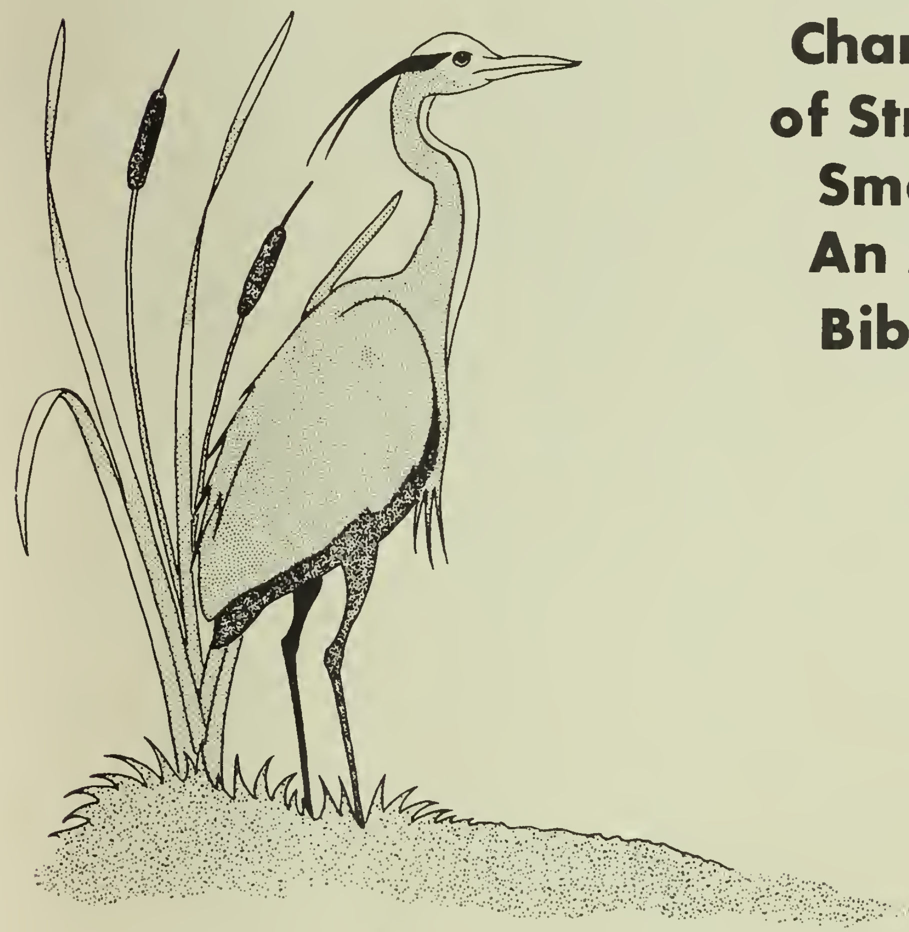
Biological Services Program

FWS/OBS-80/12
July 1980



# Effects of Bank Stabilization on the Physical and Chemical Characteristics of Streams and Small Rivers: An Annotated Bibliography



Fish and Wildlife Service

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FWS/OBS-80/12
July 1980

# EFFECTS OF BANK STABILIZATION ON THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF STREAMS AND SMALL RIVERS: AN ANNOTATED BIBLIOGRAPHY

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## PREFACE

This annotated bibliography was prepared as part of a project to synthesize and reference available information on the impacts of bank stabilization on physical and chemical characteristics of small streams. A companion document entitled "Effects of Bank Stabilization on the Physical and Chemical Characteristics of Streams and Small Rivers: A Synthesis" (FWS/OBS-80/11), presents a synthesis of selected literature from the bibliography, and provides guidelines for planning bank protection and stabilization activities. The bibliography and synthesis are intended for use by individuals concerned with the biology, chemistry, engineering, geology, and hydrology of streams that have been, or are to be, altered.

The annotated bibliography and synthesis are available from the:

Information Transfer Specialist
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## EXECUTIVE SUMMARY

This annotated bibliography provides a reference source of information on the impacts of bank stabilization on the physical and chemical characteristics of streams and small rivers. The bibliography has 213 references, and is indexed by 26 key subject headings. Papers range from technical documents to general discussions addressing the physical and chemical changes that result from various types of bank stabilization activities. Many of the annotations provide a thorough summary of pertinent information contained in the respective references.

This report was submitted in fulfillment of contract number 14-16-0009-78-035 by the Missouri Institute of River Studies, University of Missouri, Rolla, under the sponsorship of the Office of Biological Services, U.S. Fish and Wildlife Service. Work was completed as of June 12, 1979.

## TABLE OF CONTENTS

# LIST OF ABBREVIATIONS

| | |
|---|---|
| cfs | cubic feet per second |
| cm | centimeter |
| cm/sec | centimeter per second |
| cu km | cubic kilometer |
| ft | foot |
| ha | hectare |
| km | kilometer |
| km/hr | kilometer per hour |
| kw-hr | kilowatt hour |
| m | meter |
| mm | millimeter |
| mph | mile per hour |
| m/sec | meter per second |
| ppm | part per million |
| sec-ft | second foot |
| sq km | square kilometer |

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The authors are grateful to Wilma Hartman, Librarian for Public Services, Kathy Adams, Documents Librarian, and other staff members of the Linda Hall Library for Science and Technology, and to Connie McKenzie, Librarian for Region VII, U.S. Environmental Protection Agency, for their assistance in the search for, and acquisition of literature. Librarians and section personnel of the U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi, were generous in supplying literature. Edie Ramey, Information Specialist of the former National Stream Alteration Team, Fish and Wildlife Service, carried out the computer literature searches and was always helpful in answering our inquiries.

Jacquelyn S. Collins-Snow, work-study student in Biology, assisted us faithfully, and the library staff of the Volker Campus of the University of Missouri-Kansas City provided additional services. We appreciate the administrative efforts of Paul R. Munger, Director, and Jerome Westphal, Assistant Director, of the Institute of River Studies of the University of Missouri-Rolla. Finally, we are indebted to many workers with interests in bank stabilization, who provided us with literature and sources of additional information.

# INTRODUCTION

The purpose of this annotated bibliography is to provide a reference to information on the impacts of bank stabilization on physical and chemical dynamics of small streams. It is intended for use by persons concerned with management of streams whose banks have been, or will be, stabilized. Stabilization includes lining of banks, often accompanied by reshaping of the banks and channel.

There are 213 references in this bibliography, alphabetized by author. At the end of each annotation, numbers are listed which correspond to key subject headings in an index following the last reference. The reader is directed to the key word index as a means of selecting references which address one or more particular topics. Nine of the 26 subjects appearing in the index are specific stream characteristics affected by stabilization, as described by Yorke (1978). Papers of particular interest, either because they pertain to small streams, or because of their excellence as general or bibliographic references, are marked with an asterisk (*) at the beginning of the reference.

Papers referenced in this bibliography range from technical documents to general discussions of the physical and chemical dynamics of banks, channels and flows of streams and rivers. There is a paucity of quantitative information related to specific impacts of bank stabilization on the physical and chemical characteristics of small streams. Selected general references on major rivers which contain information applicable to management of streams are included. In the case of several lengthy papers, information provided in the annotation is all that the paper contains relative to the subject.

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ANNOTATED BIBLIOGRAPHY

1. Anonymous. 1925. Protecting steep banks by planting live willow poles. Eng. News-Record 94(20):822-823.

Instead of planting cuttings in slopes in Canada and the U.S., large poles of live willows with their butts buried at the toe of the slope are laid up the slope in shallow trenches and allowed to take root. The poles can obtain moisture from around their butts and are independent of the amount of moisture in the face of the bank. The bank slope is graded to uniformity, and live poles of white willow (*Salix alba*) are buried in shallow trenches. Buried butts are anchored to wooden or iron fence posts driven into the ground at the toe of the slope, and to poles of live willow set well back from the top of the bank. Poles are spaced about five feet apart. The lower edge of the slope is protected by a stone mattress made by filling a wire net with stones and securing the net to anchor posts. Above this, brush is laid between the poles and held in place by wire fencing laid over the brush and fastened to the poles. (21, 24)

2. Anonymous. 1935. Effective river control by concrete tetrahedrons. Eng. News-Record 115:470-471.

Service lives of five years on the Belle Fourche River (Devil's Tower National Monument Wyoming) and seven years on the Santa Clara River (California) attest to the durability and efficiency of skeleton concrete tetrahedrons for bank protection and channel regulation. (21)

3. Anonymous. 1957. New riprap idea at Ice Harbor Dam. Western Construction 32(1):114.

Steel mesh was used to bind riprap to withstand the strong currents of the Snake River, Washington. (21, 26)

4. Anonymous. 1971. Stream channelization destroys fishing, pp. 90-91. *In* Stream Channelization. Part I. Hearings before a Subcommittee of the Committee on Government Operations, House of Representatives, 92nd Congress, First Session, 3-4 May 1971. U.S. Government Printing Office, Washington, D.C.

Stream channelization in Missouri has diminished fishing success. North Missouri rivers, including the Chariton and Grand, are involved. Larry Belusz of the Missouri Department of Conservation compared the fishery of channelized and unchannelized portions of the Blackwater River in Johnson County, Missouri. Channelization had taken place almost 50 years before, in the 1920's. In the unchannelized portion, there were 565 pounds of fish per acre; in the lightly channelized portion, there were 298 pounds per acre; and in the heavily channelized portion, only 131 pounds per acre. (3, 4, 15)

5. Apmann, R. P., and P. H. Blinco. 1969. Experiences with bedsills in stream stabilization. Am. Soc. Civil Eng. Proc., J. Waterways and Harbor Div. 95(WW3):319-328.

In Buffalo Creek (New York), bedsills were effective in controlling stream channel degradation resulting from a cutoff of a channel meander loop system. Bedsills have stabilized the channel for more than 10 years since construction. (3, 21)

6. Apmann, R. P., and M. B. Otis. 1965. Sedimentation and stream improvement. N.Y. Fish Game J. 12(2):117-126.

Changes in a stream channel without protection of the stream geometry can affect the aquatic biota. Stream channels are in delicate balance with their sediment loads and water discharges. Construction activities in a watershed, including stream improvement, must be based on a knowledge of stream behavior and sedimentation, if unanticipated detrimental changes in the shape and location of the channel are to be avoided. If the stream bed or banks are erodible, they will add sediment to the flow. If a stream is undergoing significant degradation, a bank revetment should be founded deeply in the stream bed, so that erosion will not undermine the work. Certain stream measures are designed specifically to bring about improved stream conditions. Boulder retards, rock and log dams, deflectors, and cribbing all form local changes in geometry that are beneficial for the aquatic biota. Retards and dams cause pool formation. Deflectors induce the formation of a narrower, swifter and deeper channel. Cribbing protects banks and provides fish cover. It is important to realize that any changes made in the stream or in the watershed tend to cause new adjustments. For example, a significant amount of armoring revetment placed on stream banks would reduce the sediment supply, thereby increasing bed erosion and degradation and requiring the revetment toe to be placed deep in the existing channel bed. Placing revetment in channel bends produces the greatest erosion resultant. If bank stabilization is to succeed, structures must have certain functional qualities: (1) Durability against exposure to the atmosphere and to abrasion by transported debris; (2) stability against fluid forces in the stream, the impact of transported debris, and the lifting action of ice; (3) stability of the bank against slippage; and (4) effectiveness in preventing loss of subgrade or bank material by action of water at the boundary. (1, 7, 8, 20, 21, 22, 26)

7. Arner, D. H., H. R. Robinette, J. E. Frasier, and M. H. Gray. 1976. Effects of Channelization of the Luxapalila River on Fish, Aquatic Invertebrates, Water Quality, and Furbearers. FWS/OBS-76/08. U.S. Fish and Wildlife Service, Washington, D.C. 66 pp.

Biological data collected from July 1973 to January 1976 from an old channelized segment (over 52 years), an unchannelized segment, and a newly channelized segment of the Luxapalila River, Mississippi and Alabama, revealed that productivity of the old channelized segment has not recovered to the levels exhibited in the unchannelized segment. There were no evident differences in water quality between the three segments except for higher turbidity trends in the newly channelized segment. Sediments of the streambed in the unchannelized segment were larger than those in the old or newly channelized segments. (1, 4, 14, 15, 16, 20)

8. Baker, V. R. 1977. Stream-channel response to floods, with examples from central Texas. Geol. Soc. Am. Bull. 88:1057-1071.

Although not concerned directly with bank stabilization, this paper provides excellent insight into problems in small streams that occur after heavy rainfalls in small basins. (7)

9. Barrett, R. J. 1966. Use of plastic filters in coastal structures, pp. 1048-1067. <u>In</u> Proceedings of the Xth International Conference on Coastal Engineering, Tokyo, Japan. September, 1966.

Normally, filters for granular soils are made up of layers of graded sand, gravel, and stone materials in various combinations of thicknesses. The materials often are expensive and may be unavailable geographically. Even if such materials are accessible, proper placement is tedious and demands strict supervision. The author discusses the use of "plastic filters" as a replacement for graded filter systems and filter blankets in coastal structures. While the discussion and illustrations are limited to coastal structures, plastic filters can be, and have been, used in river, lake, canal, dam, and other hydraulic structures. (5, 22)

10. Barsdale, R. W. 1960. Bank protection on Central Valley streams. Am. Soc. Civil Eng., J. Waterways and Harbors Div. 86(WW4):1-15.

Bank protection is an important adjunct to flood control and navigation projects in the Central Valley of California. Satisfactory corrective measures for various channel types, varying from tidal waters to foot-hill streams, are described. The major river systems are the San Joaquin and Sacramento. Methods being tested include, among others, the use of hand-fitted quarry stone (expensive) and lumber mattresses. To select the riprap to be used, velocities within 10 feet of the bank are used, rather than average channel velocities. A filter blanket is needed beneath bank protection materials. Filter blankets are used,

when there is (1) considerable tidal action, (2) wave action, or (3) where bank material is incohesive and without sufficient range of sizes to serve as its own filter. (21, 22)

11. Barton, B. A. 1977. Short-term effects of highway construction on the limnology of a small stream in southern Ontario. Freshwat. Biol. 7:99-108.

During construction, suspended solids increased to a high of 1,390 mg/l, but later returned to pre-construction levels of less than 5 mg/l. Similarly, sediment deposition increased ten-fold to 0.61 g dry wt/cm$^2$/day directly below the construction site during stream rechannelization after completion of the culvert. A decreased proportion of organic matter in sediments indicated that they came from the construction site. Sediments were readily removed by spates (floods) and apparently settled out in downstream ponds. There was no change in water chemistry. There was a noticeable shift in species composition. Organisms removed during construction were replaced quickly by drift. (1, 6, 9, 14, 20)

12. Barton, J. R., E. J. Peters, D. A. White, and P. V. Winger. 1972. Bibliography on the Physical Alteration of the Aquatic Habitat (Channelization) and Stream Improvement. Brigham Young Univ. Publ., Provo, Utah. 30 pp.

The negative effects of channelization on most fish and invertebrate populations are widely recognized, but poorly documented. (2, 4, 14, 15)

13. Barton, J. R., D. A. White, P. V. Winger, and E. J. Peters. 1972. The effects of highway construction on fish habitat in the Weber River, near Henefer, Utah, pp. 17-28. In D. A. Hoffman (coordinator), Ecological Impact of Water Resource Development. REC-ERC-72-17. Bureau of Reclamation, Denver, Colo.

Highway construction can be detrimental to a river in several ways: (1) shortening the channel length by straightening a meandering channel; (2) removing cover necessary for fish; (3) exposing the channel to erosion which may increase the turbidity of the stream, which in turn may harm aquatic life; and (4) affecting aesthetic qualities. This study had as its objectives:(1) the examination of effects of channel changes on the fish and invertebrate populations of the river; (2) the evaluation of hydraulic effectiveness of various structures to create a good fish habitat; (3) the comparison of various types of structures for effectiveness; and (4) the development of plans for designing future projects, when river channel changes are needed. Structures built into the changed channels of the Weber River were effective in producing fish habitat that is comparable to, or better

than, habitats of unchanged sections. Structures made of large riprap were more economical than gabions and produced good fish habitats. Fish populations were essentially equal in changed and unchanged areas two years after construction. (3, 6, 8, 14, 15)

14. Barton, J. R., and P. V. Winger. 1973a. A Study of the Channelization of the Weber River, Summit County, Utah. Final Rept., Utah Div. Wildl. Resour. and Utah State Dept. Highways. Brigham Young Univ., Provo, Utah. 188 pp.

Construction of Interstate-80 in Henefer Valley, Utah, resulted in the channelization of 1.6 miles of the Weber River. In an attempt to ameliorate some of the adverse effects of channelization, instream structures (deflectors, check dams) were installed in altered sections. Hydrologic features in the altered portions of the river resembled those in unchanged areas. Holes were scoured around the structures, and sediments were deposited below, forming riffles. Macroinvertebrate and fish populations were similar concerning the correct placement and types of structures to be used to provide desirable fish habitat. Meanders were cut off, and there was a net loss of 0.4 mile of the Weber River. Streamside vegetation was reduced, causing a possible temperature elevation and loss of aesthetic appeal. The study showed that if channelization is necessary, installation of rehabilitation structures will improve conditions over those that would exist, if no structures were installed. (1, 3, 4, 8, 14, 15, 25)

15. Barton, J. R., and P. V. Winger. 1973b. Rehabilitation of a channelized river in Utah, pp. 1-10. In Hydraulic Engineering and the Environment. Proceedings of the Hydraulic Division Specialty Conference, Bozeman, Montana, 15-17 August 1973.

The Weber River in northeastern Utah drains 5,340 square miles and empties into the Great Salt Lake. Construction of Interstate-80 resulted in channelization of five stretches of the river. Straightened channels were 70-ft wide and lined with riprap to stabilize the banks. Instream rehabilitation structures were placed in the channel to attempt to create suitable fish habitat. These structures included gabion deflectors, check dams, rock deflectors, and random rocks. Soon after road construction and concurrent channelization, fish populations were the same in changed and in unchanged portions of the river, as far as composition, standing crop, and population estimates were concerned. Fish in altered areas appeared to be concentrated in holes near instream structures. Construction and initially unstable channel areas in altered sections caused a marked increase in erosion and turbidity. These were of short duration. The water chemistry and temperature were not altered by channelization. Structures did not alleviate the following problems associated with channelization: (1) Loss of stream length; (2) destruction of aesthetics; and (3) loss of streamside vegetation. Streamside vegetation was cleared for 100 ft on each side of the new channel. (1, 3, 4, 6, 9, 15, 20, 23)

16. Bayless, J., and W. B. Smith. 1967. The effects of channelization upon the fish population of lotic water in eastern North Carolina. Proc. Ann. Conf. S.E. Assoc. Game Fish Comm. 18:230-238.

Channelization reduces the standing crop and diversity of stream fish populations. In a study of 23 channelized and 36 unchannelized streams, it was found that channelization reduced the number of game fishes ( 6 inches long) by 90%, and reduced the weight by 80%. Only limited stream recovery was noted 40 years after the channelization. (3, 4, 15)

17. Bhowmik, N. G., and D. B. Simons. 1969. Stabilization of Alluvial Channels: Surface Water. Nat. Resour. Cent. Publ., Colorado State Univ., Fort Collins. 54 pp.

The authors examined flow dynamics and the effects of turbulent fluctuations of velocity, drag forces, lift forces, waves, and secondary circulations on the stability of riprap particles forming the perimeter of stable alluvial channels. (17, 21)

18. Bianchi, D. R., and R. Marcoux. 1975. The physical and biological effects of physical alteration of Montana trout streams and their political implications, pp. 50-59. In Symposium on Stream Channel Modification, Proceedings, Harrisonburg, Virginia, 15-17 August 1975. Available from: Stream Channel Modification Symposium, Route 1, Box 312, Grottoes, Va.

In 1973, 160 miles of six streams were surveyed. Twenty-four miles of channel and 44 miles of streambank were determined to have been altered. Trout populations were censused in three adjacent sections of the Ruby River with different amounts and types of alterations. There were approximately three times as many brown trout in a natural section as compared to a bulldozed section and two times as many as compared to a riprapped section. (3, 4, 15, 21)

19. Blackwelder, B. 1971. Statement of Brent Blackwelder, representing Friends of the Earth, pp. 327-330. In The Effect of Channelization on the Environment. Hearing before the Subcommittee on Flood Control - Rivers and Harbors of the Comm. on Public Works, U.S. Senate, 92nd Congress, First Session, 27 July 1971. Ser. No. 92-H24. U. S. Government Printing Office, Washington, D.C.

After outlining contradictions in the stream channelization program and environmental effects of stream channelization, as well as the use of faulty economics, Mr. Blackwelder warns of future destruction of streams by the Soil Conservation Service, USDA, under PL 566. (4, 8)

20. Blank, D. S. 1977. Culvert fishways. Water Research in Action 2(7):1-2.

An introduction to the work of Dr. Fred Watts, a civil engineer at the University of Idaho, who has developed a design manual entitled Culvert Fishways. The manual enables engineers to answer the questions: (1) Can a culvert be built in a particular stream so that it will not hamper fish migration?; and (2) How can a culvert best simulate the natural environs? Culvert design is crucial. (8, 15)

21. Bondurant, D. C. 1963. Channel rectification structures, pp. 353-357. In Proceedings of the Federal Inter-Agency Sedimentation Conference, Jackson, Mississippi, 28 January - 1 February 1963. Misc. Publ. No. 970. U.S. Dept. of Agriculture, Washington, D.C.

Channel rectification structures are used to prevent erosion of banks, guide the flow along a desired alignment, restrict the flow to an effective waterway, or various combinations of the above. In most instances, these structures involve solid or permeable revetments or guide structures of varied types of materials and construction. There are few, if any, rational methods for design of such projects, and it is usually necessary to plan the layout wholly on the basis of experience and judgment. The author does not discuss design criteria. He discusses the usage of revetments, permeable training structures (e.g., pilings, fencing, jacks, brush), and groins. Deficiencies in knowledge are pointed out, and the desirability of a comprehensive investigation to develop rational design is suggested. (3, 21)

22. Boussu, M. F. 1954. Relationship between trout populations and cover on a small stream. J. Wildl. Mgt. 18(2):229-239.

Small trout streams need brush or other types of overhanging bank cover. Rooted and free-floating aquatic vegetation was found to be valuable for fish cover in Trout Creek, Gallatin County, Montana. (15, 25).

