State of Colorado
Streambank Erosion Study

Summary Report
for the
Colorado State Soil Conservation Board
Colorado Association of Soil Conservation Districts

Soil Conservation Service
Denver, Colorado

November 1988

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On the COVER: Elk River at Curtis Zabel headquarters
Photography by Gene Alexander, SCS, Denver, Colorado

SUMMARY

The Colorado State Soil Conservation Board (CSSCB) and the Colorado Association of Soil Conservation Districts (CASCD) regard streambank erosion as a major resource problem within the State of Colorado. They requested the Soil Conservation Service (SCS) to conduct a "study of the problem." Problem areas identified throughout the state were screened to determine high priority areas for detailed study. Ten (10) problem areas, listed below, were selected for evaluation [SEE STUDY AREA MAP].

Currant Creek
Dolores River
Elk River
Kerber Creek
Lake Fork
Little Thompson River
Lower Fountain Creek
North Fork Gunnison River
Uncompahgre River
White River

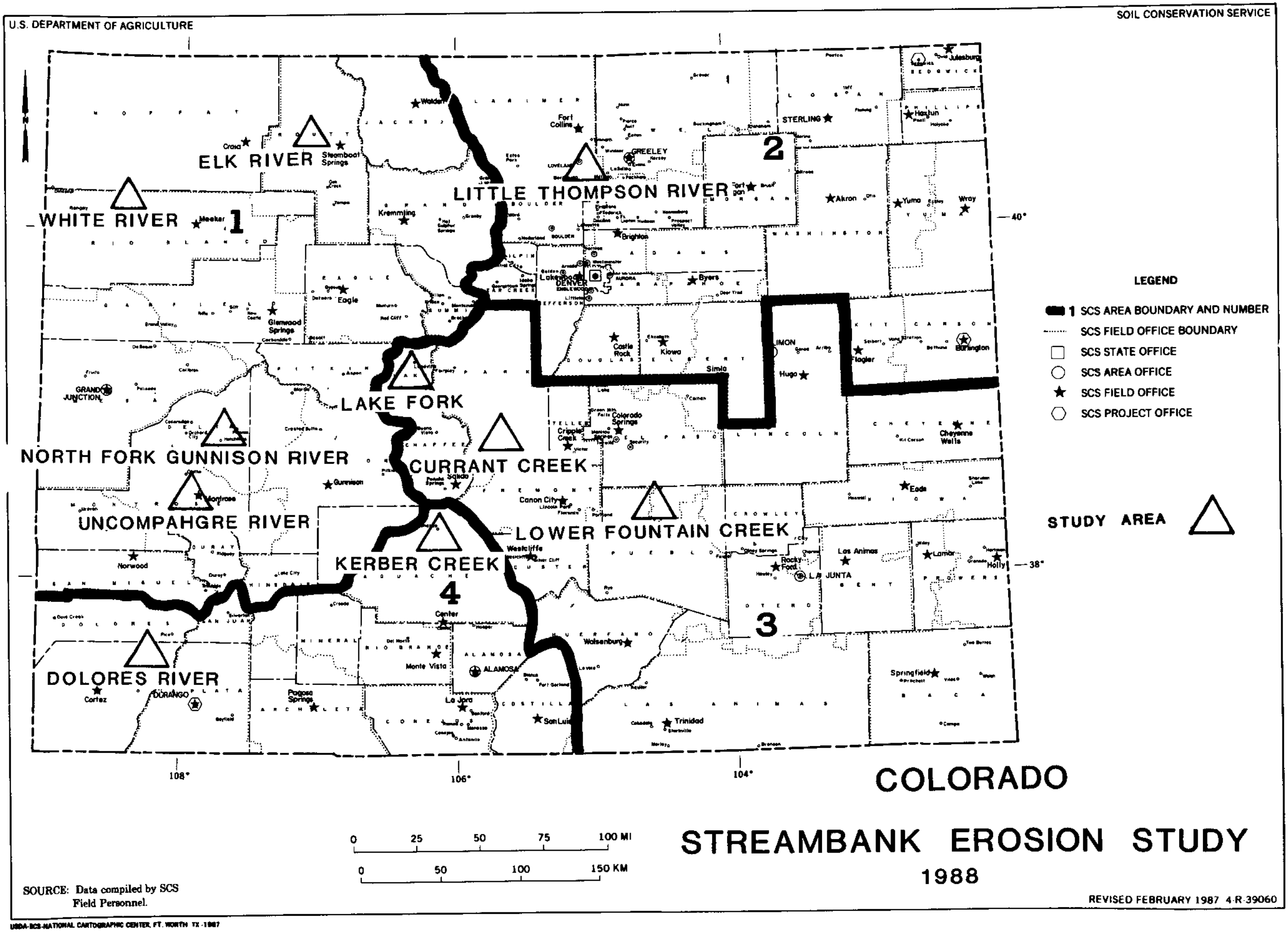
A field review was conducted in each of these areas. Comparison of old maps/photos along with newer maps/photos was made to determine the movement of the stream's channels.

The present USDA method of economic evaluation of benefits and the dollar value assigned to bank erosion may not support project type treatment. Non-project type treatment of bank erosion has been going on since man settled along streams and may possibly still be the best approach to treating the problem.

The value of the land and crops damaged would not justify any extensive installation of practices. Damages to roads, diversions, pipelines, houses and outbuildings may justify the installation of some rock riprap or rock jetty type structures.

Three study areas: Lake Fork, Kerber Creek, and Little Thompson River have water quality problems. Lake Fork and Kerber Creek also have erosion of mine tailings that yield sediment which contain damaging chemical elements.

Little Thompson River is located in a predominantly irrigated agriculture basin. It carries high levels of salt concentrations and sediment in irrigation return flows.


U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ELK RIVER
WHITE RIVER
LITTLE THOMPSON RIVER
LAKE FORK
NORTH FORK GUNNISON RIVER
CURRANT CREEK
UNCOMPAHGRE RIVER
LOWER FOUNTAIN CREEK
KERBER CREEK
DOLORES RIVER
1
2
3
4
LEGEND
1 SCS AREA BOUNDARY AND NUMBER
SCS FIELD OFFICE BOUNDARY
SCS STATE OFFICE
SCS AREA OFFICE
SCS FIELD OFFICE
SCS PROJECT OFFICE
STUDY AREA
40°
38°
108°
106°
104°
0 25 50 75 100 MI
0 50 100 150 KM
COLORADO
STREAMBANK EROSION STUDY
1988
SOURCE: Data compiled by SCS Field Personnel.
REVISED FEBRUARY 1987 4-R-39060
USDA-SCS-NATIONAL CARTOGRAPHIC CENTER, FT. WORTH TX 1987

AREA 1 - GRAND JUNCTION

Field Office	SCD No.	SCD
Craig	805	Colorado First
Delta	720	Delta
Eagle	725	Eagle County
Glenwood Springs	708	Bookcliff
	752	Mt. Sopris
	776	South Side
Grand Junction	801	De Beque-Plateau Valley
	804	Mesa
Gunnison	734	Gunnison
Kremmling	747	Middle Park
Meeker	724	Douglas Creek
	799	White River
Montrose	772	Shavano
Norwood	770	San Miguel Basin
Steamboat Springs	806	Routt County
Walden	755	North Park

AREA 2 - GREELEY

Field Office	SCD No.	SCD
Akron	702	Akron
	716	Cope
	767	Rock Creek
Brighton	761	Platte Valley
	774	Southeast Weld
	788	West Adams
Burlington	711	Burlington
Byers	719	Deertrail
	726	East Adams
Castle Rock	722	Douglas County
Flagler	729	Flagler
Fort Collins	706	Big Thompson
	730	Fort Collins
Fort Morgan	749	Morgan
Greeley	791	West Greeley
Haxtun	736	Haxtun
Julesburg	771	Sedgwick County
Kiowa	740	Kiowa
Lakewood	739	Jefferson
	789	West Arapahoe
Longmont	709	Boulder Valley
	743	Longmont
Simla	701	Agate
	803	Double El
Sterling	775	South Platte
	809	Centennial
Wray	802	Yuma County
Yuma	795	Yuma

Ogallala Water Management Office, Burlington

Sedgwick Watershed Office, Sedgwick

AREA 3 - LA JUNTA

Field Office	SCD No.	SCD
Canon City	732	Fremont
Cheyenne Wells	714	Cheyenne
Colorado Springs	713	Central Colorado
	811	El Paso County
Cripple Creek	779	Teller-Park
Eads	800	Kiowa County
Holly	753	Northeast Prowers
Hugo	737	High Plains
	798	Prairie
Lamar	762	Prowers
Las Animas	703	Bent
Pueblo	781	Turkey Creek
	807	South Pueblo County
Rocky Ford	727	East Otero
	756	Olney-Boone
	780	Timpas
	792	West Otero
Salida	741	Lake County
	784	Upper Arkansas
Springfield	812	Baca County
Trinidad	710	Branson-Trinchera
	777	Spanish Peaks
	810	Purgatoire River
Walsenburg	786	Upper Huerfano
Westcliffe	717	Custer County-Divide

East Central Colorado and Sangre de Cristo RC&D Office, Pueblo

AREA 4 - ALAMOSA

Field Office	SCD No.	SCD
Alamosa	750	Mosca-Hooper
Center	712	Center
Cortez	721	Dolores
	723	Dove Creek
	746	Mancos
Durango	742	La Plata
	759	Pine River
La Jara	797	Conejos
Monte Vista	766	Rio Grande
Pagosa Springs	769	San Juan
San Luis	808	Costilla

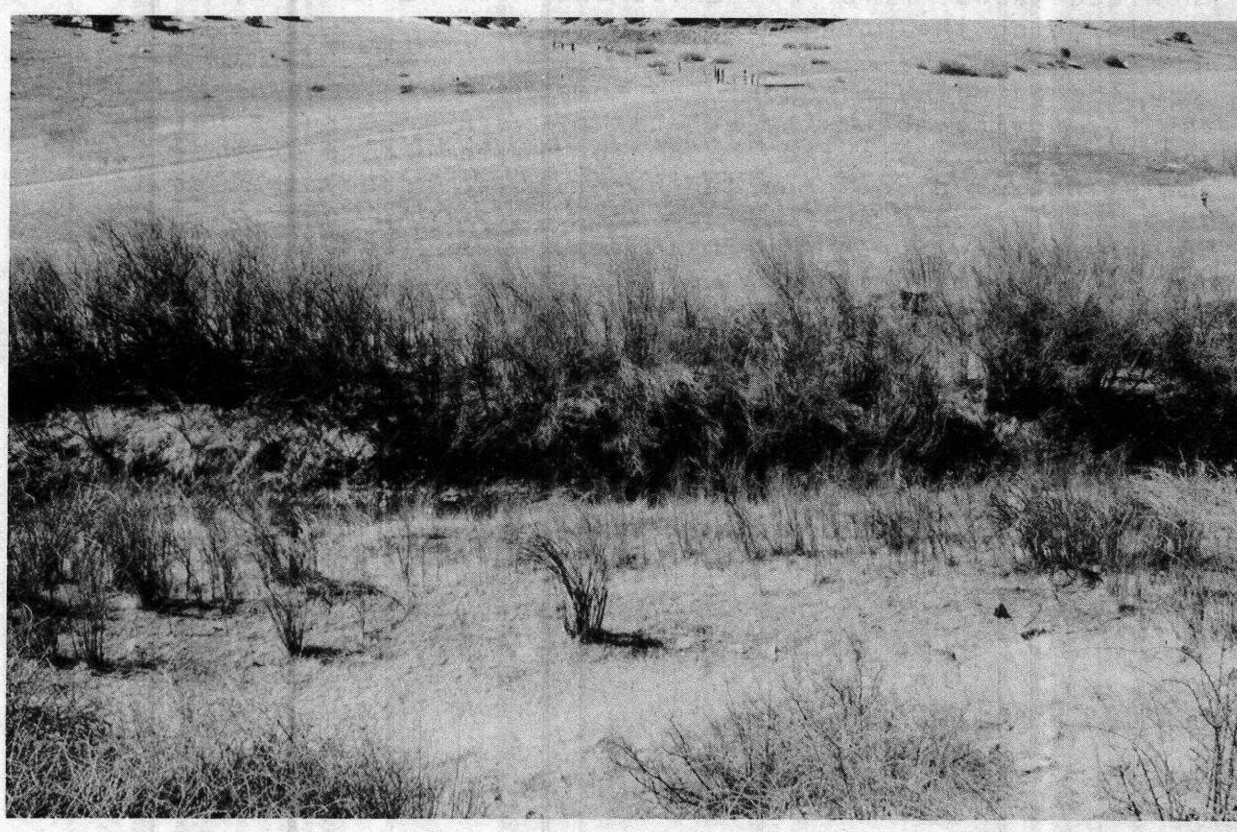
San Juan and San Luis Valley RC&D Office, Durango

CONCLUSIONS WITH RECOMMENDATIONS

Based upon the planning staffs field inspection and study of the ten areas the following conclusions and recommendations have been reached. A mix of the streambank protection practices was not dealt with in the alternatives, but this is a possibility in the planning and installation of practices.

1. Dedication of riparian zones along river banks will reduce much of the damage associated with streambank erosion. The root system developed from trees and brush along the streambank provide protection from the cutting action of water flowing against the banks. Protection from bank sloughing will also be achieved.

Other benefits, such as increased wildlife habitat, increased numbers of all wildlife, and diversity of scenery, will also be realized from riparian zones. These zones will also move the high value agricultural crops away from the streambanks, therefore, reducing the likelihood of damage to these crops.



Riparian zone on Currant Creek
Photography by Jim Thornton SCS, Denver, Colorado

Where eligible, landowners can receive assistance through the Conservation Reserve Program (CRP) administered by the Agricultural Stabilization and Conservation Service (ASCS) to develop a 66 to 99 foot wide riparian zone along streams or water bodies. To be eligible, the land would have had to be used to produce agricultural commodities 2 of the 5 years between 1981 and 1985. Rental payments for 10 years are offered as an incentive to convert the cropland to grass or trees.

Riparian zones will provide protection from the lower frequency flows. However, large flows can produce bank erosion which will destroy them. When this happens, the up rooted trees can block the channel and cause additional bank cutting.

2. This study recommends the formation of a state coordinator position. The need for a person to coordinate activities relating to stream channel improvements was identified. Many examples of work being done without consideration of the effects, both upstream and downstream, were noted during the study. This showed the lack of knowledge about river mechanics and flow patterns by the people doing the work.

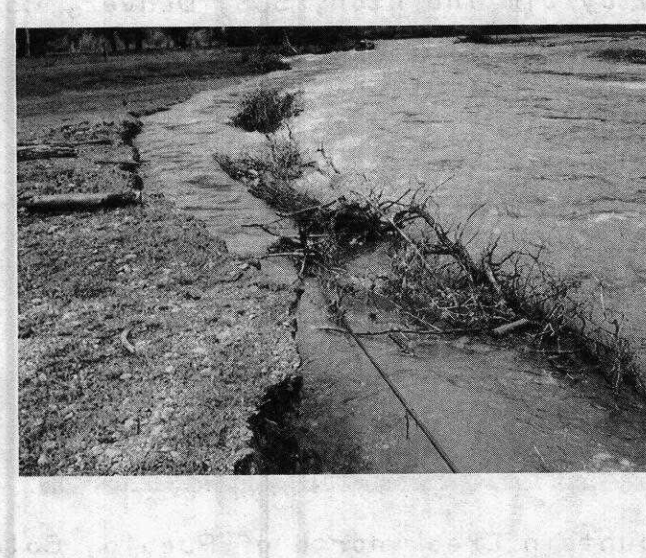
The coordinator should be someone that landowners could ask for advice about the effects of work in streams before construction is started. The coordinator could provide the assistance or direct the landowner to an agency that could help. This would not replace the U.S. Army, Corps of Engineers, Section 404 permitting process, but the coordinator could provide assistance to streamline the process.

Rock Riprap on Dolores River
Photography by Jim Thornton, SCS, Denver, Colorado

The coordinator could work with landowners to solve problems along a stream reach. By working in the total reach, the problem solutions could be coordinated for maximum efficiency. Development of riparian zones which include areas owned by several people could also be addressed by the coordinator.

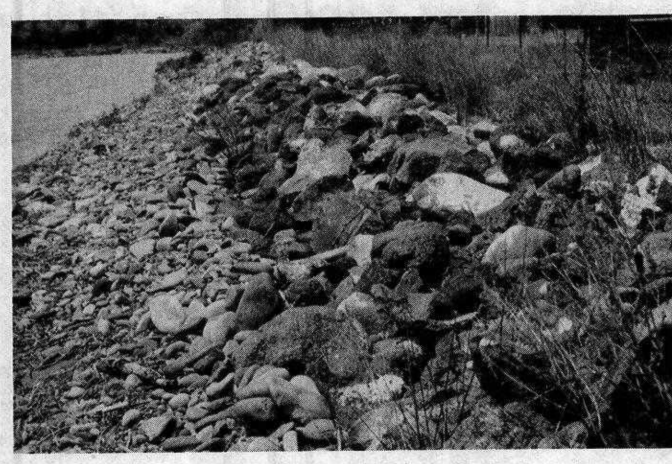
This type of "streambank erosion coordinator" should be assigned to a state agency such as the CSSCB, to provide assistance state wide, and act as a moderator in the argument between development and environmental preservation.

3. When individual streambank erosion control projects are undertaken, a thorough study of the total stream reach is needed to predict the effects of the project action upstream and downstream from the site of construction. If work is to be carried on in the riverbed the damage to the rivers armor needs to be considered as to what will take place upstream and downstream. A Section 404 permit to work in the river needs to be obtained from the Corps of Engineers to assure all persons involved have had an opportunity to respond. In areas where blanket permits have been granted a review system may need to be established to prevent unneeded damage to the river system.

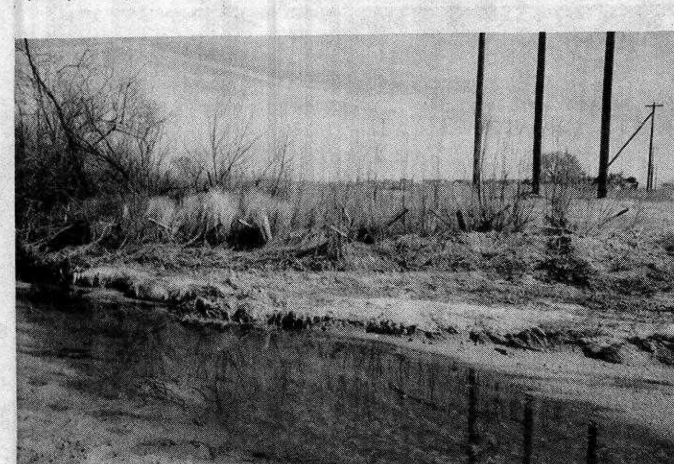


Damage to Anchored Trees on Dolores River
Photography by Jim Thornton, SCS, Denver, Colorado

4. It is not cost effective to use rock riprap or rock jetties to protect agricultural land. These types of bank protection may be cost effective where structures such as roads, homes, bridges, irrigation diversions, or other high value improvements are threatened. Anchored trees and jacks are in general the most cost effective structural control measures and may be viable only in some specific locations.



Rock Riprap potecting sewer plant
on North Fork Gunnison River
Photography by Jim Thornton, SCS, Denver, Colorado



Jacks on Fountain Creek north of Pueblo, Colorado
Photography by Jim Thornton, SCS, Denver, Colorado

5. Vegetated buffer strips, vegetative sprig revetment (bank sloping and revegetation), and riparian zones were considered viable alternatives in this study. High velocity flows on the rivers may require structural practices, such as jacks in conjunction with a vegetative practice.

Streambank erosion on the Uncompahgre River
Photography by Jim Thornton, SCS, Denver, Colorado

6. Angled rock structures (placing of large rocks with approximately 1 to 1.5 feet of drop in the river) as introduced by Dr. Donald R. Reichmuth, PE/LS GEOMAX, PC, in his short course "Living With Fluvial Systems a Short Course on River Mechanics," were not considered in the analysis because of the lack of specific cost data, effectiveness, and design information.

Angled rock structure across Elk River
Photography by Jim Thornton, SCS, Denver, Colorado

These type of structures are possible for the landowners to install at their own initiative with the use of technical assistance from consultants. They have a high maintenance and may not be as effective during high flows. Government assistance on this type of treatment may be possible if adequate design standards and specifications were prepared and approved by necessary authorities.

7. Lake Fork and Kerber Creek have large amounts of mine waters which are high in chemical elements along with mine tailings in the river.

Because of the large amount of sediment (mine tailings) deposits along Lake Fork and Kerber Creek, the state and federal agencies that address these programs should be contacted for assistance. For the state of Colorado, contact the Colorado Mined Land Reclamation Division and Board, or for the Federal Government contact the Environmental Protection Agency.

