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STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

LONG-TERM BED DEGRADATION IN MARYLAND STREAMS (PHASE 3, PART I): URBAN STREAMS IN THE PIEDMONT PLATEAU PROVINCE

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16. Abstract Estimation of potential long-term down-cutting of the stream bed is necessary for evaluation and design of bridges for scour and culverts for fish passage. The purpose of this study has been to improve predictions of this potential long-term bed degradation (LTBD) in Maryland streams through the measurement and analysis of stream bed and waterway structure survey data and bridge plans. Long-term bed degradation was defined as the vertical change in the channel profile other than that caused by local or contraction scour. Part 1 of a two-part study of urban streams in the Piedmont Plateau province was completed. Many sites were selected for sampling; the remainder of the sample will be selected in Part 2. The range of watershed drainage areas of the selected LTBD sampling sites is 0.2 mi ² to approximately 40 mi ² ; only one site, however, has a drainage area greater than 6 mi ² . The current range of impervious area of the LTBD sampling sites is approximately 19% to 58%, but only one site has an impervious area of less than 25%. The current range of valley slopes of the LTBD sampling sites is approximately 0.5% to 4%. Given the high correlation of LTBD with valley slope found in previous investigation of LTBD and the lack of data for Part 1 sites with slopes lower than 0.5%, additional data on streams with less than 0.5 % slope is needed and will be collected in Part 2. A database of preliminary estimates of LTBD was initiated. Additional data collection in regions of the urban Piedmont Plateau is required to cover the range of watershed areas, percentage of impervious area, and valley slope for a comprehensive assessment of LTBD in the urban Piedmont. Travel time and access were factors that increased the time required to screen and select sampling locations. Site selection, data collection, and analysis will be completed in Part 2 of this project. The results of this study are preliminary and should only be applied to assess data gaps.			
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GLOSSARY AND ABBREVIATIONS

Variables

DA	Drainage area (mi ²)
LTBD	Long-term bed degradation (ft). The vertical change in the channel profile other than that caused by local or contraction scour
S_v	Valley slope (ft/ft)

Units of Measure

cfs	Cubic feet per second
ft	Feet
mi²	Square miles
pcf	Pounds per cubic foot
psf	Pounds per square foot

Long-Term Bed Degradation in Maryland Streams (Phase 3, Part 1): Urban Streams in the Piedmont Plateau Province

1.0 INTRODUCTION

Federal and Maryland state standards and policies require that bridge foundations be evaluated and designed to resist worst-case conditions of scour and channel instability that may occur over the service life of a bridge. Recently implemented policies also require that crossings accommodate passage of aquatic organisms. An important component of the evaluation and design processes is the estimation of long-term changes in stream bed elevations which may occur due to down-cutting of the stream bed (degradation) or raising of the bed by deposition of sediment (aggradation).

Existing guidelines for assessing potential long-term bed degradation in Maryland streams [1] require expertise that may not be available and/or field studies that, depending on the project budgets, may be cost prohibitive, especially for replacement of county structures. The morphological techniques recommended by these guidelines also lack verification data and may lead to overly conservative estimates, unnecessarily large foundation depths, and consequently, significantly higher costs. For this reason, the Structure Hydraulics and Hydrology Division initiated a study to improve predictions of long-term bed degradation in Maryland streams. Due to funding limitations, the study is being completed in phases. Phase 1 [2] and Phase 2 [3] examined long-term bed degradation (LTBD) of streams in non-urbanized watersheds of the Allegany Plateau, Blue Ridge, and the Western Piedmont physiographic provinces. The present study, Phase 3, was limited to urban watersheds (those with impervious ground cover greater than 10%) of the Piedmont Plateau province in Montgomery, Baltimore, and Howard counties and Baltimore City.

