	2020	23.9	18.2	29.5	23.8	0.002[a]
Indian Creek	07-035	2003	14.2		23.4		
Indian Creek	07-035	2004	14.6	0.4	20.7	−2.7	−0.08
Indian Creek	07-035	2020	15	0.8	39.1	15.7	0.03
Indian Creek	07-038	2003	17.9		17.9		
Indian Creek	07-038	2020	39.3	21.4	39.3	21.4	0.04
Beaverdam Creek	08-001	2000	49.4		74.2		
Beaverdam Creek	08-001	2020	58.9	9.5	80.7	6.5	0.01
Beaverdam Creek	08-001B	2004	44.9		78.9		
Beaverdam Creek	08-001B	2020	57.8	12.9	121.6	42.7	0.005[a]

(Continues)

TABLE 3 (Continued)

Stream name	SiteID	Year	BF Xsa	BF Xsa_delta	Full Xsa	Full Xsa_delta	Sed. Yield (tons/yr.)
Beaverdam Creek	08-003	2004	27.6		72		
Beaverdam Creek	08-003	2020	30.8	3.2	167	95	0.17
Beaverdam Creek	08-014	2000	29.1		76.1		
Beaverdam Creek	08-014	2004	40.3	11.2	141.5	65.4	0.49
Beaverdam Creek	08-014	2020	32.8	3.7	60	−16.1	−0.02
Beaverdam Creek	08-016	2004	19.4		49.7		
Beaverdam Creek	08-016	2020	90.4	71	90.4	40.7	0.07
Beaverdam Creek	08-018	2000	11.2		40.7		
Beaverdam Creek	08-018	2020	21.3	10.1	64.6	23.9	0.03
Beck Branch	08-022	2000	12.8		12.8		
Beck Branch	08-022	2020	13.7	0.9	27.3	14.5	0.01
Upper Beaverdam Creek	08-035A	2000	40.1		67.3		
Upper Beaverdam Creek	08-035A	2020	47.1	7	73.6	6.3	0.01
Upper Beaverdam Creek	08-035B	2004	40.6		80.2		
Upper Beaverdam Creek	08-035B	2020	54.2	13.6	54.2	−26	−0.04
Upper Beaverdam Creek	08-039	2000	10.9		11.4		
Upper Beaverdam Creek	08-039	2020	11.7	0.8	14.3	2.9	0.002
Upper Beaverdam Creek	08-044	2000	16.5		44.9		
Upper Beaverdam Creek	08-044	2020	27	10.5	66.1	21.2	0.02
Upper Beaverdam Creek	08-046A	2004	35.1		64.7		
Upper Beaverdam Creek	08-046A	2020	52	16.9	58.9	−5.8	−0.01
Beck Branch	08-065A	2004	25.8		89.7		
Beck Branch	08-065A	2020	19.8	−6	45.4	−44.3	−0.06
Northwest Branch	09-005	2004	143.4		406.4		
Northwest Branch	09-005	2020	169.5	26.1	738.6	332.2	0.47
Northwest Branch	09-009	2004	191.3		406.4		
Northwest Branch	09-009	2020	254.3	63	509.7	103.3	0.12
Horsepen Branch	10-001	2002	37		42.7		
Horsepen Branch	10-001	2020	103.4	66.4	141.3	98.6	0.12
Horsepen Branch	10-009	2002	13.7		20.3		
Horsepen Branch	10-009	2020	30.1	16.4	139.5	119.2	0.21
Horsepen Branch	10-011	2002	7.6		10.4		
Horsepen Branch	10-011	2020	10.3	2.7	56.4	46	0.06

TABLE 3 (Continued)

Stream name	SiteID	Year	BF Xsa	BF Xsa_delta	Full Xsa	Full Xsa_delta	Sed. Yield (tons/yr.)
Northeast Branch	12-011	2004	72.8		192.9		
Northeast Branch	12-011	2020	69.5	−3.3	218.9	26	0.05
Northeast Branch	15-003A	1999	52.1		75		
Northeast Branch	15-003A	2004	55.1	3	148.9	73.9	0.03[a]
Northeast Branch	15-003A	2020	60.2	8.1	207.8	132.8	0.01[a]
Brier Ditch	16-001	2004	58.7		270.5		
Brier Ditch	16-001	2010	58.9	0.2	284	13.5	0.05
Brier Ditch	16-001	2020	118.4	59.7	231.3	−39.2	−0.06
Lower Beaverdam Creek	19-003	2000	270		293.5		
Lower Beaverdam Creek	19-003	2005	268.3	−1.7	287.8	−5.7	−0.03
Lower Beaverdam Creek	19-003	2020	265	−5	444.4	150.9	0.17
Lower Beaverdam Creek	19-005	2002	107.8		107.8		
Lower Beaverdam Creek	19-005	2020	177.9	70.1	301.9	194.1	0.30
Lower Beaverdam Creek	19-006	2002	75.5		75.5		
Lower Beaverdam Creek	19-006	2020	99.6	24.1	308.8	233.3	0.30
Lower Beaverdam Creek	19-023A	2001	62.2		284.2		
Lower Beaverdam Creek	19-023A	2020	107.6	45.4	427.4	134.2	0.19
Lower Beaverdam Creek	19-025	2002	94.9		301.2		
Lower Beaverdam Creek	19-025	2020	119.8	24.9	409.4	108.2	0.13
Lower Beaverdam Creek	19-036	2002	36		115.7		
Lower Beaverdam Creek	19-036	2020	40.2	4.2	135.5	19.8	0.02
Western Branch	21-005	2003	105.8		203.8		
Western Branch	21-005	2020	114.9	9.1	223.4	19.6	0.03
Western Branch	21-011	2003	127.4		318.9		
Western Branch	21-011	2020	120.1	−7.3	398.8	79.9	0.01[a]
Carey Branch	24-002	2000	35.3		55.3		
Carey Branch	24-002	2020	34	−1.3	50.5	−4.8	−0.01
Henson Creek	24-007	2000	97.9		129.3		
Henson Creek	24-007	2020	110.7	12.8	190.4	61.1	0.07
Henson Creek	24-009	2000	200.8		258.3		
Henson Creek	24-009	2020	206.3	5.5	236.6	−21.7	−0.03
Henson Creek	24-019	2000	124.2		237.7		
Henson Creek	24-019	2020	138.7	14.5	236.9	−0.8	−0.001

(Continues)

TABLE 3 (Continued)

Stream name	SiteID	Year	BF Xsa	BF Xsa_delta	Full Xsa	Full Xsa_delta	Sed. Yield (tons/yr.)
Henson Creek	24-020	2000	88.4		88.4		
Henson Creek	24-020	2020	93.5	5.1	113.2	24.8	0.03
Henson Creek	24-039	2000	54.6		95.4		
Henson Creek	24-039	2020	75.2	20.6	95.4	0	0
Henson Creek	24-041	2000	26.3		80.2		
Henson Creek	24-041	2020	34.2	7.9	152.1	71.9	0.01[a]
Tinkers Creek	25-005	2001	143		317		
Tinkers Creek	25-005	2020	162.9	19.9	185.8	−131.2	−0.15
Tinkers Creek	25-020A	2001	47.5		47.8		
Tinkers Creek	25-020A	2020	31.8	15.7	31.8	−16	−0.02
Tinkers Creek	25-020B	2001	52.5		52.5		
Tinkers Creek	25-020B	2020	48.1	−4.4	48.1	−4.4	−0.01
Tinkers Creek	25-020C	2001	81		101.7		
Tinkers Creek	25-020C	2020	76.9	−4.1	76.9	−24.8	−0.03
Henson Creek	28-003	2000	174.6		220.4		
Henson Creek	28-003	2020	208.7	34.1	243.1	22.7	0.03
Broad Creek	28-007	2000	51.2		143		
Broad Creek	28-007	2020	45.4	−5.8	198.9	55.9	0.005[a]
Hunters Mill Branch	29-003	2000	29.2		35.7		
Hunters Mill Branch	29-003	2020	28.4	−0.8	228.9	193.2	0.23
Mattawoman Creek	31-004B	2003	23.3		85.9		
Mattawoman Creek	31-004B	2020	21.8	−1.5	76	−9.9	−0.001[a]
Mattawoman Creek	31-025	2003	16.2		44.7		
Mattawoman Creek	31-025	2020	19.5	3.3	70.8	26.1	0.05
Spice Branch	32-003	2001	26		32.2		
Spice Branch	32-003	2020	28.4	2.4	30.7	−1.5	−0.0001[a]
Rock Creek	32-028	2001	25		61.5		
Rock Creek	32-028	2020	29.3	4.3	53.2	−6.3	−0.01
Piscataway Creek	33-007	2000	23.8		26.1		
Piscataway Creek	33-007	2020	31.6	7.8	55.9	29.8	0.04
County Line Creek	37-007B	2001	18.3		50.6		
County Line Creek	37-007B	2020	34.6	16.3	191.9	141.3	0.21

