

**DISSERTATION**

**ENVIRONMENTAL DIKE DESIGN CONSIDERATIONS  
FOR THE LOWER MISSISSIPPI RIVER**

Submitted by

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In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

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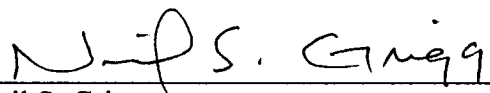
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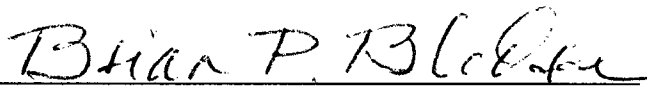
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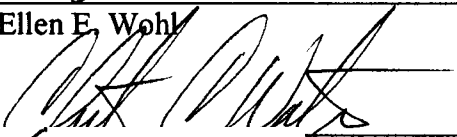
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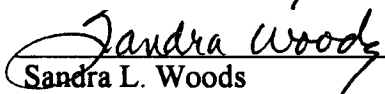
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## **ABSTRACTION OF DISSERTATION**

### **ENVIRONMENTAL DIKE DESIGN CONSIDERATIONS FOR THE LOWER MISSISSIPPI RIVER**

The purpose of the Lower Mississippi River dike system is to maintain required minimum navigation channel width and depth. In recent years, it is known that the dike structures, and the topographic features and fluvial landforms associated with dike systems, constitute a distinct aquatic habitat in the Lower Mississippi River ecosystem. However, in spite of a variety of economic and environmental benefits from dikes, no definitive hydraulic design criteria have been developed. This is primarily due to the wide range of variables affecting the performance of the dikes and the varying importance of these variables with specific applications. To optimize dike design, including dredging-free navigation channels and aquatic habitat within the dike pool area, it is very important to predict the actual river responses to dike installation. Therefore, the primary objective of this study is to suggest optimal design guidance for the dike system based on statistical and numerical methods using the data sets collected from the Lower Mississippi River dike systems.

Linear regression analysis was performed, to find relationships between dike geometric parameters (dike length, elevation, radius of curvature of the reach, etc.) and pool surface area change, which is considered the dike pool parameter most highly correlated with dike geometric parameters. It was shown that the shorter and the lower the dike, the less the pool surface area decreases, thereby preserving more habitat area.

Two kinds of multiple regression model equations were suggested; one consisting of measured parameters and the other consisting of dimensionless parameters, both of which can be used to predict the pool habitat area change represented by the pool surface area change for the given dike and channel geometry.

A HEC-6 model was used, to find relationships between dike geometric parameters and main channel parameters such as thalweg elevation depth or cross-section area. The simulated cross-section areas matched relatively well with the measured. The effect of each dike geometric parameter on thalweg elevation was predicted. It was found that the effect of the dike length on thalweg elevation is much greater than that of dike elevation. It is expected that the HEC-6 model can be used to evaluate the scenarios established at the initial stage of dike design, which are possible combinations of the dike geometric parameters satisfying the master plan for the waterway project.

The Physical HABitat SIMulation (PHABSIM) model, a software package used in the Instream Flow Incremental Methodology (IFIM), was used to predict the usable habitat area of each life stage of the representative fish (target species) within the dike field. It was shown that the dike pool surface area change can represent the aquatic habitat change for fish living in the dike field. It was also shown that cross-section geometry data calculated from the HEC-6 model can be used as input geometry data for the PHABSIM model, to predict change in aquatic habitat for fish, although there is a tendency to underestimate the usable habitat area.

Finally, procedures for environmental dike design were suggested, based on the results obtained from these analyses.

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## SYMBOLS & ABBREVIATIONS

### Symbols

A	cross-section area
A	flow area between the top of dike and an elevation of +30 LWRP [ft <sup>2</sup> ]
Ad <sup>2/3</sup>	channel factor or conveyance
B	unstandardized regression coefficient
BA	bar
CA or CV	percent change in pool surface area or volume [dimensionless]
CH	chute
CW	width of main channel that was measured from the bank head point of the dike to the opposite bank at 0 foot LWRP [L]
CX	crossing
d	mean flow depth
d	flow depth between the top of dike and an elevation of 30 feet LWRP [ft]
D	dike fields in which maintenance dredging would be required
DE	dike elevation measured from LWRP to the representative dike elevation [L]
DL	dike length [L]
DS	dike slope [dimensionless]
IB	inside bend

K	side channel conveyance [ $\text{ft}^{8/3}$ ]
L	length of dike [ft]
L	length
MC	main channel
ND	dike fields in which no maintenance dredging would be required
ND+D	dike fields in which maintenance dredging would be required for only part of the dikes
OB	outside bend
p	P-level
Q	discharge
$Q/(Ad^{2/3})$	slope-roughness factor
$R^2$	coefficient of determination
$R_c/W$	radius of curvature divided by main channel width
RC	radius of curvature of the reach [L]
SC	secondary channel
ST	straight
T	time

### **Greek**

$\beta$	standardized regression coefficient
---------	-------------------------------------

### **Abbreviations**

AHP	Above Head of Passes
ALWP	Average Low Water Plane
cfs	cubic feet per second

CHL	Coastal and Hydraulics Laboratory
CSU	Colorado State University
ERDC	Engineer Research and Development Center
HEC	Hydrologic Engineering Center
HSC	Habitat-Suitability Curves
IFIM	Instream Flow Incremental Methodology
LMREP	Lower Mississippi River Environmental Program
LMVD	Lower Mississippi Valley Division
LWRP	Low Water Reference Plane
MR&T	Mississippi River and Tributaries
MRC	Mississippi River Commission
NGVD	National Geodetic Vertical Datum
PHABSIM	Physical HABitat SIMulation
RAS	River Analysis System
RM	river mile
SA	surface area
USACE	U.S. Army Corps of Engineers
USAED	U.S. Army Engineer Districts
WUA	Weighted Usable Area
XS	cross section

# 1 INTRODUCTION

## 1.1 BACKGROUND

Dikes have been used extensively in all parts of the world as river training structures to enhance navigation, improve flood control, and protect erodible banks (Copeland, 1983). The purpose of the Lower Mississippi River dike system is to maintain required minimum navigation channel width and depth (Cobb and Magoun, 1985). On the Lower Mississippi River, dikes were constructed to contract the width and increase the depth of the main channel at low flows, close secondary channels and chutes to reduce divided flow conditions, adjust channel alignment, and increase channel stability (U.S. Army Corps of Engineers (USACE), 1977). These actions are designed to produce a self-maintaining navigation channel, i.e., a main channel that would require little or no maintenance dredging (Cobb and Magoun, 1985).

Narrowing of the main channel with dikes, results in channel deepening as a result of bed material scouring caused by increased main channel discharges and velocities. Dike systems constructed on point bars and in unstable straight reaches may function in this manner. Stabilization of the bank opposite a dike system with revetment prevents lateral channel migration and forces deepening of the thalweg (Cobb and Magoun, 1985).

Dike systems are also constructed to concentrate flows in the main channel by eliminating or reducing divided channel configurations. Flows are concentrated into the main channel by closing point bar chute channels and secondary channels. This is done

to produce a deeper low-water navigation channel by forcing greater flow into the main channel and causing degradation (Cobb and Magoun, 1985).

According to some investigators, the dike structures, and the topographic features and fluvial landforms associated with dike systems constitute a distinct aquatic habitat in the Lower Mississippi River ecosystem (Cobb and Clark, 1981; Cobb and Magoun, 1985). Cobb and Magoun (1985) divided the aquatic habitat associated with dike systems into two areas: (1) the area between adjacent dikes in a dike system, referred to as the pool area; and (2) the sandbars located between pool areas and the main channel. These habitats are discrete at low-water stages but are obscured at higher flows when all areas within the top banks of the channel environment assume main-channel conditions.

In fluvial systems with flowing water, the macroinvertebrate and fish populations respond primarily to micro habitat conditions, which according to Baker *et al.* (1988), include current speed, substrate type, temperature, dissolved oxygen, and turbidity. The large number of species found within dike pool areas shows that dikes generally provide a diverse mixture of micro habitats having a wide variety of physical conditions (Cobb and Clark, 1981). This habitat caters to a wide range of species and life stages of fish and acts as valuable nursery areas for larval and juvenile fish, and as feeding area for larger fish (Baker *et al.*, 1988).

However, there is a continuing concern that the habitat created by dike systems fills with sediments to the extent that the quality of valuable habitat is diminished (Cobb and Magoun, 1985). There is also a perception by some that observed sedimentation in dike systems is reducing the capacity of the channel to convey flow, resulting in increased river stages and the need to raise the mainline levees (Cobb, 1986).

## 1.2 OBJECTIVES

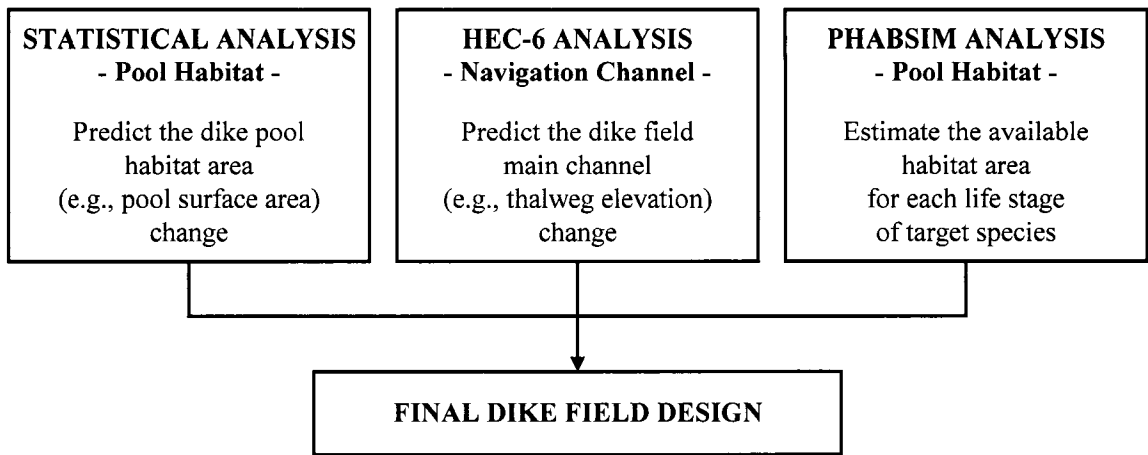
In spite of a variety of economic and environmental benefits gained from the dikes constructed in the Lower Mississippi River, no definitive hydraulic design criteria have been developed. Dike design has been based on experience and judgment within specific geographic areas. This is primarily due to the wide range of variables affecting the performance of the dikes and the varying importance of these variables with specific applications. Parameters affecting dike design include: width, depth, flow velocity, and sinuosity of the channel; size distribution and transport rate of the bed material; and length, elevation, slope, and spacing of the dikes.

For the purpose of the optimal dike design not only to maintain dredging-free navigation channels but also to secure the minimal aquatic habitat within the dike pool area to maintain existing aquatic biota, it is very important to predict the actual river responses to dike installation. Therefore, the primary objective of this study is to suggest optimal design guidance for the dike system based on statistical and numerical methods using the data sets collected from the Lower Mississippi River dike systems. Specific objectives of this study are:

- (1) To collect all data sets that can be used for analyses in this study, including dike geometry data (dike length, elevation, slope, angle with the bank, etc.), surface area and volume of each dike pool measured from hydrographic survey maps, dike construction history, and hydrographs at gauging stations within the study reach.
- (2) To identify the major parameters (dike geometry, channel alignment, water discharge, sediment load, etc.) that significantly influence the sedimentation

trends in the dike systems, and to develop dimensionless parameters that represent the major parameters identified.

- (3) To examine the applicability of Lamb and Ethridge's (1991) design line traditionally used as the USACE dike design method.
- (4) To find any particular relationships between major parameters previously identified and pool habitat parameters such as pool surface area change by performing the statistical analysis.
- (5) To predict the dike field main channel volumetric change after dike installation using a one-dimensional movable bed model (HEC-6) and suggest the relationships between dike geometric parameters and main channel parameters such as thalweg elevation or cross-section area change.
- (6) To estimate the usable habitat area for each life stage (spawning, egg incubation, fry, juvenile, adult, etc.) of the representative fishes (referred as to *target species*) living in the Lower Mississippi River using a Physical HABitat SIMulation (PHABSIM) model to predict change in aquatic habitat before and after dike installation, and also relate that pool habitat parameters like pool surface area change can be used as a representative estimator to indirectly predict change in aquatic habitat area.
- (7) Finally, to suggest environmental dike design procedures for the Lower Mississippi River using the results from the above-determined objectives. An overview of a generalized dike design procedure is presented in Figure 1.1.



**Figure 1.1: Generalized dike design procedure**

### **1.3 LOWER MISSISSIPPI RIVER AND DIKE SYSTEM**

The Mississippi River is the fourth largest drainage basin in the world (1,245,000 square miles), exceeded in size only by watersheds of the Amazon, Congo, and Nile Rivers. The river drains 41 percent of the contiguous 48 United States and a portion of Canada.

The Lower Mississippi River flows from the confluence of the Ohio and Middle Mississippi Rivers at Cairo, Illinois, to the Gulf of Mexico, a distance of approximately 975 river miles (RM). The mean annual flow at Natchez, Mississippi, approximately midway along the Lower Mississippi River, is 600,000 cubic feet per second (cfs) and the highest discharge recorded to date is 2,160,000 cfs.

Management of the lower Mississippi River and tributary streams falls under the USACE Mississippi River and Tributaries (MR&T) Project. The MR&T Project is a comprehensive flood control and navigation improvement plan that was authorized under the Flood Control Act of 1928 and is the responsibility of the Mississippi River Commission (MRC) formed in 1879. The purpose of the Channel Improvement Project,

one component of the MR&T Project, is to increase the flood-carrying capacity of the river, protect levees and other structures, and improve the alignment and depth of the river for navigation. The navigation channel has been managed, at least partially, through channel-contraction works, such as dikes. Congress authorized the construction of 296 miles of dikes in the Lower Mississippi River (Baker *et al.*, 1988). As of September 30, 1996, there were approximately 288 miles of stone dikes, 129 miles of foreshore dikes, and 1,023 miles of operative revetment on the Lower Mississippi River (USACE, 1997).

On the Lower Mississippi River, dikes are built of limestone rock and are large linear structures built within the top banks of the channel. Some pre-1960s wooden pile dikes are still visible on the Lower Mississippi River but have since been reinforced with stone. The dikes are trapezoidal in cross section and can follow three accepted planforms. The transverse (or spur) dike is the most popular, and is aligned perpendicular to the flow, either angled slightly upstream or slightly downstream. The L-head (or trail) dike starts off with a transverse dike but on the river channel end has an extra linear length added to the main stem in a downstream direction. The final dike planform is called a vane dike. This is usually much shorter than a transverse dike and to some degree runs parallel with the flow. The vane dike is somewhat different to the transverse or L-head dike as they are not anchored to the bank (Biedenharn *et al.*, 2000).

This study addresses the portions of the Lower Mississippi River (RM 374.0 to 945.7) selected by the USACE-Lower Mississippi Valley Division (USACE-LMVD) for developing a sedimentation database (surface area, volume, and depth data of each main channel, pool, and sandbar area). Each portion consists of a reach or length of river that contains at least one set of dikes, and is called a dike system. These dike systems are

composed of 35 smaller dike fields. Sixteen of the 35 dike fields within this study are managed by the Vicksburg District and the remaining 19 dike fields are managed by the Memphis District.

## 2 LITERATURE REVIEW

In order to develop appropriate hypotheses and to aid in identifying dike design factors, relevant literature was reviewed, which were classified as hydraulic analysis, aquatic habitat studies, spur dikes for bank protection, and environmental guidelines for dike fields.

### 2.1 HYDRAULIC ANALYSIS

One of the oldest Lower Mississippi River dike studies was reported by Anding (1965). He analyzed the hydraulic elements of the Mississippi River cross sections in relatively stable reaches of the river. He concluded that the channel factor ( $Ad^{2/3}$ ;  $A$  = cross-section area,  $d$  = mean flow depth) varied uniformly with stage and remained fairly constant at representative stages for individual sections in stable reaches and, therefore, channel control structures such as dikes should be planned to develop similar values of  $Ad^{2/3}$  for pools and crossings. He also reported that radius of curvature should be taken into consideration since these would partially control the spacing of dikes for any specific allowable change in angle of attack between dike locations. Therefore, this concept of constant channel factor (channel conveyance) along the channel can be an aid to predict the shape of the cross sections within the dike field. Lamb and Ethridge (1991) also developed the dike design line for the Mississippi River and tributaries using conveyance outside the main channel.

According to USACE's study (1968) of the upper portion of the Greenville Reach in the Lower Mississippi River, the channel factor ( $Ad^{2/3}$ ) increased and the slope-roughness factor ( $Q/(Ad^{2/3})$ ) decreased within the dike fields. However, the channel below the dikes deteriorated and had less channel capacity, and increased roughness and slope at low stages. Further, if dike fields result in more efficient channels and flatter slopes, energy head will be accumulated, which will have to be dissipated in the channel below. This results in increased concentrations of sediment deposition. To alleviate this condition, structures designed to dissipate the excess energy and to control the channel alignment and configuration are required. This may be accomplished by stepping transverse dikes down in the downstream direction.

Biedenharn *et al.* (2000) conducted a detailed analysis of 35 dike fields in the Lower Mississippi River. They analyzed the surface area, volume, and depth of three areas in the dike field: main channel, pools, and sand bars. According to their analysis, the pool area is dominated by decreases in surface area, volume, and mean depth, whereas the main channel area is dominated by increases in surface area, volume, and mean depth. However, the sand bar area is highly variable, experiencing both scour and fill. As a whole, the scour or fill response of all dike fields diminishes with time. The largest impacts of the dikes occur in the initial response period (first 10 to 15 years following dike construction) after which the response decreases significantly. In the long term (beyond 10 to 15 years), the annual percent of change in scour or fill approaches zero indicating that the systems are approaching an equilibrium condition.

Franco (1967) performed a variety of physical modeling for dike design. He determined the factors affecting the performance of dikes and dike systems, and provided indications of the relative effectiveness of the various factors. According to his experiments:

- Dike systems having the stepped-down effect are more effective than systems with all dikes level, and dikes with all dikes level are more effective than dikes having the stepped-up effect;
- The amount of dredging required to produce project dimensions is inversely proportional to dike elevation;
- There is also a greater tendency for dikes angled downstream to be flanked near the bank end than dikes angled upstream and for level-crest dikes to be flanked near bank end than sloping-crest dikes; and
- Level-crest dikes should be placed normal or angled downstream and sloping-crest dikes should be placed normal or angled upstream for better performance.

Franco (1982) also conducted movable-bed model studies on seven of the most complex and troublesome reaches of the Mississippi River to obtain some general indications of the effectiveness of plans proposed for the improvement and stabilization of those reaches. He concluded that these types of models predicted, at least qualitatively, most of the principal trends that actually occurred in the river with the plans tested. He also concluded that side channel closure structures were difficult to maintain because of the head over the structures and severe scouring downstream.

Franco's research (1967, 1982) qualitatively outlined general rules to be considered in dike design, and most of them have been applied in the Lower Mississippi

River dike construction. However, it did not suggest the quantitative relationships for the factors affecting dike performance that could be usefully applied in the field.

Simons *et al.* (1974) performed physical model studies of the Middle Mississippi River and side channels to examine the effects of dikes as a method of preserving side channels or improving flow through the side channels. They concluded that the life of side channels can be increased if the intakes are closed soon after side channel formation; it is possible to realign the river so that the intake to a side channel is in a favorable position and alignment to obtain clear water and very little sediment; however, this would require massive structures to resist the forces of the main channel and would be extremely expensive.

Currently, in the Lower Mississippi River dikes are built out of limestone rock. Some pre-1960s wooden pile dikes are still visible on the Lower Mississippi River but have since been reinforced with stone (Biedenharn *et al.*, 2000). Fairley and Easley (1967) reviewed contraction works of pile dikes in the Memphis District prior to the present channel improvement project. According to them, permeable pile dikes are not structurally capable of resisting the direct attack of the current, as in chute closures or attempts to force the channel into a completely new location. Pile dike systems can be considered successful when the spacing of dikes is less than 2,000 feet, and the dikes are normal or nearly normal to the channel. Littlejohn (1969) analyzed three Lower Mississippi River reaches, in which four pile dike systems had been constructed. He concluded that the effect of the pile dike systems extended for only a short distance downstream. Therefore, it can be concluded that pile dikes are less effective than stone dikes in channel contraction as well as in chute or secondary channel closure.

## 2.2 AQUATIC HABITAT STUDIES

The impacts and ecological value of the manmade habitats formed by dikes in the Lower Mississippi River were studied by Cobb and Clark (1981). The aquatic habitat of a 50-mile reach of the river (RM 480 to 530 Above Head of Passes (AHP)) was quantitatively mapped to determine special relationships among and within habitat types as a function of river stage and discharge. By use of controlled aerial photography and hydrographic survey data, aquatic habitat surface acreages were computed for three river stages (low flow = 13.2 feet (140,000 cfs), medium flow = 24.6 feet (400,000 cfs), and high flow = 38.4 feet (870,000 cfs) on the Greenville, Mississippi, gage). Results of the habitat mapping are: during the low-flow period, the main channel was the predominant habitat type; during the medium-flow period, dike fields and the main channel were the most abundant habitat types; and for the high-flow period, inundated floodplain habitats were the most common habitats.

Cobb and Magoun (1985) performed physical and hydrologic investigations on 46 dike systems in the Lower Mississippi River. Water surface area, water volume, and water depth data in each dike system were simulated for four river stages corresponding to the 0-, 5-, 10-, and 15-foot Low Water Reference Plane (LWRP) elevations. The LWRP is the water surface elevation that correspond to a discharge that is exceeded 97 percent of the time based on the 20-year period of record (1954 to 1973) and is assigned a value of 0 feet. Conclusions of the study were:

- Pool areas found at lower river stages ( $\leq 15$  feet LWRP) within dike systems constitute a significant amount of slack-water or low-velocity aquatic habitat

within the top banks of the channel in terms of both water surface area and volume;

- Dike system pools, when isolated from the channel, are limnologically similar in many characteristics to floodplain lakes but are hydrologically unstable or variable;
- Sandbar habitat is distinct from pool habitat in dike systems because flowing water conditions similar to the main channel occur even during the annual low-flow period, although velocities and depths may be less than in the channel environment; and
- The dike structures may be a significant source of secondary production of fish food organisms and are potential loci for conversion of suspended particulate organic matter to biomass within the riverine ecosystem.

They also performed the analyses of the relationships between the basic dike engineering design features of crown elevation, crown slope, and dike length and dike system pool habitat. They found that dike systems that had steeper main body slopes and lower crown elevations had larger, deeper pools. Additionally, the analyses revealed statistically significant trends, but should not be used to infer cause-and-effect relationships because many confounding factors of the complex riverine environment obscure these relationships. They noted that the interactions between many complex factors such as dike system age and size, geomorphic location, preconstruction conditions, and sediment transport processes tended to obscure relationships between design and habitat characteristics.

Nunnally and Beverly (1986) investigated quantitative and qualitative changes in aquatic habitat on the Lower Mississippi River and the association of such changes with construction of dike fields. In order to develop appropriate working hypotheses and to aid in formulating the research design, they reviewed similar studies of morphologic effects of training structures on the Missouri River. According to their review, diking of the Missouri River has caused reductions in habitat quality and habitat diversity due to reduced water surface area and disproportionate loss of slack-water environments. Dikes and revetments eliminated channel migration and the associated slack-water environments, and dams have reduced flow variability. Elimination of high discharges may have hastened sedimentation and stabilization of dike fields by reducing the magnitude and frequencies of floods that could periodically scour sediment from the dikes.

The Mississippi River has larger and more variable discharge, lower slope, and lower sediment concentration than the Missouri River. Therefore, dike field effects on the Lower Mississippi River are less evident. During a 14-year period from 1962 to 1976, total low-water surface area on the Mississippi River changed very little, but in diked reaches significant loss occurred in secondary channel area and significant offsetting gains were observed for chutes, sloughs, and pools, all of which are valuable slack-water habitats. It cannot be determined whether the slack-water habitats measured on the Lower Mississippi River are temporary features that will eventually fill with sediment or whether these represent some sort of dynamic equilibrium that will be maintained. The highly variable discharge, lower slope, and relatively low sediment load

of the Mississippi River seem to enable it to periodically scour sediments from dike fields during high flood discharges.

Sandheinrich and Atchison (1986) summarized the research conducted on the Lower Mississippi, Willamette, Arkansas, and Middle Missouri Rivers to draw overall conclusions about the environmental effects of dikes and revetments on waterways. They reported the physical and chemical characteristics of dike fields as follows:

- Deep-water areas were formed by the scouring action of the water upstream and/or downstream sides of the dikes, and these plunge pools enhance the physical diversity of the area near the dike and may provide important cover for several species of fish in winter and during periods of low flow;
- Dikes provide areas of slow and moderate current within the main stem, when not overtopped by the river;
- Substrates within dike fields are mosaiclike, consisting of patches of various sediment types arranged as a function of current across the habitat. According to detailed mapping studies of the Lower Mississippi River dike fields, during high flows, scouring occurred and sand dominated the substrate, but with lowered river stage, deposition of sediment occurred and a shift to mud and mud/sand substrates was evident;
- Water-quality conditions within dike fields are of a transitory nature and are related to the presence or absence of current. During lotic periods, dike fields are part of a well-mixed system with values for water-quality parameters similar to other habitats in the main channel. Dike fields may become partially or

totally separated from the main channel during low-flow intervals, and quality conditions assume characteristics more similar to abandoned channels;

- Dike fields provide a varied range of depths, substrates, and currents that increase habitat complexity and affect fish distributions and community diversity;
- The fish communities associated with dikes are diverse and may harbor more species than any other habitat within the main channel; and
- Macroinvertebrate communities associated with dike fields show that the distributions of benthic macroinvertebrates parallel the bottom substrate pattern.

From the characteristics observed above, they concluded as follows:

- Short-term effects of dikes and revetments may be beneficial and included increases in aquatic habitat diversity and physical stability, which in turn result in high densities and diversities of fish and macroinvertebrates within the main stem of the river;
- Long-term effects of river-training structures are difficult to isolate since the structures are used in conjunction with other engineering practices. Increased water flow in the thalweg, as a result of the current being forced into the middle of the channel by dikes, results in riverbed degradation and dewatering of backwater areas during low flow. Stabilization of the channel prevents the river from meandering and forming new oxbow lakes, secondary channels, and backwater habitats. Deposition of silt in backwaters and on the downstream side of dikes often results in the loss of these as aquatic habitats. The loss of quiet backwater areas is deleterious to the productivity of the river. Backwaters are

responsible for a major portion of the river macroinvertebrate production and provide valuable spawning and nursery areas for several river species; and

- Dike fields are areas of considerable physical and biological heterogeneity at moderate and low-water flows. These areas are densely colonized by macroinvertebrates and provide a valuable habitat for a diverse community of adult, juvenile, and larval fish species. It is recommended that dike fields be designed to prevent complete siltation.