The Phase 3 study has five primary objectives:

1. Continue development of a database of field measurements of LTBD in Maryland streams.
2. Define the range of degradation depths to be expected in streams of the urbanized (impervious ground cover greater than 10%) watersheds of the Piedmont Plateau province in Montgomery, Prince Georges, Baltimore, and Howard counties and Baltimore City.
3. Quantify risk factors identified in the first two phases of the study that may influence a site's risk (likelihood and magnitude) of LTBD.
4. Develop quantitative relations between the identified factors and measured long-term bed degradation.
5. Evaluate the possibility of developing a regional relation for LTBD by physiographic province.

The database and the relations between risk factors and LTBD may serve as a basis for decisions related both to design and planning projects involving foundations for waterway crossings, depth of utility crossings, culvert replacements requiring fish passage, and mitigation projects involving stream restoration and/or stream stability. In foundation designs, the database would establish a baseline for evaluating reasonable values of degradation, and thus it will save significant structure costs. Where the potential for bed degradation is high, LTBD data may indicate deeper foundations are needed to prevent structure failure or continuous remediation of the substructure unit. In

other locations, the LTBD data may provide evidence that shallower foundation depths may be appropriate. In the planning phase, the database could support quick decisions on the type and size of the structures needed for stream crossings in small watersheds. A reliable estimate of this degradation rate could indicate the need to propose a bridge rather than a culvert: assuming the culvert invert needs to be designed well below the expected long-term bed degradation, a culvert would be less practical than a bridge in locations where degradation is predicted to be more than 30% of the culvert diameter. Thus, the database could result in a more accurate consolidated transportation program cost in the planning phase. It would also be of great help to all counties that lack resources to perform detailed stream morphology studies on their waterway crossing projects.

Phase 3 was divided into two parts. Part 1 was funded in FY2013, and Part 2 was funded in FY2104 and will start after Part 1 is completed. Part 1 involved preliminary screening, selection of sampling sites, and an assessment of data gaps. Part 2 will involve the completion of data collection, analysis, development of prediction equations, and recommendations for application. This Part 1 report describes the screening and selection processes, preliminary analysis, and data gaps.

2.0 STUDY AREA

The study made a preliminary examination of LTBD in urbanized watersheds of Montgomery, Baltimore, and Howard counties and Baltimore City. These counties lie in the Upland section of the Piedmont Plateau. The Piedmont Plateau province rises gradually from east to the Catoctin Mountains in the west. The western part of the Piedmont Plateau is primarily rolling plains underlain by moderately to slightly metamorphosed volcanic rocks and diverse igneous and metamorphic rocks such as phyllite, slate, and marble. The rocks underlying Frederick Valley, along the Monocacy River, are Cambrian and Ordovician limestones and dolomites [4]. Land use transitions from mostly rural farmland and low-density residential development with scattered urban areas in the western portion of the Piedmont Plateau to urban and high-density residential on the eastern edge of the Piedmont Plateau.

The drainage patterns in the entire Piedmont Plateau are heavily influenced by the geologic structure and resistance of the mostly metamorphic and igneous rock. East of Frederick Valley, two ridges run from northeast to southwest: the Dug Hill Ridge and Pars Ridge [5]. The Potomac River forms the southern border of the Frederick Valley. West of Dug Hill and Pars ridges, the streams of Frederick County and northwestern Carroll County flow mainly west into the Monocacy River, which flows mainly south to its confluence with the Potomac River. East of the ridges, the Patuxent River and other major stream of the eastern Piedmont Plateau generally flow southeast to the Chesapeake Bay.

3.0 METHODS

3.1 Site Selection

Initial Screening

Several sources of information were requested from Montgomery, Baltimore, and Howard counties and Baltimore City to identify an initial set of sampling sites with emphasis on sites in urbanized areas:

- Sites with potential LTBD based on findings in existing reports

- Bridge inspection reports
- Phases I and II of Item 113 bridge inspection ratings
- Inspection reports for bridges or culverts known to have aquatic organism blockages
- Utility line surveys
- Plan sheets for box culverts and bridges

The land-use of the watersheds of each potential site was examined visually to remove sites that may have impervious cover of less than 10%. The watersheds of the remaining sites were analyzed using GIS Hydro to compute the percent impervious area and other watershed parameters. Sites with impervious areas greater than 10% were selected for potential sampling.

