

# DELAWARE RIVER WATERSHED STREAMBANK EROSION ASSESSMENT

ArcGIS® Comparison Study: 1991 vs. 2008 Aerial Photography

**UPDATED DRAFT: April 2011**



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## Executive Summary

Federal reservoirs are an important source of water supply in Kansas for approximately two-thirds of Kansas' citizens. The ability of a reservoir to store water over time is diminished as the capacity is reduced through sedimentation. In some cases reservoirs are filling with sediment faster than anticipated. Whether sediment is filling the reservoir on or ahead of schedule, it is beneficial to take efforts to reduce sedimentation to extend the life of the reservoir.

The Kansas Water Authority has established a *Reservoir Sustainability Initiative* that seeks to integrate all aspects of reservoir input, operations and outputs into an operational plan for each reservoir to ensure water supply storage availability long into the future. Reduction of sediment input is part of this initiative.

The Delaware River Watershed Assessment, an ArcGIS® Comparison Study, was initiated to partially implement the *Reservoir Sustainability Initiative*. This assessment identifies areas of streambank erosion to provide a better understanding of the Delaware River Watershed for streambank restoration purposes and to increase understanding of streambank erosion to reduce excessive sedimentation in reservoirs across Kansas. The comparison study was designed to guide prioritization of streambank restoration by identifying reaches of streams where erosion is most severe in the watershed above Perry Lake.

The Kansas Water Office (KWO) 2011 assessment quantifies annual tons of sediment eroding from the Delaware River Watershed over a 17 year period between 1991 and 2008 within the Delaware River Watershed in Kansas. A total of 115 streambank erosion sites were identified, covering 68,178 feet of unstable streambank and transporting 126,428 tons of sediment downstream per year; accounting for roughly 79.2 acre-feet per year of sediment accumulation in Perry Lake. It should be noted that the identified streambank erosion locations are only a portion of all streambank erosion occurrences in the watershed. Only those streambank erosion sites covering an area 1,500 sq. feet, or more, were identified. Streambank erosion sites were analyzed by stream reach, 10-digit Hydrologic Unit Codes (HUC10) and 12-digit Hydrologic Unit Codes (HUC12). A substantial quantity of the identified eroded sediment in the watershed is transported annually from the mainstem Delaware River reaches one, two, three, four and seven (D1, D2, D3, D4 and D7), accounting for roughly 83,329 tons of sediment annually or 65 percent of sediment eroding from all identified streambank erosion sites. These identified reaches account for an estimated 74 percent or \$2.3 million of total stabilization cost needs in the watershed. Results by HUC10 identified 1027010304 (HUC(304)) as the most active HUC10 for streambank degradation, accounting for 24,112 feet of unstable streambank, 55,951 tons (35 acre-feet) of sediment per year, and 35 percent of total stabilization costs. Results by HUC12 identified 102701030408 as the most active HUC12 for streambank degradation, accounting for 19,437 feet of unstable streambank, 51,821 tons (32.5 acre-feet) of sediment per year, and 29 percent of total stabilization costs. Based on the average stabilization costs of \$71.50 per linear foot, conducting streambank stabilization practices for the entire watershed would cost approximately \$4.9 million.

The streambank gully erosion assessment did not quantify annual tons of soil loss. However, locations of gully erosion were identified and prioritized by a high, medium or low priority using similar techniques as the streambank erosion assessment for identification. Gullies were also assessed by the same stream reaches, HUC10s and HUC12s as was the

streambank erosion assessment. The gully assessment indicated that several reaches throughout the watershed had significant numbers of gullies, including Cedar Creek reach one (CC1), Delaware River reach eight (D8), Elk Creek reach two (EC2), Little Grasshoper Creek reach one (LCG1) and Muddy Creek reach one (M1). Each of the stream reaches comprised of more than ten identified gullies, with a significant percent made up of medium priority streambank gully erosion sites. Assessments results by HUC10s indicated HUC 1027010303 (HUC(303)) as having the most gullies at 51, 29 prioritized as a medium priority gully. Results by HUC12 indicated several areas having significant amounts of identified streambank gully sites: HUC12 102701030109, 102701030204, 102701030301, 102701030303 and 102701030304. Each of the identified HUC12s comprised of more than ten identified gullies, with a significant percent made up of medium priority streambank gully erosion sites.

The KWO completed this assessment for the Delaware River Watershed Restoration and Protection Strategy (WRAPS) Stakeholder Leadership Team (SLT). Information contained in this assessment can be used by the Delaware River Watershed WRAPS SLT to target streambank stabilization and riparian restoration efforts toward high priority stream reaches, HUC10s or HUC12s in the Delaware River Watershed. Similar assessments are ongoing in selected watersheds above reservoirs throughout Kansas and are available on the KWO website at [www.kwo.org](http://www.kwo.org), or may be made available upon request to agencies and interested parties for the benefit of streambank and riparian restoration projects.

## Introduction

Wetlands and riparian areas are vital components of proper watershed function that, when wisely managed in context of a watershed system, can moderate and reduce sediment input. There is growing evidence that a substantial source of sediment in streams in many areas of the country is generated from stream channels and edge of field gullies (Balch, 2007).

Streambank erosion is a natural process that contributes a large portion of annual sediment yield, but acceleration of this natural process leads to a disproportionate sediment supply, stream channel instability, land loss, habitat loss and other adverse effects. Many land use activities can affect and lead to accelerated bank erosion (EPA, 2008). In most Kansas watersheds, this natural process has been accelerated due to changes in land cover and the modification of stream channels to accommodate agricultural, urban and other land uses.

A naturally stable stream has the ability, over time, to transport the water and sediment of its watershed in such a manner that the stream maintains its dimension, pattern and profile without significant aggregation or degradation (Rosgen, 1997). Streams significantly impacted by land use changes in their watersheds or by modifications to streambeds and banks go through an evolutionary process to regain a more stable condition. This process generally involves a sequence of incision (downcutting), widening and re-stabilizing of the stream. Many streams in Kansas are incised (SCC, 1999).

Streambank erosion is often a symptom of a larger, more complex problem requiring solutions that may involve more than just streambank stabilization (EPA, 2008). It is important to analyze watershed conditions and understand the evolutionary tendencies of a stream when considering stream stabilization measures. Efforts to restore and re-stabilize streams should allow the stream to speed up the process of regaining natural stability along the evolutionary sequence (Rosgen, 1997). A watershed-based approach to developing stream stabilization plans can accommodate the comprehensive review and implementation.

Additional research in Kansas documents the effectiveness of forested riparian areas on bank stabilization and sediment trapping (Geyer, 2003; Brinson, 1981; Freeman, 1996; Huggins, 1994). Vegetative cover based on rooting characteristics can mitigate erosion by protecting banks from fluvial entrainment and collapse by providing internal bank strength. Riparian vegetative type is an important tool that provides indicators of erosion occurrence from land use practices. Forested riparian areas are superior to grassland in holding banks during high flows, when most sediment is transported. When riparian vegetation is changed from woody species to annual grasses and/or forbs, sub-surface internal strength is weakened, causing acceleration of mass wasting processes (extensive sedimentation due to sub-surface instability) (EPA, 2008). The primary threats to wetlands and forested riparian areas are agricultural production and suburban/urban development.

Another form of erosion contributing to sedimentation in many Kansas watersheds is the development of streambank gullies. Gullies develop from the wearing away of the surface soil along drainage channels by concentrated surface water

runoff. Gullies are associated with the loss of vegetation on the soil and down cuts forming deep widening channels. The potential for surface erosion is associated in part with the amount of bare, compacted soil exposed to rainfall and runoff. Other factors contributing to gully development are high soil erodability; minimal ground cover; steep, long, continuous slopes; high intensity storms; high drainage density of the slope; and close proximity to streams.