### **2.3 SPUR DIKES FOR BANK PROTECTION**

Spur dikes are defined as linear structures, permeable or impermeable, projecting into a channel from the bank for the purpose of altering flow direction, channel bank protection, inducing deposition, or reducing flow velocity along the bank (Brown, 1985).

Copeland (1983) conducted a hydraulic model investigation to evaluate and demonstrate the effects of impermeable spur dikes as a bank-protection technique in a concave bend. Conclusions of the study were; spacing-to-length ratios as high as three may be effective in protecting concave banks with spur dikes; spur dike roots should be protected from scour caused by vortices set up along the upstream and downstream faces; the spur dike should be aligned perpendicular to the bank or flow; and aprons are effective in limiting the depth of scour at the toe of the spur dike.

Brown (1985) conducted a study of the applicability and design of spur dikes to establish design guidelines and other criteria for the use of spur dikes. The recommendations and findings were based on a thorough review of pertinent literature, analysis of field sites, and on a laboratory study conducted by the Federal Highway Administration. Recommendations from this study were; as the dike length is increased,

the scour depth at the dike tip increases; the greatest scour depths occur for dikes angled upstream, the least local scour is associated with dikes angled downstream; and impermeable dikes should be designed with a slight fall towards the dike head, thus allowing different amounts of flow constriction with stage and the accommodation of changes in meander trace with stage.

Kuhnle *et al.* (1999) measured scour hole volume in the vicinity of model spur dikes in a laboratory flume under clear-water overtopping flows. Spur dike length, flow depth, and shear velocity ratio were varied in the experiments and found to significantly influence the scour hole volume. It was found that the ratio of the flow depth to the spur dike height was an important control on the geometry of the resulting scour hole. They also proposed a preliminary technique to predict the volume of scour for spur dikes perpendicular to the bank.

Also, Kuhnle *et al.* (2002) conducted a series of experiments associated with angled spur dikes. The main goals of the experiments were to evaluate the effect of the three angles (45, 90, and 135° from downstream direction) on the volume of scour and potential aquatic habitat and on minimizing erosion adjacent to the streambanks. The experiment showed that the least erosion of the bed in the near-bank region was associated with the spur dikes with 90° angles, whereas the greatest volume of the scour hole was associated with the 135° spur dikes. Therefore, it was concluded that spur dikes with 135° angles (i.e., angled upstream) showed the best potential for providing improved aquatic habitats while minimizing the potential for erosion of the channel bank.

Spur dikes for bank protection are much different from dikes used for navigation improvement in scale and main function. Most Mississippi River dikes have been constructed to reduce navigation channel maintenance.

## **2.4 ENVIRONMENTAL GUIDELINES FOR DIKE FIELDS**

Burch *et al.* (1984) outlined the environmental guidelines for dike fields that can be used to maintain or increase fish and wildlife habitat diversity. This report may be the first that suggests dike design guidelines considering the environmental aspect of a dike field.

First, they summarized general dike design considerations for large navigation river systems:

- Dike length is determined based on the master plan for the waterway project and the channel width at each site. Constricted channel width (distance between the riverward tips of dikes and the opposite bank) of the Lower Mississippi River is from 2,500 feet to 3,000 feet;
- In general, “high” dike elevations are more effective in developing navigation channels, but the cost of dike construction increases rapidly with crest elevations. “Low” dike elevations tend to reduce sediment accretion and increase diversity of water depths, which often serves to enhance the overall habitat value of the dike field;
- Typically, dike crests are level or slope down towards the channel, although broken (stepped) crests are frequently used for closure dikes;
- Dikes are typically spaced apart the maximum distance which will achieve the desired channel constriction while preventing or minimizing bank erosion; and

- The crest elevation, crest profile, and dike angle are flexible parameters in most dike designs, as there are more design alternatives available for these three parameters.

Structural modifications that increase aquatic habitat diversity include notches, low-elevation dikes, rootless dikes, and minimum maintenance practices. Other potential techniques include dredging to remove sediment, disposing dredged material within the dike field, relocating old notches, placing additional rock, adding artificial reefs, and building control structures inside channel closure dikes. The environmental objectives applicable to all dike design, construction, and maintenance are as follows:

- Maintain or increase the aquatic habitat diversity by increasing the complexity of physical factors comprising the aquatic habitat;
- Preserve the integrity of existing off-channel aquatic habitat areas;
- Schedule construction and maintenance to avoid peak spawning seasons for aquatic biota;
- Design and maintain dike fields to prolong the lifetime of the aquatic habitat (i.e., reduce sediment accretion); and
- Maintain abandoned channels open to the river.

Environmental considerations at the master-plan level include the distribution or composition of habitats among the various habitat types (main channel, abandoned channel, island, point bar, revetted bank, natural bank, dike field, etc.) and the spatial distribution of backwater habitats along the waterway. Master plan formulation to ensure incorporation of environmental considerations includes the following steps:

- (1) Formulate a draft river training master plan to achieve navigation, flood control, and bank erosion control objectives;
- (2) Using results of a habitat mapping study, evaluate the existing composition and spatial distribution of riverine habitats;
- (3) Using a multidisciplinary team, set general long-term goals for composition and spatial distribution of aquatic and terrestrial riverine habitats; and
- (4) Modify the draft master plan to achieve these goals.

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

- (1) Evaluate the long-term potential of the dike field as aquatic habitat;
- (2) Based on step (1), determine whether design modifications or environmental features are in order;
- (3) Consider manipulation of the basic dike design parameters to reduce the elevation of sediment deposition within the dike field;
- (4) Qualitatively project the depths, velocities, and resulting substrates likely to occur in the dike field;
- (5) Consider structural modifications to improve the aquatic habitat within the dike field; and
- (6) Consider management techniques to improve aquatic habitat within the dike field after construction.

Application of the general environmental objectives and design procedure will differ from river to river. This flexibility is necessary due to highly variable characteristics of rivers, sites, and dikes.

## **2.5 DISCUSSION**

### **2.5.1 CHANNEL IMPROVEMENT**

As summarized in Table 2.1, literature about dike-field performance provided good design guidelines for channel improvement using dikes. However, most of them suggested only qualitative effect of each dike design parameter on channel improvement.

Because dike design is a mixture of engineering and art, dependent upon the waterway characteristics, site characteristics, navigation requirements, and the personal experience of the design engineer, most dikes have been designed based on trial and error, experience, observation of dike performance, and common sense (Thackston and Sneed, 1982). However, if there were more definitive hydraulic design criteria that could be directly applied in the field, it would remove some of the uncertainty in design and permit greater economy in the design of dikes by minimizing over-design as well as under-design.

### **2.5.2 AQUATIC HABITAT PRESERVATION**

As reviewed above, dike fields are areas of considerable physical and biological heterogeneity at moderate and low-water flows. These areas are densely colonized by macroinvertebrates and provide a valuable habitat for a diverse community of adult, juvenile, and larval fish species. As sediments accrete in dike fields, the valuable dike-field habitat is eliminated from the riverine ecosystem, with a net loss in amount and

**Table 2.1: Summary of the effects of dike design parameters**

<b>Literature</b>	<b>Dike Length and Elevation</b>	<b>Dike Slope</b>	<b>Stepped-up or Stepped-down</b>	<b>Dike Angle</b>	<b>Dike Spacing</b>	<b>Purpose of the Dikes</b>
Fairley and Easley (1967)				Normal or nearly normal dikes considered successful.	Pile dikes having spacing less than 2,000 feet considered successful.	Navigation improvement.
Franco (1967)	The amount of dredging required to produce project dimensions inversely proportional to dike elevation.	Level-crest dikes easier to be flanked near bank end than sloping-crest dikes. Level-crest dikes should be placed normal or angled downstream and sloping-crest dikes should be placed normal or angled upstream for better performance.	Stepped-down dike systems most effective, level dike systems secondly effective and stepped-up dikes least effective.	Dikes angled downstream easier to be flanked near the bank end than dikes angled upstream.		Navigation improvement.
USACE (1968)			Stepped-down dikes required to dissipate the excess energy in the channel below the dike field.			Navigation improvement.
Copeland (1983)				Spur dikes should be oriented perpendicular to the bank to obtain the most effective bank protection.	Spacing to length ratios as high as three effective in protecting concave banks.	Bank protection.

**Table 2.1 (Cont.)**

<b>Literature</b>	<b>Dike Length and Elevation</b>	<b>Dike Slope</b>	<b>Stepped-up or Stepped-down</b>	<b>Dike Angle</b>	<b>Dike Spacing</b>	<b>Purpose of the Dikes</b>
Cobb and Magoun (1985)	Dike length positively correlated with pool surface area and volume. The lower the crown elevations, the larger and deeper pools within the dike field.	The steeper the main body slopes, the larger and deeper pools within the dike field.				Navigation improvement.
Brown (1985)	As the dike length increases, the scour depth at the dike tip increases.	Impermeable dikes should be designed with a slight fall towards the head to allow different amount of flow constriction with stage.		The greatest scour depths occur for dikes angled upstream, the least local scour associated with dikes angled downstream.		Bank protection.
USACE (1997)					One to two times the length of the next upstream dike.	Navigation improvement.
Kuhnle <i>et al.</i> (2002)				Spur dike angled upstream (135°) has best potential for providing improved habitats (the greatest volume of scour hole) while minimizing the potential for erosion of the channel bank.		Bank protection.

diversity of riverine aquatic habitat. Burch *et al.* (1984) suggested good environmental guidelines for dike fields to maintain or increase fish and wildlife habitat diversity. However, there were few environmental guidelines for dike design that could relate the amount of habitat for representative species living in the specific reach with change in dike design parameters. Therefore, to be used for environmental dike design guideline, it is necessary to evaluate the habitat formed by dikes for each species and to predict the future change in habitat.

## 3 DATABASE

### 3.1 INTRODUCTION

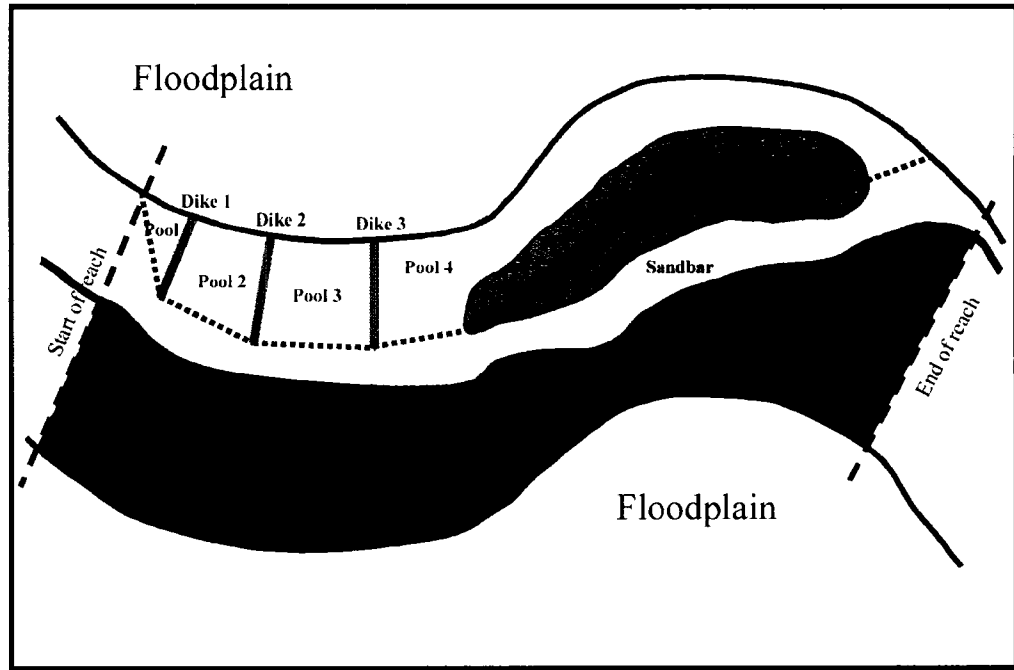
The Lower Mississippi River Environmental Program (LMREP) is a comprehensive investigation of the Lower Mississippi River and its leveed floodplain. The study is being conducted by the MRC and was started in 1981. The objectives of the LMREP are to obtain environmental inventory data on the project area and to develop environmental design considerations for navigation and flood control features of the MR&T Project such as levees, revetments and dike systems. The Sutron Corporation and USACE-Engineer Research and Development Center (USACE-ERDC) were charged with obtaining dike-field data, which was completed in 1987 (Biedenharn *et al.*, 2000).

In 2000, the USACE-ERDC completed an initial analysis of the original data. The original data and project included: the collection of survey data from USACE-LMVD files and other surveys; analysis of volume, surface area, and mean depth data for various river stages; and identification of general trends and significant factors affecting these trends. For the remainder of this study, this original data set will be referred to as the *ERDC data set*.

The ERDC data set included 35 dike fields built between 1957 and 1983. Each dike field was divided into three components: the main channel, sand bar, and pool areas

(Figure 3.1). Cobb and Magoun (1985) define the main channel, pools, and sandbars as follows:

- Pools are defined as the area circumscribed by the bank line, and a line connecting the channelward tips of the dikes and traversing at a 45-degree angle from the tip of the upstream or first dike in the system to the bank. The pool downstream of the last dike in a system was defined in one of two ways, depending on the presence or absence of a sandbar and/or emergent island and associated chute downstream of the last dike. Where a sandbar extended downstream of the last dike within a system, a chute channel (pool) typically was found downstream of the last dike between the middle bar and bank line. For this case, the pool boundary line was drawn from the tip of the last dike to the upstream end of the sandbar and thence down the center line or crest of the bar to its downstream end; the line was then extended across the mouth of the pool boundary. If no middle bar and associated chute channel was present downstream of the last dike, the downstream pool was defined the same way as the upriver of the first dike. The pool upstream of the first dike was termed pool 1, the pool between the first and second dikes was called pool 2, and so forth;
- The sandbar area associated with each dike system was defined as the bar area between the pool boundary and the -10 feet LWRP contour, the boundary of the main channel. The upstream and downstream boundaries of the sandbar area corresponded to the pool area boundaries, although it is recognized that the influence of the dike system on the associated sandbar may be more extensive; and



**Figure 3.1: Sketch of main channel, pool and sand bar areas (Biedenharn *et al.*, 2000)**

- The boundary of the main channel is the remainder of the channel up to the -10 feet LWRP contour.

Once the main channel, pool, and sandbar areas were delineated for each dike system, the water surface area and volume were measured from hydrographic survey data. The stages listed for the surface area and volume are 0, 5, 10, 15, and 20 feet LWRP. The corresponding mean depth was calculated from measured surface area and volume.

A list of the dike fields, their location, and other pertinent information is presented in Table 3.1. A dike system contains one or more dike fields. The planform categories (Figure 3.2) are divided as: straight – ST; inside bend – IB; outside bend – OB; and crossing – CX. The location categories are classified as: main channel – MC;

bar – BA; secondary channel – SC; and chute – CH. The  $R_c/W$  ratio refers to radius of curvature divided by main channel width. The base year refers to the year in which the individual dike field was built.

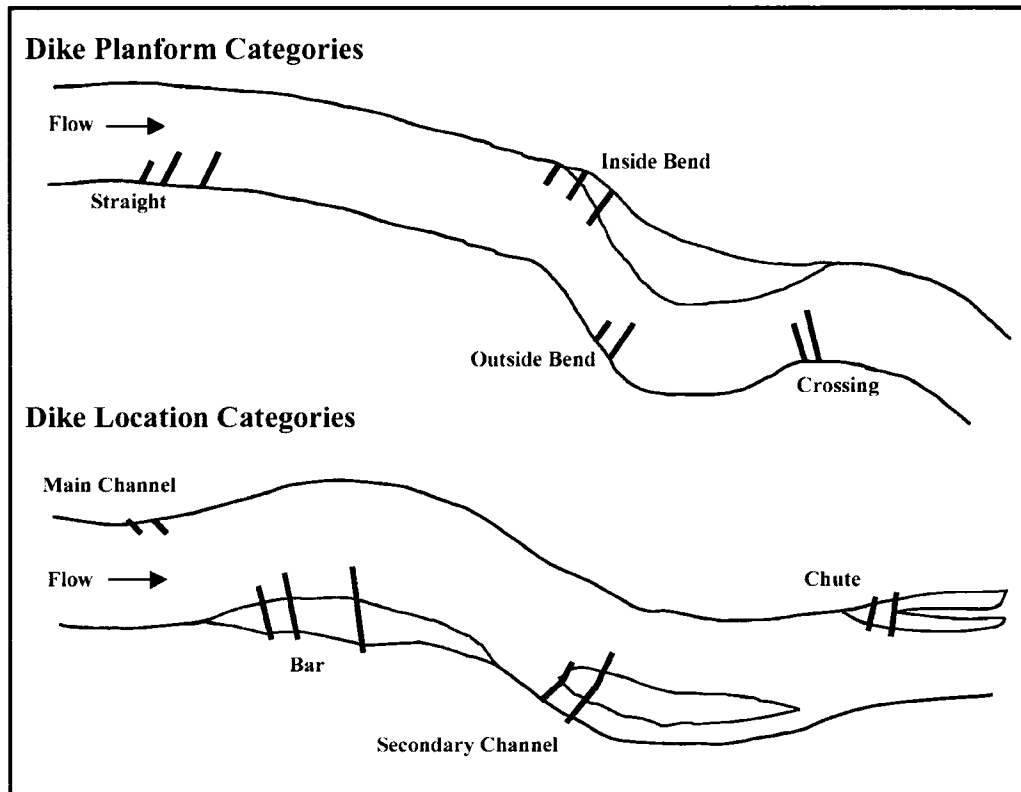


Figure 3.2: Classification of dike planform and location (Biedenharn *et al.*, 2000)

**Table 3.1: General information from ERDC data set**

Dike System Name	Individual Dike Field Name	Total Length (mi)	Width (ft)	Radius of Curvature (ft)	Side of River (Left = L / Right = R)	No. of Dikes	Planform Category**	Location Category***	R <sub>c</sub> /W Ratio	Arc Angle (deg)	No. of Pools	Ind. Base Year
Above Loosahatchie	Above Loosahatchie	4	4017	50160	L	6	ST	MC	12.5	25	8	1968
Above Loosahatchie	Redman Point	4	4017	50160	R	4	ST	SC	12.5	25	2	1956
Above Loosahatchie	Sycamore Chute	4	4017	50160	R	4	ST	SC	12.5	25	1	1956
Above Loosahatchie	Robinson Crusoe	4	4017	50160	R	2	ST	SC	12.5	25	1	1956
Ashbrook	Ashbrook-Miller Bend	7.4	4317	23760	R/L	9	IB	BA	5.5	64	9	1965
Ashbrook	Island 82-Miller Bend	7.4	4317	23760	R/L	8	IB	BA	5.5	64	10	1965
Ashbrook	Ashbrook Cutoff	7.4	4317	89760	L	4	ST	CH	20.8	10	3	1965
Baleshed	Baleshed Landing	11	4233	42240	L	5	ST	SC	10.0	60	5	1963
Baleshed	Ben Lomand	11	4233	42240	L	11	ST	SC	10.0	60	5	1963
Bondurant	Bondurant Towhead	4.5	3733	34320	R	2	CX	SC	9.2	40	3	1974
Cat Island	Cat Island	7.8	3850	15840	R	6	IB	SC	4.1	115	5	1958
Cat Island	Seyppel	7.8	3850	15840	R	5	IB	SC	4.1	115	2	1958
Cat Island	Pickett	7.8	5090	34320	L	3	CX	SC	6.7	25	2	1964
Catfish Point	Catfish Point	4.8	2533	7920	L	2	IB	CH	3.1	135	3	1972
Chicot Landing	Chicot Landing	11.2	2483	15840	R	9	IB	SC	6.4	147	4	1968
Densford	Densford*	4	1783	36960	L	3	CX	SC	20.7	33	4	1965
Dismal Point	Dismal Point	10	3767	21120	R	8	IB	SC	5.6	97	6	1966
Dismal Point	Armstrong	10	3767	21120	R	7	IB	SC	5.6	97	4	1966
Forked Deer	Forked Deer	5	3275	126720	L	5	ST	SC	38.7	13	6	1964
Island 25	Island 25	4.4	3450	5280	R	2	IB	SC	1.5	122	3	1969
Island 62	Island 62	6.4	2533	13200	R	10	IB	SC	5.2	122	7	1966
Island 62	Island 63	6.4	2533	13200	L	5	OB	SC	5.2	122	3	1961
Island 62	Island 63 Bar	6.4	2533	13200	L	2	OB	SC	5.2	122	2	1961
Island 70	Island 70	4.5	2775	34320	L	11	ST	CH	12.4	38	5	1961
Island 86	Island 86	6.4	4050	21120	R	6	IB	CH	5.2	65	4	1970

**Table 3.1 (Cont.)**

Dike System Name	Individual Dike Field Name	Total Length (mi)	Width (ft)	Radius of Curvature (ft)	Side of River (Left = L / Right = R)	No. of Dikes	Planform Category**	Location Category***	R/W Ratio	Arc Angle (deg)	No. of Pools	Ind. Base Year
Cracraft	Lower Cracraft	4.8	2967	31680	R	3	ST	SC	10.7	40	4	1970
Cracraft	Carolina	4.8	2967	31680	L	2	ST	SC	10.7	40	3	1973
Marshall Cutoff	Marshall Cutoff	4	3983	14520	R	2	IB	BA	3.6	80	3	1978
Marshall Cutoff	Forest Home Towhead	4	3983	14520	L	4	OB	SC	3.6	80	4	1980
Pritchard	Pritchard	3	4850	126720	R	5	ST	CH	26.1	7	4	1966
Pritchard	Island 1	3	4850	126720	L	3	ST	BA	26.1	7	4	1969
Randolf Point	Randolf Point	5.6	4300	47520	L	7	ST	SC	11.1	35	5	1958
Waterproof	WaterProof	6.3	3883	50160	R	6	ST	SC	12.9	39	7	1964
Wilson Point	Wilson Point	6.6	2617	18480	R	3	IB	MC	7.1	100	3	1968
Wrights Point	Wrights Point	8.4	3083	7920	R	15	IB	SC	2.6	180	6	1961

\* width measured at different elevation – taken at the -7 feet LWRP

\*\* straight – ST; inside bend – IB; outside bend – OB; and crossing – CX

\*\*\* main channel – MC; bar – BA; secondary channel – SC; and chute – CH

### **3.2 DATA-COLLECTION REVIEW**

The ERDC data set includes surface area, volume, and depth measurements for each dike field. The updated data set incorporates the ERDC data set and the following: dike length, dike elevation, dike slope, dike angle with the bank, construction year, dike location, dike type, etc. Sixteen of the 35 dike fields within this study are managed by the Vicksburg District and the remaining 19 dike fields are managed by the Memphis District. Data collected included plan and profile record maps for each dike under examination for this study from both the Memphis and Vicksburg Districts, and the latest hydrographic surveys for the corresponding dike fields. The total number of plan and profile record maps needed from both Districts was 206, and 171 (83%) of them were obtained.

From the 171 plan and profile record maps, the following study parameters were recorded into the database. Table 3.2 presents a sample database table for Prichard Dike #1, Memphis District. Tables A.1 and A.2 in Appendix A present dike summary tables for the Memphis and Vicksburg Districts, respectively.

**Table 3.2: Sample database table – Prichard Dike No. 1, Memphis District**

Year of Construction (yrs)	Year of Extension and/or Stone Fill (Latest) (yrs)	Map Year (Latest) (yrs)	Map Serial No. (no)	Map File No. (187/###) (no)	Location of Dike (Center-line) (mi)	Side of River (L or R)	Construction Type (Initial) (1, 2 or 3)	Construction Type (Latest) (1, 2 or 3)	Dike Type (1, 2 or 3)	Dike Section (1, 2, or 3)	Base-line Station (ft)	Station (From Baseline Azimuth) (ft)	Position (Along Dike Azimuth) (ft)	Crown Elevation (NGVD) (ft)	Crown Width (NGVD) (ft)	Dike Azimuth (deg)	Baseline Azimuth (deg)	Notes
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	294	0	311.5	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	327	0	311.5	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	390	0	302.5	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	410	0	298	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	430	0	295	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	470	0	292	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	500	0	291	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	550	0	291	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	600	0	290	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	640	0	288.5	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1050	0	288.5	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1100	0	288	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1200	0	288	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1250	0	289	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1300	0	289	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1350	0	288	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1380	0	288	14	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1430	0	288	6	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1450	0	288	6	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1500	0	289	6	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1650	0	289	6	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1700	0	288	6	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1850	0	288	6	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1890	0	286	11.6	298.50	27.20	
1959	1970	1970	18857	1221	944	R	2	3	1	2	34530	1900	0	286.5	13	298.50	27.20	



Additional descriptive information for column headings in Table 3.2, and Tables A.1 and A.2 in Appendix A are listed below:

- Year of Construction – Initial year of construction.
- Year of Extension and/or Stone Fill – Latest year of extension and/or stone fill.
- Map Year – Latest map year.
- Map Serial and File Number – Each map has its original serial and file number.
- Location of Dike – RM of the dike denoted in the map.
- Side of River – The side of river that the dike is located.
- Construction Type – Stone, Pile, and Stone-filled Pile dikes:
  - Stone dike: An impermeable structure of either quarry-run or graded stone.
  - Pile dike: A permeable structure built forming one to five rows of piles or clumps usually angled normal to riverflow.
  - Stone-filled Pile dike: (1) A damaged or deteriorated pile dike that has been repaired by dumping stone along its length to a specified elevation, usually midbank height, and (2) A dike built in stages for economic reasons. The piles are driven, the river deposits fill around the piles, and stone is dumped on top of the river fill. The piling enables the stone to stand on a steeper slope than the natural angle of repose for additional savings.
- Dike Type – Transverse, L-head, and Vane dikes:

- Transverse dike: Linear structures that are anchored to the bank and extended toward the channel, generally perpendicular to the axis of flow or angled slightly up or down river.
- L-head dike: Basically, a transverse dike with a section added at the channelward end that extends downstream at about a 90-degree angle relative to the axis of the transverse dike. However, in this recording, all the dikes having dike azimuth change were classified into L-head dikes.
- Vane dike: Not anchored to the bank but are built parallel or slightly oblique to the axis of flow near the border of the main channel.
- Dike Section – Bank head, Main body, and Downhill slope:
  - Bank head: The portion of the dike that is anchored into the bank.
  - Main body: The portion of the dike between bank head and downhill slope.
  - Downhill slope: Channelward terminus that has steeper slope (usually, angle of slope of stone) than main body.
- Baseline Station – Baseline station number of each dike in the 1999 hydrographic survey maps.
- Station – Distance from the baseline.
- Position – In the case of vane dikes that are connected to transverse or L-head dikes, their starting positions are denoted by the stations of those transverse or L-head dikes.

