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BIOLOGICAL AND PHYSICAL EFFECTS OF MISSOURI RIVER SPUR DIKE NOTCHING

by

C. H. Pennington, F. Douglas Shields, Jr., John W. Sjostrom

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39181-0631

and

Karla A. Myers

US Army Engineer District, Omaha
Omaha, Nebraska 68102-4910

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Since 1975, the US Army Engineer District, Omaha, has had a program of creating notches or gaps in river training structures along the Missouri River. More than 1,300 notches have been constructed either by excavating stone or by omitting repairs on small portions of damaged structures. An additional 20 spur dike training structures located in two reaches of the Missouri River near Omaha were modified in 1982 and 1983 using a new notch design. Material excavated from notches was used to construct a small reef just downstream of each notch.

Results of detailed, semiannual hydrographic surveys of the regions immediately adjacent to 12 of these notch-with-reef structures were analyzed to determine the effects of modification on depths and water surface area. Means and standard deviations of depth adjacent to dikes increased after notching, as did water surface area at a reference stage. Considerable variation in bed response to notch-with-reef construction was
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observed from dike to dike and between the two reaches studied. Increases in mean depth were greater for the reach with greatest stage variation and for dikes where notch inverts were lowest relative to adjacent downstream bed elevation.

In an effort to compare fish use of the notch-with-reef structures with that of other types of training dikes, a study was conducted in one of the two Missouri River reaches mentioned above. Fish, water quality, current velocity, and bed material were sampled during moderate flow in June and August adjacent to nine spur dikes. Three of the dikes were unmodified, three were notched with reefs, and three were simply notched. No significant differences were observed among dike types for any of the variables. However, the areas around the dikes are distinctive from the main channel--and much more valuable ecologically.

It was concluded that Missouri River spur dike notching generally causes small increases in the area of valuable low-velocity aquatic habitat.

PREFACE

This report was prepared by the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), in fulfillment of Reimbursable Order Nos. WESCW-86-147 and ENC 7618. A cooperative study was initiated between the US Army Engineer District, Omaha, and the WES as part of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. Data collection for the biological assessment was conducted by the EL. Hydrographic data collection was conducted by the Omaha District. The REMR funding for this work was discontinued in fiscal year 1987, and data analysis and report preparation for the environmental assessment were funded by the aforementioned orders. Mr. Ken Murnan of the Omaha District was the District point of contact. Ms. Karla A. Myers was the project manager for the Omaha District portion of the study and provided valuable technical assistance to the WES.

The report was prepared by Dr. C. H. Pennington of the Aquatic Habitat Group (AHG), Environmental Resources Division (ERD), and Dr. F. Douglas Shields, Jr., and Mr. John W. Sjostrom of the Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), EL, and Ms. Myers. Fieldwork was performed by Dr. Pennington and Messrs. John A. Baker, Larry G. Sanders, Richard E. Coleman, and Richard L. Kasul, AHG, and Dr. Troy B. Millican, Southeastern Louisiana University, Hammond, LA. Dr. Thomas E. Robertson, US Fish and Wildlife Service, Iowa Cooperative Fish and Wildlife Research Unit, provided valuable assistance with field collections and statistical analysis of data under Intra-Army Order No. WESCW-86-182. Hydrographic survey data were reduced by the Remote Sensing Applications Laboratory of the University of Nebraska at Omaha under contract to the Omaha District. Messrs. Dean Muirhead and Wayne Sharp, EED contract students, performed much of the data analysis. Ms. Cheryl Lloyd of the WREG proofread the draft, and Ms. Monette Ward performed several editing functions while employed under the Intergovernmental Personnel Act (IPA). The report was prepared for publication by Ms. Jessica S. Ruff of the WES Information Technology Laboratory.

Technical reviews were provided by Drs. Doug Clark of the Coastal Ecology Group, EL, and N. R. Nunnally of the University of North Carolina-Charlotte under the IPA.

The work was accomplished under the direct supervision of Drs. Shields and Paul R. Schroeder, who served as Acting Chiefs, WREG; Dr. Raymond L. Montgomery, Chief, EED; and Dr. Conrad J. Kirby, Jr., Chief, ERD; and under the general supervision of Drs. John Harrison, Chief, EL, and John Keeley, Assistant Chief, EL.

COL Dwayne G. Lee, CE, was the Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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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
acres	4,046.873	square metres
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres

BIOLOGICAL AND PHYSICAL EFFECTS OF MISSOURI RIVER SPUR DIKE NOTCHING

PART I: INTRODUCTION

Background

Missouri River Navigation Project

1. In 1844, Congress established the Missouri River Commission to improve navigation on the river by removing obstructions, installing bank revetments, and constructing pile dikes. The US Army Corps of Engineers was authorized in 1912 to stabilize the riverbanks and provide a navigation channel that was 6 ft* deep and 200 ft wide from Kansas City, MO, to the mouth. The River and Harbor Act of 1945 extended the navigation channel upstream to Sioux City, IA, and increased the channel depth and width to 9 and 300 ft, respectively. In addition, a system of six main stem dams was constructed on the upper river as part of the Pick-Sloan Plan for the comprehensive development of the Missouri River Basin as authorized by the Flood Control Act of 1944. Dikes, revetments, and reservoirs have been constructed on the river for flood control, land reclamation, bank stabilization, and control and maintenance of the navigation channel (Sayre and Kennedy 1978).

2. As a result of the construction practices, the present river channel is narrow and deep and is quite different from what was once a wide meandering river with extensive islands throughout much of its length (Hallberg, Harbough, and Witinok 1979). For example, Funk and Robinson (1974) reported a 50-percent reduction of river surface area for the Missouri portion of the river between 1879 and 1972. Hallberg, Harbough, and Witinok (1979) reported similar trends in the river bordering Nebraska and Iowa, where the river decreased in length by 9 percent, in island area by 99.9 percent, in sandbar area by 99.7 percent, and in channel area by 80 percent between 1923 and 1976. Nunnally and Beverly (1986) point out that these figures are exaggerated because they are not corrected for stage variation. Nevertheless, the loss of

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* A table of factors for converting non-SI to SI (metric) units is presented on page 5.

sandbars, islands, and river surface area has undeniably greatly reduced the diversity of habitats in the river downstream of Sioux City, IA.

Missouri River Dike Notching Program

3. Placement of river training structures and modifications of existing structures have been widely practiced as techniques for improving and reclaiming aquatic habitat (Schmitt 1983), particularly along smaller streams (Shields 1983). The effectiveness of such efforts is related to the ability of the structures to produce depths, velocities, and substrates that increase overall physical habitat diversity and suitability.

4. To preserve and reclaim aquatic habitat, the US Army Engineer Division, Missouri River, initiated a dike notching program in both the Omaha and Kansas City Districts during the 1975 navigation season. The purpose of the program was to provide a means for water to pass through the stone dikes, thus reducing sediment deposition downstream and landward of the structures, in an effort to maintain or renew shallow-water areas adjacent to the dikes (US Army Engineer District (USAED), Omaha 1982). During the period 1974-80, approximately 1,306 dikes were notched: 344 were in the river between Sioux City, IA, and Rulo, NE, and 962 were constructed from Rulo to the mouth (Burke and Robinson 1979). In general, the notches in the Omaha District are 15 to 30 ft wide, while the notches in the Kansas City District are 30 to 100 ft wide. Notch elevations are constructed 3 to 10 ft lower than the remainder of the dike.

5. In 1982, the Omaha District initiated an experimental program to test a new reef concept in conjunction with its notch program. The new concept was similar to the previously constructed notches except that the stone excavated from the spur dikes to make the notch was deposited 50 ft downstream of the notch to form a low mound or reef (Myers 1986b). Prior to this experimental program, stone excavated from notches was used to repair damaged training structures. However, the quarry-run limestone used to construct the structures is badly weathered, and Omaha District personnel considered the excavated stone to be of more use as reefs for aquatic habitat enhancement. The small reefs below the notches were intended to create more diverse and complex patterns of flow and sediment deposition in the dike fields and to serve as habitat structure for fish.

Effects of dike notching

6. The effects of dike notching are poorly understood but are generally considered to be beneficial to aquatic communities (USAED, Omaha 1982; Burch et al. 1984). Robinson and Dillard (1977) reported on the utilization of dikes by certain fishes in the Missouri River and found that habitats associated with dikes supported the greatest number of fishes, but that more species were taken from mud banks. Robinson (1980) also found that no single type of dike or modification thereof was better than another for fishes. Hesse and Newcomb (1982) also reported that many fish species were associated with dikes in the upper channelized reaches of the river. Atchison et al. (1986) studied the aquatic biota associated with dikes and revetments in the Middle Missouri and reported the catch and the number of species of fish to be quite high in the more diverse and protected habitats adjacent to dikes. Blue sucker, channel catfish, flathead catfish, and goldeye were commonly captured from the dikes fields during their study. They also found that the dike fields provided habitat for a variety of minnows, but greatest species richness and numbers of fishes were noted in abandoned channels.

7. Studies of channel response to construction and modification of spur dikes have focused on general changes across the width of the channel. Studies of local scour are less numerous, although some work has been done using physical models to study effects of variation of spur dike design parameters on local scour patterns (Klingeman, Kehe, and Owusu 1984). The USAED, Omaha (1982), reported measurements and qualitative observations made in the vicinity of notched dikes in the Missouri River. No prenotching data were reported, and thus no before-and-after comparisons were made. Areas below notched dikes tended to scour and aggrade through time in response to hydrologic events, but in general, they maintained suitable habitat conditions. No adverse effects on the navigation channel were detected. Burch et al. (1984) summarize several studies of habitat response to dike notching on other river systems. The impacts of stone reefs and their potential for fish habitat have not been studied previous to this effort.

Objectives

8. This study was conducted to provide information to describe and compare the quality and quantity of aquatic habitat in the vicinity of dikes of

three types: notched, notched with a stone reef placed downstream, and unmodified (without a notch or a stone reef). The work was a cooperative effort between the Omaha District and the US Army Engineer Waterways Experiment Station (WES). The Omaha District evaluated the effects of notched-with-reef construction on riverbed topography, and WES concentrated on training structure maintenance techniques that would improve fish habitat. Specific objectives of the study were to:

- a. Characterize the physical habitats (sediments, currents, and water quality) associated with modified and unmodified dikes.
- b. Describe and determine the differences, if any, in the relative abundance and distribution of fishes associated with modified and unmodified dikes.
- c. Determine the effects on mean depth and water surface area in the immediate vicinity of dikes modified by notch-with-reef construction.

Organization of Report

9. This document is organized into five major parts and one appendix. This introduction (Part I) is followed by brief descriptions of the study area and notch-with-reef structures (Part II). Part III deals with the environmental study conducted in 1986, and Part IV gives results of the hydrographic study conducted from 1982 through 1985. Parts III and IV each include an introduction, a brief description of methods, and a results and discussion section. Thus, a reader interested in only the environmental or hydrographic study can have access to a cohesive treatment of that data set. Conclusions and recommendations based on evaluation of both th environmental and hydrographic studies are given in Part V. References cited are listed at the conclusion of the text. Appendix A presents plots of hydrographic surveys at selected dikes before and after notch-with-reef construction.

PART II: STUDY AREA

General Description

10. Dikes from two different reaches (Figure 1) of the Missouri River were selected for evaluation during this study. One site was located upstream of Omaha, NE, between river miles 667 and 680 and was called the upstream reach. The other site was named the downstream reach and was located between river miles 517 and 583, upstream of Rulo, NE. The river channel is bordered by dikes and revetments through both reaches. The upstream reach has a sinuosity of 1.2, while the downstream reach has a sinuosity of 1.4. Bed degradation has been observed in the upstream reach subsequent to project construction. The Platte River flows into the Missouri at river mile 594.6, between the two reaches, and exerts an influence on the downstream reach hydrograph. Furthermore, the influence of the main stem storage reservoirs diminishes in the downstream direction.

Notch-with-Reef Structures

11. In 1982 and 1983, the Omaha District constructed 20 notches in spur dikes between Missouri River miles 517.0 and 677.5. The material excavated from each notch was used to build a small reef just downstream of the notch. Dimensions of the experimental notches with reefs are as shown in Figure 2. All of the notches were designed and constructed to be 20 ft wide at the Construction Reference Plane* (CRP) elevation and to have inverts (lowest points in notches) 5 ft below the CRP. Notch placement along the length of the spur dikes was varied from dike to dike, but tended to be placed on the structure at locations along the landward half of the dike. Reef dimensions varied based on the amount of stone available and the bottom topography, but were always placed at least 50 ft downstream of the notch in a perpendicular direction from the dike center line. The reef structures were oriented either perpendicular or parallel to the dike structures. In the upstream reach, reef crests were 2 ft below the CRP and approximately 25 ft long. Downstream reefs

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* An imaginary sloping plane along the Missouri River with an elevation equal to the water surface elevation for flows of a given frequency.