23. Bradt, P. T. 1974. The ecology of the benthic macroinvertebrate fauna of the Bushkill Creek, Northampton County, Pennsylvania. Ph.D. Dissertation, Lehigh Univ., Bethlehem, Pa. 182 pp.

The creek was studied from May 1972 to September 1973. It supports a brown trout (*Salmo trutta*) population. A station immediately below gabions, installed following rechannelization of the stream, had the highest number of macroinvertebrate animals, the highest mean number of taxa, and the highest mean wet weight. Most chemical parameters increased as water proceeded downstream. Gabions narrowed the stream channel, increased the velocity of flow, and caused a higher dissolved oxygen content and lower water temperature in open areas. Community groups planted ground cover and trees to aid in erosion control. (4, 9, 14, 18, 23, 26)

24. *Bradt, P. T., and G. E. Wieland, III. 1978. The Impact of Stream Reconstruction and a Gabion Installation on the Biology and Chemistry of a Trout Stream. Completion Rept., OWRT, USDI. Lehigh Univ., Bethlehem, Pa. 62 pp.

The authors' aim was to evaluate the effect of a gabion installation and stream reconstruction in a two km section of a rechanneled stream. The Bushkill Creek, Northampton County, Pennsylvania, was sampled biweekly for 16 months. Prior to sampling, stream reconstruction efforts had included both a gabion installation to narrow and deepen the stream bed and tree and shrub planting to cover bare banks and eventually to provide shade. The following water quality characteristics increased through the rechanneled area: Specific conductance, dissolved oxygen, percent oxygen saturation, and total alkalinity. Orthophosphate decreased, and flow velocity increased. Limestone springs contributed to the increase in conductance and alkalinity. Increased photosynthetic activity and water turbulence contributed to the increases in dissolved oxygen and oxygen saturation. The gabions deepened and narrowed the stream channel, resulting in a cooler stream in summer. Large rocks and small dams were placed in the stream to create pool and riffle areas. It was difficult to separate the effects of gabions and other types of stream reconstruction from those of limestone springs, increased insolation (with associated increased primary productivity), and increased diversity and biomass of the benthic macroinvertebrate fauna. (4, 9, 18, 20, 23, 26)

25. *Brusven, M. A., F. J. Watts, R. Leudtke, and T. L. Kelly. 1974. A Model Design for Physical and Biotic Rehabilitation of a Silted Stream. Completion Rept., Project A-032-IDA. Idaho Water Resour. Res. Institute, Univ. of Idaho, Moscow. 96 pp.

The aim of this study was to develop a methodology for rehabilitating a silt-polluted stream by use of in-stream sediment-flushing devices, and to measure the biological impact of rehabilitation measures on the insect community. Field work was carried out in the East Fork and main stem of Emerald Creek, a tributary to the St. Maries River in northern Idaho. Both field and laboratory studies were used. Three basic types of hydraulic structures were constructed to modify the flow characteristics of Emerald Creek. Log drop structures and two types of channel constrictors, rock-filled gabions and log dikes, were used at different locations. Changes in the aquatic insect community were monitored in conjunction with measurement of physical changes of the streambed. In-stream alterations were effective for increasing sediment transport, thereby improving insect and fish habitat. Debris jam removal, channel diversion, and gabion deflectors caused flushing of fine sediments from both runs and pools. Log-drop structures caused scouring of pools, thereby increasing the pool-riffle ratio. Post-alteration analyses of test transects yielded higher values of percent cobble, average sediment size, and mean channel depth, indicating the



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production of a more suitable insect habitat. After completion of channel alterations, insect diversity and total numbers increased. Community changes were most pronounced at gabion sites. (8, 14, 20, 21)

26. Bulkley, R. V. 1975. A Study of the Effects of Stream Channelization and Bank Stabilization on Warmwater Sport Fish in Iowa. Subproject No. 1. Inventory of Major Stream Alterations in Iowa. FWS/OBS-76/11. U.S. Fish and Wildlife Service, Washington, D.C. 338 pp.

Aerial photographs and public records were used to determine the amount of channelization of Iowa streams with drainage areas greater than 50 square miles. The extent of channelization was determined by measuring stream sinuosity (degree of meander). The author estimates that from 1,000 to 3,000 miles of streams have been lost in Iowa, since settlers first arrived in the mid-1800's. (An additional Appendix entitled "Recorded Stream Channelization Projects in Iowa," 220 pp. is available to accompany this publication.) (3, 4, 19)

27. *Bulkley, R. V., R. W. Bachmann, K. D. Carlander, H. L. Fierstine, L. R. King, B. W. Menzel, A. L. Witten, and D. W. Zimmer. 1976. Warmwater Stream Alteration in Iowa. Extent, Effects on Habitat, Fish, and Fish Food, and Evaluation of Stream Improvement Structures (Summary Report). FWS/OBS-76/16. U.S. Fish and Wildlife Service, Washington, D.C. 39 pp.

This report summarizes results of five other subprojects, conducted from 1973 to 1976, to determine the extent of stream channelization in Iowa, differences in populations of fish and fish-food organisms in channelized and unchannelized streams, effects of stream alterations for highway bridge construction, and the value of stream-bank stabilization structures to fish habitat. More than 1,000 miles of stream capable of supporting permanent fish populations were lost in Iowa through stream channelization. Channelization resulted in more uniform water depth and current velocities, coupled with a reduction in habitat diversity in affected streams. More species of fish were found in natural sections, although fish were as abundant in short-reach sections ($\pm$ 0.5 km) channelized 10-15 years ago as in natural sections, wherever brush piles and trees had accumulated in the stream. Certain structures installed in Iowa streams to protect highway bridges improved fish habitat by producing scour holes and providing cover and substrate for fish-food organisms. It was noted that stream-bank protection structures that extend far enough into the stream channel to produce a permanent scour hole encourage fish populations by providing cover. Structures made of rock enhance production of fish-food organisms, such as mayflies and caddisflies. It was recommended that devices installed for highway and bridge protection be constructed, where feasible, of rock, and that they be designed to extend into the stream 1/3 or more of the channel width to produce a permanent scour hole at the structure base. Revetments do not project into the stream and thus have caused no appreciable difference in maximum or minimum

stream depth or velocity. Retards also run parallel to the stream and have not affected maximum current velocity, but they have increased stream depth 8% to 110%. Permeable metal jetties did not affect current velocity, but maximum stream depths at the structure were greater by 7% to 94% than was the case in control area. Differences in water temperatures and turbidities were inconsistent and frequently negligible between control, structure, and below-structure areas. Although several types of bank stabilization structures studied had measurable impacts on stream habitat and on fish food organisms, their basic purpose -- to maintain a stable channel and discourage stream meandering -- is opposed to the purpose of most structures installed exclusively to improve fish habitat, i.e., to increase habitat diversity by encouraging river meanders. The authors recommended that no additional long reach (≥1.0 km) channelization be carried out. Effects of short-reach projects can be lessened by leaving as much meander in the stream as possible and by proper placement and design of bank stabilization structures. (7, 8, 14, 15, 19, 20, 21, 23, 26)

28. Bullard, W. E. 1963. Effect of highway construction and maintenance on stream sediment loads, pp. 52-56. In Proceedings of the Federal Inter-Agency Sedimentation Conference, Jackson, Mississippi, 28 January - 1 February 1963. Misc. Publ. No. 970. U.S. Dept. Agriculture, Washington, D.C.

Thousands of miles of new road being built yearly, coupled with the tremendous existing road network being maintained, cause the disturbance of hundreds of thousands of acres of land and millions of tons of soil. Much of the disturbed soil erodes and becomes sediment in streams. This can largely be avoided by proper planning and care during construction. A number of positive actions will enable builders to hold soil disturbance, erosion, and sedimentation to a minimum. (1, 8, 13, 20)

29. Burns, J. W. 1972. Some effects of logging and associated road construction on northern California streams. Trans. Am. Fish. Soc. 101(1):1-17.

Extensive use of bulldozers on steep slopes for road building and in stream channels during debris removal caused excessive streambed sedmentation in narrow streams. Four small streams were studied. Flow, physical dimensions, and water quality were measured, and the macrobenthos and fisher were monitored. (1, 6, 9, 14, 15, 20)

30. Bursali, S. 1973. Economic revetments for protecting the banks of Meric and Ergene Rivers flood canals against wave erosion, pp. 203-212. In Sediment Transportation, Vol. 1. Proceedings of the International Association for Hydraulic Research. International Symposium on River Mechanics, Bangkok, Thailand, 9-12 January 1973.

Flood levees constructed along the Meric and Ergene Rivers (Turkey) were studied to determine the chief cause of damage on the water side of the levees. Tractive forces on the slopes of the levees, constructed to protect agricultural lands from floods, were found to be less than the critical tractive force on the bottom. By studying wave effects, it was found that the dynamic action of waves was the main cause of slope erosion. The proper type of revetment and the weight of stones needed to resist wave effects were determined. (11, 17, 21)

31. Byers, W. G. 1962. Stabilization of Canadian River at Canadian, Texas. Am. Soc. Civil Eng., J. Waterways and Harbors Div. 88(WW3):13-26.

Permeable steel jetties, installed in 1926, function by reducing current speed, thereby causing deposition of suspended sediments. The river, where the jetty is installed, has a wide, shallow bed in a deep alluvial deposit. (1, 20, 21, 26)

32. Calhoun, C. C., Jr. 1972. Development of Design Criteria and Acceptance Specifications for Plastic Filter Cloths. Tech. Rept. S-72-7. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 106 pp.

Plastic filter cloths have been used as substitutes for sand and gravel filters and riprap bedding in various projects. Results of questionaires circulated to Corps of Engineers offices to determine the extent and diversification of uses of filter cloth are given. (8, 22)

33. Campbell, F. B. 1966. Hydraulic design of rock riprap. Misc. Pap. No. 2-777. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 52 pp.

The author summarizes a study of open channel flow conditions affecting riprap design and suggests a design procedure based on hydraulic principles, rather than on rule-of-thumb formulae. Riprap design is idealized by study of the stability of a cubical element. Field and laboratory investigations required for the development of firm design criteria are recommended. The author states that no single specification for riprap can cover all cases. Good field data are needed for curved and straight reaches, where new riprap of known graduation and shape has been placed. Measurements must include a vertical velocity profile of at least seven velocity observations in a single vertical. More observations are needed on bends than in straight reaches. Knowledge of the velocity profile near the bottom can be expected to yield a reasonable average velocity acting on the rock. Size of rock, in turn, affects the velocity distribution. (8, 21, 26)

34. Campbell, K. L., S. Kumar, and H. P. Johnson. 1972. Stream straightening effects on flood runoff characteristics. Trans. Am. Soc. Agric. Eng. 15(1):94-98.

The purpose of the study was to evaluate the effects of stream straightening and diking on flow characteristics of storm runoff effects. In this study of the Boyer River in Western Iowa, the emphasis was on flood-routing (peak discharge, flood-wave travel time, and duration of flooding). Many Iowa rivers have been straightened and diked to achieve drainage and flood control on riparian land. Downstream discharge is increased. Flow characteristics used were timing and magnitude of the peak discharge as the flow progressed downstream. (7, 17, 18)

35. Carey, W. C. 1966. Comprehensive river stabilization. Am. Soc. Civil Eng., J. Waterways and Harbors Div. 92(WW1):59-86.

The status of bank protection (circa 1966) on the lower Mississippi River and its tributaries is presented in relation to three major construction techniques: (1) channel dredging, (2) bank grading, and (3) bank revetment. Revetments are comprised of either (a) articulated concrete mattresses, (b) reinforced asphalt mattresses, or (c) riprap with a toe trench (for small rivers). (19, 21)

36. Carlson, J. R., and J. O. Preston. 1976. Streamco purpleosier willow. Am. Nurseryman 144(2):12, 73.

Streamco purpleosier willow, Salix purpurea, is a resilient, medium-sized shrub that has been used successfully to protect stream banks in the northeastern U.S. The species was used to revegetate stream banks after tropical storm Agnes. After two growing seasons, good plantings averaged 5-6 ft high. Streamco has been planted successfully throughout New England and in New York, Pennsylvania, New Jersey, Virginia, West Virginia, Kentucky, and Michigan. It can adapt wherever the species is found naturalized in the U.S. and Canada. It should be planted on banks that have been graded and cleared of debris and trees. (24)

37. Cederholm, C. J. 1972. The short-term physical and biological effects of stream channelization at Big Beef Creek, Kitsap County, Washington. M.S. Thesis, Univ. of Washington, Seattle. 91 pp.

During the summer of 1969, the lower 0.5 mile of Big Beef Creek was channelized, ostensibly to improve salmon and trout spawning and rearing habitat and for flood control. Channelization was carried out using two bulldozers and other heavy equipment to straighten and narrow the high flow stream channel. The artificial dikes within the channelized area were made of streambed gravels. There was much erosion of the diked banks during high flow periods. Two years after stream channelization, 54% (2,987 cubic meters) of the sediments deposited in the channelized area came from erosion of these dikes coupled with stream bed degradation within the channelized area. Due to a greatly increased streambed slope and confining of flow by the dikes, the

streambed had high rates of scour and fill. The channelized area was not improved measurably as a spawning habitat. (4, 11, 12, 15, 17)

38. Charlton, F. G. 1972. The importance of river morphology in the design of training works, pp. 29.1.159-29.1.172. In International Commission on Irrigation and Drainage, Eighth Congress, Varna, R. 11, Trans., Vol. 5, Question 29.1.

Stretches of river channel that may be considered to have attained, for practical engineering purposes, a state of dynamic equilibrium develop a channel pattern (straight, meandered, or braided), channel cross section, and slope which are governed principally by the discharge characteristics and sediment loads. The importance of understanding the interrelations of these factors on the behavior of a river, prior to undertaking river training works which may affect the hydraulic geometry of the channel, is stressed. Types of bank failures discussed include scour at the toe of the bank causing undermining, abrasion, seepage pressure effects, and bank collapse caused either by saturation of cohesive soils or the cracking of those soils. (3, 8, 11)

39. Christensen, M. 1976. The Germans plant alongside watercourses to prevent growth of water weeds. Hedeselskabets Tidsskrift 97(8): 164-165.

The author briefly describes the use of rows of trees along the banks of canals and drainage channels in the Weser-Ems region of northwest Germany for the control of water weeds. The shade reduces water temperatures as well as available sunlight. Species used included chiefly alder (Alnus glutinosa) and ash (Fraxinus excelsior), but all the usual shelterbelt species, including willows and poplars, are used. In most cases, trees are planted only on one side to allow access for maintenance. Results are good, but are even better when both sides are planted. Bank erosion, and the need for edge mowing, are reduced greatly by the tree plantings. (20, 23, 24)

40. Citizens Committee Against Channelization. 1971. Facts on channelization, pp. 247-255. In Stream Channelization (Part 1). Hearings before a Subcommittee of the Committee on Government Operations, House of Representatives, 92nd Congress, First Session, 3-4 May 1971. U.S. Government Printing Office, Washington, D.C.

A booklet containing photographs of altered streams is included in the subcommittee hearings. Graphic evidence of the results of dredging, straightening of channels, bulldozing of vegetation on stream banks, and draining of wetlands is presented. Adverse environmental effects of channelization, as listed in the booklet, include the following: (1) elimination of fish habitat and lowered aquatic production; (2) habitat destruction; (3) degradation of water quality including increased erosion and siltation; (4) increased downstream flood damages; (5) lowered water tables; (6) destruction of valuable hardwood trees; (7) destruction of archeological sites; (8) loss of aesthetic values; and (9) loss of rare and endangered species. (4, 10)

41. Congdon, J. C. 1971. Fish populations of channelized and unchannelized sections of the Chariton River, Missouri, pp. 52-62. In E. Schneberger and J. L. Funk (eds.). Stream Channelization: A Symposium. Special Publ. No. 2. North Central Division, American Fisheries Society, Omaha, Nebr.

Nearly 100% of the 1,842 miles of major streams in Missouri north of the Missouri River have been channelized or are threatened with channelization on inundation by flood control reservoirs. The objective of this study was to determine fisheries losses resulting from stream channelization. Channel straightening resulted in a loss of 103 miles of river, or a 55.2% reduction in stream length. The combined effects of a poorer environment and reduced stream length resulted in an estimated 87% reduction in total standing crop in the channelized section studied. The standing crop of catchable-size fish was reduced by 89%. The channelized section of the Chariton River has high, vertical, eroding banks; there are few trees to provide shade. (3, 4, 15, 19)

42. Cox, E. P., and C. G. Chen. 1977. Evaluation of the Corrosion Resistance of Alternate Revetment Wire Fabric Materials in the Lower Mississippi River. CE, USA, Construction Eng. Research Lab., Champaign, Ill. 62 pp.

This report contains the results of a study of the corrosion resistance and strength of alternate fabric materials for use in articulated concrete revetment mattresses to be placed on the lower banks of the Mississippi River. Three groups of materials -- stainless steels, bimetallics, and organically coated low-carbon steels -- were evaluated based on short-term electrochemical laboratory tests, laboratory sensitization evaluations, and exposures of up to about four years in freshwater and 15 months in brackish water. (21)

43. Cozzens, H. F. 1946. Steel rails for bank protection on Salinas River, California. Civil Eng 16(3):113-115.

The Salinas River, third largest in California, has a channel that meanders through a highly cultivated area. Bank stabilization measures, carried out by private interests, include wooden pile jetties, iron jacks, tetrahedrons, flexible fence, and floating training works. (3, 21)

44. Crews, J. E. 1970. Bank stabilization in the Susquehanna River Basin. Am. Soc. Civil Eng., J. Waterways and Harbors Div. 96(WW1):87-95.

Banks were stabilized to aid local farmers and to improve water quality. Riprap and gabions were most economical as means for providing continuous protection for caving streambanks in the basin. (21, 22)

45. Cuskelly, S. L. 1969. Erosion-control problems and practices on national forest lands. Trans. Am. Soc. Agric. Eng. 12(1):69-70, 85.

Too often, downstream structures have been destroyed by floods originating on relatively small source areas. Small "feeder" side drainages must be treated before working on large gullies. Treatment methods are usually expensive and require careful design and execution. Water control of the flood source is accomplished by contour trenching and/or furrowing in U.S. Forest Service lands in the Intermountain Region. Contour trenching is done only in severely eroded flood-source areas. These are seeded and vegetated at the time of construction to insure stabilization. Trenches are used on steep slopes (30-75%). Contour furrowing is used on gentler slopes ( 35%). Control methods used to reduce bank erosion include rock gabions, groins, logs anchored to banks and reinforced with grass seedings and willow plantings, and drop structures. (8, 21, 22)

46. Dale, E. E., Jr. 1975. Environmental Evaluation Report on Various Completed Channel Improvement Projects in Eastern Arkansas. Publ. No. 30. Univ. of Arkansas Water Resources Research Center, Fayetteville. (Project DACW-03-74-C-0065, U.S. Army Engineer District, Little Rock, CE, Little Rock, Ark.)

The objectives of this study were to predict the effects of channel improvement projects and maintenance on biological elements, water quality, and aesthetics in the Village Creek Basin in Randolph, Lawrence, and Jackson Counties, Arkansas. A water quality comparison was made between unchannelized streams, channelized streams, and streams in which clearing was done on one side only. There was no correlation between water quality elements and channelization projects varying in age from two to more than 50 years old. However, there was a good correlation between turbidity values and the river basin or portion of it in which projects were located. There were some correlations between turbidity and dissolved oxygen values, and between turbidity and the size of the stream. (4, 9, 20)

47. Dallaire, G. 1977. Filter fabrics can cut costs of riverbank and shore protection structures. Civil Eng. 47(3):74-79.

Over the past decade, plastic filter fabrics have been used with increasing frequency in shore-protection and river-bank protection, and in other areas where water comes into direct contact with soil. Case studies of fabric use are provided, and the utility of the fabric under varied soil conditions is described. Sand is the preferred substrate, while some fabrics may clog when placed atop silt or clay soils. (22)

48. *Darnell, R. M., W. E. Pequegnat, B. M. James, F. J. Benson, and R. A. Defenbaugh. 1976. Impacts of Construction Activities in Wetlands of the United States. EPA-600/3-76-045. U.S. Environmental Protection Agency, Corvallis, Ore. 420 pp.

Included in the primary types of construction activity which severely impact U.S. wetlands are bank and shoreline construction, and dredging and channelization. Each type of construction activity is attended by an identifiable suite of physical and chemical alterations of the wetland environment which may extend for many miles from the site of construction and which may persist for many years. In turn, each type of chemical or physical modification has been shown to induce a derived set of biological effects, many of which are predictable, in general, if not in specific detail. The most environmentally damaging effects of construction activities in wetland areas, in order of importance, are: direct habitat loss, addition of suspended solids, and modification of water levels and flow regimes. Major construction-related impacts derive also from altered water temperatures, pH, nutrient levels, oxygen, carbon dioxide, and pollutants such as heavy metals and biocides. The first 75 pages of the report constitute an introduction to the ecology of wetlands. (6, 7, 9, 10, 20)

49. Davis, F. J., L. R. Burton, A. B. Crosby, L. D. Klein, and E. R. Lewandowski. 1973. Riprap Slope Protection for Earth Dams: A Review of Practices and Procedures. REC-ERC-73-4. U.S. Bureau of Reclamation, Denver, Colo. 23 pp.

Bureau of Reclamation practices and procedures for investigation, sampling, testing, and field control of riprap slope protection for earth dams are reviewed. Economics of providing upstream slope protection, including original and lifetime maintenance costs, is the predominant factor in selecting, designing, and constructing upstream slope protection. Detailed instructions are provided for investigators of riprap sources. (21)

50. DeCoursey, D. G., and C. G. Hunt. 1976. Characteristics of stable natural channels and their relation to channel design, pp. 5-13 to 5-24. In Proceedings of the Third Federal Inter-Agency Sedimentation Conference, Denver, Colorado, 22-25 March 1976. Publ. PB-245-100. (Available from the U.S. Dept. of Agriculture, Oxford, Mass.)



328-245 - 80 - 4

Interest in the design of stable stream channels has been spurred by recent problems of channel stability on artificially straightened or newly constructed channels. Solutions are not available readily. This paper is based on data collected at straight, stable reaches of a large number of stream gaging stations in or near Oklahoma. Cross sections of two different straight, stable reaches at each station were used to calculate channel slopes, cross-sectional areas, and other characterisitcs. Samples of bank and bed materials were analyzed for Atterberg limits, pH, particle-size distribution, angle of repose, and cation exchange capacity. The authors present a regime and tractive force theories of channel design, based on the assumption that the channels are in balance, and relate the bank and bed materials characteristics to the channel characteristics through the regime and tractive force equations of stable channel design. (1, 3, 10)

51. Dorris, T. C., B. J. Copeland, and G. J. Lauer. 1963. Limnology of the middle Mississippi River. IV. Physical and chemical limnology of river and chute. Limnol. Oceanogr. 8:79-88.