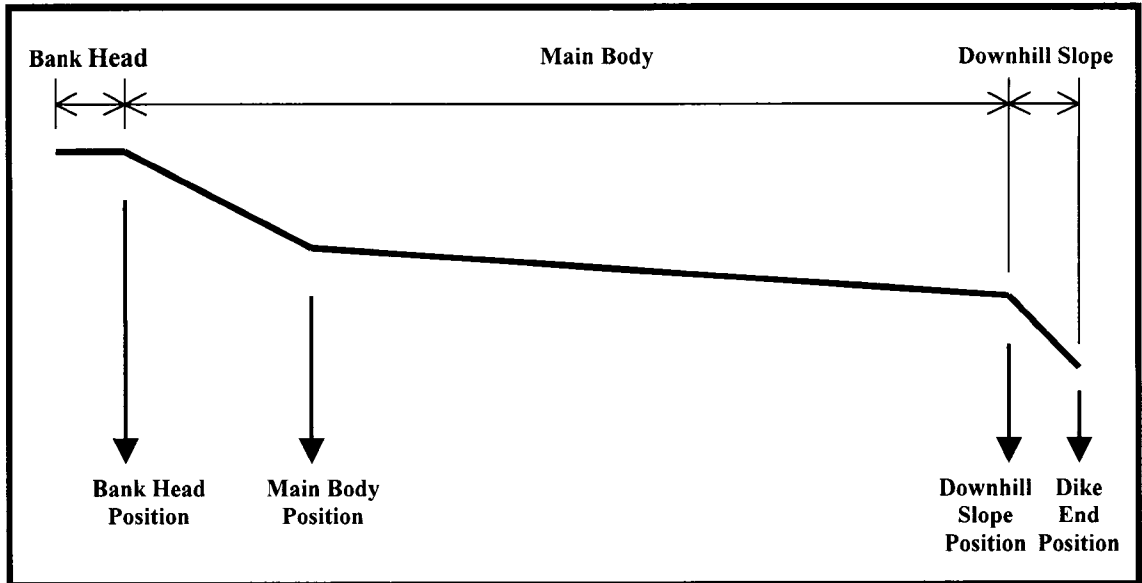
- Crown Elevation – In the case of stone or stone-filled pile dikes, the elevation of top of stone line was recorded, and in the case of pile dikes, the elevation of top of pile line was recorded.
- Crown Width – Crown width was recorded at every transition location.
- Dike Azimuth – Dike azimuth was recorded at every azimuth change location.
- Baseline Azimuth – Azimuth of baseline of each dike in the 1999 hydrographic survey maps.

### **3.3 STUDY PARAMETERS**

To perform any type of analysis, study parameters must be defined. For this study, the updated ERDC data set was utilized. Within the updated ERDC data set, there were a number of parameters chosen for analysis. Listed below are the chosen study parameters with brief descriptions as necessary:

- Dike elevation (Figure 3.3) – Crown elevation of each dike was calculated as LWRP elevation by subtracting LWRP of each dike from the National Geodetic Vertical Datum (NGVD) elevation at four positions along the dike:
  - bank head position (boundary between bank head and main body);
  - main body position (major slope change position of main body);
  - downhill slope position (boundary between main body and downhill slope); and
  - dike end position.

Additionally, the representative dike elevation (the elevation that can be assumed to represent the dike) was chosen to be used in the statistical analysis.



**Figure 3.3: Schematic of typical dike with defined elevation positions**

- Dike length – Distance between bank head position and downhill slope position (or dike end position provided there is no downhill slope position).
- Dike slope – Slope along the selected part of the dike – according to the dike profile maps, some of the pile dikes were filled with stones several years after their construction (stone-filled pile dike). When recording the crown elevations of those stone-filled pile dikes, the elevation of the top of stone line was recorded instead of the top of pile line; whereas, for pile dikes, the top of pile line was recorded. For this reason, some Memphis District dikes were recorded to be sloped in Tables B.1 through B.4 in Appendix B, even though they were usually known to be flat.
- Dike angle – Angle of the dike with respect to the bank line.
- Deflection angle – In case of L-head dikes, one or more deflection angles exist.

- Notch – Some dikes in this study have notches cut into them or are built with notches in them. The notches are incorporated to aid with restoring habitat, especially to reduce sedimentation behind the dikes (Biedenharn *et al.*, 2000).
- Width of main channel – Width of main channel that was measured from the bank head point of the dike to the opposite bank at 0 foot LWRP in the hydrographic survey map.
- Side channel conveyance – Calculated conveyance ( $= Ad^{2/3}$ ; A = area of the section; d = depth) outside of the main channel above the top of dikes and below the elevation of 30 feet LWRP (Lamb and Ethridge, 1991).
- Percent change in pool surface area – Change in pool surface area from the base year to the most recent year of data.
- Percent change in pool volume – Change in pool volume from the base year to the most recent year of data.
- Stage – The stage of the Mississippi River for which data are available includes: 0, 5, 10, 15, and 20 feet LWRP.

Tables B.1 through B.4 in Appendix B present dike geometric data tables for the Memphis District and Tables B.5 through B.8 in Appendix B present dike geometric data tables for the Vicksburg District.

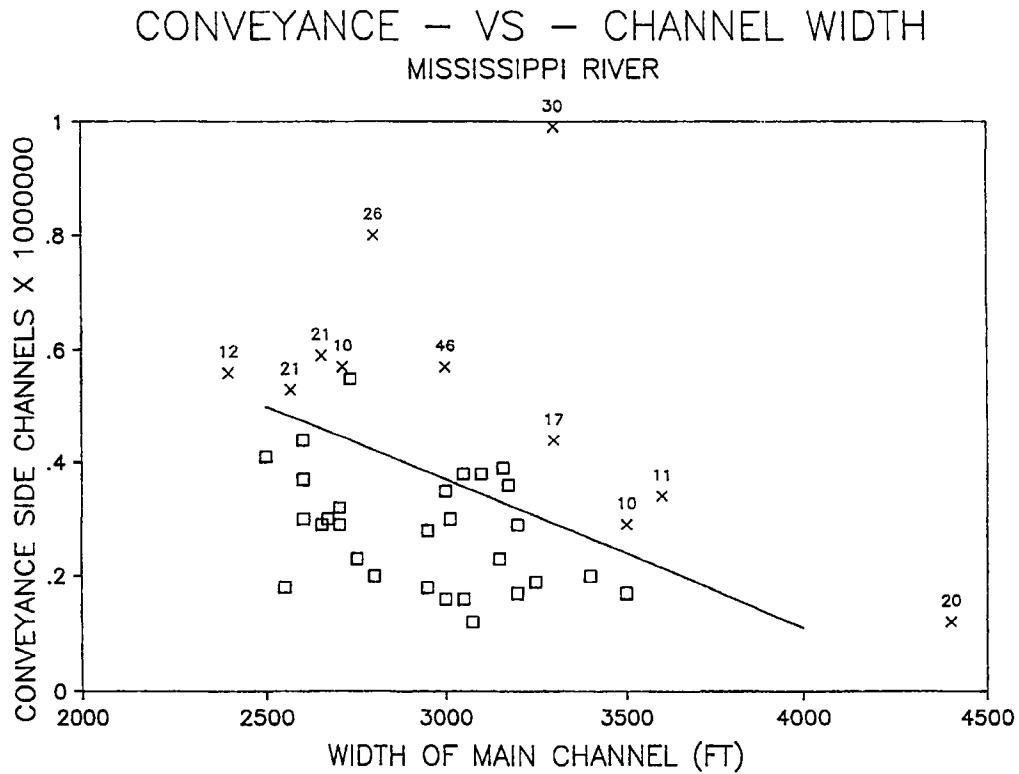
## 4 CONVEYANCE ANALYSIS

Lamb and Ethridge's (1991) conveyance design line has been most widely used in dike design for the Lower Mississippi River. In this chapter, their design line was applied to the updated ERDC data set and was examined as a dike design criterion.

Lamb and Ethridge (1991) analyzed the fringe areas of the channel (outside a predetermined main channel width) and recognized that the mean conveyance for the mean discharge remains essentially constant. Thereby, they developed an empirical relationship to show how much conveyance can be allowed in these areas and still ensure that the fill cycle for any given section does not exceed the required elevation in the navigation channel to ensure maintenance-free navigation. Lamb and Ethridge (1991) developed a reach-specific design line (for the Mississippi River – Cairo, Illinois, to Baton Rouge, Louisiana, reach) for the design of stone dike construction that relates the width of the main channel to the conveyance ( $Ad^{2/3}$ ) allowed outside of the main channel.

The conveyance outside of the main channel above the top of dikes and below an elevation of 30 feet LWRP, which was assumed as the water surface elevation corresponding to bankfull discharge, was computed; this conveyance will be referred to as *side channel conveyance* for the remainder of this study. This conveyance was then plotted against the width of the main channel as shown in Figure 4.1. The cross sections located where maintenance dredging would be required were plotted with **x**s and those where no maintenance would be required were plotted as squares. By examining Figure

4.1, two distinct groupings emerge. The line of separation between these data becomes a design line whereby one can determine the conveyance, which can be allowed outside the main channel for a given main channel width. Using this line, the elevation of the top of stone in the dikes can be determined to appropriately control conveyance.



**Figure 4.1: Lamb and Ethridge's (1991) conveyance design line**

Lamb and Ethridge's (1991) conveyance design line was applied to the updated ERDC data set. Side channel conveyance was calculated as follows:

$$K = Ad^{2/3} = Ld^{5/3} \tag{4.1}$$

where,

$K$  = side channel conveyance [ $\text{ft}^{8/3}$ ];

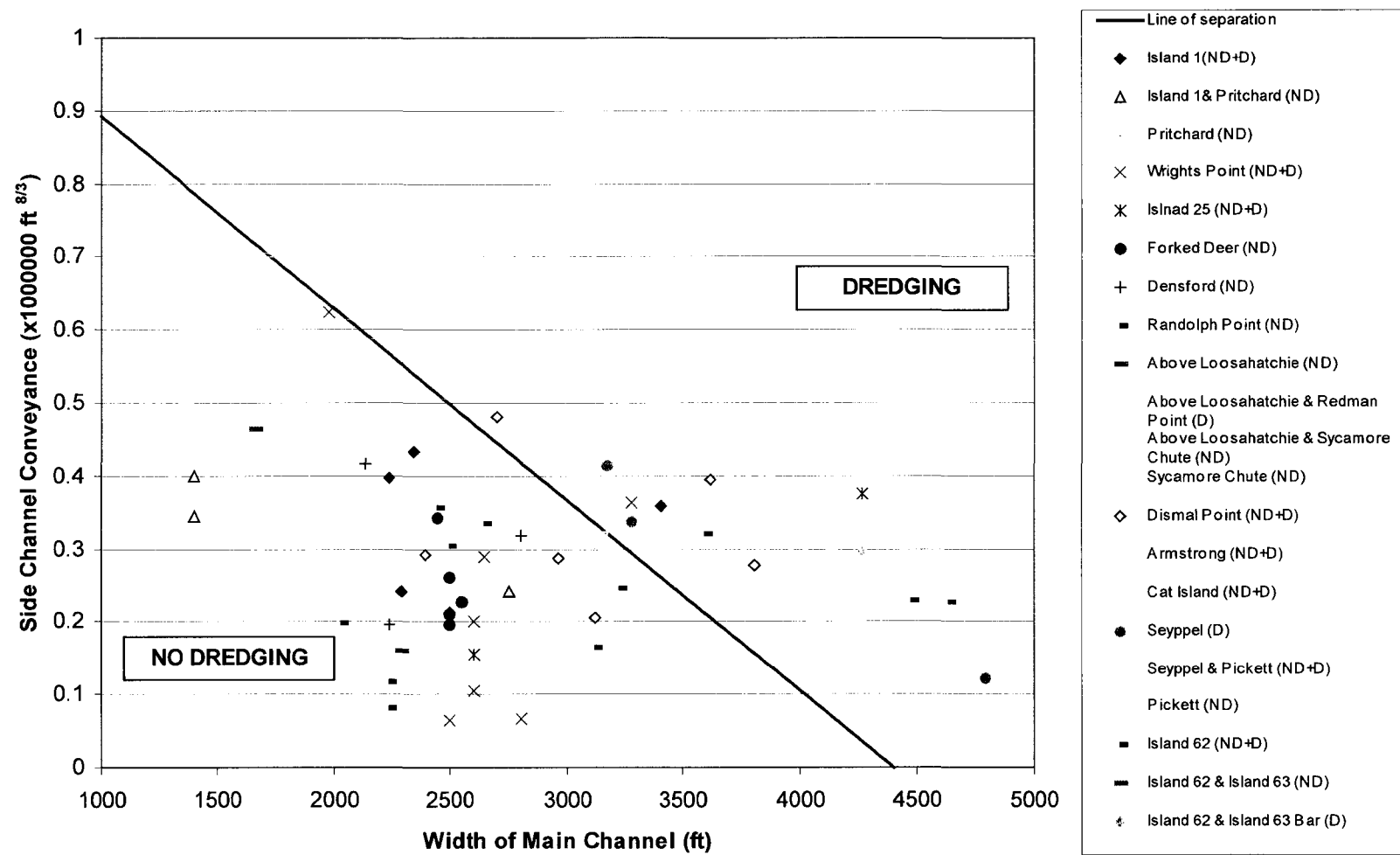
$A$  = flow area between the top of dike and an elevation of 30 feet LWRP [ $\text{ft}^2$ ];

$d$  = flow depth between the top of dike and an elevation of 30 feet LWRP [ft]; and

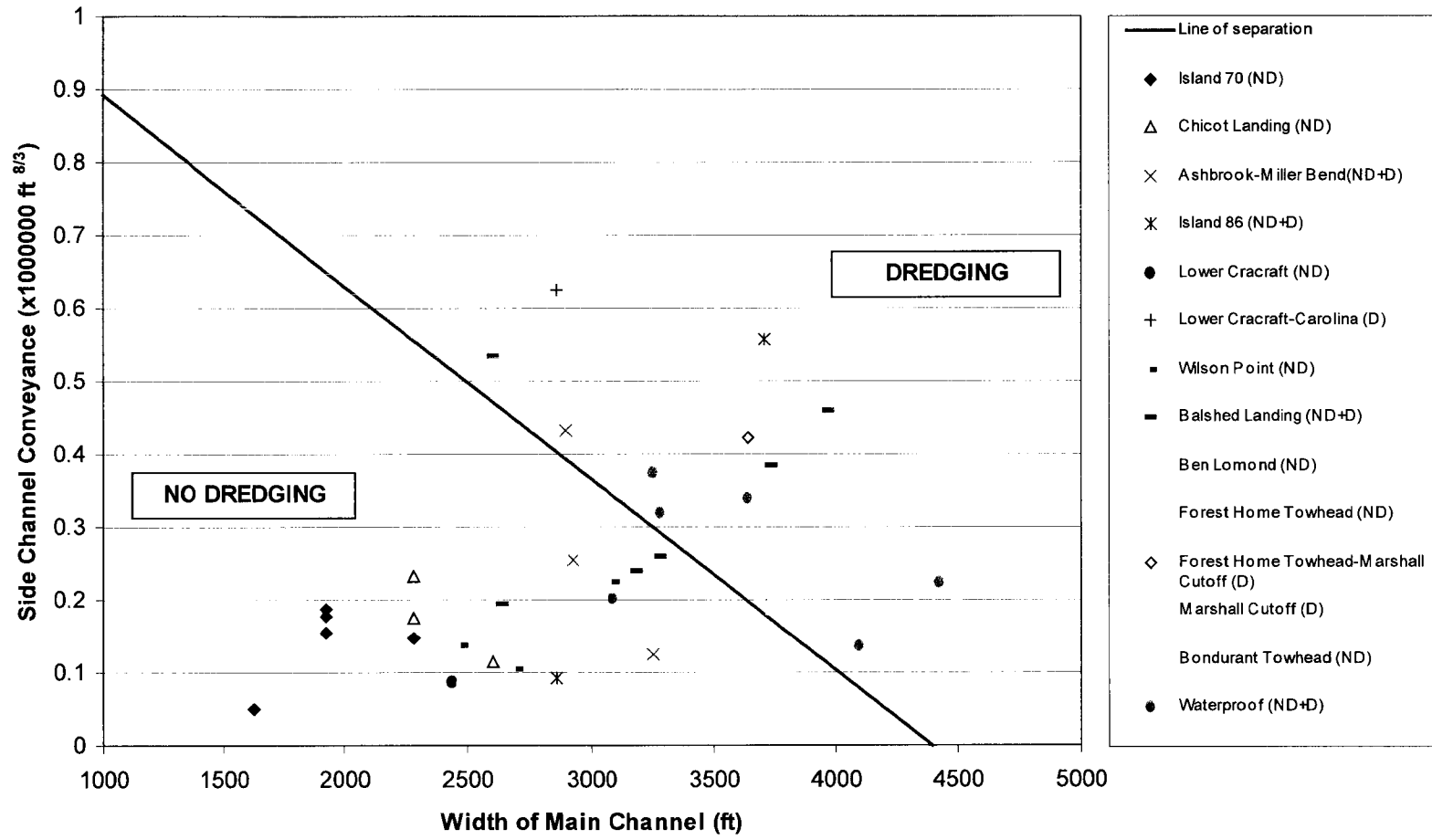
$L$  = length of dike [ft].

The main channel width was defined as the distance between the end of the dike and the surface of the bank at the other side. The width was measured from a hydrographic map of each district. It should be noted that the measured width can be different from the real width of the main channel defined above, due to the fact that measurements were obtained at approximately 0 foot LWRP but the elevation of the dikes ranged from below 0 foot LWRP to above 15 feet LWRP. Side channel conveyances for the dikes belonging to the Memphis and Vicksburg Districts were plotted against the measured main channel width, as shown on Figures 4.2 and 4.3. Using the line of separation developed by Lamb and Ethridge (1991), dikes were divided into two groups. In Figures 4.2 and 4.3, the dike fields in which maintenance dredging would be required were denoted by a D, those in which no maintenance dredging would be required were denoted by a ND, and those in which maintenance dredging would be required for only part of the dikes were denoted by a ND+D.

Although dredging records for these dike fields were needed to check the applicability of the design line, the records were not available. Assuming that Lamb and Ethridge's (1991) design line can be considered applicable to this study reach, the dikes



**Figure 4.2: Conveyance vs. main channel width – Memphis District**



**Figure 4.3: Conveyance vs. main channel width – Vicksburg District**

belonging to the dredging zone of the plot might have been dredged periodically. To determine if dredging occurred, the changes in the main channel volume were investigated. In the annual main channel volume record plot, it was inferred from a section of abrupt increase in main channel volume that dredging or dike construction had occurred. If there was no dike construction record just before or during that period, it was assumed that the main channel was dredged. As an example, Figure 4.4 shows that there was an abrupt increase in main channel volume during the period between 1972 and 1973 for the Waterproof dike field. Because the dikes in the Waterproof dike field had been constructed in 1963 and 1989, dredging was inferred from this volume record. The investigated results from main channel volume records for the Memphis and Vicksburg Districts were compared with the results from Lamb and Ethridge's design line in Tables 4.1 and 4.2, respectively. With the exception of 3 cases, the separation by Lamb and Ethridge's design line matched well with that of main channel volume record.

However, there are several problems in the above assumption. Franco (1982) recorded dike construction history for several dike fields during the period of 1968 to 1975. According to his records, Chicot Landing, Ben Lomond, Baleshed Landing, Wright Points, Forked Deer, Island 62, Island 63, and Island 63 Bar dike fields were dredged after dike construction. However, with the exception of Island 62 and Island 63, all dike fields were classified as 'No Dredging' in Tables 4.1 and 4.2. Additionally, Lamb and Ethridge's design line used side channel conveyance of an individual dikes to decide whether or not the dike field was dredged. However, the degree of main channel volume change within the dike field is affected by all the dikes within the dike field as

well as hydraulic conditions of the reach. Therefore, it must be recognized that there is a limit to using Lamb and Ethridge's design line for dike design.

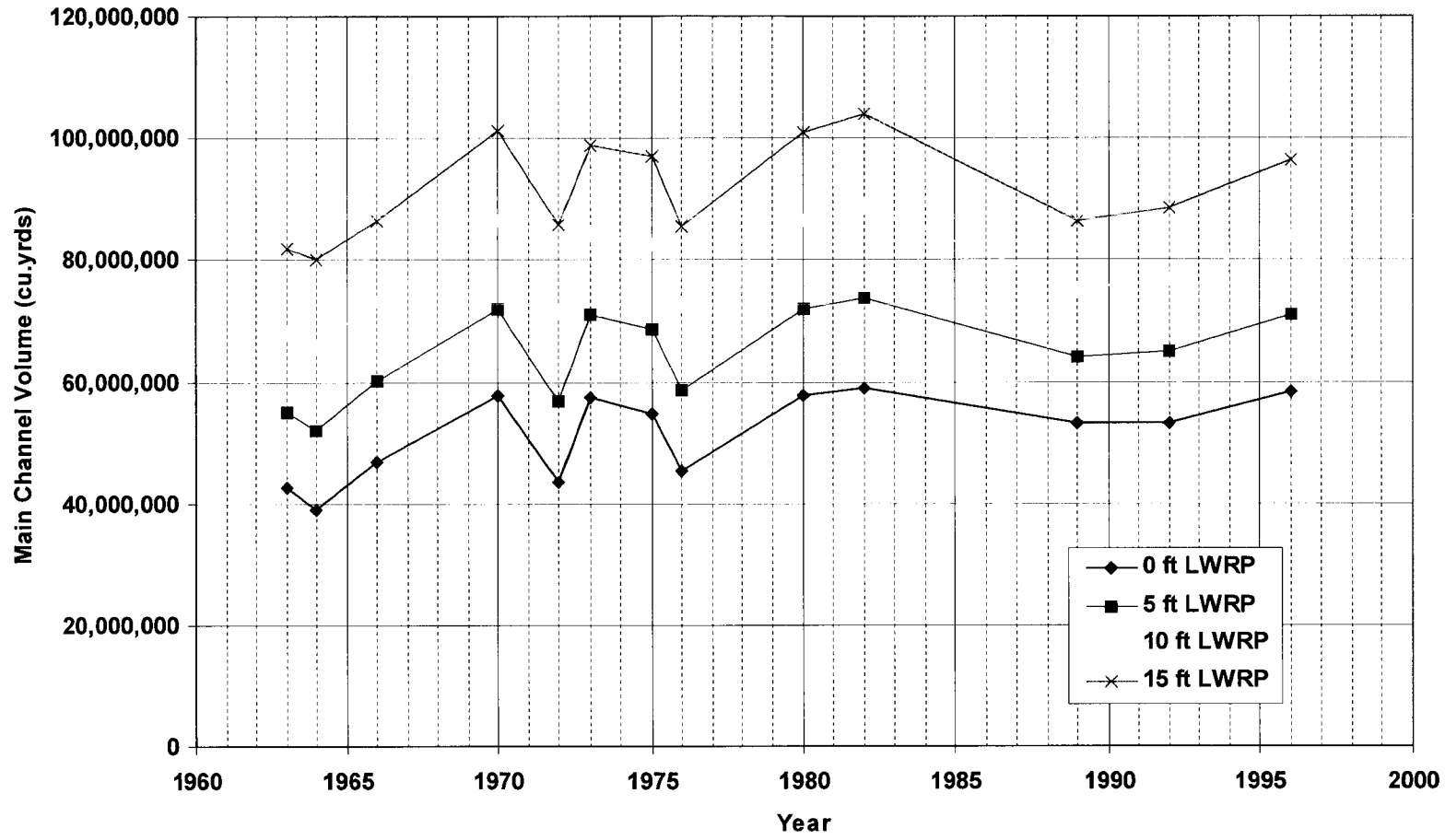


Figure 4.4: Annual main channel volume record – Waterpoof dike field

**Table 4.1: Comparison of Lamb and Ethridge's design line and main channel volume record – Memphis District**

Dike Field	Lamb and Ethridge's Design Line*	Main Channel Volume Record	Coincidence with Main Channel Volume Record	Franco's Record (1968-1975)	Coincidence with Franco's Record
Island 63 Bar	ND + D (D dominant)	ND	No	D	Yes
Island 63					
Island 62					
Pickett	ND + D (ND dominant)	ND	Yes	-	-
Seyppel					
Cat Island					
Armstrong	ND + D (ND dominant)	? (Insufficient Data)	-	-	-
Dismal Point					
Robinson Crusoe	ND + D (ND dominant)	D	No	-	-
Sycamore Chute					
Redman Point					
Above Loosahatchie					
Randolph Point	ND	ND	Yes	-	-
Densford	ND	ND	Yes	-	-
Forked Deer	ND	ND	Yes	D	No
Island 25	ND + D	ND	Yes	-	-
Wrights Point	ND + D (ND dominant)	ND	Yes	D	No
Pritchard	ND + D (ND dominant)	ND	Yes	-	-
Island 1					

\* ND: No Dredging, D: Dredging

**Table 4.2: Comparison of Lamb and Ethridge's design line and main channel volume record – Vicksburg District**

Dike Field	Lamb and Ethridge's Design Line*	Main Channel Volume Record	Coincidence with Main Channel Volume Record	Franco's Record (1968-1975)	Coincidence with Franco's Record
Waterproof	ND + D (D dominant)	D	Yes	-	-
Bondurant Towhead	ND	ND	Yes	-	-
Marshall Cutoff	ND + D (ND dominant)	ND	Yes	-	-
Foreat Home Towhead					
Ben Lomond	ND + D (ND dominant)	D	No	D	No
Baleshed Landing					
Wilson Point	ND	ND	Yes	-	-
Carolina	ND + D (equally dominant)	ND	Yes	-	-
Lower Cracraft					
Island 86	ND + D (equally dominant)	ND	Yes	-	-
Island 82-Miller Bend	ND + D (ND dominant)	? (Insufficient Data)	-	-	-
Ashbrook-Miller Bend					
Ashbrook Cutoff					
Chicot Landing	ND	ND	Yes	D	No
Catfish Point	? (No Data)	? (Insufficient Data)	-	-	-
Island 70	ND	ND	Yes	-	-

\* ND: No Dredging, D: Dredging

## 5 STATISTICAL AND HEC-6 ANALYSES

### 5.1 INTRODUCTION

For the purpose of the optimal dike design, not only to maintain dredging-free navigation channels but also to secure the minimal aquatic habitat within the dike pool area to maintain existing aquatic biota, it is important to predict the actual river responses to dike installation. If there exist any particular relationships between dike geometric parameters and sedimentation trend within the dike systems, these must be useful criteria for dike design. Statistical analysis can be used for obtaining these types of relationships.

Cobb and Magoun (1985) performed the correlation analyses between the dike geometric parameters of crown elevation, crown slope, dike length and dike system pool habitat on 46 dike systems in the Lower Mississippi River. Pool habitat variables used were volume, surface area, and mean depth. They concluded that dike systems that had steeper main body slopes and lower crown elevations had larger, deeper pools. However, correlation coefficients between dike geometric parameters and pool habitat features were relatively low, i.e., less than 0.5, indicating that only a small amount (less than 25% in terms of coefficient of determination ( $R^2$ )) of the variation among dike systems in surface area, volume, and depth was accounted for by dike parameters.

