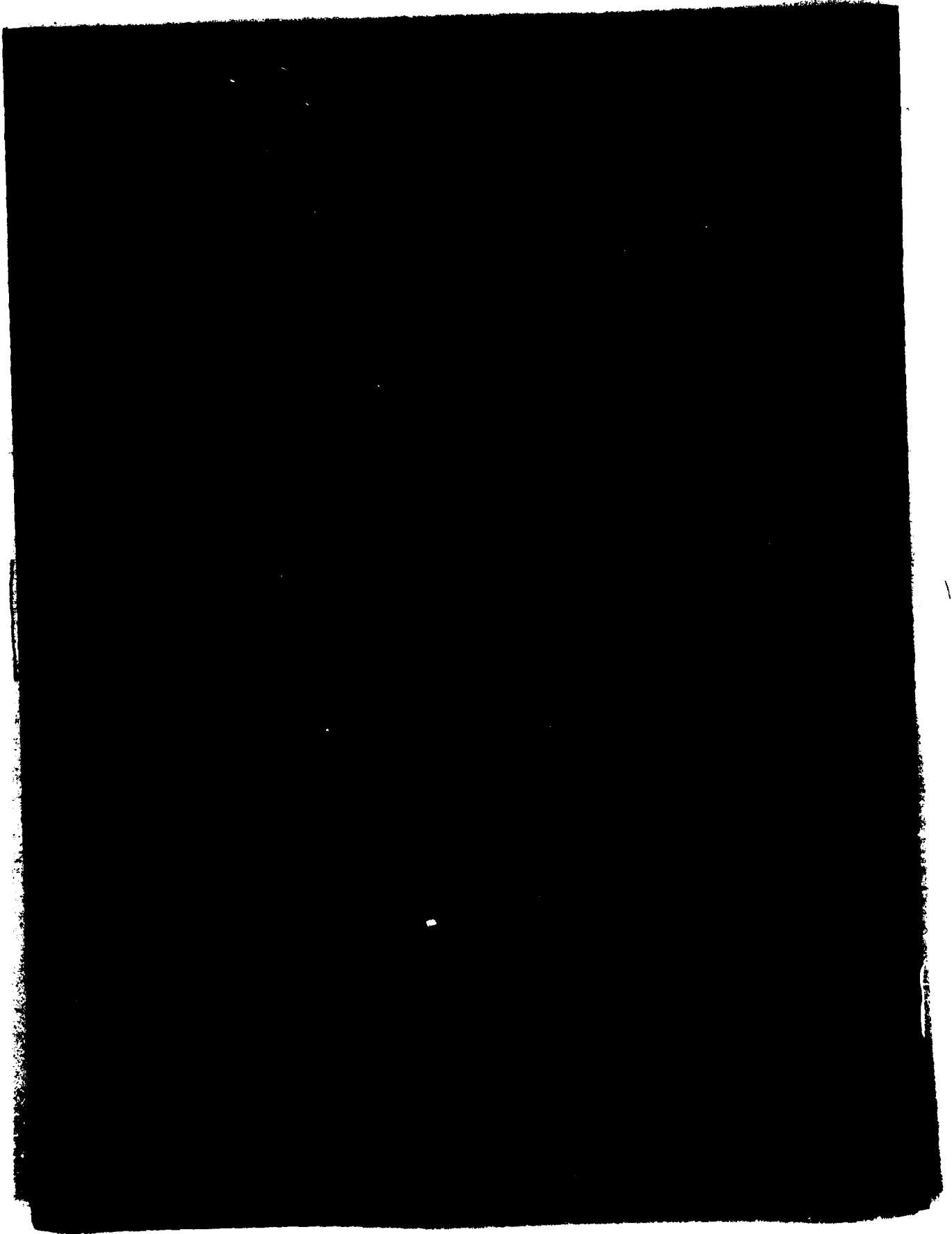


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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Waterway projects designed and constructed by the Corps of Engineers (CE) include dikes, revetments, levees, and channel modifications for flood control and navigation purposes. A review of existing CE design guidance in the form of Engineer Manuals (EMs) and personal contacts with CE field offices was performed to appraise current practices regarding consideration of environmental effects in the design and construction of waterway projects. A computer-assisted (Continued)		

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20. ABSTRACT (Continued).

review of the technical literature was also performed in order to determine observed adverse environmental effects of waterway projects. Possible adverse effects presented in the literature included wetlands drainage, loss of native vegetation, cutoff of oxbows and meanders, water table drawdown, increased erosion and sedimentation, and change of aesthetics. Other possible effects on the aquatic system may include the loss of aquatic habitat, productivity, and species diversity, and the degradation of water quality.

Alternatives to traditional channel modification were identified through the literature review. Structural alternatives to channel modification include levees, floodways, reservoirs, and land treatment measures. Additional alternatives include various forms of floodplain management; floodplain zoning; construction of bypass channels around sensitive wetland areas; construction of numerous, very small, water-retention structures; and substitution of clearing and snagging, or only snagging, for complete channelization.

Current efforts to minimize adverse environmental effects of dikes were investigated through personal contact with CE field offices. Programs of notching or gapping dikes are in progress on the Missouri and Mississippi Rivers. Studies are under way to quantify the effects of such notches on the riverine ecosystem. Case studies of the planning process are presented for two recently designed waterway projects.

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PREFACE

This report was prepared by Vanderbilt University, Environmental and Water Resources Program, Nashville, Tennessee, for the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, under Contract No. DACW39-78-M-5600, dated 29 September 1978. This study forms part of the Environmental and Water Quality Operational Studies (EWQOS), Task VI.B.1, Design and Construction Techniques for Waterway Projects to Attain Environmental Quality Objectives. The EWQOS is sponsored by the Office, Chief of Engineers, U. S. Army, and is assigned to the WES under the purview of the Environmental Laboratory (EL).

The study, a literature review and technical evaluation of existing design and construction practices that affect environmental quality objectives for waterway projects, was conducted by Dr. Edward L. Thackston and Mr. Robert B. Sneed, Environmental and Water Resources Engineering Program, Vanderbilt University. Practices current as of 1979 were studied. The principal investigator for the project and principal author of this report was Dr. Thackston, Professor of Environmental and Water Resources Engineering.

The study was conducted under the WES supervision of Dr. Raymond L. Montgomery, Chief, Water Resources Engineering Group (WREG); Mr. Thomas K. Moore, WREG; Mr. Andrew J. Green, Chief, Environmental Engineering Division; Dr. Jerome L. Mahloch, Program Manager, EWQOS; and the general supervision of Dr. John Harrison, Chief, EL.

The Commanders and Directors of the WES during this study and the preparation of this report were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. Fred R. Brown.

This report should be cited as follows:

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
acres	4046.873	square metres
cubic feet per second	0.2831685	cubic metres per second
cubic yards	0.7645549	cubic metres
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	2.54	centimetres
miles (U. S. statute)	1.609344	kilometres
pounds (mass)	0.435924	kilograms
square miles	2.589988	square kilometres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

REVIEW OF ENVIRONMENTAL CONSEQUENCES OF WATERWAY
DESIGN AND CONSTRUCTION PRACTICES AS OF 1979

PART I: INTRODUCTION

Background

1. Concurrent with fulfilling its assigned missions, the U. S. Army Corps of Engineers must also meet national environmental quality objectives. These objectives are directed at minimizing the adverse environmental impacts of a water resource project. Studies are being performed at the U. S. Army Engineer Waterways Experiment Station (WES) to identify and evaluate constraints and factors in the design and construction of waterway projects that affect environmental quality objectives. Waterway projects include the construction of dikes, revetments, levees, and channelization for flood control and navigation purposes. The possible effects of these works may include wetlands drainage, loss of native vegetation, cutoff of oxbows and meanders, water table drawdown, increased erosion and sedimentation, and change of aesthetics. Other possible effects on the aquatic system may include the loss of aquatic habitat, productivity, and species diversity, and the degradation of water quality.

Purpose

2. The purpose of this report is to provide background information on the types of design and construction practices used by Corps District Offices and their associated environmental impacts to provide input to concurrent and subsequent research efforts being conducted as part of Project VI of the Environmental and Water Quality Operational Studies (EWQOS) at the WES. Project VI is to provide new or improved guidance for incorporating environmental considerations into waterway project design, construction, maintenance, and operation.

Scope of Work

3. Waterway projects designed and constructed by the Corps meet a variety of objectives, including flood control, navigation, fish and wildlife enhancement, water supply, water quality management, power production, recreation, and others. The most common primary goals are flood control and navigation.

4. The types of projects to attain these goals include channel modification, dikes, revetments, levees, and locks and dams. Because of limited time and resources, this project is primarily focused on studying and describing the environmental effects of the design and construction of channel modification projects (channel enlargement, or channelization, and clearing and snagging), bank protection, and dikes and revetments.

5. For two of the major types of projects, channel modification and bank protection, two comprehensive reports were found that had been prepared in the last few years. No attempt was made to duplicate that work. Instead, those studies are summarized in this report, the interested reader can consult either those reports or the original works referenced in the reports.

Sources of Information

6. Several sources were used for the references and information in this report. The principal investigator had collected or was familiar with a large body of literature and considerable general background material at the start of the project. The project managers from WES had collected some material, and it was made available. The project managers and the principal investigator also visited and/or contacted several Corps District Offices to find out what general procedures, design manuals, references, and local or internal sources of information were actually being used. A computer-assisted search of the literature also was made using the Water Resources Abstracts file. The results of the computer-assisted abstracts search are discussed in a following subsection.

7. Much of the information found and/or examined was repetitive,

was only peripherally related to the subject and needs of the project, was too general, or was speculative or predictive rather than a report of actual effects (such as the environmental impact statements discussed later). Less than approximately 5 percent of the material examined or references located is actually mentioned in this report.

8. As mentioned earlier, no attempt was made to cite the individual sources of all of the material contained in the two major summary reports that served as primary sources for this report. The references contained in this report are simply to the summary report. This report is an introduction to the stated subject, and should be thought of as a first step toward finding and organizing a large body of scattered information.

Practice in District Offices

9. Five District Offices of the Corps were visited in conjunction with the study by the principal investigator, the project managers from WES, or both. Engineers in the design branch were contacted, and among other questions, were asked what material, sources of information, or references were design aids in waterways projects. Individual experience was cited as a primary design aid. Engineer Manuals were not referred to as being particularly useful in specific environmental aspects of waterway project design. The manuals were too general, too limited in scope and coverage, or too outdated.

10. The engineers contacted in most offices said that each project is treated as a totally new job, and the project engineer is encouraged to draw on his own experience and that of other members of the engineering staff in the District Office, to examine the literature, and to visit and consult with staff in other District Offices that might have had experience with similar jobs. Few comprehensive general design guides were identified.

11. The fact was mentioned in more than one case that the design engineer has relatively little latitude to greatly alter the environmental impact of a project by design changes as compared with the large options present and available to the planning staff in the original formulation of the project. Once the general form and concept of a

project have been selected from numerous alternatives by the planning team (i.e. recommendation for channel enlargement instead of a dam and reservoir), the general type and magnitude of the environmental effects are determined. There are still many opportunities to reduce adverse environmental impacts during the design phase but normally the key decisions affecting environmental impacts are made in planning stages. Discussions with the design engineers and a critical examination of the literature have led to the conclusion that the big differences in environmental impact are not among different ways that a particular project is designed or constructed, but among completely different types of projects designed to accomplish the same general objectives.

12. As a partial result of this conclusion, the subsection on alternatives to channel modification contains a brief discussion of the engineering and environmental trade-offs available to the planners and engineers faced with the task of selecting a type of project from among numerous alternatives such as channel modification, a dam and reservoir, a levee system, floodplain regulation, or floodplain purchase. It is at this stage of the planning-design process that the primary consideration of environmental impacts of the alternatives should take place. Although the planning and design phases are not completely separate, the earlier in the process that environmental factors can be specifically considered, the better the chance is to eliminate or reduce them.

13. This philosophy of early consideration of the environmental impacts of various alternatives is already Corps policy, mandated by the National Environmental Policy Act (NEPA), and in general is Corps practice.

Effects of Alternate Designs

14. The initial assumption of the project was that there were reports on the varying types or levels of magnitude of environmental impacts resulting from alternate designs or ways of construction of the same type of project. These reports ideally would describe controlled studies in which the only variable was the type of design or construction

held constant with other variables, such as location, soil type, or waterway type, and in which careful studies of the impacts were made and described. These reports, if they exist, were not found.

15. The closest approximation to such a controlled study located for this project is the study currently being conducted on the diking program on the Missouri River, and only the first year's interim report was available to these authors. The Section 32 study and demonstration project on different methods of bank stabilization (Department of the Army, Office, Chief of Engineers (OCE) 1978c) would be almost an ideal type of study of this kind if it were focused on environmental impact, but its major emphasis is on costs and effectiveness due to the dictates of the authorizing legislation.

16. Most of the located sources report the impacts of a single project with no attempt to compare them with the impacts of similar projects, or to correlate any differences in impact with differences in design. Therefore, any differences in impact that are described as being the result of different types of projects or different types of designs are generally the results of uncontrolled rather than controlled experiments.

Computer Literature Search

17. A computer literature search was performed to find references on the subject of this project and used the Water Resources Abstracts file. The following is a list of key words used for the search:

- Environmental effects
- River training
- River regulation
- Channel improvement
- Bank stabilization
- Dredging
- Dikes
- Levees
- Riprap
- Groins

18. The search resulted in a listing of 834 abstracts related to the key words. The vast majority of these entries were Environmental Impact Statements. Few new useful references were found.

19. The impact statements were not evaluated in detail because they primarily contain speculation or projection of what impacts will take place, rather than report what has actually taken place. However, a list of projected impacts mentioned in the impact statements was compiled, and is shown in Table 1. These are not the most common actual impacts, but the ones most commonly projected to happen by the Corps. However, since most impact statements today get fairly thorough review by public agencies and private groups, and few expected impacts escape inclusion and discussion in an impact statement, these impacts are probably the most common, or at least the ones of most concern to most people.

20. The tabulation is similar but less detailed than one constructed earlier by Ortolano and Hill (1972). They examined and analyzed the first 234 Environmental Impact Statements, January 1970-August 1971, prepared by the Corps. The report covered projects on both coastal and inland waters. They divided the impact statements concerning inland waters by type of project into seven categories, and tabulated and analyzed the impacts mentioned in each category. The categories were (a) channelization, (b) dams and reservoirs, (c) levees, (d) dredging, (e) spoil (dredged material) disposal, (f) construction activities, and (g) miscellaneous structures and activities.

21. Each category includes a detailed tabulation of effects mentioned in the statements, comments on how the effect was mentioned, and a summary and discussion of the effects and the statements. The report also includes a discussion of how the impact statements handled alternatives, short-term uses and long-term productivity, irreversible and irretrievable resource commitments, and controversial issues.

22. Although the Ortolano and Hill report is considerably more detailed than the tabulation in this report and would be of some interest and value to a person unfamiliar with the environmental effects of waterway projects, several problems with it should be mentioned. First, the statements examined were only those written in the first 1-1/2 years after the passage of NEPA. The requirement of the NEPA had not been fully understood by most agencies, interpreted by the courts, or explained

Table 1
Adverse Environmental Effects of Waterway Project Design and Construction Practices Found in a Computer Search*

<u>Adverse Environmental Effect</u>	<u>Number of Occurrences</u>
Loss of wildlife habitat	144
Temporary increase in turbidity	139
Disruption of benthic organisms	81
Aesthetics	75
Loss of land	74
Destruction of natural stream environment	55
Effects of disposal of dredged material	49
Changes in stream fishery	47
Increase in sediment loads (siltation)	44
Increase in erosion and sedimentation	38
General construction problems--dust, noise, traffic, etc.	33
Changes in water quality during construction	23
Land use changes	23
Demolition of houses and relocation of people	23
Loss of spawning area for fish and other aquatic life	23
Urban and industrial development	21
Alteration of riparian habitat	20
Odor	16
Increased probability of spills and leaks	16
Groundwater table changes	12
Decrease in dissolved oxygen levels	8
Changes in nutrient loading	7
Effects of construction of borrow pits	7
Change in water temperature	7
Eutrophication	7
Loss of recreational value	7
Loss of archaeological and historical sites	5
Increased concentration of minor metals	5
Fish kills due to blasting and dredging	4
Increase in wastes from developing areas	4
Increased algae growth	2
pH change in vicinity of fresh cuts	2
Increased pollution from agriculture	2
Creation of a rock quarry	2
Elimination of trout stocking	1
Increase in the mosquito population	1
Temporary danger to canoeists from jacklines during construction	1

* Computer search revealed 834 references.

by regulations for impact statement preparation from the Council on Environmental Quality or the Corps. Few people had a complete idea of what an impact statement should contain. Most of these 234 impact statements by today's standards would be considered superficial, incomplete, and inadequate. Many impacts known to be of concern and importance now were not considered previously and were not commonly mentioned. Second, some of the earlier impact statements may have omitted mention of some adverse impacts because the projects involved were usually already authorized, designed, and under construction, and there was a reluctance to cause problems by dwelling too much on controversial or incompletely understood effects for fear that the projects would be delayed while more studies were conducted or designs were changed. However, impact statements are now prepared during initial planning.

