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1.0 INTRODUCTION

1.1 PROJECT PURPOSE

The purpose of the Cobbs Creek Stream Protection and Restoration Master Plan is to provide the City of Philadelphia Water Department documentation of the existing conditions within the watershed. Rosgen methodologies were used to measure channel geometry and stability parameters to determine stream classification. A comprehensive habitat survey was also completed for the watershed. Together, the measured geomorphologic channel survey and the habitat survey will provide the City of Philadelphia the following:

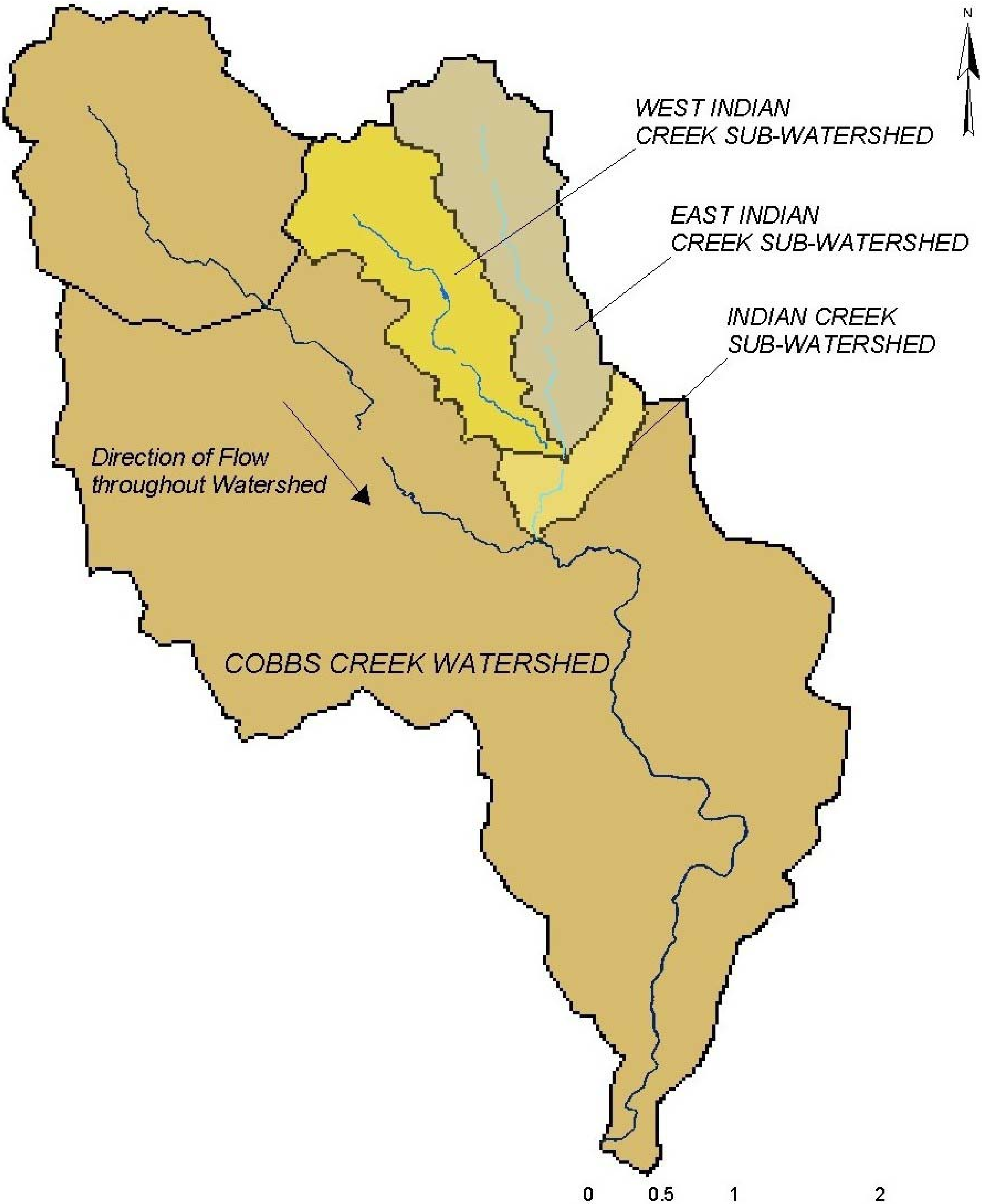
- ✓ a baseline for evaluating effects of urbanization,
- ✓ a land use and/or planning tool,
- ✓ a rating method specific to the Cobbs Creek watershed,
- ✓ potential stream and habitat restoration sites, and
- ✓ appropriate potential restoration strategies.

1.2 PROJECT DESCRIPTION

The Cobbs Creek Level IIGeomorphologic Survey consisted of Biohabitats, Inc. assessing approximately 18 miles of stream channel within the watershed. The assessment involved walking the entire length of the Cobbs Creek, East Indian Creek and West Indian Creek mainstems to record specific information about the channel and surrounding habitat. One representative stream channel cross section, including local slope, was measured per reach. Measured field data was compiled to determine stream channel types for each reach and to help evaluate channel stability. Qualitative habitat data was compiled and used to determine what types of habitat are adjacent to the stream channel and where they are located. Both the measured and quantative data were evaluated for correlations between the natural and built environment.

1.3 PROJECT LOCATION

The Cobbs Creek watershed is located primarily within the City of Philadelphia and extends approximately 2.5 miles beyond the northern City limits into the southern portion of Montgomery County, Pennsylvania. Cobbs Creek forms the western boundary between the City of Philadelphia and Delaware County beginning at PA Route 3, or Market Street, and continues downstream to the confluence with Darby Creek. East Indian Creek is located almost entirely within the City of Philadelphia and outfalls into Cobbs Creek approximately +/- 4,000 feet northwest of PA Route 3. West Indian Creek is also located mostly within the City and partially within Montgomery County. It does not outfall directly into Cobbs Creek or East Indian Creek, rather it is piped underground and is delivered to East Indian Creek upstream of Lansdowne Avenue.



N
WEST INDIAN
CREEK SUB-WATERSHED
EAST INDIAN
CREEK SUB-WATERSHED
INDIAN CREEK
SUB-WATERSHED
Direction of Flow
throughout Watershed
COBBS CREEK WATERSHED
0
0.5
1
2
Miles

2.0 MATERIALS AND METHODS

2.1 Reach Delineation and Coding

Stream reach breaks were determined according to significant changes in channel geometry and/or surrounding natural environmental features. The degree of channel alteration was most often used to break reaches and consisted of the presence of utility crossings, outfalls, and road, railroad, and/or mass transit crossings. Channel geometry characteristics were used less often because utilities were numerous and channel geometry was relatively consistent. Changes in channel geometry that were used to break reaches and consisted of a change in stream channel classification, bank condition, and/or bed materials. Natural environmental features such as changes in riparian composition and riparian width, that generally corresponded to changes in land use, were also used to break reaches. Reaches generally did not exceed 1000 feet in length.

Reaches, and the corresponding cross section, were coded by number and the name of the stream beginning at the upstream project study area limit. Hence, cross section '1 Cobbs' is the most upstream reach of Cobbs Creek and cross section '63 Cobbs' is the most downstream reach. Cobbs, East and West Indian Creek reaches were all coded using the same naming convention. Exceptions to the described coding include cross sections 29A, 32A, D1 and D2 since they were completed following initial field measurements. Cross sections 29A and 32A are between cross sections and D1 and D2 are both associated with dams in Cobbs Creek. Cross section D1 is nearest the Milbourne dam and D2 is nearest the Woodland Avenue dam. These cross sections were measured to provide additional data for hydraulic and hydrologic models. In lieu of adjusting all other cross section and reach codes, these cross sections were named individually.

2.2 Cross Section, Bank Pin and Scour Chain Site Rationales

Cross Section Rationale

Cross section locations were chosen according to multiple channel stability and geometry parameters that were representative of the entire reach. The appropriate location of cross sections in a channel exhibiting riffle/pool sequences is at the cross over reach (Rosgen 1996). A cross over reach is a straight riffle section of channel between two meander bends. This riffle is used since it is a hydraulic control. Cross sections were placed in this location when it satisfied the following criteria:

- ✓ Presence of clear bankfull indicators, or active floodplain,
- ✓ Representative of reach,
- ✓ No debris or obstructions such as rock, logs, outfalls, or instream structures, and
- ✓ No greater than 1000 feet from previous cross section.

Debris or obstructions such as rocks, logs, outfalls, or instream structures were avoided since they would influence bankfull indicators and yield a false bankfull width. In some cases, reaches were so strongly influenced, degraded and/or altered that there were no cross over reaches or riffle sections. Criteria used to determine the cross section location in these situations consisted of:

- ✓ Representative of reach
- ✓ Presence of best bankfull indicators
- ✓ Least amount of debris, obstructions, and alterations,
- ✓ Safe wading water levels, and
- ✓ No greater than 1000 feet from previous cross section.

Generally, reach lengths were no greater than 2000 feet long and cross sections were a maximum of 1000 feet apart. Collecting channel cross section data at this increment ensured that all possible Rosgen channel types would be measured and the hydraulic and hydrologic model would be reliable.

Cross section locations were marked on the downstream right and downstream left sides with 2' long, ¾" wide rebar that was installed flush with the ground, when possible. Where substrate composition, tree roots or concrete debris were encountered, rebar was not able to be installed flush with the ground. After making sure that the rebar could not be pulled out of the ground, the length of exposed rebar was noted on the data sheet. One inch yellow survey caps were placed on each rebar.

Bank Pin and Scour Chain Rationale

Bank pins and scour chains were installed at eleven (11) cross sections to characterize stream bed and bank materials and observe channel changes over time. Bank pin installation and monitoring locations were chosen according to field observed bank materials and conditions and an office evaluation of channel planform. Most sites were chosen because a high degree of ongoing bank erosion was observed on out-of-pattern meander bends. One site was chosen to serve as examples of stable, normal bank erosion to use for comparison with other sites. Scour chains were installed at each bank pin location except for cross section 14 Cobbs. A scour chain was not able to be installed at this cross section due to large, boulder sized and somewhat cemented bed materials.

A bank pin consisted of a 3' long, ¼" wide rebar. Depending on the height of the bank, three to four bank pins were installed at each cross section by inserting pins horizontally and/or vertically in the bank. Bank pins were installed vertically at the toe-of-slope when water did not reach both banks and other channel characteristics indicated that deposition may be occurring. A portion of each installed rebar was left exposed, spray painted fluorescent orange, and measured to serve as a baseline to compare with future measurements. Scour chains consisted of 2½' long, 3/8" diameter chains. When possible, the entire length of chain, except 4 links, was inserted down into the stream bed. The number of exposed links and the chain location was recorded for each site. Additionally, silver chains were installed at open, easily accessible sites and fluorescent orange chains were installed at less accessible sites.

2.3 CALIBRATING BANKFULL ELEVATION

Biohabitats, Inc. calibrated bankfull discharge using multiple methods: field cross section calculations, gauge station data, regional drainage area to peak discharge curves, and bankfull regression equations. All preliminary bankfull discharge values were compared and evaluated based on merit and strength of correlations in order to determine the most appropriate, (yet preliminary), bankfull discharge. The strongest correlations between discharges were generally considered the most reliable bankfull calibration. All preliminary bankfull discharges are presented and discussed within Section 4.4 Bankfull Calibration Results.

> *"The bankfull stage corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels."*
> *Dunne and Leopold (1978)*

Field Cross Sections
In an ideal channel, the bankfull elevation is at the top of the bank and is the point where the stream begins to overflow into the floodplain. Bankfull flows have the ability to transport sediment, shape the channel and eventually change the planform of the channel. The recurrence interval of a bankfull event is between every 1 to 2 years. Because these events occur so frequently they form features in the channel that indicate the bankfull elevation. Bankfull indicators consist of tops of point bars, changes in vegetation, and changes in bank slope. Bankfull indicators are often more difficult to identify, or not present at all, in impacted or disturbed urban streams, but are still essential to determining a bankfull elevation and discharge.

Based upon bankfull elevations identified in the field, Bankfull discharge was calculated for all surveyed cross sections, although only those that are nearest the downstream end of individual drainage areas were used for comparison with other bankfull discharges. Correlation among bankfull discharges were used to help verify calculated results.

Regression Equations
Bankfull discharge was also estimated using available regional regression equations. Applicable regional curves and/or regression equations were considered suitable for comparison with Cobbs Creek if the geologic province and land use patterns of watersheds used to develop the relationships were similar. Regression equations were also applicable if they were developed based on data for watershed sizes inclusive of

those of Cobbs Creek study locations. Based on these criteria, bankfull regional regressions from the Christina River Watershed (Delaware Dept. of Natural Resources and Environmental Council 1999) and the Baltimore County Regional Curve (Baltimore County Dept. of Environmental Protection and Resource Management, 1999) were used. Regressions required land use and drainage area information for the entire Cobbs Creek watershed. Land use information was obtained using a 1983 land use/land cover GIS file provided by the PWD. Delineated drainage areas for the Cobbs Creek mainstem and its subwatersheds were also provided by the PWD and used to determine drainage area sizes.

Stream Gauge Station Data

Stream gauge station data was used to generate flood frequency graphs showing the 1- and 2-year recurrence discharges for three locations on the Cobbs Creek mainstem. Flood frequency curves were created using gauge station data in order to determine 1 and 2 year recurrence discharges. Recurrence discharges were compared with field bankfull discharges to determine whether field indicators yielded discharges within a reasonable range. Because land use has not changed significantly since the stream flow gauges were operated, gauge station data is considered applicable to calibrating bankfull discharge for the Cobbs Creek watershed.

2.4 Stream Survey

The stream survey consisted of Biohabitats, Inc. field crews performing a field reconnaissance of the Cobbs Creek watershed. Approximately 18 miles of stream channel were surveyed and included the mainstem of Cobbs Creek, East and West Indian Creeks. The field reconnaissance included walking the entire length of stream, choosing and marking cross section locations, and making general observations of the surrounding watershed. All initial field observations and cross section locations were noted on a large scale field map prepared using data provided by the City of Philadelphia Water Department. The field reconnaissance was completed during the months of November 2001 thru early December 2001.

2.4.1 Stream Survey Data Collection Parameters

Channel and habitat parameters that are not self evident, or obvious, are briefly described within this section. Sediment supply, degree of bank erosion, reach bed stability, and reference reach potential require additional explanation since they are not measured channel parameters, but are qualitative estimations. The use of the following field assumptions assured that these parameters were rated consistently and fairly to represent the existing conditions of Cobbs, East and West Indian Creeks.

Degree of Bank Erosion

The degree of bank erosion was rated as low, moderate or high. Generally, the tallest banks (the distance from the toe-of-slope to the top-of-bank) were assigned either a moderate or high bank erosion value, and shorter banks were assigned low bank erosion values. Bank heights were relevant to channel geometry. Bank condition influenced this value if the existing condition of banks were undercut, slumping, or showed evidence of active bank erosion.

Sediment supply

Sediment supply was rated as low, moderate or high. Sedimentological indicators such as sorted lateral bars, presence of mid-channel bars, amount of steep, unvegetated banks, and lack of channel bed features were evaluated together to determine a representative sediment supply rating for each reach. Reaches with steep, unvegetated banks, and no lateral bars or bed features were assigned either a moderate or high sediment supply value. The distinction between moderate or high ratings was determined by bank height and the amount of bank erosion. Reaches assigned a low sediment supply rating typically had short, well-vegetated banks, and bed features indicative of the channels ability to move materials downstream.

Reach bed stability
Reach bed stability was rated as aggrading, degrading, or indeterminate. Aggrading reaches were those that exhibited characteristics of a channel that is depositing material and building features within the channel. Generally, these reaches may contain, or are beginning to develop, stable channel features such as lateral bars or a new, lower floodplain. Degrading reaches are those that are actively and concurrently undergoing multiple changes to their planform and geometry that do not allow the channel to remain stable. Examples include downcutting, overwidening and severe bank erosion. Indeterminate reaches exhibited no characteristics of either an aggrading or degrading channel.

Reference reach potential
Reference reach potential was determined based upon whether a reach was a stable, natural stream channel. Stream reaches that had reference reach potential were stable, not disturbed by utilities, had good to excellent riparian cover and did not appear that any changes within the immediate surrounding environment were likely to occur and adversely impact the channel.

2.5 MEASURED STREAM CROSS SECTION

Based on results of the stream survey/field reconnaissance and following additional planning and base map preparation, the measured reach portion of the stream survey was completed. The measured reach stream survey consisted of collecting data for various channel morphology, disturbance, stability, and habitat parameters. Specific channel and habitat parameters included the following:

Channel Morphology

- √ Stream Bed Materials
- √ Sinuosity
- √ Water Surface Slope
- √ Bankfull Width
- √ Bankfull Depth
- √ Floodprone Area Width
- √ Entrenchment Ratio
- √ Bankfull Cross-sectional Area
- √ Rosgen Stream Classification Type

Channel Disturbance

- √ Direct Human Channel Impacts
- √ Culvert
- √ Utilities
- √ Fish Blockages
- √ Road, Railroad, Mass Transit Crossing

Channel Habitat Characteristics

- √ Woody Debris
- √ Sediment Supply
- √ Reach Bed Stability
- √ Degree of Bank Erosion
- √ Riparian Composition
- √ Riparian Width
- √ Canopy Cover
- √ Channel Flow / Attachment Sites

The measured reach stream survey also consisted of surveying channel cross sections at each location previously chosen during the field reconnaissance. Field data sheets were used to record all data collected in the field. Appendix B contains a summary of the results of the surveyed cross sections and local longitudinal profiles. Cross section locations are shown on Figures 4.1, 4.2 and 4.3.

2.5.1 Cross Section Procedures

Each stream cross section was measured by extending a 100 foot measuring tape across the channel. Measuring tapes were extended a minimum of twice the bankfull width for each cross section and sometimes were extended the entire valley width due to the estimated floodprone width. Rod readings were taken from the downstream left bank across the channel to the end of the measuring tape on the downstream right bank. Rod readings were taken at all significant channel features, or changes in channel features, such as the thalweg, bed materials, vegetation, slope, and flow lines.

From the survey data, field data, and topographic base map, the following items were calculated:

- √ Bankfull width/depth
- √ Entrenchment ratio
- √ Shear Stress
- √ Channel slope
- √ Sinuosity
- √ Median particle size (“D_{50}”)
- √ Bankfull Discharge

2.5.2 Profile Procedures

A short channel profile was completed at every cross section location to measure local slope. A 300 foot measuring tape was stretched out, upstream to downstream, in the channel thalweg. At a minimum, profiles began 100 feet upstream of the measured cross section and extended 100 feet downstream of the cross section. Therefore, profiles were a minimum of 200 feet long. When there were no channel or line-of-sight obstructions, the profile was extended the full length of the measuring tape to 300 feet, or to the next riffle. Rod readings were taken at the top of riffles within the thalweg, unless it was a degraded reach where no riffles were present. Profile measurements were not taken for a total of three cross sections because it was not safe to wade through the channel, set up equipment and/or take measurements in those locations. Profile measurements were used as an estimate of bankfull slope and to calculate a local slope for each cross section that is shown on each cross section graph in Appendix B.

2.5.3 Stream Classification

Physical channel conditions were assessed using the procedures and methodologies for fluvial geomorphologic analysis as outlined in "A Classification of Natural Rivers" (Rosgen, 1994). As part of the field reconnaissance, the Rosgen classification system was used to categorize the stream channel into major, natural channel types. These channel types are determined on the basis of existing morphological features of the stream channel and valley. Key parameters and channel types used in the Rosgen classification system are presented in Table 2.5.