One of the main objectives of dike construction was to improve navigation conditions in the main channel by contracting the width of the river. Although the ERDC

data set used in this study include the main channel area, volume, and mean depth data, these data are not for each individual dike, but for a dike field or dike system. Therefore, the statistical analysis may not be adequate for the main channel analysis, because it is difficult to separate the main channel parameters for each dike. In this case, a numerical method may be effective to get some relationships that can be used in dike design. The numerical method has also an advantage of separating the influence of each dike geometric parameter on the main channel parameters, although dike parameters are correlated with each other.

The primary objective of this study is to suggest optimal dike design guidance. It is then necessary to use the numerical method that is practically used in dike design procedure and well-known to engineers who design dike fields. In this study, the HEC-6 model was selected as the numerical method. Because HEC-6 is a one-dimensional model, it may not be as precise as 2-D or 3-D models in predicting river profile changes. Nevertheless, the use of a one-dimensional model can be justified, since 2-D or 3-D models need more types of input data, most of which are difficult and costly to measure, and are not familiar to most of engineers.

The HEC-6 model is a software package developed by the Hydrologic Engineering Center (HEC) of the USACE to simulate a long-term average pattern of scour and deposition in rivers and reservoirs (HEC, 1993). It is a one-dimensional model with no provision to simulate meanders or lateral changes in bed slope. The model input includes channel geometry, hydraulic, sediment, and hydrologic data. The model output describes the changes in water surface elevation, sediment transport rate, and bed elevation at desired locations and times. The inflow hydrograph to the river reach

considered is approximated by a quasi-steady discharge hydrograph consisting of a series of discharges varying in steps. Standard step method of backwater computation is applied to compute depth and velocity at each cross section along the river and the vertical movement of the bed is calculated by the Exner Equation. The user can select the sediment transport capacity formulas: Toffaleti, Madden, Yang, DuBoys, etc.

To list several recent applications of HEC-6, Havis *et al.* (1996) evaluated the environmental impacts of sediment loading on gravel-bed rivers using HEC-6. The calculated long-term flushing of sand-size particles from the bed substrate of a natural gravel-bed river successfully approximated field measurement. Barbe *et al.* (2000) used HEC-6 model to analyze the long-term effects on dredging due to freshwater diversions along the Lower Mississippi River. Effects of location of diversion, sediment concentration exiting the river, and operating criteria of the diversions was assessed and quantified with HEC-6 modeling, and the model gave the cost of freshwater diversions. Rathburn and Wohl (2001) evaluated HEC-6 and GSTARS 2.0 for applicability to predict sediment removal along the steep gradient, bedrock-controlled pool-riffle North Fork Cache la Poudre River in northern Colorado. More than 50% of the actual scour and deposition within three pools was modeled using HEC-6, whereas modeling accuracy using GSTARS 2.0 was considerably lower. However, there were no cases where HEC-6 modeling was used to predict the effect on the main channel parameters due to the dikes.

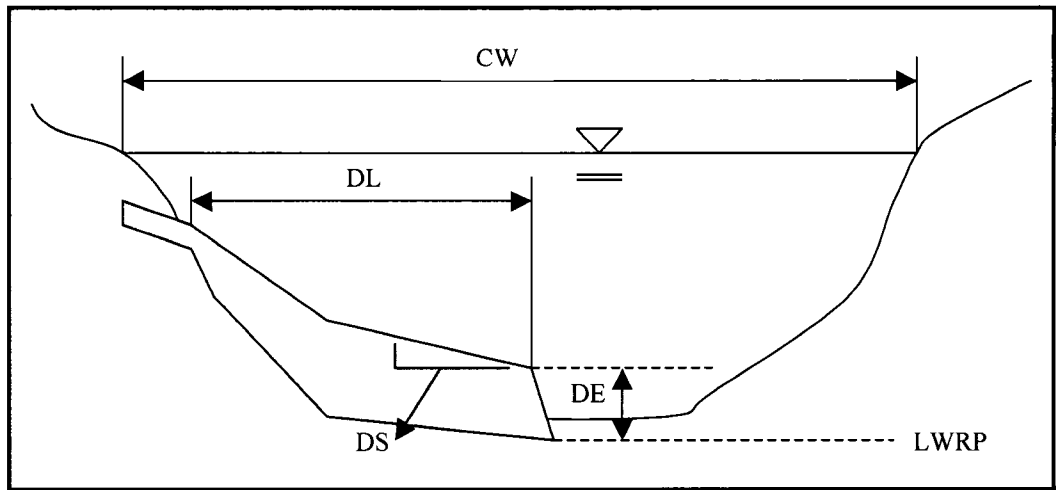
## **5.2 DIMENSIONAL ANALYSIS**

A goal of any relationship developed using field data is to make the results as widely applicable as possible. To achieve this goal, the concept of similitude can be used

so that measurements obtained on one system (e.g., the Mississippi River) may be used to describe the behavior of similar systems (e.g., the Missouri River). For the development of a general relationship between variables related to any system, the use of dimensionless combinations of variables (called dimensionless products) is often utilized. Not only does this method reduce the number of variables, but also the dimensionless combinations of variables will be independent of the system units chosen. This system of analysis is called dimensional analysis (Munson *et al.* 1998).

First, the parameters considered important in the dike system analysis were listed in terms of basic dimensions (L = length; T = time) as follows (Figure 5.1):

- 1) CA or CV = percent change in pool surface area or volume = [dimensionless];
- 2) CW = width of main channel that was measured from the bank head point of the dike to the opposite bank at 0 foot LWRP = [L];
- 3) DL = distance between bank head position and downhill slope position (or dike end position provided there is no downhill slope position) = [L];
- 4) DE = dike elevation measured from LWRP to the representative dike elevation = [L];
- 5) DS = dike slope = [dimensionless]; and
- 6) RC = radius of curvature of the reach = [L].



**Figure 5.1: Schematic of typical dike cross section with defined variables**

Using dimensional analysis and choosing CW as the repeating variable, Equation (5.1) was obtained:

$$CA \text{ or } CV = \phi \left( \frac{DL}{CW}, \frac{DE}{CW}, DS, \frac{RC}{CW} \right) \quad (5.1)$$

### 5.3 STATISTICAL ANALYSIS

Simple and multiple linear regression analyses were performed, to find relationships between dike geometric parameters and pool habitat parameters. In this regression analysis, the relationship between dike geometric parameters and percent change in surface area of the pool located downstream of the dike was examined. The downstream pool was chosen because the features of the pool were assumed to be controlled more directly by characteristics of the upstream dike (Cobb and Magoun, 1985). The percent change in pool surface area was selected as a pool habitat parameter

based on preliminary analysis indicating that the pool surface area change was more highly correlated with dike geometric parameters than the pool volume change.

Preliminary analysis also showed that the percent change in pool surface area (CA) is influenced by surrounding features like bars or vane dikes. In the event that the channelward end of the pool is blocked by bars or vane dikes, the influence of the upstream dike on pool surface area change must be much less than the pools that the channelward end is open to the main channel. Therefore, prior to the regression analysis, several criteria for the selection of dikes were established. First, after checking the availability of dike geometry and pool surface area data, the dikes without those data were excluded. Second, the dikes with pools blocked by bars or vane dikes are excluded. Third, after examining the pool surface area and dike geometry data, the dikes with pools that were considered to show unreasonable surface area change were excluded. Table 5.1 shows the list of excluded dikes and reasons for exclusion, but does not list the dikes excluded due to the first criterion. Table 5.2 presents the list of dikes and their parameters used in the linear regression analysis.

Simple linear regression analysis was performed for parameters listed in Table 5.2: the dike geometric parameters of dike length (DL), dike elevation (DE), and dike slope (DS); the channel geometric parameters of radius of curvature (RC) and main channel width (CW); and the dimensionless parameters of  $DL/CW$ ,  $DE/CW$ , and  $RC/CW$  determined from the dimensional analysis of Section 5.2. Analysis was performed for the percent change in pool surface area (CA) measured at four river stages (0, 5, 10, and 15 feet LWRP) as a dependent variable and the result for 15 feet LWRP was selected for the final analysis, because it was most highly correlated with other parameters.

**Table 5.1: Excluded Dikes**

<b>Dike Field</b>	<b>Dike Number</b>	<b>Reason for Exclusion</b>
Wrights Point	5	Blocked by vanes.
Wrights Point	6	Blocked by bars.
Wrights Point	7	Blocked by bars.
Island 25	2	Blocked by bars.
Densford	3	Blocked by bars.
Randolph Point	1	Blocked by bars.
Randolph Point	3	Blocked by bars.
Dismal Point	3	Blocked by bars.
Dismal Point	4	Blocked by bars.
Armstrong	3	Blocked by vanes.
Chicot Landing	3	Blocked by vanes and bars.
Lower Cracraft	2	Blocked by bars.
Lower Cracraft	3	Blocked by bars.
Ben Lomond	3	Blocked by vanes.
Ben Lomond	4	Blocked by vanes.
Marshall Cutoff	2	Blocked by bars.
Bondurant Towhead	2	Blocked by bars.
Waterproof	3	Blocked by bars.
Waterproof	4	Blocked by bars.
Waterproof	5	Blocked by bars.
Island 1	7	Sudden increase in pool surface area between 1973 and 1976: unrealistic.
Forked Deer	5	Sudden large increase and decrease in pool surface area: unrealistic.
Above Loosahatchie	6	Sudden large increase and decrease in pool surface area: unrealistic.
Dismal Point	1U	Almost right-angled L-head dike: same effect as the dike blocked by vanes.
Armstrong	4	Sudden increase and decrease in pool surface area: unrealistic.
Chicot Landing	1	Insufficient data and sudden decrease in pool surface area for short periods of time (1972 to 1974, 1988 to 1991).
Ashbrook-Miller Bend	1L	Downstream pool of this dike Includes another dike, which is much longer than this dike: it's not clear which dike influences the pool more, and sudden increase and decrease in pool surface area: unrealistic.
Lower Cracraft	1	The decrease in pool surface area is too much compared to the dike length.
Carolina	2	Sudden increase and decrease in pool surface area is repeated: unrealistic.
Wilson Point	1	The decrease in pool surface area is too much compared to the dike length.
Wilson Point	2	Downstream pool of this dike Includes another dike, which is much longer than this dike: it's not clear which dike influences the pool more, and sudden increase and decrease in pool surface area: unrealistic.
Baleshed Landing	1	Comparing to other dikes, dike elevation is too low.

**Table 5.2: Data utilized for linear regression analysis**

District	Dike Field	Dike Number	CA (15 feet LWRP)	DL (ft)	DE (ft)	DS (ft/ft)	RC (ft)	CW (ft)	DL/CW	DE/CW	RC/CW
Memphis	Island 1	4	2.94%	2110	14.9	0.0000	126720	4823	0.4375	0.0031	26.2750
Memphis	Island 1	5	8.34%	1640	12.8	-0.0004	126720	4823	0.3400	0.0027	26.2750
Memphis	Island 1	6	23.11%	975	10.6	0.0000	126720	4626	0.2108	0.0023	27.3931
Memphis	Pritchard	1U	-21.81%	1255	14.7	0.0000	126720	3675	0.3415	0.0040	34.4859
Memphis	Pritchard	1	-10.40%	2159	12	0.0004	126720	5052	0.4273	0.0024	25.0807
Memphis	Pritchard	2.5	-26.11%	2177	14	-0.0007	126720	4987	0.4365	0.0028	25.4107
Memphis	Wrights Point	3	3.19%	1800	12	0.0000	7920	4626	0.3891	0.0026	1.7121
Memphis	Island 25	1	-3.36%	1660	16	0.0043	5280	4626	0.3588	0.0035	1.1414
Memphis	Forked Deer	1	-6.13%	1381	9	0.0000	126720	4068	0.3395	0.0022	31.1486
Memphis	Forked Deer	2	-28.29%	2377	11	0.0005	126720	4888	0.4862	0.0023	25.9223
Memphis	Forked Deer	3	14.56%	2010	12	0.0022	126720	4724	0.4255	0.0025	26.8224
Memphis	Forked Deer	4	-0.37%	1160	4	0.0148	126720	3806	0.3048	0.0011	33.2968
Memphis	Densford	1	-11.24%	1390	11	0.0008	36960	3740	0.3716	0.0029	9.8819
Memphis	Densford	2	-39.30%	3110	12	0.0017	36960	5381	0.5780	0.0022	6.8692
Memphis	Randolph Point	1U	-22.11%	968	16	0.0001	47520	4823	0.2007	0.0033	9.8531
Memphis	Randolph Point	3U	-13.13%	1911	16.6	-0.0003	47520	5381	0.3552	0.0031	8.8318
Memphis	Above Loosahatchie	3	-20.59%	1680	16	0.0040	50160	4396	0.3821	0.0036	11.4095
Memphis	Above Loosahatchie	4	-22.04%	1490	12	-0.0012	50160	3904	0.3816	0.0031	12.8477
Memphis	Above Loosahatchie	5	-1.16%	1070	12	0.0021	50160	4003	0.2673	0.0030	12.5318
Memphis	Armstrong	1	-41.75%	5575	16	0.0015	21120	6693	0.8330	0.0024	3.1556
Memphis	Armstrong	2	-69.70%	4615	17.2	-0.0003	21120	6693	0.6895	0.0026	3.1556
Memphis	Cat Island	3A	-9.66%	1413	15	0.0000	15840	4068	0.3473	0.0037	3.8936
Memphis	Seyppel	1	-46.57%	2599.14	18	0.0000	15840	7021	0.3702	0.0026	2.2561
Memphis	Seyppel	3	-43.78%	2805	10.5	0.0000	15840	7021	0.3995	0.0015	2.2561
Memphis	Pickett	1	-4.22%	1550	11.5	-0.0007	34320	5118	0.3028	0.0022	6.7056
Memphis	Island 62	1	0.45%	1320	15	0.0000	13200	5709	0.2312	0.0026	2.3123
Memphis	Island 62	2	-49.38%	3146	16.5	0.0000	13200	6037	0.5211	0.0027	2.1866
Memphis	Island 62	3	-30.98%	2961	16.2	0.0000	13200	6660	0.4446	0.0024	1.9820
Memphis	Island 62	5	-69.47%	4280	15	0.0000	13200	5249	0.8153	0.0029	2.5146
Memphis	Island 63	4A	-12.52%	2040	12	-0.0008	13200	5052	0.4038	0.0024	2.6126

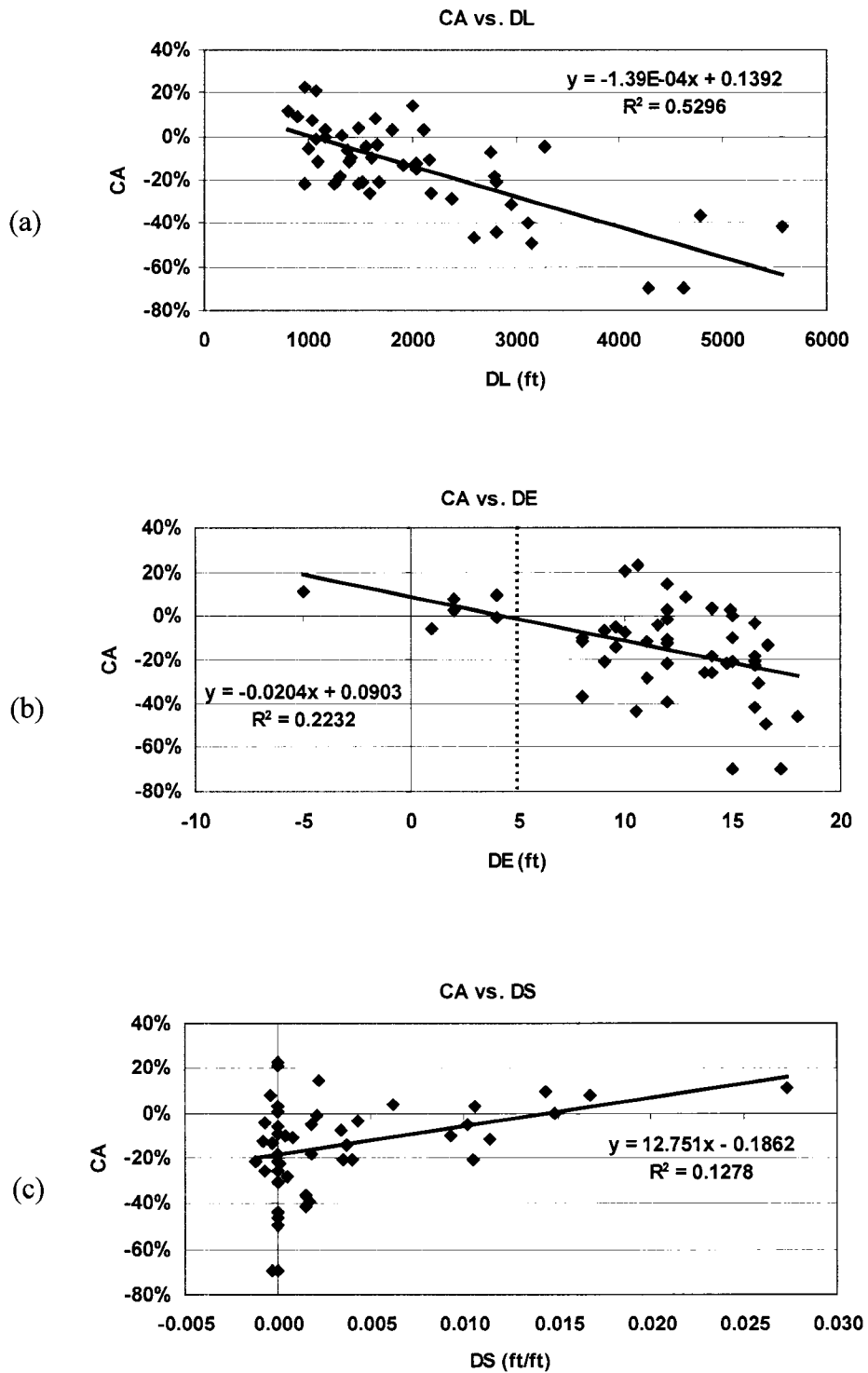
**Table 5.2 (cont.)**

District	Dike Field	Dike Number	CA (15 feet LWRP)	DL (ft)	DE (ft)	DS (ft/ft)	RC (ft)	CW (ft)	DL/CW	DE/CW	RC/CW
Memphis	Island 63	5A	-25.89%	1600	13.7	0.0000	13200	4593	0.3483	0.0030	2.8738
Vicksburg	Chicot Landing	2	-20.58%	2805	15	0.0035	15840	5085	0.5516	0.0029	3.1149
Vicksburg	Island 86	2	-36.51%	4780	8	0.0015	21120	6857	0.6971	0.0012	3.0801
Vicksburg	Ashbrook-Miller Bend	1UL	11.45%	800	-5	0.0273	23760	4199	0.1905	-0.0012	5.6579
Vicksburg	Ashbrook-Miller Bend	3L	-11.65%	1095	8	0.0114	23760	5282	0.2073	0.0015	4.4982
Vicksburg	Ashbrook-Miller Bend	2R	7.78%	1037	2	0.0167	23760	4035	0.2570	0.0005	5.8878
Vicksburg	Ashbrook-Miller Bend	3R	2.85%	1160	2	0.0106	23760	4528	0.2562	0.0004	5.2479
Vicksburg	Ashbrook-Miller Bend	4R	9.47%	900	4	0.0143	23760	4265	0.2110	0.0009	5.5708
Vicksburg	Baleshed Landing	2	-5.54%	1000	1	0.0102	42240	4003	0.2498	0.0002	10.5531
Vicksburg	Baleshed Landing	3	-14.44%	2035	9.5	0.0037	42240	4593	0.4430	0.0021	9.1963
Vicksburg	Baleshed Landing	4	-18.06%	2790	16	0.0000	42240	6102	0.4572	0.0026	6.9219
Vicksburg	Baleshed Landing	5	-4.90%	3270	9.5	0.0018	42240	6037	0.5417	0.0016	6.9971
Vicksburg	Forest Home Towhead	1	-18.18%	1300	14	0.0018	14520	3839	0.3387	0.0036	3.7826
Vicksburg	Forest Home Towhead	2	3.93%	1480	14	0.0062	14520	4692	0.3155	0.0030	3.0949
Vicksburg	Marshall Cutoff	1	-20.69%	1530	9	0.0105	14520	5118	0.2989	0.0018	2.8370
Vicksburg	Bondurant Towhead	1	-10.13%	1620	8	0.0093	34320	4724	0.3429	0.0017	7.2644
Vicksburg	Waterproof	1	-7.54%	2765	10	0.0034	50160	5315	0.5202	0.0019	9.4375
Vicksburg	Waterproof	2	20.73%	1070	10	0.0000	50160	5217	0.2051	0.0019	9.6156

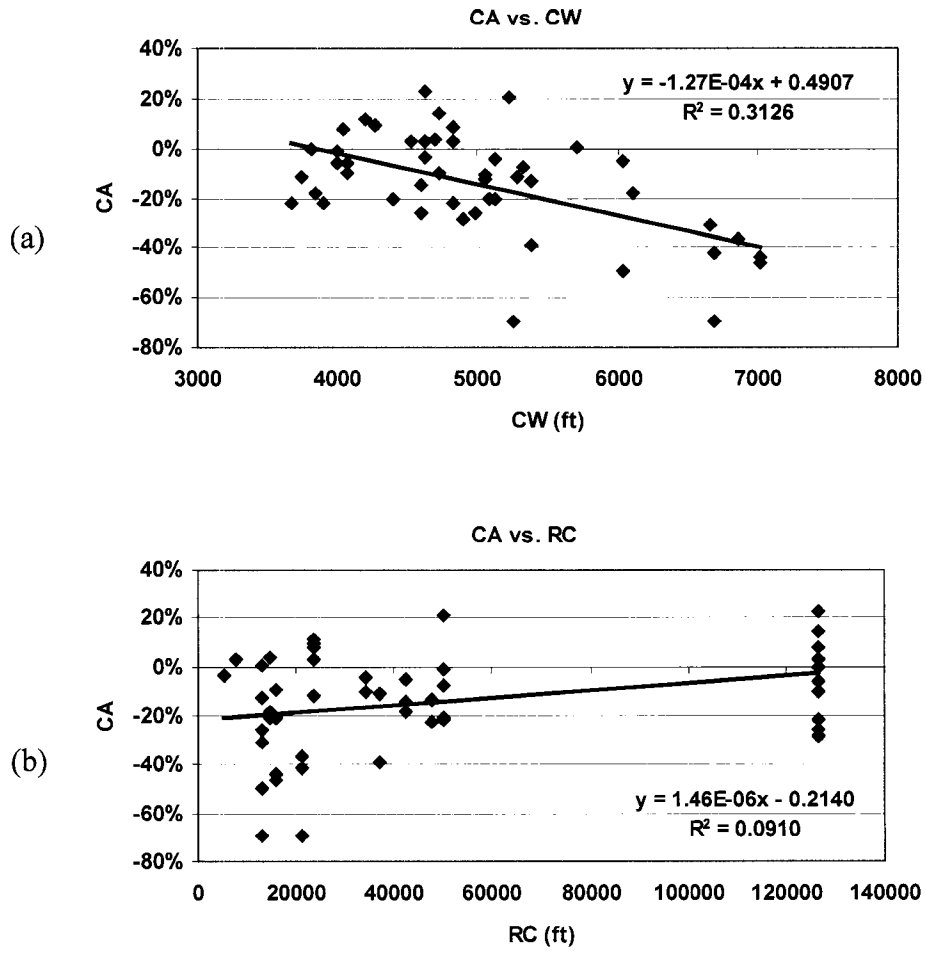
Figure 5.2 presents dike geometric parameters versus percent change in pool surface area at 15 feet LWRP. The percent change in pool surface area (CA) was inversely proportional to the dike length (DL) with a coefficient of determination ( $R^2$ ) of 0.5296 (Figure 5.2(a)), where the  $R^2$  measures the dependent variable that can be explained by the linear regression model. The percent change in pool surface area (CA) was also inversely proportional to the dike elevation (DE) with a  $R^2$  value of 0.2232 (Figure 5.2(b)). Therefore, it can be deduced from this analysis that the shorter and the lower the dike, the less the pool surface area decreases, thereby preserving more habitat area. The percent change in pool surface area (CA) was directly proportional to the dike slope (DS), but a  $R^2$  value (0.1278) was much smaller than the above two relationships (Figure 5.2(c)).

Figure 5.3 presents channel geometric parameters versus percent change in pool surface area at 15 feet LWRP. The percent change in pool surface area (CA) was inversely proportional to the main channel width (CW) with a  $R^2$  value of 0.3126 (Figure 5.3(a)), whereas the linear relationship between the percent change in pool surface area (CA) and radius of curvature of the reach (RC) gave a very small  $R^2$  value of 0.091 (Figure 5.3(b)).

