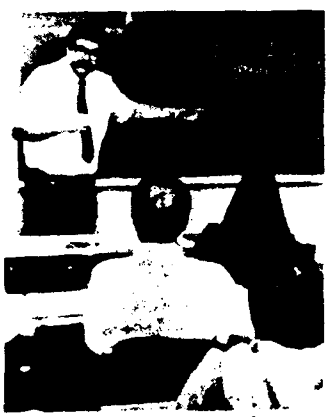
AD-A239 045

US Army Corps of Engineers



REMR RESEARCH PROGRAM

(2)

REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-HY-8

SHALLOW-DRAFT TRAINING STRUCTURE CURRENT REPAIR PRACTICES AND REPAIR GUIDELINES

by

David L. Derrick

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

April 1991

Final Report

91-06107

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under Civil Works Research Work Unit 32324

The following two letters used as part of the number designating technical reports of research published under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program identify the problem area under which the report was prepared:

	Problem Area		Problem Area
CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP — Ajax Bar Dikes, Mississippi River,
US Army Engineer District, Vicksburg

BOTTOM — Classroom scene

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
April 1991

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Shallow-Draft Training Structure Current Repair Practices and Repair Guidelines

5. FUNDING NUMBERS
WU 32324

6. AUTHOR(S)
David L. Derrick

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USAE Waterways Experiment Station, Hydraulics Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report REMR-HY-8

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers, Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
A report of the Hydraulics Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) research program. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The repair of deep- and shallow-draft training structures has continued to be a significant maintenance cost for the US Army Corps of Engineers. This maintenance includes the repair of dikes and revetments damaged as a result of floods, ice, floating debris, impacts from navigation, or undermining due to flow and/or soil conditions. Generally, no guidance is available to evaluate these damaged structures to ascertain when repair work is needed, or to determine when rehabilitation or repair is more cost-effective than replacement of the structure.

The objectives of this work unit of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) research program are as follows: (a) to inventory river training structures, (b) to document past dike repair work, (c) to facilitate technology transfer among Corps Districts through reports and workshops, (d) to document current repair methods, and (e) to formulate guidelines for structure inspection, record keeping, evaluation, and repair.

(Continued)

14. SUBJECT TERMS
Dike
Dike repair
Dike maintenance
Repair, Evaluation, Maintenance, and Rehabilitation research program
(Continued)

15. NUMBER OF PAGES
91

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		

13. ABSTRACT (Continued)

In support of these objectives, this report documents past dike repair work and current repair methods, and includes a set of guidelines for training structure inspection, record keeping, evaluation, and repair. This report also contains information on new technology applicable to the field on dike repair.

14. SUBJECT TERMS (Continued)

River training structure
River training structure repair

PREFACE

The work described in this report was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Hydraulics Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under Work Unit 32324, "Repair Techniques at Navigation Training Structures," for which Mr. David L. Derrick, Hydraulics Laboratory, US Army Engineer Waterways Experiment Station (WES) was Principal Investigator. Mr. Glen Drummond (CECW-EH) was the REMR Technical Monitor for this work.

The REMR Directorate of Research and Development Coordinator in HQUSACE was Mr. Jesse A. Pfeiffer, Jr. (CERD-C), and members of the REMR Overview Committee were Mr. James E. Crews (CECW-O), Chairman, and Dr. Tony C. Liu (CECW-EG). The REMR Program Manager was Mr. William F. McCleese (CEWES-SC-A), and the Problem Area Leader was Mr. Glenn A. Pickering, Chief, Hydraulic Structures Division, Hydraulics Laboratory.

Data for this final report on shallow-draft training structure past and current repair practices and repair guidelines were compiled during the period September 1986-July 1990 by the Estuaries and Waterways Divisions, Hydraulics Laboratory.

This report was prepared by Mr. David L. Derrick under the general supervision of Messrs. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory; R. A. Sager, Assistant Chief, Hydraulics Laboratory; W. H. McAnally, Jr., Chief of the Estuaries Division; M. B. Boyd, Chief of the Waterways Division; W. D. Martin, Chief of the Estuarine Engineering Branch, Estuaries Division; C. R. Nickles, Acting Chief of the Potamology Branch, Waterways Division; T. J. Pokrefke, Chief of the River Engineering Branch, Waterways Division; and R. F. Athow, Estuarine Engineering Branch, Principal Investigator. This report was edited by Mrs. M. C. Gay, Information Technology Laboratory, WES.

Commander and Director of WES during the preparation and publication of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

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

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

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	25.4	millimetres
miles (US statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms
tons (2,000 pounds, mass)	907.1847	kilograms

SHALLOW-DRAFT TRAINING STRUCTURE CURRENT REPAIR PRACTICES AND REPAIR GUIDELINES

PART I: INTRODUCTION

Background

1. The US Army Corps of Engineers established the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program to develop new and improved technology for extending the life of America's water resource projects. The repair of deep- and shallow-draft training structures has continued to be a significant maintenance cost within the Corps. This maintenance has included the repair of dikes and revetments damaged as a result of floods, ice, floating debris, weathering, impacts from navigation, or undermining due to river flow and/or soil conditions. No guidance is generally available to evaluate these damaged structures or to determine when repair or rehabilitation is more cost-effective than replacement.

Objectives

2. The objectives of this work unit are to inventory navigation training structures, document past dike repair work, facilitate technology transfer between Corps Districts through reports and workshops, document current repair methods, report on new technology applicable to the field of dike repair, and prepare guidelines for structure inspection, repair criteria, record keeping, evaluation, and repair.

3. These objectives are met in the following ways:

- a. This report documents past and present dike repair methods, reports on new technology in the field of dike repair, and formulates guidelines to be used for training structure inspection, repair criteria, record keeping, evaluation, and repair.
- b. An inventory of Corps-built and -maintained dikes in shallow-draft, nontidal influenced waterways is available in "Inventory of River Training Structures" (Derrick, Gernand, and Crutchfield 1989).
- c. Pankow and Trawle (1988) list structures found in estuarine and deep-draft navigable waterways.
- d. Technology transfer is handled by these three reports, the REMR Bulletin, and a workshop held at the US Army Engineer Waterways

Experiment Station (WES) in February 1987 entitled REMR Workshop on Repair and Maintenance of Shallow-Draft Training Structures. This workshop was attended by 45 individuals representing 13 Corps Districts and Divisions, plus WES personnel. Ten districts gave presentations detailing their past and present dike repair activities, along with their current evaluation and repair methods. Topics of discussion included repair techniques, repair criteria, and research needs in the field of dike repair. Two reports are available on this workshop: a written record of the minutes (Derrick 1991), and a videotape recording of all attending Districts' presentations.*

Approach

4. An examination of the existing literature was carried out. All Districts with an extensive history of dike repair work were contacted through symposia and surveys. This information was confirmed, supplemented, and enhanced by visits to District offices and follow-up telephone conversations with working level engineers within these Districts.

Philosophy of Purpose

5. A concern voiced again and again by many in the field of river engineering is that the knowledge, wisdom, and experience of the "Old Guard" river engineers who took part in the planning, design, and construction of the major river projects (some from the very beginning) are rapidly, through retirement and death, being lost forever. Most of this knowledge is not written down and is irreplaceable. These concerns led to a broadening of the information presented in this report in an attempt to capture and record a portion of this knowledge. In addition to fulfilling the stated objectives of the work unit, it is hoped that this document can serve as a broad-based primer, history lesson, and guide for young engineers starting out in the field of river engineering. To this end, sections on dike design and construction, descriptions of projects, types of river traffic, etc., have been included in the report.

---

* David L. Derrick. 1988. "Workshop on Repair and Maintenance of Shallow-Draft Training Structures, 24-25 February 1987" (unpublished video report), US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Organization of Report

6. The 12 Districts within the Corps that build and maintain dikes were treated as separate entities and are listed in alphabetical order under Part II, "Compilation of Past and Present Dike Repair Practices." The following topics are covered for each District:

a. Description of project.

b. Stage, discharge, sediment, and dredging.

c. Dike design and construction.

d. Inspections.

e. Types of dike damage.

f. Causes of dike damage.

g. Repair criteria.

h. Repairs and repair techniques.

i. Record keeping.

j. Environmental considerations.

k. New technology.

7. Part III of this report, entitled "Repair Level Guidelines and Recommended Repair Planning Procedures," consists of repair guidelines on the following subjects:

a. Inspections.

b. Repair criteria.

c. Dike repair construction techniques.

d. Record keeping.

e. New technology.

f. Funding.

8. A bibliography and a short note of thanks and appreciation to all who contributed time, information, and effort to this project ends the report.

Conclusions

9. Riverine training structures are recognized by US Army Corps of Engineers personnel as essential components of the inland waterways navigation system of the United States of America. As a result they are well maintained and have been upgraded almost continuously. Due to the cost and importance of these structures, a great deal of research has been performed throughout the

years. In the past this research has usually involved physical model studies, but some effort is now being devoted to the computer/physical model hybrids and numerical models.

10. For most of the twentieth century, timber pile dikes were the preferred choice of training structure. While effective, these dikes were subject to damage, and consequently, maintenance costs were high. In a relatively short timespan during the early 1960's, all Corps Districts changed from the use of timber piles to stone for dike construction and repair work. The stone dikes have proven to be more effective, are very durable, have a long life expectancy, are less susceptible to some types of damage, usually require less attention than the timber pile dikes, and generally require less maintenance as they age.

11. At the present, many of the Districts involved with riverine training structures are entering a period of transition. As many of the river projects are completed, or near completion, the Districts are switching from an engineering-, design-, and construction-oriented workload to a redesign, repair, and operations and maintenance workload. For the most part, construction of new dikes will be limited to the correction of localized problems.

12. Taking an overall view of dike repair throughout the Corps of Engineers, the Districts, as a whole, are doing a commendable job of dike rehabilitation and repair. Often faced with shortages in manpower and funds, the Districts are employing new technology, past experience, and keen engineering judgment to keep their projects viable for the future.

13. In the future, two areas of utmost importance will be the need to keep abreast of improvements in technology relating to the field of dike repair and the need to keep extremely complete and detailed records of the original river projects and ensuing dike repair work so that these records can serve as a guide for redesign and repair efforts by future generations of engineers working on the rivers of America.

PART II: COMPILATION OF PAST AND PRESENT DIKE REPAIR PRACTICES

Kansas City District

Description of project

14. The Missouri River, which begins in Montana and empties into the Mississippi River near St. Louis, MO, is approximately 1,900 miles* long. Since the river was shortened approximately 75 miles during the course of the navigation project, the river mileage had to be revised in 1932 and again in 1960. All locations and lengths of the Missouri River listed in this report are referenced to the 1960 mileage figures. Omaha District oversees navigation on the upper portion of the river from Sioux City, IA, to Rulo, NE, a distance of 234 miles, and Kansas City District oversees navigation on the reach of river from Rulo, NE, to the mouth, a distance of 498.4 miles. Improvement work on the river, consisting of the removal of snags, was first performed by the Corps in 1832. In 1912, authority was granted by Congress to maintain a 6- by 200-ft navigation channel from Kansas City, MO, to the mouth. In 1927 authority was extended to encompass the reach of river from Sioux City to Kansas City for a total navigable length of 734 miles. In 1945 authority was again extended to increase the channel depth to 9 ft and the channel width to 300 ft. Under the 1945 authorization, 190 million dollars was spent on the project. It was completed in 1980. With the help of over 3,500 dikes, the channel is entirely self-scouring. While no locks or dams are located within the Kansas City District, six large dams are located above Omaha, NE, in the Omaha District. Thus the river flow is controlled from Gavins Point Dam (the last dam in the series) downstream to the confluence with the Platte River, and semi-controlled below that point. With the dams operational, the annual June flood (caused by snow melt) was completely eliminated and the frequency and stages of other flood events were reduced. Flow levels can be augmented with stored water from the reservoirs when natural flows below Gavins Point Dam are too low. Theoretically the reservoirs have the capacity to supplement navigation flows through 3 years of drought. The navigation season, basically when the river is free of ice, usually runs from 1 April to 1 December.

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.

15. In 1985 6.5 million tons of commodities were transported on the river, with upbound and downbound shipments running about even. Commercial sands and gravels accounted for approximately 4 million tons of this total. Other principal upbound products were petroleum, building materials, chemicals, salt, molasses, fertilizers, and steel. Downbound commodities included grain, grain products, tallow, chemicals, and petroleum products.

16. The standard tow size is four to six barges on the river above Kansas City. Six to nine loaded barges, or as many as twelve empty barges, can make up a tow downstream of Kansas City. This number of barges would be cut in half for the low-water years 1988 through 1990.

17. A typical square-ended barge (also called a box barge) is 200 ft long, 35 ft wide, and 12 ft high. A barge with an angled end (a rake barge) is 195 ft long, 35 ft wide, and 12 ft high. Since the sloping end provides less drag, a rake barge is used as either a lead or trail unit in a tow. A single barge carries approximately 1,500 tons when loaded to the standard 9-ft draft. During periods of high water, barges can be loaded to a draft of 10 or 11 ft.

Stage, discharge, sediment, and dredging

18. The normal winter (nonnavigation) average stage on the Kansas City gage is 10 ft (referenced to a gage zero of +716.4 ft National Geodetic Vertical Datum (NGVD)) with an associated flow of 20,000-25,000 cubic feet per second (cfs). The normal summer (navigation) target stage, also called the "full service flow," is 13.9 ft on the Kansas City gage with a flow of 41,000 cfs. Because severe drought gripped this area from 1987 to 1990, flows had to be reduced to below normal levels during 1988, 1989, and 1990. The winter flow was dropped to less than 9 ft and 21,000 cfs at Kansas City, and the navigation flow was reduced to a 12-ft stage with a 38,000-cfs discharge. This low navigation flow is the "minimum service flow." Due to depletion because of the drought, it is estimated that 6 years of normal rain and runoff will be required to fill the reservoirs up to standard operating levels.

19. The sand-silt-clay sediment load before construction of the six dams on the upper Missouri River was approximately 200 million tons per year. After the dams were built, the sediment load decreased to 50 million tons per year, with the percentage of silts and clays decreasing and the percentage of sand increasing. No dredging was performed from the time the project was completed (1980) until 1988. Due to the drought and associated low stages,

some dredging was performed during 1988 and 1989 (approximately $775,000 each year) and dredging will be required in 1990. This work was carried out using a cutterhead type dredge (the *Thompson*) borrowed from the St. Paul District.

Dike design and construction

20. Early dikes on the Missouri River were constructed of timber piles in either a single row, double row, or triple row configuration, and were usually constructed on a willow or lumber mattress. The purpose of the mattress was to reduce scour at the base of the pilings. To aid navigation, a tall pile clump served as a marker at the river end of the dike. A pile clump consisted of three timber piles driven close together and angled slightly (called the batter angle) so that the tops of the piles touched. The piles were then bound together near their crowns with wire rope.

21. These dikes were very effective in accumulating sediment. As the dikes became buried in sediment (actually becoming part of the bank and then the overbank area), they would be extended into the river, further constricting the channel. However, due to increases in labor costs and the amount of damage inflicted by ice, flood, and other forces, the pile dikes were reinforced with stone.

22. Since the early 1960's, all dike construction and repair work has employed maximum-weight, 2,000-lb, quarry-run stone. Specifications state that fines smaller than 1/2 in. cannot exceed 5 percent. This stone is obtained at any of a number of quarries located adjacent to the river.

23. The "floating plant" method of construction is used almost exclusively. The procedure for this method is as follows: Corps surveyors provide a baseline from which the contractor can establish the work location. A dragline barge is then anchored in position with spuds. Rock is brought to the work site on flat-decked barges and placed using a dragline bucket controlled by the barge-mounted crane. At times a "spacer" box is placed between the material barge and the dragline barge so that rock can be dragged off the material barge and placed accurately. In situations where the dike is above water or in shallow water, stone is placed using a clamshell bucket.

24. The only structures not built by the floating plant construction method were revetments built parallel to the bank during the winter (when the river was iced over) and some secondary channel closure structures (where the water was too shallow for the construction barges). For this work, rock was hauled overland in trucks and dumped.

25. The purpose of the dikes was to constrict the width of the river and stabilize the navigation channel. This practice has been going on for a long time, and as a result, many of the dikes now extend hundreds of feet into the present-day banks. Most modern dikes are level-crested and extend 300 to 600 ft into the river. The contraction width, in this District called the "rectified channel width," varies from approximately 800 ft at Rulo, NE, to 1,100 ft at the mouth of the Missouri River (550 to 750 ft, respectively, in areas with sills). The contraction width is the distance from the river end of the dike to the opposite bank, or the river end of a dike to the river end of a dike directly across from it. The dikes are built with a specified crown width of 4 ft. The current Construction Reference Plane (CRP), which was developed in the mid-1970's, revised in 1982, and revised again in 1990, is designed to give a design consistency regarding river training structure heights. Building dikes referenced to the CRP would theoretically have all structures overtopped for the same number of days each year. The CRP is based on the flow that is equal to or exceeded 75 percent of the time (during the navigation season) and takes tributary flow into account as one moves down the river. River training structure design heights range from -2.0 to +6.0 ft CRP, depending on location and type of structure, with heights increasing as the mouth of the river is approached. Dikes are normally spaced 600 to 1,000 ft apart in the reach from Rulo, NE, to Kansas City, MO, and 800 to 1,000 ft apart from Kansas City to the mouth. Generally speaking, dikes are farther apart on convex bends and closer together in straight reaches. The spacing seems to be a function of the radius of the bend since flatter bends do not exert as much control over the flow and closer spacing is required. When additional dikes were required after the initial construction of a system, these spacing guidelines were not strictly followed. Most dikes are not marked; but in two or three cases where the dikes are a clear hazard to navigation, a pile of rock 20 ft long and 3 to 4 ft tall is used to mark the river end of the dike. This marker aids a pilot in determining the location of the dike during periods of high water when the dike is submerged. In some areas, low-elevation sills, or sill extensions on existing dikes, are employed. A sill, by this District's definition, is a dike that is submerged more than 95 percent of the time.

26. Many different types of river control structures are used, including L-head dikes, chute closure dikes, bankheads, convex dikes (located on the

inside bank of a bendway), concave dikes (located on the outside bank of a bendway), kicker control structures, crossing control structures (used to tie a kicker control structure to the bank), floodwalls, and low-elevation underwater sills.

Inspections

27. The District schedules spring, summer, fall, and almost always, winter inspections. These examinations are staffed by inspectors from the Engineering and Operations Divisions of the District, along with personnel from the Missouri River Division office and the District project office at Napoleon, MO. It is felt that a careful inspection of all river training structures four times a year is sufficient.

Types of dike damage

28. The following types of dike damage are reported by the District:

a. Settling of stone (usually in the first 2 years after a dike is built).

b. Flanking.

c. Loss of rock at the channel end of the dike.

Causes of dike damage

29. The following causes of dike damage are reported by the District:

a. Ice and ice bridging.

b. Floods.

c. Propwash.

d. Natural weathering of rock.

e. General wear and tear.

f. Towboat impacts (infrequent).

Repair criteria

30. The following criteria are used to determine when, or if, a dike is in need of repair, or redesign and reconstruction:

a. Integrity of the project.

b. Adequacy of navigation channel.

c. Presence of serious bank erosion.

d. Integrity of individual structures.

e. Integrity of structure system.

f. Environmental consequences.

g. Extent of damage.

h. Location of the structure.

i. Type of structure.

j. Available funding.

31. In some cases these criteria would be weighed equally; in other cases some items would carry more weight than others.