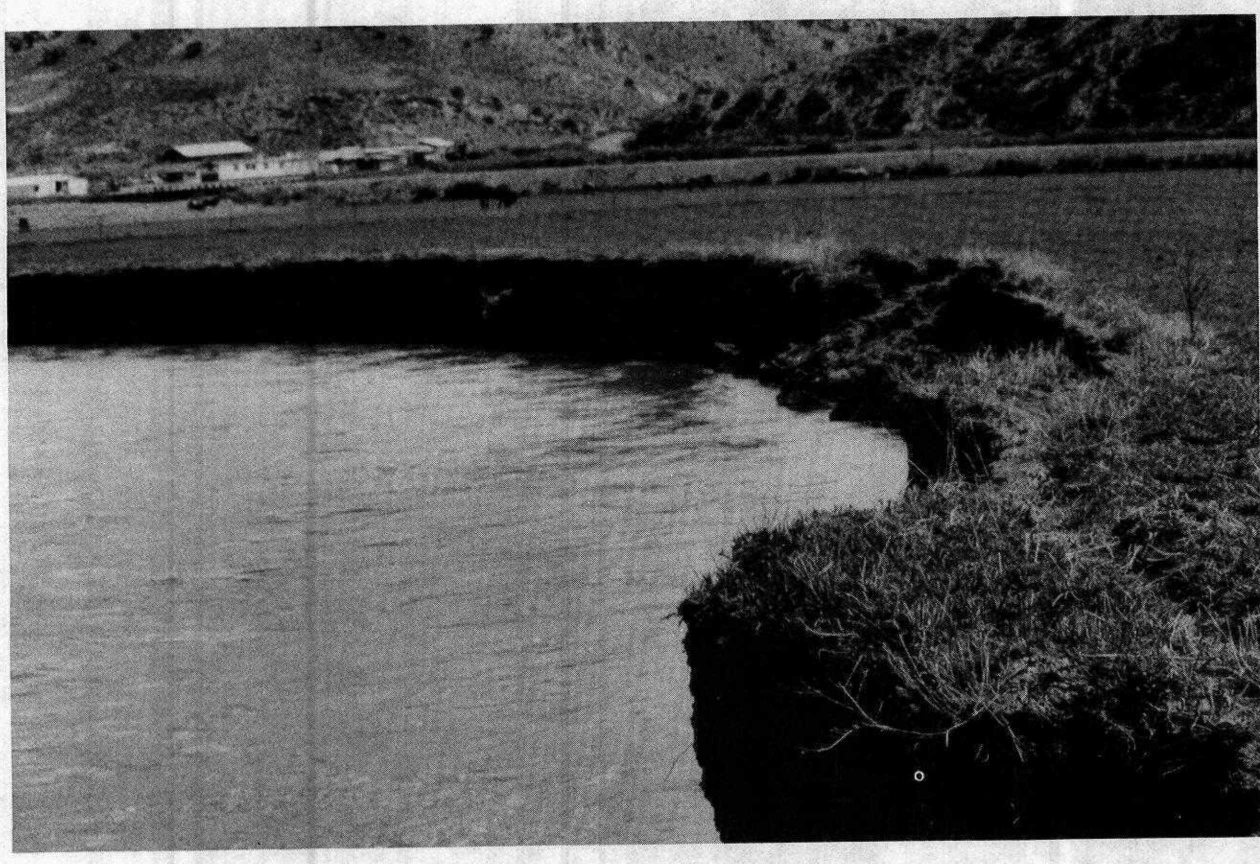
Little Thompson River's water quality is due to irrigation return flows from shallow soils overlying weathered shale formations. It's sediment is due to highly erodible soils, topography, and farming up to the river`s edge.

Mine tailings in Kerber Creek
Photography by Jim Thornton,
SCS, Denver, Colorado

Debris on bank of Little Thompson River
Photography by Jim Thornton, SCS, Denver, Colorado

In a previous report "LITTLE THOMPSON BASIN - RURAL CLEAN WATER PROGRAM APPLICATION - July 1979," Best Management Practices were identified that would reduce salt and sediment loading of the Little Thompson River. The CSSCB will be the administering agency, with a project office located in the basin. The CSSCB will be working closely with the 7-man Local Rural Clean Water Coordinating Committee, SCS, Larimer-Weld Regional Council of Governments, Soil Conservation Districts and ASCS. Larimer and Weld Counties have been designated 208 management agencies and will play an important role throughout the project period.

8. In the early 1960's an Agricultural Conservation Program (ACP) was available to provide financial and technical assistance to landowners who applied treatment to streambank erosion problems. This approach might be possible again. It would encourage proper designed treatment measures as well as financial incentive.



Streambank erosion of the White River into pastureland
Photography by Jim Thornton, SCS, Denver, Colorado

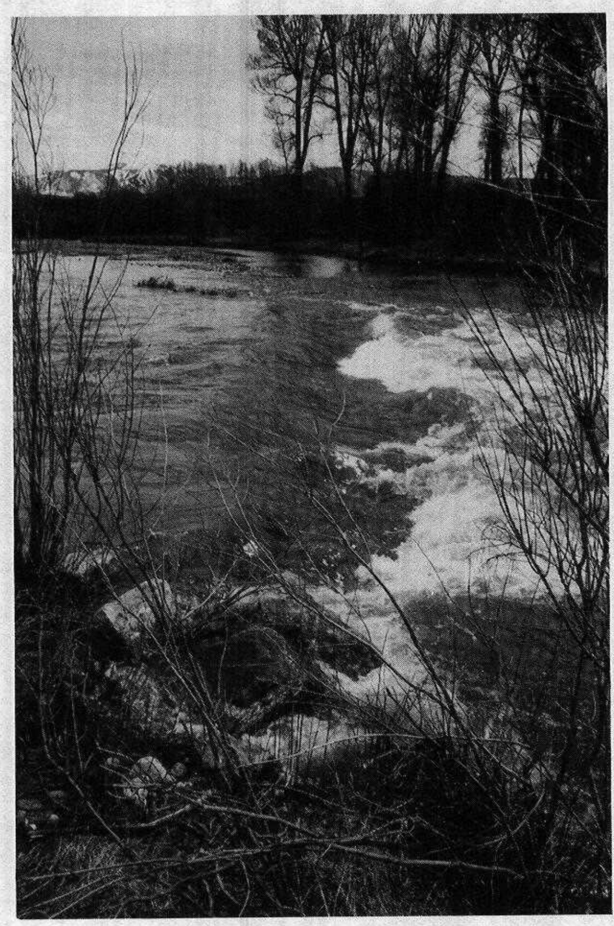
STUDY AREAS

The Soil Conservation Districts of Colorado were requested to identify the streambank erosion problems and to nominate areas for detailed study. From the list of nominated areas, ten were selected by a selection committee. These study areas are representative of the streambank erosion throughout the state of Colorado [SEE STUDY AREA MAP].

Description of the ten study areas are as follows and also include:

TABLE 1 - STUDY AREA
TABLE'S 2A, 2B, 2C, 2D, 2E, 2F, 2G, - COST ESTIMATE - COMPARISON OF BENEFITS AND COST
* TABLE 3 - ANALYSIS OF ECONOMIC, ENVIRONMENTAL, AND SOCIAL FACTORS

* (Comparison between the alternatives of the economic, environmental, and social factors were made. These factors are rated as to beneficial, adverse, or no effect, due to the type of treatment used.)



Rock drop structure on Elk River
Photography by Gene Alexander, SCS, Denver, Colorado

S U M M A R Y
TABLE 1
STATE OF COLORADO
STREAMBANK EROSION STUDY
STUDY AREA

Study Area	Area to Protect							River Bank Length Eroding	River Length Studied
	Trees Riparian Area	Pasture and Hayland	Bridges	Houses and Outbuildings	Diversions (Wells)	Roads	Pipeline		
	Ac	Ac	No	No	No	Ft	Ft	Ft	Ft
Current Creek	0	0	0	0	0	0	0	7,300	16,700
Dolores River	67	27	0	0	0	0	0	29,790	52,870
Elk River	34	11	0	1	1	0	0	7,300	10,200
Kerber Creek	0	22	0	0	0	0	0	31,600	15,800
Lake Fork	41	4	1	0	0	400	0	22,100	35,000
Little Thompson River	49	0	0	0	0	0	0	48,270	82,232
Lower Fountain Creek	0	13	1	0	0	1,000	1,000	2,720	6,500
North Fork Gunnison River	16	71	0	0	1	0	0	7,100	58,080
Uncompahgre River	24	47	0	0	0	0	0	10,100	20,100
White River	5	47	0	0	4	0	0	11,100	31,600
Total	236	242	2	1	6	1,400	1,000	177,380	329,082

S U M M A R Y
TABLE 2A
STATE OF COLORADO
STREAMBANK EROSION STUDY
COST ESTIMATE - COMPARISON OF BENEFITS AND COST (Dollars) (1)

Study Area	Structural Measures Rock Riprap (2)	Construction Cost	Engineering	Project Administration	Land Rights (3)	Total Installation	O & M (2%)	Average Annual Cost	Total Average Annual Cost with O&M (4)	Average Annual Benefits (5)
	Cy	$	$	$	$	$	$	$	$	$
Currant Creek	14,600	854,100	119,574	145,197	0	1,118,871	17,100	98,068	115,168	0
Dolores River	59,580	3,485,430	487,960	592,523	0	4,565,913	69,700	400,201	471,776	16,800
Elk River	14,600	854,100	119,574	145,197	0	1,118,871	17,000	89,069	115,069	0
Kerber Creek	63,200	3,697,200	516,608	628,524	0	4,834,332	73,980	424,518	498,498	0
Lake Fork	44,200	2,585,700	361,998	439,569	0	3,387,267	51,700	296,900	348,600	280
Little Thompson River	96,540	5,647,590	790,662	960,090	0	7,398,343	112,900	648,500	761,400	0
Lower Fountain Creek	5,440	318,240	44,553	54,101	0	416,894	6,400	36,541	44,941	1,200
North Fork Gunnison	14,200	830,700	116,298	141,219	0	1,088,217	16,614	95,382	111,994	5,375
Uncompahgre River	20,200	1,181,700	165,438	200,889	0	1,548,027	23,700	139,885	163,585	5,267
White River	22,200	1,298,700	181,818	220,779	0	1,701,297	26,000	114,119	140,119	7,670
Total	354,760	20,753,460	2,905,500	3,528,100	0	27,187,100	415,100	-	-	-

(1) Price Base: September 1987 amortized at 8 5/8 % for 50 years
(2) Rock riprap installed (with base) 2 cy per foot bank at $50 per cy = $100 per foot with a life expectancy of 50 years
(3) Corps of Engineers 404 permit to work in river
(4) Includes cost for structural measures to protect riparian habitat and 2% O&M
(5) Benefits for riparian habitat protection were not analyzed

S U M M A R Y
TABLE 2B
STATE OF COLORADO
STREAMBANK EROSION STUDY
COST ESTIMATE - COMPARISON OF BENEFITS AND COST (Dollars) (1)

Study Area	Structural Measures Anchored Trees (2)	Construction Cost	Engineering	Project Administration	Land Rights (3)	Total Installation	O & M (1%)	Average Annual Cost	Total Average Annual cost with O&M (4)	Average Annual Benefits (5)
	Ft	$	$	$	$	$	$	$	$	$
Currant Creek	7,300	170,820	23,915	29,039	0	223,774	1,700	27,150	28,850	0
Dolores River	29,790	697,086	97,592	118,505	0	913,183	7,000	110,976	117,796	16,800
Elk River	7,300	170,820	23,915	29,039	0	223,774	1,600	27,151	28,751	0
Kerber Creek	31,600	739,440	103,521	125,705	0	968,666	7,300	117,526	124,826	0
Lake Fork	22,100	517,140	72,399	87,913	0	677,453	5,200	82,200	87,400	0
Little Thompson River	48,270	1,129,518	158,132	192,018	0	1,479,668	11,300	180,000	191,400	0
Lower Fountain Creek	2,720	63,648	8,910	10,821	0	83,379	600	10,116	10,716	1,200
North Fork Gunnison	7,100	166,140	23,260	28,244	0	217,643	1,700	29,382	31,230	5,375
Uncompahgre River	10,100	236,340	33,088	40,178	0	309,605	2,500	37,565	40,065	5,267
White River	11,100	259,740	36,364	44,156	0	340,260	2,600	41,283	43,893	7,670
Total	177,380	4,150,692	581,097	705,618	0	5,437,407	41,500	-	-	-

(1) Price Base: September 1987 amortized at 8 5/8 % for 50 years
(2) Anchored trees installed at $20 per foot of bank protected with a life expectancy of 15 years
(3) Corps of Engineers 404 permit to work in river
(4) Includes cost for structural measures to protect riparian habitat and 1% O&M
(5) Benefits for riparian habitat protection were not analyzed

S U M M A R Y
TABLE 2C
STATE OF COLORADO
STREAMBANK EROSION STUDY
COST ESTIMATE - COMPARISON OF BENEFIS AND COST (Dollars) (1)

Study Area	Structural Measures Rock Jetty (2)	Construction Cost	Engineering	Project Administration	Land Rights (3)	Total Installation	O & M (4%)	Average Annual Cost	Total Average Annual Cost with O&M (4)	Average Annual Benefits (5)
	Cy	$	$	$	$	$	$	$	$	$
Currant Creek	5,240	396,540	42,916	52,112	0	401,568	12,200	35,197	47,397	0
Dolores River	17,520	1,024,920	143,489	174,236	0	1,342,640	41,000	117,682	158,581	16,800
Elk River	2,960	173,160	24,240	29,438	0	226,840	7,000	19,883	26,883	
Kerber Creek	12,640	739,440	103,521	125,705	0	968,666	29,600	84,904	114,504	0
Lake Fork	8,960	524,160	73,382	89,107	0	686,694	20,900	60,180	81,080	280
Little Thompson River	13,832	809,172	113,284	137,559	0	1,060,015	32,400	93,000	125,300	0
Lower Fountain Creek	1,680	98,280	13,758	16,708	0	128,746	4,000	11,284	15,284	1,200
North Fork Gunnison	11,440	669,240	93,693	113,775	0	876,708	26,768	76,843	103,609	5,375
Uncompahgre River	9,140	534,690	74,857	90,891	0	700,447	21,400	61,397	82,794	5,267
White River	7,680	449,280	62,899	75,378	0	588,557	17,970	46,326	64,296	7,670
Total	91,092	5,328,882	746,043	905,910	0	6,980,835	213,200	-	-	-

(1) Price Base: September 1987 amortized at 8 5/8 % for 50 years
(2) Rock Jetty installed (with base) 4 cy per foot at $50 per cy = $200 per foot with a life expectancy of 50 years
(3) Corps of Engineers 404 permit to work in river
(4) Includes cost for structural measures to protect riparian habitat and 4% O&M
(5) Benefits for riparian habitat protection were not analyzed

SUMMARY
TABLE 2D
STATE OF COLORADO
STREAMBANK EROSION STUDY
COST ESTIMATE - COMPARISON OF BENEFITS AND COST (Dollars) (1)

Study Area	Structural Measures Jacks (2)	Construction Cost	Engineering	Project Administration	Land Rights (3)	Total Installation	O & M (3%)	Average Annual Cost	Total Average Annual Cost with O&M (4)	Average Annual Benefits (5)
	Ft	$	$	$	$	$	$	$	$	
Currant Creek	7,300	85,410	11,957	14,519	0	111,886	2,700	10,030	12,730	0
Dolores River	29,790	348,543	48,796	59,252	0	456,592	10,300	40,860	51,160	16,800
Elk River	7,300	85,410	11,957	14,520	0	111,887	2,600	10,020	12,620	0
Kerber Creek	31,600	369,760	51,761	62,853	0	484,338	11,000	43,350	54,350	0
Lake Fork	22,100	254,570	36,200	43,956	0	338,725	7,700	30,320	38,020	0
Little Thompson River	48,270	564,759	79,066	96,009	0	739,834	16,900	66,230	77,530	0
Lower Fountain Creek	2,720	31,824	4,455	5,410	0	41,689	1,000	3,730	4,730	1,200
North Fork Gunnison	7,100	83,070	11,630	14,122	0	108,822	2,600	9,720	12,320	5,030
Uncompahgre River	10,100	118,170	16,544	20,089	0	154,803	3,500	13,860	17,360	5,270
White River	11,100	129,870	18,182	22,078	0	170,130	3,900	15,240	19,240	7,670
Total	177,380	2,075,346	290,548	352,809	0	2,718,703	62,300	-	-	-

(1) Price Base: September 1987 amortized at 8 5/8% for 50 years
(2) Jacks installed at $10 per foot of bank protected with a life expectancy of 40 years
(3) Corps of Engineers 404 permit to work in river
(4) Includes cost for structural measures to protect riparian habitat and 3% O&M
(5) Benefits for riparian habitat protection were not analyzed

S U M M A R Y
TABLE 2E
STATE OF COLORADO
STREAMBANK EROSION STUDY
COST ESTIMATE - COMPARISON OF BENEFITS AND COST (Dollars) (1)

Study Area	Structural Measures Buffer Strip (Vegetated) (2)	Construction Cost	Engineering	Project Administration	Land Rights (3)	Total Installation	O & M (2%)	Average Annual Cost	Total Average Annual Cost with O&M (4)	Average Annual Benefits (5)
	Ft	$	$	$	$	$	$	$	($)	($)
Currant Creek	7,300	85,410	11,957	14,519	0	111,886	1,700	9,790	11,490	0
Dolores River	29,790	348,543	48,796	59,252	0	456,592	6,900	40,020	46,920	0
Elk River	7,300	85,410	11,957	14,520	0	111,887	1,600	9,810	11,410	0
Kerber Creek	31,600	369,760	51,761	62,853	0	484,338	7,300	0	0	0
Lake Fork	22,100	254,570	36,200	43,956	0	338,725	5,200	29,700	34,900	0
Little Thompson River	48,270	564,759	79,066	96,009	0	739,834	11,300	64,850	76,150	0
Lower Fountain Creek	2,720	31,824	4,455	5,410	0	41,689	600	3,650	4,250	0
North Fork Gunnison	7,100	83,070	11,630	14,122	0	108,822	1,400	9,550	10,950	0
Uncompahgre River	10,100	118,170	16,544	20,089	0	154,803	2,400	13,560	15,960	0
White River	11,100	129,870	18,182	22,078	0	170,130	2,600	14,910	17,510	0
Total	177,380	2,075,346	290,548	352,809	0	2,718,703	41,000	-	-	-

(1) Price Base: September 1987 amortized at 8 5/8% for 50 years
(2) Buffer Strip (vegetated) installed @ $0.10 per sq. ft. (50 ft. on each side of stream or 100 ft. for one side) for a total of 100 sq. ft. for each foot of stream or $10 per foot of stream with a life expectancy of 50 years
(3) Corps of Engineers 404 permit to work in river and easement from landowner
(4) Includes cost for structural measures to protect riparian habitat and 2% O&M
(5) Benefits for riparian habitat protection were not analyzed

S U M M A R Y
TABLE 2F
STATE OF COLORADO
STREAMBANK EROSION STUDY
COST ESTIMATE - COMPARISON OF BENEFITS AND COST (Dollars) (1)

Study Area	Structural Measures Vegetative Sprig Revetment (2)	Construction Cost	Engineering	Project Administration	Land Rights (3)	Total Installation	O & M (5%)	Average Annual Cost	Total Average Annual Cost with O&M (4)	Average Annual Benefits (5)
	Ft	$	$	$	$	$	$	$	$	$
Currant Creek	7,300	42,705	5,979	7,260	0	55,944	2,100	4,910	7,010	0
Dolores River	29,790	174,272	24,398	29,626	0	228,296	8,700	20,030	28,730	0
Elk River	7,300	42,705	5,979	7,260	0	55,944	2,100	4,910	7,010	0
Kerber Creek	31,600	184,860	25,881	31,426	0	242,167	9,200	21,675	30,675	0
Lake Fork	22,100	129,285	18,099	21,977	0	169,361	6,500	14,860	21,360	0
Little Thompson River	48,270	282,384	39,535	48,005	0	369,924	14,100	32,450	46,350	0
Lower Fountain Creek	2,720	15,912	2,228	2,705	0	20,845	800	1,730	2,630	0
North Fork Gunnison	7,100	41,335	5,814	7,064	0	54,413	2,100	4,810	7,010	0
Uncompahgre River	10,100	59,085	8,272	10,044	0	77,401	2,900	6,790	9,690	0
White River	11,100	64,935	9,092	11,038	0	85,065	3,300	7,480	10,780	0
Total	177,380	1,037,678	145,277	176,405	0	1,359,360	51,800	-	-	-

(1) Price Base: September 1987 amortized at 8 5/8% for 50 years
(2) Installed @ $5 per foot of bank protected (10 ft. on each side of stream channel or 20 ft. for one side - sprigs set at approximately two foot centers) with a life expectancy of 50 years
(3) Corps of Engineers 404 permit to work in river and easement from landowner
(4) Includes cost for structural measures to protect riparian habitat and 5% O&M
(5) Benefits for riparian habitat protection were not analyzed

S U M M A R Y
TABLE 2G
STATE OF COLORADO
STREAMBANK EROSION STUDY
COST ESTIMATE - COMPARISON OF BENEFITS AND COST (Dollars) (1)