The reports and surveys of the selected sites were reviewed to identify any citations of foundation exposure or undermining, fish passage barriers, or exposure of utility crossing protection, any of which would indicate that the channel bed near a culvert or bridge had degraded, and therefore, LTBD would probably be measureable. All structures where any of these problems had been cited were considered for field evaluation.

Plan sheets for box culverts were requested because they usually provide the elevation of the culvert outlet invert, the elevation of the downstream channel, and the depth to which the culvert may have been countersunk relative to the downstream channel. Construction drawings for new or replacement bridges may provide normal water surface elevations or stream profiles through the bridge. This plan information provides an accurate reference from which to measure changes in bed elevation. All box culverts and bridges for which plans were available were considered for field evaluation.

Finally, sites for which reports or plans were not available were considered for field evaluation if bed degradation had been observed by research team members or county engineers. A total of approximately 90 sites were considered during this initial screening process.

Field Identification

The sites selected for additional evaluation were mapped for reference in the field. An initial field visit was then made to each site to evaluate them for final selection. To increase the sample size, the research team also conducted a windshield survey along state, county, and city roads in urbanized areas. During the windshield survey, the field team looked for any structures with vertical drops at the outlet as an indication of LTBD. When a vertical drop was observed, the location was identified on the topographic maps and Google Earth to visually estimate drainage area and impervious area of the watershed. These locations were selected for addition to the sample if their estimated drainage areas were between about 0.5 and 50 mi² and watershed impervious area appeared to be greater than 10 percent. Rapid measurements (see Section 3.2) were also taken at each site during this field investigation.

Preliminary Data Analysis and Part 1 Site Selection

Following the field investigation, the watershed boundaries were delineated for each of the sites that were added to the sample in the windshield survey. The boundaries were delineated using 30-meter national elevation data [6] in the web-based version of GISHydro [7], and their surface drainage areas and impervious areas were estimated. Sites where impervious area was less than 10 percent were excluded from the final sample. Preliminary analysis of watershed and valley

characteristics was also completed to verify whether the selected sample of sites would provide a complete data set. The valley slope, S_v , for each selected site was estimated from contour lines shown on USGS 7.5-minute topographic maps. For most of the sites, the change in elevation between contours was divided by the distance between the contour lines directly upstream and downstream of the structure location. At sites where the downstream contour was immediately downstream of the structure, using the above method would have resulted in the estimated slope being biased heavily in the upstream direction. For those instances, the slope was calculated using the two contour lines downstream of the site. At sites where the structure was located directly upstream of the confluence with a much larger stream, the slope upstream of the site was averaged with the slope of the larger, receiving stream's valley.

Many sites were selected for the study, but the final sample of sites is not yet complete. Data gaps identified in the preliminary analysis indicated a need for additional sites with watershed area greater than 6 mi^2 , impervious areas between 10% and 20%, and valley slopes less than 0.5% and greater than 2%. The small section of urbanized Piedmont streams of Prince Georges County proposed as part of this study had very few suitable sampling sites. Therefore, this area was excluded from the study. Furthermore, field identification of sample sites required more time than initially estimated, and as a result, the research team was unable to complete screening surveys of portions of the urbanized Piedmont Plateau. Instead of conducting detailed data collection for the incomplete sample, a decision was made in consultation with SHA to continue the screening surveys in Part 2 with the intention of identifying sites that may fill the data gaps.

3.2 Data Collection

The primary focus of the field data collection effort in Part 1 was to obtain rapid measurements of LTBD. Long-term bed degradation was defined as the vertical change in the channel profile other than the vertical changes caused by local or contraction scour. At each sampling site, the vertical drop at the outlet of the structure was measured with a pocket rod and a hand level (Photos 3.1 and 3.2). These rapid measurements were conducted where a step, a series of steps, or a steep section or riprap-protected streambed occurred at the outlet of a culvert or a bridge with a paved or riprap-protected invert or paved or riprap-protected downstream apron. The distance from the paved or riprap-protected invert to the low-flow water surface at the downstream side of the structure (Fig. 3.1) was used as an estimate of LTBD. The outlets and protected inverts were constructed at about the same elevation as the bed of the channel at the time of construction. Because these structures provide effective grade control for the channel, preventing further upstream migration of degradation from downstream impacts, their elevations are good estimates of the initial streambed elevation (i.e., the elevation at the time of construction).