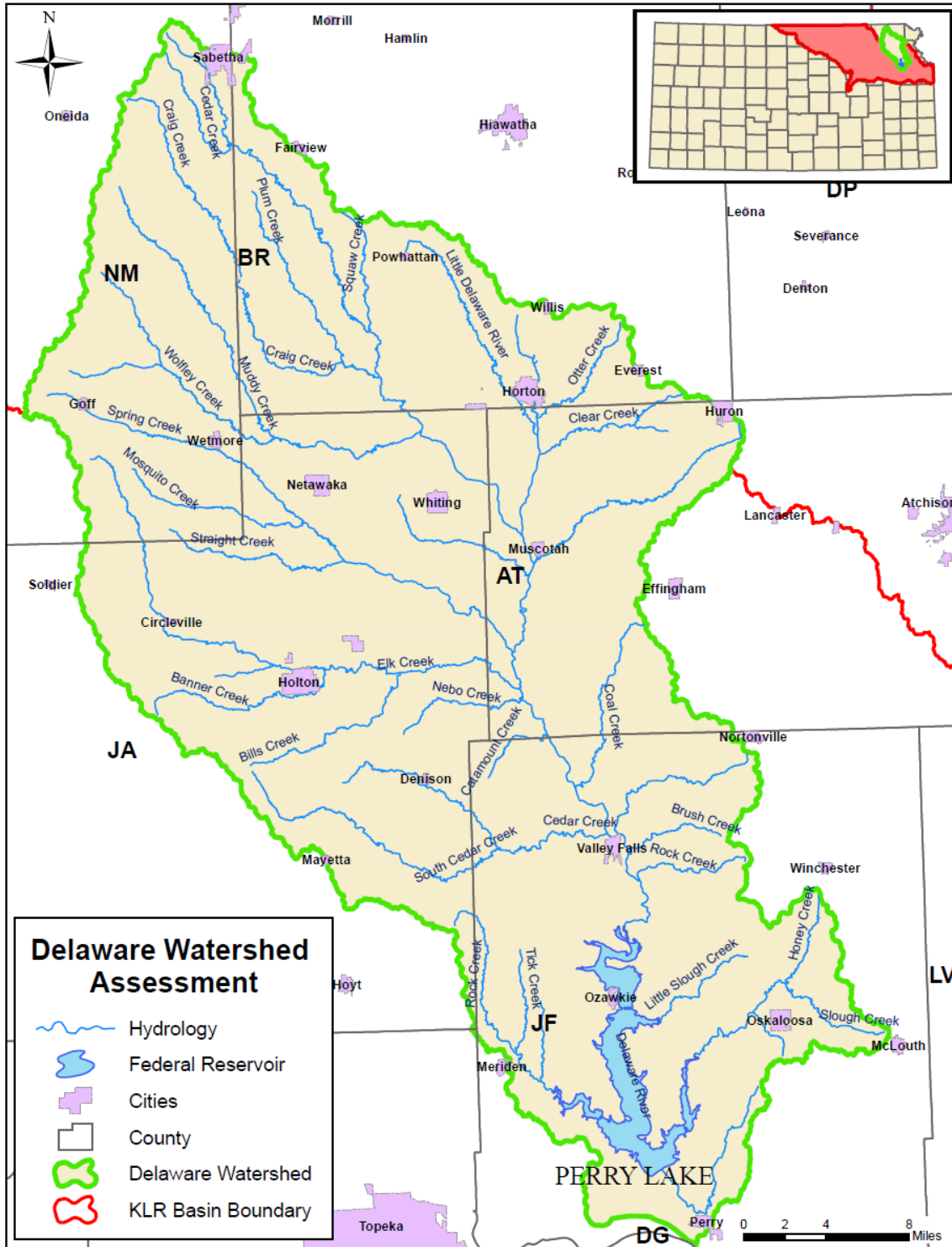
In Kansas, monitoring the extent of erosion losses is difficult, and current up-to-date inventories are needed. This assessment identifies areas with erosion concerns and estimates erosion losses to provide a better understanding of this watershed for mitigation purposes and for application of understanding to watersheds across Kansas.

## **Study Area**

Perry Reservoir is located on the Delaware River, at river mile 5.8, 4.5 miles northwest of Perry, Kansas and 17 miles east of Topeka, Kansas. The Delaware River Watershed in the Kansas Lower Republican Basin was assessed for streambank erosion with a primary focus on the Delaware River, Muddy Creek and Straight Creek above Perry Reservoir (Figure 1). The Delaware River watershed drains approximately 1,117 mi<sup>2</sup>, and includes portions of Atchison, Brown, Jackson, Jefferson, Nemaha and Shawnee county watersheds. Authorized purposes of Perry Reservoir are flood control, navigation, water supply, water quality, recreation and fish and wildlife. Major streams in the Perry Reservoir watershed include multiple tributaries that drain into the main stem Delaware River.

The multipurpose pool of the reservoir was filled in 1970. The original design life for sediment storage was 100 years with a design sediment rate of 930 acre-ft/year with the original storage capacity set at 243,220 acre-feet. The most current bathymetric survey in 2001, performed by the Kansas Geologic Survey, concluded that 19.25 percent of the 100 year design life for sediment storage in Perry Reservoir has been lost to date, calculating the current sedimentation rate at 1,143 acre-feet per year (1,824,228 tons/yr). The bathymetric survey also concluded that the current storage capacity at the reservoir is estimated at 196,394 acre-feet to date.

Figure 1: Delaware River Watershed Assessment Area



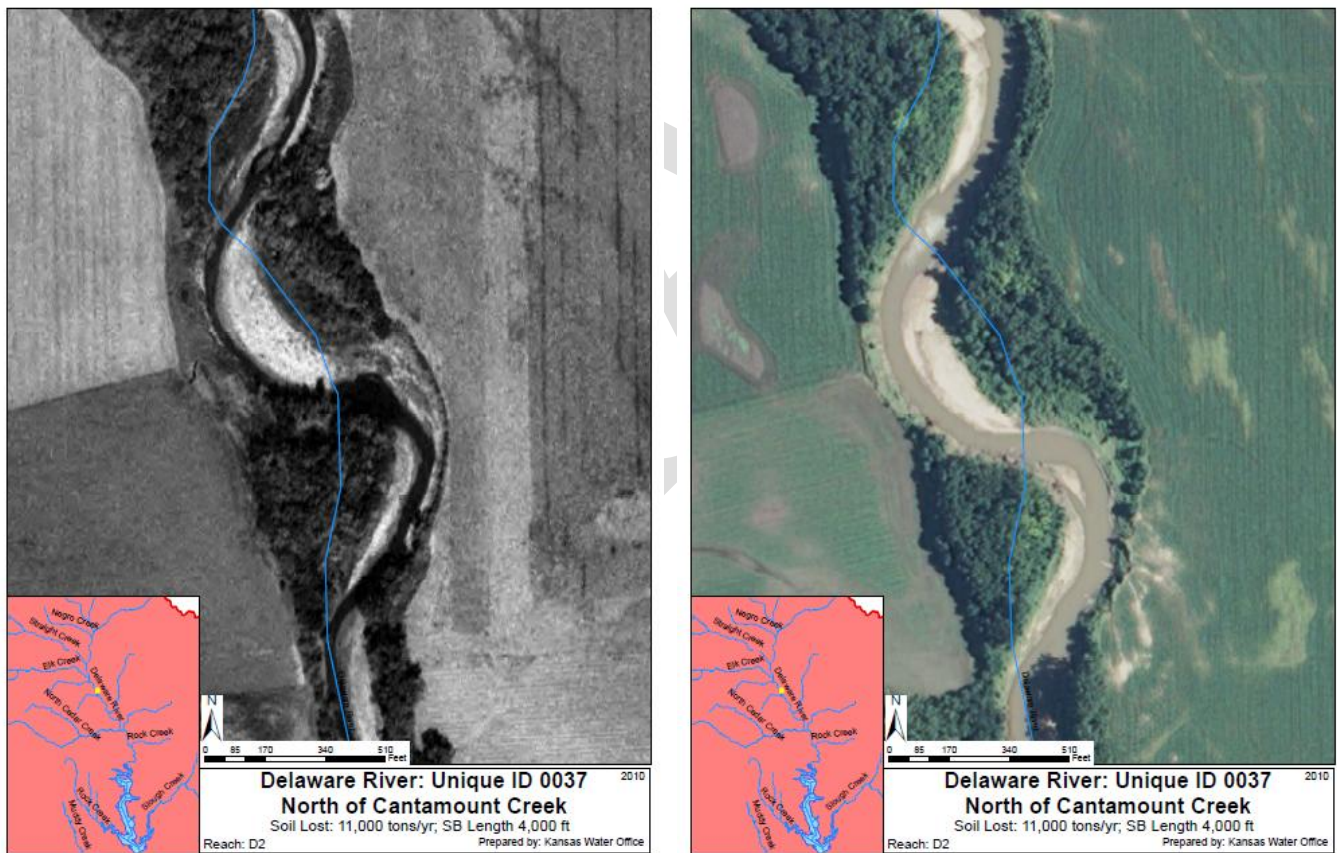
### Data Collection Methodology

The Delaware River Watershed streambank erosion assessment was performed using ArcGIS® software. The purpose of the assessment is to identify locations of streambank instability to prioritize restoration needs and slow sedimentation rates into Perry Lake. ArcMap®, an ArcGIS® geospatial processing program, was utilized to assess color aerial

photography from 2008, provided by National Agriculture Imagery Program (NAIP), and compare it with 1991 black and white aerial photography, provided by the State of Kansas GIS Data Access & Support Center (DASC).