Study Area	Structural Measures Riparian Zone (2)	Construction Cost	Engineering	Project Administration	Land Rights (3)	Total Installation	O & M (5%)	Average Annual Cost	Total Average Annual Cost with O&M (4)	Average Annual Benefits (5)
	Ft	$	$	$	$	$	$	$	$	$
Currant Creek	7,300	17,082	2,392	2,904	0	22,378	900	1,960	2,860	0
Dolores River	29,790	69,708	9,760	11,851	0	91,319	3,400	8,010	11,410	0
Elk River	7,300	17,082	2,391	2,904	0	22,377	900	1,960	2,860	0
Kerber Creek	31,600	73,942	10.352	12,571	0	96,865	3,700	8,490	12,190	0
Lake Fork	22,100	51,714	7,241	8,791	0	67,746	2,600	5,950	8,550	0
Little Thompson River	48,270	112,953	15,813	19,201	0	147,967	5,600	12,990	18,590	0
Lower Fountain Creek	2,720	6,365	891	1,082	0	8,338	400	720	1,120	0
North Fork Gunnison	7,100	16,614	2,330	2,827	0	21,771	1,100	1,900	3,000	0
Uncompahgre River	10,100	23,634	3,309	4,018	0	30,961	1,100	2,700	3,800	0
White River	11,100	25,974	3,636	4,416	0	34,026	1,400	2,980	4,380	0
Total	177,380	415,068	58,115	70,565	0	543,748	21,100	-	-	-

(1) Price Base: September 1987 amortized at 8 5/8% for 50 years
(2) Zone to extend 50-100 feet up bank - $2 per foot of bank protected with a life expectancy of 50 years
(3) Corps of Engineers 404 permit to work in river and easement from landowner
(4) Includes cost for structural measures to protect riparian habitat and 5% O&M
(5) Benefits for riparian habitat protection were not analyzed

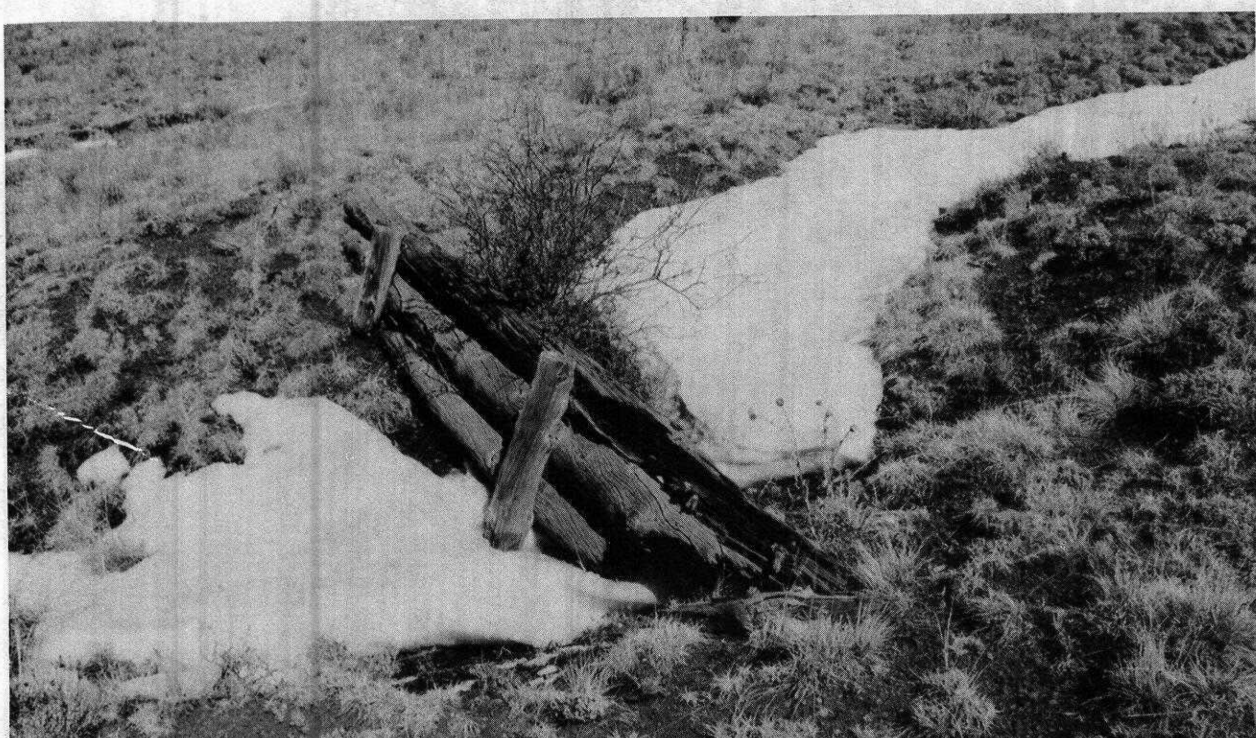
S U M M A R Y
TABLE 3
STATE OF COLORADO
STREAMBANK EROSION STUDY - 1988
ANALYSIS OF ECONOMIC, ENVIRONMENTAL, AND SOCIAL FACTORS

Factors	Alternative Treatment (1)							Remarks
	Rock Riprap	Anchored Trees	Rock Jetties	Jacks	Buffer Strips	Sprig Revetment	Riparian Zone	
Erosion Reduced	++	+	+	+	+	+	++	Streambank
Sedimentation Reduced	++	+	+	+	+	+	++	
Floodwater Reduced	o	-	-	-	-	-	-	Roughness coefficient of stream
Wetlands	o	o	o	o	+	+	+	
Wildlife	o	+	o	+	++	+	++	
Groundwater	o	o	o	o	-	-	-	Recharge and water use
Water Quality	++	+	+	+	++	++	++	Reduces erosion and sedimentation
Irrigation	++	+	+	+	++	++	++	Protects irrigation structures
Endangered Plants and Animals	o	o	o	+	++	+	++	Increases habitat
Net Economic Benefits	-	-	-	-	-	-	-	High installation cost
Recreation	-	o	-	-	+	+	++	Reduces erosion and sedimentation
Transportation	++	+	+	+	+	++	++	Reduces damage to roads and bridges
Fish Habitat	-	+	-	+	+	+	+	Reduces sedimentation
Social Resources	o	o	o	o	o	o	o	
Visual Resources	-	-	-	-	+	+	+	Reduces cutbank areas

(1) Considered Value Ratings:
- o No Effect
- + Beneficial Effect
- ++ Very Beneficial Effect
- \- Adverse Effect
- -- Very Adverse Effect

CURRANT CREEK - Park County, Colorado. It flows through rangeland and pastureland. The study area consists of 6 sites for a total of 16,700 feet (3.16 miles) of stream. The loss of pastureland, riparian areas, and damage to bridge embankments are examples of types and extent of damage. Deposition from side drainages affect the stream wherever they enter. These are a primary source of sediment due to the active head cuts. The construction of additional erosion control structures on these side drainages will decrease their sediment yields. Also pastureland and rangeland management practices will effectively reduce sediment.

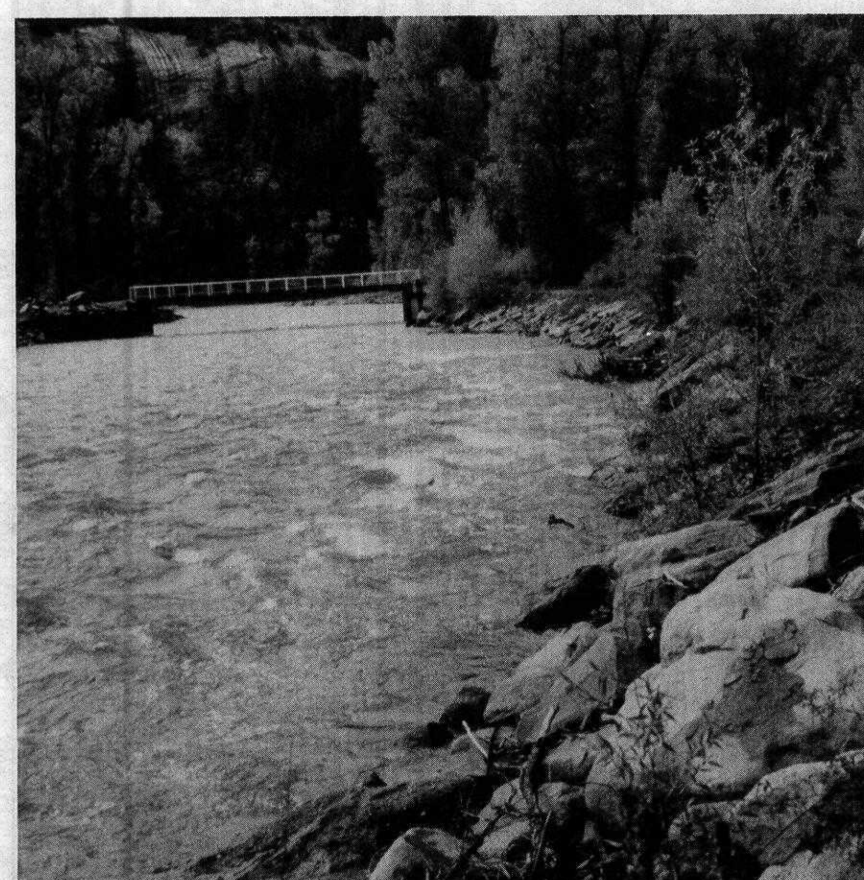
The proposed measures for improvement included rock riprap, anchored trees, rock jetties, jacks, vegetated buffer strips, vegetative sprig revetment, and riparian zones.



Timber check on side drainage to Currant Creek
Photography by Jim Thornton, SCS, Denver, Colorado

DOLORES RIVER - Montezuma County, Colorado. It flows through timbered areas, hayland, rangeland, and pastureland. The study area consists of 13 sites for a total of 52,870 feet (10 miles) of stream. The loss of farmed land, riparian areas, irrigation structures, and bridge embankments are examples of types and extent of damages.

The proposed measures for improvement included rock riprap, anchored trees, rock jetties, jacks, vegetated buffer strips, vegetative sprig revetment, and riparian zones.

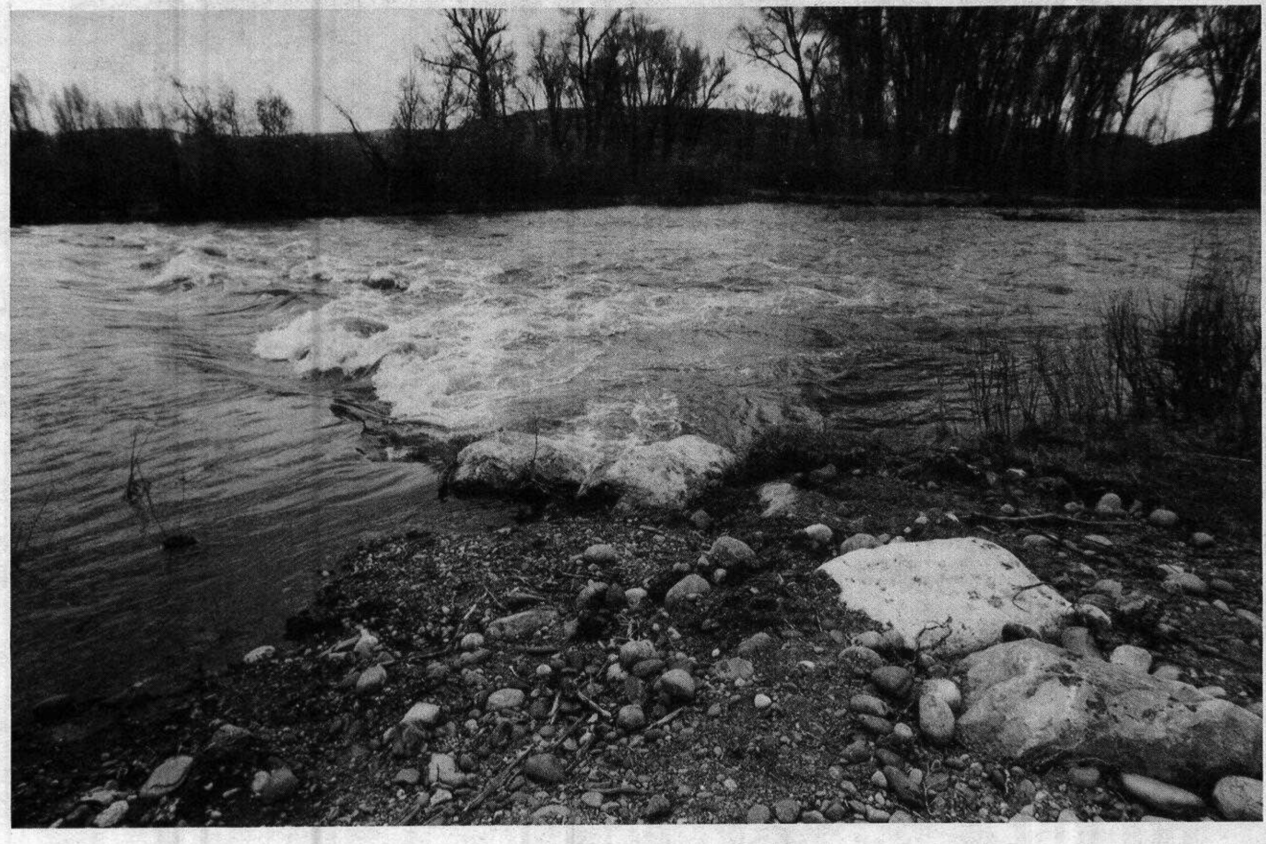


Rock riprap on Dolores River
Photography by Jim Thornton, SCS, Denver, Colorado

ELK RIVER - Routt County, Colorado. It flows through hayland, rangeland and pastureland. The study area consists of 4 sites for a total of 10,200 feet (1.93 miles) of stream.

Several landowners along the river in this area have applied Dr. Donald R. Reichmuth's rock drop practices to control the rivers direction of flow. These rock drop practices are being used to keep the water turned away from eroding banks. There still is the need, along the streambanks, to stabilize the eroding areas that have not been corrected; also to protect the farmable lands, irrigation structures, bridges, riparian areas, and farmsteads.

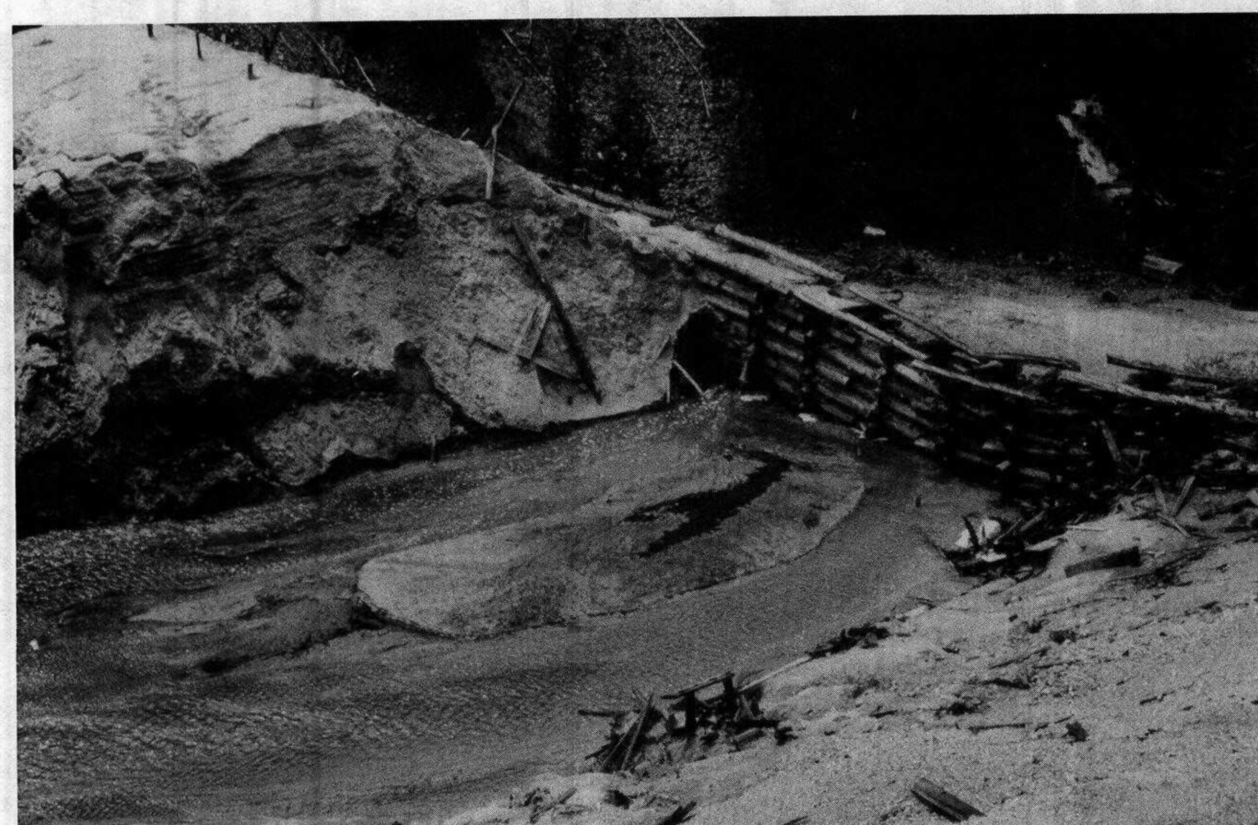
The proposed measures for improvement included rock riprap, anchored trees, rock jetties, jacks, vegetated buffer strips, vegetative sprig revetment, and riparian zones.



Rock Drop structure on Elk River
Photography by Gene Alexander, SCS, Denver, Colorado

KERBER CREEK - Saquache County, Colorado. It flows through old mill tailings, ponds, piles (built across Kerber Creek during the mining days,) pastureland, and haylands. The water quality of Kerber Creek, in the study area, is very poor primarily due to acid water draining from the Rawley Mine and mine tailings along the creek. The study area consists of 4 sites for a total of 15,800 feet (3 miles) of stream. The loss of riparian areas, irrigation structures, hayland, pastureland, and bridge embankments are examples of types and extent of damages.

The proposed measures for improvement include rock riprap, anchored trees, rock jetties, jacks, vegetated buffer strips, vegetative sprig revetment, and riparian zones. Vegetative practices would require the contaminated streambanks to be cleaned and topsoiled so that plants would grow.



Mine tailings in Kerber Creek
Photography by Jim Thornton, SCS, Denver, Colorado

LAKE FORK - Lake County, Colorado. It flows through mine tailing sediment deposits (which came from Leadville's mining days), marsh, wet alluvial area, hayland, and pastureland. The study area consists of 7 sites for a total of 35,000 feet (6.63 miles) of stream. There is a need, along the streambank, to stabilize the eroding areas, protect irrigation structures, pastureland, rangeland, bridges, ranchstead roads, and riparian areas.

The proposed measures for improvement included rock riprap, anchored trees, rock jetties, jacks, vegetated buffer strips, vegetative sprig revetment, and riparian zones. Vegetative practices would require the contaminated streambanks to be cleaned and topsoiled so that plants would grow.

Streambank erosion of mine tailings sediment on Lake Fork
Photography by Jim Thornton, SCS, Denver, Colorado

LITTLE THOMPSON RIVER - Boulder, Larimer, and Weld Counties, Colorado. The river, thoughout this reach, is characterized by a meandering channel flowing through a "V" shaped valley, surrounded by irrigated cropland. The quality of the water in the study area is poor primarily due to return flows from the reuse of irrigation water. Also there are large amounts of trash on the streambanks. The study area consists of 12 sites for a total of 82,232 feet (15.57 miles) of stream. The loss of riparian areas, damage to irrigation structures, and damage to bridge embankments are examples of types and extent of damages.

The proposed measures for improvement included rock riprap, anchored trees, rock jetties, jacks, vegetated buffer strips, vegetative sprig revetment, and riparian zones. The water quality can be improved with "Best Management Practices."

Streambank erosion into cropland on Little Thompson River
Photography by Jim Thornton, SCS, Denver, Colorado

LOWER FOUNTAIN CREEK - Pueblo County, Colorado. It flows through a valley area of bottomlands which are vegetated with cottonwood, willow, salt cedar, Russian olive, various forbs, and assorted grasses and are flanked by farmland and rangeland. The study area consists of 4 sites for a total of 6,500 feet (1.23 miles) of stream. This area suffers from streambank erosion during floods. During normal flows, the stream usually stays within the confines of the existing braided channel. Examples of types and extent of damages during flood periods are the loss of farmable and farmed land, loss of riparian areas, loss of and damage to irrigation structures, damage to pipeline crossing the streambed, and damage to bridge embankments.

The proposed measures for improvement include rock riprap, anchored trees, rock jetties, jacks, vegetated buffer strips, vegetative sprig revetment, and riparian zones.

Plank jetties on Fountain Creek protecting a high pressure gasline and cropland
Photography by Jim Thornton, SCS, Denver, Colorado

NORTH FORK GUNNISON RIVER - Delta County, Colorado. It flows through cottonwood areas, hayland, pastureland, and a few fruit orchards. The study area consists of 10 sites for a total of 58,080 feet (11 miles) of stream. The loss of homes, damaged bridges, loss of farmable and farmed land, loss of and damage to irrigation structures, and the loss of major irrigation delivery systems are examples of the types and extent of damages.