32. Specific criteria for required structure repair are as follows:

a. Serious bank erosion.

b. Inadequate navigation channel.

c. Structure degraded more than 2 ft.

d. Damaged area more than 100 ft long.

Repairs and repair techniques

33. Most repair work is now performed by private contractors. One percent or less is accomplished by Corps of Engineers crews and equipment. The contractors who work the river have years of experience and are familiar with Corps guidelines and methods. During a normal year, 200,000 to 250,000 tons of quarry-run, maximum-weight, 2,000-lb stone is used for dike repair. Specifications for this stone are the same as the stone used for dike construction. Stone cost "in place" is approximately $8 to $10 per ton (1990 costs). Typically 75 to 100 dikes are repaired each year. The floating plant method of construction is used for all repair work. Usually two repair contracts are let each year, one covering the reach from Rulo, NE, (mile 498.4) to Miami, MO (mile 262.4), and the other from Miami to the mouth of the river (mile 0.0). The length of a repair contract varies with the amount of rock required, but generally runs for 3 to 6 months. The repair contracts can be modified to add or delete dikes if a low-water inspection reveals more information. If more or less stone is needed than originally specified, the contract can be modified up to plus or minus 15 percent of the total dollar amount of the contract without having to renegotiate the contract bid price.

34. Kansas City District personnel have detected an apparent pattern for repair work regarding newly constructed dikes. During the first 2 years after a dike is built, it usually settles slightly, and a small amount of stone has to be added to the dike to bring it up to grade. Then it is typically 10 to 20 years (under normal conditions and without major ice damage) before the dike requires further repairs. Abnormal conditions may, of course, necessitate repairs at any time.

Record keeping

35. The construction and repair history of all dikes and revetments are

recorded and maintained in the "Structure History File of the Missouri River." Prior to 1979 this information was handwritten on file cards. In 1980 this file was computerized. All structure histories were entered into and are presently stored in the Kansas City District's computer.

36. The following information on each structure is included in this file:

a. Type of structure: dike, revetment, or pilot canal.

b. Structure number.

c. Location by:

(1) River mile.

(2) Region/basin.

(3) Congressional District.

(4) County.

(5) State.

(6) Beginning and ending stations.

(7) Bank of river, either left or right.

d. Cost of original structure.

e. Cost of any repair work done to structure.

f. Material used in construction or repair: timber pile, stone, or both.

g. Whether or not the river end of the dike is marked to aid in navigation.

h. Elevations of the following:

(1) Marker piles.

(2) Pilings.

(3) Stone.

All elevations are referenced to the National Geodetic Vertical Datum of 1929, i.e., mean sea level.

i. Work contract number.

j. Type of labor used: contract or hired labor.

k. Description of work performed.

l. Date dike or revetment was originally built.

m. Dates of any subsequent repairs.

n. How work was funded: either with new construction funds or maintenance funds.

o. Whether or not the dike has an environmental notch.

p. Notch type, either built in or excavated.

37. The computer program allows the user to extract certain data from the file within specific limits or geographical areas. For example, total number, cost, and length of all structures, or specific type of structure (dike, revetment, pilot canal) can be retrieved for a certain reach, bank of river, region, county, metropolitan area, Congressional District, or contract number (or hired labor) for the total period, a specific year, or other time period. It is also possible to separate construction performed with Construction General Funds from construction charged to Operations and Maintenance. The number of the various types of environmental notches can also be retrieved within the specific limits outlined in the previous paragraph. This program has proven to be a useful and powerful tool in river engineering work.

Environmental considerations

38. The project impact upon the natural environment has been a concern of the Kansas City District for many years. District personnel have worked with state conservationists and fish and wildlife personnel to develop many plans to improve the near-field aquatic environment of dikes and revetments. Toward this end the following actions have been undertaken:

a. Some previously closed chutes (secondary channels) have been reopened.

b. Water supplies to oxbow lakes are being maintained.

c. Dredged material disposal areas have been moved to 100 ft from the bank, thereby creating submerged bars or islands.

d. Dikes are not being built as high or as long as in the past.

e. Vane dikes and sills disconnected from the bank are being constructed for the purpose of preventing additional losses of aquatic area and to develop small secondary channels.

f. Environmental notches in dikes (see paragraph 40).

g. Rough dike surfaces (see paragraph 43).

h. Selective minimum maintenance (see paragraph 44).

i. Underwater sills (see paragraph 45).

39. These actions are taken only when the project purposes of navigation and bank stabilization are not adversely affected.

40. Notches in dikes. The Kansas City District has notched approximately 1,700 dike and revetment structures over the last several years. Usually a notch 50 ft wide is cut into the dike, or in the case of a dike that has suffered some degradation, this area is simply not built back to grade. The bottom elevation of the notch is usually 2 ft below the CRP. The notch

allows flow through the dike, which keeps the area downstream of the dike from accreting. This practice serves three purposes:

- a. To keep the bank from infringing on the flood-carrying capacity of the river.
- b. To increase the water-surface area for fish and other aquatic inhabitants.
- c. To form steep clay banks. These banks are prime habitat for caddis flies and mayflies, which are an important link in the food chain of fish.

41. Dike performance has not been affected by the notches, and there has been no noticeable increase in maintenance costs. The notches are designed to work at low and midbank flows. Most dikes on the Missouri extend from 300 to 600 ft into the river, with the notch located 50 to 100 ft from the bank. Even if the notch causes some bank erosion, dike failure is unlikely as most of the dikes extend hundreds of feet back into the bank (see paragraph 21). If the notch is in the L-head portion of the dike, it is usually located within 50 ft of the break in the dike. Of the 1,700 dikes notched, only about a dozen notches have had to have been filled back in, usually because of bank erosion.

42. The environmental effects of the notch program were studied at WES and are discussed in Pennington et al. (1988).

43. Rough dike surface. Representatives of the Missouri Department of Conservation prefer irregular and rough surfaces on dikes and revetments on the Missouri River. Termed "diversity of habitat," these rough surfaces allow a greater surface area for zooplankton and other important fish food chain organisms to live and grow. In the Kansas City District, the contractor uses the dragline bucket to smooth the dike after construction. However, the quarry-run stone used contains significant fines; after a period of high water the fines wash out, leaving the surface irregular. To highlight one difference in river engineering, environmentalists in the Portland District require a smooth surface on dikes and revetments on the Columbia River (see paragraph 165).

44. Selective minimum maintenance. After the biological and natural habitat responses were considered, some dike design heights and widths have been reevaluated. In dike fields on satisfactory radius bends with no navigation problems where the system has performed its function, or in areas where the dikes are felt to be too long, every other dike has been allowed to

degrade. In some cases the riverward ends of dikes have been allowed to deteriorate. In areas where no major damage is likely, alternate segments of revetments have been allowed to deteriorate to a limited degree.

45. Underwater sills. Since the mid-1970's, in areas where there is a need to further constrict the river, underwater sill extensions on existing dikes have been successfully employed. This technique has satisfied the environmentalists, who, in most cases, are opposed to the building of emergent structures. As stated earlier, the definition of a sill in the Kansas City District is a structure that is submerged at least 95 percent of the time.

Contacts

46. Kansas City District engineers contacted to provide information were Messrs. Thomas Burke and Charles Wyatt. Additional information was provided by Mr. Warren Mellema of the Missouri River Division.

Little Rock District

Description of project

47. Responsibility for navigation in the Little Rock District starts at the confluence of the White and Mississippi Rivers (mile 599), goes up the White River to the Arkansas Post Canal (mile 9.6), follows that to the Arkansas River (mile 19.0), and travels up the Arkansas River to the District boundary at Fort Smith, AR (mile 308.6). Tulsa District has jurisdiction over the Arkansas River upstream of Fort Smith. This project was authorized in July 1946 and construction began in 1957. The project was opened to navigation in 1970 and essentially completed by 1974. Some portions of the river are still being "fine tuned" (for example, numerical modeling of the reach immediately downstream of Lock and Dam 3). Channel dimensions are 9 by 300 ft for both the White River and the Arkansas Post Canal, and 9 by 250 ft for the Arkansas River. The Little Rock District presently maintains 1,018 dikes and 12 locks and dams (all locks sized 110 by 600 ft) on its reach of the Arkansas River.

48. The standard tow size on the Arkansas River is eight barges in a three-wide by three-long configuration with the towboat occupying the middle slot of the last row of barges. The maximum tow size is 17 barges in a 3 by 6 configuration with the towboat again occupying the middle slot in the last row of barges. Overall tow length is limited to 1,200 ft due to the tight radii of some bends.

49. Approximately 8.3 million tons of goods were shipped within and through the District in 1989. Commodities shipped and their percentage of total tonnage during that year included sand and gravel (24.3 percent), chemical fertilizers (17.1 percent), wheat (13.4 percent), other grains (4.8 percent), petroleum products (12.4 percent), iron and steel (9.3 percent), soybeans (6.6 percent), chemicals (2.9 percent), coal (1.3 percent), rock (0.3 percent), and miscellaneous goods (7.3 percent).

Stage, discharge, sediment, and dredging

50. Approximately 30 reservoirs located in the upper reaches of the river system (within the Tulsa District) help control the flow of the river. The maximum discharges for the Arkansas River (measured at the Little Rock, AR, gage) follow: for preproject conditions, 700,000 cfs, stage of 33.0 ft CRP, in April of 1927; and for postproject conditions, 406,000 cfs, stage of 42.1 ft CRP, recorded on 1 May 1990.

51. Suspended sediment load on the Arkansas River (measured at Little Rock) for the period 1965 to 1978 averaged 11,521,000 tons per year. Within that period the suspended sediment load varied from 1,723,000 tons (1977) to 28,555,000 tons (1973). When water supplies allow, water stored in the upstream and tributary reservoirs may be released to increase velocities in the river and scour sediment deposits from the navigation channel.

52. Each year the Little Rock District awards two maintenance dredging contracts. The contracts run concurrently, are of 1-year duration, and start in January. Both contracts cover miles 0.0 to 444.8 on the Arkansas River, the lower 20 miles of the White River, and the harbors at Rosedale, MS, and Greenville, MS. Two cutterhead type dredges are used, with one dredge assigned to the Russellville Area Office and the other to the Pine Bluff Area Office. However, both dredges are free to work in any area covered by the contracts. From 1979 to 1989, dredging varied from 329,000 (1980) to 5,953,000 (1988) cu yd per year, with an average of 1,944,090 cu yd of material dredged per year over the entire period. Total costs per cubic yard varied from $1.11 to $2.42, with an average of $1.28 over this 11-year span. These dredging cost figures include dredging, standby time, mobilization, demobilization, and transportation costs. This amount does not reflect the expense associated with raising the levees around the dredge disposal areas (which is performed under a separate construction contract). Typically the levees must be raised once every 5 to 7 years.

Dike design and construction

53. In 1946 the McClellan-Kerr Arkansas River Navigation System (encompassing the Verdigris and Arkansas Rivers, the lower 10 miles of the White River, the Arkansas Post Canal, and San Bois Creek) was authorized. The first dikes were built in the late 1950's. Their purpose was to keep the river from meandering. Upstream of Little Rock, AR, stone dikes were used (because of bedrock in the riverbed); and downstream of Little Rock, timber pile dikes (with limited stone fill) were employed. The pile dikes consisted of two rows of clumps spaced 7.5 ft apart with each clump containing three pilings bound together with wire rope. Untreated pilings were used for dikes where sediment was expected to accrete rapidly, and treated pilings were used for the riverward 100 ft of all dikes in areas where sediment was not anticipated to accumulate rapidly.

54. Pile revetments were constructed using either two rows of clumps (three pilings to a clump) spaced 7.5 ft apart, or with two rows of single piles spaced 5 ft apart.

55. All structures built after the navigation pools were raised in the late 1960's were of stone-fill construction. These dikes and revetments were designed to stabilize the banks and constrict the river, thereby helping to maintain navigable depths by clearing sediment from the channel. The contracted width of the river varies from 700 to 1,400 ft, depending on location. Maximum-weight, 1,000-lb, quarry-run stone (50 percent must weigh more than 40 lb, not more than 8 percent finer than 1/2 in.) is used for construction of all dikes having a thickness greater than 5 ft. Maximum-weight, 350-lb, quarry-run stone (50 percent must weigh more than 25 lb, not more than 8 percent finer than 1/2 in.) is used for bankheads, trench-fill revetments, and dike sections that are less than 5 ft thick. This stone is extracted from a number of quarries along the river, and from quarries located in Kentucky and Illinois. Stone samples are sent to the Geotechnical Laboratory at WES to determine suitability.

56. A few dikes are angled normal to flow, but most are angled 15 to 30 deg downstream from normal. Also, all dikes are built normal to the bank for at least their first 200 ft. Due to these design specifications, in many cases the dike is not straight, but "broken." L-head dikes are also used.

57. Stone dikes built by floating plant have a specified crown width of 0 to 5 ft. Dikes built by end dumping have a design crown width of 10 ft, but

as built, the crown is typically 12 ft or wider. Where bankheads were used, the bank was paved 25 ft upstream and 75 ft downstream from the center line of the dike. Most dikes start at a +12- or +13-ft elevation (referenced to the CRP) at the bank end and slope to a +10-ft elevation at the river end. However, some dikes and L-heads were built to elevations as high as +24 ft and as low as zero CRP. Side and end slopes were 1.00V on 1.25H.

58. Dike spacing varies. In areas where the preproject river channel was wide and had to be contracted with long dikes, the dikes were spaced far apart. In areas where the existing channel was almost narrow enough and had to be contracted only a few hundred feet, the dikes were spaced much closer together. Dikes placed on the convex side of a bend were generally spaced farther apart than those placed on the concave side of a bend. The intent of the varied spacing was to minimize the lengths of the structures required and yet provide the contraction needed to maintain navigable depths. Currents were assumed to enter the dike field from the riverward end of a dike at an angle of 15 deg to the current in the main channel. The next dike downstream was placed to intercept this entering current at a point 200 ft from the riverward end of the dike. In areas where dike lengths were less than 200 ft, the dikes were spaced to intercept the entering current before it hit the bank line. Dikes considered to be a hazard to commercial navigation were marked with a 16-ft, 10-in.-diam treated timber pile. Eight feet of the pile is below the crest of the dike encased in a 12-in.-diam steel pipe. Other dikes were marked with steel H-piles driven into the crown of the dike.

Inspections

59. Design office personnel inspect the entire river by boat once a year, usually in the fall (late September-early October). This inspection takes a week and is a continuation of the Tulsa District's inspection trip. Some Little Pock District personnel participate in the Tulsa District inspection trip (and vice versa) to get a better feel for overall conditions on the entire river. Each river training structure visible from the navigation channel is examined, damaged dikes are noted on the navigation charts, maintenance recommendations made, and needs prioritized. The only dikes not inspected are those structures submerged in the pool areas. Additional special inspections are made after floods or other unusual situations. Resident office personnel (while performing weekly channel surveys) and landowners occasionally spot and report damaged dikes and damaged bank lines. Aerial

photographs are used mainly to detect dike flanking and bank scalloping and to track the growth rate of bank scallops. A scallop is bank erosion in a semi-circular pattern occurring downstream of a dike.

Types of dike damage

60. This District experiences very few total dike failures. The majority of the dike damage would fall into the category of loss of dike height, although flanking of dikes at the bank end, bank scallops, excessive scour downstream of a dike, and scour at the toe of revetments have all caused problems.

Causes of dike damage

61. The District reports the following causes of dike damage:

a. Extreme floods.

b. Wind-driven wave action.

c. Towboat propwash.

d. Errant tows running through dikes.

e. Sandy, unstable soil (bank scallops, flanking, excessive scour, etc.)

f. Dikes being "notched" by fishermen.

Repair criteria

62. A low area of a structure is usually not repaired unless the navigation channel has become too narrow or too shallow, or if the degraded section of the dike has the potential of becoming much larger. Dredging records of the immediate area are reviewed at this point. Generally, if the crown elevation has degraded 1 or 2 ft without adverse navigation problems, action is not taken. If the crown has degraded 4 or 5 ft over a length of 25 or 50 ft or more, then stone is added to the structure to bring it up to original grade. In areas where increased navigation depths are required existing dikes can either be lengthened or raised, but in most cases the dikes are raised.

63. The District tries to ensure that all structures remain attached to the bank. Bank scallops forming downstream of a dike have been a problem in the past. These scallops can enlarge, causing the dike to be flanked. If it appears the dike will be flanked, the bankhead is extended with stone, revetting the bank from the dike root downstream to a point at least past the midpoint of the scallop, or for 150 ft, whichever is less.

Repairs and repair techniques

64. Typically 30 to 50 dikes are repaired in a normal year. All dike

repairs are performed using maximum-weight, 1,000-lb, quarry-run stone. Revetment repairs use maximum-weight, 350-lb, quarry-run stone. Cost "in place" for the 1,000-lb stone is approximately $10 to $14 per ton. Dike repair work usually runs from $600,000 to $700,000 per year. In recent years, budget restraints have caused the District to delay some needed repairs in order to use those funds to correct major problem reaches. Almost all repair work is handled by private contractors; less than 1 percent is performed by the Corps.

65. After the fall inspection, repair contract specifications are worked up over the winter, contracts are let for bids in the spring, and the actual repair work is performed during the summer low-water construction season. The repair work is handled by five or six contracts, with each contract usually covering a 1- to 2-mile reach of the river. If, however, some of the dike damage is serious and cannot wait until the next construction season, then those repairs are carried out quickly. In the event of a major flood with widespread damage, i.e., the May 1990 flood, an emergency repair contract (or contracts) would be let and repair work performed as soon as possible.

66. Both floating plant and end dumping repair techniques are employed, depending on dike location and river stages. The life of repairs is long, but because of the large number of structures, repair work is performed every year.

Record keeping

67. For record keeping purposes, the river is divided into pools and a separate book is kept on all structures within each pool. For example, all data pertaining to the structures upstream of Lock and Dam 4 but downstream of Lock and Dam 5 would be found in the volume called "the pool 4 book." The inside cover of these books feature an aerial photograph of the stretch of the river covered by the book, with all structures clearly marked and identified by structure number. The book contains a list of all structures, with the work performed on each structure listed by contract specification number and the dates that the contract work was performed. The book also contains the original design, or as-built drawings, and all subsequent repair contract drawings. It is updated every time a construction or repair contract is let.

Environmental considerations

68. No notches have been excavated from existing dikes and essentially no new dikes are being built. However, in about 20 dikes where repairs were

required due to degradation of dike height, an area has been left to act as an environmental notch. This program was initiated in 1983. The width of the degraded area is usually 10 ft, with the bottom elevation 5 ft below normal navigation pool. Most notches are in stone-fill revetments or are close to the river end of the dike. The notches increase the flow of water through the dike, thereby creating a larger backwater area with improved water quality for wildlife and fish habitat. Recreational fishermen can also use the notches to gain access to fishing areas without having to go around the end of the dike and into the main channel of the river. See paragraph 40 for more detailed information.

Contacts

69. Little Rock District engineers contacted to provide information were Ms. Leanne Minery and Messrs. Jim Baker, Don Bratton, and Robert Young.

Memphis District

Description of project

70. The Mississippi River, which begins in the state of Minnesota and empties into the Gulf of Mexico through major distributaries at Head of Passes, Louisiana, has a navigable length of 1,811 miles. Six Corps Districts have jurisdiction over specific sections of the river. Starting at the upstream head of navigation and moving downstream, the Districts are St. Paul, Rock Island, St. Louis, Memphis, Vicksburg, and New Orleans.