Detailed data (e.g., measurements of channel dimensions, bed material gradation, and other site parameters) were collected at only a few sampling sites. This data collection will be completed in Part 2.

3.3 Data Reduction and Analysis

Preliminary analysis of the LTBD variation with watershed drainage area, valley slope, and percent impervious area were conducted on the available data to identify potential trends. Final analysis of the effect of these variables on LTBD will be completed in Part 2.



Photo 3.1. LTBD measured at culvert apron of Gas House Pike, Frederick County.



Photo 3.2. Bed degradation into fractured bedrock at the Strathmore Avenue Bridge over Western Run, Baltimore City.

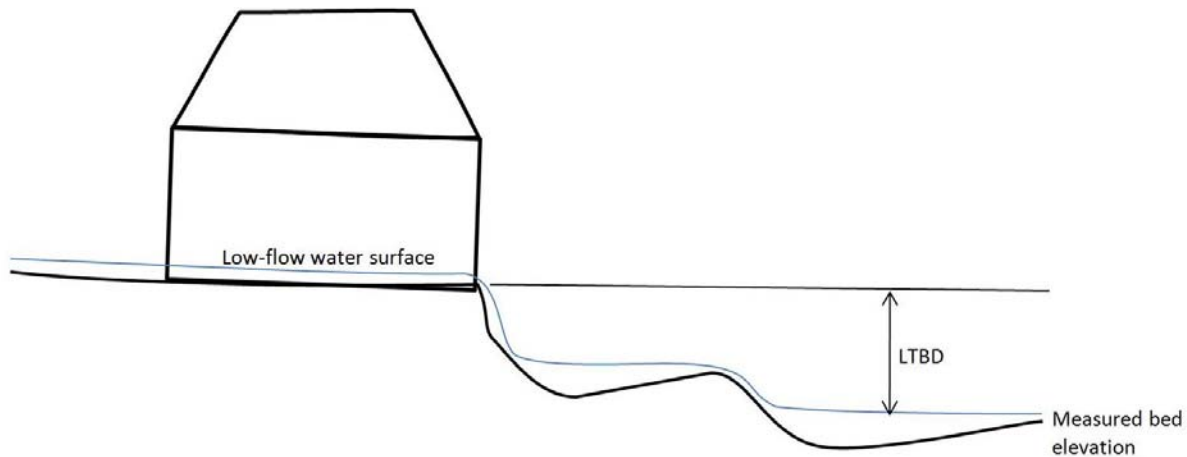


Figure 3.1. Typical bed profile of a culvert with downstream bed degradation and a scour pool.

4.0 PRELIMINARY RESULTS

Drainage Area

The current range of watershed drainage areas of the LTBD sampling sites is 0.2 mi² to approximately 40 mi²; only one site, however, has a drainage area greater than 6 mi² (Fig. 4.1). Additional data will be collected in Phase 2 for sites with drainage area greater than 6 mi².

Impervious Area

The current range of impervious area of the LTBD sampling sites is approximately 19% to 58%; only one site, however, has an impervious area of less than 25% (Fig. 4.2). Additional data will be collected in Phase 2 to add sites with impervious area between 10% and 25%.

Valley Slope

The current range of valley slopes of the LTBD sampling sites is approximately 0.5% to 4% (Fig. 4.3). Given the high correlation of LTBD with valley slope found in previous investigation of LTBD and the lack of data for sites with slopes lower than 0.5%, additional data on streams with less than 0.5 % slope is needed and should be collected in Part 2. Although some data has been collected for slopes near 3%, one data point of degradation was estimated to be 8 ft, which is higher than any other measurement made in this study and previous LTBD studies funded by SHA. Additional high slope data should be collected to provide confidence that this point is not an outlier and is representative of potential LTBD at high slopes.

