EVALUATION OF BANK STABILIZATION STRUCTURES IN THE DELTA HEADWATERS PROJECT (DHP) IN MISSISSIPPI

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Abstract The Delta Headwaters Project (DHP) provides for the development of a system for control of sediment, erosion, and flooding in the hill areas of the Yazoo River Basin, Mississippi, and provides resources for technology transfer. Stabilization of eroding streambanks is one of the primary measures being utilized to meet the erosion control goals in the DHP watersheds. Typical bank stabilization measures include longitudinal stone toe (LST) protection, transverse stone dikes, bendway weirs, and bio-engineered measures. Because, many of these structures have been in place for over 20 years, an evaluation of their performance was undertaken. In 2008, approximately 92 miles of bank stabilization structures were evaluated within the Batupan Bogue, Black Creek and Long Creek Watersheds. The field investigations were conducted both by air and by ground reconnaissance. Because of the immense area that needed to be covered for this investigation, it was decided that the most efficient method was to conduct an aerial reconnaissance by helicopter. Fostaire Helicopters, of St Louis MO, was selected for this effort because of their capability to obtain geo-referenced videos using the Red Hen equipment. The Red Hen geo-referenced videos provide latitude and longitude continuously along the entire flight route, thereby allowing the investigator to accurately locate all pertinent features along the stream. The quality of the Red Hen videos was excellent. A few locations required ground reconnaissance to verify the aerial observations. Within these streams, there were 20 different types of streambank stabilization structures. However, the predominant structures used in these streams were the LST structures (72.3 miles) and transverse dikes (12.6 miles). These have been extremely successful structures with a failure rate less than 2%. Severe failures where there was a loss of function only occurred in about 0.9% for LST and 1.3% for transverse dikes. Although there was insufficient data, due to the small number of failures, to develop any quantitative relationships, it was observed that there may a somewhat greater potential for problems where the radius of curvature to width ratio (R/W) values are less than about 5, and as stream size increases. It was also noted that special attention should be given to the central to downstream portions of a structure since this location is frequently more problematic than the upstream portion of a structure.

INTRODUCTION

The Delta Headwaters Project (DHP), formerly the Demonstration Erosion Control (DEC) Program, was initiated in 1985 with goals to provide control of erosion, sedimentation and flooding in six watersheds in the Yazoo River Basin in Mississippi. The DHP has grown over the years and now includes 16 watersheds (Figure 1). Severe channel degradation and bank erosion are commonplace in the DHP watersheds, and the associated delivery of sediment to downstream reaches is causing channel aggradation, flooding and adverse environmental impacts

to wetlands, and reservoirs. Hudson (1997) provides a general overview of the DHP. Stabilization of eroding streambanks is one of the primary measures being utilized to meet the erosion control goals in the DHP watersheds. Typical bank stabilization measures include longitudinal stone toe (LST) protection, transverse stone dikes, bendway weirs, and bio-engineered measures. Because, many of these structures have been in place for over 20 years, an evaluation of their performance was deemed appropriate.

Several years ago, the evaluation of existing grade control structures in the DHP watersheds revealed a number of issues that have led to improved understanding of the performance of the structures and will lead to improved future designs. In 2009, a similar effort was initiated for the bank stabilization features constructed in the DHP watershed. Bank stabilization features in the Batupan Bogue, Long Creek, and Black Creek watersheds were evaluated, and status and performance were documented. The location of the three watersheds is shown in Figure 1.

APPROACH

The evaluation of the bank stabilization features involved three basic tasks: (1) Data Gathering; (2) Field Reconnaissance; and (3) Data Analysis and GIS Development. A discussion of each of these tasks follows.