71. The Memphis District oversees navigation on 354.8 miles of the river from the confluence of the Ohio and Mississippi Rivers at Cairo, IL (mile 953.8), to the mouth of the White River (mile 599.0). Vicksburg District also has maintenance responsibilities over the dikes and revetments on the left descending bank of the river (adjoining the state of Mississippi) from mile 614.0 to mile 599.0. Work on the river is authorized and funded by the Flood Control, Mississippi River and Tributaries Act of 1928. There are no locks or dams located within this reach of river. The authorized navigation channel is 9 by 300 ft. The river is up to 120 ft deep in places and up to 2 miles wide, and has a meander belt 30 to 50 miles wide. Currently 273 dikes are maintained, with 105 dikes scheduled to be built by the year 2010 to complete the Master Plan for the river within this District. Three to five dikes are scheduled to be built each year until the Master Plan is complete.

72. The typical size of a tow is 25 to 30 barges in a 5-wide by 5-long, or 5-wide by 6-long barge configuration, but under ideal river conditions up to 35 barges downbound and 45 barges upbound can be moved. Tow size would depend on river stages and the mix of loaded and empty barges within the tow. Towboat power is in the 5,600- to 10,000-horsepower range.

73. Approximately 169 million tons of commodities were shipped on the reach of river from Cairo, IL, to Baton Rouge, LA, during calendar year 1988. This section of river includes all of the Memphis and Vicksburg Districts and a portion of the New Orleans District. Major commodities shipped during 1988, and their percentages of the total tonnage, included coal (18.3 percent), corn (17.8 percent), soybeans (8.5 percent), animal feed (5.3 percent), basic chemicals (4.4 percent), articulated concrete mattress (3.8 percent), wheat (3.8 percent), gasoline (3.7 percent), and miscellaneous (34.4 percent). The busiest port within this District was the city of Memphis, TN, with 10.2 million tons of goods handled in 1988.

Stage, discharge, sediment, and dredging

74. All stages and discharges listed were recorded at the Memphis gaging station in feet above an arbitrary gage zero. Maximum stage and discharge were 48.7 ft and 2,020,000 cfs, respectively, on 10 February 1937. Minimum discharge was 78,000 cfs on 25 August 1936. Minimum stage was -10.7 ft on 10-11 July 1988. The bank-full stage and discharge are 34.0 ft and 1,312,000 cfs, respectively.

75. Suspended sediment data are not collected by the Memphis District. The United States Geological Survey based in Little Rock, AR, has a gaging station at Memphis, but data are only collected six times per year. Using this source of information, for the period February 1973 to May 1990 (116 samples), the suspended sediment load averaged 268,632 tons per day. This figure is probably low, as many higher flows (which would carry the most sediment) are missed. Suspended sediment consists mainly of silts and sands.

76. An average of 28,165,267 cu yd of material per year was dredged during the period 1985-1989. Total cost per cubic yard varied from $0.29 to $0.53, with an average cost of $0.36 for the entire period. Dredging is carried out using four dustpan type hydraulic dredges. Three are Corps owned: the *Burgess* (Memphis District), the *Potter* (St. Louis District), and the *Jadwin* (Vicksburg District). The fourth, the *Lenel Bean*, is owned by Bean Dredging of New Orleans, LA, and is under a year-round rental contract with

the Memphis District. The contract length is 1 year, with a 1-year option. Since the dredging program is under Lower Mississippi Valley Division (LMVD) supervision, these four dredges are used wherever the need is greatest within the Districts comprising LMVD (St. Louis, Memphis, Vicksburg, New Orleans).

Dike design and construction

77. Several different permeable pile dike designs have been employed on the river, starting in 1881 with dikes constructed of timber piles arranged in a single row. Designs with up to six rows of pile clumps (with three pilings making up a clump) were used. Pile dikes were built up until 1966 as river training structures. In 1964 and 1965 some dikes were built of stone with a maximum upper weight limit of 2,000 or 3,000 lb. Since 1966, almost all dike construction and repair has employed Graded Stone A, a 5,000-lb maximum-weight stone. Many of the old deteriorated pile dikes have been filled to midbank height with stone.

78. The basic design criteria for stone dikes are;

a. Spacing one to one and a half times the dike length.

b. Alignment normal to flow.

c. Crown width, minimum of 6 ft, maximum of 30 ft.

d. Horizontal crest profiles set at midbank height or 15 ft above the Low Water Reference Plane (LWRP).

e. A drop of 5 ft in the first 250 ft (bank end) to the design elevation to reduce scour near the bank.

f. A drop of 10 ft in the last 500 ft of the dike (stream end).

g. Side slopes of 1V on 1.25H.

h. A stream end slope of 1V on 5H (this flatter slope has been found to reduce end scour).

79. In addition, the bankhead is graded to a 1V on 3H slope and paved with stone 35 ft upstream and 200 ft downstream of the axis of the dike. Minimum contraction width varies within the District from 3,000 to 2,500 ft. This contraction width is measured from the -10-ft (LWRP) to -10-ft contours on each side of the river. The basic dike types used by the District include transverse, closure, trail, and lateral. Transverse dikes are the most common, are usually built in systems (also called fields) of three to four dikes, and are typically angled normal to flow. The purpose of a transverse dike is to increase the cross-sectional area of the channel by concentrating flow in the low-water channel. Closure dikes generally extend from the riverbank to an island or high bar. This closes off the secondary channel, which in turn

directs more water into the main channel. A trail dike is a downstream branch of a transverse dike. It usually starts about 500 ft from the riverward end of a transverse dike and can either be angled slightly toward the river, or extend downstream parallel with flow and then angle normal to flow near its end. The purpose of the trail dike is to act as an additional transverse dike without having to be tied to the bank. A lateral dike is built on a smooth alignment along the bank and is used to straighten out any misaligned currents caused by bank scallops or pockets. The floating plant method of dike construction is used for most dike building within this District.

Inspections

80. An intensive dike inspection is carried out each year, usually in July or August, ideally when stages are at +10.0 ft LWRP or lower. A 5.0-ft stage is even more desirable as a larger portion of the dike would be visible. This inspection trip takes 2 weeks. Each dike is visually inspected and any damage is noted.

81. The Navigation Section regularly patrols the river and sometimes reports dike and revetment failures. Aerial photographs taken each year can be used to spot and analyze dike damage. Landowners and towboat captains also frequently observe and report damage.

Types of dike damage

82. The following types of dike damage are reported:

a. Top of dike degraded.

b. Flanking of the dike at the bank end.

c. Holes in the dike, usually leading to concentrated flow through the hole with deep scour occurring immediately downstream of the hole in the dike. In some cases the dike repair must be offset upstream of the original alignment to skirt the scoured area.

d. Scouring of the bank downstream of the dike, usually caused by turbulence and eddies.

Causes of dike damage

83. Dike damage is caused by the following:

a. River currents (felt to be the major cause of damage).

b. Floods or extended periods of high water.

c. Towboats hitting the dikes.

d. Drift and debris.

e. Ice (usually minor).

Repair criteria

84. The question of whether or not to repair a dike is usually left up to the project engineers. Based on experience, observation, and engineering judgment, a decision is reached. A dike with major damage, so much so that the extent of the damage could not be fully observed, would be surveyed to ascertain what losses had occurred. Low sections in a dike that concentrate flow through the dike are repaired quickly. If a dike appears to have degraded uniformly, then the condition of the channel is studied. Thought would be given as to whether or not the dike is performing its intended purpose. If the dike is still functioning well, it may not be repaired. However, a drop in performance would necessitate repairs, usually to as-built specifications.

Repairs and repair techniques

85. Generally $10 to $12 million is spent by the Memphis District on revetment and dike repairs during a typical year. About $3 million of this is for stone repairs to dikes and to the upper slope of revetments. The in-place cost of stone is approximately $10 per ton, with approximately 300,000 tons of stone used annually. Graded Stone A is used to repair substantially degraded portions of dikes. Riprap (maximum weight 125-lb stone) is used on dike bankheads, thin sections of dike restoration, and revetment repairs. The stone is transported by barge from quarries along the Upper Mississippi, Tennessee, and Cumberland Rivers. Thirty dikes are repaired during a typical year. Almost all repairs are carried out using floating plant equipment.

86. Using statistics and past experience, specifications are drafted and advertised for bids in May, and the contracts are awarded in June or July. One parcel covers the reach of river from Cairo to Memphis, and the other from Memphis to the White River. The contracts are based on a unit price for stone, earthwork, etc., plus a price for mobilization and demobilization.

87. Information obtained from aerial photographs, surveys, and the inspection trip is used to develop detailed plans, specifications, and estimates for repairs. This work is begun immediately after the inspection trip. Most repair work is performed from August through December. If more work than usual is required, the contract length is extended into January.

88. All maintenance and repair money is handled by budgetary request. Historical records are used to estimate the amount of money needed for the coming year. Floods or other unforeseen events make an accurate estimate

difficult. If funds will not cover all repairs needed during a specific year, the various repair projects are prioritized.

Record keeping

89. The files contain the original design drawings, record maps showing as-built conditions, and sometimes after-construction surveys of all dikes in the District. When repair work is performed on a structure, the record maps are modified to show the work carried out. The file is updated each time work is performed on a dike.

90. The Channel Improvement Data Report contains financial and other data on dikes and revetments. Included is the original cost, the condition of the area before dikes were built, the original purpose of the structure, the anticipated effect of the dike, dates and costs of repairs, and a brief description of the work done. Construction and maintenance costs are also included.

Environmental considerations

91. In 1990 a few new dikes are scheduled to be notched for environmental enhancement in a manner similar to the notched dikes in the Kansas City, Omaha, and St. Louis Districts. The notches vary in size. See paragraph 40 for more information on the benefits of dike notching.

New technology

92. Laser transits and other modern electronic surveying equipment are now being used to locate and position the barges when placing stone during dike construction or repair.

Contacts

93. Memphis District engineers contacted for information were Messrs. Donald Jackson, Bobby Littlejohn, Andrew Lowery, Jimmy Thompson, and Doug Young.

Mobile District

94. Since this District maintains dikes on both the Alabama and Apalachicola Rivers, the dike repair methods of each river system will be reviewed separately.

Alabama River

Description of project

95. The confluence of the Coosa and Tallapoosa Rivers form the Alabama River just north of Montgomery, AL (river mile 355). The Alabama River joins the Tennessee-Tombigbee Waterway at mile 45, and then flows into Mobile Bay near Mobile, AL (mile 0). Three locks and dams are situated on this river, all with lock dimensions of 84 by 600 ft. The Coosa and Tallapoosa rivers both have a series of hydropower dams, but the reservoirs do not have much flood storage capacity, making the Alabama River system semicontrolled. The Alabama River is navigable over its entire length. The Coosa and Tallapoosa Rivers are not navigable, although navigation feasibility studies of the Coosa River have been carried out. The River and Harbors Act of 1927 authorized the Corps to study these rivers to determine possible future uses. Construction of the locks and dams was initiated in 1962 and completed during the early 1970's. The District also built 39 dikes in the lower 72 miles of the project during this time period. Major dike revisions and additions are under construction or planned for the time period 1989-1991. The authorized channel dimensions are 9 by 200 ft. The project is not complete.

96. Typical size of a tow on the Alabama River is four barges for dry cargo in a two-barge-wide by two-barge-long configuration, and two barges in a side-by-side configuration for liquid cargo. The reason for this difference is that a liquid cargo barge is slightly larger (42 by 220 ft) than a dry cargo barge (35 by 200 ft).

97. During the period 1979 to 1984, an average of 3,068,000 tons of commodities were transported yearly. Major commodities and their percentage of the total tonnage included construction materials (51.8 percent), paper products (42.4 percent), agricultural products (2.6 percent), petroleum products (2.2 percent), and chemicals (1 percent).

Stage, discharge, sediment, and dredging

98. All stages are in feet above mean sea level, and were recorded at a gage (mile 76.0) downstream of Claiborne Lock and Dam. Highest and lowest tailwater elevations recorded were 56.6 ft (25 March 1990) and 6.0 ft (8 October 1986), respectively. Highest and lowest discharges of record were 267,000 cfs (March 1961) and 2,850 cfs (1970), respectively. Bank-full stage and discharge are 21.0 ft and 30,000 cfs, respectively.

99. The sediment load of this river is estimated at 1.5 million tons per year. Most sediment consists of silty sand with some gravel. An average of 1,047,000 cu yd of material per year was dredged for the period 1971-1986. The cost per cubic yard varied from $0.34 to $7.47, depending on the total amount dredged in a given year, but for the period 1971-1986, averaged $2.50 per yard. In years past, on some sections of the river, as much as 4 ft of overdredging was performed; however, this practice was not found to be economically sound and has been discontinued.

Dike design and construction

100. Mobile District constructed 39 stone dikes on the Alabama River in the early 1970's in an effort to improve the navigation channel and reduce dredging costs. Dikes were spaced one to one and a half times the dike length and dike fields were laid out in a stepped-down configuration. The height of the most downstream dike in a system was 1 ft above the low-water profile. The first dike in a system was angled downstream 45 deg. The lengths of the dikes were selected to reduce the channel capacity 30 to 40 percent at the low-water profile elevation. Crest width was 3 ft. Dikes were built level-crested, except in the vicinity of mile 52.8, where the dikes were constructed with a stepped-down crest profile in which the dike starts out level at the bank end, then drops down to another level section. Dike end markers consisted of a single timber pile driven into the river end of the dike, rising 15 to 20 ft above the crown elevation of the dike. A new dike end marker design is now used (see "New technology," paragraph 110). Trail dikes and vane dikes were also employed on the river. The floating plant method of construction was used.

101. This dike system was not effective in improving the navigation channel, nor in significantly reducing dredging, due largely to the following:

- a. Dikes not built to proper grade.
- b. Dikes not built on the proper alignment.
- c. Flat river slope (typically 0.1 ft per mile).
- d. Dikes not properly maintained.

102. Several years ago the Corps decided to evaluate, redesign, and repair all dikes on the Alabama River. In preparation for this redesign effort a survey of the river and all existing dikes was conducted in 1987. Crown surveys and cross-sectional surveys at intervals of 60 ft were performed on each dike and a cross section of the river was taken every 250 ft within the

dike fields. This new construction and repair will be performed in three phases. Phases I and II have been completed. Phase III is scheduled for completion in 1991. Of the original 39 dikes, 28 will be modified or repaired and 11 completely removed. Thirty new dikes will be built. Some dikes will be level-crested, some sloping, and some built with stepped-down crests. All construction and repair work will use 1,200-lb maximum, Graded Stone B. Construction costs are projected to be in the $7 million range.

Inspections

103. Inspections are not officially carried out.

Types and causes of dike damage

104. Even though official inspections were not performed, it was observed that most dike damage was caused by either high flows, which had flanked several dikes, or towboat impacts, which punched holes in the uppermost section of the dike or sheared off dike end markers.

Repair criteria

105. Since a major dike repair/redesign is underway, the following criteria were employed specifically for this effort:

a. Amount of dredging required.

b. Inadequate channel depth or width.

c. Dikes not working as well as originally anticipated.

d. Inadequate dike height.

e. Dikes improperly located, i.e., original dikes not properly positioned to meet the current redesign effort.

Repairs and repair techniques

106. These dikes were neither inspected nor repaired, except to replace damaged marker piles.

Record keeping

107. Records on the original 39 dikes are sketchy at best. No as-built drawings exist. The only records available are the original contract plans and specifications, which do not accurately reflect what was built in the river.

Environmental considerations

108. An Environmental Impact Statement (EIS) was developed in 1985 to determine the impact of dike building and estimate the project upland dredged material disposal requirements for the next 20 years for the entire Alabama River navigation project. Using the effectiveness of dike systems on the

Apalachicola River as a rough guide, it was estimated that the dikes on the Alabama River would reduce maintenance dredging by 60 percent from preproject levels. In the EIS, disposal site locations were identified, and the acreages of these sites needed to effectively handle the amount of material calculated to be dredged over the next 20 years were estimated.

New technology

109. Inexpensive aerial photography. A VHS format video camcorder has been used for several years to take aerial videotapes of the entire length of the river. This film has proved invaluable in identifying trouble spots and damaged dikes. Two advantages of this method are extremely quick turnaround times and low cost. Since the videotape does not have to be processed or developed, it can be viewed immediately. Shooting costs are limited to 4-5 man-hours for the photographer and one half-day rental of an airplane. One drawback of this method is that measurements cannot be taken directly from the videotape since it is not shot to scale.

110. New design dike marker piles. A breakaway marker pile design is currently being used to help reduce maintenance costs. The old design consisted of one timber pile driven into the river end of the dike to mark the dike end as a navigation aid during periods of high water. This pile sticks 15 to 20 ft above the crown elevation of the dike. Unfortunately these piles were frequently sheared off by passing barges and replacement costs were high. When a marker was sheared off, a new pile would have to be driven through the dike and into the underlying channel bottom for stability.

111. The new design consists of an 18-in.-diam steel casing driven through the river end of the dike and into the channel bed. The casing sticks up 6 in. above the crown of the dike. A 12-in.-diam treated timber pile is placed into this casing, sand is packed around the timber, and the sand is capped with a layer of concrete. A bolt through the casing and pile further strengthens and secures the marker. As with the old design, this timber also juts 15 to 20 ft above the crown of the dike.

112. If the marker needs to be replaced, the bolt is removed, the remainder of the pile is removed from the steel casing, and the sand and concrete are dislodged with a water jet. A new piling is placed in the casing, sand packed around it, the sand capped with concrete, and the bolt through the casing and pile reinstalled. This procedure has proven to save significant amounts of both time and money.

Contact

113. The Mobile District engineer contacted to provide information on the Alabama River was Mr. Maurice James.

Apalachicola River

Description of project

114. Mobile District oversees navigation on 106 miles of the Apalachicola River. All dikes are contained on the reach of river from mile 103 to mile 7. While the Apalachicola River is a part of the Apalachicola-Chattahoochee-Flint Rivers Navigation Project, the only dikes in the project are found on the aforementioned reach. The Apalachicola River is semicontrolled due to several hydropower dams and reservoirs located on both the Flint and Chattahoochee Rivers. While there is little flood-control storage capacity in these reservoirs (high flows basically pass through), during low-flow events, water can be released to augment the natural riverflow. One lock and dam, the Jim Woodruff, is located on the Apalachicola River just downstream of the confluence of the Chattahoochee and Flint Rivers (which join to form the Apalachicola River) Lock size is 82 by 480 ft. The authorized navigation channel dimensions are 9 by 125 ft. The project is complete.

115. Standard tow size on the Apalachicola River is either one or two barges. Two-barge tows can be configured either front to back or side by side.

116. The amount of goods shipped averaged 977,000 tons per year from 1983 to 1987. Major bulk commodities shipped include petroleum, chemicals, coal, and agricultural products.

Stage, discharge, sediment, and dredging

117. All stages and discharges cited in this paragraph were recorded at the Blountstown, FL, gage. Stages are recorded in feet referenced to the National Geodetic Vertical Datum of 1929 (NGVD). The highest stage of historical record was 53.76 ft in March 1929. No discharge was recorded for that event at this gage, but the discharge at the Chatahoochee gage was 293,000 cfs. The highest stage and discharge recorded since the project was completed were 51.71 ft and 172,000 cfs, respectively, in 1978. During 1986 the lowest stage and discharge of record were recorded, 26.98 ft and 4,680 cfs, respectively. The long-term mean stage and discharge are 37.08 ft

and 23,420 cfs, respectively. The bank-full stage and discharge are 40.46 ft and 33,050 cfs, respectively.