Between November 1954 and January 1956, weekly determinations of physical and chemical factors in the Mississippi River and Cottonwood Chute were made near Quincy, Illinois. Stream discharge exerted an overriding influence on most factors. Periods of high discharge were accompanied by increased turbidity, carbon dioxide, and solids, by lowered and more uniform water temperatures, and by decreased dissolved oxygen and photosynthetic productivity. Opposite effects were observed during periods of low stream discharge. In the study area, the Mississippi River has been modified by Lock and Dam 21 at river mile 325 above the confluence of the Mississippi and Ohio Rivers. (7, 9, 18, 20, 26)

52. Douglas, I. 1967. Man, vegetation, and the sediment yield of rivers. Nature 215:925-928.

Vegetation growth and catchment erosion are both related to the magnitude and frequency of precipitation events. Irregularly distributed rainfall occurring in storms of high intensity and short duration fails to ensure sufficient water supply for the growth of dense vegetation. At the same time, it is effective in eroding the soil. Human interference with this problem in the U.S. midwest causes the production of high sediment yields. (7, 11, 20, 25)

53. Drummond, I. N. 1972. Flood control in north-eastern Victoria, pp. 29.1.117-29.1.124. In International Commission on Irrigation and Drainage, Eighth Congress, Varna, R. 8, Trans., Vol. 5, Question 29.1.

A description is given of the wide variety of problems encountered by River Improvement Trusts in north-eastern Victoria and of the types of river control works undertaken to mitigate flooding and control erosion. The Trusts' principal objectives are to establish effective arterial drainage channels to reduce the period of inundation of lands adjacent to the rivers and streams by floodwaters and to maintain these channels in a stable condition. Bank stabilization methods include use of crib groins made from local timber and the tethering of trees and brush against an eroding bank. Basket willows (*Salix fragilis*, *S. alba*, and *S. vitellina*) were always planted in conjunction with bank protection efforts to establish a permanently protected bank. Crib groins tended to develop eddies in their vicinity; these, in turn, caused severe local erosion. Brush, if held in place and weighted, would protect willows, until they became established. However, it would do nothing to inhibit the build-up of shingle or sand bank on the opposite side of the river. The river was thus inclined to become increasingly narrow and deep opposite the brush work. In many instances the willows were not effective protection against this deep erosion; they were undermined, even when well established, and fell into the stream. (18, 19, 20, 24, 26)

54. Dupre, D. D., Jr. 1948. Willow mats economical for bank protection. Roads and Streets 91(2):92-94.

Live willows and other live tree branches were tied down with fence wire. This is practical, efficient, and inexpensive, when compared with stone riprap in Ohio. Specifications and photographs were provided. (24)

55. Eck, H. V., R. F. Dudley, R. H. Ford, and C. W. Gantt, Jr. 1968. Sand dune stabilization along streams in the southern Great Plains. J. Soil Water Conserv. 23(4):131-134.

Active sand dunes occur in isolated areas adjacent to major streams in Texas and Oklahoma panhandles and in southwestern Kansas. Dunes were found to be deficient in plant nutrients, even for the growth of native sand-binding grasses. Fertilizer must be used in revegetation. Native grasses are more suitable than introduced species. The sand must be stilled before seedlings of sand-binding grasses can be established. Hay mulch is satisfactory, but asphalt mulch did not aid in revegetation. Livestock should be excluded from dune areas. The authors provide a fertilizing-mulching regime. (8, 18, 22)

56. Elliot, R. A. 1971. Statement of Reed A. Elliot, Director Division of Water Control Planning, Tennessee Valley Authority, pp. 595-605. *In* Stream Channelization (Part 2). Hearings before a Subcommittee of the Committee on Government Operations, House of Representatives, 92nd Congress, First Session, 3-4 June 1971. U.S. Government Printing Office, Washington, D.C.

A description of TVA channel modification projects in connection with navigation, flood protection for communities, and flood relief for agricultural lands is given. To reduce adverse effects of channelization on the natural environment, work is carried out on only one bank of a stream; the other bank is left intact in agricultural land projects. Precautions were included to preserve deep pools and, where appropriate, minor trenching of the stream was undertaken to facilitate the passage of fish. In the Bear Creek Project, under which construction had just begun in 1971, a 9-mile floodway was to be constructed in lieu of modifying 18 miles of meandering stream. This floodway was to have a bottom elevation above normal stream levels, so that it would come into operation only during flood periods. Most of the time, substantial portions of this channel were to be dry, except for portions carrying local drainage. The floodway was to be planted in grass and could serve as pasture. (3, 8, 18, 19)

57. Elser, A. A. 1968. Fish populations of a trout stream in relation to major habitat zones and channel alterations. Trans. Am. Fish. Soc. 97(4):389-397.

The relationship of fish populations to major habitat zones and channel alterations was studied in Little Prickly Pear Creek, a tributary of the Missouri River in Montana, during the summers of 1965 and 1966. Five major zones were defined: Headwater, meadow, mountain, lower meadow, and Wolf Creek Canyon, with at least one representative study section in each. Approximately 23% (6 of 30 miles) of the stream had been altered. There was no pool-riffle periodicity in the altered mountain section, while successive riffles were spaced at intervals of 5.7 widths in the altered reaches. Amount of cover per acre of stream was about 80% greater in the unaltered mountain section than in the altered one. Rock deflectors in the altered section of Wolf Creek Canyon rendered the physical characters of the stream nearly comparable to those of the unaltered sections. Non-trout fishes were absent from altered sections, but constituted 30% and 58% of the total number and weight, respectively, in the unaltered mountain sections than in the altered ones (as determined by a simple mark-and-recapture census). Channel alterations resulted in a total loss of 4,700 trout with a total weight of 2,200 pounds (3, 4, 15)

58. Emerson, J. W. 1971. Channelization: A case study. Science 173:325-326.

Channelization of the Blackwater River in Johnson County, Missouri, 60 years ago nearly doubled the gradient, which caused an increase in the rate of erosion for the river and its tributaries. The present channel is wider and deeper than it was when newly dredged. Serious erosion problems were caused along stream banks, and there was much headward erosion of gullies leading to tributaries of the river.

Most county bridges have been replaced or lengthened and have had vertical extensions added to the lower supports. In most cases the ends of the present bridges are threatened by bank erosion. Downstream reduction in channel capacity due to termination of dredging has caused channel sedimentation and increased flooding. (3, 4, 7, 11, 12)

59. Fairley, J. G., R. T. Easley, J. H. Bowman, and B. J. Littlejohn. 1970. Use of Plastic Filter Cloth in Revetment Construction. Potamology Research Project II. Potamology Investigations Report 21-4. U.S. Army Engineer District, Memphis, CE, Memphis, Tenn. 52 pp.

Some bank failures in the upper bank area of Mississippi River revetments have occurred from loss of subgrade material through the voids of the articulated concrete mattress and riprap upper bank paving. A woven plastic cloth was placed in lieu of gravel as a filter in an 800-ft test section of revetment at Island 63 Bar, Mississippi. The material used was Poly-Filter X™ (a woven polyvinylidene chloride monofilament yarn) manufactured by Carthage Mills, Inc., Cincinnati, Ohio. The plastic cloth was used for the same purpose to repair scour damage around two county bridges on the St. Francis River. The plastic filter cloth was found to be highly effective in retaining subgrade material under the revetment and bridges and was superior to gravel. However, a downslope movement of material under the cloth did occur in the revetment test section. (12, 22)

60. Fajen, O. F. 1974. A Study of Methods of Stabilizing and Improving Ozark Streams. U.S. Dept. of the Interior, Fish & Wildlife Serv., Federal Aid Div., F-1-R-23-S-13, July 1973 to June 1974. Missouri Dept. of Conservation, Jefferson City.

Protocol -- The channels of Big Buffalo and Pole Hollow Creeks will be stabilized and improved by directing and confining flood flows into defined channels, insofar as possible. Log deflectors, berms, dikes, trash catchers, and other devices will be used, as required. Instream structures, such as gabions and log deflectors, will be used primarily to control bank erosion. The primary emphasis will be toward development of maximum pool size and depth. Success will be measured in terms of changes in the amount of pool habitats of various depths and changes in the standing crops of fish. (3, 8, 21)

61. Felker, R. H. 1946. Stream bank control. Soil Conserv. 12(5):114-117.

In Utah bank erosion is due to poor management and denudation of upstream watersheds, poor farming practices along streams, and poor management of the stream channel. Revetments are needed for bank stabilization. Irrigation ditches must be kept away from the edges

of stream banks, and irrigation water must not be allowed to saturate (and cause the collapse of) streambanks. Livestock trampling enhances bank cutting; livestock also eat stabilizing vegetation. Snags and other debris, after floods, can cause erosion of adjacent banks by causing variations in flow. Tree and cable revetments are economical for bank stabilization. Instructions for such revetments are provided. (11, 17, 18, 21)

62. Freeland, S. J. 1972. River training of the lower Colorado River, pp. 29.1.459-29.1.474. In International Commission on Irrigation and Drainage, Eighth Congress, Varna, R. 28, Trans., Vol. 5, Question 29.1.

Control of river flow by construction of dams requires that the consequent effect on the river channel be considered. Problems encountered include degradation of channel below dams and aggradation of channel above reservoirs with related flooding and channel instability. In the Mohave Valley Division of the U.S. Bureau of Reclamation below Davis Dam, clear water attacked the riverbed and the banks, picking up a new load of sediment, until the well-graded bottom sediments developed a gravel armor by erosive plucking of the fine particles. The armored bottom was relatively stable and the river consequently had erosive energy to dissipate in an attack on the riverbanks. Meandering was a severe problem, and caving banks, shifting of the river, and formation of low bars were common occurrences. Stabilization measures included realignment of the channel by dredging, stabilization of the riverbanks with riprap, and construction of levees to prevent avulsions during floods. Completed and planned river training programs in the Mohave, Parker, Palo Verde-Cibola, and Yuma Divisions are described. (1, 3, 12, 19, 21)

63. Fremling, C. R. 1971. Letter to Mr. Richard W. Leonard, Chief, Engineering Division, Corps of Engineers, USA, St. Paul, Minnesota, pp. 102-104. In Stream Channelization (Part 1). Hearings before a Subcommittee of the Committee on Government Operations, House of Representatives, 92nd Congress, First Session, 3-4 May 1971. U.S. Government Printing Office, Washington, D.C.

Dr. Fremling, Professor of Biology at Winona State College, Winona, Minnesota (letter dated 1 April 1971) discusses his views of channel modification based on 14 years of experience working on the upper Mississippi River. In particular, he is concerned with sand and mud accumulation on the bottom behind dams and the filling in of navigation pools. He is concerned, further, with downstream flooding caused by upstream channel aggradation and its relationship to a proposed 12-ft deep channel to be constructed by the Corps of Engineers. (1, 8)

64. Funk, J. L., and J. W. Robinson. 1974. Changes in the Channel of the Lower Missouri River and Effects on Fish and Wildlife. Aquatic Series No. 11. Missouri Dept. of Conservation, Jefferson City. 52 pp.

Between 1879 and 1972, the water surface area of the Missouri River between Rulo, Nebraska and the mouth (just above St. Louis, Mo.) has been reduced by 50%. Backwater habitats have been eliminated and snags have been removed. The full river flow is confined to a relatively narrow channel of almost uniform width, with a strong, swift current. This was done to stabilize the river and to improve navigation. It was accomplished by the use of revetments to stabilize banks and wing dikes to direct the current and cut off chutes and sloughs. Pile dikes, used originally, have been replaced by rock dikes in recent years. (18, 26)

65. Funk, J. L., and C. E. Ruhr. 1971. Stream channelization in the Midwest, pp. 5-11. In E. Schneberger and J. L. Funk (eds.) Stream Channelization: A Symposium. Special Publ. No. 2. North Central Division, American Fisheries Society, Omaha, Nebr.

This introductory paper summarizes a meeting of representatives of 15 state and provincial conservation departments, who met to discuss the nature and extent of the channelization problem and avenues of action. (4, 8, 19)

66. Fuquay, G. A. 1972. Bank erosion on low-velocity streams, pp. 29.1. 475-29.1.493. In International Commission on Irrigation and Drainage, Eighth Congress, Varna, R. 29, Trans., Vol. 5, Question 29.1.

Bank erosion occurs in streams whose bank velocity is less than 1 m/s. The severity of this erosion in clays, silts, and sands is dependent, in large measure, on wave action and is interrelated with length of time of exposure, wave height, and to a lesser extent, the type of material. Banks can be protected against erosion, and such protection can be the most economical means of curing the condition. Bank protection should not be applied without end sections at right angles to stream flow, where adjacent material of questionable erodibility exists upstream and/or downstream of the protection. Experience with wide, low-gradient streams such as the Allegheny, Monongahela, and the upper Ohio Rivers, is cited to substantiate a pattern for bank erosion and to indicate that the form of such erosion is predictable. Experience has shown that vegetative cover will assist (or delay), but will not generally cure, the bank erosion problem. Engineers generally require clearing of banks prior to establishing a new pool, this being done to prevent major snagging problems subsequent to raising the pool. From an erosion standpoint, bank clearing should not be done at all. However, from a practical standpoint, the best course of action would be one of minimizing bank clearing, consistent with anticipated maintenance requirements with regard to accumulation of debris in the stream subsequent to pool rise. (8, 11, 25, 26)

67. Garde, R. J., and K. G. R. Raju. 1977. River training and bank protection, pp. 404-436. In Mechanics of Sediment Transportation and Alluvial Stream Problems. John Wiley & Sons, New York.

The authors discuss the objectives of river training and bank protection, including flood control and protection, navigation, guiding of flow, and channel stabilization. (8)

68. Giroud, J. P., J. P. Geuoc, and F. Bally. 1978. Behavior of a Nonwoven Fabric in an Earth Dam. Translated from the French by R. McElroy Co., Custom Div., Austin, Texas, with a revised text by R. M. Parks, Monsanto Co., St. Louis, Mo. 15 pp.

In 1970, for the first time, a nonwoven fabric was used in an earth dam (Valcros Dam, France). In 1976, samples of the fabric were removed from two dam locations and tested for tensile strength and permeability after six years of field use. The polyester fabric lost little tensile strength, since it was not exposed to direct sunlight but was beneath riprap. The fabric permeability, after enveloping a gravel drain and being surrounded by silty sand, was almost identical to that of clean fabric. Therefore, the fabric, under the action of waves on the upstream side of the dam, decreased by a factor of 10. However, this was not significant, and the fabric was deemed suitable for bank protection. (22)

69. Gore, J. A., and S. B. Coyle. 1978. A dendrogram analysis of long-term effects of channelization on stream benthos. Paper presented at 26th annual meeting of the North American Benthological Society, Winnipeg, Manitoba, Canada, 10-12 May 1978. (Abstr.).

The results of benthic samples taken along the length of Rattlesnake Creek, Montana, were compared with those taken in 1942, prior to channelization of the lower reaches of the stream. Insect dominance changed from mayflies to chironomid midges (flies) in unchannelized vs. channelized sections. The reason seems to be the result of the increase in substrate particle size resulting from the falling into the stream of large bouldered embankments in the channelized portions. (Authors' address: Dept. of Zoology, Missoula, Mont.) (1, 4, 14)

70. Gorman, O. T., and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59(3):507-515.

Stream habitat complexity is correlated with fish species diversity in selected Indiana and Panama streams. Habitat diversity was measured along three dimensions judged important to a wide range of fish groups and applicable to many stream conditions: stream depth, bottom type, and current. Natural streams supported fish communities of high

species diversity that were more stable seasonally than were the lower diversity communities of modified streams. After disturbances, such as channelization, seasonal peaks in species diversity attain levels typical of undisturbed streams. Since seasonal changes in stream quality are high, the stability of the fish community is lower in modified than in natural streams. The general correlation between habitat characteristics and presence and absence of fish species suggests that most fishes of small streams are habitat specialists. (1, 4, 15, 26)

71. Goss, D. W. 1973. Relation of physical and mineralogical properties to streambank stability. Water Resour. Bull. 9(1):140-144.

Alluvial streambank materials from nine unstable and six stable reaches in river bends of the Washita River, Oklahoma, showed little variation in physical and mineralogical properties. The bulk densities of all samples were so similar, that they could be considered to be from the same population. Clay fractions were slightly, but significantly higher for stable reaches. Sand-size grains in stable areas were less rounded than those from unstable areas. This somewhat angular shape of the sand-size grains may have produced an interlocking between between them to add stability to the bank material. Also, a clay coating on the sand-sized grains may have produced cementation that gave added stability. (1, 11, 20)

72. Greeson, P. E., C. J. Velz, and D. A. Rickert. 1977. River-quality assessments. Water Resour. Bull. 13(3):445-453.

In 1972, the U.S. Geological Survey began a pilot program of river-quality assessments. The objectives of the program are (1) to define the character, interrelationships, and apparent causes of existing river-quality problems, and (2) to devise and demonstrate the analytical approaches and the tools and methodologies needed for developing water-quality information that will provide a sound technical basis for planners and managers to use in assessing river-quality problems and evaluating management alternatives. In a pilot assessment of the Willamette River basin, Oregon, the most important finding was that across-the-board advanced waste treatment was not the answer to the problem of meeting stringent water-quality standards established for the river. The assessment also showed that existing water-quality data generally are inadequate for defining the critical cause-effect relationships that control river-quality problems and that intensive, synoptic surveys keyed to local problems and conditions would be required in most river basins to develop an adequate information base for managing important river-quality problems. (8, 9, 19)

73. Grissinger, E. H., and L. L. McDowell. 1970. Sediment in relation to water quality. Water Resour. Bull. 6(1):7-14.



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The relation between sediment and water quality involves the individual relations between sediment and the physical, chemical, and biological characteristics of water. Both the physical and chemical properties of fine-grained sediments must be considered in evaluating these relations, whereas only the physical properties of coarse-grained sediments are significant. Sediments derived from land erosion exceed all other sources of pollution -- in terms of the solids loading of the nation's streams. Erosion is a selective process that results in more rapid removal of finer soil particles than of coarser particles. Clays and organic fractions of sediment have active surfaces that can react with an array of chemicals. Coarse sediments serve as buffers, modifying the erosive potential of streamflow, while fine-grained sediments tend to modify the dissolved and suspended chemical load. (1, 9, 20)

74. Groen, C. L., and J. C. Schmulbach. 1978. The sport fishery of the unchannelized and channelized middle Missouri River. Trans. Am. Fish. Soc. 107(3):412-418.

A catch survey of 502 km of the Missouri River, including the Gavins Point Dam tailwaters (6.4 km), 84 km of unchannelized river, and 412 km of channelized river, was conducted from 1 July 1972 to 30 June 1973. The unchannelized river supported the highest annual catch and harvest rates, 0.72 and 0.50 fish/h. The unchannelized river also exceeded the channelized river in angler-hours/km, number of fish caught/km, weight harvested (kg/km), and average size of creeled fish. Sauger, channel catfish, and white bass were the most abundant species creeled in the unchannelized river compared to carp, channel catfish, and freshwater drum in the unchannelized river, probably due to the presence of more backwater aquatic habitats and greater habitat diversity. (3, 4, 15, 18)

75. Haas, R. H., and J. Graham. 1969. Principles governing the design and construction of economic revetments for protecting the banks of rivers and canals for ocean and inland navigation. Section 1, Subject 6, pp. 1-29. In XXIInd International Navigation Congress, Permanent International Association of Navigation Congresses, Inland Navigation, Paris. (Address: General Secretariat of P.I.A.N.C. Residence Palace, Quartier Jordaens -- Rez-de-chaussee -- 155, rue de la Loi, Bruxelles 4, Belgique.)

The comparatively mild slopes of an alluvial stream provide the greatest opportunity for substantial open-river navigation. The banks of such a stream are unstable to a degree that is dependent on its geological environment, discharge, and slope, and it is this type of stream along which revetments (dikes, groins, etc.) are most widely used. Various measures and techniques of bank stabilization are described, including the following: (1) upper bank protection; (2) lower bank, or subaqueous, protection, both (1) and (2) being direct means of bank protection; (3) indirect bank protection, including such structures as permeable dikes and impermeable dikes. Examples of stabilization plans for various types of rivers are given. Examples of stabilization plans for various types of rivers are given. All rivers considered are major ones, such as the Mississippi, Columbia, and Arkansas Rivers. (11, 19, 21, 22)

76. Hackett, B. 1972. Landscape Development of Steep Slopes. Oriel Press, Newcastle upon Tyne, England. 143 pp.

A report on research into problems of landscape stabilization, establishment, and development, with particular reference to the steep banks of the Tyne River. (18, 22)

77. Hansen, D. R. 1971. Stream channelization effects on fishes and bottom fauna in the Little Sioux River, Iowa, pp. 29-51. In E. Schneberger and J. L. Funk (eds.). Stream Channelization: A Symposium. Special Publ. No. 2. North Central Division, American Fisheries Society, Omaha, Nebr.

Differences in certain physical factors, the macrobenthos, and fish populations were elevated in channelized and unchannelized portions of the Little Sioux River, a turbid warmwater river in Western Iowa, between 1969-1971. Stream channels are meandering and non-uniform, with a heavy vegetative cover in the unchannelized section, and relatively straight, of uniform depth, and without vegetation cover in the channelized sections. The project of channelization was completed in 1965, and involved channel straightening, rechannelization of the old channel, placement of riprap around bridges and drainage structures and along some gradual bends, and preparation of a streamside berm with a width of 50 ft. Channel erosion had been reported to be a serious problem in earlier channel-straightening projects on the Little Sioux River. Rock riprap has prevented channel erosion in certain areas of the channelized section, but in several other areas, the banks seemed irregular and the channel widened because of channel erosion. Lack of heavily rooted vegetation along the banks in the channelized section was probably responsible for the widening and for the large amounts of suspended solids in the water. Consistently higher turbidities were measured in the channelized section during low runoff, averaging 31.2% higher than those in the unchannelized section. Daily fluctuations of water temperature in July were greater, maximum daily water temperatures averaged 1.3$^{\circ}$C higher, and mean daily water temperatures were 0.3$^{\circ}$C higher in the channelized section, as opposed to the unchannelized section. (3, 4, 14, 15, 20, 23)

78. *Hansen, E. A. 1968. Stabilizing Eroding Streambanks in Sand Drift Areas of the Lake States. Forest Serv. Res. Pap. NC-21. USDA, North Central Forest, Experiment Sta., St. Paul, Minn. 12 pp.