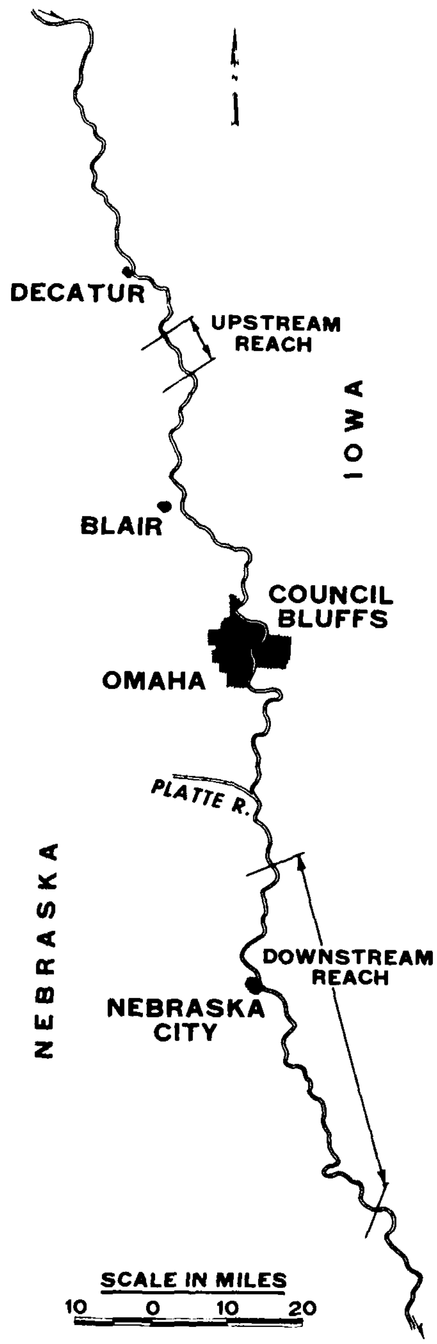
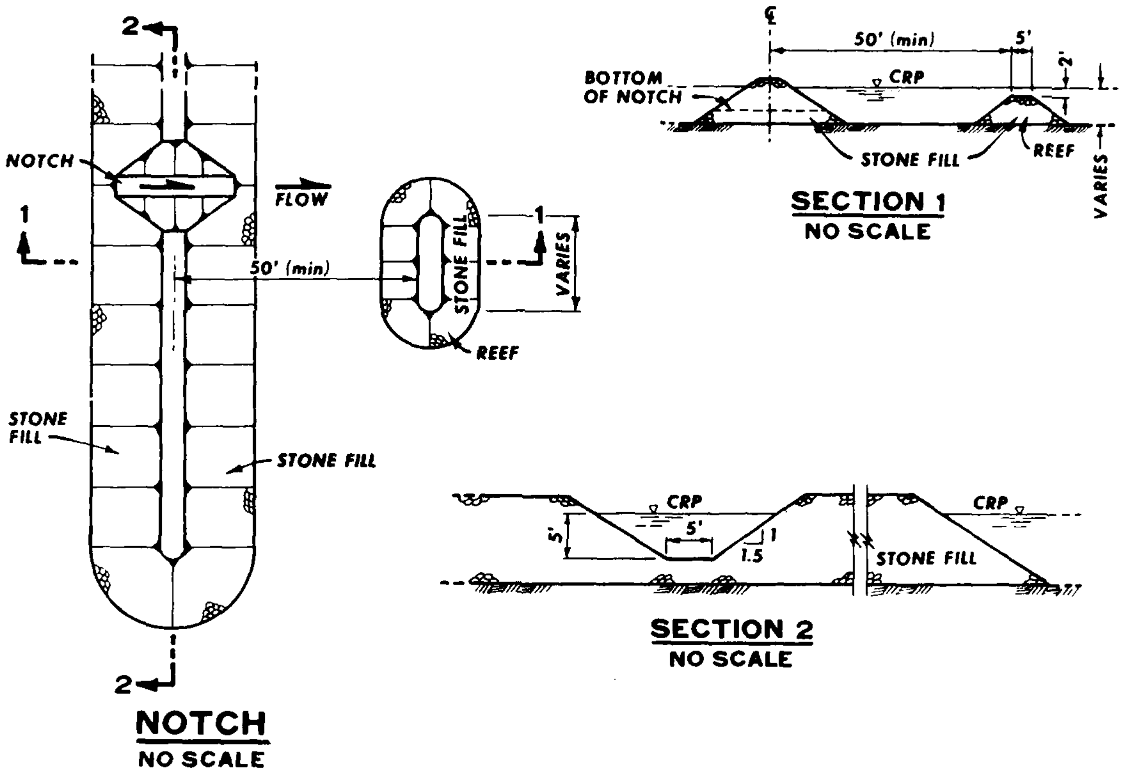
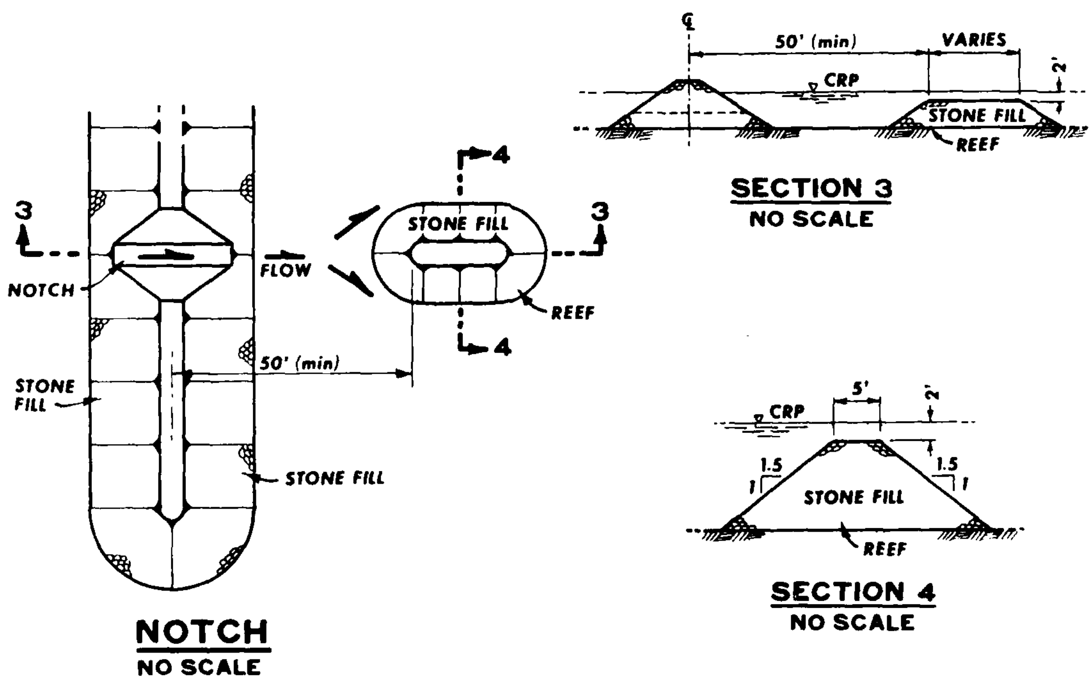


Figure 1. Vicinity map showing the two study reaches



a. Type A



b. Type B

Figure 2. Typical sections of notch-with-reef structures

PART III: DIKE HABITAT INVESTIGATION

Introduction

12. Nine dikes in the upstream reach of the Missouri River between river miles 667 and 680 (Figure 4) were selected for study to determine their value as fish habitat. The dikes were of three types: unmodified, notched, and notched-with-reef (Table 1). Unmodified dikes are those that are maintained by the US Army Corps of Engineers in a more or less original construction state. The notched dikes are those with a portion of the stones removed. This allows water to pass through the notch, creating a scour hole just downstream of the dike. High flows generally result in scour behind the nearshore portion of the dike, creating a slack-water zone during normal flow. Some of the notched dikes were further modified by depositing the excavated material to create the stone reef just downstream of the dike.

Materials and Methods of Data Collection

13. Sediments, water, and fishes were collected from stations upstream and downstream of each of nine dikes (three unmodified, three notched, and three notched-with-reef) in the upstream reach during two sampling periods in 1986 (one in June and the other in August). The station location and number

Table 1

Description of Selected Dikes in the Upstream Reach

Structure Number	River Mile	Bank Location	Modification	Data Collected*
D730.81	678.2	L	Notched--no reef	1
D730.55	678.0	L	Notched--no reef	1
D730.00	677.5	R	Notched w/Type A reef	1,2
D729.70	677.2	R	Notched w/Type A reef	1,2
D728.30	675.9	L	Notched w/Type A reef	1,2
D728.15	675.6	L	None	1
D727.65	675.1	L	None	1
D724.90	672.2	L	Notched--no reef	1
D721.95	669.0	R	None	1

* Data types: 1 = fish, water quality, velocity, substrate; 2 = hydrographic surveys.

were also about 25 ft long, but were much lower relative to the CRP. Reefs were aligned either parallel to the dike (hereafter referred to as Type A reefs) or perpendicular to the dike (Type B). Figure 3 shows one of the modified structures at extreme low stage when the reef was visible.

Figure 3. Dike 729.7, 6 March 1986

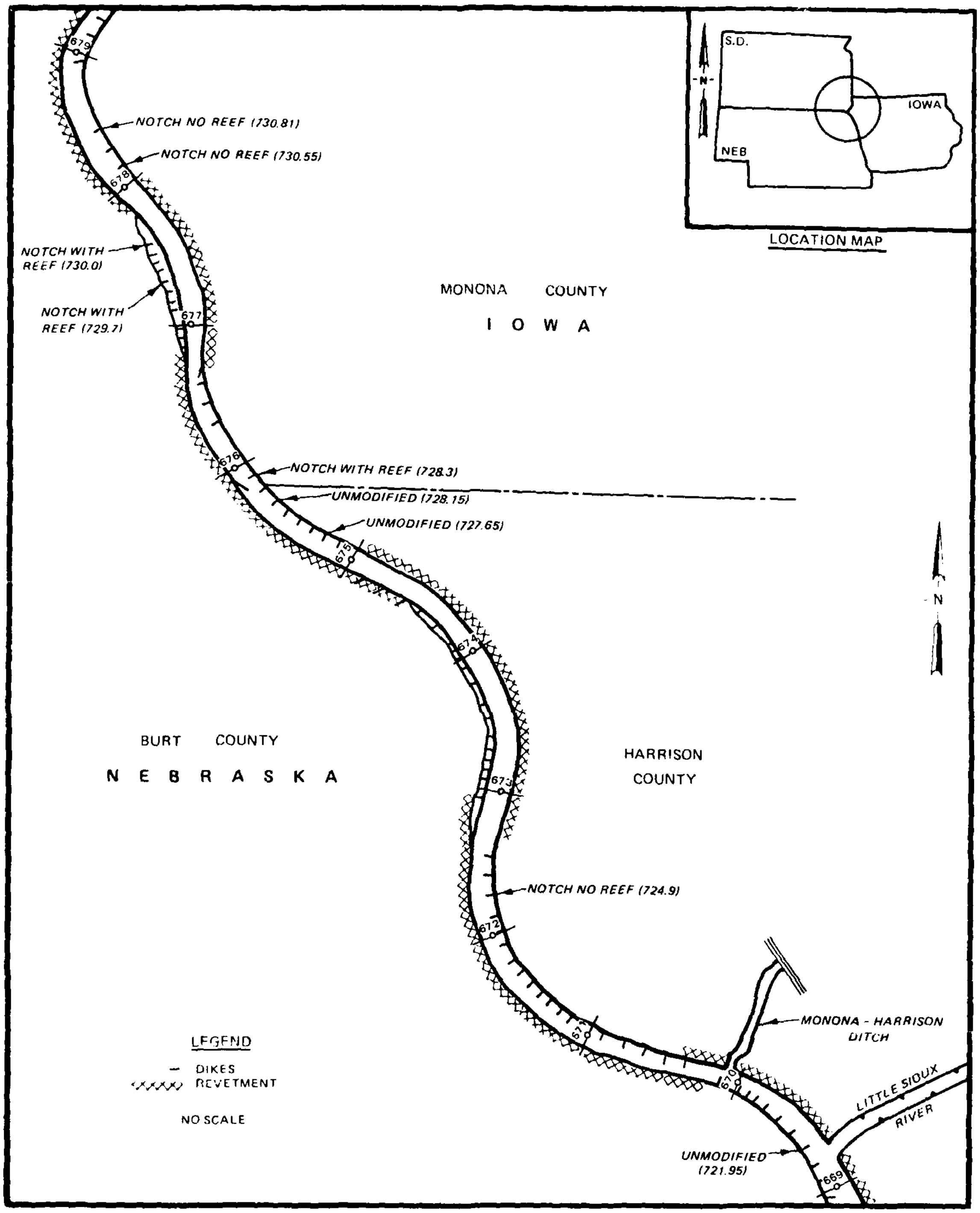


Figure 4. Map of upstream reach, with dikes identified

of samples were the same during both periods except that seining was conducted only in August. Seining was not part of the original scope of work; however, because of the low fish catches during June, seining was included as part of the August effort. A schematic representation of station placement at each dike is given as Figure 5.

Water quality and substrates

14. Water quality data were collected using a Hydrolab water quality instrument (Model 8000). Water temperature (degrees C), pH, dissolved oxygen (milligrams per litre), and conductivity (micromhos per centimetre) were measured in situ at 3-ft intervals throughout the water column at two stations upstream and four stations downstream of each dike (Figure 5).

15. Measurements of current speed and direction were made with an Endeco current meter. Current readings were recorded at 3-ft intervals throughout the water column at three stations upstream and nine stations downstream of each dike. An additional three stations were placed in the vicinity of the notch when present (Figure 5).