118. For the year 1988, the suspended sediment load averaged 1,296 tons per day and consisted mainly of clay, silt, and sand. A contract is let on a cost per cubic yard basis with a private contractor to perform all dredging on the river. Contract length is 1 year. A cutterhead-type hydraulic dredge is used. For the period 1971-1984 (after all dikes were in place), an average of 1,140,000 cu yd of material was dredged each year, although the amount varied widely on a year-by-year basis. Most dredging is required after river stages fall quickly. As examples, during 1975 and 1988 (low-water years) only 143,000 and 643,000 cu yd, respectively, were dredged. Costs varied from $2.30 to $3.30 per cubic yard during the period 1987-1989. These cost figures include all mobilization-demobilization and transportation costs.

Dike design and construction

119. The first dikes built were constructed of timber pile during the 1920's and 1930's by Works Progress Administration personnel. In 1957 a dredging program was initiated, but a stable navigation channel could not be maintained. From 1963 to 1965 timber dikes were built for the purpose of contracting the width of the river to 400 ft on the Upper Apalachicola River and 500 ft on the Lower Apalachicola River. These dikes were built on a blanket of stone 50 ft wide, extending from the high-water line to slightly beyond the river end of the dike. Dike building continued with stone and stone-filled pile dikes being built from 1965 to 1971, bringing the total number of dikes on the river to 81. The specifications on the stone gradation used are as follows: maximum size 500 lb, 40 to 60 percent must weigh 125 lb or more, and not more than 10 percent can weigh 10 lb or less. The dike fields were constructed in a stepped-down configuration, and dike spacing was one to one and a half times the dike length. Crest width for all dikes was set at 10 ft. Navigation markers consisted of a clump of three wooden piles driven into the river end of the dike rising 15 to 20 ft above the crown of the dike. Except for a trail dike to protect the State Highway 20 bridge, all dikes were angled normal to flow. Dikes constructed in 1965 had a flat crest, with dike heights varying from +7.5 ft (referenced to the dredging reference profile) in the upstream reaches of the river to +1.0 ft in the most downstream reach. The dredging reference profile is based on a 9,300-cfs constant discharge. The dikes constructed during 1971 had a sloped crest, with the stream end

elevation varying from 6.1 to 1.0 ft above the dredging reference profile from the most upstream to the most downstream dike. The floating plant method of dike construction was employed.

120. Two reaches of river were recently studied at the WES (McCollum 1988; in preparation). Different dike configurations and dike types, including Iowa Vane dikes, were modeled in an effort to reduce the amount of maintenance dredging performed in the navigation channel.

Inspections

121. From 1970 through 1986 no official inspections were conducted. During this time, dike damage was usually reported by District work crews while performing other tasks on the river. However, starting in 1987, an annual trip has been scheduled to inspect dikes, revetments, and dredged material disposal areas. Information from this inspection is contained in the "Annual Report on the Apalachicola-Chattahoochee-Flint Waterway" (US Army Engineer District, Mobile). As before, additional information is still obtained from Corps work crews.

Types of dike damage

122. The following types of dike damage are reported:

a. Flanking of dikes at the bank end (usually only the first or second upstream dike in a dike field sustains this type of damage).

b. Sheared dike marker piles.

Causes of dike damage

123. The following causes of dike damage have been reported:

a. Easily eroded, nonarmored, alluvial riverbanks.

b. Towboats running over marker piles during high water.

Repair criteria

124. The policy adopted by the District is to repair all flanked dikes, and dikes in danger of being flanked, back to the original design specifications. In the interests of navigation safety, all damaged marker piles are replaced.

Repairs and repair techniques

125. From 1970 to 1988 the only repair work the District had performed was to repair some damaged marker piles and replace a few damaged piles in some of the pile dikes. This work was done in house.

126. In the early 1980's the need for major dike repair work was realized. During inspections it was observed that 10 dikes were flanked or in

danger of being flanked. The District applied for the necessary environmental permits from the State of Florida to allow repair work, but final approval took almost 2 years.

127. A single contract was let in 1989 to repair these dikes. Work included restoring the dikes to the original design specifications and armoring the bank from the dike to a point 50 ft downstream of the center line of the dike. This work was handled by a private contractor. The amount of the contract was approximately $60,000.

Record keeping

128. All original dike design specifications and drawings are kept on file. No as-built surveys were performed. Crown profiles taken during environmental permit applications are also on file. All information pertaining to the recent dike repair efforts were added to the file. This file has no official name.

Environmental considerations

129. The section of the Apalachicola River that flows through the State of Florida is an extremely beautiful, natural, and scenic reach of river. The State is currently in the process of buying all land within the floodplain to be set aside as an intensively managed nature preserve. Because of this policy, the State of Florida requires the Mobile District to obtain an environmental permit before any work can be performed on the river. Obtaining these permits is a long, expensive, and time-consuming process. Even when a dike is being repaired back to the original design configuration, a permit is required. The District has applied for a long-term, 25-year work permit, but even if approved this permit will be extremely stringent and will include annual inspections, reviews, and reports, plus a major review every 5 years. Florida derives very few benefits from the Apalachicola-Chattahoochie-Flint Waterway Project and does not appreciate the dike-building activities of the Corps spoiling their natural river.

Contact

130. The Mobile District engineer contacted to provide information on the Apalachicola River was Mr. Kenneth Underwood.

Omaha District

131. Since there are many similarities between the two Districts, some

information presented in the section of the report on the Kansas City District will be repeated in this section.

Description of project

132. Snag removal on the Missouri River was first performed by the Corps in 1832. In 1927 authority was granted by Congress to maintain a 6- by 200-ft navigation channel from Sioux City, IA, to the mouth, a distance of 734.8 miles. In 1945 authority was extended to increase the channel depth to 9 ft and channel width to 300 ft for this reach. Using this authority, $190 million was spent. The Missouri River Project was completed by the Engineering and Construction Divisions in 1981, after which the project was turned over to the Operations Division. The Omaha District, which was formed in 1931, oversees navigation on the Missouri River from Sioux City (mile 734.8) to Rulo, NE (mile 498.4), a distance of 236.4 miles, and maintains 2,833 dikes within this reach. The present worth of channel improvement works built from 1933 to 1981 within the Omaha District is estimated at $340 million. The Kansas City District oversees navigation from Rulo to the mouth of the river.

133. Six mainstream dams located above Omaha, NE, control the flow of the river. These dams are of the earth embankment type and 4 of the 6 are among the top 20 dams of this type in the world in terms of total volume of earth used during construction. Before the Missouri River Project was initiated, the river was subject to major fluctuations in stage and usually two major floods each year. The dams became fully operational in 1967. Since that time the annual June snowmelt flood has been completely eliminated and the frequency and stages of other flood events have been significantly reduced.

134. The navigation season, when the river is free of ice, runs from 1 April to 1 December. During this time an increased amount of water is released from the upstream reservoirs to provide the necessary channel depths and widths for navigation.

135. Shortly after the dams became operational, navigation increased dramatically. The peak year was 1977 when 3 million tons of commodities were shipped. In 1989 2.3 million tons of goods moved up and down the river. Principal upbound products were petroleum, building materials, chemicals, salt, molasses, fertilizers, and steel. Downbound products included grain, grain products, tallow, chemicals, and petroleum products.

136. The standard tow size is three or four barges in a two-barge-wide by

two-barge-long configuration. Maximum tow size is six barges in a two-wide by three-long configuration.

Stage, discharge, sediment, and dredging

137. The normal winter (non-navigation) average flow at Omaha, NE, is 15,000 to 20,000 cfs. Due to drought conditions, this flow was reduced during the 1988-89 and 1989-90 winter periods. Discharge varied during the winter of 1988-89 from 15,000 to 9,500 cfs. In the winter of 1989-90 an average discharge from Gavins Point Dam of 10,500 cfs was scheduled with releases not to drop below 9,500 cfs. With these low flows there was a possibility of negative impacts on nuclear power plant and public potable water intakes. Although there was an ice effected water supply outage at St. Joseph, MO, in January 1989, the reduced flows caused no outages along the system after a program to increase communications and monitor ice was implemented.

138. The normal summer (navigation) target stage, called the "full service flow," is 16.5 ft (referenced to a gage zero of 948.2 ft MSL) on the Omaha gage (river mile 615.9) with a discharge of 32,000 cfs. The summer navigation "minimum service flow," used during periods of drought (1988-1990) to conserve water, is 26,000 cfs with a 14.6-ft stage, also measured at Omaha.

139. The six mainstream dams have had a profound effect on the sediment load of the river. Before the dams were built 200 million tons of sediment (sand-silt-clay) were transported by the river each year. After the dams were operational, this amount decreased to 50 million tons per year, with an increase in the percentage of the sand load and a decrease in the percentage of the silt and clay load.

140. No dredging of the navigation channel has been performed in this District since 1969.

Dike design and construction

141. Early dikes on the river were constructed of timber pile clumps in either a single-, double-, or triple-row configuration and were usually constructed on a willow or lumber mattress. A pile clump consists of three timber piles driven close together and angled slightly (called the batter angle) so that the tops of the piles touched. The piles were then bound together near their tops with wire rope. Three to six pile clumps were constructed at the ends of the dikes to protect the dike ends from ice damage. One of these pile clumps would be taller than the rest and would serve as the dike end marker. Most pile dikes were built from 1933 to 1940. Extensive repairs and

rebuilding occurred after the flood of 1952. Dikes ranged in length from 500 ft to a mile. Long dikes would start on a bank, cross the chute channel (or channels), cross the midbar island, and extend into the main river channel. The original purpose of the dikes was to constrict the width and stabilize the navigation channel. These dikes were very effective in accumulating sediment, and as a result many now extend hundreds of feet into the present-day banks. However, due to increased labor costs and the amount of damage suffered by the dikes, they were eventually reinforced with stone.

142. Since 1964 all dike construction and repair work has used quarry-run, maximum-weight, 2,000-lb stone. Specifications state that fines smaller than 1/2 in. cannot exceed 5 percent. The stone is obtained at any of a number of quarries located adjacent to the river. Usually the floating plant method of construction is used. Modern stone dikes are level-crested and typically extend 150 to 250 ft into the river. Dikes are angled 7 to 22 deg downstream from a line drawn normal to flow. The more a dike is angled downstream, the farther the scour hole at the river end of the dike is aimed away from the dike. Dikes angled upstream are not used due to their greater resistance to flow, increased end scour, and ability to accumulate large amounts of debris and ice. The design crest width, based on observations of the ability of dikes to resist the pressures of ice, is 5 ft. The contraction width is 600 ft (500 ft in areas with sills) from Sioux City to the confluence with the Platte River, and 650 ft (550 ft with sills) from there to Rulo. The CRP was developed by the Missouri River Division to give consistency to training structure height. All structures designed in reference to the CRP will theoretically be overtopped for the same amount of time each year. From Sioux City to the Platte-Missouri River confluence, revetments, dikes, crossing control structures, and sills are built to +1.0, 0, +2.0, and 0 to -5 ft CRP, respectively. From the Platte River to Rulo, the design heights are +2.0, +1.0, +3.0, and 0 to -5 ft CRP, respectively. Dikes are generally spaced 500 to 800 ft apart. Dikes are spaced farther apart on convex bends and closer together in straight reaches. Bendway radius affects how close the dikes can be effectively placed. In some long, flat bends, level-crested submerged sill extensions to existing dikes have been used. Their primary purpose is to align adverse flows. The river ends of stone dikes are not marked. The marker clumps on the old pile dikes are not maintained. Most have been sheared off by debris, barges, or ice. With the river in a controlled state,

dike end markers are not felt to contribute to navigation safety, and therefore, are not needed. Many different types of river training structures are used in this District, including L-head dikes, chute closure dikes, revetment, windrow revetment, dikes, crossing control structures, and low-elevation underwater sills.

Inspections

143. Two low-water inspection tours are scheduled by the District every year, one by boat, and one by air. The boat trip is scheduled for as soon as the river is free of ice, usually in late February or early March. The aerial inspection is carried out soon after the end of the navigation season, usually late in November or in the first 2 weeks of December. During the December 1988 aerial low-water inspection tour, the entire length of river under the jurisdiction of the Omaha District was videotaped using a VHS format video camera. The inspection team was very pleased with the results, and videos will be shot during all future aerial inspections.

144. In addition, three channel reconnaissance trips are carried out during the navigation season. The major tasks performed on these trips are as follows:

a. Check positions of channel marker buoys.

b. Structure inspection (dikes and revetments).

c. Observe general channel conditions.

d. Pipeline crossings are checked to see that they are properly buried and not leaking.

e. Notches in dikes checked for deterioration, debris, and any unusual erosion downstream of the notch.

f. Observe bank erosion.

g. Determine whether to fill or add notches to dikes in areas where appropriate.

h. Chronic problem areas are closely inspected, as an example, the confluence of the Platte and Missouri Rivers. In this area, where shallow channel conditions are occasionally encountered, the channel would be carefully scrutinized, cross-sectional surveys taken, and any other pertinent information collected.

i. Inspect to ensure that permit holders are carrying out permitted activities as described. Permit holders can include individuals, landowners, businesses, or other Government agencies Typical activities requiring a permit include boat ramp construction, modifications to Corps-owned structures, or the dumping of rock to protect bank lines, etc.

145. Any points of interest observed during the reconnaissance trip are recorded on film using a 35mm still camera.

Types of dike damage

146. The following types of dike damage are reported:

a. Displacement of stone in the upper region of the dike, usually at the river end of the dike.

b. Flanking (usually found on short dikes).

c. Crown sheared off.

d. In dikes that have been notched, deterioration of the notch toward the bank end of the dike causing the dike to become flanked.

Causes of dike damage

147. The following causes of dike damage have been reported:

a. Ice.

b. Debris.

c. Flows overtopping the dikes (does not necessarily have to be a flood or high flows).

d. Aging and weathering of rock.

e. Towboat impacts.

Repair criteria

148. The District uses the following repair criteria:

a. Dike must be degraded at least 2 ft over a minimum distance of 100 ft.

b. Dike flanking. Flanked dikes are, in most cases, reattached to the bank.

Repairs and repair techniques

149. Operation and maintenance costs range from $1.5 million to $2.8 million annually, the variance depending mainly on the amount of the construction contracts. During a normal year, about 50,000 tons of quarry-run, 2000-lb, maximum-weight stone is used for dike repair. Cost in place for this stone runs from $9.50 to $11.00 per ton; therefore, dike repair costs run approximately $500,000 per year, with anywhere from 100 to 200 dikes being repaired. In a flood year, 1984 for example, twice that amount of repair work may be necessary. Private contracts are let for most of the work, although as much as 10,000 tons of stone may be placed using Corps of Engineers crews and equipment. The Corps usually performs work where small volumes, long distances, or both, make the work unattractive to contractors.

150. Dike damage is usually observed during the spring low-water

inspection tour. Contracts are let to repair the dikes in early August, and repairs are performed from August through October. If an unusually large amount of repair work is required, the contract can stretch from August to the end of the navigation season (mid-November). Typically two repair contracts are let for the entire District, with the dividing point at Omaha (mile 627). However this policy has not held true recently. Due to the drought, a lack of ice damage, and other factors, structure damage has been minimal. The reach upstream of Omaha has not had a repair contract since 1985, and downstream of Omaha no contract has been let since 1987. The Corps was able to perform all needed repair work in house during those years.

151. The maintenance program is continuous, with the life expectancy of most dike repairs averaging 10 years.

Record keeping

152. Every time a dike is built or repaired, MRD Form Number 0701, "Completion Report, River Stabilization Structures," is completed. This form contains the following information:

a. Date Form 0701 is completed.

b. Type of construction.

c. Structure number.

d. Location by:

(1) River mile.

(2) Reach of river.

(3) Beginning and ending stations.

(4) Bank of river, either left or right.

e. Type of dike root: length, elevation, material used, and whether a standard or special root.

f. Type and amounts of material used in construction or repair: timber pile, stone, or both.

g. Grade and size of stone used.

h. Whether or not the river end of the dike is marked with a marker clump, and if so, the marker's station and elevation.

i. Start and completion dates of any work performed.

j. Contract number.

k. Name of contractor.

l. Work order number.

m. Whether new work or repair.

n. Corps inspector's name.

o. Total length of structure.

p. Under Remarks the following is usually noted: Description of the work performed, with the amount of materials used, where placed, elevations, stations, crown width, material suppliers, and if stone, from which quarry it was procured.

Environmental considerations

153. Notches in dikes. The Omaha District has notched approximately 400 stone dikes over the last several years. The notch is intended to increase flow through the dike, thereby increasing the flow conveyance of the river channel. The additional scour from the flow through the notch provides an environmental benefit by creating a larger backwater area for wildlife habitat. The program has proved successful. No adverse effects in dike performance have been observed.

154. In many cases when a dike has suffered some degradation, the dike is rebuilt to design height, except for the area that is to be notched. It is simply not filled, thereby creating a notch and saving stone and money. See paragraph 40 for more detailed information.

155. Reevaluation of channel width. In some areas the design channel width has been reevaluated. The stream ends of dikes have been allowed to deteriorate naturally, resulting in an increase in the overall channel width. This practice is allowed as long as no loss of navigation channel width occurs.

156. Underwater sills. Since the mid-1970's, in reaches where channel meandering tendencies in long flat bends need further correction, underwater sill extensions to existing dikes have been employed with success. This satisfies the environmentalists, who are generally opposed to building emergent structures. In fact, Nebraska State Game and Parks biologists have consistently found large fish populations in the vicinity of these structures. A sill, as defined by the Omaha District, is submerged at least 95 percent of the time.

New technology

157. During the December 1988 aerial low-water inspection tour, a VHS format video camera was used to videotape the entire length of the river within the Omaha District. This filming was deemed a success and will be considered on all ensuing aerial inspection tours.

Contacts

158. The Omaha District engineers contacted to provide information on the Missouri River were Messrs. Howard Christian, John LaRandeau, and John Remus. Additional information was provided by Mr. Warren Mellema of the Missouri River Division.

Portland District

Description of project

159. The only training structures that the Portland District has in a shallow-draft riverine environment are two timber pile dikes on the Cowlitz River. These structures were built several years ago in response to a warehouse operator's complaints of shoaling. The Cowlitz River navigation channel has not been maintained since the eruption of Mount Saint Helens on 18 May 1980. Shortly after the eruption, 40 million cubic yards of debris and volcanic ash were dredged to restore the flood-carrying capacity of this river. Sand bars have formed around these dikes.

160. All dikes on the Columbia River are in a deep-draft regime, and therefore are not covered in this report.

Inspections

161. The dikes are not inspected.

Types and causes of dike damage

162. The types and causes of dike damage are unknown.

Repairs and repair techniques

163. These dikes have not been repaired since they were built. No repair work is anticipated now or in the future.

Record keeping

164. Records of the original design drawings and as-built drawings are kept on file.

Environmental considerations

165. Ms. Fong Grey reported on a method of dike finishing, called "plating," that the Portland District uses when building or repairing stone dikes or revetments in the deep-draft channel of the Columbia River. A large slab of steel is used to pound the rock surface smooth. This method has two benefits:

a. Less debris is caught by the smooth stone.

b. The surface of the dike is smooth so fish (salmon) can migrate up and down the river without injury.

166. The plating process is written into the contract specifications and is required by the fisheries and wildlife specialists. To give an example of how different techniques are employed on different rivers, Mr. Tom Burke of the Kansas City District states that the Missouri Fish and Wildlife Department prefers a rough and irregular surface (paragraph 43).

New technology

167. Bottom-dumping rock barges. Bottom-dumping barges have been used successfully in building a series of underwater sills in a deep-draft channel near Bonneville Lock and Dam. Details are presented under the heading "Dike Repair Construction Techniques" (paragraph 323).