The proposed measures for improvement include rock riprap, anchored trees, rock jetties, jacks, vegetated buffer strips, vegetative sprig revetment, and riparian zones.

Anchored trees collecting debris on North Fork Gunnison River
Photography by Jim Thornton, SCS, Denver, Colorado

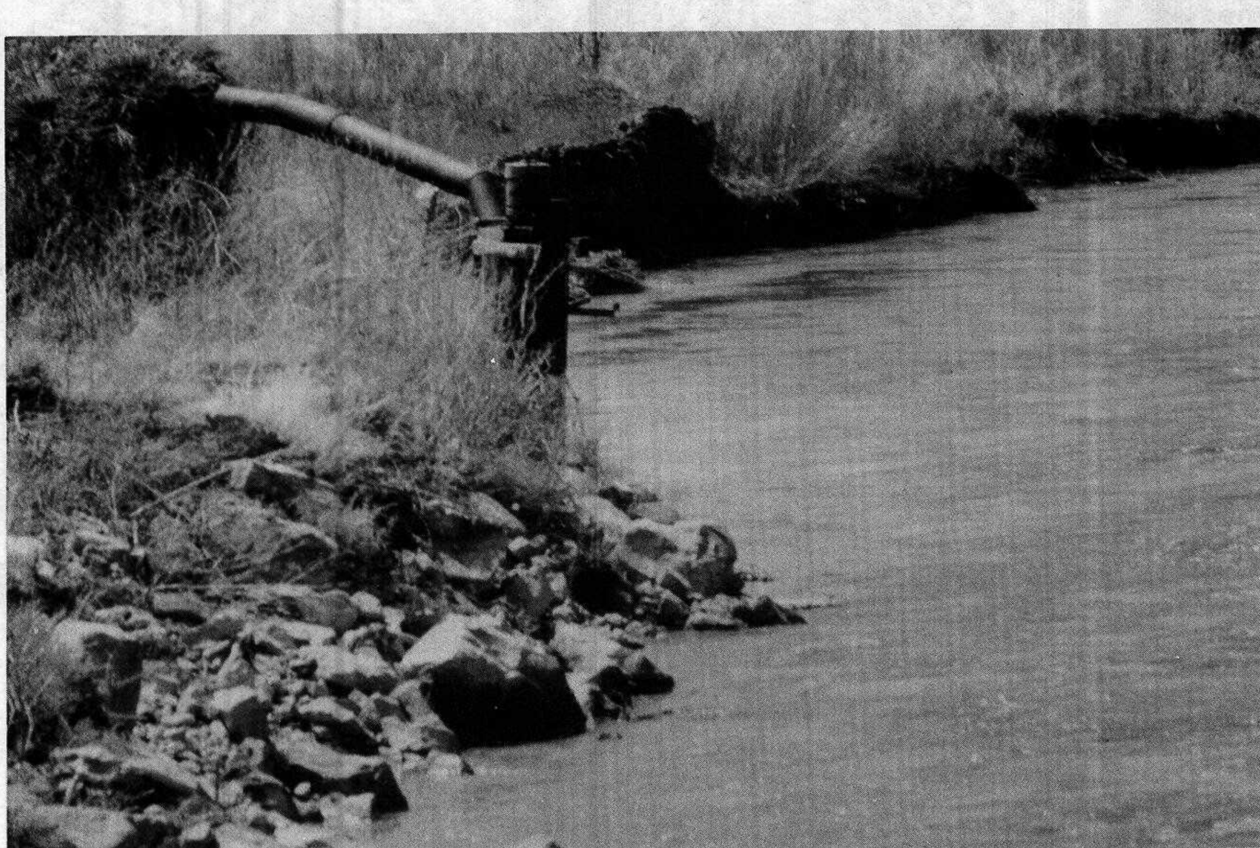
UNCOMPAHGRE RIVER - Delta and Montrose Counties, Colorado. It flows through thick stands of cottonwood, areas of row crops, vegetables, small grain, hayland, pastureland, and a few orchards. The study area consists of 13 sites for a total of 20,100 feet (3.81 miles) of stream. The loss of farmable land, pastureland, and riparian areas, loss of and damage to irrigation structures, and the damage to bridge embankments are examples of types and extent of damages.

The proposed measures for improvement include rock riprap, anchored trees, rock jetties, jacks, vegetated buffer strips, vegetative sprig revetment, and riparian zones.

Rock jetties protecting fish ponds in Uncompahgre River
Photography by Jim Thornton, SCS, Denver, Colorado

WHITE RIVER - Rio Blanco County, Colorado. It flows through timbered areas, haylands, and pasturelands. The study area consists of 7 sites for a total of 31,600 feet (5.98 miles) of stream. The loss of farmed land, riparian areas, loss of and damage to irrigation structures, and damage to bridge embankments are examples of types and extent of damages.

The proposed measures for improvement included rock riprap, anchored trees, rock jetties, jacks, vegetated buffer strips, vegetative sprig revetment, and riparian zones.



Streambank eorsion damaging irrigation pump on White River
Photography by Jim Thornton, SCS, Denver, Colorado

STREAM INVENTORIES

In 1973 the Westwide Study collected the following data:

Region	Channel Length (streamline)	Moderate Erosion (bank miles)	Serious Erosion (bank miles)	Total (bank miles)
Missouri	21,450	970	910	1,880
Arkansas	16,420	3,830	4,080	7,910
Rio Grande	7,710	20	10	30
Upper Colorado	56,680	3,170	3,520	6,690
TOTALS	102,260	7,990	8,520	16,510

For the present study the 80 soil conservation districts of Colorado were contacted to do an inventory on streambank erosion problems for each of their areas. Fifty of the districts submitted inventories giving a total of 6,009 (bank miles) of moderate erosion and 6,962 (bank miles) of severe erosion for a total of 12,971 (bank miles). Twenty-nine of the districts nominated 1,278 (bank miles) of streams to be studied. The 10 streams chosen to be studied had a total of 402 (bank miles) or a total of 201 stream miles. The actual stream miles studied for the 10 study areas was 62.31.

TREATMENT EXAMPLES

A stream should be considered as a delicately balanced mechanism that is gradually maturing. Naturally, landowners and local governments would like to find a stream in a well-balanced condition with smooth, gentle bends, well-vegetated banks free from erosion or failure, and a channel bed that is neither scouring nor building up with sediment. A stream, like the plants and animals that live near the stream, must continually adjust to new impacts in order to maintain its balance. These impacts are not only caused by man's activities but are also natural in orgin resulting from the maturing process of the stream. When the balance is upset, the stream will respond by some compensating action to bring the stream system back into balance. The most common compensating actions are streambank erosion and bed scour or buildup.

Landowners and local governments must realize that most streams are in a continuing state of adjustment (although possibly changing very slowly as compared with the human lifespan as the stream attempts to compensate for an imbalance at one location by making changes at other locations. Further, when some form of bank protection is put into place the stream will respond to this change. The response may be insignificant or it could be as serious as transferring the erosion or failure problem to a bank downstream. Thus, protection of a bank should be taken seriously, not only in light of successfully protecting the bank, but also considering the impact of the bank protection on the entire stream system.

Streambank protection practices are generally used in reaches of a stream which have a stable channel bottom. If the channel bottom is not stable, other types of practices may be more beneficial. Streambank protection practices are used to keep a streambank from eroding and causing meanders in a stream. Some of these types of practices can also be used to help heal existing meanders by slowing the velocity and allowing sedimentations to occur in the eroded area.

The practices described in the following pages [see **"Summary of Practices" TABLE 4**] are some types of measures which can be used to protect streambanks. Also included are measures that were not considered, in this study, yet may be a possible solution to streambank problems.

A few requirements are common to all types of streambank protection. The toe of any kind of bank protection must extend below the channel to a depth which will ensure that scouring will not undercut the toe of the practice. The upstream and downstream ends of the bank protection must be stable. This can be accomplished by tying the ends of the practice into stable reaches of the streambank. Generally, streambank protection extends to the top of the bank. However, it is usually acceptable to extend it only up the bank to one foot above the high water elevation. This elevation must be determined by a detailed hydrologic and hydraulic analysis of the stream.

TABLE 4
STATE OF COLORADO
STREAMBANK EROSION STUDY 1988

SUMMARY OF PRACTICES
Streambank Protection Practices

Structural Practices	Cost per Foot	Expected Life (yrs)	O&M 1/
Rock Riprap	100	50	2
Anchored Trees	20	15	1
Rock Jetty	200	50	4
Jacks	10	40	3
Vegetative Practices			
Vegetated Buffer Strips	10	50	2
Vegetative Sprig Revetment	5	50	5
Riparian Zone	2	50	5

1/ O&M is expressed as a percentage of the original construction cost.

Structural Practices

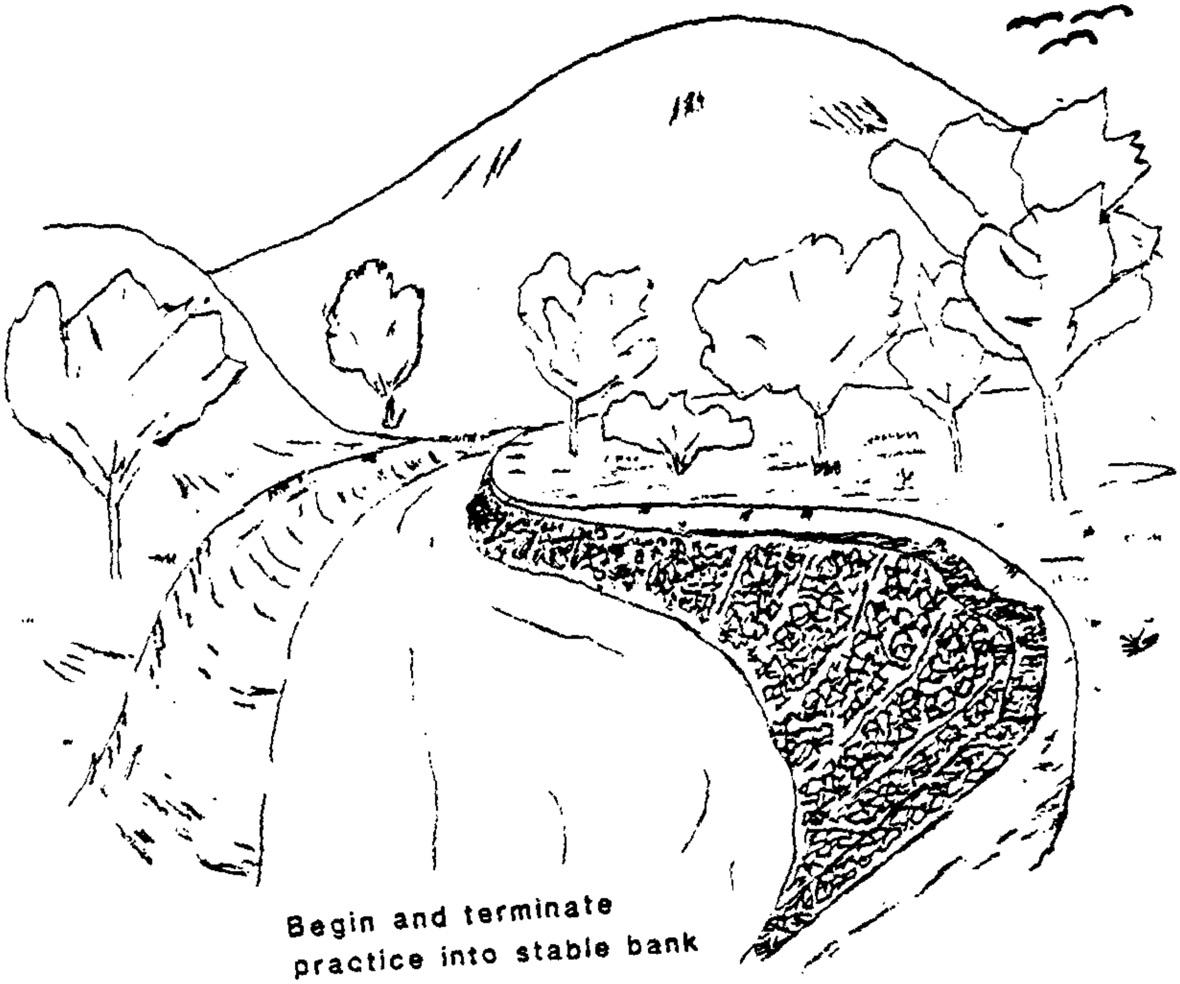
Rock Riprap

Rock riprap is an effective method of controlling stream bank erosion on nearly all streams. Rock can be placed on stream banks which are straight to severely meandering. Rock for riprap should be material which is dense, angular, and durable. Rock should be well graded to minimize air voids in the riprap blanket. The rock should be sized to withstand the force of the water in a stream without displacing the rock. Depending on the type of soil in the bank, a riprap blanket may require a filter of sand and/or gravel. The filter will prevent the piping of soil particles from the bank through the riprap blanket due to groundwater movement. The stream bank is shaped to a slope no steeper than 2.0 horizontal to 1.0 vertical prior to placement of the rock. The toe of a riprap blanket must be deep enough to prevent the stream from undercutting the bank below the riprap and causing the bank to fail. The upstream and downstream ends of the riprap blanket must be tied into the bank at a stable point.

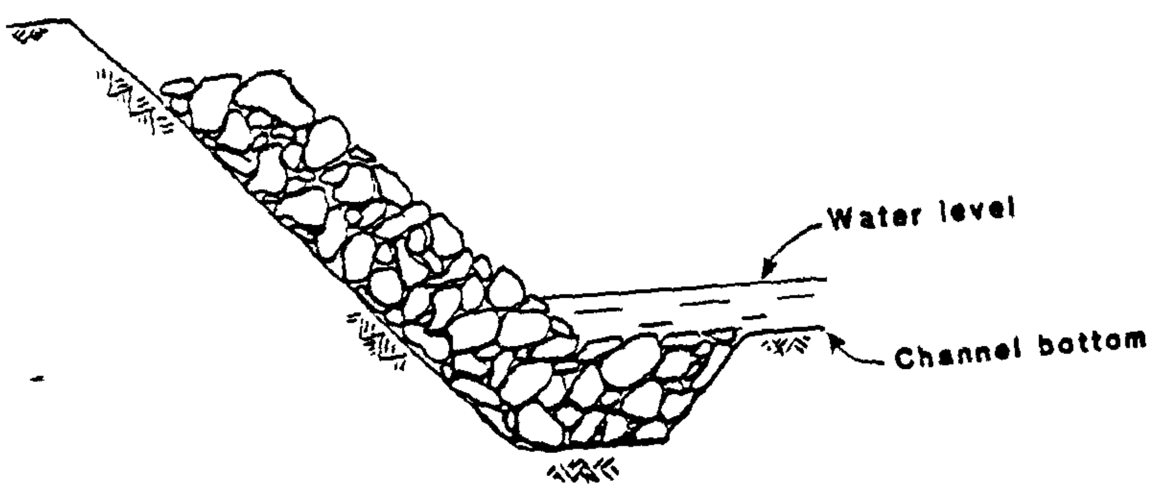
Some stream banks may not require the riprap blanket to extend to the top of the bank. An example of this could be if the bank on one side of the stream is significantly higher than the bank on the other side. The blanket should extend up the bank to a height of one foot above the high water elevation. The area above the rock should be shaped and seeded with appropriate vegetation.

A variation of this practice is to use **wire-bound rock.** The cross section would be similar to the rock riprap cross section. However, since the rock is held in place with anchored, wire-fencing material, the rock can be a smaller size. This will allow the thickness of the blanket to be reduced. Wire-bound rock is not recommended on channels with high banks or streams with a high flow velocity.

Maintenance requirements for a riprap blanket include replacing or repositioning rock if it is displaced by high flows. The upstream and downstream ends of the blanket should be checked to make sure erosion is not occurring. If scour holes have developed, the eroded areas should be filled and protected with additional riprap.



ROCK RIPRAP



TYPICAL RIPRAP SECTION

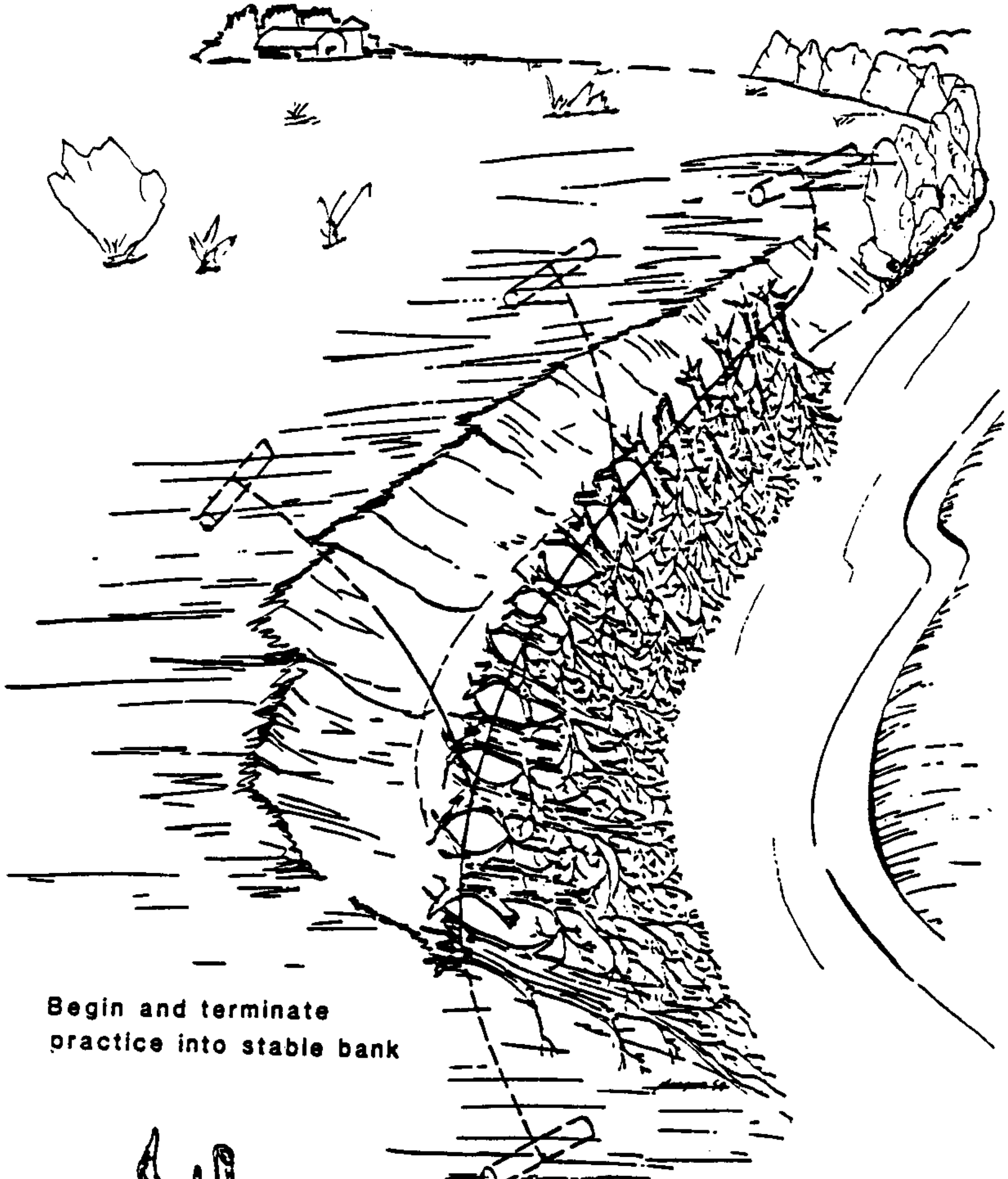
ROCK RIPRAP

Anchored Tree Revetment

Anchored trees can be used as an effective method of stream bank protection on most streams. They can be used on streams with any degree of meandering. The trees can be placed perpendicular or parallel to the bank. The trees should be as bushy as possible. Juniper and brushy willow work well. The trees are placed with the butt end of the tree against the bank and/or upstream. The trees are anchored with cable and deadmen to hold them in place. The anchors are located on the bank at least 10 feet from the edge of the bank. The area behind the trees is sometimes filled with gravel or other material. This helps hold the trees in place and also provides a surface which can be seeded. Even when the area behind the trees is not backfilled, some type of vegetation should be established. The upstream and downstream end of the reach must be protected to minimize the chance of water getting behind the trees and causing erosion. The most effective long-term result from this practice occurs when vegetation has been established along the entire reach.

Maintenance requirements for this practice include repairing damaged cable or anchors. Disturbed spots or scour holes behind the trees or on the ends should be repaired and protected.