16. A ponar or petite ponar dredge was used to collect bottom sediments from the same stations where current measurements were taken. Each sediment sample was visually classified in the field and subjectively assigned to categories of gravel, coarse sand, medium sand, fine sand, and silt-clay. Each sediment sample was also returned to the laboratory where a 20-percent subsample was selected for a complete sieve size analysis (US Army Corps of Engineers 1970).

Fishes

17. Fishes were collected from the area immediately upstream and downstream of each dike by hoopnetting and electrofishing, and by seining during August. Double-throated hoop nets (3-ft mouth diameter with 1-in.-square mesh netting) were set at each of six stations at each dike (Figure 5). The nets were set parallel to the shoreline and fished unbaited for 24 hr. Electroshocking was done with a commercially built, 230-v, pulsed d-c, boat-mounted boom shocker. A single transect was above the dike, and two transects were shocked below the dike. Fishes were captured from shallow-water areas upstream and downstream of the dikes where seining was possible with a 15- by 3-ft "common sense" seine having a square mesh size of 1/8 in.

18. The larger fishes were identified and processed in the field. Juvenile fishes, minnows, and unusual fishes were preserved in 10-percent

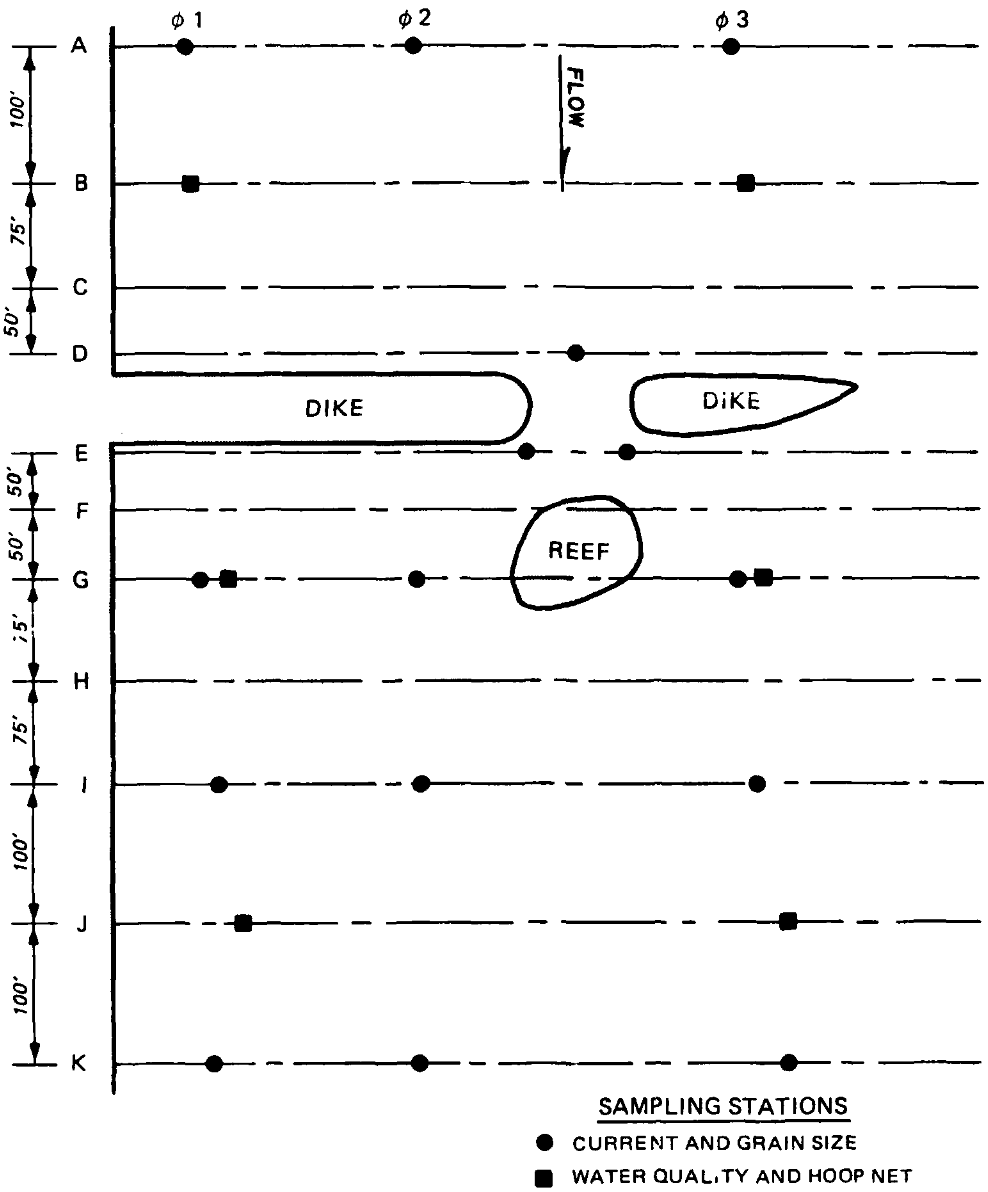


Figure 5. Schematic of sampling stations

formalin for later identification. Total length (millimetres) and weight (grams) were recorded for all specimens in good condition.

19. Estimates of fish abundance associated with each dike were determined with hydroacoustic equipment. The data were collected using a BioSonics Model 101 Dual-Beam Echo Sounder operating at 420 kHz and the appropriate auxiliary equipment (Burczynski 1979). A dual-beam transducer was towed along four transects upstream and seven transects downstream of each dike. During a survey, the transducer was suspended in the water alongside the survey boat at a depth of approximately 1.5 ft and aimed straight down. The boat was moved along each transect, beginning near the shoreline with the bow pointed toward the shore and the boat motor in reverse. This maneuvering was done to facilitate maximum coverage of the small areas, but caused problems during analysis because of turbulence created by the boat motor. Acoustic signals were recorded as echograms on chart recorder paper and on a portable video cassette recorder for later analysis in the laboratory.

20. Survey echograms of the hydroacoustic data were regenerated in the laboratory in an attempt to improve resolution and to filter background noise created by motor propwash and instream turbulence. This turbulence was particularly strong immediately downstream of notches and around reefs. Regeneration efforts met with limited success. Data on individual targets outside notched areas were satisfactory, except where depth was less than 5 ft. Data collected immediately downstream of notches were highly suspect due to turbulence induced by entrained air.

Data Analysis

21. Analysis of variance was used to evaluate differences among the three dike types (unmodified, notched, and notched-with-reef) in the variables measured. Stations just above and below the notches, transects D and E, were omitted from the analysis of the water velocity data. Grain-size analyses were performed on 20 percent of the sediment samples, and a relationship between the visual classification conducted in the field and the measured D_{50} was developed (Table 2). This relationship was used to translate the visual classifications into digital data, which were then subjected to analysis of variance. Differences in mean numerical catch per unit of effort, mean biomass catch per unit of effort, and mean number of species of fishes captured

Table 2

Median Particle Size Versus Classification

Classification	D_{50}, mm
Medium sandy mud	0.080
Fine sand and silt	0.092
Fine sandy mud	0.106
Fine sand	0.128
Coarse sand and silt	0.140
Muddy fine sand	0.230
Medium sand	0.248
Coarse sand	0.380
Gravelly coarse sand	0.620
Fine gravelly sand	0.660

with hoop nets and by electrofishing were tested. The catches per unit of effort were based on catch per net per 24-hr set for hoop nets and catch per 5-min electrofishing run. A probability of less than 0.05 was considered significant. Statistical comparisons among the dike types of mean number of fish targets detected with the hydroacoustic equipment were not conducted because of the low number or absence of targets along most transects.

Results and Discussion

Velocity and substrates

22. Velocities were significantly greater in August than in June, but differences between dike types--unmodified, notched, and notched-with-reef--were insignificant. Mean velocities are presented in Table 3. A significant difference in substrate grain size was noted between sampling dates but not among the different types of dikes. Mean D_{50} values for the substrates are presented in Table 4.

23. All sediment samples from the dikes showed a consistent pattern of particle size distribution. In general, the closer to shore the investigators sampled, the smaller the size fractions, this area being dominated by silty sand. As sampling moved offshore, the particle sizes were larger, being

Table 3

Mean Velocities

Date	Dike Design	Velocity fps
June 1986	Unmodified	1.74
	Notched	1.56
	Notched-with-reef	1.68
	All dikes	1.68
August 1986	Unmodified	2.17
	Notched	2.21
	Notched-with-reef	2.26
	All dikes	2.21

Table 4

Mean D_{50} for Substrate

Date	Dike Design	D_{50}	Number of Samples
June 1986	Unmodified	0.270	36
	Notched*	0.230	34
	Notched with reef**	0.274	35
	All dikes	0.258	105
August 1986	Unmodified	0.238	36
	Notched	0.222	36
	Notch with reef	0.298	36
	All dikes	0.253	108

* Two samples containing gravel omitted. The D_{50} value for these is 15 mm.

** One sample containing gravel omitted.

dominated by coarse sand and larger size fractions. The current velocity and direction above all three dike types were similar. Below the dikes, both the current velocity and direction were variable, and in general no consistent pattern could be delineated within any of the three dike types.

Water quality

24. No significant differences in water quality conditions were noted between dikes, between upstream and downstream locations of the same dike, or between different dike types. The mean temperature was slightly higher in August than in June (Table 5). Temperature measurements varied only 0.1° C in June, and no variability was recorded in August. Mean dissolved oxygen concentration was essentially the same during June and August and varied only 0.3 mg/ℓ during both sampling periods. Conductivity and pH measurements were both slightly higher during August than in June and exhibited little variation during both months.

25. Water in the vicinity of the dikes was well mixed as indicated by the uniform values of temperature, dissolved oxygen, conductivity, and pH. Other studies (Burress, Krieger, and Pennington 1982; Atchison et al. 1986) have also shown that water quality characteristics are similar in different habitats in the Missouri River. For example, Atchison et al. (1986) found

Table 5

Summary of Mean Values for Temperature, Dissolved Oxygen, Conductivity, pH, and Stage/Discharge

Parameter	June 1986		August 1986	
	Mean	Range	Mean	Range
Temperature, °C	21.4	21.4-21.5	23.0	23.0
Dissolved oxygen, mg/ℓ	7.5	7.4-7.7	7.6	7.4-7.7
Conductivity, μmhos/cm	771	754-777	795	791-799
pH	7.8	7.7-7.9	8.1	7.9-8.2
Stage, ft CRP	+5.1	--	+3.6	--
Discharge, cfs	46,150	--	38,450	--
Exceedance*	20		40	

* Approximate percentage of time the given discharge was equaled or exceeded, 1967-1986.

that the water in the vicinity of revetments and dikes was well mixed and noted no differences between temperature, dissolved oxygen, pH, redox potential, specific conductance, and turbidity.

Fishes

26. A total of 2,208 fishes representing 34 species were captured with hoop nets, electrofishing, and seines from the dike habitats during the study (Table 6). Twenty-nine species were collected from the three unmodified dikes, 25 from notched dikes, and 27 from the three notched-with-reef dikes. Emerald shiner was the most abundant species and comprised 56 percent of the total catch by number. Other species comprising at least 3 percent of the catch were red shiner (8 percent), sand shiner (8 percent), channel catfish (4 percent), gizzard shad (3 percent), and blue sucker (3 percent).

27. Relative abundance and species composition of the catch varied depending upon sampling gear. Hoop nets principally sampled shovelnose sturgeon, blue sucker, channel catfish, and flathead catfish. Electrofishing catches were primarily composed of gizzard shad, goldeye, carp, river carpsucker, and river redhorse. Seining was effective for such shallow-water species as emerald shiner, red shiner, and sand shiner. Twelve species were collected with hoop nets, 18 by electrofishing, and 20 by seining.

28. Statistical comparisons were made of hoop net and electrofishing catches from the three dike types within the study area. No significant differences among the three dike types were noted with regard to numerical catch per unit effort, biomass catch per unit effort, or number of species during June or August. The catches per unit of effort for both sampling periods are summarized in Table 7.

29. In August, the species composition of the seining catch at the three dikes was similar and was dominated by emerald shiner, red shiner, and sand shiner (Table 6). Slightly more fishes were captured from notched-with-reef dikes (761) than from unmodified (544) and notched (452) dikes. Species composition and numbers of fishes varied only slightly when comparing the catches from areas upstream to areas downstream of the dike structures.