168. Value engineering pile dike maintenance report. A value engineering team was formed by the Portland District to evaluate the maintenance of the pile dike systems now in place on the Columbia River. The objective of the study was to determine which dikes were effective. Each dike was individually evaluated, and the dikes deemed ineffective would no longer be maintained. The study recommended that 117 out of 236 dikes should continue to be maintained. This recommendation will result in a savings of $2,022,649 in future maintenance and reconstruction costs. Although the study was focused on a deep-draft reach of river, some readers might find the report (Robinson et al. 1988) of interest.

Contacts

169. Portland District engineers contacted for information were Mmes. Laurie Broderick and Fong Grey and Messrs. Theodore Edmister, Karl Eriksen, David Illias, and Kenneth Patterson.

Rock Island District

Description of project

170. The Rock Island District is responsible for the portion of the Illinois Waterway between La Grange, IL (mile 80), and mile 325.5 on the south branch of the Chicago River and mile 327.1 on the Calumet River. Eight locks and dams, all with lock dimensions of 110 by 600 ft (except the Thomas J. O'Brien Lock and Dam, which is 110 by 1,000 ft), are located on this reach. Channel dimensions are 9 by 300 ft, except for miles 244.6 to 247 (9 by

200 ft), and miles 291.1 to 325.5 (17 by 160 ft). The Calumet River Channel (miles 303.4 to 327.1) is 9 by 225 ft. No dikes are found on this waterway.

171. The Rock Island District is also responsible for the maintenance of 314.0 miles of the main stem Mississippi River stretching from immediately downstream of Lock and Dam 10 (mile 614.0) to immediately downstream of Lock and Dam 22 (mile 300). Twelve locks and dams are located on this reach, all having a lock size of 110 by 600 ft (with the exception of Lock and Dam 19, which is 110 by 1,200 ft). The pools above the locks and dams have little flood-control capacity; therefore, riverflow is not considered controlled. St. Paul District has jurisdiction of the Mississippi River north of Rock Island District, and St. Louis District has jurisdiction immediately to the south.

172. Rock Island District shows 1,048 dikes on the current project maps, but according to Mr. Danny Hare, many of these are no longer in existence. All dikes are submerged. The age of the dikes, along with the fact that they cannot be seen, makes an exact count difficult. The authorized channel dimensions are 9 ft deep by a width that is "suitable for long-haul common carrier vessels." Generally, when dredging, the District tries to maintain a 300-ft minimum width.

173. The standard size tow configuration is three barges wide by five barges long. Towboats are typically in the 3,200- to 6,000-horsepower range.

174. Almost 39,000 barges passed through Lock and Dam 22 in 1989, with 64.4 percent full and 35.6 percent empty. The total weight of goods shipped through this lock during 1989 was 34,937,546 tons. The major commodities shipped and their percentages of the total tonnage were grains (69 percent), coal (13.1 percent), petroleum products (3.3 percent), and miscellaneous goods (14.6 percent).

Stage, discharge, sediment, and dredging

175. All stage and discharge measurements reported in this section were recorded at Lock and Dam 22. The peak discharge and stage of the flood of record occurred in April 1973, with a discharge of 575,000 cfs and a tailwater elevation of 472.8 ft MSL, respectively. The minimum flow of record was 5,000 cfs in 1933 (1 year before Lock and Dam 22 was completed). One of the lowest flows recorded since project completion was 10,000 cfs in August 1989. Tailwater elevation for that event was 449.3 ft MSL (0.3 ft above flat pool). Lock and Dam 22 goes "out of operation" (the gates are pulled out of the

water) when the discharge exceeds 160,000 cfs.

176. Dredging on the Mississippi River within this District is usually performed by the *Thompson*, a 24-in. hydraulic cutterhead type dredge owned by St. Paul District. From 1986 through 1989 a yearly average of 570,000 cu yd of material was removed. In 1989, 572,560 cu yd was dredged from nine different sites, which includes 29,430 cu yd dredged mechanically. Mechanical dredging is usually divided up as follows; 90 percent by dragline and 10 percent using a clamshell type bucket. Cost of hydraulic dredging varies from approximately $1.50 to $4.00 per cubic yard depending on site location, disposal method, and the amount of material dredged.

Dike design and construction

177. Dike building started in the 1870's with woven willow mats topped with rock and dredged material. A few pile dikes were built next, but information on them is sketchy, and they have all since been converted to rock dikes. The majority of the dikes were built from 1900 to 1920 and were constructed of stone. Most were angled slightly upstream, although some were normal to flow. Their purpose was to establish and maintain a 4-1/2-ft-deep channel, and later, a 6-ft channel. During the 1930's the lock and dam system was built, which established the present-day 9-ft channel depth. No dikes have been built since 1948. All structures within the District are submerged, with the majority cresting at 3 to 4 ft below flat pool. Within the District these submerged dikes are called "wing dams". Approximately 10 percent of the wing dams are marked with a standard channel buoy anchored to a 1-ton concrete block to aid navigation. The Coast Guard is charged with the task of setting the navigation channel buoys. Usually at least three reconnaissance trips are performed by the Coast Guard each year with the main purpose being to survey channel depths and set and maintain the channel buoys.

Inspections

178. Routine surveys of the dikes are not performed. The only time a dike is surveyed to determine its condition, or even if it still exists, is when the dike is scheduled to be worked on. This repair is almost always in an area of the river with a severe sedimentation problem. When a dike is surveyed, plan, profile, and cross-sectional surveys are taken.

179. The river is flown over and pictures taken once every 3 or 4 years. This procedure is performed mainly to check on compliance with Corps-issued permits and for environmental purposes. Since the dikes are submerged, this

is of no help in detecting damage to dikes, but is sometimes helpful in spotting damage to bank revetments.

Types of dike damage

180. The following types of dike damage are reported:

a. General deterioration and loss of dike height over the entire length of the dike (most common).

b. Flanking.

c. Entire dike missing.

Causes of dike damage

181. The following causes of dike damage are reported:

a. Floods and associated high velocities.

b. Deterioration of the rock itself (due to age, cracking, freeze-thaw cycles, etc.).

c. Ice and ice jams.

Repair criteria

182. Since all structures are submerged, dredging frequency and quantity dredged are the only indicators used to determine if a dike field is in need of repair. Each section of the river is ranked according to the amount and cost of dredging performed over the past several years. This information is then used to devise a 5-year plan of action. A big advantage to this method is that planning so far ahead builds in a certain amount of flexibility. In 1987, some areas scheduled for repair were skipped because of environmental concerns for the fat pocketbook clam, an endangered species, but this disruption caused few problems.

183. Once a year the Committee to Assess Regulated Structures meets to review the 5-year plan. This committee consists of Planning, Engineering, Operations, and Environmental personnel. The amount of repair work for the year and which specific dikes or dike fields are in most need of repair are determined in this meeting. This procedure gives all groups involved sufficient time to plan and carry out their required tasks. Once these determinations are made, the dikes are surveyed (plan, profile, and cross section), compared to the as-built drawings, and built back to original specifications. Rarely is a single dike repaired. Usually an entire dike field, consisting of 8 to 20 dikes, is rebuilt.

Repairs and repair techniques

184. Repair of training structures in the Rock Island District is performed by Corps of Engineers equipment and crews, but the rock is purchased from private suppliers. Typically 400-lb, maximum-weight stone is used. The supplier quarries the rock from any of a number of sites located adjacent to the river and loads it onto the material barge. Trucks loaded with rock are driven directly onto the flat-decked barge and dumped. Between loads, a front-end loader is used to increase the height of the rock pile. The material barges and barge mounted dragline are then towed to the work site. A timber spacer box is set over the wing dam between the crane barge and the material barge to hold the barges apart. The rock can then be dragged off the material barge and into place accurately. The barge-mounted dragline is also used for any necessary trenching and rock placement that may be required at the bank for dike root reinforcement.

185. The amount and type of equipment owned by the Corps had limited the District's repair capabilities to placing between 60,000 and 80,000 tons of rock per year, but recent crane purchases have raised this capability. A record 92,000 tons of rock were placed during the 1988 repair season. This amount normally repairs 20 to 25 wing dams.

186. Cost of rock delivered to the riverbank runs from $5.50 to $14.00 per ton, but usually averages $9.00. It costs the Corps roughly $9 per ton to place the rock, so total cost-in-place is in the neighborhood of $18 per ton. All rock is sent off for laboratory tests to determine suitability before use.

187. The stone dikes have a long life, and repair is not expected to be required for 30 to 40 years after maintenance is performed.

Record keeping

188. For the last 10 years the repair records have been very detailed, with all necessary data compiled and recorded. Before that, the information is sketchy, with little known except when the actual repair work was performed.

Environmental considerations

189. According to Mr. Hare, the Rock Island District faces "absolutely monumental environmental problems" in maintaining the navigation channel. Emergent river training structures are prohibited, and guidelines on depositing dredged material are very strict. It is Mr. Hare's opinion that these

restrictions are greater for the Rock Island and St. Paul Districts than for the Districts overseeing the middle and lower reaches of the Mississippi River.

Contacts

190. Rock Island District engineers contacted for information included Ms. Donna Jones and Messrs. James Aidala, Bill Gretten, Danny Hare, and Donald Logsdon.

Savannah District

Description of project

191. The first training structures were built on the Savannah River in the 1930's. Building was sporadic until the 1960's when approximately 140 dikes were constructed. The last dikes were completed in the early 1970's. All dikes were constructed of timber piles. Two hundred fifty three pile dikes are listed in the current navigation charts and are found on the stretch of river encompassing miles 190 to 20. Their main purpose was to constrict the river, but in some cases they also provided bank protection in bendways. The channel dimensions are 9 by 90 ft. The project is complete.

192. At the present time this waterway is not being used by commercial traffic; therefore, the project is not being actively maintained by the Corps of Engineers. Recreational boating and fishing are the major uses of the river.

Dike design and construction

193. All dikes in this river were constructed of timber piles. The dikes are grouped in sets of four. In a typical set the upstream dike is 50 ft long. Moving downstream, the next dike is 75 ft long, and the last two dikes in the set are both 100 ft long. All dikes are level crested at an elevation 8 ft above the LWRP, and are built using two rows of single piles secured with a stringer running between them. The stringer is positioned 2 to 4 ft below the top of the piles, and is tied to the piles using 3/8 in. galvanized wire rope. Piles are driven to a depth of 10 ft into the channel bottom if 10 ft or less of the pile is above the riverbed. If more than 10 ft of the pile is above the riverbed, then the piles are driven to a depth of 15 ft. The dike extends 5 ft into the bank, and 35 tons of rock are used to armor the bank at the root. This armoring extends 25 ft up and into the bank. One-half ton of

rock per linear ft of dike is used as bed armor at the base of the piles. For the riverward 20 ft of the dike, and extending 8 ft beyond the end of the dike into the river, 1-1/2 tons of rock per linear foot of dike length is used as toe protection. At the riverward end of the dike, eight piles are clustered. All are at elevation +10 ft LWRP, except for a single center pile located at the end of the stringer. It is at elevation +16 ft LWRP and serves as an end marker for the dike.

Inspections

194. Regular inspections are not conducted for this inactive project.

Types of dike damage

195. The following types of dike damage are reported:

a. General deterioration.

b. Rusting of the steel wire pile wrapping.

Causes of dike damage

196. The following causes of dike damage are reported:

a. Weathering.

b. Accumulated debris.

c. Age.

d. Oxidation.

e. Collisions with pleasure craft.

Repair criteria

197. The following criteria are used to determine when, or if, a dike is in need of repair, or redesign and reconstruction.

a. Engineering judgment.

b. Repetitive shoaling problems.

c. Changes in river alignment due to flood events.

Repairs and repair techniques

198. The most recent repair work performed on this project was in 1979, when approximately 12 to 15 sets of dikes (4 dikes to a set) were repaired at a cost of $200,000 to $300,000. Repairs included replacement of piles, replacement of the steel wire rope pile wrapping, and the placement of additional riprap for toe protection. The stone used for the riprap repair is referred to as "one-man stone," a gradation denoting that all stones must weigh one hundred pounds or less. No repairs have been performed since 1979.

Record keeping

199. Original design drawings, as-built surveys, repair specifications,

and aerial photographs are all kept in the "Contract File."

Contacts

200. Savannah District engineers contacted to provide information were Messrs. F. Wade Seyle, Jr., and William Young.

St. Louis District

Description of project

201. The St. Louis District maintains a 29-mile reach of the Kaskaskia River, which branches off the Mississippi River near Chester, IL (mile 117.5). Channel dimensions are 9 by 300 ft. This reach contains one lock and dam but no dikes. The river sees infrequent use now.

202. The District has jurisdiction over the lower 80 miles of the Illinois Waterway from its confluence with the Mississippi River at Grafton, IL (Mississippi River mile 218), to immediately downstream of La Grange Lock and Dam (mile 80), near La Grange, IL. Channel dimensions are 9 by 300 ft. No dikes are found on this waterway.

203. The St. Louis District also maintains a 9- by 300-ft navigation channel on the Mississippi River from Hannibal, MO, to Cairo, IL, a distance of 300 miles. In the upper 100 miles (Hannibal to St. Louis, MO), navigation is aided by four locks and dams. Some dikes are located in this reach, but all are submerged. Lock dimensions are 110 by 600 ft for all locks except the replacement for Lock and Dam 26 (Melvin Price Lock and Dam), which is 110 by 1,200 ft for the main lock and 110 by 600 ft for the auxiliary lock. In the lower 200 miles, from St. Louis to Cairo, a combination of dikes, bendway weirs, dredging, and revetments are used to maintain the navigation channel. District personnel currently maintain 883 dikes on the Mississippi River. The project is not considered complete. The Master Plan is currently undergoing revision, and the project is scheduled to be completed by the year 2010. An undetermined number of dikes and bendway weirs will be constructed to complete the Master Plan.

204. The typical size of a tow on the upper 100 miles of the river within the St. Louis District (the pool area) is three barges wide by five barges long, pushed by a 3,200- to 6,000-horsepower towboat. In the lower 200 miles of open river, the usual configuration is five barges wide by five barges long for downbound tows, and five barges wide by six barges long for upbound tows.

Towboats are usually in the 5,600- to 6,000-horsepower range.

205. In 1988, 106,068,681 tons of goods were transported on the middle Mississippi River (the reach of river from the confluence with the Missouri River to the confluence with the Ohio River). Major commodities shipped and their percentage of the total tonnage included farm products (41 percent), coal (18 percent), petroleum products (9 percent), food and kindred products (9 percent), chemicals (8 percent), sand and gravel (2 percent), building cement (2 percent),and miscellaneous goods (11 percent).

Stage, discharge, sediment, and dredging

206. Highest and lowest stages ever recorded on the St. Louis gage are 43.3 ft and -6.2 ft (referenced to a gage zero of 379.94 ft MSL), almost a 50-ft difference. In a typical year, stage varies by about 20 ft. The largest discharge ever recorded at St. Louis was 1,300,000 cfs in 1844. Other high discharges were 1,016,000 cfs in 1903 and 852,000 cfs in 1973. Lowest discharge of record was 38,000 cfs in 1940. Long-term mean stage and discharge are 11.0 ft and 179,000 cfs, respectively. Bank-full stage and discharge are 30.0 ft and 495,000 cfs, respectively.

207. Anywhere from 400,000 to 1 million tons of suspended sediment is carried past St. Louis every day.

208. In the past, up to 12 dredges were used in the St Louis District. Currently two dredges are in use. The *Potter*, owned by the St. Louis District, is a dustpan type dredge. It usually works in the open river portion of the District. A cutterhead type dredge is under contract from a private firm to dredge the pool section of the river. Dredging contracts are let for 1 year and are paid on a per-cubic-yard basis. Typical cost for the dustpan dredge is $0.75 per cubic yard and $1.00 per cubic yard for the cutterhead dredge. Typically $7 million to $8 million is spent on dredging each year, but during 1988 and 1989 approximately $23 million was spent each year due to the severe drought and record low stages. During these 2 years, six additional dredges were pressed into service. Four dredges were contracted from private firms, one was borrowed from the Memphis District (the *Burgess*), and another from the St. Paul District (the *Thompson*).

Dike design and construction

209. Dike construction in the District has a long history, with the first dikes made up of screens floated by whiskey kegs. The idea behind this design was to slow down the velocity of the water so that sediment would be

deposited. The life of this type of dike was short, typically 1 year or less. Next, several different timber pile designs were employed, starting with a single row of timbers with a wire screen on the upstream face. The most successful of the pile dike designs consisted of rows of pile clumps connected by horizontal stringers. Lumber screens were added to this design to encourage sediment deposition.

210. Since the mid-1960's, Graded Stone A with a maximum 5,000-lb weight limit has been used exclusively for both dike building and repair. Most of the timber pile dikes have been filled with rock, but it was soon discovered that the rock dikes were much more effective. Therefore, only every other pile dike was filled with rock; the others were allowed to deteriorate.

211. The contraction width, which is the distance from the river end of the dike to the opposite bank, or from the river end of a dike to the river end of a dike directly across from it, is of primary importance in this District. A prototype study encompassing miles 154 to 140 on the middle Mississippi River above Cairo was completed in 1969 to determine the effects of contraction. By building new dikes and adding extensions to existing dikes, the channel width was decreased from 1,800 to 1,200 ft. Results of this study indicated that the 1,200-ft contraction width would generally develop a deeper navigation channel than the authorized 9-ft depth. After further prototype testing in the Devil's Island reach, a 1,500-ft contraction width was adopted to achieve a dependable 9-ft channel at minimum cost.

212. New dikes are angled normal to flow, are usually constructed in a stepped-down arrangement (highest dike upstream, crest heights progressively lower as one travels downstream), have 200 ft of bank paving extending downstream from the center line of the dike, do not have a marker at the river end of the dike, and are built with a uniform sloping crest profile (from the high bank elevation to around +10 ft LWRP at the river end). It was found in the past that dikes with a level-crested profile caused scour downstream of the dike at the bank; therefore, any dike having a level-crested profile now has a 300-ft section sloping from the top bank to the level-crest elevation. The first stone dikes were built with a crest width of 2 ft. After severe ice damage was sustained in 1970, it was found that the ice had sheared the tops of the dikes off, leaving a 6-ft-wide crest. Dike design specifications were modified to incorporate this, and the 6-ft crest width is now standard design practice.

213. The steps in construction of a typical dike are as follows:

a. A stone foundation is placed along the toe of the bank slope for 200 ft downstream of the dike axis.

b. The bank is generally graded to a 1V on 3H slope and graded stone 12 in. thick is placed to high bank elevation.

c. A key trench 6 to 8 ft deep and 15 ft into the bank is excavated and stone is placed in an 18-in.-thick layer from the high bank to the crest of the foundation toe.

d. One hundred feet of the dike is placed at full grade and a base at least 10 ft wide, 4 ft thick, and 200 ft long is laid out from this at the end of the work day to reduce scour. Stone is placed at grade on successive days until the design length of the dike is reached.

214. Stone is quarried at several points along the river. The stone is loaded on barges and transported to the work area, and a dragline is used for placement. This is the "floating plant" method of dike construction. Repair work is performed in basically the same manner.