Table 2.5 Rosgen Stream Classification Parameters*

Channel Type	Entrenchment Ratio	Width/Depth Ratio	Sinuosity	Channel Gradient
A	<1.4	<12	Low (<1.2)	4 to 10%
B	1.4 to 2.2	>12	Moderate (>1.2)	2 to 4%
C	>2.2	>12	High (>1.4)	<2%
D	N/A	>40	Low (<1.2)	<4%
E	>2.2	<12	Very High (>1.4)	<2%
F	<1.4	>12	High (>1.4)	<2%
G	<1.4	<12	Moderate (>1.2)	2 to 4%

*Adapted from Rosgen, 1994 and Rosgen, 1996.

Each major channel type identified in the field was further classified based upon the median particle size of the bed material. The median particle size (D_{50}) of the bed material at each cross section was determined through visual reconnaissance and average mannings n values were used in the calculations. Average mannings n values were based upon the "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (Table 1. Base values of Manning's n, modified from Aldridge and

Garrett, 1973, table 1). Numbers 1 through 6 correspond to different sediment size ranges as follows:

1 - Bedrock	**(N/A)**	4 – Gravel	(.028)
2 - Boulder	(.04)	5 – Sand	(.017)
3 - Cobble	(.032)	6 – Silt	(.017)

Field measurements taken at the cross section were then compared with the parameters in the Rosgen classification system to determine channel type. It should be noted that the stream is actively adjusting, as evidenced by eroding banks and meander migration. Identification of bankfull is extremely difficult in altered reaches and reaches undergoing adjustments like Cobbs Creek and its tributaries. In such cases, stream morphology can be expected to deviate from the Rosgen channel types, because the Rosgen classification system generally applies to channels that are in a state of "dynamic equilibrium". Additionally, for stream sections that have been highly modified such as through the placement of concrete riprap, lining with concrete, or piping, channel morphology often does not coincide with a single Rosgen channel type.

When stream reaches exhibited features of multiple channel types, the current or principle channel type was determined according to the surveyed cross section. Transitional channel features, sometimes referred to as secondary channel characteristics, were denoted by an arrow and capital letter (i.e. B5a → C). This method was employed to classify some reaches included in this study because transitioning, or secondary, channel features offer additional information about how a reach is adjusting, or migrating to another channel type.

Together, the watershed characterization and channel cross section measurements were used to determine the Rosgen channel type. Resulting reach characterizations can be referenced in the Results section and also on each cross section data sheet in Appendix B.

2.6 STREAM REACH RANKINGS

Field data was divided into two categories depending on whether it related to habitat or channel stability. Numerical values assigned to each channel stability parameter were established according to field surveyed existing channel geometry. Existing geometry determined the Rosgen channel type, which provided the basis for assigning ranking values to other stability parameters. Other background information such as soils, geology, topography, valley type and land use were also evaluated to determine geometry and habitat parameter ranking values. Given the surrounding existing landscape, those channel types that are unlikely to occur in the watershed were considered less stable and assigned higher ranking values for each geometry parameter than those channel types more likely to be present. Expected channel types were assigned lower ranking values for each parameter, indicating that since they are likely to occur based on characteristics of the surrounding landscape, they would also be more stable channels. Habitat parameters were assigned ranking values based on qualitative data collected during the field survey.

Final reach rankings were determined by adding the total geometry and habitat ranking values. The maximum, or worst, stability ranking attainable by any reach is 36, while the maximum habitat score is 33. Combined ranking values yields a 69 score that is the maximum score for those reaches that do not contain any infrastructure. Maximum scores for those reaches containing infrastructure are considerably greater since each occurrence of infrastrucuture was assigned a 1 ranking value and because the parameter subtotals were multiplied by a factor of 2 to emphasize the potential impacts to channel stability and habitat. Reach ranks were compared with photos, data sheets and field observations to ensure that the rating methodology accurately represented existing conditions. Overall reach stability and final reach ranks were used to prioritize those reaches recommended for restoration.

2.6.1 Geometry Parameters Ranking Values

Figure 2.6.1 Determination of Stability Parameter Ranking Values

Reference Reach Potential	Ranking Value
Yes	0
No	2

Channel Type	Ranking Value
C	0
E	0
B	2
G	3
F	4

Reach Bed Stability	Ranking Value
Aggrading	2
Degrading	3
Indeterminate	1
Stable	0

Channel Alteration	Ranking Value
Yes	0
No	2

Channel Alterations: Utilities/Infrastructure	Ranking Value
Manholes, Sewers, Outfalls, etc. Present	Total # of Occurrences per Reach

Infrastructure Factor	Ranking Value
Present within Reach	2
Not Present within Reach	1

Adjustment for Channelization	Ranking Value
Channelized Portions within Reach	10
No Channelized Portions within Reach	0

Bed Materials	D50 Value	Ranking Value
Sand and Silt	<2 through 12	4
Gravels	12 through 96	3
Cobbles	96 through 512	2
Boulders	512 through 4096	1
Bedrock	> 4096	0

Bank Erosion	Value	Ranking Value
Low	10-19.5	1
Moderate	20-29.5	2
High	30-39.5	3

Shear Stress	Possible Size Range of Material Moved	Ranking Value
<0.01	0.1-2	0.8
<0.02	0.2-5	1.4
<0.2	1-10	1.8
<1	10-50	2
<2	20-500	4
<10	50-1000	6

Reference Reach Potential

Reference reach potential was evaluated overall for each reach and was assigned either a "Yes" or "No" value. Reaches having reference reach potential are stable channels representative of that entire reach and also of that subwatershed. Reaches with reference reach potential were assigned a ranking value of 0 and those that are not were assigned a 2 value.

Channel Type

Channel type was assigned a ranking value according to stability and the amount of deviation from baseline conditions. A total of five Rosgen channel types, in order by values, were included in the channel type parameter: C, E, B, F, and G. C Rosgen channel types were assigned the lowest ranking value, while G channel types were considered the least expected and stable, if present, in any of the subwatershed valleys and were assigned the highest ranking value.

Reach Bed Stability

Reach bed stability was determined based on whether the streambed was actively degrading, aggrading or stable. Degrading beds exhibited evidence of active erosion and/or downcutting, while aggrading reaches contained depositional features. The highest reach bed stability ranking value of 3 was assigned to degrading reaches, while aggrading reaches were assigned a ranking value of 2. Although a channel that is aggrading is becoming more stable, a moderately high ranking value was assigned because changes to channel geometry and/or planform are considered unstable. In reaches where channel changes were not evident, reach bed stability was "indeterminate" and a ranking value of 1 was assigned. Only stable reaches were assigned the lowest ranking value of zero.

Channel Alteration: Anthropogenic Influences

Reaches were assigned a ranking value for channel alterations based upon whether any anthropogenic impacts such as footbridges, walls, fountains, landscaping, etc. were observed within the reach. Reaches containing channel alterations, regardless of whether there were multiple alterations, were assigned a ranking value of 2. Those reaches that do not contain any channel alterations were assigned a ranking value of zero.

Channel Alteration: Infrastructure

Reaches were also assigned a ranking value according to whether they contained any infrastructure. Examples of infrastructure include manholes, both active and abandoned, sewer easements, outfalls, combined sewer outfalls (CSO) and culverts and/or bridges. Channel alterations consisting of infrastructure were weighted the greatest of all parameters since they are considered capable of impacting the channel the most. Ranking values for infrastructure were assigned based upon the total number of occurrences observed within each reach. Therefore, reaches that do not contain infrastructure are considered more stable and were assigned a zero rating value since channel geometry is less influenced and subject to erosion typical of disturbance due to the presence of utilities.

Infrastructure Factor

Infrastructure is considered the most potentially influential parameter on the channel geometry. For this reason, infrastructure was weighted the greatest of all channel stability parameters and was included in the reach ranking determination multiple times to account for its importance.
Reaches that contain infrastructure were multiplied by a factor of 2 to account for the significantly increased risk to channel stability.

Adjustment for Channelization

Stream channels were considered channelized when they have been straightened and lined with manmade materials that usually consisted of concrete, brick or stone. The natural geometry is absent and has been replaced with a trapezoidal, artificial watercourse. Channelization was also included in the reach ranking and assigned one of the highest ranking values because it is not a natural channel, nor will it be until those reaches are restored. Reaches that are channelized were assigned a ranking value of 10 while those that remain as natural banks and streambeds were assigned a ranking value of zero.

Bank Materials

Existing bank materials were assigned a parameter value according to size and how easily they can be eroded from the bed or banks. Sand and silt were assigned the highest ranking value while values for more course materials increased by an increment of one. Boulders and bedrock, although they are not present within the project study area, were assigned the lowest values since they are not easily eroded.

Bank Erosion

Bank erosion was rated as low, moderate, or high based on field observations. High bank erosion, or actively eroding banks, generally steep or vertical, were assigned a ranking value of 3. Channel banks that were generally less than 4 feet tall, stabilized with vegetation and not actively eroding were rated as low and assigned a ranking value of 1. Bank erosion does not include a zero ranking value.

Shear Stress

Shear stress can be defined as the amount of force exerted on the wetted perimeter of a channel by moving water. It is not uniform along the wetted perimeter, but varies according to the channel shape, bank materials and their ability to resist erosion. The bankfull wetted perimeter, cross sectional area, bankfull slope, and hydraulic radius were calculated based upon the surveyed cross section geometry and then used to calculate the shear stress for each cross section using the following equation:

Shear Stress = $T = \gamma RS$, where
T = shear stress
γ = density of water
R = hydraulic radius (Cross sectional area/Wetted perimeter)
S = channel slope

Shear stress values calculated for all cross sections are shown on the cross section graphs within Appendix C.

Shear stress ranking values were determined by using the Shields diagram (Leopold, 1964). The Shields diagram (shear stress per grain diameter) shows the amount of stress required to initiate movement of bed and/or bank materials. Six possible ranking values were determined by grouping data points plotted on the Shields diagram into categories. Ranking values range from 0.8 for shear stress values less than 0.01, to 6 for shear stress values between 2 and 10.

2.6.2 HABITAT PARAMETERS RANKING VALUES

Habitat variables differ from channel stability parameters because they are not measured or calculated, but are qualitative. Ranking values were assigned to habitat parameter data based on ideal conditions. For example, riparian width values consisted of ‘<10 feet’, ‘10-25 feet’, ‘25-100 feet’, and ‘>100 feet’. Riparian width has a total of 4 possible values with ‘>100 feet’ being the ideal condition. The ideal value of ‘>100 feet’ was then assigned the lowest ranking value (1) and the least ideal condition was assigned the highest ranking value (7). Therefore, each habitat field data parameter was assigned a ranking value based on the ideal condition for that parameter. Figure 2.6.2 shows the ranking values assigned to each habitat parameter.

Figure 2.6.2 Determination of Habitat Parameter Ranking Values

Riparian Composition	Ranking Value
Yards/Lawn	7
Pasture	6
Vines	5
Herbaceous	4
Shrubs	3
Deciduous	2
Trees & Shrubs	1
Mixed Deciduous & Evergreen Trees	1

Canopy Cover	Ranking Value
0-20%	4
21-40%	3
41-60%	2
61-80%	1
81-100%	0

Woody Debris	Ranking Value
Absent	3
Few	2
Moderate	1
Frequent	0

Wetlands	Ranking Value
Present w/in Riparian	0
Not Present w/in Riparian	3

Attachment Sites	Ranking Value
<25% Exposed	0
25-75% Exposed	1
>75% Exposed	2

Sediment Supply	Ranking Value
Low	0
Moderate	2
High	4

Riparian Width	DSR Ranking Value	DSL Ranking Value
<10	10	10
10-25'	6	6
25-100	1	1
>100	0	0

Canopy Cover

Canopy cover was assessed according to the percent canopy directly above the channel throughout the reach. Canopy cover was divided into five categories ranging from the lowest of 0-20% to the highest, or ideal category, of 81-100%. The most ideal category was assigned a zero ranking value while all others decrease by an increment of 1 as they worsen.

Riparian Width – Downstream right and left banks

Reaches were assigned an individual ranking value for the downstream right and left riparian widths. Values range from zero for a forested riparian equal or greater than 100 feet wide and increase to a ranking value of 10 for those reaches having a riparian width less than 10 feet wide.

Woody Debris

Woddy debris, such as fallen trees and branches, are beneficial to streams because they provide habitat for fish and other aquatic organisms. Although woody debris can negatively impact the stability of a channel, for the purpose of assigning ranking values to this parameter, the ideal condition was assigned to those reaches containing the most woody debris. Reaches containing a frequent amount of woody debris were assigned a zero ranking value and those containing no woody debris were assigned a ranking value of three.

Attachment Sites

Attachment sites were assessed by determining the percent of the channel bottom that was exposed or not covered by base flow. Channel substrate not covered by base flow is unsuitable habitat for aquatic microorganisms and macroinvertebrates. Therefore, reaches that had a 75% or greater amount of channel substrate exposed were assigned the worse ranking value of 2 and reaches having 25% or less substrate exposed were assigned the ideal ranking value of zero.

Sediment Supply

Sediment supply was divided into three categories: low, moderate and high. Ranking values begin at 0 for the ideal condition, or low sediment supply, and increase by an increment of two to high having a ranking value of four. Sediment supply was highest when severe bank erosion was occurring and there was deposition occurring within the channel.

Wetlands

Wetlands were incorporated into the habitat rating according to whether or not they were present adjacent to the channel. Reaches containing wetlands were assigned a ranking value of 0, while those reaches not containing wetlands were assigned a ranking value of three (3).

2.7 SUBWATERSHED RANKING VALUES

Ranking according to subwatershed characteristics was calculated by evaluating land use and runoff potential of soils present within each subwatershed. Land use was assessed by calculating the percent impervious surfaces for each subwatershed based on the assumption that all land use types are impervious except forested, or wooded, areas. Runoff potential of soils was evaluated to help determine subwatershed rankings because the amount of runoff within a subwatershed has the potential to significantly influence the bankfull discharge, bed and bank stresses, and therefore channel stability. Characteristics of soils, such as the texture and hydrologic group, dictate the infiltration rate, or the rate at which water is capable of moving down through the soil profile, and eventually into the groundwater table. Infiltration rates are also affected by the slope of the time of concentration path (Tc), or the distance and rate at which water travels over the surface to and through the channel. Generally, it can be assumed that the higher the slope of the Tc path, the faster the velocity of runoff and the lower the infiltration rate. By decreasing the amount of time water has to infiltrate, flows will be delivered to channels at an increased velocity. Therefore, a higher runoff potential, estimated for each subwatershed by calculating the percent imperviousness and the slope of the Tc path, can serve as an estimate of potential magnitude of bed and bank erosion.

Additionally, the total subwatershed ranking according to individual reach rankings was calculated by adding all reach ranks and dividing by the maximum (worst) possible score per subwatershed. This calculation yielded a percent of the reaches within the subwatershed that were degraded. Therefore, the highest subwatershed ranking contained the greatest amount of degraded reaches, or total linear feet of degraded stream channel.

2.8 RESTORATION STRATEGIES

Restoration strategies have been recommended for each subwatershed according to reach and subwatershed ranking. Strategies were chosen by evaluating each subwatershed and identifying potential sources or causes that have led to the existing degraded stream conditions. Based on identified problem areas and preliminary causes, a restoration strategy, or combination thereof, was developed for each subwatershed. Specific restoration measures were not developed for each reach, but rather restoration strategies were developed on a watershed basis to first prioritize those portions of the Cobbs Creek watershed most in need of restoration efforts. Those reaches recommended for restoration efforts should be evaluated in more detail prior to developing restoration concept designs. Restoration strategies can be divided into three main categories: channel stability, habitat, and managing developed land.

3.0 EXISTING CONDITIONS

Table 3.0 Total Stream Assessed – Cobbs Creek, East Indian Creek, and West Indian Creek

Watershed	Total Cross Sections	Total Reaches	Total Linear Feet Assessed	Total Miles Assessed
Cobbs Creek	63	63	69,986	13.25
East Indian Creek	18	18	16,078	3.05
West Indian Creek	11	11	8,099	1.53

3.1 COBBS CREEK WATERSHED ASSESSMENT

The Cobbs Creek watershed is a total of 22.24 square miles (14,235.5 acres) and lies mostly within the City of Philadelphia, Pennsylvania. Approximately 1/3 of the total linear feet of Cobbs Creek included in this study are located outside of the City of Philadelphia within Delaware County, Pennsylvania. Cobbs Creek begins immediately southwest of the intersection of Haverford Road and Buck Lane within the town of Haverford, Pennsylvania and ends at the confluence of Cobbs and Darby Creeks (Figure 4.1).

A total of 13.25 miles of the Cobbs Creek mainstem, broken into 63 individual reaches, were assessed. Stream reach breaks were primarily chosen due to changes in channel conditions downstream of City Line Avenue and more frequently according to road crossings north of City Line Avenue. This road also marks the northern City of Philadelphia limit and a significant land use change. Land use downstream of City Line Avenue consists of primarily multi-family residential land use, while land use upstream of City Line Avenue consists of mostly single family residential land use. Two concentrated areas of commercial land use are also within the Cobbs Creek watershed. Both are adjacent to state routes: PA Route 3 and 320. These significant changes in land use correspond with changes in the quality of habitat and channel conditions. Overall, forest habitat is limited within the watershed because only 9% is forested and is almost all adjacent to Cobbs Creek. Forest habitat surrounding the Creek increases in width as it progresses downstream.

3.2 East Indian Creek

The East Indian Creek subwatershed is a total of 2.2 square miles (1,410 acres) and is situated in the northeastern corner of the Cobbs Creek watershed. Approximately 1/3 of this subwatershed is located within Montgomery County, Pennsylvania and the remaining portion is located within the City of Philadelphia. East Indian Creek begins in the vicinity of the intersection of Haverford Avenue and Mayflower Lane. Upstream of this intersection is an area of dense single family, residential land use where the upstream most portion of the channel is piped underground. East Indian Creek was assessed from immediately south of Haverford Avenue downstream to the confluence with Cobbs Creek (Figure 4.2).

East Indian Creek was broken into 18 stream reaches totaling approximately 3 miles of assessed channel. Reach breaks were chosen most often according to road crossings and less frequently according to changes in channel geometry. East Indian Creek is influenced by many instream structures and alterations to the land immediately adjacent to the creek. Downstream of the piped headwaters, East Indian Creek travels through Narberth, a single family residential neighborhood, where the creek is surrounded by a park-like setting. Land adjacent to the channel in the area is mowed up to the top of bank and multiple footpath crossings have been installed. Land use changes near Lancaster Road mark a transition to high density residential development and continued instream structures and impacts. Private property owners have installed multiple bank protection measures such as boulders, brick and concrete in an effort to stabilize the creek. The most severe disturbance to the Creek occurs just North of City Line Avenue where the creek is channelized and travels through the ground level of an apartment/condo building. Downstream of City Line Avenue, the channel becomes wider and the channel valley becomes more narrow and defined by steep slopes. Channel stability and habitat, overall in the East Indian Creek subwatershed are considered poor.

3.3 WEST INDIAN CREEK

The West Indian Creek subwatershed is a total of 1.75 square miles (1,118 acres) and shares its eastern boundary with the western side of the East Indian Creek subwatershed. The West Indian Creek subwatershed is located mostly within Montgomery County and extends into the City of Philadelphia for approximately 5000 feet. West Indian Creek begins immediately south of Sussex Road within the Township of Lower Merion (Figure 4.3).