ANCHORED TREES



ANCHORED TREE REVETMENT

TREE TYING DETAIL

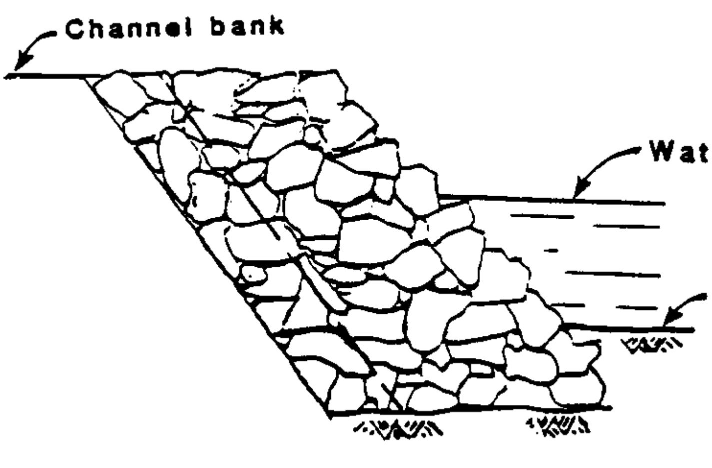
Jetty Stream Bank Erosion Control

Jetties are an effective method of controlling stream bank erosion on slight to moderately meandering curves. Jetties typically are not feasible on sharp curves. Jetties function by deflecting the flow from the stream away from the stream bank. Jetties can be constructed completely from rock or they can have a dirt, sand or gravel core with rock on the surface for erosion protection. Rock must be large enough to withstand the force of the water without being displaced. The size and spacing of the jetties depends on the physical characteristics of the stream; for example, the channel width and the sharpness of the curve. A jetty should not extend into the stream from the bank more than 20 percent of the channel width. The design of jetties requires an evaluation of the downstream channel and bank conditions to avoid causing erosion and other problems.

Jetties can be used to protect a stream bank without using any other practices. However, it is generally recommended to shape and seed the bank reaches between jetties.

Maintenance requirements for this practice include replacing or repositioning any rock which has been displaced. Over a period of a few years, sediment bars may develop near the downstream end of the jetty. These gravel bars should be removed to keep the jetty system functioning properly. A maintenance inspection should include a look at the downstream bank to check for erosion which could have been caused as a result of the jetties.

JETTY STREAMBANK EROSION CONTROL



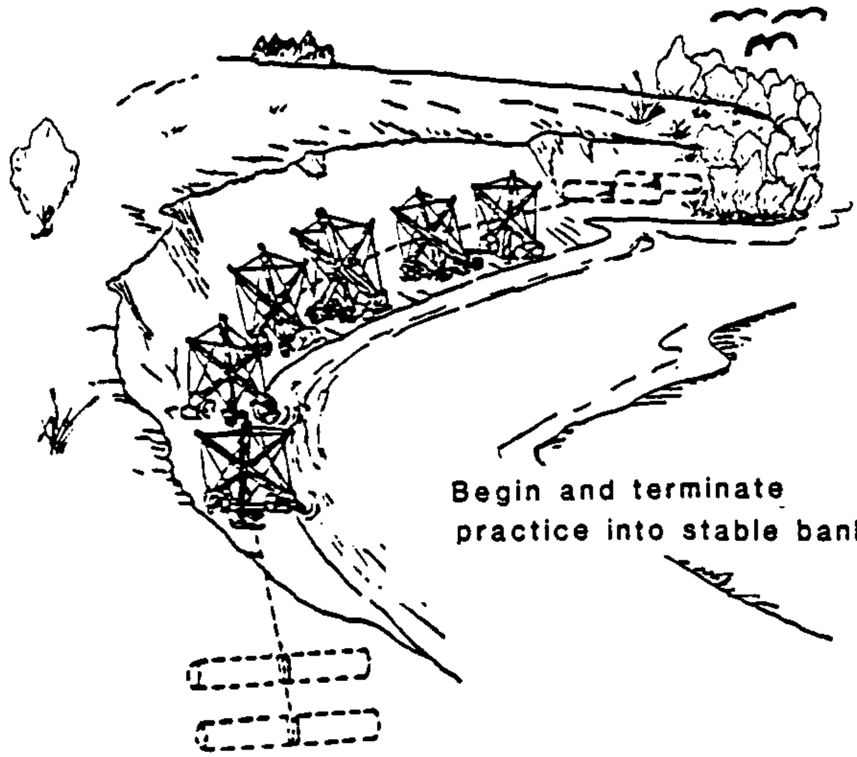
TYPICAL JETTY SECTION

JETTIES

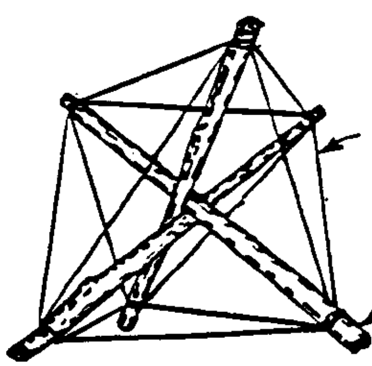
Stream Bank Erosion Control With Jacks

Jacks can be used to stabilize most eroding banks. Jacks are especially useful in streams which have wide sections due to stream bank meandering. The jacks can be located to allow eroded areas to silt in behind the row of jacks. On smaller streams and streams with fairly low flow velocities, a single row of jacks is all that would be required. The jacks can be fabricated from wood, concrete or metal. Individual jacks are fabricated by tying three posts or beams in a cross shape with wire. The jacks are placed along the toe of the bank. Rock is placed on and around the base of wood jacks to keep them from floating. The jacks are anchored to the bank with cable and deadman anchors. Vegetation should be established in the area behind the jacks.

Maintenance requirements for this practice include inspecting the jacks and repairing any loose or broken wires. Any movement of the jacks or rock should be corrected by returning it to its original location. Any scour holes or other erosion which has occurred behind the jacks should be reshaped and revegetated.



STREAMBANK EROSION CONTROL WITH JACKS



JACK DETAIL

STREAMBANK JACKS

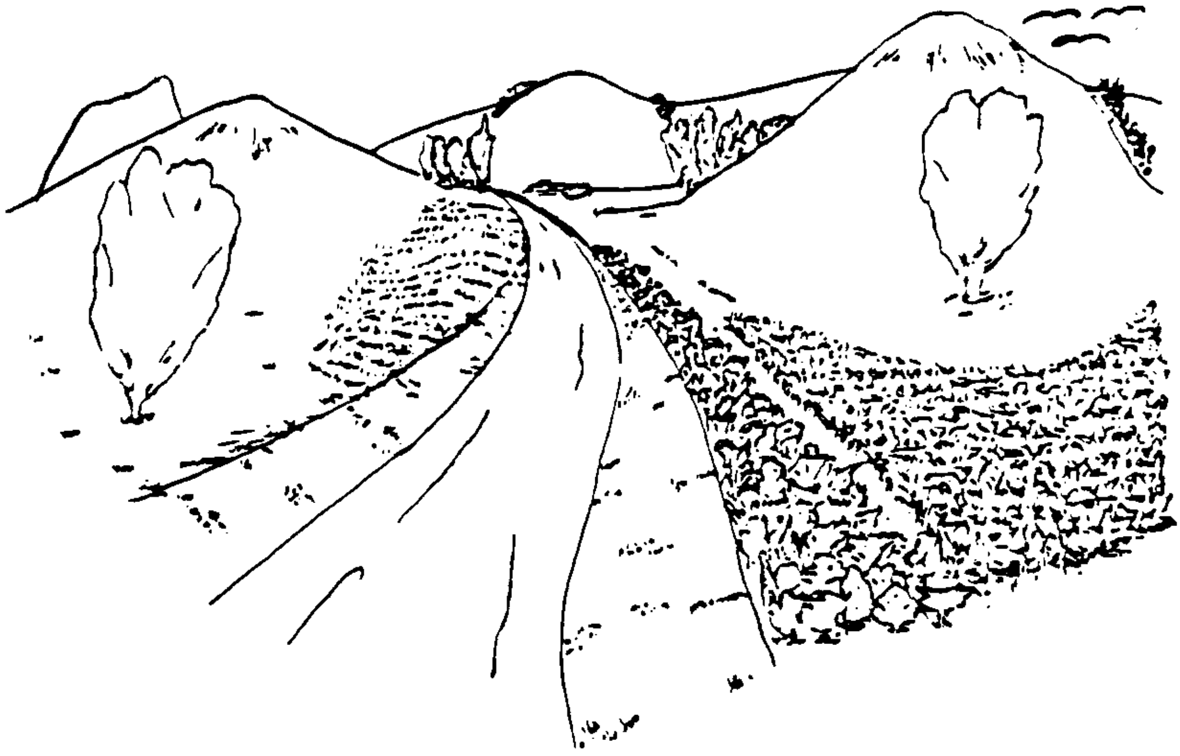
Vegetative Practices

Vegetated Buffer Strip Bank Protection

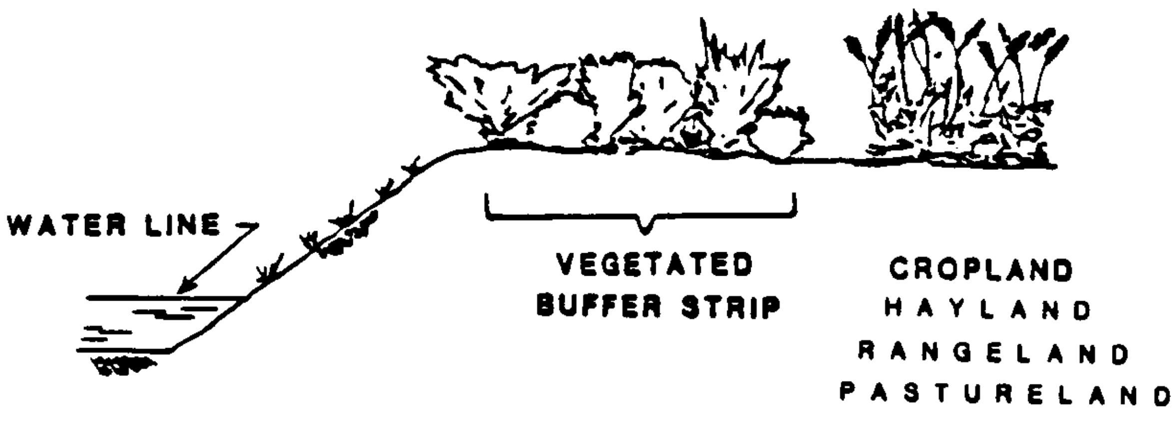
This practice is primarily related to cropland which is tilled up to the edge of stream channels without leaving a vegetative zone. These areas commonly contribute to stream bank erosion because the perennial vegetation needed for protection and stabilization is not present.

This practice would leave at least a 50 foot, and preferably a 100 foot wide, strip on each side of the stream channel. This would effectively create a buffer strip for trapping sediment coming from off channel sites and reduce erosion along the stream bank. In no case should overstory brush and tree vegetation along or within 50 feet of the stream channel be elimiated to increase crop or livestock forage production.

Maintenance requirements for this practice include brush removal in channel and periodic checks of vegetation to ensure understory vegetation is perennial. If understory vegetation is annual species, the area should be farmed and reseeded to adapted perennial species.



VEGETATED BUFFER STRIP BANK PROTECTION



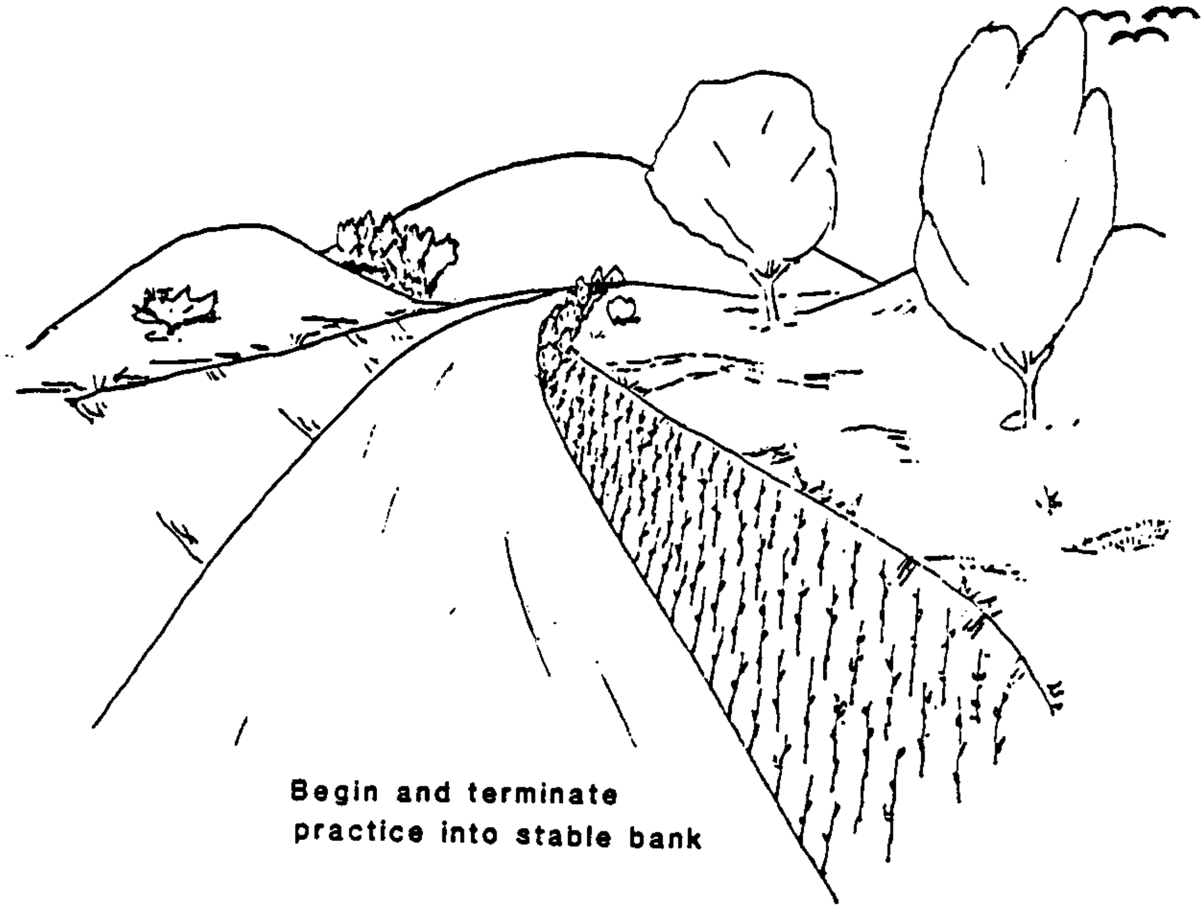
VEGETATED BUFFER STRIP

Willow/Alder/Dogwood Sprigs Revetment

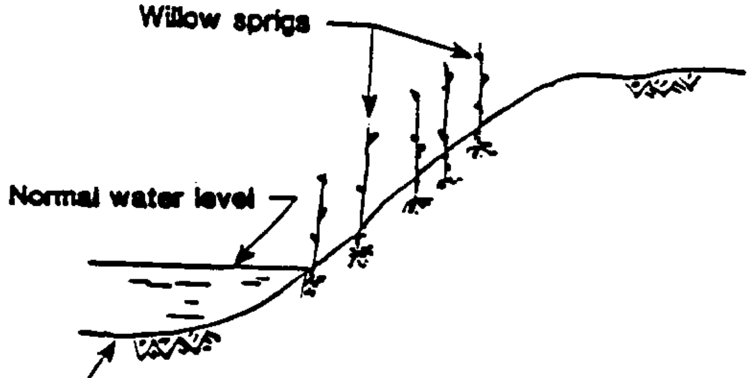
Stream bank vegetation is one of the most effective methods of controlling stream bank erosion under natural conditions. It is also the least costly method available when maintained in good condition. When streams begin to meander, bank erosion can occur if the vegetative protection is not in proper condition.

When this occurs, sprigs of adapted woody species such as willows, alders, and dogwood can be used in the wetter zone of the stream bank. This method works best on the straight stream sections where water pressure is not attempting to scour the banks. A critical requirement of this method is to sprig the cuttings deep enough or close enough to ground water to ensure moisture for at least 60 days. If water levels decrease too fast for the cuttings to root and follow the declining water table, they will die. The stream banks above the sprigged cuttings should be seeded to grass and banks may require shaping to at least 1.5 to 1 slope.

Maintenance for this practice will require replacement of dead sprigs and reshaping and seeding banks which develop scour holes.



WILLOW SPRIG BANK REVETMENT



TYPICAL BANK SECTION

WILLOW SPRIGS

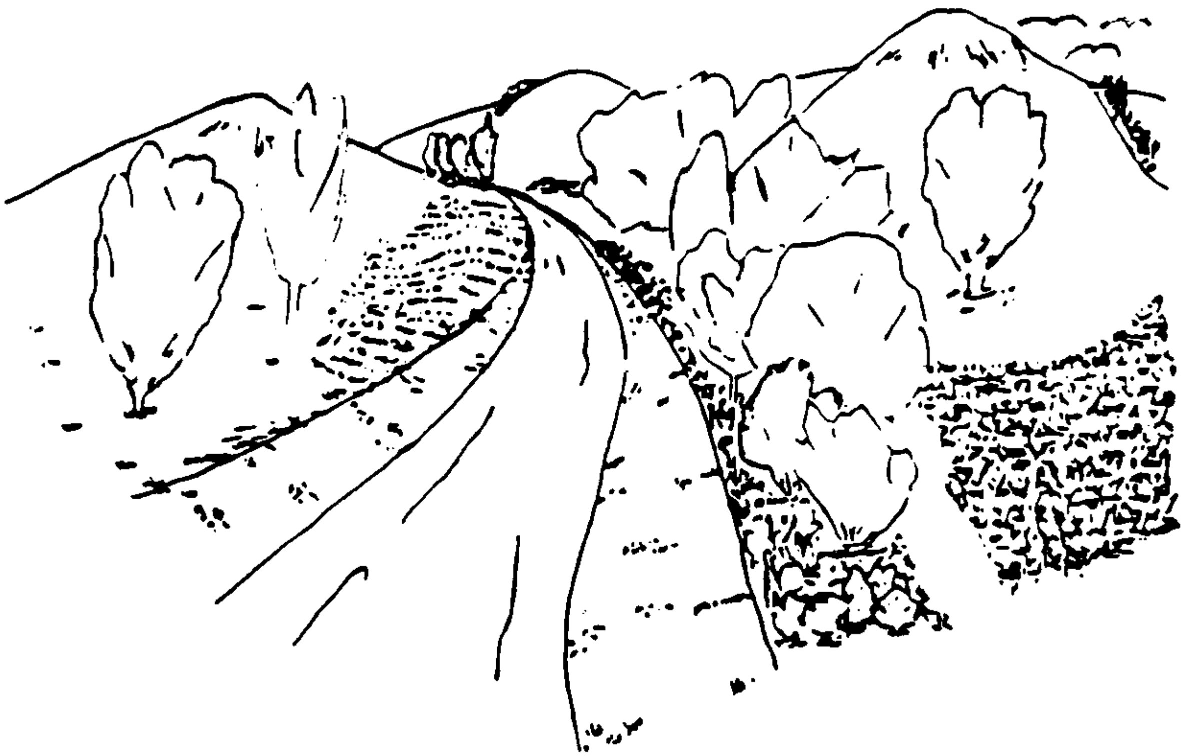
Riparian Zone

Dedication of riparian zones along the river banks will reduce much of the damage associated with streambank erosion. Riparian zones will provide protection from the lower frequency flows. However, large flows can produce bank erosion. Structural practices may be needed in some locations.

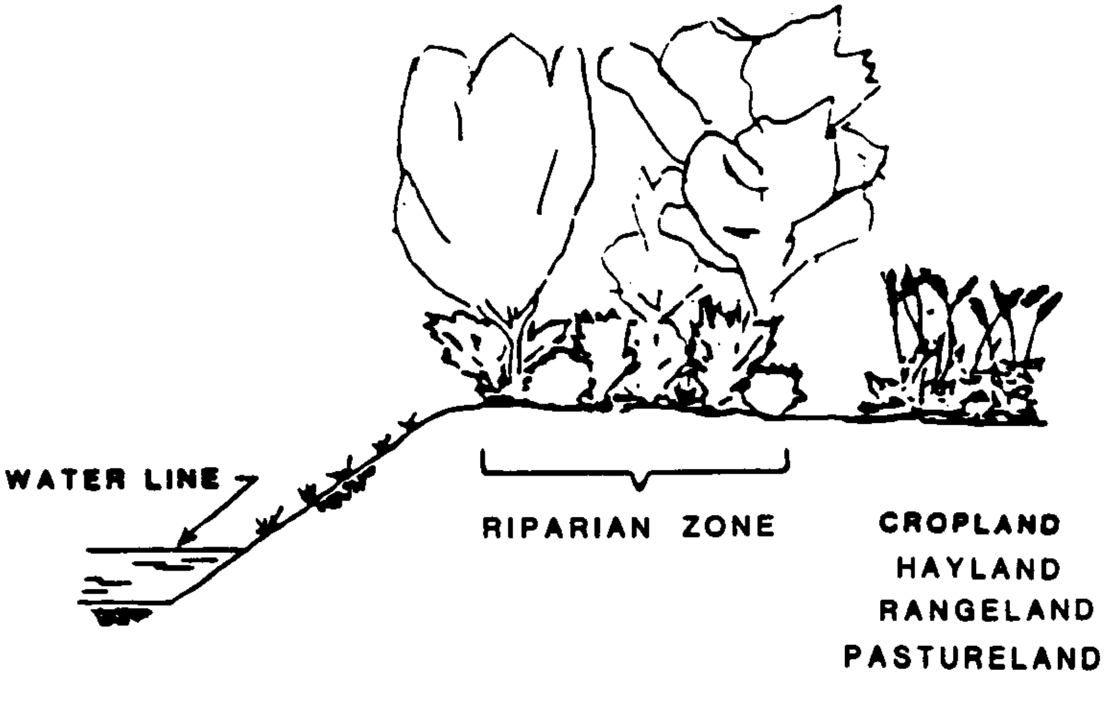
This practice would leave at least a 50 foot and preferably a 100 foot wide riparian zone along the stream. The root system developed from trees and brush along the streambank provide protection from the cutting action of water flowing against the banks. Protection from bank sloughing will also be obtained.