23. A similar study was conducted by Stanford University (1973). In this study, seminar students developed and tested a systematic methodology for the identification, description, measurement, and display of the environmental impacts associated with water resources development activities. A framework defining and relating the major factors and terms relevant to environmental impact assessment, together with a general analytical approach, is suggested, and a number of state-of-the-art reviews on the significant physical, biological, and chemical effects of impoundments, stream channelization, dredging and dredged material disposal, and flood control and recreation are presented. Requirements, problems, and issues relevant to the analysis of ecological, visual, cultural, and induced impacts, as well as staffing needs, are also included.

PART II: REVIEW OF EXISTING CORPS ENGINEER MANUALS
RELATING TO WATERWAY DESIGN

24. Guidance in planning and design of projects is provided by OCE to the District Offices in the form of Engineer Manuals (EMs), and those relating to waterway project design were reviewed. The manuals on structural design considerations, mechanical and electrical components, and similar topics had essentially no environmental considerations and are not discussed in this report. Some EMs contained references to environmental topics that are being addressed by other EWQOS work units or other programs within the Corps and are therefore outside the scope of this report. Among these were EM-1110-2-2300, Engineering and Design of Earth- and Rock-Filled Dams - General Design and Construction Considerations (OCE 1971); EM-1110-2-1602, Hydraulic Design of Reservoir Outlet Structures (OCE 1963); EM-1110-2-1603, Hydraulic Design of Spillways (OCE 1965); and Engineer Technical Letter ETL 1110-2-239, Nitrogen Supersaturation (OCE 1978b).

25. Three EMs relating directly to the design of waterway projects were selected for review in this report (OCE 1970, 1959, and 1978a). In this review some planning and design factors having environmental implications are identified and discussed. The EMs selected for review contain only general guidance for consideration of environmental factors and more detailed guidance for structural and hydraulic factors. Normally, EMs are limited in scope to one particular field or discipline. Therefore, the paucity of environmental or ecological information in hydraulic EMs is not surprising. The CE presently has no EM series dealing with environmental topics, although such a series is planned. The existing EMs reflect national and agency priorities at the time of their publication. Full consideration of environmental factors in all phases of planning and design was mandated in December 1969, with the passage of the NEPA. The interpretation and implementation of these new policies, and their subsequent clarification and incorporation into agency documents, have been ongoing processes over the last decade. Accordingly, the most recent EM of the three reviewed

contains more detailed guidance for the environmental aspects of design.

Hydraulic Design of Channels

26. Engineer Manual EM-1110-2-1601, Hydraulic Design of Flood Control Channels (OCE 1970), consists primarily of open channel flow equations and instructions for their use. However, there are some general guidelines for design of physical structures such as riprap, sediment control structures, stabilizers, drop structures, and debris basins.

27. The pure hydraulic considerations of the design of flood control channels have few environmental implications. The environmental effect of altering an existing natural stream or channel to provide increased flood-carrying capacity lies primarily in the removal from the existing natural channel of bottom structure (i.e. logs, snags, rocks, debris, and uneven bottom elevations) that not only provides stable points for attachment of benthic organisms, algae, and bacteria, but also provides resting or hiding places for larger organisms such as fish. If the alteration of the channel requires the removal of these obstructions, it makes little difference what the channel width, depth, slope, or velocity is. Once the structure is removed, the diversity of the aquatic habitat is drastically reduced and some species suffer a decline in numbers or complete elimination. Many species, particularly the higher organisms such as fish, will disappear completely if no new structure is allowed to develop or is placed in the channel. Most estimates are that approximately 90 percent of the higher organisms such as fish will be driven away (Arthur D. Little, Inc. (ADL) 1973).

28. Mitigating effects can be included, however, if a new structure is included within the design. The new channel should be as smooth as possible for flood control. However, as stated in EM 1110-2-1601 (OCE 1970):

The design of stable channels requires that the channel be in material or lined with material capable of resisting the scouring forces of the flow. Channel armoring is required if these forces are greater than those the bed and bank material can resist.

29. EM-1110-2-1601 (OCE 1970) describes design criteria on pages 35-47 for the installation of channel armoring, or riprap. A table on page 36 of the EM presents suggested maximum permissible mean channel velocities that will ensure that the channel is not subject to scour. It is reproduced here as Table 2. Scour can be an adverse environmental effect because it removes the small amount of bottom structure in an artificial channel and causes sedimentation downstream, which may cover the benthic organisms.

30. Descriptive criteria for the selection of riprap include the requirements that the stone be predominantly angular in shape rather than rounded, chunky rather than elongated or disc-shaped, and well graded. Equations are presented for the calculation of maximum design shear and the design shear that a particular sized stone can withstand. Thus, stone larger than the size of stone that could be removed by the velocity in the channel can be selected.

31. Verbal and pictorial descriptions indicate how riprap should be placed on the sides and bottom of the channel, how the revetment toe protection should be placed, and how the top and ends of a revetment area should be placed.

32. The type and amount of aquatic organisms that can live on the riprapped banks or bottom of a flood control channel are a function of several variables, including the size and gradation of the stone and their associated void spaces, the velocity of flow in the channel, the amount of sediment carried by the channel, and other water quality parameters. In general, a wide gradation of stone size is more conducive to a wide variety of aquatic life. The current design method is to calculate the smallest sized stone for the riprap that will withstand the scouring forces of the water to minimize the cost of procurement and placement of the stone. A size gradation with an average size equal to or larger than the design size is used to specify riprap. Even though a variety of sizes may provide good habitat for aquatic life by providing a variety of openings, overlarge stones are not desirable in riprap because local turbulence is generated, which may lead to scouring of adjacent smaller stones.

Table 2
Suggested Maximum Permissible Mean
Channel Velocities*

<u>Channel Material</u>	<u>Mean Channel Velocity, fps</u>
Fine sand	2.0
Coarse sand	4.0
Fine gravel	6.0
Earth	
Sandy silt	2.0
Silt clay	3.5
Clay	6.0
Grass-lined earth (slopes less than 5%)**	
Bermuda grass - sandy silt	6.0
- silt clay	8.0
Kentucky Blue Grass - sandy silt	5.0
- silt clay	7.0
Poor rock (usually sedimentary)	10.0
Soft sandstone	8.0
Soft shale	3.5
Good rock (usually igneous or hard metamorphic)	20.0

* From OCE (Jul 1970).

** Keep velocities less than 5.0 fps unless good cover and proper maintenance can be obtained.

Navigation Locks

33. Engineer Manual EM-1110-2-2601, Engineering Design of Navigation Locks (OCE 1959) discusses primarily the planning, location, layout, and sizing of locks and the selection of the type of structural configuration to be used. Factors in the design of navigation locks that have environmental implications include the location of the structure and the design of the lock intakes. When the upstream reservoir or lock pool is deep enough to stratify, location of the lock intakes influences release water quality. An example of this principle is in Part VI of this report, which contains a discussion of the design study for Bay Springs Lock and Dam.

Levees

34. Engineer Manual EM-1110-2-1913, Design and Construction of Levees (OCE 1978a), sets out basic principles for the design and construction of earth levees. The manual is general in nature and not meant to supplant judgment of the design engineer on a particular project.

35. A levee is defined as an embankment to provide flood protection from seasonal high water. It is therefore subject to periodic water loading for the period of a few days or weeks a year. Embankments subject to permanent or prolonged loading periods (longer than normal flood protection requirements) should be designed in accordance with earth dam criteria.

36. Although levees are similar to small earth dams, they differ in three important respects. Levee embankments may become saturated for only a short period of time beyond the limit of capillary saturation; flood protection requirements dictate levee alignment, which often result in construction on poor foundations; and borrow is generally obtained from shallow pits or channels adjacent to the levee, which produces less than ideal fill material.

37. Numerous factors must be considered in levee design, and because these vary from project to project, no specific step-by-step procedure can be established. General, logical steps based on past

successful projects and detailed information for implementing procedures are provided in EM-1110-2-1913 (OCE 1978a). The method of levee construction is a factor directly affecting water quality and the environment. The following procedures are common to most projects.

38. Minimum requirements for foundation preparation of levees consist of clearing and grubbing, and in most cases, some degree of stripping is required. Clearing consists of the removal of objectional or obstructional matter above ground, such as trees, fallen timber, brush, vegetation, loose stone, structures, fencing, and other similar debris. Grubbing consists of removing all old stumps, roots, buried logs or pilings, old paving, drains, and the like from within the levee foundation area.

39. Stripping follows clearing and grubbing in the process of foundation preparation. Low-growing vegetation and organic topsoil are removed to a depth determined by local conditions, usually 6 to 12 in.* Stripped material suitable for topsoil is stockpiled for use on slopes and berms. Debris obtained from clearing, grubbing, and stripping operations is either burned where permitted by local regulations, or buried in sloughs, ditches, or depressions outside the limits of the embankment foundation.

40. The foundation under a levee must be stable, or able to support the weight of the levee without excessive settlement. Foundation deposits that may cause problems are soft clays, sensitive clays, loose sands, natural organic deposits, and debris deposited by man. General methods of dealing with these problems are excavation and replacement, displacement by end dumping, and stage construction. Details on these techniques are found in EM-1110-2-1913 (OCE 1978a).

41. The levee embankment is placed by normal earthmoving and consolidation techniques common to highway or dam embankment construction. The greatest environmental impact from erosion can take place at this time if the slopes are not protected before they are vegetated, riprapped, or paved.

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

42. The earth-fill section of the levee is usually trapezoidal with a broad base and flat side slopes, from a minimum ratio of 2H:1V up to as much as 10H:1V. This provides stability against hydrostatic pressure and erosion and facilitates maintenance. The top of the embankment is usually at least 10 ft wide to allow access to inspection and maintenance vehicles. The flat side slopes require very wide bases and thus large land requirements, which is probably the most significant environmental impact.

43. The riverside slope must withstand wave erosion forces and stream currents, and the requirement for riverside slope protection varies, depending on factors such as the length of time floodwaters act against the levee, the susceptibility of the embankment materials to erosion, the riverside slope, the structures riverside of the levee, and the levee alignment.

44. Types of slope protection include grass cover, gravel, sand-asphalt paving, concrete paving, articulated concrete mat, and riprap. The side slopes generally are sodded and mowed. The more durable types of slope protection such as riprap, articulated mat, or paving are usually reserved for critical locations or areas where sod cannot be established, such as under bridges. Riprap is most commonly used when greater protection is needed than grass cover. The trapezoidal cross section of levees leads to large land requirements. Floodwalls, which serve the same purpose as levees, have much smaller land requirements but require considerably more expensive masonry construction.

45. Levees must be of sufficient height to contain the design flood flow with a reasonable freeboard of 2-5 ft. Freeboard allowances are determined based on considerations such as design uncertainties, probable channel blockages, wave action, and flank buildup. The required height of the levees depends on the width of the channel between them. For the same design flood flow, lower levees may be used with a wider channel, or taller levees may be used with a narrower channel. The minimum cost of a levee system for a specified performance is determined through an optimization procedure that considers several channel width and levee height combinations.

46. Seepage through the levee under conditions of prolonged high water influences the cost of the levee system. Foundation underseepage control alternatives include cutoff trenches, riverside impervious blankets, landside seepage berms, pervious toe trenches, and pressure relief wells.

47. Tributaries that cross levees can cause problems. Backflow up these tributaries can be prevented by the installation of control structures at the levee crossing. However, another problem arises when these structures are closed during flood flows. The tributary becomes blocked, creating interior drainage problems. The tributary water that collects behind the levee may be pumped over the levee into the main channel. Alternatively, the tributary flow can be channeled downstream on the protected side of the levee to a point where it can be introduced to the main channel by gravity flow. A third alternative is to divert the tributary into a pressure conduit upstream of the levee and pass it under the levee to the main channel. The conduit must be designed so that the tributary flow will have sufficient head to force the tributary water into the main channel against the flood stage.

48. The upstream and downstream effects of a levee system may be significant. Some levees tend to increase the flood stage in the leveed reach. Therefore, flood stages upstream and peak flows downstream will also increase. Because of these reasons, levees should be used on a particular reach only if they are part of a comprehensive watershed plan and if their potential upstream and downstream effects are known.

49. Major environmental impacts of levee systems include losses of natural habitat in the space occupied by the levee embankment, the erosion and water quality degradation caused by the disruption and movement of soil during construction, the disruption of drainage patterns, and the visual and aesthetic effects of the levee blocking the view of the stream from the landside of the levee. The basic purpose of levee systems--elimination or reduction of flooding in the protected area--is itself a major environmental impact. Creation of dryer conditions on the landside of levees can cause shifts in plant and animal communities and encourage land use changes. Levees undoubtedly affect the hydraulics

of the natural channel, but the magnitude and significance of these effects are not usually known.

50. Environmental impacts of levees may be addressed in a number of ways. The levee embankment may be graded in smooth and rounded cross-sections instead of the normal sharp angles and abrupt changes in grade. The existing woodland may be considered when planning levee alignment; existing vegetation may be utilized to screen views of project structures; and adjacent woodland may be selectively thinned to avoid a uniform strip of cleared forest. Although plantings on levee slopes are subject to strict regulations, they can be utilized in some situations to provide food and cover for wildlife and to reduce aesthetic impacts. Such plantings must be carefully maintained, however, because they can encourage pest species or interfere with visual inspections of levee slopes.

51. Erosion and water quality degradation during construction can be controlled and minimized, although probably not eliminated, by suitable and careful construction techniques and erosion control methods common to all earthmoving projects, such as quick seeding and mulching, straw bale barriers, drainage control, and settling ponds.

PART III: CHANNEL MODIFICATION

52. Certain types of channel modification, popularly referred to as channelization, have been very controversial for at least two decades, although they are a very simple and straightforward method of solving some types of water resources problems and are often the only economically feasible alternative that comes close to meeting local objectives. However, some forms of channel modification such as channel enlargement can cause significant alteration of aquatic habitat, changes in water quality, and various other environmental problems. Therefore, environmental groups have opposed many channelization projects and the process itself.

53. Two aspects of channel modification will be discussed in the following sections: planning/engineering and environmental impacts. Alternatives to channel modification and recent improvements in the design of channel modification projects will also be discussed.

Engineering Aspects of Channel Modification

54. The prevention of flood damage can be accomplished by one of several structural alternatives. Structural alternatives include the use of reservoirs to slow or contain flood flows, the construction of levees or floodwalls to contain flows within a predetermined floodplain, the use of off-channel floodways that provide emergency flood conveyance capacity and are used only during a flood, and modification of channels in several degrees and forms. Two alternatives are available for drainage improvements: open channels and closed drainage conduits.

55. The engineering aspects of channel modification, design, and construction are discussed in this section. The use of reservoirs and levees in conjunction with or as an alternative to channel modification is also discussed. Physical effects of the various alternatives are described in another section.

Engineering principles

56. Water which falls to the earth's surface as precipitation and

runs off moves downhill to a receiving water body due to the force of gravity. Flow characteristics are controlled by the magnitude of the flow of water and sediment, the steepness of the slope, and the characteristics of the materials the water flows through or over. The velocity of the flowing water is directly related to the channel slope (or water surface slope, if flow is uniform), and the cross-sectional area of the flow. The flow velocity is inversely related to the perimeter of the flow and the channel roughness or resistance. The ratio of the cross-sectional area of the flow to the perimeter of this area is called the hydraulic radius. Velocity is directly related to the hydraulic radius.

57. Flow characteristics for alluvial channels also depend on the nature and amount of sediment being transported. Transport of sediment requires additional energy. The alluvial channel form adjusts itself under the influence of changing inputs of water and sediment. Alluvial channel forms, water discharge, and sediment load interact in complex fashions that are not presently fully understood.

58. Channel resistance retards the flow and creates turbulence. The resistance of a channel is due to the roughness of the bed material, bends, bars, obstructions to flow such as boulders or bridge abutments, snags, pools, riffles, and outcrops. Overbank channel or floodplain roughness is affected by the nature of the vegetation.

59. The flow capacity of a channel is increased, therefore, by increasing the slope, increasing the cross-sectional area, decreasing the channel resistance, and by changing the cross-sectional shape so as to increase the hydraulic radius. The design of modifications for alluvial channels to increase flow capacity is difficult since the channel geometry will react to changes in key physical variables.

Clearing and snagging

60. The flow conveyance capacity of a natural channel can be increased by removing specific large impediments from the channel. This clearing and snagging process involves the removal of large trees, rocks, and other debris from the streambed and the clearing of brush and trees from the banks. These impediments act to retard flow in two ways.

The impediments themselves generate increased friction and turbulence in the flowing water, leading to the inefficient dissipation of available energy. Second, the impediments may cause debris carried by flood flows to hang up across the channel and further impede flow. Clearing and snagging may be done with hand tools, but it is usually accomplished with bulldozers and cables for dragging the impediments clear of the channel. Clearing and snagging generally yields only a modest improvement in conveyance capacity.

Channel excavation

61. Greater improvement in flow-carrying capacity can be achieved through channel excavation. The required excavation can range from the removal of a few shoals to an order of magnitude increase in the depth and width of the channel. The basic, accepted channel cross-section is the trapezoid, as shown in Figure 1. The basic design parameters are the bottom width w , channel depth d , and the slope of the sidewalls. The side slopes would approach 2H:1V (or a half hexagon shaped channel) for maximum hydraulic efficiency. However, for channel stability, flatter values of side slope are sometimes used. The value of the side slope actually used depends on the characteristics of the soil through which the channel passes and the degree of artificial bank protection that can be justified. Typical values of side slopes for various materials from Linsley and Franzini (1972) are presented in Table 3.