West Indian Creek was divided into eleven reaches that totaled approximately 1.5 miles of assessed channel. Land use patterns within the West Indian Creek subwatershed were vary similar to those within East Indian Creek subwatershed. West Indian Creek begins underground, continues downstream through single family residential neighborhoods, and becomes wider as it continues downstream beyond City Line Avenue. The same change in land use from less to more dense residential development is seen within the West Indian Creek subwatershed. Development density and also the amount of forested riparian buffer also increases as the creek progresses downstream, although the subwatershed is only 19% forested.

3.4 ADDITIONAL OBSERVATIONS

In addition to qualitative data collection and cross section measurements, other channel characteristics were observed throughout the Cobbs Creek watershed that influence channel stability. Dominant influences on channel stability throughout the watershed, aside from land use, consisted of utility infrastructure and dams.

3.4.1 UTILITY INFRASTRUCTURE

Per a field survey completed by the PWD, there are a total of 238 utility structures present throughout the Cobbs Creek watershed, either within the channel or within close vicinity of the channel. Principle utilities present consist of sewer infrastructure and stormdrain systems. Manholes, various pipes, and outfalls associated with these systems tended to be located within the channels. Overall, most systems were observed in good or fair condition while fewer are considered an immediate concern to water quality. Those that are considered a concern to water quality consist of combined sewer outfalls (CSO), and exposed sewer pipes that are in poor condition. CSO's and exposed sewer pipes in poor condition have been shown on Figure 5.0 Restoration Strategy Opportunities and were taken into account and discussed within Section 7.0 Prioritization. It should be noted that the presence of all utilities and any associated structures are considered an immediate concern to channel stability and also water quality as it relates to increased sediment supply.

3.4.2 DAMS

There are two dams present within the Cobbs Creek watershed: Milbourne and Woodland Avenue. These dams were most likely installed to generate power for mills and were abandoned when technology advanced during the late 19th and early 20th centuries. Powder mills and sawmills were the principle types of mills operated within the Schuylkill River watershed (Upper Perkiomen Watershed Coalition, Sept. 5, 2002). Other possible uses consist of irrigation, flood control, and/or water supply. Although these are both small structures relative to the width of the channels, it is likely that they are impacting the channel downstream. Potential adverse impacts of these dams consist of:

- ✓ impacting or eliminating fish species
- ✓ decreasing base flow,
- ✓ excessive aggradation upstream of the dam,
- ✓ significant changes to the sediment supply regime downstream of the dams,
- ✓ changing and/or potentially eliminating aquatic habitat,
- ✓ changing channel geometry, and
- ✓ influencing the riparian vegetation.

None of these impacts can be identified as consequences of the existing dams on Cobbs Creek without knowing, or having data, for conditions that existed prior to their installation. However, future impacts may be monitored over time to gain additional insight regarding how to manage the existing dams and minimize any future impacts to the channels downstream.

3.4.3 THREATENED & ENDANGERED PLANT AND ANIMAL SPECIES COORDINATION

Coordination with the Wildlife and Heritage Division of the Maryland Department of Natural Resources, Pennsylvania Natural Diversity Inventory, National Wildlife Federation, and other local or state agencies is important to ensure that species of concern are not adversely impacted. This coordination should take place during the initial stages of project implementation. Although coordination for the entire Cobbs Creek watershed did not take place for this study, coordination for other smaller projects within the watershed have revealed the presence of species of concern. Known species of concern located within the Cobbs Creek watershed (as of March 2002) consist of:

*Elephantopus carolinianus - Elephants foot, an endangered plant, and

*Alopecurus aequalis - Short-awn foxtail, tracked plant in Pennsylvania.

4.0 RESULTS

4.1 COBBS CREEK REACHES

Channel cross section measurements and calculations show that the entire Cobbs Creek classifies as a Rosgen type F channel. A Rosgen type "F" channel is entrenched, has a width/depth ratio greater than 12, and has a low sinuosity. A low entrenchment ratio (<1.4 = a highly entrenched channel), allows for very high bank erosion, sediment supply and lateral overwidening rates. F channel types often have completed downcutting and are continuing to overwiden in an effort to create a new floodplain within the channel. Lateral bars and moderated riffle/pool sequences are often present. F channel types generally have low slopes, ranging from <1-1%. Figure 4.1 shows the locations of all measured cross sections in the Cobbs Creek subwatershed and cross section calculations, graphs and the resulting Rosgen channel types can be referenced in Appendix C.

4.1.1 BANKFULL ELEVATION INDICATORS

Principle bankfull indicators used throughout the Cobbs Creek watershed consisted of watermarks, debris flow lines, cobble and gravel bars, and undercutting banks. Identifying bankfull indicators throughout Cobbs Creek was difficult due to the number of instream structures installed predominantly in the headwaters, by private homeowners. Bankfull elevation and corresponding indicators are influenced by the degraded condition and instream structures such as footbridges, manmade ponds, and stone/cobble/concrete walls that divert flow and do not allow natural bankfull indicators to develop. Where natural indicators were not present, the best available bankfull indicators consisted of watermarks and/or moss lines on in-stream structures.

Bankfull indicators are more apparent as Cobbs Creek progresses downstream and fewer instream structures are present. Dominant bankfull indicators used throughout this mid-section of Cobbs Creek consisted of the back of gravel/cobble bars when there was evidence that the bar was actively forming, and the top of gravel/cobble bars when there was evidence that the bar had completed forming. Non-active lateral bars were found nearest the downstream portion of the mid-section of Cobbs Creek.

Further downstream, bankfull indicators were the most difficult to identify or not present at all since the channel is highly entrenched and banks are severely eroded and vertical. The best bankfull indicators available in this portion of the channel consisted of undercutting trees and watermarks on debris within the channel. Debris often consisted of concrete remnants, large household trash, and in general, objects that were too large for a bankfull storm to move downstream. Confidently identifying a bankfull elevation beginning downstream of the Woodland Avenue dam within reach 58 and continuing downstream to the confluence with Darby Creek was extremely difficult. Existing hydrology for this portion of Cobbs Creek is complicated because it is tidally influenced by Darby Creek. For this reason and the goal/scope of the Level II Geomorphological Survey, the best available field bankfull indicators were used and bankfull discharge was assumed to occur independent of Darby Creek.

4.1.2 Stream Condition and Stability

Bank conditions throughout Cobbs Creek vary throughout the watershed and generally worsen as the Creek progresses downstream. Channel banks within the headwaters are no taller than 5 feet and are at least 60% vegetated. Bankfull width of the Creek in the headwaters is an average of 25 feet wide. As the Creek progresses downstream, banks transition to greater than 6 feet tall and less than 50% vegetated. Bankfull width varies from 25 feet to approximately 60 feet wide.

Existing sediment supply and reach bed stability also worsen as the Creek continues downstream. Reaches in the headwaters are an average of 25 feet wide at bankfull and increase to an average width of 60 feet near the confluence with Darby Creek.

4.1.3 Expected Future Channel Changes

Generally, it is the goal of an F channel type to cease downcutting and begin depositing bed materials as alternating lateral bars. Deposition forming lateral bars in turn continues overwidening. Alternating lateral bars will slowly build over time through an exchange of sediment during bankfull storm events to effectively decrease the width of the channel accessible by base flow. Limiting the width of the channel through the creation of alternating lateral bars, will yield a greater sinuosity and a new, lower floodplain. Although an F channel type is not considered stable, generally, it will migrate to a stable C channel type over geologic time.

Currently, the majority of Cobbs has ceased downcutting and is continuing to overwiden. Evidence of overwidening is exhibited as undercutting and vertical banks. The majority of Cobbs Creek is expected to continue widening through bank erosion. The upstream most portion is expected to begin to downcutting and become more entrenched prior to beginning the overwidening stage that the remainder of the Creek is currently undergoing. The rate of channel overwidening will slow, or cease, when deposition is initiated in the channel.

Cobbs Creek Watershed
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47 COBBS
48 COBBS
49 COBBS
50 COBBS
51 COBBS
52DSR
53DSL
54DSR
55DSR
56DSR
57DSL
58 COBBS
59 COBBS
60 COBBS
61 COBBS
62 COBBS
63 COBBS
HAVERFORD
LANCASTER
CITY
63RD
MARKET
0
0.5
1
2
3
Miles

4.2 East Indian Creek Reaches

Cross section surveys of East Indian Creek resulted in mostly "B" Rosgen channel types and a small number of "F" Rosgen channel types (Figure 4.2 and Appendix C). A Rosgen channel type "B" is moderately entrenched, has a width/depth ratio greater than 12, and has moderate sinuosity. B channel types differ from F channel type since they generally have less steep, tall banks, and a deeper, more varied channel bed rather than consistently flat. Sediment supply and bank erosion are usually high since they are actively changing through bed and bank erosion. Those East Indian Creek reaches classified as F channel types have completed downcutting and have undergone enough bank erosion to create a wide, flat bottom channel.

4.2.1 Bankfull Elevation Indicators

East Indian Creek is surrounded by single family residential neighborhoods throughout the majority of the subwatershed making a large percentage of the Creek altered. Only 3 of the 18 total reaches are not altered and/or influenced by instream structures, bridges or culverts associated with road crossings. The least disturbed reaches are all located downstream of City Line Avenue where the widest riparian buffer is present and the channel exhibits the best bankfull indicators. Undercutting banks were the principle bankfull indicator observed within the East Indian Creek subwatershed.

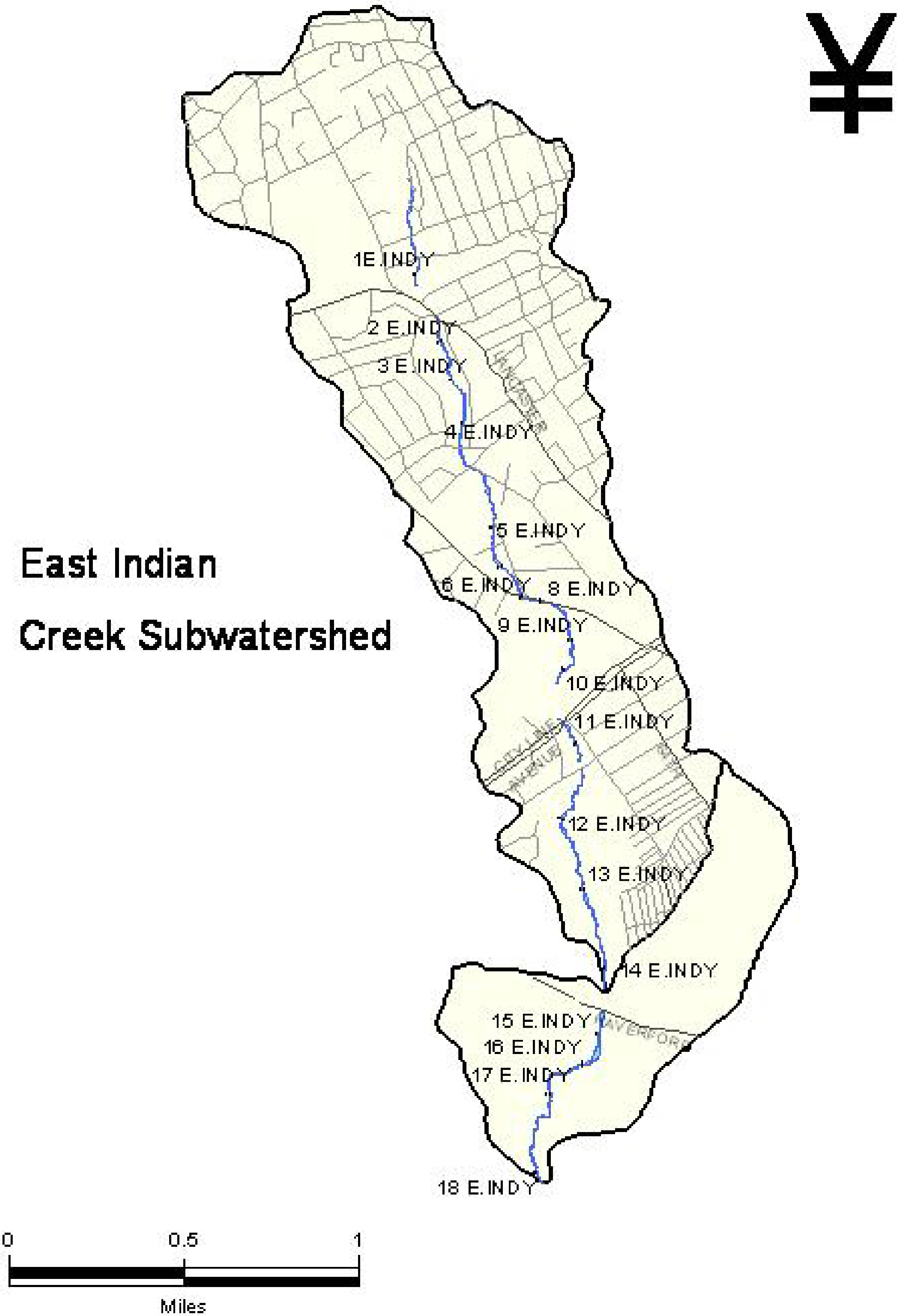
4.2.2 Stream Condition and Stability

Bank conditions throughout East Indian Creek range from relatively stable in undisturbed areas to moderately eroded upstream of Lansdowne Avenue. Residential land use and regular mowing has limited the development of a forested buffer, increased sediment supply and facilitated bank erosion. Channel banks are the most degraded within Reaches 13 and 14 where banks and adjacent slopes are the steepest within the subwatershed. These reaches are uncharacteristic of the remainder of the East Indian subwatershed and are most similar to topography and valley types within the Cobbs Creek watershed. Channel condition and stability for the entire East Indian subwatershed are influenced by the following throughout the subwatershed:

- √ numerous road crossings and associated bridges and/or culverts,
- √ 4-6" plastic drain pipes from local residents,
- √ Mowed park areas – pet waste
- √ Stormwater management practices (Reach 5)
- √ Channelized portion travelling under a large condo/apartment building
- √ Dam within Reach 10
- √ Footbridges installed by private homeowners
- √ Adjacent golf courses, mowed up to channel, no riparian (introduced at x/s 17)

4.2.3 Expected Future Channel Changes

Measured cross sections resulting in an "F" Rosgen channel type are located nearest the confluence with Cobbs Creek. These reaches have completed downcutting and possibly overwidening prior to the upstream reaches classified as "B" channel types. Existing channel geometry for the East Indian Creek suggests that the downstream end of East Indian Creek is further ahead in the channel migration process than the upstream portion. Over time, all reaches within East Indian Creek are expected to become F channel types and follow the same channel migration pattern over geologic time to transition to a stable C channel type, as described for Cobbs Creek.


East Indian
Creek Subwatershed
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2 E.INDY
3 E.INDY
4 E.INDY
5 E.INDY
6 E.INDY
8 E.INDY
9 E.INDY
10 E.INDY
11 E.INDY
12 E.INDY
13 E.INDY
14 E.INDY
15 E.INDY
16 E.INDY
17 E.INDY
18 E.INDY
0
0.5
1
Miles

4.3 West Indian Creek Reaches

West Indian Creek reaches are classified as "B" and "F" channel types (Figure 4.3). Overall, the upstream most portion of the channel is a B channel type and the downstream portion is an F channel type. The mid section of West Indian Creek contains a transitional area where short overwidened F sections alternate with sections of entrenched, actively degrading B portions. West Indian Creek contains a greater percentage of F channel types than East Indian Creek, although both are still actively adjusting.

4.3.1 Bankfull Elevation Indicators

The presence of a high amount of channel disturbance attributed to adjacent residential land use, made bankfull indicators difficult to identify. Principle bankfull indicators that were present consisted of flow lines on stone walls and/or boulders, slope breaks and point bars, and undercut banks. Flow lines were used both in the headwaters area when local residents installed stone walls in the channel banks and also within the downstream portion where boulders were present. Bankfull indicators were the most apparent throughout the middle section of West Indian Creek where multiple slope breaks and point bars were present.

4.3.2 Stream Condition and Stability

Most of West Indian Creek is surrounded by residential development where private homeowners have cleared forested buffers to make them more narrow, create additional lawn space or to landscape their yards. Reaches 13 through 15, located downstream of City Line Avenue, are the only areas within the subwatershed where a minimum of a 100 foot forested buffer remains. Additionally, only five of the total 15 reaches assessed are not disturbed by in-stream structures, utilities or road crossings.

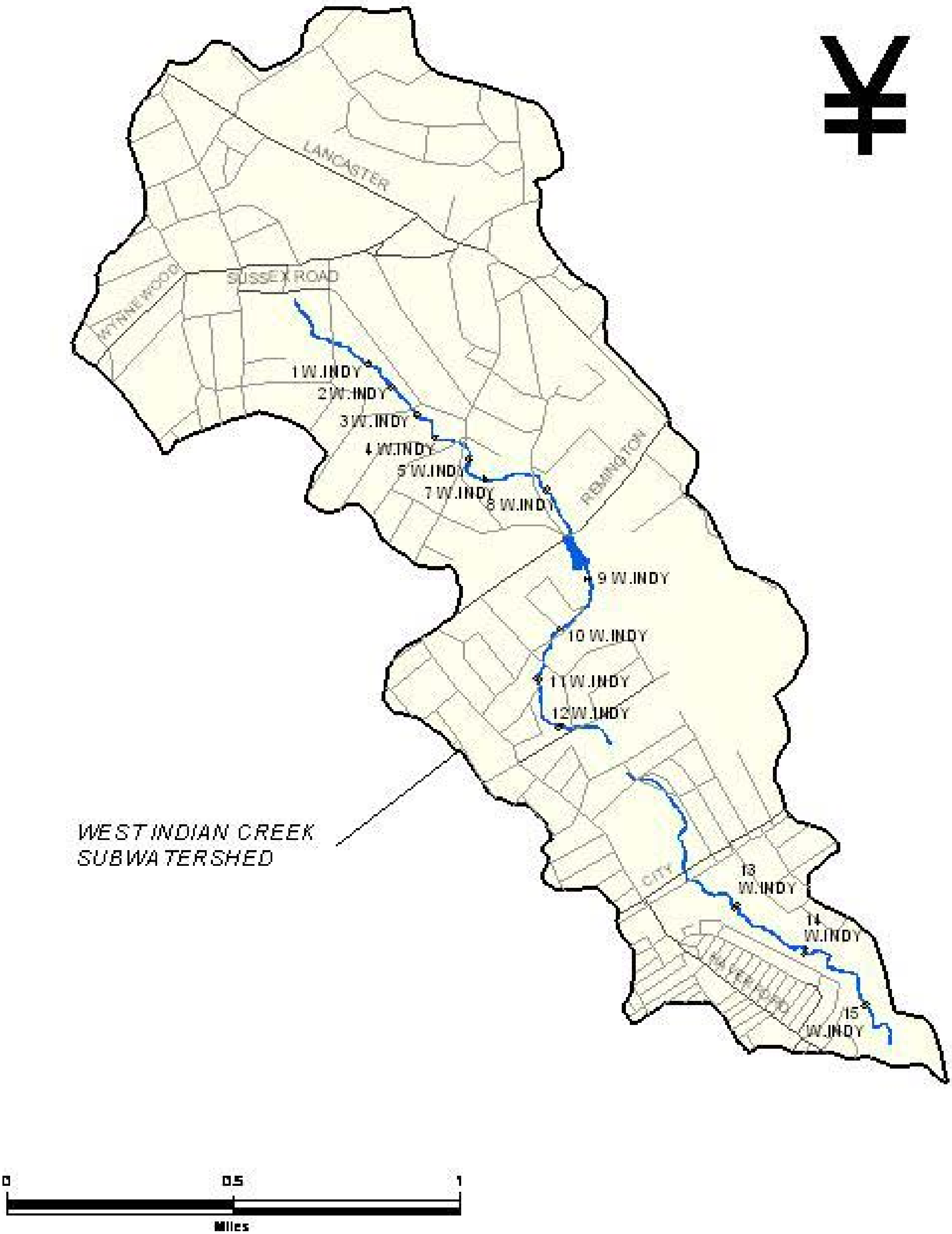
Overall, bank erosion and sediment supply within the West Indian subwatershed were low and only a few isolated occurrences of more degraded banks were observed. None of the reaches assessed were determined to have high bank erosion or sediment supply ratings. Banks throughout this subwatershed are an average of 5 feet tall, although there are few instances of banks that are higher than 6 feet tall. Additionally, existing conditions of West Indian Creek provide few indications of whether the channel is aggrading or degrading. Therefore, the reach bed stability was indeterminate throughout West Indian Creek.