TABLE 3 (Continued)

Stream name	SiteID	Year	BF Xsa	BF Xsa_delta	Full Xsa	Full Xsa_delta	Sed. Yield (tons/yr.)
County Line Creek	37-011B	2001	23.9		71.5		
County Line Creek	37-011B	2020	28.8	4.9	112.8	41.3	0.05
Mataponi Creek	38-023	2002	53.7		76.4		
Mataponi Creek	38-023	2020	58	4.3	129.5	53.1	0.08
Mataponi Creek	38-027	2002	50		39.6		
Mataponi Creek	38-027	2020	39.6	−10.4	75.5	35.9	0.04
Swan Point Creek	39-042A	2002	7.3		26.7		
Swan Point Creek	39-042A	2020	12.1	4.8	129.6	102.9	0.12
Honey Branch	39-075	2002	12.7		13.9		
Honey Branch	39-075	2020	15	2.3	193.7	179.8	0.26
Mt. Nebo Branch	39-080	2002	16.7		127.9		
Mt. Nebo Branch	39-080	2020	34.1	17.4	279.5	151.6	0.21
Mill Branch	39-084	2002	40		200.9		
Mill Branch	39-084	2020	46	6	231.9	31	0.05
Green Branch	39-092	2002	20.8		259.1		
Green Branch	39-092	2020	42	21.2	226.8	−32.3	−0.04
Collington Branch	40-013	2003	75.9		199.6		
Collington Branch	40-013	2020	89.3	13.4	212.9	13.3	0.02
Black Branch	40-016	2000	26.9		101.5		
Black Branch	40-016	2005	26.9	0	135.1	33.6	0.11
Black Branch	40-016	2020	42.7	15.8	122.7	20.5	0.02
Collington Branch	40-031	2003	22		67.6		
Collington Branch	40-031	2020	23.9	1.9	83.2	15.6	0.02
Collington Branch	40-035	2003	33.1		95.5		
Collington Branch	40-035	2020	64.1	31	101.6	6.1	0.01
Collington Branch	40-037	2003	33.4		35.7		
Collington Branch	40-037	2020	53.2	19.8	53.2	17.5	0.01
Collington Branch	40-047	2003	12		46		
Collington Branch	40-047	2020	7.2	−4.8	12	−34	−0.04
Federal Spring Branch	41-009	2001	32.4		103.8		
Federal Spring Branch	41-009	2020	29.8	−2.6	99	−4.8	−0.01

Note: "Delta" is the change in area across the time intervals (year). Sediment yield is calculated using change in full XSa, and by converting the volume (tons) of sediment lost (degradation) or gained (aggradation) into annual changes. One (1) ton = 0.907185 metric tons. See Table 2 for crosswalk between Site ID and Site no.

[a] Indicate SY values calculated using a regional average bulk density, rather than site-specific.

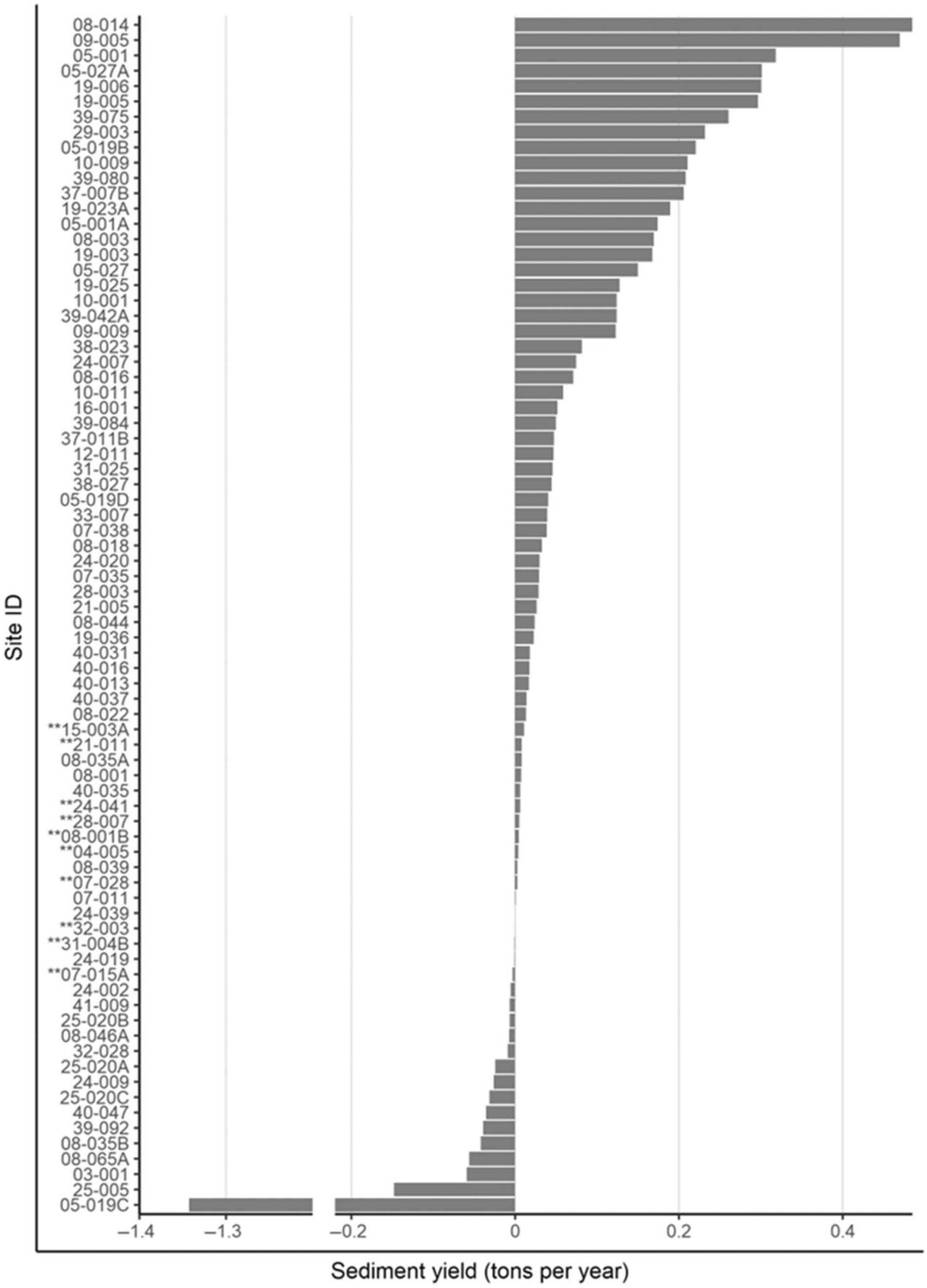

FIGURE 3 Sediment yield (tons/year) with sites sorted in descending order, top to bottom, along y-axis. Those sites with the greatest yield (loss) are at the top of the graph. SY for site ID with trailing asterisk (*) is calculated with regional average soil density.

12. NHDplus_Flowline_2019_Clip: line file of flowlines clipped to the watersheds.
13. NHDplus_Flowline_2019_Buffer: polygon file of NHD 25 m buffer.

LULC categories were developed by summing spatial area into three aggregated categories. Low-, medium-, and high-intensity developed land use were summed to DEVELOPED; deciduous, evergreen, mixed, shrub/scrub, and herbaceous were summed to FORESTED; and hay/pasture and cultivated crops, to CULTIVATION. We ran land use temporal trend plots for the upstream watershed of each geomorphic reach (site), as well as a bar chart showing a county-wide summary of the same data. The NRCS (2007) categorizes soils by hydrologic groups defined by similar infiltration and runoff characteristics, and we summarized soil conditions in each subwatershed by the dominant group. Soils with the lowest infiltration rates and poorly drained tend to have a higher content of clay, whereas those with the highest infiltration rates are well-drained and tend to be sandy. The four hydrologic soil groups are, as defined by NRCS, as follows:

- Group A—high infiltration rates; usually deep, well-drained sands or gravels typically with little runoff potential.
- Group B—moderate infiltration rates; usually moderately deep and well-drained soils.

TABLE 4 Natural fluvial/geomorphic processes in stream channels include both degradation (erosion) and aggradation (deposition).