Data Gathering The first task in the bank stabilization evaluation was the data gathering effort. This involved searching the files at the Vicksburg District and the Mississippi Valley Division (MVD) to find all available plans for the bank stabilization features in the Batupan Bogue, Long Creek, and Black Creek Watersheds. This search focused on gathering general plans, plans and specifications, aerial photography, mapping, reports, computer data bases, and any other information pertinent to the design and construction of the bank stabilization features. Some of the design plans were available electronically, while others were available only as hard copies. All the hard copy plans were scanned for use in the DHP GIS. Examples of typical types of design plans and details that were gathered are shown in Figures 2 and 3.

Field Reconnaissance The field investigations were conducted both by air and by ground reconnaissance. Because of the immense area that needed to be covered for this investigation, it was decided that the most efficient method was to conduct an aerial reconnaissance by helicopter. Fostaire Helicopters, out of St Louis MO, was selected for this effort because of their capability to obtain geo-referenced videos using the Red Hen equipment. The helicopter, with the attached camera apparatus is shown in Figure 4. The Red Hen geo-referenced videos provide latitude and longitude in a continuous fashion along the entire flight route, thereby allowing the investigator to accurately locate all pertinent features along the stream. In total, about 92 miles of bank stabilization structures were evaluated within the three watersheds. The quality of the Red Hen videos was excellent. However, there were a few locations where a closer examination was required in order to verify the aerial observations. In these instances, a field investigation on the ground was accomplished.