The stream condition and stability of West Indian Creek are also influenced by a dam and pond located just downstream of Remington Road. West Indian Creek appears to have been redirected to the dam and away from the original channel located to the west of the pond. The original channel is approximately 5-8 feet wide, which is considerably smaller than the creek both upstream and downstream of the pond, and appears stable. Although the dam and associated structures appear to be in good condition, water in the pond was stagnant at the time of the field assessment. Because the dam and pond outfall downstream of Remington Road interrupts flow through the West Indian Creek they are influencing the stability of the channel downstream.

4.3.3 Expected Future Channel Changes

West Indian Creek is also expected to follow the same channel migration pattern as Cobbs and East Indian Creeks. West Indian Creek most likely was a stable B or C channel that began downcutting when development increased and has continued to adjust since that time. Since a greater percentage of West Indian Creek then East Indian Creek has migrated to an F channel type, existing conditions suggest that West Indian Creek is further ahead in the channel migration process. Stream reaches within the West Indian Creek that are currently classified as B channel types are expected to overwiden and become F channel types over geologic time. Should no additional land use changes occur within the watershed, West Indian Creek will most likely begin forming depositional features and creating a more narrow, meandering channel within the old channel banks.

West Indian Creek Subwatershed



4.4 BANKFULL CALIBRATION RESULTS

Field Cross Section Calculations

Principle bankfull indicators for the Cobbs Creek mainstem consist of watermarks, cobble and gravel bars, and undercut banks. Identifying bankfull indicators in the headwaters was the most difficult due to the number of instream structures installed by private homeowners. Dominant bankfull indicators used throughout the mid-section of Cobbs Creek consisted of the back of gravel/cobble bars when there was evidence that the bar was actively forming, and the top of gravel/cobble bars when there was evidence that the bar had completed forming. Progressing downstream, bankfull indicators consisted of undercut trees and watermarks on large debris within the channel.

Bankfull elevation indicators were somewhat similar for East and West Indian Creeks in the headwaters since both are highly disturbed by private homeowners and difficult to identify. The middle section of both Creeks contain the best bankfull indicators which includes undercut banks for East Indian Creek and slope breaks and point bars for West Indian Creek.

Regional Curves and Regression Equations

The Baltimore County Regional Curve for Urban Areas, the Christina River Watershed Regional Curve, the USGS regression equation for Maryland Piedmont streams (Dillow 1996), and the Maryland Geological Survey regression equation (Carpenter 1993) were used to calibrate bankfull discharge. The Maryland USGS regression equation was used instead of the Pennsylvania USGS regional curve because the Pennsylvania Piedmont curve does not provide discharges for the 2-year storm. All calculated values are presented in Table 4.4a.

The Christina River watershed curve was developed using data from watersheds within the Piedmont geologic province that have drainage areas greater than four square miles. The curve was developed for primarily urban watersheds with little forest cover in Northern Delaware. This curve is considered suitable for bankfull calibration within the Cobbs Creek watershed due to similarities between the two watersheds. The Baltimore County Regional Curve was also considered suitable for calibrating bankfull discharge for the Cobbs Creek watershed since it was also developed for small, urban watersheds within the Piedmont province. Although this regional curve was developed for Maryland streams mostly located in the Piedmont, characteristics of Piedmont streams, such as a higher slope, larger bed materials, shorter times of concentration and higher discharges were expected of streams in the Cobbs Creek watershed since it lies wholly within the Piedmont province.

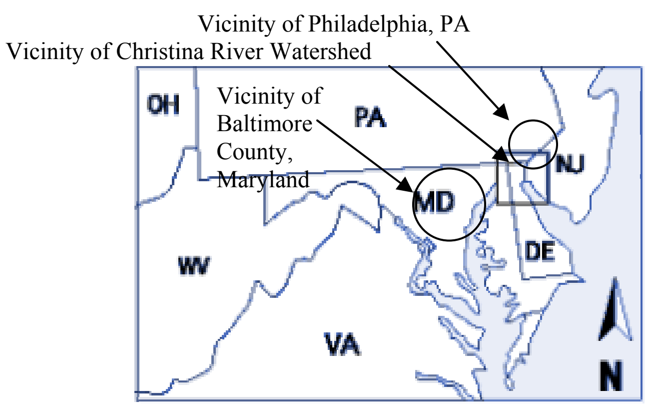


Figure 4.4a Location of Christina River Watershed

Gauge Station Data

Data for three USGS stream gauge stations along the Cobbs Creek mainstem were evaluated. These consist of stations 01475530 - Cobbs Creek at U.S. 1 at Philadelphia, 01475540 – Cobbs Creek at Darby, and 01475550 – Cobbs below Indian Creek Near Upper Darby, Pennsylvania (Figure 4.4b). The downstream most gauge station is located at the Woodland Avenue dam.

Gauge station data was evaluated according to the nearest cross section. Cobbs Creek cross sections 19 and 20 are nearest station 01475530 and Cobbs Creek cross sections 30 through 33 are nearest station 01475540. Gauge station 01475550 is located within Reach 57 and is nearest cross sections 57 and 58.

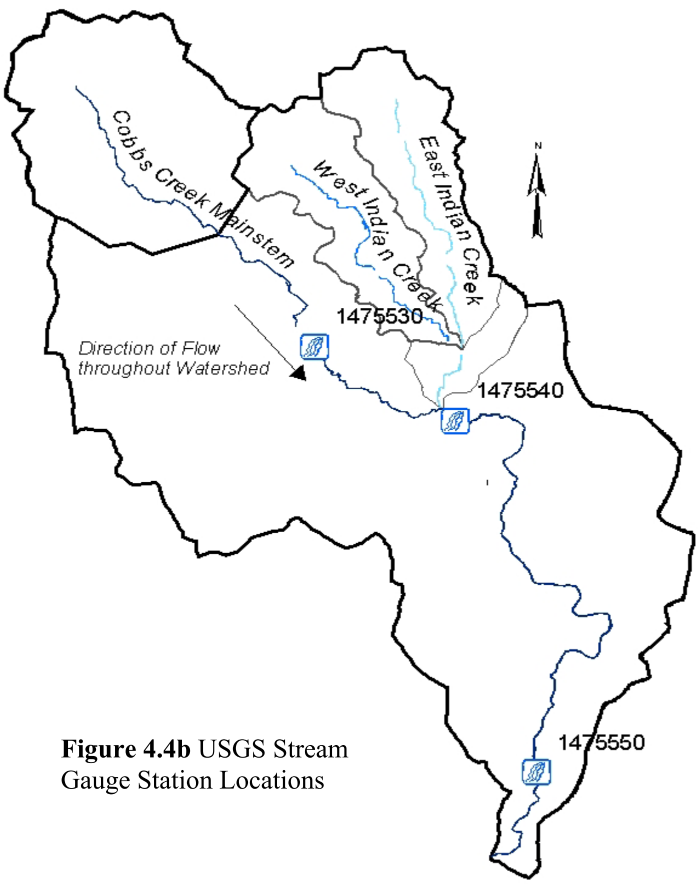
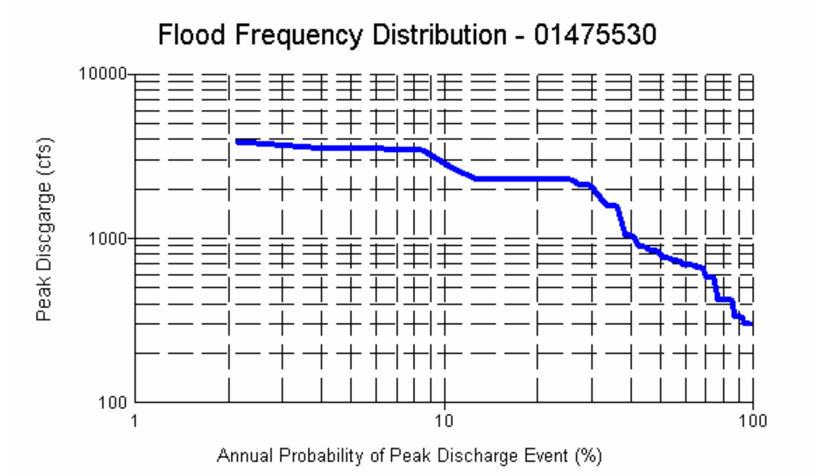


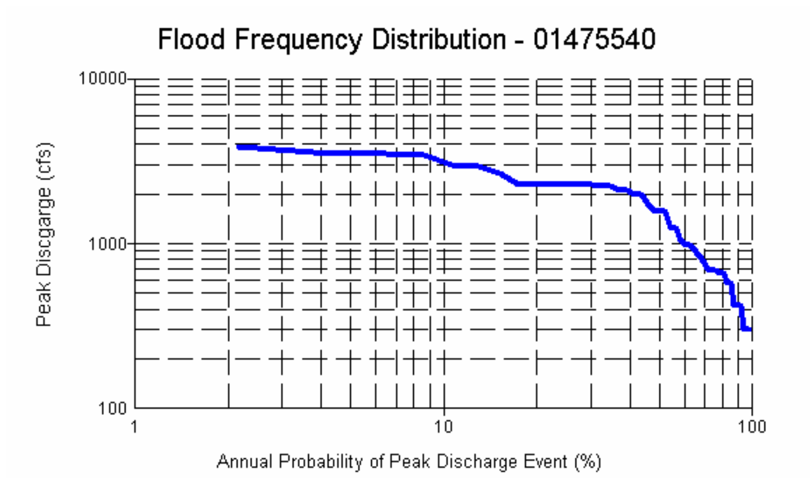
Figure 4.4b USGS Stream Gauge Station Locations

Flood frequency curves for the upstream most station, above the confluence with East and West Indian Creeks, show that there is a 100% chance that within any given water year (Oct. thru Sept.) a flow event will occur that is a minimum of 300 cfs. Recurrence discharges range from 300 cfs (1 Year) to 764 cfs (2 Year). Bankfull field discharges for cross sections nearest this gauge station yielded similar, yet lower overall discharges and ranged from 536 cfs to 632 cfs. Moving downstream to the mid section of Cobbs Creek, field bankfull discharges ranged from 698 cfs to 1064 cfs. Although these cross sections are all nearby the gauge station, only one field cross section (Cobbs 31 – 923 cfs) was not influenced by the dam or significantly impacted. The range of recurrence discharges for this mid-section of Cobbs Creek are somewhat higher than field discharges, but also largely overlap (857 cfs (1 Year) to 1580 cfs (2 Year)).

Gauge station data for the downstream most portion of Cobbs Creek yielded recurrence discharges for the 1 and 2 year storms of 425 cfs and 2010 cfs, respectively.

Field discharge for the nearest cross section upstream of the dam and gauge station was 2082 cfs, while the field discharge downstream of the dam was significantly lower (1218 cfs). Due to the impacts the dam may have on channel geometry immediately upstream, the cross section downstream of the dam is considered more reliable.





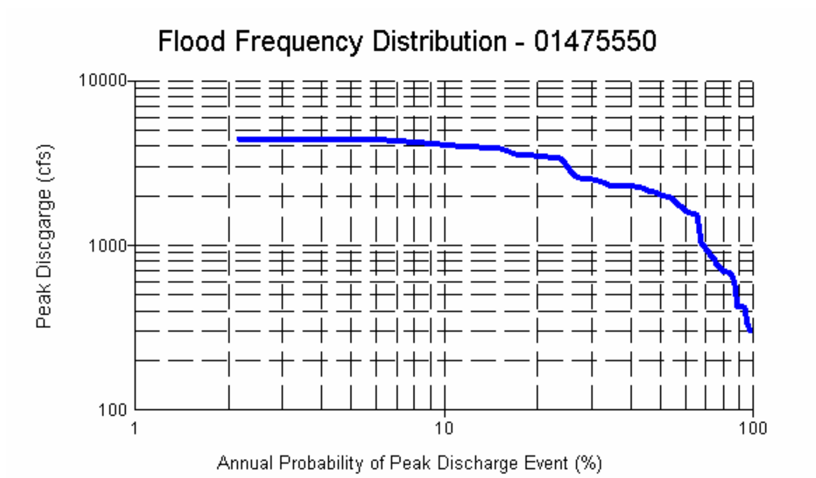


Figure 4.4c Flood Frequency Graphs

Comparison

Table 4.4a Comparison of Discharges Used to Calibrate Bankfull Discharge

D/S Cross Section	Name of Subwatershed / Drainage Area (mi²)		Field Discharge	Christina River Regional Curve[1]	Balt. Co. Urban[2]	MGS[3] 2 Yr.	USGS[4] 2 Yr.	Gauge Station Data[5]
			Bankfull Discharge			Recurrence Interval		
18	East Indian	2.20	269	619	424	251	330	N/A
15	West Indian	1.75	114	603	373	220	296	N/A
19-20	Cobbs Creek - *530*	6.70	536-632	772	790	621	720	300 (1 Yr.) 663 (1.5 Yr.) 764 (2 Yr.)
30-33	Cobbs Creek – *540*	16.7	923	1113	1318	1216	1275	300 (1 Yr/) 857 (1.5 Yr.) 1580 (2 Yr.)
57, 58	Cobbs Creek - *550*	22.62	1218	1302	1548	1502	1526	425 (1 Yr.) 1236 (1.5 Yr.) 2010 (2 Yr.)
63	Cobbs Creek	22.62	1454	1302	1548	1502	1526	N/A

[1] Christina River Watershed Regional Curve – US EPA and the DNREC, January 1999.
[2] Baltimore County Regional Curve – Urban developed primarily for Piedmont streams, watersheds 2 square miles and greater, and >20% impervious
[3] Maryland Geological Survey (MGS) – Carpenter 1983
[4] United States Geological Survey (USGS) – Dillow 1996
[5] Stream Gauge Station Data for USGS station #01475530 and 01475540

Cobbs Creek Mainstem

The strongest correlations between calculated bankfull discharges were seen between the Christina River Watershed Regional Curve and the Baltimore County Regional Curve. Bankfull discharge calculated for the Cobbs Creek mainstem using these equations yielded the most similar discharges. Bankfull discharges calculated using stream gauge station data also yielded values similar to the regional curves. The discharge and recurrence interval for the 1- and 2-year storms were both evaluated amongst all other discharge values since how often a bankfull storm occurs can vary. Since the strongest correlation was found among bankfull discharges for the Baltimore County regional curve, Christina River watershed curve, and field discharges, Biohabitats has the most confidence in bankfull discharges between the range of 500 cfs for upstream reaches and 1500 cfs for downstream reaches. It follows that headwater reaches upstream of cross section 19, (the upstream most delineated drainage area), have smaller drainage areas and therefore bankfull discharges less than 500 cfs.

East and West Indian Creeks

Bankfull discharge calculated using the MGS and the USGS equations showed the strongest correlation for the East and West Indian Creeks, although the majority of all calculated discharges fall between 220 to 330 cfs. Field calculated bankfull discharge for the East Indian Creek also falls within this range. It should be noted that all regional curves and equations were developed using data from watersheds larger than that of the

East or West Indian Creek. Therefore, more scatter among bankfull discharge values was expected for the smaller subwatersheds such as the headwater reaches of Cobbs Creek, and East and West Indian Creeks. Weak correlation of bankfull discharges for the East and West Indian Creeks is attributed to the amount of instream disturbances/structures built by residents/home owners.

Bankfull discharge strongly influences, if not governs, all channel characteristics used to determine the Rosgen channel classification. Therefore, the bankfull elevation is essential to reach classification and in turn, reach ranking and prioritization. All bankfull discharges calculated for this master plan are considered preliminary because they are not intended to be used for stream restoration design. Additional bankfull calibration must be performed to supplement and/or support all values calculated specifically for channel classification.

4.5 BANK PIN AND SCOUR CHAINS

Relationships between land use changes and channel stability, characterization of bed and bank materials, and the effects of land use can be estimated and/or measured through long-term monitoring. Long-term monitoring of Cobbs, East and West Indian Creeks would provide a valuable resource planning tool that would allow future channel changes to be predicted and prevented. Bank pins are used to determine the rate, if any, of lateral erosion and scour chains measure bed scour and aggradation.

Bank pins and scour chains were installed at a total of 11 sites that are representative of current ongoing changes to channel planform, pattern, and/or geometry within Cobbs, East and West Indian Creeks. Table 4.4 provides a summary of the total number of bank pins and scour chains installed and recommended for long-term monitoring.

Table 4.5 Total Bank Pin and Scour Chain Installation Summary

Reach	Nearest Cross Section	Bank Pins		Total Bank Pins	Scour Chain Installed
		Total Installed in DSR Bank	Total Installed in DSL Bank		
COBBS CREEK					
6 Cobbs	x/s 6	1	2	3	Yes
14 Cobbs	x/s 14	0	4	4	*No*
24 Cobbs	x/s 24	0	3	3	Yes
30 Cobbs	x/s 30	1	2	3	Yes
39 Cobbs	x/s 39	3	1	4	Yes
50 Cobbs	x/s 50	2	1	3	Yes
61 Cobbs	x/s 61	1	2	3	Yes
EAST INDIAN CREEK					
6 EIndy	x/s 6	0	3	3	Yes
13 EIndy	x/s 13	2	1	3	Yes
WEST INDIAN CREEK					
5 Windy	x/s 5	0	3	3	Yes
14 Windy	x/s 14	1	2	3	Yes

4.5.1 ON-GOING MONITORING INSTRUCTIONS

Bank Pins

Bank pin and scour chain monitoring provides additional data that when compared with baseline conditions, lends insight as to how a channel is changing. Ideally, so that channel changes can be more likely attributed to bankfull events, monitoring should be performed following a bankfull storm. To yield consistent data, banks pins should be measured at the same place (i.e. on the upstream side of the bank pin) following a rain event. Rainfall data that would confirm the magnitude of the storm would help verify the discharge and velocity of water needed to move different sized materials and change the channel geometry and/or planform. If bank pins are buried, the depth of material removed to find the pins should be measured and recorded. Periodically remarking the rebar ends with spray paint and re-measuring distances from different, multiple benchmarks will help ensure that bank pins can be found if previous benchmarks are no longer present. Bank pins located in less conspicuous areas may be marked with survey flagging, but only in circumstances where the pins will not be pulled out. Should the bank pin monitoring site be vandalized, the site should be evaluated prior to reinstalling new pins.

Scour Chains

Scour chains should be measured at the same time bank pins are measured. Scour chains are measured according to how many links are exposed and compared with the baseline conditions or previous measurement. As with the bank pin procedure, if the scour chain is buried, the depth of bed material removed should be measured and recorded. In some cases, such as a greater than bankfull storm event or a very high sediment transport, the scour chain may wash downstream. A new chain should be installed if the site will continue to be monitored.