The streambank erosion assessment was performed by overlaying 2008 NAIP county aerial imagery onto 1991 DASC county aerial imagery (Figure 2). Using ArcMap® tools, “aggressive movement” of the streambank between 1991 DASC and 2008 NAIP aerial photos were identified, at a 1:6,000 scale, as a site of streambank erosion. “Aggressive movement” represents areas of 1,500 sq. feet or more of streambank movement between 1991 DASC and 2008 NAIP aerial photos. Streambank erosion sites were denoted by geographic polygons features “drawn” into the ArcGIS® software program through the ArcMap® editor tool. The polygon features were created by sketching vertices following the 2008 streambank and closing the sketch by following the 1991 streambank at a 1:2,500 scale. Data provided, based on the geographic polygon sites include: watershed location, unique ID, stream name, type of stream and type of riparian vegetation.

**Figure 2: 1991 DASC & 2008 NAIP of a Streambank Erosion Site on the Delaware River**



The streambank erosion assessment data also includes approximations of tons of soil loss from the erosion site. This portion of the assessment is performed by utilizing the identified erosion site polygon features. Tons of soil loss was estimated by incorporating perimeter, area and streambank length of the polygons into a regression equation. Perimeter and area were calculated through the *field calculator* application within the ArcGIS® software. The streambank length of

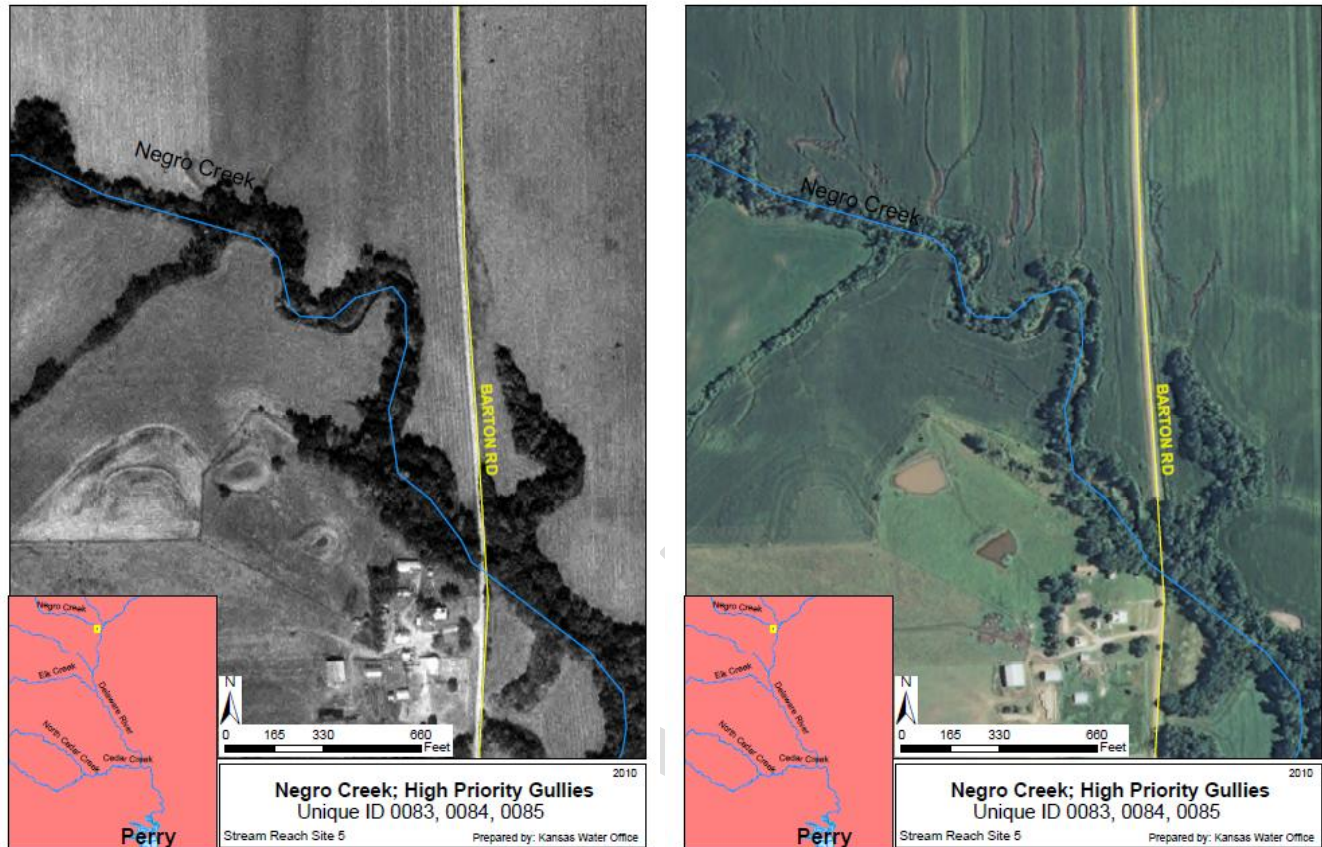
identified erosion sites was computed through the application of a regression equation formulated by the KWO office. This equation was developed by taking data from the *Enhanced Riparian Area/Stream Channel Assessment for John Redmond Feasibility Study*, a report prepared by The Watershed Institute (TWI) and Gulf South Research Corporation (GSCR), and relating the erosion area (in sq. feet) and perimeter length of that erosion area (in feet) to the unstable stream bank length (in feet). The multiple regression formula of that fit (R-square = .999) is  $([Area\_SqFt]*-.00067) + ([Perimtr\_ft]*.5089609)$ . The intercept of the model was forced to zero.

Tons of soil loss was estimated by first calculating the volume of sediment loss and then applying a bulk density estimate to that volume for the typical soil type of identified sites. The volume of sediment was found by multiplying bank height and surface area lost over the 17 year period between the 1991 and 2008 aerial photos and soil bulk density. This calculated volume is then divided by the 17 year period, to get the average rate of soil loss in mass/year (Avg Soil Loss Rate(Tons/yr)=[Area\_SqFt]\*[BankHgtFt]\*SoilDensity(lbs/ft<sup>3</sup>)/2000(lbs/ton)/([NAIP\_ComparisonPhotoYear]-[BaseAerialPhotoYear])).

To complete the analysis for the equation above for tons of soil lost, streambank height measurements of select identified erosion sites were needed. The Kansas River Basin Regional Sediment Management Section, 204 Stream and River Channel Assessment, performed by the Gulf South Research Corporation (GRSC) and The Watershed Institute, Inc. (TWI), through contracts with the U.S. Army Corps of Engineers (Corps), was incorporated into this assessment. The assessments conducted stream channel morphologic and riparian assessments to identify future sediment control opportunities within the Kansas River basin, including streambank heights available from several surveyed locations within the Delaware River Watershed. These locations were the basis for extrapolating streambank height measurements in the Delaware River Watershed.

The streambank gully erosion assessment was performed with similar techniques as the streambank erosion assessment. However, calculating tons of soil erosion was not part of this assessment. Using ArcMap® tools, streambank gully erosion was indicated by line features “drawn” into the ArcGIS® software program. Gully data was compiled and categorized by high, medium or low priority as another effort in rehabilitation prioritization. The identification of a low priority gully indicates that sheet erosion has been identified and a gully could form in the area that is perpendicular to the stream. A low priority gully does not indicate visible channel cutting or any visible streambank riparian erosion. A medium priority gully identifies visible channel cutting perpendicular to the streambank but no visible erosion of the riparian area of the streambank. High priority gullies identify a deeply incised channel cutting perpendicular to the stream, including a significant portion of the riparian area eroded from the streambank (Figure 3). In some instances, gullies were increased to a medium or high priority, even if they exhibit “low priority” gully identifiers, if there was a visibly identifiable sizeable amount of land erosion or gullies present in the same vicinity.