Other benefits, such as increased wildlife habitat, and diversity of scenery will be realized from riparian zones. These zones will also move the high value agricultural crops away from the streambanks, therefore reducing the likelihood of damage to these crops.

Maintenance requirements for this practice include tree and brush removal that can block channel and cause additional bank cutting. Fencing to keep livestock out of the riparian areas during certain times of plant growth.



RIPARIAN ZONE BANK PROTECTION

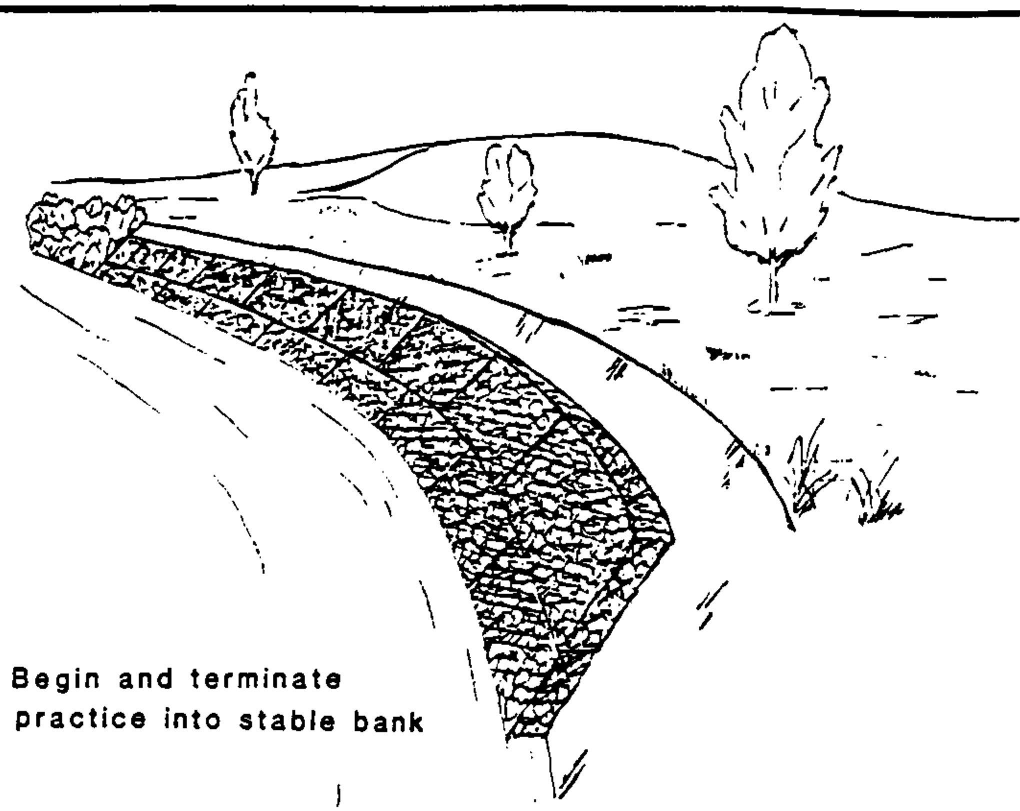


RIPARIAN ZONE

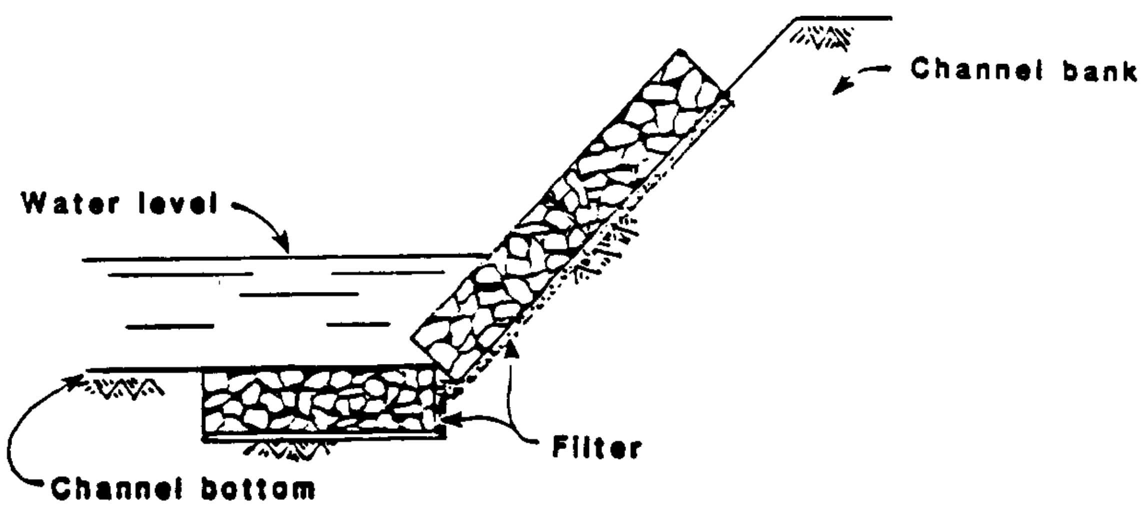
Gabion Revetment

Gabions can be used to stabilize stream banks in nearly every situation. Gabions consist of wire baskets filled with rock. Bank protection using gabions can be constructed using either a mattress revetment or a retaining wall. The installation of gabions must consider the potential scour depth in the channel. The gabion baskets usually require a filter between the baskets and the base material. The filter can be either a sand or gravel filter or a filter fabric. If a mattress revetment is used, the banks should be shaped to a slope no steeper than 1 horizonal to 1 vertical prior to placing the gabions. If a retaining wall is used, the banks may be vertical.

Maintenance requirements for this practice include inspecting the gabion baskets and repairing any broken wires.



GABION REVETMENT



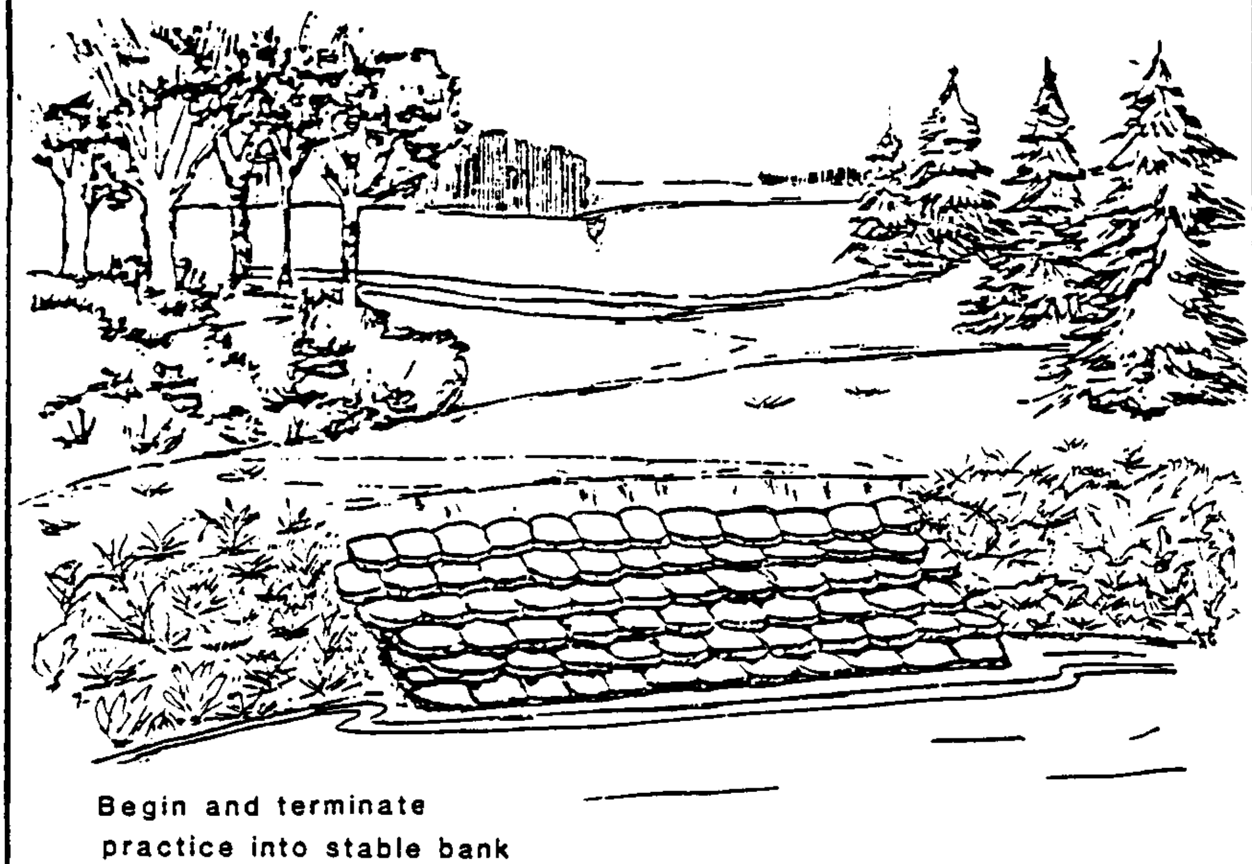
TYPICAL GABION SECTION

GABIONS

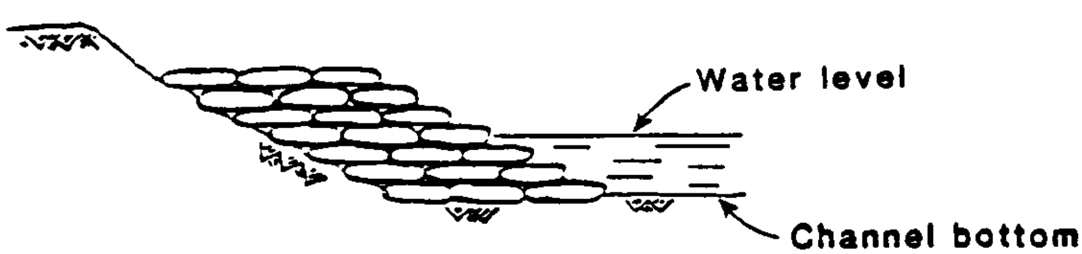
Sack Concrete Revetment

Sack concrete revetments can be used to control bank erosion in nearly every situation. The stream bank should be shaped to a slope no steeper than 1 horizontal to 1 vertical. Burlap or plastic sacks are filled with soil-cement or sand-cement mixtures. The sacks are then stacked along the bank. The toe for the sacks should be placed below the channel bottom to prevent any under-cutting of the sacks. After the sacks have been placed, they can be hosed down to get a quick set or they can be left to harden from natural precipitation. The durability of this practice will depend on the quality and proportions of the mixture in the sacks. The sacks should extend up the bank to at least one foot above the high waterline. If the sacks do not extend to the top of the bank, the bank should be shaped and seeded.

This practice should be maintained by inspecting for broken-up concrete and erosion at the ends of the revetment. Any broken-up concrete should be patched. Scoured areas at either end of the revetment should be shaped and protected.



SACK CONCRETE REVETMENT



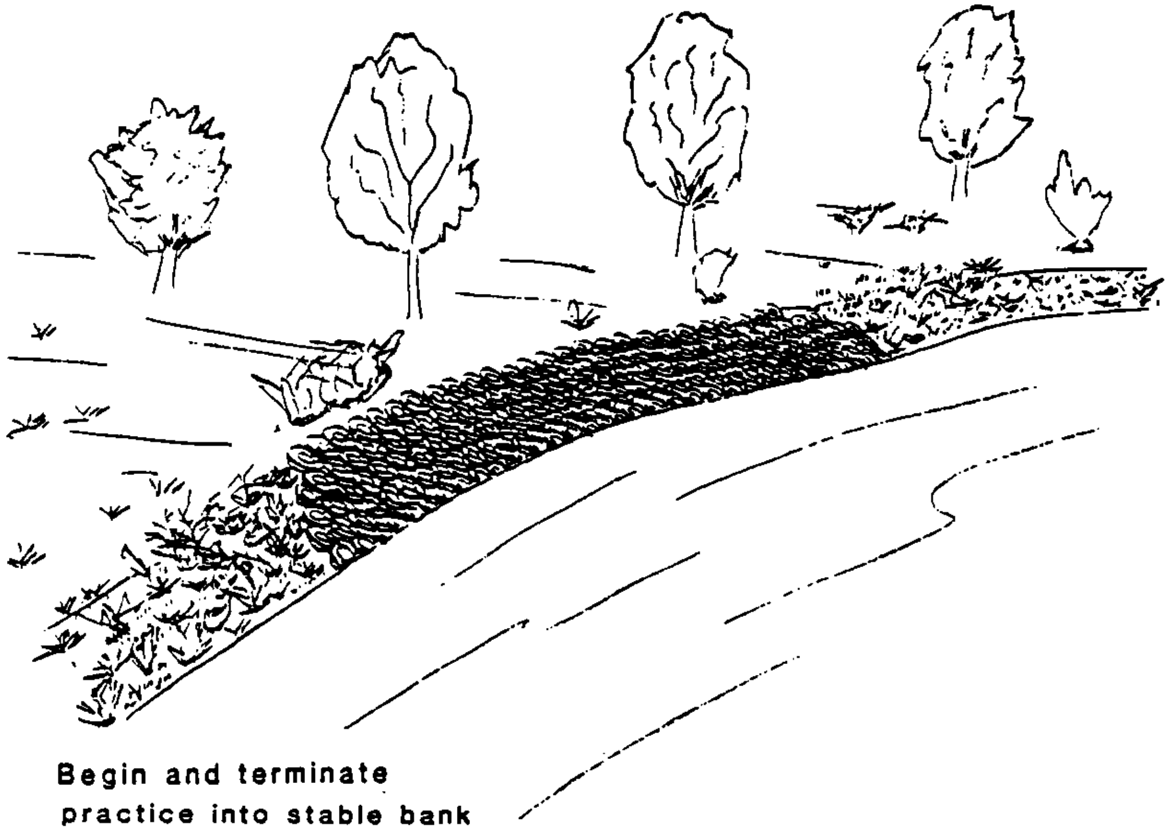
TYPICAL REVETMENT SECTION

SACK CONCRETE

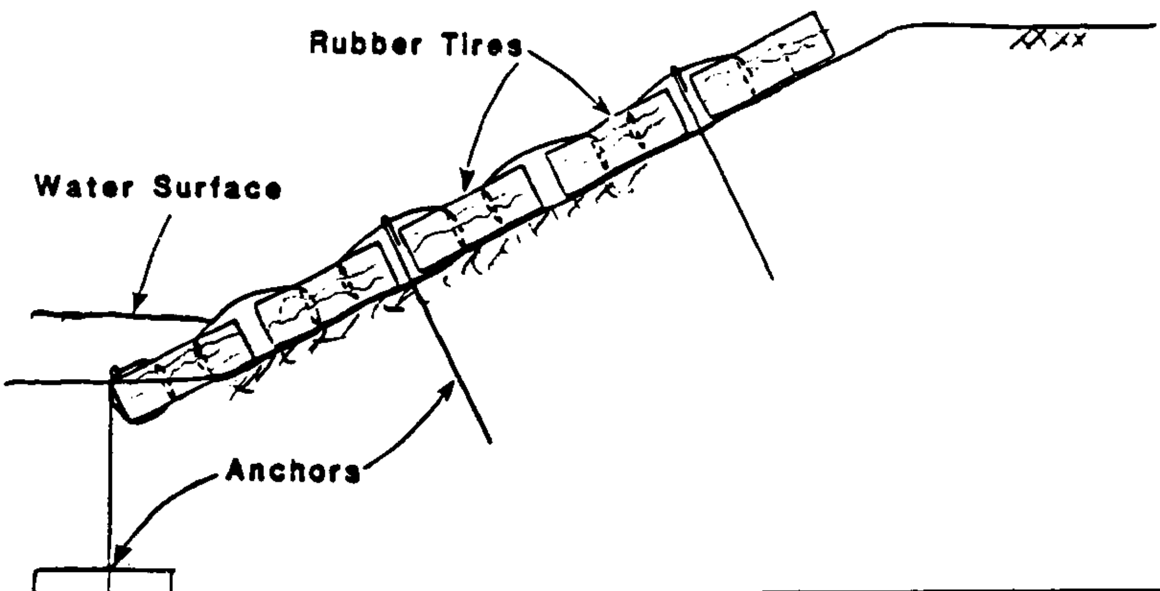
Anchored Tire Revetment

Anchored tires can be used to control bank erosion in streams which do not have high flow velocities. High flow velocities make it difficult to get vegetation established. High velocities also increase the chance of erosion occurring around the tires. The stream banks are shaped to a slope no steeper than 2 horizontal to 1 vertical. Tires are then tied together and placed on the slope. They should extend up the bank to a height of one foot above the high water elevation. The area above the tires should be shaped and seeded to appropriate vegetation. The mat of tires is anchored to the slope to keep it from floating when it is submerged. The toe of the tire mat should be protected with rock to prevent the stream from undercutting the tires. Vegetation should be established over the tire mat.

Maintenance requirements for this practice include replacement or repair of broken tire wires or anchors. Vegetation which has been damaged due to high flows should be reestablished.



ANCHORED TIRE REVETMENT



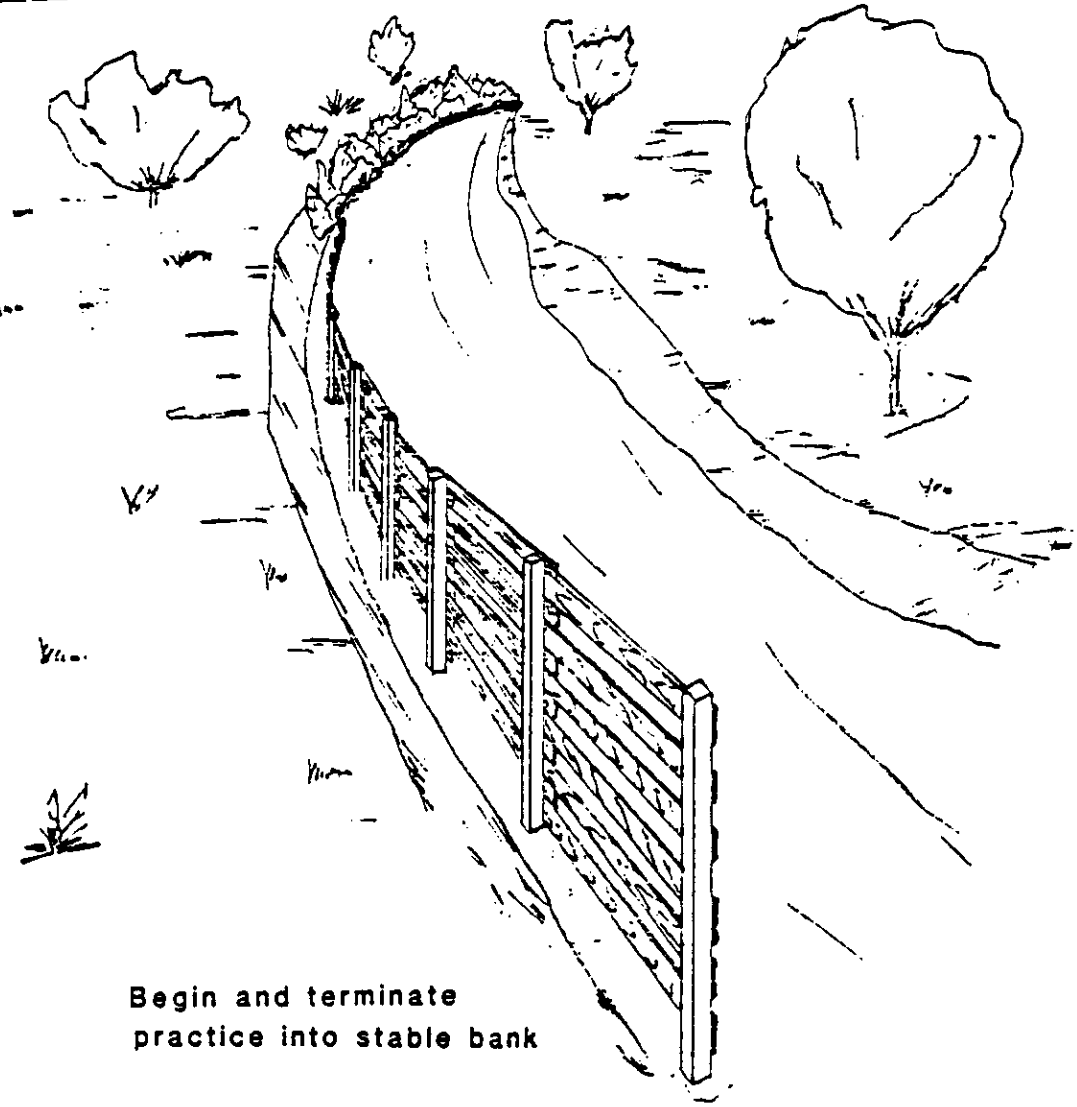
ANCHORED TIRE DETAIL

ANCHORED TIRES

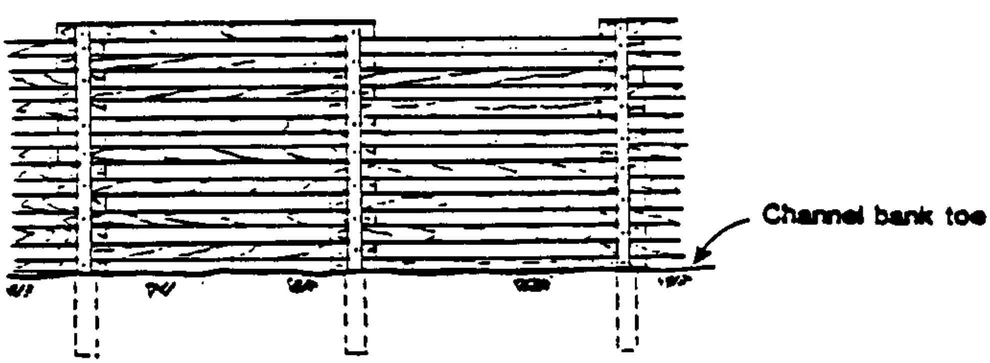
Posts and Planks Bank Protection

This practice consists of building a post and plank or pole barrier along the toe of the channel bank. This practice can be used on most streams with moderate to low flow velocities. It is especially useful in streams which have wide sections due to stream bank meandering. The post and plank or pole barriers can be located to allow eroded areas to silt in behind the barrier. Posts are placed at approximately a 12 foot spacing. Three-inch thick planks are bolted to the channel side of the posts. The bank behind the barrier should be shaped to a slope no steeper than 1.5 horizontal to 1 vertical and then seeded.