Site no.	Site ID	Stream name	Year A	Year B	Sed. yield (tons/yr)	ΔXSa (%)
Degradation/Channel enlargement						
3	05-001	Paint Branch	2001	2020	0.32	51.1
5	05-019B	Little Paint Branch	2001	2020	0.22	47.4
9	05-027A	Little Paint Branch	2004	2020	0.30	60.6
18	08-014	Beaverdam Creek	2004	2020	0.49	46.2
28	09-005	Northwest Branch	2004	2020	0.47	45.0
31	10-009	Horsepen Branch	2002	2020	0.21	85.4
37	19-005	Lower Beaverdam Ck.	2001	2020	0.30	64.3
38	19-006	Lower Beaverdam Ck.	2002	2020	0.30	75.6
57	29-003	Hunters Mill Branch	2000	2020	0.23	84.4
68	39-075	Honey Branch	2002	2020	0.26	92.8
Aggradation/channel reduction						
1	03-001	Walker Branch	2000	2020	−0.06	−52.9
6	05-019C	Little Paint Branch	2004	2020	−1.34	−111.3
23	08-035B	Upper Beaverdam Ck.	2004	2020	−0.04	−48.0
27	08-065A	Beck Branch	2004	2020	−0.06	−97.6
46	24-009	Henson Creek	2000	2020	−0.03	−9.2
51	25-005	Tinkers Creek	2001	2020	−0.15	−70.6
52	25-020A	Tinkers Creek	2001	2020	−0.02	−50.3
54	25-020C	Tinkers Creek	2001	2020	−0.03	−32.2
71	39-092	Green Branch	2002	2020	−0.04	−14.2
77	40-047	Collington Branch	2002	2020	−0.04	−283.3

Note: Of the 78 reaches re-visited for this study, these 20 were the most active in terms of accelerated processes and sediment loss and gain. ΔXSa is change in cross-sectional area, presented as percentage (%). "Site no." is used to label map locations in Figure 2.

- Group C—slow infiltration rates; typically have finer textures with slow water movement.
- Group D—very slow infiltration rates; high clay content with poor drainage, and usually high runoff potential.

Within the County soils information, there are also included two dual groups: B/D and C/D. The first letter signifies the group in drained conditions, and the second in undrained conditions.

8 | RESULTS AND DISCUSSION

8.1 | Sediment yield

Of the 78 reaches evaluated, seven had 3 XS surveys and the remaining reaches had 2 XS surveys (for graphical representation, see Appendix B). The magnitude of changes in XSa range from -135.6 to 332.2 ft^2 (=-12.6 to 30.9 m^2) with negative values indicating reduction (deposition) and positive values, enlargement (erosion) (Table 3). There are 24.4% of the XS experiencing increased sediment deposition ($n = 19$), while 74.4% are unstable and undergoing sediment loss ($n = 58$). There is 1.3% ($n = 1$) of the reaches that is apparently stable, *Henson Creek* (site 24-039), indicators suggesting there has been little to no change in channel XS morphology over the 15–21-year interval. For those stream reaches eroding as demonstrated by increases in XSa, sediment yield ranges from 1.4×10^{-4} to 0.47 tons per year, while those with decreases in XSa have sediment deposition at rates of 1.4×10^{-4} to 0.18 tons per year.

Using calculated sediment yields, we arranged reaches in ascending order (Figure 3), graphically illustrating the majority of those evaluated in this study are experiencing accelerated erosion. Further, we isolated the 20 most geomorphically active reaches in terms of active enlargement or reduction (Table 4). Spatially partitioning the channels, 10 are in the northwestern part of the County in the Anacostia River basin, five are in the Patuxent River basin, and five are in Potomac River basin (Figure 4). The largest number of degrading channels ($n = 7$) is in the Anacostia River basin; there are two in the Patuxent River basin (*Horsepen Branch* [site 10–009], *Honey Branch* [39–075]); and one in the Potomac River basin (*Hunters Mill Branch* [29–003]). Of the 10 channel reaches most actively aggrading, four are in the Potomac River basin, and three each in the Anacostia and Patuxent River basins. Two examples in the Anacostia are *Little Paint Branch* (site 05-019C) and *Beck Branch* (site 08-065A); and in the Patuxent, *Walker Branch* (site 03-001) and *Collington Branch* (site 40-047). Streams and

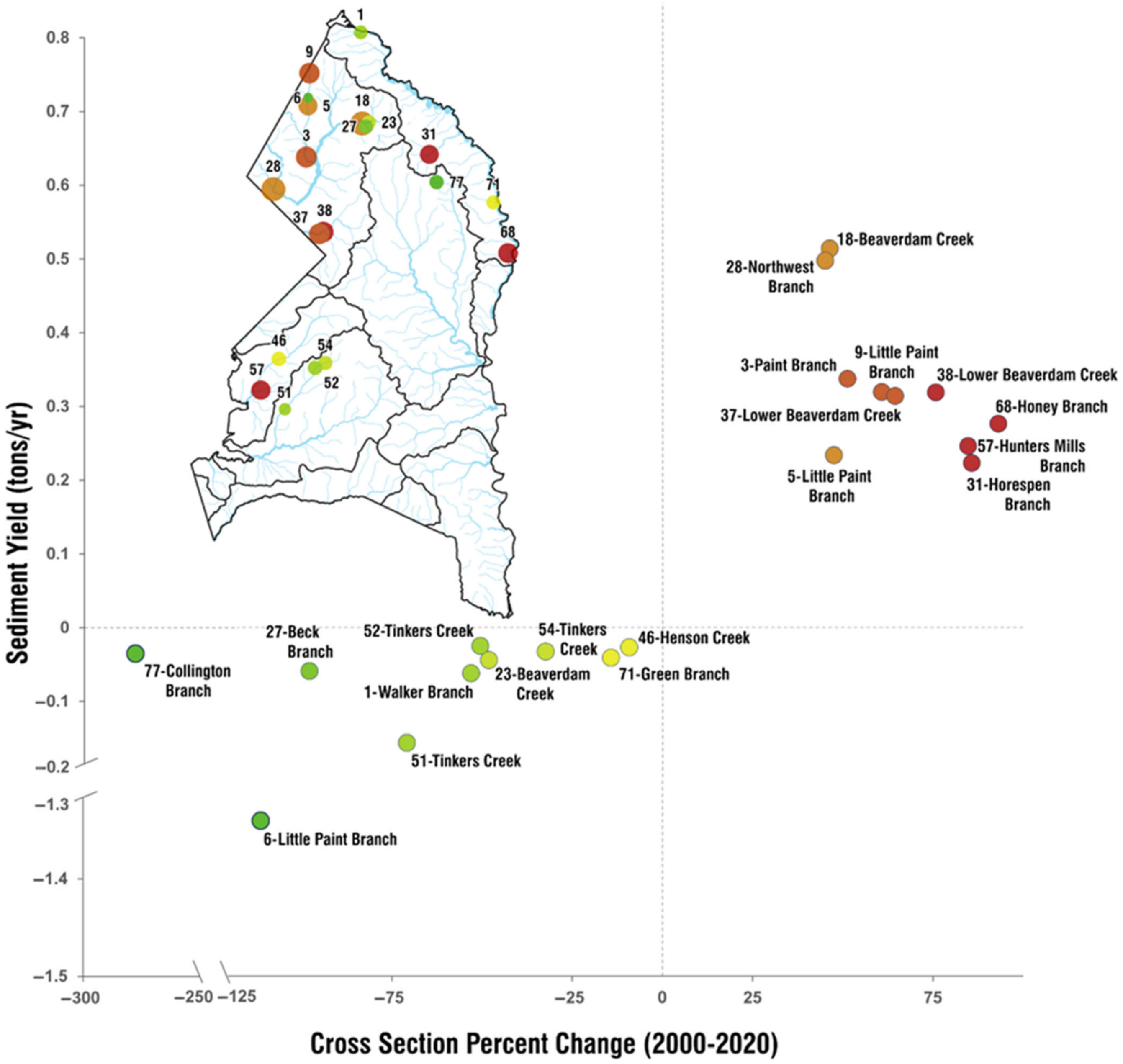

FIGURE 4 Locations of the most geomorphically active channels evaluated in this study in Prince George's County. Channels undergoing accelerated erosion (degradation) are in the upper right portion of the graph (brown to gold); those in the process of accelerated sediment deposition (reduction) are yellow to green in the lower left. [Color figure can be viewed at wileyonlinelibrary.com]

watersheds of the south/southeastern regions of the County are apparently relatively more stable than those in other regions, largely agreeing with observations of the spatial distribution and extent of stream biological degradation.

We examined the relationship between watershed area (km^2) and ASY (tons/year). Jayakaran et al. (2013) stated that watersheds with erosion rates in dynamic equilibrium, that is, with a minimum of human-induced accelerated erosion, will have what can be considered normal geomorphic activity. Given that, even normal rates of erosion and sedimentation will attenuate for areas of the watersheds with larger drainage areas. They further suggest that should the observed relationship between those variables be weak, a conclusion of human influence could be determined, at least in part. The weak correlation shown by the low R^2 resulting from our analysis ($R^2 = 0.002$ [$y = 0.0321 + 0.0079^*x$]; $p = 0.6822$) seems to align with their suggestion, that is, human influence has disrupted normal geomorphic processes.