Bank protection planning balances the immediate real cost of stabilization against a probably future benefit. The immediate cost of stabilization can be estimated fairly accurately and can be improved upon with the experience gained from treating the first few banks. Future benefits, such as protection of on-site values or reduction in reservoir or lake sedimentation rates, can be estimated and expressed in economic terms. However, the possible future benefit from attempting to increase fish populations through bank stabilization is obscure. Consequently, present justification of such an objective will have to be stated in qualitative terms such as reduced sediment load or possibly improved fish habitat. There are many stabilization techniques that can be used for bank protection. Rock riprap is probably the best material to use for stabilizing the lower bank, since there is little that can deteriorate with time. However, rock of sufficient size and quantity is often difficult to obtain in the Lake States. In such cases, alternative methods employing wire, wood, or live vegetation may be used. The upper bank will vegetate naturally. However, sloping and application of seed, fertilizer, and mulch will accelerate the revegetation process. Maintenance should be a planned part of a bank stabilization program, because of the possibility of some structural failure in the future and the beginning of new points of erosion as a result of normal stream meandering. (8, 20, 21)

79. *Hansen, E. A. 1971. Sediment in a Michigan Trout Stream: Its Source, Movement and Some Effects on Fish Habitat. Forest Serv. Res. Pap. NC-59. USDA, North Central Forest Experiment Sta., St. Paul, Minn. 20 pp.

The Pine River, a tributary of the Manistee River of the northwestern part of Michigan's Lower Peninsula, was studied from 1967-1969. Much stream improvement work, including bank stabilization, has been done to reduce the already low sediment concentrations in streams in the Lake States that lie in a deep mantle of sandy glacial drift. Such streams generally have lower sediment concentration than those in other areas of the U.S. This paper is concerned with a determination of sediment sources, the size and quantity of bank sediments, the timing of delivery, and the method of transport. The change in sediment load and streambed composition, and some possible effects of streambank stabilization are also presented for a section of stream with many eroding banks. The volume of sediment eroded from individual streambanks ranged from 0 to 2,400 cubic yards over a three-year study period. Eroding bank sediment contributions were much greater in the lower two-thirds of the study area due to higher banks and, possibly, to the greater stream discharge and gradient. Volume of eroding bank sediments increased in direct proportion to bank height. During the three-year study, the eroding bank sediments contributed 55% of the total sediment load increase that occurred within the study section. Most of the streambank sediment came from large banks

in the most severe erosion class. A 74% reduction in eroding bank sediments could be achieved by stabilizing only 40% of the eroding waterline. The best estimate of the reduction of the Pine River sediment load following complete streambank stabilization along the 26-mile study section was 45%. A complete streambank stabilization program would reduce the sediment load significantly, but it would not affect the particle-size distribution of the moving sediment. It was hypothesized that a reduction in sediment load following bank stabilization would tend to increase the area of streambed covered with gravel, decrease the area of sand, and decrease the sand content in existing exposed gravels. (1, 11, 20)

80. Headrick, M. R. 1976. Effects of Stream Channelization on Fish Populations in the Buena Vista Marsh, Portage County, Wisconsin. FWS/OBS-76/24. U.S. Fish and Wildlife Service, Washington, D.C. 38 pp.

Stream channelization in the Buena Vista Marsh reduced year-round instream cover, decreased substrate stability, and increased silt accumulation and stream temperature. Several recommendations for brook trout management were generated from the study. If streams are to be redredged: (1) Bank vegetation should be maintained; (2) cattle should be kept out of ditches to control bank erosion and reduce siltation; and (3) permanent stream improvement structures, e.g., wing deflectors, should be installed to encourage meandering, form pools, and to provide conditions that will promote growth of overhanging vegetational cover. (1, 4, 8, 15, 20, 23)

81. Heede, B. H. 1968. Conversion of Gullies to Vegetation-lined Waterways on Mountain Slopes. Forest Serv. Res. Pap. RM-40. USDA, Rocky Mountain Forest and Range Experiment Sta., Fort Collins, Colo. 11 pp.

Four gullies were converted successfully to waterways on slopes of the Rocky Mountains in Colorado. Three years after treatment, they had lost only 9% as much soil as comparable untreated gullies. (11, 24)

82. Heede, B. H. 1976. Gully Development and Control: The Status of Our Knowledge. Forest Serv. Res. Pap. RM-169. USDA, Rocky Mountain Forest and Range Experiment Sta., Fort Collins, Colo. 42 pp.

Gully formation is discussed in terms of mechanics, processes, morphology, and growth models. Establishment of an effective vegetation cover is the long-term objective. Structures are often required, the least expensive being simply built loose-rock check dams. (3, 11, 21)

83. Heede, B. H. 1977. Study of a Watershed Rehabilitation Project: Alkali Creek, Colorado. Forest Serv. Res. Pap. RM-189. USDA, Rocky Mountain Forest and Range Experiment Sta., Fort Collins, Colo. 18 pp.

Generally, conversions of gullies to vegetation-lined waterways should be restricted to first- and second-order channels in broad valley bottoms. These waterways must be meandering to achieve the necessary increases in length and width and decreased gradients compared with the original gullies. Potentials for plant growth must also be good. The headwaters of Alkali Creek watershed were fenced and cattle grazing excluded from 1958 to 1966. In 1963, check dams or vegetation-lined waterways were constructed in half of the gullies. Treated waterways experienced only one-third of the net erosion seen in untreated gullies. Perennial streamflow was regained. (8, 21)

84. Henegar, D. L., and K. W. Harmon. 1971. A review of references to channelization and its environmental impact, pp. 79-83. In E. Schneberger and J. L. Funk (eds.). Stream Channelization: A Symposium. Special Publ. No. 2. North Central Division, American Fisheries Society, Omaha, Nebr.

Briefly annotated references are given for downstream flooding, drainage outlets, sediment damage, groundwater recharge, and fishery and wildlife losses. Sixty-three references in all. (2, 4)

85. Henson, K. W. 1967. Humble Gas tames the wild Homochitto River. Pipe Line Industry, Sept. 1967. 4 pp.

The author, President of the Hold-That-River Engineering Co., Houston, Texas, designed and received a patent on a system of permeable spur jetties that rearrange a river flow pattern to stabilize a channel at the base of a bank, thus avoiding undercutting and rapid bank erosion. (21)

86. Hoffman, G. R. 1977. Artificial establishment of vegetation and effects of fertilizer along shorelines of Lakes Oahe and Sakakawea, mainstem Missouri River reservoirs, pp. 95-109. In Proceedings of the Workshop on the Role of Vegetation in Stabilization of the Great Lakes Shoreline. Great Lakes Basin Commission, Ann Arbor, Mich.

The two reservoirs have annual water level fluctuations that averaged 3.58 m and 3.45 m, respectively, between 1969 and 1975. The portion of the shore-line flooded annually does not support permanent vegetation, but it does become established each year. Experiments have been carried out in which a number of plant species were grown in the fluctuation zone, with and without the addition of fertilizers. Biomass

increased on fertilized plots from 0.5% to 10% above that on unfertilized control plots. Longterm effects caused by fertilization of shoreline vegetation are unknown. (24)

87. Holtz, W. G., and K. D. Hansen. 1976. The use of compacted soil-cement in water control structures, pp. 251-278. In Commission Internationale des Grands Barrages, 12th Congres des Grands Barrages, Mexico, Q. 44, R. 13.

After more than 10 years of use, the performance of dams and other embankments and channels faced with correctly designed and well compacted soil-cement has been excellent. When severe wave action is anticipated, consideration must be given to using the most suitable sandy soils for the soil-cement with adequate cement contents. (17, 21)

88. Howells, D. H. 1970. Proceedings, Workshop on Stream Channelization and Wetland Drainage. Held at Quail Roost Conference Center, Rougemont, North Carolina, 18 November 1970. 105 pp.

The objectives of the workshop were to explore the beneficial and adverse effects of stream channelization and wetland drainage, to facilitate more effective project review, and to identify research needs. Proceedings include: Objectives of stream channelization and wetland drainage; alternatives; beneficial effects; adverse effects; documentation of effects; effectiveness of mitigating measures; broader planning implications; public education; and research and study needs. (4, 8, 18)

39. Hunt, R. L. 1968. Effects of Habitat Alteration on Production, Standing Crops, and Yield of Brook Trout in Lawrence Creek, Wisconsin. Wisconsin Dept. of Nat. Resources, Div. of Conservation, Waupaca. 32 pp.

Installation of bank-cover and current-deflection devices increased trout abundance. This was due to increased protective cover, pool depth, and pool area. (7, 15, 21, 24)

90. Hunt, W. A., and R. J. Graham. 1972. Preliminary Evaluation of Channel Changes Designed to Restore Fish Habitat. Dept. of Civil Engineering and Engineering Mechanics and Cooperative Fisheries Unit, Montana State Univ. Bozeman. 78 pp.

An evaluation of the fish habitat in two meanders constructed in the Clark Fork River, west of Drummond, Montana, showed the hydraulic, topographic, and fish population characteristics of these artificial meanders to be similar to those found in comparable natural sections of the river. A design procedure, based on observations of meanders in the stream being altered, is recommended. The random placement of riprap containing a high percentage of pieces with volumes greater than one cubic yard each will provide bank stability and create a diversity of habitat for aquatic life. Riprap should be placed as steep as practicable within the slope stability limitations of the bank. The toe of the riprap should extend out into the stream and to a depth below the design bed grade to prevent scour holes from undercutting the riprap. The depth of the scour holes and their proximity to the bank may be based on data obtained from conditions in natural meanders of the same stream. The design of a riprap section with fine bed material placed slightly above the design high water level will allow vegetation to be established. (3, 8, 15, 21, 24)

91. Hynes, H. B. N. 1970. The ecology of flowing waters in relation to management. J. Water Poll. Control Fed. 42:418-424.

Drawing upon much work published previously, the author emphasizes that we should understand more thoroughly what we are doing, when we manage rivers. Further, we should be able to weigh the results of our actions dispassionately, balancing losses against gains in an objective way. (8, 10)

92. Hynes, H. B. N. 1970. The Ecology of Running Waters. Univ. of Toronto Press, Toronto, Canada. 555 pp.

This book, frequently out of print at the publisher, is the comprehensive work in English on stream limnology. It is indispensable. The first three chapters (pp. 1-52) are devoted to water flow and stream channels, physical characteristics of flowing water, and chemical characteristics of flowing water. There is a 67-page bibliography at the end. (2, 7, 9, 10, 20)

93. Idaho (State of). 1975. Stream Channel Alterations. Dept. of Water Resources, State of Idaho, Boise. 40 pp.

Idaho statutes covering stream channel protection are presented, including structure construction and location diagrams. (3, 8, 21)

94. Illk, F. K. 1963. Methods and criteria for bank protection on the lower Colorado River, pp. 366-372. In Proceedings of the Federal Inter-Agency Sedimentation Conference, Jackson, Mississippi, 28 January - 1 February 1963. Misc. Publ. No. 970. U.S. Dept. of Agriculture, Washington, D.C.

The most effective type of bank protection for the conditions encountered on the lower Colorado River is quarry-run rock riprap. This material is

suited particularly for the stabilization of new banks created by channelization and raw banks caused by erosion. (3, 21)

95. Jaaback, G., and P. Muzzell. 1971. The establishment of vegetation in civil engineering work. Proc. Grassland Soc. South Africa 6:181-184.

Civil engineering construction denudes soil of vegetation. To prevent soil erosion, areas must be revegetated quickly. Recent advances in hydroseeding (spraying seed into steep banks) are explored. Grass species used in South Africa are named. Plastics are recommended for soil stabilization, while seeds germinate. Alternatively, plastic emulsions may be used. (22, 24)

96. Jackson, B. J. 1974. Stream bed stabilization in Enfield Creek, New York. N. Y. Fish Game J. 21(1):32-46.

Observations were made of the performance of bed sills in stabilizing a high-gradient trout stream subjected to severe headcutting. Gabions were installed in the creek in 1967. Sills were immediately effective in arresting headcutting and in accumulating gravel. They had a distinct stabilizing effect for almost 0.8 mile downstream. (1, 21)

97. Johnson, J. H., R. C. Solomon, C. R. Bingham, B. K. Colbert, and W. P. Enge. 1974. Environmental Analysis and Assessment of the Mississippi River 9-ft Channel Project Between St. Louis, Missouri, and Cairo, Illinois. Tech. Rept. Y-74-1. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi. 143 pp.

In the middle Mississippi River, 122 miles of revetments stabilize the river-banks by preventing or greatly reducing erosion. By this method, bend migration has been reduced to the extent that the river is no longer free to migrate and to produce new side channels. The loss of potential new natural channels is offset by the formation of human-made channels constructed during river development and modification. Some of the effects of revetments on river morphology and behavior are similar to those of dikes, since both revetments and dikes serve cumulatively to contract the river. Colorado State University workers, as part of this study, have shown that contraction of the river has generally caused the reduction of river surface area, island area, river-bend area, river width, and corresponding bank-full channel and cross-sectional areas. Because revetments have kept the river channel narrow, riverbed degradation has occurred with a subsequent lowering of the riverbed elevation. As a consequence of areal reductions, the potential habitat available for aquatic organisms has been reduced. However, preliminary field observations by the Waterways Experiment Station (Corps of Engineers, USA) personnel indicate that rock revetment may create a superior habitat by providing great diversity for aquatic organisms through stabilization of the river banks. Ecology of the revetments needs further study. (7, 18)

98. Joshi, G. C., and K. P. Shukla. 1970. Soil cement in river training works. J. Indian Nat. Soc. Soil Mech. Found. Eng. 9(1):73-89.

Laboratory and field tests of soil cement, using locally available Indian soils, yielded the following advantages over stone: Economy; blocks can be cast in situ in any size or shape; soil-cement strength increases with age; construction is rapid; repairs are not costly. Soils for use in soil-cement fall within the grading classification of clay (8-15%), silt (12-25%), and sand (60-80%). Cement needed to stabilize the soil ranges from 9-10%, by weight, of the soil. Clay soils can be stabilized with cement to which hydrated lime has been added. (22)

99. Kallemeyn, L. W., and J. F. Novotny. 1977. Fish and Fish Food Organisms in Various Habitats of the Missouri River in South Dakota, Nebraska, and Iowa. FWS/OBS-77/25. U.S. Fish and Wildlife Service, Washington, D.C. 100 pp.

Since only 143 km of unimpounded, unchannelized Missouri River still exist below the Fort Randall Dam, stream alteration should be kept to a minimum in the future. Structures to reduce bank erosion should be designed to have the least possible impact on the aquatic environment. Structures should be constructed of such materiais as large rocks that provide suitable substrates for fish food organisms such as mayflies and caddisflies. (3, 8, 14, 15)

100. Karr, J. R., and O. T. Gorman. 1975. Effects of land treatment on the aquatic environment, pp. 120-150. In Non-point Source Pollution Seminar. EPA-905/9-75-007. U.S. Environmental Protection Agency, Chicago, Ill.

Clearing and modification of streambanks may be undertaken in an effort to "beautify" a section of stream. Often such activities result in significant negative effects, because original streams often are in a dynamic equilibrium with terrestrial environments. Accelerated erosion, bank slippage, and reduced stream productivity are consequences of poorly planned bank modifications. The authors discuss effects of channelization with particular emphasis on the effects on the fishery of the Black Creek Basin, Indiana. (4, 9, 15, 20, 25, 26)

101. *Karr, J. R., and I. J. Schlosser. 1977. Impact of Nearstream Vegetation and Stream Morphology on Water Quality and Stream Biota. EPA-600/3-77-097. U.S. Environmental Protection Agency, Athens, Georgia. 91 pp.

As humans modify watersheds by removal of natural vegetation and stream channelization, disequilibria in both the terrestrial and aquatic environments result. These disequilibria are the major problem in controlling sediments and nutrients from nonpoint sources and improving the quality of the stream biota. In this report the authors review the literature dealing with (1) the possible uses of near-stream vegetation to reduce the transport of sediment and nutrients from the terrestrial to the aquatic environment, and to decrease stream temperature fluctuations; (2) the effect of stream morphology on sediment transport; and (3) how near-stream vegetation and stream morphology affect the biota of streams. Results of this review suggest proper management of near-stream vegetation and channel morphology can lead to significant improvements in both the water and the biological quality of many streams. (1, 3, 9, 20, 23, 25, 26)

102. *Karr, J. R. and I. J. Schlosser. 1978. Water resources and the land-water interface. Science 201:229-234.

Development and implementation of the local and regional plans to control non-point sources of pollution from agricultural land are major mandates of Section 208 (Public Law 92-500). Many planners tend to equate erosion control with improvements in water quality. Others implement channel management practices that degrade, rather than improve, water quality and thereby decrease the effectiveness of other efforts to control nonpoint sources. Planners rarely recognize the importance of the land-water interface in regulating water quality in agricultural watersheds. More effective planning can result from the development of "best management systems" that incorporate theory from all relevant disciplines. (3, 8, 9, 20, 23)

103. Keller, E. A. 1975. Channelization: A search for a better way. Geology 3(5):246-248.

Reproduction of channel forms produced by natural fluvial processes will minimize some adverse effects of channelization. Design criteria intended to improve drainage or control flooding should, in many cases, include the construction of pools and riffles. An optimal spacing of pools and riffles, averaging about six times the channel width, will improve the modified stream. (3, 4, 8)

104. Keller, E. A. 1976. Channelization: Environmental, geomorphic and engineering aspects, pp. 115-139. In D. R. Coates (ed.). Geomorphology and Engineering. Dowden, Hutchinson, and Ross, Stroudsburg, Pa.

The behavior of alluvial streams is not well understood. Therefore, until more information concerning relations between fluvial processes, channel form, and biological systems in streams is available for application to channel design, it is recommended that channelization be minimized. Minimum control should be provided to obtain the desired (or modified) objectives. Engineering trends in channelization are away from construction of a uniform straight channel with uniform channel cross section and gradient toward construction of more natural appearing streams. (3, 8)

105. Keller, E. A. 1978. Pools, riffles, and channelization. Environ. Geol. 2(2):119-127.

The addition of regularly spaced pools and riffles that provide a variety of flow conditions, areal sorting of stream-bed material, wildlife cover, and a positive aesthetic experience, may be desirable in many channel projects. There appear to be no significant differences with respect to channel width between pools that form in natural streams and those in streams affected by a variety of human uses. Experiments in Gum Branch near Charlotte, North Carolina, support the hypothesis that channel form and process evolve in harmony and that manipulation of cross-channel morphology stability in Gum Branch consisted of incipient point bars, pools, and riffles that were maintained over a period of high magnitude flooding, only to be degraded later by a wave of sediment derived from upstream construction and streambank failures. (1, 3, 8, 18, 20, 26)

106. *Keown, M.P., N. R. Oswalt, E. B. Perry, and E. A. Dardeau, Jr. 1977. Literature Survey and Preliminary Evaluation of Streambank Protection Methods. Tech. Rept. H-77-9. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi. 262 pp.

A preliminary study of streambank erosion control was conducted with the major emphasis on an extensive literature survey of know streambank protection methods. In conjunction with the survey, preliminary investigations were conducted to identify the mechanisms that contribute to streambank erosion and to evaluate the effectiveness of the most widely used streambank protection methods. This indispensable reference contains the following sections useful to workers on bank stabilization in small streams: (1) Preliminary investigation of streambank erosion (25 pp.); (2) Preliminary assessment of streambank protection methods (46 pp.); (3) New methods of streambank protection (2 pp.); and (4) Conclusions and recommendations (3 pp.). There are 88 text references. Several tables summarize information concerning (1) causes of erosion and bank protection methods used, (b) streambank protection materials, structures, or methods; and (c) classification of alluvial river channels, nonscour velocities for soils, and dollars costs for streambank protection. Appendices include (A) Section 32 of the Water Resources Development Act of 1975; (B) a list of commercial concerns that market streambank protection products; (C) a glossary of streambank protection terminology; and (D) an extensive literature survey of streambank protection materials and methods. (1, 2, 3, 11, 17, 20, 21, 26)

107. King, L. R., and K. D. Carlander. 1976. A Study of the Effects of Stream Channelization and Bank Stabilization on Warmwater Sport Fish in Iowa: Subproject No. 3. Some Effects of Short-reach Channelization on Fishes and Fish Food Organisms in Central Iowa Warm Water Streams. FWS/OBS-76/13. U.S. Fish and Wildlife Service, Washington, D.C. 217 pp.

Six central Iowa streams were studied in 1974 to determine whether fish and fish-food organisms were affected by short-reach channelization associated with bridge replacement in the last 15 years. In all cases, streams had been modified previously by construction of the original bridges. Stream length lost in three streams ranged from 151 m to 429 m; in the remaining streams, there was no loss of channel length. There was no evidence that dissolved oxygen, turbidity, or stream macroinvertebrates, as measured by core, drift or artificial substrate samples, differed upstream, in the channel, or downstream below the channel. The most evident impact of short-reach channelization was the removal of cover in the altered area and the loss of stream length. (3, 4, 9, 14, 15, 20)

108. Knighton, A. D. 1973. Riverbank erosion in relation to streamflow conditions, River Bollin-Dean, Cheshire. East Midland Geographer 5(8):416-426.

The amount and location of bank erosion along the Bollin-Dean, a stream with cohesive banks, are related to discharge and velocity conditions. The effectiveness of the erosion-producing discharges was a function, not only of their magnitude, but also of their variability characteristics, which affected bank erodibility, and of the degree of asymmetry in the distribution of velocity. The rapidity with which erosion occurred at certain sections can be attributed to the surprisingly wide range of flows involved and the flashiness of the stream's regime. (11, 17, 26)

109. Koisch, F. P. 1971. A national assessment of streambank erosion, pp. 314-321. In The Effect of Channelization on the Environment. Hearing before the Subcommittee on Flood Control -- Rivers and Harbors -- of the Committee on Public Works, U.S. Senate, 92nd Congress, First Session, 27 July 1971. Serial No. 92-H-24. U.S. Government Printing Office, Washington, D.C.