This practice is maintained by repairing or replacing any broken or loose planks. Eroded areas or scour holes should be reshaped and seeded.



POST AND PLANK BANK PROTECTION



POST AND PLANK DETAIL

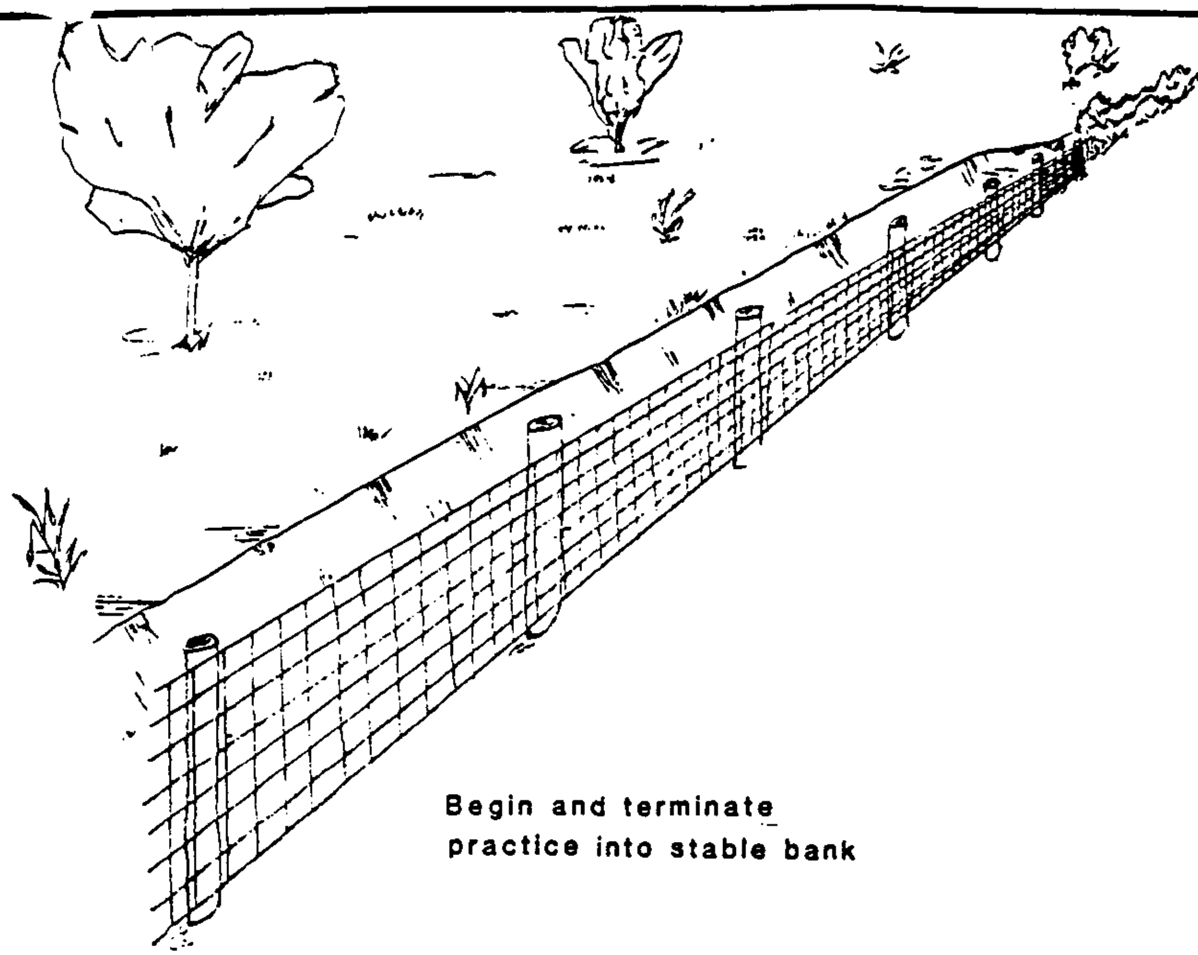
POST AND PLANK

Woven Wire Fence Revetment

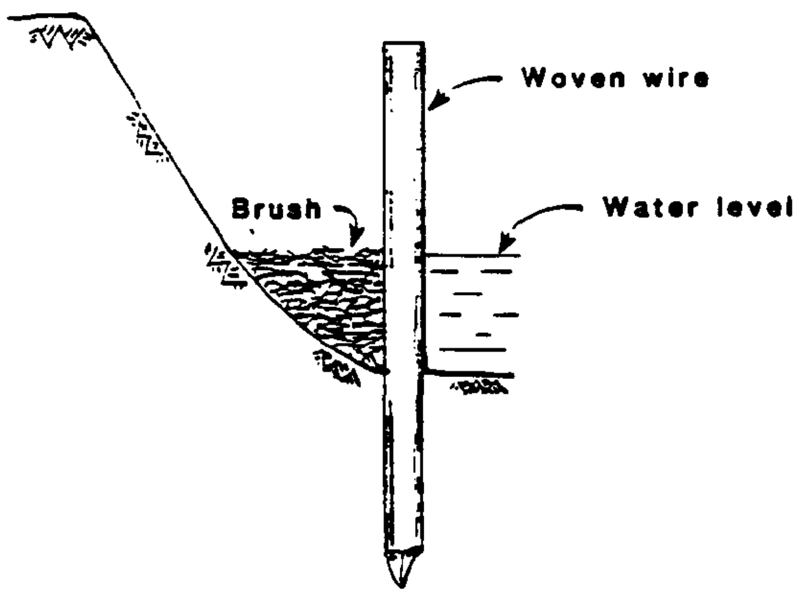
Woven wire fence can be used to stabilize stream banks with relatively low velocities. Posts are driven into the channel along the toe of the bank at six to eight feet spacings. Woven wire-fencing material is attached to the posts on the channel side of the posts. The bank behind the fencing should be shaped to a slope no steeper than 1.5 horizontal to 1 vertical and then seeded. This practice has achieved its intended results when the bank behind the fence has been completely stabilized with vegetation.

Another variation to this practice is to use live willow posts. These posts should be three to five inches diameter and spaced on a four foot spacing. Fiber netting is tied to the posts to provide protection at the toe until the willows get established. The bank behind the willow posts should be shaped and seeded.

Maintenance on these practices includes inspecting the fencing and vegetation. Any loose or broken wires should be repaired. Any seeded areas which have been eroded should be reshaped and seeded.



WOVEN WIRE FENCE REVETMENT



TYPICAL FENCE SECTION

WOVEN WIRE FENCE

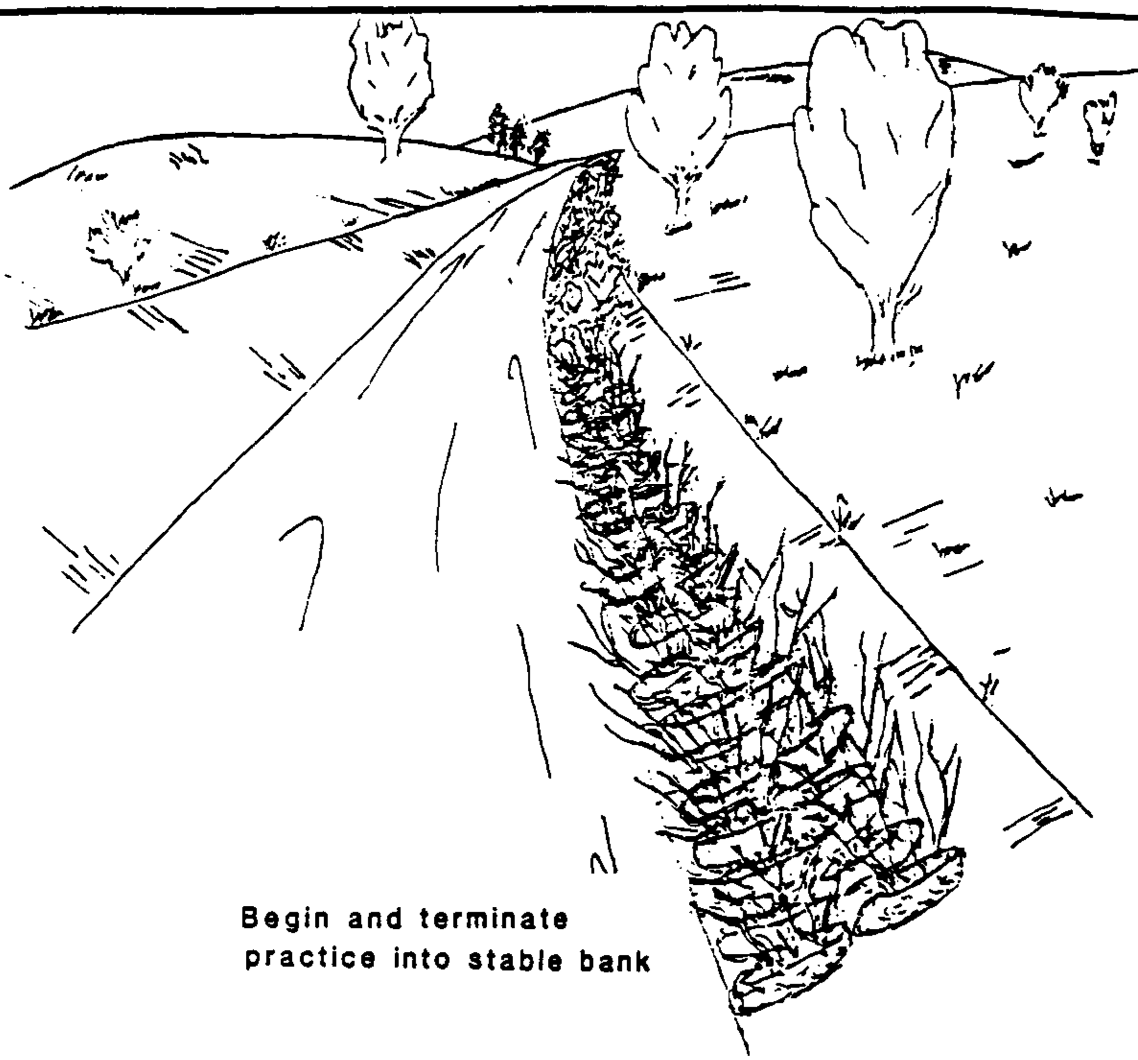
Willow Clump Revetment

When meander erosion is occurring, clumps of live willows can be relocated from local areas which have excess willows to protect either straight or meander type erosion.

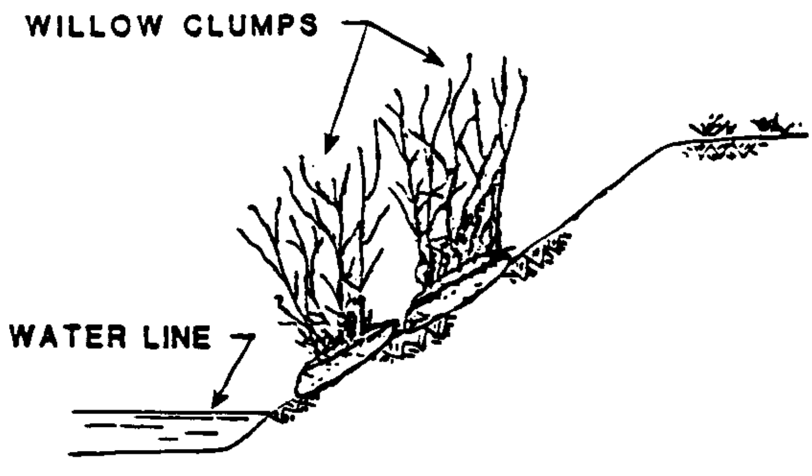
The clumps can be dug and transported using a front end loader or backhoe tractor and placed directly into the stream bottom against the bank. Willows should normally be placed in locations where they receive perennial water/moisture.

The clumps should be placed so stream flow can not get behind or between clumps. On meanders, clump protection such as steel posts with woven wire fence should be installed to ensure the clumps stay in place until well rooted (one year's protection is adequate). This protection may also be necessary on straight channel sections if stream flows are high enough to endanger washing out of freshly placed clumps. The woven wire should be installed high enough up bank on the ends to ensure the clumps and fence are not washed out the first season. The banks can then be sloped to 1.5 to 1 or greater slope and seeded with an adapted grass or local clumps of sod to speed up the total bank rehabilitation. This may not be necessary as the clump protected banks will slough and revegetate naturally, but will help in weed control.

Maintenance requirements for this practice include replacing sections that wash out and reseeding those sections that do not establish adequate grass stands.



WILLOW CLUMP BANK REVETMENT



WILLOW CLUMPS

Seeding With Fabric Mat Revetment

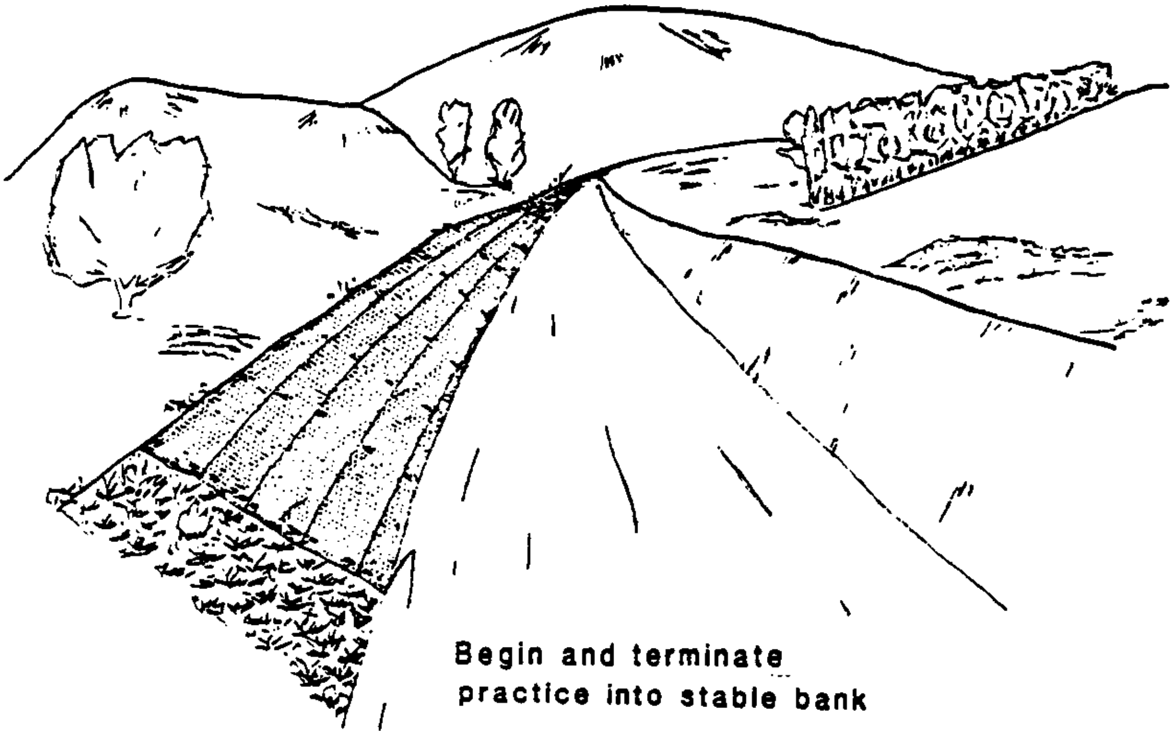
On disturbed stream sections where vegetative type protection is desirable without willows, seeding grasses with fabric mat protection may be the solution.

Stream banks should be shaped to a 3:1 slope or greater and seeded with a mix of adapted grasses. The mix should include species capable of withstanding excessive moisture to species which are quite drought tolerant (i.e. canarygrass/creeping foxtail - brome - wheatgrasses). The seeded section should then be covered with erosion control revegetation mat and staked down to stabilize the section until sod is established. This practice can be used below the temporary high water line, but not normally where perennial flows occur.

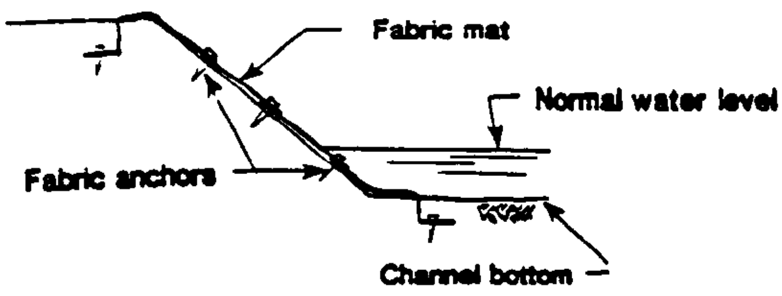
Some straight reaches and reaches with a slight meander can be protected by just shaping and seeding the banks. This can be done in channels above the water line and where the flow velocity is low.

Maintenance requirements for this practice include periodic checks to ensure fabric mat is adequately staked and additional seeding if necessary.

This practice may be applied along with structural stabilization projects.