In Figure 5.4, the relationship between dimensionless parameters (DL/CW, DE/CW, and RC/CW) and percent change in pool surface area (CA) at 15 feet LWRP was examined. The percent change in pool surface area (CA) was inversely proportional to DL/CW with a  $R^2$  value of 0.5029 (Figure 5.4(a)), and it was also inversely proportional to DE/CW with a very small  $R^2$  value of 0.0682 (Figure 5.4(b)). The



**Figure 5.2: Dike geometric parameters versus percent change in pool surface area**



**Figure 5.3: Channel geometric parameters versus percent change in pool surface area**

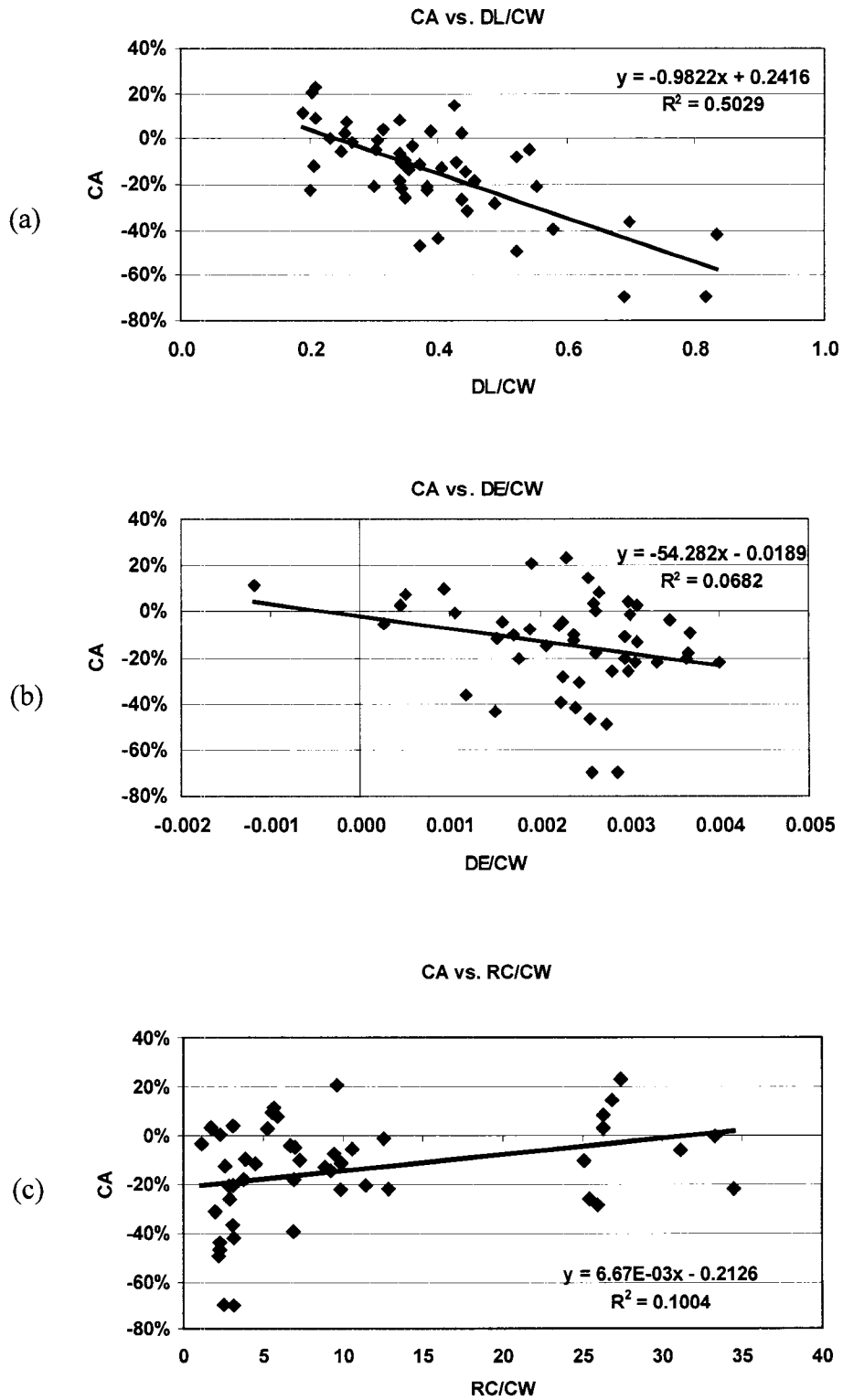
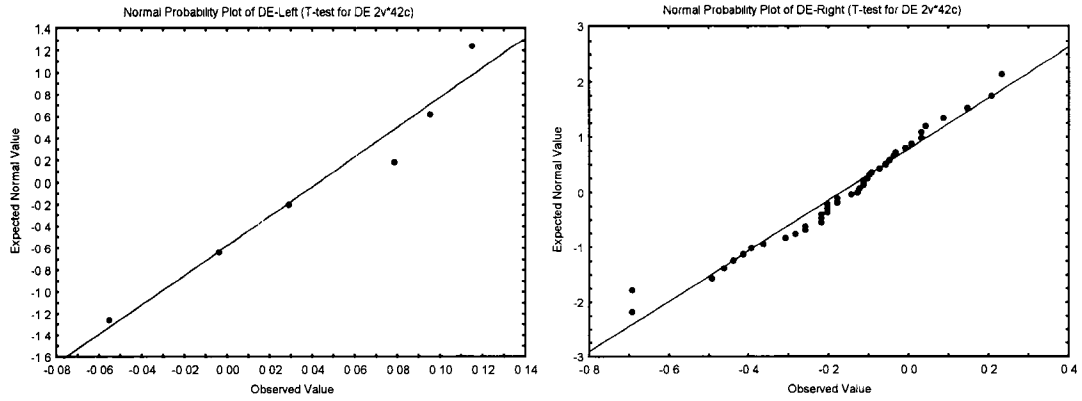


Figure 5.4: Dimensionless parameters versus percent change in pool surface area

percent change in pool surface area (CA) was directly proportional to RC/CW, with a  $R^2$  value of 0.1004 (Figure 5.4(c)).

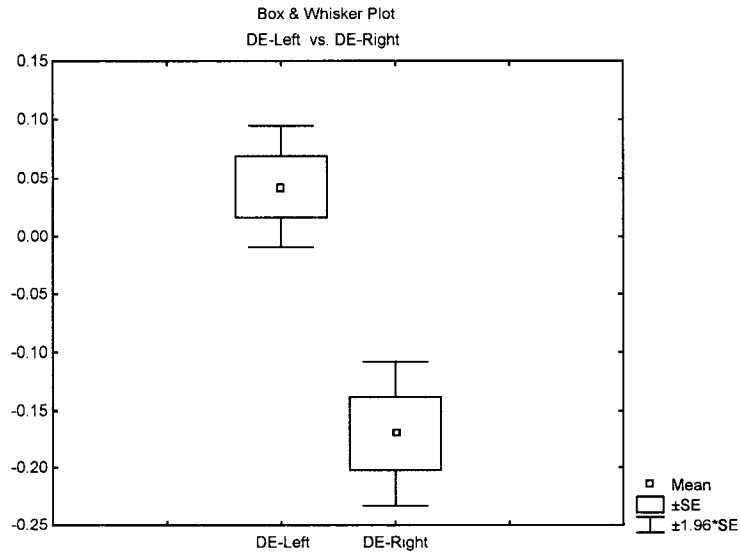
In Figure 5.2(b), it was obvious that the dike elevation (DE) data points were separated into two groups by the 5-foot dike elevation line. Most of the data points on the left side of the line at 5 feet have positive percent change in pool surface area (CA), whereas most of the points on the right side of the line have negative CA. If this inference is reasonable, the 5-foot dike elevation can be regarded as the maximum dike elevation to keep the dike pool habitat maintained without sedimentation. Two-sample t-test for CA was then performed to confirm whether the dikes on the left side of the 5-foot line were statistically different from other dikes. Because the two-sample t-test is based on the assumption that the population distributions are both normal, normal probability plots of CA of the dikes on the left side of the line and the other dikes were constructed, respectively. The linear pattern shown in Figure 5.5 confirmed that the distributions of both groups were normal. Based on one-tailed probability and equality of variances assumption in the two-sample t-test results (Table 5.3), the P-level is 0.0085; therefore, the null hypothesis of no difference in the average of CA for the two groups of the dikes can be rejected at the significance level of 0.01. Comparative box-whisker plot for both groups of the dikes (Figure 5.6) confirms that most dikes less than 5 feet in elevation have positive CA value. Based on these tests, it can be concluded that the 5-foot dike elevation can be approximately regarded as the maximum dike elevation to keep the dike pools maintained without sedimentation, and it can be used as an environmental design guideline for dike elevation.



**Figure 5.5: Normal probability plots for both groups**

**Table 5.3: Result from two-sample t-test**

<b>t-value</b>	2.4744		
<b>P-level</b>	0.0085		
<b>Group</b>	<b>N</b>	<b>Mean</b>	<b>Standard Deviation</b>
<b>Dikes on left of 5-foot line</b>	6	0.0427	0.0649
<b>Dikes on right of 5-foot line</b>	42	-0.1702	0.2077



**Figure 5.6: Comparative box-whisker plot for both groups**

Multiple linear regression analysis was performed by using STATISTICA for Windows v. 6.0, which is a well-known statistical computer software package, produced by StatSoft®. The analysis was performed for two groups of parameters: a group of the measured parameters consisting of DL, DE, DS, RC, and CW; and a group of the dimensionless parameters consisting of DL/CW, DE/CW, DS, and RC/CW.

In multiple linear regression, often the use of the subset of the predictors (i.e., independent variables (DL, DE, DS, etc.) collected to predict the dependent variable (CA)) instead of using all predictors collected, makes the resulting model more manageable, and also results in a model that is easier to interpret and understand than one with more predictors. Therefore, it is necessary to examine regressions involving all possible subsets of the predictors using criteria to select the best subset of the predictors (Devore, 2000). In this analysis, the backward elimination method was used for the selection of the predictors. This method starts with the model with all predictors. Then the t-ratio of each predictor is calculated, and the predictor corresponding to the smallest absolute ratio is eliminated from the model. This process continues until P-levels of all predictors are less than the prespecified constant. In this analysis, a P-level of 0.05 (95% confident) was used as an acceptable error level. Tables 5.4 and 5.5 are the backward elimination results for the group of measured parameters and the group of dimensionless parameters, respectively. In Table 5.4, the model with two parameters DL and DE was selected for the group of measured parameters, since at Step 4 no predictor could be eliminated. Table 5.5 shows that the model with two parameters, DL/CW and RC/CW, was selected for the group of dimensionless parameters, since at Step 3 no predictor could be eliminated.

From multiple linear regression analysis for the independent variables selected from the group of measured parameters (DL and DE) summarized in Tables 5.6, the following equation was developed:

$$CA (\%) = -1.23 \times 10^{-4} DL(ft) - 9.33 \times 10^{-3} DE(ft) + 2.13 \times 10^{-1} \quad (5.2)$$

In Table 5.6, the coefficient of multiple determination ( $R^2$ ) is 0.5687, indicating that 57 percent of the variability in the data is explained by the relationship. According to the model utility test, the F-Statistic is 29.67, and the corresponding P-level is  $6.05 \times 10^{-9}$ , which is a highly significant result. P-levels of both independent variables were less than 0.05, which was usually treated as an acceptable error level. Therefore, it can be concluded that there is a useful linear relationship between dependent variable, CA, and two independent variables, DL and DE, in the model. The basic plots recommended for an assessment of model validity and usefulness were constructed. Figure 5.7 presents a normal probability plot of the residuals for the dependent variable, CA. The straightness of the plot proves the assumption that the random error term (or random deviation) in the model is normally distributed. Figure 5.8 displays a plot of predicted values versus the residuals for the dependent variable, CA. Data points form a homogeneous distribution of points around the horizontal centerline, verifying that the relationship is linear. Figure 5.9 displays a plot of observed values versus predicted values for the dependent variable, CA. Figure 5.9 indicates that Equation (5.2) can be considered a reliable prediction equation, having points both above and below the line of equal prediction.

**Table 5.4: Backward elimination results of measured parameters**

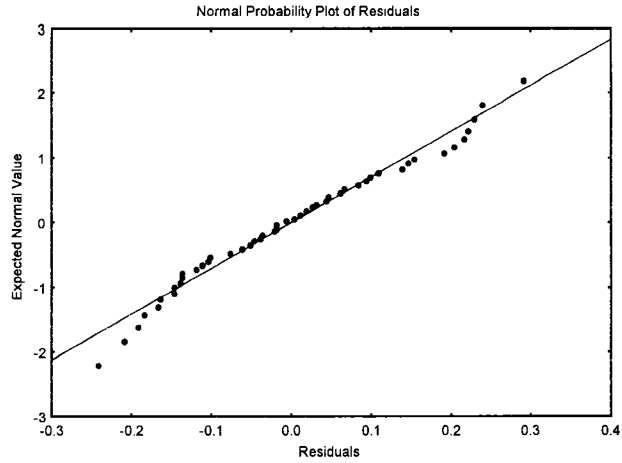
Step	Multiple R <sup>2</sup>	R <sup>2</sup> Change	t-ratio				
			DL	DE	DS	RC	CW
1	0.6032		-4.4286	-1.6556	-0.4144	1.6045	0.5647
2	0.6016	-0.0016	-4.4535	-2.2093		1.8798	0.5986
3	0.5983	-0.0033	-5.6666	-2.1595		1.7987	
4	0.5687	-0.0295	-6.0046	-2.0212			

**Table 5.5: Backward elimination results of dimensionless parameters**

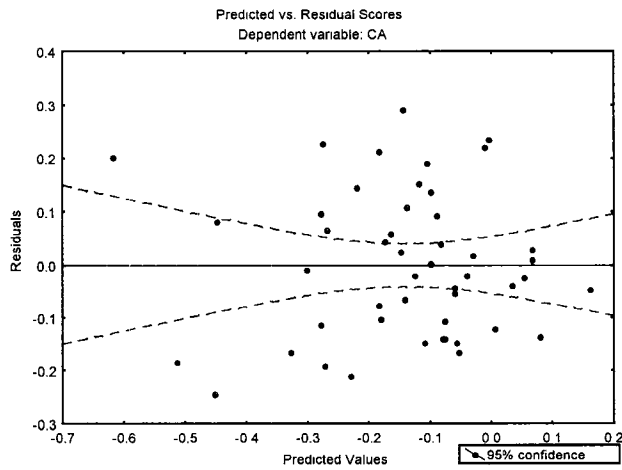
Step	Multiple R <sup>2</sup>	R <sup>2</sup> Change	t-ratio			
			DS	DL/CW	DE/CW	RC/CW
1	0.5686		0.1984	-5.6081	-0.8219	2.2804
2	0.5682	-0.0004		-6.2244	-1.4924	2.2974
3	0.5464	-0.0219		-6.6519		2.0783

**Table 5.6: Multiple linear regression summary statistics corresponding to Equation (5.2)**

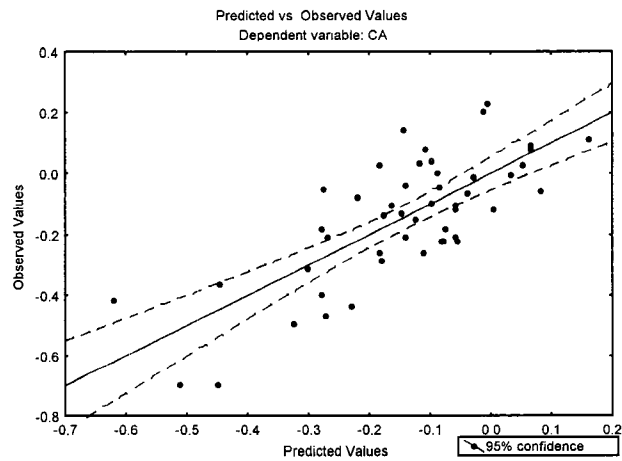
<b>Number of Measurements</b>	48					
<b>Dependent Variable</b>	CA					
<b>Independent Variables</b>	$\beta$	<b>Standard Error of <math>\beta</math></b>	<b>B</b>	<b>Standard Error of B</b>	<b>t(45)</b>	<b>P-level</b>
<b>Intercept</b>			2.13E-01	0.056298	3.77582	0.000465
<b>DL</b>	-0.641368	0.106812	-1.23E-04	0.000020	-6.00463	0.000000
<b>DE</b>	-0.215893	0.106812	-9.33E-03	0.004614	-2.02124	0.049228
<b>Multiple R =</b>	0.75413					
<b>Multiple R<sup>2</sup> =</b>	0.56872					
<b>Adjusted R<sup>2</sup> =</b>	0.54955					
<b>F(3,44) =</b>	29.67018					
<b>P-level</b>	6.05E-09					
<b>Standard Error of Estimate</b>	0.13940					



**Figure 5.7: Normal probability plot of residuals – measured variables**



**Figure 5.8: Predicted values versus residuals – measured variables**



**Figure 5.9: Observed versus predicted values – measured variables**

Multiple linear regression analysis for the group of dimensionless parameters (DL/CW and RC/CW) is summarized in Tables 5.7. The following equation was developed:

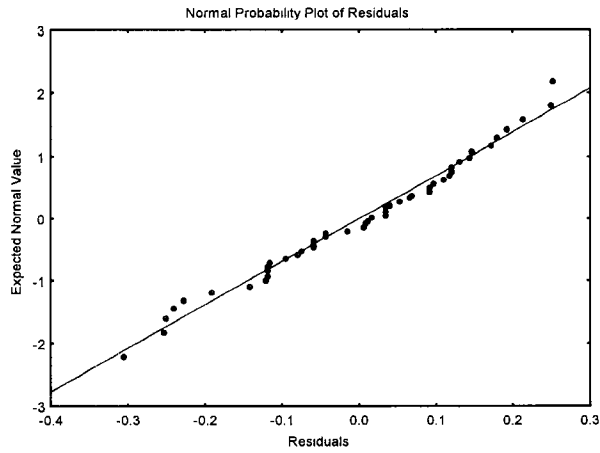
$$CA (\%) = -0.9365 DL/CW + 0.0045 RC/CW + 0.1777 \quad (5.3)$$

In Table 5.7, the coefficient of multiple determination ( $R^2$ ) is 0.5464, indicating that 55 percent of the variability in the data is explained by the relationship. According to the model utility test, the F-Statistic is 27.10, and the corresponding P-level is  $1.88 \times 10^{-8}$ , which is a highly significant result. The P-levels of both independent variables were less than 0.05. Therefore, it can be concluded that there is a useful linear relationship between dependent variable, CA, and two independent variables, DL/CW and RC/CW, in the model. Figures 5.10, 5.11, and 5.12 show the basic plots for an assessment of model validity and usefulness. All of them prove the appropriateness of multiple linear regression on the given data for the same reasons explained above.

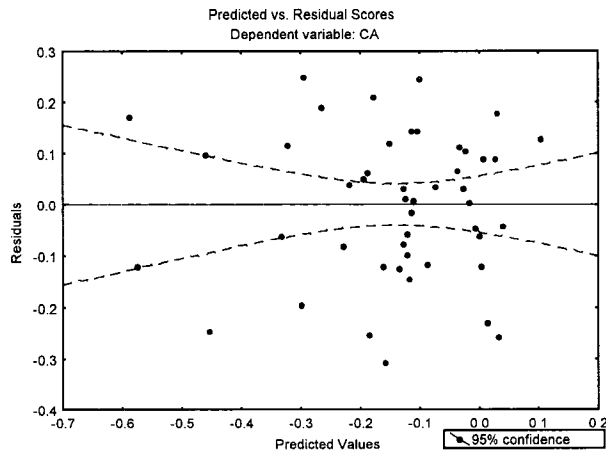
Both Equations (5.2) and (5.3) can be used to predict the pool habitat area change represented by the pool surface area change for the given geometry of the dikes (dike length and elevation) and the channel (radius of curvature). Because (5.3) consists of dimensionless parameters and is independent of the units, it can be more widely used in the field. However, one shortcoming of Equation (5.3) is that it does not include the dike elevation (DE), which was selected as an important independent variable in Equation (5.2). Thus, it is recommended to use Equation (5.3) with the consideration of the maximum 5-foot dike elevation to keep the dike pools maintained without sedimentation.

**Table 5.7: Multiple linear regression summary statistics corresponding to Equation (5.3)**

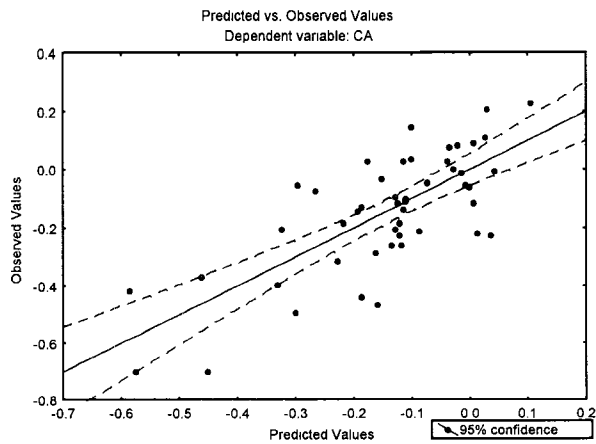
<b>Number of Measurements</b>	48					
<b>Dependent Variable</b>	CA					
<b>Independent Variables</b>	$\beta$	<b>Standard Error of <math>\beta</math></b>	<b>B</b>	<b>Standard Error of B</b>	<b>t(37)</b>	<b>P-level</b>
<b>Intercept</b>			0.177686	0.065916	2.69565	0.009845
<b>DL/CW</b>	-0.676142	0.101646	-0.936487	0.140785	-6.65191	0.000000
<b>RC/CW</b>	0.211253	0.101646	0.004450	0.002141	2.07832	0.043412
<b>Multiple R =</b>	0.73918					
<b>Multiple R<sup>2</sup> =</b>	0.54639					
<b>Adjusted R<sup>2</sup> =</b>	0.52623					
<b>F(3,44) =</b>	27.10252					
<b>p &lt;</b>	1.88E-08					
<b>Standard error of estimate</b>	0.14296					



**Figure 5.10: Normal probability plot of residuals – dimensionless variables**



**Figure 5.11: Predicted values versus residuals – dimensionless variables**



**Figure 5.12: Observed versus predicted values – dimensionless variables**

## 5.4 HEC-6 ANALYSIS

The HEC-6 model was used, to find relationships between dike geometric parameters and main channel parameters. Two dike fields were selected for the application of the HEC-6 model: Bondurant Towhead and Baleshed Landing, both managed by the Vicksburg District, which have hydrographic survey data for three years (1964, 1975, and 1988). These hydrographic survey data stored in MicroStation® file format, contain cross-section geometry data measured at intervals of 0.2 mile (1,056 feet), which is adequate to be used in the HEC-6 model.

The Bondurant Towhead dike field (Figure 5.13) is comprised of three dikes: two dikes constructed in 1975 (Dikes 1 and 2) and one dike constructed in 1991 (Dike 1U). In 1991, Dikes 1 and 2 were also raised. Therefore, the HEC-6 model with two dikes (Dikes 1 and 2) constructed in 1975 was constructed using cross-section geometry data measured in 1975, and the results were compared with those measured in 1988. The Bondurant Towhead dike field is located on the right bank between RM 390.5 and 395.0.

The Baleshed Landing dike field (Figure 5.14) is comprised of six dikes: five dikes constructed in 1965 (Dike 1 through 5) and one dike constructed in 1992 (Dike 6). In 1989, Dikes 4 and 5 were raised and extended. Therefore, the HEC-6 model with five dikes (Dike 1 through 5) constructed in 1965 was constructed using cross-section geometry data measured in 1964, and calibrated using data measured in 1975. The

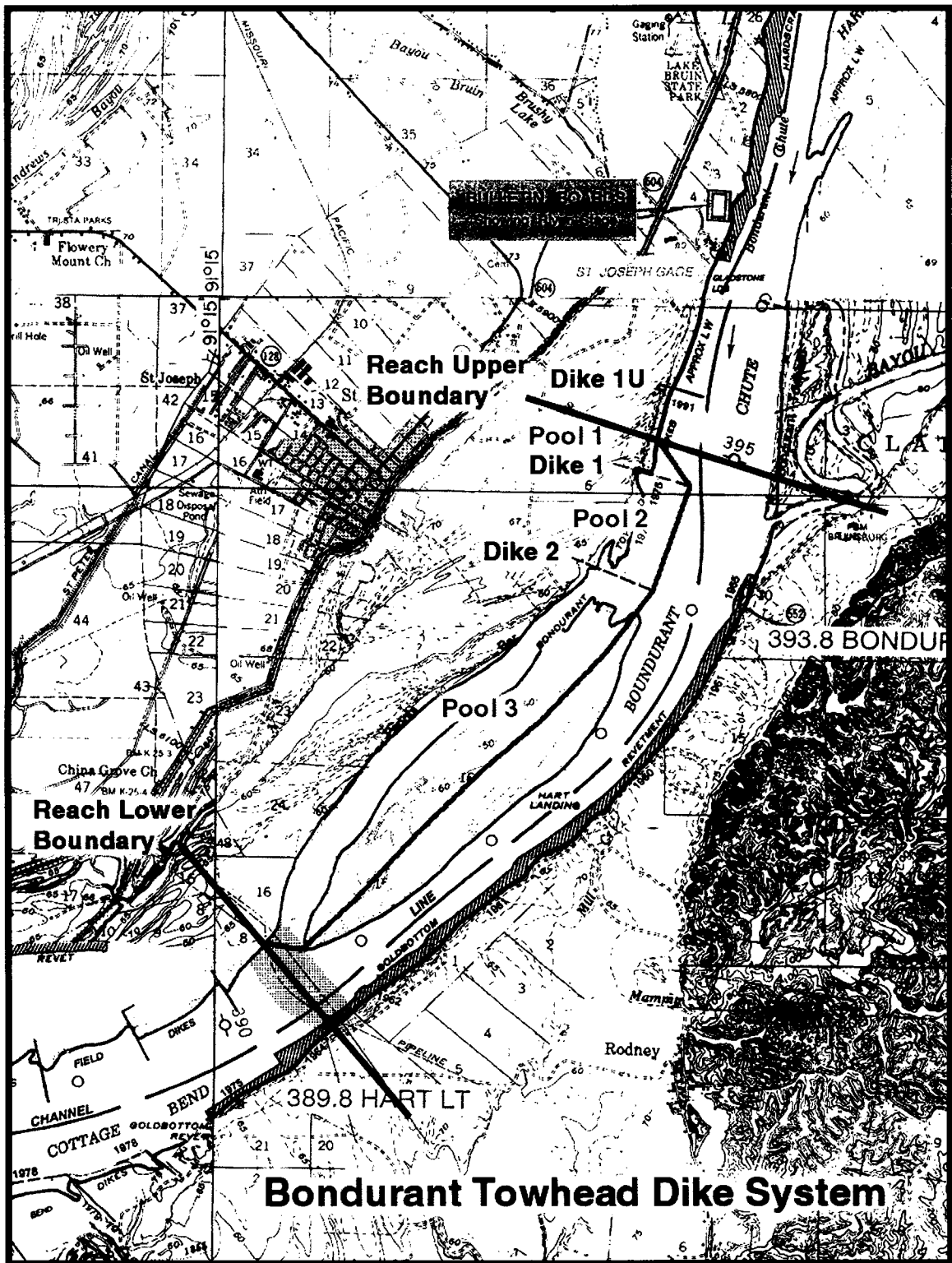


Figure 5.13: Map of Bondurant Towhead dike field (Biedenharn *et al.*, 2000)

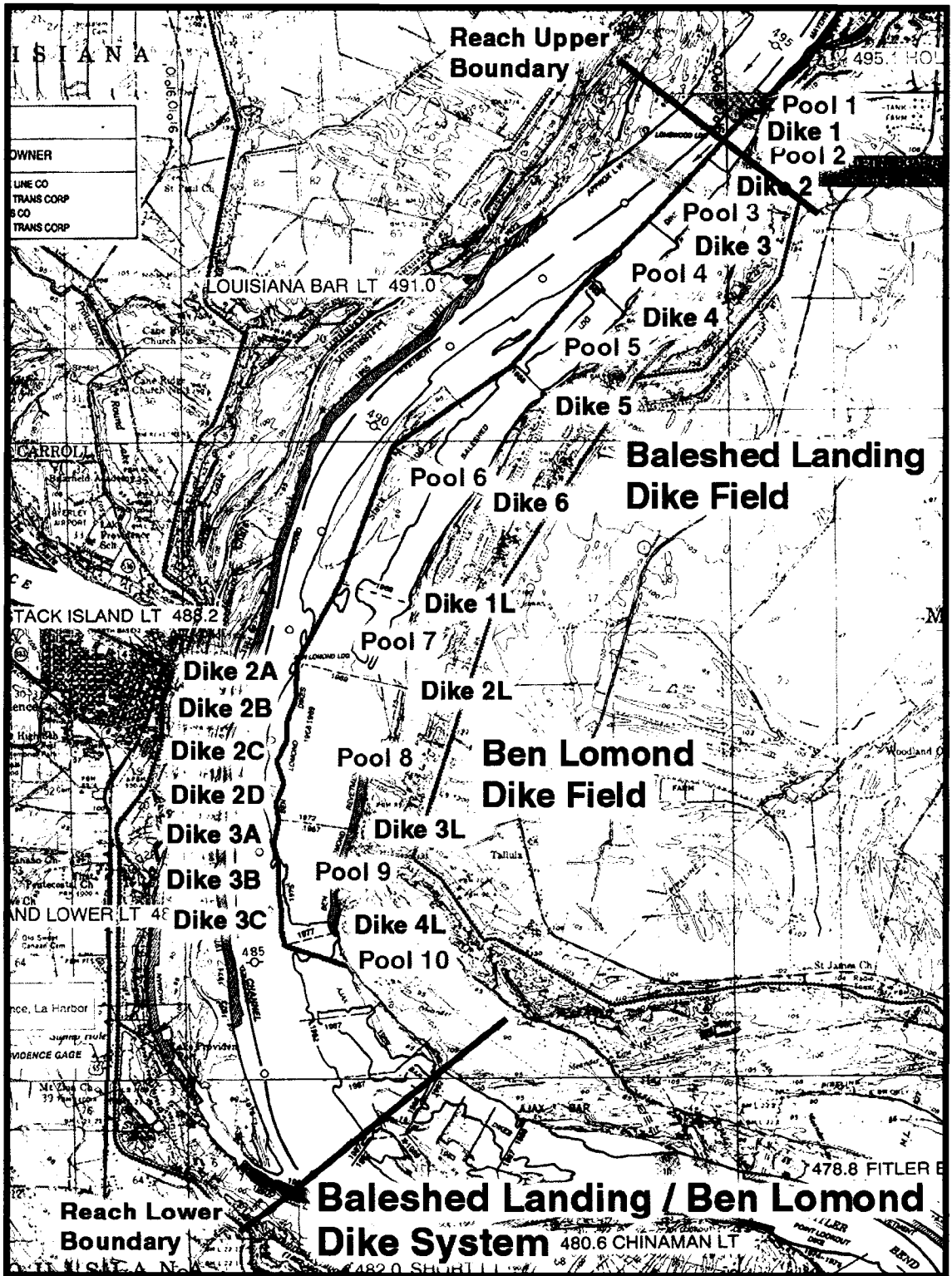


Figure 5.14: Map of Baleshed Landing/Ben Lomond dike system (Biedenharn *et al.*, 2000)

Baleshed Landing dike field ties into the Ben Lomond dike field on the lower part of the reach. It is located on the left bank between RM 489.0 and 494.0.