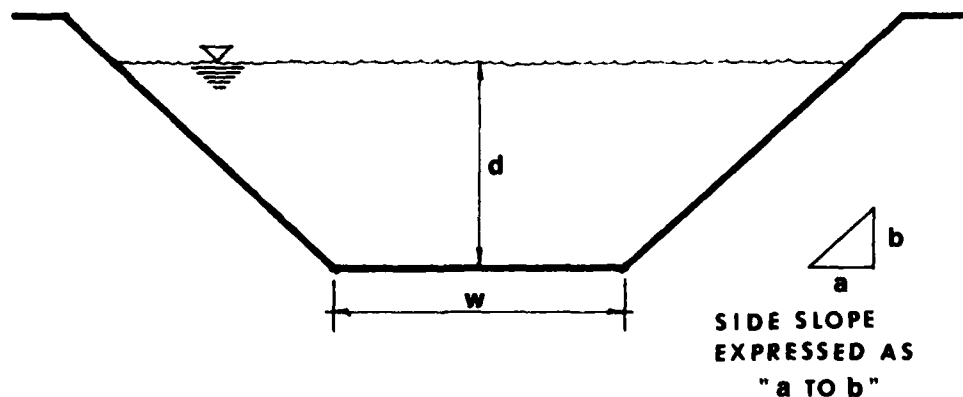


Figure 1. Trapezoidal channel

Table 3
Allowable Side Slope*

<u>Material</u>	<u>Slope</u>	
	<u>Horizontal to Vertical</u>	
Firm rock	1/4 to 1	
Fissured rock	1/2 to 1	
Firm soil	1 to 1	
Gravelly loam	1-1/2 to 1	
Sandy soil	2-1/2 to 1	

* After Linsley and Franzini (1972).

Chow (1959) presents a similar table that recommends slightly flatter side slopes.

62. An additional requirement is that slopes that are to be grassed and mowed must have a slope of at least 3 to 1 to accommodate mowing machinery. Land costs also affect the choice of side slopes. Flatter side slopes produce wide channels and require large amounts of land. For example, a v-shaped channel with 3 to 1 side slopes and the same conveyance capacity as a rectangular channel will have a top width approximately 2.5 times that of the rectangular channel. Rectangular channels offer the advantage over triangular and trapezoidal channels of not requiring additional top width for freeboard.

63. The maximum allowable velocity that can be accommodated without significant bed erosion is determined by channel bed material characteristics. Maximum permissible velocities are greater for old, seasoned channels than for new ones, greater for deeper channels than shallower ones, and greater for straight channels than sinuous ones. A rough guideline for maximum allowable velocities is shown in Table 2, but exact determination is usually based on experience and judgement (Chow 1959).

64. Specific man-made and geologic structures also influence channel design. The presence of rock outcroppings affects both the size and the alignment of the channel. The presence of buildings, highways, and bridges limits the size of channel that can be utilized without extensive relocation and modification of existing structures.

65. The above factors influence the design of channels for flood conveyance, and their influence may lead to the inclusion of additional structural elements within the channel to meet all requirements. As an example, a channel design with sufficient cross-sectional area to carry the expected flood flows may result in a velocity that would scour the channel. To overcome this difficulty, several options are available. Some velocity reduction can be obtained by using wider, shallower channel with a smaller hydraulic radius. This option increases the amount of land required for the channel and may lead to an unstable channel configuration.

66. A second channel stabilization alternative is the placement of grade control structures at intervals along the channel that will dissipate energy under controlled conditions. Several types of grade control structures are in common use. The streambed downstream of the structure is normally paved or riprapped for a short distance to prevent erosion of the streambed by falling water.

67. A third alternative is stabilization of the channel bed to withstand design conditions without scouring. Vegetation on side slopes has a stabilizing effect. For example, as shown in Table 2, silt clay has a maximum permissible velocity of 3.5 fps. However, silt clay covered with Kentucky blue grass has an allowable maximum velocity of 7.0 fps, and silt clay covered with Bermuda grass can withstand velocities up to 8.0 fps.

68. The high land costs in urban areas discourage the use of wide channels, especially in situations where there is extensive floodplain encroachment. Instead, narrow channels with steep side slopes are required. The steep side slopes sometimes require structural reinforcement of the banks. Side slopes as steep as 1 on 1.5 can be protected by riprapping if the flow velocity is not excessive (OCE 1978a). Vertical sheet piling is also used for bank protection. The cost of streambank protection may limit its use to critical areas where erosion is likely to occur such as concave sides of bends.

69. Protection of streambanks can also be accomplished with jetty or dike fields. Jetty fields consist of a series of permeable piers

projecting from the bank into the channel. These jetties serve to slow the flow, prevent scour of the bank, and encourage planned sediment deposition.

70. Complete stabilization of open channel banks and bottoms can be obtained by paving the channel, which has very severe environmental effects when all natural habitats are removed. Paved channel slopes can be quite steep or even vertical, which minimizes land requirements. In certain cases where a high hydraulic gradient is available, the flow can be fed into a completely enclosed cylindrical pressure conduit. This structural configuration allows maximum usage of the hydraulic gradient to force water through the conduit. The water flows under pressure much like in a water distribution system. This option also has rather severe environmental effects. It does have the advantage of very low land requirements, and thus is most useful in urban areas.

71. The choice of a particular channel design is determined based on several considerations. Project cost, which principally consists of the costs of real estate, construction, operation (if any), and maintenance is weighed against the project benefits, principally a given level of flood protection. Environmental, aesthetic, cultural, and recreational impacts are also considered. Extremely high land costs may favor the use of channel lining since lined channels tolerate higher velocities and thus have greater flow capacity for a given cross-sectional area. On the other hand, lined channels are generally more expensive to construct than unlined.

72. Detailed channel design is performed for sections known as reaches. The length of a reach is generally governed by a change in conditions of the channel. Such changes may include the entry of a tributary, a change in soil conditions, a change in slope, or others. Under constant conditions, an arbitrary maximum reach length is normally assumed. Computer programs are normally used to compute water surface profiles for several designs and a range of flow conditions.

Methods of excavation

73. The excavation of small channels is usually conducted from the channel bank with conventional power shovels or draglines. To reduce

construction costs and downstream turbidity, dry excavation normally is done as much as possible. Dry excavation can be accomplished in a number of ways. Excavation often is done during the summer and fall seasons when flows are normally low. A pilot channel is sometimes excavated first to contain low flows, which allows the remainder of the channel to be excavated on dry land. Temporary culverts are occasionally installed to divert the entire flow during construction, allowing all parts of the channel and the channel banks to be dug completely in the dry.

74. Conventional dredging equipment can be utilized on large channels. Three basic types of dredge are in use, and the choice among them depends on the size of the channel, the nature of the material being dredged, and provisions for disposal of the dredged material (Merritt 1968). The dipper dredge, a floating power shovel, is used only on small jobs. Ladder dredges consist of an endless chain of buckets that bring up material from the bottom and carry material via a series of belt conveyors to the disposal area. These dredged material conveyors are limited to a maximum length of 300 ft. Suction dredges pick up the bottom material and water in suction pipes and pump the mixture through a series of pipes to the disposal area. A suction dredge is limited to areas devoid of large stones and boulders.

75. The disposition of the dredged material often presents difficulties and is dependent on the nature of the dredged material, the overall channel design, and the use of the land surrounding the project. If the surrounding land is farmed, the dredged material is often spread over the land and seeded. When the overall channel design calls for the construction of levees or dikes, the dredged material is formed into levees or dikes parallel to the channel to provide additional flood protection. In some cases, the dredged material may be in demand for use in road construction processes. The dredged material is then trucked away for use elsewhere and is sometimes sold.

76. Channel excavation impacts on riparian areas arise from operation of heavy equipment on the bank or in the channel and placement of the excavated material. Trees must be removed to provide access and operating room for draglines, backhoes, and similar equipment. Access

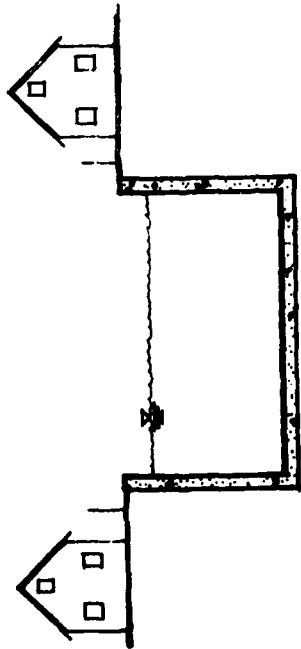
roads are sometimes built along the channel, which also requires clearing. Excavated material is normally placed in piles adjacent to the channel or spread uniformly. Either alternative requires clearing.

77. Impacts on the riparian areas are somewhat less when equipment operation is restricted to one side of the channel or when riparian trees are merely thinned or topped and excavated material is lifted over the remaining vegetation. Impacts may be further reduced by using equipment such as small hydraulic dredges that are capable of operating in the existing channel. Removal of riparian trees is then limited to areas that are to be excavated. Some clearing may also be required to route the dredge pipeline to a diked dredged material containment area. Additional impacts are associated with the containment area, but it can be located away from the critical riparian area or in an area already cleared.

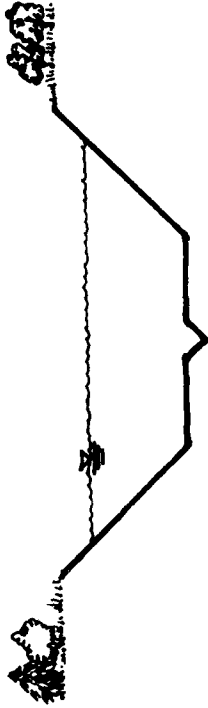
Design alternatives for channels

78. The excavated channel can be incorporated in the overall design of the flood conveyance system in a variety of ways. A simple flood conveyance structure consists solely of the excavated channel. Alternatively, the excavated channel may be combined with levees and/or floodways in the overall design of the flood conveyance structure.

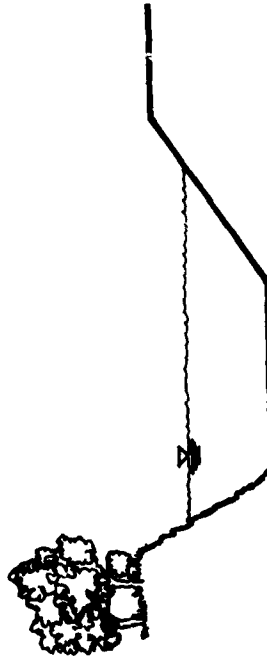
79. Figure 2 shows some typical cross sections of flood conveyance structures (Arthur D. Little, Inc. (ADL) 1973). In Figures 2a, 2b, and 2c, the excavated channel constitutes the entire structure. The channel is combined with berms and levees in Figure 2d for the overall design. Figure 2a shows the paved channel, which is typically used in urban areas where land costs are extremely high. Figure 2b shows a trapezoid designed to carry the entire flow. This design also incorporates a notch in the base to convey low flow. The low-flow channel provides two main advantages: first, it provides a definitive channel at low flow which tends to reduce sediment deposition in the channel, and second, it allows for maintenance of a fishery passageway during periods of low flow. Figure 2c shows a modification of the trapezoidal channel in which only the bottom and one side are excavated. The other side is left in its natural state to provide wildlife habitat and visual aesthetics. Figure 2d shows a trapezoidal channel used in combination with



a. Rectangular paved channel



b. Trapezoidal earth channel with low-flow notch



c. Earth channel with one bank excavated



d. Trapezoidal earth channel with berms and levees

Figure 2. Typical flood conveyance structures (Arthur D. Little, Inc. (ADLI) 1973)

berms and levees. The excavated channel is designed for a relatively frequent flood event, perhaps the 5-year flood, whereas the berms and levees are designed to contain a flood of larger magnitude. The berms and levees are kept clear of woody vegetation to allow for the passage of large flows. These areas typically are seeded and mowed. Since the floodway between the levees is inundated only periodically, this area is often utilized for agriculture. Floodways can provide outdoor recreation in urban and suburban areas.

Arrangement of the channel

80. The excavated channel either may follow the natural path of the stream or it may be realigned. Realignment is most often used when the stream follows a widely meandering path. By realigning a sinuous channel into a straighter configuration, the channel can be shortened and the channel made steeper. A less sinuous channel offers less resistance to flow. Shorter channels may also be cheaper to construct. However, the increased channel slope sometimes necessitates additional structural channel stabilization such as lining, streambank protection, or grade control structures. Navigation channels are sometimes realigned to make bends gradual enough for tow traffic to pass safely. Channel alignments are planned with consideration of land availability, and the preservation of existing bridges and structures.

Maintenance of channel banks

81. Historically, channel enlargement and alignment for flood control involved removal of all woody vegetation along the channel banks for equipment access and placement of excavated material. Some recent projects, particularly those still in planning stages, include provisions for retaining some vegetation on one or both banks. Retaining vegetation increases project cost because it restricts access and freedom of movement for excavation equipment. Retaining vegetation also requires more detailed specifications and close supervision of construction.

82. The optimum situation for banks of completed channels is for sufficient vegetation to remain to stabilize the banks but for

minimum vegetation to project into the channel. Well-mowed grass is the realization of this ideal. Hydraulic efficiency requires the removal of large vegetation for a variety of reasons. First, large vegetation retards flow as it creates frictional dissipation of available potential energy. Second, debris carried by flood flows tends to catch on stands of trees along the bank and further restricts flow. Finally, large trees may become uprooted during flood flows, be carried downstream, and subsequently hang up across bridge abutments to catch debris and block flow. This situation can have particularly serious consequences.

83. The extensive removal of large trees and accompanying underbrush destroys wildlife habitat. Thus, this policy is generally opposed by fish and wildlife interests. Bank vegetation policies acceptable both to channel designers and fish and wildlife interests must be worked out. There are various types of brush and low vegetation that provide wildlife habitat, yet do not significantly reduce flood carrying capacity. Also, the size of trees left along the streambank is subject to reasonable compromise.

Design of drainage channels

84. The design of drainage channels (SCS 1971), as distinct from those for flood conveyance, includes most of the previously discussed considerations. However, there are additional aspects that are significant. First, the excavation of drainage channels seldom involves contact with natural streams. The work generally consists of enlarging existing man-made channels or excavation of channels where none previously existed. Second, drainage channels are sized based on average conditions rather than on extreme events. Finally, channel depth is governed in part by the need to provide outlets to low-lying areas and not solely to carry flood flows. The SCS recommends that inverts of perforated pipe underdrains be 1 to 1.5 ft above the channel bottom. Channels that serve both flood conveyance and drainage purposes usually have more extensive flood conveyance requirements, which dominate the

design. However, channel depth may be determined by drainage requirements.

Structural Alternatives to Channel Modification

Levees

85. Flood-prone areas may be protected from high flows by levees or floodwalls. These structures are essentially dams erected parallel to the streambed. A levee is an earthen dike, whereas a floodwall is usually a masonry or concrete structure. These structures provide flood protection without alteration to the stream unless channel bed material is excavated to construct the levee.

86. According to ADL (1973), land requirements for a leveed channel are frequently greater than those for an excavated channel of the same capacity for two main reasons: (a) the broad foundation base and wide, flat side slopes required for embankment stability and maintenance and (b) the setback from the streambank required for sufficient floodway cross-sectional flow area. The construction costs of a levee system may be higher or lower than those of channel excavation, depending on a number of factors, including soil characteristics and availability of borrow material. Regular maintenance is required for levees to prevent erosion of the side slopes and to maintain structural integrity.

87. Levees also require more complex and usually more expensive methods of handling side drainage in the protected floodplain than do excavated channels. The collection systems, interior drains, and pumping stations all require space, and their construction causes an environmental impact, not only because of the actual land occupied, but also because of the construction disruption and the drainage pattern disruption.

88. Floodwalls are utilized in urban flood protection projects where land costs are high or land availability is low. Floodwalls are often located at critical points where the proximity of buildings to the channel bank precludes sloping the bank for stability or continuing the levee.

Floodways

89. Another alternative to channel excavation is the floodway that bypasses the natural stream in the area to be protected. The floodway is normally a trapezoid and is kept clear of large vegetation. It is designed so that the natural stream handles the normal flows, and water flows through the floodway only when flood flows raise the stage elevation. The amount of flow through the floodway can be controlled in a number of ways. One control feature is the fuse plug levee; this is a low levee that rapidly washes out when overtopped by the flood flow. Fuse plug levees are rarely built anymore. Alternatively, overflow can be calibrated to occur at a definite river stage by installing a fixed weir at the entrance to the floodway. A third alternative is the use of stop logs or gates at the floodway entrance that are removed when diversion through the floodway is desired.

90. The floodway has the distinct advantage of leaving the natural stream untouched. Peak flows downstream of the downstream confluence of the floodway and the stream may be increased or reduced. This downstream effect must be considered in the design of a floodway system.

91. The local topography of many areas precludes the use of floodways. The land must be relatively flat laterally to the channel, or the required amount of excavation is excessive. However, unit excavation costs are normally moderate since the excavation can be accomplished entirely in the dry. The land requirement associated with floodways is a significant factor in the economic comparison of floodways with other forms of flood protection. The floodway is generally comparable in width to the natural channel. The floodway channel is normally dry, and productive use of the land is restricted but not totally denied. The land uses may include raising low-value crops, cattle grazing, and recreation. Production of high-value crops or the erection of buildings is precluded. Care must also be exercised so that sufficient warning of impending floodway use is given to allow clearing of the floodway.