30. The species composition of fishes captured in this study with seines, electrofishing, and hoop nets was similar to the catches reported by Atchison et al. (1986) using similar gears in dike habitats in the same river reach. They captured 21 species with seines, 13 by electrofishing, and 14 with hoop nets. Species abundance varied only slightly when comparing their

Table 6

Total Number of Fish Collected by Gear Type*

from Unmodified, Notched, and Notched-with-Reef Dikes

	Type of Dike									
	Unmodified			Notched			Notched/Reef			
Species	ES	HN	SN	ES	HN	SN	ES	HN	SN	Total
Shovelnose sturgeon	--	2	--	--	2	--	--	7	--	11
Shortnose gar	2	--	--	1	--	--	--	1	--	4
Gizzard shad	8	--	2	3	--	16	21	--	12	62
Goldeye	6	--	--	7	3	--	9	--	--	25
Carp	4	--		1	--		1	--	--	6
Silver chub	--	--	1	--	--	6	--	--	3	10
Emerald shiner	--	--	434	--	--	245	--	--	509	1,188
River shiner	--	--	5	--	--	21	--	--	12	38
Bigmouth shiner	--	--	--	--	--	7	--	--	--	7
Red shiner	--	--	60	--	--	58	--	--	57	175
Sand shiner	--	--	31	--	--	46	--	--	99	176
Fathead minnow	2	--	--	3	--	1	7	--	--	13
Notropis spp.	--	--	1	--	--	2	--	--	--	3
River carpsucker	8	2		11	--	--	14	1	--	36
Quillback	--	--	3	--	--	19	--	--	26	48
Carpoides spp.	--	--	2	--	--	--	--	--	28	30
White sucker	1	--	--	--	--	--	--	--	--	1
Blue sucker	2	16	--	4	16	--	5	15	--	58
Smallmouth buffalo	1	--	1	--	--	1	--	--	--	3
Bigmouth buffalo	1	--	--	--	--	--	--	--	--	1
River redhorse	7	4	--	9	2	--	8	1	--	31
Shorthead redhorse	--	--	--	--	--	--	--	--	1	1
Catostomidae	--	--	1	--	--	25	--	--	3	29
Brown bullhead	--	2	--	--	--	--	--	--	--	2
Channel catfish	4	29	1	1	33	3	2	13	6	92
Flathead catfish	2	11	--	1		--	--	7	--	35
White bass	--	--	--	1	--	--	--	--	3	4
Bluegill	1	1	--	--	--	1	1	--	--	4
Redear sunfish	--	--	--	--	--	--	--	--	1	1
Largemouth bass	--	--	--	--	--	--	--	--	1	1
White crappie	1	--	--	--	--	--	--	--	--	1
Sauger	1	--	--	--	--	--	1	--	--	2
Walleye	--	--	2	--	--	1	1	--	--	4
Freshwater drum	1	1	--	--	1	--	1	1	--	5
Total number	52	68	544	42	71	452	71	46	761	2,107
Number of species	17	9	13	11	7	15	12	8	13	34

* ES = electrofishing, HN = hoop net, and SN = seine.

Table 7

Summary of Mean Catch per Unit of Effort (Hoop Nets and Electrofishing) and Hydroacoustic Surveys, June and August 1986

	Type of Dike					
	Unmodified		Notched		Notched/Reef	
Technique	Jun	Aug	Jun	Aug	Jun	Aug
Hoop net						
Number	2.3	1.4	1.9	1.8	1.7	0.8
Biomass, g	1,729	703	1,904	1,912	1,384	969
No. species	1.5	1.0	0.9	1.0	1.1	0.6
Electrofishing						
Number	2.3	1.7	2.2	1.5	2.2	2.0
Biomass, g	947	466	780	738	902	987
No. species	1.5	0.4	0.5	0.4	0.7	0.6
Hydroacoustics						
No. targets	19	13	25	5	15	13

catches with those in this study. Newcomb (1986) reported the capture of 12 species by electrofishing during the winter months between river miles 666.5 and 676. His catch was similar in composition to the ones reported herein but was dominated by four species (channel catfish, carp, freshwater drum, and river carpsucker) that were found to be less abundant in this study.

31. Hydroacoustic surveys detected a total of 59 fish targets in June, 19 from unmodified dikes, 25 from notched dikes, and 15 from habitats associated with notched-with-reef dikes (Table 7). During the August surveys, only 31 fish targets were detected, 5 from notched dikes and 13 each from the unmodified and notched-with-reef dikes. The number of fish targets detected with hydroacoustics was so low at the sites that statistical comparisons among the three dike types were considered to be of little value. However, the data did substantiate the greater numerical catch in June than in August with hoop nets and by electrofishing.

PART IV: HYDROGRAPHIC INVESTIGATION

Introduction

32. Detailed hydrographic surveys were performed in the vicinity of 20 dikes modified by notch-with-reef construction. Ten dikes were located in the upstream study reach, and 10 were in the downstream reach (Figure 1). Surveys were conducted roughly twice a year between 1982 and 1985 and were used to monitor the riverbed in areas most affected by the notches and reefs to determine impacts of the depositional patterns on bed topography.

Materials and Methods of Data Collection

Data collection techniques

33. Before notching, hydrographic surveys were conducted in fall 1982 (downstream reach) and spring 1983 (upstream reach) at each of the 20 dikes selected for notch-with-reef modification (Table 8). This was followed by postnotching surveys in fall 1982, spring 1983, spring 1984, fall 1984, spring 1985, and fall 1985. One to four postmodification surveys are available for each modified dike. Emergent bars and overbank areas were not surveyed.

34. Two techniques for data collection were used during the project. Survey data collected before 1984 were obtained with the *Thornton*, a 40-ft survey boat. A Raytheon sounder was mounted in the hull, midway between the bow and stern. Results of these surveys showed that the Thornton was too large to easily survey the small, shallow areas directly affected by dike notching. Furthermore, the Thornton data were inadequately controlled to be easily comparable with subsequent surveys (Myers 1986b).

35. A new procedure was used for surveys after 1983. A rectangular area around each dike was surveyed using a flat-bottomed 19-ft johnboat with a hull-mounted transducer. The rectangular area extended from 100 ft upstream to 200 ft downstream of the dike center line and from the water's edge to approximately 200 ft riverward of the dike riverward tip. Ranges parallel to the dike center line and spaced 10 ft apart were surveyed each time, yielding easily compared results. Surveys were controlled by using the dike center line as the reference (Myers 1986a). Results of one of these surveys are shown in digital form in Figure 6.

Table 8

Notch-with-Reef Structure Descriptions

Structure Number	River Mile	Bank Location	Reach	Modification
D730.00	677.5	R	Upstream	Notch w/Type A reef
D729.83	677.4	R	Upstream	Notch w/Type A reef
D729.70	677.2	R	Upstream	Notch w/Type A reef
D729.55	677.0	R	Upstream	Notch w/Type B reef
D728.30	659.9	L	Upstream	Notch w/Type A reef
D726.85	673.9	R	Upstream	Notch w/Type A reef
D724.15	671.4	L	Upstream	Notch w/Type B reef
D724.05	671.2	L	Upstream	Notch w/Type A reef
D723.90	671.0	L	Upstream	Notch w/Type B reef
D722.30	669.0	R	Upstream	Notch w/Type A reef
D626.70	583.4	L	Downstream	Notch w/Type A reef
D616.90	571.5	R	Downstream	Notch w/Type A reef
D614.70	568.4	L	Downstream	Notch w/Type B reef
D610.20	564.5	R	Downstream	Notch w/Type A reef
D608.40	562.5	L	Downstream	Notch w/Type B reef
D605.34	559.4	R	Downstream	Notch w/Type B reef
D592.55	546.8	L	Downstream	Notch w/Type B reef
D578.90	536.4	L	Downstream	Notch w/Type B reef
D571.35	529.6	R	Downstream	Notch w/Type A reef
D558.70	517.0	L	Downstream	Notch w/Type A reef

Data reduction

36. All hydrographic and related data were tied to a ground survey (Cartesian coordinate) control system. The area of interest was laid out in grid fashion with survey lines projecting parallel and perpendicular to the center line of each dike. Dike locations were verified using construction drawings. These same coordinate axes were used for each subsequent survey at each dike. The areas examined were limited to a region extending from 100 ft upstream of the dike center line to 200 ft downstream of the dike center line. The region of interest extended 300 ft riverward from a baseline that ran perpendicular to the dike center line and roughly parallel to the bank line. For ease of analysis, the survey data were subdivided into three subareas, each measuring 100 by 300 ft, as shown in Figure 7. Subarea A was immediately upstream of the dike, subarea B was just downstream, and subarea C was further downstream.

37. For use as input to a kriging computer routine (Sampson 1978) and for statistical calculations, the survey area depicted in Figure 7 was

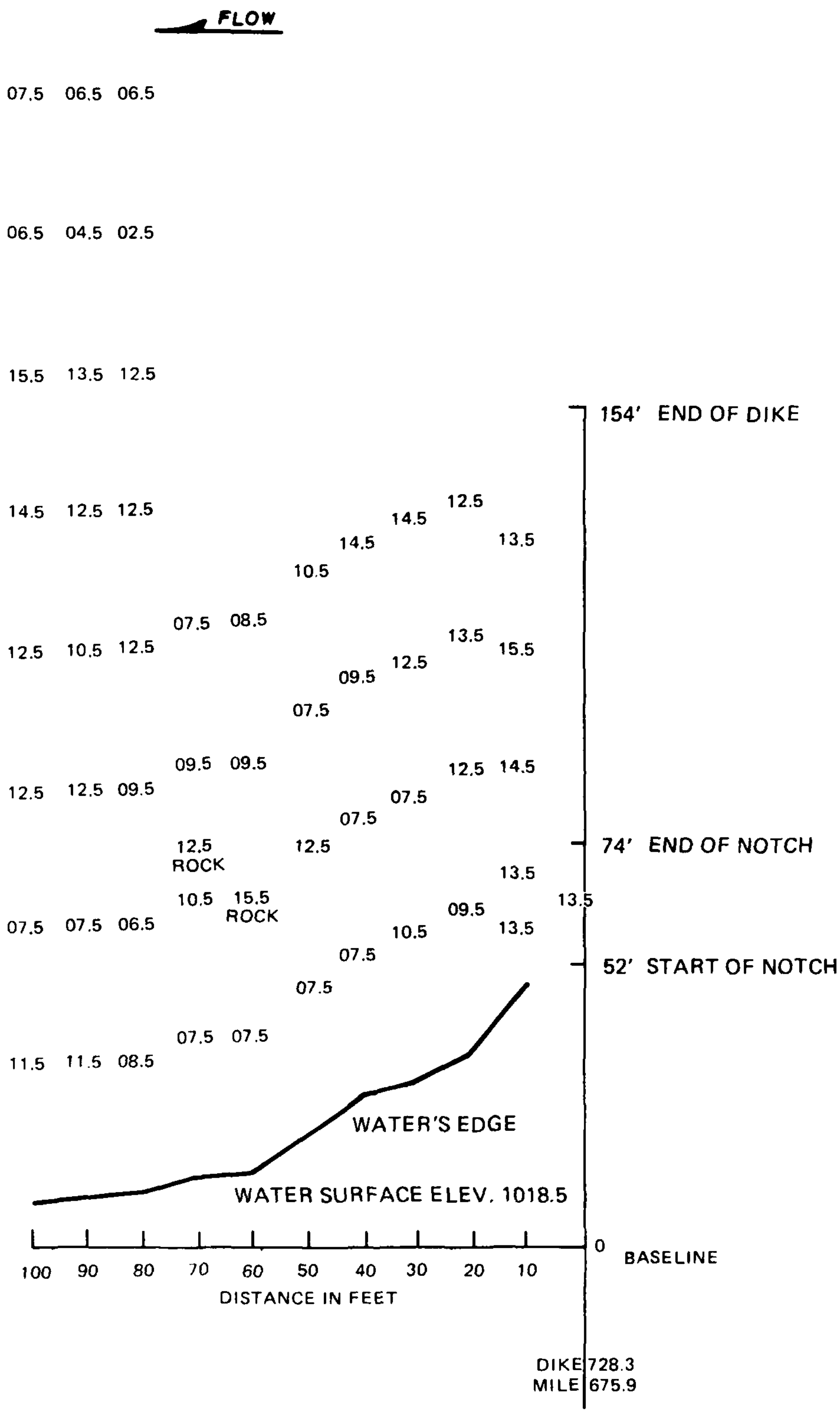


Figure 6. Survey results in digital form (Myers 1986a)

relabeled based on the 100 (units) by 100 (units) matrix created with the Surface II kriging interpolation (refer to Figure 8). The subareas A, B, and C, each depicted by an area of 33 by 100 units, coincide with the three subareas shown in Figure 7.

38. The kriging routine interpolated elevations at each node of the 33- by 100-unit grid for each subarea. Whenever too few data points existed for accurate interpolation, the computer routine generated missing value codes. Using Surface II computer software (Sampson 1978), gridded data were then used to plot two- and three-dimensional contour plots. This software package was also used to compute the mean and standard deviation of the bed elevation in each subarea.

39. Surveys with insufficient spatial coverage were removed from the data base. Insufficient spatial coverage was detected by examining the two-dimensional contour plots. The Surface II software would plot broken contours or would omit contours when fewer than a set number of data points were found in a given region.