According to Biedenharn *et al.* (2000), the largest impacts of the dikes occur in the first 10 to 15 years following dike construction, after which the response decreases significantly, indicating that the systems are approaching an equilibrium condition. Therefore, it can be considered that the modeling periods for both dike fields are sufficient to approach an equilibrium condition.

#### **5.4.1 BONDURANT TOWHEAD DIKE FIELD**

##### **5.4.1.1 MODEL INPUT**

The HEC-6 model with two dikes (Dikes 1 and 2) was constructed using cross-section geometry data measured in 1975, and was calibrated using data measured in 1988. Input data for the HEC-6 model consist of geometric data, sediment data, and hydrologic data. Geometric data include cross-section geometry, reach lengths, Manning's n values, the movable bed portion of each cross section, and the depth of bed sediment material available for scour.

Cross-section geometry data within the Bondurant Towhead dike field were obtained from the 1975 hydrographic survey data. However, these cross-section geometry data did not have the coordinate points (stations and elevations) for the overbank area. Therefore, the points for the overbank area at each cross section were generated from the HEC-RAS geometric data measured in 1988 by interpolation. This follows because the 1988 HEC-RAS geometric data were the only available HEC-River

Analysis System (HEC-RAS) model, and measured at intervals much longer than the 1975 hydrographic survey data (more than a mile). The generated points for the overbank area were then combined with the 1975 hydrographic survey data to generate the cross-section data to be used for the HEC-6 geometric data.

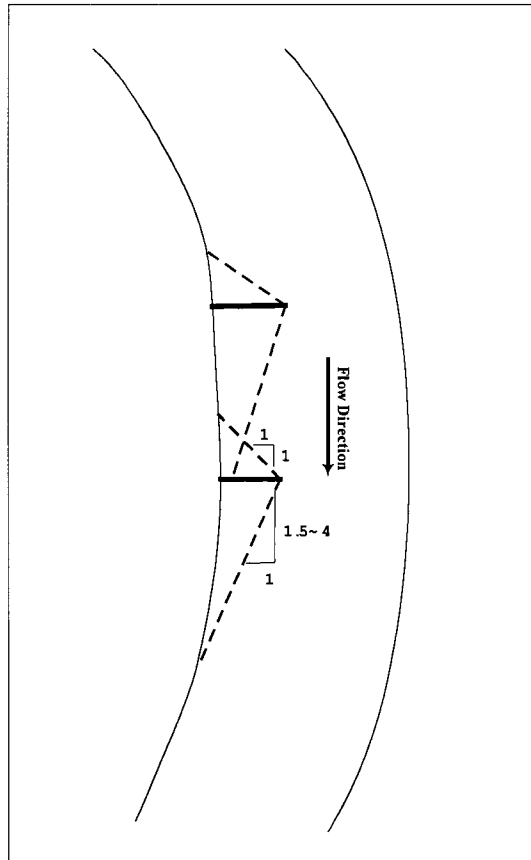
Manning's  $n$  roughness coefficients were adopted from the 1988 HEC-RAS data. The depth of bed sediment material available for scour was set to 30 feet below the starting elevation of the thalweg. Thirty feet is an approximate maximum depth of scour calculated from hydrographic survey data.

In the dike-field simulation, it is necessary to predict the flow pattern diverted by the dikes. Although eddies develop in the dike pool area not affected by the main current, these eddies are known to provide some protection to the bank (Copeland, 1983), and it was assumed that eddies do not contribute much to bed elevation change, because they could not be predicted in a one-dimensional model such as HEC-6. Therefore, on the assumption that bed elevation change is affected only by the main current, it is necessary to predict the angle of the flow diverted by the dike, to decide the movable bed portion of the cross sections in the dike field. The portion of the movable bed of the cross sections including the dike should be the main channel section excluding the dike portion within it.

The HEC (1995) investigated the expansion and contraction of the flow around bridges using field data and two-dimensional hydraulic modeling (RMA-2) for use in one-dimensional models such as HEC-2. Based on the similarity between bridge abutments and dikes, it was assumed that the investigation about bridges by the HEC (1995) could be applied to the dike study to predict the angle of the flow diverted by the

dike. The HEC (1995) suggested the equations for the expansion (downstream side of the bridge) and contraction (upstream side of the bridge) ratios that are the function of Froude number and discharge. However, because the ratios calculated from these equations changed according to the water surface elevation and discharge, a single ratio representing the whole range of discharges was necessary for use in the HEC-6 geometric data. The HEC (1995) concluded that the traditional rule-of-thumb, which recommends the assumption of an expansion ratio of 4:1 (unit downward:unit outward), overestimates the reach length in most cases. The mean and median value of the expansion ratio suggested by the HEC (1995) was 1.5:1. Therefore, to find the adequate expansion ratio for the HEC-6 model, expansion ratios from 1.5:1 to 4:1 were tested, as explained in Section 5.4.1.2. The standard rule-of-thumb regarding contraction reach lengths, which assumes 1:1 (unit upward:unit outward), was not refuted by the HEC; therefore, an 1:1 ratio was used for contraction (Figure 5.15).

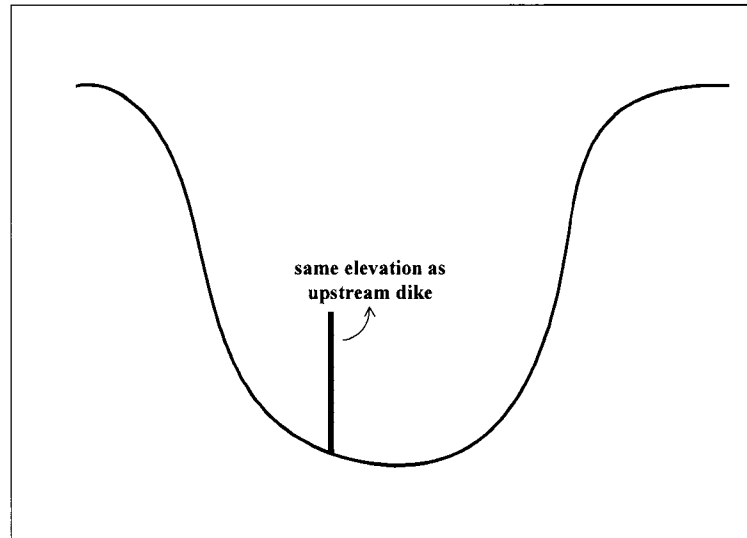
When the dikes are overtopped, the flow condition within the dike field becomes similar to the main channel; therefore, the portion of the movable bed of each cross section should be extended from the portion decided from the ratios suggested above to the whole width of the main channel. To consider this kind of change in the movable bed in the HEC-6 model, the ineffective flow area option in HEC-6 was used. Originally, the ineffective flow option in HEC-6 is intended to represent the levees or structures, which prevent water from flowing into a subsection. The subsection blocked by the structure is ineffective for conveying flow and is not used for hydraulic and bed elevation change computations until the water surface exceeds the top elevation of the structure (HEC, 1993). To apply the ineffective flow area option to each cross section in the dike field, an



**Figure 5.15: Schematic of expansion and contraction ratios**

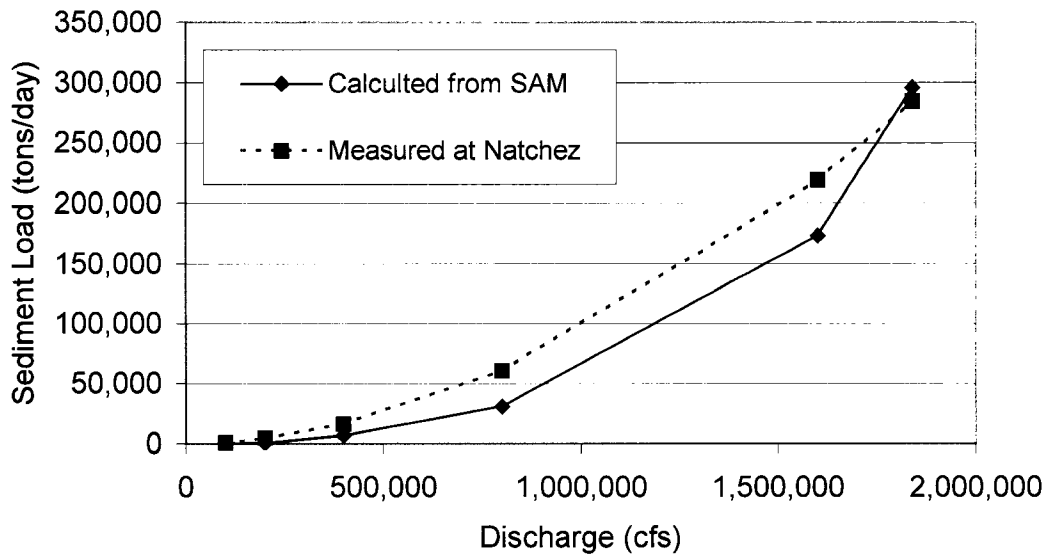
artificial thin wall having the same elevation as an upstream dike was added at the location determined from the expansion or contraction ratio (Figure 5.16). Thus, when the water surface elevation is lower than the elevation of the upstream dike, bed elevation change (scour or deposition) occurs within the portion between the artificial thin wall and the bank station point at the opposite side of the dike, and when the water surface elevation is higher than the elevation of the upstream dike, bed elevation change occurs within the whole width of the main channel.

Sediment data include the bed material gradation and the inflowing sediment load. The bed material gradation was obtained from Nordin and Queen (1992). The bed



**Figure 5.16: Schematic of ineffective flow area**

material gradations measured at RM 393.8 were selected for the Bondurant Towhead dike field. The inflowing sediment loads were calculated using SAM.sed, which is one of three modules of the SAM package and can calculate a sediment discharge rating curve based on hydraulic conditions and bed gradations. SAM is an integrated system of programs developed by the Coastal and Hydraulics Laboratory (CHL) of ERDC, to aid engineers in analyses associated with designing, operating, and maintaining flood control channel and stream restoration projects (Thomas *et al.*, 2002). Inputs of hydraulic condition to SAM were calculated by using the 1988 HEC-RAS model at RM 396.4, which is the upstream boundary of the reach simulated by the HEC-6 model. The bed material gradations measured at RM 397.9 were selected for the bed gradation of SAM. The inflowing sediment load data calculated from SAM were then calibrated by the measured sediment load data collected by Louisiana Hydroelectric (1999). Natchez, the gauging station closest to the Bondurant Towhead dike field was selected for calibration. Figure 5.17 presents the comparison of the sediment discharge rating curves

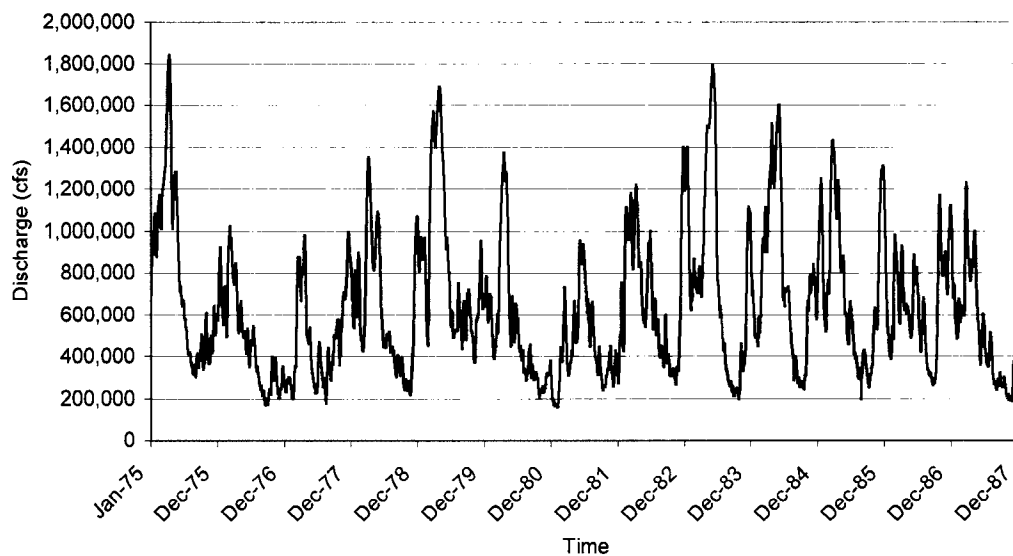


**Figure 5.17: Comparison of sediment load calculated from SAM and measured at Natchez**

calculated from SAM and measured at Natchez, where the sediment discharge rating curves were constructed by the regression of the sediment load data for the period of 1984 to 1987. The sediment load data calculated from SAM were calibrated using data measured at Natchez.

According to Tingsanchali and Supharatid (1996), the selection of the sediment transport equation has the most significant effect on the computed results. Thomas (1999) confirmed that Toffaleti's transport function was adequate for use in HEC-6 modeling of the Mississippi and Atchafalaya Rivers using 1998 hydrodynamic and sedimentary data, and also Toffaleti's transport function itself was developed for the Mississippi, Red, and Atchafalaya Rivers. Therefore, Toffaleti's transport function was selected for the model.

Hydrologic data include the water discharge and flow rating curve at the downstream boundary. The U.S. Geological Survey (USGS) gauge closest to the Bondurant Towhead dike field was at Vicksburg (RM 435.7); therefore, the daily discharge data measured at Vicksburg (Figure 5.18) were used for the model. The flow rating curve at the downstream boundary was calculated from the rating table at the Natchez gauge (USACE, 1990) using the HEC-RAS model.



**Figure 5.18: Input hydrograph measured at Vicksburg**

#### **5.4.1.2 MODEL CALIBRATION AND BASE TEST**

The HEC-6 model with two dikes (Dikes 1 and 2) was run for the period of 1975 to 1987, and its results were compared with the cross-section geometry data from the 1988 hydrographic survey. As mentioned above, the flow expansion ratios were varied until the observed and calculated data matched reasonably well.

Before the comparison, it should be noted that one-dimensional models like HEC-6 may not precisely reconstitute thalweg elevations, because the thalweg behavior is a three-dimensional process. Therefore, HEC (1992) recommended using cross-sectional area changes or other volumetric measures rather than thalweg elevation change when calibrating. Amounts of scour/deposition may not be exactly reproduced at specific cross-section locations when calibrating. Therefore, for comparison with the measured data, the cross-section areas were calculated from the 1975 and 1988 hydrographic survey data, and the cross sections simulated by the HEC-6 model, respectively. When calculating the cross-section area, the water surface elevation of 36 feet NGVD was used, which was considered as the maximum water surface elevation to reflect change in main channel correctly.

Table 5.8 presents the measured and simulated cross-section areas of each flow expansion ratio, and absolute values of the errors of the simulated cross-section area relative to the measured cross-section area to decide the adequate flow expansion ratio to be used in the model. As shown in Table 5.8, the expansion ratio of 3:1 showed the smallest average value of the errors (8.9%) and it was used for the base and plan tests. In the comparison of Table 5.8, the cross sections at dike locations (RM 394 and 394.8) were excluded, because they were surveyed a little upstream or downstream of dike locations; therefore, the cross sections of surveyed data at dike locations must be different from the original cross sections at dike locations.

Figure 5.19 shows the comparison of the measured cross-section areas with those simulated from the base condition using the expansion ratio of 3:1. The simulated cross-section areas at all cross sections except RM 394.6 matched relatively well with the

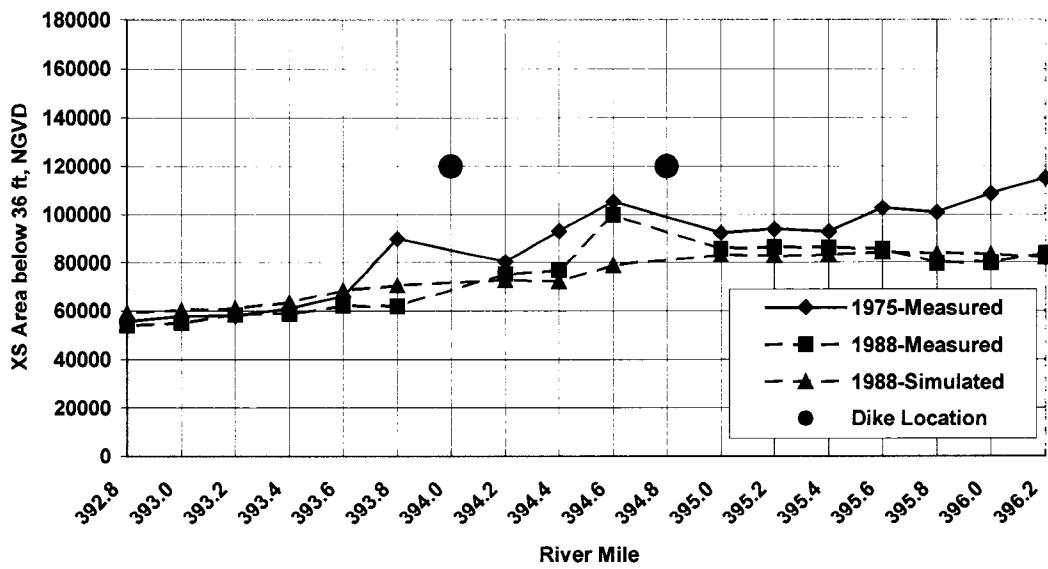
**Table 5.8: Comparison of the measured and simulated cross-section areas to decide the flow expansion ratio**

RM	Measured in 1988	Simulated			
		1.5:1		2:1	
	XS* Area below 36 feet NGVD (ft <sup>2</sup> )	XS Area below 36 feet NGVD (ft <sup>2</sup> )	Absolute Value of Relative Error	XS Area below 36 feet NGVD (ft <sup>2</sup> )	Absolute Value of Relative Error
396.2	83,872	82,256	1.9%	82,256	1.9%
396.0	80,042	83,405	4.2%	83,405	4.2%
395.8	79,821	83,832	5.0%	83,832	5.0%
395.6	85,680	84,306	1.6%	84,308	1.6%
395.4	86,278	83,061	3.7%	83,087	3.7%
395.2	86,388	82,570	4.4%	82,709	4.3%
395.0	85,541	83,017	3.0%	83,050	2.9%
394.6	99,691	79,170	20.6%	75,300	24.5%
394.4	76,876	55,513	27.8%	55,608	27.7%
394.2	75,254	76,687	1.9%	77,437	2.9%
393.8	61,931	71,803	15.9%	72,391	16.9%
393.6	62,245	69,818	12.2%	69,916	12.3%
393.4	58,807	63,585	8.1%	64,498	9.7%
393.2	58,569	60,939	4.0%	61,194	4.5%
393.0	54,951	60,581	10.2%	60,498	10.1%
392.8	53,961	59,656	10.6%	59,606	10.5%
Average of XSs within dike field (RM 392.8~395)			11.4%		12.2%
RM	Measured in 1988	Simulated			
		2.5:1		3:1	
	XS Area below 36 feet NGVD (ft <sup>2</sup> )	XS Area below 36 feet NGVD (ft <sup>2</sup> )	Absolute Value of Relative Error	XS Area below 36 feet NGVD (ft <sup>2</sup> )	Absolute Value of Relative Error
396.2	83,872	82,294	1.9%	82,296	1.9%
396.0	80,042	83,496	4.3%	83,473	4.3%
395.8	79,821	83,876	5.1%	83,875	5.1%
395.6	85,680	84,333	1.6%	84,333	1.6%
395.4	86,278	83,137	3.6%	83,160	3.6%
395.2	86,388	82,599	4.4%	82,759	4.2%
395.0	85,541	82,963	3.0%	83,046	2.9%
394.6	99,691	79,651	20.1%	78,994	20.8%
394.4	76,876	57,996	24.6%	72,134	6.2%
394.2	75,254	76,964	2.3%	72,802	3.3%
393.8	61,931	72,398	16.9%	70,736	14.2%
393.6	62,245	69,575	11.8%	68,450	10.0%
393.4	58,807	64,176	9.1%	63,634	8.2%
393.2	58,569	61,136	4.4%	61,028	4.2%
393.0	54,951	60,121	9.4%	60,267	9.7%
392.8	53,961	59,169	9.7%	59,223	9.8%
Average of XSs within dike field (RM 392.8~395)			11.1%		8.9%

**Table 5.8 (cont.)**

RM	Measured in 1988 XS Area below 36 feet NGVD (ft <sup>2</sup> )	Simulated			
		3.5:1		4:1	
		XS Area below 36 feet NGVD (ft <sup>2</sup> )	Absolute Value of Relative Error	XS Area below 36 feet NGVD (ft <sup>2</sup> )	Absolute Value of Relative Error
396.2	83,872	82,297	1.9%	82,298	1.9%
396.0	80,042	83,496	4.3%	83,473	4.3%
395.8	79,821	83,967	5.2%	83,896	5.1%
395.6	85,680	84,355	1.5%	84,355	1.5%
395.4	86,278	83,135	3.6%	83,160	3.6%
395.2	86,388	82,566	4.4%	82,755	4.2%
395.0	85,541	82,626	3.4%	83,017	3.0%
394.6	99,691	74,332	25.4%	76,234	23.5%
394.4	76,876	71,187	7.4%	72,593	5.6%
394.2	75,254	70,971	5.7%	72,558	3.6%
393.8	61,931	73,091	18.0%	71,510	15.5%
393.6	62,245	70,485	13.2%	68,293	9.7%
393.4	58,807	65,027	10.6%	64,664	10.0%
393.2	58,569	61,678	5.3%	61,290	4.6%
393.0	54,951	60,337	9.8%	60,482	10.1%
392.8	53,961	59,313	9.9%	59,444	10.2%
Average of XSs within dike field (RM 392.8~395)			10.9%		9.6%

\*XS-Cross Section



**Figure 5.19: Comparison of the measured and simulated cross-section areas – Bondurant Towhead**

measured areas. As suggested by HEC (1992), the total volumes of the section between RM 392.8 and 395, which includes all the cross sections affected by the dike field, were compared. As shown in Table 5.9, the simulated total volume of the section between RM 392.8 and 395, and below the water surface elevation at 36 feet NGVD, was 90.4% of the total volume measured in 1975, whereas the measured total volume was 90.3% of that. In terms of the volume, it can then be said that the relative error of the HEC-6 model is 0.2%, which can be considered acceptable.