**Figure 3: 1991 DASC & 2008 NAIP of a High Priority Streambank Gully Erosions on Negro Creek**



## Analysis

To adequately analyze streambank erosion sites, stream reach sections were delineated to better accommodate streambank rehabilitation project focus. Streambank erosion prioritization by stream reach sections include: CC1, D2, D4, D5, D6, D7, D8, EC1, EC2, LGC1, M1, M2, NC1, S1, S2, S3, S4 and S5 (Figure 4). Stream reach sections were identified by the stream name and in numerical order from downstream to upstream. Streambank erosion sites were also analyzed by 10-digit Hydrologic Unit Codes (HUC10s) and 12-digit Hydrologic Unit Codes (HUC12s) (Figure 5 and Figure 6). Streambank erosion sites were analyzed for: streambank length (feet) of the eroded bank; annual soil loss (tons); percent of streambank length with poor riparian condition (riparian area identified as having cropland or grass/crop streamside vegetation); estimated sediment reduction through the implementation of streambank stabilization BMPs at an 85% efficiency rate; and streambank stabilization cost estimates for eroded streambank sites. Streambank stabilization costs were derived from an average cost to implement streambank stabilization BMPs, as reported in the TWI *Kansas River Basin Regional Sediment Management Section 204 Stream and River Channel Assessment*; \$71.50 per linear foot was used to calculate average streambank stabilization costs (Figure 7).

Streambank gullies were assessed based on the proportion of high, medium and low priority identifications, also within stream reach sections, HUC10 and HUC12 areas (Figure 4 & 5 & 6). Explanation of prioritization is found in the data collection and methodology above. No further assessment was performed.