In summary, bank pin and scour chain monitoring steps are as follows:

1. Find bank pins and/or scour chain using benchmark measurements
2. Measure pin reveal or depth of material & record pin length and number of chains exposed/buried
3. Remark Pins/Chain with paint or flagging if necessary
4. Reinstall Pins/Chain if necessary

Appendix D contains the baseline conditions, or the measurements taken at the time of installation, and detailed descriptions for each site. No additional monitoring beyond the baseline conditions has been performed as of the completion date of this Master Plan.

4.6 STREAM REACH RANKINGS

Stream reach ranking was determined by combining channel geometry and habitat ranking values for each reach. Tables 4.5a thru 4.5c provide the total geometry and habitat ranking values for each reach according to subwatershed. All habitat and geometry parameter values assigned to each reach can be referenced in Appendix X. Reaches were prioritized according to final reach ranks and restoration priorities in Section 7.0.

Table 4.6a East Indian Creek Reach Ranks

Reach	Cross Section	*Total Habitat Ranking Value*	*Total Channel Geometry Ranking Values*	*Reach Rank (Worst to Best)*
East Indian Creek				
1 EAST INDY	1	37	64	101
9 EAST INDY	9	23	70	93
10 EAST INDY	10	27	66	93
4 EAST INDY	4	14	58	72
7 EAST INDY	7	20	48	68
2 EAST INDY	2	33	32	65
3 EAST INDY	3	32	26	58
8 EAST INDY	8	26	28	54
5 EAST INDY	5	11	38	49
18 EAST INDY	18	34	14	48
6 EAST INDY	6	15	32	47
14 EAST INDY	14	12	16	28
15 EAST INDY	15	9	17	26
11 EAST INDY	11	12	10	22
13 EAST INDY	13	10	12	22
17 EAST INDY	17	12	9	21
12 EAST INDY	12	9	11	20
16 EAST INDY	16	8	9	17

Results of the reach ranking for the East Indian Creek subwatershed reveal that the downstream portion of the Creek is more stable than the upstream portion. Degradation and corresponding higher geometry scores within the upstream portion of the Creek can be attributed to a far greater number of disturbances to the channel by landowners. Disturbances such as landscaping, fountains, footbridges, etc. occur less frequently as the East Indian Creek flows downstream. Additionally, as the East Indian Creek flows downstream, land use transitions to less concentrated single family residential development and/or commercial businesses. This change in land use correlates with the width of riparian buffer present and is reflected in the reach habitat scores for the downstream portion of the East Indian Creek. Overall, the downstream portion of the East Indian Creek is considered the most stable while the upstream portion is currently the most degraded. Furthermore, the downstream portion of the East Indian Creek contains the lowest ranked reaches, or the most stable reaches, in the entire Cobbs Creek watershed.

Ranking of reaches in the East Indian Creek subwatershed yielded an average ranking of 50 and approximately 39% of the subwatershed is degraded. The highest (worst) stability score possible for each reach was 36 or greater, depending on the number of utilities located within that reach. The highest possible habitat score was 33, making the combined highest final reach rank 69 or greater. Scores over 69 indicate that there is infrastructure present within that reach since the subtotal was multiplied by a factor of 2.

Table 4.6b West Indian Creek Reach Ranks

Reach	Cross Section	*Total Habitat Ranking Value*	*Total Channel Geometry Ranking Values*	*Reach Rank (Worst to Best)*
West Indian Creek				
10 WEST INDY	10	37	62	99
12 WEST INDY	12	33	64	97
5 WEST INDY	5	31	64	95
11 WEST INDY	11	31	62	93
1 WEST INDY	1	26	60	86
9 WEST INDY	9	28	54	82
8 WEST INDY	8	22	46	68
7 WEST INDY	7	32	30	62
2 WEST INDY	2	30	22	52
4 WEST INDY	4	32	13	45
3 WEST INDY	3	30	14	44
13 WEST INDY	13	8	36	44
15 WEST INDY	15	13	17	30
14 WEST INDY	14	10	13	23

Results of the West Indian Creek ranking revealed similar results as were found for the East Indian Creek. Land use trends for both subwatersheds are alike in that the headwaters are primarily single family residential areas where a large amount of channel disturbances have occurred. Reach ranking reveals that the middle section of the Creek are the least stable and lack the most amount of natural habitat. West Indian Creek headwater reaches, although some reach ranks suggest this portion of the channel is more stable, are considered the least stable due to anthropogenic changes. Approximately 30% of the total linear feet of channel within this subwatershed have been altered. It follows that the most stable portion of West Indian Creek are the three downstream most reaches (Reaches 13 through 15) where the riparian width is the widest and the fewest channel disturbances are present. The average rank for reaches in the West Indian Creek subwatershed is 66.

Table 4.6c Cobbs Creek Reach Ranks

Reach	Cross Section	*Total Habitat Ranking Value*	*Total Channel Geometry Ranking Values*	*Reach Rank (Worst to Best)*
Cobbs Creek				
7 COBBS	7	30	72	102
8 COBBS	8	38	62	100
2 COBBS	2	24	70	94
23 COBBS	23	38	56	94
24 COBBS	24	36	56	92
16 COBBS	16	31	60	91
10 COBBS	10	24	66	90
5 COBBS	5	29	56	85
55 COBBS	55	25	56	81
29A COBBS	29A	24	56	80
11 COBBS	11	21	58	79
34 COBBS	34	21	58	79
58 COBBS	58	14	62	76
22 COBBS	22	14	60	74
35 COBBS	35	18	56	74
26 COBBS	26	16	56	72
25 COBBS	25	10	60	70
13 COBBS	13	33	34	67
29 COBBS	29	27	40	67
53 COBBS	53	25	42	67
28 COBBS	28	23	42	65
15 COBBS	15	31	32	63
21 COBBS	21	21	42	63
43 COBBS	43	20	40	60
14 COBBS	14	21	38	59
27 COBBS	27	19	38	57
38 COBBS	38	13	44	57
19 COBBS	19	14	42	56
40 COBBS	40	24	32	56
1 COBBS	1	21	32	53
30 COBBS	30	19	34	53
42 COBBS	42	13	38	51
9 COBBS	9	15	34	49
46 COBBS	46	20	28	48
57 COBBS	57	31	14	45
45 COBBS	45	14	30	44
59 COBBS	59	27	17	44
41 COBBS	41	13	30	43
39 COBBS	39	25	16	41
4 COBBS	4	21	19	40
20 COBBS	20	22	18	40
50 COBBS	50	24	16	40
32A COBBS	32A	19	18	37
33 COBBS	33	19	18	37
36 COBBS	36	19	18	37
48 COBBS	48	20	17	37
32 COBBS	32	20	16	36
47 COBBS	47	21	15	36
51 COBBS	51	22	14	35.8
52 COBBS	52	20	16	35.8
3 COBBS	3	20	15	35
49 COBBS	49	21	14	35
61 COBBS	61	14	20	34
56 COBBS	56	17	16	33
31 COBBS	31	16	16	32
12 COBBS	12	17	14	31
37 COBBS	37	14	17	31
62 COBBS	62	15	16	31
60 COBBS	60	14	16	30
54 COBBS	54	14	15	29.4
18 COBBS	18	13	15	28
63 COBBS	63	13	15	28
6 COBBS	6	14	14	27.8
44 COBBS	44	8	18	26
17 COBBS	17	10	14	24

Reach ranking results for the Cobbs Creek subwatershed revealed that the headwater reaches are the most degraded and the least degraded reaches are located south of City Line Avenue nearest the confluence with Darby Creek. The two highest ranked reaches in the Cobbs Creek watershed also occur within the headwaters of this subwatershed. Reach ranks of 102 and 100 for Reaches 7 and 8 respectively, can be attributed to the presence of infrastructure, channelization, and a very narrow riparian buffer. These are all parameters that were weighted the most heavily in the reach ranking methodology and are also the most concentrated upstream of the confluence with East Indian Creek. The average reach rank is 54 and approximately 55% of the channel in the Cobbs Creek subwatershed is degraded. As Cobbs Creek progresses downstream, overall reach ranks tend to decrease and the channel becomes more stable. However, individual habitat ranks follow the opposite trend and gradually worsen as the Creek flows downstream.

4.7 SUBWATERSHED RANKING

Results of the both subwatershed ranking methods revealed that the least stable subwatershed is Cobbs Creek, followed by the West Indian Creek and East Indian Creek subwatersheds. Greater than half of the total linear feet of channel within the Cobbs Creek subwatershed are degraded and/or influenced by runoff. Although the percent impervious surfaces for West Indian Creek is less than East Indian Creek, West Indian Creek was considered less stable because it has a considerably higher Tc path slope and greater percentage of degraded linear feet of channel. Additionally, because East Indian Creek contains the least amount of degraded channel and has a lower Tc path slope, future impacts to East Indian Creek are expected to be less significant than those that may occur within the West Indian Creek subwatershed.

Table 4.7 Subwatershed Ranking Results

Subwatershed	Stability & Habitat Parameters			Subwatershed Characteristics			Subwatershed Rank
	Worst Possible Score for Subwatershed	Total Ranking (Actual)	% Linear Feet of Degraded Channel	% Impervious*	Avg. Slope of Tc path	Total # of Infrastructure	
Cobbs Creek	6363	3507	55	91	0.82	114	1
West Indian Creek	1515	675	45	81	1.27	69	2
East Indian Creek	1818	705	39	85	0.90	49	3

*Percent impervious surfaces were calculated using 1995 GIS Land Use data provided by the PWD. Each drainage area was divided into pervious and impervious surfaces based on the assumption that only forested areas were pervious. The percent imperviousness was calculated by dividing the total amount of impervious surfaces by the drainage areas provided by PWD.

4.8 GIS LAYER CREATION

All base mapping data was provided to Biohabitats, Inc. by the City of Philadelphia Water Department (PWD). Original geographic information systems (GIS) data used for base mapping was obtained from multiple sources and was not edited. Following field data collection by Biohabitats, Inc. and PWD, data was converted to a dgital format compatible with existing base mapping. Database files were created using Microsoft Excel 2002 and then linked to new shapefiles created in the Pennsylvania State Plane survey datum. A total of 6 shapefiles were created using the field data. The following layers were created and used to rank stream reaches and prioritize proposed restoration efforts.

File Name	Type of Shapefile
• cobbsreaches_final2	Polygon
• eindyreaches_final	Polygon

• windyreaches_final	Polygon
• cobbs_intersect_final	Line
• eindy_intersect_final	Line
• windy_intersect_final	Line
• winokurcobbs	Point
• winokureastindy	Point
• winokurwestindy	Point

Polygon and line shapefiles were created and edited to include field data collected during the stream survey and cross section surveys. All raw data, Rosgen stream types, final reach ranks and reach prioritization were incorporated into final shapefiles. Principle shapefiles created as a result of field data collection were then used to query, display and rank stream reaches as presented in Section 4.6. Appendix F – GIS Metadata provides additional detailed information regarding layers created from field efforts.

5.0 RESTORATION STRATEGIES

Stream restoration consists of various components that make up a small portion of a watershed and an even smaller part of the dynamic equilibrium relationship between land and water. Stream corridors, a micro-ecosystem within a watershed consists not only of the channel, but also of the adjacent floodplain and a transitional area where the floodplain ends and merges into an upland area. Stream restoration, therefore is the restoration of multiple micro-habitats that are a part of a larger watershed.

A comprehensive approach to watershed management and restoration is key and should be planned and prioritized according to representative watershed indicators and identified issues. All information should be organized, maintained and be made easily accessible to residents. Components of an ideal watershed master plan should include information broken down on a subwatershed basis for channel existing condition, impervious cover, sewer and storm drain infrastructure, drainage network, stormwater outfalls, stormwater hotspots, industrial sites, open space, and natural areas. The assessment of the Cobbs Creek watershed and all stream corridors has provided some of these essential elements that can be used independently or built upon to identify and prioritize watershed indicators and issues. All strategies should complement existing regulations, management strategies, and community efforts. A list of existing applicable studies, references, and programs can be found at the end of Section 9.0 – References. Based all available information, this section prioritizes stream reaches within the Cobbs Creek watershed principally according to existing conditions and information collected regarding the sewer and stormwater infrastructure.

Restoration strategies were developed that would alleviate or minimize identified direct and future cumulative impacts to the Cobbs Creek, East Indian Creek and West Indian Creek subwatersheds. Restoration strategies, presented broadly within the following sections, are divided into three categories:

- Restoration Strategy Category I: **Channel Stability**,
- Restoration Strategy Category II: **Habitat**, and
- Restoration Strategy Category III: **Land management**.

Individual strategies were chosen based on final ranking values and field observations. Stream reaches that have the worst rankings and would benefit the most from each of the three restoration strategy categories are shown individually on Figures 5.0a, 5.0b, and 5.0c.

5.1 RESTORATION STRATEGY CATEGORY I: CHANNEL STABILITY

Bank Stabilization

Channel banks throughout the Cobbs watershed were evaluated for stability based upon the degree of erosion observed. Generally channel banks were most stable in the watershed headwaters and the least stable through the mid-section of Cobbs Creek, the highest priority bank stabilization area. Channel banks rated as moderate or high should be evaluated further for site specific bank stabilization measures. Bank stabilization measures can vary, based on the severity of the erosion and whether it is localized or continues for some distance along a bank, from small plantings to the installation of boulder walls. Because the mid-section of Cobbs Creek is the highest priority bank stabilization area and degraded the most, bank stabilization measures may consist of boulder bank, and boulder toe. Boulder structures would also be used in smaller channels when it is eroding and overwidening to the point where property is, or is expected, to be lost. Other more natural bank stabilization methods such as bioengineering, root wads, plantings and log and woody structures should be used in areas where the bankfull width is less wide and significant additional channel changes are not expected. These methods are best suited to small, local areas of bank erosion scattered throughout in the East and West Indian Creek headwaters where discharges are the lowest. Advantages of bank stabilization consist of reduced erosion, sediment supply, tree fall, channel widening and migration.

Bed Stabilization

Bed stabilization is recommended for those reaches that are currently degrading through incising, or downcutting. Although all stream reaches that were assessed are undergoing changes to their pattern, planform and geometry, a greater percentage of West Indian Creek (44%) and Cobbs Creek (40%) are actively degrading. The percent actively degrading reaches was calculated according to the "channel stability" data sheet rating. Bed stabilization for all West Indian Creek reaches was rated as indeterminate. Bed stabilization measures such as rock/log vanes with grade control, rock/log cross vanes, and using naturally occurring boulders and bedrock are examples of methods that could be used to stabilize channel beds. Rock/log vanes differ from cross vanes because they do not extend the entire width of the channel. However, both structures provide grade control while diverting flow away from the channel banks. Bed stabilization should be used to eliminate headcuts or knickpoints. Advantages of bed stabilization consist of bank protection through diverting flow and elimination of migrating bed scour through providing grade control.

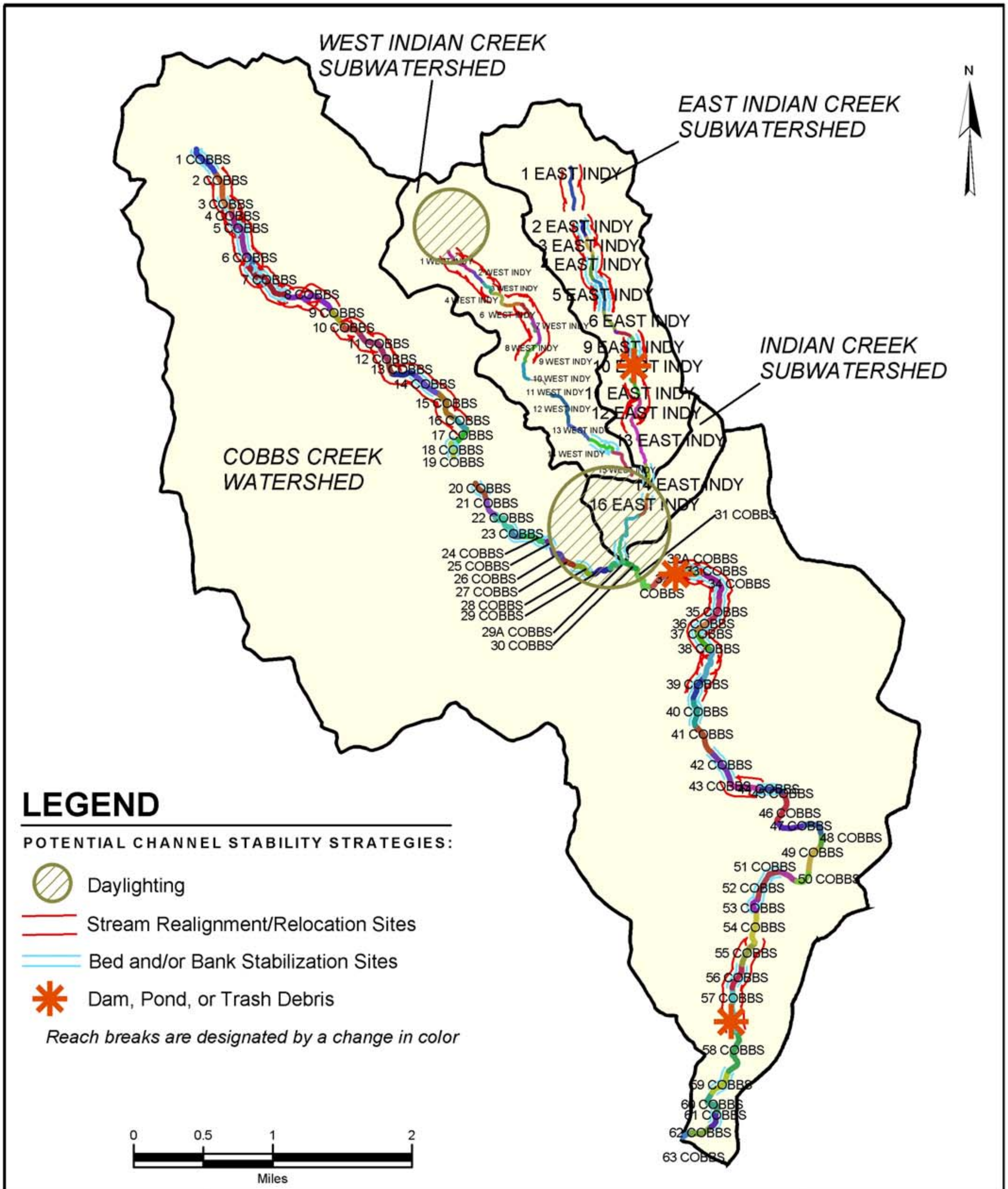
<u>*Realignment & Relocation*</u>

Stream channel realignment and relocation are the most severe restoration measures involving the greatest amount of channel changes. These methods should be employed when it is more advantageous to realign the channel than it is to stabilize degrading, out-of-pattern sections. Channel realignment and relocation is commonly implemented for portions of a channel rather than for an entire length of channel due to construction and maintenance costs, and the amount of disturbance that occurs to existing natural habitat. Stream channel realignment and relocation is best suited to consecutive severely degraded reaches. A preliminary evaluation of field data revealed five (5) portions of Cobbs Creek, four (4) portions of East Indian Creek and two (2) portions of West Indian Creek that are potential stream realignment and relocation areas. The downstream most portion of West Indian Creek and a short section just upstream of City Line Avenue are the most degraded within this subwatershed and would benefit from daylighting since they are currently piped underground. All potential realignment and relocation sites are shown on Figure 5.0.