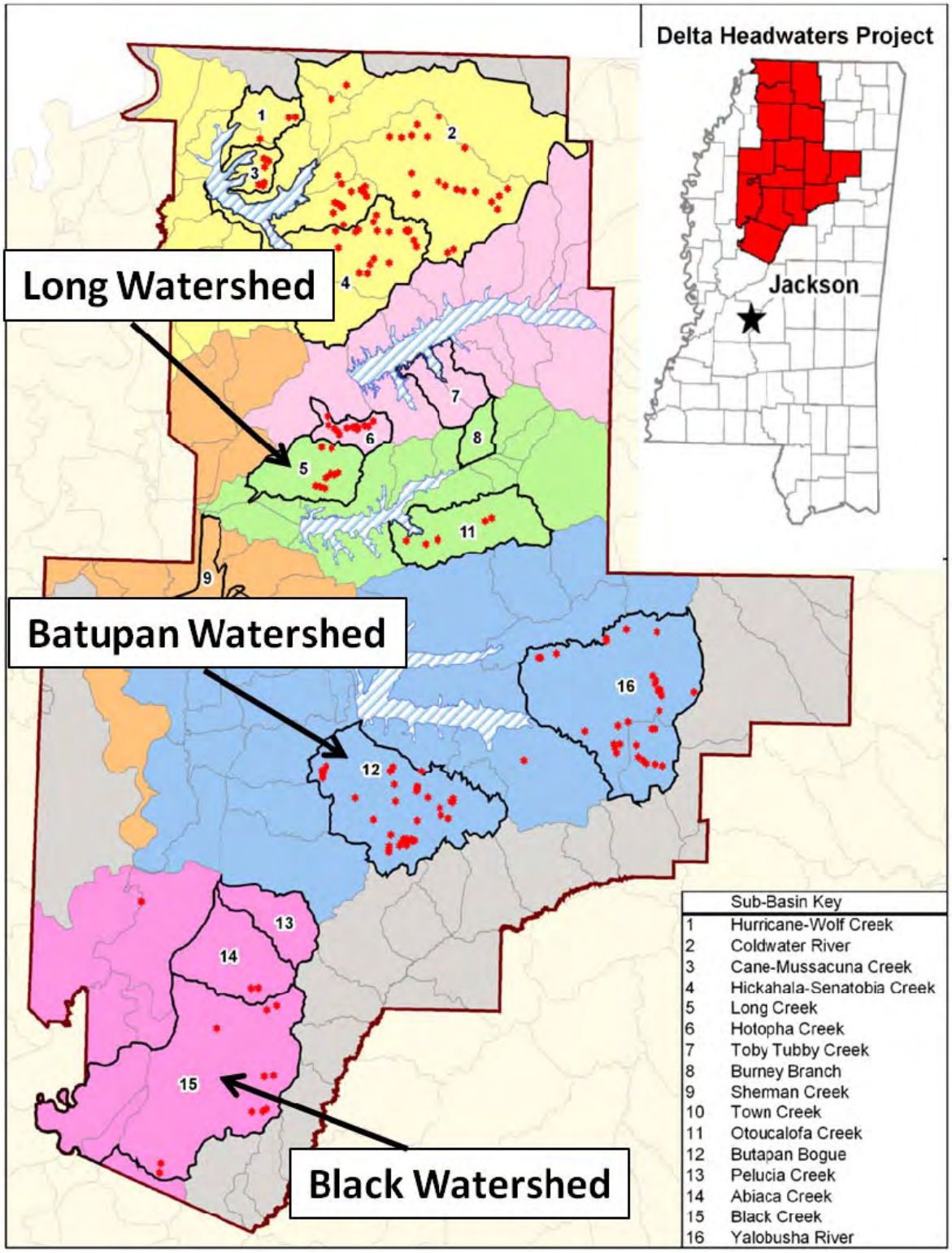

Figure 1 Location map for the Black Creek, Batupan Bogue, and Long Creek Watersheds.

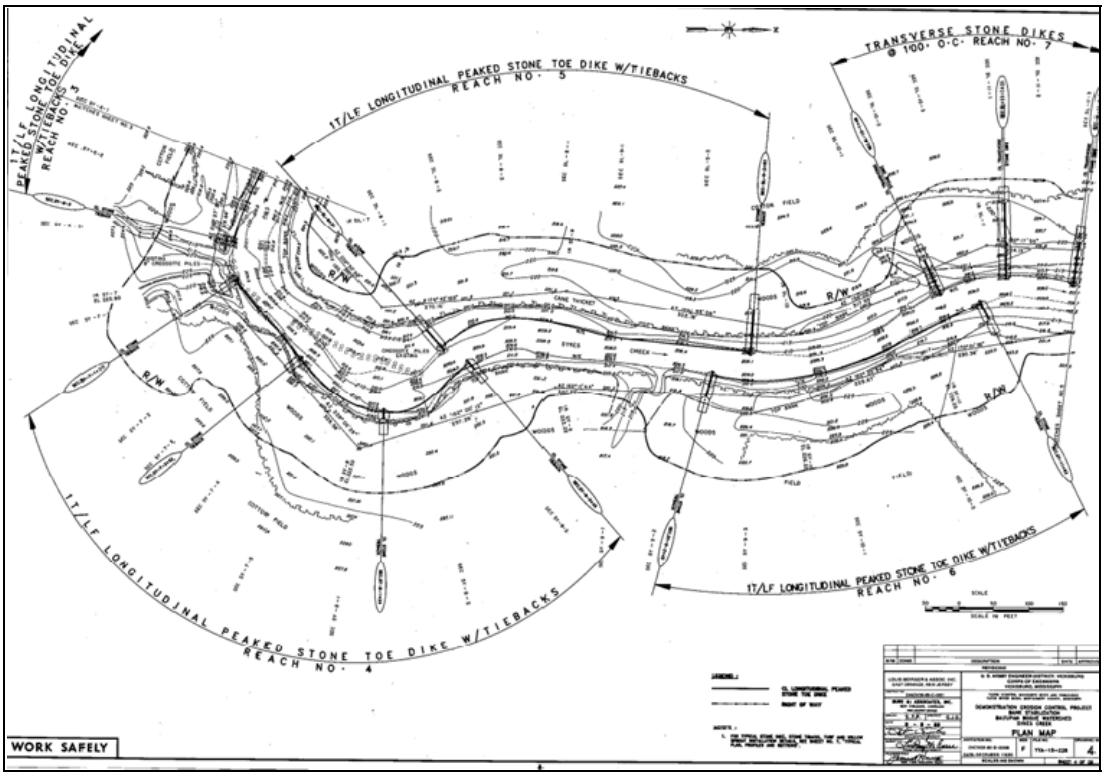

Figure 2 Typical bank stabilization plan map.