Figure 4: Delaware River Watershed Assessment Stream Reaches

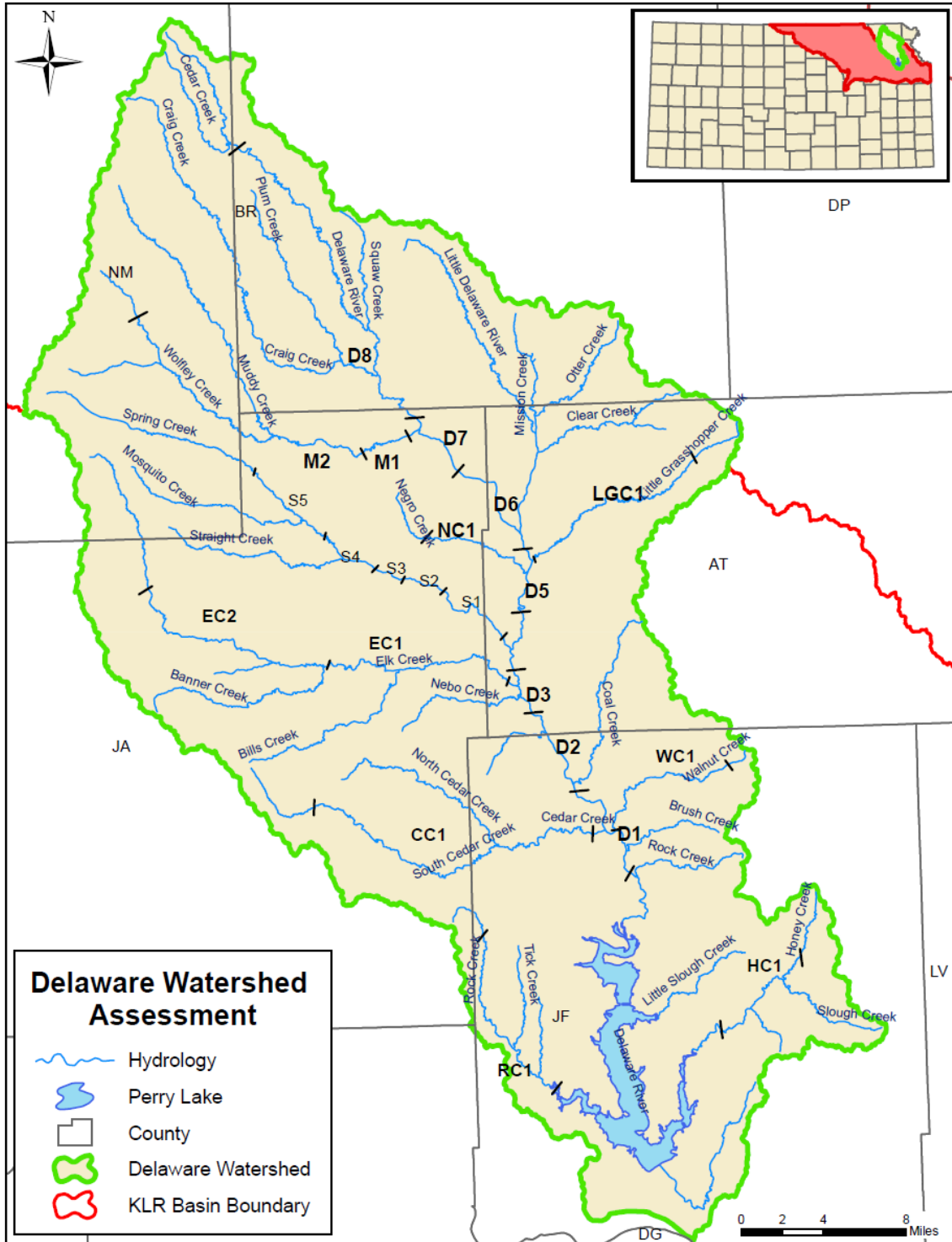


Figure 5: Delaware River Watershed Assessment Area HUC10s

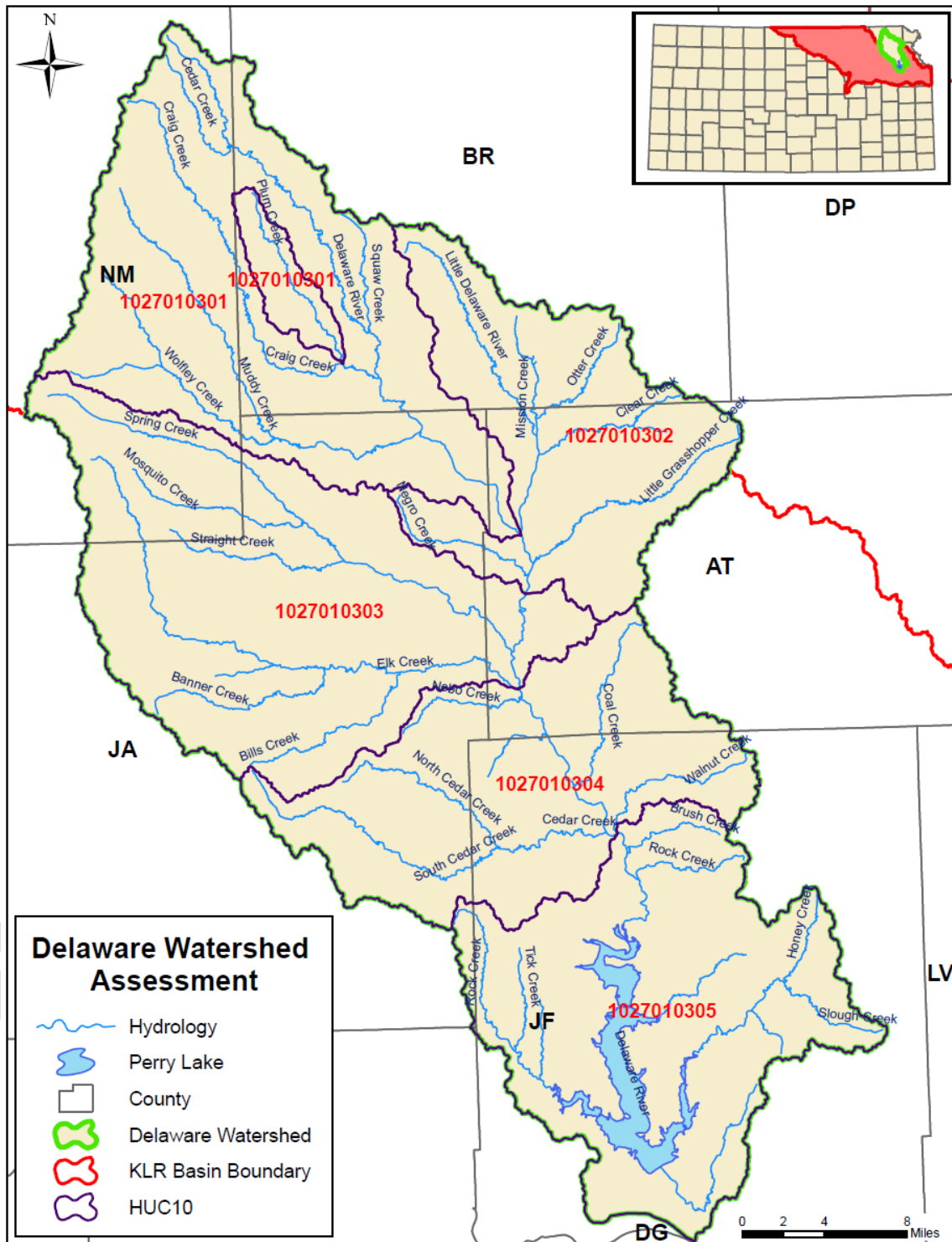


Figure 6: Delaware River Watershed Assessment Area HUC12s



**Figure 7: TWI Estimated Costs to Implement Streambank Stabilization BMPs**

| BMP Cost Description   | Cost estimate per linear foot (in dollars) |
|--|--|
| 1. Survey and design<br>Rock delivery and placement<br>As-built certification design<br>Bank Shaping                       | \$50 - \$75                                |
| 2. Vegetation (material and planting)<br>Cover Crop<br>Mulch<br>Willow Stakes<br>Bare root seedlings<br>Grass filter strip | \$5  |
| 3. Contingencies<br>Unexpected site conditions requiring extra materials and construction time                             | \$3 - \$5.5                                |
| <b>TOTAL</b>   | <b>\$58-\$85.5</b>                         |

## Results

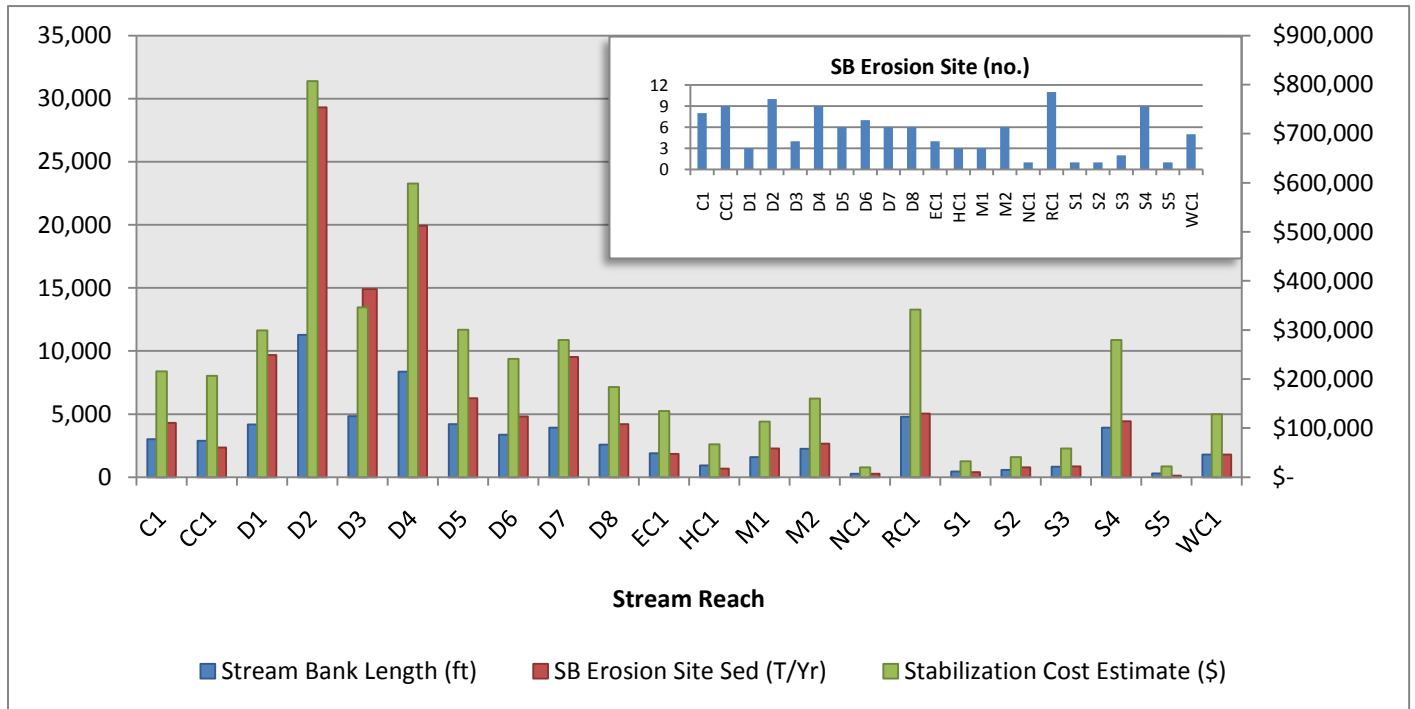
The Kansas Water Office (KWO) 2011 assessment quantifies annual tons of sediment eroding from the Delaware River Watershed over a 17 year period between 1991 and 2008 within the Delaware River Watershed in Kansas. A total of 115 streambank erosion sites, covering 68,178 feet of unstable streambank were identified. Seventy-seven percent of the identified streambank erosion sites were identified as having a poor riparian condition (riparian area identified as having cropland or grass/crop streamside vegetation). Sediment transport from identified streambank erosion sites accounts for roughly 126,428 tons of sediment downstream per year, accounting for roughly 79.2 acre-feet per year of sediment transported from the Delaware River Watershed to Perry Lake. This sediment accounts for roughly seven percent of the total load estimated from the most recent bathymetric survey performed by the Kansas Geological Survey in 2001.

A substantial quantity of the identified eroded sediment in the watershed is transported annually from the mainstem Delaware River reaches one, two, three, four and seven (D1, D2, D3, D4 and D7). These five stream reaches account for roughly 83,329 tons (52.2 acre-feet) or 65 percent of sedimentation and an estimated \$2.3 million or 74 percent of total stabilization cost needs of all identified streambank erosion sites (Table 1 and Figure 8). Results by HUC10 identified 1027010304 (HUC(304)) as the most active HUC10 for streambank degradation, accounting for 24,112 feet of unstable streambank, 55,951 tons (35 acre-feet) of sediment per year, and 35 percent of total stabilization costs (Table 2 and Figure 9). Results by HUC12 identified 102701030408 as the most active HUC12 for streambank degradation, accounting for 19,437 feet of unstable streambank, 51,821 tons (32.5 acre-feet) of sediment per year, and 29 percent of total stabilization costs (Table 3 and Figure 10). Based on the average stabilization costs of \$71.50 per linear foot, conducting streambank stabilization practices for the entire watershed would cost approximately \$4.9 million.