FABRIC MAT WITH SEEDING BANK REVETMENT



TYPICAL BANK REVETMENT SECTION

FABRIC MAT
WITH SEEDING

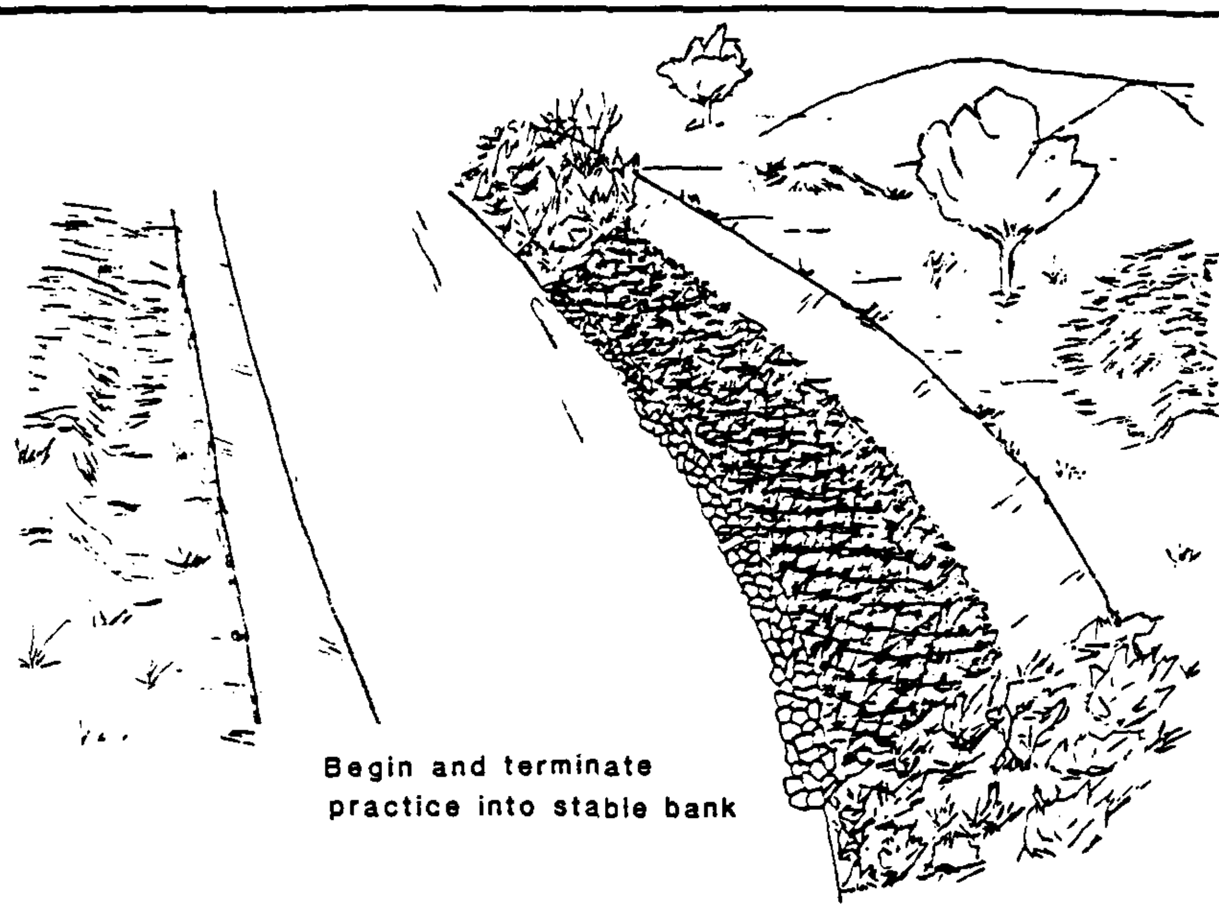
Rock and Brush Revetment

Rock and brush mat revetments can be used to control stream bank erosion in most areas where rock riprap can be used. There are two conditions when this practice would not be recommended. The first is on a sharp curve. The second is on reaches with large flows and a high velocity. The bank is sloped back to a slope not steeper than 1.5 horizontal to 1 vertical. A rock toe is placed at the bottom of the slope to protect the bank from undercutting. Brush is then laid with the butt ends up the slope and transverse to the stream bank. The brush is anchored in place with wire and stakes. If the mat does not extend to the top of the bank, the unprotected area should be seeded.

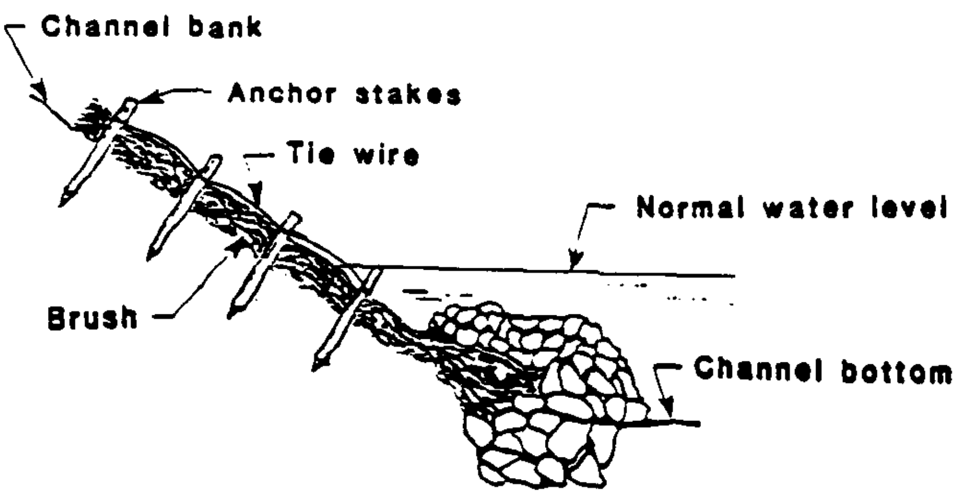
A variation to this practice is to use all **bundled brush or willows.** This would not be recommended on channels with high flow velocities. The brush would replace the rock in the toe and bottom part of the slope.

It is recommended to use live brush for the above practices. If live brush is used, loose dirt should be placed over or around the bundled brush. This will enable more of the brush to sprout faster and form vegetative protection for the bank.

These practices should be maintained by inspecting the wire anchors and the rock toe. Any wires which have been pulled loose should be repaired. Brush or rock which has been dislodged should be replaced.



BRUSH AND ROCK BANK REVETMENT



TYPICAL REVETMENT SECTION

BRUSH AND ROCK

GLOSSARY

A listing of terms commonly used to describe streambank erosion and instability mechanisms, as well as terms related to streambank protection and river mechanics, is provided below:

Abrasion - Removal of streambank material due to entrained sediment, ice or debris rubbing against the bank.

Angle of repose - The maximum angle (as measured from the horizontal) at which gravel or sand particles can stand.

Aggradation (bed) - A progressive buildup or raising of the channel bed due to sediment deposition. Aggradation is an indicator that a change in the stream's discharge and sediment load characteristics is taking place.

Alluvial fan - A cone-shaped deposit of sediment formed at the confluence of a stream and its tributary. If the sediment load of the tributary cannot be carried away by the stream, an alluvial fan forms.

Armoring - (a) Natural process whereby an erosion-resistant layer of relatively large particles is formed on a streambank due to the removal of finer products by streamflow. (b) Placement of a covering on a streambank or filter to prevent erosion.

Articulated concrete mattress - Rigid concrete slabs usually hinged together with corosion-resistant wire fasteners; primarily placed for lower bank protection.

Asphalt block - Precast or broken pieces of asphalt that can be hand-placed or dumped on a streambank or filter for protection against erosion.

Asphalt (bulk) - Mass uncompacted asphalt usually dumped from a truck (upper bank protection) or a barge (lower bank protection) that is placed to protect the bank against erosion.

Avulsion - A change in channel course that occurs when a stream suddenly breaks through its banks; usually associated with a catastrophic event.

Backfill - The material used to refill a ditch or other excavation, or the process of doing so.

Backwater area - The low-lying lands adjacent to a stream that may become flooded during periods of high water.

Bank - The side slopes of a channel between which the streamflow is normally confined.

Bed - The bottom of a channel

Bed load - Sediment that moves by saltation (jumping), rolling or sliding in the bed layer of a stream.

Bedrock - The solid rock underlying soils and overlying the mantle rock, ranging from surface exposure to depths of several hundred feet.

Bed slope - The inclination of the channel bottom.

Bituminous mattress - An impermeable rock-, mesh-, or metal-reinforced layer of asphalt or other bituminous material placed on a streambank to prevent erosion.

Blanket - Material covering all or portion of a streambank to prevent erosion.

Braided stream - A relatively wide and shallow stream with multiple channels formed by islands and bars in the waterway.

Buffer zones - Areas of trees, grass, or other vegetation located between top bank and adjacent pastures or cultivated fields (also called greenbelts).

Bulkhead - A vertical or nearly vertical retaining wall or structure supporting a natural or artificial streambank.

Cation-exchange capacity (CEC) - The sum total of exchangeable cations that a soil can absorb; expressed in *milliequivalents per gram or 100 grams of soil.

Caving - The collapse of a bank by undercutting due to wearing away of the toe or an erodible soil layer above the toe.

Cellular-block mattress - Regularly cavitated interconnected concrete blocks placed directly on a streambank or filter to prevent erosion. The cavities can permit bank drainage and the growth of either volunteer or planted vegetation when filter fabric is not used between the mattress and bank.

Channel - A natural or man-made waterway that continuously or periodically passes flow.

Chemical stabilization - Streambank protection technique involving the application of chemical substances to increase particle cohesiveness and to shift the size distribution toward the coarser fraction. The net effect is to improve the erosion resistance of the material.

Clay - Material passing the No. 200 (0.074 mm) U.S. Standard Sieve that exhibits plasticity (putty-like properties) within a range of water contents and has considerable strength when air-dry (Unified Soil Classification System).

Clay blanket - Layer of compacted clay placed over cohesionless bank soils to protect them against erosive streamflow.

Concrete block - Precast concrete material placed on a streambank or filter to prevent erosion.

Confluence - The junction of two or more streams.

Constriction (flow) - A reduction in channel cross-sectional area that results in greater stream velocities and/or water depth.

Crib - A frame structure, filled with earth or stone ballast, designed to absorb energy and to deflect streamflow away from a bank.

Critical shear stress - The minimum amount of shear stress exerted by passing stream currents required to initiate soil particle motion.

Cross section - A diagram or drawing cut across a channel that illustrates the banks, bed, and water surface.

Crossing - The relatively short and shallow reach of a stream between bends; also called a crossover.

Current - Water flowing through a channel.

Cut bank - The concave wall of a meandering stream.

Cutoff - A new, relatively short channel (natural or artificial) formed when a stream cuts or is realigned through the neck of an oxbow or horseshoe bend. A cutoff can also develop as successive high-water flows develop a chute across the inside of a point bar.

Degradation (bed) - A progressive lowering of the channel bed due to scour. Degradation is an indicator that a change in the stream's discharge and sediment load characteristics is taking place.

Dike (groin, spur, jetty) - A structure extending from a bank into a channel that is designed to (a) reduce the stream velocity as the current passes through the dike, thus encouraging sediment deposition along the bank (permeable dike) or (b) deflect erosive currents away from the streambank (impermeable dike).

Discharge - Volume of water passing through a channel during a given time, usually measured in cubic feet per second.

Drainage basin - An area confined by drainage divides, often having only one outlet for discharge.

Eddy current - A vortex-type motion of a fluid flowing contrary to the main current, such as the circular water movement that occurs when the main flow becomes separated for the bank.

Energy grade slope - An inclined representing the total energy of a stream flowing from a higher to a lower elevation.

Ephemeral stream - A stream that flows only in direct response to precipitation and receives little or now water from springs or no sustained supply from snowmelt or other sources. An ephemeral stream's channel is at all times above the water table.

Erosion - Removal of soil particles from the land surface due to water or wind action.

Erosion control matting - Fibrous matting (e.g. jute, paper, etc.) placed or sprayed on a streambank for the purpose of preventing erosion or providing temporary stabilization until vegetation is established.

Fabriform - Grout-filled fabric mattress used for streambank protection.

Fascine - A bundle of brush, sticks, or timber used to make a foundation mat or to construct a revetment to protect a streambank against erosion.

Fence - A streambank protection technique consisting of wire mesh or timber attached to a series of posts, sometimes in double rows; the space between the rows may be filled with rock, brush, or other materials. Fences may be placed either parallel to the bank or extended into the stream, in either case these structures decrease the stream velocity and encourage sediment deposition as the flow passes through the fence.

Fetch - The area in which waves are generated by wind having a rather constant direction and speed; sometimes used synonymously with fetch length.

Fetch length - The horizontal distance (in the direction of the wind) over which wind generates waves and wind setup.

Filter - Layer of fabric, sand, gravel, or graded rock placed, or developed naturally where suitable in-place materials exist, between the bank revetment and soil for one more of three purposes: to prevent the soil from moving through the revetment by piping, extrusion, or erosion; to prevent the revetment from sinking into the soil; and to permit natural seepage from the streambank, thus preventing buildup of excessive hydrostatic pressure.

Flanking - Erosion resulting from streamflow between the bank and the landward end of a river-training or a grade-control structure.

Flow slide - Saturation of a bank to the point where the soil material behaves more like a liquid than a solid; the soil/water mixture may then move downslope resulting in a bank failure.

Gabion - A wickerwork or wire mesh basket or cage filled with stone or

Gobi Block - Precast cellular concrete block often used as a substitute for riprap.

Geomorphology - That branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and in the buildup of erosional debris.

Grade-control structure (sill, check dam) - Structure placed bank to bank across a stream channel (usually with its central axis perpendicular to flow) for the purpose of controlling bed slope and preventing scour or head-cutting.

Gravel - Rounded or semirounded particles of stone.

Grout - A fluid mixture of cement and water or of cement, sand, and water used to fill joints and voids.

Hard point - A streambank protection technique whereby "soft" or erodible materials are removed from a bank and replaced by stone or compacted clay. Some hard points protrude a short distance into the channel to direct erosive currents away from the bank. Hard points also occur naturally along streambanks as passing currents remove erodible materials leaving nonerodible materials exposed.

Head-cutting - Channel bottom erosion moving upstream through a basin indicating that a readjustment of the basin's slope and its stream discharge and sediment load characteristics is taking place. Head-cutting is evidenced by the presence of waterfalls or rapidly moving water through an otherwise placid stream. Head-cutting often leaves streambanks in an unstable condition as it progresses through a reach.

Helical flow - Three-dimensional movement of water particles along a spiral path in the general direction of flow. These secondary-type currents are of most significance as flow passes through a bend; their net effect is to remove soil particles from the cut bank and deposit this material on the point bar.

Hydraulic radius - The cross-sectional area of a stream divided by its wetted perimeter.

Jack (jackstraw, Kellner jack) - A component of a river training structure consisting of wire or cable strung on three mutually perpendicular metal, wooden, or concrete struts.

Launching - Release of undercut material (stone riprap, rubble, slag, etc.) downslope; if sufficient material accumulates on the streambank face, the slope can become effectively armored.

Levee - An embankment generally landward of top bank that confines flow during highwater periods, thus preventing overflow into lowlands.

Longard tubing - Sand-filled tubes (synthetic material) placed either parallel or at an angle to the streamflow for streambank protection.

Lower bank - That portion of a streambank having a elevation less than the mean water level of the stream.

Mattress - A covering of concrete, wood, stone, or other material used to protect a streambank against erosion.

Meandering stream - A single channel waterway having a pattern of successive deviations in alignment and flow direction.

Middle bank - That portion of a streambank having an elevation approximately the same as that of the mean water level of the stream.

Natural levee - A low, alluvial ridge adjoining the channel of a stream formed by sediment deposited by floodwaters that have overflowed the channel banks.

Organic mixtures and mulches - Any of a number of agents (e.g. petrochemicals or vegetative matter) used to stabilize a streambank against erosion by providing protection and nutrients while vegetation becomes established. These agents, which may be in the form of liquids, emulsions, or slurries, are normally applied by mechanical broadcasters.

Overbank flow - Water movement over top bank either due to a rising stream stage or to inland surface-water runoff.

Oxbow - The abandoned bow-shaped or horseshoe-shaped reach of a former meander loop, that is left when the stream cuts a new shorter channel across the narrow neck between two closely approaching bends of the meander.

Pavement - Streambank surface covering, usually impermeable, designed to serve as protection against erosion. Common pavements used on streambanks are concrete, compacted asphalt, and soil cement.

Peaked stone dike - Riprap placed parallel to the toe of a streambank (at the natural angel or repose of the stone) to prevent erosion of the toe and induce sediment deposition behind the dike.

Perennial stream - A channel that has continuous flow.

Phreatic line - The upper boundary of the seepage water surface landward of a streambank.

Pile - An enlongated member, usually made of timber, concrete, or steel, that serves as a structural component of a river-training structure.

Piping - Removal of soil material through subsurface flow of seepage water that develops channels or "pipes" within the soil bank.

Point bar - The convex side of a bend that is built up due to sediment deposition.

Quarry-run stone - Natural material used for streambank protection as received from a quarry without regard to gradation requirements.

Rapid drawdown - Lowering the water against a bank more quickly than the bank can drain, which can leave the bank in an unstable condition.

Reach - A portion of a channel between any two points.

Refusal - Erosion-resistant material placed in a trench (excavated landward) at the upstream end of revetment ot prevent flanking.

Reinforced-earth bulkhead - A retaining structure consisting of vertical panels and attached to reinforcing elements embedded in compacted backfill for supporting a natural or artificial streambank (a specific type of retaining wall).

Retaining wall - A vertical structure used to maintain an elevation differential between the water surface and top bank while at the same time preventing bank erosion and instability.

Retard - Structure placed parallel to a streambank to prevent erosive currents from attacking the bank.

Revetment - Cover of erosion-resistant material placed to protect a streambank.

Riparian - Pertaining to anything connected with or adjacent to the banks of a stream.

Riprap - See stone riprap

River training structure - Any configuration constructed in a stream or placed on, adjacent to, or in the vicinity of a streambank that is intended to deflect currents, induce sediment deposition, induce scour, or in some other way alter the flow and sediment regimes of the stream

Rock-and-wire mattress - A flat or cylindrical wire cage or basket filled with stone or other suitable material placed on a streambank or filter as protection against erosion.

Rubble - Rough, irregular fragments of random size placed on a streambank to retard erosion. The fragments may consist of broken concrete slabs, masonry, or other suitable refuse.

Runout - See discharge.

Sack revetment - Streambank protection consisting of sacks (e.g. burlap, paper, or nylon) filled with mortar, concrete, sand, stone, or other available material placed on a bank to serve as protection against erosion.

Sand - Soil material that can pass the No. 4 (4.76 mm) U.S. Standard Sieve and be retained on the No. 200 (0.075 mm) sieve.

Scour - Erosion due to flowing water; usually considered as being localized as opposed to genera bed degradation.

Sediment load - The sediment carried through a channel by streamflow.

Sediment yield - The total sediment outflow from a drainage basin during a specific period of time. The outflow includes bed load as well as suspended load, and usually is expressed in terms of weight or volume per unit time.

Seepage - The slow movement of water through small cracks and pores of the bank material.

Sill - A structure built across the bed of a stream to prevent scour or head-cutting; see also grade-control structure.

Silt - Material passing No. 200 (0.074 mm) U.S. Standard Sieve that is nonplastic or very slightly plastic and exhibits little or no strength when air-dried (Unified Soil Classification System)

Sloughing - Shallow movement of a soil mass down a streambank as the result of an instability condition oat or near the surface (also called slumping). Conditions leading to sloughing are: bed degradation, attack at the bank toe, rapid drawdown, and slope erosion to an angle greater than the angle of repose of the material.

Soil-cement - A designed mixture of soil and portland cement compacted a a proper water content to form a veneer or structure that can prevent streambank erosion.

Spur dike - See dike.

Stable channel - A condition that exists when a stream has developed just the right bed slope and cross section for its channel to transport the water and sediment delivered from the upstream watershed without any of the sediment being deposited or without any soil particles being removed from the bed or bank.

Stage - Water-surface elevation of a stream with respect to a reference elevation.

Stone riprap - Natural cobbles, boulders, or rock dumped or placed on a streambank or filter as protection against erosion.

Streambank erosion - Removal of soil particles or a mass of particles from a bank surface due primarily to water action. Other factors such as weathering, ice and debris abrasion, chemical reactions, and land-use changes may also directly or indirectly lead to streambank erosion.

Streambank failure - Collapse of a bank due to an instability condition.

Streambank protection - Any technique used to prevent erosion or failure of a streambank.

Suspended-sediment load - That part of a stream's total sediment load which is transported within the body of fluid and has very little contact with the bed.

Synthetic mattress, matting, or tubing - A grout- or sand-filled, manufactured, semiflexible casing placed on a streambank to prevent erosion.

Tetrahedron - Component of river-training works made of six steel or concrete struts fabricated in the shape of a pyramid.

Tetrapod - Bank-protection component of precast concrete consisting of four legs joined at a central joint, with each leg making an angle of 109.5 deg with the other three.

Thalweg - The line extending down a channel that follows the lowest elevation of the bed.

Tieback - Structure placed between revetment and bank to prevent flanking.

Timber or brush mattress - A revetment made of brush, poles, logs, or lumber interwoven or otherwise lashed together. The completed mattress is then placed on the bank of stream and weighted with ballast.

Toe - That portion of a stream cross section where the lower bank terminates and the channel bottom or the opposite lower bank begins.

Toe-fill - Break in slope between the bank and the overbank area.

Tractive force - The drag on a streambank caused by passing water which tends to pull soil particles along with the streamflow.

Trench-fill revetment - Stone, concrete, or masonry material placed in a trench dug behind and parallel to an eroding streambank. When the erosive action of the stream reaches the trench, the material placed in the trench armors the bank and thus retards further erosion.

Turbulence - Motion of fluids in which local velocities and pressures fluctuate irregularly in a random manner as opposed to laminar flow where all particles of the fluid move in distinct and separate lines.

Upper bank - The portion of a streambank having an elevation greater than the mean water level of the stream.

Van dikes - Structures designed to direct streamflow away from an eroding bank line, but permitting limited amounts of both water and sediment to pass landward of the structure.

Vegetation - Woody or nonwoody plants used to stabilize a streambank and retard erosion.

Velocity (of water in a stream) - The speed that water travels in a given direction; expressed as a distance traveled during an interval of time.

Watershed - See drainage basin.

Wave attack - Impact of waves on a streambank.

Windrow revetment - A row of stone (called a windrow) placed on top bank landward of an eroding streambank. As erosion continues the windrow is eventually undercut, launching the stone downslope, thus armoring the bank face.

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