**Table 5.9: Comparison of the measured and simulated cross-section areas and volumes – Bondurant Towhead**

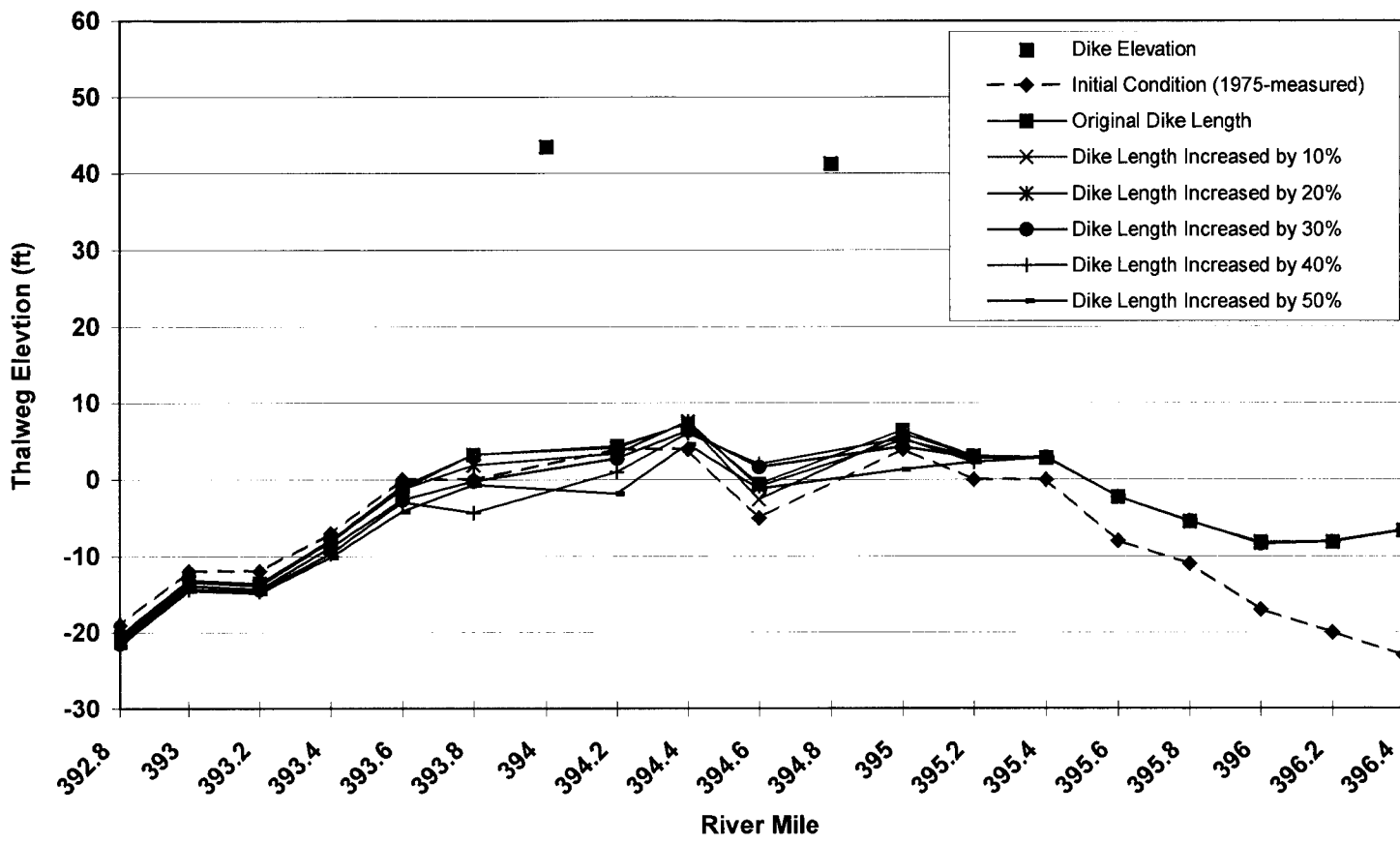
RM	Measured in 1975		Measured in 1988		Simulated (using expansion ratio 3:1)		
	XS Area below 36 feet NGVD (ft <sup>2</sup> )	Volume (ft <sup>3</sup> )	XS Area below 36 feet NGVD (ft <sup>2</sup> )	Volume (ft <sup>3</sup> )	XS Area below 36 feet NGVD (ft <sup>2</sup> )	Absolute Value of Relative Error	Volume (ft <sup>3</sup> )
396.2	114,773		83,872		82,296	1.9%	
396.0	108,672		80,042		83,473	4.3%	
395.8	100,612		79,821		83,875	5.1%	
395.6	102,449		85,680		84,333	1.6%	
395.4	92,852		86,278		83,160	3.6%	
395.2	93,944		86,388		82,759	4.2%	
395.0	92,235	48,699,816	85,541	45,165,521	83,046	2.9%	43,848,145
394.6	105,176	111,066,278	99,691	105,273,981	78,994	20.8%	83,417,970
394.4	93,058	98,268,794	76,876	81,181,056	72,134	6.2%	76,173,620
394.2	80,484	84,990,924	75,254	79,467,886	72,802	3.3%	76,878,553
393.8	89,869	94,901,136	61,931	65,399,115	70,736	14.2%	74,697,237
393.6	65,763	69,445,665	62,245	65,731,174	68,450	10.0%	72,283,168
393.4	61,012	64,428,176	58,807	62,100,456	63,634	8.2%	67,197,314
393.2	57,879	61,120,488	58,569	61,849,339	61,028	4.2%	64,445,272
393.0	57,603	60,828,831	54,951	58,028,742	60,267	9.7%	63,642,438
392.8	55,709	29,414,194	53,961	28,491,334	59,223	9.8%	31,269,902
SUM		723,164,302		652,688,604			653,853,621
%				90.3%			90.4%
Relative Error							0.2%

### 5.4.1.3 PLAN TESTS

The HEC-6 model was run by modifying the base test condition, not only to find the relationships between dike geometric parameters and main channel parameters, but also to get an idea for better dike-field design.

First, the effect of dike length on thalweg elevation was predicted by increasing the length of the dikes using the HEC-6 model. Because Dike 2 is much longer than Dike 1 (more than double), it was considered that Dike 2 had more influence on the main channel than Dike 1. Therefore, the dike length was increased proportional to the length of Dike 2, and the length of Dike 1 was increased by the same amount as Dike 2. Figure 5.20 presents the comparison of thalweg profiles at different dike lengths. Figure 5.20 predicted that thalweg elevation decreases within the dike field (RM 392.8 to 395) as dike length increases. However, thalweg elevation of the cross section at RM 394.4 did not decrease much relative to the other cross sections, even when the dike length was increased by 50%. This result then suggests that it is necessary to install an additional dike between two existing dikes as well as to increase the dike length to constantly improve the navigational condition within the dike field. Table 5.10 and Figure 5.21 show the average thalweg elevation change of cross sections within the dike field relative to the base condition by increasing the dike length from 10% to 50% of the original length of Dike 2. Figure 5.21 shows that the average thalweg elevation change can be approximated by a second-order polynomial equation.

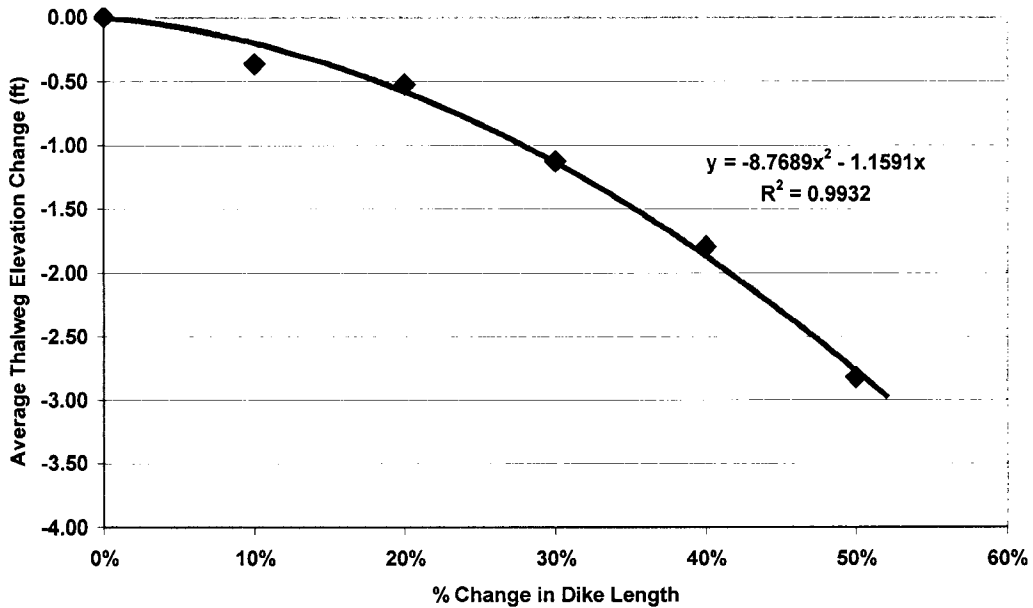
Next, the effect of dike elevation on thalweg elevation was predicted by increasing the elevation of the dikes using the HEC-6 model. In this case, the elevation of both dikes was increased from 1 foot to 6 feet instead of increasing the percent of the



**Figure 5.20: Thalweg comparison according to dike length change – Bondurant Towhead**

**Table 5.10: Average thalweg elevation change relative to the base condition according to dike length change – Bondurant Towhead**

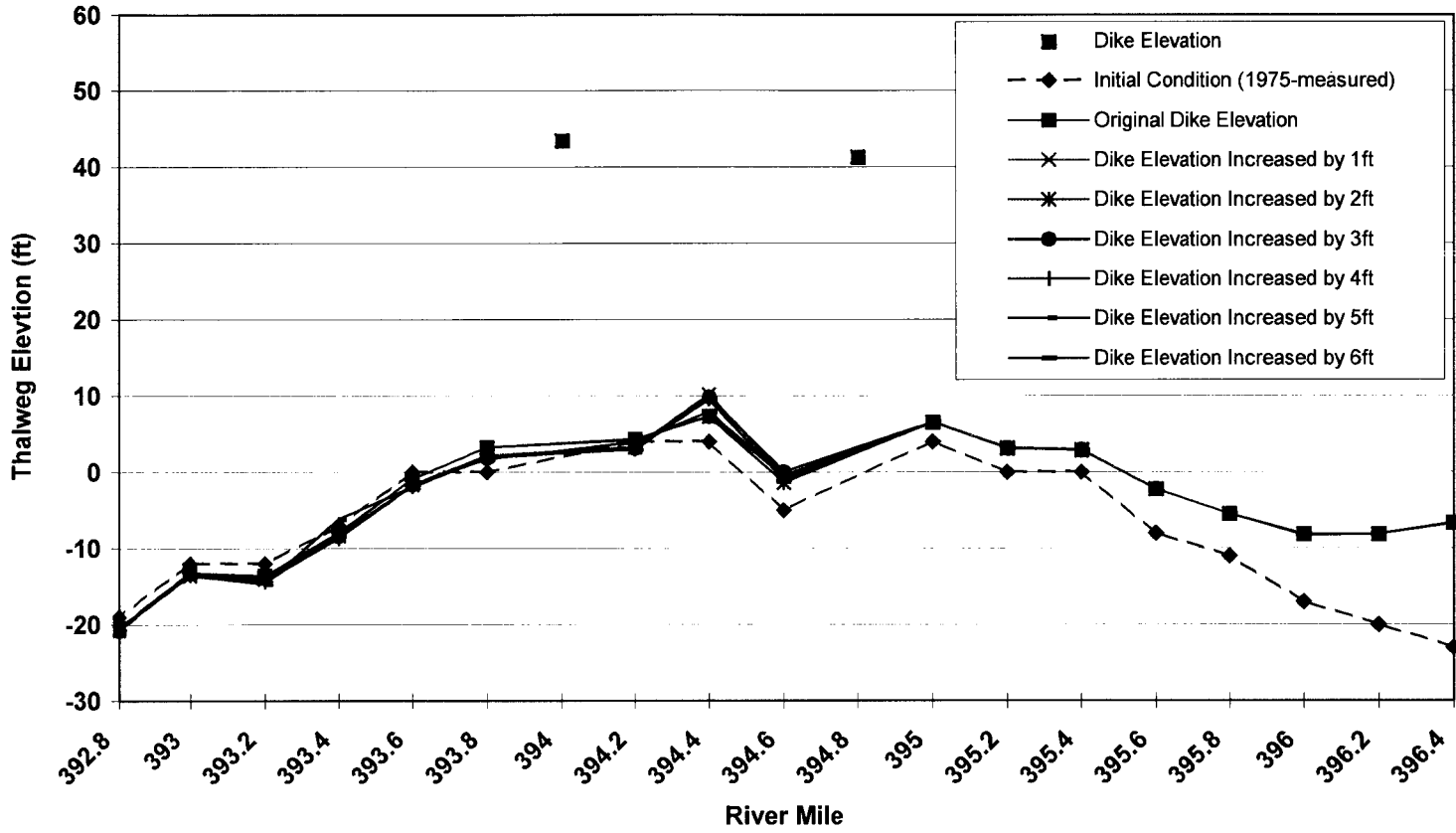
Plan	Amount of Increase (ft)	Average Thalweg Elevation Change (ft)
Original Length	0	0
Increased by 10%	245	-0.37
Increased by 20%	489	-0.53
Increased by 30%	734	-1.13
Increased by 40%	978	-1.80
Increased by 50%	1223	-2.82



**Figure 5.21: Average thalweg elevation change relative to the base condition according to dike length change – Bondurant Towhead**

original dike elevation, because the dike elevation is a relative value measured above LWRP. Figure 5.22 presents the comparison of thalweg profiles at different dike elevations. Figure 5.22 predicted that thalweg elevation decreases within the dike field as dike elevation increases, but the degree of decrease in thalweg elevation was very small compared to the dike length change. Table 5.11 and Figure 5.23 show the average thalweg elevation change of the cross sections within the dike field relative to the base condition by increasing dike elevation. In Table 5.11, the percent increase in dike elevation relative to the elevation of Dike 2 (11.5 feet) was calculated for comparison with the dike length change test. The scale of y-axis of Figure 5.23 was adjusted to have the same range as Figure 5.21 for comparison. Figure 5.23 shows that the effect of dike elevation change on thalweg elevation is much smaller than dike length change. For a better comparison with dike length change test, the average thalweg change according to dike elevation change was plotted against the percent increase in dike elevation relative to the elevation of Dike 2 (Figure 5.24). Figure 5.24 clearly shows that the effect of dike length on thalweg elevation is much higher than dike elevation.

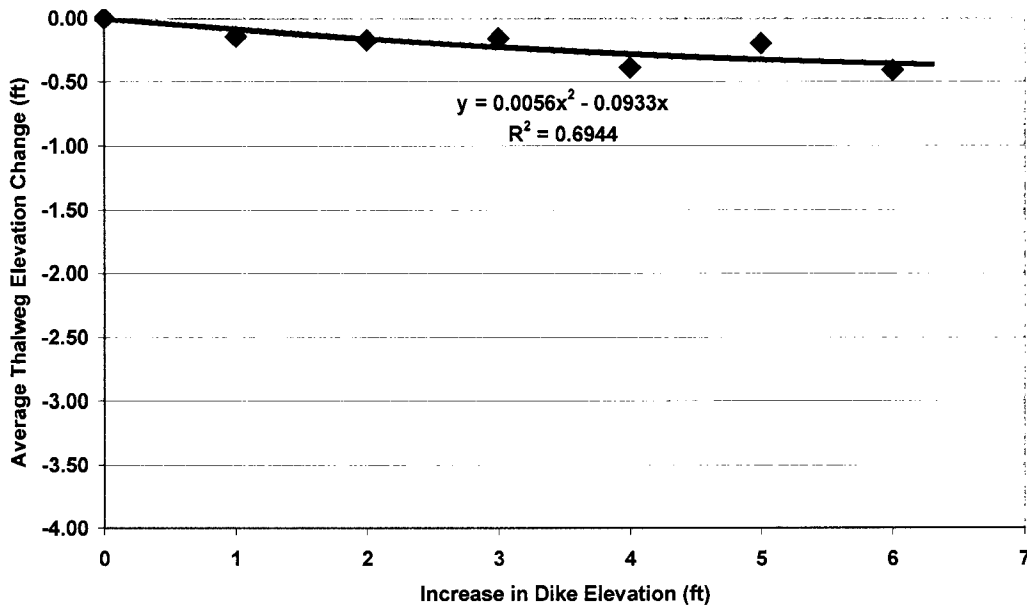
In the statistical analysis of Section 5.3, the 5-foot dike elevation was suggested as the maximum elevation to keep the dike pools maintained without sedimentation. After decreasing the elevation of both dikes into 5 feet, if thalweg elevation change is not too much to maintain the navigational condition, it can be considered as one of the alternatives in maintaining the habitat area within the dike field. To test this condition, the HEC-6 model was run after the elevation of Dike 1 was decreased by 2.3 feet, and the elevation of Dike 2 was decreased by 5.5 feet resulting in both having a 5-foot elevation.



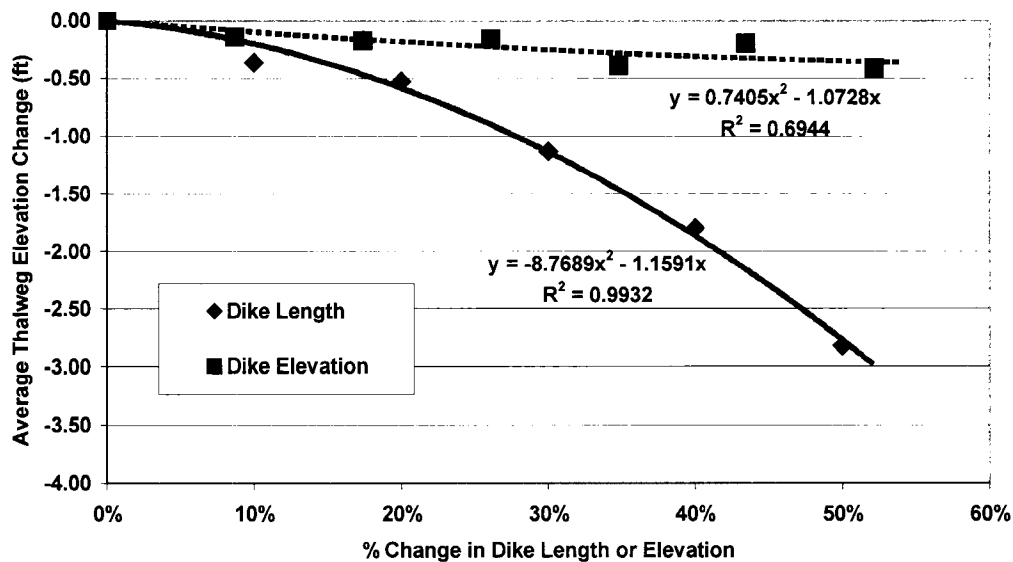
**Figure 5.22: Thalweg comparison according to dike elevation change – Bondurant Towhead**

**Table 5.11: Average thalweg elevation change relative to the base condition according to dike elevation change – Bondurant Towhead**

Plan	% Increase Relative to Dike 2 Elevation	Average Thalweg Elevation Change (ft)
Original Elevation	0%	0
Increased by 1 foot	9%	-0.15
Increased by 2 feet	17%	-0.18
Increased by 3 feet	26%	-0.16
Increased by 4 feet	35%	-0.39
Increased by 5 feet	43%	-0.20
Increased by 6 feet	52%	-0.41



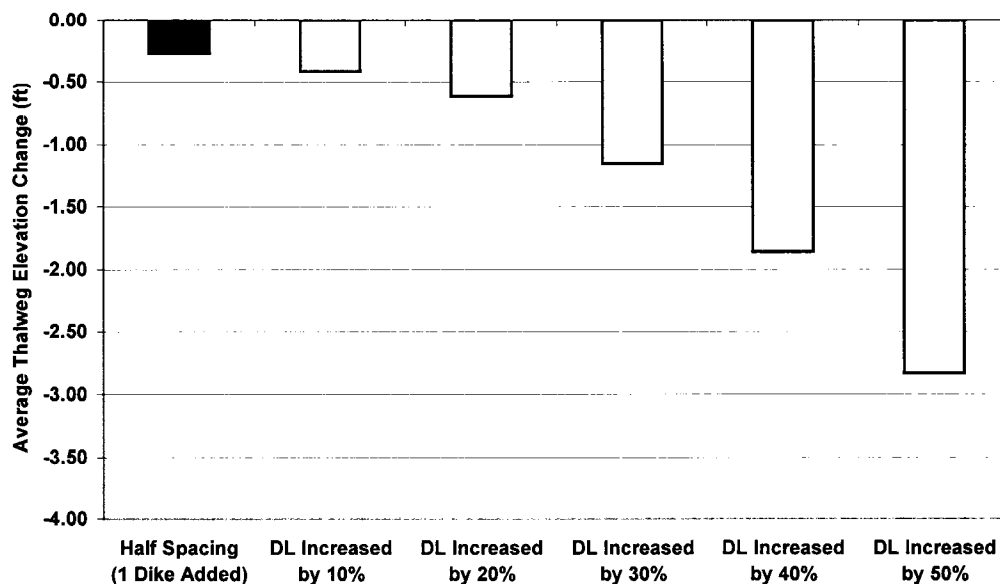
**Figure 5.23: Average thalweg elevation change relative to the base condition according to dike elevation change – Bondurant Towhead**



**Figure 5.24: Average thalweg elevation change relative to the base condition according to dike length or elevation change – Bondurant Towhead**

The simulation result showed that the average thalweg elevation increases only by 0.24 foot, which can be considered a relatively small value when compared with the test results performed above such as the 0.37-foot decrease in thalweg elevation by increasing the dike length by 10%. Thus, it can be an environmental design example to increase the dike length by less than 10% instead of decreasing both dike elevations to 5 feet.

Finally, the effect of dike spacing on thalweg elevation was predicted by adding a dike between two existing dikes. For the added dike, average length and elevation of the two dikes were used. Figure 5.25 shows that the effect of decreasing dike spacing by half is less than that of 10% increase in dike length. Therefore, this simulation result also suggests that the addition of a dike should be accompanied by the increase in dike length



**Figure 5.25: Comparison of average thalweg elevation change between half dike spacing and dike length change – Bondurant Towhead**

to increase the channel depth and maintain a constant navigational condition within the dike field.

The above plan test results are only several examples showing that the HEC-6 model can be used as a tool for dike design. The HEC-6 model also can be used to evaluate the scenarios established at the initial stage of design, which are possible combinations of the dike geometric parameters satisfying the master plan for the waterway project. After running the HEC-6 model for each scenario, the dimension and location of each dike within the dike field can be determined by considering the minimum navigation requirement and economy.

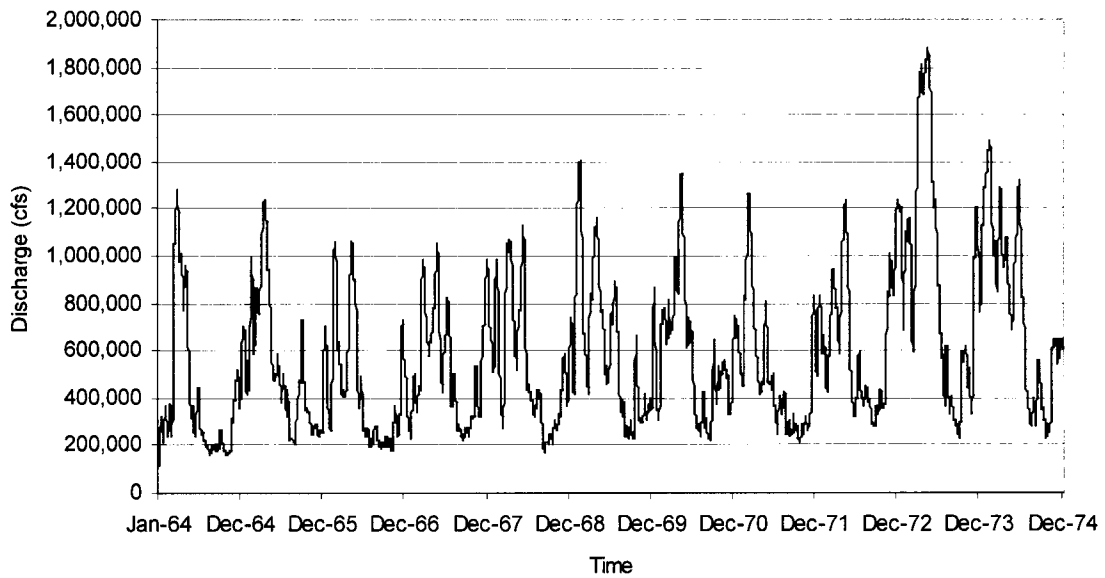
## **5.4.2 BALESHEDED LANDING DIKE FIELD**

### **5.4.2.1 MODEL INPUT**

For the Baleshed Landing dike field, the HEC-6 model with five dikes (Dikes 1, 2, 3, 4, and 5 of Figure 5.14) was constructed using the cross-section geometry data measured in 1964, and was calibrated using the data measured in 1975. For input data, the same procedure as the Bondurant Towhead dike field was used. However, in the case of the Baleshed Landing dike field, there was difficulty in deciding the input data and calibration, because this dike field was dredged periodically after construction according to Franco's (1982) record during the period of 1968 to 1975. Therefore, only the cross sections upstream of the upstream-most dike of this dike field were compared when calibrating the model.

The bed material gradations measured at RM 490, 491.8, and 495.1 were used for the model. The inflowing sediment loads were calculated using SAM, and the inputs of hydraulic conditions to SAM were calculated at the upstream boundary (RM 495.6). The bed material gradations measured at RM 495.1 were selected for the bed gradation of SAM. Because the sediment load data measured at the gauging stations close to this dike field were not available during the modeling period (1964 to 1974), the inflowing sediment load data calculated from SAM were adjusted as explained in Section 5.4.2.2.

The USGS gauge closest to the Baleshed Landing dike field was at Arkansas City (RM 554.1); therefore, the daily discharge data measured at Arkansas City (Figure 5.26) were used for the model.



**Figure 5.26: Input hydrograph measured at Arkansas City**

#### **5.4.2.2 MODEL CALIBRATION AND BASE TEST**

The HEC-6 model was run for the period of 1964 to 1974, and its results were compared with the cross-section geometry data from the 1975 hydrographic survey. As mentioned above, the inflowing sediment load data calculated from SAM were varied until the areas of cross sections upstream of the upstream-most dike of this dike field (RM 495 to 495.6) matched reasonably well. When calculating the cross-section area, the water surface elevation of 70 feet NGVD was used, which was considered as the maximum water surface elevation to reflect change in the main channel correctly in this dike field. The simulation results showed that when using 50% of the inflowing sediment load calculated from SAM, the simulated cross-section areas upstream of the upstream-most dike of this dike field matched best with those measured.

Figure 5.27 shows the comparison of the measured cross-section areas with those simulated using 50% of the inflowing sediment load calculated from SAM. The simulated cross-section areas downstream of RM 492.8 matched relatively well with the measured areas, whereas the simulated cross-section areas between RM 492.8 and 494.4 did not match well with the measured areas. It is thought that the difference is due to dredging inside the dike field, as mentioned in Section 5.4.2.1. The total volumes of the section between RM 490.8 and 494.4, which includes all the cross sections affected by the dike field, were compared. As shown in Table 5.12, the simulated total volume of the section between RM 490.8 and 494.4 and below the water surface elevation at 70 feet NGVD was 108.9% of the total volume measured in 1964, whereas the measured total volume was 116.5% of that. In terms of the volume, the relative error of the HEC-6 model is 6.5%, which is much higher than the simulation for the Bondurant Towhead dike field.

