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ENVIRONMENTAL GUIDELINES FOR DIKE FIELDS

by

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The environmental guidelines for dike fields contained within this report consist of environmental objectives, design procedures, and river-specific examples of currently employed environmental features that can be used to maintain or increase fish and wildlife habitat diversity. Design, construction, and maintenance of dikes can alter the water depth, current velocity, and substrate composition to increase habitat diversity of US Army Corps of

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Engineers waterway projects.

Features discussed herein that can be incorporated into dike fields to increase diversity are notches, low-elevation dikes, rootless dikes, and minimum maintenance practices. Other potential techniques include dredging to remove sediment, disposing of dredged material within the dike field, relocating old notches, placing additional rock, adding artificial reefs, and building control structures in side channel closure dikes.

Two case studies--one on the Missouri River, one on the lower Mississippi River--of river response to dike field construction are presented. Aquatic habitat requirements of representative vertebrate species and of aquatic invertebrates in general, as well as a subject reference index, are given in appendixes.

PREFACE

This report was sponsored by the Office, Chief of Engineers (OCE), US Army, under Contract No. DACW39-82-C-0026, as part of the Environmental and Water Quality Operational Studies (EWQOS) Work Unit VIB entitled Design and Construction Techniques for Waterway Projects to Attain Environmental Water Quality Objectives. The OCE Technical Monitors for EWQOS were Mr. Earl Eiker, Dr. John Bushman, and Mr. James L. Gottesman.

The work was conducted during the period from May 1982 through August 1983 by the Environmental Planning Division of Versar Inc. The report was prepared by Mr. Carey W. Burch, AICP, Mr. Phillip R. Abell, Dr. Michael A. Stevens, Dr. Robert Dolan, and Ms. Brenda L. Dawson of Versar Inc., and by Mr. F. Douglas Shields, Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES). The report was monitored by Mr. Shields; general supervision was provided by Mr. Michael R. Palermo, WREG, Mr. A. J. Green, Chief, EED, and Dr. John Harrison, Chief, EL. Dr. Jerome Mahloch was Program Manager of EWQOS.

Commander and Director of WES during this study and the preparation of this report was Col. Tilford. C. Creel, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

> Burch, C. W., et al. 1984. "Environmental Guidelines for Dike Fields," Technical Report E-84-4, prepared by Versar Inc., Springfield, Virginia, and the Environmental Laboratory, Waterways Experiment Station, for US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

SUMMARY

As part of the Environmental and Water Quality Operational Studies (EWQOS) Program, Project VI, the U. S. Army Engineer Waterways Experiment Station (WES) is conducting research into the development of environmental guidelines for design, construction, operation, and maintenance of U. S. Army Corps of Engineers (CE) waterway projects. A portion of this research effort is focused on development of environmental guidelines for dike fields, which are groups of dikes. Dikes are longitudinal structures used to maintain stable navigation channels through effects on channel depth and alignment. Basically, dikes constrict low and intermediate flows, causing the channel velocity to increase within the reach and thereby scour a deeper channel.

Dike design and construction practices differ among CE Divisions and Districts and depend largely on the personal experience of each design engineer. While there are basic similarities among all dikes, there are few environmental guidelines available for dike design. Existing dike fields often provide a diversity of aquatic habitats for fish and other biota. However, in some cases, sediment accretion within dike fields reduces the amount of aquatic habitat and habitat diversity. Where vegetation becomes established on accreted sediments, permanent terrestrial habitats are often formed. Many of these newly formed terrestrial areas along the Missouri River have been cleared for agriculture, resulting in a loss of fish and wildlife habitat.

The environmental guidelines for dike fields contained herein can be used to maintain or increase fish and wildlife habitat diversity. Aquatic habitat diversity reflects the diversity of the key physical factors of water depth, current velocity, and substrate composition. Design, construction, and maintenance of dikes can alter these physical factors to increase aquatic habitat diversity. Dike field environmental features which increase aquatic habitat diversity include notches, low-elevation dikes, rootless dikes, and minimum maintenance practices. Other potential techniques include dredging to remove sediment, disposing dredged material within the dike field, relocating old notches, placing additional rock, adding artificial reefs, and building control structures in side channel closure dikes.

Environmental guidelines for dike fields contained within this report consist of environmental objectives, design procedures, and river-specific examples of currently employed environmental features. The environmental objectives are applicable to all dike design, construction, and maintenance. These are

a. Maintain or increase the aquatic habitat diversity by increasing the complexity of physical factors comprising the aquatic habitat.

b. Preserve the integrity of existing off-channel aquatic habitat areas.

c. Schedule construction and maintenance to avoid peak spawning seasons for aquatic biota.

d. Design and maintain dike fields to prolong the lifetime of the aquatic habitat (i.e., reduce sediment accretion).

e. Maintain abandoned channels open to the river.

A series of general steps was developed for incorporating environmental considerations into dike design, construction, and maintenance (see Part V). The procedure includes steps to be followed during formulation or update of the river master plan, as well as during design of a given dike or dike field. The procedure can be used in an attempt to achieve the broad goal of increasing aquatic habitat diversity or the narrower goal of developing habitat for preferred species.

Application of the general environmental objectives and design procedure will, of necessity, differ from river to river and by CE Divisions and CE Districts. This flexibility is necessary due to highly variable characteristics of rivers, sites, and dikes. Examples of existing environmental features are given in Part VI for the main waterways with dikes. Examples of key species found in each river and their habitat requirements are found in Appendix B.

The physical and biological effects of the environmental features have been observed to vary with site conditions and dike field design. However, some generalizations can be made regarding typical river responses to these techniques and their biological effects. These responses and effects are summarized in Part IV.

Two case studies of river response to dike field construction were performed (one on the Missouri River and one on the lower Mississippi River). These case studies provide specific examples of morphological effects of dike fields. An effort was made to redesign the dike fields at the two case study sites to meet environmental as well as river training objectives. Environmental designs were formulated for both existing and preconstruction conditions.

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CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	0.4046873	hectares
acre-feet	1233.489	cubic meters
cubic feet per second	0.02831685	cubic meters per second
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
feet per mile	0.1893936	meters per kilometer
feet per second	0.3048	meters per second
inches	0.0254	meters
miles (U.S. statute)	1.609347	kilometers
pounds	0.4535924	kilograms
square miles (U.S. statute)	2.589998	square kilometers
tons (2,000 lbs.)	907.1847	kilograms

PART I: INTRODUCTION

Project Scope

Problem statement

1. Dikes are used on navigable waterways as part of an overall U.S. Army Corps of Engineers (CE) river training program. For the purposes of this report they are defined as longitudinal structures placed in alluvial waterways to help stabilize the navigation channel; small dikes used on nonnavigable streams for bank protection are not addressed. Dikes are usually constructed of stone, pile clusters, or piling with stone fill and may or may not be connected to the bank. Dikes may be used in conjunction with other river training measures including floodways, bank protection (revetments), dredging, cutoffs, and levees.

2. Dike fields are constructed to change the morphology of natural alluvial waterways. Their desired effects are to (a) develop, regulate, and stabilize the waterways for navigation and flood control and (b) stabilize eroding banks. Specifically, dike fields are intended to develop a channel with dimensions and alignments suitable for navigation and/or flood control purposes. Dike fields accomplish this by stabilizing the position of bars, controlling flow through secondary channels, and reducing channel width over some range of discharges. Dike fields are normally used in conjunction with revetments to develop and stabilize the channel.

3. Dike fields change river morphology by decreasing the channel width in the vicinity of the dike fields, decreasing the surface area of the waterway, increasing depths through bed degradation, and sometimes shifting the channel position. As the flow is realigned and/or constricted, the bed is scoured by locally higher velocities. Decreased velocity within the dike field itself leads to accretion of sediment in this area. Usually it is necessary or desirable for engineering reasons to locate dike fields in natural depositional areas, such as on convex sides of bends. This practice often augments the described morphological changes.

4. The changes to the waterway morphology and hydraulics attributable to dike fields are directly translatable to changes in fish and wildlife habitat. The environmental effects of changes in fish and wildlife habitat may be beneficial or adverse. Beneficial environmental effects are related

to the diversity of substrates, depths, and velocities created by the dike fields. Individual dike structures often provide a diverse habitat with a relatively high level of biological activity. Adverse effects which dike fields may have on fish and wildlife are related to sediment accretion, alterations in river depth and stage, reduction in aquatic surface area and wetted edge, locally increased main channel velocities, and a reduction in slack water habitat caused by the closure and subsequent sedimentation of chutes, sloughs, and secondary channels.

5. Specific design and construction practices vary among CE Districts and are often dependent upon the individual experience of each design or project engineer. The variability of the waterways involved, both from river to river and reach to reach, is an additional factor affecting the variation in dike design and construction. While basic similarities in design exist throughout the CE, no formal guidance is available concerning techniques to improve the net environmental effects of dikes. The environmental effects of altering dike designs (through changing such factors as crest elevation, dike spacing, length, height, and angle to the bank) are not fully documented.

Purpose

6. The CE is committed to implementing the National Environmental Policy Act (NEPA) and other environmental statutes, regulations, and executive orders. The CE has issued several documents that contain general environmental guidelines and policies, and a review of these is presented by Shields and Palermo (1982). Specific design guidance to implement these guidelines and policies is still needed. The CE is currently conducting a large-scale, multiyear research program, the Environmental and Water Quality Operational Studies (EWQOS), to address high-priority environmental problems. Part of this program (Work Unit VIB) is aimed at providing environmental design and construction guidance for specific types of waterway projects. This guidance will be used by CE field offices to implement Federal and CE environmental policies.

7. Environmental guidelines for four main types of projects have been produced under EWQOS Work Unit VIB: flood control channels (Shields 1982, Nunnally and Shields 1983), levees (Hynson et al. 1983), streambank protection, (Henderson and Shields 1983) and dike fields. Background

information is available from Thackston and Sneed (1982) and Shields and Palermo (1982). These categories were set up in a somewhat arbitrary fashion to facilitate information collection and review, and there is some overlap. Thackston and Sneed (1982), and Shields and Palermo (1982) contain limited information on environmental aspects of CE dike fields.

8. The purpose of this report is to describe environmental features for dike fields and present environmental guidelines compatible with the basic purposes of dikes. The environmental guidelines described below are applicable to a variety of river systems, engineering and navigation requirements, and ecological settings. These guidelines should provide a means of balancing the historical emphasis on development and maintenance of the navigation channel with more recent concerns for the preservation and enhancement of environmental quality.

Study Methodology

9. The development of environmental guidelines for dike fields was conducted in three steps. The first step was collection and synthesis of state-of-the-art information on dike fields, involving a literature search, an unpublished information search, and a synthesis of the information collected. The second step consisted of the identification of environmental features for dike fields and the development of the environmental guidelines. Two case studies were performed to test the environmental guidance developed. Step three was the preparation of a technical report describing the study findings.

Published data search

10. The published data search consisted of an initial search effort of computerized bibliographic data bases supplemented by a manual search of several major libraries. Published data were also solicited from engineers and life scientists familiar with dike fields. The Lockheed DIALOG Information Retrieval Service was used to perform the automated literature search, accessing the following eight files:

a. Biosis Previews.

b. Compendex.

c. Conference Papers Index.

d. Selected Water Resources Abstracts.

e. Comprehensive Dissertation Index.

f. Enviroline.

g. Environmental Periodicals Bibliography.

h. Transportation Research Information Service.

11. Materials examined by manual search included the holdings of four major libraries: Office, Chief of Engineers (OCE) Library, Washington, D.C.; CE Engineering Library, Fort Belvoir, Virginia; U.S. Geological Survey (USGS) Library, Reston, Virginia; and the U.S. Department of the Interior Library, Washington, D.C. In addition, published data were solicited from various CE Districts, State agencies, and universities.

Unpublished information search

12. Engineers and life scientists familiar with dike fields were identified during the search for published data. These persons were contacted and interviewed by telephone, mail, and in face-to-face meetings to gain information on state-of-the-art practices and river-specific conditions. Field trips were conducted on the Missouri River, the upper Mississippi River, and the lower Mississippi River. A list of the individuals contacted is contained in Table 1.

Information synthesis

13. All relevant published and unpublished information was collated according to significant topics. These topic areas included dike types and use, design factors, dike field effects on waterway morphology and hydraulics, dike field effects on biota, and techniques to reduce adverse environmental impacts. Information in each topic area was assessed according to its generic or river-specific applicability. The focus of the information synthesis was to identify and synthesize information relevant to the development of environmental guidelines. A subject index of literature cited is supplied (Appendix A) for those readers requiring additional detail.

Table 1

List of Contacts

NAME	TITLE	AFFILIATION	TELECONS	LETTERS	INTERVIEWS
Buell Atkins	Chief, Environmental Resources	U.S. Army Engineer District, Tulsa	X		
Al Austin	Chief, River Design	U.S. Army Engineer District, Little Rock	X	X	
Dick Baker	Chief, Channel Maintenance	U.S. Army Engineer District, Rock Island	X	X	X
Manuel Barnes	Biologist	U.S. Army Engineer District, Little Rock	X	X	
Byron Blankenship	Civil Engineer	U.S. Army Engineer District, Portland	X		
Jerry Brantley	Engineer	U.S. Army Engineer District, New Orleans	X		
Dave Bork	Engineer	U.S. Army Engineer District, Rock Island	X	X	X
Gene Buglewicz	Limnologist	U.S. Army Engineer Division, Lower Mississippi Valley			X
Tom Burke	Chief, River Development	U.S. Army Engineer District, Kansas City	X	X	X
Steve Cobb	Chief, Environmental Analysis	U.S. Army Engineer Division, Lower Mississippi Valley	X		X
Dan Coble	Leader, Cooperative Fishery Unit	University of Wisconsin, Stevens Point	X		
Frank Collins	Chief, Environmental Analysis	U.S. Army Engineer District, Rock Island	X		
Bill Dieffenbach	Biologist	Missouri Department of Conservation	X		X
Charles Elliott	Chief, River Stabilization	U.S. Army Engineer District, Vicksburg	X	X	X
Tim Grace	Fishery Biologist	Missouri Department of Conservation	X		X
Gary Grunewald	Fishery Biologist	Minnesota Department of Natural Resources	X		
Susan Hawes	Supervisor, Environmental Resources	U.S. Army Engineer District, New Orleans	X	X	
Larry Hesse	Biologist	Nebraska Game and Parks	X		
Jim Hildreth	Chief, Environmental Quality	U.S. Army Engineer District, Mobile	X		
Jim Hines	Engineer	U.S. Army Engineer Division, Lower Mississippi Valley			X
James Holzer	Biologist	Wisconsin Department of Natural Resources	X		
Don Johnson	Engineer	U.S. Army Engineer District, Memphis	X		
Bobby Littlejohn	Chief, River Stabilization	U.S. Army Engineer District, Memphis			X
Pete Long	Engineer	U.S. Army Engineer District, St. Louis	X		
Donald Logdon	Engineer	U.S. Army Engineer District, Rock Island	X		
Morris Mauney	Fishery Biologist	U.S. Army Engineer District, Memphis	X	X	
George McMann	Chief, Hydraulics and Hydrology	U.S. Army Engineer District, Savannah	X	X	
Ron Mead	Engineer	U.S. Army Engineer District, Huntington	X	X	
Warren Mellema	Chief, Hydraulics and Hydrology	U.S. Army Engineer Division, Missouri	X	X	X
Ken Murnan	Chief, Channel Stabilization	U.S. Army Engineer District, Omaha	X	X	X
Wayne Odum	Engineer	U.S. Army Engineer District, Mobile	X		
C. H. Pennington	Fishery Biologist	U.S. Army Engineer Waterways Experiment Station, Vicksburg			X
Gail Peterson	Biologist	U.S. Fish and Wildlife Service, Rock Island	X	X	X

(Continued)

Table 1 (Concluded)

NAME	TITLE	AFFILIATION	TELECONS	LETTERS	INTERVIEWS
John Pitlo	Biologist	Iowa Conservation Commission	X	X	X
Tom Pokrefke	Chief, Potamology	U.S. Army Engineer Waterways Experiment Station	X		X
Jim Randolph	Biologist	U.S. Army Engineer District, Tulsa	X		
Jerry Rasmussen	Biologist	U.S. Fish and Wildlife Service, Rock Island			X
John Robinson	Fishery Biologist	Missouri Department of Conservation	X	X	X
Bill Ruland	Chief, Environmental Resouces	U.S. Army Engineer District, Mobile	X	X	
Charles Segelquist	Biologist	U.S. Fish and Wildlife Service	X	X	
Roger H. Smith	Potamologist	University of Missouri, Rolla	X		
Claude Strauser	Potamologist	U.S. Army Engineer District, St. Louis	X	X	X
Norm Stuckey	Biologist	Missouri Department of Conservation			X
Oscar Tinkle	Engineer	U.S. Army Engineer District, Portland	X		
Jim Tuttle	Engineer	U.S. Army Engineer Division, Lower Mississippi Valley			X
Rolf Wallenstrom	Biologist	U.S. Fish and Wildlife Service, Rock Island	X		
Bob Whiting	Chief, Project Evaluation	U.S. Army Engineer District, St. Paul	X		
Howard Whittington	Engineer	U.S. Army Engineer District, Mobile	X	X	
Brian Winkley	Engineer	U.S. Army Engineer Division, Lower Mississippi Valley	X	X	X
Charles Wyatt	Engineer	U.S. Army Engineer District, Kansas City			X
Bill Zigler	Biologist	U.S. Fish and Wildlife Service, Carbondale		X	X

Environmental Guidelines

Guidelines approach

14. The explicit cause-and-effect pathway between dike design techniques and ecological values is highly complex, consisting of at least five components:

a. The response of the river hydraulics to the dike field over the entire hydrologic range .

b. Sediment erosion, transport, and accretion, which are functions of the river hydraulics.

c. The resulting changes in river morphology.

d. The morphological impacts upon habitat characteristics.

e. The response of aquatic and terrestrial biota to the changing habitat characteristics.

15. For explicit formulation of environmental guidelines, this five-step pathway must be traced for each reach of each river, adding another (river-specific) dimension to the complexity.

16. Most of the available information on biological effects relates observed environmental responses to specific dike field descriptions without characterizing the hydrology, hydraulics, sedimentation, or morphology of each dike field site. Therefore, explicit determination of components a-d using available information is impossible.

17. A simpler but less exact approach was selected for formulation of the guidelines contained in this report. First, available information on the physical and biological effects of dike fields was compiled and synthesized. Information on the habitat characteristics of selected animal species was also compiled. The guidelines consist of procedural frameworks for using the compiled information in all phases of dike field projects to achieve environmental as well as river training objectives.

18. Two features are incorporated below to ameliorate the imprecision and lack of reproducibility caused by combining steps 1-4. First, site-specific physical parameters are included in the descriptions of currently employed environmental features. The information synthesis in Part IV includes a summary table (Table 4) which lists observed physical effects of the environmental features. These effects were gleaned from the literature where they were often presented to partially explain biological observations.

19. The second feature is the inclusion of two detailed case studies (Part VII) which include all or portions of the five fundamental steps. The case studies provide limited empirical verification of the guidelines. Additional case studies (beyond the scope of this study) might provide more complete verification and eventually permit the fulfillment of all five cause-and-effect components, approaching the ultimate goal of a quantitative set of environmental guidelines. The guidelines in this report, while falling short of this ultimate goal, are still useful since they present the state of the art on the relationship between dike field designs and environmental values.

20. The environmental guidelines for dike fields are designed to allow flexibility when applied to specific sites. The effects of river training on waterway morphology are extremely complex. Dike designs vary by river conditions, site conditions, and specific design goals. Tradeoffs between dike design, river morphology, and habitat characteristics are not clearly documented, with conflicting conclusions expressed in the literature and by engineers and life scientists familiar with dike fields. Thus, application of the guidelines is highly dependent upon both the dike designer and the procedure used to incorporate the guidelines into the design process.

21. The environmental concerns and guidelines should be incorporated into the river training process at two levels of planning and design: the master plan for stabilization of an entire river or major reach, and the site-specific design of a dike field or single dike. The master plan should reflect the general guidelines. The dike field design procedure may be used to incorporate environmental considerations on a case-by-case, site-specific basis.

Case studies

22. Two case studies were performed to provide a limited verification of the guidelines and to serve as examples of guidelines application. Case studies were performed on a selected Missouri River dike field and a selected lower Mississippi River dike field. Case study sites were selected from several alternative sites on the Missouri River and the upper, middle, and lower portions of the Mississippi River. Criteria used in selecting sites for the case studies were:

- a. The degree to which the site was representative of other potential dike field locations.
- b. The degree to which the existing dike field design and construction were representative of other dike fields.
- c. The existence and ready availability of site-specific physical and biological data to evaluate river conditions and dike field performance.

Report format

23. The information compiled in this report is assembled in several sections, allowing the user to focus on just the information or guidance required, without sifting through the entire report. Part II describes existing dike design and construction procedures. Part III provides an evaluation of dike field effects on waterway hydraulics, morphology, and biota. Part IV describes environmental features for dike fields. General environmental guidelines are presented in Part V. Examples of currently employed environmental features are given in Part VI. Part VII presents two case studies, and Part VIII is a summary. Part IX combines conclusions and recommendations. A subject index for the literature cited and habitat requirements for selected species are given in Appendices A and B, respectively. Appendix C provides background information for one of the case studies in Part VII. Appendix D contains the scientific names for all species discussed.

PART II: EXISTING DIKE DESIGN AND CONSTRUCTION PROCEDURES

Purposes of Dikes

24. The basic purpose of dike construction is to alter the morphology of a natural alluvial waterway so as to provide a stable navigation channel. More specifically, dikes and other river training works (revetments) may be used to:

a. Concentrate the flow into a single channel.

b. Constrict low flows, thus increasing depths.

c. Reduce dredging requirements.

d. Develop and maintain a favorable channel alignment.

Dikes are also used to protect river banks and levees from erosion and thus play a vital role in flood protection. Other benefits which are sometimes part of the overall scope of a waterway project that involves dike fields include recreation, enhanced fish and wildlife habitat, and water quality maintenance or improvement (by reducing suspended solids concentrations) (Lindner 1969).

Dike Types

25. There are several types of dikes currently in common use on navigable waterways. These types are used individually and in combination to achieve the desired results. A combination or cluster of dikes on the same side of a waterway is called a dike field. Names for the individual dike types are variable, with numerous terms in use for each dike type. Descriptions of the dike types, the terms used in this report, and the common use of each dike type are given below. Additional information is given by U.S. Army, Office, Chief of Engineers (OCE) (1980).

Spur dikes

26. Spur dikes are the most common type of dike used on major waterways. Other common names for spur dikes are transverse dikes, wing dams, jetties, cross dikes, and river groins. Spur dikes are used to constrict flow through deflection of the current, concentrating the flow into a single channel during low flows; this increases water depths at low flow and tends to stabilize the river within the diked reach. Adjacent spur dikes often have significant sediment deposition between them. The dikes,

usually used in groups (i.e., fields), are aligned perpendicular or at a slight angle to the direction of the flow in the channel. Spur dikes extend from the bank toward the channel, as shown in Figure 1.

L-Head dikes

27. L-head dikes are a variation of spur dikes and consist of a spur dike with a connected segment angled downstream (Figure 1). The spur dike portion typically runs roughly perpendicular to the direction of flow and the L-head segment, or trail, is parallel or at a slight angle to the flow. Lesser used variations of the L-head are the J-head, with the addition to the spur dike portion angled upstream, and the T-head, with both upstream and downstream additions. L-head dikes were developed to improve protection of concave banks of bendways on the Missouri River over that provided by spur dikes (Lindner 1969). Advantages of L-head dikes are reduced roughness of flow through the concave portion of the thalweg and reduced scour behind the dike (Linder, Christian, and Mellema 1964).

28. In a study conducted at the U.S. Army Engineer Waterways Experiment Station (WES) utilizing a sand bed physical model similar to a reach of the lower Mississippi River, Franco (1967) observed the following effects: (a) L-heads tended to prevent sediment-carrying bottom currents in the main channel from moving into the area between dikes in a field, (b) L-heads had lower crest elevations than the main spur dike section, (c) flow over the L-head section tended to cause scour along the landward face of the L-heads, (d) L-heads reduced maximum scour depths at the riverward tips of the spur dike section, and (e) L-heads resulted in an appreciable reduction of the elevation of accreted sediments between the dikes. Franco qualified his observations as preliminary, however, and some observers have noted significant sediment accretion behind L-heads on the Missouri River.

Closure dikes

29. Closure dikes are used to reduce flow in secondary channels so as to maintain the desired main channel alignment. Other common names are chute closure dikes, side channel closure dikes, and wing dams. Closure dikes may be placed at the head of the secondary channel (Figure 1), or within the secondary channel. Common placement areas are convex banks where natural cutoffs have formed and in straight reaches where multiple channels have formed. Two or more closure dikes constructed at different crest

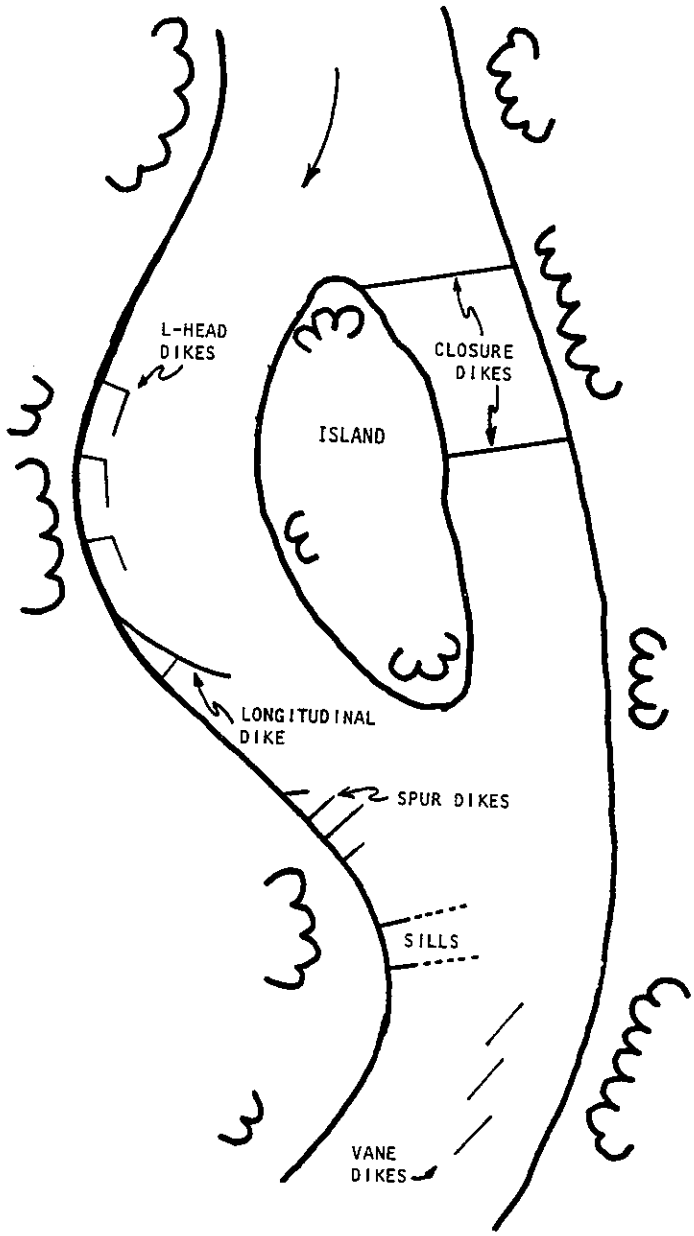

Figure 1. Common dike types

elevations are often used to step the differential head through the secondary channel in order to reduce downstream scour.

30. Closure dikes are also used to reduce sediment deposition in bendways isolated from the main channel by engineered cutoffs. These cutoff bendways are potential harbors and valuable fish and wildlife habitat, but can be quickly filled with sediment. Closure dikes are typically constructed to reduce the amount of sediment entering the bendway by allowing flow through the secondary channel during high-water periods. Thus, the closure dikes may be used to protect recreation and fish and wildlife resources in addition to concentrating the flow in the main channel (OCE 1980). However, closure dikes are not always effective in preventing sedimentation in cutoff bendways.

31. At many locations, particularly on the Missouri River (Burke and Robinson 1979), private landowners have obtained title to the cutoff islands and accreted land. Laws controlling ownership of islands and accreted land vary from state to state. Closure dikes, if high enough and wide enough, are sometimes capped with gravel or earth by private landowners and used for access to these lands. The rights-of-way are usually conveyed to the landowners through lease agreements with the appropriate CE Districts, although in some cases there are no formal agreements regarding access.

Longitudinal dikes

32. Longitudinal dikes are placed near the existing bank and extend generally downstream and roughly parallel to the direction of flow (Figure 1). The terms "longitudinal dikes" and "revetments" are often used interchangeably. For the purposes of this report, however, a revetment is a bank protection structure placed on the bank, such as riprap or articulated concrete mattress, while longitudinal dikes are structures placed in the waterway. The longitudinal dikes are commonly placed along concave banks to reduce the curvature of sharp bends, develop stable channel alignments, and provide bank erosion protection (Shields and Palermo 1982). Longitudinal dikes are sometimes used by the U.S. Army Engineer District, Omaha, to improve channel flow entering a crossing. Short spur dikes often link the longitudinal dikes to the bank for support. As the longitudinal dikes are roughly parallel to the flow, a gradual transition in the flow is achieved, minimizing resistance; spur dikes, in contrast, purposely provide high

resistance to flow. Longitudinal dikes are used primarily on the Missouri River.

Vane dikes

33. Vane dikes are dikes placed out from the bank at a slight angle to the alignment of the currents (Figure 1). The gaps or spacings between the dikes are usually 50 to 60 percent of the length of each vane dike (OCE 1980). Vane dikes can be used independently or in conjunction with spur dike systems. Vane dikes are often cheaper to construct than spur dikes as they can be placed in relatively shallow water parallel to the edge of the channel. Vane dikes were developed as a result of model studies and are most effective when placed where there is movement of sediment. Vane dikes function by developing a lateral differential in water level and thus produce little disturbance to flow. Vane dikes generally should not be placed just upstream of spur dikes or landward of the channel ends of spur dikes as they do not develop the lateral differential in water level effectively in these configurations (OCE 1980).

34. Vane dikes have been used sucessfully on the Mississippi, Missouri, and Arkansas Rivers. A common placement of vane dikes on the lower Mississippi River is on a shallow middle bar adjacent to a deep secondary channel. The dikes are angled 10 to 15 degrees to the direction of flow. The configuration is used in conjunction with an L-head dike as lead (Figure 2) to prevent further development of the secondary channel

Sills

35. Sills are underwater extensions of dikes used primarily on convex banks to deflect flow towards the channel along the concave bank, while minimizing adverse effects on flood flow conveyance. Sills are typically added to spur dikes.

Dike Structures

36. Dike structures are of two general categories, permeable and impermeable. Early river training efforts used primarily permeable dikes composed of brush (typically willow) and timber piling. Timber pile dikes and steel dikes are examples of permeable structures still in use. In the early 1900's, quarried stone structures were used in addition to and in lieu

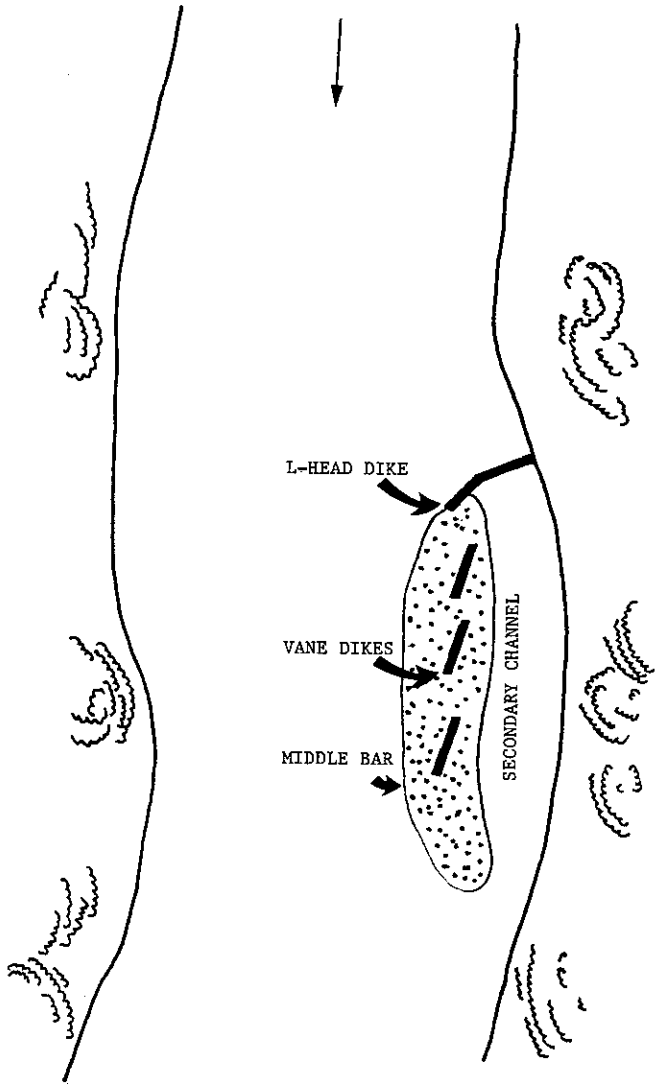

Figure 2. Vane dike configuration on the lower Mississippi River

of the permeable pile and brush dikes. The addition of the stone strengthened the pile dikes, eliminated the need for a foundation mattress, and reduced maintenance requirements (U.S. Army Engineer District, Omaha undated; Pokrefke 1978). Until the 1950's the permeable timber pile dike was the standard structure for constricting a river channel. Gradually, impermeable stone dikes have replaced permeable pile dikes on most river systems in the United States. Stone along pile, stone fill, and earth core dikes are examples of impermeable dike structures. Present day construction consists almost entirely of stone dikes, typically stone fill. The notable exception to this is U.S. Army Engineer District, Portland, which continues to favor timber pile dikes on the Columbia River (Dodge 1978).*

37. Permeable dikes are designed to slow the velocity of the waterway to induce sediment deposition downstream of the dikes and protect the bank from scour (Simons et al. 1975). The accreted sediment enables the dike field to constrict the flow in an effective manner (Degenhardt 1973). Permeable dikes are thus best situated in a waterway carrying a substantial load of coarse sediment which can be induced to deposit by a moderate reduction in velocity (Lindner 1969).

38. Impermeable dikes are designed to protect banks from scour and constrict the flow along the thalweg by deflecting the flow away from the bank. Deposition of sediment occurring within the impermeable dike field increases the dike field's capability to constrict the flow, although the dikes do not require sediment deposition in order to function (Simons et al. 1975).

Timber pile dikes

39. The typical pile dike consists of a double or triple row of pile clusters connected by a set of stringers. The dikes are anchored to the bank using cables, deadmen, and piles, and terminated at the river end with a large cluster of piles. The pile clusters consist of three piles each, lashed together and driven tripod fashion to a penetration of not less than 20 ft (Omaha District undated). The clusters of each row are staggered with

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* Oscar Tinkle. Portland District. Personal Communication. 15 June 1982.

the clusters of adjacent rows, and the rows are joined by stringers lashed to the clusters (Figure 3). The wire rope lashings give the pile dike some elasticity and advantage when exposed to heavy drift or running ice.

40. Brace dikes are a form of the timber pile dike used where additional strength is required or penetration of the piling is less than 20 ft but more than 8 ft (Omaha District undated). Brace dikes are a timber pile dike with an additional row of pile clumps driven roughly 30 ft downstream from the main structure and connected by horizontal and diagonal braces.

41. Crib dikes are another form of the timber pile dike used where pile penetration into the bed is 8 ft or less. Crib dikes are composed of timber cribs (approximately 20 by 30 ft) placed end to end. The cribs are weighted down by stone ballast, and anchored to the bank by cables and deadmen. Foundation mattresses were sometimes used downstream of crib dikes to prevent scour (U.S. Army Engineer District, Kansas City 1948).

42. Timber piles are selected from live trees according to straightness, lack of defects (e.g., knots, shakes, splits, heart rot, insect damage, etc.) and species. In 1956, treated piling replaced untreated piling which was subject to rot in five to ten years (Pokrefke 1978). Corrosion-resistant hardware is also employed on the pile dikes. The tabulation below shows acceptable species and minimum diameters for piles used on the Missouri River.

Species	Minimum Diameter (in.) 3 ft from Base	Minimum Diameter (in.) at Tip
Black walnut (*Juglans nigra*)	12.5	7.0
Pecan (*Carya illinoensis*)	12.5	7.0
Black locust (*Robinia pseudoacacia*)	12.5	7.0
Southern pine* (*Pinus spp.*)	12.5	7.0
Rock elm (*Ulmus racomosa*)	12.5	7.0
White oak (*Quercus alba*)	12.5	7.0
Douglas fir (*Pseudotsuga taxifolia*)	12.5	7.0
Bald cypress (*Taxodium distichum*)	12.5	7.0
Norway pine (*Pinus resinosa*)	13.5	8.5
Western larch (*Larix occidentalis*)	13.5	8.5
Tamarack (*Larix laricina*)	13.5	8.5
Bald cypress with peck (e.g., decay)	14.0	8.0

*Pine piles shall be cut from dense southern yellow pine (*Pinus* spp.) trees and shall show not less than an average of five annual rings to the inch, measured over the third, fourth, and fifth inches on any radial line from the pith and containing not less than one-third summerwood.

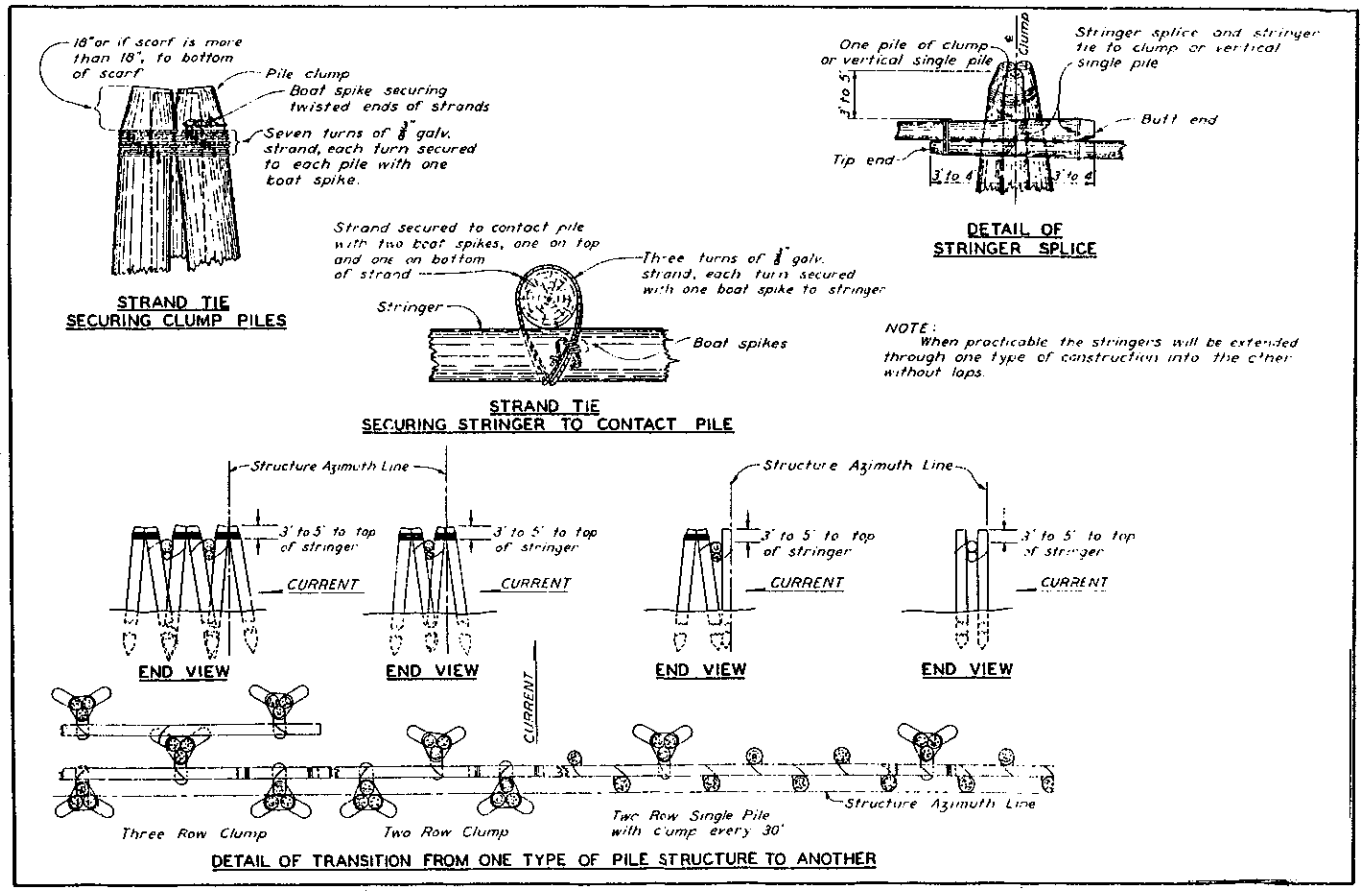


Figure 3. Timber pile dikes (from Omaha District undated)

43. Portland District uses timber pile dikes on the Columbia River. The pile dikes are constructed of untreated Douglas fir, often in water as deep as 35 ft (Dodge 1971). Some of the existing piles are nearly 100 years old, which is attributed to the fact that they are overtopped almost daily (Dodge 1978).

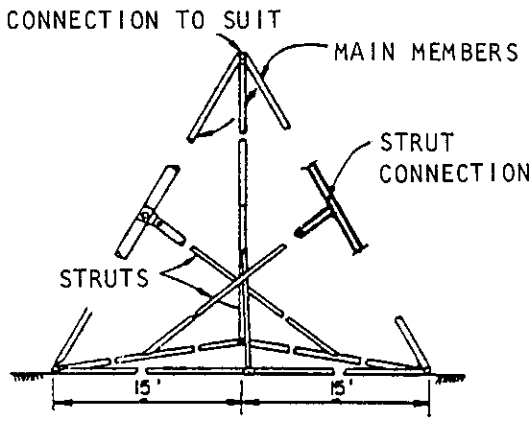
44. Timber pile dikes have several problems according to Pokrefke (1978) which affect their use, including:

- a. Deterioration of the piles and lashings.
- b. Scour which undermines the piles.
- c. Scour by eddy action downstream of the piles.
- d. Caving of the bank.
- e. Flanking of the dike.
- f. Limitations of piling in deep water.
- g. Ice and drift damage.

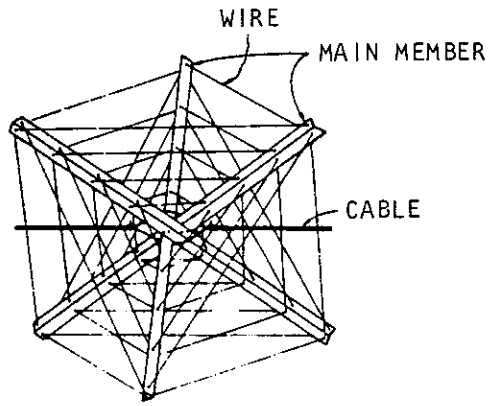
45. As a result of these problems and because of the advantages of impermeable stone dikes, timber pile dikes are now seldom used for river training purposes (with the exception of the Columbia River). However, timber pile dikes are being recommended as possible stream bank erosion control structures (Simons 1979).

Steel dikes

46. Steel dikes are a less common type of permeable dike composed of steel tetrahedrons or jacks in place of timber pile clumps (Figure 4). The steel jack is more common than the tetrahedron because it requires fewer components. The purpose of the jacks is to add roughness to the dike field area, deflecting the current away from the bank and causing bar formation within the dike field, thereby constricting the flow (Lindner 1969). A typical steel jack consists of three steel angle beams bolted or welded together at their midpoint. The jacks are arranged in rows and connected by cable. The Kellner jack field is the common configuration for steel dikes and is in effect a series of permeable L-head dikes connected at their outer ends. The Kellner jack fields are dependent upon collection of drift (e.g., drifting brush, flotsam, etc.) and sediment



(a) TYPICAL TETRAHEDRON



(b) KELLNER JACK

Figure 4. Steel dikes (from Richardson et al. 1975)

deposition to constrict flow (Lindner 1969). Placement of Kellner jack fields is mainly on wide, shallow, sediment-laden streams where the primary purpose is to prevent bank scour. Kellner fields have been used on the Arkansas, Canadian, Frenchman, Rio Grande, and Russian Rivers (Schnick et al. 1981).

Stone dikes

47. Stone dikes are impermeable structures in which the basic component is stone. There are two types of stone structures, stone-along-pile and stone fill. Stone-along-pile dikes consist of a two-row pile structure with stone placed along it, with the center line of the stone coinciding with the center line of the upstream row of piling (Figure 5). Stone-along-pile structures are used where deep water and high velocities exist (Omaha District undated), or where a pile structure requires strengthening. Stone fill dikes are built entirely of stone. Some stone fill dikes are constructed around a single row of piles or pile clumps used as markers during the stone placement. Stone structures often include a stone revetment or apron extending a short distance along the bank (Lindner 1969).

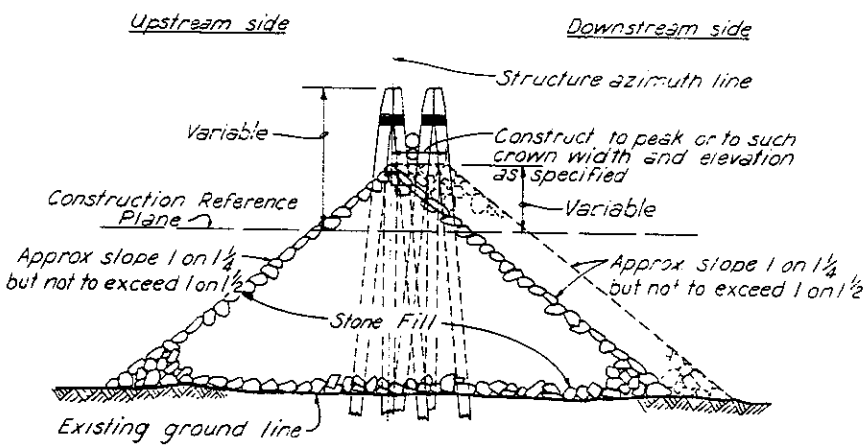


Figure 5. Stone-along-pile dike (from Omaha District undated)

48. Stone used in dike construction is typically quarry-run stone, free of overburden, spoil, or other unsuitable material (Pokrefke 1978). Size of the stone used is dependent upon the stone available in the area, with most quarry-run stone having an extremely wide size gradation. Stone specifications requiring stone gradation vary by CE District, reflecting the requirements of different river systems and the characteristics of local stone. Examples of stone sizes are shown below:

CE District	Stone Size (lbs)
Omaha (Missouri River)	500-2,000 (max. sizes depending on use)
Memphis and Vicksburg (lower Mississippi River)	5,000 (max.)
Little Rock (Arkansas River)	400-3,000 (50 percent within this interval, none larger)
Portland* (Columbia River)	50-800 (75 percent within this interval, none smaller)

* Foundation mattress for timber pile dikes.

49. There are many advantages to using impermeable stone dikes instead of pile dikes. Hartke (1966) described impermeable dikes as being more effective river trainers than permeable dikes. Additional advantages listed by Hartke were increased spacing between dikes in a dike field, increased dike durability, and relative ease of maintenance. Christian (1978) noted the following advantages of stone dikes:

a. Stone is generally available.

b. Stone displaces vertically so the dike is somewhat selfhealing.

c. Labor costs for construction are lower compared to pile dikes.

d. Stone withstands ice pressures better.

e. Maintenance requirements decrease over time.

f. Stone dikes provide good aquatic habitat.

However, some of these advantages, particularly in regards to providing good aquatic habitat, are not always applicable to every dike.

Earth core dikes

50. Earth core dikes are impermeable structures composed of a sand or dredged material inner core with a stone toe and a covering outer layer of stone (OCE 1981). Earth core dikes are not common structures and are primarily used for bank erosion protection. They are occasionally used on the Missouri River as closure dikes for shallow secondary channels or across shallow middle bars.* An advantage of the earth core dike is the savings accrued by using less stone. One design for earth core dikes includes planting vegetation along the top surface. This allows the dikes to blend into the natural appearance of the waterway. These have been used successfully on the Yellowstone River for bank protection.**

Dike Design

51. Dike design is a mixture of engineering and art, dependent upon the waterway characteristics, site characteristics, navigation requirements, and the personal experience of the design engineer. Most dikes have been designed based on trial and error, experience, observation of dike performance, and common sense (Thackston and Sneed 1982). The many types of dike designs currently used have been developed in order to deal with the variety of river conditions and circumstances for which dikes are used. Design attention has been focused primarily on the navigation channel. Less information is available on the effects of the designs and design factors on the ecologically valuable off-channel areas.

52. On large navigable river systems, the general placement of dikes is determined by the river master plan. Both design and placement of dikes in the master plan and the design and placement of specific dikes or dike fields are largely dependent upon the river conditions at the time of design. The actual sequence of dike design and construction is highly dependent upon economic considerations as well. Cost often imposes a constraint on dike design and placement.

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* Warren Mellema. MRD. Personal Communication. 20 July 1982.
** Dr. Michael Stevens. Versar Inc.. Personal Communication. 13 October 1982.

53. The design factors (Figure 6) of crest height or elevation, length, crest profile, and angle are the key characteristics which control the amount of flow constriction (Pokrefke 1978). Length is determined based on the width of the waterway at the site and the river master plan. Crest elevation, crest profile, and angle are chosen based on site characteristics and economics. Other design factors include crest width, side slope, end slope, and spacing. As mentioned in paragraph 28, WES has conducted physical model investigations regarding the relative effects of dike crest heights, crest profiles, and angle and position of dikes with respect to currents and desired channel alignments (Franco 1967). However, much information regarding the effects of dike design, particularly design effects on the shallow water off-channel areas, is still needed. Another physical model study has been initiated at WES, but will take several years to complete.

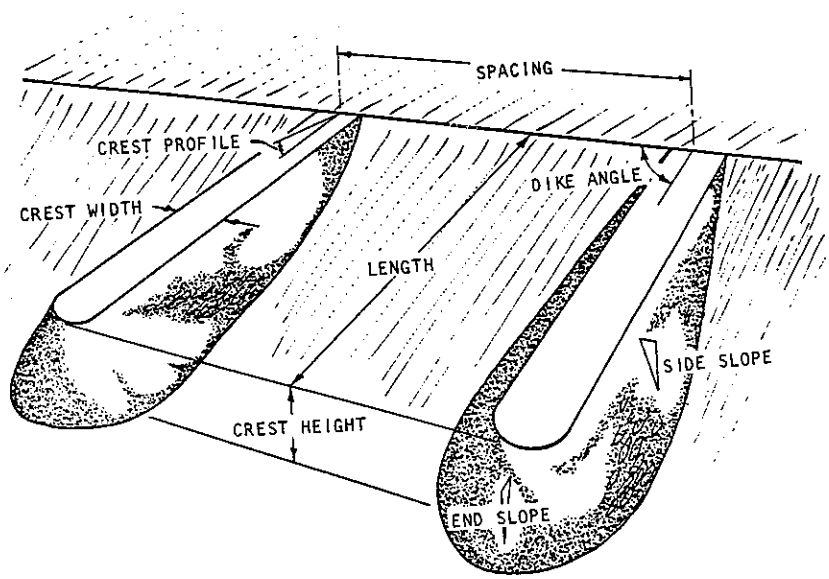

Figure 6. Basic design parameters for dikes
(from Shields and Palermo 1982)

Dike crest elevation

54. Crest elevation is the height of the dike, normally referred to as an average height above or below some reference plane. The Low Water Reference Plane (LWRP) is used on the Mississippi River. The LWRP is based on an accumulated past record of minimum stages and flows and is equalled or exceeded 97 percent of the time. The Construction Reference Plane (CRP), which is used on the Arkansas and Missouri Rivers, is the theoretical water surface profile which would exist if certain target flows were experienced at all of the main gaging stations. The flow corresponding to the CRP is equalled or exceeded seventy-five percent of the time during the navigation season (Robinson 1980).

55. There are three general designs of crest elevations for dike fields: stepped up, stepped down, and normal. A stepped-up dike field is one in which the difference between the river ends or the overall crest elevations of successive dikes and the reference plane increases progressively downstreamward. A stepped-down dike field is one in which the river ends or overall crest elevations of successive dikes are lowered progressively downstreamward relative to the reference plane. A normal dike field is one for which the crest elevations on successive dikes are constant relative to the reference plane.