215. A recent development in river training structures is the bendway weir, which was developed at WES after extensive model tests on two bends in the Dogtooth Bend physical movable-bed model. A problem for the St. Louis District is the encroachment of the point bar on the navigation channel in bends, narrowing the channel and causing towboats to "flank" (a series of stops and turns) through the bends, causing considerable delays in navigation. The bendway weirs address this problem by widening the channel through the bend. Other hydraulic benefits exhibited in the model tests include the following: sediment is deposited on the toe of the revetment on the outside of the bend stabilizing the bank, top water currents are more uniform and do not concentrate on the outside bank of the bend, and the navigation channel in the crossing downstream of the bend is deeper and wider. Two environmental benefits of the weirs are that they are submerged 100 percent of the time and have no negative effects on water quality, and they change the cross section of the bend from a deep triangle to a shallower and wider trapezoid. This shape provides more fish habitat as studies have shown that very few fish live in the deep sections of the Mississippi River. The bendway weirs are level-crested at -15 ft LWRP, spaced approximately 700 ft apart, and angled 30 deg to a perpendicular drawn to the bank line at the bank end of the weir. Length is determined by the distance from the -15-ft-LWRP contour on the outside of the bendway to the -15-ft elevation on the inside of the bend. One weir was

installed in Dogtooth Bend during the fall of 1989 and twelve more were installed in the same bendway during the 1990 construction season. Since this is a new concept, the weirs will be extensively monitored and analyzed during their first year of existence. Surveys taken shortly after the weirs were built show significant channel improvement.

Inspections

216. A low-water inspection tour is scheduled once every year, usually in June. Corps personnel also view dikes on an almost weekly basis while performing other tasks. Aerial photographs, ice floe pictures (see paragraph 231), and bed soundings taken in the vicinity of a damaged dike are integral parts of the inspection process. Riverboat pilots and landowners also report dike damage to the Corps.

Types of dike damage

217. The following types of dike damage are reported:

- a. Holes in the upper section of the dike.
- b. Flanking.
- c. Top portion of the dike sheared off (ice).
- d. Deterioration of the river end of the dike.

Causes of dike damage

218. The following causes of dike damage are reported:

- a. Ice floes.
- b. Ice dams or ice bridging.
- c. Scour at the dike root.
- d. High river current velocities.
- e. Towboat impacts, usually more numerous in tight bends.
- f. Bad dike alignment.

219. A graphic example of the almost unbelievable destructive force of ice occurred in 1970. Ice inflicted extensive damage to over 106 dikes and 26.5 miles of revetment. Repair costs were over $18 million! Again in 1977 ice inflicted over $2 million worth of damage.

Repair criteria

220. There are no established criteria for determining maintenance needs. The following points, combined with experience and engineering judgment, are considered in determining whether or not a dike will be repaired:

- a. The question "What are the consequences of failure?" must be answered. This question is usually divided into two categories: engineering consequences and political or public relations consequences. All failure scenarios need to be thought out and evaluated and the possible effects calculated. In some repair cases, this will be the most important question asked. As an example, a dike or floodwall protecting a town or populated area cannot be allowed to fail. Therefore that structure would be given first priority in any ranking of repair projects.

b. Possible loss of channel alignment.

c. Impact on private landowners.

221. Dredging is not used as a repair criterion in this District. The relationship between training dike maintenance and dredging is not readily apparent because hydrographic surveys are performed only once every 2 years, while structure maintenance is done as needed without waiting for a survey.

222. Mr. Claude Strauser, potamologist for the St. Louis District, states, "There has never been enough maintenance money to take care of all the problems; you have to set priorities." The ideal situation is to repair all problem areas within 1 year. When this is not possible, usually because of budget constraints, dikes in bendways are repaired first, then dikes in the crossings and straight stretches. Generally, damaged dikes in the bendways and crossings exhibit a quicker rate of deterioration due to the greater river forces working on them. If two problems of equal severity are encountered, the problem with the most political or public pressure is usually repaired first, although this type of pressure is not allowed to override the engineering considerations involved.

223. Again, Mr. Strauser stresses, "The final decision in many instances boils down to using engineering judgment. Variables cannot be put into an equation and an answer cranked out."

Repairs and repair techniques

224. Typically 210,000 to 270,000 tons of maximum-weight, 5,000-lb, Graded Stone A is used for dike repairs each year. Cost in place for this grade of stone runs from $5.00 to $6.50 per ton. The stone is obtained from the closest of any of a number of quarries located adjacent to the river. Between 50 and 75 dikes are repaired in a typical year. Private contractors perform all work; no dike repairs are performed by the Corps. Typically three dike repair contracts are let, each covering a 100-mile reach of the river. The length of a repair contract is 365 days, which allows the contractor to pick the river conditions that are the easiest and most economical in which to work. The contractors used are very experienced in river work and are

familiar with the guidelines and techniques used by the Corps.

225. The contractors use barge-mounted cranes with drag or clamshell type buckets for placing stone. Flat-deck material barges are used to haul the stone. They are generally loaded by trucks that back over ramps onto the barges. At the repair site the contractor is sometimes able to locate the equipment so that the stone can be dragged over the edge of the barge onto the dike. In cases where they cannot locate over the dike (flanking or repairs above the waterline), a clamshell type bucket is used for rock placement. The life of a stone dike is long, and in many cases the time between repairs is 20 to 25 years.

226. Construction inspection is critical in the St. Louis District. If substandard stone or stone with too many fines is used, the dike will deteriorate rapidly. All dike repair inspections are performed by experienced Corps personnel.

Record keeping

227. Reliable records of construction and subsequent maintenance work are of utmost importance to the St. Louis District. The histories of all river training structures are contained in "The Regulating Works Book of Contracts." All pertinent information on the dikes and dike repair contracts is contained within. Attempts to microfilm or computerize this vast amount of information have proved unsuccessful.

Environmental considerations

228. St. Louis District, through February 1986, had notched 81 dikes. Sixty-three percent of the notches were located in the middle third of the dike, 16 percent in the river third, and 21 percent in the landward third of the dike. The notch is never located closer than 100 ft from the bank. Depths of the notches vary from 2 to 15 ft, with an average of 12.3 ft. Width of the notch varied from 90 to 400 ft, but 84 percent of the notches were either 100 or 150 ft wide. The notch is either a V-shaped (49 percent) or a trapezoid (51 percent). The notch dike program has proved to be successful from both the environmental and river engineering points of view. The notches have not hurt dike performance and the few problems encountered have pertained to deep scour downstream of the notch.

New technology

229. Dike dress-up. Recently St. Louis District has required the contractor to come back and "dress up" any dikes that were repaired during

periods of high water. It is written into the repair contract that the contractor must come back during a low-water period and add rock to any thin or low areas of the repaired dike to bring it up to contract specifications. This practice has proved to increase the life of the dike with no appreciable increase in cost.

230. Discharge measurement. In recent years the St. Louis District has used an electromagnetic current meter to measure discharge. A probe manufactured by the Marsh-McBirney Company is lowered to different depths over a specified cross section. The probe measures current directions and velocities in both the x- and y-directions of the horizontal plane. This information is fed directly into a personal computer. The computer tabulates the position of the survey boat, the depth of the probe, the depth of the river bed below the probe, the x- and y-components of the velocity measurement, and the magnitude and direction of the resultant velocity vector. After all positions in a cross section are measured, then the total discharge for that cross section is calculated. This information may then be plotted, or stored on a floppy disc and fed into an 80386-based personal computer. Using the commercially available contour software package SURFER, version 4.15, this computer can plot and contour a hydrographic survey of the area. A directional surface velocity grid can also be generated and plotted. The velocity grid can be used to monitor surface velocity patterns around dikes, weirs, or dams, or in the open river. All of this activity takes place on the survey boat, giving the survey crew an almost instantaneous look at the data that were just collected.

231. Ice floe pictures. Standard practice for the St. Louis District since the mid-1970's has been to fly over the river and take color aerial photographs of the ice floes moving on the water. The floes act as giant pieces of confetti and give a remarkably clear pattern of river flow patterns. These pictures, which are to scale, are analyzed to determine how effectively the dikes are performing, pinpoint which dikes are receiving the most attack, and to study in detail flow patterns around dikes and through dike fields. This information is then used to optimize dike lengths and dike spacing in any design or redesign efforts. Pictures are taken when approximately 25 percent or less of the river is covered by ice. Usually pictures are taken in January or February, but in 1989 pictures were taken in December to study flow patterns during an extremely low stage (-4.0 ft LWRP on the St. Louis gage). Pictures are taken only on the 200 miles of open river containing emergent

training structures. Total cost of the fly-over and photo development is less than $2,500.

232. <u>Side-scan sonar.</u> An imaging side-scan sonar is used by the District to examine the bed condition of the river. The side-scan sonar can output sonar-generated pictures giving exceptional detail of bed dune formations and the underwater portions of dikes, revetments, weirs, bridge piers, and other submerged objects.

233. The sonar pictures can also be used by fish and wildlife personnel to ascertain fish population densities.

<u>Contacts</u>

234. St. Louis District engineers contacted to provide information were Messrs. Robert Davinroy, Stephen Reddington, and Claude Strauser.

St. Paul District

<u>Description of project</u>

235. The navigable reach of the Mississippi River under the jurisdiction of St. Paul District extends from a turning basin (mile 857.6) just upstream of the Upper St. Anthony Falls Lock and Dam, near Minneapolis, MN, to just downstream of Lock and Dam 10 (mile 614.0), a distance of 243.6 miles. The authorized channel dimensions are 9 by 300 ft from miles 614.0 to 815.2, 9 by 200 ft from miles 815.2 to 853.4, and 9 by 150 ft from miles 853.4 to 857.6. Three other rivers that branch off the Mississippi River are also navigable. The names, channel dimensions, and total navigable miles are as follows: St. Croix River, 9 by 200 ft, 24.5 miles; Minnesota River, 9 by 100 ft, 14.7 miles; and the Black River, 9 by 100 ft, 1.4 miles. None of these rivers contain dikes.

236. St. Paul is the northernmost of the five Districts with jurisdiction over the Mississippi River. Rock Island District is immediately to the south. St Paul District maintains 1,518 dikes on their reach of the river. A series of 13 locks and dams are the primary means of maintaining navigation depths. The dimensions of all locks are 110 by 600 ft. The upstream reservoirs and the locks and dams have little flood capacity; therefore, river flow is not considered controlled. The project is complete.

237. The river completely freezes over every year within this District.

The navigation season, when the river is free of ice, usually runs from mid-March to the end of November.

238. A typical tow size is 15 barges configured 3 wide by 5 long, with towboats ranging from 3,200 to 6,000 horsepower.

239. The amount of goods shipped through Lock and Dam 10 in 1989 was 17,887,000 tons. Major commodities and their percentage of the total tonnage included agricultural products (64.2 percent), coal (12.7 percent), chemicals (8.3 percent), petroleum products (6.3 percent), nonmetallic minerals (4.0 percent), stone, clay, and cement (2.8 percent), metal ores and metal products (1.4 percent), and miscellaneous goods (0.3 percent).

Stage, discharge, sediment, and dredging

240. All stages and discharges in this paragraph were measured at Lock and Dam 10. The peak stage and discharge of the flood of record occurred on 24 April 1965 with a discharge of 305,500 cfs and a tailwater stage of 623.61 ft MSL (referenced to the 1912 datum). The minimum flow of record occurred on 3 December 1976 with a discharge of 8,900 cfs and a tailwater stage of 603.06 ft MSL. The average discharge and tailwater elevation for the period 1859 to 1989 was 46,290 cfs and 606.58 ft MSL, respectively. Lock and Dam 10 goes out of operation (the gates are pulled out of the water) when the discharge exceeds 73,000 cfs.

241. For the period 1975 to 1989, an average of 750,000 cu yd of material was dredged each year. As stated in paragraph 176, St. Paul District owns the *Thompson*, a 24-in. hydraulic cutterhead type dredge. It dredges an average of 600,000 cu yd per year at a cost of $2.50 per yard. Approximately 150,000 cu yd per year was contracted out to private firms using mechanical dragline type dredges. A single contract for the mechanical dredging is let each year calculated on a unit cost basis. Total cost was $6.64 per cubic yard in 1989 (includes such costs as mobilization/demobilization and transportation costs). The Corps then directs the contractor to any areas that need dredging. The long-term trend within the District shows that the amount of dredging performed is decreasing. A number of factors contribute to this: surveys are more frequent and more accurate due to improved surveying equipment, channel widths have been reduced at many locations, and in many places dredging depth is being limited to -11 or -12 ft. In the mid-1970's it was common practice to dredge to -13 ft.

242. In the last few years the *Thompson* has also been loaned out to

assist the Rock Island, St. Louis, and Kansas City Districts with their maintenance dredging.

Dike design and construction

243. Within the District the channel control structures are submerged, and are called wing dams. The first structures were built between 1878 and 1920. Construction materials consisted of rock and dredged material placed on woven willow-brush mats. Their purpose was to create and maintain a 4-1/2-ft-deep channel. Most were angled upstream slightly, although a few were angled normal to the flow. The wing dams were modified, and additional structures added during the 1920's to increase the channel depth to 6 ft. In the late 1930's, a 9-ft channel was developed with the construction of the present-day lock and dam system, which submerged the training structures to approximately 2 ft below low control pool elevation.

244. The wing dams are still considered to be working effectively. Many, but not all, are marked at the river end with a navigation buoy for safety's sake.

245. Since the 1930's, virtually nothing has been done to the structures; no maintenance or repairs were needed.

246. In 1984 a program was implemented to evaluate, modify, and rehabilitate some wing dams to make them more effective. At that time six rock wing dams were built on the Mississippi River at mile 664 near Lansing, IA. Crest width was 8 ft, with side slopes of 1V:1.1.75H. Quarry-run stone with a maximum diameter of 36 in. and a minimum diameter of 4 in. was used. A front-end loader with tines spaced 4 in. apart was used to place the stone. This work decreased the amount of dredging in this area by 120,000 cu yd over the 5-year period from 1985 to 1989. In 1989 the navigation channel at Winter's Landing, MN (mile 708), was realigned with some wing dams being extended and the side channels partially closed off to increase flow in the main channel. Currently Wild's Bend, WI (mile 730), where repetitive dredging has been necessary, is being studied. Computer modeling employing the TABS-2 program (Thomas and McAnally 1985) will be used to study present-day conditions and determine the optimum channel alignment and dike design. Wildlife habitat improvement is also being studied for this area.

247. Two additional sites, Jackson Island and Smith Bar-Upper Light, are also under study. A possibility of some repair and/or a slight lengthening of the wing dams is being considered. Side channel closures and habitat

improvement are also being examined at these sites.

248. It is felt that in the future the elevations of some wing dams will have to be raised to improve navigation channel conditions at certain sites.

Inspections

249. Regular dike inspections are not carried out.

Types of dike damage

250. Holes in the upper section of the dike or general degradation of the dike are the major forms of wing dam damage.

Causes of dike damage

251. Mr. Dan Krumholtz feels that towboats running near the dikes or towboats grounding on dikes are the principal causes of dike damage. Additional damage is sustained when a towboat attempts to free itself from the dike. Since the wing dams are submerged, floods and ice are not felt to be major causes of dike damage.

Repair criterion

252. Similar to Rock Island District, St. Paul District uses dredging as its sole criterion to determine whether dike repair or rehabilitation should be performed. If dredging costs are high, the entire reach is surveyed to determine the condition of the dikes and the channel. An engineering brainstorming session follows to determine what course of action needs to be taken.

Repairs and repair techniques

253. From the late 1930's to 1990 little repair work was performed.

Record keeping

254. Even though some of the dikes date back to the late 1870's, records are fairly thorough and complete. The original construction logs are available. They contain the amounts of rock and brush used to construct the wing dams, along with the dike number, length, and elevations. All elevations are referenced to the 1864 low water datum. Although most data appear correct, dike locations in these logs are not felt to be completely accurate.

New technology

255. The St. Paul District now possesses three state-of-the-art surveying systems that have proven satisfactory. Two of the systems consist of a 35-ft aluminum boat equipped with two booms. Each boom carries four transducers. The boats themselves are equipped with one high-speed transducer. This arrangement can sweep an area up to 50 ft wide. Usually channel trouble spots are located using the high-speed transducer mounted on the boat, then the area

of interest is swept, parallel with the flow, using the full system (boat and booms). The data gathered is stored on floppy computer discs. The floppy discs are edited, in part, on the boat. Further corrections are made in the office. Data is then plotted and contoured using an in-house processing system. The engineers working with the system feel that it is extremely versatile. The survey can be enlarged, reduced, colored, plotted in three dimensions, and contoured using intervals as small as 1 ft. Mr. Dan Krumholz states that "the wing dams stand out quite well with the 1-ft contours. Enlargements to any scale can be done of specific areas within the survey area." Contours can also be plotted in a variety of colors. A study was performed on the Winter's Landing reach of the river with excellent results. This study consisted of a wing dam modification project where the new surveying equipment was used to analyze the condition of the existing wing dams.

256. Equipment consists of a Del Norte 542 positioning system, a Ross Laboratories depth system, a Hewlett Packard 9020-C computer for data logging and processing, and a Hewlett Packard 7585-B plotter. All software used is supplied by Ross Laboratories.

257. The third surveying system consists of a small trailerable boat with a similar survey and positioning system, but with only one transducer. It is used at remote locations and in shallow water.

258. These systems has helped tremendously with the accuracy, cost, speed, and presentability of survey information.

Contacts

259. St. Paul District engineers contacted to provide needed information were Ms. Donna Jones and Messrs. Jon Hendrickson, Dan Krumholtz, and Clifford Schlueter.

Tulsa District

Description of project

260. Navigation in the Tulsa District starts on the Arkansas River at Fort Smith, AR (mile 308.6), goes upstream to the mouth of the Verdigris River (mile 395), and follows that up to the head of navigation at Catoosa, OK (mile 445.3). Channel dimensions are 9 by 250 ft on the Arkansas River and 9 by 150 ft on the Verdigris River. A 13.8-mile reach of San Bois Creek, which empties into the Robert S. Kerr Reservoir, is also navigable. Channel

dimensions are 9 by 225 ft. This waterway was originally built to transport coal out of the Keota area but is now used infrequently. Navigation on the Arkansas River from Fort Smith downstream to the mouth is under the jurisdiction of the Little Rock District. Tulsa District is responsible for the upkeep of 114 dikes on its reach of the Arkansas River. No dikes were built on either the Verdigris River or San Bois Creek. Within Tulsa District a series of five locks and dams with a total lift of 141 ft aid navigation. Two are located on the Verdigris River and three on the Arkansas River. The lock size on all five is 110 by 600 ft. The two highest lock and dams incorporate hydroelectric power plants with generating capacities of 110 and 60 Mw of power. A feasibility study is now underway to determine the benefit/cost ratio for a low-head power plant at Lock and Dam 14.

261. The standard tow size on both the Verdigris and Arkansas Rivers is eight barges in a three-wide by three-long configuration with the towboat occupying the middle slot in the last row of barges.

262. Shipping tonnage is approximately 3.5 million tons per year and consists mainly of coal, petroleum products, grain, and fertilizer.

<u>Stage, discharge, sediment, and dredging</u>

263. The flood of record occurred in May of 1943 with a stage of 38.0 ft (referenced to a gage zero of +372.4 ft MSL) and a discharge of 850,000 cfs at the Van Buren gage (located just upstream of Lock and Dam 13). The largest flow since the project was completed was in October 1986. At the Van Buren gage the stage was 34.74 ft with a discharge of 384,000 cfs.

264. There are approximately 30 reservoirs, with 11 having significant flood storage capacity within this river system, giving the Corps a great deal of control over a wide range of flows. The system operating plan is as follows:

- <u>a</u>. If the storage reservoirs are less than 40 percent full, then the discharge flow is dependent on the current amount of storage.

- <u>b</u>. If the storage reservoirs are more than 40 percent full, then 150,000 cfs will be allowed to pass at the Van Buren gage for as long as is needed until the reservoirs are again less than 40 percent full. This flow would be 2 ft above flood stage.