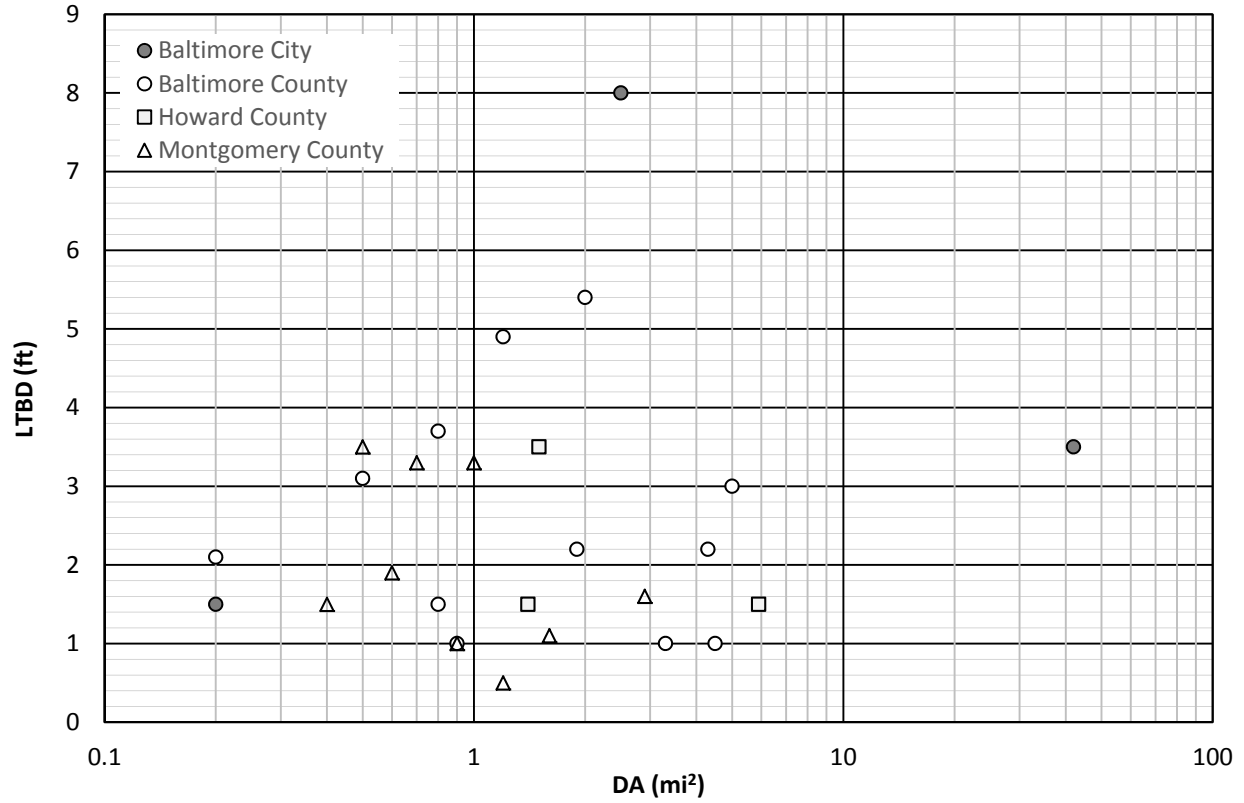


Figure 4.1. Variation of LTBD with drainage area.