Data are presented on the nature and scope of streambank erosion damages throughout the U.S. Streambank erosion is a complex subject from the standpoints of its genesis, its effects, and its prevention. An estimated 549,000 miles of bank, 8% of the U.S. total, are undergoing some degree of erosion. Effective protection measures are costly to install and to maintain. For this reason, a substantial research program is needed to develop less costly and more effective treatment methods. Major General Koisch (Acting Chief of Engineers) outlines a number of factors in the production of streambank erosion, nature of the damages, and experiences in streambank protection. (11, 19)

110. Kuenzler, E. J., P. J. Mulholland, L. A. Rulev, and R. P. Sniffen. 1977. Water Quality in North Carolina Coastal Plain Streams and Effects of Channelization. UNC-WRRI-77-127. Project B-084-NC, OWRT, USDI. Water Resources Research Institute of Univ. of North Carolina, North Carolina State Univ., Raleigh. 160 pp.

A study was made of the physical and chemical characteristics of seven small coastal plain streams of eastern North Carolina. Three natural streams that flow through relatively undisturbed bottomland hardwood forests were compared to four streams that had been channelized for the purpose of reducing agricultural losses caused by flooding. Waters of channelized streams were restricted to their channels; they attained higher velocities, carried greater particulate loads, and were more turbid than were natural streams. Waters of channelized streams, on the average, had lower color, but higher conductivities, turbidities, pH's, and phosphorus concentrations, and were very rich in nitrate as compared to natural streams. Measurements during the course of one summer and one winter spate showed that peak concentrations of nitrate, ammonium, filterable reactive-P, particulate-P, turbidity, and particulate silicon, aluminum, and iron usually occurred 1-2 days before maximal discharge in both a natural and a channelized stream. (4, 5, 9, 17, 18, 20, 26)

111. Kumra, P. N., S. N. Gupta, and P. K. Parthasarathy. 1972. State of art of river training in Brahmaputra Valley, pp. 29.1.173-29.1.195. <u>In</u> International Commission on Irrigation and Drainage. Eighth Congress, Varna, R. 12, Trans., Vol. 5, Question 29.1.

The physiographic, hydrologic, and hydraulic features of the Brahmaputra River are outlined. A complex problem of bank erosion occurs, because of flow curvature that results from sediment transport in excess of the transport capacity of the river during flood season. There is a resultant formation of shoals in the vicinity of banks causing restriction of the waterway for flood passage. The behavior of protection measures at Dibrugarh, consisting of stone spurs, timber pile spurs, and stone revetments was studied for 15 years (1955-1970). Stone spurs, longer than those constructed and spaced closer together, would have provided superior hydraulic action to achieve bank stabilization. Return flows and eddy actions cause bank erosion between the spur dike system and the revetment. (11, 20, 21)

112. *Lake, J., and J. Morrison. 1977. Environmental Impact of Land Use on Water Quality: Final Report on the Black Creek Project - Technical Report. EPA-905/9-77-007-B. U.S. Environmental Protection Agency, Chicago, Ill. 280 pp.

This is the final report of a 4.5 year study of sediment control in Black Creek, a tributary of the Maumee River. A study of streambank erosion in the summer of 1975, involved 29.3 stream miles (58.6 bank miles). It was determined that there were 7.2 eroding bank miles, producing approximately 400 tons of sediment annually. There did not appear to be any correlation between bank erosion and adjacent land use, or whether or not banks were fenced. However, 80% or more of the total tons of streambank erosion were produced by two soil types, Eel 59.4% and Shoals 25.1%. Yet, those soils account for only 18.7% and 7.3%, respectively, of the total miles of streambank. Channel bottom erosion produced unstable channel banks in several areas. Channel stabilizing structures and bank stabilizing activities have eliminated many severe problems. Rock drop structures were particularly useful. Seeding of the banks to establish vegetative cover is most successful, where slopes are 2:1 or flatter. The advantage of the flatter slopes justifies the additional land area required to install them. Mulch is necessary to establish a good seeding, stone mulch materials being the most successful. The stone mulch has the advantage of not being washed away during periods of high flow. (1, 11, 12, 20, 21, 22, 24)

113. Lamberton, B. A. 1969. Revetment construction by Fabriform™ process. Am. Soc. Civil Eng. Proc., J. Construction Div. 95(1):49-54.

The Fabriform™ process employs a high-strength, water-permeable, synthetic fabric as a concrete forming material. The water-cement ratio is reduced by forcing vehicle water through the fabric, causing substantial increase in strength and very rapid stiffening. Proper fabric design is essential for avoiding mortar loss. When applied to the construction of erosion-control revetments, dual-wall fabric is placed on the surface to be protected and filled with mortar. The two layers of fabric may be woven together at regular intervals to form filter points, thus providing relief from hydrostatic uplift. A uniform cross-section is also available, containing internal fiber reinforcement. Fabriform™ is a reliable method for placing revetments of predictable dimensions above and below the water surface. It may be applied to columns and thin-shell structures. Du Pont Condura™ nylon was used. It is affected by ultraviolet radiation, but suffers no damage when covered by water, dirt, or asphalt. In 1969, polyester was being tested, but no data were available. In 1969, costs of materials exceeded those for labor. (21)

114. Larimore, R. W., and P. W. Smith. 1963. The fishes of Champaign County, Illinois, as affected by 60 years of stream changes. Ill. Nat. Hist. Surv. Bull. 28(2):295-382.

Two prior investigations of fishes in the streams of Champaign County, Illinois (1899 and 1928) prompted a third study, in 1959, aimed at evaluating the effects of ecological changes that occurred over ap-

proximately 60 years in an area that included both intensive farming and urbanization. Over the years, draining and dredging reduced the the water-holding capacity of the watersheds, resulting in a lower water table and in extreme fluctuations in stream flow. Canalization altered stream courses and habitats and produced more uniformity in stream environments. During the 30 years ending in 1959, the environmental trends in the streams were toward a decrease in depth and an increase in overhanging vegetation. Many fish species showed little change in occurrence over 60 years, despite the great changes that took place in the stream habitats. (1, 7, 15, 17, 18)

115. Lavagnino, S. 1974. Gabions guard river banks against 50,000 cfs flow. Civil Eng. 44(5):88-89.

The author describes the design and construction of gabion baskets and their use on cliff-like slopes above stream-side logging roads and along streambanks to prevent washouts of logging-roads. A modified gabion revetment was used to stop bank erosion in a bend of northern Californa's Eel River. Its construction was sufficiently elastic to make it possible to predict its actual behavior and to approximate, with fair accuracy, effects of flow rate, embankment, and foundation conditions. (21)

116. Leopold, L. B., and T. Maddock, Jr. 1953. The Hydraulic Geometry of Stream Channels and Some Physiographic Implications. Prof. Pap. No. 252. U.S. Geological Survey, Washington, D.C. 57 pp.

Some hydraulic characteristics of stream channels -- depth, width, velocity, and suspended load -- vary with discharge as simple power functions at a given river cross section. When discharges are of equal frequency at different points along a river (i.e., equalled or exceeded the same percent of time), the velocity, as well as the width and depth of flow, increases with discharge downstream. This is because the increase in depth overcompensates for the decrease in slope. The tendency for velocity to increase downstream exists on most streams despite the decreasing particle size downstream. Stream depth and width, as well as velocity, are functions of the load transported in the channel. For example, if the discharge is constant, an increase in width at constant velocity is accompanied by a decrease in suspended sediment load and an increase in bed load. Suspended load per unit volume of water tends to decrease downstream. (3, 7, 20, 26)

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

This book deals with landform development under processes associated with running water. There are good basic chapters on water and sediment in channels (Ch. 6; pp. 151-197) and channel form and process (Ch. 7; pp. 198-332). (3, 20)

118. Lester, H. H. 1946. Streambank erosion control. Agric. Eng. 27(9):407-410.

Loess and alluvial soils in the southern U.S. were eroded by floods that caused bank caving. Only small streams, creeks, and branches were studied. Protective measures included (1) mechanical control using timber or rock jetties, followed by (2) vegetative control, which, in turn, was followed by (3) maintenance of streambank protective vegetation. (21, 24)

119. Li, R. M., D. B. Simons, P. H. Blinco, and M. A. Samad. 1976. Probabilistic approach to design of riprap for river bank protection, pp. 1572-1591. In American Society of Civil Engineers, Rivers '76 -- Symposium on Inland Waterways for Navigation, Flood Control, and Water Diversions. Third Ann. Symp., Waterways, Harbors, and Coastal Engineering Div., ASCE, Colorado State Univ., Fort Collins, 10-12 August 1976, vol. 2, ASCE, New York, N.Y.

The recommended deterministic riprap design method is based on the stability of a single particle and utilizes only the mean shear stress. This deterministic model is comparable to accepted riprap design methods. A sensitivity analysis of the developed model is made to evaluate the applicability of the method. Based on the deterministic model, and the probability distribution of boundary shear stress, a probabilistic model is developed. The probability of failure can be determined for a riprap design using this approach. (8, 21)

120. Linder, W. M. 1976. Design and performance of rock revetment toes, pp. 2.168-2.179. In Proceedings of the Third Federal Inter-Agency Sedimentation Conference, Denver, Colorado, 22-25 March 1976. Sedimentation Committee, Water Resources Council, Washington, D.C.

One of the major causes of failure of rock riprap revetments is undercutting or erosion of bank material below the base of the revetment. When this occurs, rock from the side slope migrates downward and exposes areas of unprotected bank, subjecting the entire revetment to progressive destruction. The author has been involved in several model and prototype tests of the performance of various shapes of revetment toes. His studies indicate that while shape is important, the volume of reserve rock provided in the revetment toe is probably more significant. Rock from a revetment toe generally migrates downward on approximately a 1-Vertical on 2-Horizontal slope to form a protective layer one to two rock diameters in thickness. Protection will continue as long as there is sufficient rock remaining in the toe structure to prevent separation of the side-slope protection. (8, 21)

121. Lindner, C. P. 1969. Channel improvement and stabilization measures, chapter VIII (57 pp.). In G. B. Fenwick (ed.). State of Knowledge of Channel Stabilization in Major Alluvial Rivers. Tech. Rept. No. 7. Committee on Channel Stabilization, U.S. Army Corps of Engineers, Vicksburg, Miss.

The author deccribes types of stabilization, primarily for large rivers. He states that much is not yet known regarding channel stabilization. Without the aid of models, it is doubtful that many problems will be solved, as is borne out by years of field experience that still leaves a wide gap in our knowledge. (21)

122. *Lund, J. A. 1976. Evaluation of Stream Channelization and Mitigation on the Fishery Resources of the St. Regis River, Montana. FWS/OBS-76-07. U.S. Fish and Wildlife Service, Washington, D.C. and Cooperative Fishery Research Unit, Montana State Univ., Bozeman. 49 pp.

Stream morphology and gamefish populations of the St. Regis River, Montana were studied during the summers of 1973-1975 to determine the effects of stream channelization caused by highway and railroad construction. Instream structures used to mitigate fish losses also were evaluated. Channel structures produced stream bottom contours similar to those found in unaltered sections. Mitigating structures in altered channels were effective in providing fish habitat comparable to the unaltered sections. Gamefish populations in altered sections with mitigation recovered from construction work in about one year. Erosion and turbidity caused during channel construction and the initial unstable channel bottom were of relatively short duration and seemed to have no long-term effects on the biology of downstream areas. New channels usually stabilized after one high-water period. Changes in water termperature and water chemistry due to channel alterations were undetectable. Properly constructed jetties and random rock clusters of large riprap material produced good, economical trout habitat. Fisher-persons favored unaltered or partially altered stream sections, compared to altered sections, probably for aesthetic reasons. Several problems associated with channelization were not alleviated, as follows: (1) Loss of stream bank vegetation; (2) destruction of natural stream aesthetics; and (3) loss of stream lengths in most cases. The author recommends that original stream channels be altered only when necessary, and that such alterations be kept to a minimum. Vegetation along new channels should be retained to provide both bank stability and shade. When riprap is needed to hold the stream in a new channel, it should be covered with subsoil and topsoil down to the high-water mark and then revegetated with grass, shrubs, and trees. Jetties, random rock clusters, and other instream devices used to create pools must be engineered properly to withstand the annual high-water and occasional floods that occur. (3, 4, 6, 8, 15, 20)

123. Maddock, T., Jr. 1976. A primer on floodplain dynamics. J. Soil Water Conserv. 31(2):44-47.

The author defines a floodplain in geologic and hydrologic terms. He generalizes concerning constraints placed on a river system's meandering. Levees can control overbank flow. This, in turn, increases the stress on the stream channel, which normally would result in an increase in stream width, a reduction in slope, or a combination of both, which produces meandering. The tendency is to deliver the products of bank erosion downstream. As a result, most levee systems graduate to bank protection systems. This increases stream depth and results in coarsening of bed material and transported sediment, which produces a continual maintenance problem. Shortening a stream channel increases slope. This must be countered by an increase in width, an increase in depth, or an increase in the concentration and size of the sediment transported. An increase in size or concentration of sediment entering a reach with no change in discharge requires a reduction in width or an increase in slope. The opposite is true for a decrease in sediment size or concentration. A decrease in concentration accompanied by an increase in size results in no change. Bridges and culverts generally obstruct a portion of a normal stream cross section. This results in less slope upstream and more slope downstream. A greater velocity is needed upstream, if sediment is to be transported. Sediment deposition thus can be expected upstream, because a higher velocity requires a smaller section. The stream tends to enlarge its section downstream to accomodate the lower velocity associated with the steeper slope. Downstream erosion also replaces some of the material deposited upstream. The boundaries of a stream channel -- the bed and the banks -- are probably more important than the fluid itself in determining the survival of the biota. Much of the stream food web is associated with bed and banks. (1, 3, 18, 20, 26)

124. McClellan, T. J. 1974. Ecological Recovery of Realigned Stream Channels. FHWA/OR-74/1. Federal Highway Administration, Portland, Ore. 90 pp.

A field investigation of eighteen highway related stream channel changes in Oregon was made in 1973 to evaluate the effectiveness of natural processes in restoring conditions favorable or conducive to use of the altered streams as habitat by fish and streamside areas by small game. Known conditions prior to channelization, channel design, construction methods, and any measures taken to mitigate harm to stream ecology were used as bases for comparing localized effects of various types of alteration. Harmful design features are discussed in the report along with measures designed to alleviate or prevent damage during future highway construction. (4, 6, 8, 10)

125. McMahon, J., J. Wolf, and Sr. M. Diggins. 1972. Chironomidae, Ephemeroptera and Trichoptera in the benthos of unchannelized and channelized portions of the Missouri River. Proc. South Dakota Acad. Sci. 51:168-181.

The macrobenthos of channelized and unchannelized sections of the river near Whiting, Iowa (channelized) and Vermillion, South Dakota (unchannelized) were compared. The Chironomid midge (Diptera) density was 4.5 times greater in the main channel of the channelized section. This was due probably to stronger currents in the channelized section, than in the unchannelized one. (4, 14, 26)

126. Menzel, B. W., and H. L. Fierstine. 1976. A Study of the Effects of Stream Channelization and Bank Stabilization on Warmwater Sport Fish in Iowa: Subproject No. 5. Effects of Long-reach Stream Channelization on Distribution and Abundance of Fishes. FWS/OBS-76/15. U.S. Fish and Wildlife Service, Washington, D.C. 108 pp.

Relationships between habitat characteristics and the distribution and abundance of fishes were studied in eleven natural and channelized warmwater stream segments of the upper Des Moines River basin, Iowa, during the summers of 1974 and 1975. Four channelized prairie stream stations were characterized by a low degree of channel sinuosity, low gradient, predominantly sand bottom, and a monotonous pool-run bedform. Two natural prairie stream segments were highly sinuous, of low gradient and predominantly soft substrate, and with only an ill-defined pool-riffle sequence. Five woodland stream sites were of intermediate sinuosity, moderate to high gradient, firm bottom, and well established pool-riffle sequence. The sinuosity index was not very useful as an indicator of fish community structure. Because of the broad habitat tolerances of many of the resident prairie stream fishes, past channelization has probably had only a limited long-term impact on the ichthyofauna. Larger fishes, at least, move freely between straightened and meandering stretches. Channelized areas may act more as travel corridors between favorable reaches of habitat than as areas of permanent residence. The impact of channelization in central Iowa prairie streams is minimal, when confined to limited stretches of low gradient flow. Substantial negative impact is anticipated if channelization is extended into downstream higher gradient reaches. Within channelized segments, impact would be reduced by construction designs that would contribute to greater habitat diversity. For example, riprap along shores would provide substrate for growth of fish food organisms, cover for small fish, and would perhaps prevent scouring around the base, while also providing stabilizing bank cover. (1, 3, 4, 15)

127. Mifkovic, C. S., and M. S. Petersen. 1975. Environmental aspects -- Sacramento bank protection. Am. Soc. Civil Eng., J. Hydraulics Div. 101(HY5):543-555.

Bank protection work on the Sacramento River (California) has been centered at critical erosion sites where much, if not all, of the existing berms and levees have been lost. Future work will involve protection of berms that will, in turn, protect levees. Also projected are modifications that minimize disruption of riparian habitat and aesthetics. Promising possible modifications include the following: (1) Selective clearing and retention of vegetation and replacement of lost vegetation at construction sites; (2) restoration of bank-side berm areas; (3) preservation of existing berms; (4) requiring construction from the waterside by use of floating equipment; (5) reducing the top of rock revetment to a high sustained flow level; (6) preservation of habitat on protected berms by strong environmental easements; and (7) inclusion of recreation facilities at selected bank-side construction sites. (8, 18)

128. *Miller, C. R., and W. M. Borland. 1963. Stabilization of Fivemile and Muddy Creeks. Am. Soc. Civil Eng., J. Hydraulics Div. 89(HY1): 67-98.

Inherent in the development of an irrigation project are changes in regime and stability of the natural drainageways within or adjacent to the project area. The authors examine the deterioration of Fivemile and Muddy Creeks in the area of the Riverton Project, Wyoming, and analyses used in arriving at a comprehensive plan for stabilization. Emphasis is placed on stabilization methods used, the adequacy and effectiveness of the protective works installed, and the results obtained after seven years. Stabilizing methods included the use of brush or rock-filled groins, jacks, vegetation, and pervious fencing. All methods met with some success. (3, 7, 8, 18, 20, 21, 22, 26)

129. Morris, L. A., R. N. Langemeier, T. R. Russell, and A. Witt, Jr. 1968. Effects of main stem impoundments and channelization upon the limnology of the Missouri River, Nebraska. Trans. Am. Fish. Soc. 97(4):380-388.

Rigid control has been imposed on the Missouri River by impounding over one-half of the upper 1,500 miles and by channelizing most of the remaining river within permanent narrow riprapped banks. Chanenlization has reduced both the size and variety of aquatic habitats by destroying key productive areas. (3, 4, 19)

130. Morrison, W. R., and L. R. Simmons. 1977. Chemical and Vegetative Stabilization of Soils. Laboratory and Field Investigations of New Materials and Methods for Soil Stabilization and Erosion Control. REC-ERC-76-13. U.S. Bureau of Reclamation, Denver, Colo. 161 pp.

This report summarizes three types of effort: (1) Laboratory studies -- (a) Results of screening tests of 30 liquid soil stabilizing materials and development of tentative performance requirements for water-based soil stabilizers; (b) Special studies conducted on materials and methods to waterproof problem soils, to arrest slope erosion, and to bind gravel together for riprap applications; (2) Field applications -- where various chemical and vegetative methods have been used on new construction, rehabilitation, or operation and maintenance; and (3) State-of-the-art survey -- a survey on chemical stabilization of soils, and revegetation methods and materials for erosion control. The paper has 293 references. (2, 22, 24)

131. Murphy, T. E. 1967. Drop Structure for Gering Valley Project, Scottsbluff County, Nebraska: Hydraulic Model Investigation. Tech. Rept. No. 2-760. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. 30 pp.

Tests were conducted on a 1:12-scale model of a rectangular drop structure designed to stabilize channel beds and minimize bank erosion in the Gering Valley drainage system. Of primary concern were development of the optimum dimensions for the various elements of the structure and determination of riprap requirements in the vicinity of the structure. (1, 8, 21)

132. Naegamvala, J. P., and R. B. Shah. 1972. Review of river training measures in India, pp. 29.1.142-29.1.157. In International Commission on Irrigation and Drainage, Eighth Congress, Varna, R. 10, Trans., Vol. 5, Question 29.1.

River training in India is of great importance due to annual recurring flood damage, 80% of the cost of which is due to crop losses. A national flood control program for river training began in 1954. Although various methods of training and flood control have been used, major emphasis, so far, has been on the construction of embankments. About 7,000 km of embankments have been constructed in the last 16 years. Another major activity is the construction of antierosion works, such as spurs, revetments, etc. The main factors governing the adoption of the embankments are that these could be constructed quickly with local resources, and large areas could be protected with a minimum of funds. In addition, embankments can be constructed on the basis of the available meager hydrological data, and they can be raised and strengthened subsequently, as more data become available. River works are described on the Kosi, Brahmaputra, Subernarekha, Tapi, and the rivers of northern Bihar. (17, 19, 21)

133. New York (State of). 1971. Bank and Channel Protective Lining Design Procedures. Soils Design Procedure SDP-2. N.Y. Dept. of Transportation, Albany, N.Y. 65 pp.

This design manual provides procedures and guidelines for the design of bank and channel protective linings to achieve adequate protection against detrimental erosion by the most economical means. Soil properties are a factor in erosion, and the effects of soil type on the requirements for protection are discussed. Various types of bank and channel protection are described along with limitations and advantages as determined from construction experience and field performance. (8, 20, 21)

134. Noble, C. A., and R. C. Palmquist. 1968. Meander growth in artificially straightened streams. Proc. Iowa Acad. Sci. 75:234-242.

Two rivers (Skunk River and Squaw Creek) near Ames, Iowa, were straightened artificially in 1900 and are developing meander patterns. Correlations (based on regression analyses) betwen meander parameters and bank materials and discharge were low. (3)

135. Nolan, M. E., M. M. Hatano, R. B. Howell, and E. C. Shirley. 1976. Control of Ditch Erosion Using Fiberglass Roving (Type B Study). CA-DOT-TL-7225-1-76-41. California Dept. of Transportation, Sacramento. 52 pp.