8.2 | Substrate particle size

Pebble counts provide a description of substrate particle size distribution in channel reaches. Cumulative distribution curves (Appendix C) from current and historical pebble counts provide information for reach-specific interpretation. For example, the 2004 and 2020 *Northwest Branch* 09-005 results chart similarly. Although the median particle size (D50) fell within the different size classes (Table 5) of very coarse gravel and small cobble, respectively, examination of the full curve suggests relative stability.

8.3 | Geomorphic classification

Comparison of fluvial geomorphic conditions using the Rosgen (1994) classification system organizes several pieces of data and information to help interpret relative stream channel stability, including entrenchment ratio, width:depth ratio, sinuosity, slope, and substrate characteristics (Table 5). Results from current and historical data showed that 45 reaches were classified as having experienced little to no change. That group includes streams that were originally categorized (Time A) as being unstable or stable with a similar classification in 2020 (Time B). Elevated channel instability is generally associated with F- and G-type channels, and those of relative geomorphic stability, E-, C-, and B-type channels. We compared classifications from the original field geomorphic characterization to those taken in 2020 (Table 5). Combining them by different stability narratives suggests that 57.7% ($n = 45$) are similar (channel type changes C >> > B, F >> > G, and G >> > F) between Time A and B or have not changed (Table 5). Twenty-three (23; 30.8%) of the channels have become less stable, with E-type channels changing to B, C, F, and G, along with C >> > F and B >> > G, and there are nine (9; 11.5%) that became more stable: F-type channels changing to B, C, and E; and G-types changing to B and E.

Based on changes in geomorphic channel forms (Rosgen-type categories [1994]), there are 21 reaches that have increased channel instability over the period of record. Of those, 13 are in the **Anacostia River** watershed: *Paint Branch* (05-001, 05-001A), *Little Paint Branch* (05-019C, 05-027, 05-027A), *Upper Beaverdam Creek* (08-001, 08-001B, 08-035A, 08-035B, 08-003), and *Lower Beaverdam Creek* (19-005, 19-006, 19-036). Six are in the **Patuxent River** basin: *Bear Branch* (04-005), *Mill Branch* (39-084), *County Line Creek* (37-007B), *Mataponi Creek* (38-023), *Honey Branch* (39-075), and *Collington Branch* (40-037). There are two in the **Potomac River (non-Anacostia) watershed**, one each in *Piscataway Creek* (33-007) and *Mattawoman Creek* (31-004B).

McCandless (2003) performed field geomorphic measurements and Rosgen classifications at a series of coastal plains streams in the mid-Atlantic region which were (and presumably still are) hosting US Geological Survey gauging stations. The purpose of her survey was to develop regional curves for the mid-Atlantic coastal plain and the stream types for the 14 locations were all E ($n = 6$) and C ($n = 8$), two of the more stable types in the Rosgen classification system. As discussed, in their current conditions, streams characterized in this study represent classes B, C, E, F, and G. Exactly 50% of the XS surveyed ($n = 39$) are E- and C-type channels. The makeup of the dataset relative to that of McCandless (2003) may be related to the different purposes and thus designs of the two projects. Where her study focused on appropriate sites co-located with gauging stations, this one is largely based on selecting sites using a stratified-random approach demonstrating a difference in generalizability of the two datasets.

8.4 | Precipitation

The mean annual precipitation recorded at BWI is 43.9″ over the 24-year period, ranging in that time from a low of 27.8″ in 1998, to the high of 71.8″ in 2018. The nine wettest years occurred in the 14-year period from 2004 to 2018. It appears as if the magnitude of precipitation and storm events increased in the 2003–04 timeframe, continuing to present. However, a substantially longer period is needed, several decades if not a century or more and including data from Camp Springs (Joint Base Andrews, Air Force Base), as well as National and Dulles, to be more informative and provide insight into broader climate change-related issues.

8.5 | Land use

The principal focus of this land use (LU) analysis is on changes in three land use/cover types over a 17-year time interval, from 2001 to 2016: developed, forested, and cultivation. The surface area (km^2) upstream of each XS reach evaluated was delineated, clipped with GIS, and merged with NLCD to associate with appropriate data. To obtain values for each XS and year, we summed areas of different LU categories to obtain total areas. For developed LU, we summed low, medium, and high-intensity development; for forested, we summed deciduous, evergreen, mixed, shrub/scrub, and herbaceous; and for cultivation, hay/pasture, and crops. Location specific temporal comparisons depicted as bar charts are provided in Appendix D. We sorted sites by ascending or descending magnitude of area change in km^2 (Table 7) in developed, forested, and cultivated land cover.

Increases in developed area range from no change to just below 5 km^2. Sites in this study that had no to very little additional development are in areas in the south-southwestern part of the County, including *Mattawoman Creek* (31-025), *Spice Branch* (32-003), *Rock Creek* (32-028 [fig. 11]), unnamed tributary to the *Lower Potomac River* (33-007), and *County Line Creek* (37-011B). Among the sites with the most substantial increase in development are *Western Branch* and *Mattawoman Creek* (41-030 [fig. 12] and 31-004B, respectively) with greater than 4.4 km^2 increases. There are a total of 30 sites in this study that have had >0.5 km^2 increases in developed areas, eight with between 0.25–0.49 km^2 increases, and 49 (of the 87) with increases of <0.25 km^2.

It is expected that those sites/watersheds undergoing increases in developed areas would exhibit corresponding decreases in forest cover. This is illustrated by the top 10 sites having lost forest cover are among the top 15 sites with developed area increases (Table 7). Those subwatersheds undergoing the most active land cover

TABLE 5 Channel geomorphic characteristics for 78 reaches evaluated in this study, including entrenchment ratio (ER), width: depth (W/D) ratio, sinuosity (Sin.), slope (Slp), median substrate particle size (D50, in mm), and Rosgen Class (RC).

SiteID	Yr	ER	W/D	Sin.	Slp	D50	RC	Δ St
03-001	2000	1.3	21	1.51	2.6	99.5	F3c	
03-001	2020	1.2	6	1.51	2.6	66.6	G3c	NC
04-005	2000	2.4	9.8	1.02	0.5	26.7	E4	
04-005	2020	1.6	9.4	1.02	0.5	20.4	G4c	NG
05-001	2001	2.8	23	1.04	0.16	23.4	C4	
05-001	2020	1.5	31.7	1.04	0.16	17.6	F4	NG
05-001A	2004	3.8	17.5	1.03	0.42	22.9	C4	
05-001A	2020	1.5	22.5	1.03	0.42	28	F4	NG
05-019B	2001	2.9	16	1.06	0.7	12.7	C4	
05-019B	2020	2.8	15	1.06	0.7	25.1	C4	NC
05-019C	2001	1.7	24.7	1.1	0.44	43.1	B4	
05-019C	2004	2.7	25.6	1.1	0.44	52.3	C4	NC
05-019C	2020	1.7	10.5	1.1	0.44	35.8	G4c	NG
05-019D	2004	2.9	14.2	1.11	0.61	20.6	C4	
05-019D	2020	3.2	43.4	1.11	0.61	21.8	C4	NC
05-027	2001	5.3	11.6	1.1	0.31	9.14	E4	
05-027	2020	4.2	14.4	1.1	0.31	28	C4	NG
05-027A	2004	5.9	10.2	1.1	0.4	16	E4	
05-027A	2020	4	15.9	1.1	0.4	29.7	C4	NG
07-011	2005	5.2	10.5	1.04	0.34	0.97	E5	
07-011	2020	2.3	11.2	1.04	0.34	0.3	E5	NC
07-015A	2004	2.9	17	1.08	0.32	1.83	C5	
07-015A	2020	3.6	14.9	1.08	0.32	0.25	C5	NC
07-028	2003	2.7	6.3	1.05	1.3	0.0625	E6	
07-028	2020	3.1	11	1.05	1.3	23.5	E4	NC
07-035	2003	1.9	9.5	1.12	0.3	0.203	G5c	
07-035	2004	3.5	9.1	1.12	0.3	0.104	E5	PS
07-035	2020	1.7	12.1	1.12	0.3	0.5	B5c	NG
07-038	2003	3.2	13.3	1.11	0.41	0.75	C5	
07-038	2020	2.2	52	1.11	0.41	8.7	C4	NC
08-001	2000	4.8	8.7	1.01	1	0.2	E5	
08-001	2020	7.1	13.5	1.01	1	1.5	C5	NG

TABLE 5 (Continued)