- <u>c</u>. If the reservoir storage capacity is 100 percent full, then, of course, whatever enters the system will be discharged from the system.

- <u>d</u>. A tapered recession of flow is employed. The flow is not dropped by more than 20,000 cfs during a 24-hr period. Through

> experience it has been found that the coarser sands drop out quickly, causing shoaling problems downstream of the locks and dams in both the Tulsa and Little Rock Districts.

265. Sediment on the Verdigris consists mainly of coarse sands and gravels, while on the Arkansas River sand is the major sediment component. Dredging amounted to 50,000 cu yd during 1989. The average per year is 100,000 cu yd, but this varies from 40,000 to 400,000 cu yd dependent on river stages and other factors. All dredging is performed by a private contractor using a cutterhead type dredge. Average cost is slightly more than $1 per cubic yard.

Dike design and construction

266. Prior to 1937 the entire Arkansas River was under the jurisdiction of the Little Rock District. In 1946 the McClellan-Kerr Arkansas River Navigation System (encompassing the Arkansas and Verdigris Rivers, San Bois Creek, the lower 10 miles of the White River, and the Arkansas Post Canal) was authorized. Construction started in 1957. The project was completed and opened to navigation in 1970. The first commercial vessel to travel the entire length of this waterway ended its journey at the Port of Catoosa on 21 January 1971 at precisely 2:20 pm.

267. From the late 1940's through the 1950's 33 single-row pile dikes were constructed using treated timber piles. All have since been converted to stone-filled pile dikes. These early pile dikes were not navigation channel training structures. Their purpose was to keep the river from changing course during times of high flow. The dikes were intended to encourage deposition, and having accomplished their purpose, are now buried in sediment. Since the early 1960's, 81 dikes have been constructed of either maximum-weight 2,000- or 1,000-lb stone. The stone size used is dependent on dike location and the amount of attack from the river. The construction method used for dikes built from 1960 to 1965 was end dumping; and for dikes constructed from 1966 to 1970, floating plant construction methods were employed. Crest width is specified as a 10-ft minimum for either method of construction. For long dikes built by end dumping, truck turnarounds were built on the downstream face of each dike. Dike fields were constructed starting with the upstream dike and working downstream. Dikes are level-crested at an elevation 16 ft above the CRP. The riverbank at the root end of the dike was paved 20 ft upstream and 200 ft downstream of the center line of the dike.

268. No dikes were built from 1970 to 1988. One dike was constructed in 1989 and three more dikes were scheduled to be constructed in 1990.

269. Each year the Tulsa District Operations Division and towboat industry personnel meet to discuss navigation problems. From this meeting dikes identified as potential hazards are marked with a 10-ft-long, 4-in.-diam iron pipe set in a trapezoidal concrete base. Reflective tape is wrapped around the pipe to increase visibility. When flows are high, or if drift hits the marker, it sometimes falls over. District personnel then must go out and set it upright again. This design has proved very satisfactory, and over the years very few have been lost.

Inspections

270. Two inspections involving personnel from both the Operations and Engineering Divisions are carried out every year, usually in the spring and fall when water levels are low. The fall inspection trip covers the entire length of the McClellan-Kerr Arkansas River Navigation System and is staffed with personnel from both the Tulsa and Little Rock Districts. This inspection gives these Districts a better feel for the overall condition of the entire river system. Observations from these inspection trips are recorded under the title "Report of Maintenance Inspection." Data gathered during the spring inspection are used to prepare repair contracts for the summer construction season.

271. The buoyed lines of the navigation channel are surveyed once a month. During these trips, general river conditions (including the condition of all dikes) are checked.

Types of dike damage

272. The following types of dike damage are reported:

a. Bank sloughing at the dike root.

b. Vertical displacement of stone.

c. Displaced dike end marker piles.

Causes of dike damage

273. The following causes of dike damage are reported:

a. High water and associated wave action.

b. General deterioration.

c. Fishermen with dynamite.

d. High flows or debris which tip over the concrete and steel pipe dike end markers.

274. The most serious damage to dikes within this District has occurred at the confluence of two rivers or where a major tributary enters a river.

Repair criteria

275. The following criteria are used to determine when, or if, a dike is in need of repair, or redesign and reconstruction.

a. Shoaling of the main channel.

b. Amount of dike deterioration, a judgment call made by the engineer in charge based on experience and knowledge of the river. Degradation of from 1 to 3 ft or more usually requires attention.

c. Availability of funds.

Repairs and repair techniques

276. Approximately $50,000 is spent on revetment and dike repair each year, but the majority of this is spent on revetment repair. An average of five dikes are repaired each year. The dikes require very little maintenance. Not much repair work was performed during the 1980's. Very small jobs, requiring three or four dump truck loads of stone, are carried out by Corps personnel, but generally most work is performed under contract with a private firm. Contracts are let for either a single dike or all dikes within a pool that require repairs. The contractor that performs most of the repair work owns a quarry and rock is barged from there. Maximum weight 1,000-lb stone, with at least 40 percent 400 lbs or more, and 8 percent or less fines smaller than 1/2 in., is used for most dike repair. Stone with a 2,000-lb maximum weight is used in some areas where velocities are high and attack by the river is great. Most repair work is performed using floating plant equipment. Rock is placed with a barge-mounted crane using a clamshell type bucket. When shore work is required, excavation of trenches and placement of stone are commonly done with a back-hoe. When the dike has degraded slightly and a small quantity of rock brings it back up to grade, the dike is said to have been "sweetened."

277. The project has been operational for 20 years. As stated earlier, relatively little dike repair has been performed. Mr. Dennis Johnson feels that this is changing and more repair work will be required in the future.

Record keeping

278. The original as-built construction drawings are kept on file. When a dike is surveyed and/or repaired, these data are filed with the as-built

construction drawings. While not an official title, this data file is referred to as the "As Builts."

Contacts

279. Tulsa District engineers contacted to provide information included Messrs. Dennis Johnson, Alfred Steele, John Walker, and Jim Wilson.

Vicksburg District

Description of project

280. Major rivers within the Vicksburg District include the Red River, the Yazoo River, the Arkansas River, the Ouachita River, and the Mississippi River, but essentially all of the District's training structure maintenance efforts are focused on the Mississippi River at this time. A major navigation project on the Red River is currently underway with five locks and dams and several river stabilization and control structures either planned, under construction, or recently completed. However, since the project is new, little repair work has been needed.

281. Vicksburg District has responsibility for approximately 280 miles of the Mississippi River, from mile 599.0, at the confluence of the White and Mississippi Rivers, to mile 320.6, upstream of the Old River Control Structure. The District also has maintenance responsibilities for dikes and revetments on the left descending bank of the river from mile 614.0 to mile 599.0. No locks or dams are located within this District. Memphis District has jurisdiction on the river immediately to the north, and New Orleans District to the south.

282. Channel improvement works in this District began prior to 1900. From 1936 to 1944 river work was limited to bank protection works and increasing the discharge capacity of the river. Major stabilization works and channel alignment for flood control and navigation began after 1944. A channel improvement project review was completed in 1956, and a long-range Master Plan, designed to bring about the desired alignment of the Mississippi River, was initially developed at that time. The Vicksburg District uses a combination of revetments, dikes, and dredging to maintain the 9- by 300-ft navigation channel (a 12- by 300-ft channel is authorized). Work on the river is authorized and funded by the Mississippi River and Tributaries Act of 1928.

283. The project within this District is not considered complete. One hundred and eight dikes are scheduled to be built on the river between 1988

and 2010 to complete the Master Plan for the District. Plans call for four to five dikes to be built each year.

284. The standard size of a tow on this section of the Mississippi River is 30 to 35 loaded barges downbound and 30 to 45 barges upbound, depending on river conditions and the mix of loaded and empty barges within the tow. Towboats range from 5,600 to 10,500 horsepower.

285. Approximately 169 million tons of commodities were shipped in 1988 on the reach of river under the jurisdiction of the Vicksburg District. Some major commodities shipped include coal, corn, soybeans, animal feed, chemicals, articulated concrete mattress, wheat, and gasoline.

Stage, discharge, sediment, and dredging

286. The flood of record occurred on 17 and 19 February 1937 with a discharge of 2,060,000 cfs and a stage of 52.7 ft (referenced to a gage zero of +46.2 ft MSL). The lowest flow of record occurred on 21 August 1936 with a discharge of 93,800 cfs and a stage of -3.4 ft. Flood stage is 43.0 ft with an associated discharge of 1,460,000 cfs. The preceding stages and discharges were measured at the Vicksburg, MS, gaging station.

287. The suspended sediment load on the Mississippi River (measured at Natchez, MS) for the period 1984 to 1989 averaged 102,081,000 tons per year. Of this total 22 percent was sands (mostly fine sands) and 78 percent was silts. Bed load material consists of medium to coarse sands and some gravel.

288. From 1984 to 1989 an average of 2,285,500 cu yd of material were dredged each year. Total cost per cubic yard varied from $0.32 to $0.76, with an average of $0.59 for the entire period. Most dredging is performed using two dustpan type dredges, the *Jadwin*, owned by Vicksburg District, and the *Lenel Bean*, owned by a private contractor and under year-round contract to the Memphis District. In addition to working in Vicksburg District, the *Jadwin* is usually loaned out to New Orleans District for a good portion of each year.

Dike design and construction

289. The first dikes were constructed of untreated timber piles. Two to three piles would be driven close together and bound with wire rope to form a clump. Dikes usually consisted of from one to three rows of clumps.

290. From 1964 to 1976 all dike construction and repair used a 3,000-lb, maximum-weight, graded stone. Since 1977 5,000-lb, maximum-weight, Graded Stone A has been used. Over the years, in the course of repair and improvement works, the pile dikes have either been converted to, or replaced by,

stone dikes. Of the 173 dikes on the Mississippi River, all but 5 are either stone dikes or stone-filled pile dikes. The few remaining pile dikes are found in the back channel areas. For the most part dikes in this District were built for flood control or to control the navigation channel. The dikes accomplish the following: constrict the channel and stabilize crossings, prevent or limit development of secondary channels, control long straight reaches, and provide bank protection. From experience it appears that the location of the dike system is the most important design parameter, and the river alignment generally dictates where the dikes will be located. The District generally constructs the dike systems in areas of natural deposition, such as a point bar.

291. The design parameters presently used are very much site dependent. The bank end of the dike usually extends from 100 to 300 ft into the bank (excavated trench filled with stone), depending on the amount of attack the dike is expected to receive. Since the dike is deeply rooted, bank paving is not generally employed, except in special cases where it is not possible to excavate the trench for a dike root. Dike height is not governed by a general criterion, and in a dike system, dikes may be stepped-up, stepped-down, or the same elevation. The dike profile is sloped over the entire length of the dike with the first 200 to 300 ft coming from the top bank elevation down to approximately midbank height. The stream end is usually 7 to 12 ft above the existing channel bottom with an end slope at times as flat as 1V to 10H. The dike spacing depends on the river alignment and the dike length is a function of the river width (measured from top bank to top bank). The dike angle is such that the bank end is perpendicular to the bank line and the stream end is perpendicular to the flow. Therefore, in some cases, the dike is not straight, but "broken." Three methods of building dikes in stages are employed: vertical stages (or lifts) on individual dikes in a single construction season, construction of a dike field starting with the upstream dike, and vertical construction in stages over a period of years that allows sediment to accumulate within the dike field, resulting in a savings in rock. The floating plant method of construction is preferred and is used where the water is deep enough for floatation of plant. End dumping from trucks is the usual method of construction when building dikes on bars in dry conditions. These dikes are generally short and therefore are built extra wide for strength and stability (this helps to maintain the crest elevation). Crown

widths vary from "peaked" to 5 ft for dikes constructed using floating plant, and 14 to 25 ft wide for hauling equipment (end dumping) applications. Dike end markers are not used, but if the end of the dike is close to the navigation channel, a standard channel buoy is used as a marker. Generally, stone dikes have been found to be very effective and quite durable.

Inspections

292. At least one, and sometimes two, low-water inspection tours are carried out each year to specifically inspect dikes and revetments. These consist of a dike-by-dike onsite inspection and include hydrographic surveys for underwater portions of the structures. Survey boats are routinely used to inspect dikes and, where possible, survey damaged dikes to determine the depth and width of failure areas. Aerial reconnaissance is also used for dike inspection.

293. Damage is sometimes reported by personnel on the Corps survey boats or by District personnel on the channel patrol boats used to set channel buoys.

Types of dike damage

294. The following types of dike damage are reported:

a. Flanking at the bank end of the dike, which usually happens when the dike is first built.

b. Holes through the upper portion of the dike. These can be anywhere from 100 ft wide to 600 ft or more, but usually are in the 200- to 300-ft range.

c. Loss of dike at the river end (due to scour).

Causes of dike damage

295. The following causes of dike damage are reported:

a. High flows (scour around dikes).

b. Major floods (high flow over dikes).

c. Towboat impacts.

Repair criteria

296. Since repair monies are limited, all dikes requiring repair are studied and prioritized according to severity of damage. It has been found through experience that the height of the structure is usually of greater importance to proper dike function than the length. Therefore, as soon as money is available, dike height is restored to as-built specifications.

297. If 50 to 100 ft of a dike's length has been lost, it is usually not

repaired, but the effect of the dike on the navigation channel would be analyzed. If shoaling or loss of navigation channel width results, the dike is repaired. If more than 100 ft of the dike is lost, it is usually repaired as soon as monies allow. Due to the continuous character of the maintenance program, the relationship between dike deterioration and repair and the need to dredge is not clear.

Repairs and repair techniques

298. Two types of repair contracts are let in the Vicksburg District, major and minor. Approximately 120,000 tons of rock are used for dike repairs during a typical year.

299. Approximately $1 million per year are spent on major repair contracts. With this type of contract the repair sites and amounts of stone are detailed and specified. Stone costs from $7 to $9 per ton, and is barged in from quarries located in Kentucky and Missouri.

300. Funding for the minor dike repair contract generally runs about $150,000 per year. Cost in place is from $11 to $14 per ton. This is an open-ended contract, wherein the contractor can be directed to work anywhere on the river, dependent upon need.

301. The life of a dike generally depends on the following:

a. The river's unpredictable behavior.

b. Major floods.

c. Riverflow.

d. Dike configuration.

e. Navigation operations (usually minimal damage)

Record keeping

302. All records of dike maintenance are contained in the "Channel Improvement Data Report." Copies are maintained of the as-built drawings for each dike in the District. Each time the dike is worked on all information pertaining to that work is recorded on the original as-built drawing. This method ensures that the entire history of the dike is contained on one sheet.

Environmental considerations

303. Approximately 10 percent of the dikes within the Vicksburg District have been notched over the last several years. In most cases with a deteriorated dike, an area is simply left low. Some newly built dikes have also been notched; in fact, where space allows, two notches have been employed. Typically the notch is 25 ft wide at the bottom with side slopes of 1V on 5H or 1V

on 10H. The bottom elevation of the notch can be anywhere from 5 to 20 ft below the elevation of the surrounding dike. The notches are designed to increase flow through the dike, thereby creating a larger backwater area with improved water quality for wildlife and fish habitat. More information on dike notching can be found in paragraphs 40-42.

Contacts

304. Vicksburg District engineers contacted to provide information included Messrs. T. K. Grant, Danny Harrison, Jim Hines, Henry Noble, John Sadler, and Jerry Stewart.

PART III: REPAIR LEVEL GUIDELINES AND RECOMMENDED REPAIR PLANNING PROCEDURES

Introduction

305. With such a diverse group of rivers and river systems, a set of rigid recommendations to encompass every situation encountered would be next to impossible to formulate. The following, therefore, may be interpreted as more of a philosophy, path, and guide, rather than a rigid set of rules.

Inspections

306. Systematic inspection, photography, and surveys are essential parts of dike repair work and can benefit a river project in many ways. Accurate inspections in many cases can be very cost effective. A brief review of both site inspection and survey advantages and techniques follows.

Site inspection

307. The necessity for onsite inspection of the river and river training structures is obvious. Assessment of conditions is impossible otherwise. Less obvious is the need for observing the river upstream and downstream of the structures. Changes here may have a significant future impact on these training works. Aerial inspection is usually cost effective. Oblique and/or vertical photography is particularly useful in documenting progressive changes. Photographs can serve four primary purposes: document changes more reliably than memory; can be used in the office while reviewing river conditions or designing repairs; are useful in briefing higher levels of command; and are helpful when justifying increased repair funding levels (see paragraph 339). Persons working or living close to the project (locals) should be encouraged to observe and report their findings to District personnel.

Surveys

308. Two types of surveys are generally carried out: monitoring and design. Monitoring surveys must be comparable to previous surveys; i.e., cross sections must be at the same location and have common stationing, whereas surveys for design or repair work should be tailored to the specific one-time need. Spending enough time and money for adequate surveys for design of repairs will usually result in an overall savings of time, materials, and

money. Repair work will be optimized and scour holes and other hazards can be identified and avoided.

309. No matter what inspection techniques are employed, at a minimum, enough information must be gathered to allow the District to perform the following:

a. Establish a baseline condition for all structures in the project. Depending on circumstances and the amount of information available, this baseline condition could consist of as-built drawings, original construction drawings, or if those materials are not available or accurate, a complete recent survey and detailed inspection of all structures.

b. Accurately evaluate the rate of deterioration of all structures.

c. Accurately determine the cause and effect between events on the river and the damage these events do to the river structures.

d. Perform inspections often enough so that all repair work can be planned and executed in an orderly manner. Emergency situations with their inherently higher costs should be avoided if possible (the no-surprises strategy).

e. In the event of damage, to make an accurate estimate of the volume of material needed to repair or reconstruct the structure.

f. Determine in the case of extensive damage whether or not the dike should be rebuilt on the original alignment (i.e., to avoid scour holes and save rock).

g. Make enough information available to accurately prioritize all repair work if a shortage of funds is anticipated.

310. Inspection methods employed to satisfy the preceding seven objectives will depend largely on the specific circumstances the District is faced with, the funds available, and the inspector's judgment. The particular methods used should yield the most effective rate of return of information per dollar spent. In most cases it is advantageous for the inspector, or inspectors, to be as familiar as possible with the project. Inspections should be performed after the spring high-water period and also after any unusual events (drought, flood, rapid rise or fall of river stages, etc.). Other regularly scheduled inspection trips are usually based on the District's past experience and the amount of funds available. One point to remember is that the first 2 years and the first major flood flow are critical periods in the life of new river training works. A by-product learned from frequent inspections is

insight into river behavior, which can be useful in future repair and design work.

311. Due to the obvious differences between the Districts with submergent structures (Rock Island and St. Paul) and the Districts with emergent structures (all the rest), the following points of interest for the Districts to consider will be divided into two sections, "Emergent structure inspection" and "Submergent structure inspection."

Emergent structure inspection

312. Videotape/low-water inspection trip combination. As the Mobile and Omaha Districts have shown, videotaping the river from the air has proved to be an excellent tool for the purpose of dike inspection (see paragraph 106). This low-cost technique gives a good overall view and feel for what is happening on the river, but of course cannot deliver the details. Therefore, to combine the strong points of the aerial videotape with the strengths of an on-site inspection would seem to be an appropriate and prudent course of action. Normally the most important examination is the first low-water inspection of the calendar year. For many Districts this is the first chance to observe the river after winter ice and/or spring high water. Many repair decisions for the upcoming low-water construction season will be based on information gathered during this inspection. Unfortunately the inspectors and engineers making the trip are usually unaware of even the general location or extent of damage that has occurred. Therefore, an aerial videotape shot prior to this inspection trip and studied by the inspectors beforehand would be extremely helpful in preparing the participants on what to expect, and at which locations they should concentrate their powers of observation during the tour. This procedure should result in the gathering of more complete and detailed information.