This study demonstrated the use of fiberglass roving with vegetation for erosion control in drainage ditches. Three sites in the state were treated that had various soil types and different climatological conditions. Fiberglass roving with vegetation was effective in reducing erosion at all three sites. Grasses planted prior to treatment emerged through the fiberglass with little or no difficulty. (21, 24)

136. O'Brien, J. T. 1951. Studies of the Use of Pervious Fence for Streambank Revetment. Rept. No. A-70.1, Hydrodynamics Labs., California Inst. of Technology, Pasadena. Tech. Publ. SCS-TP-103. USDA, Soil Conservation Service, Washington, D.C. 66 pp.

Fence revetments, as constructed in southern California, give considerable protection to channel banks. The amount of protection varies with a number of factors, including mesh size of the fencing, water depth, fence location in the channel, and the amount of debris present. A fence covered with debris or backed up with brush will provide more protection to banks than will the fence alone. Groins constructed of impervious materials give more protection to banks than those made of pervious materials. Impervious groins should be placed at angles 45$^{o}$ with the flow and pointing downstream. Revetments cause the slope of the channel bed to increase over that of unreveted channels. (7, 21)

137. Osborne, D. J., and W. B. Gilbert. 1978. Use of hardwood bark mulch

for highway slope stabilization. Agronomy J. 70(1):15-17.

Highway slopes may be mulched in summer with shredded hardwood bark mulch (a mixture of yellow poplar, white oak, and black gum shredded into particles of the size range 2 mm - 2.5 cm) and left unseeded until an optimum fall seeding date with adequate erosion control, obviating the need for recultivation currently used to establish permanent cover after a "temporary seeding" during the summer. (24)

138. Osterkamp, W. R. 1977. Effect of Channel Material on Width-Discharge Relations for Perennial Streams, with Emphasis on Streams in Kansas -- a Progress Report. Open File Rept. 77-38. U. S. Geological Survey, Lawrence, Kansas. 44 pp.

Using consistent procedures for width measurement at established streamflow-gaging stations, data were compiled to develop a power-function relation between width and mean discharge for high-gradient perennial streams. High-gradient channels, which generally exhibit low variability for most factors influencing the width-discharge relation, were selected to define a standard exponent in the power-function equation. Regression analysis of silt-clay channels of Kansas gave an exponent similar to that determined for high-gradient streams, thus supporting the use of a standard exponent. To account for the effects of sediment on channel morphology, silt-clay percentages of bed and bank material from 98 perennial streams of the western and midwestern U.S. were introduced into the standard width-discharge relations. Bed and bank cohesiveness, as indicated by silt-clay content, is considered a measure of channel resistance to erosion. Multiple-regression analysis of data limited to Kansas streams yielded an equation more typical of stable conditions than that of the larger area, because widespread destructive flooding and channel widening have not occurred in Kansas recently. The regression equations provide refinement to the channel-geometry technique of estimating discharge characteristics of ungaged basins. The equations also provide a means of anticipating changes in channel morphology resulting from hydraulic structures. (1, 7, 8, 20)

139. Otis, M. B. 1974. Stream improvement, pp. 99-122. In J. M. Migel (ed.). The Stream Conservation Handbook. Crown Publishers, New York. 242 pp.

The author of Chapter 5 discusses materials and techniques for improvement of trout streams, his examples including streamside vegetation, fencing, streamside structures, and instream structures. He provides construction hints, such as usage of available materials, taking advantage of actual conditions that exist in the stream, and avoidance of artificiality. (8, 15)

140. Parsons, D. A. 1963. Vegetative control of streambank erosion, pp. 130-136. In Proceedings of the Federal Inter-Agency Sedimentation Conference, Jackson, Mississippi, 28 January - 1 February 1963. Misc. Publ. No. 970. U.S. Dept. of Agriculture, Washington, D.C.

Vegetation may protect a streambank in at least three ways: (1) By reduction of water speeds and tractive forces at the soil surface to a value below that required to cause erosion; (2) protection of bank materials as a buffer against ice, logs, and other transported materials. Trees withstand hard blows; pliant shrubs bend with impact; and (3) close-growing vegetation will contribute to bank stability within a narrow range of conditions by inducing deposition of materials. (25, 26)

141. Parsons, D. A. and R. P. Apmann. 1965. Cellular concrete block revetment. Am. Soc. Civil Eng., Proc., J. Waterways and Harbors Div. 91(WW2):27-36.

An experimental revetment of specially designed cellular concrete revetment blocks was constructed on an eroding streambank in western New York. Over a period of eight years, the 4-inch thick revetment has given satisfactory performance under severe conditions. In contrast, an adjacent revetment of quarried stone riprap has been less effective in withstanding erosive forces. Square holes run entirely through the depth of the concrete block. These holes serve several purposes: (1) They mechanically hold gravel and crushed stone in place, thus reducing the erosive forces at the surface of the bank; (2) they allow planting of vegetative materials on the bank; and (3) they reduce the block weight facilitating handling. (21)

142. Pavoni, J. L., and D. E. Stein. 1975. Environmental Impact of Riverbank Revetment. U.S. Army Engineer District, Louisville, CE, Louisville, Kentucky. 157 pp.

The authors review existing environmental impact assessment methodologies and their pertinence to assessment of bank revetment projects. Emphasis is given to technical, economic, and environmental feasibilities of common bank revetment techniques. A review of assessment procedures, along with visual evaluation of various revetment projects, provided a basis for the establishment of an assessment procedure to be used in bank revetment projects. In the Louisville District, CE, quarried stone, artificial riprap, "mattresses", and various forms of monolithic bank protection have been used in revetments. Riprap is the most widely used and most satisfactory means of bank protection, due to the low cost, technical superiority, and aesthetic acceptability. Of the several types of artificial riprap considered technically feasible for bank protection use, soil cement blocks and asphalt stabilized soil blocks have the greatest potential for replacing quarried stone. None of the monolithic bank protection materials reviewed have significant potential at present, when compared to uncompacted asphalt pavement. Some monolithic methods that have potential include soil cement, synthetic elastomer sheets, and uncompacted asphalt pavement. At present, monolithic methods are restricted more by drainage than by anything else. Many materials have been used to fabricate mattresses for bank revetment, but the economics involved in fabrication and placement of mattresses preclude their use for all but the largest sites. A single layer of synthetic material has the greatest economic potential for bank protection, but problems associated with deterioration and anchorage have not yet been solved. There is a bibliography with 114 references. (2, 8)

143. Pennak, R. W. 1971. Toward a classification of lotic habitats. Hydrobiologia 38(2):321-334.

A world-wide system for classifying brooks, streams, and small rivers is proposed, using the following criteria: Width, flow current speed, substrate, summer temperatures, winter temperatures, turbidity, total dissolved organic matter, total dissolved inorganic matter, water hardness, dissolved oxygen, rooted aquatic plants, and streamside vegetation. (1, 7, 9, 18, 20, 23, 25, 26)

144. Peters, J. C., and W. Alvord. 1963. Man-made Channel Alterations in Thirteen Montana Streams and Rivers. Montana Fish and Game Dept., Helena. 10 pp.

There were 1,987 individual alterations in the 786 miles of Montana stream channel inventoried. As a result of human alterations, the total length of the channels was shortened by 68 miles. Agricultural activities accounted for the greatest length of channel altered, followed by railroad construction, road construction, and urban and industrial development. Relocated channels accounted for the greatest length of channel altered, followed by riprapping, diking, and channel clearance. Standing crops of game fishes were several times higher in natural, meandering channels than in altered ones. (3, 15, 19)

145. Pfankuch, D. J. 1975. Stream Reach Inventory and Channel Stability Evaluation: A Watershed Management Procedure. U.S. Dept. of Agriculture, Forest Service/Northern Region, Lolo National Forest, Missoula, Montana. 31 pp.

A pocket manual and inventory card were prepared containing procedures developed to systematize measurements and evaluations of the resistive capacity of mountain stream channels to the detachment of bed and bank materials. Correct procedure use will aid in determining the capacity of the streams to adjust to, and recover from, potential changes in flow and/or increases in sediment production. (3, 8)

146. Pickett, E. B., and B. J. Brown. 1977. Guidelines for Monitoring and Reporting Demonstration Projects; Section 32 Program, Streambank Erosion Control Evaluation and Demonstration Act of 1974. Instruction Rept. H-77-1. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi. 52 pp.

This document contains guidelines to aid in providing brief, thorough, uniform documentation of the data to be collected by field monitoring and reported for the numerous demonstration projects to be carried out under the Streambank Erosion Control Evaluation and Demonstration Act of 1974 (Sect. 32, P.L. 93-251). Streambank protection is to be considered from the standpoints of historical and design data, construction data, performance data, economics, and impact on the surrounding land. (8, 21)

147. Popkin, B. P. 1974. Hydrologic aspects of land-use planning at Tumamoc Hill, Tucson, Arizona, pp. 309-324. In Hydrology and Water Resources in Arizona and the Southwest, Vol. 4. Proceedings of Ariz. Acad. Sci. and Amer. Water Resources Assoc., Hydrology Section, Flagstaff, Arizona, 19-20 April 1974.

Tumamoc Hill is an 869-acre desert near Tucson, which is being considered as a controlled-access environmental site. The largest of three watersheds that drain the hill is rapidly being urbanized upstream, presenting potential flooding and erosion hazards. These problems may be reduced simply, economically, and wisely in a land-use plan. The region can be managed to reduce hydrologic hazards by widening stream channels, installing low checkdams, and by vegetating the drainageways. These procedures will slow runoff velocities, increase the cross-section area of flow and roughness coefficient, and provide more water for vegetation and wildlife. (3, 7, 8, 17, 18, 26)

148. Posey, C. J. 1957. Flood-erosion protection for highway fills. Trans. Am. Soc. Civil Eng. 122:531-555.

A method, using rock sausages, was developed for constructing highway fills in Iowa. Fills were not damaged appreciably by inundation, even when subjected to high velocities of flow over a grade or along the side slopes. (17, 21)

149. Posey, C. J. 1973. Erosion Control: Stability of Rock Sausages. Rept. A-035-CONN., OWRR, USDI. Institute of Water Resources, Univ. of Connecticut, Storrs. 15 pp.

The author has developed criteria for rock sausages (wire-bound rocks) for predicting the size of sausage that will resist being moved by a given depth and velocity of flow. Although rock sausages have been little used in the U.S., an increase in their use can be expected. (They were invented by the Chinese centuries ago.) Less rock is needed than for riprap, and smaller sizes can be used. Especially where rock is scarce, this gives an advantage over the alternatives of concrete or asphalt. If washed out by unexpectedly heavy flows, sausages can be salvaged and used in rebuilding. They can be used repeatedly, when needed for temporary protection. An improved installation method, developed by the author, prevents fine material from being leached out from beneath the sausages. (7, 17, 26)

150. Rastogi, M. C., and B. L. Dhawan. 1974. Stabilization of sandy soils by chemical additives. I. Adsorption of surface active agents at soil/water interface. Indian J. Chem. 12(2):158-160.

In this study of soil mechanics, the adsorption of dodecylpyridinium chloride (DPyCl) was studied on purified and classified samples of sandy Indian soils from Jamshedpur. (22)

151. Ree, W. O., and V. J. Palmer. 1949. Flow of Water in Channels Protected by Vegetative Linings. Tech. Bull. No. 967. U.S. Dept. of Agriculture, Washington, D.C. 115 pp.

This paper contains a complete, detailed record of studies of the effects of various grasses used as vegetal linings, on the capacity and stability of small channels constructed at an outdoor hydraulic laboratory near Spartanburg, South Carolina. Such channels are used for the correct distribution and disposal of water on farmlands. (21, 25)

152. Remillieux, M. 1972. Development of bottom panels in river training. Am. Soc. Civil Eng. Proc., J. Waterways, Harbors, and Coastal Eng. Div. 98(WW2):151-162.

In the medium-sized Loire River (France) and Chao Phya River (Thailand), bottom panels did not increase bank erosion or worsen flooding. (21)

153. Richardson, E. V., S. Karaki, K. Mahmood, D. B. Simons, and M. A. Stevens. 1975. Highways in the River Environment -- Hydraulic and Environmental Design Considerations. Training and Design Manual. Dept. of Civil Eng., Colorado State Univ., Fort Collins, and the National Highway Institute, Washington, D.C. 479 pp.

A course was developed to give training in the practical application of the concepts of open channel flow, fluvial geomorphology, and river mechanics to the planning, location, design, construction, maintenance, and operation of highways; and to enable the participants, graduate engineers in a two-week course, to apply these concepts to environ-

mental problems associated with highway crossings and encroachments. The manual has eight chapters, the titles of several of which are as follows: Open channel flow; Fluvial geomorphology; River mechanics; River stabilization; Bank protection and scour; and Hydraulics and environmental considerations of highway river crossings and encroachments. The authors have also prepared a basic instructor's lesson plan for the course. (3, 6, 8, 10, 17, 21, 26)

154. Rickert, D. A., and W. G. Hines. 1978. River quality assessment: Implications of a prototype project. Science 200:1113-1118.

The U.S. Geological Survey recently completed an intensive river quality assessment study of the Willamette River basin, Oregon. It was found that existing water quality data collected under monitoring and surveillance type programs are inadequate for defining the critical cause-effect relationships that control river quality problems. Intensive, synoptic surveys keyed to local problems and conditions are required to provide an adequate information base for making key management decisions. (8, 9)

155. Rindge, S. D., and D. A. Gaskin. 1977. The Effectiveness of Two Erosion Control Fabrics in Retarding Soil Loss. Tech. Note. U.S. Army Cold Regions Research and Engineering Lab., CE, Hanover, New Hampshire. 17 pp.

The capabilities of two types of erosion control fabrics to reduce soil loss at construction sites in cold regions was studied in Hanover, New Hampshire from May 1976 to April 1977. The two materials tested were fiberglass netting (Owens-Corning Fiberglass Corp.) and plastic netting interwoven with strips of paper (Gulf Paper Co.). Both fabrics were installed on plots previously treated with fertilizer and grass seed. In October, it was found that treated plots had a good to excellent vegetative cover, while the control plot had approximately 5% cover. Soil loss measurements taken after one year indicated that both fabric types are effective in reducing soil loss when compared to the stripped control. The fiberglass had an average effectiveness value of 96.7% and the woven paper had a single value of 96.4%, compared to the control plot loss of 76.9 tons/acre during the study. (22)

156. Sarles, R. L., and D. M. Emanuel. 1977. Hardwood bark mulch for revegetation and erosion control on drastically disturbed sites. J. Soil Water Conserv. 32(5):209-214.

Use of bark as a mulch on seeded areas offers an outlet for large amounts of this timber mill residue. In southern West Virginia, bark compares favorably with straw and wood-fiber mulches for stabilizing soils on disturbed sites. (22)

157. *Schneberger, E., and J. L. Funk (eds.). 1971. Stream Channelization: A Symposium. Special Publ. No. 2. North Central Div., American Fisheries Society, Omaha, Nebraska, December 1971. 83 pp.

Eight papers, several of which are annotated in this bibliography. (3, 4, 18)

158. Siddoway, F. H., and R. H. Ford. 1971. Seedbed preparation and seeding methods to establish grassed waterways. J. Soil Water Conserv. 26(2):73-76.

Two grassed waterways were studied in eastern Roosevelt County, Montana. One was seeded in early spring and the other in late autumn, with a 1:1 mixture of smooth bromegrass (Bromus inermis) and western wheatgrass (Agropyron smithii). Various mulches, fertilization measures, methods of seedbed preparation, and seeding methods were compared. Fertilization shortened the period required for stabilization by increasing the rate of grass and weed growth. Wheat straw mulch protected the fall-seeded waterway against heavy snowmelt runoff in the spring of the establishment year. (17, 24)

159. Silberberger, L. F. 1959. Streambank stabilization. Agric. Eng. 40(4):214-217.

Precast concrete toe blocks were useful in stabilizing Buffalo Creek at Buffalo, New York. (21)

160. Simons, D. B., P. F. Lagasso, Y. H. Chen, and S. A. Schumm. 1975. The River Environment -- a Reference Document. CER 75-76 DBS-PFL-YHC-SAS-14. Eng. Research Center, Colorado State Univ., Fort Collins. Prepared for the U.S. Fish and Wildlife Service, Twin Cities, Minnesota. 569 pp.

This reference volume contains current information on the environment of major rivers from the standpoints of fluid mechanics, geomorphology, hydraulics, and river mechanics. The volume is meant to serve a threefold purpose, as a (1) reference document, (2) teaching aid, and (3) guide for decision-making relative to the evaluation of river response to alternate river development plans. There are chapters on river mechanics, morphology, and responses, and data needs and sources (8 chapters in all), as well as three appendices (references, basic equations of open channel flow, and a glossary). (2, 3, 7, 8)

161. Skladnev, M. F., and I. A. Sherenkov. 1971. Concrete blocks for earth slope protection. Hydrotechnical Construction 2:182-185.

Prefabricated concrete blocks of varying shapes and weights are used widely in Japan for protecting riverbeds and banks from erosion. Block placement methods and basic characteristics of seven types of blocks are discussed. (1, 20, 21)

162. Smith, D. G. 1976. Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river. Geol. Soc. Am. Bull. 87:857-860.

A series of experiments were performed on bank materials of anastomosed channels in floodplain silt deposits in the Alexandra Valley in Banff Park, Alberta, to determine the effect of vegetation roots on bank erodibility and lateral migration of channels. Underground roots from the dense growth of meadow grass and scrub willow provide the reinforcement of bank sediment and a riprap-like protection of channel banks from river erosion. Experimental results suggested that in cool environments with aggrading river conditions where overbank deposition of silt, clay, and fine sand dominate the valley fill, vegetation roots are able to rapidly accumulate and decay very slowly, thus affording protection to banks from erosion in deeper parts of the channels. Experimental results, using a specially designed erosion box, indicated that bank sediment with 16-18% of roots, by volume, had 20,000 times more resistance to erosion than comparable bank sediment without vegetation. (3, 18, 25)

163. Smith, P. W. 1968. An assessment of changes in the fish fauna of two Illinois rivers and its bearing on their future. Trans. Ill. State Acad. Sci. 61(1):31-45.

Based on a comparison of fish collections taken prior to 1901 and between 1956-1966 in the Vermilion and Embarras River drainages of east-central Illinois, evidence assembled indicates that one species has been extirpated and 20 species decimated in the two systems. Factors responsible include alteration of the physical habitat, e.g., rate of flow and bottom type; increase in the amount of suspended silt with subsequent loss of aquatic vegetation; and reduction in stream size. Dams have been constructed, and there have been extensive dredging and canalizing activities. (1, 3, 15, 18, 20, 26)

164. Smythe, A. 1969. Countering erosion. NZ Harbour and Shipping and Export Review, June 1969. 2 pp.

Gabions are used successfully throughout New Zealand. One of the first sack gabions used in Italy for river works over 75 years ago was recently examined and found to be in perfect condition. (21)

165. Solomon, R. C., and J. J. Johnson, C. R. Bingham, and B. K. Colbert. 1974. Physical, Biological, and Chemical Inventory and Analysis of Selected Dredged and Disposal Sites, Middle Mississippi River. Final Rept. WES Misc. Paper Y-74-6. U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi and U.S. Army Engineer District, St. Louis, Missouri. 207 pp.

Sediments deposited in the channel by fluvial processes and materials derived from the products of bank erosion pose a continuous dredging and disposal problem in the Mississippi River navigation system. Only limited data are available concerning the physical, chemical, and biological characteristics of the middle Mississippi River as related to dredging and disposal operations. The study was undertaken (1) to provide background information on the physical, chemical, and biological characteristics of selected dredged and disposal sites; (2) to establish uniform procedures for sampling dredged materials and the biota in a riverine system; and (3) to describe the environmental impacts of dredging and disposal activities. (1, 6, 8, 10)

166. Solomon, R. C., D. R. Parsons, D. A. Wright, B. K. Colbert, C. Ferris, and J. E. Scott. 1975. Environmental Inventory and Assessment of Navigation Pools 24, 25, and 26, Upper Mississippi and Lower Illinois Rivers. Summary Report. Tech. Rept. Y-75-1. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. 97 pp.

The River and Harbor Act of 3 July 1930 authorized the construction and maintenance of a 9-ft-deep by 300-ft-wide channel in the upper Mississippi and lower Illinois Rivers. Construction of locks and dams supplemented by dredging and bank stabilization was required to maintain the 9-ft depth, particularly during low flow periods. An investigation was carried out before and after man-made changes and overall changes in geomorphology. Limited studies have shown that rock revetment may create a superior habitat as compared to natural shorelines by providing greater diversity for aquatic organisms through stabilization of the river's banks. Productivity and diversity of biotic communities associated with revetments, on both the land and water sides, need to be investigated and compared with nonrevetted areas. (3, 7, 14, 18)

167. Stanton, C. R., and R. A. McCarlie. 1962. Streambank stabilization in Manitoba. J. Soil Water Conserv. 17(4):169-171.

Streambank protection efforts, initiated more than a decade before on Edwards Creek (Manitoba, Canada) were designed to employ a minimum of mechanical methods and maximum vegetative control of bank erosion. Six different methods of bank erosion control were tried, including sloping, seeding, and planting; lining with piles; laying netted rock riprap; dumping low rock toes; establishing rolled willow toes; and installing pile jetties. (21, 24)

168. Steinberg, I. H. 1966. Russian River channel works. Am. Soc. Civil Eng., J. Waterways and Harbors Div. 86(WW4):17-32.

The author evaluated channel (and bank) stabilization works constructed in 1956 by the U.S. Army Engineer District, San Francisco, CE, along a four-mile test reach of the Russian River of California. The work was designed to halt bank erosion. The Russian River rises and falls rapidly; the channel capacity is 20,000 cfs, and flood peaks reach 46,000 cfs. Types of works installed in the test reach included flexible fence, channel training works, barrier jacks, single and double lines of jacks parallel to the bank, wire mesh and gravel blanket, willow tree pendants, belt planting, and check dams. All were successful. (17, 21)

169. Stevens, M. A., D. B. Simons, and G. L. Lewis. 1976. Safety factors for riprap protection. Am. Soc. Civil Eng., J. Hydraulics Div. 102(HY5):637-655.

The merit of a particular riprap design can be represented by a numerical value for the riprap safety factor, defined as the ratio of moments resisting particle motion to the moments tending to rotate the particle out of the riprap blanket. From theoretical considerations, a relationship was established between the riprap safety factor and the magnitude and direction of the flow velocity in the vicinity of the riprap, the angle of repose for the riprap. The author presents stability equations for the design of riprap protection on plane beds, side slopes, and embankment slopes. (8, 21, 26)

170. *Striffler, W. D. 1960. Streambank Stabilization in Michigan -- A Survey. USDA, Forest Serv. Res. Pap. 84. Lake States Forest Experiment Sta. and Michigan Dept. of Conservation, East Lansing and Lansing. 14 pp.