56. The aforementioned model investigation by Franco (1967) compared stepped-up, stepped-down, and normal dike fields. Different designs were rated based on five factors: increase in channel depth, channel alignment, dredging index, scour, and the average elevation of deposition in the dike field. Factor weights for the ratings were arbitrarily assigned, and sediment deposition was treated as a positive, and thus desirable, factor. Franco found that:

a. Stepped-down dike fields were more effective in terms of developing and maintaining the navigation channel than normal dike fields.

b. Normal dike fields were more effective than stepped-up dike fields.

c. The amount of dredging required to maintain project dimensions was inversely proportional to average length-weighted dike crest elevation.

57. Stepped-down dike fields and normal dike fields are widely used by the CE (Pokrefke 1978). Normal dike fields are the most common and include a variety of dike designs, such as spur dikes, vane dikes, and L-head dikes. Stepped-down spur dike fields are used by many CE Districts at channel crossings, where the thalweg is forced across towards the opposite bank.

58. Stepped-up dike fields are used less frequently. On the lower Mississippi River, stepped-up dike fields are sometimes used to extend the upper end of a point bar in order to force the channel away from the bar. This design follows the natural tendency of the point bar to develop with increased elevation downstream.*

59. Dike crest elevations vary from river to river, between CE Districts, and by types and locations of specific dikes (Figure 7). In general, "high" dike elevations cause increased flow constriction in the channel and sediment accretion in the dike field and are thus more effective in developing navigation channels. However, the cost of dike construction increases rapidly with crest elevations since the volume of an embankment increases geometrically with height. "Low" dike elevations tend to reduce sediment accretion and increase diversity of water depths, which often serves to enhance the overall habitat value of the dike field. Thus, in selecting a crest elevation there are three main considerations:

a. The optimum crest elevation to develop and maintain the navigation channel, given the river and site conditions and dike design.

b. The optimum crest elevation achievable with the funds available for construction.

c. The environmental effects of a "high" dike versus a "low" dike, particularly in regards to the habitat value of the dike field. (Although this has not been a major consideration in the past due to the emphasis on development of the navigation channel, consideration of environmental effects of dikes is increasing.)

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* Charles Elliott. U.S. Army Engineer District, Vicksburg. Personal Communication. 21 July 1982.

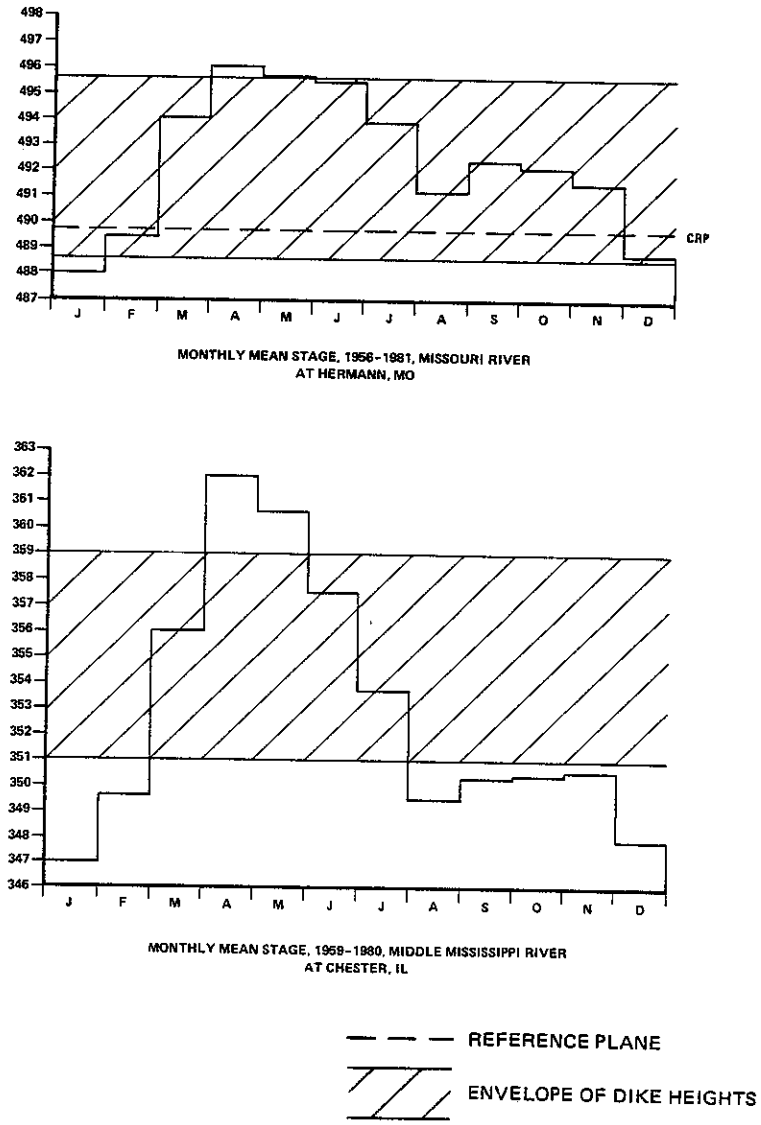
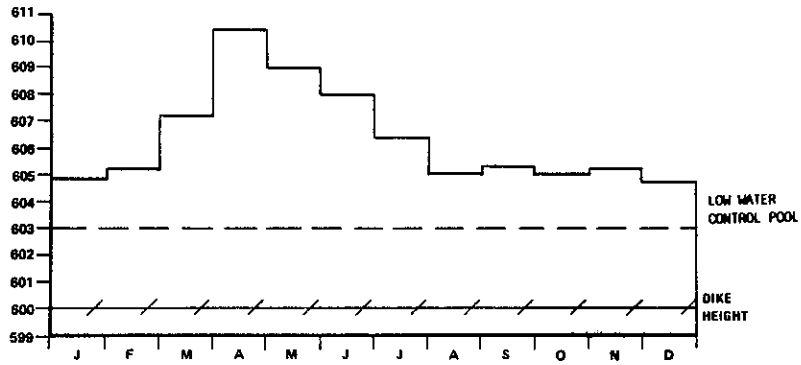
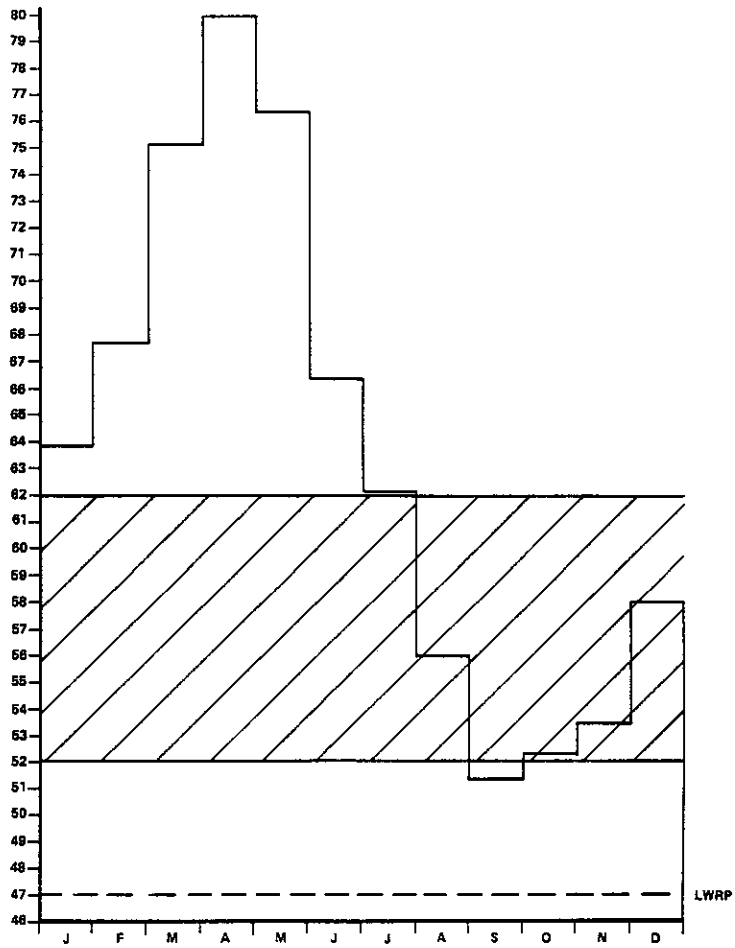


Figure 7. Mean monthly stages in feet above MSL and envelopes of dike heights. Elevation of reference plane is shown for a given gage location. The envelope, a crude estimate of the range of dike design crests elevations, was computed using the elevation of the reference plane at a particular gage location and an estimate of the range of design crest elevations in terms of the reference plane obtained from CE personnel in the appropriate District offices. Actual dike crest elevations vary from design elevations due to structural degradation, modifications, etc. This figure should not be used for any type of quantitative analysis, but it does illustrate the heights of dikes relative to the water surface for the major diked waterways and the differences in stage fluctuations among these waterways (Continued)



MONTHLY MEAN STAGE, 1935-1981, UPPER MISSISSIPPI RIVER
AT GUTTENBERG, IA



MONTHLY MEAN STAGE, 1940-1974, LOWER MISSISSIPPI RIVER
AT VICKSBURG, MS

Figure 7. Concluded

Dike length

60. Dike length is dependent upon the width of the existing river and the desired navigation channel width or amount of flow constriction desired. The channel width or flow constriction desired varies from river to river according to the navigation requirements. Thus, dike length is a highly variable parameter from site to site. The distance between the riverward tips of dikes and the opposite bank, which is usually revetted, is called the constricted channel width. Constricted channel widths are established for the major navigable river systems in the river master plans. Constricted channel widths of some major river systems are shown below:

River	Channel Width (ft)
Upper Mississippi River	300*
Middle Mississippi River	1,500
Lower Mississippi River	2,500 - 3,000
Missouri River	
Sioux City - Rulo, Nebraska	600
Rulo Nebraska - Kansas River	700 - 800
Kansas River - Grand River	800 - 900
Grand River - Osage River	900 - 1,000
Osage River - Mouth	1,000 - 1,100

These constricted channel widths are based on consideration of:

a. The ability of the channel to convey high flows.

b. The need to maintain flow velocities at an acceptable level.

c. The ability to control the river's tendency to meander.

d. The need to induce sufficient scouring action to maintain the channel without excessive dredging (Omaha District undated).

* The Rivers and Harbors Act of 1930 authorized a 9-ft-deep and 300-ft-wide navigation channel to be constructed using locks and dams (in addition to dikes and other structures). Actual constricted widths are often greater than 300 ft.

61. Selection of the proper dike length for a given situation requires balancing the considerations above and navigation requirements. Generally, longer dikes reduce channel width and increase velocity. Shorter dikes cause less flow constriction and have less effect on the navigation channel.

Crest profile

62. Crest profile is an important parameter in controlling the amount of flow constriction at different stages. Three general types of crest profiles are used: sloped, level, and broken (Figure 8). Crest profiles vary by CE District, the dike location, and the desired flow constriction and channel alignment at different stages.

63. A dike with a level crest profile has a constant crest elevation along the entire length and is the most common profile used by the CE (Pokrefke 1978). In Franco's (1967) study level crests on spur dikes and vane dikes performed better than sloping crest and broken crest dikes, although Franco concluded that sloping crest dikes could be designed to be as effective as level crest dikes. Level crest dikes often have a tendency to be flanked near the bank end. This flanking tendency can be reduced by including a short segment that slopes from the top of the bank down to the design elevation (Franco 1967; Strauser 1978).

64. A sloping crest dike has a profile which slopes from the bank line (usually from the top bank line) down to a lower elevation at the channelward end of the dike. Sloped dikes are useful (a) where a wide range of river stages is encountered (and river contraction is desirable at all stages), (b) if a decrease in contraction is desirable with an increase in river stage, and (c) if some scour of the accreted sediment downstream of the dike is acceptable (Lindner 1969). The sloping crest dikes require less material and are less costly to construct than the level crest dikes. Franco (1967) found that sloping crest dikes were most effective when placed normal to the flow or angled upstream. Sloping crest dikes are not as likely to be flanked at the bank as level crest dikes.

65. A broken crest dike has a profile which is broken into different sections at different elevations. Broken crest dikes are typically stepped down towards the channel, although stepped-up versions are used. Closure dikes with broken crests are often designed with a low-elevation section in the center of the dike, allowing increased conveyance of flow while still providing some flow constriction. The stepped-down broken crest functions in a similar manner as the sloping crest, allowing flow constriction to vary with stage. The key difference is that a broken crest dike creates abrupt

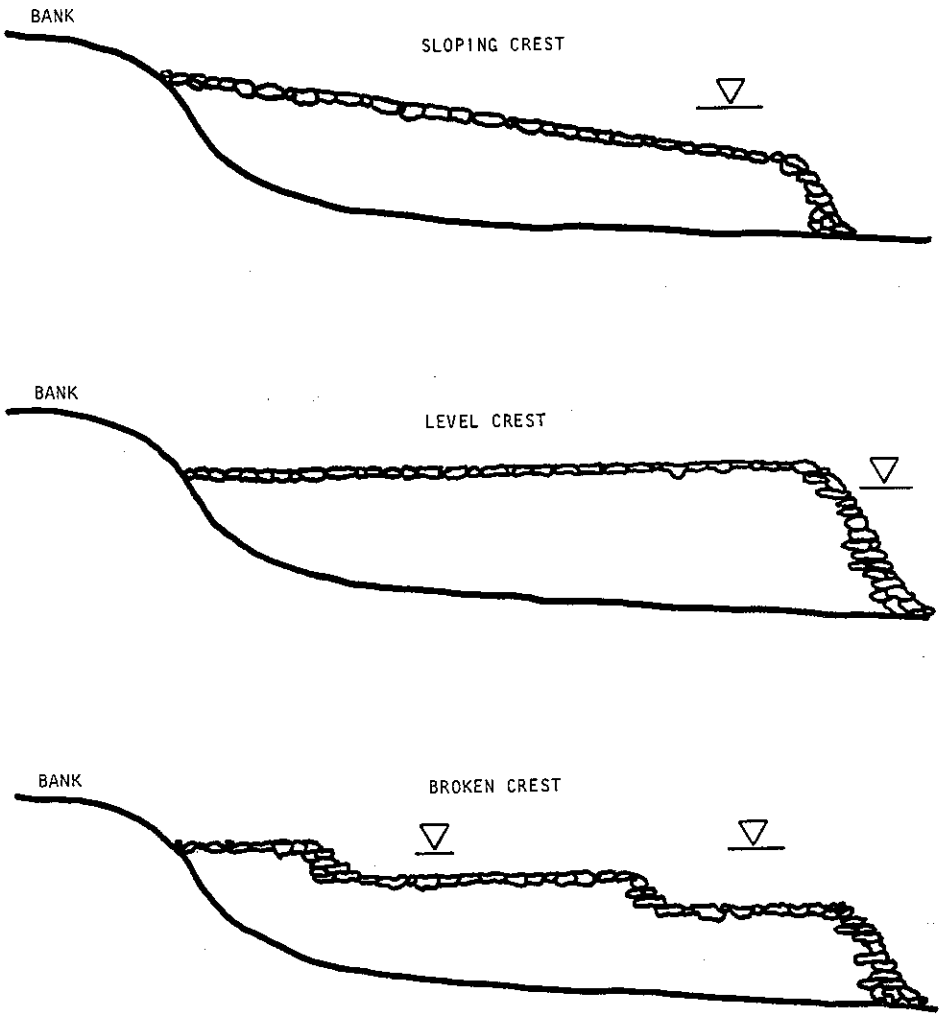


Figure 8. Dike crest profiles

changes in the amount of flow constriction related to different stages, while a sloping crest dike induces gradual changes in flow constriction.

66. Dikes are often designed with a gradually sloping channelward tip. This feature reduces flow constriction, scour, and roughness of the flow at the tip. A sloping tip may be incorporated into any of the other crest profile designs.

67. Crest profiles vary from river to river and by CE District. While there are no standards, there are a few widely accepted design practices:

a. Level crest dikes are preferred on the narrower rivers, such as the Missouri River (Mellema 1978).

b. Level crest profiles typically provide greater flow constriction.

c. Sloped crest profiles are used on the rivers with marked stage fluctuations, such as the lower Mississippi River.

d. Sloped crest and broken crest profiles are usually less expensive to construct.

e. Sloped crest profiles reduce the potential for flanking problems and bank erosion.

Dike spacing

68. Dike spacing refers to the distance between dikes in a dike field. Dike spacing on bends is directly related to the radius of the bend, with short radius bends requiring closer spacing of dikes than long radius bends.

69. The main criterion for spur dike spacing is to place the dikes close enough so that the low-water navigation channel does not meander into the areas between the dikes (Pokrefke 1978). This criterion also applies to vane dikes. Spur and vane dike spacing is thus a function of the dike length and the river alignment, and it varies by river and CE District. Spacing rules-of-thumb are used by the Districts as generally accepted design guides. An example of a rule-of-thumb is to space dikes 1.0 to 1.5 times the dike length. These rules-of-thumb guides are altered to fit the specific site requirements. Another example of a spacing guide is the system used on the Missouri River based on the premise that the main current will migrate one foot from the end of the dike towards the bank for every 4 to 5 ft traveled longitudinally downstream. The purpose is to place the next

dike downstream so that it intercepts the current before the current touches the bank, thus reducing bank scour (Thackston and Sneed 1982). Specific spacing and other design criteria have been developed for dikes on the Red River Waterway (New Orleans District 1972) as follows:

a. Dikes along concave banks. A dike system along a concave bank usually consists of a leadoff structure at the upstream end, approximately parallel to the flow and connecting with the bank far enough upstream to avoid being flanked, and a series of spur dikes extending out from the natural bank to the rectified channel control line. Spur dikes are generally constructed at an angle downstream about 5 degrees from normal to the channel control line to insure that flow is not directed toward the landward end of the dike. The landward 100 to 200 feet of the dike is constructed normal to the existing bank line to insure that flow across or through the structure continues downstream essentially parallel to the bank to prevent flanking.

(1) The proposed rectified channel is first layed out. A line through the centroids of flow for the rectified channel sections is outlined on the layout.

(2) The leadoff structure is then layed as discussed above. An attack line is drawn tangent to the line of centroids and through the downstream end of the leadoff structure.

(3) The first spur dike is spaced such that the attack line intersects the dike in the outer one-third of the length of the structure. For extremely long dikes, the length that would be exposed to the main forces of the river should be reduced by the exercise of judgment, to prevent an excessively long portion of the structure from being under direct attack.

(4) Another attack line is then drawn tangent to the line of centroids and through the riverward end of the first spur dike. The angle between this attack line and the tangent to the channel control line at the riverward end of the dike is bisected and an adjusted attack line projected along this angle. The next downstream spur dike is then located such that the adjusted attack line intersects the next spur dike in the outer one-third of the structure. The result of the use of the adjusted attack line is to allow a wider spacing of subsequent dikes. Experience has shown that turbulence which develops off the ends of spur dikes tends to direct the attack further downstream than would otherwise occur. The adjusted attack line compensates for this phenomenon.

(5) The procedure discussed in the above paragraph is repeated for the remaining spur dikes in the system.

(6) Where the control line is a considerable distance from the existing concave bank, the dikes may have to be extended in stages to allow time for the new channel to develop past the ends of the dikes. When this is done, the dike spacing must meet the above criteria at the intermediate construction stages, as well as ultimately, since several years may elapse between stages, depending on flow conditions. As an alternative, depending upon economy of construction, the complete dike system could be constructed in conjunction with channel excavation to develop the new channel.

b. Dikes in straight reaches and along convex banks. A dike system in a straight reach or along the convex side of a bend is constructed to promote accretion, enlarge and stabilize the navigation channel, close off chutes and swales, or prevent the development of new chutes. In general, the dikes within the system can have a much wider spacing than dikes on the concave side, and the system is generally used in only about the upper third of the bend (unless contraction is required). The spacing of these structures depends upon the location of existing sand bars, direction of attack through these bars, and the overall channel conditions. In some instances, attack lines using the meander channels and existing sand bars as guides can be developed as discussed and used in spacing these structures; however, considerable judgement with knowledge of the existing channel is generally required to develop a properly spaced dike system.

70. Spacing of L-head dikes is typically described according to the percent of closure achieved by the L-head portion of the dike. For example, if two L-head dikes are 300 ft apart and the upstream dike has an L-head portion 100 ft long, then a 33 percent closure has been achieved.

71. Analysis of laboratory data by Linder, Christian, and Mellema (1964) indicated that a minimum of 50 percent closure was necessary for effective channel development and stabilization by L-head dikes on bends of medium radii (6,000-16,000 ft). The effectiveness of L-head dikes was found to diminish after 65 percent closure was reached. (As the closure increases, the L-head dikes begin to resemble a longitudinal dike.) However, L-head dikes are often unequally spaced within a bend, and spacing varies between bends. A special analysis (Linder, Christian, and Mellema 1964) of unequally spaced L-heads indicated that the total closure should be 45-60 percent.

Dike angle

72. Dike angle refers to the angle between a spur or vane dike and the river bank, and is an important factor in controlling the location and amount of scour near the end of the dike (Pokrefke 1978). Dike angle is a highly variable design factor, dependent upon the site characteristics and the flow constriction desired. There are considerable design differences between CE Districts, with little data available regarding effects of various angles.

73. In Franco's (1967) model study at WES, dike angle was investigated by comparing level and sloping crest dike systems with all dikes normal to the flow, with all dikes angled 30 degrees downstream, and with all dikes angled 30 degrees upstream. The best performance (rated by increase in depth, channel alignment, dredging index, scour, and deposition indices) occurred with the dikes angled downstream, and the worst performance with the dikes angled upstream. Level crest dikes angled upstream in Franco's study produced the least depth of scour, but the scour area was greater. Dikes angled upstream also produced greater disturbance to flow. The performances of dikes placed normal or angled downstream were similar, with dikes angled downstream slightly more effective at increasing the controlling depth. Dikes angled downstream showed a greater tendency to scour at the bank end, but this factor was not included in the rating. In addition, dikes angled downstream probably cost more to construct than dikes normal to the bank due to their greater length. Sloping crest dikes showed better results with dikes angled upstream.

74. Sills are typically constructed at the same angle as the dike to which they are attached, however, there are some variations in the angles. A model study of sills (U.S. Army Engineer Division, Missouri River (MRD) 1966) investigated several sill designs and determined that the optimum location and angle of a sill are largely determined by the angle of attack by the flow. However, sills perpendicular to the flow were found to provide greater flow deflection than sills angled downstream or upstream. Sills angled fifteen degrees upstream from dikes on the convex bank were successful in diverting flows to the concave bank, although significant scour and attack occurred on the channel ends of these sills. L-shaped

extensions on the ends of sills did not appear to increase the flow deflection, although scour around the ends of the sills was reduced.

75. Although there are no standards regarding dike angle, there are several common design practices, including:

a. The first dike in a field is angled downstream with subsequent dikes normal to the flow.

b. Dikes angled upstream are not commonly used.

c. Most dikes are roughly normal to the flow.

76. In summary, the most common design angles are normal to the flow and slightly angled downstream. Angled dikes develop the navigation channel better than normal dikes on many rivers, but problems with bank scour often limit their use.

Dike design practices by CE District

77. As previously stated, dike design is a highly variable mixture of engineering and art, being dependent upon the waterway characteristics, site characteristics, navigation requirements, and the personal experience of the design engineer. However, there are certain design practices which are common to all rivers, a specific river or river reach, or a CE District. The general design practices of the CE Districts on the major navigable rivers with dike fields are shown in Table 2.

Construction of Dikes

78. Construction of dikes is typically an incremental affair due to economic constraints and uncertainties over river response. Based on the river master plan, waterway characteristics, and navigation goals, sites that require new construction or modification of existing dikes are determined. As construction money becomes available, CE personnel prioritize sites for work on a benefit/cost basis. Benefits are typically defined in terms of maintaining and developing the navigation channel and bank stabilization. Stage or phase construction of dikes is a common approach for both single dikes and dike fields.

Table 2

Dike Design Practices of CE Districts

RIVER SYSTEM	CE DISTRICT	DIKE TYPES	CREST EVELATION	DIKE LENGTH	CREST PROFILE	DIKE SPACING	DIKE ANGLE
MISSOURI RIVER • River Mile 734 to 498.5	OMAHA	Spur Vane L-Heads Longitudinal Sills Closure	Convex dikes at 0 to +1 CRP; concave dikes at +2 CRP; kickers at +4 CRP[1]; normal	100' maximum[1]	Level and irregular[3]	4.0 times length of lead dike, based on premise that current travels 1' towards bank for every 4 - 5' downstream, dikes spaced to prevent current from scouring bank. L-Heads with 50% closure **	Dikes angled downstream 7 to 22°"; sills angled 15° upstream
• River Mile 498.5 to Mouth	KANSAS CITY	Spur Vane L-Heads Longitudinal Sills Closure	Spur concave +3 to +5 convex +1 to +3 L-heads +1 to +3 Longitudinal +3 to +5 Sills -1 to -2 Crossing control structure +4 to +6	300' to 500'[2]	Level and irregular[2]		
UPPER MISSISSIPPI RIVER • River Mile 868 to 614	ST. PAUL	Spur Closure	Dikes built early 1900's for 6' channel, dams built for 9' channel submerged dikes[5]				Spur dikes normal to flow
• River Mile 614 to 300	ROCK ISLAND	All but 5% are submerged closure dikes; rest are Spurs, L-Heads, Longitudinal[6]	95% of dikes are submerged at low water[6], built for 6' channel prior to dams built for 9' channel[6]				
MIDDLE MISSISSIPPI RIVER • River Mile 300 to 0 (Cairo, IL)	ST. LOUIS	Spur Closure Longitudinal	Midbank elevation, normal or stepped down at 2' per dike[7]		Sloped. Constant slope from high bank elevation to riverward tip		Dikes angled downstream and normal to flow[8]
LOWER MISSISSIPPI RIVER • Cairo, IL to River Mile 599	MEMPHIS	Spur Closure Vane L-Head	Midbank elevation[9] may be normal or stepped down		Sloped over last 500', with a vertical drop of 10' to reduce flow constriction and scour[10]	1.0 to 1.5 times the dike length[7], vane dikes typically 500 - 1000' apart[11]	Spur dikes at normal alignment[10]

(Continued)

Table 2 (Concluded)

RIVER SYSTEM	CE DISTRICT	DIKE TYPES	CREST ELEVATION	DIKE LENGTH	CREST PROFILE	DIKE SPACING	DIKE ANGLE
LOWER MISSISSIPPI RIVER (cont'd) • River Mile 599 to 320	VICKSBURG	Spur L-Heads (few) Closure Vane	Midbank or 10 - 15' above ALWP[3]; may be normal, stepped down, or stepped up[12]		Sloped over entire length: first 200-300' slopes from top bank to midbank elevation, then slopes to end of dike at 7-15' above bottom[13]	Spur dikes are spaced 1.5-3 times dike length. Vane dikes are spaced equal to length, commonly 1000' to 1200'[12]	Generally normal to flow. In some cases, bank end of spur dike is perpendicular to bankline and stream end is perpendicular to flow.[13] Angle changes near the middle of the dike, and thus plan resembles a shallow V. Vane dikes at angle of 10-15° to flow
ARKANSAS RIVER	LITTLE ROCK	Spur L-Heads Closure Vane Longitudinal	Spur dikes equal in elevation to natural bars or 2 - 3' above average navigation pool elevation[14]				
COLUMBIA RIVER	PORTLAND	Spur (double rows of piling with stone apron)		100' to 200'		Spaced to encourage sediment deposition in dike field[15]	Right angles to direction of flow[10]
ALABAMA RIVER AND APALACHICOLA RIVER	MOBILE	Spur Vane (few)	Normal or stepped down[16]		Sloped and broken[16]	1.0 to 1.5 times the dike length[16]	Angle first dike in a dike field 45° downstream, subsequent dikes normal to flow[16]

*Design practices described are "rules of thumb" design approaches and general characteristics common to each CE District. Specific dikes or dike fields may or may not be similarly designed due to the variability in river and site characteristics.

**% closure refers to the distance between two adjacent spur dikes closed by the addition of an L-head trail.

1 John LaRandeau, Omaha District. Personal communication. 11 January 1983.
2 Tom Burke. Kansas City District. Personal communication. 27 July 1982.
3 Mellema 1978.
4 U.S. Army Engineer District, Kansas City 1980a.
5 Bob Whiting. U.S. Army Engineer District, St. Paul. Personal communication. 21 June 1982.
6 Dick Baker. U.S. Army Engineer District, Little Rock. Personal communication. 22 June 1982.
7 Claude Strauser. U.S. Army Engineer District, St. Louis. Personal communications. 28 July 1982, and 17 January 1983.
8 Strauser 1978.
9 Don Johnson. Memphis District. Personal communication. 16 June 1982.
10 Littlejohn 1978.
11 Bobby Littlejohn. U.S. Army Engineer District, Memphis. Personal communication. 9 August 1982.
12 Charles Elliot. Vicksburg District. Personal communication. 21 July 1982.
13 Elliott 1978.
14 Pokrefke 1978.
15 Portland District 1976.
16 Whittington 1978.

Single dikes

79. Construction of a dike typically involves bank or site preparation and stone placement. Bank preparation activities include clearing, grubbing, snagging, and bank grading. Excavation of a root trench, which is a dike section keyed into the bank, may be required. Stone placement is normally accomplished by dragline from barges or end-dumping from trucks. Construction by end-dumping is more difficult, since stone sizes tend to segregate when dumped.

80. The first step in construction is bank preparation, which begins with clearing, grubbing, and snagging. These activities are typically limited by the specifications to those bank areas at the point of intersection with the dike and for required distances where bank protection will be placed. Clearing consists of removing trees, brush, and other obstructions. Grubbing is the removal of buried stumps, limbs, and roots to finished grade or below. Snagging is the removal of all inwater stumps, limbs, and obstructions. The riverbank which will be covered by stone is then graded to slopes required by slope stability considerations. Where a root trench is required, a trench is excavated into the bank and filled with stone to provide a firm tie between the bank and the dike. A riprap revetment is sometimes placed downstream (extending a few hundred feet) of the dike in lieu of the root trench.

81. Placement of stone for the dike typically proceeds from the bank channelward. Constructing a stone dike to its design crest elevation and length in a single stage will complete the channel constriction. However, this method typically results in increased scour at the river end of the dike, and thus in increased costs since more stone is required to fill the scour hole that develops (Pokrefke 1978). The end scour may be reduced somewhat by maintaining a blanket of stone several feet thick in advance of the main dike section. The entire dike length may also be constructed in lifts, placing a layer of stone the length of the dike and then repeating the process until the design crest elevation is achieved for the full dike. Stage construction may be extended over several seasons or years, allowing the river to gradually adjust to the dike, thus avoiding excessive scour. Extending stage construction over a period of time also takes advantage of flow constriction provided by sediment accretion. Where these low-elevation

or partially completed dikes perform adequately they may not require further construction. Accreted sediments may also reduce stone requirements for future construction.

Dike fields

82. Dike fields are usually constructed starting with the upstream dike and progressing downstream. This may be done by either constructing the entire first dike prior to initiating construction of the second, or by constructing all of the dikes sequentially using stage construction. Where construction funds are insufficient to install an entire dike field, the first dike built is usually the most critical in terms of improving the navigation channel.* Constructing the upstream lead or critical dike first allows observations of river response which may necessitate design changes (e.g., changing crest elevations, length, cancellation of a dike, etc.) within the dike field (Omaha District undated). Lead dikes generally cause deeper local scour than subsequent dikes. Local scour is often reduced by building the lead dike shorter and/or lower than downstream dikes, angling downstream, or using an L-head. The lead dike may promote sediment deposition downstream which reduces material quantities and costs for subsequent construction of downstream dikes.

Data Needs and Ongoing Research

Data needs

83. Data requirements for the design and construction of dikes are numerous, and unfortunately much of the desired data do not exist or are not available in a readily accessible form. Compiling meaningful data sets is difficult due to the numerous variables involved and less-than-perfect understanding of the relevant river processes. A major element is the lack of understanding of the effects of dike design factors (e.g., crest elevation, length, profile, spacing, and angle) on the hydraulics and morphology of both the main channel and the backwater areas within the dike field.

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* Charles Elliot. Vicksburg District. Personal Communication. 21 July 1982.

Ongoing research

84. WES is currently conducting a research effort to address physical effects of dike design and construction, with the objective of developing an Engineer Manual for hydraulic design of dikes. WES's effort involves a physical model study of the dike design factors of crest elevation, crest profile, spacing, and angle; guidance on dike height and spacing is anticipated to appear in May 1984. Output from this research effort will be criteria for dike design in the form of envelopes (i.e., ranges) for the various design parameters. The end product will be entitled "Navigation Channel Stabilization Using Dikes and Revetments.*

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* Tom Pokrefke. WES. Personal Communication. 21 July 1982.

PART III. DIKE FIELD EFFECTS

Effects on River Hydraulics and Morphology

General scour

85. High dikes. Dikes and revetments are used to contract river channels, forcing all flow through a narrower width. The resulting increased velocity erodes the bed to a lower equilibrium elevation (Figure 9). If we assume steady conditions, and if we further assume that the dikes are not overtopped, we may combine the equations of continuity for water and sediment with formulas for the transport rates of water and sediment and derive the relative depth in the contracted section. Straub (1935) and Anderson (1962) and Anderson and Davenport (1968) presented the following equation:

$$\frac{Y_n}{Y} = \left(\frac{W}{W_n}\right)^{0.429} \left\{ \frac{-\tau_c/\tau + [(\tau_c/\tau)^2 + 4(1-\tau_c/\tau)(W/Wn)]^{1/2}}{2\ (1 - \tau_c/\tau)} \right\}^{0.429}$$

where Y is channel depth, W is channel width, and τ is the mean boundary shear for sediment composing the river bed, all prior to contraction. The same variables with the subscript n denote values for the contracted channel (Figure 9). This complex equation may be approximated, however, by

$$\frac{Y_n}{Y} = \left(\frac{W}{W_n}\right)^{\theta}$$

The exponent, θ, ranges from 0.643 for very high rates of sediment transport to 0.857 for small rates of transport.

86. Komura (1963) revised this analysis employing more recent work to describe the transport of sediment over moveable beds. His results were essentially the same, except he proposed a value of 0.686 for θ.

87. Low dikes. For a situation where flow conditions are steady, but the dikes are overtopped, Anderson (1968) showed that

$$\frac{Y_n}{Y} = \left(\frac{Q_c}{Q}\right)^{0.857} \left(\frac{W}{W_n}\right)^{\theta}$$

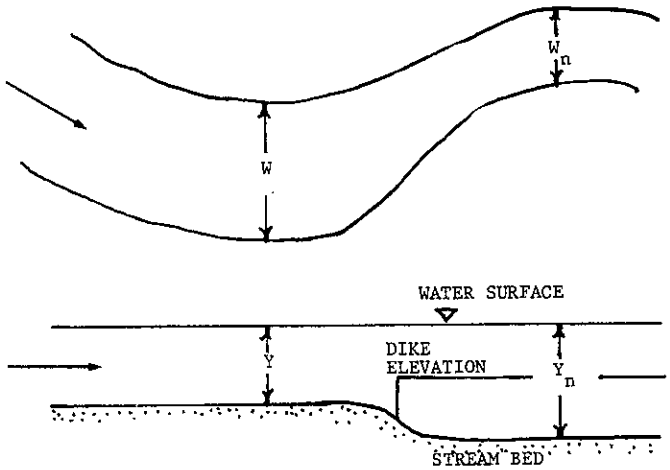

Figure 9. Bed scour caused by flow constriction of high dikes

where Q_c is the flow in the main channel (contracted section) and Q is the total flow. Q_c, of course, is directly proportional to the height of the dikes. This relationship was tested using a small laboratory flume where $W/W_n = 2$. Fairly good agreement with predicted values was obtained; however, there was a tendency for the depth ratio to be larger than predicted.

88. Anderson and Davenport (1968) argued that low dikes were more desirable than high dikes because high dikes cause excessive scour at high flows. Scour is really needed only to provide navigable depths during low flows. Using the equation presented above for low dikes, we see that the bed of the channel is scoured at low flows ($Q_c = Q$, $Q_c/Q = 1$), but as flow increases and overtops the dikes, the bed elevation tends to increase to its original value (Figure 10). Low dikes thus have less impact on flood flows and bed regime than high dikes.

89. Empirical relationship. Gill (1968) reported the empirical relationship

$$Y_{n_{max}} = K\left(\frac{Q}{W_n}\right)^{0.667}$$

for scour in channels contracted by spur dikes, where $Y_{n\ max}$ is the depth of maximum scour below the water surface, and K is an empirical constant, usually between 1.2 and 1.5. Gill also reported that scour was slightly greater for spur dikes angled upstream than for those perpendicular to flow or angled downstream.

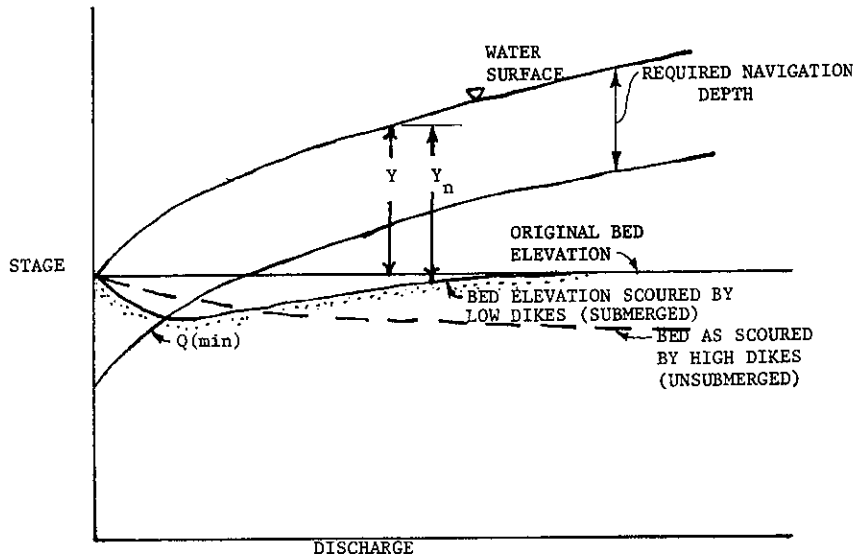

Figure 10. Bed scour by low dikes compared to high dikes

Local scour

90. The flow field around the end of each dike is very complex. Acceleration of the water around the tip of an isolated dike causes a large scour hole to develop at its channel end. The typical form of the hole is as shown in Figure 11. The sediment from this hole is deposited in a long, low bar downstream and behind the dike. The bar also accretes sediment from other sources. The form of the bar is such that the water is still rather deep along the bankline immediately behind the bar (i.e., the backwater area developed by the dike). The level of the bar does not increase as quickly after the initial scouring.

91. Generally, the bar can grow to the approximate elevation of the crest of the dike but not much higher except when vegetation becomes established. Thus, low dikes tend to have low bars, and high dikes tend to have high bars. However, some dikes on the lower Mississippi River have accreted bars higher than the dike crests, without vegetation.

92. In general, the isolated dike does not cause lowering of the river bed in any part of the river except at the local scour hole because the acceleration of the flow is local only. When dikes are placed in fields, they cause a general acceleration of the flow in the reach (Lindner 1969), which in turn causes the river bed to lower throughout the reach. Local scour still occurs at the end of dikes in dike fields. Lead dikes are generally subjected to more attack by the current than downstream dikes,

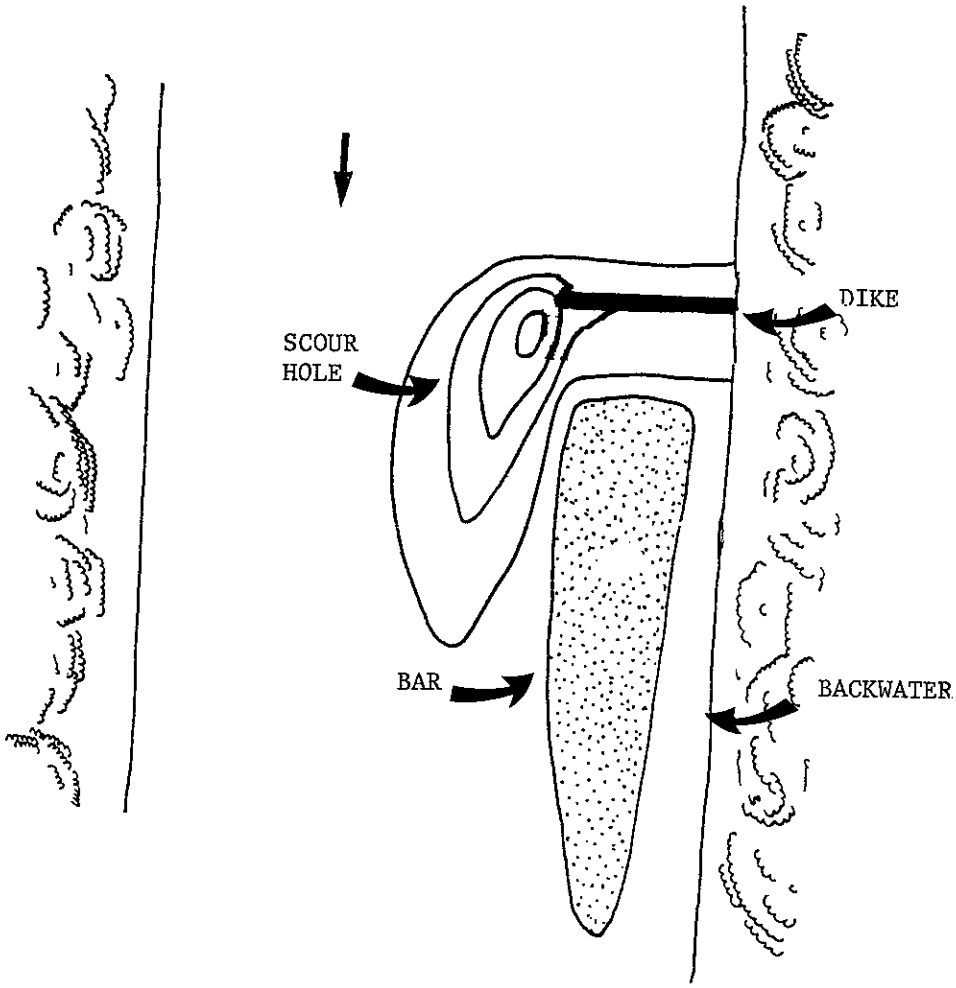

Figure 11. Typical morphological effects of an isolated dike. A local scour hole forms at the channel end of the dike. The scoured sediments are deposited in a bar immediately downstream from the dike. A backwater area is formed between the bar and the bank behind the dike

resulting in deeper local scour holes at their channel ends. This deep scour can be mitigated by changing the alignment and type of dike used as the lead dike in a dike field, as described in Part II. Within dike fields there is a similarity of scour patterns downstream from the dikes in the field (Smith et al. 1982). Generally, scour occurs on the downstream side when the dikes are overtopped.

Vegetation interactions

93. The primary pioneer species on new river deposits in the Mississippi River system are willow and cottonwood (Vicksburg District 1976). These hardy trees can affect the morphology of a river reach by decreasing the velocity over a bar, thereby inducing sediment deposition. There is typically an abundance of seeds for these species in all reaches of the Mississippi River system.

94. According to Fowells (1965), ripe seeds of the cottonwood and willow are produced in the period from April to August, with ripening occurring later in the South. The viability of the seeds is reduced if they are not kept moist. Very moist (almost flooded) exposed silt, sand, or gravel substrate is necessary for satisfactory germination of the seed. In full sunlight fresh seeds germinate in 48 hours and seedlings develop with great vigor. The seedlings are extremely delicate in the first weeks, being intolerant of shade and requiring a constant supply of moisture.

95. Pure stands of cottonwood or willow are the general rule, with willow on the wetter sites and cottonwood occupying the slightly drier areas. When mixed stands of seedlings occur, the cottonwood asserts dominance in 10 to 20 years, crowding the willow out by overtopping and shading.

96. Both willow and cottonwood grow rapidly. Under favorable conditions cottonwood seedlings grow 4 to 5 ft per year; willows reach a height of as much as 4 ft in the first year (Fowells 1965).

97. Once well established on new bars in a dike field, stands of willows and cottonwood can become almost indestructible. Willows can withstand complete submergence during summer months for up to five years (Fowells 1965). Willows and cottonwood seedlings survive even after floodwaters have stripped away their leaves. Seedling stems are extremely flexible and do not break but merely bend when exposed to fast current. The

saplings are well anchored by large roots which can extend deeply into the sand in search of an uninterrupted supply of moisture. Willows extend new root systems annually when sediment deposition rates are large. The new roots, which can be even more tolerant to flooding, grow out of the stems into the new deposits.

98. Unless the colonized sand bar is scoured away, the vegetation causes deposits of new sediment which typically raise the level of the bar up to that of the floodplain. The vegetation is very effective in converting the sand bars from aquatic to terrestrial habitat.

99. Some dikes produce sediment deposits with elevations so low that cottonwood and willow seeds typically do not germinate. As long as the bar is completely submerged, no germination can occur. Also, if there are no seeds available when the bar emerges from the water, no growth can become established. For each reach of river, there is some general elevation to which bars can accrete without becoming vegetated.

100. Extreme low flows can allow the encroachment of vegetation onto bars. Sandbars which would be totally submerged during growing seasons with normal runoff can become exposed and vegetated during growing seasons with low flows. For the river to reclaim these newly vegetated bars as its riverbed, it must destroy the vegetation by eroding away the bar. Extreme floods are the most effective at scouring the accreted bars, as normal flows may increase the height of the vegetated bar through deposition of sediment.

101. A hypothetical example of the growth of a sandbar developed by a dike is illustrated in Figure 12. In the first flood season, the bar grows rapidly within a few feet of the height of the dike. Suppose that under normal hydrologic conditions, no vegetation can be established. The bar height stabilizes at this level. During large floods some erosion may occur on the surface. Then during a prolonged period of low flow, conditions are favorable for vegetation and willows colonize the bar. Thereafter, the sandbar grows in height as sediment which would have passed on downstream over the unvegetated bar is deposited in the willows. Ultimately, the bar height approaches that of the floodplain. If the bar becomes attached to the bankline, the bar becomes indistinguishable from the floodplain. When no attachment occurs, the vegetated bar becomes an island.

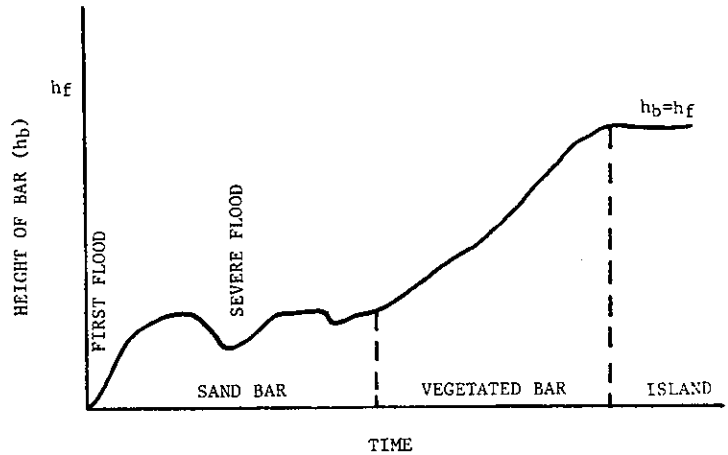

Figure 12. Development of a sand bar behind a dike. The height of the bar (h_b) is measured from the original (before dike) bed level. The hypothetical sequence illustrated here is one of a severe flood followed by prolonged low flow, colonization of the bar with willows, and then conversion to an island at the level of the floodplain (h_f)

102. The effect of pioneer vegetation on the morphology of dike fields varies with the size of the river system. In the lower Mississippi River the yearly stage can change as much as 60 ft (Beckett et al. 1983), and new vegetation forming on bars in dike fields is destroyed by the fast currents and very large sediment transport rates much more readily than in smaller rivers where stages, velocities, and transport rates do not vary as much. For example, in the lower Mississippi River, pioneer vegetation can be buried as bars change shape during the passage of the annual flood. An average bar in the lower Mississippi River can contain as much as 100,000,000 tons of alluvium above the low-water line (Winkley 1980).

Stages

103. Dike fields modify the stage-discharge relationship for the affected reach of river. The modifying factors are the changes in cross-sectional area of the river, changes in hydraulic roughness, and the amount of riverbed degradation. Also, there are backwater effects when the diked reach is very short or the river slope is very mild.

104. Floods. Low dikes are less prone to change flood stages than high dikes which induce willow and cottonwood growth and increased sedimentation on areas which were previously riverbed.

105. When the dike field does cause a reduction in the bankfull cross-sectional area of the reach, this tends to increase flood stages. However, this tendency may be offset by two factors. First, the dike field causes the riverbed to degrade. Second, in wide sand and gravel-bed rivers, the hydraulic roughness generally decreases at flood stages when the unit discharge is increased, and dikes which narrow the channel increase unit discharge. The decreasing roughness results in less depth of flow. The water surface elevation (stage) is obtained by adding the depth of flow to the riverbed elevation.

106. Dike fields may increase, decrease, or not affect flood stages, depending on the degree of contraction, the amount of degradation, the development of bars and vegetation, and the roughness-versus-unit-discharge relation for a particular reach.

107. Low flow. The same type of analysis for low flow leads to the general conclusion that dikes can raise or lower the low-flow stage. Degradation lowers the riverbed, but constricting the flow increases the channel depth. The net effect can be a lowering of the stage during the low-flow season as in a section of the middle Mississippi River (Degenhardt 1973) or a raising of the stage (as described in Part VII in the Sandy Hook Bend case study).

Other factors

108. The supply of water and sediment to rivers changes over time. These changes in supply affect the response of the rivers to dikes. For example, dams constructed on the Missouri River between 1940 and 1964 have decreased the sediment supply to the lower reaches by one-third and have reduced the size of annual flood peaks. The reach of the Missouri River above the mouth of the Platte River has undergone marked degradation in response to the reduced sediment load. Dike fields downstream, however, have accreted more sediment at higher elevations due to reduced scour from reduced annual flood peaks.

Uniqueness

109. Rivers, and in some cases river reaches, have a unique character. They may differ from one another in one or more of the following principal factors affecting hydraulics and morphology:

a. Supply of water (amount and duration).

b. Supply of sediment (amount, size, and duration).

c. Natural width.

d. Natural sinuousity.

e. River bed and bank roughness.

110. In addition, rivers developed as commercial waterways differ from one another and from reach to reach in navigation requirements such as depth, width, allowable curvature, and maximum velocity. The main types of pioneer vegetation, willow and cottonwood, are a common factor for all reaches of the Mississippi River basin upstream from the delta, including the Missouri River.

111. The lower reaches of the Mississippi River are in general more difficult to deal with than the upper reaches and tributaries for two reasons. The flat slope of the river bed in the lower river means that effects reach long distances upstream and downstream of any dike field. Also, in the lower river there are bends with very large deflection angles and relatively short radii of curvature. In these bends, the thalweg makes one or more crossings of the channel within the bend. The hydraulics of these bends is very difficult to analyze, and therefore physical models are often used to design dike fields for these bends.

River-specific effects

112. Missouri River. The dike field construction program on the Missouri River is essentially complete, and significant effects on the morphology and hydraulics have been observed. Low-flow stages are at lower elevations than previously, indicating bed degradation has occurred, probably due to the dikes and reduction of sediment discharge caused by the mainstem reservoirs (Omaha District 1981). These lower stages cause lowering of the water levels in ground water tables, ponds, lakes, and backwater areas in the vicinity of the navigation channel (Omaha District 1981; Persons 1979). Sediment has accreted in shallow water areas between dikes and downstream of dikes, reducing the total water surface area (Omaha

District 1975). Channel constriction efforts, including dike fields, revetments, and cutoffs, have caused a general increase in slope (Kansas City District 1980a).

113. Upper Mississippi River. Physical responses of the upper Mississippi River to the dike fields include a reduction of water surface area and surface width and the formation of new islands from dike-induced sedimentation (Simons et al. 1981a). The average riverbed elevations have aggraded slightly (0.8 ft average), decreasing the slope (Simons et al. 1975). The effects of the dikes are masked by a series of navigation dams on the river. In pooled reaches the dams raise water levels at low and intermediate flows above the before dam levels, which increases the depth of flow, decreases the velocity and sediment movement, and increases the water-surface slope (Simons et al. 1975).

114. Middle Mississippi River. On the middle Mississippi River the construction of dikes with relatively high crest elevations has degraded the river bed, increasing the slope in many areas. Simons, Schumm, and Stevens (1974) concluded that for all discharges the depths were greater than before modification by dike fields, reflecting the deepening of the main channel. Their findings indicated that changes in the river's cross section caused by dikes and levees have reduced the flow-carrying capacity of the river for flows greater than bankfull. They based this conclusion on the fact that flood stages are greater for comparable discharges prior to dike construction. However, the early data used in this study are of poor quality and data from the entire river were not examined. Thus whether or not a reduction in flow capacity has occurred is open to question. Westphal and Clemence (1976) noted that the river has undergone a considerable decrease in surface width since the construction of dikes due to sediment deposition in the dike fields.