SiteID	Yr	ER	W/D	Sin.	Slp	D50	RC	Δ St
08-001B	2004	6.8	4.9	1.01	1	0.714	E5	
08-001B	2020	3.4	14.9	1.01	1	1.864	C5	NG
08-003	2004	3.4	39.7	1.1	2	0.0625	C6	
08-003	2020	1.2	29	1.1	2	0.125	F5b	NG
08-014	2000	5.1	13.2	1.1	0.2	0.173	C5	
08-014	2004	1.6	14.5	1.1	0.2	0.148	B5c	NC
08-014	2020	5.2	11.1	1.1	0.2	0.327	E5	PS
08-016	2004	1.4	14.6	1.06	0.5	0.27	F5	
08-016	2020	4.5	5.4	1.06	0.5	0.0625	E6	PS
08-018	2000	1.4	13.4	1.08	1.4	0.104	F5	
08-018	2020	1.2	10.2	1.08	1.4	0.0625	G6c	NC
08-022	2000	3.1	8.9	1.01	0.3	0.206	E5	
08-022	2020	3.7	7.5	1.01	0.3	0.121	E5	NC
08-035A	2004	4.7	11.2	1.21	0.4	0.388	E5	
08-035A	2020	3.3	19.2	1.21	0.4	1.086	C5	NG
08-035B	2004	3.6	6.8	1.16	0.2	0.347	E5	
08-035B	2020	3.3	16.7	1.16	0.2	1.179	C5	NG
08-039	2000	2.8	28.7	1.2	1.1	0.092	C6	
08-039	2020	2.5	13.6	1.2	1.1	0.512	C5	NC
08-044	2000	1.3	10.6	1.2	1.5	0.273	G5c	
08-044	2020	2.4	10.6	1.2	1.5	8	E4	PS
08-046A	2004	4.6	13.7	1.2	0.2	0.367	C5	
08-046A	2020	5.5	6.3	1.2	0.2	1.3	E5	PS
08-065A	2004	1.4	34.3	1.12	0.2	0.381	F5	
08-065A	2020	1.1	9.4	1.12	0.2	0.198	G5c	NC
09-005	2004	1.3	15.8	1.04	0.5	36.85	B4c	
09-005	2020	1.6	24.1	1.04	0.5	69	B3c	NC
09-009	2004	1.4	13.6	1.12	0.4	38.86	F4	
09-009	2020	1.6	8.8	1.12	0.4	75.8	G3c	NC
10-001	2002	3.3	2.2	1.21	0.3	0.211	E5	
10-001	2020	2.7	4.7	1.21	0.3	16	E4	NC
10-009	2002	2.8	2.1	1.22	0.9	0.16	E5	
10-009	2020	1.1	17.5	1.22	0.9	1	F5	NG

(Continues)

TABLE 5 (Continued)

SiteID	Yr	ER	W/D	Sin.	Slp	D50	RC	Δ St
10-011	2002	1.2	1.8	1.1	1.7	0.068	G5c	
10-011	2020	1.2	6.6	1.1	1.7	0.4	G5c	NC
12-011	2004	1.1	20.7	1.01	0.4	28.44	F4	
12-011	2020	1.2	22.2	1.01	0.4	9.2	F4	NC
15-003A	1999	4.7	8.5	1	0.4	N/A	G4c	
15-003A	2004	1.3	10.5	1	0.4	CTC	G4c	NC
15-003A	2020	1.6	8.9	1	0.4	CTC	G4c	NC
16-001	2004	1	37.2	1.44	2	CTC	F4b	
16-001	2010	1.1	30.6	1.44	2	18.5	F4b	NC
16-001	2020	3.9	22	1.44	2	26.3	C4	PS
19-003	2000	3.6	11.4	1.01	0.05	9.8	E4	
19-003	2005	3.6	11.4	1.01	0.05	8	E4	NC
19-003	2020	3.6	11.7	1.01	0.05	5.3	E4	NC
19-005	2002	2.8	3	1.14	0.2	0.03	E5	
19-005	2020	1.3	23	1.14	0.2	11.4	F4	NG
19-006	2002	3.8	2.3	1	0.9	3.3	E4	
19-006	2020	1.4	14.9	1	0.9	14.3	F4	NG
19-023A	2001	1.2	13.1	1.11	0.33	0.102	F5	
19-023A	2020	1.1	15.3	1.11	0.33	1	F5	NC
19-025	2002	3.6	2.4	1.03	0.29	0.198	E5	
19-025	2020	1	15.9	1.03	0.29	1.5	F5	NG
19-036	2002	6.1	2.1	1.08	1.1	0.108	E5	
19-036	2020	1.1	10.2	1.08	1.1	1	G5c	NG
21-005	2003	4.8	16.5	1.32	0.36	0.96	C5	
21-005	2020	4.7	16.1	1.32	0.36	7.7	C4	NC
21-011	2003	1.3	21.2	1.01	0.16	6.4	F4	
21-011	2020	1.5	15.5	1.01	0.16	4519	B1c	PS
24-002	2000	1.7	17.2	1.02	2	45.6	B4	
24-002	2020	1.6	21.6	1.02	2	31.3	B4	NC
24-007	2000	3.2	10.3	1.08	0.64	42	E4	
24-007	2020	3	10.1	1.08	0.64	34.3	E4	NC
24-009	2000	3.3	18.2	1.13	0.14	35.4	C4	
24-009	2020	4.5	21.3	1.13	0.14	33.7	C4	NC

TABLE 5 (Continued)

SiteID	Yr	ER	W/D	Sin.	Slp	D50	RC	Δ St
24-019	2000	3.7	24	1.22	0.31	11	C4	
24-019	2020	3.6	22.2	1.22	0.31	18.1	C4	NC
24-020	2000	4.4	23.2	1	0.5	16	C4	
24-020	2020	2.7	15.2	1	0.5	4413	C1	NC
24-039	2000	4.9	7.5	1.13	0.11	1.9	E4	
24-039	2020	3.5	10.8	1.13	0.11	9	E4	NC
24-041	2000	1	16.2	1.01	1	14.9	F4	
24-041	2020	1.1	51	1.01	1	32	F4	NC
25-005	2001	1.2	21.4	1.25	0.28	21.2	F1	
25-005	2020	3.4	21.6	1.25	0.28	32	C4	PS
25-020A	2001	3.1	22	1.11	1.5	6.3	C4	
25-020A	2020	2.9	36.6	1.11	1.5	20.6	C4	NC
25-020B	2001	3.9	16.9	1.14	0.42	3.3	C4	
25-020B	2020	2.9	24.4	1.14	0.42	23.7	C4	NC
25-020C	2001	5.1	18.8	1.17	0.29	7.5	C4	
25-020C	2020	2.5	20.9	1.17	0.29	22.5	C4	NC
28-003	2000	3.4	19.3	1.12	0.31	12.6	C4	
28-003	2020	2.7	26	1.12	0.31	16.9	C4	NC
28-007	2000	1.1	23.3	1.1	0.6	16	F4	
28-007	2020	1.4	23.2	1.1	0.6	64	F4	NC
29-003	2000	4.6	16.4	1.09	1.2	35	C4	
29-003	2020	1.6	21.1	1.09	1.2	16	B4c	NC
31-004B	2003	4.9	6.4	1.18	0.18	0.43	E5	
31-004B	2020	1.1	36.4	1.18	0.18	8.3	F5	NG
31-025	2003	1.5	10.4	1.19	0.57	15.36	G4c	
31-025	2020	1.1	19	1.19	0.57	23.8	F4	NC
32-003	2001	7.3	7.2	1.13	0.17	0.0625	E6	
32-003	2020	7.1	6.9	1.13	0.17	0.0625	E6	NC
32-028	2001	2.8	13	1.31	0.17	0.44	C5	
32-028	2020	4.3	18.2	1.31	0.17	6	C4	NC
33-007	2000	3.6	11.6	1.75	0.43	7.2	E4	
33-007	2020	1.5	29.7	1.75	0.43	18.9	B4c	NG
37-007B	2001	3.4	11.6	1.31	2.09	0.0625	C6b	
37-007B	2020	1.1	17.7	1.23	2.09	0.6	F5b	NG

(Continues)

TABLE 5 (Continued)