A survey of streambank stabilization in northern lower Michigan was made during the summer of 1958. Data were collected and analyzed from 113 untreated and 115 treated banks on three treated watersheds and one untreated one, with the following results: (1) Bank stabilization is highly effective in stabilizing waterlines, reducing bank erosion, and increasing the density of vegetative cover. Serious erosion on treated banks averaged 7%, compared with 47% on untreated banks. Waterlines of treated banks were 93% stabilized, compared with 28% on untreated banks. The density of the vegetative cover on treated banks averaged 50%, compared with 26% on untreated banks. (2) Of the physical bank features examined, only the texture of the soil bore any consistent relationship to the stability of the bank. Clay banks generally had more serious erosion, less stabilized waterlines, and less ground vegetation. Sand and clay banks both responded to treatment to the same degree. (3) Once the banks were well stabilized by planting, volunteer vegetation usually took over from planted vegetation.

(4) The success of stabilization was adversely affected by cattle grazing or trampling or the recreational use of the bank. Fencing the bank to keep out livestock is of utmost importance. (11, 19)

171. Striffler, W. D. 1963. Suspended sediment concentrations in a Michigan trout stream as related to watershed characteristics, pp. 144-150. In Proceedings of the Federal Inter-Agency Sedimentation Conference, Jackson, Mississippi, 28 January - 1 February 1963. Misc. Publ. No. 970. U.S. Dept. of Agriculture, Washington, D.C.

Streambank erosion is one of the more important sources of suspended sediments in the Tobacco River watershed of Michigan's lower peninsula. Estimates of its contribution range from 26% to 30%. Such erosion can be controlled to improve the stream as a trout habitat. (11, 20)

172. Tarplee, W. H., Jr., D. E. Louder, and A. J. Weber. 1971. Evaluation of the effects of channelization on fish populations in North Carolina's coastal plain streams, pp. 188-210. In Stream Channelization (Part 1). Hearings before a Subcommittee of the Committee on Government Operations, House of Representatives, 92nd Congress, First Session, 3-4 May 1971. U.S. Government Printing Office, Washington, DC.

The authors point out detrimental effects of stream channelization on fish populations and on the flora and bottom fauna of streams. Their results also show that, following channelization and with no channel maintenance, nature can restore a stream and its fish populations to a stage reasonably near its natural condition in a period of approximately 15 years, provided no further alterations of the stream bed, banks, forest canopy, or aquatic vegetation occur. (3, 4, 15)

173. *Task Committee on Channel Stabilization Works. 1965. Channel stabilization of alluvial rivers. Am. Soc. Civil Eng., J. Waterways and Harbors Div. 91(WW1):7-37.

The Task Committee examined all of the U.S. major river systems, where channel stabilization works have been used extensively, and they reached several conclusions; (1) Because of the complex nature of alluvial streams, design of channel stabilization works is based largely on experience. Spacing, elevation, length and permeability of dikes, groins, and jetties continue to depend on the engineer's judgement; knowledge of the diverse characteristics of the individual stream is essential. (2) Causes of caving banks is important and should be given primary consideration in choosing revetment materials. One of the most common causes of bank failure is the attack of the stream on the toe of the underwater slope. (3) Stone is the most commonly used material for upper bank paving for revetments; it is durable and

conforms to minor irregularities in the slope. (4) Permeable intermittent structures are more successful in streams with a high concentration of sediments than in relatively clear-water streams. Steel and wooden jack jetties have been successful principally where slopes are steep, and large quantities of sand are transported, so that the stream is braided or tends to become braided. In such cases, the jetties become additional objects of roughness to slow the velocities within the jetty fields to promote deposition of sediments. Thereafter, flows become confined, largely, between the jetty fields or between the jetty field and the opposite bank. (3, 8, 18, 19, 20, 21, 26)

174. Taube, C. M. 1967. Stabilization of an eroded river bank. J. Soil Water Conserv. 22(6):249-250.

High sand and clay banks were eroded in Michigan's Pine River ( a major trout stream and branch of the Big Manistee River) after heavy rains. The silt load destroyed fish habitat and fish food organisms. Bank stabilization measures had been taken 30 years before (1936-1939) by installation of a rock (3-16 in. in diameter) current deflector. The deflector, built by the Civilian Conservation Corps, still exerted an influence in 1966. Several wooden deflectors installed at the same time, were washed out by 1939. Even without riprap or seeding, vegetation recolonized the bank by the deflector. Stabilization would have occurred even faster with placement of more effective deflectors, riprapping of the base of the steep cliff bank with rock, and planting of vegetation to augment natural seeding. (17, 20, 21)

175. Thornburg, A. 1977. Use of vegetation for stabilization of shorelines of the Great Lakes, pp. 39-54. In Proceedings of the Workshop on the Role of Vegetation in Stabilization of the Great Lakes Shoreline. Great Lakes Basin Commission, Ann Arbor, Michigan.

The area to be vegetated must be on a stable slope for the material, and adapted plants must be used. The author discusses the criteria for selection of species, the role of introduced and native species, and techniques for site preparation and establishment developed by the Soil Conservation Service, U.S. Dept. of Agriculture. The paper includes a guide to species adaptation to various moisture ranges. The guide includes native and introduced grasses, legumes, trees, and shrubs. (24)

176. Thronson, R. E. 1976. Nonpoint Source Pollution Control Guidance. Construction Activities. U.S. Environmental Protection Agency, Washington, DC. 112 pp.

Chapter 3 (55 pp.) contains selected practices for control during construction activities, including methods and structure design for sediment control. Some of the methods and designs are useful in bank design for streams. (6, 8, 20)

177. Tiefenbrun, A. J. 1963. Bank stabilization of Mississippi River between the Ohio and Missouri Rivers, pp. 387-399. In Proceedings of the Federal Inter-Agency Sedimentation Conference, Jackson, Mississippi, 28 January - 1 February 1963. Misc. Publ. No. 970. U.S. Dept. of Agriculture, Washington, D.C.

The earliest plan of improvement in the middle Mississippi River consisted of closing dams or solid dikes constructed of brush and stone to confine the flow to a single channel. These gave way to permeable structures consisting of pile dikes and crib dikes. Although dikes cause deposition and accompanying accretions, in many instances the dike system may induce a heavy attack on the opposite bank downstream. Unless banks are protected, large scale caving will occur. Standard bank protection consists of an underwater part (lumber mattress and stone ballast) and upper bank part (riprap paving). In addition to controlling the trace of the channel at high stages, experimental stone foundation has been used in the repair of revetments where the river attack is mild and the toe of the bank is above or near the low water plane. This type of foundation is more stable and less costly than lumber mattress foundation. Sediment from upstream overbank areas and from bank erosion still are factors in regulating river works, but their contribution is diminishing. We are now entering a stage in the middle Mississippi River, where impermeable dikes may be needed. (3, 19, 20, 21)

178. Tilton, G. A., Jr. 1943. New combination bank protection constructed on Eel River near Dyerville. Calif. Highways and Public Works 21(1):4-5, 20.

Rock and riprap and wire mattress were used to protect a stream with banks comprised of alluvial silt. Highwater spring discharges reached 300,000 second-ft, and the stream rose 30-35 ft above the low-water stage. (17, 21)

179. Tobiaski, R. A., and N. R. Tripp. 1961. Gabions for stream and erosion control. J. Soil Water Conserv. 16(6):284-285.

Gabions were used in the North River, George Washington National Forest, Virginia. Advantages of gabions include the following: (1) Flexible -- conform to shifting contours and absorb impacts; (2) Permeable -- hydrostatic pressure behind them is reduced; (3) Stable -- one can wire many gabions together to achieve great stability while retaining flexibility; (4) Easy to repair, alter, or replace; breaks in the wire mesh do not open wider readily and are mended easily; and (5) Economical -- (a) foundation preparation is not needed; (b) construction is simple and can be accomplished with unskilled labor. (21)

180. Toronto. 1973. Erosion Control and Bank Stabilization in Metropolitan Toronto -- 10-Year Programme and 5-Year Project. The Metropolitan Toronto and Region Conservation Authority, Downsview, Ontario, Canada. 31 pp.

Stream erosion is the most active agent rearranging the land in metropolitan Toronto. In the springtime, local streams carry large amounts of soil particles in suspension, causing high turbidity; in late summer, metropolitan headwater streams are clear. The paper outlines the causes of watershed erosion in metropolitan Toronto, and includes tables of methods of stabilizing slide areas, river erosion, and slope erosion. (11, 13, 20, 21, 22)

181. Trautman, M. B., and D. K. Gartman. 1974. Re-evaluation of the effects of man-made modifications on Gordon Creek between 1887 and 1973 and especially as regards its fish fauna. Ohio J. Sci. 74(3): 162-173.

Gordon Creek, a tributary of the Maumee River in northwestern Ohio, was investigated in 1887 by Meek, in 1929-1938 by Trautman, and by Ohio Division of Wildlife personnel between 1954 and 1973. It was studied by Trautman and Gartman in 1973. Dredging and ditching in this area were begun about 1850, continuing until the present, with major channelization occurring in 1935. Channelization, together with the effects of dams and pollution, has had a major effect on the stream fishes. (3, 4, 15)

182. U.S. Army Corps of Engineers. 1963-1966. Symposium on Channel Stabilization Problems. Tech. Rept. No. 1. Committee on Channel Stabilization, Vicksburg, Mississippi. 4 vols.

Vol. 1. September 1963. 7 chapters. Bank and channel stabilization on the Arkansas River (Chapter 3), middle Rio Grande River (Chapter 5), and Columbia River (Chapter 6).
Vol. 2. May 1964. 8 chapters. Five chapters concerning the Arkansas River (Chapters 3, 4, 5, 7, 8).
Vol. 3. June 1965. 5 chapters. Two chapters on middle Rio Grande River stabilization (Chapters 1, 2) and three chapters on the Willamette and Columbia Rivers (Chapters 3, 4, 5).
Vol. 4. February 1966. 8 chapters. Stabilization and bank protection at Vicksburg on the Mississippi River (Chapter 1), middle Mississippi River (Chapters 2, 3), Red River (Chapter 4), Appalachicola River and Savannah River (Chapter 8). (3, 19)

183. *U.S. Army Corps of Engineers. 1966. Channel Stabilization Publications. Tech. Rept. No. 4. Commission on Channel Stabilization, Vicksburg, Mississippi. 130 pp.

Section VIII (pp. 101-130) is entitled "Channel improvement and stabilization measures". References are cited completely and are annotated. (2, 21)

184. U.S. Army Engineer District, Louisville, CE. 1974. Final Environmental Impact Statement, Newburgh, Indiana Bank Protection Project. Louisville, Kentucky. 73 pp.

Bank protection is planned, as part of the Newburgh Lock and Dam project at Newburgh, Indiana. A revetment, using approximately 37,500 cubic yards of stone (limestone) will be constructed. There will be a beneficial long-term impact on water turbidity, since the riprapped riverbank will not be susceptible to massive bank failure or erosion, although there will be short-term turbidity increases due to construction. Several alternative structural means are suggested, and rejected. These include groin or jetty, concrete wall, or sheet pile structures. For construction, rock revetment was the method selected based on economic, engineering, and environmental factors. (20, 21)

185. U.S. Army Engineer District, Omaha, CE. 1973. Final Environmental Statement, Missouri River: Garrison Dam to Lake Oahe. Omaha, Nebraska. 58 pp.

There is an average acreage loss of 1.2 acres per river mile per year, due to bank erosion in the Missouri River from Garrison Dam to below Bismark, North Dakota, based on data collected between 1954 and 1968. This is less than the 12-acre loss per river mile per year sustained prior to the construction of the main stem system of reservoirs. Losses will continue to diminish, as channel banks are stabilized. To date, construction has been completed on 17 miles, approximately 10% of the bankline miles between Garrison Dam and Lake Oahe. Riverflows, from one erosion reach into the next, are considered in order to incorporate protective work into functional order without waste, misalignment, or undesirable flow characteristics. These regulated and confined flows should partially reduce turbidity caused by riverbank erosion. Clearing and shaping of the riverbank for revetment placement causes only temporary turbidity and current pattern changes. (3, 11, 20)

186. *U.S. Army Engineer District, Omaha, CE. 1978. Final Environmental Statement, Missouri River, South Dakota, Nebraska, North Dakota, Montana: Streambank Erosion Control. Omaha, Nebraska. 256 pp.

This document contains a proposal for erosion control work under Section 32 of the Water Resources Development Act of 1974, as amended by Section 161, 1976. Bank erosion along the Missouri River is a natural phenomenon; its form and intensity have varied, as people have altered the river environment. Even with major upstream

reservoirs, and diminution of both floods and the suspended sediment load, erosion of high banks continues. High valley lands that are never replaced elsewhere are being converted to river channel and sandbars, while the width between high banks continues to widen. Ultimately, the river will become a wide area of sandbars and channels that occupy much of the valley width between bluffs. Factors affecting erosion include water volume, bluff contacts, and bed armoring. Various structural techniques are considered (with accompanying figures). These include flow control structures, vane dikes, windrow revetment, artificial harpoints, composite bankline revetment, sandfill revetment, and tree retards. (1, 3, 7, 8, 11, 18, 20, 21, 26)

187. U.S. Army Engineer District, Portland, CE. 1976. Final Environmental Impact Statement Supplement, Lower Columbia River Bank Protection Project (Washington and Oregon). Portland, Oregon. 304 pp.

Approximately 12 miles of bank protection works (38 sites) are proposed along the Columbia River and major tributaries. Most works will be revetments of dumped stone (riprap) to protect existing levees from bank erosion. Positive impacts include protection against breaching of levees, reduction of turbidity and sediment load caused by bank erosion, and stabilization of stream channels. Adverse impacts include loss of shoreline habitat on both sides of bank protection structures, and temporary increases in turbidity and erosion. To reduce the potential for escape of turbid water into the river during construction, material excavated from toe trenches is placed parallel to the river bank to form a protective berm. Siltation that occurs during the construction period is impeded from entering the waterway by the berm. Initial placement of the berm, however, does itself create turbidity. The increased siltation during revetment construction and the permanent loss of overhanging and emergent vegetation at project sites could have local effects on the aquatic biota. Dependence upon vegetative cover to provide protection for riverbanks has not proven to be a successful alternative along the Columbia River. Most of the bank areas above normal high water are covered with wild grasses, shrubs, vines, and trees. Below normal high water, however, the relatively long duration of high flows acts to limit or kill vegetation. Exposed earth surfaces result, and erosion begins promptly on the unprotected bank before new cover can become established. Among the possible structural alternatives to stone revetments, the installation of pile dikes is used on the Columbia River where the bank protection problem is complicated by the presence of a generally shifting river channel. Such dikes cost far more than does a revetment alone. In some sections of the river, sand removed from a ship channel within the river has been placed along the bank where it has been prevented much erosion damage while, at the same time, it has formed recreational beaches. (1, 6, 8, 20, 21)

188. U.S. Army Engineer District, Sacramento, CE. 1972. Final Environmental Statement, Sacramento River Bank Protection Project, California. Sacramento, California. 85 pp.

This project entails levee protection and erosion control works along the Sacramento River and its tributaries from Collinsville (river mile 0) to the vicinity of Chico, California (river mile 184). The bank protection program and accompanying maintenance will prevent the continuing erosion of levees and loss of riparian lands and vegetation. Loss of aesthetic, wildlife, and other natural riparian values of the river cannot be avoided at some sites. However, such values would be lost ultimately to erosion, if the project was not constructed. Present bank protection construction practices include measures to mitigate or reduce the adverse effect on wildlife habitat and aesthetics, including (1) minimum vegetative clearing requirements; (2) retention of berms and associated vegetation; (3) selective clearing of trees and other vegetation to retain them where levee safety is not affected; and (4) reseeding and replanting construction areas. (6, 8, 10, 20)

189. U.S. Army Engineer District, Sacramento, CE. 1971-1974. Office Memoranda: Bank Protection Test Sites, Cottonwood Creek, Tehama County, California. Rept. No. 1 (15 October 1971; 4pp.); Rept. No. 2 (1 February 1972; 3 pp.); Rept. No. 3 (1 February 1973; 3 pp.). Sacramento, California.

Test installations were prepared using discarded tire and fibre mat techniques on the right bank of Cottonwood Creek near Cottonwood, California. These materials were tested as possible alternatives to rock for bank erosion control in streams of the Sacramento and San Joaquin Valleys. The creek flows vary from about 50 c.f.s. in summer to a standard project floodflow of about 130,000 c.f.s. A 550-ft-long site was prepared with 250 linear ft of discarded tires banded together with metal straps and about 300 ft of fibre matting. Tires were anchored to the slope with concrete anchors with interwoven cables between anchor blocks. Fibre mats were anchored to the waterside slope of the levee and channel with steel pins driven into the ground. Floodflows of 23,000 c.f.s. and 24,000 c.f.s. occurred within one week in January 1973. No significant damage was done to either the discarded tire or fibre mat reaches of the bank. Silting and vegetation growth have given the test site a "natural bank" appearance. Floodflows on 16 January 1974 (66,000 c.f.s.) caused damage to both types of bank protection. The tire bank protection was damaged for about 90 of its 250-ft reach, probably due to undermining of the tire band from the upstream end. About 210 ft of the downstream portion of the 300-ft-long reach of fibre mat was destroyed totally. This was accompanied by bank and levee erosion. There is evidence that floodflows overtopped the levee about 40 ft upstream from the downstream end of the matting test site, which may have initiated damage and subsequent failure of the fibre mats. It is also possible that fibre materials had experienced some deterioration, and since the test site

was subjected to floodflow exceeding the design capacity (50,000 c.f.s.), the failure may have resulted from the inability of the matting to withstand high water velocities. It is believed that the tire protection would have withstood the floodflows, if the upstream erosion had not exposed the slope protection to undermining. The area will be abandoned as a test site, according to a final memorandum of 28 February 1974. (11, 17, 20, 21)

190. *U.S. Army Engineer District, San Francisco, CE. 1972. Draft Environmental Impact Statement, Russian River Basin (Channel Improvement and Bank Stabilization), Sonoma and Mendocino Counties, California. San Francisco, Calfifornia. 33 pp.

The proposed project was part of a continuing "channel improvement" and bank stabilization program. In the proposed action, three sites in Mendocino County and four sites in Sonoma County were to be protected with flexible fence, jacklines, or riprap. In the Russian River, the southern-most major river draining into the Pacific Ocean north of San Francisco Bay, bank and sheet erosion cause damage to agricultural land, stream meandering, and flooding. The proposed construction would entail removal of some segments of riparian habitat, although slowing or stopping of bank erosion by redirecting channel flow or stabilizing the banks could not only save, but enhance, some valuable riparian growth. Protection works would also minimize the loss of agricultural lands. Operation of equipment in the streambed during construction would cause a minimal increase in stream turbidity, and the removal of vegetation in the stream channel would cause some resuspension of silts during periods of high river flows. Modular jacklines have been criticized as hazards to boaters, but this criticism is unjustified. Problems arise when jacks, placed by local interests, break loose and roll into the channel. Flexible fence, one of the structural alternative possibilities, is an extremely effective protective work, when properly constructed and maintained. Use of fences saves valuable riparian vegetation from erosion. Steel jacks have a prolonged visual impact, depending on materials trapped by the jacks and the time needed for the establishment of a vegetative cover. Other methodologies discussed include stationary works utilizing riprap, wooden pilings, and wire-mesh and gravel blankets. Vegetative barriers proposed include tree pendents and willow sprigs. (3, 8, 17, 20, 21)

191. U.S. Army Engineer District, Vicksburg, CE. 1972. Final Environmental Statement, Yazoo Basin, Delta Area, Mississippi (Bank Stabilization). Vicksburg, Mississippi. 50 pp. (Note: This EIS was not filed as a final statement with the Council of Environmental Quality.)

This review report contains results of studies to determine the advisability of providing bank stabilization works along streams within the 6,600 square miles of the Yazoo Basin delta area of northwestern

Mississippi. The 1,500 miles of streams in the area are subject to various degrees of bank caving and recession. Bank cavings have damaged bridges, utility crossings, pipelines, and other structures. Caving and eroding streambanks also add substantially to high sediment loads carried by certain delta streams. The sediments, coupled with unstable channel conditions, result in reduced channel dimensions and flow capacities. Stabilizing the banks of streams would remove a source of sediment and aid in maintaining the operating capability of the existing flood control project. Loss of valuable lands and fixed structural improvements (e.g., bridges, pipelines) would be minimized. Habitats for the aquatic biota would be improved. Types of works to be employed in the area include vegetation, Gobi-block matting, transverse stone dikes, stone dike toe protection, articulated concrete mat, or other appropriate measures. All of the major streams in the area have undergone physical alterations resulting from the construction of various flood control, drainage, and navigation projects. These works have been effective in achieving a desired reduction of flood heights and long duration of flooding, once prevalent throughout the area. Streams have been shortened and stream slopes and velocities increased. Increased velocity is a major cause of an increase in the rate and extent of bank caving in many areas. Lands being lost due to bank caving are being replaced by smaller land areas of nominal value being deposited at lower elevations in downstream areas and by deposits that fill in channels. A major beneficial effect of bank stabilization in streams in the alluvial delta area will result in trends toward more stabilized channel geometry and narrower and deeper pools with riffles. This, along with reduced channel maintenance dredging, will improve fish habitat and stream aesthetics. Adverse effects include temporary disturbances and damages to streambanks and streamside vegetation, as well as increased sedimentation. After bank stabilization, it may prove difficult to control uses of streambank lands that may contribute to unstabilized bank conditions in the future. (1, 3, 8, 11, 18, 20)

192. *U.S. Department of Agriculture. 1969. Wildlife Habitat Improvement Handbook. Forest Service Handbook 2609.11. U.S. Dept. of Agriculture, Forest Service, Washington, DC. 146 pp.