**Table 1: Delaware River Watershed Streambank Erosion Assessment Table by Stream Reach**

| STREAM REACH                             | STREAM BANK LENGTH (FT) | SB EROSION SITE SED (T/YR) | STABIL. COST ESTIMATE (\$) | SB EROSION SITE (NO.)                       | YIELD LOSS/BANK LENGTH | POOR RIPARIAN COND/SB LENGTH (FT) | EST. SED REDUCTION (T/YR) | % SB LENGTH W/ POOR RIPARIAN COND. |
|--|-------------------------|----------------------------|----------------------------|---|------------------------|-----------------------------------|---------------------------|------------------------------------|
| <b>C1</b>                                | 3,018                   | 4,314                      | \$215,778                  | 8   | 1.4                    | 3,018                             | 3,667.14                  | 100.00%                            |
| <b>CC1</b>                               | 2,884                   | 2,344                      | \$206,187                  | 9   | 0.8                    | 1,644                             | 1,992.42                  | 57.00%                             |
| <b>D1</b>                                | 4,179                   | 9,687                      | \$298,807                  | 3   | 2.3                    | 1,304                             | 8,233.92                  | 31.21%                             |
| <b>D2</b>                                | 11,286                  | 29,297                     | \$806,937                  | 10  | 2.6                    | 6,882                             | 24,902.74                 | 60.98%                             |
| <b>D3</b>                                | 4,839                   | 14,899                     | \$346,006                  | 4   | 3.1                    | 4,839                             | 12,664.32                 | 100.00%                            |
| <b>D4</b>                                | 8,372                   | 19,926                     | \$598,623                  | 9   | 2.4                    | 7,100                             | 16,937.12                 | 84.80%                             |
| <b>D5</b>                                | 4,198                   | 6,255                      | \$300,178                  | 6   | 1.5                    | 4,198                             | 5,316.86                  | 100.00%                            |
| <b>D6</b>                                | 3,371                   | 4,808                      | \$241,051                  | 7   | 1.4                    | 3,053                             | 4,087.08                  | 90.56%                             |
| <b>D7</b>                                | 3,911                   | 9,519                      | \$279,652                  | 6   | 2.4                    | 3,240                             | 8,091.48                  | 82.83%                             |
| <b>D8</b>                                | 2,568                   | 4,203                      | \$183,616                  | 6   | 1.6                    | 2,141                             | 3,572.92                  | 83.36%                             |
| <b>EC1</b>                               | 1,883                   | 1,850                      | \$134,605                  | 4   | 1.0                    | 1,883                             | 1,572.44                  | 100.00%                            |
| <b>HC1</b>                               | 933                     | 680                        | \$66,722                   | 3   | 0.7                    | 695                               | 577.69                    | 74.51%                             |
| <b>M1</b>                                | 1,584                   | 2,273                      | \$113,247                  | 3   | 1.4                    | 1,354                             | 1,931.64                  | 85.49%                             |
| <b>M2</b>                                | 2,239                   | 2,650                      | \$160,102                  | 6   | 1.2                    | 2,239                             | 2,252.47                  | 100.00%                            |
| <b>NC1</b>                               | 283                     | 259                        | \$20,234                   | 1   | 0.9                    | 283                               | 220.18                    | 100.00%                            |
| <b>RC1</b>                               | 4,781                   | 5,050                      | \$341,810                  | 11  | 1.1                    | 1,583                             | 4,292.84                  | 33.12%                             |
| <b>S1</b>                                | 449                     | 398                        | \$32,077                   | 1   | 0.9                    | 0                                 | 338.43                    | 0.00%                              |
| <b>S2</b>                                | 572                     | 785                        | \$40,909                   | 1   | 1.4                    | 572                               | 667.47                    | 100.00%                            |
| <b>S3</b>                                | 821                     | 866                        | \$58,669                   | 2   | 1.1                    | 821                               | 736.24                    | 100.00%                            |
| <b>S4</b>                                | 3,913                   | 4,441                      | \$279,768                  | 9   | 1.1                    | 3,913                             | 3,774.45                  | 100.00%                            |
| <b>S5</b>                                | 303                     | 127                        | \$21,643                   | 1   | 0.4                    | 303                               | 107.98                    | 100.00%                            |
| <b>WC1</b>                               | 1,792                   | 1,795                      | \$128,134                  | 5   | 1.0                    | 1,315                             | 1,525.78                  | 73.37%                             |
| <b>TOTAL</b>                             | <b>68,178</b>           | <b>126,428</b>             | <b>\$4,874,755</b>         | <b>115</b>                                  | <b>31.8</b>            | <b>52,379</b>                     | <b>-107,464</b>           | <b>76.83%</b>                      |
| <b>Est Stabilization Cost/Linear Ft.</b> |                         |                            | <b>\$71.50</b>             | <b>Stabilization/Restoration Efficiency</b> |                        |                                   | <b>0.85</b>               |                                    |

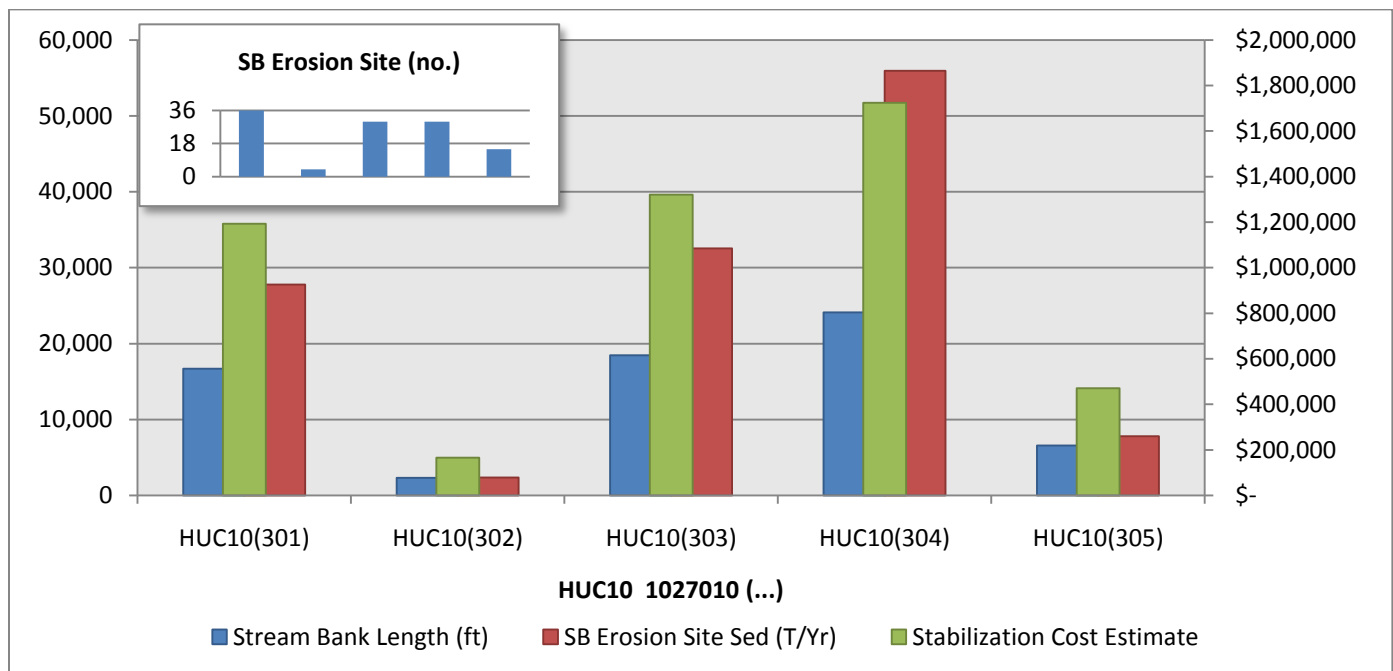
**Figure 8: Delaware River Watershed Streambank Erosion Assessment Graph by Stream Reach**



**Table 2: Delaware River Watershed Streambank Erosion Assessment Table by HUC10**

| HUC10 1027010...                         | STREAM BANK LENGTH (FT) | SB EROSION SITE SED (T/YR) | STABIL. COST ESTIMATE (\$) | SB EROSION SITE (NO.)                       | YIELD LOSS/BANK LENGTH | POOR RIPARIAN COND/SB LENGTH (FT) | EST. SED REDUCTION (T/YR) | % SB LENGTH W/ POOR RIPARIAN COND. |
|--|-------------------------|----------------------------|----------------------------|---|------------------------|-----------------------------------|---------------------------|------------------------------------|
| HUC10(301)                               | 16,692                  | 27,768                     | \$1,193,445                | 36  | 1.7                    | 15,045                            | 23,602.73                 | 90.13%                             |
| HUC10(302)                               | 2,328                   | 2,381                      | \$166,478                  | 4   | 1.0                    | 2,328                             | 2,024.00                  | 100.00%                            |
| HUC10(303)                               | 18,465                  | 32,526                     | \$1,320,227                | 30  | 1.8                    | 16,744                            | 27,647.18                 | 90.68%                             |
| <b>HUC10(304)</b>                        | <b>24,112</b>           | <b>55,951</b>              | <b>\$1,724,041</b>         | <b>30</b>                                   | <b>2.3</b>             | <b>15,984</b>                     | <b>47,558.67</b>          | <b>66.29%</b>                      |
| HUC10(305)                               | 6,581                   | 7,801                      | \$ 470,561                 | 15  | 1.2                    | 2,279                             | 6,631.04                  | 34.62%                             |
| <b>TOTAL</b>                             | <b>68,178</b>           | <b>126,428</b>             | <b>\$4,874,755</b>         | <b>115</b>                                  | <b>8.0</b>             | <b>52,379</b>                     | <b>-107,464</b>           | <b>76.83%</b>                      |
| <b>Est Stabilization Cost/Linear Ft.</b> |                         |                            | <b>\$71.50</b>             | <b>Stabilization/Restoration Efficiency</b> |                        |                                   | <b>0.85</b>               |                                    |