<u>*Dam, Debris & Pond Maintenance And/Or Removal*</u>

Large structures or facilities within the channel interrupt natural flow patterns and alter the hydrology and hydraulics of the Creek in which they are present. Anthropogenic alterations to the natural balance, or progression towards the natural balance, between land and water generally have adverse impacts on the channel. The largest structure or facility that has altered the Cobbs Creek hydrologic regime is a dam and an associated pond located on West Indian Creek. Three other dams are located within the Cobbs Creek watershed: 1 on East Indian Creek within Reach 10 and 2 on Cobbs Creek within Reaches 32 (cross section D1) and 57 (cross section D2). Reaches downstream of these structures are likely to have undergone a greater amount of channel degradation than those channels not influenced by dams. Despite this fact, the installation of these structures may have created beneficial habitat. Additional consideration must be given to the fact that any beneficial habitat may now rely on the existence of these dams, in which case removing dams to create a more natural channel may outweigh the benefits that resulted from its installation. Overall, dam and pond removal have been presented as possible channel stability restoration measures. It should be noted that careful evaluation of all environmental costs and benefits, specifically habitat and any potential historical significance associated with each structure must be taken into consideration.

Debris, or trash, is the most abundant in Cobbs Creek within the City of Philadelphia, although it is also present within East and West Indian Creeks. Manual removal and installing trash racks are methods that could be implemented to decrease debris in the channels. Should removal be feasible, benefits include reestablishing natural flow patterns, decreasing nutrient levels, improved water quality, and improved habitat for macroinvertebrate and aquatic vegetation species.



Cobbs Creek, Philadelphia, PA

Geomorphologic Survey - Level II

Guiding Principles for Fluvial Geomorphologic Restoration

Figure 5.0a Restoration Strategy Category I: Channel Stability

Final February 2003

5.2 RESTORATION STRATEGY CATEGORY II: HABITAT

Reforestation

An evaluation of the existing land use within the Cobbs Creek watershed revealed very few areas available for reforestation. Lands adjacent to the creek that are not developed and are currently unforested are priority reforestation sites. According to the 1997 GIS landuse data, few areas adjacent to Cobbs Creek meet the criteria for high priority reforestation areas. Generally, reaches surrounding these potential reforestation sites had corresponding low existing habitat values. Other large tracts of land that remain unforested are currently used for golf courses, hospitals, seminaries, cemetaries and ballfields. Existing ballfields located adjacent to the channel could also be evaluated for potential reforestation sites.

Additionally, reforestation that occurs adjacent to the channel will also provide wetland habitat and other associated benefits. Although priority reforestation areas consist of floodplains, steep slopes, and wetlands, smaller areas such as public right-of-ways, parks, schools, and neighborhoods also provide reforestation opportunities. Benefits of reforestation are numerous: cooler temperatures, rainfall interception, reduced runoff, reduced sediment load, reduced discharge velocities, increased groundwater recharge, increased species diversity and habitat, and improved air quality and aesthetics.

Invasive Species Management

Maintaining a healthy riparian plant community along Cobbs Creek, and East and West Indian Creeks will retain biodiversity and support a healthy stream ecosystem. Invasive species provide little value to native animals that depend on native species for habitat and/or food. Although a detailed invasive species assessment was not completed for the Cobbs Creek watershed, Japanese knotweed (*Polygonum cuspidatum*) is the one prevalent invasive species that was observed during the field reconnaissance. In many areas, knotweed, due to its agressive nature, has already out-competed native vegetation. Because of this threat to the biodiversity of native communities, an invasive species management plan would assist natural succession within the riparian buffer through decreasing possible further impacts of invasive species. An invasive species management plan will require, at a minimum, a three-year commitment to ensure success. Planting plans for all restoration efforts should compliment the invasive species management plan by recommending appropriate native planting to supplement areas where invasives have been eliminated. Although invasive species management priority areas are considered those that contain 80% or greater invasive species, invasive species management should also be implemented for all preliminary recommended channel restoration sites.

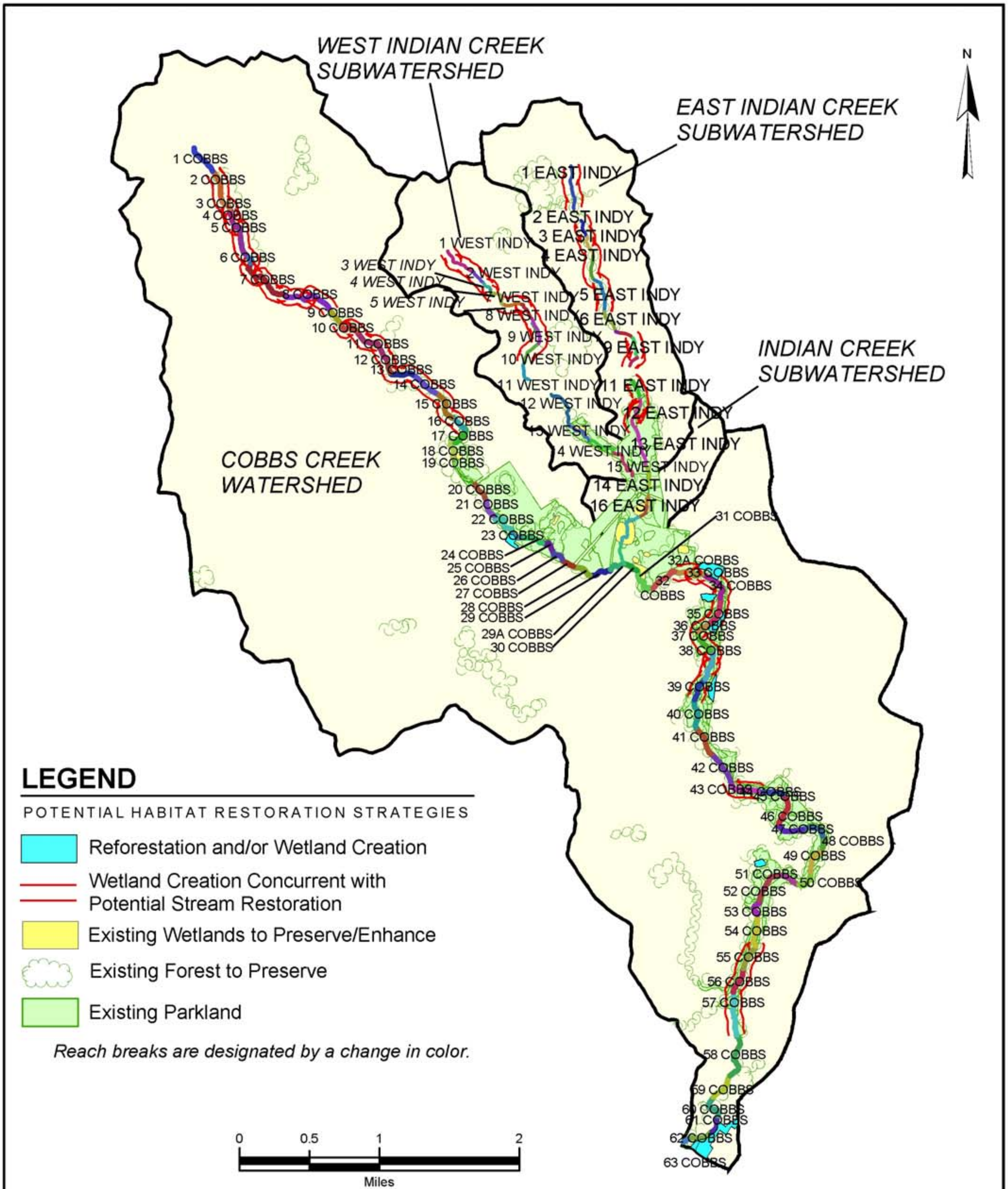
Wetland Creation

Land currently available for reforestation located adjacent to the channel is also ideal for wetland creation. Wetland creation adjacent to the channel is best suited to those areas where stream relocation and realignment are suitable. Because stream relocation and realignment typically involve large quantities of grading, replanting the disturbed areas can be customized to create specific habitats. Wetlands, a rich habitat that relies on saturated soils and vegetation adapted to these conditions could be created concurrently with channel relocation and realignment. Therefore, the best opportunities for wetland creation are adjacent to those channels that are also suitable relocation /realignment sites.

Further investigation of all potential restoration and realignment sites should include the following: rainfall data collection and evaluation, runoff calculations, soils investigation, water budget, native species investigation, and groundwater monitoring. Ideally, groundwater levels for all potential wetland creation sites should be monitored to determine their suitability prior to design. Advantages of wetland creation are groundwater recharge, increased habitat, increased plant and animal species diversity, and improved water quality.

Preservation of Existing Forested Areas

Existing forests are valuable habitat and should be protected. All of these areas throughout the watershed should be protected and managed, if necessary, to preserve the small amount of forested riparian buffer present surrounding all Creeks within the watershed. Educational/informational signage, creating small parks or designated green space, and installing fences or prohibiting access in areas where the riparian has been disturbed are additional strategies to help preserve existing forests.



Cobbs Creek, Philadelphia, PA

Geomorphologic Survey - Level II

Guiding Principles for Fluvial Geomorphologic Restoration

Figure 5.0b Restoration Category II: Habitat

Final February 2003

5.3 RESTORATION STRATEGY CATEGORY III: LAND MANAGEMENT

Reduce Impervious Surfaces

The Cobbs Creek, East Indian and West Indian Creek subsheds are no greater than 20% forested and are generally greater than 80% impervious. Stream channels within each subshed have responded to high density development and increased runoff through downcutting and overwidening in an attempt to accommodate higher flows. Since there is little land available for reforestation or to protect from becoming developed, the amount of existing impervious surfaces should be reduced. Examples of strategies to reduce the amount of existing impervious surfaces and/or the amount of runoff include:

- √ Stormwater management basins – both wet/dry ponds have the ability to collect storm flow, hold water temporarily and release water to a stream at a constant rate. Disadvantages of basins are finding the available land to build them and the associated maintenance over many years. In areas where additional development is still possible, or re-development may occur, stormwater management ponds are a suitable method to reduce runoff. Planned species selection for vegetating the pond perimeter, banks, and edges may also help reduce nutrients delivered to streams. Similarly, in areas where adequate space is not available, grass swales can be used to increase infiltration while decreasing the velocity of runoff prior to delivering it to the Creeks.

- √ Bioretention – bioretention facilities are similar to stormwater management ponds in their function, but differ since they are much better suited for small areas. Bioretention facilities can be installed next to parking lots, curbs, major roads, etc. to immediately catch runoff, filter sediment and allow rainwater to infiltrate back into the groundwater table. These facilities are well suited to the Cobbs watershed because the majority of the watershed is already developed, available space is limited and the size and shape of bioretention facilities are extremely adaptable.

- √ Parking Lot Island Installation and Plantings – parking lot islands can be installed and planted within large paved areas to create less contiguous impervious surfaces. Islands can be depressed to catch stormwater and planted to provide water quality benefits, shade and aesthetic value. Often, planted parking lot islands can serve dual purposes and provide water quality benefits if they are also bioretention facilities. At a minimum, efforts should aim to steady the existing percent impervious surfaces associated with parking lots. When and if the opportunity arises, unnecessarily paved and oversized parking lots could be converted to have smaller spaces and contain islands to create less contiguous paved surfaces. Parking lots and other paved right-of-ways should also be evaluated when adding or relocating utilities. To fully utilize existing paved surfaces instead of creating new impervious surfaces utilities could be located underneath existing pavement.

Infrastructure Management – Relocation/Retrofit

Managing existing infrastructure is an important component in protecting channels within the Cobbs Creek watershed. Ideally, those utilities located in or within close vicinity of the channel should be redesigned, retrofitted or relocated. The first priority should be given to those structures causing the most severe impact resulting from infrastructure. These are considered to be sewer outfalls discharging untreated wastewater, or all combined sewer outfalls (CSO). These discharge sites should be eliminated if possible, or retrofitted in order to remove some or all pollutants from the water prior to allowing it to discharge into the Creek.

Generally, in order to eventually eliminate or retrofit all combined sewer outfalls, a management plan, specifically for infrastructure, implemented over many years, should be developed. This plan should first identify all CSO sites. Project feasibility should then be evaluated for each to determine whether enough discharge would be treated in comparison with the cost of the retrofit. Following this analysis, individual projects could then be implemented. Based on data collected for this Stream Protection and Restoration Master Plan and data provided by the PWD regarding the stability of existing infrastructure within the Cobbs Creek watershed, a total of 7 exposed sewer pipes in fair condition and 3 exposed sewer pipes rated poor are recommended for immediate evaluation. Benefits of removing or retrofitting utility infrastructure within the watershed consist of minimized accelerated erosion, reduced pollutant loads, and overall improved aquatic habitat.

Other watershed based techniques that would help improve water quality consist of regular street sweeping, park and golf course management, trash removal, recycling, snow removal and disposal, and littering enforcement.

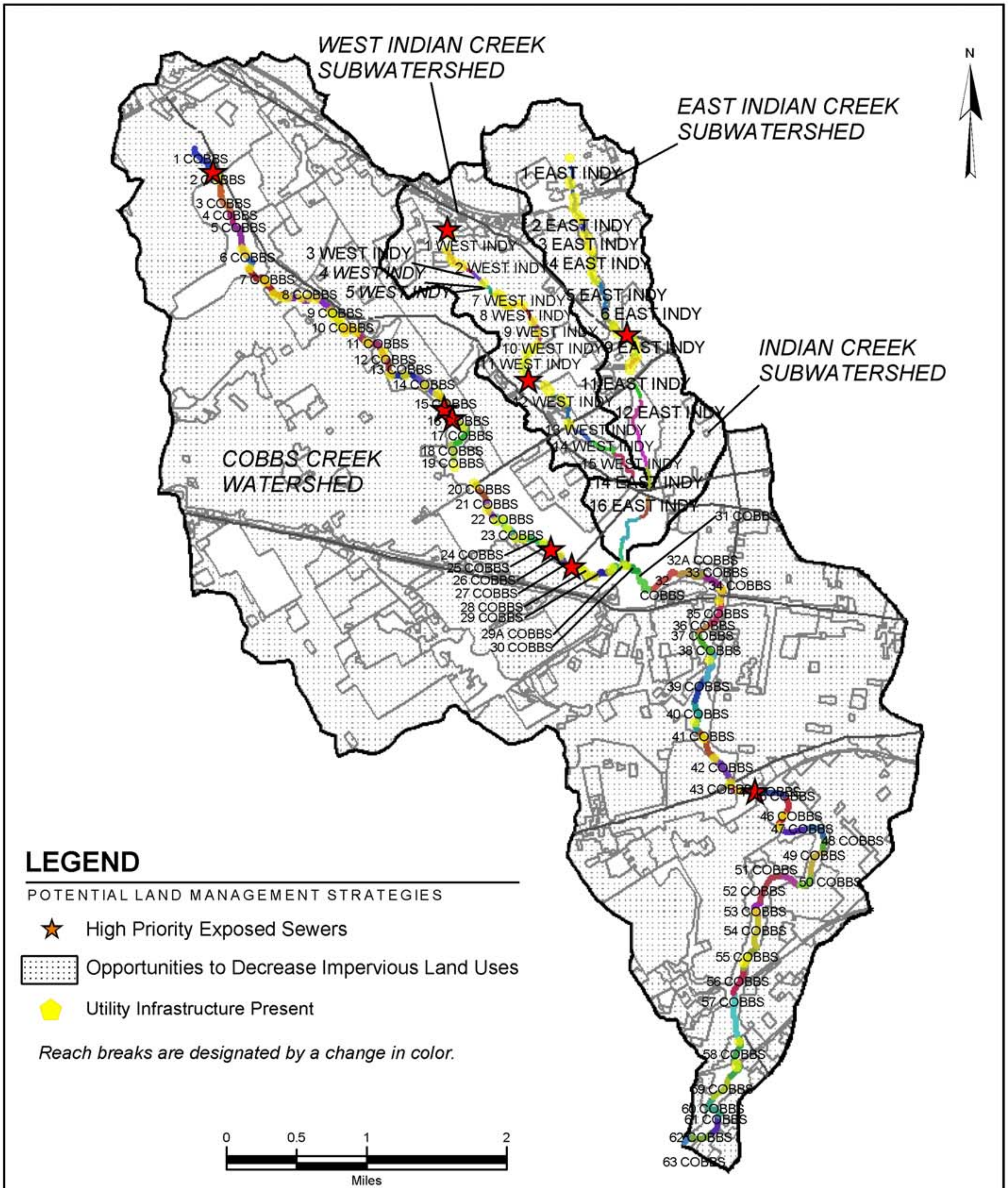
Appropriate Road and Culvert Maintenance

Often inappropriately sized culverts or poorly stabilized roads will impact a channel through eroding the bed and banks. Bed scour may cause a headcut or knickpoint that is capable of migrating upstream. A headcut or knickpoint will continue to scour the bed and deepen the channel as it moves upstream until it is inhibited by a natural bed formation or man-made structure resistant to erosion. Although the headcut or knickpoint may have stopped migrating, it is still present in the channel and if channel conditions change may begin to migrate again.

Public Education

Anthropogenic "improvements" are most abundant within the Cobbs Creek watershed upstream of City Line Avenue. Disturbances such as fountains, footbridges, landscaping, and mowing adjacent to the channel will continue so long as public education and awareness are not increased. Public education provides opportunities to relate the importance of stream habitat and stability and to influence and/or change the behavior of residents.

Public education begins with public involvement. One principle avenue for educating residents is through forming local watershed groups. Local watershed groups are most effective when strong, mutually beneficial relationships are established early between the volunteers and local government agencies. Planning agencies and volunteers could then communicate and work together to educate neighbors through activities such as stream clean-ups, revegetating stream banks, long-term monitoring, and publishing articles in the local newspaper(s), among many others. Additional opportunities for the community to participate in all aspects of the planning/development phase increases not only public education, but also recreation and habitat enhancement opportunities.



Cobbs Creek, Philadelphia, PA

Geomorphologic Survey - Level II

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Figure 5.0c Restoration Strategy Category III: Land Management

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6.0 Preliminary Construction Cost Estimate and Cost/Benefit Analysis

A general, preliminary construction cost and cost benefit analysis were completed to help determine the most beneficial reach restoration order. Since restoration efforts have not been defined according to specific concept designs for individual reaches, the cost/benefit analysis was completed according to subwatersheds. Numerical values were assigned to each expected benefit and cost, then totaled to determine a cost/benefit value (total benefits minus total cost). Given the condition of the channels within the Cobbs Creek watershed, benefits of restoration generally would exceed project costs. Only very small-scale and/or site specific projects are expected to have greater costs than benefits associated with restoration efforts. Calculated cost/benefit values were interpreted as follows:

- All cost benefit values that resulted in a positive number indicated that restoration benefits outweigh expected costs, and
- Cost/benefit values that resulted in a negative number indicated that restoration costs are greater than the benefits.

All cost/benefit values, shown in Table 6.0, showed that restoration within each subwatershed would be beneficial. Restoration of the Cobbs Creek Mainstem would result in the greatest benefits, followed by the West and East Indian Creeks. Cost/benefit values provided an additional tool used to prioritize reach restoration.