This handbook for field personnel contains methods of improving fish and wildlife habitat. It is designed to stimulate interest in wildlife habitat management by National Forest and Ranger District personnel. Chapters contain information for the design and use of structures as well as planning methodology. Chapter 10 (Stream improvement) includes materials on dams, rock and wire structures, deflectors, boulder placement, and bed preparation. There are additional chapters concerning lake improvement, wetland improvement, upland improvements, and other structural improvements. (The work contains five chapters, although they are designated as Chapters 10, 20, 30, 40, and 50.) (8, 15, 16, 21)

193. U.S. Environmental Protection Agency. 1972. Guidelines for Erosion and Sediment Control. Planning and Implementation. Environmental Protection Technology Series, EPA-R2-72-015. U.S. Environmental Protection Agency, Washington, D.C. 228 pp.

Although intended for urban developments, specifically Columbia, Maryland, this document provides information concerning maintenance of streamwater quality and stabilization of waterways, as well as four appendices containing specific information relative to chemical soil stabilizers and mulches, erosion and sediment control structures, and special erosion and sediment control practices. (8, 20, 21, 22)

194. U.S. Environmental Protection Agency. 1978. Best Management Practices Guidance, Dredged or Fill Activities. Draft Document. U.S. Environmental Protection Agency, Water Planning Div., Nonpoint Source Branch, Washington, D.C. 91 pp.

Chapter 4 is entitled "Enhancement or the Replacement, Relocation, or Reconstruction of Existing Environment: There are six pages devoted to stream management and channel relocation. (3, 8, 10)

195. U.S. Fish and Wildlife Service. 1976. Fish and Wildlife Management Plan for Sacramento River Bank Protection Project, California. U.S. Fish and Wildlife Service, Sacramento, California. 78 pp.

This report contains descriptions of the importance of riparian vegetation to fish and wildlife, identifications of habitat losses attributable to the project, and a plan to reduce the project impact on the biota. Impacts of the project include loss of riparian woodland and other riparian vegetation, loss of 80 miles of vegetated streambank, and loss of that river bank habitat for aquatic mammals such as bank beaver and muskrats. The cobble-lined banks will also have an adverse impact on river otter and mink. It is feared that virtually all 368 miles of river bank within the project limits could be cobble-lined in the future. The writers appreciate the concern of the Corps of Engineers that the integrity of levees and banks be protected. However, it is the integrity of the entire river system that has been violated ecologically and hydrologically. The system must be examined, as a whole, before additional funds are spent and design errors are made. For example, installation of bank protection rock cobble at numerous erosion sites shifts the current and its attendent erosive forces to other areas of lesser resistance, thereby necessitating corrective actions elsewhere. Modification of the maintenance program could achieve partial habitat protection and restoration by allowing riprap and cobble river banks to revegetate. Appendix I contains a partial literature review of the adverse effects of stream and/or river alterations on the fishery. (2, 3, 8, 10, 16, 20)

196. Volkart, P., J. Tschoop, and E. Bisaz. 1973. The effect of sills on river bed, pp. 167-178. In Proceedings of the International Association for Hydraulic Research, International Symposium on River Mechanics, Bangkok, Thailand, 9-12 January 1973. Vol. 1, Sediment Transportation.

General statements were derived for the two-dimensional steady stress case on the basis of model tests. The statements define the size of the scouring basin between transverse sills in the natural river bed. They also indicate the great influence of sill spacing on scouring depth and stability of the scouring basin. In addition, a basis is provided for calculating the dimensions of riprap protection for the natural bed in relation to the discharge, the gradient, and the arrangement of sills. (1, 8, 12, 21)

197. Weber, W. G., Jr., D. B. Chittenden, and M. Bittenbender. 1975. 74-24 Report on the Use of Fiber Glass Channel Lining. Pennsylvania Dept. of Transportation, Bureau of Materials, Testing and Research, in cooperation with the U.S. Dept. of Transportation, Federal Highway Administration, Washington, D.C. 10 pp.

Louisiana Dept. of Highways personnel found that fiber glass roving offered erosion protection in ditches at water velocities of 9 ft per second. Pennsylvania personnel tested the material in Lancaster County in a drainage ditch, and found it satisfactory in erosive soils at a water velocity of 8 ft per second and in nonerosive soils at a velocity of 10 ft per second. It is recommended as a standard treatment for channel protection. (21, 26)

198. Weller, H. E. 1970. Brahmaputra River bank protection in India. Irrigation and Power 27(2):177-189.

This paper deals with bank stabilization of the unstable Brahmaputra River for about 643 km from Dibrugarh to Dhubri. There is constant bed and bank erosion in the river. Types of structures used and stabilization efforts, and their effectiveness, are discussed. Many of the structures were fabricated from bamboo. The Brahmaputra River is one of the three largest rivers in India, the other two being the Indus and Ganges Rivers. (3, 20, 21)

199. Wheaton, R. Z. 1974. Streambank stabilization, pp. 86-92. In Non-point Source Pollution Seminar, Section 108(a) Demonstration Projects Report. EPA-905/9-75-007. U.S. Environmental Protection Agency, Washington, D.C.

This paper summarizes studies of (1) a soil mechanics streambank stabilization evaluation, and (2) an evaluation of the effects of streambank slope and mulch materials on establishing vegetation after reconstruction. The study was carried out in the Black Creek Basin of Indiana and was part of a larger survey described in Lake and Morrison

(1977). Conclusions from the soil mechanics study were that stream channels in upland and transition areas are apt to be unstable because of slope and less cohesive soils, while channels in the lakebed area are apt to be stable with lower channel gradients and more cohesive soils. All mulches were found to be effective in controlling erosion. Mulches used were crushed limestone, wood chips, straw, sawdust, and chemical soil stabilizer. (22, 24)

200. *White, R. J., and O. M. Brynildson. 1967. Guidelines for Management of Trout Stream Habitat in Wisconsin. Tech. Bull. No. 39. Wisconsin Dept. Nat. Resources, Div. of Conservation, Madison. 65 pp.

This well-written and illustrated bulletin outlines succinctly the main principles of trout stream management and protection. Devices used to maintain sufficient channel depth and cover include wing deflectors, bank covers, dams, and revetments. Nonrecommended measures are also described. (8, 15)

201. Wilder, C. R. 1977. Soil-cement for water resource structures. Trans. Am. Soc. Agric. Eng. 20(1):109-112.

Since 1961 soil-cement has been used in more than 100 water control structures, as slope protection for earth dams and embankments and impervious lining for reservoirs and lagoons. Laboratory and field research has demonstrated its technical suitability and economic advantages. Adequate and reliable material testing, design, and construction procedures have been developed. (3, 7, 22)

202. Williams, R. P. 1975. Erosion and Sediment Transport in the Owens River Near Bishop, California. Water-Resources Investigations 49-75. U.S. Geological Survey, Menlo Park, California. 56 pp.

Closure of Pleasant Valley Dam in 1954 has almost eliminated the supply of gravel to the 16-mile study reach of the Owens River. Because of armoring of the channel, scour has been limited to approximately 1 ft in the upper 2.3 miles. Bedload transport is dependent on the hydraulics of a section and the availability of material. Ninety-eight percent, by weight, of the sampled bedload transported between sites 1 (upstream) and 6 (downstream) in the study reach was finer than 8 mm, although only 6-12% of the material in the bed available for transport was finer than 8 mm. Bank material, a prime source of new material for transport, was predominantly finer than 16 mm. Bank erosion rates, as interpreted from aerial photographs, indicated average annual erosion rates of 750 tons from 1947-1967, 1,970 tons from 1968-1971. Hydraulic geometry of the six sites indicated a shift in the river system regime since 1954. These changes progressed downstream from the dam to a point between sites 4 and 5. Farther downstream channel changes will occur, until the channel stabilizes. (1, 3, 11, 12, 17) changes will occur, until the channel stabilizes. (1, 3, 11, 12, 17)

203. Winegar, H. H. 1977. Camp Creek channel fencing -- Plant, wildlife, soil, and water response. Rangeman's J. 4(1):10-12.

Four miles were fenced along the channel of Camp Creek, a tributary of the Crooked River, Crook County, central Oregon. Native riparian vegetation became well established. The plant cover affected soil deposition and channel stabilization. It apparently retained much of the suspended solids formerly carried by the flow. The sediments accumulated on the stream bottom and raised the water table within the protected channel. Within nine years, 36 inches of material had been deposited between the vegetated bank and the stony stream bed. This process buries the vegetation. Plants then regrow, and the process repeats itself to establish bankside meadow. (1, 20, 24, 25)

204. Winger, P. V. 1972. The Effects of Channelization and Water Impoundment on the Macroinvertebrates in the Weber River, Summit County, Utah. PhD. Dissertation, Brigham Young Univ., Provo, Utah. 113 pp.

Macroinvertebrate populations in the Weber River were analyzed to determine the effects of channelization, resulting from construction of Interstate-80, and water impoundment on the standing crop, species diversity, and species composition. Gabions and rock deflectors, placed in the altered stream channel, allowed holes and riffles to be formed that resembled those in unaltered sections. Rich standing crops were found around the structures, with gabions having a larger invertebrate standing crop. Water chemistry was similar above and below the channelized area, except for elevated sulfate and phosphate values in the autumn of 1968 below the construction area. A brief period of high turbidity occurred following channelization. Streamside vegetation loss resulted in a reduction in aesthetics, as well as the loss of an important buffer zone. The most serious effect of channelization on the macroinvertebrates was the loss of river length and resultant loss of organisms. (3, 4, 6, 9, 20)

205. Winger, P. V., C. M. Bishop, R. S. Glesne, and R. M. Todd, Jr. 1976. Evaluation Study of Channelization and Mitigation Structures in Crow Creek, Franklin County, Tennessee, and Jackson County, Alabama. SCS Contract No. AG47 SCS-00141. Soil Conservation Service, USDA, Nashville, Tennessee. 369 pp.

Thirteen stations were established for a two-year study on the effects of channelization and instream grade stabilization structures on the chemical, physical, and biological characteristics of Crow Creek. Station 1 was upstream from channel improvement work, and station 2 was cleared and snagged. Stations 3, 5, 10, and 13 contained no structures; however, Stations 3 and 5 had riprap installed on bends for bank stabilization. Stations 4, 6, 7, 9, and 11 contained instream grade stabilization structures. Stations 8 and 12 were nonevaluated oxbows. Water chemistry parameters were generally lower at Station 1 than at Station 10. Discharge increased from upstream to downstream, and it was related directly to precipitation. Water temperature increased significantly from Station 1 downstream. Substrate particle size was not markedly different between stations. Rock riprap apparently increased the amount of stable surface area for colonization by periphyton. Physical characteristics of the stream were important to the distribution of certain species of fish. Catastomidae (suckers) preferred areas with cover and pools. Centrarchidae (sunfishes) abundance was positively correlated with percent of cover, and both rock riprap cover and log and brush cover were important. Channelization affected several physical parameters in Crow Creek. Streamside vegetation was reduced markedly at channelized stations, contributing to higher water temperatures downstream. Stream bank height was higher in channelized reaches, than in unchannelized ones, and banks were generally unstable and exposed to erosion forces, particularly during high flow. Much stream length was lost, due to cutting off of meanders. Some fish and benthic populations recovered from the defaunate conditions present immediately after channelization. However, certain creek stations contained low standing crops, due to loss of habitat diversity. Structures at certain stations did not enhance the habitat, because they were installed too close together and at too high an elevation. Riprap proved effective for stabilizing erodable banks and as cover for game fish. The riprap also provides a stable substrate for periphyton and benthic macroinvertebrates. There was a loss in aesthetic appeal and biotic potential by leaving high, steep, unstable banks in channelized sections. There is a need for installation of proper grade stabilization structures using care to insure proper structure elevation and horizontal placement. Riprap should be installed on unstable banks, particularly on bends where erosion forces are greatest. Steep, high, unstable banks should be sloped and seeded to reduce erosion, facilitate stream access, and improve aesthetics. Stream length should not be reduced drastically by cutoff of meanders. Available habitats, channel storage capacity, and stream gradient are affected adversely by drastic shortening. (3, 4, 7, 9, 15, 16, 17, 20, 23, 26)

206. *Witten, A. L., and R. V. Bulkley. 1975. A Study of the Effects of Stream Channelization and Bank Stabilization on Warmwater Sports Fish in Iowa: Subproject No. 2. A Study of the Impact of Selected Bank Stabilization Structures on Game Fish and Associated Organisms. FWS/OBS-76/12. U.S. Fish and Widlife Service, Washington, D.C. 116 pp.

Four types of bank stabilization structures installed mainly for highway protection -- revetments, retards, permeable jetties, and impermeable jetties -- were studied during the summer and fall of 1974 to determine their impact on game fish habitats in Iowa streams. Stream width, depth, current velocity, water temperature, and turbidity were

measured. Permeable jetties and retards deepened the channel near the structures. Maximum stream depth at or near these structures was from 7% to 110% greater than maximum depth in control sections of the streams. No other significant differences in physical parameters between structured and nonstructured sections of stream were found. Effects of bank stabilization structures on stream morphology (width and depth) and current velocity were difficult to assess. Most bank stabilization structures for highway protection are placed on concave stream banks, where the current velocity and stream depth are expected to be the greatest. Since it was impossible to duplicate the structure-area channel meanders in control areas, simple comparisons of current velocity and depth in structure areas vs. control areas did not give a totally accurate picture of the influence of the structure on stream morphology. It is difficult to separate the effects of the structures on stream morphology from natural variations in current velocity and depth. Soldier River permeable jetties, however, were on an almost straight reach of the river; large differences in depth between structure and control areas were found at these sites. The stream near the structures was significantly deeper than was the case in the control area. Revetments, which do not project into the stream but protect an existing bank, have no apparent effect on stream morphology. Neither retards or permeable jetties affected appreciably the maximum current velocities, but depths were greater near the structures. A long rock jetty, extending far enough into the stream to produce a scour hole, would combine most of the advantages noted for the structures studied. From the standpoint of habitat improvement, rock seems superior to steel as a construction material, and structures that cause the formation of scour holes are superior to those that do not deepen the stream.
(3, 7, 18, 20, 21, 23, 26)

207. Wolman, M. G. 1959. Factors influencing erosion of a cohesive river bank. Am. J. Sci. 257:204-216.

The sinuous channel of Watts Branch, Montgomery County, Maryland, was studied between 1953-1957. The river bank, comprised primarily of cohesive silt, underwent as much as 7 ft of lateral erosion in the five-year period. Approximately 85% of the observed erosion occurred during the winter months of December through March. As much as 0.4 ft of sediment was eroded at specific bank points in a period of several hours during which a bankfull flow attacked banks that had been wetted thoroughly. Erosion was most severe at the water surface. Little or no erosion was observed in summer, despite the occurrence of the highest flood on record. Second in erosion effectiveness were cold periods during which wet banks, frost action, and low rises in stage, combined to produce 0.6 ft of erosion in six weeks during the winter of 1955-1956. In addition, crystallization of ice and subsequent thawing, without benefit of changes in stage, also produced some erosion as did summer flash floods, even on hard dry banks. There may be a crude correlation between precipitation and erosion during selected intervals of time. Precipitation exerts an effect, both through increasing

discharge in the channel and by increasing the moisture in the bank. Frost action similarly holds moisture in the soil and comminutes surface material, thus preparing it for erosion. (3, 11, 17, 20)

208. Woodson, R. C. 1961. Stabilization of the middle Rio Grande in New Mexico. Am. Soc. Civil Eng., J. Waterways and Harbors Div. 87(WW4): 1-15.

A Kellner jetty system, well adapted for silt-laden rivers that are subject to channel scour, was used. The system was first used on a small stream near Topeka, Kansas by the developer, H. F. Kellner, in the early 1920's. Early models were made of willow poles lashed together. (20, 21)

209. *Workman, D. L. 1974. Evaluation of Stream Improvements on Prickly Pear Creek, 1971-1973. Final Report. Montana Project Nos. F-9-R-19, F-9-R-20, F-9-R-21, F-9-R-22. Job II-a. Montana State Fish and Game Commission, Great Falls. 13 pp.

Willow shoot plantings were made in May 1968 to reestablish woody streamside vegetation that had been removed in the relocation of a portion of the Prickly Pear Creek channel during construction of Interstate Highway 15. Sixty-one percent of the willows planted in double rows survived the first summer, and 26% of those planted in single rows survived. In 1969, evaluation of the planting indicated further losses resulting in poor success overall, because of unstable soil and heavy losses due to bank erosion. In April 1971, rock and soil berms were constructed at the toe of four steep eroding banks to stop streambank sloughing along the relocated channel of the creek. The berms were used in shrub experiments to test the survival of naturally occurring species, when transplanted to reestablish streambank vegetation. Survival of naturally occurring shrubs was tested from spring plantings and summer plantings. In addition, survival was compared from different treatment of the plants. The best results were obtained from spring-planted horizontal willows (i.e., cuttings from a horizontal, rather than a vertical shoot); 70.2% of the 84 planted survived the first summer. Spring plantings of vertical willow (cuttings from vertical shoots) and dogwood (<u>Cornus stolonifera</u>) had survival rates of 38.0% and 12.5%, respectively. Blanket riprap was used to protect the highway grade from stream erosion. Willow (<u>Salix</u> sp.) shoots were planted in spaces between the large rocks at the water level to speed up revegetation. In an area left to natural seedings, only three live willows were present after more than two years. In areas where willows were planted, 167 of 282 plantings were alive after 2.5 years. Natural seeding in areas where good soil quality existed accounted for the reestablishment of dense vegetation on berms and back slopes of the experimental sites. Rainbow and brown trout populations in 1972 had returned to preconstruction (1967) levels. The author recommends the retention of the physical characteristics of the original channel, where streams must be altered or relocated. (3, 6, 15, 24)

210. Yearke, L. W. 1971. River erosion due to channel relocation. Am. Soc. Civil Eng., Civil Eng. 41:39-40.

Channel relocation work is a phase of hydraulics little known by highway engineers. A channel change in New Hampshire's Peabody River was studied from 1961 through 1968. The river was shortened by approximately 850 ft, and its alignment was straightened. Immediately post-construction, the channel began to seek its hydraulic gradient through erosion and scour. The major adjustment took place in the first year with decreasing adjustments each year thereafter. The original channel had an average fall of 52 ft/mi, and the relocated channel was steepened to 80 ft/mi seven years post-construction. The upstream end of the channel degraded, and the downstream end underwent aggradation. One possible solution to erosion and scour problems in small streams carried under a highway in a drainage structure is to place the stream on its natural slope upstream and downstream of the structure. (3, 12)

211. *Yorke, T. H. 1978. Impact Assessment of Water Resource Development Activities: a Dual Matrix Approach. FWS/OBS-78/82. U.S. Fish and Wildlife Service, Washington, D.C. 27 pp.

A dual-matrix system is presented which provides a framework for collecting and synthesizing the information needed for impact assessment, and provides the base for a computer system capable of providing early and effective input by the Fish and Wildlife Service into the planning and decision making processes of the development agencies. Most water development activities have common physical impacts upon stream and associated riparian habitats. Since the physical changes will have the same impact on the biota no matter what the cause, a dual matrix system was developed that will (1) relate the resource development to physical change and then (2) relate the physical change to the biota. This report presents the generalized matrix of the physical and chemical impacts of stream alteration activities. It consists of summary statements of the impact of the twelve most common water development activities (channel enlargement, channel realignment, clearing and flood protection levees, flood control and storage impoundments, hydroelectric impoundments, locks and dams, diversion dams and transbasin augmentation) on ten physical and chemical characteristics of streams (depth and stage, water surface area, channel configuration, velocity, temperature, suspended solids, bed material, dissolved substances, light transmissivity, and flow variability). (1, 3, 4, 6, 7, 8, 9, 17, 18, 19 20, 23, 26)

212. Zimmer, D. W., and R. W. Bachmann. 1978. Channelization and invertebrate drift in some Iowa streams. Water Resour. Bull. 14(4):868-883.

Habitat diversity and invertebrate drift were studied in a group of natural and channelized tributaries of the upper Des Moines River during 1974 and 1975. Channelized streams in this region had lower sinuosity index values than natural channel segments. There were significant (P=0.05) positive correlations between channel sinuosity and the variability of water depth and current velocity. Invertebrate drift density, expressed as biomass and total numbers, also was correlated with channel sinuosity. Channelization has decreased habitat variability and invertebrate drift density in streams of the upper Des Moines River Basin, and probably has reduced the quantity of water stored in streams during periods of low flow. (3, 4, 14)

213. Zimmerman, R. C., J. C. Goodlett, and G. H. Comer. 1967. The influence of vegetation on channel form of small streams, pp. 255-275. In Symposium on River Morphology. Reports and Discussions. Publ. No. 75. International Association of Scientific Hydrology, General Assembly of Bern, 25 September - 7 October 1967. L'Association Internationale d'Hydrologie Scientifique, Braamstraat 61, Gentbrugge, Belgeque (Belgium).

Data on channel width of several small streams in the Sleepers River Basin of northern Vermont have provided some measure of the influence of vegetation on channel form. Along five streams, for which there are complete records of variation in channel width, width does not increase in a downstream direction as far as points with drainage areas of 0.2 to 0.8 square mile, presumably as a result of disturbance and encroachment by vegetation. In one basin with an area of 0.8 square mile, channel width is clearly related to type of vegetation, as the channel is alternately wide under forest, and narrow in sod. Along one stream, width increases in response to increases in discharge where the drainage area exceeds 0.3 square mile, but the variability in width (expressed as the standard deviation from the mean and as a coefficient of relative variability) also increases, reaching a maximum where the drainage area is about 2 square miles. Relatively uniform channel widths occur, on the other hand, where the drainage area is about 6 square miles. In the Sleepers River Basin, there are apparently two thresholds along streams. In a downstream direction, the first threshold occurs at points with drainage areas of 0.2 to 0.8 square miles. Upstream from these points, width does not increase in a downstream direction, living tree roots cross the channel, and dams of organic debris are common. The flow is commonly underground. Points with drainage areas of about 5 square miles are apparently the second threshold. These points have annual high flows in the range of 100-150 cfs. Beyond these points, the influence of vegetation on channel form is marginal compared with that of geologic differences and the sinuosity of the flow itself. Vegetation influences channel form by altering the roughness and shear strength of bed and banks. In addition, nonfluvial processes such as the windthrow or frost-heaving of streambank trees may locally double or triple the channel dimensions that would occur with the same discharge regime in the same geologic setting. (7, 18, 25)

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This annotated bibliography provides a reference source of information on the impacts of bank stabilization on the physical and chemical characteristics of streams and small rivers. The bibliography has 213 references, and is indexed by 26 key subject headings. Papers range from technical documents to general discussions addressing the physical and chemical changes that result from various types of bank stabilization activities. Many of the annotations provide a thorough summary of pertinent information contained in the respective references.

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