40. All of the hydrographic surveys used the water surface elevations as datum. To convert measured depths to bed elevations, water surface

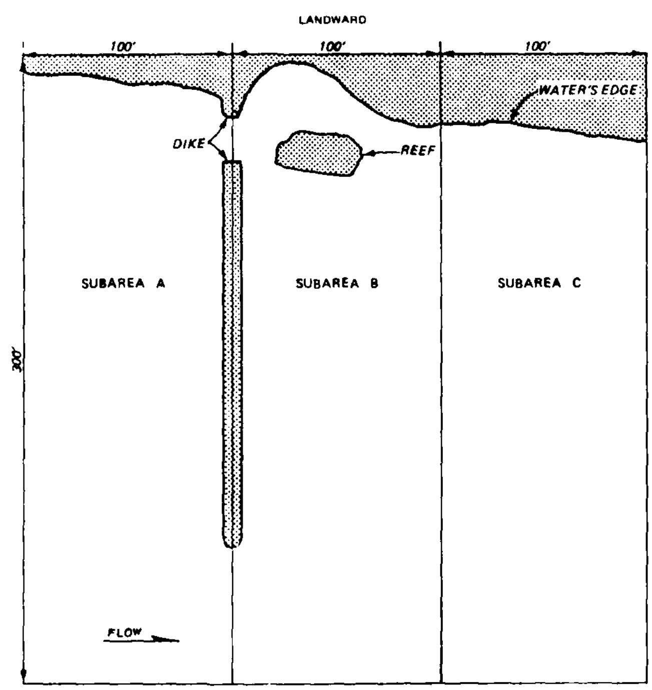


Figure 7. Schematic of subareas
created for data analysis

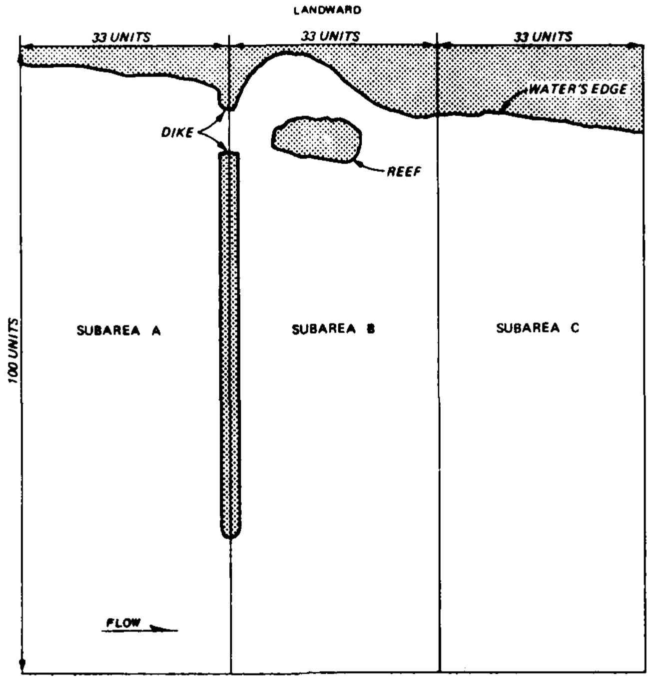


Figure 8. Analysis matrix and submatrices

elevations at each of the study dikes for each survey date were computed by linear interpolation using stages from the two nearest gage readings. Stage elevations were derived from gages at Nebraska City, Blair, and Decatur. Surveys for which an exact survey date could not be determined (i.e., for some surveys, only the month or season was recorded) were removed from the data base. After deleting surveys with no date or insufficient spatial coverage, prenotching and postnotching data for 12 dikes remained. Table 9 summarizes the hydrographic survey data screening. Table 10 shows the computation of water surface elevations at each dike.

41. The CRP elevations at each dike were added to the data base. Mean bed elevations were expressed in feet above or below CRP by subtracting the CRP elevation in mean sea level (msl) from the mean bed elevation in MSL.

42. Mean bed elevations referenced to CRP were then computed for each of the following categories:

- a. Each dike for each survey date.
- b. Each of the 12 structures.
- c. Each of the two reaches (upstream and downstream) for each survey date.
- d. Each of the two reef types (A and B) for each survey date.
- e. All prenotching data and all postnotching data.

Table 9

Summary of Hydrographic Survey Screening*

Dike No.	1982	1983	1984	1985
D558.70	8 Sep(B)			27 Mar(B)/10 Oct(GG)
D571.35				21 Mar(GG)/1 Oct(B)
D578.90	25 Sep(GG)		Oct(N)	10 Oct(GG)
D592.55	24 Aug(GG)/Oct(N)			22 Mar(GG)/30 Sep(GG)
D605.34	26 Aug(GG)/Oct(N)			28 Mar(GG)/26 Sep(GG)
D608.40	27 Aug(B)/Oct(N)			19 Mar(GG)/27 Sep(No Cont)
D610.20	27 Aug(GG)/Oct(N)			19 Mar(GG)/24 Sep(GG)
D614.70	8 Sep(B)/Oct(NB)		Oct(N)	9 Sep(B)
D616.90	8 Sep(GG)/Oct(N)		Oct(N)	26 Sep(GG)
D626.67	9 Sep(B)/Oct(NB)		Oct(NB)	25 Sep(GG)
D722.30		24 May(B)	10 May(GG)/1 Oct(GG)	10 Apr(GG)/10 Oct(B)
D723.90		24 May(GG)	9 May(GG)/1 Oct(GG)	12 Apr(GG)/10 Oct(GG)
D724.05		24 May(B)	1 Oct(GG)	12 Apr(GG)/10 Oct(GG)
D724.15		31 May(GG)	10 May(GG)/1 Oct(GG)	11 Apr(GG)/21 Oct(GG)
D726.85		31 May(GG)	9 May(GG)/Oct(N)	16 Apr(GG)/11 Oct(GG)
D728.30		31 May(GG)	8 May(GG)/2 Oct(GG)	11 Apr(B)/21 Oct(GG)
D729.55		1 Jun(B)	9 May(GG)/2 Oct(GG)	9 Apr(GG)/23 Oct(GG)
D729.70		1 Jun(GG)	8 May(GG)	17 Apr(GG)/23 Oct(GG)
D729.83		1 Jun(GG)	7 May(GG)/2 Oct(GG)	17 Apr(GG)/23 Oct(GG)
D730.00		2 Jun(GG)	2 Oct(GG)	17 Apr(GG)/24 Oct(GG)

* Abbreviations are defined as follows: GG = specific date and good contours, NB = nonspecific date and bad contours, N = nonspecific date (good contours), and B = bad contours (specific date).

Table 10

Interpolated Water Surface Elevations

Gaging Station	River Mile	Datum Elevation ft msl	CRP Elevation ft msl
Nebraska City	562.6	905.4	914.0
Blair	648.3	987.6	993.6
Decatur	691.0	1,010.0	1,031.8

Gaging Station	Dike No.	River Mile	Survey Date	Interpolated WSE	Nebraska City ft msl	Blair WSE ft msl	Decatur WSE ft msl	Water Surface Slope ft/mile
	D578.90	536.4	25 Sep 82	891.0	915.27	994.77		0.93
	D578.90	536.4	1 Oct 85	891.3	915.24	993.51		0.91
	D592.55	546.8	24 Aug 82	900.7	915.26	994.15		0.92
	D592.55	546.8	22 Mar 85	902.4	916.58	993.33		0.90
	D592.55	546.8	30 Sep 85	900.8	915.21	993.32		0.91
	D605.34	559.4	26 Aug 82	912.4	915.38	994.15		0.92
	D605.34	559.4	28 Mar 85	913.5	916.39	993.78		0.90
	D605.34	559.4	26 Sep 85	912.2	915.14	993.44		0.91
Nebraska City		562.6						
	D610.20	564.5	27 Aug 82	917.1	915.35	994.15		0.92
	D610.20	564.5	19 Mar 85	918.3	916.61	993.02		0.89
	D610.20	564.5	24 Sep 85	917.0	915.30	993.58		0.91
	D616.90	571.5	8 Sep 82	923.2	914.95	994.33		0.93
	D616.90	571.5	26 Sep 85	923.3	915.14	993.44		0.91
Blair		648.3						
	D723.90	671.0	24 May 83	1,015.4	918.525	994.41	1,033.96	0.93
	D723.90	671.0	9 May 84	1,017.7	925.253	997.10	1,035.87	0.91
	D723.90	671.0	1 Oct 84	1,017.5	917.618	996.05	1,036.44	0.95

(Continued)

Notes: Water surface elevation (WSE) for Dike Nos. D578.90, D592.55, and D605.34 are linearly extrapolated using Nebraska City and Blair gaging stations.
Water surface elevations for all other dikes are linearly interpolated using gaging stations located upstream and downstream.

Table 10 (Concluded)

Gaging Station	Dike No.	River Mile	Survey Date	Interpolated WSE	Nebraska City ft msl	Blair WSE ft msl	Decatur WSE ft msl	Water Surface Slope ft/mile
Blair (Continued)	D723.90	671.0	12 Apr 85	1,014.7	916.03	993.39	1,033.44	0.94
	D723.90	671.0	10 Oct 85	1,014.5	915.02	993.23	1,033.30	0.94
	D724.15	671.4	31 May 83	1,015.6	917.05	994.39	1,033.56	0.92
	D724.15	671.4	10 May 84	1,017.9	924.31	996.81	1,035.77	0.91
	D724.15	671.4	1 Oct 84	1,017.9	917.62	996.05	1,036.44	0.95
	D724.15	671.4	11 Apr 85	1,015.0	916.05	993.22	1,033.44	0.94
	D724.15	671.4	21 Oct 85	1,014.9	915.63	993.29	1,033.29	0.94
	D726.85	673.9	OK Oct 84		915.40	996.50	1,036.60	0.94
	D726.85	673.9	31 May 83	1,017.9	917.05	994.35	1,033.56	0.92
	D726.85	673.9	9 May 83	1,020.3	925.25	997.10	1,035.87	0.91
	D726.85	673.9	16 Apr 85	1,017.3	915.76	993.40	1,033.33	0.94
	D726.85	673.9	11 Oct 35	1,018.3	914.98	996.04	1,033.20	0.87
	D728.30	675.9	31 May 83	1,019.7	917.05	994.39	1,033.56	0.92
	D728.30	675.9	8 May 84	1,022.1	925.40	997.39	1,035.63	0.90
	D728.30	675.9	2 Oct 84	1,022.1	917.58	995.87	1,036.52	0.95
	D728.30	675.9	21 Oct 85	1,019.1	915.63	993.29	1,033.29	0.94
	D729.70	677.2	1 Jun 83	1,021.0	917.14	994.19	1,033.83	0.93
	D729.70	677.2	8 May 84	1,023.3	925.40	994.39	1,035.63	0.90
	D729.70	677.2	17 Apr 85	1,020.5	915.55	993.34	1,033.40	0.94
	D729.70	677.2	23 Oct 85	1,020.4	915.79	993.30	1,033.30	0.94
	D729.83	677.4	1 Jun 83	1,021.2	917.14	994.19	1,033.83	0.93
	D729.83	677.4	7 May 84	1,023.5	924.53	997.05	1,035.82	0.91
	D729.83	677.4	2 Oct 84	1,023.6	917.58	995.87	1,036.52	0.95
	D729.83	677.4	17 Apr 85	1,020.6	915.55	993.34	1,033.40	0.94
	D729.83	677.4	23 Oct 85	1,020.6	915.79	993.30	1,033.30	0.94
	D730.00	677.5	2 Jun 83	1,021.2	916.99	994.03	1,033.82	0.93
	D730.00	677.5	2 Oct 84	1,023.7	917.58	995.87	1,036.52	0.95
	D730.00	677.5	17 Apr 85	1,020.7	915.55	993.34	1,033.40	0.94
	D730.00	677.5	24 Oct 85	1,020.7	915.63	993.30	1,033.31	0.94
Decatur		691.0						

Other Physical Data

43. Since the same notch-with-reef design (with the exception of reef alignment--Types A and B) was used for all modified dikes, differences in notch effectiveness from one structure to another must be related to differing hydrologic or channel conditions. To study factors controlling the effectiveness of the notches, physical variables descriptive of the location of each of the surveyed dikes were also measured and tabulated. The length and radius of each river bend containing a study dike were scaled from maps. Inflection points between bends were taken as end points. Channel width was also scaled from maps at several points in each reach. The distance along the channel center line from each study dike to the upstream end of the bend was also tabulated.

Results and Discussion

Water surface area

44. Changes in water surface area in the vicinity of notched dikes were evaluated by comparing areas enclosed by the 0-, -2, and -4-ft CRP elevation contours before notching and at the most recent postnotching survey. Areas of the riverbed at or below 0 CRP are inundated about 70 percent of the time in the upstream reach during the monitoring period.

45. The effects of spur dike modification on riverbed elevation contours are summarized in Table 11. Areas enclosed by contours at 0, -2, and -4 ft CRP increased after notch-with-reef construction at most of the study dikes. Surveys for 8 of the 12 dikes studied showed an increase in area enclosed by the 0-CRP contour after dike notching. The net change in total area at this elevation for all 12 dikes was a 3.5 percent (0.6-acre) increase. Area enclosed by the -2-ft CRP contour increased at 7 of the 12 study dikes after notching. The net increase in area at this elevation was 1.0 acre, or 7 percent. Eight of the 12 dikes showed increases in area at -4 ft CRP, with net gains in area of 1.40 acres, or 11.2 percent. Effects of notching on stage-area curves are shown in Figure 9. Evidently, notching had little effect on the area of 0 CRP aquatic habitat but substantially increased habitat at -4 ft CRP.

Table 11

Change in Area Enclosed by Indicated Contour After Notching

Area	-4 CRP	-2 CRP	0 CRP
	As Percent of Initial Area		
All dikes	11.2	7.0	3.5
Downstream reach	32.1	21.4	12.0
Upstream reach	1.2	-0.7	-1.3
Reef Type A	8.5	2.3	0.0
Reef Type B	16.0	15.3	9.7
	In Acres		
All dikes	1.4	1.0	0.6
Downstream reach	1.3	1.1	0.7
Upstream reach	0.1	-0.1	-0.1
Reef Type A	0.7	0.2	0.0
Reef Type B	0.7	0.8	0.6

46. Table 11 also shows that notch-with-reef construction had negligible effects on dike field habitat in the upstream reach. However, in the downstream reach, areas in the vicinity of modified dikes having notch-with-reef construction were scoured and enlarged after notching. Increases in aquatic habitat area appeared to be greater for Reef Type B than for Type A.