Reservoirs

92. Flood control reservoirs are designed to store a portion of the flood flow so that the flood peak will be minimized at the point to be protected downstream. The stored flood water is released after the normal flood flow has abated and at a rate that will not cause flood damage downstream. There are two basic types of reservoirs: retarding basins and storage reservoirs. They differ only in the manner in which the outlet flow is controlled. The flood control storage reservoir is often used for purposes other than flood control. These purposes include generation of hydroelectric power, supply of municipal or irrigation water, water quality control, and recreation. Outlet control is accomplished by gates and valves that are operated according to prescribed operating guidelines for the purposes described. The larger dams of the Corps, the Tennessee Valley Authority (TVA), and the Water and Power Resources Service are usually of this type.

93. Retarding basins automatically regulate the outflow in accordance with the amount of water in storage with fixed, ungated outlets. The outlet may consist of a riser pipe and culvert through the containing dam, or one or more ungated sluiceways. These reservoirs are normally equipped with an emergency spillway that automatically releases excess floodwater before the dam can be overtopped. Retarding basins are often designed with excess capacity for sediments washed in from upstream.

94. The flood protection provided at a particular point on the stream by a reservoir is partially a function of the fraction of the watershed area above the reservoir and the runoff distribution. Immediately downstream of a reservoir, flood protection is essentially complete. Further downstream, as runoff from the watershed area below the reservoir increases and becomes appreciable, the degree of flood protection is progressively reduced.

95. The feasibility of a flood control reservoir as an economically viable alternative to channel modification for flood protection depends primarily on the topography and geology of the watershed upstream from the point to be protected. To be effective, a site suitable for

the dam and impoundment must be available not too far upstream of the point in question. Factors that determine the suitability of a particular reservoir site include surface topography, foundation conditions for the embankment, and existing land use in the area to be inundated.

96. Construction of the containing dam and purchase of the inundated land are the principal costs associated with a reservoir. This land and the natural stream are removed from their present use. The filling of the reservoir destroys the existing habitat for fish and wildlife. Proper management of the reservoir can produce an important fishery resource, although it will be different from that native to the undisturbed stream. Dry bed reservoirs where no permanent pool is maintained are different from ordinary impoundments. These reservoirs may continue to provide significant fish and wildlife habitat and continue to be used for agricultural and recreational purposes.

97. The use of flood control reservoirs is an alternative to channel modification nearly always considered by each of the construction agencies. Topography in flat areas precludes the use of reservoirs. Several alternatives, including reservoirs in lieu of or in combination with varying amounts of channel modification, are studied when natural sites are available. ADL (1973) argues that channel modifications tend to be more economically attractive than small reservoirs to both the constructing agency and local sponsors. Actually, channel modifications and small reservoirs are not direct substitutes for one another.

Land treatment measures

98. Management of vegetation on watershed lands can significantly reduce the amount of runoff entering the stream from light rainfalls, but it has little effect on rainfall typically associated with flood flow. Land treatment is therefore considered as a complement rather than an alternative to flood control. Land treatment measures do have the significant effects of reducing erosion and of retaining and utilizing rainfall during drier periods. The SCS actively promotes these measures and incorporates them in their rural protection and drainage projects.

Selection among
structural alternatives

99. A flood problem can be solved in a variety of ways, but the actual selection is made primarily on the basis of economics. Land requirements are generally greater for floodways and reservoirs than for channel modification. These land requirements discriminate against these alternatives in two ways. First, the cost of acquiring easements on the land is significant. Second, the basic purpose of the sponsors and the constructing agency is to protect land and property from floods and free it for more productive use. Land required for the project is taken out of production and therefore the flood protection benefits associated with the project works are likewise reduced.

100. Reservoirs face the added disadvantage in economic comparison with other alternatives of providing flood protection that cannot be localized where it is most needed. The flood control reservoir provides flood protection for all downstream riparian lands, but the degree of protection afforded diminishes with distance from the reservoir. Some of this land would not flood because of local topography, and some land would remain undeveloped. The value of damage averted on some protected land may consequently be negligible. Therefore, some of the flood protection afforded by a reservoir is of little economic value and contributes little to the benefit side of the benefit-cost analysis. By contrast, a flood control project based on channel modification affords protection at the point of the modification and can be finely tuned to result in a maximum benefit-cost ratio. The designer has the option of adding to the scope (length) of the project only if the additional benefits accrued warrant the extension. However, channel projects must include measures to prevent increased damages upstream or downstream of the modified reach caused by higher flood levels or accelerated flow. These factors may also affect the length of the modified channel.

Environmental Effects of Channel Modification

Basic problems

101. The environmental effects of channel modification are many. Traditional channel excavation usually alters the entire character of the stream and completely destroys the existing aquatic habitat. Although some postconstruction recovery will take place, most sources agree that many of the aquatic populations will reach only about 10 to 20 percent of their original levels (ADL 1973, U. S. House of Representatives 1971). Thus, the major effects of channel modification are the great change in visual or aesthetic effect from natural to man-made, and the loss of aquatic and riparian wildlife. The range of effects will be discussed in the following paragraphs.

Congressional hearings

102. Public opposition to "channelization" during the 1960's finally resulted in a series of Congressional Hearings in 1971 (U. S. House of Representatives 1971). The hearings took testimony on the effects of programs conducted or financially aided by the Corps of Engineers, the Water and Power Resources Service, the SCS, and the TVA to dredge, channelize, or modify the nation's rivers and streams. The hearings were held for a dual purpose: to identify the accomplishments achieved through stream dredging and modification and to ascertain the improvements needed in the various federal programs under which the works are being carried out. The effects of these programs on the natural environment were also examined, and many of the adverse effects of channel modification were brought to public attention for the first time.

Arthur D. Little, Inc.
(ADL) report on channelization

103. At about the same time, the Council on Environmental Quality (CEQ) entered into a contract with ADL to do a factual assessment of the environmental, economic, financial, and engineering aspects of

channel modification. The ADL report (ADL 1973) was submitted to CEQ on 15 March 1973, and immediately became the standard work in the field of channel modification. The report was organized into two parts.

104. Volume I summarizes the findings and Volume II contains field evaluation reports on 42 channel modification projects throughout the nation. The topics discussed in Volume I include the following:

- a. Historical perspective, legislation and program magnitudes.
- b. The environmental setting.
- c. Project description and formulation.
- d. Assessment of physical effects.
- e. Effects on fish and wildlife resources, habitat, special diversity, and productivity.
- f. Appraisal of economic merits.
- g. Cost sharing and financial arrangements.
- h. Channel modification and its structural alternatives.
- i. Nonstructural alternatives.

105. No attempt was made during this project to resurvey the ADL literature; rather, a summary of the ADL report is included in this report. Several references to post-1973 reports and articles were found, but many of the reports and articles could not be located. The ones that were located, and the abstracts of the ones that were not, did not indicate any new or different findings.

106. Chapter 4 of the ADL report summarized the findings of the literature and the field evaluation on the physical effects of channel modification. These topics, which will be discussed, include the following:

- a. Wetland drainage and land-use changes.
- b. Bottomland hardwoods.
- c. Cutoff of oxbows and meanders.
- d. Water table changes and stream recharge.
- e. Erosion.

- f. Sedimentation and channel maintenance.
- g. Downstream effects.
- h. Aesthetics.

107. Chapter 5 of the ADL report, prepared by the Philadelphia Academy of Sciences under a subcontract, discusses the effects on fish and wildlife resources, habitat, species diversity, and productivity in 42 projects. The field evaluations examined 36 completed and 6 proposed projects. The projects ranged from virtually untouched, natural conditions to totally altered surroundings. The soils encountered were varied, ranging from light organic muck lands to heavy clay with pure sand, gravel, boulders, and clay silt in other places. Precipitation and vegetation were also widely varied. Streamflow varied from rapid to slack, and water quality varied from pristine and to grossly polluted. Streambeds ranged from bone-dry sandy conditions to bank-full flood flows. Fish and wildlife resources were numerous, scattered, or absent. Generalizations on effects of stream modifications are not feasible when project sampling is so diverse (ADL 1973).

108. The following discussion summarizes the literature reviewed and the results of field evaluations discussed in the ADL report. The reader is referred to the ADL report for the details of the original references and for discussions of the individual projects.

Wetland drainage
and land-use changes

109. The drainage of wetlands results in a number of detrimental effects on the environment. Physical effects are a function of the following variables: soil permeability and transmissibility, cropping patterns, cultural features, evaporation, topography, vegetation, capillary forces, transpiration, rainfall, temperature, and infiltration and surface runoff.

110. The drainage of wetlands alters and usually reduces vegetation. The loss of vegetation leads to a reduction of evapotranspiration rates, the speeding of runoff in areas adjacent to the channel, and the reduction or destruction of food and forage for wildlife. The interre-

lated surface and groundwater system is altered as a direct consequence of wetland drainage. New dominant plant species develop as they adjust to the new supply and quality of water.

111. Construction reduces or eliminates grass and woody species in the right-of-way taking area. The loss of canopy and shade results in an increased temperature. This leads to drying of the forest floor, and an increased fire hazard. Evapotranspiration rates are reduced as a consequence of the reduced vegetation, and runoff in immediate areas is hastened and presents serious problems.

Bottomland hardwood forests

112. Hardwood forests in floodplains are a valuable natural resource. The values of a hardwood forest are both diverse and immense. Forests provide a source of lumber and refuge and a breeding ground for wildlife, as well as the basis for a great variety of detritus, which is food for the stream ecosystem. These forests act as sediment traps and greatly reduce the sediment load in streams. Leopold (Leopold et al. 1964) estimates that cutting down a forest may increase the sediment load to a value eight times that which existed prior to removal. An increased sediment load results in reduced stream capacity at the same time that runoff increases, leading to greater flooding. As a result of clear-cutting of vegetation along streams, the nitrate level in the stream also tends to increase significantly. Thus, natural vegetation is very important in controlling sediments, nutrients, and runoff.

113. Eliminating trees from the immediate bank of a stream has several effects on aquatic life in the stream. Overhanging branches provide a variable light pattern that results in greater habitat diversity in the stream. Different species of aquatic life require varying light intensities. Overhanging tree branches in the summer shade the stream, which reduces the water temperature. When the canopy is removed, the higher summertime temperatures contribute to the reduction of species diversity in the stream. Many species, such as trout, cannot survive during the summer months when stream temperatures exceed 75°F.

114. Bank-side trees have other values. Tree leaves and insects

that feed on them fall into the stream and form a detrital base for aquatic life in the stream. Detritus has been found to be extremely important to the forest stream ecosystem. The wide variety of plant species found along the stream provides a varied detritus food source. Man often upsets this balance either by replanting with only one species or does not replant at all. Streamside vegetation serves a further role as a retardent to bank erosion.

115. Severe damage is caused to the stream environment when dredged material banks are piled up along the streambank. This prevents the occurrence of two very important events: drainage and inundation. Drainage, or flowthrough, is very important to a swamp. An insufficient flow will cause anaerobic conditions, and instead of having high productivity and decomposition, vegetative matter becomes peat. Nutrients normally available for plant growth are locked up in the peat. This condition has happened in the Florida Everglades and numerous northern bogs. Many plants that are native to swamps require a regular inundation of water to receive nutrients and water. When dredged material is piled along the stream, this necessary inundation is cut off. The result is often the loss of bottomland hardwoods. The species that are lost are often important food sources for a variety of wildlife. As a result, beaver, mink, otter, and sometimes muskrats and racoons are eliminated. The loss of acorns, tupelo berries, grape, holly, hackberries, and other foods places a hardship on other wildlife forms.

116. The loss of bottomland hardwoods following channelization changes annual stream flow patterns by magnifying peak flows and depressing low flows, alters nutrient flow in the stream, and increases the water temperature of the stream, especially during summer months. The drained forest and the remaining vegetation become far more vulnerable to the threat of fire. Forest fires will accelerate the inevitable transition of vegetation from bottomland hardwoods to stands of pine or mixed conifer-hardwood forests.

Cutoff of oxbows and meanders

117. Oxbows and meanders are natural characteristics of streams.

The meandering pattern provides more in-channel storage capacity than a straight configuration. A meander typically consists of two sections: a cutting edge and a depositing or shoaling bank, which is the shallow section of the stream and is the center for aquatic life. Shallow areas within the photosynthetic zone provide spawning sites for a variety of organisms. The cutting edge provides deep pools to which fish retreat during warm weather. The diversity of current patterns that arise from the current meandering permits a greater number of species to exist. The shoaling side of the meander is typically composed of a variety of substrates. The diversity of current patterns coupled with the substrate variety increases the number of habitats. In turn, species variation and individual abundance are increased.

118. Oxbows are formed when meanders are cut off from the main flow of the river. These cutoffs are naturally occurring events. However, oxbows often are formed when channels are straightened. The flow through an oxbow is much slower than that through a meander, and it may occur either only during high water or possibly not at all. Sediments are carried into the oxbow and deposited as a result of the lower velocities. The water in the lower end of an oxbow tends to be very clear. The photosynthetic zone may extend the entire width of the channel. As a result, these areas are excellent feeding and rearing grounds for a variety of organisms. Most species collect here at one time or another to feed. For this reason, fish samples are often collected in oxbows when population size and diversity are of interest. The oxbow is a sensitive system. Sediment buildup at the entrance to the oxbow blocks the flow of water into the oxbow that causes a loss of riverine characteristics. The free exchange of organisms between the oxbow and the river is also prevented by such blocks.

119. The straightening of streams usually eliminates oxbows. Attempts are sometimes made to save oxbows, but these attempts are futile without regular maintenance of the oxbows. The elimination of feeding grounds provided by oxbows invariably reduces species diversity and productivity in the main channel. Trapezoidal channels are often utilized when channels are dredged to increase laminar flow which, in

turn, destroys turbulence and upstream-directed eddy flow. Fish seek out these areas of direction-compensating velocity during periods of high flow. Other aquatic life can exist only under conditions of eddy flow. Rutner (1963) points out that current is one of the most important density-independent factors in determining the ability of species to live in a given area. Therefore, it is the straightening of channels and the cutting out of highly productive areas such as oxbows and meanders that results in swifter water flow and a destruction of aquatic habitats and subsequent productivity.

120. Another current-related potential effect of channel straightening was pointed out by A. B. Herndon in a letter to ADL.* Herndon asserted that the assimilation of nutrients by bacteria and the subsequent die-off of bacteria cannot occur in a fast-moving stream as it does in a slow-moving stream. The nutrients and bacteria are consequently transferred downstream to the receiving body of water.

121. In some cases channelization severely reduces the number of larger fish and total fish production. Whitney and Bailey (1959) state that channelization reduces the size of fish that are present. Their studies following habitat alteration indicated a reduction in the number and weight of game fish longer than 6 in. Irizarry (1969) found in his study of 29 Idaho streams that channelization not only reduced the length of the streams 38 percent, but reduced the number of catchable whitefish 10 times and catchable size trout 6.5 times. The average fish production poundage was 7.5 times greater in the natural stream; the numbers in the natural stream were 5.7 times greater than those in the altered stream.

Water table levels and stream recharge

122. River swamp and stream water tables are interconnected and any change to one part will alter other parts of the system. Water

* Letter, dated 21 September 1976, from A. B. Herndon, Environmental Protection Agency, Atlanta, Ga., to J. M. Wilkinson, Arthur D. Little, Inc., Cambridge, Mass.

draining slowly from the swamp to the main stream helps to maintain streamflow during periods of low precipitation. During periods of heavy precipitation, the swamp acts as a sponge, absorbing and storing the excess flow, so that the peak runoff is reduced. A comparison of the two flood hydrographs is illustrated in Figure 3. Downstream flooding is decreased as a result of the swamp's dampening effect. Aquatic life of the swamp and river is dependent on the quality and quantity of water during the entire year. Plant and animal life are affected by anything that affects the underground storage reservoir, especially during the critical periods of low flow.

123. The lowering of the water table by dredging a deeper channel in the stream inevitably results in the draining of adjacent swamplands, and ultimately a shift occurs in the species composition of the floodplain and the swamp area. Channel straightening hastens runoff and reduces the amount of water available to the water table. Fast-moving streams contribute less water to the water table than would slower moving, bank-filled streams. The groundwater system is dependent on periodic flooding of the floodplain during periods of heavy precipitation or high flows for recharge. Channel straightening prevents flooding of the floodplain and hastens runoff from heavy precipitation.

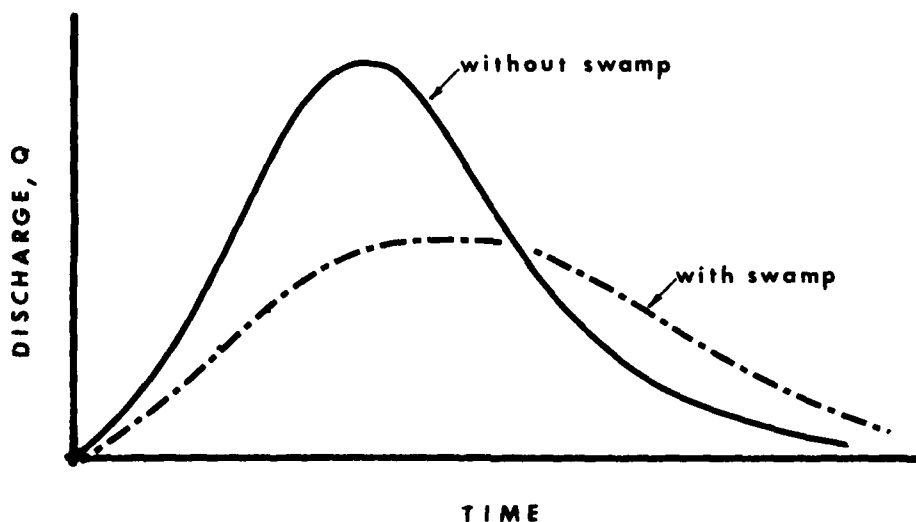


Figure 3. Flood hydrographs for streams with and without adjacent swamps

124. Insufficient groundwater to maintain streamflow during periods of prolonged drought may cause a significant alteration in productivity and diversity of aquatic life. A stream that becomes dry for short periods of time during such droughts is classified as an intermittent stream. An intermittent stream will eliminate species that require water at all times.