SiteID	Yr	ER	W/D	Sin.	Slp	D50	RC	Δ St
37-011B	2001	1.4	18	1.23	1.02	0.12	F5	
37-011B	2020	1	18.7	1.23	1.02	1.3	F5	NC
38-023	2002	4	11.5	1.35	0.3	14.6	E4	
38-023	2020	3.3	15.6	1.35	0.3	11.1	C4	NG
38-027	2002	4.1	9.1	1.72	0.52	0.123	E5	
38-027	2020	5	10.2	1.72	0.52	7.7	E4	NC
39-042A	2002	1.1	3.4	1.19	0.62	0.24	G5c	
39-042A	2020	1.2	15.4	1.19	0.62	1.4	F5	NC
39-075	2002	2.2	10.7	1.42	0.93	0.25	E5	
39-075	2020	2.1	16.8	1.42	0.93	11.6	B4c	NG
39-080	2002	1.1	19.2	1.31	0.36	0.16	F5	
39-080	2020	1.1	25.9	1.31	0.36	0.7	F5	NC
39-084	2002	4	3.1	1.26	0.31	0.25	E5	
39-084	2020	1.2	17.4	1.26	0.31	1.6	F5	NG
39-092	2002	1.1	4.6	1.51	0.32	0.09	G5c	
39-092	2020	1.1	17.8	1.51	0.32	4	F4	NC
40-013	2003	1.3	9.9	1.31	0.1	0.182	G5c	
40-013	2020	1.4	10.3	1.31	0.1	0.4	G5c	NC
40-016	2000	1.2	7.9	1.2	0.2	0.125	G5c	
40-016	2005	1.2	9.8	1.2	0.2	0.142	G5c	NC
40-016	2020	1.3	9.9	1.2	0.2	0.6	G5c	NC
40-031	2003	1.4	10.7	1.03	1	0.13	G5c	
40-031	2020	1.3	12.2	1.03	1	0.2	F5	NC
40-035	2003	1.2	13.6	1.05	0.23	0.0625	F6	
40-035	2020	4	9.6	1.05	0.23	0.6	E5	PS
40-037	2003	2.9	10.5	1.06	0.15	0.0625	E6	
40-037	2020	3.4	16	1.06	0.15	0.0625	C6	NG
40-047	2003	1.2	304.3	1.12	1.5	0.0625	F6	
40-047	2020	5.3	14.8	1.12	1.5	0.0625	C6	PS
41-009	2001	1.3	10.2	1.25	0.17	0.318	G5c	
41-009	2020	1.3	7.7	1.25	0.17	1.9	G5c	NC

Note: Change in channel stability (Δ St) based on sequential RC rating are indicated as similar or no change (NC), increasing instability, negative (NG), or decreasing instability, positive (PO). Values shown are from historic and current (2020) data collections. See Table 2 for crosswalk between Site ID and Site no.

Abbreviations: CTC, concrete trapezoidal channel; N/A, not applicable.

TABLE 6 Dominant hydrologic soil groups in drainage areas for each cross-section location (Site ID/Waterbody name).

Site ID	Waterbody name	Soil group	Site ID	Waterbody name	Soil group
03-001	Walker Branch	B	19-025	Lower Beaverdam Creek	B/D
04-005	Crows Branch	B/D	19-036	Lower Beaverdam Creek	D
04-005B	Crows Branch	B/D	21-005	Southwest Branch	C/D
05-001	Paint Branch	C	21-011	Southwest Branch	C/D
05-001A	Paint Branch	C	24-002	Carey Branch	C
05-017	Little Paint Branch	C	24-007	Henson Ck. (Broad Creek)	B/D
05-019B	Little Paint Branch	C	24-009	Henson Ck. (Broad Creek)	B/D
05-019C	Little Paint Branch	C	24-019	Henson Ck. (Broad Creek)	B/D
05-019D	Little Paint Branch	C	24-020	Henson Ck. (Broad Creek)	B/D
05-027	Little Paint Branch	B	24-039	UT to Henson Ck. (Broad Ck.)	B/D
05-027A	Little Paint Branch	B	24-041	UT to Henson Ck. (Broad Ck.)	C
05-028	Little Paint Branch	B	25-003	Tinkers Creek	C/D
07-011	UT to Indian Creek	B/D	25-005	Tinkers Creek	C/D
07-015A	Indian Creek	B/D	25-020A	Tinkers Creek	C/D
07-028	Indian Creek	B/D	25-020B	Tinkers Creek	C/D
07-035	Mistletoe Run	B/D	25-020C	Tinkers Creek	C/D
07-038	Indian Creek	B/D	28-003	Broad Creek	B/D
08-001	U. Beaverdam Ck.	B/D	28-007	UT to Broad Creek	B/D
08-001B	Beaverdam Creek	B/D	29-003	Hunters Mill Branch	B/D
08-003	Beaverdam Creek	B/D	31-004B	Mattawoman Creek	B/D
08-007	U. Beaverdam Creek	B/D	31-025	Mattawoman Creek	B/D
08-014	UT to U. Beaverdam Ck.	B/D	32-003	Spice Branch	na
08-016	UT to Beaverdam Ck.	B/D	32-028	Rock Creek	B/D
08-018	UT to U. Beaverdam Ck.	B/D	33-003	UT to Lower Potomac R.	C/D
08-022	Beck Branch	B/D	33-007	UT to Lower Potomac R.	C/D
08-035A	Beaverdam Creek	B/D	37-007B	Swanson Creek	B/D
08-035B	Beaverdam Creek	B/D	37-011A	County Line Creek	B/D
08-039	UT to U. Beaverdam Ck.	B/D	37-011B	County Line Creek	B/D
08-044	U. Beaverdam Creek	B/D	38-023	Mataponi Creek	C/D
08-046A	UT to Beaverdam Ck.	B/D	38-027	Mataponi Creek	C/D
08-065A	Beck Branch	B/D	39-042A	Swan Point Creek	B/D
09-005	Northwest Branch	B/D	39-075	Honey Branch	C/D
09-009	Northwest Branch	B/D	39-080	Mt. Nebo Branch	B/D
10-001	Horsepen Branch	B/D	39-084	Mill Branch	C
10-009	Horsepen Branch	B/D	39-092	Green Branch	B
10-011	Horsepen Branch	B/D	40-013	Collington Branch	C/D

Note: See Table 2 for crosswalk between Site ID and Site no.
Abbreviation: UT, unnamed tributary.

conversions are *Lower Beaverdam Creek*, *Paint Branch*, *Little Paint Branch*, and Northwest Branch tributary watersheds to the Anacostia River, and *Collington Branch*, *Black Branch*, and *Western* Branch of the Middle Patuxent River drainage.

We also see ongoing changes in land area under cultivation. Without additional analyses, it is not possible to know whether decreases in area of pasture or cropland means it is being converted to development or allowed to go fallow, ultimately destined for forest re-generation. Regardless, it is possible to look at patterns in how the sites/watershed are ranked by changes (Table 7). Substantially, *Collington Branch* (cumulatively, sites 40-013, 40-031, 40-035, 40-037) has had approximately 7.1 km^2 go out of cultivation. *Northwest Branch* had two sites as part of this study that had 2.2 km^2 converted from cultivation to other uses. Ten of the 14 sites/watersheds exhibiting

TABLE 7 Land use (LU) changes between 2001 and 2016 associated with surface area drainages to 87 stream reaches in Prince George's County, Maryland.

Site ID	Stream name	Delta, km^2	Site ID	Stream name	Delta, km^2	Site ID	Stream name	Delta, km^2
DEVELOPED **area, increased >0.75 km^2**			**FORESTED** **area, decreased >0.5 km^2**			**CULTIVATED** **area, decreased >1.0 km^2**		
41-030	Western Branch	4.6278	31-004B	Mattawoman Creek	−5.8374	40-013	Collington Branch	−2.1717
31-004B	Mattawoman Creek	4.4982	41-030	Western Branch	−5.2956	41-030	Western Branch	−1.8117
40-013	Collington Branch	2.7783	40-013	Collington Branch	−2.9916	40-031	Collington Branch	−1.5138
05-001	Paint Branch	1.449	21-005	Southwest Branch	−1.3914	40-037	Collington Branch	−1.3032
05-001A	Paint Branch	1.449	40-031	Collington Branch	−1.368	40-035	Collington Branch	−1.3005
21-005	Southwest Branch	1.4139	05-001	Paint Branch	−1.1295	09-005	Northwest Branch	−1.1169
40-031	Collington Branch	1.413	05-001A	Paint Branch	−1.1295	09-009	Northwest Branch	−1.116
09-005	Northwest Branch	1.2915	40-035	Collington Branch	−1.0503	**CULTIVATED** **area, decreased 0.1-0.9 km^2**		
40-035	Collington Branch	1.1088	40-037	Collington Branch	−1.0458	40-047	Collington Branch	−0.8433
40-037	Collington Branch	1.1025	40-016	Black Branch	−0.9531	31-004B	Mattawoman Creek	−0.6939
09-009	Northwest Branch	0.9747	09-005	Northwest Branch	−0.9297	40-016	Black Branch	−0.4932
28-003	Broad Creek	0.8892	05-017	Little Paint Branch	−0.8631	05-001	Paint Branch	−0.4473
19-003	Beaverdam Creek	0.8505	05-019B	Little Paint Branch	−0.8505	05-001A	Paint Branch	−0.4473
19-005	Lwr. Beaverdam Cr.	0.8289	05-019C	Little Paint Branch	−0.8496	21-005	Southwest Branch	−0.3258
40-016	Black Branch	0.7659	05-019D	Little Paint Branch	−0.8496	38-023	Mataponi Creek	−0.3213
DEVELOPED **area, increased 0.5–0.74 km^2**			19-003	Lwr. Beaverdam Cr.	−0.8136	38-027	Mataponi Creek	−0.3213
05-017	Little Paint Branch	0.666	19-005	Lwr. Beaverdam Cr.	−0.8136	37-007B	Swanson Creek	−0.2007
24-007	Henson Cr.	0.6597	09-009	Northwest Branch	−0.7785	25-003	Tinkers Creek	−0.1935
24-009	Henson Cr.	0.6525	21-011	Southwest Branch	−0.6435	07-015A	Indian Creek	−0.189
40-047	Collington Branch	0.648	40-047	Collington Branch	−0.5949	07-038	Indian Creek	−0.189
05-019B	Little Paint Branch	0.6471	**FORESTED** **area, decreased 0.25–0.5km^2**			37-011A	County Line Creek	−0.1827
25-003	Tinkers Creek	0.6138	19-023A	Lwr. Beaverdam Cr.	−0.4932	41-009	Federal Spring Branch	−0.1809
24-019	Henson Cr.	0.5949	19-023B	Lwr. Beaverdam Cr.	−0.4932	37-011B	County Line Creek	−0.1701
07-015A	Indian Creek	0.594	19-025	Lwr. Beaverdam Cr.	−0.4932	25-005	Tinkers Creek	−0.1359
24-039	UT to Henson Cr.	0.594	10-001	Horsepen Branch	−0.4698	39-092	Green Branch	−0.117
07-038	Indian Creek	0.5841	04-005B	Crows Branch	−0.4473	04-005B	Crows Branch	−0.1089
21-011	Southwest Branch	0.5841	04-005	Crows Branch	−0.4473	04-005	Crows Branch	−0.1089
05-019C	Little Paint Branch	0.5724	25-003	Tinkers Creek	−0.432	**CULTIVATED** **area, decreased 0–0.9 km^2**		
05-019D	Little Paint Branch	0.5724	07-015A	Indian Creek	−0.4257	07-028	Indian Creek	−0.0819
25-005	Tinkers Creek	0.5589	07-038	Indian Creek	−0.4257	05-017	Little Paint Branch	−0.0765
24-020	Henson Cr.	0.5148	28-003	Broad Creek	−0.414	05-019B	Little Paint Branch	−0.0765