Table 6.0a Cost/Benefit

	Reduce Sediment Supply	Improve Water Quality	Reduce Bank Erosion	Reduce Bed Erosion	Increase Wildlife Habitat	Increase Instream Habitat	Enhance Riparian Buffer	Creation of More Contiguous Forest	Reconnect Channel to Floodplain	Increase Native Vegetation	Decrease/Eradicate Invasive Vegetation	Increased Public Awareness	**Total Benefits**	Difficult Access	Clearing Forests	Removal of Significant Trees	Wetland Disturbance (Veg., Soils, and/or Hydrology)	Limitations by Utilities	Limitations by Property Owners/Right-of-Way	**Total Costs**	**Cost/Benefit Value**
Cobbs Creek	1.5	1	1.5	1.5	0.5	1.5	1	1.5	1.5	1	1	1	**15**	0	0	1	0	3	2.5	**6.5**	**8**
West Indian Creek	1	1.5	1	1	1	0.5	1	0.5	1	1	1	1.5	**12**	0.5	0	1	0	3	2.5	**7.0**	**5**
East Indian Creek	1	1.5	1	1	1	0.5	1	0.5	1	1	1	1.5	**12**	0.5	0	1	0	3	2.5	**7.0**	**5**

Benefit Values					
Low	0.5	Moderate	1	High	1.5

Possible costs:	Costs Values
Difficult access	0.5
Clearing Forests	1.5
Removal of Significant Trees	1
Wetland Disturbance (Vegetation, Soils and/or Hydrology)	2
Limitations due to Property Owners/Right-of-Way	2.5
Limitations due to Utilities Present	3

General, preliminary construction cost estimates were prepared to provide an understanding of the differences in costs and level of effort involved with each of the restoration strategies. Preliminary construction cost estimates are not intended for project construction and are not inclusive of all parts of a stream restoration project. The following preliminary costs provided in Table 6.0b should only be used to estimate the level of effort associated with recommended restoration strategies.

Table 6.0b Preliminary Cost Estimate Summary

Strategy	Unit Cost		Estimated Total
Boulder Bank Stabilization	60 tons/structure	\$60/Ton	\$3,600 / Structure
Non-Structural Bank Stabilization	N/A LUMP SUM		\$1,500 / Structure
Bed Stabilization	150 tons/Structure	\$60/Ton	\$5,000 / Structure
Realignment and Relocation	\$200,000 - \$500,000 per Mile (5,280 linear feet)		
Dam, Debris and Pond Removal	*Varies*		
Reforestation:			
Trees	150 / Acre	\$18 Each	\$2,700 / Acre
Shrubs	300 / Acre	\$14 Each	\$4,200 / Acre
Seed	4,840 SY / Acre	\$0.50 / SY	\$2,420 / Acre
Wetland Creation:			
Trees	150 / Acre	\$18 Each	\$2,700 / Acre
Shrubs	300 / Acre	\$14 Each	\$4,200 / Acre
Seed	4,840 SY / Acre	\$0.50 / SY	\$2,420 / Acre
Grading / Excavation	Grading / Excavation Lump Sum per Acre \$10,000		\$10,000
Road and Culvert Maintenance	*Varies*		
Reduce Impervious Surfaces:			
Stormwater Management Practices	LUMP SUM - RANGING FROM \$10,000 (GRASS SWALES) TO \$100,000 (NEW BASIN)		
Bioretention Facilities			
Plantings	\$1000 – \$10,000 (100 s.f. – 1 Acre)		Dependent on Size & Depth
Materials	\$20-\$35 per square foot		Dependent on Size & Depth
Parking Lot Plantings	5 - 8"-12" Caliper trees / Island	\$500 / Tree Installed	\$2,500 / Parking Island
Public Education	*Varies*		

As shown in Table 6.0b, stream restoration methods range in preliminary construction costs from \$1,500 to \$500,000 depending on the method(s) chosen for an individual site. The least expensive restoration methods suitable for reaches within the Cobbs Creek watershed are non-structural bank stabilization, bioretention, and planting parking lot islands. Although these methods are effective and less expensive, it is important to remember that they are not suitable for all sites. Often, multiple methods are incorporated into a design to alleviate specific areas/causes of channel degradation.

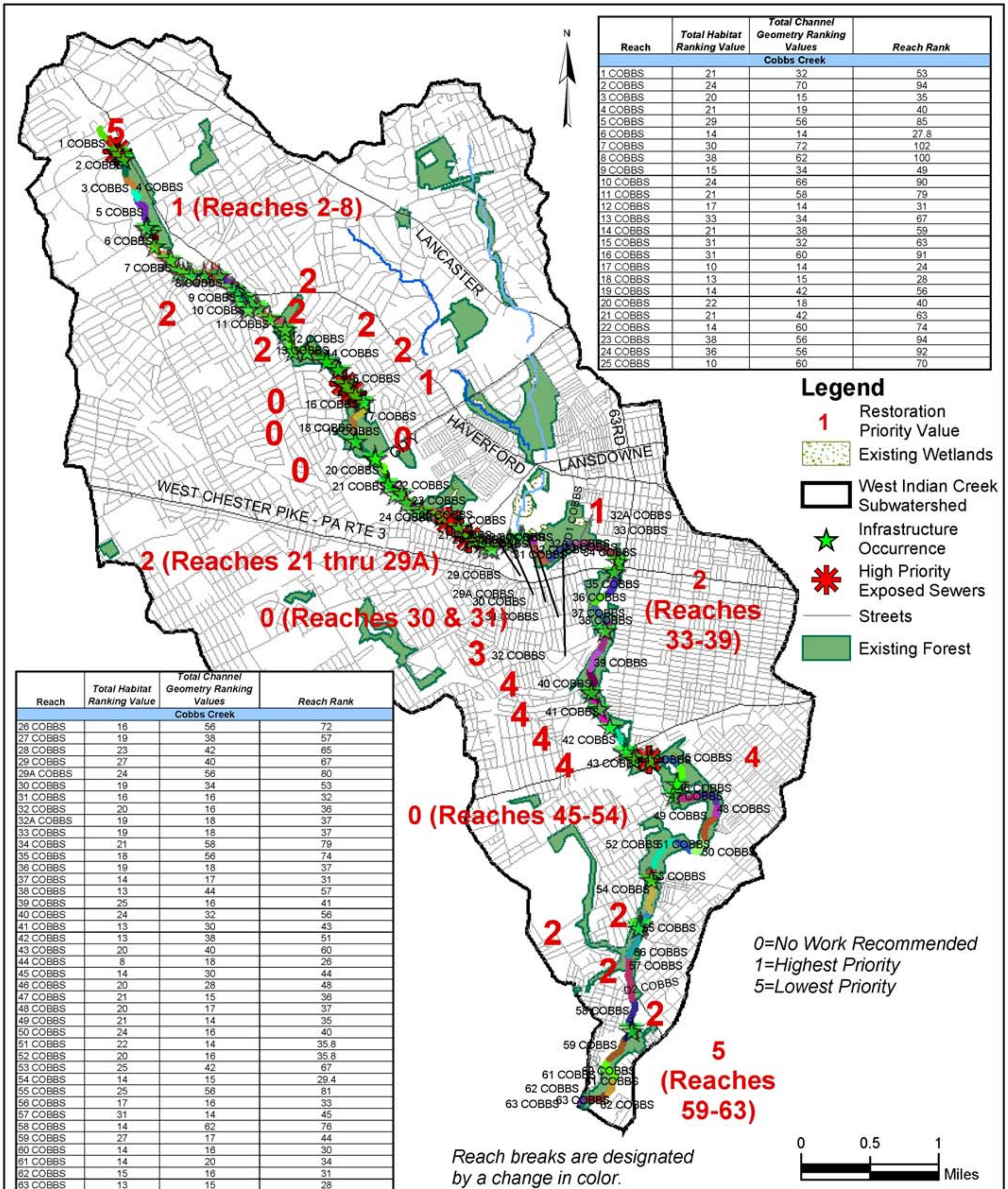
7.0 SUBWATERSHED AND REACH PRIORITIZATION

Restoration throughout the Cobbs Creek watershed was prioritized according to existing conditions, stability scores, preliminary construction costs, cost/benefit values and any potential site constraints. Reach location within the subwatershed affected the prioritization since headwater reaches should be restored before downstream reaches. Based on these factors, reaches were assigned a number priority of 1 through 5, 1 being the highest priority and 5 being the lowest. No restoration is recommended for reaches assigned a 0 restoration priority, although some of these reaches may also be degraded. In these case, restoration was not considered worthwhile either because project costs outweighed project benefits or because the channel is expected to stabilize itself in the near future. Reaches assigned the same rank were grouped because of shared possible access points and may be considered a recommended restoration project. All prioritization scores are shown in Tables 7.0a, 7.0b, and 7.0c and on Figure 7.0.

Cobbs Creek

Overall, based on existing conditions, the Cobbs Creek subwatershed contains the greatest amount of degraded channel and has the highest restoration priority. Reaches assigned the highest restoration priority within this subwatershed are those that are severely degraded and/or continue to degrade. In all cases, the highest priority reaches contain infrastructure. Utilities present within these reaches that are of concern consist of exposed sewer pipes and dams. Reaches both upstream and downstream of these utilities sometimes were included in the prioritization because they are being impacted by these structures or because expected future, restoration/retrofit designs may require additional channel length. Multiple consecutive reaches that yielded high final ranking scores, generally those that were greater than the average stability score for the subwatershed, were also assigned a high restoration priority. The least amount of restoration is recommended for the downstream portion of Cobbs Creek.

Potential restoration for Cobbs Creek should be completed first because the negative impacts of channel degradation will have greater adverse impacts on the watershed. For example, severe erosion of Cobbs Creek will deliver much more sediment to Darby Creek than would result from severe erosion of West or East Indian Creeks. Therefore, greater watershed benefits are associated with addressing Cobbs Creek reaches first than those benefits associated within a smaller subwatershed.



Reach	Total Habitat Ranking Value	Total Channel Geometry Ranking Values	Reach Rank
Cobbs Creek			
1 COBBS	21	32	53
2 COBBS	24	70	94
3 COBBS	20	15	35
4 COBBS	21	19	40
5 COBBS	29	56	85
6 COBBS	14	14	27.8
7 COBBS	30	72	102
8 COBBS	38	62	100
9 COBBS	15	34	49
10 COBBS	24	66	90
11 COBBS	21	58	79
12 COBBS	17	14	31
13 COBBS	33	34	67
14 COBBS	21	38	59
15 COBBS	31	32	63
16 COBBS	31	60	91
17 COBBS	10	14	24
18 COBBS	13	15	28
19 COBBS	14	42	56
20 COBBS	22	18	40
21 COBBS	21	42	63
22 COBBS	14	60	74
23 COBBS	38	56	94
24 COBBS	36	56	92
25 COBBS	10	60	70

Reach	Total Habitat Ranking Value	Total Channel Geometry Ranking Values	Reach Rank
Cobbs Creek			
26 COBBS	16	56	72
27 COBBS	19	38	57
28 COBBS	23	42	65
29 COBBS	27	40	67
29A COBBS	24	56	80
30 COBBS	19	34	53
31 COBBS	16	16	32
32 COBBS	20	16	36
32A COBBS	19	18	37
33 COBBS	19	18	37
34 COBBS	21	58	79
35 COBBS	18	56	74
36 COBBS	19	18	37
37 COBBS	14	17	31
38 COBBS	13	44	57
39 COBBS	25	16	41
40 COBBS	24	32	56
41 COBBS	13	30	43
42 COBBS	13	38	51
43 COBBS	20	40	60
44 COBBS	8	18	26
45 COBBS	14	30	44
46 COBBS	20	28	48
47 COBBS	21	15	36
48 COBBS	20	17	37
49 COBBS	21	14	35
50 COBBS	24	16	40
51 COBBS	22	14	35.8
52 COBBS	20	16	35.8
53 COBBS	25	42	67
54 COBBS	14	15	29.4
55 COBBS	25	56	81
56 COBBS	17	16	33
57 COBBS	31	14	45
58 COBBS	14	62	76
59 COBBS	27	17	44
60 COBBS	14	16	30
61 COBBS	14	20	34
62 COBBS	15	16	31
63 COBBS	13	15	28

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Cobbs Creek, Philadelphia, PA

Geomorphologic Survey, Level II

Guiding Principles for Fluvial Geomorphologic Restoration

Figure 7.0a Cobbs Creek Reach Rankings and Prioritization

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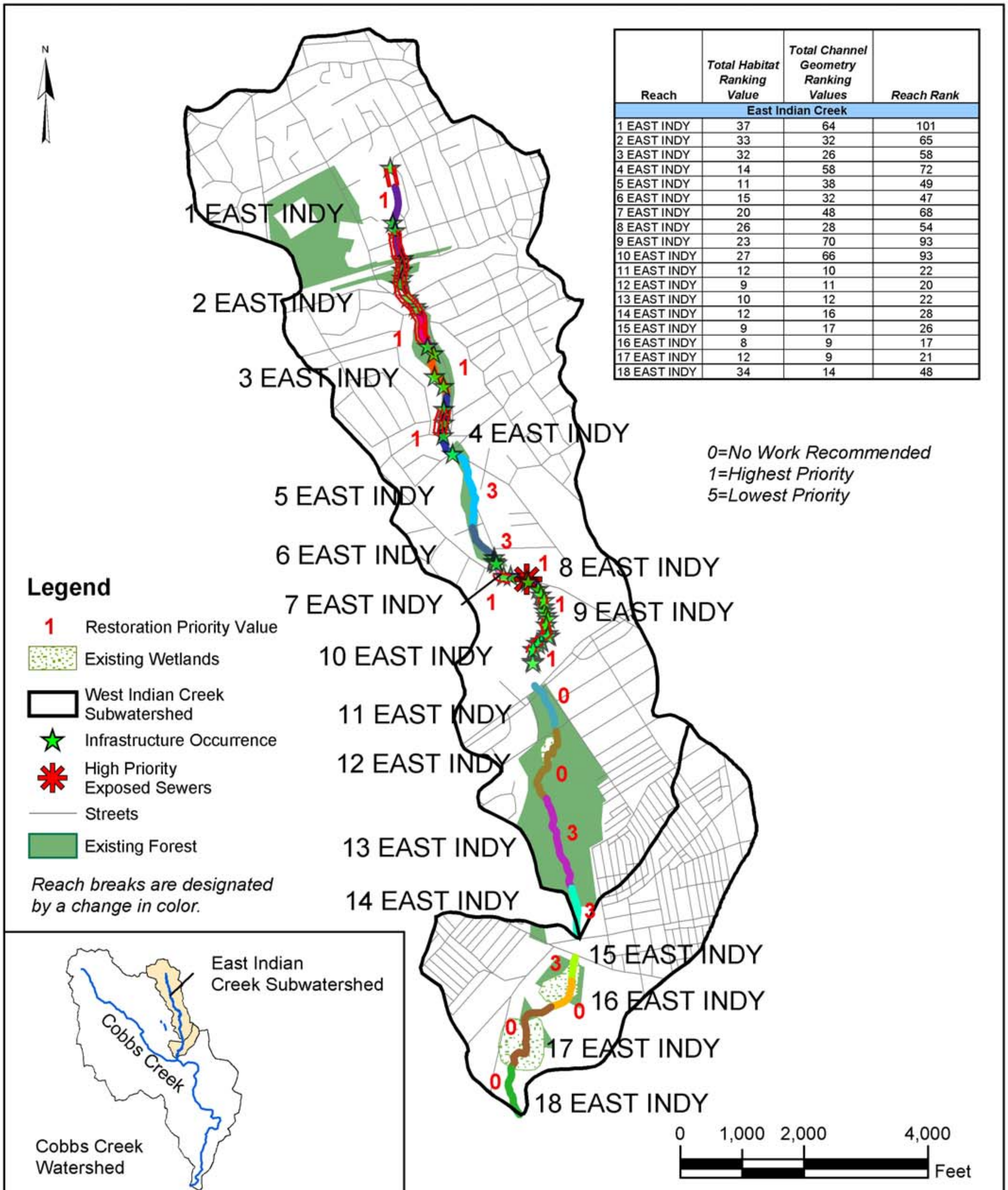
Table 7.0a Cobbs Creek Reach Ranking and Prioritization

Reach	Subshed	Rosgen Channel Type	Reach Rank	Cost/Benefit Value	Restoration Prioritization
2 COBBS	Cobbs Mainstem	F5	94	8	1
3 COBBS	Cobbs Mainstem	F3	35	8	1
4 COBBS	Cobbs Mainstem	F5	40	8	1
5 COBBS	Cobbs Mainstem	F3	85	8	1
6 COBBS	Cobbs Mainstem	F4	27.8	8	1
7 COBBS	Cobbs Mainstem	F4	102	8	1
8 COBBS	Cobbs Mainstem	F5	100	8	1
15 COBBS	Cobbs Mainstem	F4	63	8	1
16 COBBS	Cobbs Mainstem	F3	91	8	1
32A COBBS	Cobbs Mainstem	F4	37	8	1
43 COBBS	Cobbs Mainstem	F3	60	8	1
9 COBBS	Cobbs Mainstem	F3	49	8	2
10 COBBS	Cobbs Mainstem	F3	90	8	2
11 COBBS	Cobbs Mainstem	F3	79	8	2
12 COBBS	Cobbs Mainstem	F5	31	8	2
13 COBBS	Cobbs Mainstem	F3	67	8	2
14 COBBS	Cobbs Mainstem	F3	59	8	2
21 COBBS	Cobbs Mainstem	F4	63	8	2
22 COBBS	Cobbs Mainstem	F5	74	8	2
23 COBBS	Cobbs Mainstem	F5	94	8	2
24 COBBS	Cobbs Mainstem	F4	92	8	2
25 COBBS	Cobbs Mainstem	F3	70	8	2
26 COBBS	Cobbs Mainstem	F4	72	8	2
27 COBBS	Cobbs Mainstem	F4	57	8	2
28 COBBS	Cobbs Mainstem	F5	65	8	2
29 COBBS	Cobbs Mainstem	F4	67	8	2
29A COBBS	Cobbs Mainstem	F4	80	8	2
33 COBBS	Cobbs Mainstem	F4	37	8	2
34 COBBS	Cobbs Mainstem	F4	79	8	2
35 COBBS	Cobbs Mainstem	F4	74	8	2
36 COBBS	Cobbs Mainstem	F4	37	8	2
37 COBBS	Cobbs Mainstem	F4	31	8	2
38 COBBS	Cobbs Mainstem	F5	57	8	2
39 COBBS	Cobbs Mainstem	F4	41	8	2
55 COBBS	Cobbs Mainstem	F4	81	8	2
56 COBBS	Cobbs Mainstem	F5	33	8	2
57 COBBS	Cobbs Mainstem	F5	45	8	2
58 COBBS	Cobbs Mainstem	F4	76	8	2
32 COBBS	Cobbs Mainstem	F5	36	8	3
40 COBBS	Cobbs Mainstem	F4	56	8	4
41 COBBS	Cobbs Mainstem	F4	43	8	4
42 COBBS	Cobbs Mainstem	F4	51	8	4
44 COBBS	Cobbs Mainstem	F4	26	8	4
1 COBBS	Cobbs Mainstem	F3	53	8	5
59 COBBS	Cobbs Mainstem	F5	44	8	5
60 COBBS	Cobbs Mainstem	F5	30	8	5
61 COBBS	Cobbs Mainstem	F5	34	8	5
62 COBBS	Cobbs Mainstem	F5	31	8	5
63 COBBS	Cobbs Mainstem	F5	28	8	5
17 COBBS	Cobbs Mainstem	F3	24	8	0
18 COBBS	Cobbs Mainstem	F4	28	8	0
19 COBBS	Cobbs Mainstem	F4	56	8	0
20 COBBS	Cobbs Mainstem	F4	40	8	0
30 COBBS	Cobbs Mainstem	F4	53	8	0
31 COBBS	Cobbs Mainstem	F5	32	8	0
45 COBBS	Cobbs Mainstem	F4	44	8	0
46 COBBS	Cobbs Mainstem	F4	48	8	0
47 COBBS	Cobbs Mainstem	F4	36	8	0
48 COBBS	Cobbs Mainstem	F5	37	8	0
49 COBBS	Cobbs Mainstem	F4	35	8	0
50 COBBS	Cobbs Mainstem	F4	40	8	0
51 COBBS	Cobbs Mainstem	F5	35.8	8	0
52 COBBS	Cobbs Mainstem	F5	35.8	8	0
53 COBBS	Cobbs Mainstem	F5	67	8	0
54 COBBS	Cobbs Mainstem	F4	29.4	8	0