115. Lower Mississippi River. While large quantities of sediment have been deposited within lower Mississippi River dike fields, floodplain land has not accreted around dikes as much as on other rivers. Extreme stage fluctuations hinder the establishment of permanent vegetation and limit the elevation of bars. Nevertheless, some morphologic changes have occurred that appear to be attributable to dike field construction.

a. Increased thalweg depth. Case studies of dike fields on the lower Mississippi (Wells 1982, paragraphs 342 to 371 of this report) reveal that thalweg depths adjacent to dike fields are increased by scouring over a period of years following dike field construction, especially when dikes are constructed on point bar locations. Effects on the thalweg downstream and upstream of dike fields are less consistent.

b. Decreased width. Several studies show decreases in river width over the period of most active dike construction. Westphal and Clemence (1978) noted a decrease in top bank width of about 4 percent in the Memphis reach from 1961 to 1972 and a decrease of about 20 percent in the Vicksburg reach from 1962 to 1974. Tuttle and Pinner (1982) found that river width in the Vicksburg reach measured at the elevation of the low water reference plane decreased by about 22 percent between 1962-64 and 1975. Nunnally and Beverly (1983) found a decrease in low water width, excluding bars and islands, of about 11 percent between 1962 and 1976 for the Vicksburg and Memphis reaches combined. Their data were measured from low water photographs taken at comparable stages.

Information gaps

116. Despite the number of studies concerning dikes and dike fields, two notable information gaps still exist. First, studies of processes and results have focused on the main channel, and processes within the dike fields have received little attention. Thus, little is known about how dike field placement, river hydrology, and dike design parameters influence patterns of sediment accretion within dike fields. Second, laboratory and theoretical work has failed to simulate the complex dynamics of field situations. Most laboratory studies have been model studies of specific river reaches that do not allow results to be generalized, or they have been flume studies designed to resolve questions about specific design parameters under simplified conditions in which nonexperimental variables are held constant or are severely constrained. As a result, relatively little is known about how dike field design parameters interact under natural conditions. More extensive and systematic studies will be required to resolve these questions.

Effects on Biota

117. It is difficult to determine dike effects on biota, due to the complexity of riverine ecosystems and the scarcity of predike data. Both the physical and biological components of riverine systems are extremely complex, and generalizations regarding the functioning of these systems or their responses to dikes are difficult to make. Riverine biological populations fluctuate from year to year in response to natural events such as floods or low-flow conditions; therefore, several years of sampling are usually required to characterize the biological community. The effects of dikes on biota probably vary by river, by the design of the dike or dike field, and by site-specific factors.

118. Some baseline information about the biological community is necessary to gage the effects of dikes. While some information is available, the density and diversity of biological communities in most large river reaches has been described only superficially. In many cases the only predike information available is the nontechnical reports of early explorers, settlers, and journalists. For the Missouri River some data are available which allow description of the biota of the unchannelized portion of the upper Missouri. With caution, this information can be compared to the data available for the channelized lower portion of the river, and some generalizations can be made regarding the effects of dikes. In some cases information regarding predike habitat characteristics (physical factors) can be obtained from predike engineering surveys, maps, and descriptions.

119. The available literature regarding effects of dikes on biota is summarized below for each of the major waterways with stone dikes. A few general conclusions about the effects of dikes on biota follow these summaries. Summaries of literature regarding enhancement features and designs are included in Part IV.

Missouri River

120. Morris et al. (1968) compared randomly established transects of adjacent diked and undiked reaches of the Missouri River. Benthic fauna and drift were also sampled. Average width in the diked reach was only 789 feet, while the average width in the undiked reach was 2,363 feet. Chutes (small, quiet side channels) composed 15.8 percent of the aquatic

habitat in the undiked reach but only 2.0 percent in the diked reach. Although benthic density was similar for both kinds of reaches, standing crop was reduced due to the 67 percent reduction in aquatic area. Standing crop of drift was 8 g per acre-ft in the diked reach and 68 g per acre-ft in the undiked reach.

121. Funk and Robinson (1974) documented the extent of changes made in the channel of the Missouri River in the past 90 years, described how these changes resulted in a loss of fish and wildlife habitat, and evaluated these losses in present-day terms. Their information was obtained from various historical records, particularly commercial fishery reports. The study area encompassed the Missouri River from Rulo, Nebraska, to the mouth. Between 1879 and 1972 the water surface area of the river was reduced by 50 percent and most of the backwater habitat was lost. The authors concluded that habitat changes, particularly the loss of backwaters, contributed greatly to the decline of the fishery in the Missouri River. They also attribute the decline in wildlife and waterfowl to this loss of backwater habitat.

122. Clapp (1977) conducted a study to determine the value to wildlife of the free-flowing portion of the Missouri River. He also attempted to identify and measure habitats and assign a value to each of the natural habitats. The eight distinct habitat types sampled were agricultural, urban, sandbar, sand dune, cattail marsh, cottonwood-willow, cottonwood-dogwood, and elm-oak areas. Only vegetation was sampled. The habitats were rated for big game, upland game mammals, furbearers, small mammals, upland game birds, waterfowl, other water and marsh birds, terrestrial birds, reptiles, and amphibians.

123. Three terrestrial habitat types were described as being particularly valuable. Sandbars provided feeding locations for breeding shorebirds and resting areas for migrating waterfowl. Cattail marshes provided excellent habitat for aquatic furbearers such as muskrat and mink by supplying both food and cover. Cattail marshes also provided valuable resting cover for migrating waterfowl. The only habitat which was of value to all nine groups studied was the cottonwood-willow association.

124. Several studies have compared the aquatic habitats of the channelized and unchannelized portions of the Missouri River. Schmulbach (1974) studied the biota in the unchannelized river prior to construction of

bank-stabilizing structures. Later, Groen and Schmulbach (1978) inventoried the sport fishery in both the channelized and unchannelized portions of the river. In the unchannelized river, Schmulbach (1974) found cattail marshes and sandbars to be valuable aquatic habitats which were intensively utilized as nursery grounds by immature fishes of many species.

125. Schmulbach (1974) also studied the aufwuchs community and reported that the unchannelized river had a standing crop of drift organisms per acre-ft which was approximately eight times greater than in the stabilized river. He attributed this difference in abundance to the great diversity of microhabitats and niches in the unchannelized river. Groen and Schmulbach (1978) concluded that this diversity of niches and microhabitats was also responsible for the larger standing crops and higher harvest rates of sport fish in the unchannelized river as compared to the stabilized river. They attributed the decreased habitat diversity in the channelized river largely to the loss of aquatic backwater habitat.

126. Another comparison of the channelized and unchannelized Missouri River was made by Kallemeyn and Novotny (1977). The purpose of their study was to examine the abundance of fish and fish food organisms in the natural and stabilized river. They sampled channels, channel borders, chutes, backwaters, marshes, pools, sandbars, notched spur dikes, notched longitudinal dikes, notched closure dikes, and unnotched spur dikes. Fish were sampled with gill nets, trammel nets, hoop nets, seines, a drop trap, and an electroshocker. A plankton net was used to sample fish larvae and zooplankton.

127. Fish were most abundant in backwaters and marshes in the free-flowing rivers. The fish community was less diverse in the channelized portion, with 70 percent of the catch consisting of carp, channel catfish and river carpsucker. The largest catches in the channelized section were in the habitat created by notching dikes. Fish catches in this habitat were similar to those from backwaters and chutes in the unchannelized river. This led the authors to conclude that it was feasible to restore some habitat diversity to the channelized river. They recommended that some flow be directed to backwater areas and chutes to prevent sediment accumulation and to maintain habitat diversity.

128. Burress, Krieger, and Pennington (1982) compared the relative values for fish and macroinvertebrates of nine habitats along the unchannelized portion of the Missouri in North Dakota. Sampled habitats consisted of six bank stabilization structures and three locations unaltered by structures. The bank stabilization structures evaluated were an earth core dike, three hard points*, two revetments, two spur dikes, and four L-head dikes. The natural areas examined were two widely separated areas of natural bank and a chute behind two small islands. Fish were sampled with a bag seine, gill nets, hoop nets, and an electroshocker. In addition, a plankton net was used to collect fish larvae and stomach analyses were performed on carnivorous fish. Macroinvertebrates were collected by grab sampling with a Shipek dredge and hand collecting rock fauna.

129. Burress, Krieger, and Pennington (1982) found no significant difference in the numbers of taxa of benthic invertebrates collected per station, but highly significant differences in the mean number of organisms per station. This depended largely on physical characteristics such as current velocity and substrate type, with the current-swept rocks of dikes, revetments, and hard points supporting more kinds and far greater numbers of macroinvertebrates per unit area than the stream substrate.

130. Dike fields had the most diverse fish community of all habitats sampled. The authors attributed this to the presence of somewhat more sheltered and diverse habitats and the greater efficiency of collecting fish with seines and gill nets in areas with shallow shoreline waters and little or no current. Species diversity and abundance were greatest in the L-head dike field and least at the hard points. Natural banks and revetted banks had similar fish species diversity and abundance. The stomach analyses performed on carnivorous fish revealed that the large and diverse assemblage of macroinvertebrates consumed by fish was similar to the assemblages associated with dike fields and revetted banks.

131. Robinson (1973) also evaluated the use of rock dikes and revetment in the Missouri River as habitat for fish and macroinvertebrates. Fish were

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*Hard points are used extensively along shallow Missouri River shorelines. They are similar to spur dikes in cross section but project only 50-60 ft from the bank.

sampled with trammel nets, gill nets, hoop nets, frame nets, rotenone, and electrofishing. Benthic macroinvertebrates were collected with rock-filled barbecue baskets and multiple-plate samplers. Robinson found virtually the same assemblages of fish species in each section. The study did show that fishes were present behind the dikes and may use them as feeding, nesting, and rearing areas. Many of the kinds of invertebrates collected in the study area were found in the stomachs of carp and river carpsuckers, implying that these fish were feeding in the area.

132. Hesse and Newcomb (1982) obtained estimates of fish abundance in the channelized Missouri River during two winters. Winter was chosen as the best time to sample because of reduced movement of fish and the reduced stream flow which tends to concentrate the fish population. They used electrofishing to sample around dikes, which they considered the "best" habitat. The study areas were 16 miles apart, and widely varying densities for similar species were found in the two sections of the river. The authors concluded that this variability was important because casual observations of the channelized river gave the impression that the aquatic habitat was fairly homogeneous throughout. It should be noted however, that the two areas were sampled during different winters. Although the authors did not discuss this, year-class variations could have contributed to the varying densities. In a related study Hesse (1982) examined the food items important to channel catfish in the channelized Missouri River. He found that channel catfish up to 23 in. total length fed principally on insects, crustaceans, and plants. Zooplankton were important in the diet of young-of-the-year channel catfish.

Upper Mississippi River

133. Ellis, Farabee, and Reynolds (1979) selected three side channels representing three stages of riverine succession and compared limnological and fish community characteristics. Fish were collected by electrofishing and hoop netting in a riverine side channel, a lacustrine side channel, and a transitional side channel. The authors found that the relative abundance of catfish and predatory rough fish were similar in the three side channels. Game fish and panfish were more abundant in the lacustrine side channel and nongame fish (forage fish and rough fish) were more abundant in the riverine channel. The authors concluded that side channels having low

flow in late summer and fall probably served as nursery areas for juvenile fish. The authors suggested that reopening side channels may serve as a corrective tactic to reduce the effects of main channel maintenance on fish communities in certain areas; however, the effects should be more thoroughly understood before management decisions are made.

134. Holzer (1979) sampled fish with an electroshocker at dikes, riprap, and sand areas to document their value as fishery habitat. Gizzard shad dominated the catch at the sand site, smallmouth bass and rock bass at the riprap sites, and longnose gar and shorthead redhorse at the wing dams. The largest number of fish species were collected over the riprap sites. Larger gamefish such as walleye, sauger, and smallmouth bass preferred dike habitat. The author concluded that rock riprap is an important fish habitat in the upper Mississippi River, serving as a nursery area for desired gamefish such as smallmouth bass, walleye, sauger, crappie, and bluegill. The dikes provide feeding areas for larger fish with access to deep water sheltered from current. Holzer (1979) found sand habitat was utilized primarily at night as migration routes and feeding areas for smaller walleye, sauger, and other gamefish species.

135. Pitlo (1981) sampled fish around spur and closure dikes in an effort to inventory, describe, and classify the physical properties of approximately 125 upper Mississippi River dike structures by determining those characteristics important to fish. He sampled fish with trammel nets, experimental gill nets, frame nets with leads, hoop nets, and an electroshocker. Commercially harvested fish were more abundant around dike structures than sport fish. Structures located on concave river bends had significantly higher catch/effort and species numbers than those located on convex river bends. There were also more fish reproductively active at structures on concave bends.

136. Pitlo (1981) concluded that water depth over each structure and structure location in relation to the thalweg were the two most important physical characteristics affecting fish populations. Dikes submerged 5 ft or less on concave bends supported the greatest species diversity. Pitlo also concluded that spur and closure dikes provided shelter from current if excessive sediment accretion had not occurred below the dikes.

137. Hall (1980) did a prenotching study of the aquatic macroinvertebrates associated with dikes and an adjacent side channel. Benthic organisms were collected with a Ponar grab sampler, rock-filled baskets, and multiple-plate samplers. He found the total benthic invertebrate density, biomass, and number of taxa to have a significant positive relation to the percent of silt-clay in the substrate. A significant negative correlation existed for the percent of sand in the substrate. The highest benthic invertebrate density, biomass, and number of taxa were found in gravel substrate. Basket samplers placed on dikes yielded nearly 27 times the number of macroinvertebrates than did Ponar grab samples from predominantly sand substrate near the dikes. Hall characterized the dikes as rock oases in a sea of shifting sand.

Middle Mississippi River

138. Ragland (1974) studied three side channels possessing a diversity of habitat types and the main channel border of the middle Mississippi River to evaluate the importance of side channel areas as fish habitat. Fish were collected with electrofishing gear, experimental gill nets, experimental trammel nets, hoop nets, and trap nets. Stomach samples were taken from those species which were present in relatively high numbers. Benthos were collected with rock-filled baskets and multiplate samplers. Plankton was collected by taking composite water samples. Species differences were noted between the main channel border and the side channels. Carp, gizzard shad, bluegill, shortnose gar, bowfin, black crappie, bigmouth buffalo, white bass, and largemouth bass were relatively abundant in the side channels but scarce in the main channel border where freshwater drum and sauger were relatively abundant. No firm conclusions could be drawn regarding habitat preferences from the benthos samples, and no significant difference was found in plankton diversity between the two habitat types. Ragland (1974) concluded that both the main channel border and the side channel habitats were important as fish habitat in the middle Mississippi River.

139. Environmental Science and Engineering (1982) studied all aquatic habitats within the floodplain to identify, characterize, and quantify these habitats and to characterize the aquatic biota associated with each of the habitats. Habitats sampled included stone dikes, pile dikes, main channel, main channel border, and side channels. Fish were collected with

electroshockers, gill nets, trammel nets, hoop nets, frame nets, otter trawl, seines, and, in one side channel, chemofishing. Benthic invertebrates were collected with a Ponar dredge. Observations were made of nonaquatic fauna during all aquatic sampling activities. General faunal-habitat associations observed for both fish and benthic invertebrates indicated that critical determining factors were current speed, substrate composition and stability, and quality of cover. The authors concluded that the habitats having the highest value were river lake, slough, navigation pool, littoral, side channel, and dike field. These aquatic habitats were consistently more productive of aquatic fauna than other habitats sampled.

140. Schramm and Lewis (1974) conducted a literature review of the ecological value of riverine backwater areas, with emphasis on fish species and habitat conditions in the middle Mississippi River. Aquatic habitats were evaluated according to physical and chemical factors (current, turbidity, substrate, and dissolved oxygen). Schramm and Lewis concluded that the complex of off-channel habitats (side-channels, river lakes and ponds, and sloughs) provided the most favorable habitat for fish on the middle Mississippi. Backwater areas were noted as being especially important due to the production of phytoplankton, a primary food source for many fish species, particularly during early life stages. Main channel habitat and other swift water areas did not provide adequate conditions for phytoplankton or rooted aquatic plants.

Lower Mississippi River

141. Wright (1982) summarized the results of a pilot study on the lower Mississippi River, river mile 480 to 530. The pilot study provided significant guidance on sampling, experimental design, data management, and initial ecological observations of fish and benthic invertebrates in several riverine habitats. Twelve major aquatice habitats were identified and mapped. Samples of benthic macroinvertebrates were taken from nine habitat types. Dikes were determined to serve as effective collectors of main channel drift (organisms) and contained an abundance of lentic- and lotic-adapted taxa. The dike structures were the most productive habitat sampled for benthic macroinvertebrates. Dike fields were also found to have the most diverse fish community, based on adult fish sampling. Larval fish sampling at dike fields found relatively low mean densities of larval fish

and a high diversity of taxa. Wright concluded that from an overall view, dike fields, abandoned channels, temporary secondary channels, and oxbow lakes were extremely valuable habitat.

142. Mathis, Bingham, and Sanders (1982) and Bingham (1982) conducted studies designed to identify sampling techniques which would provide quantitative estimates of the composition and relative abundance of aquatic macroinvertebrate assemblages associated with dike structures on the lower Mississippi River. They also obtained basic data on spatial distribution patterns of aquatic macroinvertebrate populations over the dike structures. Macroinvertebrates were sampled by implanting rock-filled rectangular wire baskets into the dike structures. The net-spinning caddisfly (Hydropsyche spp.) was the most abundant taxon collected, but chironomids, isopods, and mayflies were also abundant. The upstream side of the structure had a significantly higher average number of taxa compared to both the top and downstream portions of the structure.

143. The authors concluded that the dike studied was inhabited by a diverse and productive macroinvertebrate assemblage, and they attributed the potential habitat value of stone dike structures to increased habitat (substrate) diversity as well as to habitat stability. Bingham (1982) concluded that the benthos populations of the stone dike structures were characteristic of a benthos-rich riffle habitat.

144. Beckett et al. (1983) conducted a study to (a) characterize the various aquatic habitats in terms of their macroinvertebrate composition, (b) determine to what degree the habitats' species compositions change with variations in river stage, and (c) discover the effects of dike fields on macroinvertebrate distribution and densities. Beckett et al. sampled three dike fields (Lower Cracraft, Leota, and Chicot Landing), a natural bank area, a permanent secondary channel, and an abandoned channel for macroinvertebrates. A Petite Ponar grab sampler was used in soft depositional areas, and a Shipek grab sampler was used in areas of strong current and hard clay substrate.

145. Beckett et al. (1983) found that the bottom substrates of the dike fields were mosaic-like, consisting of patches of various sediment types arranged as a function of current across the habitat. The distributional pattern of macroinvertebrates paralleled this pattern of sediment

distribution. The permanent secondary channel, with shifting sand and gravel substrate, was the least productive of the habitats studied in terms of macroinvertebrate densities. The natural clay bank was an optimal habitat for the large river-burrowing mayflies, and the abandoned channel supported an assemblage of organisms characteristic of eutrophic lentic systems. The authors noted that when flow decreased the substrate dominance in dike fields shifted from erosional (sand) to depositional (mud-silt) and this shift was paralleled by changes in the macroinvertebrate community. They further concluded that changes in the physical structure of the dike field, such as notching the dikes, resulted in changes in the substrate composition of the dike field which concomitantly changed the composition of the macroinvertebrate community.

146. Pennington, Baker, and Bond (1983) quantitatively described fish species diversity, abundance, and distribution in four habitats in the lower Mississippi River. Fish were collected with gill nets, hoop nets, electroshocker, seines, and minnow traps from dike fields, revetted banks, natural banks, and an abandoned river channel. The greatest number of species was captured in the dike field habitat(53), followed in order by the abandoned channel(31), revetted banks(27), and natural banks(24). They concluded that the differences in species, relative abundances, and length frequencies observed among habitats suggested that each was valuable in maintaining the overall riverine ichthyofauna. Furthermore, the loss of dike field habitat due to sediment accretion would seriously have affected the overall quality of the river's fish habitat.

147. Pennington, Baker, and Bond (1983) made three recommendations based on the findings of their study. First, they recommended that engineering features be incorporated into dikes to increase the longevity of dike field aquatic habitat by reducing sediment accretion rates. They recommended that care be exercised in placing dikes and revetments to ensure that side channel and off channel habitat integrity is not greatly altered. Finally, additional sampling is needed to determine whether fish found over dikes and revetments are resident or transient.

148. Bond, Pennington, and Baker (1983) sampled three dike fields, including one where a dike was notched (Chicot Landing), to determine fish populations during low-flow conditions. At low flow, isolated pools form

within the dike fields behind a large middle bar. Fish were collected by seining and electroshocking. Lower Cracraft and Chicot Landing dike fields showed a decrease in catch/effort with decreased flow, while Leota showed a significant increase. It was concluded that dike fields were a large and diverse habitat offering a wide range of depths, currents, and substrates which could affect fish distribution.

149. Conner, Pennington, and Bosley (1983) sampled ichthyoplankton to assess the relative importance of dike fields and revetted banks to planktonic fish larvae and to characterize the seasonal changes in local distribution of ichthyoplankton within a dike field. Their sampling was done in the main channel, a temporary secondary channel, an abandoned channel, dike fields, and along revetted banks. Shads and herring, sunfishes, freshwater drum, and carpsuckers constituted 95 percent of all larvae collected. While most of the more common and abundant kinds of fish larvae occurred in all main-stem habitats at times, certain major taxonomic groups were either absent or extremely rare in abandoned channel habitat. However, the abandoned channel supported the highest larval fish densities among the studied habitats.

150. The authors concluded that the abandoned channel was distinctly more productive in terms of abundance than the main-stem habitats. Ninety-five percent of all sunfish larvae collected were taken in the abandoned channel. The authors also observed that the dike field ichthyoplankton community was actually two communities under low-water conditions: the pool community, inside the middle bar and the riverside community. The greatest concentrations tended to be inside the middle bar. Fishes comprising this "inside" community were mainly shads, bluegill, and inland silversides. Along the riverside of the middle bar, however, the ichthyoplankton community was not substantially different from that of the main channel.

151. Conner, Pennington, and Bosley (1983) recommended maintaining the integrity of abandoned channels and other off-channel habitats because of the apparent importance of these habitats for the larvae of forage and sport fish. These areas, they advised, should be left undisturbed during construction and maintenance of channel alignment structures. They also recommended that placement of dikes and revetments should not coincide with

the peak spawning season, May through July, for the majority of the warmwater fish in the lower Mississippi River.

Conclusions

152. Habitat for diverse and productive communities of fish and macroinvertebrates have been observed in existing dike fields, particularly at low to moderate stages when the dikes create large zones of still or low-velocity water. The stone dike structures themselves provide an excellent habitat for aquatic macroinvertebrates adapted to rock and cobble substrates. A definite correlation has been observed in a number of studies between the substrate type within dike fields and the macroinvertebrate community structure. The greatest diversity in macroinvertebrate communities results when dikes produce a variety of substrate types.

153. Dikes and revetments are designed and placed to prevent lateral migration of the river channel. Therefore no new backwater habitats (abandoned channels, chutes, sloughs, oxbow lakes, etc.) are formed to replace those that are gradually filled by sediment accretion. The loss of backwater habitat has been described by numerous authors as a major factor contributing to the decline of fish and wildlife resources in the large river ecosystems. In some cases dike fields provide habitat physically and ecologically similar to the backwater habitat and thus tend to "replace" that type of habitat. However, if the dike fields fill with sediment, the result is a net decline in the overall physical and biological diversity of the riverine system. For this reason, several of the biological and physical studies of dikes and dike fields have attempted to define those conditions or dike designs that preserve the aquatic habitat of dike fields.

154. Dike fields can also provide habitat (both aquatic and terrestrial) useful to some terrestrial species. Adverse impacts on terrestrial species occur when the riparian forest land accreted within the dike field is converted to grazing or agricultural uses. Funk and Robinson (1974) and MacDonald, Frayer, and Clauser (1979) describe the loss of bottomland forests as a major factor in the decline of wildlife along the major rivers.

PART IV: ENVIRONMENTAL FEATURES FOR DIKE FIELDS

155. Dikes have traditionally been designed to induce sediment deposition in the dike fields. Although deposition is necessary for permeable (timber-pile) dikes to function properly, stone dikes do not necessarily have to fill with sediment to be effective. However, dike fields are often located in zones of natural deposition such as point bars. The dikes often stabilize and increase the elevation and area of these deposits.

156. As sediments accrete in dike fields, the valuable dike field habitat is eliminated from the riverine ecosystem, with a net loss in the amount and diversity of riverine aquatic habitat. Recently some attention has been given to maintaining the open-water areas in dike fields for flood conveyance considerations and to enhance fish and wildlife habitat. Maintenance of open-water areas in many dike fields can be encouraged through variations in the dike design factors and through design features such as notches or rootless dikes. These techniques (and others) are described in this part. The bulk of the available information on design features deals with the Missouri River, where dike construction is essentially complete. Relatively little information is available for the lower Mississippi River, where most future construction will occur. Examples of specific dike fields with environmental features are described in Part VI.

Variation of Design Factors

157. All dike fields are sediment traps to some degree because of the slack water area which develops downstream of each structure (Smith et al. 1982). The rate and extent of sediment accretion in dike fields are dependent upon numerous variables, with key variables being location of the dike with respect to the overall channel alignment and the dike design factors. Dike field location has a greater influence on sediment accretion than dike design (Smith et al. 1982). However, dike design factors are usually easier to manipulate to achieve environmental objectives than dike location, which is determined by navigation requirements. There is little

information available regarding the effects of dikes on scour and deposition within dike fields relative to the amount of information available regarding main channel processes. If more were known about the effects of dikes on sediment scour and deposition within the dike field, dike fields could be designed to retain open water within the dike field and provide desirable aquatic habitat without compromising river training objectives. Franco's (1967) physical model tests provide limited information regarding the effects of varying dike design parameters on deposition rates and patterns. Prototype experience with low-elevation dikes indicates that using low-crest elevation holds some promise as an environmental feature.

Physical modeling

158. In a model investigation of factors affecting the performance of dikes and dike fields on the lower Mississippi River (see also paragraphs 28 and 56), Franco (1967) addressed the effects of design parameters on the elevation and extent of sediment accretion within dike fields. His results were preliminary and his conclusions were qualified. As Franco was primarily interested in providing information for use in design of dikes to improve navigation conditions, sediment accretion within the dike fields was considered a positive effect. The performance of different dike designs in regard to sediment accretion was measured by a deposition rating. The deposition rating for a given dike field design was based on the average of the maxiumum elevations of sediment deposits below each dike related to the average elevation of the dikes. Thus, the deposition rating was not always directly related to areal extent of sediment accretion.

159. Dike systems composed of three level-crest dikes were tested in the model with level, stepped-up, and stepped-down crest elevations. The deposition rating was greatest for the stepped-down and least for the stepped-up dike field system. The overall best performance rating went to the stepped-down system, which also had the lowest length-weighted average crest elevation. The performance rating is described above in paragraph 56. Franco explained these results by observing that some of the flow entering a stepped-up dike field has to move channelward at each successive dike, producing disturbances in the main channel flow over the range of stages simulated (Figure 13). He did not point out, but it is useful to note here that the stepped-up field would have received almost as high a

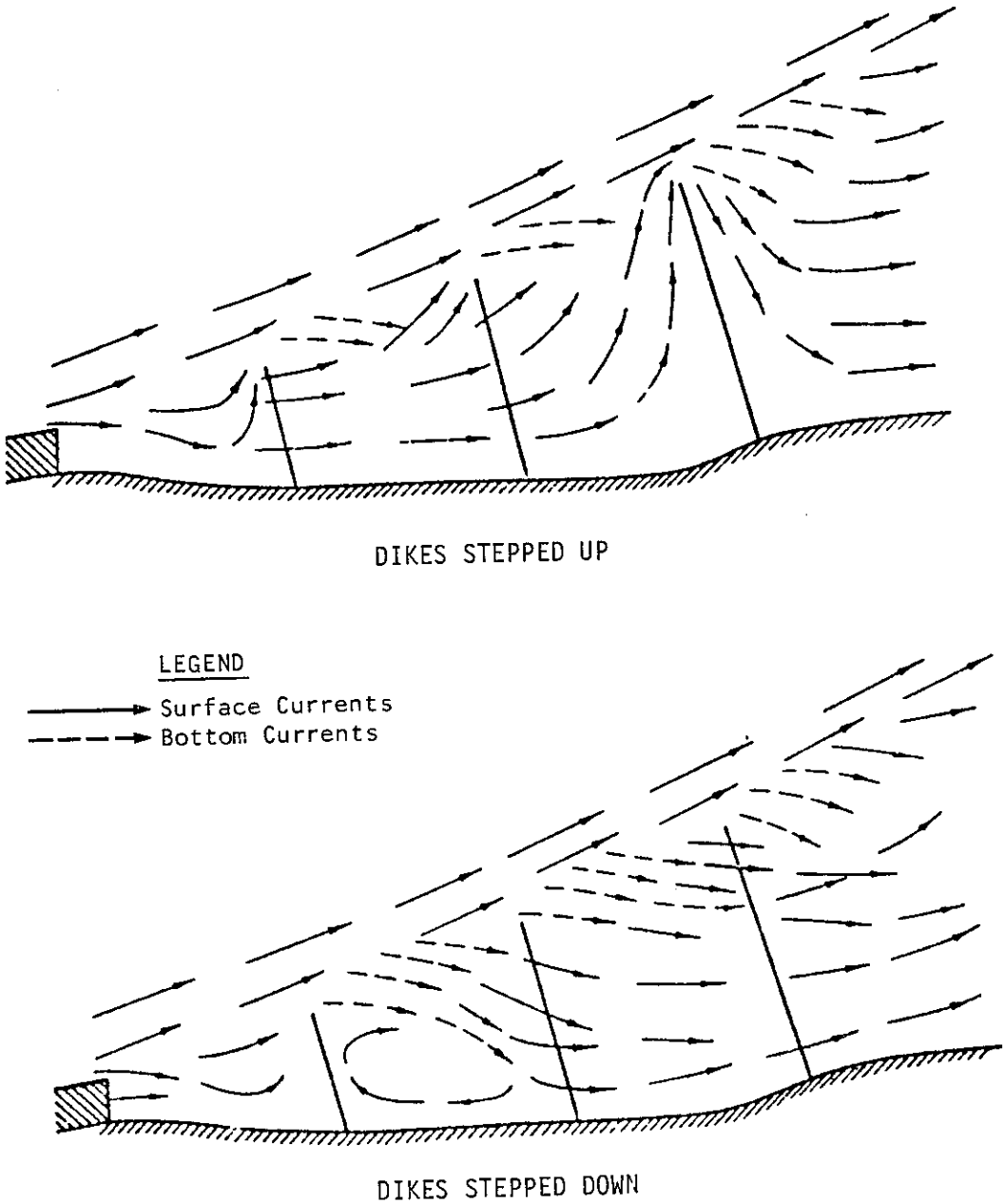

Figure 13. Flow through dike fields (from Franco 1967)

performance rating as the stepped-down field had it received a better rating for the channel alignment factor.

160. The flow moving channelward also tends to prevent sediment-laden bottom currents from entering the dike field. With a stepped-down dike field, some of the flow from the channel moves around the end of the first "high" dike into the area behind the dike and towards the next dike (which is at a lower elevation). The faster moving surface currents in the channel tend to continue in the channel, leaving the slower moving bottom currents to enter the dike field and deposit sediment.

161. Sloping crest dike systems were also investigated by Franco (1967). In this case, the bank ends of the dikes were maintained at the same elevation and the river end elevations were stepped-up, stepped-down, and level. The stepped-down sloping crest dike system had a significantly higher deposition rating than the other two dike systems.

162. Level crest dike systems were tested with all dikes normal to the flow, with all dikes angled 30° upstream, and with all dikes angled 30° downstream. The deposition rating was greatest for the normal and 30° downstream angle dike systems and least for the 30° upstream angle system. However, the 30° upstream angle system had the poorest overall performance in developing the desired navigation conditions.

163. Franco also tested L-head dikes. The length of the trail was equal to half the distance between adjacent dikes, and trail crest elevation was less than the main spur dike. The L-head dikes restricted sediment-carrying bottom currents from moving into the area between the dikes. Flow over the L-head produced scour along the landward face of the trail portion of the dike. The L-head dikes reduced both maximum scour at the ends of the dikes and the elevation of deposition between the dikes compared to the other dike systems modeled.

164. Franco also addressed dike elevation by testing each of the three dike field longitudinal profiles (stepped-up, stepped-down, and level) at different crest elevations. Franco observed that the size of the areas covered by deposition downstream of the dikes generally increased with a decrease in length-weighted average dike elevation for all three profiles. Effects of dike elevation on the elevation of dike field sediment deposits

were not reported. Dredging requirements were found to be inversely proportional to dike crest elevation.

Prototype experience with low-elevation dikes

165. Low-elevation dikes are dikes built to an elevation which is frequently overtopped or is continuously submerged, thus preventing bar buildup to an elevation that allows the establishment of vegetation. Low-elevation dikes are built to reduce costs, improve aquatic habitat by developing more diverse water depths, and reduce adverse effects on flood conveyance (Burke and Robinson 1979). Staged or phased approaches to dike construction also produce low-elevation dikes. Dikes are raised in stages, and low dikes are not raised if they adequately develop and maintain the navigation channel. Sills, described in Part II, may be thought of as a type of low-elevation dike.

166. Low-elevation dike design. There are no standard design parameters or crest elevations for low-elevation dikes. Due to the variability of dike designs, river characteristics, and site characteristics, there are significant differences in normal crest elevations between river systems and between CE Districts. For example, the crest of a low-elevation dike on the Missouri River may be above water as much as a normal elevation dike on the lower Mississippi River (Figure 7).

167. Low-elevation dikes on the Missouri River. In 1975, Kansas City District lowered the design elevation for new dike crests 4 ft to 2 ft below CRP, which is below the water surface 95 percent of the time (Burke and Robinson 1979). Many of the dikes currently constructed are sill extensions to existing dikes that have completely filled with sediment; 2 ft below CRP is standard height for these sills. If dikes do not adequately stabilize the channel, then they are raised in stages up to the maximum crest elevations (1-6 ft above CRP). Dikes adjacent to rapidly eroding banks are raised to high elevations initially; most dikes built on concave banks fall into this category. About seventy-five percent of the dikes constructed since 1975 have been allowed to remain at 2 ft below CRP. The low-elevation dikes prevent high sediment accretion elevations and resultant establishment of permanent terrestrial vegetation and have been effective in developing more diverse water depths (Burke and Robinson 1979). Typically,

a scour hole develops downstream of each dike, and a submerged bar (2 to 5 ft below CRP) forms just downstream of the hole.*

168. Low-elevation dikes on the upper Mississippi River. Dikes on the upper Mississippi River are not true low-elevation dikes since they were not originally built to a lower-than-normal crest elevation. The dikes were originally built to develop and sustain a 6-ft navigation channel and were later submerged when a series of locks and dams was built to provide a 9-ft channel. The dikes are generally maintained or rebuilt (as necessary to reduce dredging requirements) to an elevation approximately 3-5 ft below the minimum regulated water surface elevation to provide for boating safety and access. Many of the submerged dikes have been observed to have a self scouring ability and do not fill with sediment.** However, some dikes are "lost" by being covered by sediment accretion (Pitlo 1981). Typically, a scour hole develops around the end of the dike, as with higher dikes.

169. Low-elevation dikes on the middle Mississippi River. U.S. Army Engineer District, St. Louis, does not normally construct low-elevation dikes on the middle Mississippi River. The use of low-elevation dikes to slow sediment accretion in the dike field is perceived as an inefficient use of the river's energy at the expense of channel development.†

170. Low-elevation dikes on the lower Mississippi River. Memphis District constructs some closure dikes with low-elevation sections over the deepest portion of secondary channels. As a minimum cross section of stone is maintained, the crest profiles are often irregular, dipping through side channels and rising over middle bars. The deepest part of the low elevation sections may be as much as 35 ft below the normal crest elevation.†† For Memphis District, any dike built 10 ft or less above LWRP is considered low

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* Tom Burke. Kansas City District. Personal Communication. 21 July 1982.

** Dick Baker. Rock Island District. Personal Communication. 4 August 1982.

† Claude Strauser. St. Louis District. Personal Communication. 28 July 1982.

†† Bobby Littlejohn. Memphis District. Personal Communication. 9 August 1982.

elevation. Very few of the District's dikes are at a low elevation, and these are built with low elevations due to economic considerations and/or excessive depths.

171. Vicksburg District constructs closure dikes with low-elevation sections in the same manner as Memphis District, although different design parameters are used (for Vicksburg District, a low elevation is approximately 5 ft above LWRP). In addition, Vicksburg District constructs some low-elevation dikes by using the stage method of construction with waiting periods between lifts. Sediment accretion, particularly on the upstream side of the dike, sometimes reduces stone requirements for subsequent dike raising.

172. Effects of low-elevation dikes on habitat. Effects of low-elevation dikes on habitat diversity occur through changes in water depth and sediment characteristics. These changes are determined by the behavior of the flow over the crests of the dikes. Typically 95 percent of the flow is over the crest. Local flow accelerations have been observed over submerged dikes.* On the Missouri River, these accelerated flows usually develop a deep scour hole immediately downstream of the dike with a submerged bar forming downstream of the hole (Burke and Robinson 1979.) This pattern is also common on the upper Mississippi River for submerged dikes.**

173. Franco's (1967) preliminary results indicated that lower elevation dikes tended to accrete larger sediment deposits (measured by areal extent) within the dike field than higher elevation dikes. Both Corley (1982) and Pitlo (1981) observed low-elevation dikes with the downstream area completely filled in with sediment. However, Simons, Schumm, and Stevens (1974) found that the higher the dike, the more rapidly secondary channels and backwaters filled with sediment and the more rapidly a bar was produced below the dike. These differences perhaps can be explained by considering the Smith et al. (1982) statement that location has

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* Tom Burke. Kansas City District. Personal Communication. 27 July 1982.

** Dick Baker. Rock Island District. Personal Communication. 4 August 1982.

more influence on the rate and extent of sediment accretion than dike design. Thus, a dike built in a zone of deposition will be likely to accrete sediment, regardless of its crest elevation.

174. Low-elevation dikes have been reported as having beneficial impacts upon aquatic habitat diversity. The deep scour holes which are formed by low-elevation dikes and sills on the Missouri River provide important shelter for fish during the winter low-flow season.* The submerged sandbars which form downstream of scour holes on the Missouri River (Burke and Robinson 1979) provide shallow-water habitat which provides nursery areas for many fish species. The scour hole and submerged bar thus provide local habitat diversity. The Environmental Work Team (1981) found smallmouth bass, northern pike, and walleye associated with submerged dikes on the upper Mississippi River. These species all prefer deepwater habitat, and their presence may well be influenced by the availability of the deep scour hole. Pitlo (1981) reported that dikes submerged 5 ft or less and located on concave sides of upper Mississippi River bends supported greatest fish species diversity of the dikes he sampled. Baker** and Pitlo† are both of the opinion that the submerged dikes along the upper Mississippi provide valuable habitat and are ecological assets.

Notches

175. Notches are gaps or indentations in the crests of dikes, occurring either by design or failure of a portion of the dike. The purpose of a designed notch is to allow water to flow through a portion of the dike at intermediate stages to develop or maintain side channels and prevent additional sediment accretion. Notches may be wide and shallow or narrow and deep. Failure notches are typically narrow and deep.

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* John LaRandeau, Omaha District. Personal Communication. 11 January 1982.

** Dick Baker. Rock Island District. Personal Communication. 14 February 1983.

† John Pitlo. Iowa Conservation Commission. Personal Communication. 18 February 1983.

176. Advantages of using notches as an environmental feature are:*

a. Existing navigation authority (maintenance provisions) can be used.

b. Work can be performed from a floating platform.

c. No large expenditures are required; notches may save costs of stone on new construction or repairs.

177. Dike notches have been designed and constructed extensively on the Missouri River (over 1600 in the Omaha and Kansas City Districts) and to a lesser extent on the middle Mississippi River (64 in the St. Louis District). A few notches have also been constructed or allowed to develop on the upper Mississippi River (Rock Island District) and the lower Mississippi River (Vicksburg and Memphis Districts).

Notch design

178. Notches may be designed with various shapes and sizes to fit the specific river situation, structure, and purpose involved. Notches may be wide and shallow or narrow and deep, and usually have either a V-shaped or trapezoidal configuration. Design and placement of notches is best considered for an entire dike field or river reach, with the notches built with a variety of dimensions in order to provide a diversity of slack water habitat under differing river conditions (Omaha District 1982). Omaha District (1982) presents guidelines for design of notches for Missouri River dikes and Smith et al. (1982) presents findings of engineering and biological studies on middle Mississippi River notched dikes. A more complete discussion of notch design, which summarizes relevant sections of these references, is contained in Part V below.

Examples of notches

179. Notches on the Missouri River. Omaha District has constructed approximately 300 notches on the Missouri River in three design widths: 15, 20, and 30 ft. A survey of the notches after construction revealed widths and depths which varied considerably from the design dimensions; Figure 14 depicts the design dimensions. Notches in spur and L-head dikes attained

* Tom Burke. Kansas City District. Personal Communication. 27 July 1982.

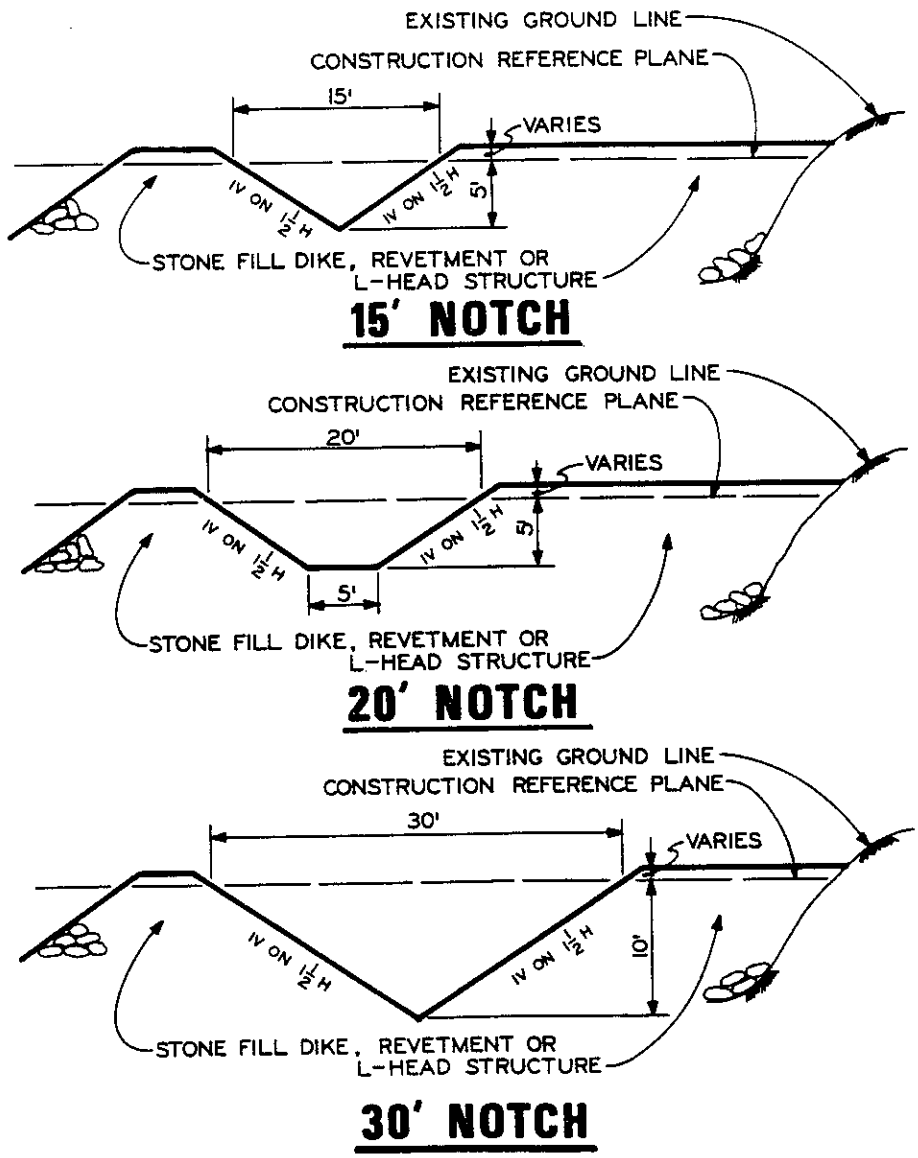

Figure 14. Notch design. (As-built dimensions varied considerably from these designs) (from Omaha District 1982)

the discharges necessary to inhibit sediment deposition more often than the notches in longitudinal dikes. The 15-ft notches had problems with debris accumulation. Notches located in closure dikes at the heads of secondary channels sometimes resulted in greater erosion of the banks due to the increased flow within the secondary channel. A comprehensive (biological and morphological) evaluation indicated that the notched dikes are generally maintaining the slack-water habitats for which they were designed. Recommended dimensions are 1 to 2 ft below CRP for the Omaha District and 2 to 3 ft below CRP for the Kansas City District and 20 to 50 ft top width for both districts (Omaha District 1982). Depth recommendations are given in terms of average depth because a range of depths (both within a notch and from dike to dike) is desirable. A variety of notch sizes and widths up and down the river are desirable in order to produce slack-water conditions over a range of stages.

180. Kansas City District has constructed approximately 1,300 notches on the Missouri River from Rulo, Nebraska, to the mouth, primarily in 20- 50- and 100-ft widths (although a variety of other widths were constructed as well). The 50-ft width is generally preferred, as the notches 20 ft wide collected some debris, and the notches 100 ft wide did not always produce benefits sufficient to offset the increased construction costs.* The notches are usually built to a depth designed to pass flow 95 percent of the time. Most of the notches were cut in L-head dikes (only because most of Kansas City District's maintenance and construction work has occurred on these structures during recent years). Two notches typically are used, one each at the upstream and downstream ends. Notches in longitudinal dikes are placed at the upstream and downstream ends and at every transverse support dike (short spur dikes built from the bank to the longitudinal dike as support structures).* Debris is not considered a serious problem on this portion of the Missouri River due to the river's natural fluctuation and the wider notch widths.

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* Tom Burke. Kansas City District. Personal Communication. 27 July 1982.

181. Omaha District (1982) lists the following construction and maintenance costs for notched dikes on the Missouri River separated by notch size and structure type because of the different excavation and maintenance requirements.

	Notch Width (ft)				
	15	20	30	50	100
Construction cost					
Spur dike	$450	$600	$800	$1,200	$2,500
Longitudinal	400	500	700	1,000	2,000
Maintenance cost					
Spur dike	$30	$35	$40	$45	$85
Longitudinal	25	25	20	25	40
Percent of notches requiring maintenance each year					
Spur dike	14%	12%	10%	8%	7%
Longitudinal	12%	9%	6%	5%	4%

These construction costs are rough approximations, as the actual costs vary substantially depending on the notch and structure location. Maintenance costs include removal of debris and any additional repairs.

182. Culverts on the Missouri River. Culverts are steel or concrete pipes used in lieu of notches on closure dikes which serve as access routes for landowners to the attached islands. The purposes of the culverts are to reduce sediment accretion in the backwater area and create and maintain a diversity of secondary channels and aquatic habitat, while not interfering with use of the dike for access to the island. Culverts of varying sizes, shapes, and configurations have been used on the Missouri River. There are no standard designs for dike culverts; each set of culverts is designed separately. Culverts generally have met with limited success and are often damaged by ice or blocked by accreted sediment. Typically, large diameter culverts have performed better than small ones.

183. Notches on the upper Mississippi River. Rock Island District has constructed a few notches on the upper Mississippi River; however, the dikes are not very suitable for notching as they are almost always submerged (water levels are controlled by a series of locks and dams, and are variable by pool). Notches 50 ft wide and 5 ft deep from the crest of the dike have

been placed in several closure dikes to provide recreational boating access into the enclosed backwater or secondary channel.* Notches have also been constructed at a depth of 5 ft from the dike crest on several spur dikes. However, sediment had already accreted to within 2 ft of the dike crests, limiting the effectiveness of the notches in promoting the scouring of backwater area (Corley 1982).

184. Notches on the middle Mississippi River. The St. Louis District has constructed both V-shaped and trapezoidal notches with widths ranging from 100 to 400 ft in 64 middle Mississippi River dikes. Notch depths range from 2 ft below LWRP to 20 ft above LWRP, with the majority of the notches at 5 to 10 ft above LWRP. Fourteen notches were placed on the landward third of the dikes, 40 were placed on the middle third, and 10 were placed on the channelward third of the dikes. All of the notches are on spur dikes. Most of the notches contain flow approximately 50 to 75 percent of the time.

185. Notches on the lower Mississippi River. Some of the low-elevation sections in side channel closure dikes mentioned in paragraphs 170.and 171. are narrow enough to be considered notches. These sections are usually 15 to 20 ft below the dike crest elevation, and range from 50 to hundreds of feet wide. The exact depth of the notch or lowered section depends on the depth of the site, the flow constriction desired, and economic considerations. A minimum cross section of stone is always constructed to maintain the structural integrity of the dike.

186. Deep, narrow failure notches are also occasionally found. Although they are not planned, these notches are allowed to remain when there are no adverse effects on the navigation channel.** Failure notches tend to be progressive in the Memphis District and are regarded as detrimental.†

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* Tom Burke. Kansas City District. Personal Communication. 27 July 1982.

** Charles Elliott. Vicksburg District. Personal Communication. 21 July 1982.

† Bobby Littlejohn. Memphis District. Personal Communication. 9 August 1982.

Notch effects on river habitat

187. Missouri River. A study coordinated by the Omaha District (1982) assessed the extent to which the notch program had maintained the flow-conveyance capability of the channel and whether notching had maintained or increased the amount of shallow-water habitat. Impacts on the navigation channel and bank stability were also assessed. Sediment deposits adjacent to six notches were surveyed during two different years, three in longitudinal dikes and three in spur dikes. Surveys of the longitudinal structures indicated that above-normal discharges promoted scour and low discharges promoted deposition. Surveys of the spur dikes showed only small changes in water surface area and water depth, even though river discharges varied from 32,000 cfs to 50,000 cfs on the basis of similar hydrographic surveys. When a notch was placed in an L-head dike where the landward area was filled in with sediment, a scour hole 20 to 50 ft wide usually developed downstream of the notch. When higher discharges occurred the entire area landward of the dike often scoured out. Some problems with bank erosion were noted when the notch was placed in a closure dike at the head of a secondary channel or too close to the bank. However, the study concluded that the notched dikes were maintaining the diversity of slack-water habitats.

188. Reynolds and Segelquist (undated) found that deeply notched dikes encouraged the removal of accumulated sediments behind the dikes. Scouring was noted to be most effective in winter when the sediment load of the inflowing water is least. However, sediment-laden currents entering the area behind a dike through a deep notch tended to deposit the material. Reynolds and Segelquist determined that shallow notches provided a good buffer to high sediment loads by operating only at high river stages.

189. The orientation of the notched dike has a significant impact on the functioning of the notch. As reported by Peterson and Segelquist (undated), 88 percent of those notches in dikes on the concave bank of the upper portion of the Missouri River were not passing flow when surveyed in 1976. However, 79 percent of the notches in longitudinal dikes and 97 percent of the notches in dikes on the convex bank had flowing water. The notched dikes on convex banks and the notched longitudinal dikes had three basic patterns of sediment deposition (Figure 15). Typically, notched dikes

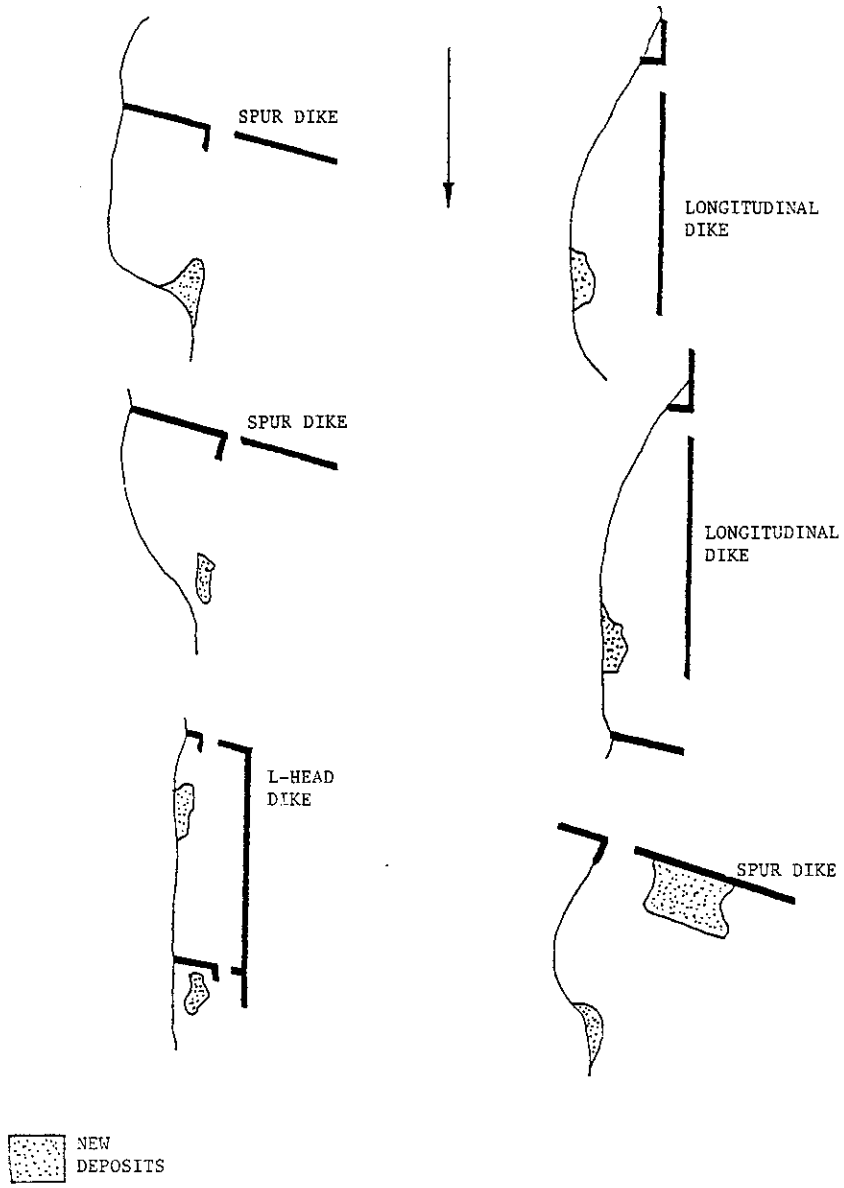

Figure 15. Depositional patterns for notched dikes (from Murnan et al. 1977)

developed a scour hole and a sandbar below the notch. Peterson and Segelquist caution against extrapolating these findings to other rivers with larger stage fluctuations.