125. A reduced stream often becomes a series of pools instead of a free-flowing system. As mentioned earlier, current is a very important ecological factor in maintaining stream life. Current is destroyed when a stream is reduced to a series of pools. These pools are frequently quite shallow, and the temperature becomes elevated. The warmer water contains less oxygen than cooler water. The combination of no flow, high temperature, and low-oxygen carrying capacity renders these pools unsuitable habitats, and many stream species are driven away until current is re-established.

126. Channelization often reduces but does not eliminate streamflow. A result of the reduced flow is an increase in nutrient concentrations. Nuisance growths of algae often develop in late summer under these conditions. Populations of many species at the higher levels of the food web are reduced. The lack of a desirable food species causes fish to die.

Downstream effects

127. Downstream effects are basically of three types: increased sediment loads, increased flash flooding, and downstream transfer and assimilation of nutrients. Sediment transfer may be caused by bank erosion, dredging, and degradation due to change in the slope of the streambed. These sediments are carried downstream and deposited on the bottom. The sediments reduce channel roughness and destroy niches and other small habitats as they become berms of the riverbed. These sediments are often unstable and tend to shift. Shifting sediments are detrimental to the establishment of benthic algal communities that form a very important part of the food web. Invertebrates are also unable to establish on these shifting sediments.

128. Channelization projects tend to increase the velocity of

flow in a stream. Hence, nutrients and toxic substances transfer downstream more readily. Downstream species shift to those that can tolerate the heavy nutrient load. The downstream channel may not be able to carry the new flow created by increased upstream runoff. The result is periodic flash flooding. These floods dislodge organisms upstream and carry them downstream, upsetting the balance of both ecosystems. Varying degrees of severity may be encountered.

Aesthetics

129. Evaluation of aesthetic quality is a subjective matter since perceptions vary from individual to individual. Some degree of objectivity may be obtained by defining aesthetic degradation as a change from the original or pre-project appearance of a stream and its adjacent riparian area to a more symmetrical appearance with less random and diverse vegetation. The greatest amount of change of appearance is immediately after project construction, before denuded areas revegetate. Vegetation tends to gradually recover its original appearance, subject to project maintenance and clearing associated with land use changes.

130. The 42 projects surveyed by ADL (1973) exhibited aesthetic degradation (as defined above) ranging from negligible to severe. Major factors that affected the degree of aesthetic degradation included the pre-project conditions and factors affecting plant growth such as soils and climate. Project features that reduce aesthetic impacts include single bank excavation with revegetation of the excavated bank, smoothing and contouring of excavated material, and preservation of vegetation through special efforts in planning, design, construction, and maintenance.

Erosion and sedimentation

131. Erosion and sediment transport lead to increased turbidity of the water or the deposition of sediments within the channel. Three types of sediment load are present in a stream: dissolved solids, suspended sediment, and bed load. The current carries suspended sediment downstream until the current slows and the particles settle out. The particle size and the amount that drops out are functions of how much the current is reduced. Bed load consists of those particles that roll

and bounce along the bottom of the stream. These particles tend to be heavier than the suspended solids. The processes of erosion and sedimentation are strongly associated with the high velocities of flood flows.

132. A bed load occurs naturally in streams that flow through unconsolidated sediments, but it increases in many streams from the bank erosion that follows channelization. Increased bed load also develops from sediments derived from other sources, primarily those connected with agricultural activity.

133. Fine-grained particles may be carried great distances by a stream. The primary importance of fine-grained particles is that they adsorb such materials as ammonia, phosphates, and heavy metals. Thus, the concentrations of total nutrients or toxic compounds in a stream often increase as sediment load increases.

134. Unstable streambanks are created when snags or trees are removed. These unstable banks erode and contribute a sediment load when the roots of the plants are no longer able to hold the material in place, and it slumps into the stream. Slumped material either remains along the edge of the stream or may form consolidated or unconsolidated berms within the stream channel. Some of the fine-grained particles that are carried downstream increase the turbidity of the water. These conditions are frequently encountered following storms.

135. Turbidity may also be increased by streambed erosion. A slope or gradient greater than that characteristically found in the stream develops sometimes when the stream is shortened and dredged. The stream seeks to regain equilibrium. This is accomplished as the stream degrades upstream and aggrades downstream. The resulting sediment is carried downstream, and in areas of low velocity it is deposited as unstable berms or bars within the channel.

136. The clear-cutting of forests in conjunction with channelization may bring about erosion of the floodplain. Sediment is also supplied by agricultural activity associated with the newly cleared land. As before, this sediment is carried downstream and deposited as berms or bars.

137. As mentioned earlier, the sediment load entering a stream carries nutrients such as ammonia and phosphates. The introduction of these nutrients may upset the natural balance of nutrients in the stream. Algal species are particularly sensitive to nutrient concentrations. Since fine-grained particles tend to adsorb dissolved substances, higher concentrations of these particles may remove significant amounts of undesirable substances from solution and immobilize them in deposited sediments, thus reducing or eliminating their short-term environmental impacts.

138. Filter-feeding organisms in streams may be damaged or killed by a continuous, heavy sediment load. Although some organisms are adapted to waters with high concentrations of suspended sediments, others can endure only brief periods of high sediment load. A storm event may increase the sediment load briefly, but the aquatic system will recover in a short time. Continuous, heavy sediment loads in impacted streams will destroy, distend, or abrade the epithelial cells in the gills of some fish. Some filter-feeding insects may be eliminated as sediment clogs their oxygen exchange apparatus. Some species of mayflies, caddisflies, and black-fly larvae are very sensitive to high sediment loads and serve as good indicator organisms.

139. The turbidity caused by a sediment load reduces the depth to which light can penetrate in a stream. Since light is required for photosynthesis, turbidity limits the zone in which algae can live and reproduce. Algae form one of the most important food bases, and the most important food base in some cases, of the food web. Anything that reduces the productivity of the algae will in turn reduce the overall productivity of such an ecosystem. Conversely, some detritus-based streams are naturally too turbid for algae to be a major food base, but are quite productive.

140. The suspended load, when it settles out on the streambed, serves to homogenize the bed surface. The diversity of the streambed is greatly reduced then the crevices between rocks are filled in and covered with a layer of sediment. The streambed is then composed of

sediments of similar sized particles. The flow is usually uniform in pattern and faster under these conditions. This combination of substrate homogeneity and uniform flow pattern greatly reduces species variability and productivity by eliminating diverse species habitats.

141. Many organisms, fish in particular, often deposit their eggs in beds built on gravel shoals or in clean sand in riffles, or at the lower end of a pool. This is particularly true in high-gradient, swift streams. The water that filters through the sand is rich in oxygen, which makes the area an ideal habitat for the hatching of eggs and for the young larvae. Suspended sediment particles often settle out between the sand and gravel particles and fill the interstitial spaces. Water with its oxygen is thus prevented from entering the breeding ground. The sediment thus tends to suffocate eggs and newly hatched larvae.

142. The three most important direct causes of increased sediment load are the straightening of the stream channel, the deposition of unconsolidated berms or bars of sand and finer sediments, and the production of unstable banks. The secondary effect of cutting down of the adjacent forest and subsequent man-made uses of the floodplains are also important contributors.

143. When a channel is dredged too wide to accommodate mean flow, an unstable berm within the channel often develops. This berm develops for two reasons: the rate of flow of the shallower water is reduced and particles settle out on the channel bottom, and the stream tends to develop a more appropriate channel to accommodate mean flow within the dry channel.

Channel maintenance

144. Stream maintenance involves the removal of bank-side vegetation and of sediments and debris from the stream channel. Bank-side vegetation is removed by either drag lines or herbicides. The amount of channel maintenance apparently dictates the amount of recovery a stream makes following channelization. When the bed of the river is allowed to stabilize and plant growth is permitted on berms, stable habitats are created and aquatic life develops within the stream channel.

The development of bank-side vegetation controls erosion and supplies shade and detritus to the stream. These functions are extremely important to the recovery of aquatic life in the stream. In contrast, very little aquatic life is found in areas of continual maintenance. These streams are never permitted to recover.

145. Channel maintenance slows down the rate of recovery of a stream because the bank-side vegetation is destroyed and the creation of stable substrates in the river channel is prevented. Toxic substances such as herbicides may also be introduced into the stream. The destruction of bank-side vegetation encourages erosion, eliminates sources of detritus, and destroys habitats of organisms that live on or in the bank. The clearing of debris from the channel bottom deters the establishment of stable benthic habitats.

Improvement of Channelization Designs

146. As environmental organizations and the general public became more aware of the environmental effects of channelization in the 1960's and early 1970's, there was not only public and congressional pressure, but also pressure from top management of the major construction agencies (i.e. the Corps of Engineers and the SCS), on these agencies to modify their channelization designs and construction practices in order to reduce environmental impacts. There has been a gradual trend away from channelization as a solution to flooding or navigation problems. Some channelization is still being done, but it is less than in the past, and other alternatives are always investigated (as they must be under the directives of NEPA). When channelization is adopted as the recommended alternative to a flooding or navigation problem, modified design and construction practices are employed wherever possible to reduce the environmental impact.

147. A review of all of the environmental impact statements or design memoranda for all channelization projects from the Corps of Engineers and SCS is impractical. Four projects that illustrate the

trend toward environmentally sensitive designs are reviewed below. A comparison between the Obion-Forked Deer River Basin Project, part of the West Tennessee Tributaries Project, and the Obion Creek Project, part of the West Kentucky Tributaries Project, shows changes in design philosophy that have occurred between the 1950's and 1970's. Two other designs, one for a project in North Carolina and another for a project in Florida, are also discussed below.

148. The Obion-Forked Deer River Basin Project was authorized in 1946 for the purpose of draining winter floodwaters earlier in the spring from existing agricultural lands (U. S. Army Engineer District, Memphis 1975). The drainage was to reduce flooding damage, allow earlier planting, increase farm productivity, and stop the swamping and killing of bottomland hardwood forests. Completed portions of the project have not preserved the bottomland hardwoods; in fact, considerable forest acreage has been cleared for conversion of the land to soybean production (SCS 1972). Basic design for the project was done in the early 1950's and called for the excavation of a straight channel. The design flow rate was calculated using the modified Cypress Creek equation, which produces a flow with a return period of approximately 1.05 years. No other flow rates were studied to optimize net benefits of the project. Although no measures were included in the original authorization to mitigate damage to fish and wildlife habitat, pressure from sportsmen later induced Congress to pass an amendment to the authorization that provided for the purchase and transfer of 32,000 acres of bottomland wildlife habitat to the Tennessee Wildlife Resources Agency. Construction of the project is approximately one-third complete, but it was stopped in 1972 as a result of a lawsuit challenging the adequacy of the Environmental Impact Statement (EIS). A more extensive EIS was also ruled inadequate in 1977 (Bureau of National Affairs (BNA) 1978).

149. The Obion Creek portion of the West Kentucky Tributaries Project is a much smaller but very similar project. Both are within the same CE District. The project design was completed in the middle 1970's. The EIS (Memphis District 1976a) and the general design memorandum

(Memphis District 1976b) give evidence of not only much more extensive preproject investigations, but also much better engineering design.

150. There is a much more extensive evaluation of different alternatives than there was in the West Tennessee Tributaries Project. One major change was that different types of alternatives and various alternative details were considered. For instance, three alternative designs were considered for three different flows (i.e., three different storm return periods). Design A was a channel designed to provide protection from a flood with an approximately annual return interval. Design B was a channel designed to the maximum size allowable without causing any additional bridge relocations than those required for Design A. Design B provided protection from floods with a recurrence interval of approximately 1.5 years. Design C was a channel designed to provide protection from a flood with a recurrence interval of approximately 3 years. Economic studies of all three designs were conducted, and Design B was selected because it had both the largest benefit/cost ratio and the largest excess of benefits over cost. This study resulted in a somewhat crude economic optimization of the design. On the other hand, the failure to investigate different designs for different flows was one of the major criticisms of the West Tennessee Tributaries Project and was one of the major reasons cited by the judge in his decision to reject the second EIS (BNA 1978).

151. In the case of the West Kentucky Tributaries Project, three different designs were considered for the outlet of Obion Creek to the Mississippi, and the one selected appeared not only to produce the least amount of environmental damage, but also to provide the greatest excess of benefits over cost. The pros and cons of each alternative design in the EIS were discussed extensively. Different alternatives of routing the channel around wetlands and alternative methods of handling the dredged material that might be deposited in wetlands were later described in a supplement to the EIS (Memphis District 1978). Alternatives were selected that would cause the least amount of environmental damage, although the cost of construction was more. The West Tennessee Tributaries Project design had not investigated any alternatives for

rerouting that would attempt to protect wetlands or consider other environmental amenities.

152. The detailed design of the West Kentucky Tributaries Project devoted more attention to the environmental aspects than many channelization projects in the past have done and certainly more than the West Tennessee Tributaries Project did. For instance, the design provided for channelizing from one side only in many places to avoid disturbing fish habitat along the bank and the shade of the tree canopy; for integrating the design hydraulically with the design of the SCS projects in the area to prevent degradation of the streambed of the smaller side channels because of lower elevations in the main channel; for moving the channel laterally to avoid going through valuable wetlands; for depositing the dredged material from the channel outside of the wetlands area; and for keeping the channel well away from a unique environmental study area.

153. The EIS for the West Kentucky Tributaries Project also seemed to be somewhat more accurate in the description of the environmental and ecological effects of channelization. Better estimates were provided of land acreage expected to be cleared, for both construction of the project itself and its secondary effects. The term secondary effects refers to the clearing of the forest land to provide more agricultural land, made more economically attractive by project-provided flood control.

154. The Rockfish Creek Flood Control Project, located in Duplin County, North Carolina, consists of deepening and widening on one side of the channel only, thus leaving one side uncleared and in its natural state (U. S. Army Engineer District, Wilmington 1971). The project is expected to have no effect on any present or future water supply and is expected to affect water quality only during construction. A pond and a wildlife area are being provided to mitigate damages to the fish and wildlife resources in the project area. These damages are estimated at a loss of about 80 percent of the standing fish crop in the reaches to be channelized and a loss of about 251 acres of cover due to clearing. The changes in vegetative types due to reduced wetlands will benefit certain types of wildlife that prefer a dry-land type habitat and harm

other types of wildlife that prefer the original wetlands type of habitat.

155. Environmental considerations were discussed in a proposal for alterations to the upper St. Johns and Indian Rivers in each central Florida to show how ecological disruption could be minimized through proper planning (Scott 1972). These two rivers are very important due to their ecological values, recreation potential, industrial development, residential housing, and commercial navigation. The area is also valuable for shad fishing.

156. This proposal, dating back to the late 1960's, was for two navigation projects to be built to increase commercial and recreational activities in the project area. The first project was to provide small boat navigation facilities through numerous lakes and marshes in the St. Johns River. The other project called for the construction of a barge canal connecting St. Johns River with Indian River, with eventual access to the Cross-Florida Barge Canal and the east coast Intercoastal Waterway.

157. Coordinating the engineering design with environmental and ecological concerns became an overriding theme in the design. The original conception of both projects was to excavate the navigation channels in the river thalweg. The excavated material would then be deposited along the river with little regard for fish or wildlife habitat. The original design also called for the straightening of the St. Johns in many reaches and the conversion of sandy, gentle, sloping riverbed sides into either vertical or very steep cuts. This design proved to be unacceptable.

158. Public agencies responded to the original design with a list of four requests:

- a. The canal should not be used to convey floodwaters from St. Johns River to Indian River.
- b. The structure must be kept closed except during boat passage to avoid the loss of river water.
- c. The dredged material should be placed continuously along the canal to prevent any reclamation of the channel.
- d. The canal must be dug in the dry.

In addition, lifts were to be provided at each lock for small boats, which would reduce the number of lockages and the subsequent loss of water.