Reach	*Total Habitat Ranking Value*	*Total Channel Geometry Ranking Values*	*Reach Rank*
East Indian Creek			
1 EAST INDY	37	64	101
2 EAST INDY	33	32	65
3 EAST INDY	32	26	58
4 EAST INDY	14	58	72
5 EAST INDY	11	38	49
6 EAST INDY	15	32	47
7 EAST INDY	20	48	68
8 EAST INDY	26	28	54
9 EAST INDY	23	70	93
10 EAST INDY	27	66	93
11 EAST INDY	12	10	22
12 EAST INDY	9	11	20
13 EAST INDY	10	12	22
14 EAST INDY	12	16	28
15 EAST INDY	9	17	26
16 EAST INDY	8	9	17
17 EAST INDY	12	9	21
18 EAST INDY	34	14	48

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Cobbs Creek, Philadelphia, PA

Geomorphologic Survey - Level II

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Figure 7.0b West Indian Creek Reach Rankings and Prioritization

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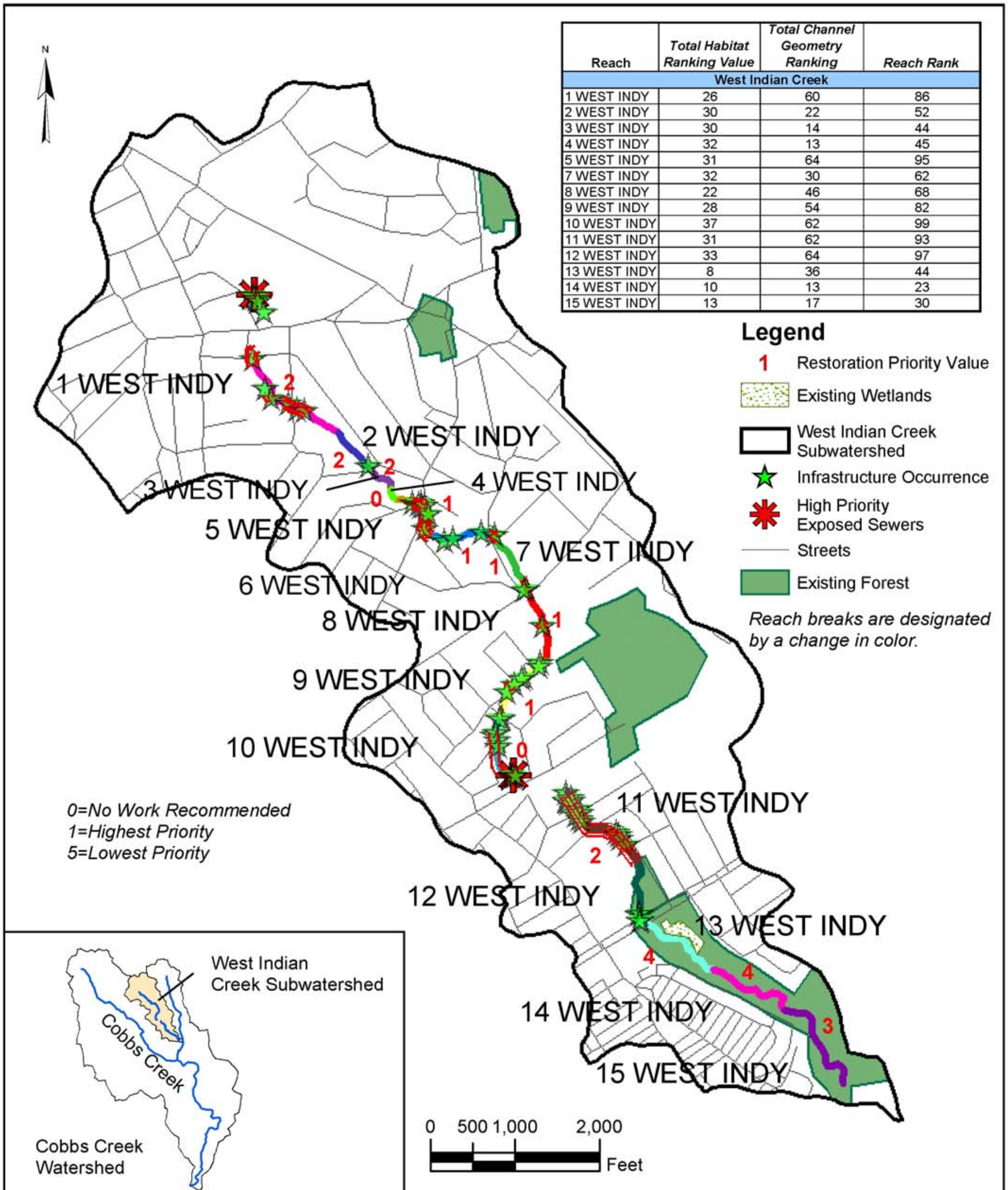
West Indian Creek

Table 7.0b West Indian Creek Reach Ranking and Prioritization

Reach	Subshed	Rosgen Channel Type	Reach Rank	Cost/Benefit Value	Restoration Prioritization
1 WEST INDY	West Indian Creek	B3	86	5	1
2 WEST INDY	West Indian Creek	B3	52	5	1
3 WEST INDY	West Indian Creek	F3	44	5	1
4 WEST INDY	West Indian Creek	F3	45	5	1
5 WEST INDY	West Indian Creek	F4	95	5	1
Piped D/S Portion	West Indian Creek	N/A	N/A	N/A	1
9 WEST INDY	West Indian Creek	F3	82	5	2
10 WEST INDY	West Indian Creek	B4	99	5	2
11 WEST INDY	West Indian Creek	B4	93	5	2
12 WEST INDY	West Indian Creek	F4	97	5	2
15 WEST INDY	West Indian Creek	F4	30	5	3
13 WEST INDY	West Indian Creek	F4	44	5	4
14 WEST INDY	West Indian Creek	B3	23	5	4
7 WEST INDY	West Indian Creek	F4	62	5	0
8 WEST INDY	West Indian Creek	B3	68	5	0

Restoration efforts for West Indian Creek should be implemented following the completion of efforts for Cobbs Creek. West Indian Creek headwater reaches have the highest restoration priority due to the amount of channel disturbance. Channel disturbance was caused both by infrastructure and landowner channel alterations. The headwaters of West Indian Creek are highly impacted by channelization. Channel banks in these areas are lined from the toe of slope to the top of bank with stone or concrete walls. The downstream portion of West Indian Creek also has a high restoration priority because it is piped underground. This portion of West Indian Creek should be restored last so as not to undermine any upstream efforts.



Reach	Total Habitat Ranking Value	Total Channel Geometry Ranking	Reach Rank
West Indian Creek			
1 WEST INDY	26	60	86
2 WEST INDY	30	22	52
3 WEST INDY	30	14	44
4 WEST INDY	32	13	45
5 WEST INDY	31	64	95
7 WEST INDY	32	30	62
8 WEST INDY	22	46	68
9 WEST INDY	28	54	82
10 WEST INDY	37	62	99
11 WEST INDY	31	62	93
12 WEST INDY	33	64	97
13 WEST INDY	8	36	44
14 WEST INDY	10	13	23
15 WEST INDY	13	17	30

Cobbs Creek, Philadelphia, PA

Geomorphologic Survey - Level II

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Figure 7.0c West Indian Creek Reach Rankings and Prioritization

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East Indian Creek

Table 7.0c East Indian Creek Reach Ranking and Prioritization

Reach	Subshed	Rosgen Channel Type	Reach Rank	Cost/Benefit Value	Restoration Prioritization
1 EAST INDY	East Indian Creek	C3	101	5	1
2 EAST INDY	East Indian Creek	B3	65	5	1
3 EAST INDY	East Indian Creek	B4	58	5	1
4 EAST INDY	East Indian Creek	B4	72	5	1
7 EAST INDY	East Indian Creek	B3	68	5	1
8 EAST INDY	East Indian Creek	B4	54	5	1
9 EAST INDY	East Indian Creek	B4	93	5	1
10 EAST INDY	East Indian Creek	B3	93	5	1
5 EAST INDY	East Indian Creek	F4	49	5	3
6 EAST INDY	East Indian Creek	B4	47	5	3
13 EAST INDY	East Indian Creek	B3	22	5	3
14 EAST INDY	East Indian Creek	F3	28	5	3
15 EAST INDY	East Indian Creek	F4	26	5	3
11 EAST INDY	East Indian Creek	B3	22	5	0
12 EAST INDY	East Indian Creek	B3	20	5	0
16 EAST INDY	East Indian Creek	B4	17	5	0
17 EAST INDY	East Indian Creek	B4	21	5	0
18 EAST INDY	East Indian Creek	E4	48	5	0

The East Indian Creek subwatershed was ranked the best according to channel stability and therefore has lowest restoration priority. Although by comparison, channels within this subwatershed are the most stable, approximately 39% are still considered degraded. The most degraded channels occur in the headwaters, as did in all other subwatersheds. Degraded channel conditions are primarily do to channelization and the presence of utility infrastructure. Portions of East Indian Creek that are the highest restoration priority contain multiple stormwater outfalls that drain water from the adjacent single family residential neighborhoods. The lowest restoration priority reaches are located nearest the confluence with Cobbs Creek where the forested riparian buffer is the widest in the entire Cobbs Creek watershed.

8.0 SUMMARY AND RECOMMENDATIONS

The Cobbs Creek watershed is strongly influenced by existing land use and anthropogenic channel changes. Cobbs, East Indian and West Indian Creeks are all adjusting to increased flows and velocities that have resulted from extremely high amounts of impervious surfaces and the presence of structures associated with utilities. Changes to channel planform, pattern and geometry will continue to occur. Cumulative impacts seen today and that are expected to occur throughout the watershed are bed and bank erosion, channel overwidening, channel downcutting, the lack or abundance of sediment, less or no connection to the floodplain, and increased invasive species. Reach ranking results have shown that the Cobbs Creek subwatershed is the least stable, followed by West Indian and then East Indian Creeks. Headwater reaches in each subwatershed are more degraded than reaches more near the confluences with Cobbs Creek and Darby Creek. Final reach ranks also suggest that land use adversely impacts habitat to a greater degree than it impacts channel stability, while infrastructure is the opposite.

This master plan has provided the City of Philadelphia Water Department with the following:

- ✓ Qualitative data describing the existing conditions for channel stability and habitat throughout the Cobbs Creek watershed
- ✓ A stream reach ranking methodology,
- ✓ Detailed GIS layers,
- ✓ Restoration strategies specific for the Cobbs Creek watershed, and
- ✓ Potential and recommended stream restoration projects according to recommended strategies.

All restoration strategies recommended for the entire Cobbs Creek watershed would be best implemented if they are approached in small steps, while still thinking on a watershed basis. Land management strategies are dependent on increasing public education in order to modify behavior and existing land use. These strategies, although they are more time intensive, tend to be less expensive than channel stability and habitat restoration strategies. Channel stability restoration strategies are best implemented concurrently with ongoing land management strategies, while habitat strategies could, in most cases, piggyback channel restoration efforts.

In summary, the Cobbs Creek mainstem has the highest restoration priority, followed by West Indian Creek and East Indian Creek. Restoration of either the West or East Indian Creeks would provide secondary benefits to Cobbs Creek and also to Darby Creek. Aside from land management strategies, all restoration efforts are recommended for implementation beginning in headwater reaches and continuing downstream to avoid undermining any previous efforts. However, restoration projects for the East and West Indian Creeks may occur simultaneously with ongoing efforts upstream of the confluence of East Indian Creek and Cobbs Creek.

Prioritization of all reaches included in the Level II geomorphologic survey yielded a total of 12 recommended stream restoration projects as follows:

Cobbs Creek		Total Length (ft)
1)	Reaches 2 through 7	6,394
2)	Reaches 8 in its entirety	2,084
3)	Reaches 10 through 16	6,976
4)	Reaches 21 through 29A	6,874
5)	Reaches 32A through 39	7,225
6)	Reaches 43 in its entirety	1,195
7)	Reaches 55 through 57	3,659

West Indian Creek		Total Length
1)	Reaches 1 through 5	3,186
2)	Reaches 9 through 12	8,025
3)	Daylighting the downstream most portion of West Indian Creek currently piped underground, and outfalls into East Indian Creek	

East Indian Creek		Total Length
1)	Reaches 1 through 4	4,138
2)	Reaches 7 through 10	1,940

Total lengths for each recommended stream restoration project were obtained by adding reach lengths in their entirety. This does not necessarily indicate that each reach should be restored in its entirety.

8.1 RECOMMENDATIONS

In addition to recommended strategies, Biohabitats, Inc. offers the following recommendations:

- ✓ Build relationships with community groups and governing agencies to facilitate public education, volunteer efforts, data exchange, collaborative efforts, and possible project funding

- ✓ Complete an invasive species management plan for the watershed to target extreme areas and to use as a reference when projects are implemented

- ✓ Conduct a watershed wide impervious surfaces survey to determine potential locations to begin reducing runoff

- ✓ Establish a long term channel stability monitoring plan using baseline bank pin and scour chain conditions. Long term monitoring data could be used to estimate land use effects and as a watershed planning tool

- ✓ Conduct a watershed wide survey of all road crossings and culverts and incorporate into a long term restoration plan

- ✓ Continue to maintain the infrastructure inventory completed in conjunction with this master plan and develop a long term plan

- ✓ Use of Reach Ranks and Restoration Prioritization

  Biohabitats, Inc. has completed an assessment of Cobbs Creek, East Indian Creek and West Indian Creek for the purpose of prioritizing reaches for restoration within the watershed. Restoration of only the most degraded reaches according to the ranking is not considered worthwhile, nor recommended, since restoration of this type is not stable for the long term. Therefore, aside from specifically mentioned headwater reaches, low stability or ranking scores are more indicative of the amount of restoration required to stabilize reaches, given project benefits outweigh the costs. Lastly, the restoration prioritization is dependent on existing conditions within the Cobbs Creek watershed of the at the time of this assessment and should be reevaluated prior to implementation.

9.0 REFERENCES

Barnes, H.H. Jr., 1967. Roughness Characteristics of Natural Channels. U.S. Geological Survey Water-Supply Paper 1849.

Baltimore County Department of Environmental Protection and Resource Management, 1999. Hydrologic, Hydraulic and Geomorphological Assessment of Streams in the Piedmont Region of Maryland.

Carpenter, D.H. Characteristics of Streamflow in Maryland. Department of Natural Resources, Maryland Geological Survey, 1983.

Center for Watershed Protection. *An Eight-Step Approach to Stormwater Retrofitting: How to Get Tem Implemented*. Retrieved June 6, 2002 from http://www.lib.duke.edu/libguide/bib_webpage.htm

Center for Watershed Protection. *Site Planning Model Development Principles.* Retrieved June 6, 2002 from http://www.cwp.org/22_principles.htm

Center for Watershed Protection. *Elements of a Smart Watershed Program.* Retrieved June 6, 2002 from http://www.cwp.org/SMART_WATERSHED_PROGRAM.htm

Dillow, Jonathan J.A. Technique for Estimating Magnitude and Frequency of Peak Flows in Maryland. United States Geological Survey, 1996.

Lane, Emory W. 1955. "Design of Stable Channels," Transactions, American Society of Civil Engineers, Vol 120, Paper No. 2776.

Leopold, L.B., Wolman, M.G., and J.P. Miller, 1964. Fluvial Processes in Geomorphology, W.H. Freeman and Company, San Francisco, 522 pp.

Limerinos, J.T., 1970. Determination of the Manning coefficient from measured bed roughness in natural channels: U.S. Geological Survey Water-Supply Paper 1898-B.

McCuen, R.H. 1989. Hydrologic Analysis and Design, Prentice-Hall Inc., 15: 724-730.

Upper Perkiomen Watershed Coalition. *Upper Perkiomen Watershed Coalition Conservation Plan.* Retrieved September 5, 2002 from http://www.phillywater.org/Schuylkill/Watershed/watershed_history.htm

Rosgen, D. L., 1994. A classification of natural rivers. Catena, 22: 169-199.

Rosgen, D.L., 2001. A Practical Method of Computing Streambank Erosion Rate, Federal Interagency Sedimentation Conference 2001.

Rosgen, D.L., 1996. Applied River Morphology, Wildland Hydrology, Pagosa Springs, CO.

Collier, Michael and Robert H. Webb, and John C. Schmidt. Dams and Rivers, A Primer on the Downstream Effects of Dams. USGS Circular 1126, 2000.

USDA Urban hydrology for Small Watersheds 1986

US Environmental Protection Agency and the Delaware Department of Natural Resources and Environmental Council. Christina River Watershed Stream Restoration Study. NPS Project 98-8. January 1999.

Wolman, M.G., 1954. A method of sampling coarse river-bed material. Transactions of American Geophysical Union, 35: 951-956.

Wolman, M.G. & W.P. Miller, 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology, 68: 54-74.

RELEVANT REPORTS:

DEP Environmental Futures Planning Report for designated Watershed 03G

DEP Watershed Restoration Action Strategy for designated Watershed 03G

PWD Darby-Cobbs Watershed Technical Memorandums 1 – 4
Technical Memorandum No. 1; Collection and Analysis of Existing Data for the Darby and Cobbs Creek Watershed

Technical Memorandum No. 2; Analysis of 1999 Monitoring Data for the Darby and Cobbs Creeks Watershed

Technical Memorandum No. 3; A Screening Level Contaminant Loading Assessment for the Darby and Cobbs Creeks Watershed

Technical Memorandum No. 4; Preliminary Documentation on the Biological Assessment of the Darby and Cobbs Creeks Watershed

NLREEP Cobbs Master plan

Program Act 167 Stormwater Management Plan for the Darby and Cobbs Creeks Watershed, Phase I: Scope of Study

DCVA Darby River Conservation Plan (Coming soon – now available in DRAFT form)
Darby-Cobbs Watershed Management Plan (Coming soon – now available in DRAFT form)

Act 537: Sewage Facilities Plan, Municipal and Authority Inflow and Infiltration Study, Summary Report

Ecological Assessment 1997 Cobbs Creek Delaware and Philadelphia Counties, Pennsylvania

Darby Creek Stream Valley Park Master Plan

RELEVANT PROGRAMS:

Act 167 Stormwater Management

Unassessed Waters Program

Philadelphia Watershed Management Initiative

PWD Wetland Assessment

NWI

TMDL

SW Phase II

FGM Study

303d

Fish Advisories

EPA SSO Rule

NPDES

PWD CSO LTCP

EPA CSO Control Policy

CROSS SECTION PICTURES:
COBBS, EAST INDIAN AND WEST INDIAN CREEKS

APPENDIX A

QUALITATIVE STREAM SURVEY SUMMARY DATA: COBBS, EAST INDIAN AND WEST INDIAN CREEKS

APPENDIX B

MEASURED REACH CROSS SECTION GRAPHS:
COBBS, EAST INDIAN AND WEST INDIAN CREEKS

APPENDIX C

BANK PIN AND SCOUR CHAIN INSTALLATION LOCATION PICTURES

APPENDIX D

INITIAL BANK PIN AND SCOUR CHAIN DATA

APPENDIX E

REACH RANKING SPREADSHEETS

APPENDIX F

GIS METADATA

APPENDIX G