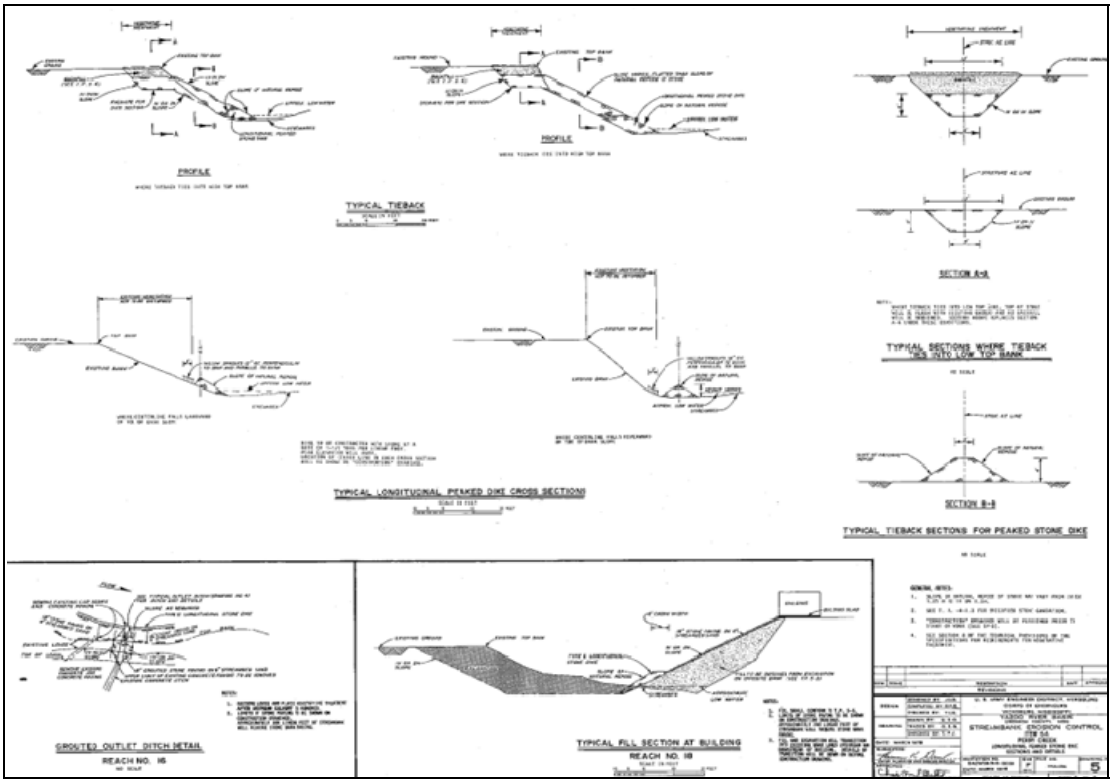

Figure 3 Typical bank stabilization details.

Figure 4 Red Hen video camera mounted beneath the Fostaire helicopter.

Data Analysis and GIS Development Following the field reconnaissance, the Red Hen videos were analyzed to evaluate the performance of the bank stabilization features in the three watershed, and the results were input to an excel spreadsheet. Although in many cases, the bank stabilization along a stream was continuous, the structures may have been constructed at different times under different contract plans. Using the available design plans, each stream was divided into reaches based on these plans. A stream reach with bank stabilization, but no available design plans was identified as a separate reach. Table 1 is an example spreadsheet showing the reach descriptions and plan availability for Black Creek. As shown in Table 1, Black Creek was divided into four separate reaches. The latitude and longitude of the upstream and downstream limits for each of these reaches as well as the total reach length was established. The file name of the design files, if available, is also shown. For this example, Reaches 2 and 4 did not have design files available. Table 2 is an example spreadsheet showing the length and location of the various structure types in Black Creek. Twenty different types of bank stabilization features were identified in this study. Each structure type was identified for each reach and the length of the stabilization feature measured.