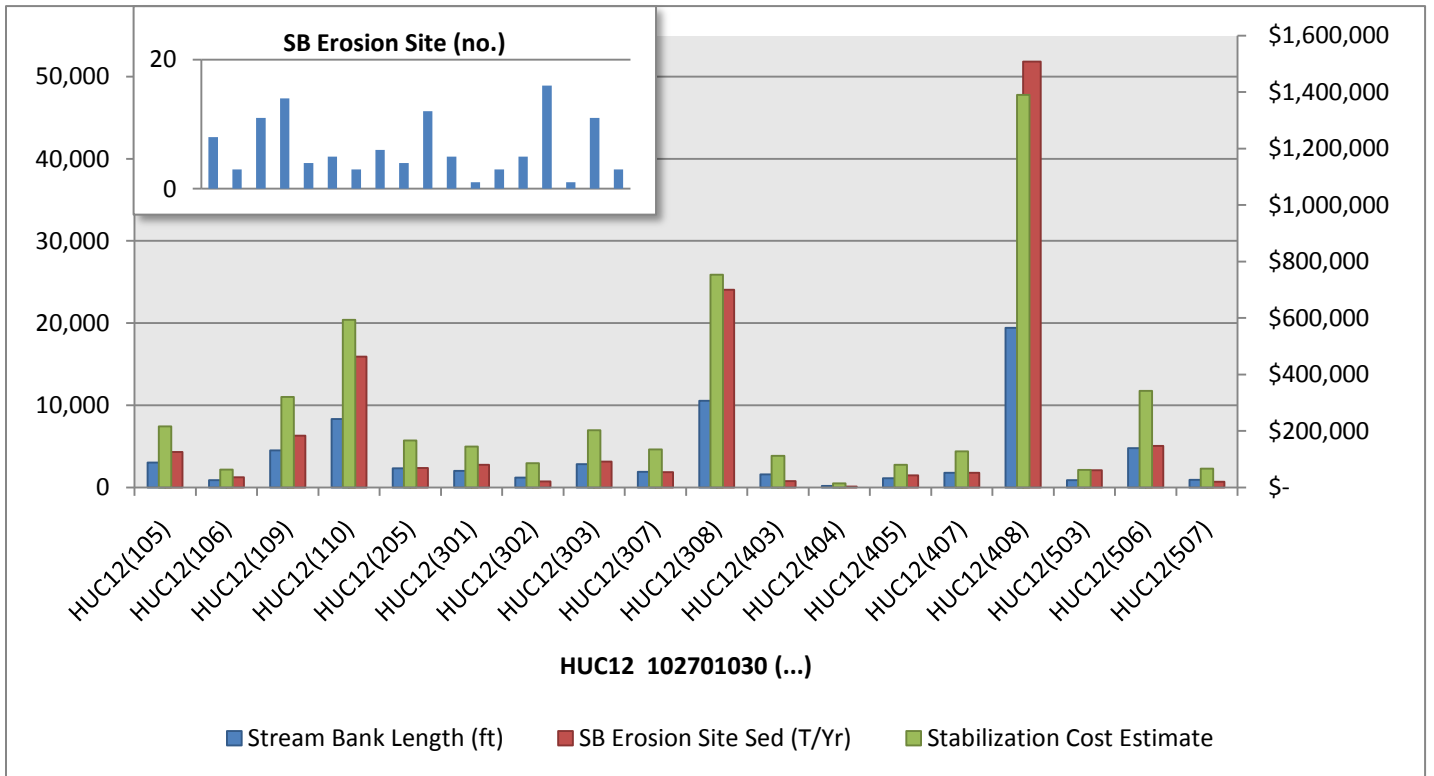
**Figure 9: Delaware River Watershed Streambank Erosion Assessment Graph by HUC10**



**Table 3: Delaware River Watershed Streambank Erosion Assessment Table by HUC12**

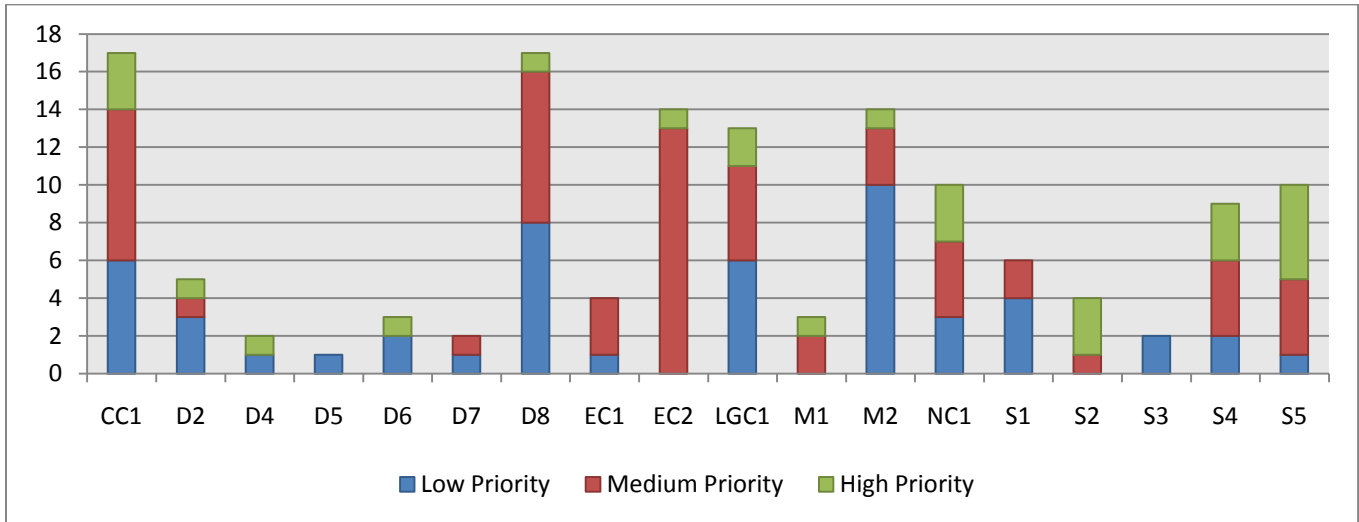
| HUC12<br>102701030...                    | SB<br>LENGTH<br>(FT) | SB<br>EROSION<br>SITE SED<br>(T/YR) | STABIL.<br>COST<br>ESTIMATE (\$) | SB<br>EROSION<br>SITE<br>(NO.)              | YIELD LOSS/<br>BANK<br>LENGTH | POOR<br>RIPARIAN<br>COND/SB<br>LENGTH (FT) | EST. SED<br>REDUCTION<br>(T/YR) | % SB LENGTH<br>W/ POOR<br>RIPARIAN<br>COND. |
|--|----------------------|-------------------------------------|----------------------------------|---|-------------------------------|--|---------------------------------|---|
| HUC12(105)                               | 3,018                | 4,314                               | \$ 215,778                       | 8   | 1.4                           | 3,018                                      | 3,667                           | 100.00%                                     |
| HUC12(106)                               | 885                  | 1,240                               | \$63,309                         | 3   | 1.4                           | 885  | 1,054                           | 100.00%                                     |
| HUC12(109)                               | 4,486                | 6,307                               | \$320,723                        | 11  | 1.4                           | 4,256                                      | 5,361                           | 94.88%                                      |
| HUC12(110)                               | 8,303                | 15,906                              | \$593,636                        | 14  | 1.9                           | 6,886                                      | 13,520                          | 82.93%                                      |
| HUC12(205)                               | 2,328                | 2,381                               | \$166,479                        | 4   | 1.0                           | 2,328                                      | 2,024                           | 100.00%                                     |
| HUC12(301)                               | 2,027                | 2,753                               | \$144,916                        | 5   | 1.4                           | 2,027                                      | 2,340                           | 100.00%                                     |
| HUC12(302)                               | 1,198                | 724                                 | \$85,638                         | 3   | 0.6                           | 1,198                                      | 615                             | 100.00%                                     |
| HUC12(303)                               | 2,832                | 3,140                               | \$202,513                        | 6   | 1.1                           | 2,384                                      | 2,669                           | 84.16%                                      |
| HUC12(307)                               | 1,883                | 1,850                               | \$134,605                        | 4   | 1.0                           | 1,883                                      | 1,572                           | 100.00%                                     |
| HUC12(308)                               | 10,525               | 24,059                              | \$752,556                        | 12  | 2.3                           | 9,253                                      | 20,450                          | 87.91%                                      |
| HUC12(403)                               | 1,571                | 782                                 | \$112,333                        | 5   | 0.5                           | 569  | 665                             | 36.24%                                      |
| HUC12(404)                               | 194                  | 107                                 | \$13,886                         | 1   | 0.5                           | 194  | 91                              | 100.00%                                     |
| HUC12(405)                               | 1,118                | 1,455                               | \$ 79,968                        | 3   | 1.3                           | 880  | 1,237                           | 78.70%                                      |
| HUC12(407)                               | 1,792                | 1,795                               | \$128,134                        | 5   | 1.0                           | 1,315                                      | 1,526                           | 73.37%                                      |
| HUC12(408)                               | 19,437               | 51,812                              | \$1,389,721                      | 16  | 2.7                           | 13,025                                     | 44,040                          | 67.01%                                      |
| HUC12(503)                               | 868                  | 2,071                               | \$62,030                         | 1   | 2.4                           | 0  | 1,761                           | 0.00%                                       |
| HUC12(506)                               | 4,781                | 5,050                               | \$341,810                        | 11  | 1.1                           | 1,583                                      | 4,293                           | 33.12%                                      |
| HUC12(507)                               | 933                  | 680                                 | \$ 66,722                        | 3   | 0.7                           | 695  | 578                             | 74.51%                                      |
| <b>TOTAL</b>                             | <b>68,178</b>        | <b>126,428</b>                      | <b>\$4,874,755</b>               | <b>115</b>                                  | <b>23.7</b>                   | <b>52,379</b>                              | <b>-107,464</b>                 | <b>76.83%</b>                               |
| <b>Est Stabilization Cost/Linear Ft.</b> |                      |                                     | <b>\$71.50</b>                   | <b>Stabilization/Restoration Efficiency</b> |                               |  | <b>0.85</b>                     |   |