190. Kallemeyn and Novotny (1977) investigated notches in spur dikes, L-heads, and longitudinal dikes. The results of the notches were variable. Some spur dikes with notches developed a small pool approximately 6 ft deep. Notched L-head dikes developed small secondary channels within the area behind the dike. These small channels had a velocity approximately one half that of the area channelward of the dike. The notched longitudinal dikes investigated had little current landward of the dikes except at the notches. Deposition inside the notches often made these areas susceptible to being cut off from the river during low-water stages.

191. In summary, notches in dikes on the Missouri River have generally been successful in allowing flow into areas behind the dike and in reducing sediment accretion in those areas. Typically flow through a notch causes a scour hole immediately downstream and may cause a small bar to form below the scour hole. Sediment accretion behind notched dikes will generally continue, but at a slower rate than without the notches. Morphology of the area behind a notched dike is variable with time, as accreted areas are highly transient. Scour and deposition of sediments adjacent to notched dikes occur at various times depending upon the magnitude and duration of flows.*

192. Middle Mississippi River. Smith et al. (1982) evaluated aquatic habitat diversity, accretion patterns, flow patterns, and bed material gradation existing around several dikes, five of which were notched. Bed material samples collected during this study indicated that the bed material deposited below notched dikes contains a higher percentage of sand than material deposited below other dikes. L-head dikes with notches had less sand deposited than spur dikes with notches. A correlation was observed between the flow pattern downstream of dikes and the types and patterns of accretion, with notched dikes having accretion patterns different from dikes without notches. Significant daily changes in water area within a dike

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* Tom Burke. Kansas City District. Oral presentation, WES. 6 January 1983.

field may occur due to the dynamic deposition and/or scouring of the bed material. However, Smith et al. believe that most of the observed changes in water area could be accounted for locally within the same dike field. Scour at one location was balanced by deposition at a nearby location, so entire dike fields experienced little change in water surface area during the study.

193. Lower Mississippi River. Few dikes have notches on the lower Mississippi River, and even fewer have been studied. Beckett et al. (1982) described a dike field with a failure notch in one dike as having a predominantly mud (silt) substrate, with sediments ranging from coarse sands and gravels to fine silt-clay. A higher percentage of sand and gravel occurred below the notch. Although sediment types and percentages in lower Mississippi River dike fields tend to vary with river stage, sediments below the failure notch were consistently sand and sand mixed with gravel. The shifting sand and gravel below the notch were less valuable macroinvertebrate habitat than stable, finer grained deposits.

194. Summary of habitat effects. Notch effects on habitat vary considerably from river to river. Key design variables affecting notched dikes' influence on hydraulics and morphology are the size and shape of the notch, the location of the notch on the dike, and the location of the dike. Notched dikes on the Missouri River typically develop a scour hole and sandbar below the notch, providing a diversity of aquatic habitat. Notches on the middle and lower Mississippi River, while increasing the diversity of the habitat within the dike field, sometimes create a sandy substrate habitat resembling that of the main channel.

Notch effects on biota

195. Notching can regulate a dike's effect on the physical factors that control habitat diversity. (These physical factors are sediment characteristics, current velocity, and water depth; their importance to habitat diversity was described in Part III.) Random dike notching has resulted in both positive impacts and some minor negative impacts to habitat diversity and hence to biological diversity.

196. Burke and Robinson (1979) noted the tendency of notched dikes on the Missouri River to produce submerged sandbars downstream from the notch.

These shallow, sandy areas appeared to provide valuable nursery areas for young fish. This also increases the aquatic edge habitat.

197. The observed effect on water depth is generally beneficial to the aquatic community if the dike field does not fill in entirely. Funk and Robinson (1974) listed accretion as a major problem, but noted that problem existed only if the accretion was extensive enough to convert aquatic habitat to terrestrial habitat. In at least some cases, notches seem to control the accretion and provide small chutes and submerged sandbars which provide valuable shallow-water habitat.

198. Notches can also alter the current velocity in the vicinity of the dike. Burke and Robinson (1979) observed that notches often create areas of fast water which flathead catfish and freshwater drum prefer. Changes in current velocity tend to produce tradeoffs though, since Reynolds and Segelquist (undated) conducted a study to determine the types of habitat created by notching dikes and the value and use of these habitats for fish and wildlife. They noted in at least one case that a dike area supported a larger population of centrarchids before notching than after the notch was installed. This is not surprising since centrarchids prefer the slow-moving conditions typical of backwater ponds. Reynolds and Segelquist found that the chutes formed by flow through the notches were important as rearing areas for young fish, and as habitat for certain fast-water fishes (channel catfish, flathead catfish, and freshwater drum). These areas also had high species diversity of riverine minnows.

199. Beckett et al. (1983) examined macroinvertebrate populations at Chicot Landing Dike Field where there was a failure notch in one of the dikes. Currents through the dike field immediately above and below the notch were typically strong and swift. At low flows large portions of the Chicot Landing Dike Field, like other lower Mississippi River dike fields, contain silt substrates which are colonized by dense populations of tubificid worms. Because of the strong currents, however, the bottom substrates near the notch at Chicot Landing consist of sand, even at low flows. Although this sand is inhabited by Asiatic clams and two chironomid species which are specific for sand substrates in large rivers, total macroinvertebrate densities in the sandy area near the notch are markedly

lower than those found in the silt substrates elsewhere in the dike field, and in the other dike fields investigated.

200. Jennings (1979) compared morphometric changes at eight notched dikes to biological parameters to evaluate their suitability as aquatic habitat for fishes. He collected benthic organisms with artificial substrate samplers and examined fishery data supplied by state investigation teams from Nebraska, Iowa, and Kansas. Zooplankton samples were also collected. The abundance of gizzard shad, an important forage species, in enclosed pools was believed to be related to the abundance of zooplankton in these areas. Jennings concluded that based on the elevation at which notches in dikes are presently being constructed, moderate or high river stage years are needed if the notches are to allow the passage of enough water to effectively scour and transport accreted sediment from behind the dikes and maintain the pool habitat there.

201. Reynolds and Segelquist (undated) conducted a study to determine the types of habitat created by notching dikes and the value and use of these habitats for fish and wildlife. They studied notched spur dikes, L-head dikes, and longitudinal dikes. Fish were collected by electrofishing, hoopnetting, and seining behind each structure. Excluding minnows, the most abundant species were gizzard shad, freshwater drum, river carpsucker, and carp. Economically important species which were apparently spawning near the structures or using them as nursery areas were carp, channel catfish, white bass, white crappie, sauger, and freshwater drum. Chute habitats were important as rearing areas for young fish and as habitat for fast water fishes such as channel catfish, flathead catfish, and freshwater drum. The author noted that the notches provided the chute areas with current flow, especially during low river stages, and thus kept the chutes open. Reynolds and Segelquist (undated) concluded that connecting backwater ponds with the main channel by notching the closure dikes is beneficial to the fishery of the Missouri River because it provides fish with access to essential spawning areas.

202. A related study by Peterson and Segelquist (undated) evaluated the effect of the notching program on wildlife including the mammals, birds, reptiles, and amphibians associated with riparian and aquatic habitats along the channelized Missouri River. They recorded wildlife observations made

incidental to aquatic sampling. Wildlife were observed on and around notched dikes, swift water, slack water, sandbars, cattail marshes, bottomland forests, and agricultural lands. These field data were supplemented with existing information sources to determine how the notching program might affect Missouri River riparian and aquatic habitats and to predict wildlife responses to anticipated habitat changes. Birds comprised the bulk of the observed wildlife usage of the notched structures and related habitats. Other species frequently recorded included the raccoon, beaver, whitetailed deer, and muskrat. Most animals and/or animal signs were observed on sandbars and mudflats although this could simply be because these areas provide the best substrate for tracks.

203. Peterson and Segelquist (undated) concluded that the major change in wildlife habitat produced by the notches appears to be the accretion of sandbars in open waters behind the dikes, the maintenance of chutes between newly accreted bars and the river bank, and the maintenance of deeper lake-like pools behind certain structures. The chutes may provide habitat for aquatic furbearers, wading birds, and shorebirds, but their main value is the maintenance of islands and the prevention of the usual agricultural encroachment that follows the filling of abandoned chutes on the Missouri River. Pools provide aquatic organisms for food and a resting place for waterfowl.

204. A study was conducted by Robinson (1980) to determine the effect of modified dikes on fish habitat diversity. He sampled waters adjacent to notched dikes, rootless dikes, and low-elevation dikes for fish with gill nets, trammel nets, hoop nets, and an electroshocker. He also studied the availability of fish food by sampling for benthic organisms with a multiple-plate sampler and rock-filled barbecue baskets. The narrow range of values for diversity indices indicated that fish populations at each dike were uniformly similar in diversity, suggesting that the habitat conditions were favorable for river species at all dikes. The benthos studies were inconclusive. Robinson (1980) recommended the use of many different dike designs and types of modifications of dikes to develop a wide variety of habitat conditions which would meet the requirements of fish and wildlife populations at varying water levels. He also suggested that rootless dikes

may have the best potential for developing the needed diversity of habitat in the Missouri River.

205. Corley (1982) did the follow-on study after notching for the area on the upper Mississippi studied by Hall (1980) to determine the effects on fish and aquatic macroinvertebrates. Fish were collected with electrofishing gear, hoop nets, and small-mesh seines. Benthic invertebrates were collected with a Ponar grab sampler and artificial substrate samplers. The benthic macroinvertebrate density and biomass in the main channel border were significantly greater after notching at most wing dams; however, benthic densities, biomass, and number of taxa in the side channels did not change significantly after notching. No effect was observed on fish populations after spur dike notching. Corley (1982) concluded that the negative effects of spur dike notching at the upper Mississippi River site he studied seemed to outweigh the positive effects. The negative effects he reported were an increase in sand deposition in the side channels, inhibition of benthos populations in the side channels due to the increased sand, and a reduction in the amount of productive substrate for aquatic organisms caused by removal of wing dam rock.

206. Coble (1980) also performed a before-and-after study of the biological response to dike notching on the upper Mississippi River. He collected benthic organisms with a Ponar grab sampler and artificial substrates. Fish were collected with hoop nets and an electroshocker. Before notching he found fish to be most abundant in the side channels followed by the river border habitat, with the emergent dike having the least abundance and diversity. After notching there were relatively more rough fish and fewer panfish in both the dike and side channel habitat.

207. Pitlo (1981) sampled waters around 24 spur dikes for adult fish populations on the upper Mississippi River. Sampling equipment included trammel nets, gill nets, frame nets with leads, hoopnets, and electrofishing. Commerical fish species were the most abundant with redhorse sp., freshwater drum, carpsucker sp., and shovelnose sturgeon contributing 27, 12, 9, and 6 percent of the total catch, respectively. More fish were captured downstream of dikes than upstream. Pitlo found water depth over a dike and dike location to be the most important parameters affecting fish location. Dikes less than 5 ft in depth

(corrected to operating pool levels) had significantly higher catch/effort than deeper dikes. Dikes located on concave sides of bends had significantly high catch/effort and number of species than dikes on convex sides of bends.

208. Smith et al. (1982) studied eight rock dikes on the middle Mississippi River, five of which were notched, and the habitat around these dikes. This study was performed to evaluate habitat diversity around channel-regulating structures and to recommend structure modifications to maintain or improve existing fish and wildlife habitat while preserving the geometry needed to maintain an acceptable navigation channel. Fish were collected with electrofishing gear, hoop nets, gill nets, and trammel nets downstream of each dike. Aquatic macroinvertebrates were sampled with artificial substrate samplers and a grab sampler. Casual observations were also made of the use of aquatic and adjacent riparian habitat by mammals, birds, reptiles, and amphibians.

209. The authors found that diversity of fish communities was slightly greater at notched dikes than unnotched dikes; however, this difference was not significant. Notched dikes had relatively high numbers of caddisflies and flies while unnotched dikes had more aquatic earthworms. The diversity of aquatic invertebrate communities was significantly greater at notched dikes. The authors contributed this to the greater variety of habitats created below the notched structures.

210. Summary. Overall, notched structures generally improve fish habitat and increase the species diversity of the fish community. This is consistent with the concept that increased habitat diversity leads to increased biological diversity. The creation of small chutes within the dike field, the presence of submerged sandbars, and increased edge habitat are valuable forms of aquatic habitat diversity. Increased aquatic habitat diversity resulting from notched dikes not only benefits the fish community, but the macroinvertebrate community as well.

Rootless and Vane Dikes

211. Rootless dikes are a type of notched spur dike, with the gap or notch between the bank and the dike so that the dikes are unattached to the bank. Rootless dikes allow flow between the dike and the bank to reduce sediment accretion and create a diversity of current velocities, depths, and substrates. Flow around both ends of rootless dikes provides potential for development of multiple secondary channels, creating more aquatic habitat diversity. Vane dikes (as previously discussed in Part II) are also unattached to the bank, but are at a slight angle to the current rather than almost perpendicular.

Rootless dike design

212. Rootless dike design varies by river and CE District, with few common design practices. Rootless dikes should not be built where the opening between bank and dike concentrates enough flow to scour the bank (Omaha District 1982). Optimum locations are on middle bars just downstream of a dike attached to the bank.* Rootless dikes often require some form of bank protection to prevent scour, or locations where some bank erosion will not be detrimental.

Examples of rootless dikes

213. Rootless dikes on the Missouri River. Kansas City District builds rootless dikes perpendicular to the flow. The dikes are 150 to 300 ft long,

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* Tom Burke. Kansas City District. Personal Communication. 27 July 1982.
Charles Elliott. Vicksburg District. Personal Communication. 21 July 1982.

with the landward end of the dikes from 50 to 250 ft from the bank (Burke and Robinson 1979). Crest elevations are normally 2 ft below CRP; the rootless dikes are also low-elevation dikes. Field inspections and observations of the rootless dikes indicate excellent results in maintaining habitat diversity (Burke and Robinson 1979). Typically, flow develops around the landward end of the dike, reducing sediment accretion between the bank and the dike and resulting in a low sandbar downstream of the dike. Often, a scour hole develops downstream of each end of the rootless dikes.*

214. The Omaha District has built several vane dikes. These vane dikes are almost parallel to the flow, with a 10 to 15 degree angle as shown in Figure 2. Some are built in series, and some are individually placed between two widely spaced spur dikes.

215. Rootless dikes on the upper Mississippi River. Rootless dikes are not designed or constructed on the upper Mississippi River. Since all the dikes are submerged, no need is perceived for rootless dikes.** Some rootless structures exist, however, due to flanking of existing dikes by raised water levels due to dam construction. No data are available on these structures.

216. Rootless dikes on the middle Mississippi River. St. Louis District does not use rootless dikes. Rootless dikes are perceived as causing bank scour.†

217. Rootless dikes on the lower Mississippi River. Memphis District does not design rootless dikes; however, a few rootless structures exist due to flank failures. These flank failures are progressive and tend to

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* Tom Burke. Kansas City District. Personal Communication. 27 July 1982.

** Dick Baker. Rock Island District. Personal Communication. 4 August 1982.

† Claude Strauser. St. Louis District. Personal Communication. 28 July 1982.

increase in width due to ongoing erosion until they are repaired. In one unusual instance, the distance between the dike and the bank is 1500 ft.*

218. As previously discussed, Vicksburg District builds vane dikes generally parallel to the current, with a slight angle of 10 to 15 degrees towards the current at the downstream end (Figure 2). These vane dikes are typically placed on a middle bar as part of a dike field, with a spur or L-head dike as the lead dike.

Effects of rootless dikes on habitat

219. Little data are available regarding the effects of rootless dikes on hydraulics and morphology. Rootless dikes typically prevent sediment from depositing landward of the dike. Local increases in velocities occur around the ends of the dike, often causing eddies to form.**

220. As noted above, the flow around both ends of a rootless dike provides potential for multiple secondary channels and bars to form in the dike field, and sometimes rootless dikes cause bank scour. Only a limited number of Missouri River rootless dikes and notches have caused enough bank scour to require additional protection (Omaha District 1982).

221. The development of multiple secondary channels and bars increases habitat diversity by increasing the amount of edge habitat available. Flow in these channels prevents complete filling in of areas between the dikes. One disadvantage which must be considered, however, is the potential for serious bank erosion at the landward end of the rootless dikes (Burke and Robinson 1979).

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* Bobby Littlejohn. Memphis District. Personal Communication. 9 August 1982.

** John Robinson. Missouri Department of Conservation (MDOC). Personal Communication. 27 July 1982.

Minimum Maintenance

222. Minimum maintenance is the practice of conducting the minimum dike maintenance necessary to maintain the channel. After construction, dikes frequently develop lowered and irregular-crest profiles due to erosion of the dike stone, yet often remain functionally adequate. A variety of flow patterns occur downstream of the irregular crests resulting in a diversity of depths, velocities, and aquatic habitat.* Notches and rootless dikes are also sometimes the result of failure and minimum maintenance.

223. Normal maintenance procedures vary between CE Districts and are highly dependent upon economic considerations and individual dike performance. Typically, dikes are not maintained unless there are problems with developing and maintaining the navigation channel, undue bank scour, or threats to the structural integrity of the dike. Thus, normal maintenance activity focuses on dike fields adjacent to a channel area requiring increased dredging, dikes adjacent to problem bank scour, or dikes which are being rapidly flanked or eroded. These situations are determined through analysis of dredging records, hydrographic surveys, and observation. Dike maintenance consists of repairing or rebuilding eroded areas to the original design or making a minor design change to correct a problem (e.g., restoring the dike to an elevation higher or lower than the original grade, or extending dike length). Major design changes, such as adding a longitudinal section to a spur dike to form a L-head, may also sometimes be considered maintenance.

Minimum maintenance approaches

224. There are no existing criteria for minimum maintenance of dikes beyond requirements regarding development and maintenance of the navigation channel. Minimum maintenance practices are thus highly variable by CE District, by waterway characteristics, and particularly by specific dikes and site characteristics. Dikes vary in their suitability for minimum maintenance. Dikes critical to the development of the

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* John Robinson. MDOC. Personal Communication. 27 July 1982.

channel and subject to attack by high flows require frequent attention, while dikes whose performances are less critical are typically not maintained with the same frequency.

225. Three approaches to applying the minimum maintenance technique are:

a. Apply minimum maintenance to every other dike in a dike field.

b. Apply minimum maintenance to specific dike sections, e.g., channel ends of dikes.

c. Apply minimum maintenance techniques to all dikes (or all suitable dikes).

226. The first approach involves simply allowing every other dike in a dike field to degrade towards some minimum allowable level determined based on the dike fields' effectiveness. The other dikes are maintained at their design or "as constructed" conditions ("as constructed" conditions are similar but not identical to the original design, due to the difficulties of underwater stone construction). This approach was frequently used during the conversion from pile dikes to stone dikes. Stone was typically applied to every other pile dike, and the remainder was allowed to deteriorate. The second minimum maintenance approach is to allow less critical sections of dikes to degrade. For example, allowing the channel end of a dike to degrade while maintaining the remainder of the dike would probably result in a relatively long flat slope at the channel end. This approach results in a shorter dike length, depending on the stage of flow. Some dikes are designed and constructed with sloping crests on "nose" sections, to begin with. The third approach is the most common: application of the minimum maintenance technique to all dikes, while recognizing that dikes critical to the development of the channel require more maintenance attention. This third approach is used to some extent by all CE Districts for economic reasons.

Effects of minimum maintenance on habitat

227. Minimum maintenance typically results in dikes with irregular crest profiles and creates a variety of downstream depths and velocities when flow overtops the dikes. There are no data on the effects of minimum

maintenance on hydraulics and morphology. In addition, as minimum maintenance is not a designed environmental feature, the effects are extremely site-specific and dependent upon erosion of the dike or dike field. However, as minimum maintenance allows a dike to degrade to some minimum level, several potential effects can be projected.

228. Structures with notches, lower elevation, or no roots due to minimum maintenance have effects on hydraulics and morphology typical of structures with designed modifications. However, there are some notable differences between these effects. A failure notch is usually narrow and deep and can be expected to have greater flow velocity through the notch than typical designed notches, which are relatively wide and shallow. Rootless dikes caused by flanking are more likely to have narrower gaps between banks and dikes than are designed structures; bank scour is also more likely to be a problem. Low-elevation dikes with irregular crests create a high diversity of conditions.* As the dike crests degrade, duration and frequency of submergence will gradually increase, as will the velocity of the water flowing over the dikes (Jennings 1979).

Summary of Environmental Design Practices

229. Design criteria used by seven CE districts for dike field features which have positive environmental aspects are presented in Table 3. The wide variation in dike designs reflects the distinctive nature of the project settings. The dimensions given in Table 3 are intended to be characteristic, and exceptions are common.

Potential Environmental Features

230. There are several techniques for maintaining and increasing aquatic habitat diversity that have been tried only in a few cases, or not at all, in dike fields. Some of these techniques have been successfully applied in small streams, estuaries, and reservoirs.

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* John Robinson. MDOC. Personal Communication. 27 July 1982.

Table 3

Design of Environmental Features

RIVER SYSTEM	CE DISTRICT	ENVIRONMENTAL FEATURES				REMARKS
		NOTCHES	LOW-ELEVATION DIKES	ROOTLESS DIKES	MINIMUM MAINTENANCE	
MISSOURI RIVER • River Mile 734 to 498.5	OMAHA	DEPTH: 1'–2' below CRP WIDTH: 20'–30' SHAPE: V-Shape and trapezoid DIKES: Spur, L-head, longitudinal, closure	ELEVATION: 2-5' below CRP* SUBMERGED: 95% of time		Minimum maintenance of all dikes, subject to performance, structural integrity, and economic consideration	
• River Mile 498.5 to mouth	KANSAS CITY	DEPTH: 2'–3' below CRP WIDTH: 50' SHAPE: V-Shape and trapezoid DIKES: Spur, L-head, longitudinal, closure	ELEVATION: 2' below CRP SUBMERGED: 95% of time	LENGTH: 150'–300' BANK GAP: 50'–250' ALIGNMENT: perpendicular to flow ELEVATION: 2' below CRP	Minimum maintenance of all dikes, subject to performance, structural integrity, and economic consideration	
UPPER MISSISSIPPI RIVER • River Mile 614 to 300	ST. PAUL		Dikes are submerged by 0.5'–6' of water		Minimum maintenance of all dikes, subject to performance, structural integrity, and economic consideration	Dikes are submerged due to dams built to develop the 9' channel. Dikes were originally built to develop a 6' channel
• River Mile 300 to 0	ROCK ISLAND	DEPTH: 5' from dike crest WIDTH: 50' SHAPE: Trapezoid DIKES: Closure, spur	Dikes are submerged 98% of time; depth is variable by location; rebuilt dikes are at 4' below LWRP		Minimum maintenance of all dikes, subject to performance, structural integrity, and economic consideration	Dikes are submerged due to dams built to develop the 9' channel. Dikes were originally built to develop a 6' channel
MIDDLE MISSISSIPPI RIVER • River Mile 300 to 0 (Cairo, IL)	ST. LOUIS	DEPTH: 5'–10' above ALWP WIDTH: 100'–150' SHAPE: V-Shape and trapezoid			Minimum maintenance of all dikes, subject to performance, structural integrity, and economic consideration	
LOWER MISSISSIPPI RIVER • Cairo, IL to River Mile 599	MEMPHIS	DEPTH: Shallow WIDTH: Wide SHAPE: Trapezoid DIKES: Closure	ELEVATION: less than 10' above LWRP; some closure sections built 35' below crest		Minimum maintenance of all dikes, subject to performance, structural integrity, and economic consideration	Notches and low-elevation sections are similar, built to save costs of construction. Some failure notches
• River Mile 599 to 320	VICKSBURG	DEPTH: 15'–20' from dike crest WIDTH: 50'–several hundred feet SHAPE: Trapezoid DIKES: Closure	ELEVATION: 5' above LWRP	LENGTH: 1000'-1200' ALIGNMENT: 10° - 15° angle to flow ELEVATION: 10' - 15' above LWRP	Minimum maintenance of all dikes, subject to performance, structural integrity, and economic consideration	Notches and low-elevation sections are similar, built to save costs of construction. Some failure notches

*Omaha District's low-elevation dikes are actually sills.

Dredging to remove sediment

231. Dredging could be used to remove sediment from dike fields, extending the lifetime of the dike field aquatic habitat as well as providing increased habitat diversity by increasing shallow, slack-water areas. Reynolds and Segelquist (undated) noted that several investigators have suggested using dredging or pumping to create or maintain oxbows or side channels. The dredging could be done as a specific project or as part of a commercial sand and gravel mining operation, subject to regulatory constraints. A key advantage would be the ability (within the limitations of dredging equipment) to sculpt the habitat configuration desired for each site. However, there are several potential drawbacks to the technique:

a. The costs associated with dredging are high.

b. Dredging is only a temporary remedy. However, if combined with other measures such as notching, it might provide long-term results.

c. Adverse impacts are associated with dredging, particularly in a backwater area between dikes.

d. There are problems locating suitable dredged material disposal sites.

232. A possible additional drawback might be the effects on the navigation channel of removing large quantities of accreted sediment. If the sediments were deposited during a period of greater sediment load, the dike fields might not exert sufficient control without the sediment. This drawback would be limited to certain sites, with Missouri River sites the most likely candidates. This adverse effect could be guarded against by limiting the quantity of sediment to be removed and by maintaining a bar between the interior of the dike field and the main channel.

Disposal of dredged material

233. Selective disposal of dredged material from the navigation channel within the dike field may be used to increase habitat diversity three ways:

a. Creating submerged bars which provide shallow water habitat.

b. Creating islands which provide habitat for waterfowl and other terrestrial biota, as well as increasing aquatic habitat diversity.

c. Building up the middle bar in order to slow sediment deposition within the pools in the interior of the dike fields.

234. Placement of dredged material allows the selective sculpting (within limits) of the habitat, both in terms of morphology and substrate. An additional benefit is the productive use of dredged material, often an unwanted or unrecognized resource. This technique would require uncontaminated dredged material with suitable grain size distribution and careful planning to avoid adverse impacts sometimes associated with aquatic disposal of dredged material.

235. A drawback to this technique is the unknown response of the waterway to the dredged material. Waterway response would likely range from scouring the dredged material to depositing additional sediments and increasing the rate of sediment accretion within the dike fields. The addition of dredged sediments to a dike field would still be subject to the processes which shaped the dike field morphology and probably would not cause any long-term alterations.

Relocating notches

236. Over a long period, sediment deposition may fill some notches or create narrow ditch-like channels below notches with swift current and shifting substrate similar to main-channel habitat conditions. Habitat diversity could be increased by filling the existing notch and excavating a new one. New notches would create a new configuration of secondary channels within a dike field, increasing habitat diversity. After a notch was closed, the old scour hole would provide a large slackwater area at moderate and low flow. Benefits of using this technique are (a) the familiarity of the notching concept, (b) the initial success of most notches in improving aquatic habitat, (c) and its suitability for incorporation into an overall dike maintenance/notching program.

237. Omaha District (1982) suggests a slightly different version of this concept. Wide, deep notches are effective at concentrating flows and scouring sediments. However, once the desired water area size has been reached, the size of the notch could be reduced to provide still or slowly moving water at low and intermediate stages.

Placing additional rock underwater

238. Aquatic habitat diversity has been successfully improved in many areas through placement of rock for use as cover, substrate, and current deflectors. The rock may be placed in a dike field in piles, as a layer on the bottom, or singly for large stones. Potential sources of rock are rocks removed during notch excavation or excess rock from dike construction/ maintenance activities. This technique is unsuitable for dike fields with extremely soft or erodible bottoms. The rocks settle in unconsolidated mud or cause scour holes to develop downstream that undermine and bury the rocks, negating their purpose. Deposits of shifting sediment (sand, silt and gravel) over the rocks are also a problem in many areas and are a limiting factor. An additional limiting factor is the cost of the stone.

239. The Omaha District has constructed notches in ten spur dikes and placed the stone excavated from each notch in piles or "reefs" 50 ft downstream of the notched dike. Piles are in a variety of shapes and are placed so that their crests are 2 ft below the CRP.

240. Kallemeyn and Novotny (1977) noted the importance of large rocks as substrates for fish food organisms in the Missouri River. Beckett et al. (1983), Bingham (1982), Hall (1980), and Holzer (1979) all found rock riprap to be a highly productive substrate for a diverse assemblage of aquatic macroinvertebrates. There is typically little rock substrate available in the rivers under consideration except for that found in man-made structures. Quarry-run stone, with its extremely wide size gradation (small gravel to large boulders) is especially valuable (Hynes 1970).

Artificial reefs

241. An environmental feature similar to the placement of rock is construction of artificial reefs or cover within the dike fields. Artificial reefs or cover has been used successfully in many aquatic environments. Potential drawbacks of this technique are:

a. Costs of initial construction/installation.

b. Possible interference with recreational boating.

c. Potential for increasing sediment accretion.

242. Two of the most common types of reefs are brush shelters and tire shelters. Brush shelters are designed to provide additional cover and feeding habitat. Kallemeyn and Novotny (1977) noted the value of snags and brush piles along the Missouri River as cover for fish and substrate for fish food organisms, and Smith et al. (1982) reported that crappie were most often found near remains of old pile dikes within middle Mississippi River dike fields. A brush shelter can be designed in a multitude of styles, but it is basically an interwoven pile of brush anchored to a large tree or piling (Figure 16). Brush shelters should be anchored securely and not subjected to repeated wetting and drying because of increased decomposition rates (Nelson, Horak, and Olson 1978). Sediment accretion in and around the brush shelters may limit their effectiveness. Brush shelters are highly vulnerable to severe damage by ice in colder climates.

243. Tire shelters, like brush shelters, provide substrate for periphyton and provide cover and substrate for zooplankton and fish (Nelson, Horak, and Olson 1978). Tire shelters are constructed by binding tires together in varying configurations. The tires are slashed to prevent trapped air pockets and then sunk using concrete or other ballast to form the shelter. The shelter may be anchored to piling. Used tires are generally available and do not deteriorate rapidly when used underwater.

Gates in closure dikes

244. Gates or control structures could be used to control low and intermediate flows through secondary channel closure dikes or closure dikes built to close off old chutes or cutoff bendways. The control structures can be operated to allow fish passage during critical periods and perhaps to reduce inputs of sediment into the secondary channel or cutoff bendway by closing the structure when sediment loads were high. Of course, large floods (which usually carry the most sediment) would overtop the structure. Other drawbacks include construction and operation costs.

Summary of Effects of Environmental Features on Dike Field Habitat

245. Table 4 presents a summary of the effects of environmental features on dike field habitat.

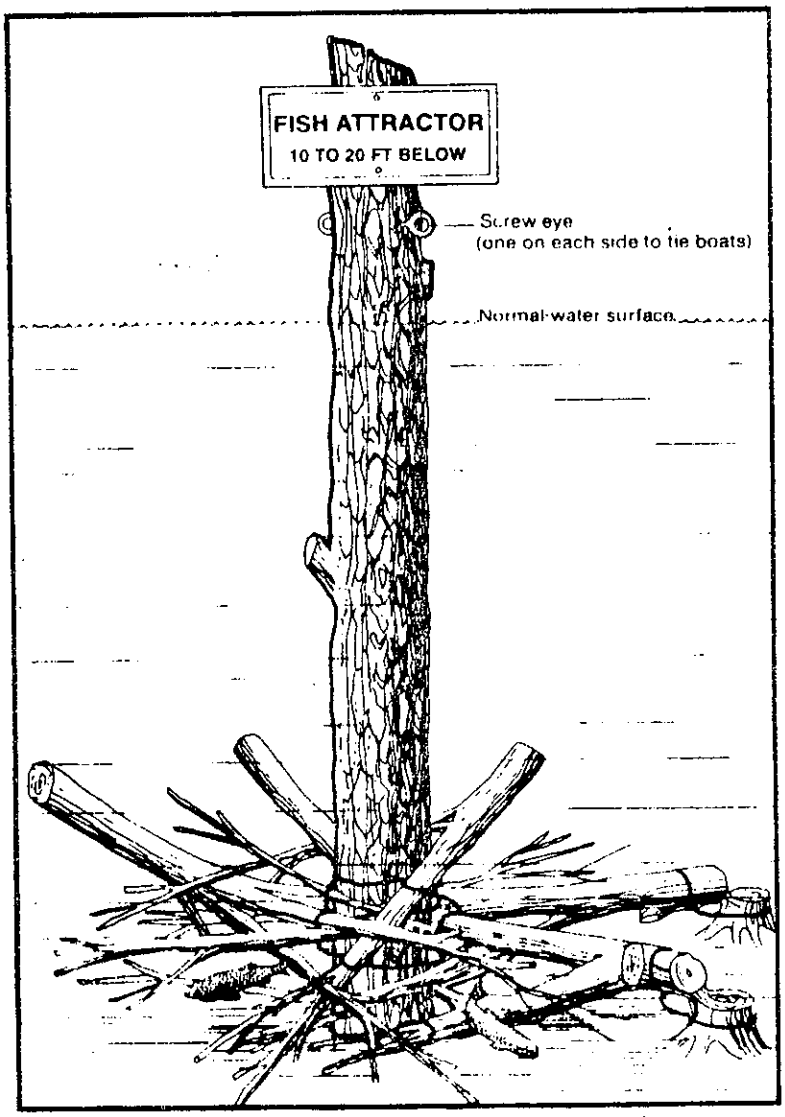

Figure 16. Example brush shelter (from Nelson et al. 1978)

Table 4

Summary of Effects of Environmental Features on Dike Field Habitat

ENVIRONMENTAL FEATURE	SCOUR	SEDIMENT DEPOSITION	LOCAL CURRENT VELOCITY	WATER DEPTH
ACTUAL				
(1) NOTCHES • Dike Notches	Scour hole forms immediately downstream of notch	Sandbars form downstream of unnotched portion of spur dikes and closure dikes	Flow accelerates through notch. Flow patterns in vicinity of notch exhibit a wide range of velocity magnitudes and directions	Wide range of depths and diversity of flow conditions
• Culverts		Culverts tend to fill in with sediment	Velocity slightly increases through culverts	
(2) LOW-ELEVATION DIKES	Scour hole forms immediately downstream of the dike	Submerged bar develops downstream of scour hole, sediment accretion sometimes occurs level with the crest elevation of the dike	Local velocities increase as flow passes over slightly submerged dikes. Flow acceleration is insignificant when submergence is more than 5 - 6'	Depending on location and structure, dike field depths may either be maintained or decreased
(3) ROOTLESS DIKES • Rootless Spur Dikes • Rootless Vane Dikes	Scour hole downstream of each end of dike, may cause bank scour	Shallow bar develops immediataly downstream of the dike, typically also develops multiple secondary channels and other sandbars	Velocities increase around both ends of the dike, often forming eddies	Local depth changes according to pattern of scour and sediment deposition
(4) MINIMUM MAINTENANCE • All Dikes	Variable	Variable	Local velocity increases as flow overtops the dikes	Variable
POTENTIAL				
(5) DREDGING TO REMOVE SEDIMENT*		Sediment will deposit in dredged area if it is an area of natural deposition		Increase depths where dredged
(6) DISPOSAL OF DREDGED MATERIAL*	Dredged material may be scoured	Placement of dredged material may encourage additional sediment deposition		Decrease depths where dredged material is placed
(7) RELOCATE NOTCHES*	Create new scour holes downstream of notches	Create new sandbars or shift existing sandbars to fit new flow patterns	Local velocity increases through notch	Diversity of depths
(8) PLACING ADDITIONAL ROCK*	May create scour holes downstream of rock piles or single boulders	May cause sediment deposition upstream of rock piles	Local increase in velocity as flow passes over or around rock obstacles	
(9) ARTIFICIAL REEFS*			Slight velocity decrease as current passes through reef	
(10) GATES IN CLOSURE DIKES*	Reduced scour by reduced entry of erosive flows dependent on gate operation	Sediment deposition may increase, dependent on gate operation	Velocity will decrease, dependent on gate operation	Goal would be to maintain depths while excluding some sediment-laden flows

*Effects of these techniques have not been reported.
The described effects are speculative.

PART V: GENERAL ENVIRONMENTAL GUIDELINES

246. As discussed in Part II, design of dikes and dike fields is a highly river- and site-specific process, and there are no specific design criteria for dikes which are applicable to all situations. This is also true for environmental features for dike fields. Existing knowledge regarding specific river ecosystems and river response to dikes is inadequate to allow certain prediction of ecological effects of various design alternatives. However, using existing information and professional judgement to incorporate environmental concerns should provide aquatic habitat superior to that produced by designs based solely on river training objectives.

247. One approach to incorporating environmental concerns into dike field design is to identify the habitat requirements of various representative animal species, and then attempt to design dike fields that satisfy these habitat requirements while still meeting river training objectives. An alternative approach would be to attempt to design dike fields to provide scarce and valuable types of habitat without considering requirements of specific species. Theoretically both approaches would result in a net increase in the overall physical diversity of the riverine system. From an ecological standpoint, diverse current, depth, and bed material conditions provide a diverse set of aquatic habitats. Habitat diversity allows development of diverse animal and plant communities (biological diversity).

Importance of Habitat Diversity

248. Biological diversity is an important indicator of the "health" of an ecosystem, as it reflects the inherent nature of resource divisions, competition, and survival mechanisms of species. Local biological diversity is determined by many factors, including properties of the habitat, characteristics of the species, and interactions between species and habitat. Habitat diversity is an important determinant of biological diversity. For example, Gorman and Karr (1978) found a strong correlation between habitat diversity (as determined from measurement of several key

physical factors) and fish species diversity in small streams in Indiana and Panama.

249. Habitat diversity has both a spatial (structural) component and a temporal component (determined by environmental fluctuation over time). The structural component is composed of physical factors which determine the size, shape, texture, and composition of the habitat and influence the use of an area by a particular species. These physical factors also influence the effects of the temporal component upon biological diversity. Thus, physical factors are a prime feature of habitat diversity. The greater the complexity of the physical factors, the greater the habitat diversity and biological diversity.

250. In a lotic environment, the physical factors of importance include substrate, bottom morphology, the depth, velocity, and water quality (Gorman and Karr 1978). Dikes and dike fields directly influence these factors (although water quality effects are limited to slack-water pools isolated within the dike fields at low flow (Sabol et al. 1983)). The dike structures provide stable, stony substrate for a diverse assemblage of benthic macroinvertebrates (Mathis et al. 1982). By concentrating low flows into narrower and deeper channels, dikes increase main channel velocities, reduce shoaling at thalweg crossings, increase the rate of sediment deposition around the dikes, and stabilize the locations of sediment accretion. Sediment accretion can increase the amount of terrestrial habitat and reduce the aquatic habitat diversity by eliminating shallow-water and slack-water habitats, particularly at low and moderate stages. The overall diversity of the riverine system is also reduced as backwater areas naturally fill with sediment and the stabilized river channel is no longer free to create new ones. As discussed in Part III, existing dikes and dike fields provide significant aquatic habitat in many rivers; however, this habitat is often short-lived.

Representative Species

251. The state of knowledge regarding habitat requirements of certain species of animals is sufficiently advanced to outline these requirements by season and life stage. The expression "habitat requirements" generally

refers to observed favorable conditions for a given species. The range of conditions that allows organisms of a given species to merely survive or under which a species has been found at one time or another is much broader than the habitat requirements.

252. Habitat requirements for five species of fish, five terrestrial species, and general requirements for aquatic invertebrates are presented in tabular form in Appendix B. These tables are summarized in prose commentary, also in Appendix B. The selected species were chosen based on the following criteria:

a. Representation of different fish reproductive guilds (Balon 1975).

b. Broad geographical distribution including major United States waterways with dikes.

c. Sport or commercial importance.

d. Availability of information on habitat requirements.

253. The information in Appendix B is not provided for indiscriminate use in dike field design and maintenance. Instead, this information serves as an example of the type of information currently becoming available regarding habitat requirements. As noted below, geographical differences in habitat requirements do occur, and local authorities and studies should be consulted when using information derived from studies in other regions.

254. Examination of Tables B1 through B6 reveals strong preferences for still or slow-moving water; shallow depths (with deep holes for wintering in colder climates); and stable, diverse substrates. Only one of the five selected fish species favors main channel conditions (deep, swift water). The information in Tables B1 through B6 supports the conclusions of most of the references cited in Part III. For the selected species, unfilled dike fields with their low velocities, range of depths, length of wetted edge, and mosaic of substrates provide extremely valuable habitat.

Environmental Guidelines

General goals

255. Environmental features and techniques in dike design,

construction, and maintenance should be used with the following general goals in mind:

a. Maintain or increase the aquatic habitat diversity of the river or river reach by increasing the complexity of physical factors comprising the aquatic habitat (Kallemeyn and Novotny 1977).

b. Preserve the integrity of existing off-channel aquatic habitats. (Off-channel habitats include such areas as secondary channels, chutes, dike fields, abandoned channels, oxbow lakes, and borrow pits.) Cobb and Clark (1981) give good descriptions of riverine aquatic habitat types.

c. Avoid conducting dike construction or maintenance during peak spawning seasons for the majority of aquatic biota. Peak spawning seasons vary by species, river, and location; however, the majority of aquatic species spawn in the spring (Conner, Pennington, and Bosley 1983).

d. Prolong the "lifetime" of the dike field (i.e., avoid sediment accretion which converts aquatic habitat to terrestrial habitat (Pennington, Baker, and Bond 1983; Kallemeyn and Novotny 1977). Large pools of open water within the dike field during periods of low water are valuable habitat (Beckett et al. 1983).

e. Maintain abandoned channels open to the river to provide slack-water habitat (Beckett et al. 1983; Conner, Pennington, and Bosley 1983; Pennington, Baker, and Bond 1983).

Master plan

256. As noted in Part II above, the ultimate configuration of the navigation channel and the approximate locations of dikes and revetments to produce that channel are determined during formulation of the river master plan. Adjustments and refinements of the master plan are made as construction progresses over a period of years, but the general training scheme follows the master plan. Environmental considerations at the master plan level include the distribution or "composition" of habitats among the various habitat types (main channel, abandoned channel, island, point bar, revetted bank, natural bank, dike field, etc.) and the spatial distribution of backwater habitats along the waterway. Master plan formulation might be conducted as follows to ensure incorporation of environmental considerations:

a. Formulate a draft river training master plan to achieve navigation, flood control, and bank erosion control objectives.

b. Using results of a habitat mapping study, evaluate the existing composition and spatial distribution of riverine habitats.

c. Using a multidisciplinary team, set general long-term goals for composition and spatial distribution of aquatic and terrestrial riverine habitats. These goals may be set by major reaches.

d. Modify the draft master plan to achieve these goals.

257. If modification of existing dikes and dike fields is being planned rather than new construction, a similar approach may be used. Extensive modifications performed on long reaches are preferred to intensive concentration on only a few structures. A comprehensive program is the best approach. A system of priorities should be used to determine which structures should be modified first. Highest priority should be assigned to locations most likely to give good results (in terms of habitat development) (Omaha District 1982).

Dike field design

258. Since dike fields have been shown to be valuable habitat, the process described above for master plan formulation may result in recommendations to preserve and enhance dike field aquatic habitat. The following steps are suggested for design of a specific dike or dike field:

a. Evaluate the long-term potential of the dike field as aquatic habitat. Smith et al. (1982) concluded that the location of middle Mississippi dike structures with respect to the thalweg influences the size gradation of sediment deposits and the sediment accretion rate and pattern more than does the type or location of notches or other types of structural modification. Location has been observed to be more important than design parameters in determining sediment accretion in lower Mississippi River dike fields as well.* Dike fields located in natural depositional zones such as convex bank point bars tend to fill rapidly, while dike fields subject to direct current attack tend to remain open.

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* Bobby Littlejohn, Memphis District. Personal communications. Charles Elliott, Vicksburg District. Personal communications.

b. Based on the above evaluation, determine if design modifications or environmental features are in order. Dike fields prone to fill rapidly are probably poor candidates for environmental work. However, the preference of many important species for still or slowly-moving water (Omaha District 1982; Beckett et al. 1983; Appendix B) indicates that "depositional" dike fields may provide a valuable habitat prior to filling. It seems that an "ideal" dike field would provide still or slowly moving water connected with the main channel at low and intermediate stages, but would scour at high stages.

c. Consider manipulation of the basic dike design parameters to reduce the elevation of sediment deposition within the dike field. At some sites, longer, lower dikes might achieve river-training goals but produce lower sediment deposits. As noted above, Franco (1967) observed that L-heads, and stepped-up crests tended to reduce deposition elevation in his lower Mississippi-type physical model.

d. Qualitatively project the depths, velocities, and resulting substrates likely to occur in the dike field. Evaluate the dike field in light of habitat requirements for selected species such as those in Appendix B. Alternatively, the dike field habitat may be evaluated in light of goals set for habitat diversity and composition for the entire reach or river (as described above).

e. Consider structural modifications on measures to improve the dike field habitat. For example, notches might be selected in order to provide deep scour holes. Other dike structure modifications discussed in this report include rootless dikes, culverts, and control structures. Parts IV and VI of this report and the cited references and individuals should be consulted prior to design of any of these measures. Existing design criteria for these measures are summarized in Table 3.

f. Consider management techniques to improve dike field habitat subsequent to construction. Management techniques are discussed in Part IV above and include dredging accumulated sediments, placing dredged material to raise a middle bar or form islands, relocation of notches, placing additional stone, constructing brush or tire reefs, and minimum maintenance. There are no existing design criteria for these techniques. A few general guidelines for minimum maintenance and brush shelters are given in Part IV.

Monitoring

259. Since there are so many unknowns associated with dike field environmental features and dike designs in general, the ongoing monitoring effort of the river stabilization program should be extended to within dike field phenomena, particularly dike fields with environmental features. Such

monitoring will allow estimation of maintenance costs and refinement of design criteria. Omaha District (1982) notes that the response of dike field habitat to features such as notches is a function of the subsequent hydrologic record. Therefore, long periods of time (15-20 years) may be required to thoroughly evaluate effects of environmental features.

Design of structural modifications

260. Notches. The following steps are suggested for design of dike notches.

a. Study the design and performance of notches in locations similar to the site in question. If no notches have been constructed in similar situations, perhaps there are a few failure notches.

b. Determine which dikes to notch.

(1) Omaha District (1982) recommends that: large numbers of structures over long reaches be modified rather than conducting intensive notching in isolated localities; notches should not be placed near structures such as cabins or pipeline crossings where small amounts of bankline erosion or bed scour might cause problems; notches in spur dikes are generally more effective than notches in longitudinal dikes in terms of developing open water; notches in pairs or series are frequently effective, with the upstream notch and backwater serving as a settling basin for downstream areas (Figure 17); and L-head dikes constructed just upstream from tributary inflows should be notched to prevent sediment buildup at the tributary mouth.

(2) Smith et al. (1982) noted that both notched and unnotched structures provide habitat for distinct assemblages of fish. Therefore, not every dike should be notched.

(3) Additional experience on the Missouri River indicates selected dikes should be accessible to a floating plant and free of sediment deposits, or with only recently accreted sediment deposits free of established vegetation.*

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* Ken Murnan. Omaha District. Personal communication. 28 July 1982.

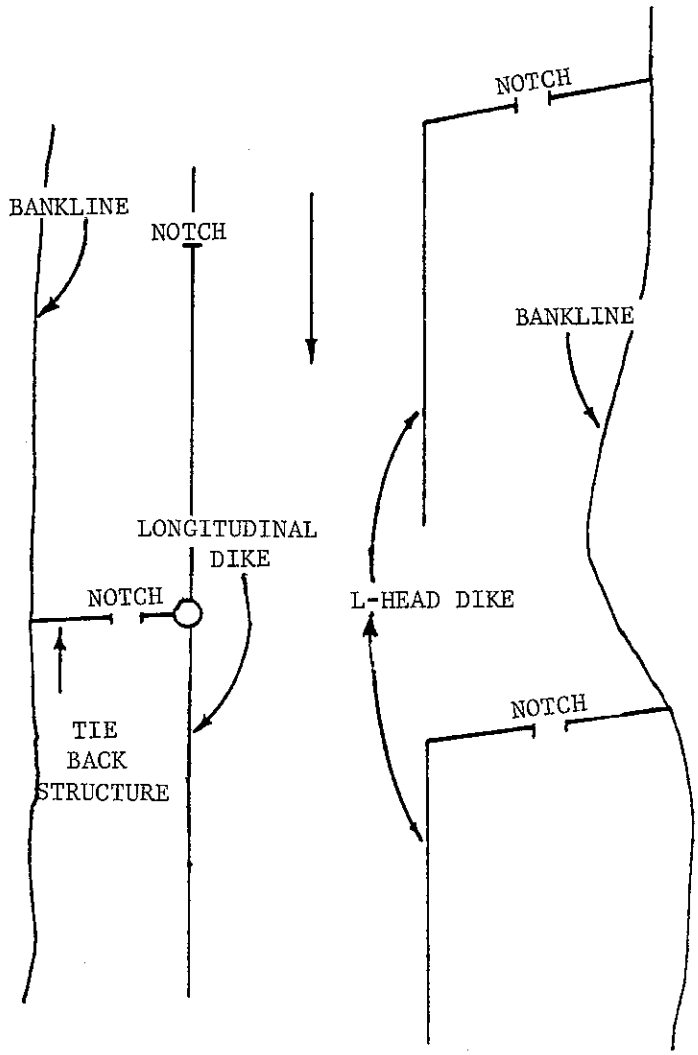

Figure 17. Examples of L-head and longitudinal structures where notches should be considered in pairs

(4) If a large number of notches are to be constructed, locations notched first should be those where notches would tend to produce the best habitat. Along the Missouri River, notches which preserved or developed chutes and pools found landward of L-heads and crossing control dikes were most likely to produce best results, followed first by spur dikes, and then by longitudinal dikes in the middle of bends (Omaha District 1982).

c. Determine the location of the notch on the dike. Notches should be far enough from the bankline to prevent flanking problems (25 ft for the Missouri River). The distance from the notch to the riverward tip should be varied to produce diversity (Omaha District 1982).

d. Select notch width. Wide notches are less susceptible to debris blockage. However, in some cases, increased width tends to reduce scour downstream of the notch. In general, notch width should be 10-25 percent of the riverward length of the structure. Notches must be wide enough to develop desirable habitat, yet not wide enough to induce damaging erosion, structural failure, or undesirable effects on the navigation channel. Notch width should increase with dike angle.

e. Select notch shape and depth. Notches may be either trapezoidal or triangular. Flow through a triangular notch is a stronger function of depth than flow through a trapezoidal notch.

(1) Extremely deep notches are effective at developing a downstream scour hole and high velocities. However, once the scour hole is formed, lower velocities and resultant finer grained substrate are more desirable from a habitat standpoint (Smith et al. 1983; Beckett et al. 1983; Pennington, Baker, and Bond 1983; Omaha District 1982). In some cases it may be advantageous to construct deep, wide notches at first and partially close them after some initial development (Omaha District 1982).

(2) Smith et al. (1982) noted that samples of bed material collected downstream of an L-head dike with a notch in the spur portion were finer than samples collected downstream of ordinary notched spur dikes.