The vast majority of the bank stabilization features in these watersheds were performing successfully with little signs of failure. However there were some locations were problems were observed. Table 3 is an example spreadsheet for Black Creek showing the failure data. The latitude and longitude of each failure was documented and a still photograph was captured from the Red Hen video. The length of the failure was then measured and the structure type identified according to the structure designation code in Table 4. The radius of curvature to width ratio (R/W) was also measured at each failure location. An attempt was made to identify the failure location, degree of failure, and cause of failure at each site according to the code in Table 5.

Recommendations for continued monitoring or possible repair were also made. After the assessment of all the streams was completed, the full data set, including plans, photography, analysis and spreadsheets, was transferred to the DHP GIS.

Table 1 Example reach descriptions and plan availability for Black Creek.

Reach	Longitude	Latitude	Description	File Name	Reach Length (ft)
1	90 11.4804'W	33 7.1705'N	Downstream end	Black Y-15-190	9,150
	90 10.3627'W	33 6.7679'N	Upstream end		
2	90 10.2419'W	33 6.8682'N	Downstream end	Not Available	815
	90 10.2105'W	33 6.9817'N	Upstream end		
3	90 8.8090'W	33 6.9031'N	Downstream end	Black BS-90-09	15,445
	90 7.2394'W	33 6.8169'N	Upstream end		
4	90 5.8840'W	33 7.0152'N	Downstream end	Not Available	41,450
	90 1.1263'W	33 6.5376'N	Upstream end		

Table 2 Length and location of the various structure types in Black Creek. See Table 4 for Structure Type designations.

Reach	Structure Location		Structure Type (see Table 4)	Structure Length (ft)
	Longitude	Latitude		
1	90 10.5962'W	33 7.1207'N	9	3,830
1	90 11.0825'W	33 7.1962'N	3	6,000
2	90 10.2568'W	33 6.9323'N	1	815
3	90 7.8987'W	33 7.2249'N	9	7,160
3	90 7.8987'W	33 7.2249'N	3	3,110
3	90 7.9902'W	33 7.2353'N	8	150
4	90 3.43202'W	33 6.3630'N	1	19,000
4	90 4.4433'W	33 6.6632'N	3	4,050

Table 3 Failure characteristics for Black Creek. See Tables 4 and 5 for structure types and failure designations.

	Structure Failure Characteristics			
Failure Name	Black 1	Black 3	Black 5	Black 6
Reach	3	3	4	4
Longitude	90 8.4751'W	90 8.0544'W	90 4.7710'W	90 4.3730'W
Latitude	33 6.9573'N	33 7.1066'N	33 6.8174'N	33 6.6550'N
Length (ft)	130	100	175	200
Structure Type	10	10	1	3
R/W	11.8	9.6	7.1	3.1
Failure Location	2	3	1	1
Degree of Failure	2	3	1	1
Cause of Failure	2	2	6	3
Recommendations	2	2	1	1

Table 4 Designation code for the DHP stabilization structures.

Structure Designation	
Longitudinal Peaked Stone w/ Tie Backs	1
Longitudinal Stone Fill with Tie Backs	2
Transverse Dike	3
Bendway Weir	4
Willow Post	5
Board Fence Dikes	6
Sand cement Bag Revetment	7
Longitudinal Peaked Stone 2t/f w/ Tie Backs	8
Longitudinal Peaked Stone 1t/f w/ Tie Backs	9
Longitudinal Board Fence with tie backs	10
Longitudinal Peaked Stone 0.5t/f w/ Tie Backs	11
Tire Post Retard	12
Jacks	13
Chevron Weirs	14
Longitudinal Peaked Stone w/ Barbs	15
Longitudinal Peaked Stone w/ Bendway weir	16
Longitudinal Peaked Stone 3t/f no tiebacks	17
Longitudinal Peaked Stone 2t/f no tiebacks	28
Longitudinal Peaked Stone 0.5t/f no tiebacks	19
ARS Vegetation and Toe Protection	20