TABLE 7 (Continued)

Site ID	Stream name	Delta, km^2	Site ID	Stream name	Delta, km^2	Site ID	Stream name	Delta, km^2
DEVELOPED area, increased 0.25–0.5 km^2			25-005	Tinkers Creek	−0.3915	05-019C	Little Paint Branch	−0.0765
19-023A	Lwr. Beaverdam Cr.	0.4518	39-084	Mill Branch	−0.3483	05-019D	Little Paint Branch	−0.0765
39-084	Mill Branch	0.4464	05-027	Little Paint Branch	−0.3123	05-027	Little Paint Branch	−0.0603
19-023B	Lwr. Beaverdam Cr.	0.4437	24-007	Henson Cr.	−0.2763	05-027A	Little Paint Branch	−0.0603
04-005B	Crows Branch	0.4401	24-009	Henson Cr.	−0.2763	39-075	Honey Branch	−0.045
04-005	Crows Branch	0.4374	05-027A	Little Paint Branch	−0.2745	05-028	Little Paint Branch	−0.0378
19-025	Lwr. Beaverdam Cr.	0.4374	19-006	Lwr. Beaverdam Cr.	−0.2601	39-084	Mill Branch	−0.0369
19-006	Lwr. Beaverdam Cr.	0.315	10-009	Horsepen Branch	−0.252	39-080	Mt. Nebo Branch	−0.0306
10-001	Horsepen Branch	0.27	**FORESTED area, decreased 0–0.25 km^2**			28-003	Broad Creek	−0.0279
DEVELOPED area, increased 0–0.25 km^2			24-019	Henson Cr.	−0.2232	08-022	Beck Branch	−0.0225
25-020A	Tinkers Creek	0.2421	24-039	UT to Henson Cr.	−0.2232	08-065A	Beck Branch	−0.0225
25-020B	Tinkers Creek	0.2151	08-003	Beaverdam Creek	−0.198	10-001	Horsepen Branch	−0.0198
25-020C	Tinkers Creek	0.2133	08-001B	Beaverdam Creek	−0.189	39-042A	Swan Point Creek	−0.018
05-027	Little Paint Branch	0.1971	08-007	Upr. Beaverdam Cr.	−0.1872	21-011	Southwest Branch	−0.0171
41-009	Federal Spring Branch	0.1908	08-001	Upr. Beaverdam Cr.	−0.1764	10-009	Horsepen Branch	−0.0153
05-027A	Little Paint Branch	0.1809	24-020	Henson Cr.	−0.1566	33-003	UT to Lwr. Potomac R.	−0.0135
10-009	Horsepen Branch	0.1557	08-035A	Beaverdam Creek	−0.1566	10-011	Horsepen Branch	−0.0099
08-001	Upr. Beaverdam Cr.	0.1368	08-035B	Beaverdam Creek	−0.1566	07-035	Mistletoe Run	−0.009
08-001B	Beaverdam Creek	0.1359	07-028	Indian Creek	−0.1395	32-028	Spice Creek	−0.009
08-003	Beaverdam Creek	0.1269	28-007	UT to Broad Creek	−0.1305	03-001	Walker Branch	−0.0081
08-007	Upr. Beaverdam Cr.	0.1269	16-001	Brier Ditch	−0.0846	24-007	Henson Cr.	−0.0072
07-028	Indian Creek	0.1098	08-039	UT to U. Beaverdam Cr.	−0.0792	24-009	Henson Cr.	−0.0072
19-036	Lwr. Beaverdam Cr.	0.099	08-044	Upr. Beaverdam Cr.	−0.0774	24-019	Henson Cr.	−0.0072
28-007	UT to Broad Creek	0.0936	08-046A	UT to Beaverdam Creek	−0.0774	24-039	UT to Henson Cr.	−0.0072
08-035A	Beaverdam Creek	0.0855	10-011	Horsepen Branch	−0.0765	24-020	Henson Cr.	−0.0072
08-035B	Beaverdam Creek	0.0855	41-009	Federal Spring Branch	−0.0729	28-007	UT to Broad Creek	−0.0063
37-007B	Swanson Creek	0.0855	03-001	Walker Branch	−0.0639	29-003	Hunters Mill Branch	−0.0027
29-003	Hunters Mill Branch	0.081	05-028	Little Paint Branch	−0.0621	19-006	Lwr. Beaverdam Cr.	−0.0009
08-044	Upr. Beaverdam Cr.	0.0783	29-003	Hunters Mill Branch	−0.0594	07-011	UT to Indian Creek	0
08-046A	UT to Beaverdam Creek	0.0783	15-003A	Well's Run	−0.0333	08-016	UT to Beaverdam Cr.	0
16-001	Brier Ditch	0.0702	25-020A	Tinkers Creek	−0.0324	08-018	UT to U. Beaverdam Cr.	0
05-028	Little Paint Branch	0.0666	24-041	UT to Henson Cr.	−0.0234	12-011	UT, NE Br. Anacostia R.	0
12-011	UT to NE Br. Anacostia R.	0.0531	07-035	Mistletoe Run	−0.0198	15-003A	Well's Run	0
24-002	Carey Branch	0.0522	07-011	UT to Indian Creek	−0.0162	19-023A	Beaverdam Creek	0

(Continues)

TABLE 7 (Continued)