313. Late-season videotape. An aerial videotaped fly-over of the river in the late fall would establish an excellent baseline with which to compare the videotape shot in the spring. This comparison would be helpful in establishing when damage had occurred, and benefit in determining cause and effect relationships between river events and observed dike damage. Taping in the fall without leaves on the trees would also help in the evaluation of bank and secondary channel conditions.

314. Ice floe pictures. For several years St. Louis District has taken a set of aerial photographs when the ice floes are moving freely on the river as

a means of analyzing dike performance. The ice floes act as giant pieces of confetti, and give a detailed pattern of river flow in and around the dikes and dike fields. These pictures are used to analyze current dike performance and to optimize dike length and dike spacing in any dike design or redesign efforts. For more information, see paragraph 231.

315. Inspection training for noninspectors. As many of the Districts have mentioned, dike damage is reported by various Corps-employed work crews while performing other duties on the river. Many of these crew members are hired on a seasonal basis and are not always familiar with the dikes or the river. A short inspection orientation course to familiarize these workers with the navigation project, the river structures, the purpose of the river structures, and what to look for in the way of dike damage should result in earlier, better, and more detailed information.

Submergent structure inspection

316. Surveying. Until recently, inspection of submergent structures was nearly impossible and economically unfeasible. With the advent of new technological advances in survey equipment (see paragraphs 255-258), this is no longer true. The system in use by St. Paul District can contour at intervals as small as 1 foot and has proven to be an extremely accurate method of surveying dikes.

317. Establishing structure baseline conditions. The Districts with submergent structures need to execute a comprehensive survey of all dikes to determine the exact locations and present condition, or whether or not the dikes are still even in existence. Many of these structures are very old (60 to 100 years) and have never been surveyed. A survey would give the District the needed information to plan dike repairs and dike modifications in advance, without having to rely on the amount of dredging performed, which is the sole repair criteria in use today. Once a baseline condition of the dikes is established, the Districts would then be able to start to determine cause and effect relationships between river events and dike damage. Then future dike repairs can be accomplished before the dikes deteriorate and allow channel shoaling, thus preventing expensive dredging. If dredging costs could be reduced by timely dike repairs, this would result in a sizeable savings for the District involved.

Repair Criteria

318. River engineering is by no means an exact science. In most cases the engineer must use personal experience learned on a particular section of river as guidance. In many cases, what works on one river, or stretch of river, cannot be transferred to another stretch and be expected to work as well, or in some cases, at all. In fact, results could be the exact opposite of what was anticipated. Mr. Danny Hare of the Rock Island District noted, "It is important to recognize that maybe one end of the river has different characteristics than the other end of the river and things that you might say in general for one reach of the river are not really applicable, or so applicable, in another reach."

Repair criteria parameters

319. Many Districts use certain physical parameters, or combinations of parameters, to determine when or if a dike is in need of repair. Some parameters will have specific threshold values set by the District. These thresholds, when exceeded, indicate from past experience that the dike needs to be repaired. Typical parameters in use by some Districts include:

- a. Loss of dike length.
- b. Loss of dike height.
- c. Navigation channel becoming too shallow or too narrow.
- d. The river becoming wider than desired (unconstricted).
- e. The dike becoming flanked and separating from the bank.
- f. Presence of serious bank erosion.
- g. Environmental consequences.
- h. Frequency of dredging operations or large volumes of material dredged.

320. Mr. Claude Strauser, potamologist ith the St. Louis District, states, "The final decision (on dike repair) in many cases boils down to using engineering judgment. Variables cannot be put into an equation and an answer cranked out." With that statement in mind, and using all knowledge and experience obtainable, some or all of the following questions and sources of information must be reviewed, analyzed, and answered by the project engineer before final decisions on dike repair can be reached:

- a. Is the dike needed (Robison et al. 1988)?

b. Does the amount of damage present exceed any of the dike repair parameter thresholds currently in use by the District?

c. Does the condition of a single dike, or the entire dike field, need to be analyzed?

d. What negative impact(s) is the deteriorated dike having on the surrounding waterway (inadequate navigation channel width or depth, etc.)?

e. Can the "rate of deterioration" of the dike be ascertained?

f. Can the cause and effect between events on the river and the damage incurred on the training structures be accurately determined? In some cases answering this question can lead to a change in dike design criteria. St. Louis District ran into a problem of ice shearing off the tops of the dikes until the crown of the dike was 6 ft wide. All dikes up to that time had been built with a crown width of 2 ft. After investigation and review, a decision was reached to build all new dikes with a crown width of 6 ft, thereby solving this problem.

g. A review of records is now in order to determine if a similar situation has existed in the past, what was done then, and what results were obtained from the corrective actions taken.

h. What are the frequency of dredging and quantities dredged in the immediate area? What are the costs associated with this activity?

i. Have any towboat groundings been reported in the area?

j. How much of the river is affected by the dike because of its present deteriorated condition?

k. How much of the river will the dike affect if it is repaired and/or redesigned and modified?

l. What are the environmental effects of any dike repair or modification work?

m. What are the environmental effects of not performing any repair work?

n. Does the dike need to be repaired back to the as-built specifications? In some cases the dike might not have to be repaired back to as built specifications. A partial repair could be all that is needed.

o. Did the dike perform up to original expectations? If not, then some dike modification or enhancement would seem to be in order.

p. Is the dike located in an area of the river where it is under heavy attack from the forces of the river? Normally the first and second upstream dikes in a dike field or dikes located in a bendway receive the brunt of the river's fury.

q. Is the attack on the dike by the river likely to increase or decrease? In some cases dike damage could cause increased attack. As an example, a low section of a dike could allow concentrated flow through the dike. If unchecked, this flow could further degrade the dike, thereby causing additional damage and further attack.

r. Will the structure still be functional without maintenance? If so, what percentage is this of the dike's normal performance before the damage occurred?

s. What effects will the specific site geomorphology have on the dike repair?

t. What are the "consequences of failure"? In other words, what effects will be felt if the structure were to fail? This question has many ramifications. There are of course the engineering consequences (such as effects on the river and the navigation project), effects of possible bank failure or damage, and political or public relations consequences (loss of dwellings or farmland, loss of life, etc.). In some cases this will be the most important question asked. For example, if a structure is protecting a town or populated area, it cannot be allowed to fail, so that structure would be repaired first and at any cost.

u. What is the cost of the planned dike repair work?

v. If the cost of all needed dike repair work exceeds the money available for repairs, which repairs get funded and which repairs get delayed (prioritized)?

Prioritization

321. A District's capability for maintenance depends on many variables: river conditions, budget, manpower, environmental considerations, and amount of construction equipment available. However, the limiting factor is usually the amount of money available. In many cases there is not enough money to do all repairs that the engineers deem necessary; therefore, the District has to set priorities. First, all proposed repair projects have to be analyzed and ranked according to importance. The high-priority repair jobs are performed first and the less important repairs are delayed, usually until the next fiscal year or the next low-water construction season. A few of the important questions to consider when prioritizing repair jobs are as follows:

a. What are the consequences of failure?

b. What is the rate of deterioration of the dike?

c. How much more will channel maintenance (dredging, etc.) cost if dike repair work is delayed?

d. If an estimate of the cost of the delayed repairs can be made accurately, when compared to the cost of repairs if performed immediately, is the delay reasonably cost effective?

322. Another possibility worthy of consideration is that partial repairs

on a number of dikes might be performed with fewer detrimental effects and lower long term costs than if some dikes are completely repaired and others receive no attention at all. In some situations the river will work to the engineer's advantage if the dike is partially repaired and the river deposits sediment in that area. The second phase of repair work will then cost less as less rock will be needed to complete the repair work.

Dike Repair Construction Techniques

323. As many of the major navigation projects near completion or have been completed, the significance of the maintenance aspects of these projects will intensify. Certainly the age of the projects will be increasing, and in some cases, with this increased age will come increased maintenance. The costs associated with this maintenance must be analyzed, and reduced whenever possible.

324. The diversity found among the various Districts and the rivers they work on precludes making a fixed set of repair technique recommendations. Obviously all of the Districts and/or contractors employed by the Districts have vast amounts of experience working on their respective rivers and have learned through this experience what works best, and the most economical ways in which to accomplish the work. This experience, coupled with new technology, will be the ticket for Districts to survive the tight budget years ahead and still be able to maintain a viable and fully functional project.

325. The following paragraphs discuss two recent developments in construction repair techniques for all Districts to analyze, and where practical, put to use.

326. Dike dress-up. One point brought out by Mr. Greg Bertoglio of St. Louis during the REMR Workshop was the fact that the St. Louis District requires the contractor to come back and "dress up" dikes that were repaired during periods of high water, as described in paragraph 229. This term means that the contractor comes back to the repaired dike during a low-water period and adds rock to any low spots or areas where the dike is thin or not up to the repair contract specifications. This has proved to increase the life of the dike with no appreciable increase in costs.

327. Bottom-dumping rock barges. Both Portland and St. Paul Districts have used bottom-dumping barges during dike construction and repair with

excellent results. In the case of the Portland District, these barges were used in the construction of a series of seven underwater sills in a deep-draft channel. Rock needed to be dumped through more than 70 ft of water with as much accuracy and control as possible. The bottom-dump barges worked extremely well in this regard. In fact, the as-built surveys show a crest variation of only ±1 ft. The dump barges used by the Portland District are standard size (35 by 200 ft) and draft 10 to 12 ft, but differ from a standard barge in the fact that the barge is hinged at the bow and the stern. The barge is loaded with stone, either by crane or Ute (a large off-road dump truck), towed into position, aligned, and the load of rock dumped out through the bottom of the barge. Using this method, rock placement is extremely accurate, saving both time and material.

Record Keeping

328. As in any endeavor where history plays an important role, complete and comprehensive records are a valuable necessity. The importance of this within the field of dike repair cannot be overemphasized.

329. A concern voiced by many during the REMR Workshop was the fact that the knowledge and experience of the "Old Guard" river engineers are rapidly, through death and retirement, being lost forever. Most of this knowledge is not written down, and is in fact irreplaceable. Supplanting the Old Guard will be a pack of young, bright, eager, high-tech engineers, who unfortunately will lack the vast experience of the retirees. Many of these young engineers might not ever have the opportunity to evaluate, design, and construct a dike field. For this reason the repair records of the dikes must be kept as up to date and complete as possible. In fact, they will have to become more than records, for in many cases they will be the only guide that the young engineer will have. Besides the factual information, these records need to include the thinking and decision-making process of why dikes were or were not repaired, and how these decisions were made. In other words, what path and what variables did the planners and engineers consider in coming up with their recommendations on whether or not to repair certain structures, and if repaired, to what extent should they be repaired and/or redesigned?

330. The factual data needed for dike repair records should begin with the original construction contracts and as-built drawings along with such

documents as all subsequent repair contracts and drawings. The factual information should at the minimum include, but not be limited to, the following:

a. Type of structure: dike, revetment, etc.

b. Structure number.

c. Location by:

(1) River mile.

(2) Region/basin.

(3) Congressional District.

(4) County.

(5) State.

(6) Beginning and ending stations.

(7) Bank of river, either left or right.

d. Cost of the original structure.

e. Cost of any repair work done to the structure.

f. How work was funded, either with new construction funds or maintenance funds.

g. Type and amounts of material used in construction or repair: i.e., timber piles, stone.

h. Whether or not the river end of the dike is marked with a marker pile.

i. Elevations of:

(1) Marker piles.

(2) Pilings.

(3) Stone.

j. Crest width.

k. Work contract number.

l. Type of labor used: contract or hired labor.

m. Description of work performed.

n. Year original dike was built.

o. Dates of any subsequent repairs.

p. Listing and details of unusual features of the dike, i.e., environmental notches and truck turnarounds.

q. Angle of the dike to the bank, and, if possible, the reasoning or philosophy behind it.

r. All drawings, layouts, sketches, contracts, as built drawings, specifications, and other documents associated with the dikes.

s. A synopsis of all factors considered, and the thinking and decision-making process that transpired before the determination was reached to repair the dike.

331. Of course, even with complete and accurate logs of dike construction and repair on hand, the information needed to analyze and make future dike repair decisions would not be complete. Dredging records, information on towboat groundings (US Coast Guard Records), and channel surveys are also used extensively in the dike repair decision-making process. Many times channel conditions or the amount of channel maintenance performed were the factors that caused the condition of the dikes to be examined in the first place.

New Technology

332. The explosion in technology produces new products, equipment, and techniques almost daily, many of which could, and should, be incorporated into the field of dike repair. Districts in the future will need to make a concentrated effort to keep up with the new technology, but the sheer volume and diversity found in the marketplace will make this a difficult task.

333. The following is a list of new methods and new technology discussed in this report that are currently used by some Districts:

- a. Notches in dikes. See paragraph 40. Notches are also used by the Omaha, St. Louis, Memphis, and Vicksburg Districts.
- b. Inexpensive aerial photography. See paragraph 109. This technique is also used by the Omaha District.
- c. New design dike marker piles. See paragraph 110.
- d. Value engineering pile dike maintenance report. See paragraph 168 and Robison et al. (1988).
- e. State-of-the-art surveying system. See paragraphs 255-258.
- f. Dike dress-up. See paragraph 229.
- g. Discharge measurement. See paragraph 230.
- h. Ice floe pictures. See paragraph 231.
- i. Side-scan sonar. See paragraph 232.
- j. Bottom-dumping rock barges. See paragraph 327.

These topics need to be reviewed, analyzed, and where possible, adopted and used by the various Districts.

334. Some Districts have discovered new products, equipment, and techniques (see preceding paragraph) that have been invaluable in saving precious time and money. Unfortunately, information about these discoveries, even when

put to use and proven by a specific District, is not usually shared with the other Districts. Some form of effective communication needs to be employed to rectify this situation.

Technology Transfer

335. A biannual or annual newsletter would be extremely helpful in communicating advances in new products, new technology, or improved methods of performing dike repairs. At present there is little or no formal communication between the various Districts listed in this report regarding applicable new technology. A newsletter would provide a forum in which the Districts could give short, but detailed, reports of new products, equipment, software, and other advances with examples of what they could do, how they could be applied, and the final results obtainable. The newsletter could also provide information to the other Districts of any new or improved techniques or procedures that a District had come up with to solve a specific problem or improve the efficiency of performing any task involving or related to dike repair.

336. Furthermore, in a workshop conducted at WES in February 1987 (Derrick 1991), the participants were constantly getting sidetracked by the subjects of dike design and construction. In today's world, rarely is a dike simply repaired without evaluating the effects of the dike and its interaction with surrounding training structures and/or the reach of river on which it is located.

337. With this thought in mind, a comprehensive newsletter that covered the interrelated subjects of dike design, construction, and repair, and revetment design, construction, and repair plus any advances in research in these areas would be of real value to the engineers and future engineers working on America's river projects.

338. In an era of ever-tightening budgets and the real need to make every dollar count, information on any new products or techniques that will save time and money should, and must, be promptly conveyed throughout the Corps and adopted as expediently as possible. A newsletter would be able to spread this information in a timely, all-encompassing, and cost-effective manner.

Funding

339. Mr. Ross Jarrell of the Lower Mississippi Valley Division states that "you have to get your money first before you can do any work." Headquarters, US Army Corps of Engineers (HQUSACE), uses five budget levels. Under each level 103 separate items are prioritized according to importance. Dike and revetment maintenance funds are just 2 of these 103 items. When a District submits a budget request for the year, HQUSACE is going to review the budget package "by exception." In other words, if any item deviates by more than 10 percent from the previous year's budget, HQUSACE will require an explanation. The District then has to confer with Division personnel and draft a justification as to why the budget item has deviated by more than 10 percent from the previous year. Most justifications are one or two pages in length and consist of a drawing or pictures of the work along with a short written explanation. Mr. Jarrel feels that if the District impresses upon the right people that dike and revetment maintenance is very important and deserves higher priority, then obtaining additional funds should not be difficult.

340. In a similar vein, Mr. Steve Ellis states that if a District has inadequate funds to perform all dike maintenance deemed necessary, and this happens for several years in a row, then efforts to obtain additional funds should be initiated now before the backlog of repair work gets out of hand. To obtain these funds, the District is going to have to do a selling job using a plan of action, backed by factual data (e.g., photos, surveys), and a well-thought-out analysis of the consequences of failure question.

341. In some cases, restoration of a dike to the original elevation and length, after scour and stone displacement have occurred subsequent to construction, can logically be done with construction funds, even though at first glance it would seem to be a maintenance activity. The logic would be that the restoration is simply the second phase of construction, and that it maximizes efficient use of construction funds by allowing the river to identify the parts of the structure that must be reinforced before the dike can be considered complete. The feasibility of this approach must be evaluated on a project-by-project and site-by-site basis.

REFERENCES

Derrick, David L. 1991 (Apr). "Proceedings of REMR Workshop on Repair and Maintenance of Shallow-Draft Training Structures, 24-25 February 1987," US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Derrick, David L., Gernand, Herbert W., and Crutchfield, James P. 1989 (Jan). "Inventory of River Training Structures in Shallow-Draft Waterways," Technical Report REMR-HY-6, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

McCollum, R. A. 1988 (Aug). "Blountstown Reach, Apalachicola River; Movable-Bed Model Study," Technical Report HL-88-17, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

McCollum, R. A. "Chipola Cutoff Reach, Apalachicola River; Movable-Bed Model Study" (in preparation), US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Pankow, Walter, and Trawle, Michael J. 1988 (Aug). "Inventory of Training Structures in Estuaries," Technical Report HL-88-20, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Pennington, C. H., Shields, F. Douglas, Sjostrom, John W., and Myers, Karla A. 1988 (Sep). "Biological and Physical Effects of Missouri River Spur Dike Notching," Miscellaneous Paper EL-88-11, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Robison, Mac, Patterson, Ken, Chesser, Steve, Illias, Dave, and Broderick, Laurie. 1988 (Mar). "Value Engineering Study of Columbia River Pile Dike Maintenance, Phase 1," Value Engineering Study NPP-87-02I, US Army Engineer District, Portland, Portland, OR.

SURFER Version 4.15. Golden Software, PO Box 281, Golden, CO 80402.

Thomas, William A., and McAnally, William H., Jr. 1985 (Jul). "User's Manual for the Generalized Computer Program System: Open-Channel Flow and Sedimentation, TABS-2," Instruction Report HL-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

US Army Engineer District, Mobile. "Annual Report on the Apalachicola-Chattahoochee-Flint Waterway," Mobile, AL.

BIBLIOGRAPHY

Burch, Carey W., Abell, P. R., Stevens, M. A., Dolan, R., and Dawson, B. 1984 (Sep). "Environmental Guidelines For Dike Fields," Technical Report E-84-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Pokrefke, Thomas J. 1978 (Oct). "Minutes of Meeting, 14-15 March 1978, Symposium on Dike Design of Groins and Dikes," US Army Engineer Waterways Experiment Station, Vicksburg, MS.

THANKS AND APPRECIATION

The author would like to extend a wholehearted THANK YOU! to all who have generously given thought, time, effort, and reference materials toward the preparation of this report. This is especially true of the people mentioned under the "Contacts" heading for each District in the Compilation of Past and Present Repair Practices section of the report. Also a special thank you is extended to Messrs. Charles Elliott and Steve Ellis of the Lower Mississippi Valley Division. Again, thanks everybody!