Recent Development of Alternatives
to Channel Excavation

159. In addition to major changes in the planning and design of channelization projects, the SCS and the Corps of Engineers have been giving increased attention to alternative means of satisfying the objectives of a particular project. These alternatives may include various forms of floodplain management; floodplain zoning; construction of bypass channels around sensitive wetland areas; land treatment as a means of both retarding runoff and decreasing erosion and sedimentation, with its subsequent reduction in flow-carrying capacity of the stream; construction of numerous very small water retention structures; and the substitution of clearing and snagging, or only snagging, for more traditional, complete channelization. Substitution of clearing and snagging for channel enlargement has been found to satisfy project objectives in some cases even though the end product has a lower design flow rate. Lower design flows are acceptable in many agricultural or forested areas because most farmland and forestland can withstand considerable periods of inundation without damage so long as the inundation does not extend greatly into the growing season. All that is needed in some regions is enough flow capacity to allow normal winter floodwaters to drain off of farmland and forestland in time for crops to be planted. It is not necessary to completely prevent flooding in the first place, but only to ensure that the floods drain off easily and completely. It is also usually not necessary to provide an extremely rapid drainage (1 or 2 days). Providing for complete drainage in a time of 7-10 days is sometimes equally effective and is much more economical and less environmentally damaging. This type of flood control is applicable only in regions where the wet season does not coincide with the crop-growing season. However, many of the states with a major fraction

of the existing channel projects do experience this type of climate.*

160. In addition to the more serious considerations of other alternatives, such as those discussed in the preceding paragraph (which may be more properly termed a change in planning approach rather than a change in design), some agencies are experimenting with different types of construction practices for clearing and snagging in an attempt to reduce environmental damage. East (1977) describes work done by Williams County, Ohio, to renovate 80 miles of the log-choked and flood-prone St. Joseph and Tiffin Rivers. Workers, using only hand tools and chain saws, cleared the 80 miles of river of log jams, topped trees in danger of falling into the river, limited bank erosion with man-made jams of logs and debris, essentially restored the flood-carrying capacity of the stream, and restored the attractiveness of the stream for canoeists. The work was completed for slightly more than \$80,000, or an average of \$1,000/mile. The farmers and landowners in the area have expressed almost complete satisfaction with the work, and a spokesman for the U. S. Fish and Wildlife Service stated that the project has apparently been accomplished with little or no environmental damage. The cost of \$1,000/mile was less than 1 percent of the normal cost for complete channel enlargement. A similar approach was used by a mosquito control district in Onslow County, North Carolina, although the mosquito control district did use a combination of hand tools and drag lines. Within 1 year after the completion of the project, the visual evidence of the disturbance had disappeared. Fish populations returned to normal in approximately 2 years.

161. The clearing and snagging project that has probably gotten the most attention has been the Chicod Creek project in North Carolina, an SCS PL-566 Small Watershed Project. Originally designed as a traditional channel enlargement project, the Chicod Creek project was enjoined by a Federal court because of an inadequate and misleading EIS. One of the points that the court found inadequate was an insufficient discussion of the alternatives to the project. The Chicod Creek project

* According to ADL (1973) the following states contain 77 percent of the total mileage of channel modifications: Texas, Arkansas, Louisiana, Mississippi, Georgia, Florida, North Carolina, North Dakota, and California.

has now been redesigned into a clearing and snagging project, and innovative guidelines* were recently drawn up for the project by representatives of several Federal and State agencies and private organizations. These guidelines call for:

- a. No excavation of sediments in the channel except to reopen highway bridge crossings.
- b. No removal of imbedded logs or snags, and no removal of logs that are parallel to the channel and that do not significantly impede flow.
- c. No removal of rooted trees, alive or dead, unless they are hanging so far over the channel that they are soon liable to fall in and block the flow, or their removal from the floodplain is required to secure access for equipment.
- d. Small debris accumulations to be left in the stream unless they are collected around logs that must be removed.
- e. Construction of deep pools at or below road crossings for sediment traps.
- f. No vehicle access to the stream except at selected locations and along lines perpendicular to the stream.
- g. Protection of old growth trees or younger live trees that provide important mast and canopy coverage to the low-flow stream, or of dead trees that provide ecosystem sustenance or den habitat.
- h. Cutting of logs or trees into small lengths by hand so that they can be dragged out with cables rather than bringing tractor equipment into the floodway.
- i. Marking of all materials to be removed before the job begins.

162. An updated and improved version of these guidelines was recently adopted by the Tennessee Office, U. S. Soil Conservation Service,** for emergency work on the Wolf River in Fayette County, Tennessee. This approach is slowly gaining credence and favor with several construction agencies.

* U. S. District Court, Eastern District of North Carolina. "Clearing and Snagging Guidelines," Appendix B, Consent Decree in Natural Resources Council Versus Grant.

** Memorandum dated 14 November 1978, from Donald C. Bivins, State Conservationist, to Joseph W. Haas, Assistant Administrator, Water Resources, U. S. Soil Conservation Service, Tenn.

PART IV: BANK PROTECTION AND EROSION CONTROL

The Current Situation or Problem

163. Natural streams and man-made channels are constantly subject to the degrading effects of erosion. Erosion is a completely natural process, but it is accelerated and intensified by the effects of man's activities, such as wave wash produced by boats, high velocities immediately downstream from outlet works of dams, and the repeated rapid rise and fall of water levels downstream from hydroelectric power plants used for peaking.

164. Streambanks and channels subjected to these accelerated erosive forces frequently require bank protection or channel lining to prevent severe erosion, deepening of the channel, undercutting and sloughing or caving of the banks, and damage to adjacent land and structures.

165. Section 32 of Public Law 93-251, the Streambanks Erosion Control Evaluation and Demonstration Act of 1974, authorized a 5-year program of problem assessment and analysis, research, evaluation of existing bank protection techniques, and construction and monitoring of demonstration projects to evaluate the most promising bank protection methods and techniques.

166. The Corps, in a 1978 Interim Report to Congress (OCE 1978c), estimated that out of 3.5 million streambank miles, 575,000 miles were undergoing erosion. The total damage was estimated at \$270 million per year, and the damage from serious erosion at \$200 million per year. However, the cost of preventing only the severe erosion was estimated at \$870 million per year. The thrust of the research and demonstration program is therefore directed toward finding methods of protection at a lower cost.

Survey of Bank Protection Methods

167. Keown and others (1977) surveyed the literature pertaining to previous causes of bank erosion and the methods of protection used, and assessed the most effective available methods of streambank protection.

The report states that a variety of methods have been used and many experiments were undertaken to determine the most effective and economical protection methods. However, Keown also reports that

no specific guidelines have resulted that can be used to assist the engineer in developing design specifications for a particular bank protection problem. What has developed is the use of a group of methods that has found subjective favor in the engineering community.

These methods are popular because they have been used somewhat successfully in the past.

Commonly used methods

168. Keown discusses 11 methods of bank protection that have been used extensively. Each method is described and is accompanied by excellent illustrations. The advantages and disadvantages of each method are discussed and a cost estimate is given where available.

169. The methods most widely used are classified as:

- a. Stone riprap.
- b. Concrete pavement.
- c. Articulated concrete mattress.
- d. Transverse dikes.
- e. Fences.
- f. Asphalt mix.
- g. Jacks.
- h. Vegetation.
- i. Gabions.
- j. Erosion-control matting.
- k. Bulkheads.

170. Stone riprap is probably the most widely used method. It has a number of advantages: flexibility, simplicity, easy maintenance, relatively natural appearance, and permeability. This riprap also has the ability to be covered with vegetation in time, providing an even more natural appearance. The design variables involved in the selection of specifications for stone riprap, and the possible environmental effects, were discussed earlier in the review of EM-1110-2-1601,

Hydraulic Design of Flood Control Channels (OCE 1970).

171. Concrete pavement is costly and is used only in severe cases in urban areas. Articulated concrete mattresses are used only on the lower Mississippi River.

172. Transverse dikes are indirect bank protection methods. Rather than armor the bank itself, they direct the current away from the bank. An extensive discussion of dikes and revetments is provided in Part V.

173. Asphalt mix and mattresses were once used on the lower Mississippi River but proved to be inferior to articulated concrete mattresses. They are now seldom used.

174. Vegetation is natural in appearance and effect, but is not as effective against high velocities as heavier or stronger material. The use of vegetation, and the velocities that can be withstood by different types of vegetative channel linings, is discussed in the review of EM-1110-2-1601, Hydraulic Design of Flood Control Channels. (See Part II, paragraphs 26 through 32 herein.)

175. In urban areas, or other areas of limited space, and where there is a need for heavy protection, gabions have been used much more extensively in the past few years. Gabions are rectangular wire baskets, which are filled with rock, stacked neatly, and wired together to form a wall. The baskets are available in cube shapes, used for walls, and "mattress" shapes, used for slope or bed protection. They serve as a somewhat intermediate method that is between loose stone riprap and reinforced concrete retaining walls. They can be stacked much steeper than loose riprap, but not quite so vertical as concrete retaining walls. Gabions offer certain aesthetic advantages over some types of bank protection: they are usually allowed to vegetate, and when the exposed face of a gabion wall is constructed of hand-placed stone, the resulting resemblance to a native stone wall can be quite appealing. Revegetation may also add additional stability to the gabion assembly.

176. Burroughs (1979) described the use of gabions to provide bank erosion control for streams in parks and subdivisions in Lincoln, Nebraska. Gabions were selected because they were porous and would

allow spring water to seep through the channel banks; the system had a pleasing natural appearance; the gabions were flexible and therefore were easily adaptable to curving channel configurations; they could be placed on a steeper slope than riprap (2.0V to 1.0H); they are flexible and can easily conform to the streambed if settling occurs; the cost is somewhat lower than the cost of rigid concrete linings; the cost of maintenance is low; they can be placed with unskilled, common labor; and they can be placed in wet and cold weather (even underwater).

177. There are some possible drawbacks of gabions, such as possible tearing of the baskets by heavy debris in the channel; corrosion of the wire by acid or saltwater, although some wire baskets have a PVC coating that should greatly reduce this problem; vandalism by people cutting baskets to obtain stone to build dams in the stream or decorate their rock gardens; the labor intensiveness of the construction required; and the possible high cost of contractors unfamiliar with the techniques of construction.

178. Gabions and rock riprap provide a much more natural and pleasing appearance than concrete lining. Both will eventually fill in with sediments and support vegetation. However, gabions can be installed on a much steeper slope and can utilize much smaller and readily available rock. Rock riprap will usually also require more stone because riprap will probably have to be placed in thicker layers.

179. The article (Burroughs 1979) also described the use of gabions on a Corps of Engineers stream project, Four-Mile Run in northern Virginia, near Washington, D. C. The use of gabions for slope protection was selected after model studies of the project were conducted at the WES. Rejected alternatives were concrete, grouted riprap, and loose rock riprap.

Other methods

180. Keown (Keown et al. 1977) also lists and describes other methods used for streambank protection that have not seen general acceptance or widespread use. These methods include such items as old automobile bodies, cellular blocks, ceramic materials, concrete blocks, rock and wire mattresses, rubble, sack revetment, soil cement, synthetic

mattresses, matting and tubing, temperature control (in cold regions), tetrapods, and used-tire matting.

Obsolete methods

181. Keown (Keown et al. 1977) lists and describes other methods of streambank protection that were previously used but are no longer used because of high labor costs, lack of materials, or lack of effectiveness compared with newer methods. These include fascine mattresses, timber and brush mattresses, logs and cables, stone-filled timber cribs, and tetrahedrons.

New methods

182. Several new methods that Keown (Keown et al. 1977) states are the most promising of those currently being discussed and have been field evaluated on a limited basis are as follows:

- a. Used-tire mattress of interconnected tubes positioned perpendicular to the stream (modular units composed of tires stacked on edge, filled with sand and gravel, and interconnected with a steel cable through concrete; filled tires are placed on either end of the sand- and gravel-filled tires to complete the modular unit).
- b. Membrane encapsulated soil systems (continuous bank paving and soil-filled bag revetment).
- c. Chemical stabilization (portland cement, lime, or asphalt) to form monolithic stabilization, stabilized soil blocks, stabilized soil trenches parallel to the stream, chemically grouted soil piles, and continuous armor coating.
- d. Rigid or collapsible honeycombed material backfilled with soil.
- e. Reinforced earth systems employing membranes and fabrics.
- f. Local waste products (without treatment, with minor processing, chemically treated, or membrane encapsulated).
- g. Military surplus products (lightweight pierced landing mat, antisubmarine net, and floating bridges).

183. Some of these new methods and many of the old methods are being field evaluated by the Corps under the Section 32 program mentioned earlier. The Interim Report to Congress (OCE 1978c) describes and illustrates each of the demonstration projects now being designed, constructed, or monitored.

Environmental Effects of Bank Protection

184. All methods of bank protection have some environmental effect because they alter the normal, natural processes of erosion and deposition. As mentioned earlier, rough, uneven banks, logs, roots, snags, and rocks commonly found along streambanks provide the best aquatic habitat. If a bank protection method covers this natural environment with one that is smoother and more even, habitat is lost.

185. Those methods that result in a rougher bank that is more conducive to the regrowth of natural vegetation will generally facilitate habitat recovery the most. However, no references were found that reported on controlled studies comparing the environmental effects of different bank protection methods under identical conditions.

186. The U. S. Fish and Wildlife Service (FWS) prepared a Coordination Act report for the Section 32 demonstration projects on the Missouri and Yellowstone Rivers (Gritman 1978). The report stated that any method of bank protection could effectively reduce lateral erosion of the Yellowstone River, and eventually reduce the total stream length, number of islands, and amount of land-water interface. The quantity and quality of aquatic habitat would be directly affected by reducing the diversity of riparian vegetation by eliminating or limiting successional phases, and by decreasing water surface area.

187. The report also states that stabilization of the bank line appears to encourage additional land clearing, which further alters the natural environment and wildlife habitat. Recommendations of the FWS report include that bank stabilization be done only when absolutely necessary, and then using "soft" types, and done in a way that will not reduce channel widths, eliminate oxbows, or induce erosion at new locations. The report also suggests that in some locations public acquisition of the eroding land may be both the least-cost solution to private land damage and the most preferable from an environmental standpoint.

188. Other environmental aspects of bank protection are discussed in Part V, including some attempts at mitigation (the notched dike program on the Missouri River).

PART V: DESIGN AND CONSTRUCTION OF DIKES

Purpose and Types of Dikes

189. Dikes are common structures used by the Corps of Engineers in the maintenance of navigation channels in meandering rivers. Although nomenclature is highly varied and confusing, dikes are usually defined as free-standing structures extending from the bank toward the center line of the stream. They are usually connected to the bank (spur dikes), but they may also be disconnected (vane dikes). Dikes may also have sections near the stream end that are parallel to the flow and extend downstream from the dike (L-head dikes). Dikes may be normal to the flow in the main channel, which is most common, or they may be angled downstream slightly. A few dikes are angled upstream. Dikes must be designed to be low enough so that they do not increase the overall channel roughness or decrease cross-sectional area to such a degree that they significantly impede the passage of floodwaters. The slowed floodwaters would raise the stage during flooding and inundate more land along the river.

190. Dikes have two primary purposes. The most common purpose is to constrict the channel at low-water stages to force the reduced flow into a narrower width. This temporarily increases the velocity and the scouring potential of the river, thus deepening the channel remaining between the ends of the dikes. The end result is that the navigation channel can be maintained at the required depth with either considerably less or no dredging. The second primary purpose of dikes is to deflect the water away from a bank to reduce bank erosion. Dikes are usually combined for this purpose in an overall system with revetments, which are protective structures laid directly on the bank or parallel to the bank and slightly offshore.

Common Practice

191. There is no Corps of Engineers manual for guidance in the design of dike systems, and design practice varies considerably among

the various Districts. A research project, entitled "Hydraulic Design of Groins and Dikes," has been started at the WES to develop some design criteria. The design criteria will be used to develop the necessary dike characteristics for a particular application with maximum efficiency and minimum environmental effect. One of the first activities of the project was a symposium on the design of groins and dikes in March 1978. The minutes of this symposium (Pokrefke 1978b) reveal the wide variation in common practice used by the different Districts, as well as the wide variation in design criteria, model study results, or field test analyses available to and used by some Districts, and the very simple criteria used by others. Most dikes are designed based on trial and error, experience, observation of dike performance, and common sense.

192. The presentation by the engineers of the various Districts indicates that up until about 5 years ago, very little, if any consideration whatsoever was given to environmental effects of the dikes. Design was based purely on the hydraulic efficiency of the structure and its ability to resist the forces of scour, ice, and debris. Therefore, little information is available on the environmental effects of the widely varying design parameters.

193. Environmental effects of various types of dikes and revetments are also being investigated at the WES as part of Project VII.B.2 of EWQOS, which is a field study of the lower Mississippi River. Additional work in this area is proposed as part of the Great River Resource Management Study, an interagency effort that includes collection of chemical and biological data on the middle Mississippi River.

Historical Development

194. Pokrefke (1978a) has prepared a historical overview concerning the design of groins and dikes as a prelude to the hydraulic research project at the WES. The paper includes a historical overview of dike construction in major U. S. rivers from 1876 to 1964. The first successful type of dike was a permeable pile dike, consisting of single or

multiple rows of single piles or pile clumps that extended from the bank out toward the center of the stream. The theory of the pile dike was that at low flow, with slow velocities along the banks, the dike would sufficiently impede the flow along the bank so that most of the river flow would be directed to the main navigation channel; but at high flows, the dike would be permeable to flow and would not impede flood flow. The pile dikes were usually accompanied by a willow or timber mat laid on the bottom along the dike axis to control scour. Experience indicated that pile dikes were subject to damage by ice and floating debris, and they required much maintenance. The willow mattresses to control scour also had limited lifetimes. The first stone dikes were constructed in 1884 on the Mississippi River at New Orleans. Stone fill was being placed along the pile dikes by the 1890's in an effort to protect them from rapid deterioration. Stone dikes became gradually more common and almost completely replaced pile dikes as the standard Corps of Engineers construction method by 1950. Essentially all dikes presently constructed by the Corps are stone fill, and piles are used only as mooring points.

Stone Dike Design

195. Pokrefke (1978a) also discusses the variations in the characteristics for the design of stone dikes and includes a literature review on the design of stone dikes. These findings are summarized in this report, and the reader is referred to Pokrefke's paper for details and individual references.