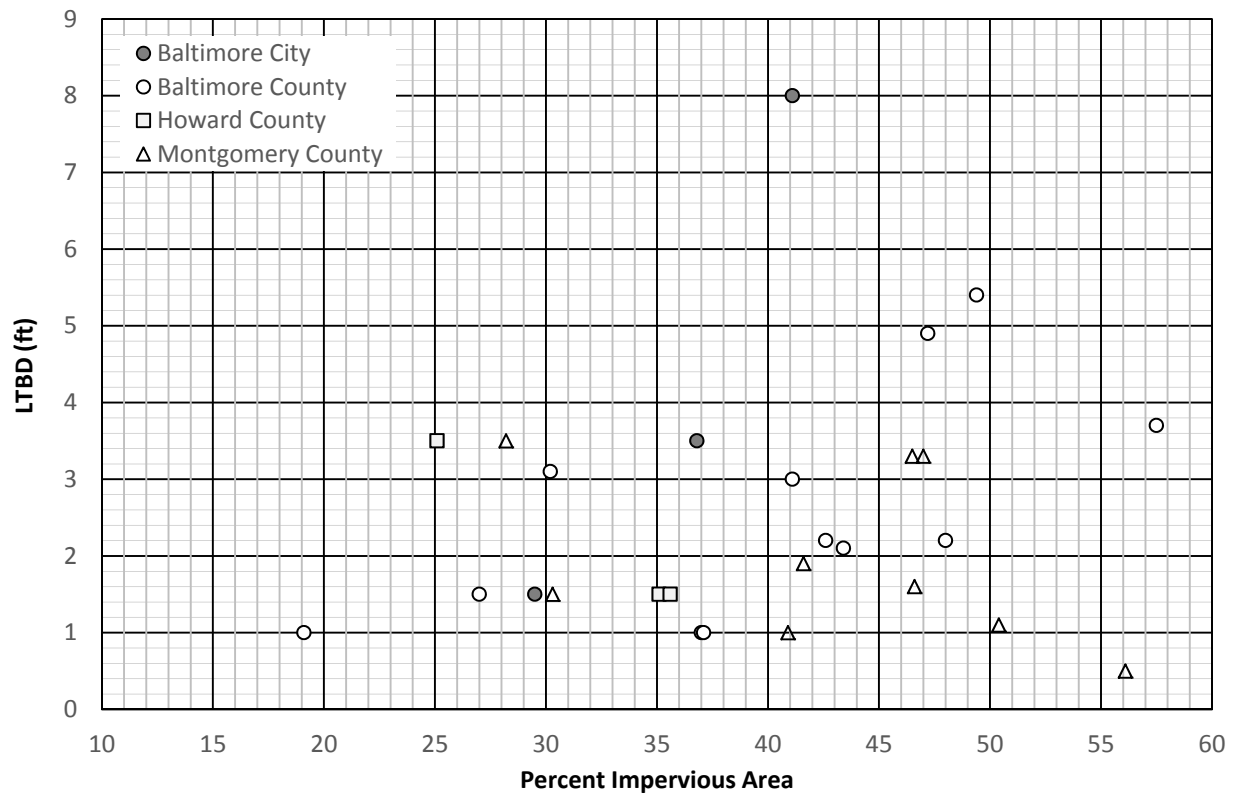


Figure 4.2. Variation of LTBD with percent impervious area.