47. Simplified contour maps for survey areas adjacent to typical dikes from both the upstream and downstream reaches are shown in Figures 10 and 11. Although the area enclosed by the 0-CRP contours changed very little after notching, significant changes at the greater depths did occur. Three-dimensional plots of areas adjacent to six of the dikes before and after notching are presented in Appendix A.

Bed elevations

48. Mean bed elevation in the areas around the 12 dikes decreased an average of 2.0 ft after notching (Table 12). Mean bed elevations in subareas A, B, and C decreased by 1.2, 3.1, and 1.7 ft, respectively. Greatest changes in mean bed elevation were observed in Subarea B, immediately downstream of the notch, and in the downstream reach. Mean bed elevation in the vicinity of the five study dikes in the downstream reach decreased almost twice as much as for the seven dikes in the upstream reach. Bed elevation change in the two

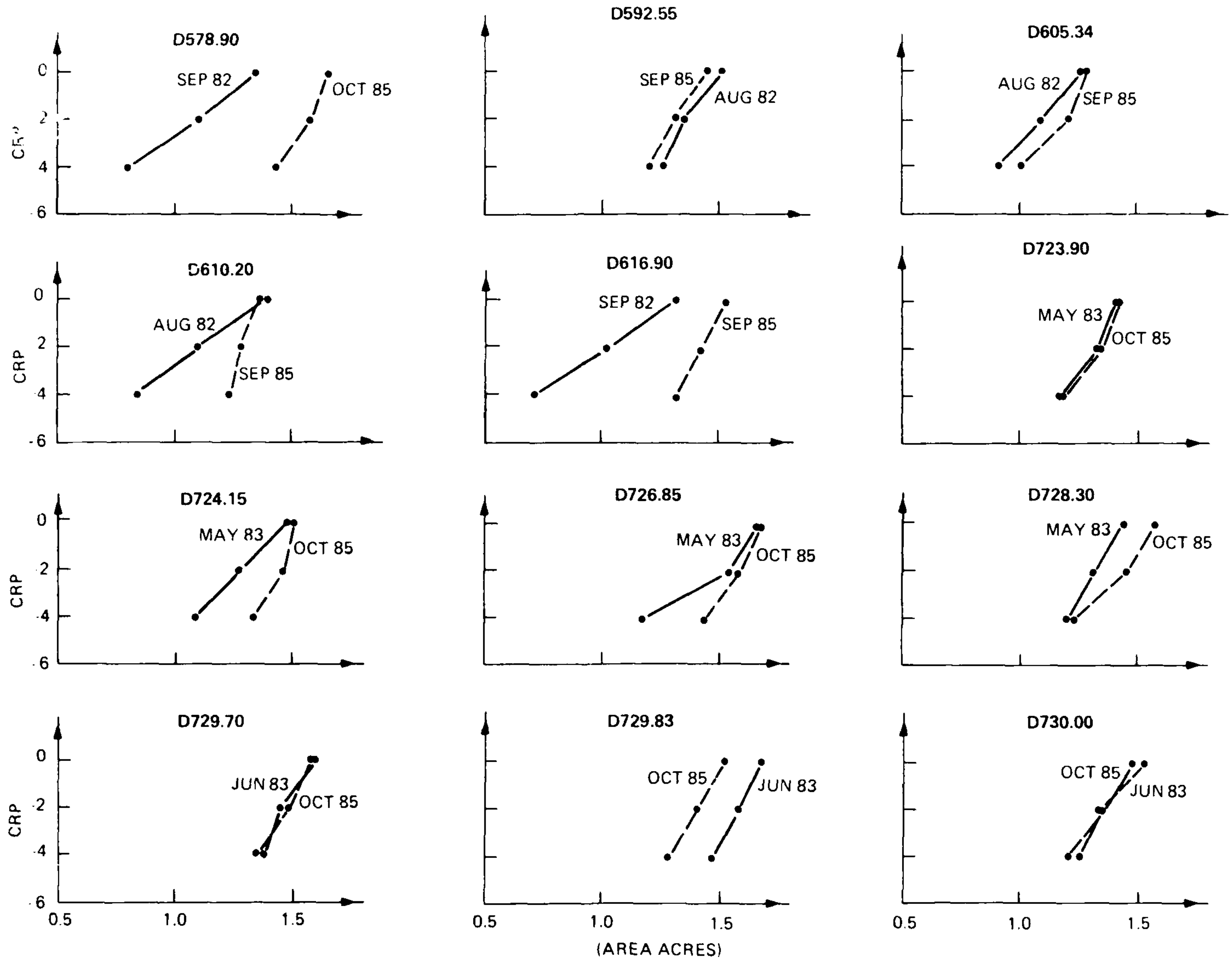
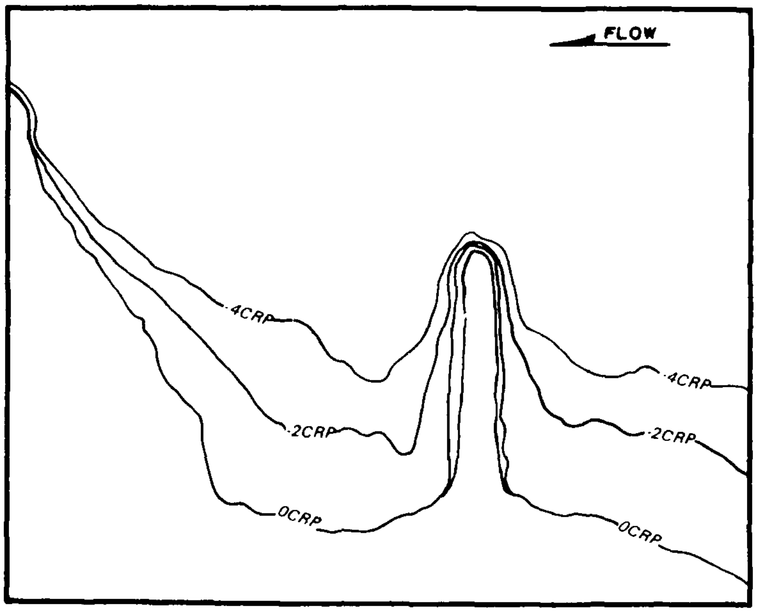
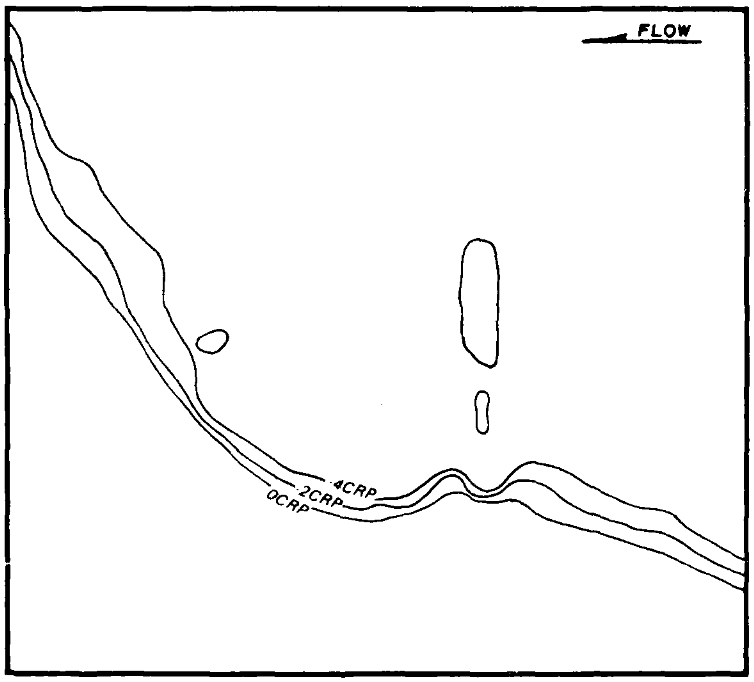


Figure 9. Stage-area curves for zones adjacent to spur dikes before and after notching

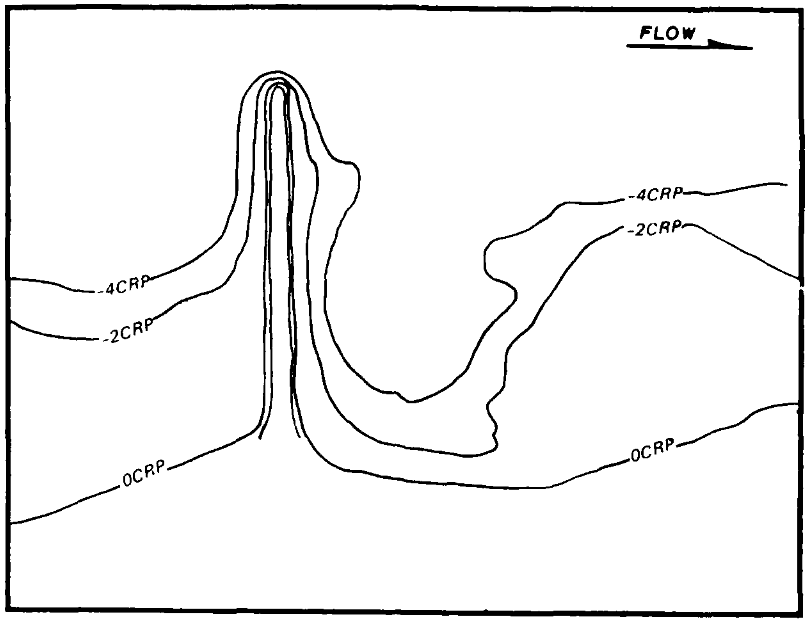


a. 31 May 1983

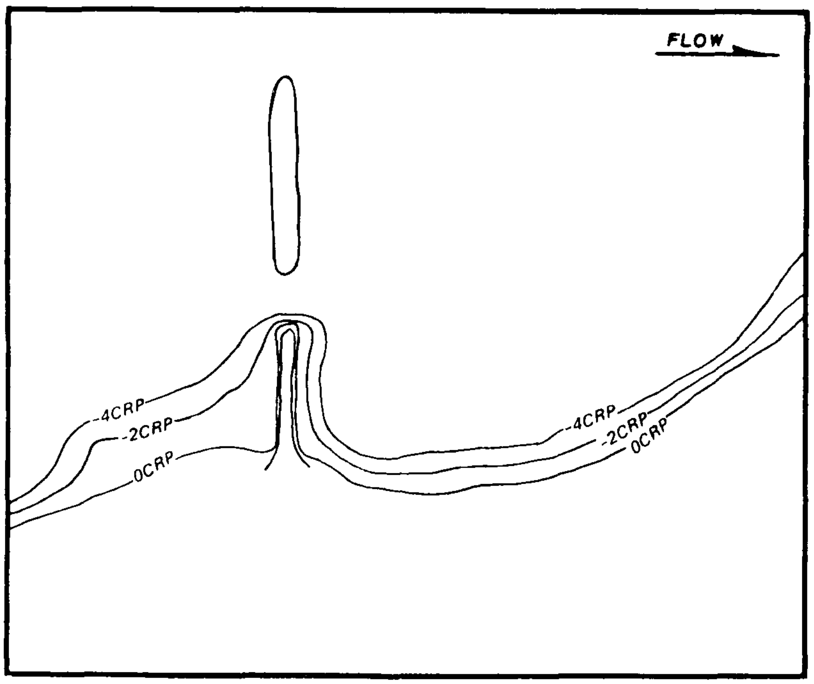


b. 21 October 1985

Figure 10. Hydrographic surveys, Dike 724.15 (upstream reach) before and after notching



a. 27 August 1982



b. 24 September 1985

Figure 11. Hydrographic surveys, Dike 610.20 (downstream reach) before and after notching

Table 12

Mean Bed Elevation Change After Notching (in Feet)

Area	Entire Area (300 by 300 ft)	Subareas* A	Subareas* B	Subareas* C	Number of Dikes
All dikes	2.0	1.2	3.1	1.7	12
Upstream reach	1.1	1.1	1.9	0.3	7
Downstream reach	3.2	1.5	4.7	3.5	5
Reef Type A	1.8	1.2	2.4	1.8	7
Reef Type B	2.3	1.2	3.9	1.6	5

* Positive numbers indicate bed lowering.

subareas downstream of the notch (B and C) was nearly four times greater in the downstream reach. Similar changes in bed elevation were observed for both reef designs (A and B).

49. The stated changes were determined by comparing mean bed elevations from the prenotching survey and the most recent survey. However, some variation through time was apparent (Table 13). Bed elevations lowered through time after notching, except during fall 1984 in the upstream reach, which showed a 0.6-ft rise over the previous survey (spring 1984). Stages for summer 1984 were the highest recorded during the study period (Figure 12), and this may explain the temporary rise in average bed elevation. However, unknown factors, such as local thalweg migration, may have also influenced dike field bed elevations.