196. Most dikes are designed so that they extend above the water surface at low-water stages. The height of dikes above low water depends upon the expected variation in stages. They may extend above low water from 2 to 15 ft and be submerged from 25 to 75 percent of the time.

197. The slope of the surface or crest of the dike from the bank end to the stream end is usually level, although many dikes are constructed so that the last 100 or 200 ft of the crest rises as the surface approaches the bank and meets the top of the natural bank. A few dikes are designed with a 5-ft drop in crest elevation in the last 400-500 ft near the stream end.

198. The method of construction generally determines the crest width of a stone dike, although most of the references agree that the minimum crest width is approximately 4-5 ft. Crests too narrow are subject to rapid deterioration (i.e. dislodging of stones by floating debris). Most dikes constructed from a barge have crest widths of 8-10 ft, and those constructed from stone hauled outward from the banks by truck have crest widths of 10-20 ft, which provides room for maneuvering of the trucks.

199. The side slopes of stone dikes range from about 1V on 1.25H to 1V on 2H. Many Districts design for the natural angle of repose, which is approximately 1V on 1.5H. The slope of the stream end of the stone dike is usually flatter, sometimes as much as 1V on 5H.

200. Most dikes are constructed either perpendicular to the bank or angled slightly downstream, from 10-20 deg. Several studies have shown that dikes angled upstream produce more disturbance to the river-flow and tend to trap debris between the dike and the riverbank at low flows.

201. The spacing between adjacent stone dikes is highly variable and ranges from one third the length of the upstream dike to about three to four times the length of the upstream dike. Dikes are usually spaced close enough so that the low-water navigation channel does not meander between the dikes, and so that return flow around the tip of the dike does not reach the riverbank and cause bank erosion between the dikes.

202. The stone size in most Districts is quarry run, with sizes varying with local practices and stone type. Maximum stone sizes range from 500 to 3000 lb. Dikes are usually designed so that larger stones are specified for the outer layers to protect the dike against deterioration from erosion.

203. The riverbanks are often paved or revetted for approximately 100 ft upstream from the dike axis and approximately 200 ft downstream. Dikes are also frequently keyed into the bank using a trench excavated to the level of the riverbed. These measures help prevent erosion of the bank and undermining of the bank end of the dike, sometimes called flanking.

204. The U. S. Army Engineer District, Omaha (1964) produced an excellent short report on dike design and construction in conjunction with the design memorandum on the Missouri River Bank Stabilization and Navigation Project, which provides for a continuous 9-ft navigation channel 300 ft wide. The channel extends from the mouth of the river at St. Louis, Missouri, to Sioux City, Iowa, a distance of 734.8 miles. The objective of the project was to constrict the low-water channel to such an extent that the 9-ft navigation depth could be maintained continuously without dredging. The lower 730 miles of the river has been almost completely stabilized and channelized by the construction of dikes and revetments, and very little dredging is now necessary. The evolution of the present design criteria used by the Omaha and Kansas City Districts is the result of experience and observation of the performance of various types of dike structures constructed in the past. In order to maintain the authorized 300-ft navigation channel, by observation and measurement it was concluded that a clear channel width of 600 ft was necessary in the upper reaches of the river, widening toward the mouth at St. Louis to approximately 1100 ft. Dikes are designed to angle downstream 10 to 22 deg from a line normal to the current.

205. The Missouri River had to be frequently realigned to achieve the alignment desired for efficient navigation. Alignment often consisted simply of allowing one bank to erode somewhat as dikes were built out from the opposing bank, but in some cases, it required complete realignment and moving of the channel. The report describes the methods used for channel realignment in different types of situations. The Omaha and Kansas City Districts use dikes on the convex side of the river, or inside of bends, and use revetments on the outside of bends, or on the concave side of the river (Figure 4).

206. Dike spacing is based on the premise that the main current will migrate from the end of the dike toward the bank line about 1 ft for every 4 ft of longitudinal travel. The next downstream dike is placed so that it intercepts the flow before the return flow line actually touches the bank. This placement prevents the main current from attacking the bank and flanking the dike at the landward end.

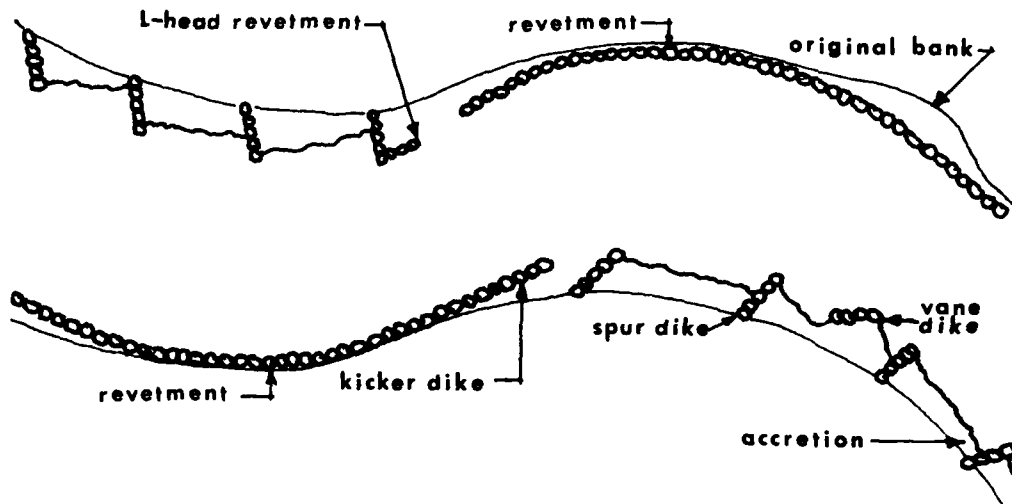


Figure 4. Typical arrangement of different dike types common to the Missouri River

207. The Omaha District report (1964) also includes an excellent description of the different types of dike structures that have been used in the Omaha District, including permeable pile dikes, brace dikes, crib dikes, foundation mattresses, standard revetments, stone-along-pile structures, stone-fill structures, and toe trench revetments. Pile dikes, brace dikes, and crib dikes were used until the mid-1940's. The use of quarry stone around the pile dikes in place of the foundation mattress was found to be economically beneficial, and piles and stone were gradually replaced by stone only in dike construction. Current construction consists almost entirely of stone-fill structures.

208. Practically all of the possible types of paving and underwater mattresses have been tried on the Missouri River as bank revetments, including concrete slab, asphalt, stone paving, willow mats, lumber mats, and asphalt mattresses with concrete blocks, asphalt blocks, and various forms of stone in compact layers placed along the shoreward edge of the mattress at the junction with the bank paving. Problems and failures with all of the other types led them to be rejected in favor of a flexible paving of cast stone. Flexible stone paving has

been found to be lower in initial cost, cheaper and easier to maintain, and more satisfactory in furnishing protection to the bank. The stone is placed on a graded slope to a minimum depth of 8 in. at the top of the slope and 15 in. at the bottom of the slope with an enlarged toe section.

209. Dikes are normally constructed on the convex or inside of the bend so that the crest elevation is from zero to three ft above the construction reference plane (CRP). The CRP is defined as the elevation or stage of the flow that is equalled or exceeded 75 percent of the time during the navigation season. Dikes on the concave or outside of a bend normally have crest elevations one to five ft above the CRP. Revetments are designed so that the crest elevation is one to five ft above CRP.

210. Most of the Missouri River is now well stabilized, and very few new dikes are being built. Most of the newer dikes on the Missouri River are either vane dikes or low elevation dikes constructed one to two ft below the CRP. Vane dikes are angled downstream and are not connected to the bank. Thus, water can flow behind the dikes, discouraging accretion.

Environmental Effects of Dikes

211. The construction of a dike field has an obviously great effect on the aquatic environment of a river. The dike field not only covers part of the river bottom with rock, but also increases the water velocity in the main channel, causing scouring action on the channel bottom. These changes are necessary if the dike field is to accomplish the purpose of deepening the navigation channel during low flow. However, the aquatic habitat for fish and other aquatic life is greatly modified. Sediment contained in the water that enters the backwater areas between the dikes tends to settle between the dikes, particularly on the downstream side of each dike. The amount of sediment deposited by high flows gradually increases, and the elevation of the sediment eventually becomes higher than the water level during low flow. The increased sediment elevation allows vegetation, such as willows, to

invade and grow on the accreted land during low-flow periods. Increased surface roughness caused by this vegetation then traps even more sediment during high flows, and the elevation of the accreted land grows higher during each high-water season until eventually it can become several feet higher than the normal water level. The end result of this process is a significant decrease in the area of aquatic habitat and an increase in the area of land habitat.

212. The change from aquatic to terrestrial habitat is not necessarily an adverse impact, but it is an impact. The change does become a significant adverse impact from the standpoint of the natural environment if and when the terrestrial habitat is eventually cleared for and converted to agricultural purposes. Funk and Robinson (1974) have reported that 50 percent, or 60,785 acres, of the original water surface area of the lower Missouri River was lost to aquatic habitat by conversion to terrestrial habitat during the period 1879-1972. Areas between dikes on the Missouri River as wide as 1,800 ft have been completely filled in with sediment, and most of the new land has been cleared and is now being farmed. Dikes as long as 3,000-4,000 ft have been built on the Mississippi River to constrict the channel from original widths as wide as 2 miles to a stable navigation channel 2,500-3,000 ft wide. Much of the area between these long dikes either has or will eventually silt in and become terrestrial habitat.

213. Although sufficient information has been found on the conversion of aquatic habitat to terrestrial habitat, little information has been found concerning the precise impact of various types of dikes, with one exception (the notched dike program on the Missouri River), which will be discussed below. Almost all of the dikes now being constructed by the Corps of Engineers are rock- or stone-fill dikes for reasons of economics and structural stability, and little good would be accomplished by extensive research of the differences in environmental impact between stone-fill and pile dikes. Very few new pile dikes or crib dikes will ever be built again because experience has shown that they will not withstand the normal forces encountered in a major river. No information has been found to indicate that the common design

variables associated with stone-fill dikes (i.e. angle, crest elevation, crest width, length, or stone size) have significantly varying environmental effects, except that they do alter the sediment deposition patterns in the vicinity of the dikes. The impact of sediment accretion and habitat conversion is so great that it seems to overwhelm all other effects.

214. The one variable in the above list that might have some impact on aquatic habitat is stone size and gradation. The rubble stone boundaries of a dike or revetment furnish a much more stable and protective environment for small aquatic organisms than does the shifting, movable bed of the silt-laden stream. Kallemeyn and Novotny (1977) studied the fish and fish food organisms in various habitats in the Missouri River in South Dakota, Nebraska, and Iowa and found that macroinvertebrate densities in the Missouri River increased downstream in the channelized portion below the large storage dams on the upper Missouri River. They speculated that one of the reasons for the increased macroinvertebrate population was the presence of a rubble substrate along the border for most of the area. One might intuitively suppose that a stone dike with a very large range of stone sizes would provide better habitat for a wider range of organisms than would a dike made up of closely fitted small stones with little spaces between them. The very large spaces would not provide the smaller organisms much protection from their predators. However, no references have been found to indicate that this variable of dike design has been studied for this purpose. Most stone-fill dikes are now being built with quarry-run stone for economic reasons, and no changes are anticipated. This type of stone probably provides a habitat as good as could be achieved by a stone-fill dike, although no evidence supporting this theory has been found.

215. Donald Logsdon, U. S. Army Engineer District, Rock Island, reported at the WES-sponsored symposium in 1978 (Pokrefke 1978b) that he always saw more people fishing along the rock banks and on the stream end of the dikes in Rock Island District than anywhere else, although many people had stated that dikes ruin the fishing in streams. Both of

those statements are probably correct. Dikes, by decreasing the amount of shallow-water aquatic habitat, do reduce the amount of fish in the stream. However, fish that are left in the stream probably do tend to congregate along the protective surfaces of the dikes and revetments.

216. Kallemeyn and Novotny (1977), reporting on the fish in the Missouri River, stated that the principal fish species in the nonchannelized part of the river (approximately 100 miles below the last dam) were similar to those in the channelized portion of the river downstream. They found that the fish in the unchannelized river were most abundant in the backwater areas. They stated that the backwater habitat and the associated marshes were particularly important because so many species used them for spawning and nursery grounds. The number of species found in the normal part of the channelized river decreased. The primary species were channel catfish, carp, and river carpsucker. Most fish in the channelized portion of the river came from the habitat around a dike field that had either not been filled in by sediment, or had been created by cutting gaps in some of the dikes. The fish found in these habitats were similar to the fish from the backwaters and sloughs of the unchannelized river. Kallemeyn and Novotny concluded from this study that it was feasible to recreate some backwater habitat in the channelized portions of the river by opening gaps in some of the dikes and letting water flow slowly through the remaining open water, and possibly by scouring away some of the already deposited sediment and creating new open water.

Notched dike (Environmental Gap) program

217. A careful reading of the 1978 symposium on the design of groins and dikes (Pokrefke 1978b) held at the WES reveals that although there has been a lot of practical experimentation with different types of dikes to determine more effective and more stable configurations, very little investigation has been made on effects of different types of dikes on environmental variables. There is one major exception. Engineers with the Missouri River Division became concerned in 1972 about the continuing loss of shallow, backwater habitat between dikes

and behind revetments on the Missouri River. The small amount of remaining slack-water habitat behind the dikes and revetments on the Missouri River was rapidly filling in because of sediment deposition. The Omaha and Kansas City Districts formulated several proposals for correcting this situation, but the proposals were disallowed because they were outside the existing authority of the Missouri River Bank Stabilization and Navigation Project. The Districts found one way to attack the problem was through the existing authorization for structural modifications.

218. The program started experimentally by cutting notches or gaps in about 100 of the existing dikes on the Missouri River. A small flow of water was allowed to enter the slack-water areas behind the dikes and revetments in an effort to create sufficient current to prevent silt from settling in these few remaining open-water areas and converting them to terrestrial habitat also. Initial results seemed to be promising, and design memoranda were produced in 1975 by the Omaha and Kansas City Districts (1975), which described the plan, gave cursory guidelines, and listed several hundred dike and revetment structures proposed for modification. The objectives of the program were to maintain as much as possible of the existing open-water habitat, to increase the number of slower moving water areas as much as possible, and to reduce the accumulation of sediment within the control structure systems. Gaps were proposed that would open old chutes and oxbow lakes, allow water flow into shallow areas between spur dikes on the convex bank, and allow water to flow into areas landward of L-head revetment segments. Most of the gaps were proposed for placement as close to the existing shoreline as possible to provide water circulation in the largest possible portion of the cutoff area. The distance that a gap could be placed from the bank was limited primarily by how close a floating barge with a dragline could get to the existing bank. In the Omaha District, gap lengths of 15, 20, and 30 ft were proposed and are described as follows (Omaha District 1975):

The 15-foot gaps are triangular in shape, with a 15-foot width at CRP elevation and sides sloping on a 1.0V to 1.5H. The 5-foot depth below CRP was selected in order to allow minor flow at lower river stages and

also limit the maximum gap flow to avoid increased future maintenance. The hydraulic radius of this section is 2.08.

The 20-foot gaps are trapezoidal in shape with a 20-foot width at CRP and side slopes of 1.0V to 1.5H. The hydraulic radius of the 20-foot gap is 2.70.

The 30-foot gaps are triangular shaped, 30 feet wide at CRP, and have side slopes of 1.0V to 1.5H. 10-foot gaps are proposed in order to determine their effectiveness in both navigation and non-navigation flows. The hydraulic radius for this size gap is 4.16.

A larger hydraulic radius indicates a better hydraulic section. Therefore, the 20-foot gap designs are proposed for crossings in convex bends where the concentration of velocity is less than along the concave bank. Where the velocity concentration is higher, the construction of 15-foot gaps is proposed.

In the Kansas City District gap lengths of 20 and 50 ft width were recommended with a bottom elevation equal to the elevation equaled or exceeded 95 percent of the time by the water surface. The estimated costs of the program in 1974 prices were between \$1500 and \$2000 per gap.

219. The proposed program received unanimous and enthusiastic support from the U. S. Fish and Wildlife Service and from the game and fish agencies of Iowa, Missouri, and Nebraska. A program of cooperative research and monitoring was established.

220. A January 1977 report described the status of the program at that time (Omaha District 1977). A total of 221 gaps had been constructed, and 43 percent of these gaps were narrower than the design width and 57 percent were shallower than design depth. Water was unable to flow through 69 gaps when the water level was at approximately the CRP level. Flow velocity in the remaining gaps was less than 1.0 fps in 54 gaps and greater than 1.0 fps through 91 gaps. However, preliminary results seemed to show that the gaps were apparently a useful method of maintaining shallow-water habitat in and around dike fields, and the program was recommended for continuation.

221. A recent design memorandum gives additional information (Kansas City District 1980). In the lower 500 miles of the Missouri River, 960 dikes had been notched and 130 vane dikes had been constructed.

Most of the notches were successful in maintaining or creating open water areas upstream and downstream of the structure.