(3) Omaha District (1982) recommends two alternative philosophies for selecting notch depth: either choose a depth that will allow flow almost all the time, or choose a depth that is only overtopped at moderate and higher stages, thus providing slack water at lower stages. Deep notches are recommended for locations with wide stage

fluctuations. Use of a variety of notch dimensions throughout a reach will provide habitat diversity with changes in stage.

f. If notches are to be excavated in existing structures, select a method for disposal of excavated stone. Alternatives include piling the stone in the dike field to develop aquatic habitat as described in Part IV, using the stone for ongoing maintenance, or stockpiling for future maintenance.

261. Rootless dikes. Design of rootless dikes may be done following steps similar to those outlined above for notches. Extra care is needed when determining which dikes should be rootless, since there is some potential for flanking and bank erosion. Best locations tend to be downstream of or between existing rooted structures. Determination of the width of the opening between the landward end of a rootless dike and the bank is analogous to selections of notch width; Omaha District (1982) recommends that this gap be wide enough to prevent excessive flow concentration and scouring (more than 150 ft for the Missouri River) and that the bankline have some protection for periods of high discharge.

262. Culverts and Control Structures. No detailed criteria for design of culverts or control structures for dikes were found during this study. Experience with culverts on the Missouri and upper Mississippi Rivers is described in Parts IV and VI. Culverts tend to clog with sediment and debris and to be damaged by ice. The major problem associated with design and operation of these types of structures is compatibility with the range of hydrologic conditions encountered.

PART VI: EXAMPLES OF ENVIRONMENTAL FEATURES

263. Specific examples of dike field environmental features used at selected locations are described in this part. The rivers listed below, discussed in this part, are the sites of most CE dike design, construction, and maintenance activities:

a. Missouri River
b. Upper Mississippi River
c. Middle Mississippi River
d. Lower Mississippi River
e. Arkansas River
f. Columbia River
g. Alabama River
h. Apalachicola River

264. General characteristics of these rivers are shown in Table 5. A wide range of climates, flow conditions, aquatic habitats, and dike design practices are represented.

Missouri River

265. Early river training efforts on the Missouri River began with snag removal in 1832 (Burke and Robinson 1979). However, very little construction was performed prior to the late 1920's, except for occasional dikes or revetments adjacent to some towns (Burke and Robinson 1979). In 1912, Congress authorized a 6-ft navigation channel to be built from Kansas City, Missouri, to the river mouth. Subsequent project design modifications have resulted in a minimum navigation channel 9 ft by 300 ft from Sioux City, Iowa, to the river mouth. This has been accomplished through construction of dikes, revetments, and bendway cutoffs. The dikes constructed prior to the 1950's are primarily timber piling, with later additions of stone fill. Newer dikes and revetments are stone.

266. From 1940 to 1964, six large multipurpose dams were built on the upper reaches of the Missouri River. These dams provide water storage for flood control, power production, and irrigation and provide supplemental flows for downstream navigation. The dams have resulted in reduction of

Table 5

General Characteristics of Rivers with Major Dike Fields

RIVER	RIVER CHARACTERISTICS					
	DRAINAGE BASIN (square miles)	RIVER LENGTH (miles)	RIVER WIDTH (feet)	FLOW (cubic feet per second)	TOTAL SEDIMENT LOAD (tons)	DIKES
MISSOURI RIVER	591,000	2,522 (with 730 channelized with dikes)	600-1100 (channelized portion)	80,000 mean at mouth	260,000 of sand, silt, and clay per day, mean at mouth	Spur Vane L-head Longitudinal Sills Closure
UPPER MISSISSIPPI RIVER	713,199			95,000 mean annual		Spur L-head Closure (Submerged)
MIDDLE MISSISSIPPI RIVER	700,000	195	2,200 (average)	175,000 mean annual at St. Louis, MO	500,000 of sand, silt, and clay per day, mean at St. Louis, MO	Spur L-head Closure
LOWER MISSISSIPPI RIVER	1,245,000	950		569,000 mean annual at Vicksburg, MS	695,000 of sand, silt, and clay per day, mean at Vicksburg, MS	Spur L-head Vane Closure
ARKANSAS RIVER	160,500	1,450 (with 448 channelized with dikes)				Spur L-head Closure
COLUMBIA RIVER	250,000	1,207 (lower 145 are tidal)		256,000 mean annual		Spur (made of timber)
ALABAMA RIVER	22,500	315	500 – 1,000	31,000 average at mile 82		Spur Vane Longitudinal
APALACHICOLA RIVER	19,000	107 (lower 25 are tidal)		21,000 average at mile 107	Low silt-content sands to gravelly sands with no silt	Spur Vane Longitudinal

flood peaks and stage fluctuations. Average annual sediment load has been reduced by almost 81 percent, and the grain size distribution of the sediment has shifted toward sand and away from silt-clay since closure of Gavins Point Dam in 1954 (Slizeski, Andersen, and Dorough 1982).

Notches

267. Dike 682.45. Dike number 682.45 at River Mile 639.7 in the middle of Calhoun Bend is an example of the use of dredging and dike notching to open a secondary channel. The Omaha District reopened a secondary channel by dredging accreted sediments and notching the closure dike so that flow would take a direct route from the main channel through the secondary channel.* The secondary channel has emergent aquatic vegetation growing along the edge. Observations by Omaha District indicate that the secondary channel is remaining open.

268. Dike 186.1. Dike number 186.1 at River Mile 178.5 is an example of an L-head dike with two notches and a low-elevation trail portion, a standard design for Kansas City District. One of the notches is on the upstream end of the trail immediately downstream of the spur dike. The second notch is at the end of the trail and is actually a gap between the trail and the next downstream dike (Figure 18). Water flows parallel to the notch and must change direction to flow into the area behind the dike. A scour hole has developed behind the first notch. According to Jennings (1979), this dike notching has not been effective in halting sediment accretion or in removing existing sediment. A 50-ft notch is scheduled to be constructed in Dike 186.1 approximately 200 ft landward of the riverward end during 1983. The area behind the dike provides habitat for slow water forms of benthic organisms and marginal habitat for fish (Jennings 1979).

269. Dike 182.05. Dike 182.05 at River Mile 174.4 is an example of an L-head dike with a notch in the spur dike portion and in the trail. As the notch in the spur dike is perpendicular to the direction of flow, more current is channeled into the area behind the dike than for Dike 186.1. This is a preferred notching design for Kansas City District.** A scour

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* Ken Murnan. Omaha District. Personal Communication. 28 July 1982.

** Tom Burke. Kansas City District. Personal Communication. 27 July 1982.

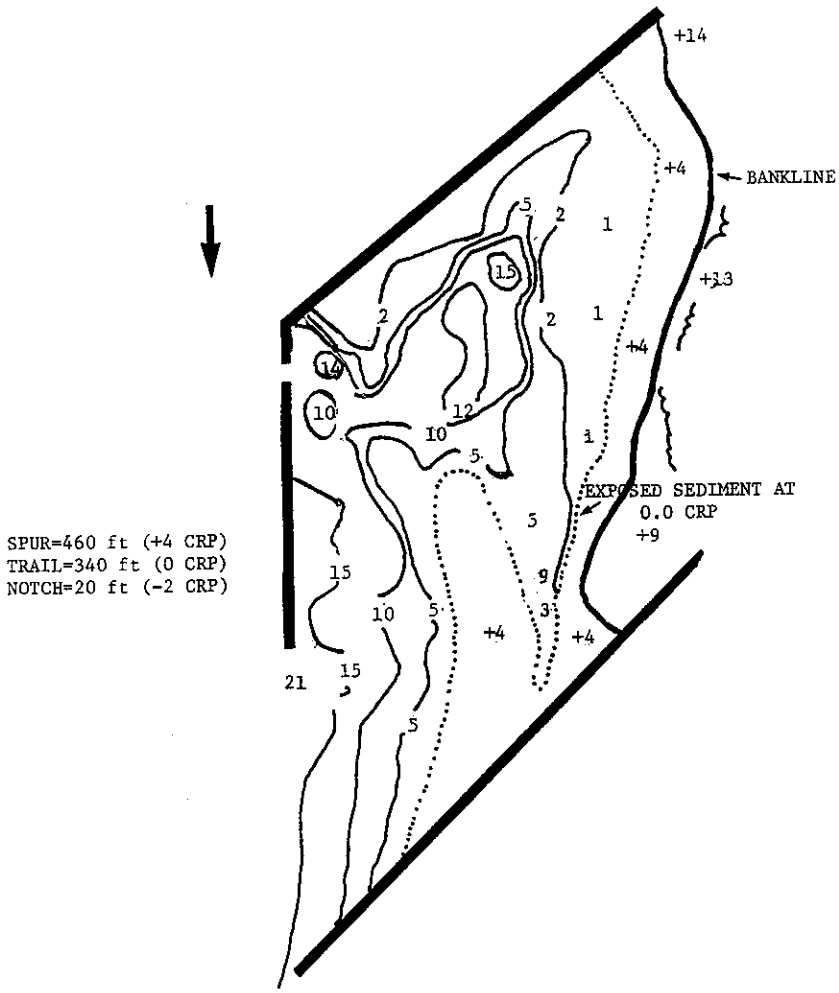

Figure 18. Dike 186.1 (contours shown referenced to CRP) (from Jennings 1979)

hole formed below the spur notch. Figures 19, 20, and 21 show the morphological changes which occurred after notching the spur and then notching the trail. Jennings (1979) reported that sediment accretion behind Dike 182.05 closed off access to the secondary channel from the river, but theorized that the closure was a result of a low-water year (1976), not the notches. After notching, there was a notable shift in the benthic community from slow-water to fast-water organisms, as well as an increase in density (measured by mean catch per sampler). Jennings judged the fish habitat as marginal.

270. Dike 185.81. Dike 185.81 at River Mile 178.2 is an example of a spur dike with two notches. The first notch is approximately 30 ft from the bank and is separated from the second notch by 100 ft The structure (with notches) was built in 1976 (Figure 22). Approximately 150 ft of bank was protected with riprap below the dike. Some bank erosion occurred at the downstream end of the riprap. The crest elevation of the dike was eroded 2 ft to an elevation of 0 CRP by 1979 (Robinson 1980). No land accretion has occurred since dike construction. Several secondary channels and a sandbar developed between this dike and the next one downstream (Dike 185.71) which was also notched. Robinson (1980) observed that the area behind Dike 185.81 was providing excellent habitat for fish.

Culverts

271. St. Aubert's Island. Dike 130.0 is a closure dike used as an access route to St. Aubert's Island. A culvert was installed to allow flow through the dike while maintaining access to the island. The culvert is a multiplate steel arch 12.5 ft by 10 ft, with a concrete collar and stone apron around it. Unlike other smaller culverts built by Kansas City District, the arch was not clogged by sediment accretion. However, the arch, damaged by ice flows, had closed by 50 percent. Kansas City District is now working on plans to repair the arch opening and secure it to a concrete headwall.*

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* Tom Burke. Kansas City District. Personal Communication. 27 July 1982.

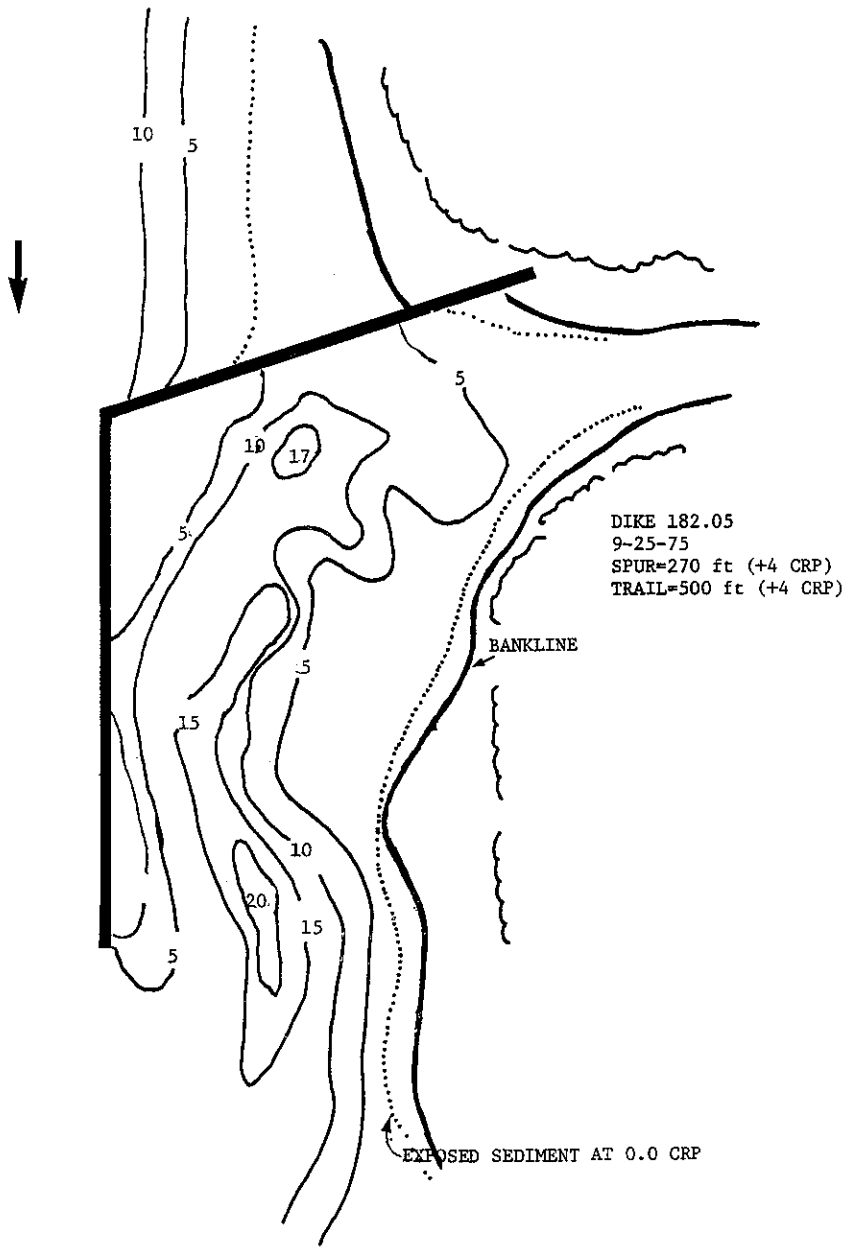

Figure 19. Dike 182.05 before notches (contours are referenced to CRP) (from Jennings 1979)

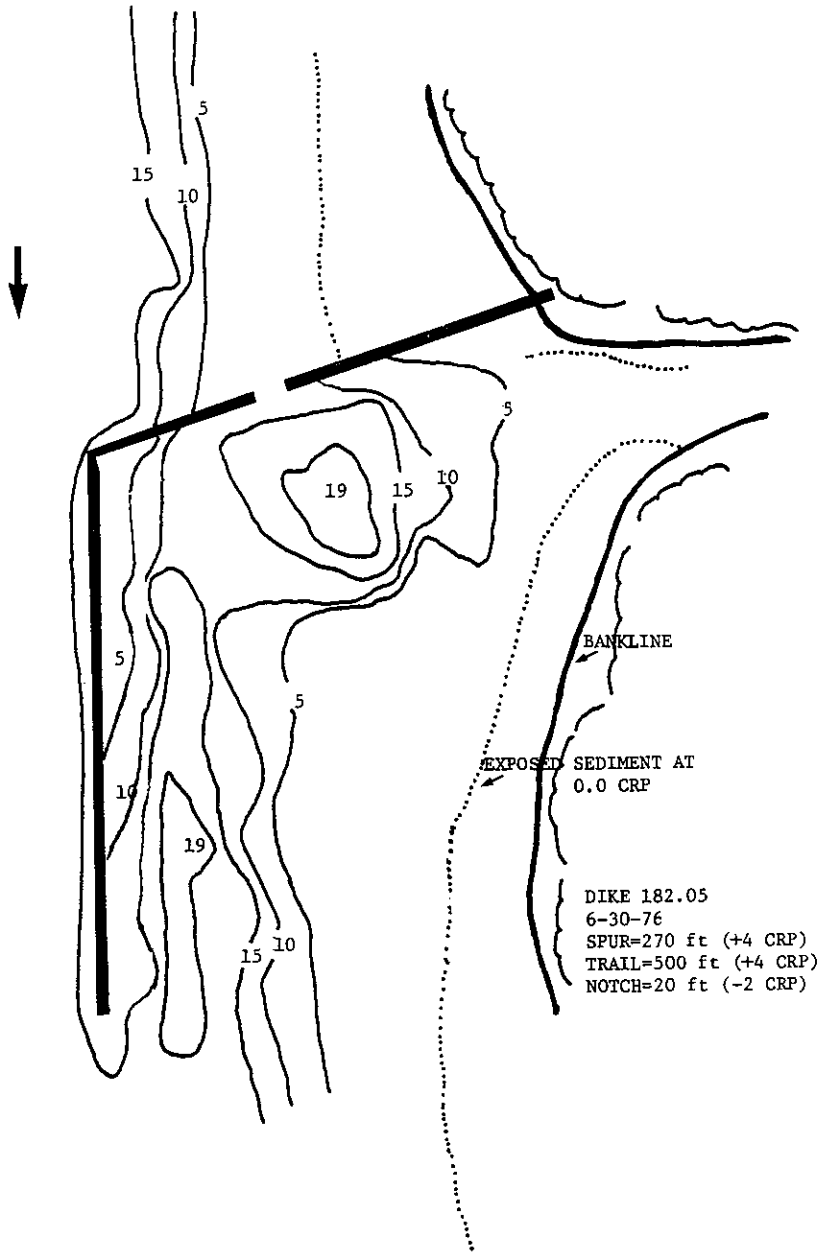

Figure 20. Dike 182.05 with spur notch (contours are referenced to CRP) (from Jennings 1979)

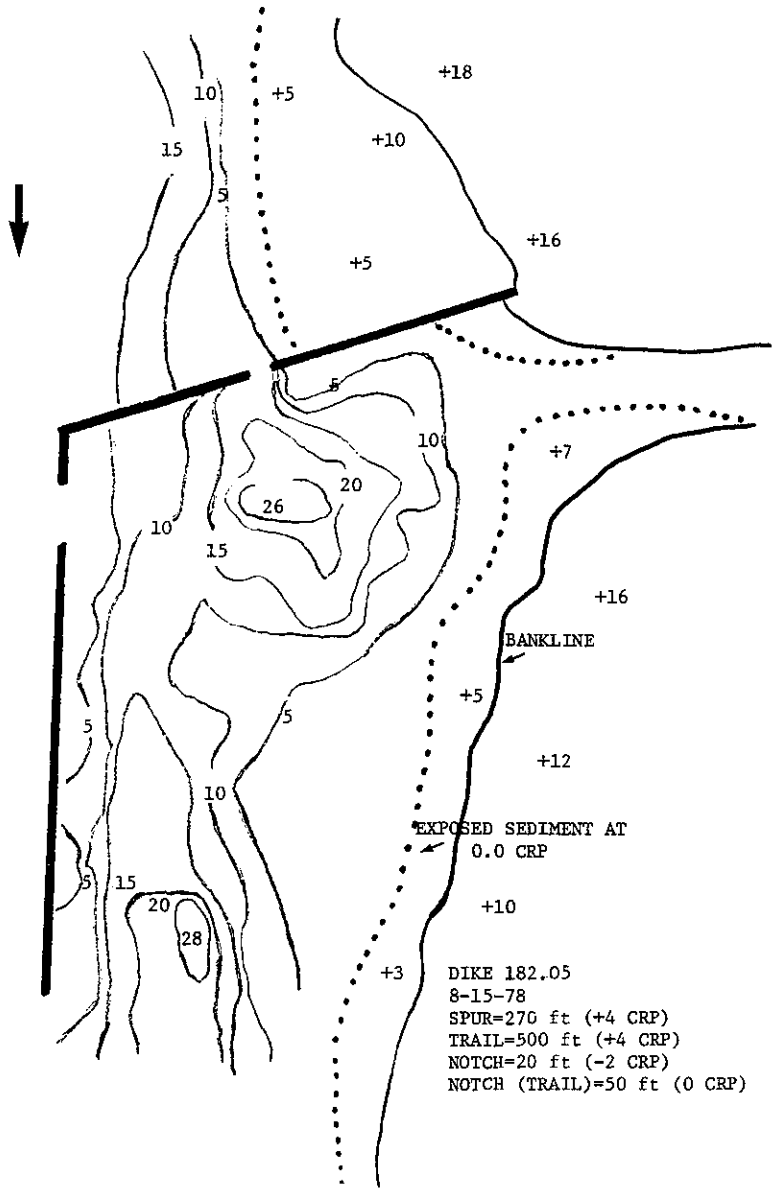

Figure 21. Dike 182.05 with spur and trail notches (contours are referenced to CRP)(from Jennings 1979)

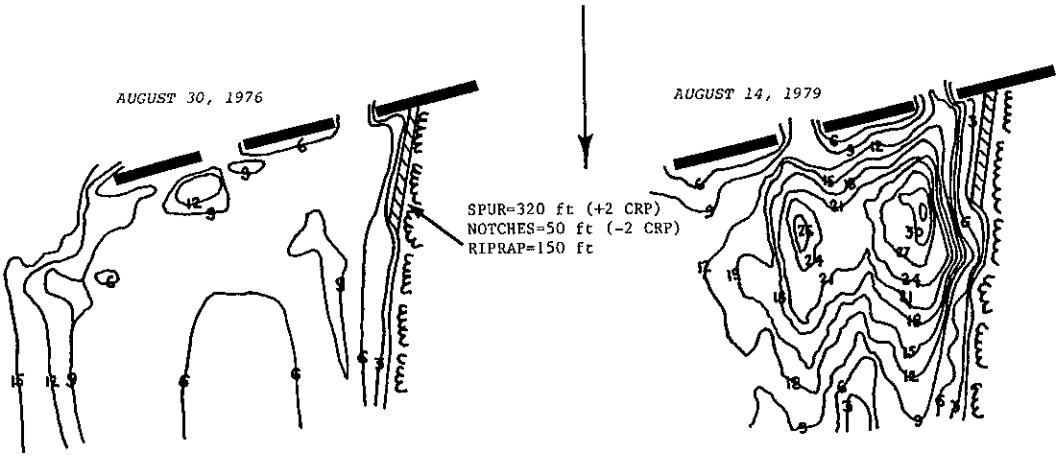

Figure 22. Dike 185.81 (contours are referenced to CRP) (from Robinson 1980)

272. Boyer Chute. Boyer Chute is several miles long, contains three closure dikes and valuable wetland habitat, and is regarded as one of the more promising secondary channels available for aquatic habitat development.* The middle dike is used as an access route to the island and was initially constructed with a culvert which is now partially clogged with sediment. Omaha District installed six 26-in. circular culverts in the lead closure dike at River Mile 637.6 to provide additional flow through the chute. The culverts are unique in that they are small and submerged at normal stages. This design controls the flow into the chute, particularly at high river stages. (A notch built deep enough to allow flow during low stages would allow excessive flow at high stages.) Observations indicate that the culverts are successful in maintaining some flow through Boyer Chute.*

Low-elevation dike

273. Dike 191.0 L at River Mile 183.3 is an example of a low-elevation spur dike. The dike, 240 ft long at an elevation of 2 ft below CRP, was built in 1976. The bank is revetted with degraded riprap (stones of uneven shapes and sizes) adjacent to the dike root. The design elevation of 2 ft

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* Ken Murnan. Omaha District. Personal Communication. 28 July 1982.

below CRP allows flow over the dike 95 percent of the time and prevents high sediment accretion elevations (and subsequent vegetation) from becoming established (Burke and Robinson 1979). The diversity of stone sizes in both the dike and the bank riprap and the development of a deepwater area downstream of the dike (Figure 23) provide excellent aquatic habitat (Robinson 1980).

Rootless dike

274. Dike 176.5R at River Mile 168.8 is an example of a rootless structure which created problem bank scour in addition to increasing aquatic habitats. The dike, built in 1976, was 275 ft long and 4 ft below CRP. The dike was 165 ft from the bank. Accelerated bank scour occurred as soon as the dike was completed due to development of a secondary channel landward of the dike (Robinson 1980). A shallow sandbar also formed immediately downstream of the dike. To prevent further scour, the dike was joined to the bank and notched. The final dike was 440 ft long, consisting of a 115-ft section at CRP next to the bank, a 50-ft notch at 4 ft below CRP, and the remainder raised to 2 ft below CRP. Approximately 650 ft of riprap was placed on the bank for additional protection. Scour holes formed immediately downstream of the notch and the channelward end of the dike (Figure 24). A low sand deposit formed, with channels on both sides. The dike was considered effective in developing diverse aquatic habitat (Robinson 1980). Many rootless dikes on the Missouri River have been successful in developing secondary channels landward of the dike without creating problem bank scour.*

Minimum maintenance

275. Dike 175.7 at River Mile 167.7 is an example of a spur dike which has not been maintained at its design elevation (i.e., no maintenance has occurred since 1970). In 1970 the dike was 800 ft long at 2 ft above CRP. High water and ice flows degraded the dike, resulting in a low uneven structure at 4 ft below CRP. Variable water depths developed below the dike, and a small roundout (bank scour) occurred where the dike joins the bank (Figure 25). Sediment accretion downstream of the dike was reduced,

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* John Robinson. MDOC. Personal Communication. 27 July 1982.

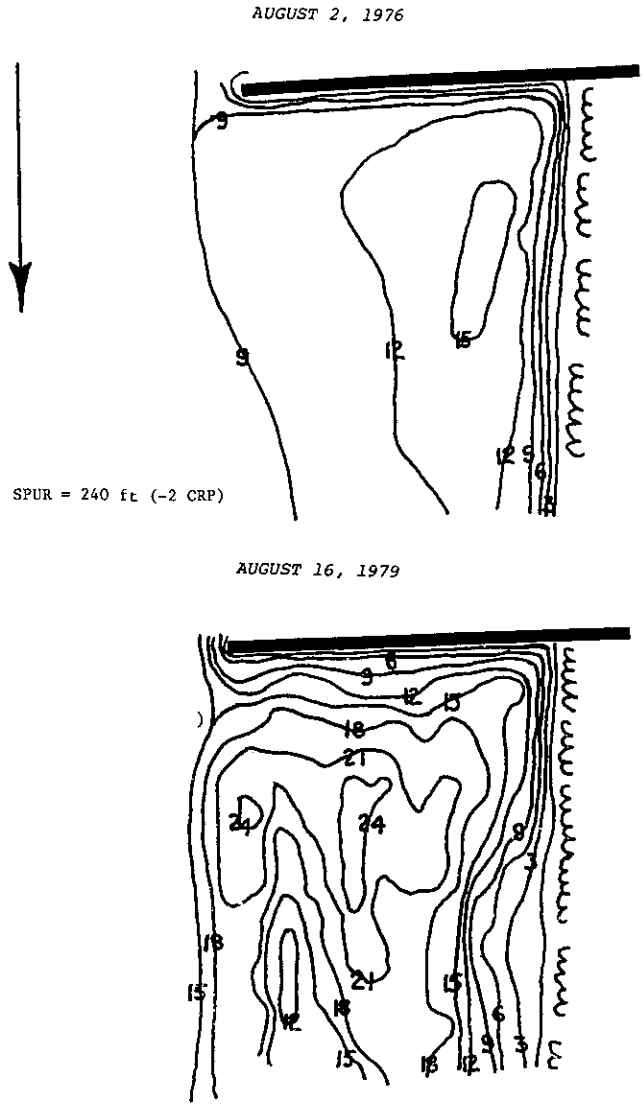

Figure 23. Dike 191.0L (contours are referenced to CRP) (from Robinson 1980)

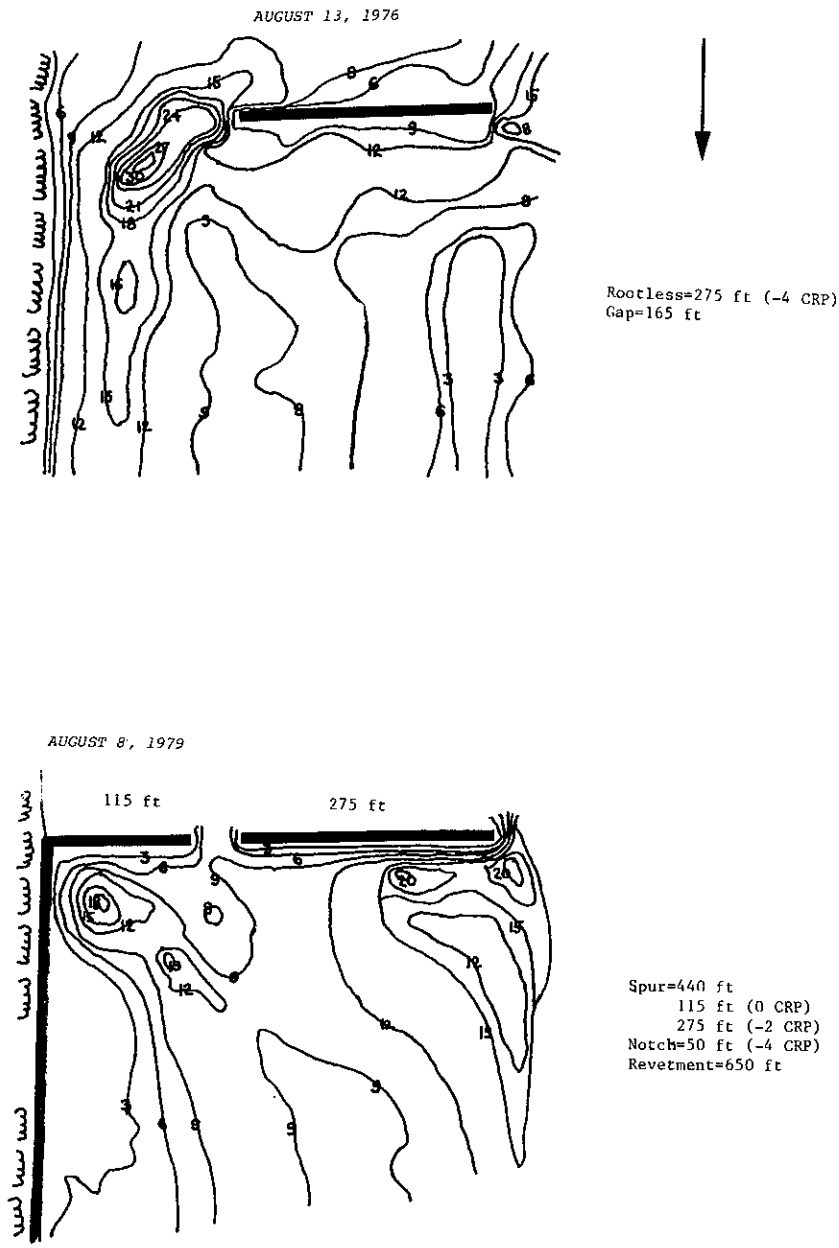

Figure 24. Dike 176.5R (contours are referenced to CRP) (from Robinson 1980)

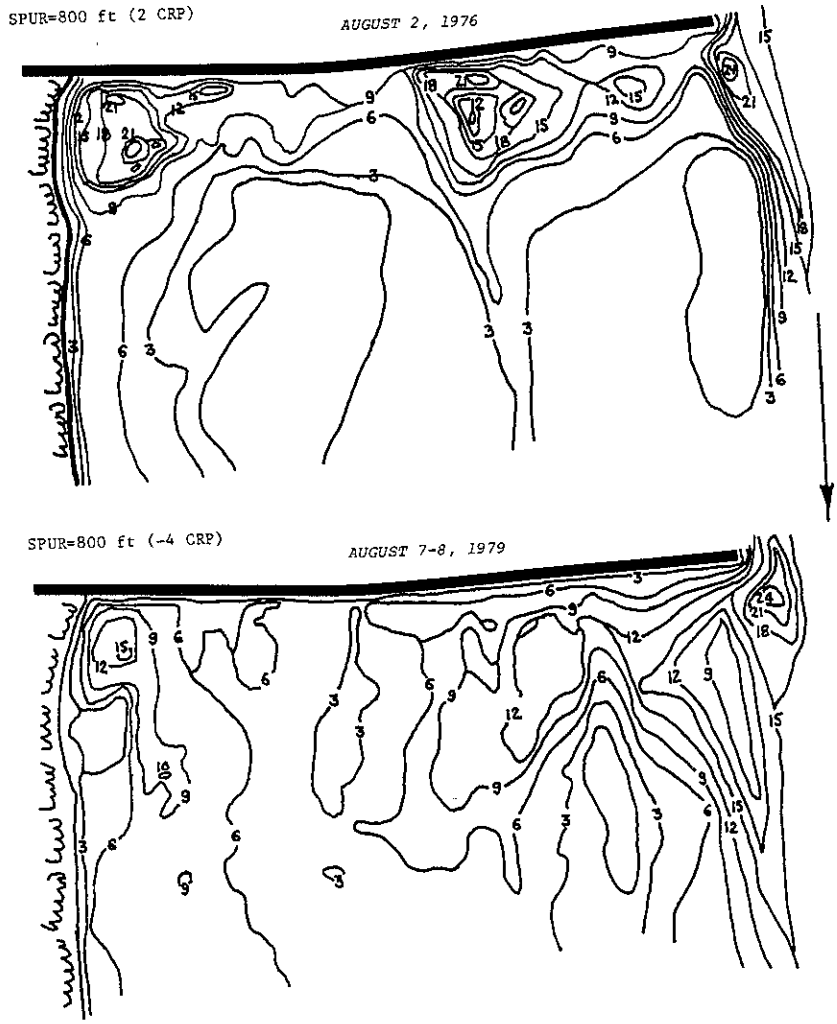

Figure 25. Dike 175.7 (contours are referenced to CRP) (from Robinson 1980)

increasing the amount of aquatic habitat for fish, wildlife, and benthic organisms. Dike 175.7 was used by Kansas City District as a prototype for notching and low-elevation designs (Robinson 1980).

Summary

276. Environmental features used on the Missouri River dikes by the Omaha and Kansas City Districts include notching (and culverts), low-elevation dikes, rootless dikes, and minimum maintenance. The features are employed in a variety of dike types and locations. Although every feature is not effective at all sites, the overall results are considered extremely beneficial in terms of increasing aquatic habitat diversity (Omaha District 1982; Kansas City and Omaha Districts 1981; Robinson 1980).

Upper Mississippi River

277. Dikes on the upper Mississippi River were constructed primarily of brush and stone during early river training efforts (Simons et al. 1981b). In 1878, a 4.5-ft navigation channel was authorized using brush dikes. In 1907, a 6-ft channel was authorized using stone and brush dikes. In 1930, a 9-ft channel 300 ft wide was authorized using a system of locks and dams and dredging. The use of dikes to create a navigation channel caused a slight decrease in river width between 1890 and 1930. The river's response to the locks and dams was an immediate increase in pool width; however, the long-term response has been decreases in width below the dams and slight increases in width just above the dams (Simons et al. 1981b). Almost all of the dikes have been continuously submerged since closure of the navigation dams.

Notches

278. Dike 11A. Dike 11A is a submerged closure dike crossing Andalusia Slough at Smith Island (River Mile 475.7). The dike has a notch 4.5 ft deep and 50 ft wide built to provide recreational boating access into the slough.* A deep scour hole formed immediately downstream of the notch.

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* Dick Baker. Rock Island District. Personal Communication. 4 August 1982.

This type of aquatic habitat (i.e., scour holes) is considered highly valuable for fish on the upper Mississippi by the U. S. Fish and Wildlife Service (FWS) and the Iowa Conservation Commission (ICC).*

279. Dike 26. Dike 26 in Pool 13 is a spur dike (emergent during low flow) with a notch 5 ft deep. The biology of the dike area was studied by Hall (1980) and Pierce (1980) prior to notching and by Corley (1982) after notching. However, the notch was constructed before the prenotching studies were completed. Prior to notching, sediment had accreted to within 2 ft of the crest of the dike. Thus when the 5-ft notch was constructed, the result was a hole 3 ft deeper than the surrounding sediment.** Corley (1982) reported an increase in velocity through the notch as compared to current over the dike; increased densities of benthic organisms downstream of the notch due to exposure of gravel substrate; and no effects on fish populations, water temperature, or dissolved oxygen levels.

280. Culverts. The upstream end of Davenport Harbor at River Mile 480.6 depends upon flow through three 48-in. culverts to remain open. These culverts were placed in a road embankment connecting an island to the bank. Although these structures are not in a dike, they are an example of how culverts have been used to provide flow though a closed secondary channel to maintain the aquatic habitat.†

Low-elevation dike

281. Dike 29 at River Mile 457.8 was built in 1924, raised and repaired in 1968, and has not been maintained since then. Dike 29 has a failure notch and a large scour hole immediately downstream from the notch. Flow over the top of the dike has prevented rapid sediment accretion around the dike.†

Rootless dike.

282. Dike 28 in Pool 18 at River Mile 426 is a rootless structure designed and built in 1925 to develop the 6-ft navigation channel. This dike is unique in the Rock Island District, as it was originally designed

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* Jerry Rasmussen. FWS. Personal Communication. 4 August 1982.
John Pitlo. ICC. Personal Communication. 4 August 1982.

** Gail Peterson. FWS. Personal Communication. 4 August 1982.

† Dick Baker. Rock Island District. Personal Communication. 4 August 1982.

as a rootless dike. (Most rootless dikes existing now were not designed as such, but were flanked by rising water levels from the dams installed for the 9-ft channel.) After the rise in water level, a secondary channel 25 to 35 ft deep developed landward of Dike 28. This secondary channel is diverting flow from the main channel, thus increasing dredging requirements in the main channel. Plans have been developed to tie the dike into the bank to close the secondary channel and protect the bank from erosion. Performance of the dike under its design conditions (prior to construction of the locks and dams) is unknown.

Summary

283. Environmental features (and dikes in general) on the upper Mississippi River provide a diversity of aquatic habitats. The low-elevation dikes, although not a result of intentional design, are performing well in terms of channel maintenance, and the dike fields are considered valuable aquatic habitat.* In fact, new construction or rehabilitation of existing structures will be limited to low-elevation (submerged) dikes.**

Middle Mississippi River

284. Between 1836 and 1840, two dikes were constructed near St. Louis, Missouri, on the middle Mississippi River; these were among the first river training structures applied to the Mississippi River. In 1881 timber pile dikes were in use to reduce the width of the river (Strauser undated). By 1927, a navigation program was underway to develop a 9-ft-by-300-ft channel using timber pile dikes and revetments. In 1965 a program was started by the St. Louis District to convert 800 timber pile dikes to stone filled dikes (Simons, Schumm, and Stevens 1974). Currently all dikes are built of stone. About 64 of these dikes have been notched in recent years. Descriptions of three of the notched dikes are below. Results of biological sampling adjacent to the dikes are given in Table 6, and contour maps of the dike fields are presented in Figures 26-28.

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* Gail Peterson. FWS. Personal Communication. 4 August 1982.
** Dick Baker. Rock Island District. Personal Communication. 14 February 1983.

Table 6

Summary of Biological Data for Middle Mississippi River Example Sites

Dike	Description	Benthic macroinvertebrates		Fish	
		No. of Taxa	Catch per Unit Effort**	No. of Species	Catch per Unit Effort[τ]
102.2 L	L-head; notch between straight and angled portion; below side channel entrance	34	1470	24	159
98.9 L	Straight; 2 notches	33	1622	26	139
100.1 R	L-head; notch in straight	23	828	25	200
All notched dikes (5)		51	1346	42	157
All unnotched dikes (3)		30	791	33	145

* Adapted from Smith et al. (1982). Sampling occurred during 4 sampling periods between April and October 1981.

** Number of organisms per sample (artificial substrate and dredge both used downstream of each dike).

τ Eletrofishing catch per hour.

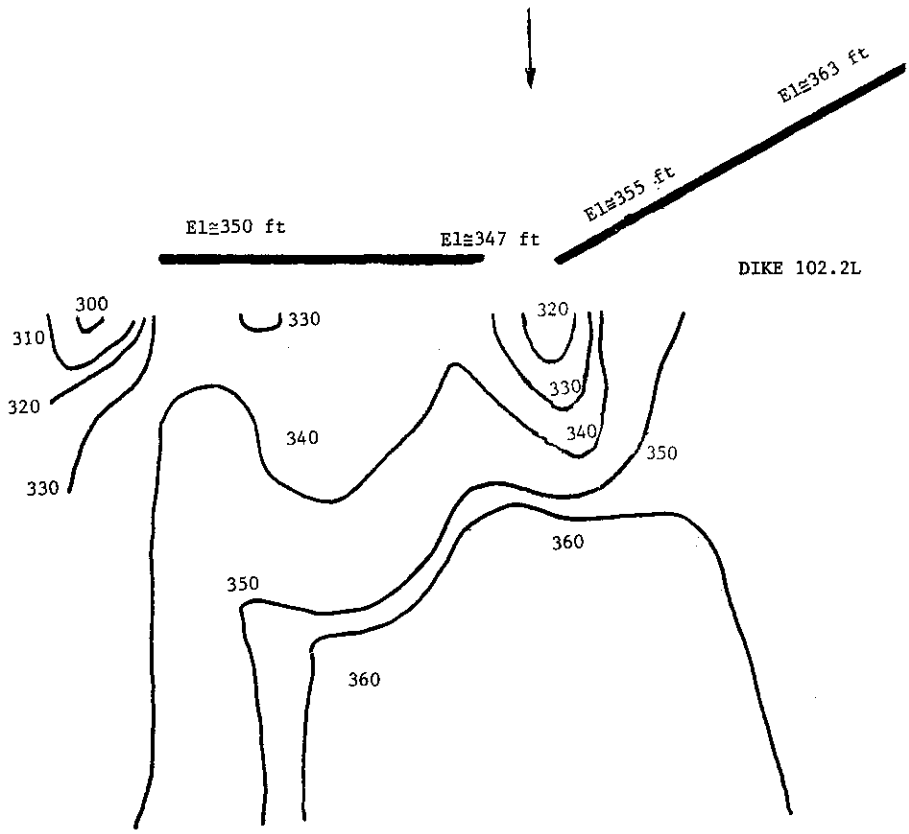


Figure 26. Dike 102.2L, October 15, 1981 (contour lines scale 1 in. = 50 ft; contours referenced to ft above MSL) (from Smith et al. 1982)

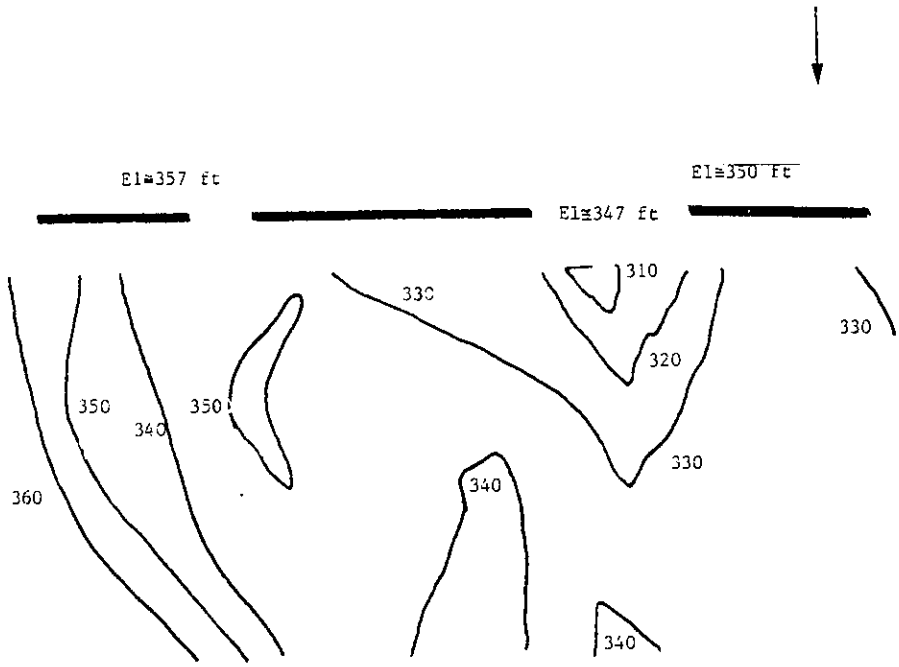


Figure 27. Dike 98.9R, October 13, 1981 (contour lines scale 1 in. = 50 ft; contours referenced to ft above MSL) (from Smith et al. 1982)

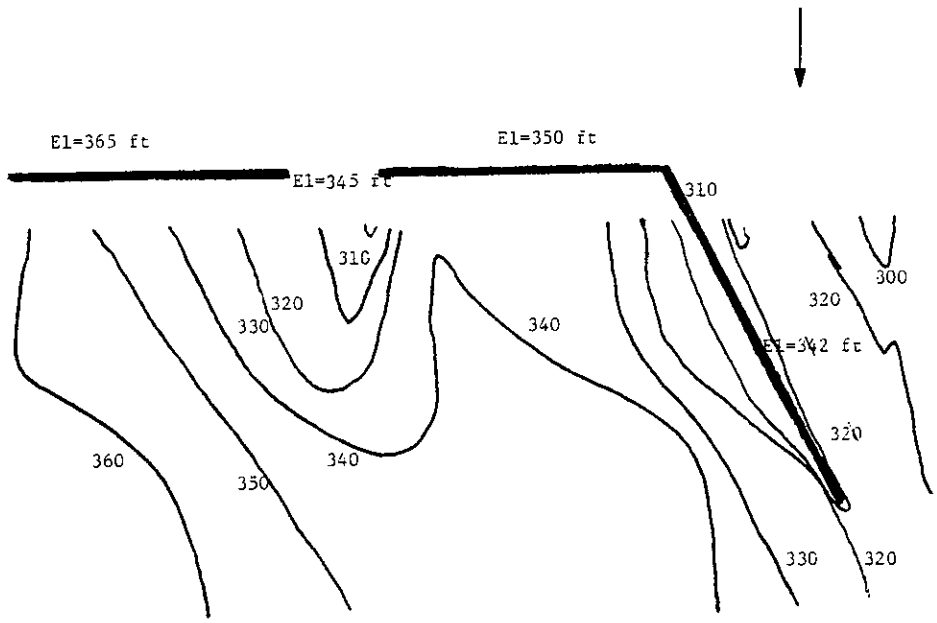


Figure 28. Dike 100.1R, October 18, 1981 (contour lines scale 1 in. = 50 ft; contours referenced to ft above MSL) (from Smith et al. 1982)

Notches

285. Dike 102.2L. Dike 102.2L is a sloping crest spur dike with a 150-ft-wide-by-8-ft-deep notch midway along its length. The dike is angled slightly downstream from the bank to the notch; it is perpendicular to the channel from the landward edge of the notch to the end. A large sandbar occurs downstream of the dike and is exposed during low flow. Figure 26 shows the morphology below the dike on 15 October 1981. The notched dike has created a diversity of aquatic habitats evidenced by high species diversity, as reported by Smith et al. (1982). Caddisflies and flies were abundant in benthic samples.

286. Dike 98.9 R. Dike 98.9R at River Mile 98.9 is a sloping crest spur dike with two notches that angles slightly downstream (Figure 27). A shallow notch of unknown dimensions is near the bank, and a deeper notch, 7 ft by 300 ft, is approximately halfway between the midpoint and the end of the dike. Remnants of an old submerged pile dike are immediately below the deep notch extending downstream at a 20-degree angle. Old pile dikes provided good habitat for crappie. Some bank erosion has occurred just downstream of the intersection of the dike with the bank, undercutting several trees. Figure 27 shows the morphology below the dike. Major components of fish samples were sturgeons, catfish, walleye and sauger, carp, herring, buffalo, and freshwater drum. Aquatic invertebrates were fairly diverse, with mayflies and flies abundant (Smith et al. 1982).

287. Dike 100.1R. Dike 100.1R is a sloping crest L-head dike with a notched spur portion and a low-elevation trail. The notch is 150 ft wide and 10 ft deep. The trail is usually submerged and is half as long as the spur portion. The entire structure is angled downstream and occurs within a field of similar dikes. A relatively high sand-silt island is located just downstream of the channelward half of the dike, and some old pilings remain just downstream of the notch. Figure 28 illustrates the morphology below the dike. Major components of fish samples were white bass, yellow bass, buffalo, carpsuckers, paddlefish, and herring. Aquatic invertebrates were less abundant and less diverse than for dikes 102.2L and 98.9R (Smith et al. 1982).

Summary

288. Notching and minimum maintenance are the primary environmental features in use on the middle Mississippi River. Smith et al. (1982) reported the results of biological sampling at eight dikes (five notched, three unnotched) during four sampling periods between April and October 1981. Abundance and diversity of aquatic invertebrates and abundance and diversity of fish communities were found to be greater at the notched dikes than the unnotched dikes. However, the differences in fish abundance and diversity were not statistically significant. Invertebrate communities at notched dikes tended to be dominated by caddisflies and flies, while aquatic earthworms were significantly more abundant at unnotched dikes.

Lower Mississippi River

289. The lower Mississippi River is the largest waterway with CE dike fields. Early river training efforts were submerged sloping spur dikes of stone in willow cradles, built at New Orleans, Louisiana, in 1884 (Pokrefke 1978). Timber pile and brush dikes were used to develop the 9-by-300-ft channel authorized in 1929 (Miller 1981). The Flood Control Act of 1944 authorized a 12-by-300-ft channel; however, authority to proceed with construction is still pending. In 1964, both Memphis and Vicksburg Districts began using stone dikes on the lower Mississippi (Pokrefke 1978).

Notched dike

290. The Chicot Landing dike field at River Mile 565 was built in 1967-1969 to divert flow from the secondary channel behind Choctaw Bar (Figure 29). The original dike field consisted of two spur dikes, one L-head, and two vane dikes downstream of the L-head. A failure notch occurred in the L-head (Dike 3 in Figure 29) and has been allowed to remain. In 1975, the rootless vane dikes were connected to the L-head and extended downstream. Thus the last dike is now an L-head dike with a notch in the spur portion and an extremely long trail. The dike elevation beside the notch is at 20 ft above LWRP, while the trail portion has elevations ranging from 10 ft below to 38 ft above LWRP. The pool below Dike 2 is generally shallow with little to no flow at low river stages, with a sandbar separating it from the main channel except at the lower end of the pool.

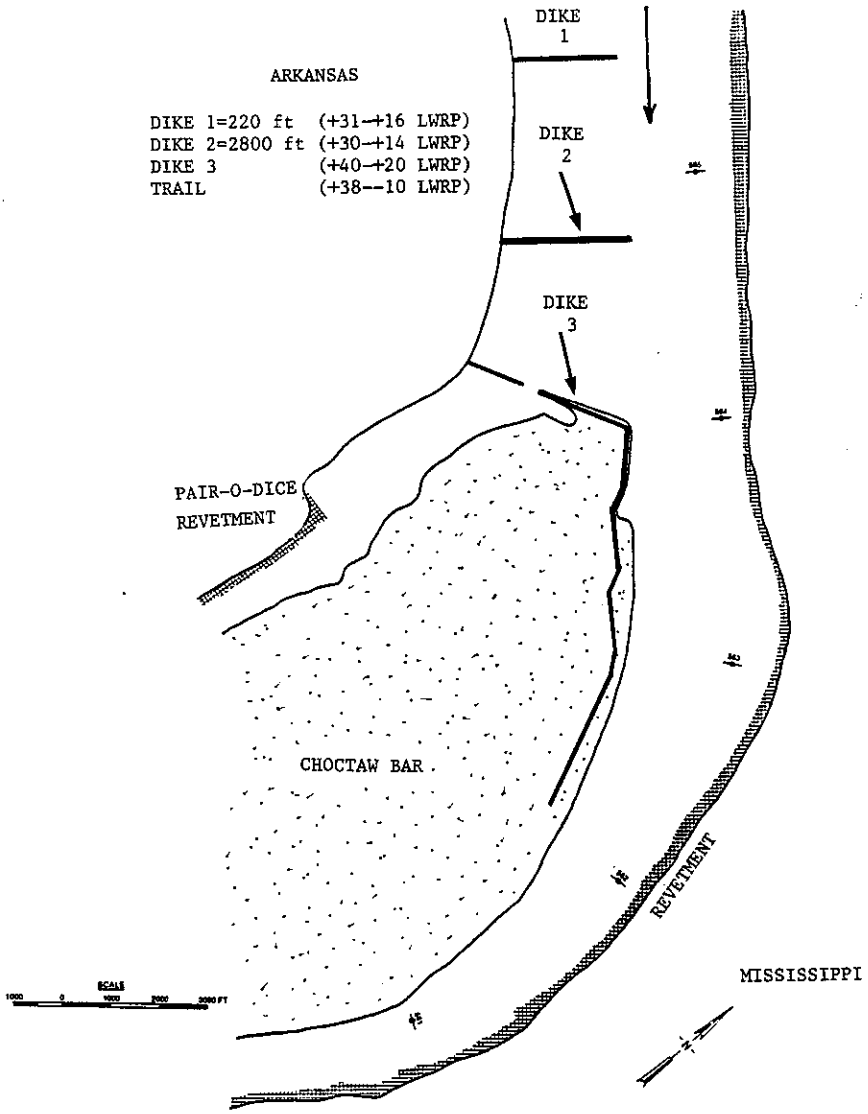


Figure 29. Chicot Landing dike field (from Pennington, Baker, and Bond 1983)

The secondary channel below the L-head dike is separated from the main channel by Choctaw Bar.