Table 5 Codes for failure locations, degree of failure, cause of failure, and recommendations

Failure Location	
Upstream End	1
Downstream End	2
Center	3
Degree of Failure	
Severe (loss of function)	1
Moderate (failure of a substantial part of the structure, but that the function of the structure is not threatened)	2
Minor (some local scour or other small problems were observed, but are not considered to be a threat to the structure)	3
Cause of Failure	
Toe scour	1
Overtopping	2
Flow Impingement	3
Alignment	4
Rock sliding	5
Toe scour and overtopping	6
Toe scour and flow impingement	7
Recommendations	
Detailed examination required - possible repair	1
Monitor - immediate action not likely	2

RESULTS

A summary of the observed structure failures is provided in Table 6. The total length of streambank stabilization structures evaluated in the three study watersheds was about 92 miles, yet only 3.18 miles (about 3.5%) was observed to have experienced any type of failure. These statistics are somewhat skewed by the complete failure of the 1.39 miles of experimental willow post work on Harland Creek. The willow post treatment was part of an experimental test and is no longer considered as a stand-alone treatment for bank stabilization in the DHP. If the willow post structures are eliminated, then there was only about 1.8 miles of observed failure out of a total of 90.5 miles of structures, or only about 2%.

As illustrated in Table 6, there are many variations of the longitudinal stone toe (LST) protection. This by far the most common treatment technique used in the DHP stream. Taken as a group, there was 72.3 miles of LST protection in the three study watersheds. The next most common technique is the transverse dikes at 12.55 miles. These two structure types account for

almost 85 miles out of a total of about 90.5 miles of protection (excluding the willow post). Figures 5 and 6 show typical LST and transverse dike structures used in the DHP watersheds. When all failure types (severe, moderate, and minor), the failure rates were extremely small (less than 2%) for both of these techniques. Only 0.92 % of the LST structures and 1.28% of the transverse dikes experienced severe failure.

Figure 5 Typical longitudinal stone toe protection used in the DHP watersheds.

Figure 6 Typical transverse dikes used in the DHP watersheds.

An attempt was made to determine if there was any correlation between channel width and structure failure. Table 8 shows the channel width statistics for all failure sites as well as for all the bends in the study. As shown in Table 8, only about 30% of all the bends in the study had channel widths greater that about 65 feet. However, 75% of the structure failures occurred in these wider bends. The fact that there is a greater potential for failure as stream size increases is intuitively obvious, particularly when similar structures are used for the large and small streams. For instance, an LST protection at one ton/foot may be quite satisfactory in small streams, but as stream size increases, there may be a point where a heavier treatment (2 ton/foot, or more) may

Table 6 Summary of structure types and lengths of observed failures.

Structure Type	Length of Bank Stab (Miles)	Length of All Failure (Miles)	Percent Failure
Longitudinal Peaked Stone w/ Tie Backs	24.34	0.05	0.21
Longitudinal Stone Fill with Tie Backs	3.48	0.17	4.90
Transverse Dike	12.55	0.23	1.85
Bendway Weir	1.04		
Willow Post	1.39	1.39	100.00
Board Fence Dikes	0.74		
Sand cement Bag Revetment	0.22		
Longitudinal Peaked Stone 2t/f w/ Tie Backs	23.54	0.51	2.15
Longitudinal Peaked Stone 1t/f w/ Tie Backs	19.75	0.59	3.01
Longitudinal Board Fence with tie backs	1.92	0.16	8.20
Longitudinal Peaked Stone 0.5t/f w/ Tie Backs	0.25		
Tire Post Retard	0.19		
Jacks	0.15		
Chevron Weirs	0.59		
Longitudinal Peaked Stone w/ Barbs	0.27		
Longitudinal Peaked Stone w/ Bendway weir	0.07		
Longitudinal Peaked Stone 3t/f no tiebacks	0.05		
Longitudinal Peaked Stone 2t/f no tiebacks	0.11		
Longitudinal Peaked Stone 0.5t/f no tiebacks	0.78	0.08	9.66
ARS Vegetation and Toe Protection	0.45		
Total Length (miles)	91.88	3.18	3.46
Without Willow Post	90.49	1.79	1.98

Table 7 Failure statistics by severity of failure for LST and transverse dikes.