**Figure 10: Delaware River Watershed Streambank Erosion Assessment Graph by HUC12**

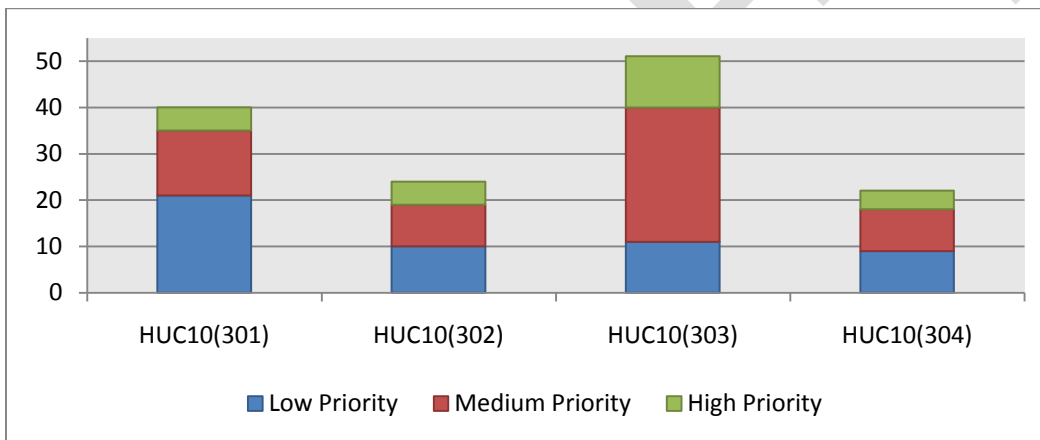


The streambank gully erosion assessment did not quantify annual tons of soil loss. However, locations of gully erosion were identified and prioritized by a high, medium or low priority using similar techniques as the streambank erosion assessment for identification. Gullies were also assessed by the same stream reaches, HUC10s and HUC12s as was the streambank erosion assessment. The gully assessment indicated that several reaches throughout the watershed had significant numbers of gullies, including Cedar Creek reach one (CC1), Delaware River reach eight (D8), Elk Creek reach two (EC2), Little Grasshopper Creek reach one (LCG1) and Muddy Creek reach one (M1). Each of the stream reaches comprised of more than ten identified gullies, with a significant percent made up of medium priority streambank gully erosion sites (Figure 11). Assessments results by HUC10s indicated HUC 102701030 as a high priority HUC10 area, having the most gullies at 51; 29 of the 51 were prioritized as medium priority gullies (Figure 12). Results by HUC12 indicated several areas having significant amounts of identified streambank gully sites: HUC12 102701030109, 102701030204, 102701030301, 102701030303 and 102701030304. Each of the identified high priority HUC12 areas comprised of more than ten identified gullies, with a significant percent made up of medium priority streambank gully erosion sites (Figure 13).

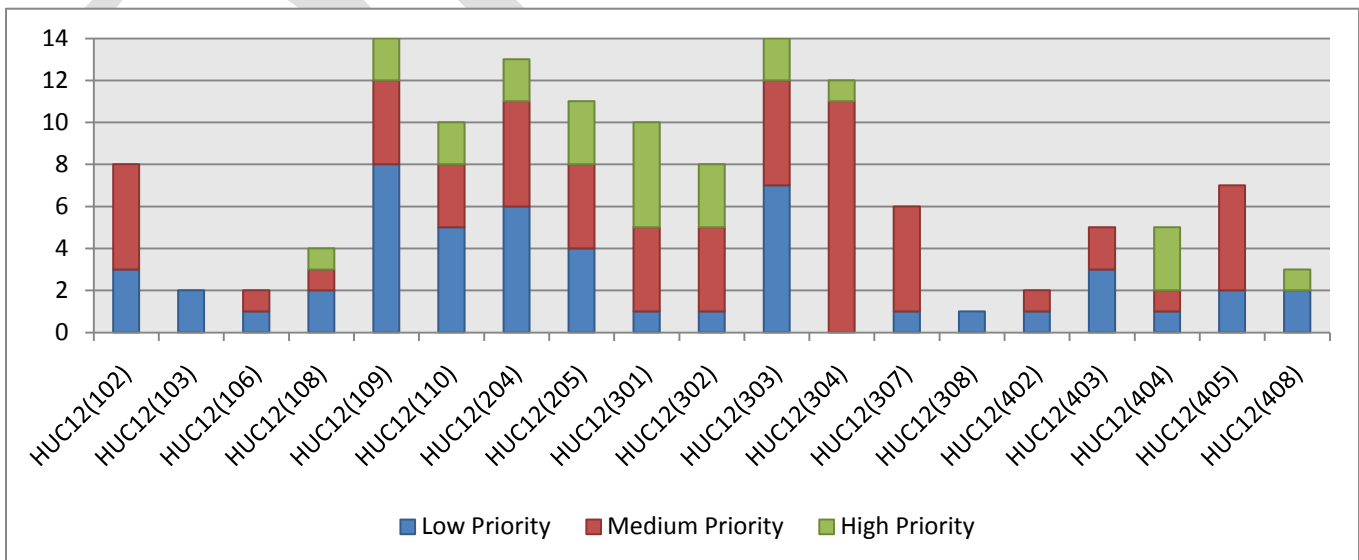
**Figure 11: Delaware River Watershed Streambank Erosion Assessment Graph by Stream Reach**



**Figure 12: Delaware River Watershed Streambank Erosion Assessment Graph by HUC10**



**Figure 13: Delaware River Watershed Streambank Erosion Assessment Graph by HUC10**



## **Conclusion**

The KWO completed this assessment for the Delaware River Watershed Restoration and Protection Strategy (WRAPS) Stakeholder Leadership Team (SLT). The Draft and Final report will be submitted for internal review at KWO. After internal review, the Draft and Final Report will be submitted to the Delaware River WRAPS SLT. Information contained in the assessment can be used by the Delaware River WRAPS SLT to target streambank stabilization and riparian restoration efforts toward high priority stream reaches within the Delaware River Watershed.

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