291. Pennington, Baker, and Bond (1983) reported sampling 42 species of fish from the Chicot Landing field. Blue catfish, river carpsucker, and gizzard shad comprised 30.9, 16.8, and 14.4 percent of the catch by weight, respectively. Beckett et al. (1983) found that mud substrates supported a greater abundance of aquatic invertebrates than sandy areas in the Chicot Landing dike field. With decreased flow, substrate dominance shifted from sandy substrates to mud substrates. However, the notch in Dike 3 maintained a strong current-sand substrate area in the secondary channel, even at low flows.

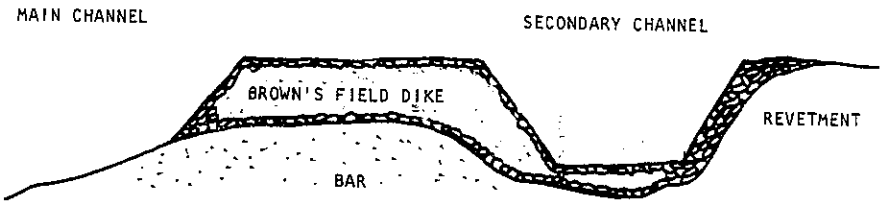
Rootless dike

292. An example of a rootless dike (in addition to the many vane dikes constructed by Vicksburg District) is Brown's Field Dike at River Mile 388 (Figure 30). Brown's Field Dike is actually a "semirootless" dike (the dike is attached to the bank as shown in Figure 30) built across the lower end of a secondary channel with little flow. The bank was already protected by an old revetment. Access to the river by small craft from a launching ramp upstream of the dike was an additional design consideration. The dike was built to an elevation of 17 ft above LWRP, while the 200-ft-long segment closest to the bank was built to an elevation of 5 ft below LWRP.

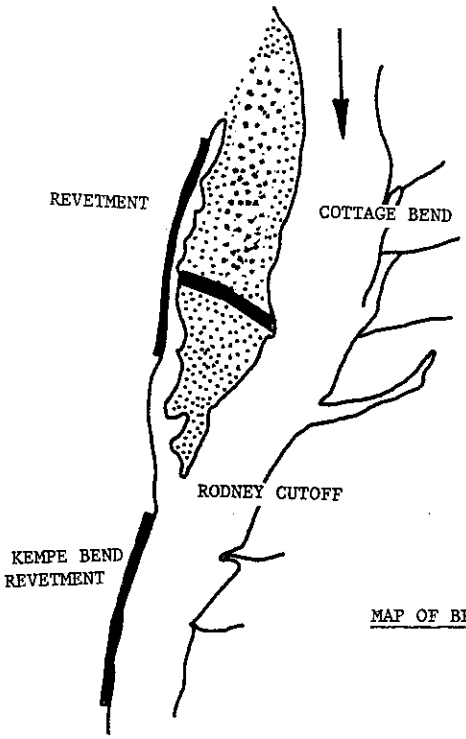
Summary

293. A few notches, low crest elevations, rootless dikes, and irregular crests caused by minimum maintenance are found on the lower Mississippi River, although none of these features have been incorporated for purely environmental purposes. Few generalizations can be made based on available data regarding the performance of environmental features.

294. Pennington, Baker, and Bond (1983) concluded that lower Mississippi River dike fields harbored more fish species than other habitat types (revetted banks, natural banks, and abandoned river channels) and that dike fields provide suitable habitat for life stages from larva to adult for many fish species. Diversity of fishes at the dike fields was attributed to the variety of microhabitats available (habitat diversity). Although these conclusions apply to dikes in general (not necessarily dikes with environmental features), the value of the dike field habitat was due to the



PROFILE OF BROWN'S FIELD DIKE



MAP OF BROWN'S FIELD DIKE

Figure 30. Brown's Field Dike

tendency of the dikes to develop a variety of depths, currents, and substrates. Environmental features may be used to produce additional habitat diversity and increase the longevity of the valuable dike field habitat.

Other Rivers

295. Other rivers with significant CE dike construction and maintenance activity are the Arkansas, Columbia, Alabama, and Apalachicola Rivers. The CE Districts responsible for these rivers (Little Rock, Portland, and Mobile Districts, respectively) have not used any environmental features in dike design, construction, and maintenance.* However, it is likely that minimum maintenance and dike failure or degradation have combined in some instances to produce failure notches, low-elevation dikes, or rootless dikes.

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* Oscar Tinkle. Portland District. Personal Communication. 15 June 1982.
Howard Whittington. Mobile District. Personal Communication. 21 June 1982.
Al Austin. Little Rock District. Personal Communication. 16 June 1982.

PART VII: CASE STUDIES

296. To illustrate the principles outlined above, two case studies have been conducted. These studies consisted of reviewing the histories of developments and corresponding river responses in short reaches of the Missouri and lower Mississippi Rivers. Dike field designs incorporating selected environmental features were formulated for each site for both present and preconstruction conditions.

Missouri River Case Study: Sandy Hook Bend

297. Sandy Hook Bend is located approximately 25 miles southeast of Boonville, in central Missouri. Shown in Figure 31, the dike field of interest in Sandy Hook Bend consists of four dikes identified by the river stationing, which are the river miles upstream from the mouth of the Missouri north of St. Louis, Missouri. Robinson (1973) designated the areas between the four dikes as Bays A, B, and C. Bay A is the upstream area. Robinson's designation is used in this study.

Background

298. Geology. The study reach is in the White Cliffs Region, where the river valley is carved into the Burlington Limestone. The bluffs are erosion-resistant massive limestone, white to light buff in color. The valley floor is only 1.7 miles wide at Sandy Hook Bend. The valley floor is too narrow to allow the full development of meanders while the river was in its pristine state. This is illustrated by the unusual shape of the river at Providence Bend in 1879 as shown by Funk and Robinson (1974). The entire 30-mile reach of the Missouri River in the White Cliffs Region has a floodplain width of only 3 to 4 miles.

299. The generalized stratigraphic framework for the Missouri River floodplain has been summarized by Hallberg (1979) as follows:

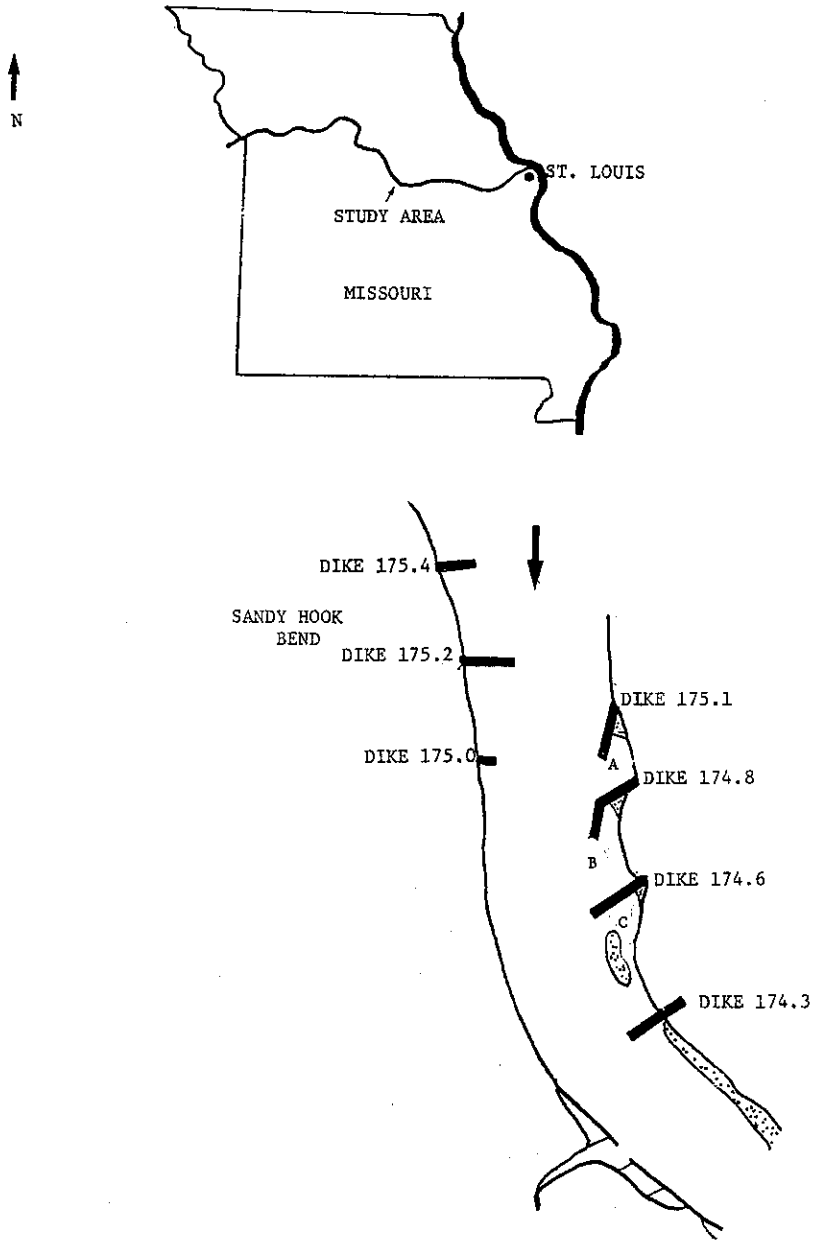

Figure 31. The Missouri River case study area (from Robinson 1973)

a. The upper increment is fine-textured sediment (clays, silts, and fine sands) variable in thickness, recent in age, and occurring as overbank and channel-fill deposits. The oldest of these sediments is but a few hundred years in age.

b. Below the top increment are deposits of relatively uniform medium sands, also variable in thickness. These are the bar deposits and accretions of the Missouri River which have accumulated over the last 10,000 years. Within the sands are lenses of the fine-textured sediments and occasional deposits of coarse sands and gravel.

c. Below the uniform medium sands lie deposits of coarser sediments varying from coarse cobbles to coarse sand with fine gravel. Their radiocarbon dates are 10,000 to 17,000 years. The deposits lie, in general, 30 to 90 ft below the floodplain.

During large floods, the riverbed has been locally scoured into this coarse basal fill, moving the gravel downstream and depositing it as channel slag, subsequently covered by sands.

300. Historical benchmarks. In its pristine state, the Missouri River in Missouri was an active alluvial river, subject to wide variation in discharge and carrying a large sediment load. Man's influence in the Missouri River began in the early 1800's, but developments have been sporadic. A brief summary of these developments is given in Appendix C.

301. The Missouri River at Sandy Hook Bend was essentially unaffected by development until 1914 when revetment was placed on the right bank. Until 1929, efforts to stabilize the river were piecemeal and not totally effective (U.S. Army Corps of Engineers 1952). The need for additional dikes was accentuated by the long drought during the 1930's. The first timber pile dikes were constructed in 1933 on the left bank as part of the 6-ft navigation channel project authorized in 1912. The pile dikes were filled with rock during the 1950's and have since been raised and lengthened periodically as part of the 9-ft channel project authorized in 1945.

302. The construction of dams and reservoirs in the Missouri River Basin has had a profound effect on the streamflow and sediment transport at Sandy Hook Bend (Keown, Dardeau, and Causey 1981). There are presently 69 reservoirs upstream from Sandy Hook Bend with design storage capacities equal to or greater than 75,000 acre-ft, and four of these projects (Fort Peck, Fort Randall, Garrison, and Oahe) provide 71.5 percent of the total storage. Fort Peck was the first of the four built and was closed in 1937.

Oahe was the latest, with closure occurring in August 1958. The development of storage for Missouri River Basin waters is illustrated in Figure 32. The locations of the four large CE reservoirs are shown on the insert map.

303. Hydrology. Runoff from the Missouri River Basin is characterized by two major annual floods (Burke and Robinson 1979). The first flood occurs for 1 or 2 weeks in April and is the result of ice breakup and melting snow in the lowlands of the upper sections, augmented by rain in the lower basin. The second flood, known as the June Rise, lasts from 3 to 5 weeks and is the runoff from snowmelt in the higher mountains.

304. The gage at Boonville, Missouri, some 31 miles upstream from Sandy Hook Bend, provides a long-term record of flows through the study reach (Kansas City District 1980b). There are no significant tributaries between the gage and the dike field.

305. The mean annual flow at Boonville for the 50-year period 1929 to 1979 is 56,600 cfs. The annual flow sequence is shown in Figure 33. The record is homogeneous with respect to average annual flow, the mean being 55,000 cfs during the predam era, 1929 to 1955, and 58,600 cfs during the postdam era, 1956 to 1978. Predam annual flows vary more than postdam flows. From 1929 to 1955, the coefficient of variation for annual flows is 0.40; thereafter, it is only 0.29.

306. The mean monthly flows for the 50-year record at the Boonville gage have also been divided by the Kansas City District into pre- and postdam periods. The effect of flow regulation by the mainstem dams is reflected in the monthly means shown in Figure 34. Part of the runoff from April, June, and July, the flood months, is stored in the mainstem reservoirs to be released in the late navigation season, August through November, when flows are naturally low.

307. Consumptive use of water in the Missouri River Basin has been increasing rapidly, especially in the last few decades. Keown et al. (1981) estimated that 17.6 million acre-ft of water, or 30 percent of the basin yield, was withdrawn from the basin's streams in 1975 for consumptive use. Mean annual flow at Boonville is 41 million acre-ft. Consumptive use is partially offset by imports from the Colorado River Basin (407,000 acre-ft annually) and from the St. Mary-Milk River System (135,000 acre-ft annually).

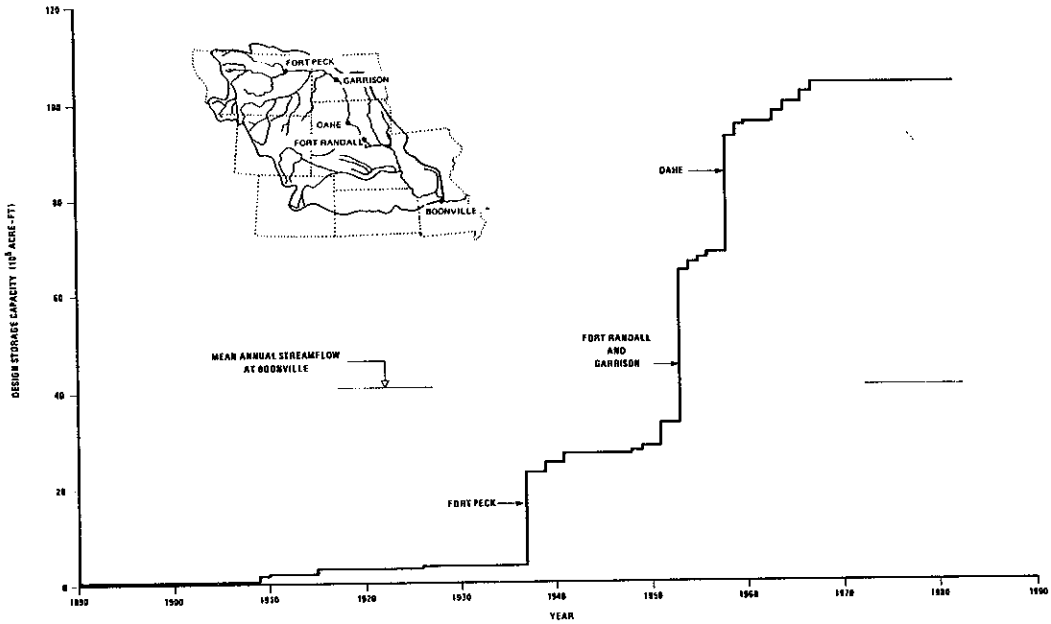

Figure 32. Storage capacity in the Missouri River basin upstream from Boonville, Missouri

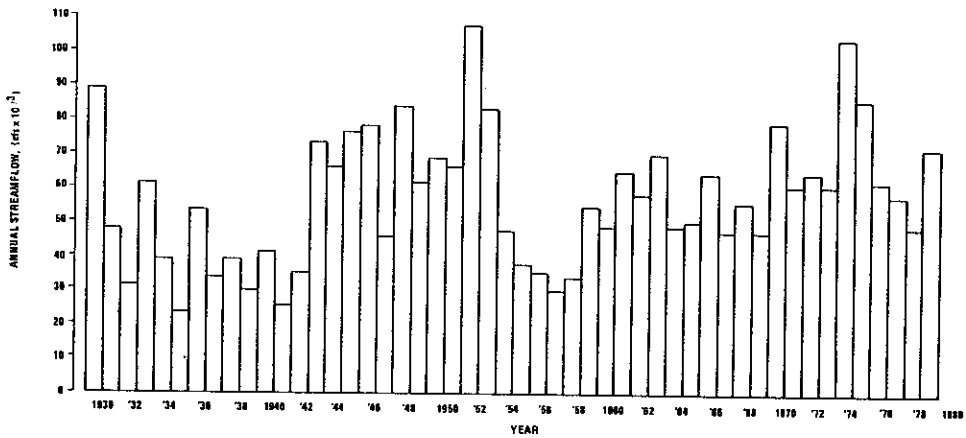

Figure 33. Annual streamflow, 1929-1979, Missouri River at Boonville, Missouri

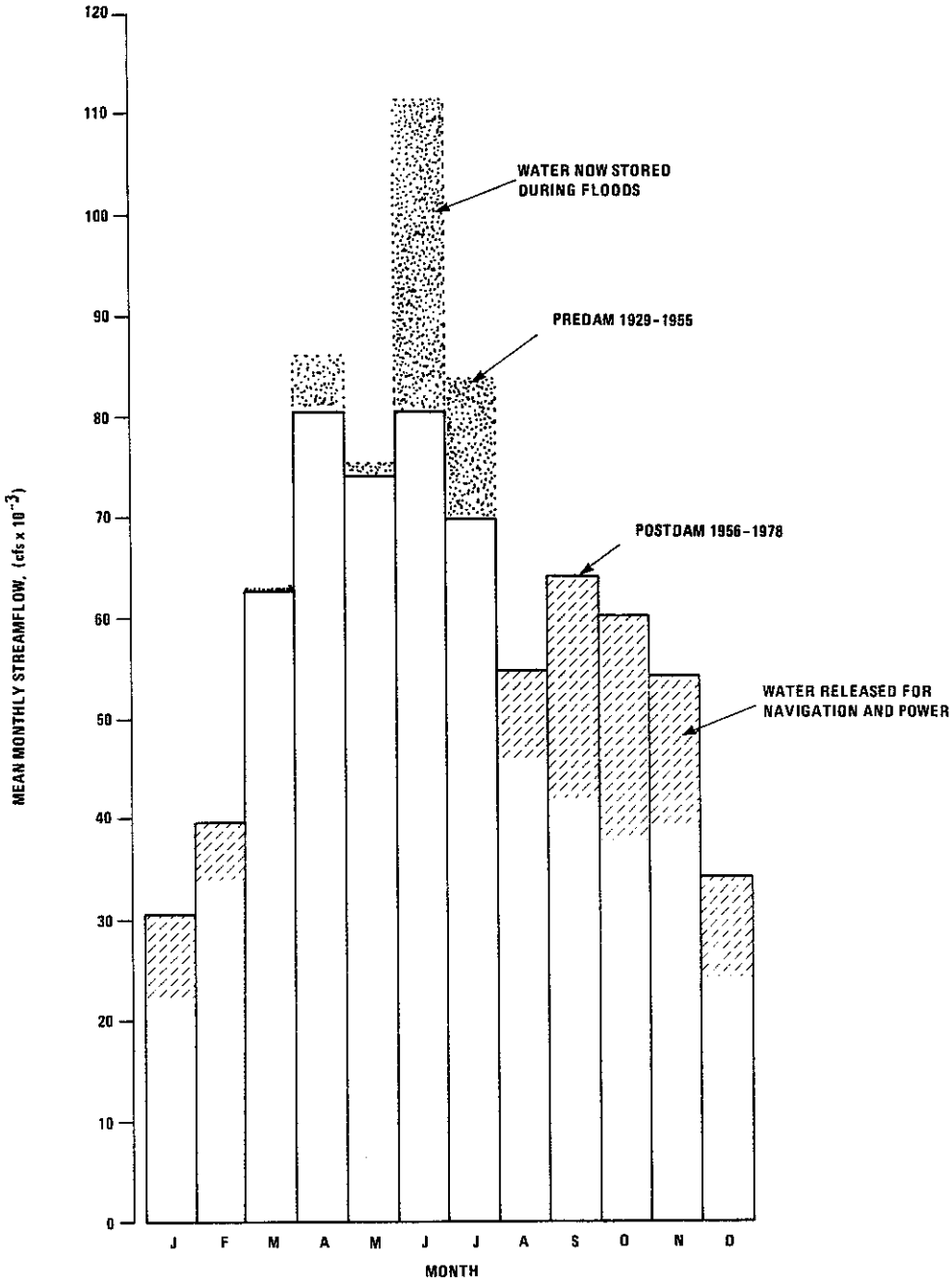

Figure 34. Mean monthly streamflow, 1929-1979, Missouri River at Boonville, Missouri

308. The CE projects the consumptive use to increase to more than 28.5 million acre-ft per year by the turn of the century. Thus, the streamflow at Sandy Hook Bend will decrease by nearly 25 percent in the next 20 years. Streamflow may be maintained during the summer months by increasing releases from storage reservoirs. If this is done, flood frequency should decrease. Past discharge reductions have been followed by encroachment of vegetation onto the sand bars and ultimately a decrease in aquatic environment.

309. Flood discharges have been measured at Boonville since 1926. The maximum discharge for the period of record is 550,000 cfs. This flood peak occurred on 17 July 1951 and was primarily the result of heavy and prolonged rainfall in the Kansas River Basin (Keown et al. 1981). The maximum annual stage record is plotted in Figure 35. Since the closure of Fort Randall and Garrison Dams in 1953, maximum flood stages have been lower than in the 1940's.

310. Flood stage records for the Missouri River at Boonville date from 1874 (Kansas City District 1980b). Flood stage is 21.0 ft on the Boonville gage. The level of the annual maximum stage above or below flood stage is shown in Figure 39 for the entire 106 years of record.

311. During the 60 years prior to dike construction in the study reach, maximum annual stages at Boonville exceeded the flood stage only 23 percent of the time; thereafter, the precentage almost tripled to 64 percent.

312. Continued efforts to levee, confine, and stabilize the Missouri River in the Boonville reach have increased flood levels even as flood storage capacity was being constructed on the mainstem upstream. When the record is divided into predam (1874-1955) and postdam (1956-1978) periods, annual predam flood levels have exceeded flood stage 32 percent of the years, and for postdam the flood stage is exceeded in 65 percent of the years.

313. In addition, stages for the flood peak are greater in the controlled river than in former times. For example, on 25 September 1926, a flood with a peak discharge of 175,000 cfs passed Boonville. The corresponding stage was 17.4 ft, 3.6 ft below flood stage. On 2 June 1959, the peak discharge was again 175,000 cfs. This time, however, the corresponding stage was 21.4 ft, 0.4 ft above flood stage.

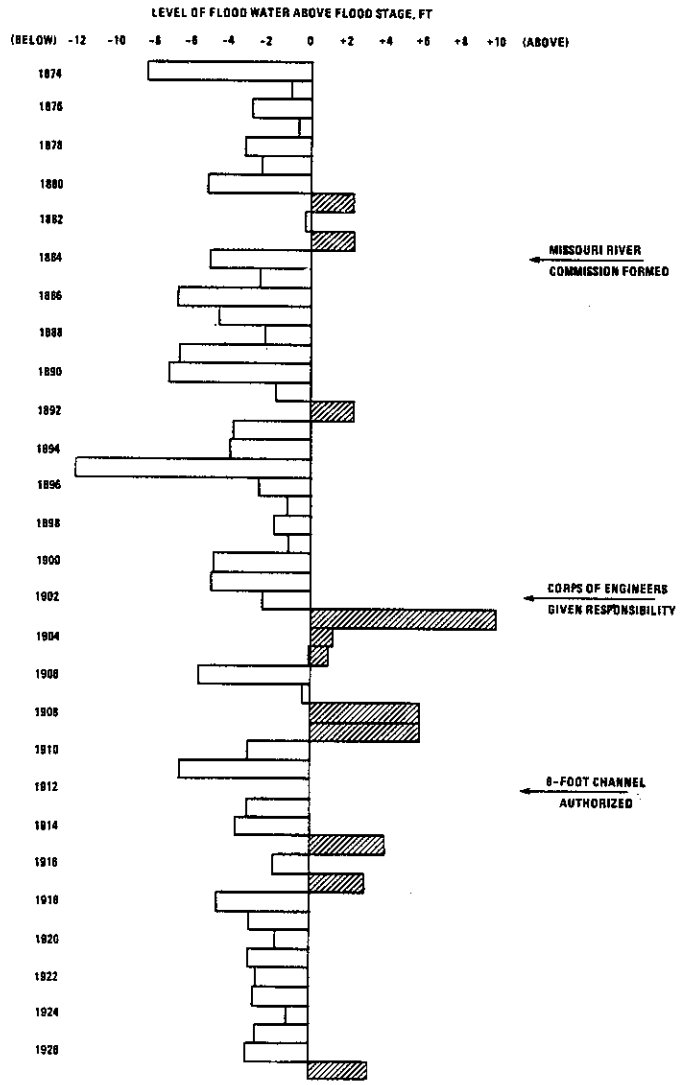

Figure 35. Maximum annual river stages, 1874–1980, Missouri River at Boonville, Missouri (Continued)

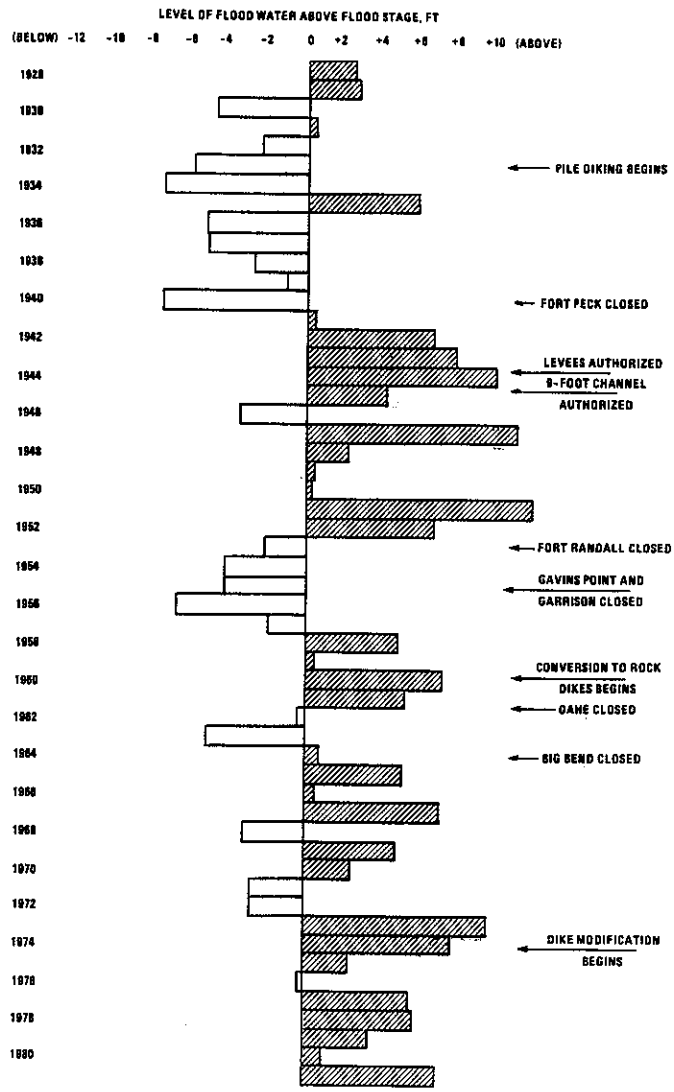

Figure 35. (Concluded)

314. Minimum stage records at Boonville also date from 1874 (Kansas City District 1980b). The annual minimum stage depends on the magnitude of the low flow and the elevation of the riverbed. On the average, the annual minimum stage increased slightly from 1874 to 1927, then decreased progressively by 6 ft, reaching a minimum in 1936, the middle of the drought decade. Thereafter, the minimum has been slowly increasing again.

315. The annual range of stages (maximum minus minimum) at Boonville has increased on the average from approximately 15 ft prior to man's influence to 20 ft after the construction of dikes, levees, and reservoirs. Minimum stages are now fairly constant due to the regulation of flow by the CE. Flood stages at Boonville are not so well controlled. Variation of the annual flood stages has increased since the river has been confined to a narrower channel. This is impressive in light of the fact that the variation of discharge has decreased.

316. Sediment. The amount of sediment transported in suspension in the Missouri River has been measured upstream from the study reach at Kansas City at River Mile 366. The annual suspended sediment load is shown in Figure 36. There was a sharp decline starting in 1953, the year that the Fort Randall and Garrison dams were closed (Slizeski, Anderson, and Dorough 1982; Kansas City District 1980b). With the sudden decrease in suspended sediment, the Missouri River is no longer able to add sediment to its floodplain, islands, and backwater areas as quickly as before.

317. River slope. Cutoffs and other realignments of the Missouri River have produced changes in the riverbed slope (Kansas City District 1980b). In the reach between Boonville and Hermann downstream, the length of the river channel has varied as follows:

Year	Length (miles)
1890	102.2
1932	99.8
1960	99.2

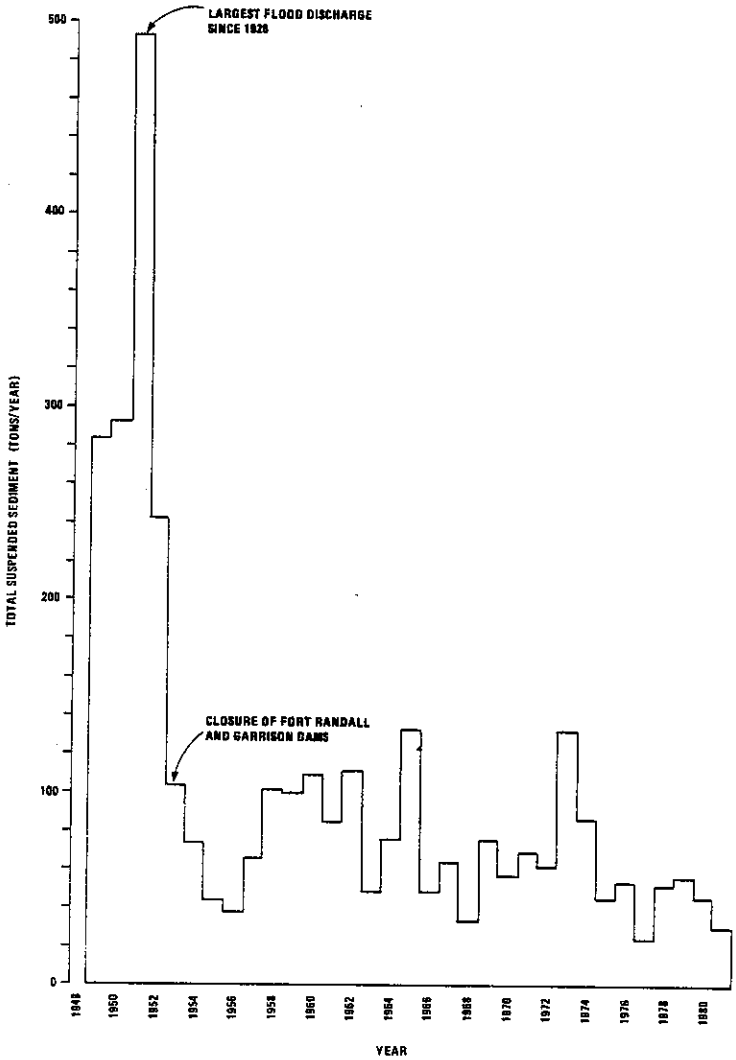

Figure 36. Annual suspended sediment load, 1948-1980, Missouri River at Kansas City

In the first period, there was a 2.4 percent reduction in length; in the second period the reduction was 0.6 percent. In this reach the riverbed slope has changed as follows:

Year	Riverbed slope (ft per mile)
1879	0.825
1938	0.848
1952	0.822
1978	0.860

Baseline conditions

318. In 1911, the major feature of the existing channel was a 12,000-ft sand bar along the right bank (Kansas City District 1911). The left bank was migrating downvalley while the right bank had remained fixed, at least since 1895. There was a backwater channel between the sand bar and the right bank. The distance between cross sections of the 1911 survey (about 1 mile) preclude more detailed description of baseline conditions. By 1920, a revetment was placed on the left bank (Kansas City District 1920). The right bank moved downvalley, narrowing the width between high banklines.

Baseline to present

319. Construction. In 1933, timber piles were used to construct the left bank dike field at Sandy Hook Bend as shown in Figure 37. The original height of the pile dikes is unrecorded, but the piles extended well above the low-water level. The lead dike was a 585-ft extension of the older left bank revetment. Its purpose was to deflect the current to force a thalweg crossing. The other three dikes were normal to the left bank and rooted in the revetment. The downstream one was the longest, 920 ft. Since 1933 these four dikes have been filled in with stone, raised, lengthened, and repaired. Two were notched in 1980. A chronology of dike field construction and repair activities is given in Table 7.

320. The right bank dike field just upstream of Sandy Hook Bend was constructed in 1934 on the area previously occupied by the large, long sand bar. This field has a large effect on the behavior of the study reach; its purpose was to decrease the channel width. This dike field has also been extended and rehabilitated.

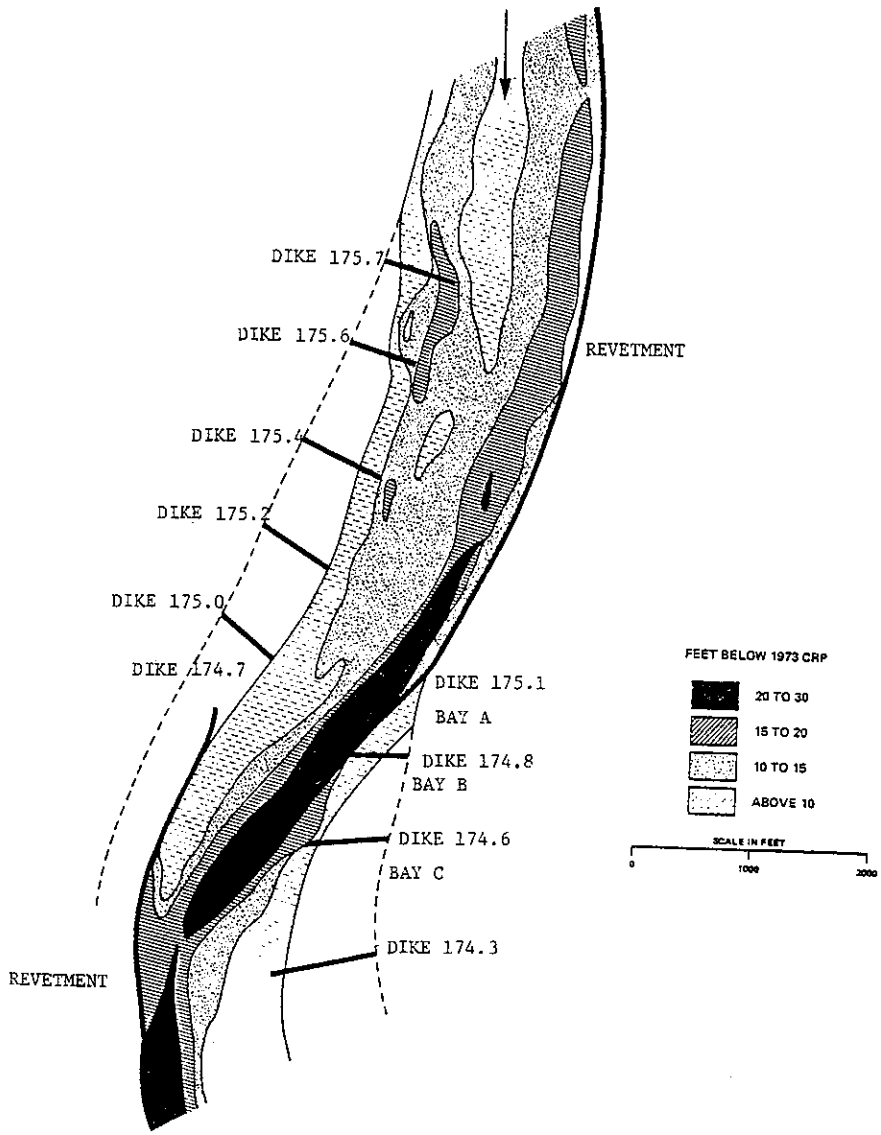

Figure 37. Missouri River hydrographic survey, 1941

Table 7

Summary of Construction

Year	Month	Dike 175.1	Dike 174.8	Dike 174.6	Dike 174.3
1933	December	Timber pile dike 585 ft long was constructed	Timber pile dike 531 ft long was constructed	Timber pile dike 820 ft long was constructed	Timber pile dike 920 ft long was constructed
1946	October	End of dike repaired	End of dike repaired	End of dike repaired	--
1952	July	Converted to stone-fill Crest elevation 548 ft	Converted to stone-fill; crest elevation 542 ft	Converted to stone-fill; crest stepped down from elevation 552 ft to elevation 542 ft for the riverward 300 ft	--
1958	August	Crest raised to elevation 549 ft	Crest raised to elevation 549 ft	Crest raised to elevation 549 ft	Converted to stone-fill with crest at elevation 549 ft; extended 129 ft into channel.
1959	July August		Crest raised to elevation 552 ft	Crest raised to elevation 552 ft and dike lengthened 34 ft	
1961	August September	Crest raised to elevation 552 ft			
1963	June		Repaired		
1966	April		L-head added, 450 ft long with crest at elevation 550 ft	Extended 128 ft long with crest at elevation 550 ft	Extended 336 ft long with crest at elevation 544 ft
1967	May	Repaired	Repaired	Repaired and crest raised to elevation 555 ft	Repaired
1968	October November	Crest raised to elevation 555 ft	Crest raised to elevation 557 ft	Repaired	Crest of riverward section raised to elevation 546 ft and the rest to elevation 552 ft

(Continued)

Table 7 (Concluded)

Year	Month	Dike 175.1	Dike 174.8	Dike 174.6	Dike 174.3
1970	September			Repaired center portion of exposed dike	
1971	September	Repaired			
1973	August September		Repaired	Repaired	
1975	October		Repaired with crest at elevation 553 ft L-head crest raised to elevation 552 ft		
1980	May	Repaired to design grade	Repaired to design grade	Notch constructed, 50 ft wide with invert at elevation 548 ft; rest of dike repaired to design grade	Notch constructed, 50 ft wide with invert at elevation 548 ft; rest of dike repaired to design grade

321. River response. The response of the river at Sandy Hook Bend to the dike fields was a narrowing of the channel width and increased sedimentation within the dike fields. Available measurements of the channel geometry and associated flow conditions made between 1911 and 1980 are summarized in Table 8. Table 8 shows that the main channel has narrowed and lowered since dikes were first constructed. Figures 37, 38, and 39 also depict hydrographic changes during the period since dike construction. Unfortunately, preconstruction surveys were not detailed enough to allow preparation of a similar figure for preconstruction conditions.

Table 8

Summary of Channel Conditions

Date	Width of Main Channel (ft)	Discharge (cfs)	Water Surface Elevation* (ft msl)	Average Bed Elevation of Main Channel (ft)
21 Sept 1911	2,000	-	547.7	539.1
19 Aug 1941	920	26,000	545.9**	536.2
13 Oct 1952	1,060	35,200	545.2	536.1
23 Oct 1958	1,060	39,000	547.6	536.7
8 Nov 1960	1,000	39,000	547.8	535.0
28 Oct 1965	1,000	53,000	550.1	537.2
26 Sept 1968	900	48,000	549.3	536.3
2 Nov 1970	820	58,000	551.4	535.7
4 Oct 1975		70,000	550.6	
15 Sept 1980	750	44,500	548.2	535.0

Note: * The water surface elevation is that opposite the middle of the dike field (River Mile 166.8, 1960 thalweg).

** This value is interpolated from gage readings taken on the same day at Boonville and Jefferson City.

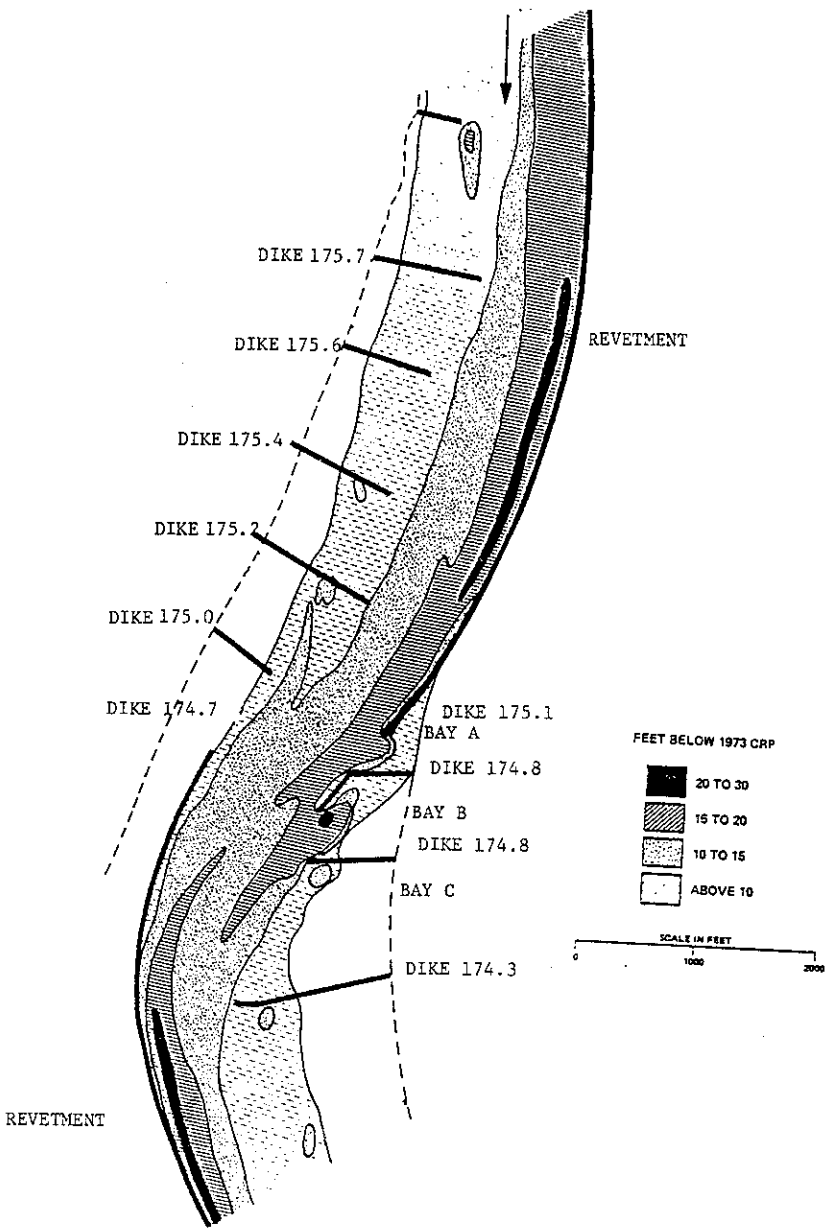

Figure 38. Missouri River hydrographic survey, 1968

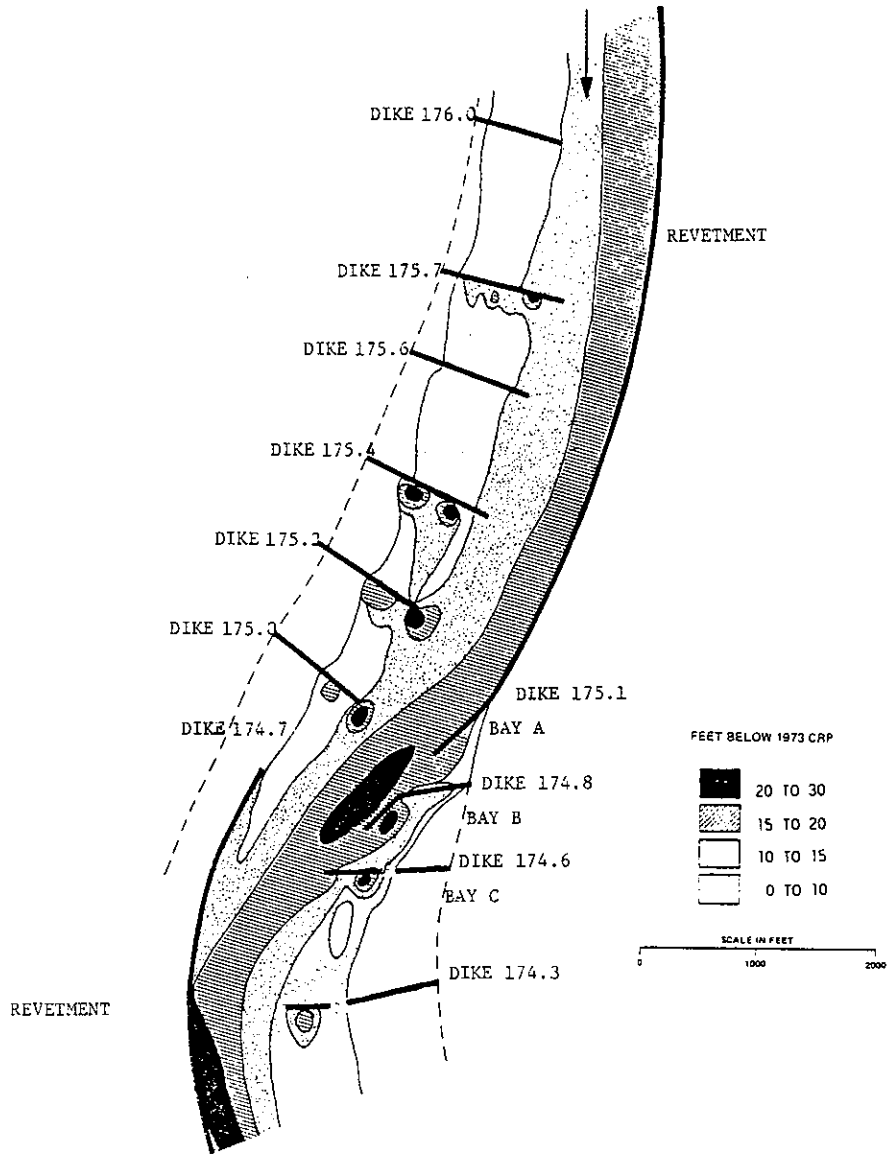

Figure 39. Missouri River hydrographic survey, 1980

322. Within the left bank dike field significant sediment deposition occurred, creating a pattern of land accretion (with colonization by willows) which fluctuated over time. A series of aerial photographs and hydrographic surveys shows the accretion and scour of multiple bars within the bays and the development and closing of a small secondary channel. Table 9 summarizes the more notable developments within the dike field. The extent of the sediment accretion is shown in Figure 38.

323. Notches. In May 1980, 50-ft-wide notches were excavated next to the vegetated bank in Dikes 174.6 and 174.3, and all dikes were repaired to design grade. Profiles of the notched dikes are shown in Figure 40. The effect of the notches on dike field morphology is difficult to assess. The 1980 hydrographic survey (Figure 39) shows that the scour holes downstream of Dikes 174.8, 174.6, and 174.3 were slightly larger and deeper than in 1968 (Figure 38). However, Robinson's (1980) measurements (Figure 41) show that, although the notch in Dike 174.6 caused a slight increase in local scour immediately downstream, most of the area downstream of Dike 174.6 (Bay C) experienced filling between 1976 and June 1980. This filling could have been the result of raising the crests to design grade in May 1980. In studies of bars and scour holes in dike fields on the Missouri River, the scour hole depths were observed to fluctuate with magnitude and duration of flows.* Smith et al. (1982) reported the same behavior in the middle Mississippi River. Over a longer period of time, the notches in Dike 174.6 may result in more of the accreted sediments being scoured.

Summary of changes from baseline to present

324. Since the construction of the four timber pile dikes on the left bank of the Missouri River at Sandy Hook Bend in 1933, the study reach progressively narrowed and the riverbed lowered in elevation. Channel depth (below CRP) was greatest in 1941 (Kansas City District 1941) and has decreased slightly since then. These changes have been prompted by filling the timber pile dikes with stone, by increasing the crest elevation of the stone dikes, and by extending the stone dikes farther into the channel.

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* Tom Burke. Kansas City District. Personal communication. 6 January 1983.

Table 9

Summary of Background Sediment Accretion and Scour

Date/Source	Bay A	Bay B	Bay C	Notes
December 1944 aerial photograph	Sand-bed channel at the inside of the bays along the old revetment; channel entrance through pilings in Dike 174.8			
July 1952 aerial photograph	Mostly water	Sand bars formed	~50% of bay covered by vegetated bar	Three upstream dikes converted to stone fill
October 1952 hydrographic survey (Kansas City District 1952)				A large sand bar was moving through Sandy Hook Bend, along outside of bend
October 1958 hydrographic survey (Kansas City District 1958)	Scour hole in the entrance	Vegetated bar covers all but 150 ft next to channel	Vegetated bar has risen to 14 ft above CRP*	All dikes raised, Dike 174.3 converted to stone
October 1960 aerial photograph	Secondary channel at the inside of the bays has closed and is overgrown with willows			
October 1965 hydrographic survey (Kansas City District 1965)	Mostly sand accretion, with small willows		Vegetated bar continues to grow	

* In 1973, the CE raised the CRP 5.2 ft in the study reach. The change was based on the 1972 summer rating curve for the stream-gaging stations on the Missouri River (Kansas City District 1980b). The reference elevation of the CRP changed from the low-water profile to a profile nearly equal to normal navigation stage. All references to the CRP have been converted to the "after 1973" defintion of the plane.