Structure Type	**Percent Failure**			
	All Failures	Severe Failures	Moderate Failures	Minor Failures
Longitudinal Stone Toe	1.93	0.92	0.56	0.45
Transverse Dikes	1.85	1.28	0.42	0.15

Table 8 Channel width statistics for all bends and for those with failures.

Width for All Failures			**Width for All bends**		
Width (ft)	Number in Group	Percent	Width (ft)	Number in Group	Percent
<65	9	24.3	<65	369	69.5
65 to 85	20	54.1	65 to 85	111	20.9
>85	8	21.6	>85	51	9.6

be needed. Unfortunately there is insufficient data to develop quantitative criteria to describe this relationship between stream size and stone quantity. Consequently, this will continue to be a design consideration that the engineer must assess based on engineering judgment and experience.

The radius of curvature to width ratio (R/W) was measured for all the bends in the study area. The results are shown in Table 9. As shown in Table 9, the R/W distribution is about the same for the failure sites as for the entire data set of all bends. The data indicate that about 78% of the failures occurred in bends with R/W values less than 5. This is not surprising given that the greatest erosion rates on rivers occur in bends with R/W less than 5 (Biedenharn et al, 1989, Thorne 1991, and Nanson and Hickin 1986). These higher erosion rates occur because at smaller

Table 9 R/W statistics for all bends and for all failure sites.

R/W for All Failures			**R/W for All bends**		
R/W	Number in Group	Percent	Width (ft)	Number in Group	Percent
<2	5	13.5	<2	65	12.2
2 to 5	24	64.9	2 to 5	364	68.5
< 5	8	21.6	< 5	102	19.2

Table 10 Location of failures.

Failure Location	**Number in Group**	**Percent**
Upstream	4	10.81
Downstream	19	51.35
Center	14	37.84

R/W values (less than 5), the bend effects (flow impingement and centripetal forces) become

pronounced. Thus, the forces on bank stabilization structures in these small radius bends is greater than in the longer radius bends. For this reason, the potential for increased stresses on the structures due to the bend effects in small radius bends (R/W < 5) should be considered in the design.

Table 10 shows the statistics for the location of the failure along the structure. As shown in Table 10, at about 50% of the failures occurred along the downstream end of the structure. Another 38% of the failures occurred at the center and only about 11 percent occurred at the upstream end. Once again, this agrees with the observations of flow dynamics in bends. As the flow stage increases, the flow begins to cut across the point bar area and begins attacking the middle to downstream portion of the bend. This increases the flow impingement on the bank (or structure) which would explain why this area would be more susceptible to failure.

SUMMARY

Approximately 92 miles of bank stabilization structures were evaluated within the Batupan Bogue, Black Creek and Long Creek Watersheds. Within these streams, there were 20 different types of streambank stabilization structures. However, the predominant structures used in these streams were the LST structures (72.3 miles) and transverse dikes (12.6 miles). These have been extremely successful structures with a failure rate less than 2%. Severe failures where there was a loss of function only occurred in about 0.9% for LST and 1.3% for transverse dikes. Although there was insufficient data, due to the small number of failures, to develop any quantitative relationships, it was observed that there may a somewhat greater potential for problems where the R/W values are less than about 5, and as stream size increases. It was also noted that special attention should be given to the central to downstream portions of a structure since this location is frequently more problematic than the upstream portion of a structure.

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