Study of environmental effects of notching dikes

222. The U. S. Fish and Wildlife Service, in cooperation with the University of Missouri, the University of Kansas, the Nebraska Game and Parks Commission, and Iowa State University, studied a number of the structures in 1975 and 1976. Each structure was visited monthly during May through October, and data were collected on water surface temperature, water clarity, water level, and current velocity. Visual observations on the condition of the structure were noted, and fish samples were collected behind each structure by electrofishing, hook netting, and seining. Reynolds (1977) reported that the preliminary results seemed to indicate that the notched structures apparently did create types of habitat not created or provided by the standard, unnotched dikes; that certain species of fish were attracted to the habitats created by the notched structures; and that the most beneficial types of habitat created seemed to be the relatively large surface areas of quiet, flat waters during medium to low river stages. One possible problem identified was that water flowing too slowly through an open-water area increased the sedimentation rate; the sedimentation rate would be lower if no water or resulting sediment flowed into the area. Therefore, Reynolds recommended that the gaps be designed so that high-stage flows could sweep through the backwater areas with scouring velocity to transport sediments out of the area. The backwater areas would otherwise eventually become filled with sediment and become part of the permanent floodplain.

223. A letter* from the U. S. Army Engineer Division, Missouri River, to OCE, reported the preliminary results of the studies in May 1978. The results indicate that the program was a worthwhile endeavor, the notches were successful in maintaining existing open-water areas,

* Letter, dated 12 May 1978, from Division Engineer, Missouri River Division, Omaha, Nebr., to Engineering Division, Office, Chief of Engineers, Washington, D. C.

and the shallow areas created as a result of the notches seemed to be attracting significant numbers and species of fish. No complaints were received from commercial navigation interests, and the Corps had not noted any adverse impact of the notching program on the navigation channel. Trash and sediment accumulating in some of the openings were presenting a maintenance problem in certain places. Nearly 1000 openings had been created at the time of this report. The letter concluded that the advantages of the program seemed to far outweigh the adverse characteristics.

224. A letter from the Directorate of Civil Works, Office, Chief of Engineers, commented in July 1978 that the program appeared to be a success and commended the Division and the District for their imaginative approach.* A Missouri River Division Disposition Form** (DF), describing a conference between engineers of the Missouri River Division and the St. Louis District, stated the differences between the dike notching programs on the Mississippi River and the Missouri River. Many more notches had been created in Missouri River dikes and they were smaller (30-50 ft) than those on the Mississippi River (100-400 ft). The Missouri River dikes passed water more often (95 percent of the time) than do those of the Mississippi River (50-75 percent of the time) during the navigation season. The location of the notches is somewhat different. Most of those on the Missouri are built in areas where open water presently exists on both sides of the structure, whereas some of the notches on the Mississippi are constructed landward of the low-water bank line in areas where considerable deposition existed before creation of the notch. The St. Louis District reported that many of the notches in their District do not stay open and some of those that do stay open

* Letter, dated 3 July 1978, from Engineering Division, Office, Chief of Engineers, Washington, D. C., to Division Engineer, Missouri River Division, Omaha, Nebr.

** Disposition Form, dated 14 December 1977, Subject: Trip Report - Coordination Meeting Between Kansas City District and St. Louis District on Missouri-Mississippi Navigation Projects, for files, Missouri River Division, Omaha, Nebr.

adversely affect the navigation channel by siphoning off portions of the flow.

225. One of the differences between the Missouri and Mississippi Rivers is the much greater stage fluctuation on the Mississippi River, which is not controlled by upstream dams. The St. Louis District must maintain navigation throughout the year in the face of considerable stage fluctuation, whereas the Omaha and Kansas City Districts do not maintain navigation through the winter because of heavy ice flow, and the stage fluctuation is considerably less. The St. Louis District has had to resort to almost continuous dredging to maintain the navigation channel on the Mississippi. The goal of the Missouri River Division is not only to maintain open waters for the propagation of fish and wildlife but also to discourage sediment deposition in order to maintain the area open for the passage of flood flows.

226. The notches in the Missouri River dikes are generally smaller and deeper and thus pass water most of the time, but the amount is not enough to adversely influence the navigation channel. The notches on the Mississippi River are usually higher in elevation, but they are wider, thus passing more flow but on a less frequent basis. The DF concluded that the dike notching program was worthwhile and should be continued.

227. In November 1977, another Missouri River Division DF* noted that there were some conflicting goals in the dike notching program:

....they desire to open up back chute and water areas to the river, yet with no deposition and no moving water. These goals conflict with each other and are not totally attainable; however, we will attempt to work toward arriving at the optimum solution.

Additional research

228. A long-term field study is being conducted by the WES to provide information on the environmental effects of dikes and revetments.

* Disposition Form, dated 28 November 1977, Subject: Trip Report - Notched Dike Study Progress Meeting, for files, Missouri River Division, Omaha, Nebr.

The Mississippi River Dike and Revetment Studies are part of Project VII of the EWQOS and are an ambitious program of the collection of physical, chemical, and biological data on a selected 50-mile reach of the lower Mississippi River. The dual goal of this effort is to assess the relative ecological importance of channel alignment and bank stabilization structures in the riverine ecosystem, and to provide data to formulate environmental quality guidelines for use by Corps of Engineers Districts in designing and planning new structures and modifying existing ones. A similar effort is planned on the middle Mississippi River by a multi-agency committee conducting a study entitled Great River Resources Management Study (GREAT). The effects of various dike design parameters on the riverine environment will be studied.

PART VI: PLANNING PROCESS EXAMPLES OF TWO
WATERWAY PROJECTS

229. A meeting was held with personnel of the Engineering Division, U. S. Army Engineer District, Nashville, Tennessee, to investigate planning procedures for specific waterway projects. The Nashville District personnel responded with material on two very different types of waterway projects: Sunbright, Tennessee, Local Protection Project, and Bay Springs Lock and Dam. These two projects exemplify how consideration of natural resources and environmental protection are included in the planning process.*

Whiteoak Creek Flood Control Project

230. The Whiteoak Creek Flood Control Project consists of widening Whiteoak Creek to 60 ft along a 0.7-mile reach within Sunbright, Morgan County, Tennessee (Nashville District 1979). The design also calls for selective riprapping of the streambank where necessary. The project will alleviate the present flash flooding problem in Sunbright and thus reduce property damages and the threat to human life.

231. Whiteoak Creek is presently a sluggish stream with an average channel width of 40 ft, and pool and riffle depths of 3 ft and 5 in., respectively. Whiteoak Creek has a stream length of 25 miles and a drainage area of 103 square miles. A floodplain makes up 90 percent of the total area. The narrow floodplain is 200-300 ft in width, and it consists mainly of mixed hardwood forests (90 percent). Some small spaces have been cleared for agriculture. The area is habitat for five endangered species: Indiana bat, gray bat, Southern bald eagle, American peregrine falcon, and red-cockaded woodpecker. The creek is used mostly for fishing, bait collecting, and camping. The EIS contains

* Letter, dated 18 June 1979, from E. C. Moore, Nashville District, Nashville, Tenn., to Dr. E. L. Thackston, Vanderbilt University, Nashville, Tenn.

tables of aquatic invertebrates, fish, wildlife, and flora found in the vicinity of Whiteoak Creek.

232. The letter* further explained that

As with all Corps of Engineers water resources projects, the Water Resources Council's Principles and Standards for Planning Water and Related Land Resources were used in developing the selected alternatives for providing flood protection at Sunbright. The principles were established to ensure a coordinated effort in developing water resources of the United States.

Alternatives considered included clearing and snagging, a completely cleared channel with protected sides, a reservoir, floodplain management, flood insurance, flood warning system, flood proofing, relocation, and no action (Nashville District 1979).

233. Clearing and snagging would result in adverse environmental effects similar to channel enlargement. These effects include elimination of wildlife niches dependent on riparian habitat, destruction of riffle areas, loss of fish cover, increases in sediment pollution and water temperature, and severe degradation of aesthetic qualities. The increased noise levels and a reduction of air quality would also cause some annoyance to local citizens.

234. A reservoir would inundate 130 acres of land and remove 3 miles of free-flowing stream. Aquatic organisms dependent on a stream environment would be adversely affected as would terrestrial flora and fauna. Air pollution and noise levels would also be increased during construction. The reservoir would enhance those organisms preferring a lake environment. It would supply a 1-cfs minimum flow of good quality and natural temperature. Another benefit would be the creation of habitat for beavers, muskrats, and wood ducks. The reservoir proved to be economically infeasible for Federal participation. It was too expensive to achieve the necessary flood protection.

235. A variety of nonstructural alternatives was considered. A nonstructural alternative must provide ample protection, be economically

* Letter from E. C. Moore, op. cit.

feasible, and be socially acceptable. The nonstructural alternatives considered were floodplain management, flood insurance, a flood warning system, flood proofing, relocation, and no action. The no-action alternative is a direct requirement of the NEPA.

236. Floodplain management would not provide a solution to the immediate flooding problem. However, additional flood damages would be prevented by prohibiting future development. Sunbright has no legal authority to enforce a floodplain management plan since it is unincorporated. Flood insurance provides for the risk that is always involved with flooding. However, one of the specific requirements of obtaining flood insurance is to enlist a floodplain management plan. Since Morgan County voted not to participate in the National Flood Insurance Program, flood insurance is not a possible alternative. A flood warning system would avoid injury or loss of life and would prevent damage to movable property, but it would not eliminate major damages. Flood proofing proved to be unacceptable and undesirable to local property owners. Relocation was economically infeasible and publicly unacceptable. The no-action alternative would ignore the desires of local citizens concerned about flood damages. However, it would avert destruction of terrestrial and aquatic habitats, deterioration of water quality, and aesthetics.

237. The selected design calls for the widening of the channel to 60 ft. Only one bank will be altered. The other is to remain in its natural state. Certain trees on the altered bank will be marked prior to construction to be saved. The altered bank will have a side slope of 1V on 2H. Due to the presence of bedrock, lowering of the streambed is not feasible. Some channel realignment is required to eliminate rock excavation. Highway 27 crosses Whiteoak Creek at river mile 20.1; the project extends from river mile 20.2 to river mile 19.5. Riprap will be placed upstream and downstream of the Highway 27 Bridge to provide protection. The riprap size selected will not only provide adequate strength for the bridge but will also create suitable habitat for aquatic organisms. Turf grasses will provide sufficient protection for the remainder of the channel because of the

lower velocity flows. Construction specifications require the contractor to seed and mulch disturbed areas immediately after the completion of each section.

238. Completion of the project will require the removal of 54,000 cu yd of material. The selected disposal areas have the least amount of impact on wildlife and aesthetics. The disposal area will be graded and planted with indigenous species to present a natural appearance.

239. The disposal areas will be a source of siltation until they are revegetated. Siltation reduces diversity and numbers of organisms. In addition, suspended solids reduce photosynthesis, irritate the gills of fish, reduce the ability of sight-feeding fishes to locate food, and increase water temperature. The deposited solids can smother fish eggs and bottom-dwelling organisms.

240. Channel improvements will yield a 97 percent reduction of flood damages during the 50-year economic life of the project. Channel capacity will be increased from a present value of 1200 cfs to one of 2600 cfs after channel enlargement. The increased capacity will contain the 10-year flood in the banks. The project has a benefit-cost ratio of 6, based on an interest rate of 6-5/8 percent and a 50-year project life.

241. The project will have certain adverse environmental effects. Construction activity will cause temporary increases in traffic, dust, noise, exhaust emissions, erosion, stream turbidity, and sedimentation. Other effects include loss of aquatic flora and fauna and of riparian vegetation affording fair wildlife habitat. Aquatic fauna is expected to reestablish itself in a short period of time. Terrestrial populations will be slower. However, fauna will never reach preproject conditions.

Bay Springs Lock and Dam Project

242. The Bay Springs Project is part of the Divide Section of the Tennessee-Tombigbee Waterway being constructed by the Corps of

Engineers (Wilhelms 1976). The Tennessee-Tombigbee Waterway passes through Alabama, Mississippi, and Tennessee. The completed waterway will greatly reduce transportation costs, which is the largest part of the economic justification for the project. Fish and wildlife enhancement, recreation and area development also contribute to the economic justification.

243. Water quality requirements established by state environmental and wildlife agencies must be met for water within and released from Bay Springs Lake. The two primary water quality parameters of interest are water temperature and dissolved oxygen (DO). Since water will be released through a lock system, the location of the lock intakes was evaluated with respect to their ability to meet these water quality parameters. Research was conducted at the WES on the relationship of the location of the lock intakes to water quality (Wilhelms 1976).

244. The result of the WES work was a model to predict water temperature and DO of water within and released from Bay Springs Lake. A combination of the two physical models and one mathematical model was used to define the hydrodynamics, DO, and temperature of the divide-cut canal. The divide-cut canal is 27 miles in length and has an average bottom width of 300 ft.

245. The two physical models were the lock intakes model and the lake hydrodynamics model. The lock intakes model determined the steady-state withdrawal characteristics of the lock intakes. The lake hydrodynamics model aided in defining the hydrodynamics of Bay Springs Lake resulting from dynamic and unsteady operating conditions representative of the prototype. The mathematical model, WESTEX, was a numerical simulation model that predicted the downstream release water quality characteristics and the internal structure of DO and temperature for Bay Springs Lake. These models are fully discussed in the report.

246. Seven years of climatological data were selected through an appropriate procedure. Simulations with the two physical models indicated that WESTEX should be utilized for two local lock topography elevations (el 373 and el 384 ft msl) and three lockage rates (5, 12, and 24 lockages per day). WESTEX simulations indicated that a design calling

for the lock topography at el 384 would result in release temperatures closer to the preproject stream temperatures and higher DO concentrations than a design with local lock topography at el 373. Other values for the local lock topography elevation did not significantly improve water quality.

PART VII: CONCLUSIONS

247. A summary of this report is not possible because many different subjects are discussed and because each comment stands by itself and is not necessarily related to other comments in a logically progressive fashion. However, some conclusions are presented. Each of these conclusions has been stated earlier in this report, and most have been discussed in some detail. Therefore, they will simply be restated and highlighted without repeating the explanations or justifications.

248. Corps of Engineers waterway projects involve a number of environmental effects, and these are primarily the loss of aquatic and terrestrial fish and wildlife habitats caused by disruption or change of the natural environment, and the increases in turbidity and sediment load.

249. The chief resource used by the design engineer in designing a project and trying to minimize the environmental effects is the experience of the engineer and his colleagues in the Corps. The Corps has employed a large number of individuals with expertise in environmental sciences. Most of these individuals work in planning units.

250. The major decisions relating to the type and magnitude of environmental effects occur when project alternatives are selected rather than during detailed design. The Corps provides more guidance in environmental matters to planners than to design engineers.

251. Channel modification probably produces more (or certainly as many) environmental effects or more severe effects and more public opposition than any other type of commonplace Corps waterway project.

252. Few, if any, major studies have been done systematically and scientifically to compare the environmental effects resulting from alternate designs or methods of construction for the same type of project.

253. Most of the current EMs relating to the design of waterways projects were written prior to 1970 and make little mention of environmental effects or factors in design. They provide little effective guidance to the designer in the specific area of minimizing environmental

effects through proper selection of design parameters.

254. Channel modification causes many environmental effects, including elimination or reduction of bottom and edge habitat for aquatic life; drainage of wetlands and modification of terrestrial wildlife habitat; induced clearing of bottomland hardwood forests and other major land-use changes; increases in stream temperature and turbidity; cutoff, isolation, and silting in of oxbows and meanders; lowering of water tables; increase in flash flooding downstream from the modified stream reach; and more rapid transfer of nutrients downstream for assimilation in lower stream reaches. Some of these effects can be reduced by good engineering design, such as excavating from one side only, careful placement of dredged material, placement of drainage and level-control structures at the lower end of cutoff meanders, and routing the channel around sensitive or highly productive areas.

255. Alternatives to channel modification have received more attention in recent years, but many of the suggested alternatives would not be effective or economical in achieving the locally desired goals of reducing damage to current development. The greatest promise seems to be for the use of modified design (as mentioned above) and construction methods, such as more use of hand labor, which may be suitable and effective in some areas. Additional work is needed to develop and document design criteria for these modified designs.

256. Any method of bank protection will have some environmental effects. Cast stone riprap or gabions will probably have a less severe impact and will be cheaper than protection methods employing more artificial barriers (i.e. concrete paving or asphalt mats). Since it has been estimated that \$870 million would be required to prevent \$200 million worth of erosion damage, bank protection purely for prevention of erosion damage is likely to be uneconomical except in some urban areas.

257. Dikes are commonly used by the Corps sometimes to deflect currents away from banks as a method of bank protection, but primarily to concentrate flow in the center of a stream so scouring action will help maintain a deeper channel for navigation. However, there is no design manual on dikes, and common engineering practice varies among

Corps Districts. Differences in dike design and construction practices among Corps field offices usually reflect the varied character of their respective waterway systems and regional situations. Many dike construction methods were tried in the past, but almost all dikes being built at the present time are of stone, which is usually placed from a barge. The chief environmental effect is the loss of aquatic habitat where the dike is actually placed and where silt accretion fills in the space between adjacent dikes. This creates new terrestrial habitat in the place of aquatic habitat, but the new land is likely to be cleared for farming, which virtually eliminates the area for wildlife use. Accretion can be reduced and some backwater area between dikes can be kept open for aquatic habitat by cutting notches in the dikes near the landward end, which allows water to flow at all but the lower river stages. Additional work is needed to develop dike designs which maintain an adequate navigation channel yet also provide lasting aquatic habitat. Dike notching design criteria should be developed and documented.

258. Additional systematic research should be conducted to determine the relative magnitude of various environmental effects resulting from either various engineering design decisions or various construction methods.

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REVIEW OF ENVIRONMENTAL CONSEQUENCES OF WATERWAY DESIGN AND CON--ETC(U)

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