(Continued)

Table 9 (Concluded)

Date/Source	Bay A	Bay B	Bay C	Notes
April 1968 aerial photograph	Small willows; mostly scoured	Willows giving way to cottonwoods in Bays B and C at elevation 16 ft above CRP (floodplain)		Dike crests raised
November 1970 hydrographic survey (Kansas City District 1970)	Bay is scoured of sand	Scour hole develops	New bar and scour hole form	
1973 (Robinson 1973)	New colonies of willows forming on sand bars			
December 1975 aerial photograph			Accreted land cleared and converted to agriculture	
December 1975 aerial photograph	Deposition along bankline	Deposition along bankline behind Dike 174.8	Accretion between sand bar and bankline	

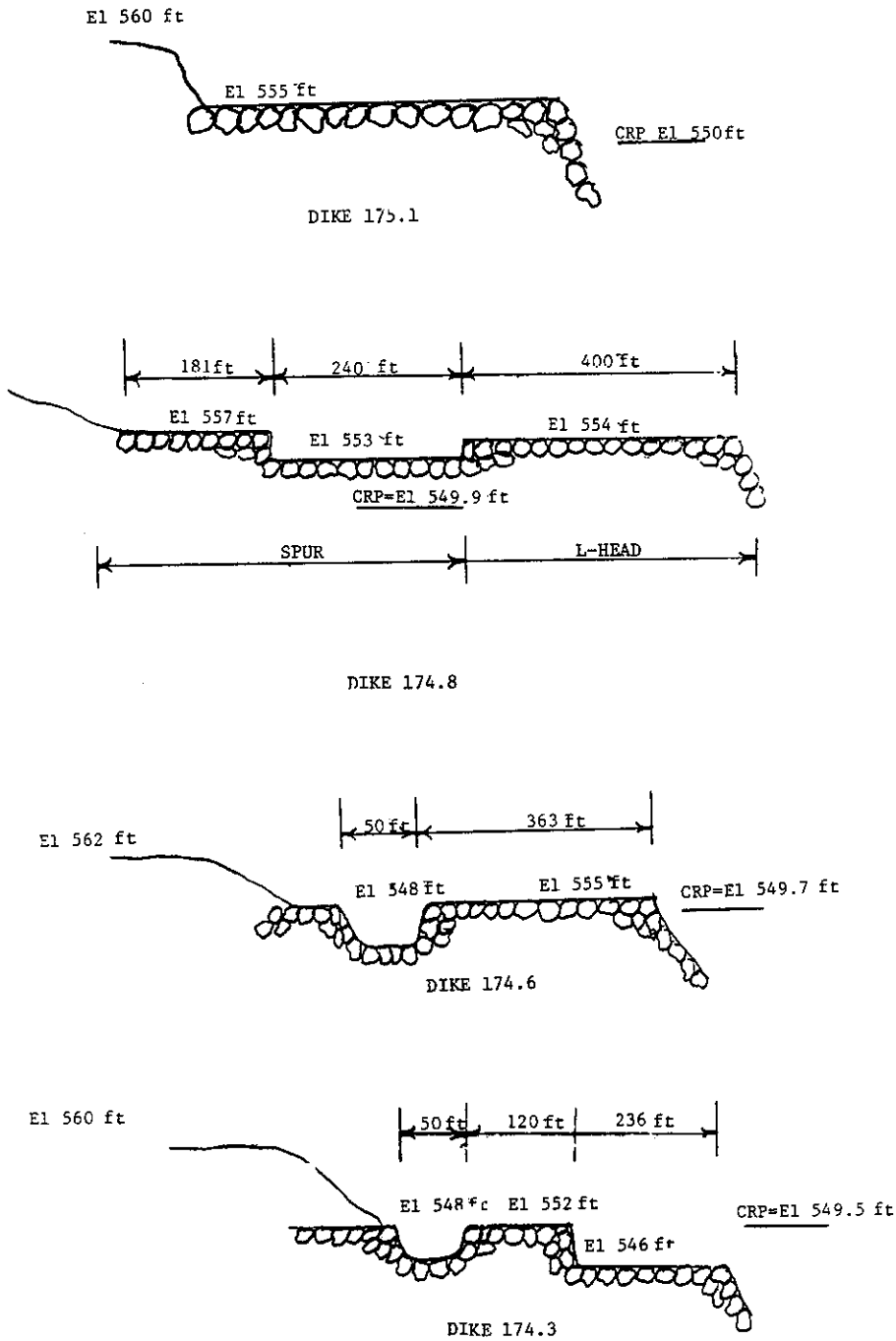


Figure 40. Profile of the left bank dikes in 1980

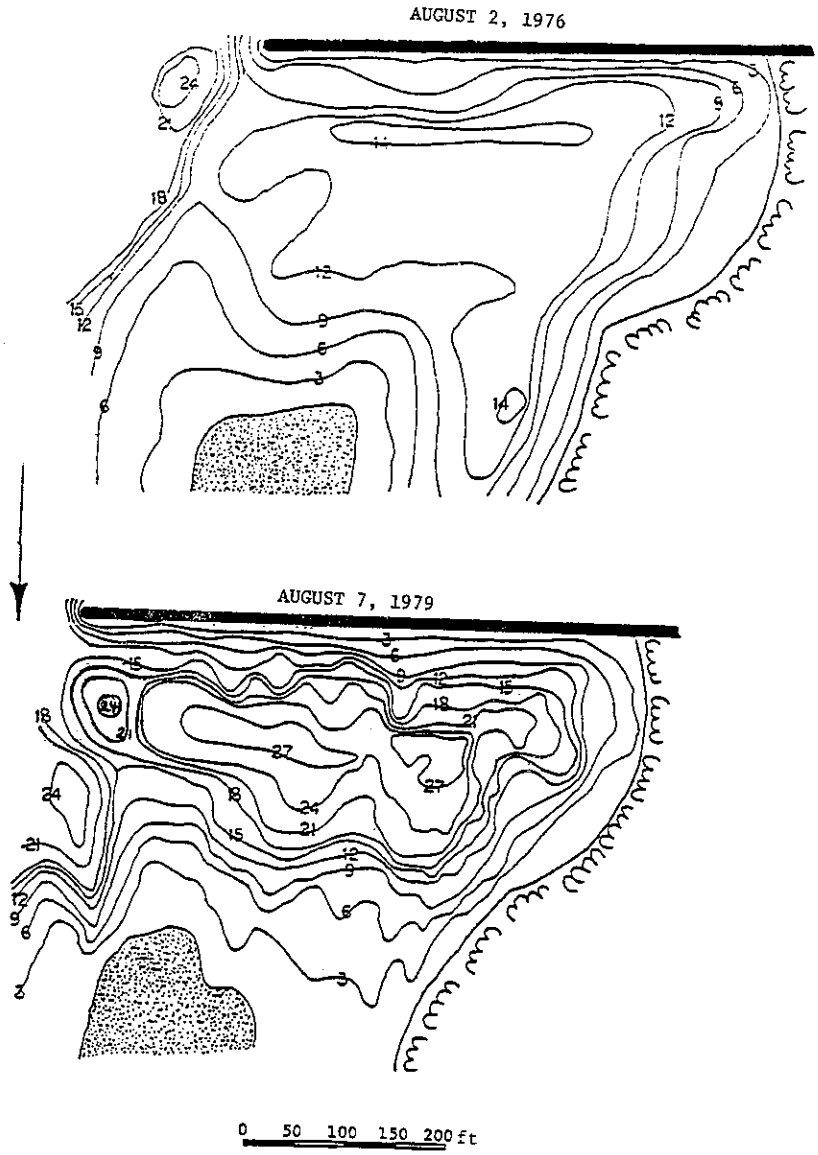


Figure 41. Scour hole downstream from Dike 174.6
(contours referenced to CRP)
(from Robinson 1980) (Continued)

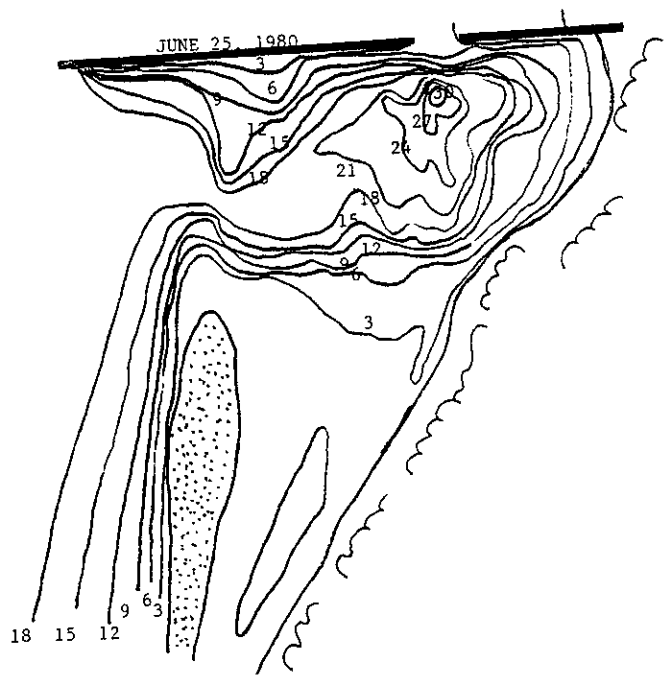


Figure 41. (Concluded)

325. Within the dike fields, sedimentation has occurred since construction. When these sandbars accreted to a level sufficient for willows to become established, the rate of accretion increased. Cottonwoods succeeded willows, and the new land accreted to the level of the floodplain. Sedimentation also resulted in the closure of the backwater channel which initially formed along the bankline at the roots of the dikes. This backwater channel was invaded by willows after the adjacent sandbars had become timbered islands at the elevation of the adjacent floodplain.

326. Bay A has remained almost free of vegetation, even though willows have appeared there at least three times in the 48 years studied. Each time the willows and the bar on which they were growing were eroded away. The surface area inside Bay A is approximately 3.6 acres. The surface area of Bay B between the riverward end of the 1980 dikes and the 1933 bankline is 13 acres. Thirty percent of this area was cottonwood timber in 1980. For Bay C, the surface area is 25 acres, of which slightly more than 50 percent was timbered or cultivated in 1980. This conversion of aquatic habitat to cultivated farmland is the largest single factor in the changing distribution of habitat types in the study area.

Present habitat deficiencies

327. The conversion of aquatic habitat to vegetated bars and cultivated land has reduced the diverse aquatic habitat created in the dike field when the dikes were first constructed in 1933. Accretion occurs at times in all bays, but periodic erosion in Bays A and B have preserved some or all of the aquatic habitat in those two bays. The two notches on the dikes forming Bay C should reduce the rate of accretion and may prevent the continued extension of the floodplain toward the riverward ends of the dikes.

328. Bay A has withstood cycles of erosion and sedimentation and is basically aquatic now. There is a great variety of depths from edge water a few inches deep to 20 ft in the scour hole at low flow. During the late summer and winter seasons, this area is sheltered from the main current so the velocities within are those induced by the shear of the main current going by the opening. As this bay has survived almost 50 years as an aquatic habitat, it seems appropriate to leave it "as is."

329. The substrate in Bay A probably changes from time to time during the year. At flood stage, water flows over Dike 175.1 and scours out the hole in the bay. During low flow, some new sediment is carried into this area. The amount of sediment is not great since the opening to the main channel is small. Substrate is probably fairly unstable and uniform during parts of the year when the dike is overtopped.

330. The situation in Bay B is now stabilized. In the past, vegetation had encroached on new accretions to the bankline. However, this sedimentation appears to have stopped in the last decade. The different types of habitat in the bay have reached a relatively steady-state condition. There is a deep scour hole near the L-head and a diversity of depths in the bay. Robinson (1973) found 36 species of fish in the study area with no significant differences in fish species composition between years or within sections. The dike field served as a nursery for juvenile fish of all species found. Benthic invertebrates were primarily insects, with species composition typical of that associated with the substrates (as discussed in Part III).

331. The key factor in remedying present habitat deficiencies is arresting sedimentation and creating greater aquatic habitat diversity in Bay C. First, the willow-covered bar should be removed. If not, it will continue to accumulate sediment and may grow in lateral extent and reduce further the amount of habitat in the bay. Secondly, it is necessary to assure that the newly created notches result in the development of a backwater channel along the vegetated bankline. Otherwise, accretion along this bankline will reduce the amount of aquatic habitat.

332. It is assumed that the landowner who has cleared and cultivated a part of Bay C would resist modifications to the dike field which would cause erosion to this land, especially if he were not compensated. Thus no efforts which threaten the presently cultivated land are considered feasible.

Formulation of improved designs

333. Modification of existing dikes. The existing notches in the dikes forming Bay C should arrest the accretion along the vegetated bankline in this bay. The notches presently pass flow approximately 90 percent of the time. The notches are located in the best place, next to the vegetated bankline, but with enough distance to prevent flanking. The intake of the

backwater channel is in Bay B and should receive a good supply of relatively sediment-free water during the low-flow season. However, when the flow spills over Dike 174.8 and the L-head causing scour in Bay B, the sediment supply to the backwater channel may increase. These sediments may be fine-grained, as were found behind notched L-head dikes on the Mississippi River (Smith et al. 1982).

334. Whether the backwater channel grows in cross section through scour or accretes depends not only on the supply of water, but also on the supply of sediment. The present backwater channel is not in a good location to survive sedimentation. Lowering the notch inverts to 3 ft below CRP would allow more flow through the notches if the backwater channel scoured down to this level; deeper notches are more effective at developing a downstream scour hole. However, once the scour hole is formed, lower velocities and the resultant fine-grained substrates are more desirable as habitat. Thus, the notches should be constructed deep at first and partially closed after some initial development of the backwater channel. With the existing notch depths, accretion will probably continue in the area downstream from Dike 174.3, and the flow of water in the backwater channel will probably decrease.

335. Figure 39 causes one to question the continued need for Dike 174.3. The scour hole near the riverward end is an indication that the dike still diverts flows into the navigation channel. However, it seems probable that this dike and Dike 174.6 upstream could be lowered to allow more flow through Bay C and over the point bar farther downstream without endangering the navigation channel. The rock removed from the crests could be used, if necessary, to extend Dike 174.3 riverward to compensate for the lowering.

336. If Bay C continues to collect sediment regardless of the notches, there is an alternative which would potentially regenerate the whole dike field as shown in Figure 42 and described below:

a. Open a notch in Dike 175.1 at the bankline. This is an ideal location to get strong currents from the main channel without a large supply of sediment. The old revetment would be put to use again to prevent erosion of the 1933 bankline in Bay A. The invert of this notch and all downstream notches would be 3 ft below CRP so that the entire backwater channel would hardly ever be dry and so that vegetation would not invade. Willow seeds could not germinate.

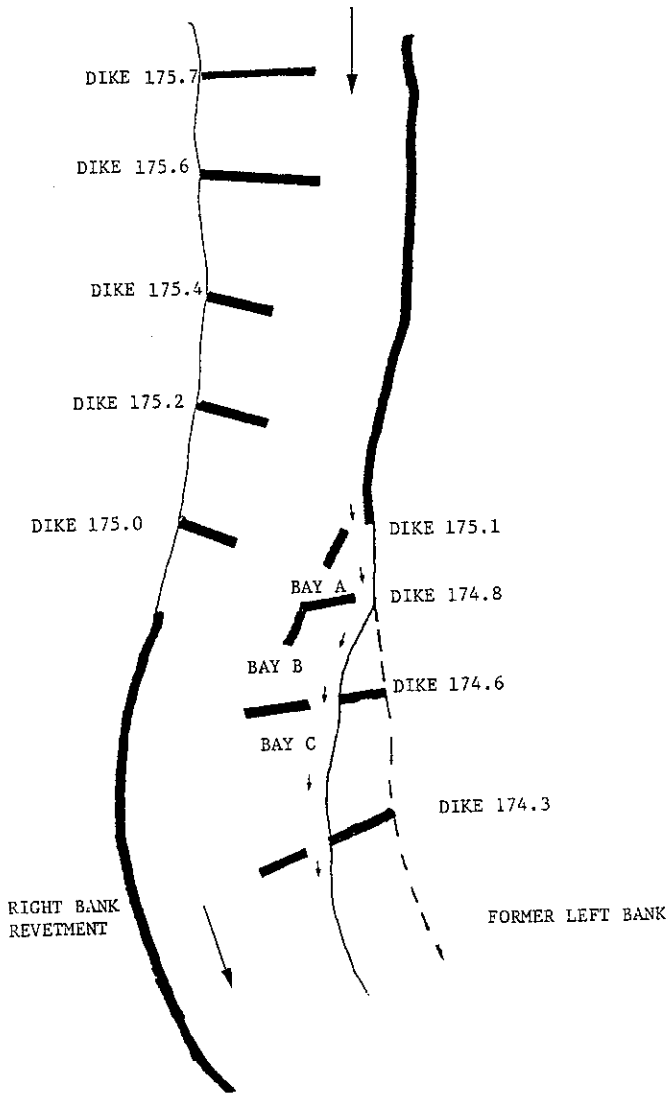


Figure 42. Modification of existing dikes

b. Open a notch in Dike 174.8 at the bankline. Again, the old revetment would prevent erosion of the bankline.

c. Enlarge the existing notches in Dikes 174.6 and 174.3 by lowering the notch inverts to 3 ft below CRP.

d. To guarantee that the channel will carry water and not fill with sediment, dredge a pilot channel through Bay C and then out to the main channel downstream from Dike 174.3. The dredged material could be put in the timbered portion of the bay.

e. Lower the crests of Dikes 174.6 and 174.3 slightly to arrest sedimentation near the riverside of Bay C where the new willow bar is growing.

337. The backwater channel developed by the above steps should enlarge and remain functional, although the development of slack water may be limited. Maintenance may be required to reestablish the correct shape of the notches after severe floods. The backwater channel will carry flow during the low-flow season, thus diverting a small amount of water from the navigation channel. To maintain the navigation channel at its present depth and width, more narrowing of the main channel may be necessary. This can be accomplished by extending Dikes 174.6 and 174.3 on the left bank and Dikes 175.0 and 175.2 on the right bank.

338. Decreasing the crest levels of dikes and extending them farther into the main channel will probably increase the maintenance costs. However, in addition to the benefit derived by creating more aquatic habitat, there is the potential benefit that flood stages may decrease in frequency and duration in the study reach. On the deficit side, the creation of backwater channels and low dikes will stop the creation of new land which can be farmed.

339. "Hindsight" dike design. If the stabilization works in Sandy Hook Bend were to be redesigned for the baseline (1933) conditon and the procedures for dike field design presented in Part V could be used, response of local habitat conditions to this "hindsight" design could be estimated using the information in Parts IV and VI. Figure 43 shows what might have been a dike field layout for Sandy Hook Bend in 1933. It incorporates the following environmental enhancement techniques:

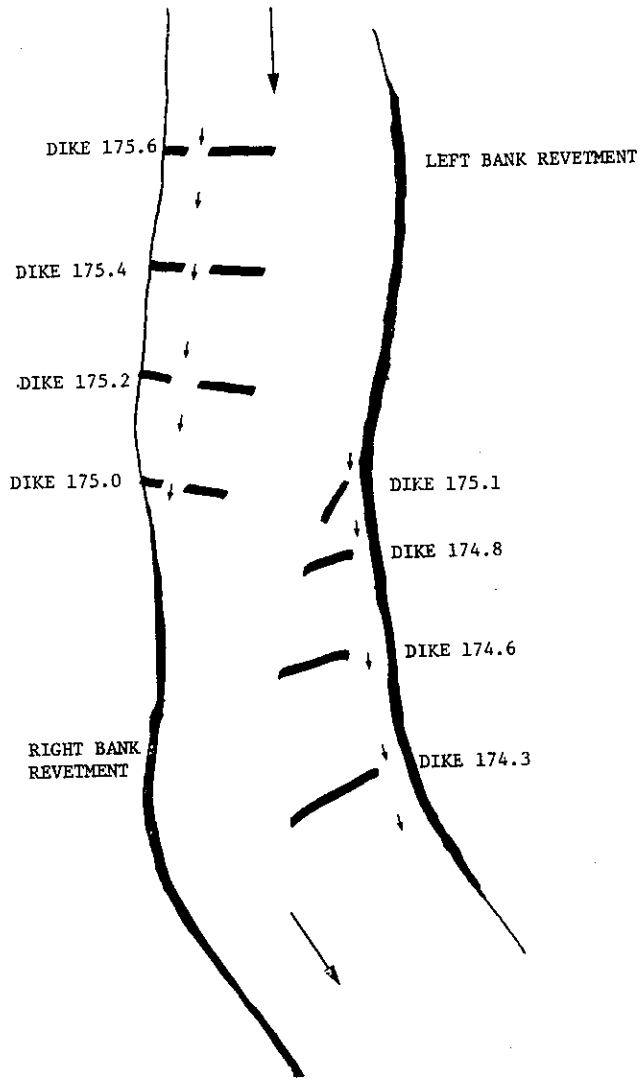


Figure 43. Retrospective design for aquatic habitat

a. A backwater channel is created along the inside of Sandy Hook Bend utilizing low (2 ft below CRP), rootless dikes and the then existing revetment along the left bank. The revetment is extended beyond Dike 174.3. The gap between the dikes and revetment should be approximately 150 ft (minimum) to prevent excessive flow concentration and scouring. The L-head is eliminated because it cannot be extended into the main channel if it becomes necessary to narrow the main channel.

b. In the upstream right bank dike field, the dikes are also constructed to about 2 ft below CRP. Here, notches are made at least 25 ft away from the bank because there is no revetment to prevent the bankline from eroding. The intake to this backwater channel must be located upstream at the end of the bend immediately upstream from Providence Bend.

c. All dikes are extended in stages to develop a narrow channel which would be 9 ft deep and a minimum of 300 ft wide during the low-flow season.

340. This design would probably have prevented the growth of willows on sandbars within the dike field and the subsequent encroachment of agriculture onto accreted land in the river channel. The design of the left bank dike field would have allowed flow through the dike field at low stages, preventing or reducing the rate of sedimentation. If the navigation channel did not develop sufficiently at low stages, then the length of the dikes could have been extended to further constrict the flow. A second option would have been to attach Dike 175.1 to the bank, making the dike an angled spur dike instead of a rootless dike. This would have helped to prevent excessive flow diversion into the backwater channel.

341. The retrospective dike design would probably have developed a diverse aquatic habitat, particularly at low flows. Robinson (1980) suggested that rootless dikes have the best potential for developing diverse aquatic habitat in the Missouri River. The low, rootless dikes would have developed low sand bars downstream of each dike, with scour holes downstream of both ends of each dike, and a backwater channel along the bank. Pools might have developed during low flow, although pool size might have been limited by flow through the backwater channel. Based on studies of notched and rootless structures on the Missouri River by Jennings (1979), Reynolds and Segelquist (undated), Peterson and Segelquist (undated), and Robinson (1980), the habitat conditions predicted would have been favorable for many

species of fish and macroinvertebrates native to the Missouri River. The predicted habitat diversity would have provided spawning, feeding and resting areas at low and moderate flow.

Lower Mississippi River Case Study: Leota Dike Field

342. The Leota dike field spans River Miles 510.5-515.5 on the lower Mississippi River, approximately 70 miles north of Vicksburg, Mississippi. The study area is bordered to the west by Arkansas and to the east by Mississippi (Figure 44).

Background

343. Geology. The lower Mississippi River is part of the Central Gulf Coastal Plain consisting of Mesozoic and Cenozoic deltaic marine formations which were deposited during a series of transgressions and regressions of the ancient ocean. The character of the Coastal Plain has been further modified by tectonism and erosion, resulting in a region of relatively low relief (Vicksburg District 1976). The floodplain in the region of the Leota Dike Field is a Holocene sedimentary deposit almost 40 miles wide. The Pleistocene channel of the river is more than 200 ft below the surface of the present alluvial plain. Sediment filling the Pleistocene valley consists of material grading upward from coarse at the base to very fine silts and clays at the surface.

344. Historical benchmarks. Aerial photographs show that numerous avulsions have occurred in the past; abandoned channels and oxbow lakes are readily evident. Ridge and swale topography is also present, providing evidence of large-scale lateral movements of the river. The river reach which includes the Leota dike field has historically been recognized as an unstable region. The shifting channel and movement of sand bars have created navigational hazards and necessitated frequent dredging. The pattern of channel migration prior to dike construction was leading to the development of a large point bar in the Leota area. Stabilization of this section was planned as part of a comprehensive channel improvement project. Severe navigation problems and high dredging requirements dictated that this reach be given a high priority for permanent stabilization using dikes and revetments.

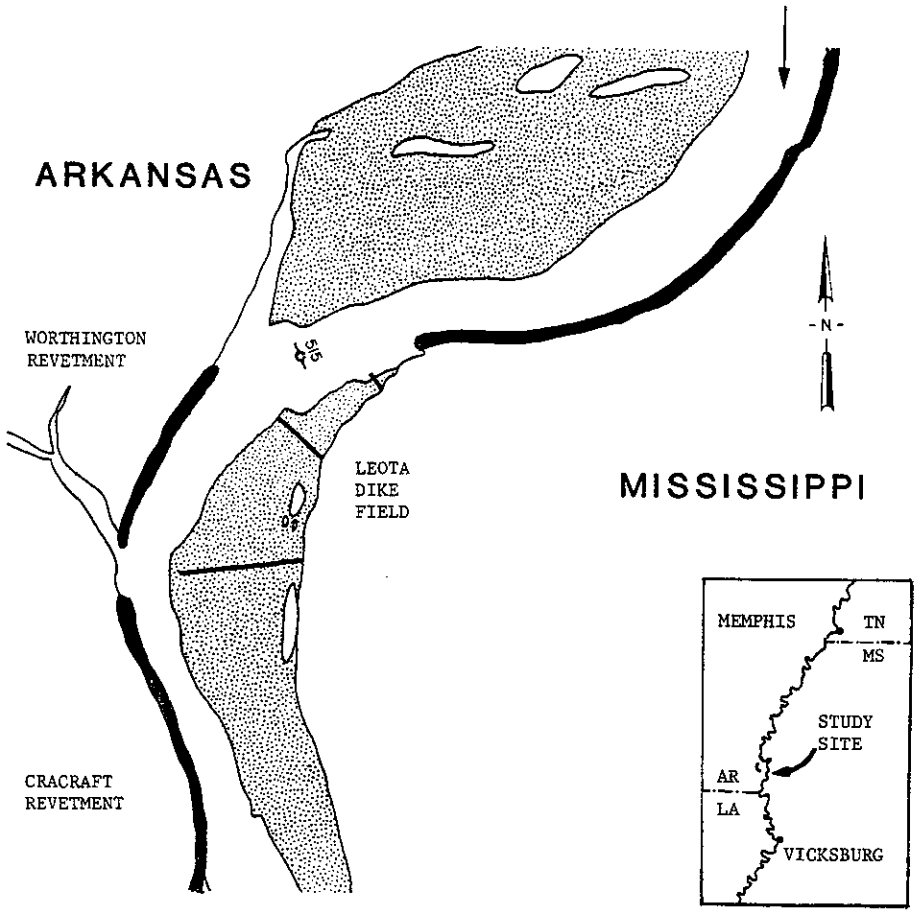


Figure 44. Leota dike field location map
Scale 1:62,500

345. Hydrology. The Mississippi River drains 1,232,598 sq miles of the North American continent. The average annual runoff is greater than 15 in., and heavy rainfall or rapid snowmelt periodically results in large inflow into the lower Mississippi from its major tributaries. Floods and large stage fluctuations are thus common.

346. In 1871, gages were installed at Memphis, Tennessee, and Vicksburg, Mississippi, as well as at other locations along the lower Mississippi River. The average flow for the period of record at Vicksburg (approximately 73 miles south of the study area) is 561,000 cfs, and the average water velocity is 3-6 ft/sec. The highest discharges occur in February to May and the lowest discharges in July to October (Pennington, Baker, and Bond 1983). Table 10 gives maximum yearly stage data from 1965-1981.

347. The Vicksburg gage data indicate flooding was a relatively frequent occurrence through the years 1931 to 1945; overbank flows took place seven times during this period. However, in the subsequent period from 1946-1972, flows of this magnitude have occurred only twice. The period from 1973-1981 also had a number of floods: four floods took place during this time span. The 1973 flood was a very high-magnitude event (1,962,000 cfs) exceeded only by the 1937 flood of 2,080,000 cfs.

348. Sediment. Suspended sediment in the lower Mississippi River is supplied primarily by the upper and middle portions of the Mississippi River, which includes the sediment supplied by the Missouri River. As the predominance of engineering structures designed to protect the river banks and retain sediment has increased, the amount of suspended sediment has decreased (Keown, Dardeau, and Causey 1981). At Vicksburg, Mississippi, the bed material is composed primarily of medium and fine-grained sands. Average suspended sediment transport is 616,000 tons per day (Keown, Dardeau, and Causey 1981).

Baseline conditions

349. Prior to construction of the Leota dike field, the river from River Mile 510.0-515.5 was a dynamic region with constantly shifting sandbars (Figure 45). This made the area particularly hazardous for navigation, and dredging volumes were large. The main channel was prone to lateral migration. Although revetments were constructed to stabilize the

Table 10

Maximum Yearly Stage*

Year	Arkansas City		Vicksburg, Mississippi	
	Stage (ft)	Day	Stage (ft)	Day
1965	34.30	Apr. 19-22	38.72	Apr. 23
1966	30.05	May 14	34.35	May 16
1967	30.14	May 29	34.11	June 1
1968	31.47	Apr. 14	36.5	Apr. 15
1969	34.67	Feb. 18	39.2	Feb. 19
1970	36.79	May 15	40.7	May 17
1971	33.2	Mar. 12-14	37.6	Mar. 14
1972	33.80	May 10	37.4	May 13
1973	47.6	May 11-13	51.6	May 13
1974	37.5	Feb 10	44.25	Feb. 11-12
1975	42.85	Apr. 10	48.05	Apr. 14-15
1976	27.6	Mar. 5-6	32.40	Mar. 7
1977	27.78	Apr. 17	32.39	Apr. 21
1978	35.40	Apr. 8	39.80	Apr. 11
1979	35.40	Apr. 26-27	47.90	Apr. 26-29
1980	34.3	Apr. 5-6	40.5	Apr. 14
1981	28.0	June 13	32.5	June 14-17

*Date is taken from yearly hydrograph records. Values listed are actual gage measurements. Bankful stage is 43.00 ft.

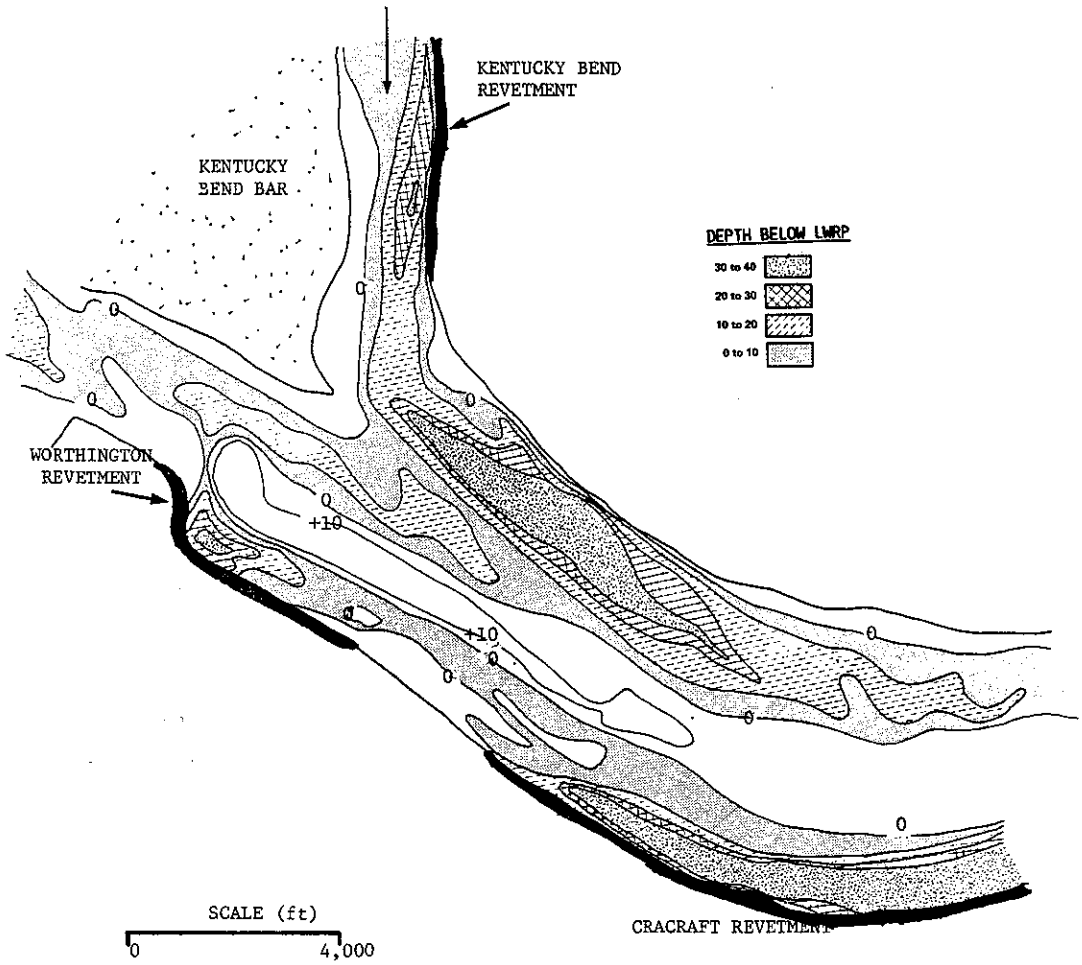


Figure 45. Leota dike field hydrographic survey, June 1962

river bank on the western (right bank) side, the left bank was a developing point bar prior to the emplacement of the dikes. Construction of the dikes accelerated this naturally occurring process. A hydrographic survey of the region in January and February 1967 (prior to dike construction) indicated that the thalweg of the channel was fairly close to the right bank, but the remainder of the main channel contained numerous sand bars and shoals (Figure 46). The sandbars supported little vegetation, as the substrate was unstable and subject to periodic immersion by high flows.

350. The floodplain on either side of the main channel shows evidence of recent avulsions and lateral migration. An oxbow lake is present on the right bank floodplain as well as an abandoned river channel (Matthews Bend). On the left bank floodplain, there is distinctive ridge and swale topography.

Baseline to present

351. Construction changes. The Cracraft revetment was constructed between 1955 and 1958, working upstream. The Worthington revetment was built during 1966 and 1967. The Leota dike field was constructed in 1967 in order to stabilize a point bar and to discourage the development of secondary channels at low and intermediate flows. The field consists of three spur dikes of stone utilizing a stepped-down design. Table 11 contains information on individual dike length, angle, crest elevation and date of construction.

Table 11

Background Information on the Leota Dikes

	Date Constructed	Length (ft)	Angle Formed with bank	Elevation Above LWRP (Bank End) (ft)	Elevation Above LWRP (Channel End) (ft)
Dike 1	June 28-Sept. 1 1967	1,080	65°	21	16
Dike 2	Aug.23-Dec.5 1967	2,340	65°	19	14
Dike 3	Sept.2-Oct.9 1967	3,720	100°	17	11

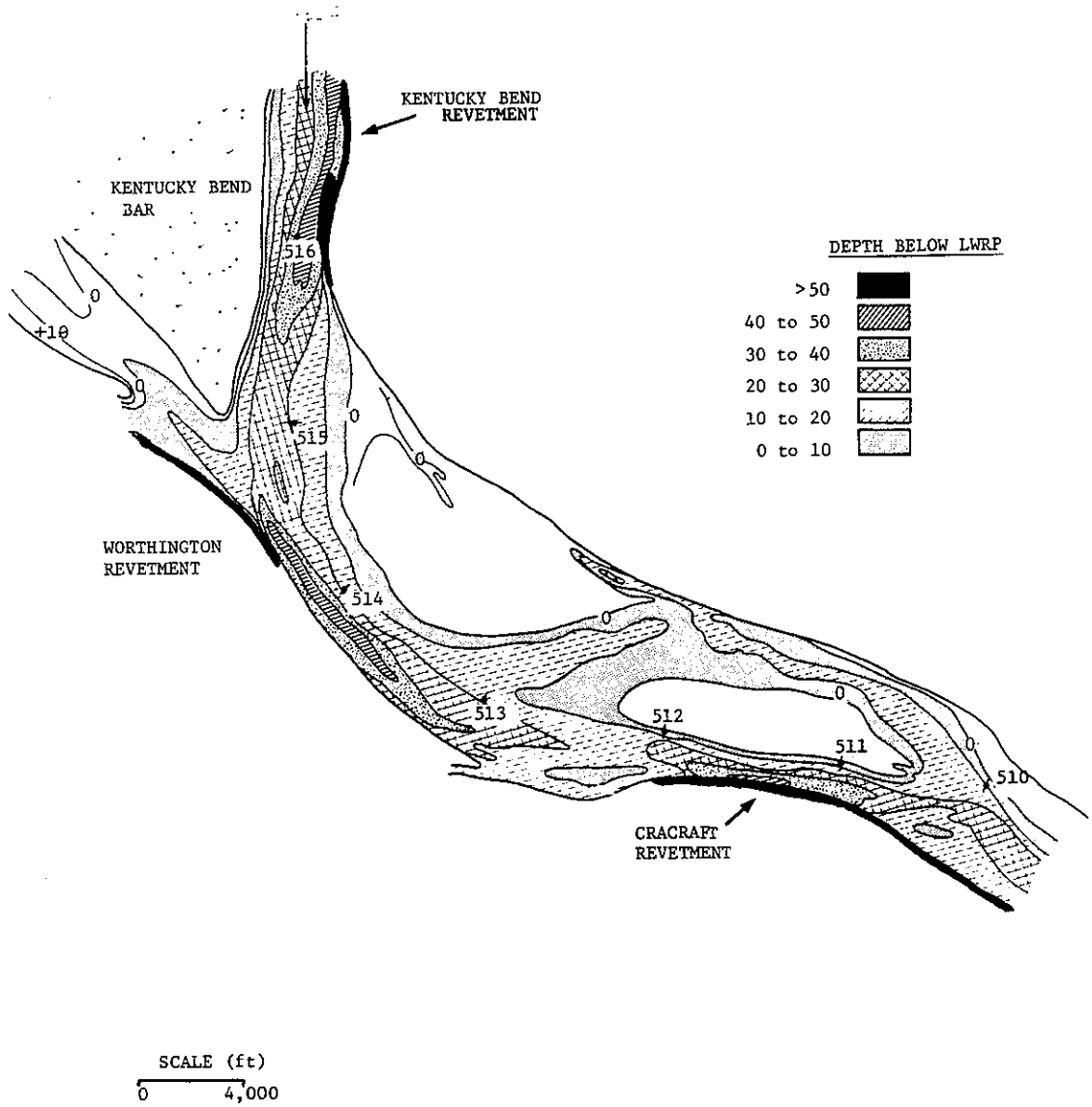


Figure 46. Leota dike field hydrographic survey, February 1967

352. River response. The 1968 hydrographic survey (Figure 47) shows a decrease in low water channel width due to a large increase in the size of the point bar at Leota. The right bank remained stationary due to the presence of the Worthington and Cracraft revetments. The channel depth below LWRP has increased. As the point bar grew and extended downstream, a secondary channel formed between the bar and the left bank downstream of Dike No. 3. A 1969 aerial photograph shows vegetation (probably willows) colonizing the bar.

353. Secondary channels as described in Part III are usually shallow and have slow-moving or still water at low flow; they are known to be very productive aquatic habitats. In various studies, secondary channels and slackwater pools have been found to provide habitat for dense and diverse fish communities (Pennington, Baker, and Bond 1983), high densities of benthic macroinvertebrates (Beckett et al. 1983), and zooplankton and phytoplankton (Lubinski et al. 1981). Thus, the Leota area in 1969 was probably a region of diverse aquatic habitat which supported a large number of species.

354. The 1975 hydrographic survey (Figure 48) shows a continued decrease in channel width and increase in bar size, with the entire dike field area at elevations above LWRP. Portions of the bar accreted to +30 ft LWRP, several feet above the dike crest elevations. Sediment filled the secondary channel below Dike No. 3, and the point bar extended several miles downstream. The channel depth has increased, particularly along the revetments on the right bank. A 1976 aerial photo shows an increase in bar area covered by vegetation, with larger trees apparent.

355. The 1982 hydrographic survey (Figure 49) shows little change in channel width or bar area since 1975. Channel width appears to have increased slightly due to erosion of the point bar. Also, a small portion of the bar has eroded away from the downstream face of Dike No. 1. The bar elevation remained high (+ 20 ft LWRP), and the channel depth appears stable. A 1981 aerial photograph shows continued establishment of vegetation in the bar area below Dike No. 3. Thus it appears that the dikes have enlarged and stabilized the point bar. However, since the time period since the dikes were constructed is short, conclusions regarding river response are somewhat speculative. In addition, along the lower Mississippi

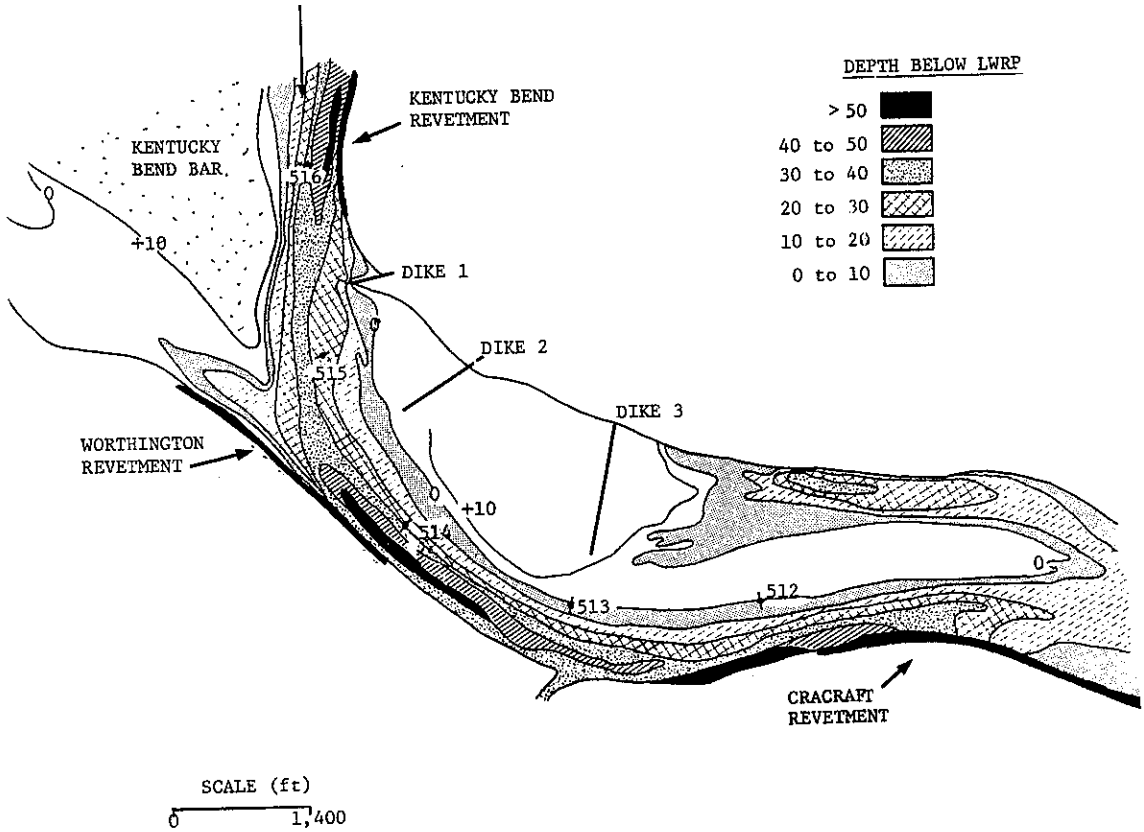


Figure 47. Leota dike field hydrographic survey, March 1968

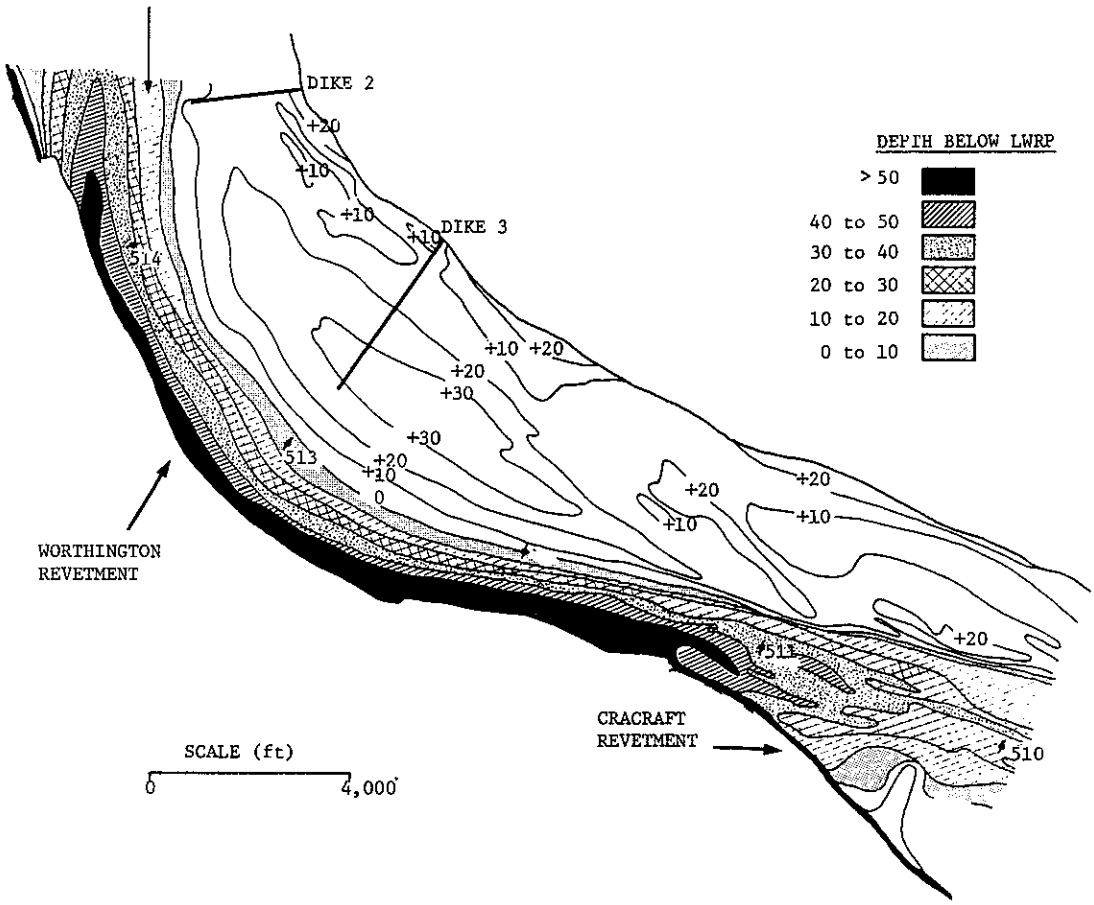


Figure 48. Leota dike field hydrographic survey, May 1975

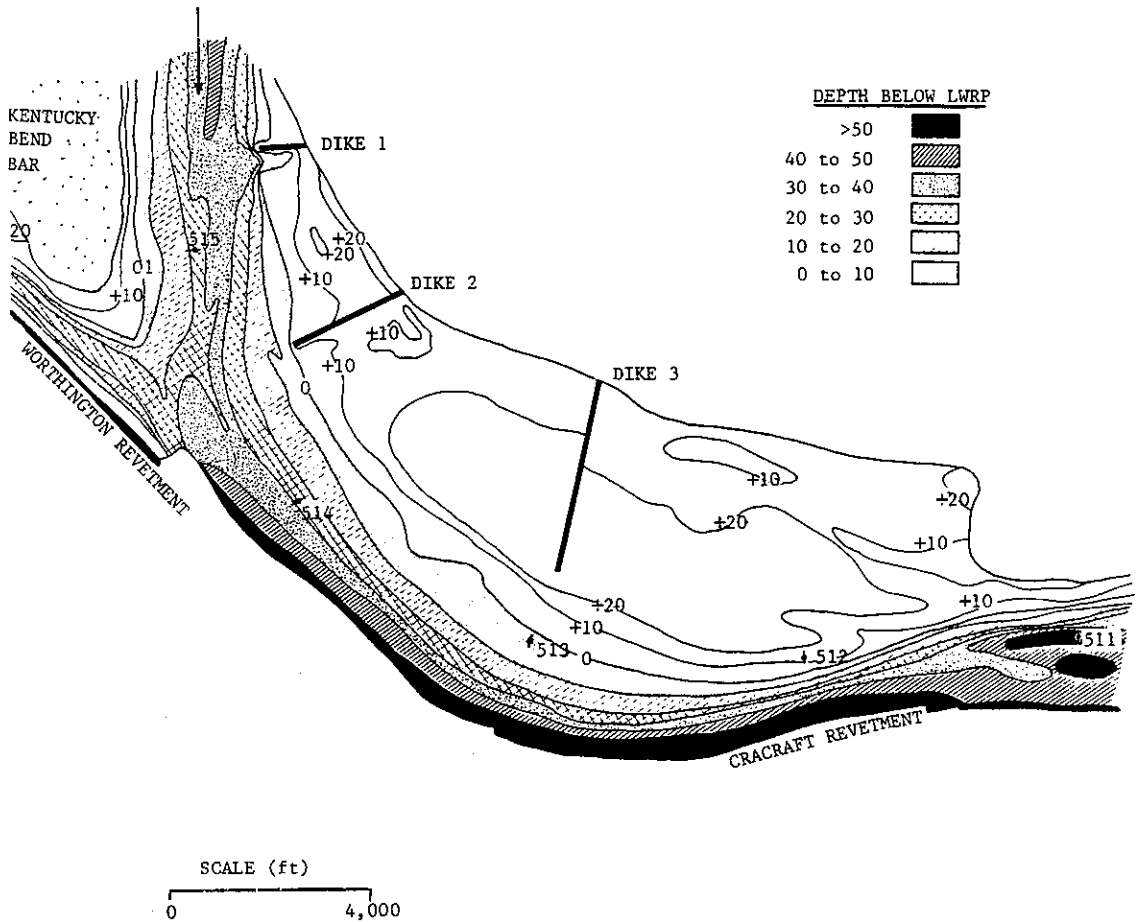


Figure 49. Leota dike field hydrographic survey, March 1982

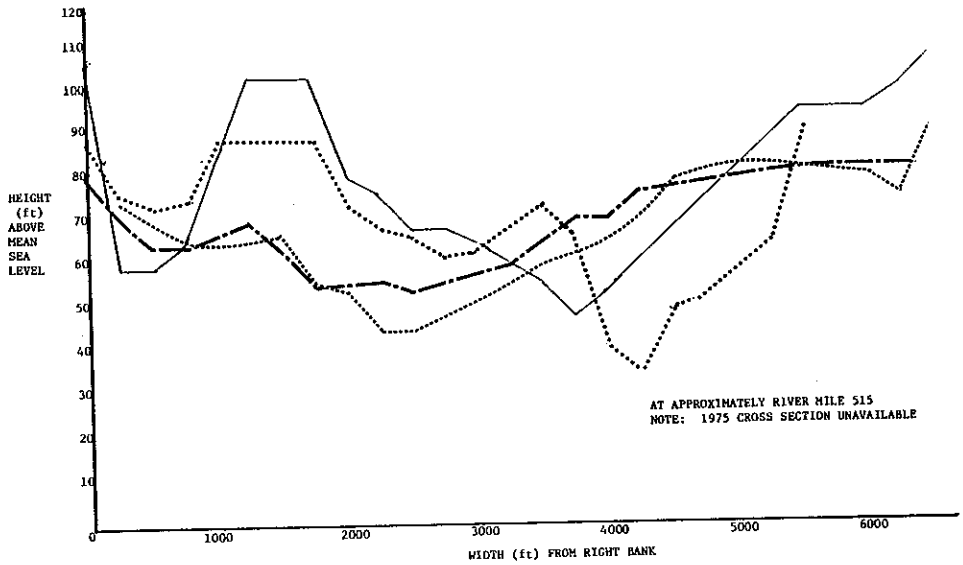
River it is difficult to distinguish between changes due to the presence of dikes and those due solely to natural processes.

356. Cross sections. Cross sections (Figure 50) were plotted at three locations on the channel (approximately River Miles 515, 513.9, and 512) using fixed survey points along the stable right bank as reference points. Each cross section covers 1962, 1967, 1968, 1975, and 1982 (with the exception of River Mile 515 which is missing data for 1975). The cross sections show that the main channel has scoured and become narrower and deeper through time--channel changes which are expected to occur in response to dike field emplacement in a bend. This indicates that the dike field and the upstream changes in channel alignment resulted in a navigable waterway which is narrower and deeper at low flows. As the channel shifted, there was an accumulation of sediment around the dikes, causing the point bar to rapidly accrete. The thalweg moved away from the accreting bar towards the opposite bank. The cross section at River Mile 515 shows the influence of the southern tip of Kentucky Bend Bar through accumulation of sediment in the central portion of the profile. Cross section 513.9 reveals that a point bar had developed prior to the installation of dikes in 1967 and that the dike field stabilized the bar and increased its size, resulting in scour of the thalweg.

357. Dredging. No dredging has been required to maintain the navigation channel between River Miles 502 and 520 since construction of Leota dike field. In the 4 years just prior to construction, approximately 3.9 million cu yards were dredged from the navigation channel between River Miles 509 and 516. The annual dredging volumes in cubic yards is as follows:

Year	Dredging Volume (cu yards)
1963	233,289
1964	2,754,832
1965	796,922
1966	133,303

The elimination of dredging in the Leota reach is an indication of the effectiveness of the dike field in deepening the low-water channel.