Site ID	Stream name	Delta, km^2	Site ID	Stream name	Delta, km^2	Site ID	Stream name	Delta, km^2
10-011	Horsepen Branch	0.0513	12-011	UT, NE Br. Anacostia R.	−0.0153	19-023B	Beaverdam Creek	0
03-001	Walker Branch	0.0486	24-002	Carey Branch	−0.0108	19-025	Lwr. Beaverdam Cr.	0
24-041	UT to Henson Cr.	0.045	08-022	Beck Branch	−0.0108	19-036	Lwr. Beaverdam Cr.	0
39-092	Green Branch	0.0414	08-065A	Beck Branch	−0.0108	24-002	Carey Branch	0
08-022	Beck Branch	0.0333	39-080	Mt. Nebo Branch	−0.0063	24-041	UT to Henson Cr.	0
08-065A	Beck Branch	0.0333	32-028	Spice Creek	−0.0063	25-020A	Tinkers Creek	0
07-011	UT to Indian Creek	0.0297	08-014	UT to U. Beaverdam Cr.	−0.0027	25-020B	Tinkers Creek	0
39-080	Mt. Nebo Branch	0.0261	25-020B	Tinkers Creek	0	25-020C	Tinkers Creek	0
15-003A	Well's Run	0.0198	25-020C	Tinkers Creek	0	32-003	Spice Creek	0
39-075	Honey Branch	0.0189	19-036	Lwr. Beaverdam Cr.	0	33-007	UT to Lwr. Potomac R.	0
07-035	Mistletoe Run	0.018	08-016	UT to Beaverdam Creek	0	**CULTIVATED area, increased**		
38-023	Mataponi Creek	0.0108	08-018	UT to U. Beaverdam Cr.	0	08-044	Upr. Beaverdam Cr.	0.0009
38-027	Mataponi Creek	0.0108	33-007	UT to Lwr. Potomac R.	0	08-046A	UT to Beaverdam Creek	0.0009
08-014	UT to U. Beaverdam Cr.	0.0072	32-003	Spice Creek	0	19-003	Beaverdam Creek	0.0018
08-016	UT to Beaverdam Creek	0.0072	**FOREST cover, increased**			19-005	Lwr. Beaverdam Cr.	0.0018
08-018	UT to U. Beaverdam Cr.	0.0072	31-025	Mattawoman Creek	0.0063	16-001	Brier Ditch	0.0018
08-039	UT to U. Beaverdam Cr.	0.0072	33-003	UT to Lwr. Potomac R.	0.0126	08-014	UT to U. Beaverdam Cr.	0.0027
33-003	UT to Lwr. Potomac R.	0.0018	39-075	Honey Branch	0.0171	31-025	Mattawoman Creek	0.0126
37-011A	County Line Creek	0.0018	39-042A	Swan Point Creek	0.018	08-001	Upr. Beaverdam Cr.	0.0477
39-042A	Swan Point Creek	0.0018	37-007B	Swanson Creek	0.0882	08-001B	Beaverdam Creek	0.0603
31-025	Mattawoman Creek	0.0009	39-092	Green Branch	0.0972	08-007	Upr. Beaverdam Cr.	0.0603
33-007	UT to Lwr. Potomac R.	0.0009	37-011B	County Line Creek	0.1701	08-039	UT to U. Beaverdam Cr.	0.0621
37-011B	County Line Creek	0.0009	37-011A	County Line Creek	0.1827	08-035A	Beaverdam Creek	0.063
32-003	Spice Creek	0	38-023	Mataponi Creek	0.2772	08-035B	Beaverdam Creek	0.063
32-028	Spice Creek	0	38-027	Mataponi Creek	0.2772	08-003	Beaverdam Creek	0.0711

Note: Primary (preprocessed) data from the National Land Cover Dataset (NLCD). Rank order of reaches within categories partitioned by magnitude of LU change. See Table 2 for crosswalk between Site ID and Site no.

Abbreviation: UT, unnamed tributary.

increases in cultivated area (though, cumulatively only ∼0.4 km^2) are in the *Upper Beaverdam Creek* watershed. As the Henry A. Wallace Beltsville Agricultural Research Center (BARC; Beltsville, Maryland) property coincides with it, there is potential these changes are related to smaller plots being used for studies in agricultural sciences, or otherwise as demonstrations.

8.6 | Soils

Examining soil group distribution among the XS drainage areas reveals that the study area is dominated, in descending order, by groups B/D (58.1%), C/D (23.3%), C (10.5%), B (5.8%), and D (2.3%). The percentage is the proportion of sites in this study with the upstream drainage area dominated by the indicated soil group. Individual XS sites and the associated dominant soil groups (Table 6) are provided to assist in the consideration of potential stormwater management approaches. More specifically, in the context of soil groups and the predicted climate change-related increases in flashiness (Dupigny-Giroux et al., 2018), those drainages dominated by Group C and D soils could be considered as having a lower potential for accelerated erosion than those dominated by Group B soils.

9 | CONCLUSIONS AND RECOMMENDATIONS

Efforts at watershed scale restoration and management necessarily require a complex mindset, with researchers calling for consideration of a broad set of factors such as ecological characteristics, soils, water quality, changing climate and precipitation patterns, ever-changing socioeconomic drivers, goods and services, and basic human behavior (Allan et al., 2013; Chessman et al., 2006; Grabowski et al., 2014; Nietch et al., 2005; Soar et al., 2017; USEPA, 2006; Walsh et al., 2005; Waters, 1995). There is a well-established recognition that uncertainties associated with restoration are substantial, and that expectations of what can be considered as successful or effective actions or programs require accepting them, more specifically defining goals and/or thresholds, consistent and routine monitoring, and being ready and willing to apply adaptive management to meet and address unexpected situations and outcomes (Beechie et al., 2010; Bernhardt & Palmer, 2011; Jayakaran et al., 2015; Palmer, 2005; Phillips, 2001). It is also broadly recognized that the most effective (and absolute) indicator of successful ecological restoration is one that objectively documents *positive biological response* to the reduction or elimination of physical, chemical, hydrologic, and biological stressors in the system), which is the principal objective of Clean Water Act [CWA] of 1972 (§101[a]), that is, the protection, restoration, and maintenance of ecological integrity of waters (Karr et al., 2021; Wurtzebach & Schultz, 2016). Though not presented in this paper, Prince George's County watershed-scale biological monitoring and assessment has been ongoing since 1999. The ultimate association of the ecological status and biological condition of streams and watersheds with results presented in this study will provide substantial evidence for supporting and prioritizing restoration and management decisions.

Stressor management can be undertaken in terms of both restoration and protection. Restoration can be thought of as reducing or eliminating stressors and their sources already in the system or buffering their effects. The flip side of restoration is protection, which, in terms of stressors, is preventing or managing the development of new sources of stressors (or pollution) in areas where they exist at only minimal levels or not at all.

We recommend an increased frequency of re-surveys for selected sites as a matter of routine, revisiting every 4–5 years to improve documentation of erosion rates and sensitivity of geomorphic data in detecting source areas. Another potential approach would be to take, for example, the top five sites from each of the degrading/aggrading lists (Table 6) and establish two XS at each, separated by approximately 500 m and surveyed annually. More frequent stability assessments should be better able to document changes in annual rates of change due to increased frequency or flashiness of storm events, or in response to changes/upgrades to stormwater management actions.

Stormwater and erosion management actions in implementing BMP at the sources of sediment and flow in the headwaters of a watershed will increase stormwater retention, capture sediments, and reduce the production of sediment and discharge to active stream channels. Further, analyses of trends in biological conditions will be crucial in documenting the actual ecological effectiveness of the restoration and implementation of stressor control strategies.

The results of this study can aid in restoration by (1) helping prioritize streams or small watersheds for management actions, (2) providing data to assist in determining the type(s) of resource management actions necessary, and/or in conceptual or actual design of the actions, and (3) evaluating potential credits for sediment and nutrients (MDE, 2023) retained as a result of channel stabilization and other management actions.

Many of the papers and studies we cite in this paper discuss the inherent complexity of ecological restoration decision-making, and that most ecological degradation is from exposure to multiple and complex stressors and stressor loads that express wide spatial and temporal variability. The application of the XS survey results will be most effective in restoration (e.g., ecological restoration, BMP implementation, public outreach) by simultaneously considering the intensity of land use and cover changes, the direction of changes in channel form, particle size distribution, and sediment yield.

Taken together, the spatial interrelationships among watershed characteristics we examined can potentially assist practitioners in prioritizing subwatersheds for stormwater management attention. Current LULC conditions exposed to projected increases in storm intensities and flashiness of flows will exacerbate the instability of channels already experiencing accelerated rates of erosion. Information and data in this report can be used as a roadmap for selecting and targeting areas of watersheds for stormwater management and restoration/protection activities. Though this is not a stepwise procedure, the most important information for this decision-making is contained in a few tables and sections of text that if considered simultaneously provide an understanding of reach and subwatershed conditions.

Restoration or stormwater management practitioners in the County should initially consider sites listed in more than one of the following ranked lists:

- *Sediment yield* (Table 3). The most geomorphically active sites are ranked as undergoing the most erosion or sedimentation over intervals of 15–21 years.
- *Channel instability increases* (Table 5). Information provided in this section details changes in Rosgen level 2 (RL2) stream types as moving to a more unstable channel following an interval of 15–21 years.
- *Land use changes* (Table 7). This table provides rank-order lists of sites showing the amount of surface area (km^2) change that has occurred over the period from 2001 to 2016 in terms of (a) increased development, (b) decreased forest, and (c) decreased cultivation.

The above will allow the County to have increased focus on one or more reaches or watershed areas based on these factors. The next step is to evaluate associated data on biological and physical habitat conditions as documented in annual countywide biological monitoring and assessment reports. If available, evaluate coverages of other potential known sources such as point/non-point, ongoing active or incipient stressor loading events, and whether they are direct or indirect stressors on aquatic biota. Taken together, this information helps identify locations potentially requiring stormwater controls. The County would need to conduct follow-up ground-truthing site visits for potential additional measurements and analyses to be used in determining the best engineering, management, or restoration solutions for reducing or eliminating stressors and stressor sources. We also recommend consulting current regional guidelines (e.g., MDE, 2023) for information on acceptable approaches to restoration.

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DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

ENDNOTES

[i] This value is an average of the factors for the two nontidal physiographic provinces in which most of Prince George's County lies: Coastal Plain Lowland Non-Tidal (factor, 0.061) and Coastal Plain Dissected Uplands Non Tidal (factor, 0.064) (Schueler & Stack, 2014).

[ii] https://nhdplus.com/NHDPlus/.

[iii] https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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