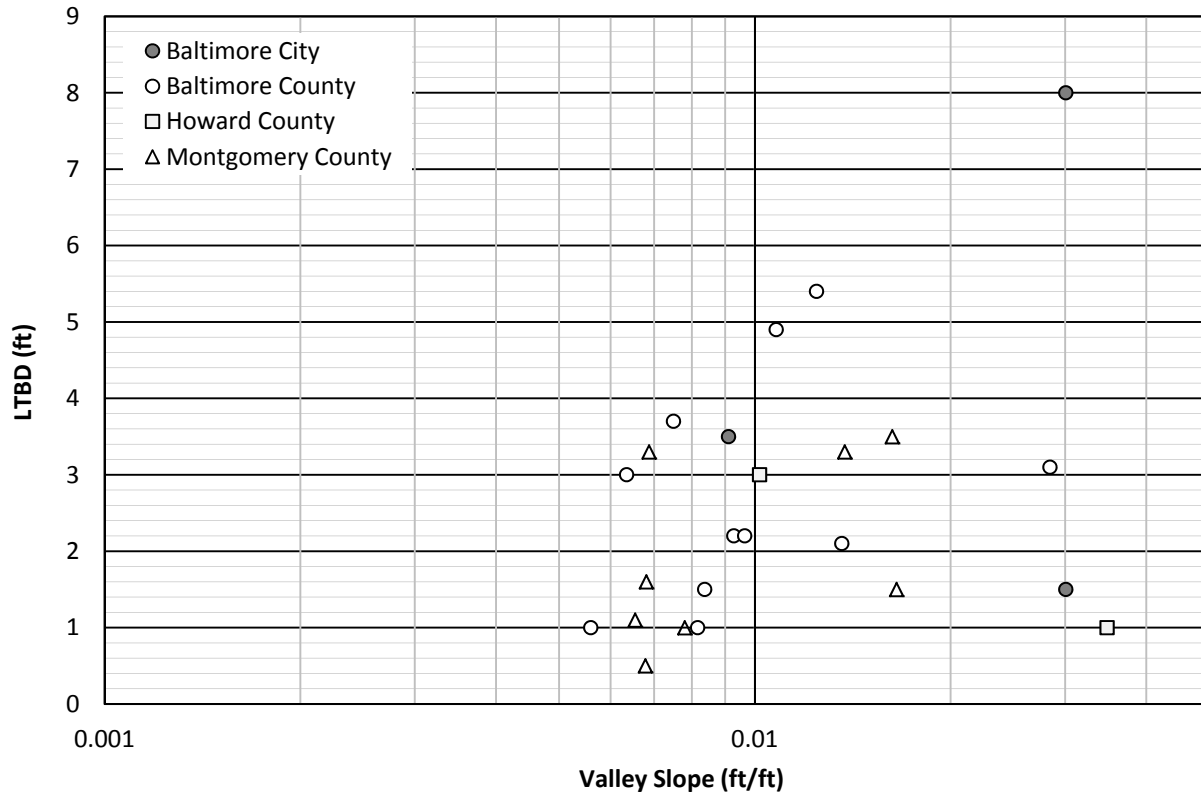


Figure 4.3. Variation of LTBD with valley slope.

5.0 APPLICATION

The results of this study are preliminary and should only be applied to assess data gaps.

6.0 CONCLUSIONS

A database of preliminary estimates of LTBD was initiated. Additional data collection in regions of the urban Piedmont Plateau is required to cover the range of watershed areas, percentage of impervious area, and valley slope for a comprehensive assessment of LTBD in the urban Piedmont Plateau. Travel time and access were factors that increased the time required to screen and select sampling locations. Site selection, data collection, and analysis will be completed in Part 2 of this project.

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REFERENCES

1. Parola AC and Hansen C. 2007. Chapter 14: stream morphology. In Hydrology and Hydraulics Manual. SHA Office of Structures, Structure Hydrology and Hydraulics Division, Maryland Department of Transportation. Available at http://www.gishydro.umd.edu/sha_soft.htm, accessed Sep2011.
2. Parola AC, Oberholtzer WL, and Black D. 2011. Long-term bed degradation in western Maryland streams. Technical report MD-11-SP909B4G, Maryland State Highway Administration, Baltimore, MD. 20 pp.
3. Parola AC, Oberholtzer WL, and Black D. 2012. Long-term bed degradation in Maryland streams (Phase 2): Blue Ridge and Western Piedmont provinces. Technical report MD-12-SP109B4K, Maryland State Highway Administration, Baltimore, MD. 29 pp.
4. Maryland Geological Survey. 2009. A brief description of the geology of Maryland. Available at <http://www.mgs.md.gov/esic/brochures/mdgeology.html>, accessed Sep2011.
5. Stose AJ and Stose GW. 1946. The physical features of Carroll County and Frederick County. Maryland Department of Geology, Mines, and Water Resources, Baltimore, MD.
6. US Geological Survey (USGS). 2006. National elevation dataset. Available at <http://ned.usgs.gov/>, accessed Sep2010.
7. University of Maryland Department of Civil and Environmental Engineering and Maryland State Highway Administration (UMD and SHA). 2010. GISHydro: A GIS-based hydrologic modeling tool. Available at <http://www.gishydro.umd.edu/>, accessed Sep2011.