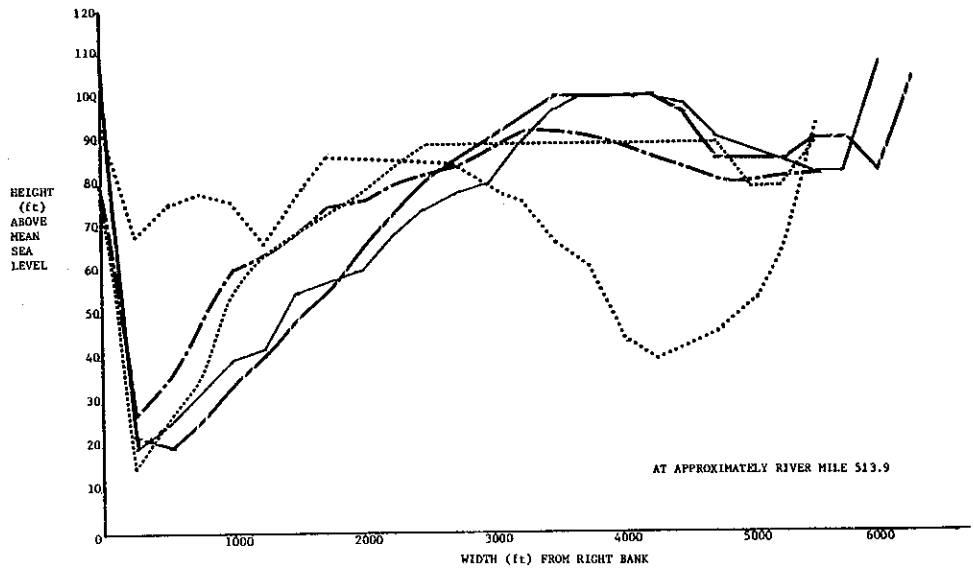
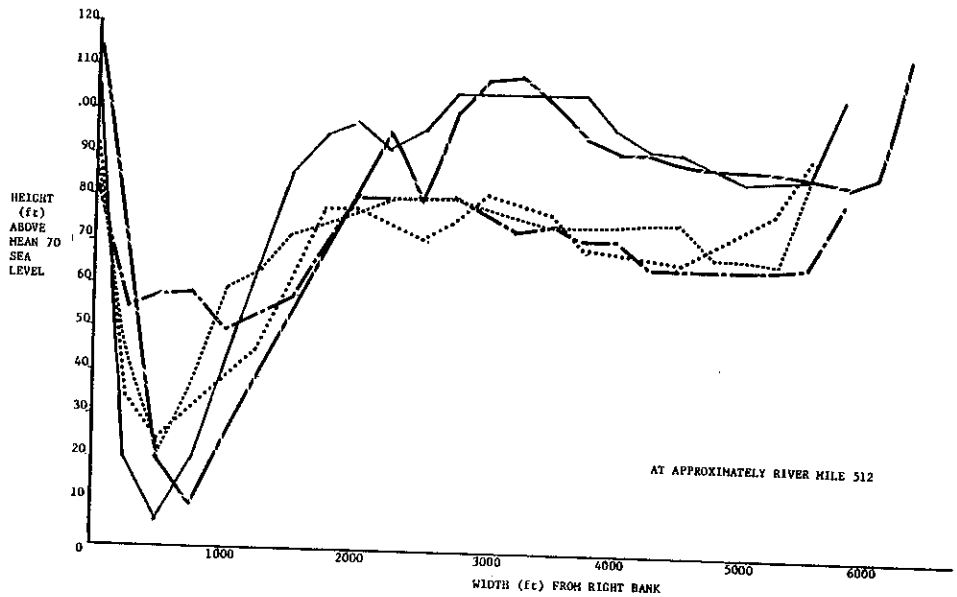


Figure 50. Cross sections, Leota dike field (Continued)



WATER SURFACE ELEVATION IN FEET, MSL

1962	94.5	R.M. 511.6
1967	81.30	R.M. 513.4
1968	86.43	R.M. 512.95
1975	113.66	R.M. 512.6
1982	105.2	R.M. 514.2

CROSS SECTION CONTOURS

1962
1967
1968
1975
1982

Figure 50. Cross sections, Leota dike field (Concluded)

358. Summary of changes from baseline to present. The construction of the Leota dikes has created a change in the morphology of the reach. During the initial accretion of the point bar, a large amount of low-flow slack water was created. This backwater was a productive, diverse habitat which possibly compensated for the loss of habitats which were present in the unaltered channel environment. However, since 1968, the amount of low-flow slack water has decreased. In addition, the presence of the dike field and point bar has caused the channel to become narrower and deeper. Much of the former habitat diversity of the channel environment (shoaled areas, sand bars, etc.) has been destroyed.

Present habitat deficiencies

359. Present aquatic habitat within Leota dike field is dominated by the point bar and accreted sediments. At low-flow conditions, Cobb and Clark (1981) described the aquatic habitat as limited to small slack-water pools within the dike field near the junction of Dike No. 3 and the bank and a fringe of sandbar habitat along the channelward edge of the bar. Almost all the dike field area was dry land. At moderate-flow conditions, the slack-water pools become submerged sandbar habitat, as does approximately half of the bar area (previously dry land). During high flow conditions the entire area within Leota dike field is described as submerged sandbar habitat.

360. Pennington, Baker, and Bond (1983) found that the Leota dike field supports high fish species diversity relative to other habitat types in this river reach. Forage species were the most numerous in their samples, followed by sport-commercial species. The dike field provides habitat for a range of life stages, particularly juveniles, for many species. However, habitat for larval fishes is limited during low flows to small, shallow, isolated pools within the dike field (Conner, Pennington, and Bosley 1983).

361. Beckett et al. (1983) found that Leota dike field substrates are primarily sand and sand mixed with gravel at high and moderate flows and some mud and mud mixed with sand at low flows. Macroinvertebrate densities increase in the mud substrates in low-flow periods. Macroinvertebrate populations in Leota dike field are limited by the size of the point bar (primarily sand substrate) and the lack of the mud substrate associated with slackwater pools.

362. The Vicksburg District (1976) noted that the portion of the main channel with an average depth of greater than 5 ft supports primarily predaceous fish, some omniverous organisms, and plankton feeders. That portion of the channel averaging less than 5 ft, however, is extremely productive at all trophic levels. This shallower portion is the area that is most affected by the construction of dikes. In the Leota area the river banks have steepened, the average depth has increased, and midchannel sand bars have been eliminated. This means that much of the area that was previously less than 5 ft deep at low flows no longer exists. Thus, the overall productivity of the aquatic habitat in the study area at low stages has probably decreased.

363. As shown by the cross section plots in Figure 50, the Leota dike field reduced the topographic variability of the channel bottom, creating a single main channel with a definite single thalweg and steep slopes; all necessary steps to produce a stable channel for flood control and navigation. However, the adverse impacts on aquatic habitat associated with the creation of a deep, narrow channel may be reduced if sufficient areas of backwater are maintained.

364. Reduction of aquatic habitat diversity would have serious environmental consequences for the river system. Pennington, Baker, and Bond (1983) suggested that the conversion of the lower Mississippi River dike field aquatic habitats to dry land would seriously affect the overall quality of fish habitat. Development of aquatic areas with still or very slow currents and resultant fine-grained substrate provides an alternative habitat to replace abandoned channels, sandbars, and pools lost due to river stabilization.

Formulation of improved designs

365. Modification of existing dikes. Unless measures are taken to maintain the slack-water areas, which appear at low flow, the point bar will probably eventually fill in the slack-water area. This means the dike field will become terrestrial habitat during low flow. Also, the main channel will be maintained as a narrow, deep thruway since it cannot migrate westward due to the revetments. As discussed previously, the deep channel will support only a relatively small number of species. In the long run,

the Leota dike field will probably cause a substantial decrease in the overall diversity of aquatic habitat of the reach at low stages.

366. The Leota dikes could be modified to enhance the diversity of the riverine habitats and still maintain a navigable waterway. Notches could be excavated in the dikes to allow water to pass, thus scouring sediment and creating secondary channels. These shallow channels could provide still or slow-moving waters at low flow--ideal habitats for for many types of benthic macroinvertebrates, fish, zooplankton, and phytoplankton.

367. The other alternative for improving the existing dike field is a minimum-maintenance approach. This approach involves allowing the dikes to degrade without repairing them unless absolutely necessary to maintain navigation. The unrepaired dikes would have irregular crests; therefore, channels or pools of various sizes and shapes would develop within the dike field.

368. However, in the Leota dike field case there are practical considerations which essentially preclude the use of any major environmental enhancement features on the existing dike field. Recent surveys of the area reveal that the sandy point bar has built up to elevations as much as 10 ft higher than the dike crests. The height and constant shifting of these sediments deter consideration of long-term environmental enhancement techniques because of the risk of incurring considerable maintenance expense.

369. Notching is often a relatively simple means of creating secondary channels within a dike field. However, maintenance of a channel through the dike field is only possible if this channel is periodically scoured free of excess sediment. In a situation like Leota, where there is a surplus of sediment, notches might not be capable of inducing enough scour.

370. Hindsight dike design. If the Leota dike field were to be redesigned for the baseline (1962) condition, a number of techniques might be utilized to preserve and develop diverse aquatic habitats. Procedures described in Part V might be used to formulate a design along the lines of the layout shown in Figure 51. If notches had been incorporated into the original design of the dikes, they might have been more effective in maintaining a scoured secondary channel than if they had been excavated after sediment accumulation had occurred.

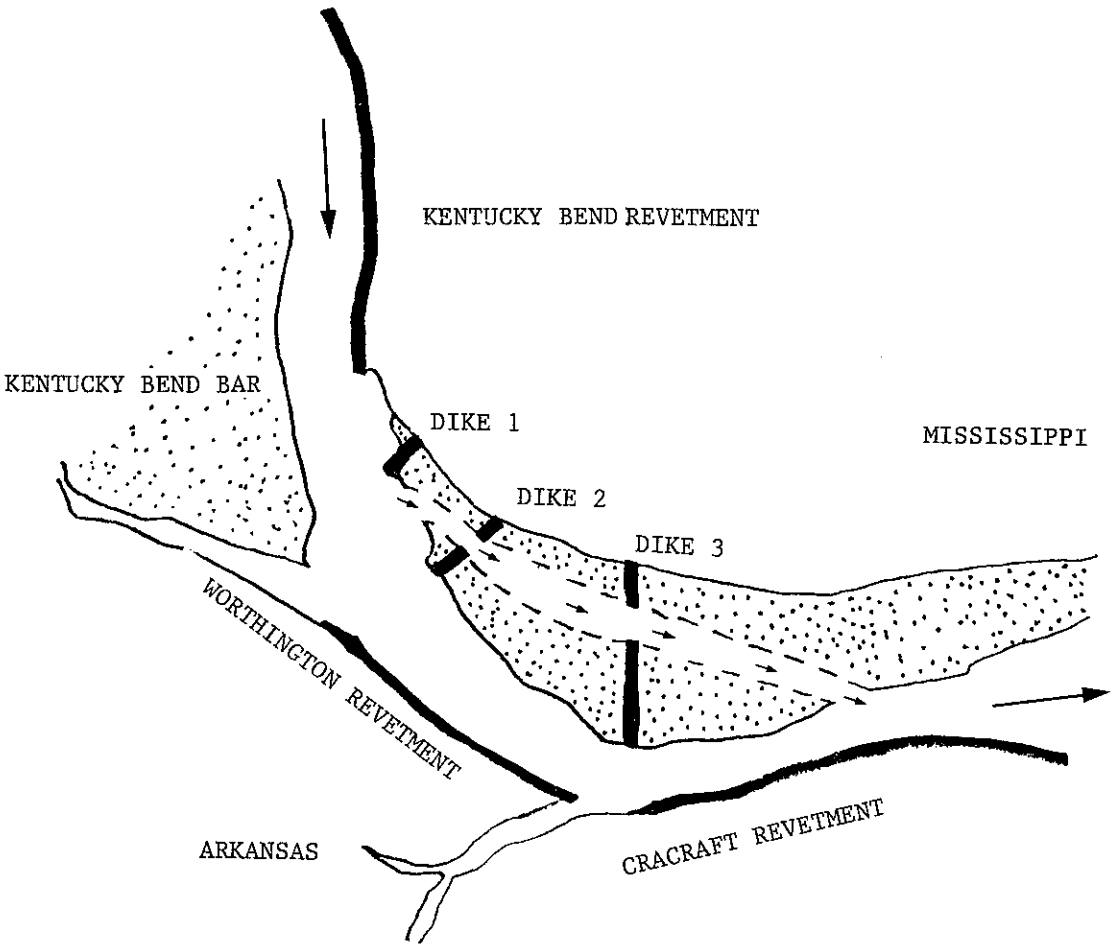


Figure 51. Retrospective Leota dike field design for aquatic habitat

371. Lower and possibly longer dikes might also have created a dike field with more diverse habitats, which still accomplished channel stabilization goals. The depth of scour produced by the existing dikes seems to indicate that lower dikes of the same length would probably be sufficient. However, if the desired channel development did not take place, the dikes could be extended to provide more contraction at low river stages. Low-elevation dikes might have allowed flow over the dike crests frequently enough to remove accreted sediment, maintaining slack-water areas and increasing diversity of aquatic habitat. The second and third dikes might also have been notched to improve development of secondary channels and to maintain the slack-water areas within the dike field.

PART VIII. SUMMARY

Dike Design and Construction Procedures

372. Dike designs vary by CE Division and District and by river and river reach and are site-specific, taking into account waterway and site characteristics, navigation requirements, and available funds. Dike designs are also highly dependent upon the personal experience and judgement of each design engineer. However, there are some generalizations which can be made. Present dike construction and maintenance, with the exception of the Columbia River (where Portland District uses timber pile dikes), is done with stone placed from either barge or truck. Typical dike designs are spur dikes, vane dikes, L-head dikes, longitudinal dikes, closure dikes, and sills (low underwater extensions to dikes).

373. Dike length, crest elevation, crest profile, and angle to flow are prime dike design parameters. Dike length is determined based on the master plan for the waterway project and the channel width at each site. Formulation of the master plan also usually includes determination of dike locations and types. Crest elevations vary from river to river, with an intermediate dike on one river corresponding to a low dike on another river. For example, upper Mississippi River dikes are overtopped continously while middle Mississippi River and Missouri River dikes are overtopped less than twenty percent of the time. Within a dike field, crest elevations of succeeding dikes may be nearly level, stepped down, or stepped up; level and stepped-down dike fields are more common. Crest profiles are either level, stepped, sloping, or sometimes irregular. Typically, dike crests are level or sloping down towards the channel, although stepped crests are frequently used for closure dikes. The angle of the dike to the flow ranges from perpendicular to angled 45 degrees downstream, with spur dikes angled typically perpendicular to 30 degrees, and vane dikes at 10 to 15 degrees. Dikes are typically spaced apart the maximum distance which will achieve the desired channel constriction while preventing or minimizing bank erosion. The crest elevation, crest profile, and dike angle are flexible parameters in most dike designs, as there are more design alternatives available for these three parameters.

374. Construction of a stone dike is typically done in lifts. Dike fields are also constructed in stages, with either the lead dike or the most critical dike constructed first. Staged construction, particularly when spaced over several seasons, allows rivers to gradually adjust to the constriction and prevents undue scour from developing at the end of the dike under construction.

Dike Field Effects

Hydraulics and morphology

375. Dike fields constrict the flow of the river, increasing both channel depth and velocity. The river increases its depth primarily by scouring the bed: the increased velocity increases scour. Other associated effects are reduced flow resistance and changes in the slope of the water surface. Local scour holes develop at the channel end of the dike due to acceleration of water around the tip of the dike. Sediment is deposited in a bar downstream and behind the dike, often forming a backwater area between the bar and the bank.

376. Establishment of vegetation (such as willows or cottonwood) can raise the bar above the elevation of the dike. The vegetation slows the current passing over the bar, inducing sediment deposition. Often, a vegetated bar will accrete sediment until it becomes an island. If the backwater area also becomes filled with sediment and vegetated, the island is joined to the bank as a new portion of the floodplain.

377. Dike fields modify river stages at both high and low flows by changing the cross-sectional area, the roughness coefficient of the river bed, and sometimes by causing degradation of the river bed. If the dike field reduces the bankfull cross-sectional area of the reach, the flood stage tends to increase. However, this tendency is mitigated by bed degradation and the decrease in flow resistance when the unit discharge is increased. The narrower, deeper channel produced by dike fields has a larger hydraulic radius (a more efficient cross section) and a smoother, less sinuous alignment. These factors may be sufficient to offset entirely any decrease in cross-sectional area. Dike fields usually produce lower stages for low flows due to main channel degradation.

Biota

378. Dike fields create a diversity of aquatic habitat by influencing physical habitat factors such as water depths, substrate, and current velocities. Dikes also are habitat themselves, providing cover and stone substrate scarce in many large river systems. Several investigators have observed diverse fish and invertebrate communities inhabiting dike fields and/or dike structures. Sediment accretion within the dike field reduces the amount of aquatic habitat and the percentage of the riverine environment that is off-channel habitat. Accreted land within dike fields sometimes provides additional terrestrial habitat. However, along the Missouri River this land is typically cleared for agriculture.

Environmental Features

379. Environmental features for dike fields are dike designs, structural modifications, or maintenance practices used to enhance aquatic habitat diversity, usually by reducing rates of sediment accretion in the dike fields. Although riverine habitat diversity may be enhanced by incorporating dike field environmental features, the location of a given dike field with respect to the overall channel alignment is often the most important design parameter affecting river response. Common dike field environmental features include notches, low-elevation dikes, rootless dikes, and minimum maintenance practices. Untested or minimally tested environmental features include dredging within the dike field to remove sediment, disposal of dredged material within the dike field, relocating notches, placing additional rock underwater, artificial reefs, and control structures in closure dikes.

Notches

380. A notch is a gap in a dike that is either constructed or developed by scour and allows water to pass through the dike. Flow through the notch typically develops a scour hole immediately downstream and develops or preserves secondary channels within the dike field. Design of notches varies considerably by CE District and river reach.

Low-elevation dikes

381. A low-elevation dike is a dike built to an elevation which is frequently over-topped or continuously submerged so that bar buildup to an elevation that allows the establishment of vegetation is prevented. Low-elevation dikes are often selfscouring, thereby limiting sediment accretion, although they can become filled with sediment. Design elevations for low-elevation dikes vary from CE District to District and from one river to another. Low-elevation dike designs are often utilized because of their lower cost.

Rootless dikes

382. A rootless dike is not tied into the bank, thus it allows water to flow between itself and the bank. Development of this secondary channel reduces sediment accretion and provides for potential development of multiple secondary channels. A problem with rootless dikes is their tendency to promote bank scour, requiring bank protection in the form of riprap or revetment. Rootless dikes typically develop local scour holes below each end and form a bar downstream of the center of the dike.

Minimum maintenance

383. The practice of minimum maintenance involves maintaining dike fields at the minimum level possible without adversely affecting the navigation channel. Minimum maintenance typically results in dikes with irregular crest profiles, often at lowered elevations. Minimum maintenance may be applied selectively to a few structures or on an overall basis. Minimum maintenance is most frequently practiced for the sake of economy.

Other potential environmental features

384. Other potential features (all untested or minimally tested) are dredging to remove sediment, selective disposal of dredged material within dike fields, locating notches, placing additional rock, constructing artificial reefs, and placing control structures in closure dikes. Two of these techniques address the removal or flushing of accreted sediment from dike fields (dredging and relocating notches). Placing additional rock, building artificial reefs, and selective placement of dredged material to form islands and bars might be done to enhance existing open-water habitat within a dike field. The use of control structures to regulate flow through dike fields or placing sediment to raise middle bars might be tried to

exclude sediment-laden flows from the dike field. All of these techniques are largely untested in dike fields although they have been successfully used in other aquatic environments such as reservoirs and small streams. The major problems associated with implementation of these concepts involve economics and instability of sediments in the river environment.

Environmental Guidelines for Dike Fields

General goals

385. There are several environmental objectives applicable to all dike design and construction:

a. Maintain or increase the aquatic habitat diversity by increasing the complexity of physical factors comprising the aquatic habitat.

b. Preserve the integrity of existing off-channel aquatic habitat areas.

c. Schedule construction and maintenance to avoid peak spawning seasons for aquatic biota.

d. Design and maintain dike fields to prolong the lifetime of the aquatic habitat (e.g. reduce sediment accretion).

e. Maintain abandoned channels open to the river.

Design procedures

386. The ultimate configuration of the navigation channel and the locations of dikes and revetments to produce that channel are determined by the river master plan. Master plan formulation to ensure incorporation of environmental considerations includes the following steps:

a. Formulate a draft river training master plan to achieve navigation, flood control, and bank erosion control objectives.

b. Using results of a habitat mapping study, evaluate the existing composition and spatial distribution of riverine habitats.

c. Using a multidisciplinary team, set general long-term goals for composition and spatial distribution of aquatic and terrestrial riverine habitats. These goals may be set for major reaches.

d. Modify the draft master plan to achieve these goals.

A system of priorities based on anticipated results (in terms of habitat development) should be used to determine which structures should be modified first.

397. The process described above for master plan formulation may result in recommendations to preserve and enhance dike field aquatic habitat. The following steps are suggested for design of a specific dike or dike field:

a. Evaluate the long-term potential of the dike field as aquatic habitat.

b. Based on the above evaluation, determine whether design modifications or environmental features are in order.

c. Consider manipulation of the basic dike design parameters to reduce the elevation of sediment deposition within the dike field.

d. Qualitatively project the depths, velocities, and resulting substrates likely to occur in the dike field.

e. Consider structural modifications to improve the aquatic habitat within the dike field.

f. Consider management techniques to improve aquatic habitat within the dike field after construction.

Existing Environmental Features

388. Environmental features or modifications to dike designs occur on the Missouri River, and the upper, middle, and lower Mississippi Rivers. Dikes on the Missouri River contain the most environmental modifications. Techniques employed include notches, low-elevation dikes, vane dikes, and minimum maintenance practices. Notches are the most common, over 1600 having been constructed. Environmental features occurring on the upper Mississippi River are primarily low-elevation dikes and minimum maintenance practices. Notches and low-elevation modifications have been employed on the middle Mississippi River on approximately 75 dikes (64 notches and 11 low elevations); minimum maintenance practices are also used. Dikes on the lower Mississippi River have few environmental features, although notches,

low-elevation dikes, vane dikes and minimum maintenance practices are all found there; the notches, however, are not designed, but occur by failure and are allowed to remain where there is no adverse impact upon the channel.

PART IX. CONCLUSIONS AND RECOMMENDATIONS

389. This report and the guidelines it contains should be regarded as preliminary and subject to refinement based on findings of future studies, in particular those which provide new data. Existing data are not adequate to support quantitative conclusions or specific dike design modifications which are applicable to all dikes or dike fields.

390. The bulk of available information regarding environmental features for dike fields deals with the Missouri River, where construction is essentially complete. Relatively little information is available for the lower Mississippi, where most future construction will be done. Application of principles based on Missouri River experiences to other river systems, in particular the middle and lower Mississippi, should only be done with care since the hydrologic and geologic characteristics of the systems are so different. Due to the closure of the mainstem reservoirs, the frequency and range of Missouri River hydrographic variations are extremely damped, and the sediment load is greatly reduced.

391. Dikes and dike fields provide valuable aquatic habitat, both on the structures and in the area below or between the dikes. The type of habitat provided resembles the naturally-occurring backwater habitat typically in short supply on rivers subjected to training for navigation purposes. The dike field habitat has been found to support diverse and productive communities of fish and invertebrates through a complete range of life stages.

392. The dike field aquatic habitat is often limited by sediment accretion which reduces the diversity of the aquatic habitat and, in some cases, converts aquatic habitat to terrestrial habitat. Manipulation of basic dike design parameters and the modification of the dike designs to incorporate environmental features (notches, rootless dikes, low elevations, and minimum maintenance practices) can reduce the rate of sediment accretion and increase the diversity of aquatic habitat. However, dike fields modified to meet environmental objectives must still perform river training functions acceptably. River training works must be designed to be functional, not only over the observed range of discharges, but also during the project flood which has potential for significant channel change with

its attendant social and economic impacts. For this reason, environmental features which compromise structural integrity past some point dictated by engineering judgement cannot be incorporated. Additional information regarding hydrologic, morphological, and ecological effects of dike fields is needed to reduce the subjectivity presently inherent in evaluation of dike field environmental features.

393. The use of these environmental guidelines (incorporating the goals and design procedures contained herein) in dike design, construction, and maintenance will provide benefits to the riverine ecosystems through increased biological diversity created by increased aquatic habitat diversity. Increased biological diversity, in addition to indirectly benefitting man, produces direct benefits in the form of healthier sport and commercial fisheries. Monitoring will be necessary to determine not only the long-term effects of the recommended environmental features on biological diversity, but also the extent of the benefits. It is recommended that monitoring be made part of an ongoing program of dike maintenance.

394. Consideration should also be given to periodic updating of the information and guidelines contained herein. As monitoring efforts and other studies generate additional information, it should be incorporated into the guidelines to ensure that the best available designs and environmental features are utilized.

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APPENDIX A: SUBJECT INDEX OF REFERENCES

1. References cited in the report are organized below by their major topic or topics into several general subjects. Most of the references are listed under more than one subject area. The references are indicated by numbers which correspond to numbers in the References section.

Dikes

Dike design and construction

2, 11, 17, 18, 19, 20, 25, 26, 31, 32, 43, 44, 45, 50, 54, 63, 67, 86, 88, 90, 92, 105, 106, 108, 109, 110, 123

Dike effects on hydraulics and morphology

7, 17, 25, 32, 43, 54, 56, 67, 77, 80, 82, 106, 112, 120, 121

Dike effects on biota

4, 6, 8, 14, 15, 16, 26, 28, 30, 36, 39, 40, 48, 51, 53, 54, 58, 60, 61, 64, 66, 68, 69, 72, 73, 74, 85, 89, 104, 106, 108, 127

Environmental enhancement features

7, 14, 16, 23, 26, 28, 33, 38, 39, 54, 55, 57, 66, 68, 69, 72, 75, 76, 77, 85, 89, 104

Background

Biological information

3, 4, 5, 10, 12, 13, 14, 21, 22, 23, 24, 26, 29, 34, 35, 37, 70, 46, 47, 49, 51, 52, 53, 55, 59, 62, 64, 65, 68, 69, 70, 71, 73, 74, 76, 83, 84, 88, 107, 113, 114, 115, 116, 117, 118, 119, 127

Hydraulics and morphology information

1, 17, 41, 42, 44, 46, 56, 67, 80, 81, 82, 87, 90, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 111, 120, 121, 122, 124, 125, 126

APPENDIX B: REPRESENTATIVE SPECIES

1. In order to provide examples of ways in which the river environment can be enhanced for aquatic and terrestrial biota, habitat preferences of representative species from several biological groups were examined. The habitat preferences of these species can be used to characterize the desired effects of dike field environmental features. Habitat characteristics and species composition of biological communities inhabiting the major diked waterways vary greatly; thus, the species used in this report are merely examples.

2. Due to the nature of dike fields, the emphasis in selecting representative species was mainly on aquatic biota. Fish are at or near the top of aquatic food chains and thus may serve as biological indicators of changes in river conditions and habitat characteristics. In addition, fish have recreational and commercial value. Therefore, fish were emphasized over other groups of aquatic species. Selection of representative fish species was based upon three criteria:

a. Availability of habitat suitability indices.

b. Relative species value to sport and commercial fisheries, or value of the species as a forage fish consumed by game or commercial species.

c. Representation of the major river reproductive guilds or spawning types found.

3. Generally, fish utilize most of the major habitats within an aquatic ecosystem for spawning, therefore reproductive guilds were an important criterion for the selection of fish species. There are basically four major guilds which populate the important habitats of the large river systems of the United States (Pierce 1980; Balon 1975). The major spawning habitats are:

a. Gravel areas.

b. On or in aquatic vegetation.

c. Sand substrates.

d. Crevices or hollows.

4. The second criterion used in selecting fish species was the availability of habitat suitability indices (HSI) or species life requirement models from the U.S. Fish and Wildlife Service's Habitat Evaluation Procedures (HEP) (U.S. Department of the Interior 1980a). HSI models provide readily available up-to-date information on the life requirements of the species for which they are available. HSI models are designed to evaluate before and after conditions of a planned project by calculating habitat suitability indices for the baseline conditions and the conditions anticipated under various alternatives. The HSI calculations are based on parameters such as water depth and substrate. The guidelines use several of the HSI parameters to identify the preferred/required habitat characteristics of the representative species. These parameters are relatively adaptable over the entire range of the species.

5. The third criterion for selecting fish species was their relative value to sport or commercial fisheries or their value as a forage fish consumed by game or commercial species. Valuable species occurring in several waterways were chosen whenever possible.

6. Other aquatic biota are represented by the consideration of the general habitat requirements for phytoplankton, zooplankton, and macroinvertebrate organisms. These organisms were considered in groups due to the large number of species and their ability to utilize the same habitats as the fish species. Benthic and planktonic organisms were selected on the basis of their utility as fish food and their position in the overall food chain within the aquatic ecosystem.

7. The terrestrial environment, although not influenced by dike modifications to as great a degree as the aquatic environment, can undergo some changes which affect terrestrial biota. In addition, many terrestrial species use the aquatic environment and would be affected by changes in the aquatic ecosystem. Therefore, general habitat requirements related to waterways were compiled for a limited number of birds, mammals, and reptiles. The availability of HSI models (as a source of information) was the primary criterion for selection of terrestrial species.

Examples of Representative Aquatic Species/Habitat Requirements

Aquatic biota

8. Largemouth bass. The largemouth bass is one of the most important freshwater game fishes in North America and is found in almost every state. The largemouth thrives in weedy lakes or in river backwaters and is usually found in water less than 20 ft deep (McClane 1978). The major physical habitat requirements of the largemouth bass are tabulated in Table B-1. In general, the largemouth bass requires fairly shallow water with the availability of deeper areas for winter cover in the more northern river systems. Low velocities such as those found in backwaters are favorable for all life stages of the species. Soft, silty substrates are probably optimum if gravel areas are also available for spawning purposes.

9. Bluegill sunfish. The bluegill sunfish is a popular panfish and is distributed throughout most of the United States. Bluegills prefer quiet waters with abundant aquatic vegetation where they can hide and feed (McClane 1978). The major physical habitat requirements of the bluegill sunfish are tabulated in Table B-2. In general, bluegills require water depths ranging from shallow areas for spawning to moderately deep areas for escape from predators and cover in the winter. Low current velocities such as those found in quiet backwaters are most favorable for all life stages. The only documented substrate preference is fine gravel or sand for nesting purposes during the reproductive season.

10. Channel catfish. The channel catfish is a very important commercial and sport fish distributed throughout much of the United States. This catfish inhabits lakes and large rivers having clean bottoms of sand, gravel, or boulders (McClane 1978). The major physical habitat requirements of the channel catfish are tabulated in Table B-3. In general, the channel catfish requires water depths ranging from deep pools for the adults to edge habitat for the larvae and juveniles. Low-velocity areas are preferred, and the optimum substrate is clean sand, gravel, or rock bottoms with hiding places such as boulders or crevices (U.S. Department of the Interior 1980b).

11. Freshwater drum. The freshwater drum is an important sport and commercial species (Rasmussen 1979) distributed from the Missouri River drainage eastward (McClane 1978). The species primarily inhabits large

Table B-1

Physical Habitat Requirements for Largemouth Bass

	ADULT	LARVAE	JUVENILES
	GENERAL REQUIREMENTS DURING WARM MONTHS		
Water Depth	Slight decrease in water level during midsummer may be beneficial by concentrating prey species	Stable to increased summer water level is optimal to increase cover availability	Slight decrease in water level during midsummer may be beneficial by concentrating prey species
Current	Low velocity (≤0.2 ft/sec is optimal	Velocity <0.1 ft/sec is optimal. Cannot tolerate velocity <0.9 ft/sec	Low velocity (<2 ft/sec) is optimal
Substrate	Soft bottoms optimal.	Flooded terrestrial vegetation is important because of cover provided	Soft bottom optimal
	REPRODUCTIVE SEASON (MAY-JUNE)		
Water Depth	Average depth of nests is 1-3 ft. Stable water levels during spawning are optimal		
Current	Velocities <0.3 ft/sec are avoided for spawning	N/A	N/A
Substrate	Gravel is preferred. Will nest on vegetation, roots, sand, mud, and cobble		
	WINTER REQUIREMENTS		
Water Depth	Require deep water areas (10-50 ft) to successfully overwinter in cold climates	N/A	Require deep water areas (10-50 ft) to successfully overwinter in cold climates
Current	Data gap		Data gap
Substrate	Data gap		Data gap

Table B-2

Physical Habitat Requirements for Bluegill Sunfish

	ADULT	LARVAE	JUVENILES
	GENERAL REQUIREMENTS DURING WARM MONTHS		
Water Depth	A range of depths from shallow to moderately deep appears optimal. Pools necessary	Data Gap	Data Gap
Current	Mostly restricted to areas with low velocity (<0.3 ft/sec preferred). Backwaters favored. Will tolerate up to 1.5 ft/sec	Optimum <0.2 ft/sec. Backwaters very important	Prefer velocities <0.2 ft/sec. Can tolerate up to 0.5 ft/sec. Backwaters very important
Substrate	No particular preference	Data Gap	Data Gap
	REPRODUCTIVE SEASON (SPRING THROUGH SUMMER)		
Water Depth	Shallow (3-10 ft) water[2] 1-3 feet [1]		
Current	Optimum <0.2 ft/sec; >1 ft/sec unacceptable	N/A	N/A
Substrate	Almost any substrate may be used, but prefer fine gravel or sand		
	WINTER REQUREMENTS		
Water Depth	Require deep areas in winter to avoid ice. May move into deeper water in October[2]		Data Gap
Current	Data Gap	N/A	Data Gap
Substrate	Data Gap		Data Gap

[1] Rasmussen 1979. [2] Pierce 1980

Table B-3

Physical Habitat Requirements for Channel Catfish

	ADULT	LARVAE	JUVENILES
	GENERAL REQUIREMENTS DURING WARM MONTHS		
Water Depth	Large, deep pools with cover such as rocks provide shelter during the day. Move to shallower riffle areas at night to feed	Prefer shallows such as riffles, submerged sand bar areas, or shallow edges	Prefer shallows such as riffles, submerged sand bar areas, or shallow edges. Bottom in deeper water[1]
Current	Low velocity (<0.5 ft/sec) in pools and backwaters	Require slow-flowing areas (<0.5 ft/sec)	Prefer slow-flowing areas (<0.5 ft/sec)
Substrate	Prefer areas with sand, gravel or rubble substrate	Rocks, rubble, gravel, or sand. Also utilize mud substrate edges of flowing turbid channels. Sandbars[2]	Rocks, rubble, gravel, or sand. Also utilize mud substrate edges of flowing turbid channels
	REPRODUCTIVE SEASON (MAY-JULY)		
Water Depth	Often move into shallow, flooded areas to spawn		
Current	Low velocity (<0.5 ft/sec)	N/A	N/A
Substrate	Dark, secluded areas required such as boulders, crevices, burrows		
	WINTER REQUIREMENTS		
Water Depth	Deep water required. Scour holes are sometimes utilized		Variable. May overwinter under large rocks in riffle areas or move to cover in deeper water.
Current	Probably prefer low velocity		Probably prefer low velocity
Substrate	Large rocks or other cover is important		Require large rocks or other cover

[1] Pennington, Baker, and Bond 1983 [2] Schramm and Pennington 1981

rivers and lakes throughout its range. The major physical habitat requirements of the freshwater drum are tabulated in Table B-4. This information was gathered from various sources in the literature which are cited as footnotes to Table B-4. In general, the freshwater drum prefers large, deep bodies of water. Drum are apparently able to tolerate a wide range of current velocities and are primarily found in large streams. No information was found regarding substrate preferences.

12. River carpsucker. The river carpsucker is a species of some commercial importance (Rasmussen 1979) and is considered to prefer large river systems (McClane 1978). The carpsucker is one of the few commercial species whose reproductive habits place it in the guild known as psammophils (Pierce 1980). Psammophils deposit their eggs on the surface of sandy bottoms (Balon 1975). The major physical habitat requirements of the river carpsucker are tabulated in Table B-5. In general, the river carpsucker inhabits water ranging from deep, quiet pools to shallow areas such as sandbars. A sandy substrate is required during the reproductive season; however, river carpsuckers do not show any marked substrate preference during the rest of their life cycle. The species seems to prefer lower velocities such as those found in backwater areas.

Aquatic invertebrates

13. Many different fish species feed on aquatic invertebrates. Table B-6 summarizes the physical habit requirements of the major categories of aquatic invertebrates. The table illustrates the desirability of habitat diversity. For example, high current velocities tend to favor certain types of macroinvertebrates (substrate surface dwellers) while lower velocities will favor other types (burrowing forms). It should be pointed out that water depth has a minimal effect on most invertebrate forms, which is the reason it is not included in the table.

Summary of effects of environmental features on habitats for representative species

14. When the effects of environmental features on depth, velocity, and sediment transport (as presented in Table 4 of the main text) are considered alongside the habitat requirements for the representative aquatic species, some generalizations can be made regarding biological effects of the features. Accordingly, Table B-7 presents an estimate of the effects of the

Table B-4

Physical Habitat Requirements for Freshwater Drum

	ADULT	LARVAE	JUVENILES (Become juveniles in late June)[1]
	GENERAL REQUIREMENTS DURING WARM MONTHS		
Water Depth	Main channel border[2] Shallow water[3]	Tend to concentrate in the main channel[1] Main channel and main channel border[4]	Main channel border[1] Main channel[1] Chutes[5]
Current	Slow-moving next to mud banks[6]	Favor flowing water habitat[7]	Data Gap
Substrate	Data Gap	Data Gap	Data Gap
	REPRODUCTIVE SEASON (LATER APRIL-JULY)1		
Water Depth	Spawn in main channel.[1] Eggs buoyant and float to surface		
Current	Data Gap	N/A	N/A
Substrate	Not applicable since eggs are pelagic		
	WINTER REQUIREMENTS		
Water Depth	Deep water[3]		Data Gap
Current	Data Gap velocity		Data Gap
Substrate	Data Gap		Data Gap

[1]Environmental Work Team 1981
[2]Ragland 1974
[3]Rasmussen et al. 1979
[4]Kallemeyn and Novotny - 1977
[5]Jennings - 1979
[6]Robinson - 1973
[7]Schramm and Pennington - 1981

Table B-5

Physical Habitat Requirements for River Carpsucker

	ADULT	LARVAE	JUVENILES
	GENERAL REQUIREMENTS DURING WARM MONTHS		
Water Depth	Prefer deep, quiet pools and backwaters[1]	Mainly shallow water[2]	Shallow areas such as sandbars and cattail marshes[3]
Current	Low velocity [1,4] Backwaters[5]	Backwaters[2]	Prefers quiet water[2]
Substrate	Soft bottom.[1] Mud.[4] Cattail marshes and sand bars in Missouri River[3]	Sandbars[2] Natural banks[6]	Sandbars[3]
	REPRODUCTIVE SEASON (MAY-JULY)[2] (LATE APRIL-JULY[7] (MAY-JUNE) ON MISSOURI RIVER)[8]		
Water Depth	Data Gap		
Current	Data Gap	N/A	N/A
Substrate	Sandy bottom[9]		
	WINTER REQUIREMENTS		
Water Depth	Generally migrates out of shallow areas in late August, September[3]		Juveniles move out of shallow areas on the Missouri River in late August - September[3]
Current	Data Gap		Data Gap
Substrate	Data Gap		Data Gap

[1]Walburg et al. 1981
[2]Kallemeyn and Novotny - 1977
[3]Schmulbach 1974
[4]Robinson 1973
[5]Pennington, Baker, and Bond 1983
[6]Schramm and Pennington 1981
[7]Carlander 1969
[8]Persons 1979
[9]Balon 1975

Table B-6

Physical Habitat Requirements for Aquatic Invertebrates

SUBSTRATE	MACROINVERTEBRATES	ZOOPLANKTON	PHYTOPLANKTON
Silt-Clay	Beneficial to most forms[1] Favors burrowing organisms[2]		
Sand	Detrimental to most forms[1]		
Gravel	Beneficial if stable[1]	N/A	N/A
Rock	Provides valuable habitat[1] Ideal habitat for periphyton[2]		
CURRENT			
High-velocity	High bottom velocity is detrimental to burrowing forms; tends to favor attachment-type species if stable substrate is available.[3] Favors substrate surface dwellers[2]	No data available but probably not favorable	No data available but probably not favorable
Low-velocity	Low (<3 ft/sec) is favorable to those benthos inhabiting soft bottom substrates[3] Favors burrowing organisms[2]	Closed ponds (no current) on Missouri River had highest productivity[4] Backwaters with slow current velocity are very productive areas for zooplankton[2]	Decreased turbulence favors a larger more diverse phytoplankton community[5] Lower velocity favors planktonic algae[6] Slow backwaters are very productive areas for phytoplankton[2]

[1]Hall 1980
[2]Lubinski and Seagle 1981
[3]Burress, Krieger, and Pennington 1982
[4]Persons 1979
[5]Solomon et al. 1975
[6]Schnick et al. 1981

Table B-7

Summary of Effects of Environmental Features on Habitats for Representative Aquatic Species

KEY ENVIRONMENTAL FEATURES	KEY PHYSICAL AQUATIC HABITAT CHARACTERISTICS			COMMENTS
	DEPTH	VELOCITY	SUBSTRATE	
(1) NOTCHES • Notches • Culverts in Closure Dikes	Creates local scour hole below notch, potential bar formation downstream of scour hole; catfish and bass are favored Maintains open water by reducing rates of deposition; favors bass, carpsucker, and catfish; partially favors bluegill	Local increase through notch; slight negative impact on sunfish Increase in velocity in secondary channel; minimal effects on fish	Bar formation favors catfish and carpsucker; scour hole with gravel bed favors catfish Reduces sedimentation; favors catfish and bluegill	Notches are valuable for reducing rate of sedimentation and maintaining open secondary channel and backwater habitat
(2) LOW-ELEVATION DIKES	If self-scouring, maintains deeper water; catfish, carpsucker, and bass are favored. If not self-scouring, sedimentation creates shallower habitat; favors juvenile stages of fish	Local increases over the top; slight negative impact on sunfish		
(3) ROOTLESS DIKES	Creates two scour holes (one at each end) and multiple bar formation downstream; juvenile stages of fish favored by increased wetted edge	Local increase around ends of dike; negative impact on sunfish	Increase in bar formation, typically sand substrate; favors juveniles and carpsucker	Scour of natural bank has an adverse effect on macroinvertebrates
(4) MINIMUM MAINTENANCE	Increases diversity of depths; enhances overall aquatic habitat	Increases diversity of velocities; enhances overall aquatic habitat	Increases diversity of substrates; enhances overall aquatic habitat	Effects of minimum maintenance are site-specific and difficult to predict
(5) DREDGING TO REMOVE SEDIMENT*	Increases depth; catfish, bass, and carpsucker favored			Effects on substrate and velocity are site-specific
(6) DISPOSAL OF DREDGED MATERIAL*	Reduces depth over middle bar; shallow habitats favor juveniles	Reduces velocity over bar; favors bluegills and juveniles	Dependent upon dredged material; if from channel, then it is typically coarse sediments; gravel favors benthos; sand favors carpsucker	
(7) RELOCATING NOTCHES*	Increased depth due to scour when notch is opened	Reduced velocity when notch is closed	Closing notch would induce deposition of finer substrate	
(8) PLACING ADDITIONAL ROCK*		Provides cover from high velocities; favors catfish	Additional rock substrate and cover; favors benthos; may provide breeding cover for catfish	Diversity of rock sizes and shapes is beneficial in creating diversity of habitat
(9) ARTIFICIAL REEFS*		Provides cover from high velocities; may slightly reduce local velocity; favors catfish, bass, and bluegill	Increased cover and substrate dependent upon form of reef; favors catfish, bass, bluegill, and carpsucker	Slight potential for reef to act as a permeable dike and increase sedimentation, dependent on location
(10) CONTROL STRUCTURES IN CLOSURE DIKES*	Maintain or increase existing depths; bass are favored	Potential increase in velocity; dependent on gate operation	Reduced sedimentation maintains existing substrate	

*These techniques are untried in dike fields, thus effects are speculative.

environmental features on habitats of the selected aquatic species. However, since the physical effects of the features are highly site-dependent, and since aquatic populations are heavily affected by many nonstructural biotic factors and influences such as hydrology, the entries in Table B-7 should be regarded as only a crude estimate of potential biological responses to the environmental features. Entries in Table B-7 which state that a certain feature favors certain species should not be interpreted relative to the other features, but relative to the diked waterway without environmental features.

Examples of Representative Terrestrial Species/Habitat Requirements

Terrestrial biota

15. Wood duck. The wood duck is an important game species of waterfowl inhabiting creeks, rivers, and floodplain swamps (Bellrose 1976). Water depth and current velocities are important considerations for wood duck breeding requirements and are the major factors which can be influenced by dikes. Ideal breeding habitat is water 3-18 in. deep, still or slow-moving current, and shelter from the wind. The more shoreline per unit area of water, the more desirable the habitat, provided the distance between opposite shores is at least 100 ft (U.S. Department of the Interior 1980c).

16. Dike fields which preserve and enhance slow-moving, sheltered backwaters would be most beneficial to wood duck populations. Backwaters adjacent to bottomland hardwoods, which provide optimal nesting habitat, are particularly valuable.

17. Blue-winged teal. The blue-winged teal is a very abundant and important game species of waterfowl. The bird is primarily a migrant species in most of the major river systems where dikes exist. Sediment deposition is the most important habitat characteristic of dike fields, since mud flats are a preferred feeding area for blue-winged teal (Bellrose 1976).

18. If suitable pond areas are available, the blue-wing may nest far south of its normal range. Temporary ponds are also used. There are reports of blue-wings nesting in southern Illinois as a result of ponds created by high floods (Bellrose 1976). Dike designs which enhance quiet backwaters and create mudflats are beneficial for this species.

19. Muskrat. The muskrat is one of the most valuable furbearers in the United States. The species is chiefly aquatic and feeds mainly on aquatic vegetation but also eats frogs and fish (Burt and Grossenheider 1976). The physical factor most important to the life requirements of the muskrat which can be influenced by dikes is water depth. Water level is the key to winter survival because muskrats in shallow marshes are susceptible to freezeout and because access to food is restricted (Environmental Work Team 1981). Dike designs which prevent silting in of backwater areas provide habitat benefits for muskrats. Designs which promote high velocities near bank areas and hence promote erosion are detrimental since natural banks are used for denning.

20. Mink. The mink is a very valuable semiaquatic furbearer which inhabits stream and river banks and marshes. Rivers with braided channels and gradual banks are of more value to the species than are large single-channeled rivers with steep, undercut banks or extensive open areas (U.S. Department of the Interior 1980d). An abundance of crayfish and amphibians provides an optimal food supply for the mink. Dike designs which enhance shallow backwaters provide the most benefit for the species. As with muskrats, designs which promote bank erosion are detrimental since the mink also uses stable, natural banks for denning areas.

21. Snapping turtle. The snapping turtle is a large, aggressive turtle found in a wide variety of aquatic habitats throughout the United States east of the Rocky Mountains (U.S. Department of the Interior 1980e). The species is most abundant in quiet waters with a soft, muddy substrate and abundant aquatic vegetation. Shallow water is optimum since the species spends much time resting on the bottom with the head extended to the surface for air. Dike designs which affect water depth, current velocity, and substrate characteristics can be used to enhance the habitat for snapping

turtles. Optimum habitat is a quiet, shallow backwater with a silty bottom. Dike designs which promote or maintain such areas would be beneficial to the species.

Summary of terrestrial species requirements

22. The maintenance of backwater areas is perhaps the single most important habitat requirement for the selected terrestrial species. Table B-8, which summarizes the habitat requirements of the terrestrial species, shows that the backwater habitat is valuable for all of the representative terrestrial species. Again, as with the aquatic biota, the concept of habitat diversity is well illustrated. For example, the wood duck, mink, and snapping turtle have optimum habitat conditions when there is an abundance of shallow water, while the muskrat requires deeper water.

Table B-8

Physical Habitat Requirements for Terrestrial Species

SPECIES	WATER DEPTH	CURRENT VELOCITY	SUBSTRATE CHARACTERISTICS
Wood Duck	Shallow 3-18 in deep	Still or slow-moving backwaters	N/A
Blue-winged teal	N/A	Quiet, pond-like backwaters	Abundance of mud flats
Muskrat	Deep backwater areas most beneficial	High, eroding velocities near natural banks are detrimental	Natural bank substrate valuable for denning areas
Mink	Shallow backwaters very valuable	High velocities, natural banks detrimental	Stable natural banks used for denning areas
Snapping turtle	Shallow backwaters beneficial	Low velocity favorable	Soft, muddy substrate preferred

APPENDIX C: NAVIGATION DEVELOPMENTS ON THE MISSOURI RIVER

1. Man's influence on the Missouri River began in the early 1800's. Developments have been sporadic; the impetus to change the river ebbed or grew depending on political, economic, and natural events. A short summary is given below:

a. 1838. Congress authorized the Corps of Engineers to remove snags from the Missouri River (U.S. Army Corps of Engineers 1952) to aid in the navigation of steamboats. In the next half century, a small amount of revetment and occasional pile dikes were constructed to protect small towns.

b. 1884. By Congressional action, the Missouri River Commission was formed. Its objectives were to improve navigation by contracting the river width, fixing the location and direction of the stream and protecting eroding banks. The first revetments were willow bush ballasted with rock; being weak, they washed away over time in many places. Pile clumps and pile dikes were used to protect revetments and close chutes.

c. 1902. By this time there had been a serious reduction in the freight tonnage hauled on the Missouri River. The railroads had captured the freighting business, and appropriations from Congress for navigation improvements had stopped. Congress repealed the act which created the Missouri River Commission. Prior to 1902, most of the work had been in the channel between Jefferson City and Hermann, Missouri. Congress then turned responsibility for the Missouri River over to the U.S. Army Corps of Engineers.

d. 1912. Between 1902 and 1912, no maintenance was done and most of the river training structures washed out. In 1912, Congress authorized construction of the 6-ft navigation channel from Kansas City, Missouri, to the mouth. This navigation channel was to be achieved by shaping the river into the desired alignment and then "pegging it down and hold it in place" (U.S. Army Corps of Engineers 1952). The realignment was to be accomplished principally by the use of permeable pile dikes. The pegging and holding were to be done with rock revetment of the slopes. The work began in 1912.

e. 1922. In this year construction activity directed at flood protection was begun.

f. 1927. The extension of the 6-ft channel to Sioux City, Iowa, was authorized. Pile dikes were used to form a realigned narrow channel for navigation.

g. 1929. It was not until 1929 that piecemeal efforts to stabilize the river ceased and a comprehensive program was begun. Thereafter, funds were available in sufficient amounts for the river work to be carried out in an orderly fashion (U.S. Army Corps of Engineers, 1952).

h. 1937. Fort Peck, the first major mainstem dam on the Missouri River, was closed. It was near Glasgow, Montana, just upstream from the confluence with the Yellowstone River.

i. 1944. The Flood Control Act of 1944 authorized 5 additional dams on the mainstem downstream from Fort Peck. Gavins Point, near Yankton, South Dakota, is farthest downstream. Also, levees were built as funds were made available.

j. The dams provide flood control, irrigation, municipal, and industrial water supplies, low-flow augmentation for navigation, power, and recreation. As a consequence of the dams downstream flows in the spring and sediment transport were greatly reduced. In addition, more than 150 dams on Missouri River tributaries add to the depletion and regulation of the streamflow in the mainstem.

k. 1945. The Rivers and Harbors Act of 1945 authorized a 9-ft-deep-by-300-ft-wide navigation channel in the Missouri River from the mouth near St. Louis, Missouri to Sioux City, Iowa. This was to be accomplished by constructing permeable dikes to contract and attain proper direction for the river channel and to provide continuous progressive control. Revetted banks would hold the alignment in place. Occasional dredging and snag removal would be required.

l. The high banks were to be protected from erosion by confining all water to a single channel. A curved alignment for the channel was chosen consisting of a series of bends 3 to 5 miles long with varying radii of curvature that decreased from upstream to downstream. The optimum width was desired, that being the maximum which can be maintained without the formation of middle bars.

m. The reach from Gavins Point near Yankton, South Dakota, to a point about 20 miles upstream of Sioux City, Iowa, remains unchannelized.

n. 1960. Replacement of pile dikes with stone fill dikes began. New dikes and revetments were also constructed with rock. By 1967, the navigation and stabilization project was 98 percent complete. Some setbacks had been caused by floods.

o. 1974. Modifications to dikes were undertaken to improve the diversity of water habitat in the areas of the dike fields, to maintain existing fish and wildlife habitat, and to provide more flood-carrying capacity. Generally, these modifications consisted of opening notches in dikes to allow flow to scour out vegetation and sediment from the dike fields. Other changes were to lower dike crest levels, to leave dikes unattached to any bank, and to put culverts in dikes closing chutes between the floodplain and islands.

APPENDIX D. SCIENTIFIC NAMES OF SPECIES

Terrestrial

Fauna

Beaver (*Castor canadensis*)
Blue-winged teal (*Anas discors*)
Mink (*Mustela vision*)
Muskrat (*Onadatra zibethiea*)
Raccoon (*Procyon lotor*)
Snapping turtle (*Chelydra serpentina*)
White-tailed deer (*Odocoileus virginianus*)
Wood duck (*Aix sponsa*)

Flora

Cottonwood (*Populus* spp.)
Willow (*Salix* spp.)

Aquatic

Asiatic clam (*Corbicula fluminea*)
Bigmouth buffalo (*Ictiobus cyprinellus*)
Black crappie (*Pomoxis nigromaculatus*)
Bluegill (*Lepomis macrochirus*)
Bowfin (*Amia calva*)
Carp (*Cyprinus carpio*)
Channel catfish (*Ictalurus punctatus*)
Crappie (*Pomoxis* spp.)
Flathead catfish (*Pylodictis olivaris*)
Freshwater drum (*Aplodinotus grunniens*)
Gizzard shad (*Dorosoma cepedianum*)
Inland silversides (*Menidia beryllina*)
Largemouth bass (*Micropterus salmoides*)
Longnose gar (*Episosteus osseus*)
Northern pike (*Esox lucius*)
River carpsucker (*Cyprinus carpio*)
Rock bass (*Ambloplites rupestris*)
Sauger (*Stizostedion canadense*)
Shad (*Alosa sapidissima*)
Shorthead redhorse (*Moxostoma macrolepidotum*)
Shortnose gar (*Lepistosteus platostomus*)
Smallmouth bass (*Micropterus dolomieui*)
Walleye (*Stizostedion uitreum*)
White bass (*Morone chrysaps*)