50. The standard deviations of the depths in Subareas A, B, and C were also computed using the gridded data. Average values of these standard deviations are shown in Table 14. Evidently, depths grew more variable and less uniform after notched-with-reef construction downstream of the dikes (Subareas B and C) but remained relatively unchanged upstream (Subarea A). The three-dimensional plots in Appendix A also indicate more complex bed topography after notching in most cases.

Determinants of notch effectiveness

51. Greater changes in depth were observed after notching in the downstream reach than in the upstream reach. This difference is probably due to the higher stages in the downstream reach, as shown in Figure 12, which resulted in deeper flows through the notches there. Table 11 shows that

Table 13

Temporal Variation of Mean Bed Elevation in Vicinity of Notched Dikes

Date	Mean Elevation (ft below CRP)
Downstream Reach	
August-September 1982 (prenotching)	4.4
March 1985	7.5
September-October 1985	7.6
Upstream Reach	
May-June 1983 (prenotching)	7.7
May 1984	8.0
October 1984	7.4
April 1985	8.4
October 1985	8.8

prenotching bed elevations were much higher in the downstream reach than in the upstream reach. This may be due to the influence of the sediment from the tributaries on accretion in the downstream dike fields and to general bed degradation in the upstream reach. For whatever reason, the response to notching was more pronounced in the downstream reach where initial bed elevations were higher.

52. Correlation analyses were used to find association between the response variables (changes in depth and in area enclosed by specific elevation contour) and the independent geometric variables such as bend length and radius shown in Table 15. In the upstream reach, the response variables were directly related to dimensionless bend length. Evidently, the longer bends tend to have stronger currents through the dike fields at higher flows. The only significant relationship found for the downstream reach was between ΔZ and Z_n.* A scatter plot of ΔZ versus Z_n is shown as Figure 13. Greatest changes after notching were associated with dikes where initial mean

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* Variables ΔZ and Z_n are defined in Table 15.

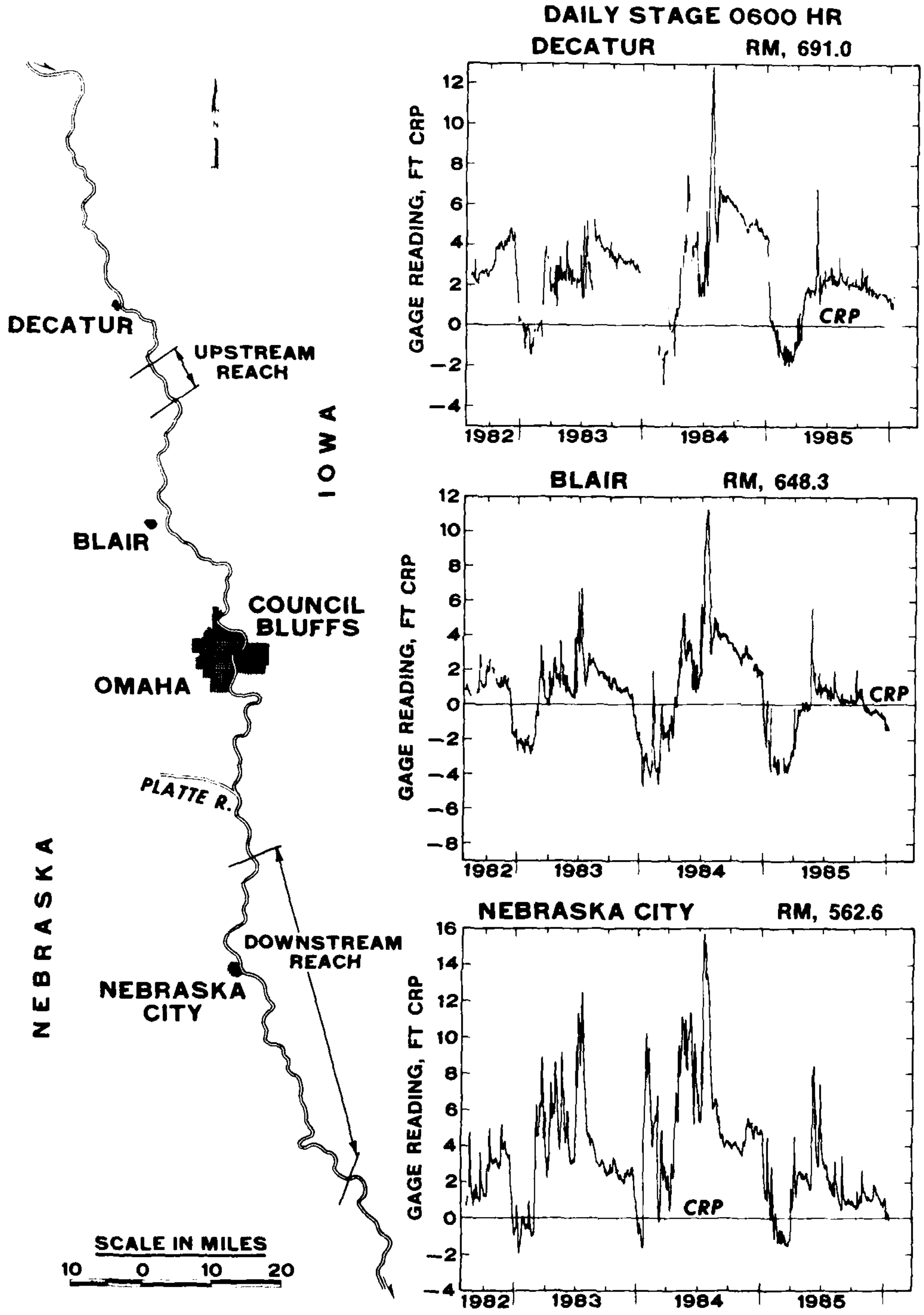

Figure 12. Stage hydrographs for study reaches

Table 14

Averages of Standard Deviation of Bed Elevation (In Feet)

Location	Prenotching	Postnotching
All dikes		
Subarea A	3.34	3.31
Subarea B	4.43	5.31
Subarea C	3.30	4.49
Upstream reach		
Subarea A	3.37	3.29
Subarea B	4.58	5.36
Subarea C	3.73	4.59
Downstream reach		
Subarea A	3.30	3.53
Subarea B	4.22	5.77
Subarea C	2.70	4.96

elevation in Subarea B (just downstream of the notch) was slightly higher than the notch invert elevation. Dike fields where Subarea B was initially lower than the notch did not respond well to notching.

Table 15

Effects of Dike Notching--Independent and Dependent Variables*

Dike No.	L_d/L_b	r_c/W	L_b/W	Z_n	ΔZ	ΔA_o	ΔA_4
				Downstream Reach			
578.90	31.8	8.2	14.5	0.27	1.23	0.44	0.17
592.55	84.4	10.8	21.1	1.21	0.28	0.02	-0.03
603.34	27.0	14.4	24.4	1.14	4.50	0.05	0.26
610.20	27.3	11.8	14.5	1.41	3.73	0.03	0.42
616.90	43.3	12.3	19.8	0.97	6.57	0.18	0.49
Mean	50.0	10.4	14.6	1.00	2.0	0.05	0.12
				Upstream Reach			
723.90	78.3	8.6	15.2	1.73	2.72	0.03	0.08
724.15	60.9	8.6	15.2	1.68	2.75	0.06	0.23
726.85	47.6	9.5	13.9	1.31	0.68	-0.05	0.18
728.30	47.4	11.8	12.5	1.83	0.77	0.11	0.00
729.70	66.7	9.6	7.9	1.29	0.43	-0.02	-0.11
729.83	50.0	9.6	7.9	1.44	0.32	-0.15	-0.20
730.00	41.7	9.6	7.9	1.50	0.09	-0.12	-0.10
Mean	56.0	9.6	11.5	1.54	1.1	-0.02	0.01

* Definitions are as follows:

L_d/L_b = distance from upstream end of bend divided by length of bend.

r_c/W = bend radius divided by channel width.

L_b/W = bend length divided by channel width.

Z_n = mean distance from CRP to bed in Subarea B prior to notching divided by the distance from CRP to the notch invert.

ΔZ = initial mean bed elevation minus final mean bed elevation.

ΔA_o = area enclosed by CRP elevation contour in 300- by 300-ft survey area after notching minus the same area prior to notching.

ΔA_4 = area enclosed by -4-CRP contour in 300- by 300-ft survey area after notching minus the same area prior to notching.

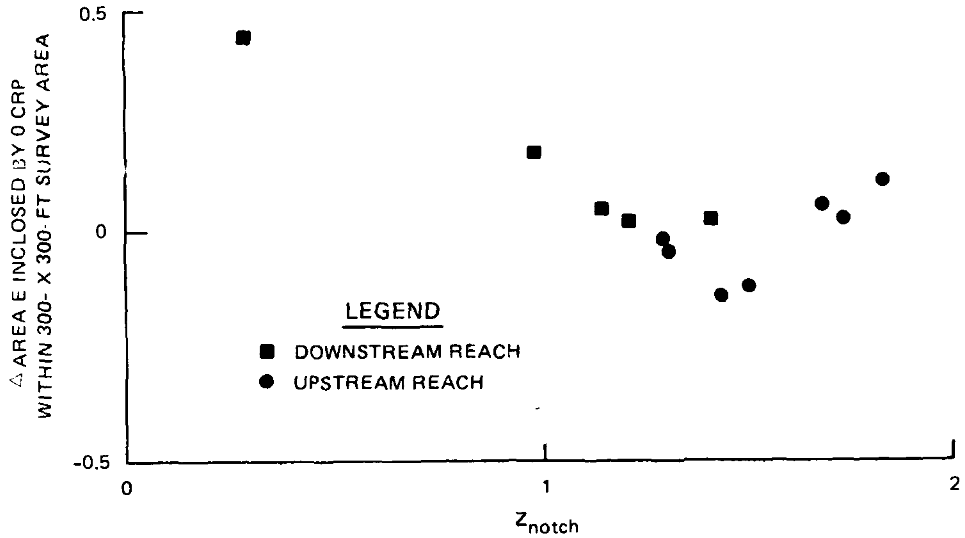

Figure 13. Response of 0-CRP contour to notching versus Z_n

PART V: EVALUATION, CONCLUSIONS, AND RECOMMENDATIONS

Notch Effectiveness as a Habitat Management Technique

53. The value of dike fields as aquatic habitat along stabilized rivers has been well established by biological field studies (Sandheinrich and Atchison 1986). However, the effectiveness of techniques such as notching for creating, maintaining, or enhancing dike field aquatic habitat is not as well understood, even though several studies of notched dikes have been performed. Most of the studies tended to present findings in regard to physical effects of notching that are vague and qualitative. The study most relevant to the one described herein is described by the USAED, Omaha (1982).

54. It is difficult to compare the results of this study with the USAED, Omaha (1982), study because different study plans were used. For example, the latter study involved collection of hydrographic survey data after notching, and no before-and-after comparisons were made. Areas enclosed by the 0-CRP contour just below three spur dikes located just downstream of the Platte River confluence were measured twice several years after notching at 2-year intervals. Areas were essentially unchanged, and mean bed elevations lowered from 7.8 to 10.2 ft below CRP during the same period.

55. Although sequential surveys were conducted for a 4-year postnotching period at some 40 dikes in the USAED, Kansas City, reach of the Missouri River, data are presented for only a few "typical" structures. Mean bed elevations in the vicinity of three spur dikes lowered an average of 1.8 ft, but considerable fluctuation occurred from survey to survey.

56. The USAED, Omaha (1982) concluded that bend radius, notch invert elevation (or notch depth), and initial bed elevation downstream of the notch were important determinants of notch effectiveness. The study described in this report found that notch invert elevation relative to flood stage and initial bed elevation below the notch influenced notch effectiveness, as did bend length. Findings of the two studies regarding initial bed elevation below the notch were apparently contradictory: the Kansas City District portion of the USAED, Omaha (1982) evaluation stated that notches in spur dikes with substantial accretion already above and below the structure would be ineffective, while notch effectiveness in the downstream reach of this study was directly related to the prenotching mean bed elevation just downstream of the notch.

These differences are most likely due to differences in the reaches studied and in the ranges of the independent variables that were encountered by the two studies.

57. One of the primary reasons dike fields are valuable habitat is that they offer regions of lower velocity relative to the main channel. For the flows occurring during the 1986 sampling dates for the study described herein, typical channel velocities in the upstream and downstream reaches fall between 6 and 7 fps (Slizeski, Andersen, and Dorough 1982), while the velocities measured in the dike fields were only 25 to 35 percent as great. This velocity differential is similar to that observed in physical model studies described by the US Army Corps of Engineers (1981). The USAED, Omaha (1982), reported that velocities through the notch were less than 2 fps for more than half of some 557 notches inspected in the Omaha District reach.

58. Results of the study described by this report indicate that water quality and distribution and abundance of fishes were not significantly different among the three dike types studied. The presence of reefs in the areas immediately downstream of a dike notch did not influence the fish numbers, number of species, or biomass. However, this study did not investigate the reef as being a potential spawning site. Pflieger (1975) has identified several lotic fish species that require rocky substrates for spawning. Robinson (1980) reported that no single type of dike or modification thereof was more suitable than another for fishes. This is consistent with findings of this study.

Conclusions

59. Although spur dike notching evidently had no effect on the water quality or abundance of fishes in the aquatic habitat adjacent to the dikes, notching of spur dikes was effective in increasing the quantity of dike field habitat available, particularly in the downstream reach. The area enclosed by the -2-ft-CRP contour in the zones around the dikes increased 0.22 acre/dike in the first 3 years after notching. A rough estimate based on the maps published by the USAED, Omaha (1979), indicates that if all the spur dikes in the downstream reach (river miles 517-573) were similarly notched and if the areas adjacent to these dikes responded as those in the study did, the spur dike

field habitat (-2 ft CRP) in this reach would be increased by about 60 acres, or roughly 16 percent.

60. The notch-with-reef modifications had greater effect on mean depths adjacent to the dikes than on water surface area. This is due in part to the fact that the notches have been designed and constructed to cause very little bank erosion, rather than to maximize it. Notches and other types of dike modifications could probably be designed to increase the amount of bank erosion and thus to increase the aquatic habitat area that occurs after notching. However, the problems that would be experienced by riparian landowners would have to be addressed.

Recommendations

61. Even though no differences in water quality or fish abundance were evident among the three dike types, it is recommended that the dike modification program continue. Though some scouring behind the modified dikes has taken place, the extent of the physical changes in the habitat in the upstream reach has probably not been great enough to allow for changes in the fish community.

62. There is need for continued investigation of the influences of notching and reef construction on the Missouri River biotic communities. In future studies, a greater number of dikes should be sampled to decrease the high variability of results. Modification of hydroacoustic survey design to reduce problems encountered in this study is also recommended.

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APPENDIX A: THREE-DIMENSIONAL PLOTS OF HYDROGRAPHIC SURVEYS OF SELECTED DIKES BEFORE AND AFTER NOTCHED-WITH-REEF CONSTRUCTION

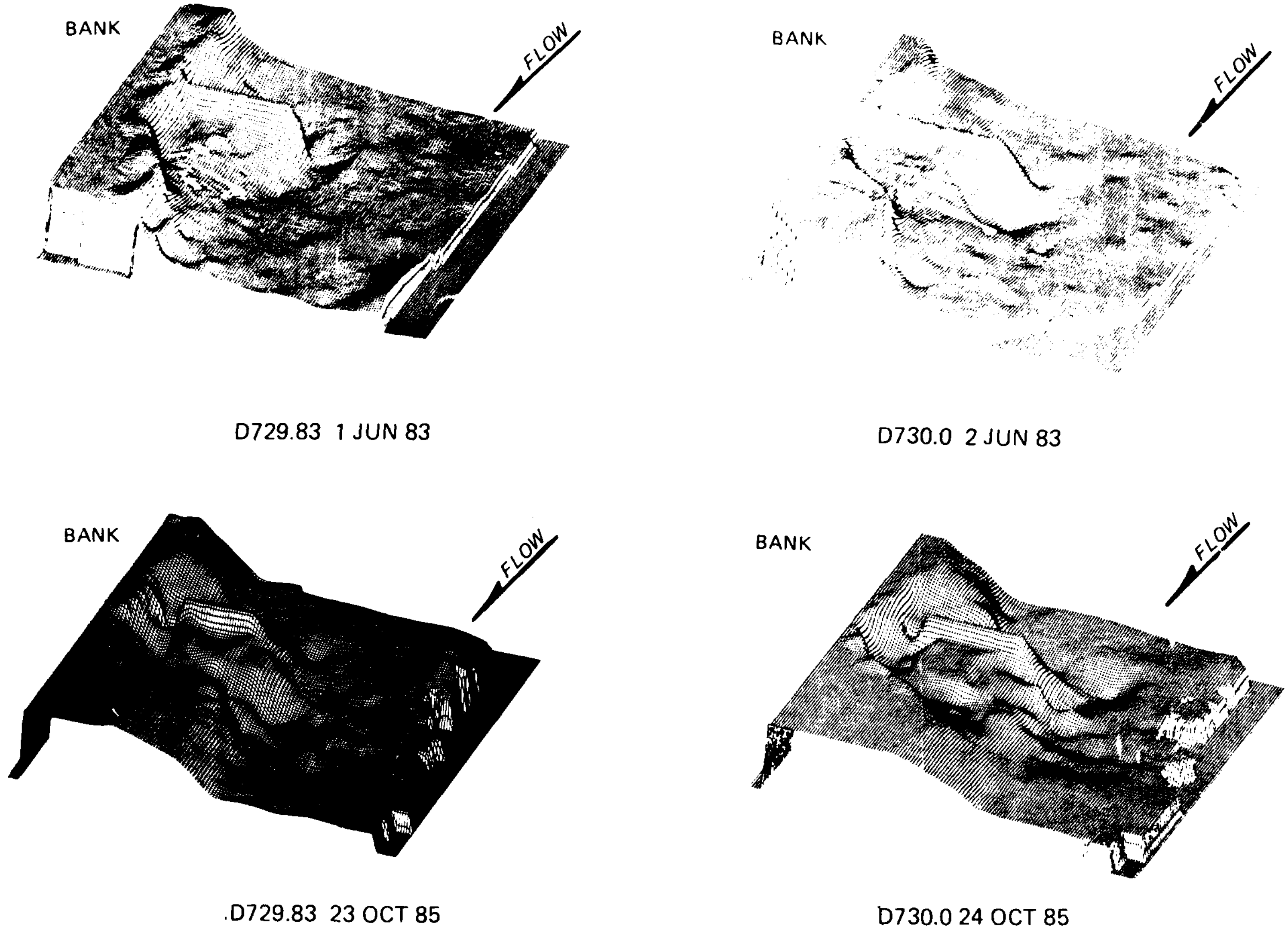

Figure A1. Three-dimensional depiction of bed topography adjacent to D729.83 and D730.0 before and after notching

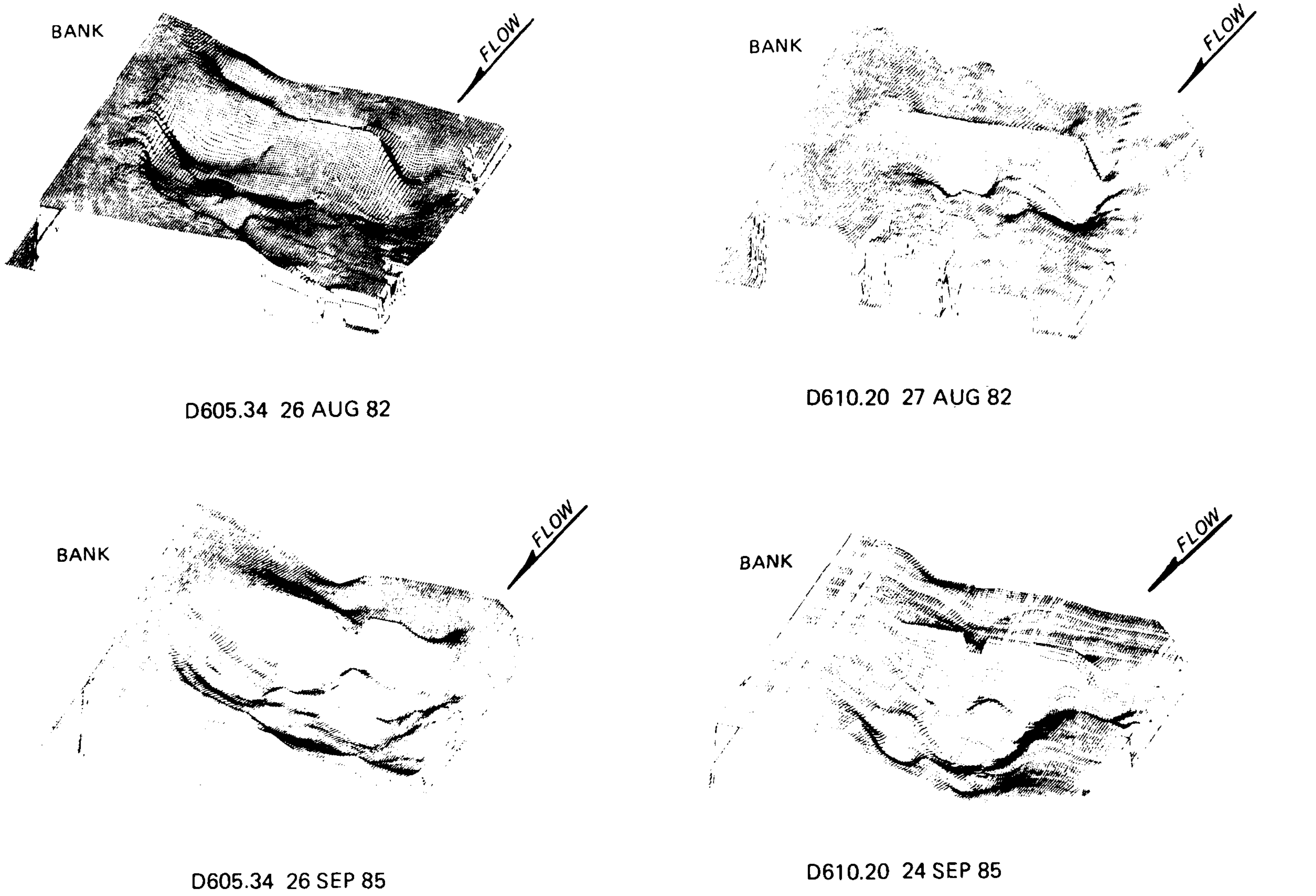

Figure A2. Three-dimensional depiction of bed topography adjacent to D605.34 and D610.20 before and after notching

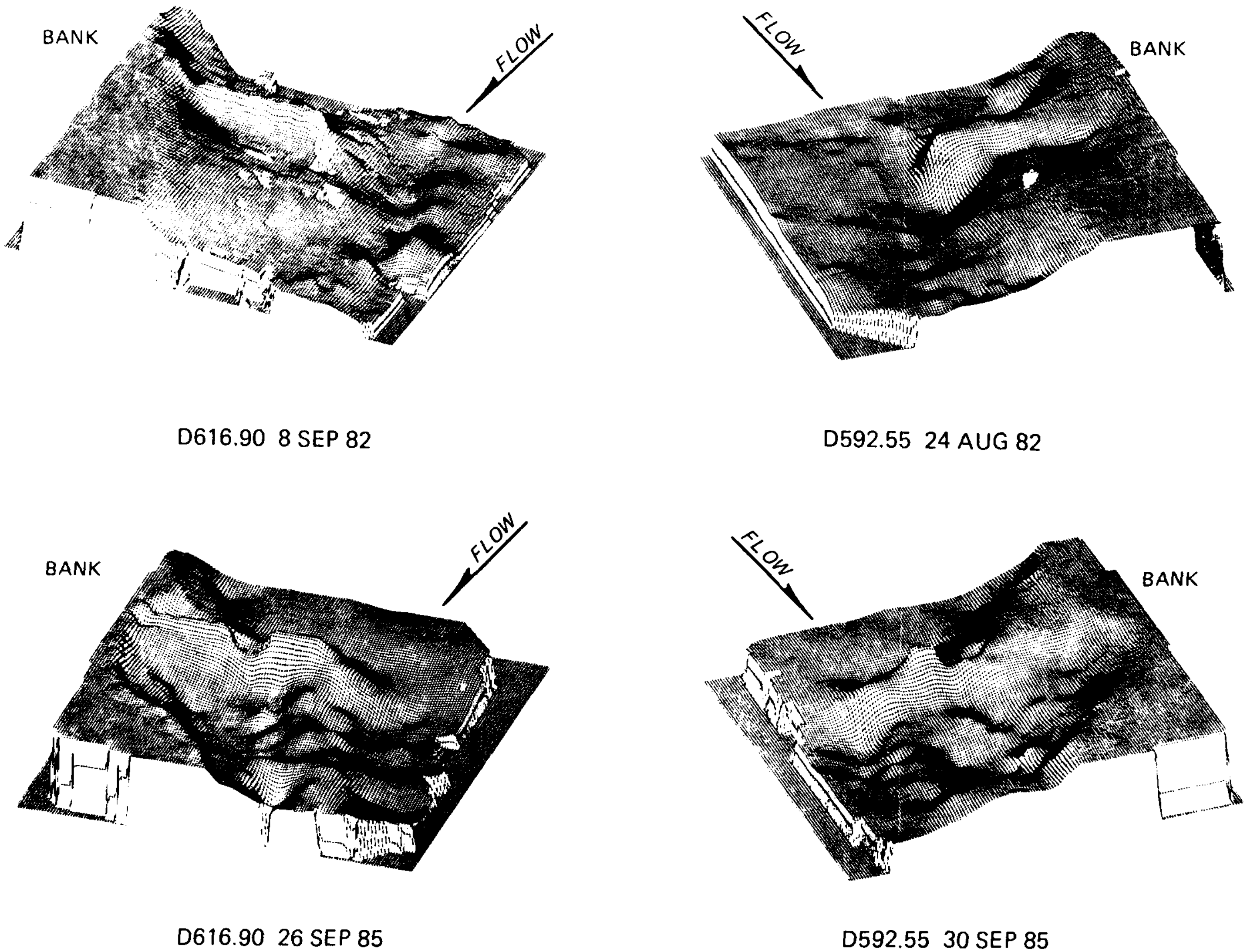

Figure A3. Three-dimensional depiction of bed topography adjacent to D616.90 and D592.55 before and after notching