### **5.4.2.3 PLAN TESTS**

First, the effect of dike length on thalweg elevation was predicted by increasing the length of the dikes using the HEC-6 model. Because it was determined that Dike 3 had more influence on the main channel than the other dikes, the dike length was increased proportional to the length of Dike 3 and the lengths of the other dikes were increased by the same amount as Dike 3. Figure 5.28 presents the comparison of thalweg profiles at different dike lengths. It predicted that thalweg elevation decreases within the dike field (RM 490.8 to 494.4) as dike length increases. However, the effect of Dikes 1 and 2 on thalweg elevation change was very small compared to Dike 3, because the length and elevation of those two dikes were much smaller than Dike 3. The effect of Dikes 4 and 5 on thalweg elevation change was also much smaller than for Dike 3,

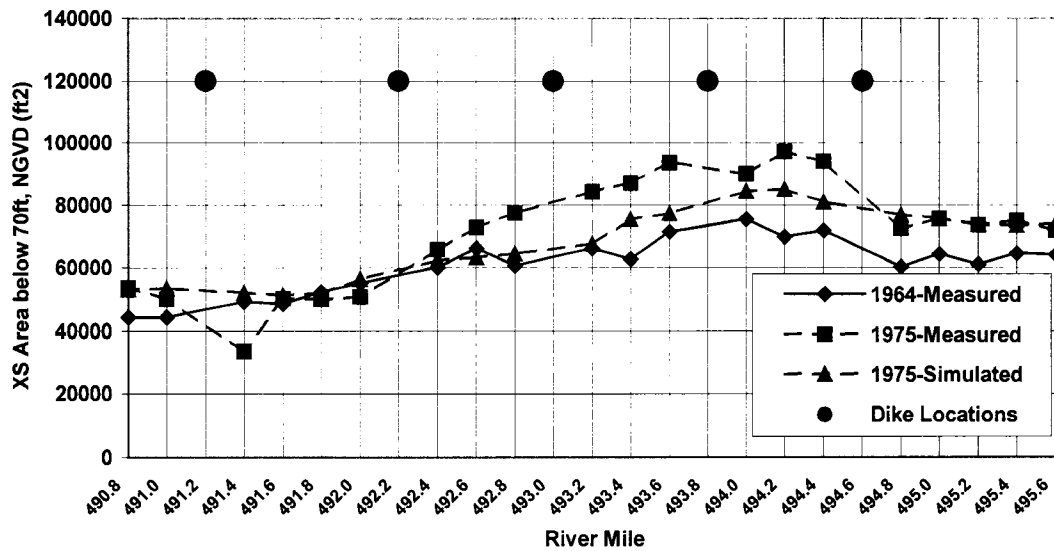


Figure 5.27: Comparison of the measured and simulated cross-section areas – Baleshed Landing

Table 5.12: Comparison of the measured and simulated cross-section areas and volumes – Baleshed Landing

RM	Measured in 1964		Measured in 1975		Simulated	
	XS Area below 70 feet NGVD (ft <sup>2</sup> )	Volume (ft <sup>3</sup> )	XS Area below 70 feet NGVD (ft <sup>2</sup> )	Volume (ft <sup>3</sup> )	XS Area below 70 feet NGVD (ft <sup>2</sup> )	Volume (ft <sup>3</sup> )
495.6	64,097		71,838		74,103	
495.4	64,487		75,121		73,449	
495.2	61,006		73,656		73,947	
495.0	64,170		75,819		75,713	
494.8	60,122		72,424		77,056	
494.4	71,900	37,963,158	94,138	49,704,964	80,991	42,763,206
494.2	69,779	73,686,434	97,146	102,586,271	85,057	89,820,403
494.0	75,508	79,736,532	89,992	95,031,383	84,439	89,167,140
493.6	71,491	75,494,042	93,658	98,903,017	77,347	81,678,126
493.4	62,563	66,066,517	87,231	92,116,316	75,539	79,769,585
493.2	66,037	69,735,336	84,365	89,089,419	67,493	71,272,724
492.8	60,528	63,917,072	77,576	81,920,573	64,467	68,076,835
492.6	66,205	69,912,723	72,811	76,888,289	63,245	66,786,625
492.4	60,026	63,387,139	65,658	69,334,563	62,163	65,644,381
492.0	55,011	58,091,500	50,786	53,629,541	56,293	59,444,954
491.8	52,138	55,057,612	49,915	52,710,261	51,991	54,902,813
491.6	48,442	51,154,435	50,214	53,026,332	51,123	53,986,152
491.4	49,223	51,979,287	33,483	35,358,122	51,939	54,847,542
491.0	44,154	46,626,518	49,915	52,710,335	53,331	56,317,916
490.8	44,221	46,697,471	53,726	56,734,339	52,975	55,941,927
SUM		909,505,777		1,059,743,726		990,420,330
%				116.5%		108.9%
Relative Error						6.5%

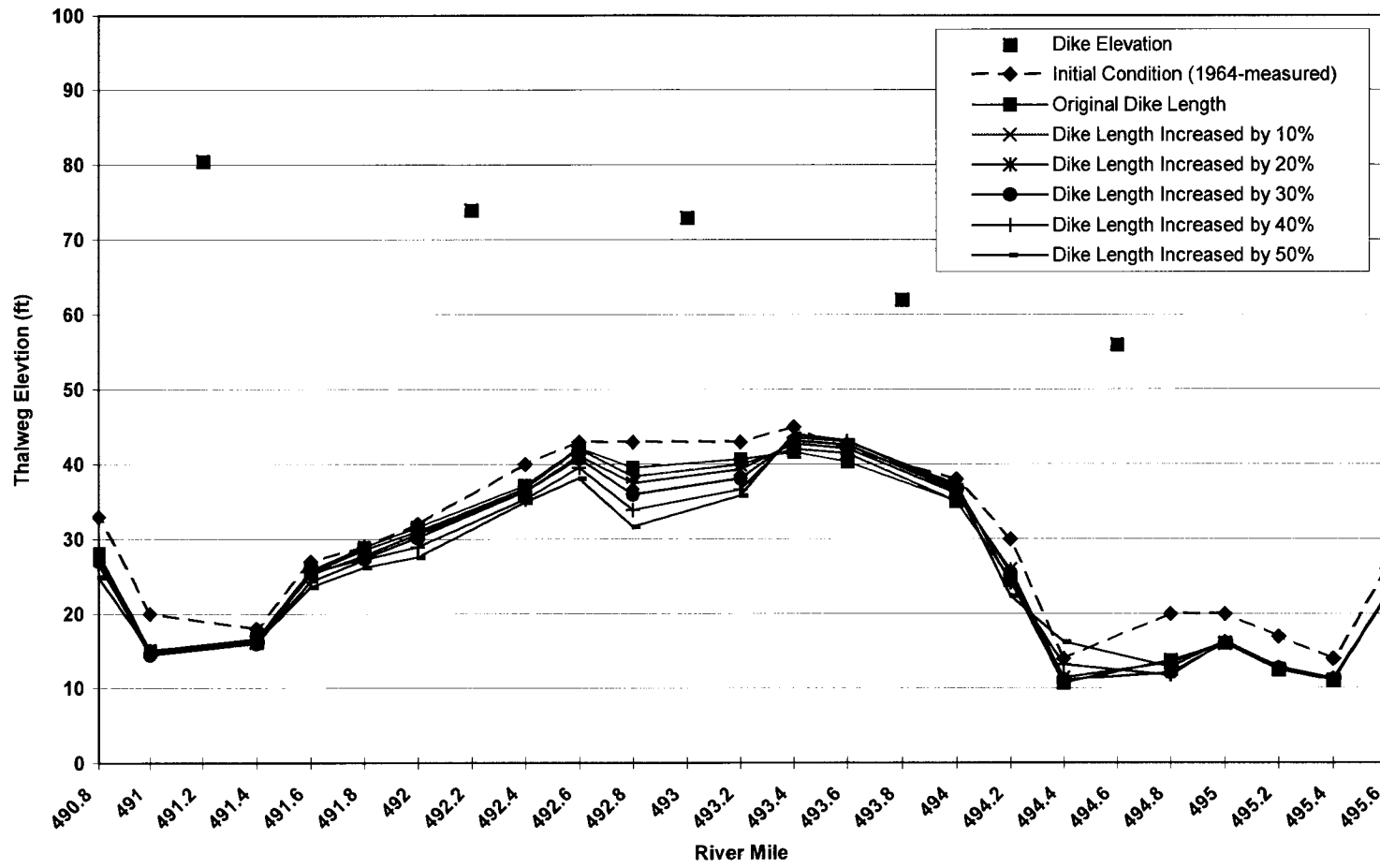


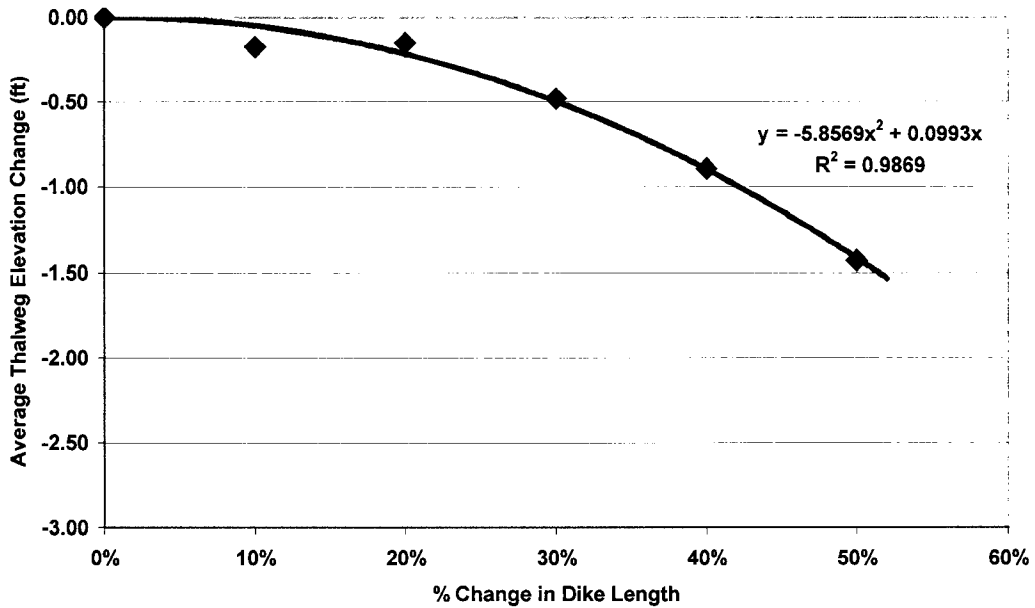
Figure 5.28: Thalweg comparison according to dike length change – Baleshed Landing

because those two dikes were located inside the secondary channel block by a middle bar (Figure 5.14). Table 5.13 and Figure 5.29 show the average thalweg elevation change of the cross sections within the dike field relative to the base condition by increasing the dike length from 10% to 50% of the original length of Dike 3.

Second, the effect of dike elevation on thalweg elevation was predicted by increasing the elevation of the dikes using the HEC-6 model. The elevations of all dikes were increased from 1 foot to 5 feet instead of increasing the percent of the original dike elevation. Figure 5.30 presents the comparison of thalweg profiles at different dike elevations. It predicted that thalweg elevation decreases within the dike field as dike elevation increases, but the degree of decrease in thalweg elevation was very small compared to the dike length change, in the same manner as the Bondurant Towhead dike field. Table 5.14 and Figure 5.31 show the average thalweg elevation change of the cross sections within the dike field relative to the base condition by increasing dike elevation. In Table 5.14, the percent increase in dike elevation relative to the elevation of Dike 3 (4 feet) was calculated for the comparison with the dike length change test. Figure 5.31 also shows that the effect of dike elevation change on thalweg elevation is much smaller than dike length change. For a better comparison with the dike length change test, the average thalweg change according to dike elevation change was plotted against the percent increase in dike elevation relative to the elevation of Dike 3 (Figure 5.32). Figure 5.32 clearly shows that the effect of dike length on thalweg elevation is much higher than dike elevation. To test the 5-foot dike elevation as the maximum elevation to keep the dike pools maintained without sedimentation, the HEC-6 model was run after Dike 4 elevation was decreased by 1 foot, and that of Dike 5 was decreased by 7.5 feet to decrease both to

**Table 5.13: Average thalweg elevation change relative to the base condition according to dike length change – Baleshed Landing**

Plan	Amount of Increase (ft)	Average Thalweg Elevation Change (ft)
Original Length	0	0
Increased by 10%	181	-0.17
Increased by 20%	362	-0.15
Increased by 30%	543	-0.48
Increased by 40%	724	-0.90
Increased by 50%	905	-1.43



**Figure 5.29: Average thalweg elevation change relative to the base condition according to dike length change – Baleshed Landing**

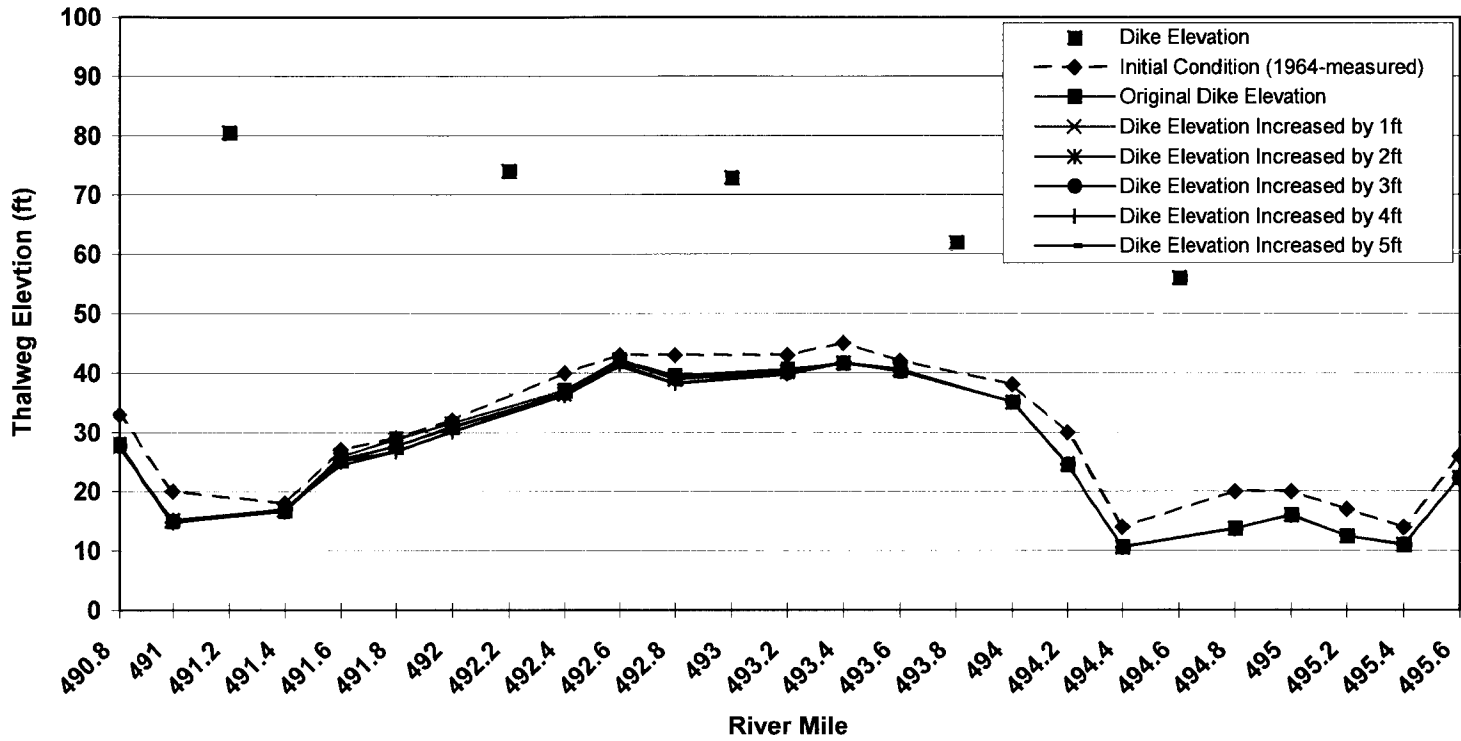
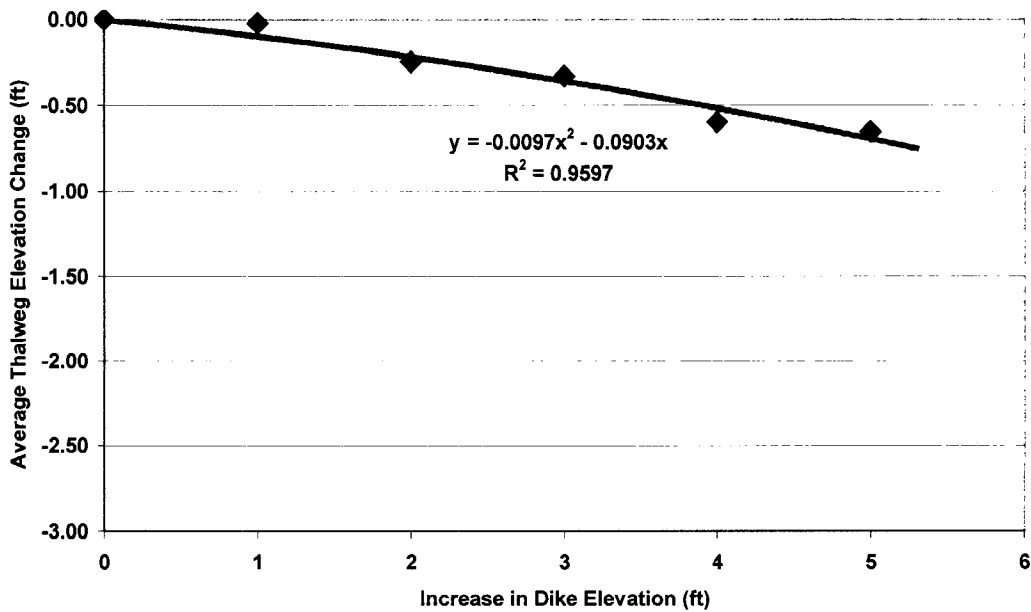


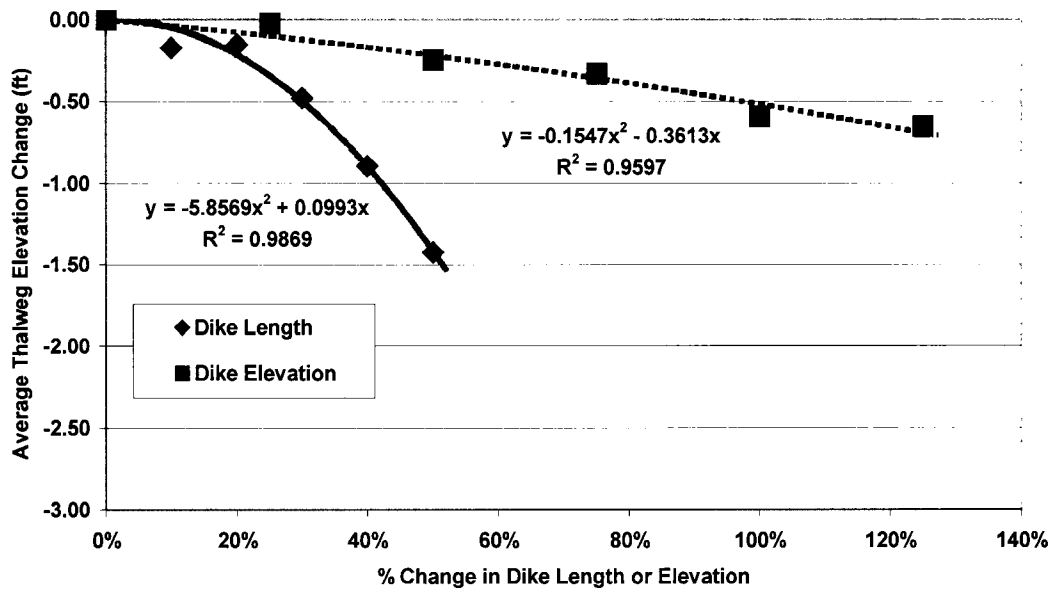
Figure 5.30: Thalweg comparison according to dike elevation change – Baleshed Landing

**Table 5.14: Average thalweg elevation change relative to the base condition according to dike elevation change – Baleshed Landing**

Plan	% Increase Relative to Dike 2 Elevation	Average Thalweg Elevation Change (ft)
Original Elevation	0%	0
Increased by 1 foot	25%	-0.02
Increased by 2 feet	50%	-0.25
Increased by 3 feet	75%	-0.33
Increased by 4 feet	100%	-0.59
Increased by 5 feet	125%	-0.65



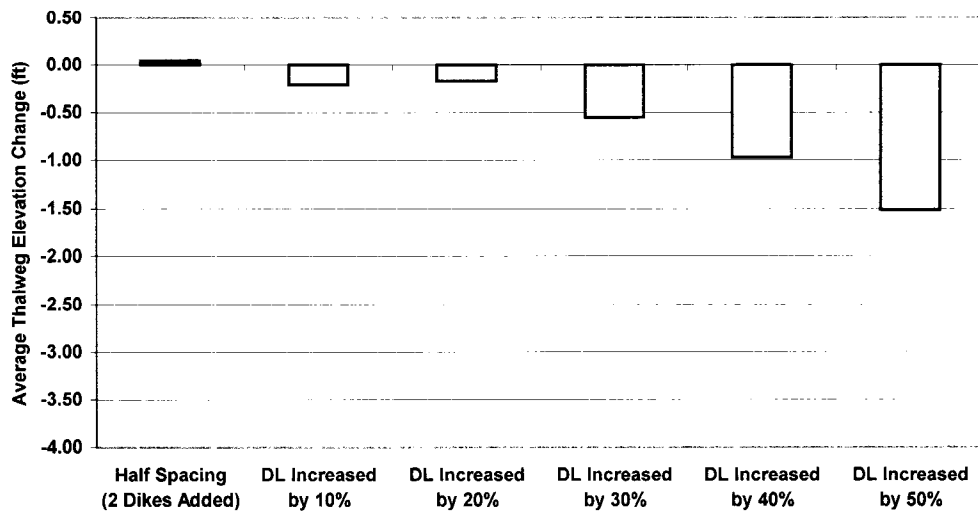
**Figure 5.31: Average thalweg elevation change relative to the base condition according to dike elevation change – Baleshed Landing**



**Figure 5.32: Average thalweg elevation change relative to the base condition according to dike length or elevation change – Baleshed Landing**

a 5-foot elevation. The elevations of the other dikes were not changed, because the elevations of those dikes were smaller than 5 feet. The simulation result showed that the average thalweg elevation increased only by 0.05 foot, which can be considered a relatively small value when compared with a 0.17-foot decrease in thalweg elevation by increasing dike length by 10%.

Next, the effect of dike spacing on thalweg elevation was predicted by adding two dikes; one between Dikes 2 and 3, and the other between Dikes 3 and 4, because it was not necessary to add dikes inside the secondary channel or between Dikes 1 and 2, which were much smaller than the other dikes. As shown in Figure 5.33, thalweg elevation increased by 0.05 foot when decreasing the dike spacing by half, which means that it is not necessary to reduce the dike spacing. To increase the main channel depth, it is thought necessary to increase the elevations of Dikes 1 and 2 much higher than the base



**Figure 5.33: Comparison of average thalweg elevation change of half dike spacing and dike length change – Baleshed Landing**

condition, at which the elevation of Dike 1 is -14 feet and the elevation of Dike 2 is -7 feet.

Finally, the relationships obtained from the two dike fields were compared. In Figures 5.34 and 5.35, the effect of dike length on thalweg elevation and the effect of dike elevation on thalweg elevation were compared, respectively. The regression equations for the relationship between dike length and thalweg elevation are relatively similar to each other (Figure 5.34), whereas those for the relationship between dike elevation and thalweg elevation for two dike fields have an opposite sign for the second-order term (Figure 5.35). This comparison shows that it is better to run the HEC-6 model for each dike field to get the relationships to be used in dike field design rather than to use the relationships obtained from other dike fields.

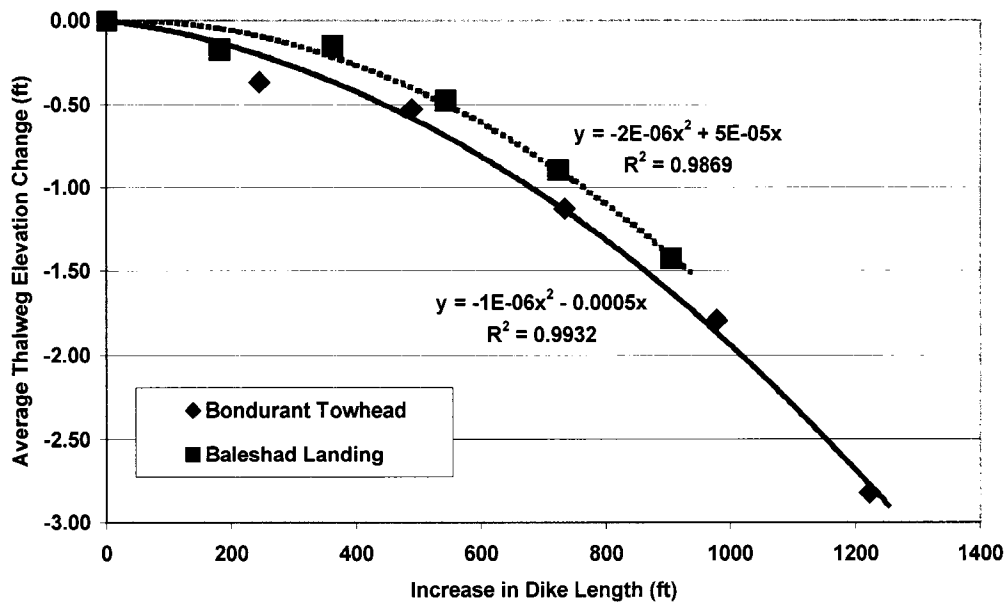


Figure 5.34: Comparison of average thalweg elevation change according to dike length change between Bondurant Towhead and Baleshad Landing

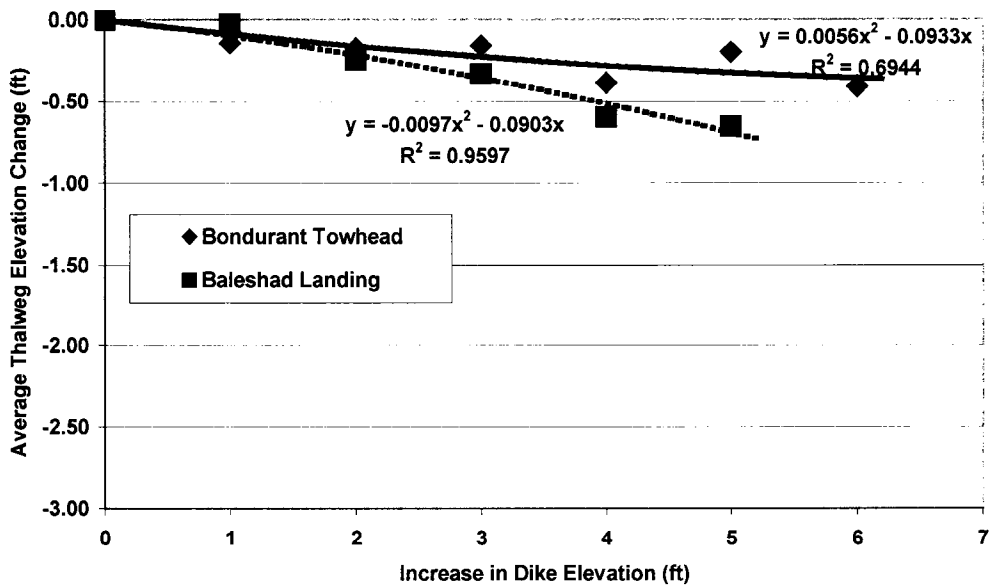


Figure 5.35: Comparison of average thalweg elevation change according to dike elevation change between Bondurant Towhead and Baleshad Landing

## 6 PHABSIM ANALYSIS

### 6.1 INTRODUCTION

Dike fields provide a varied range of depths, substrates, and currents that increase habitat complexity and affect fish distributions and community diversity. The fish communities associated with dikes are diverse and may harbor more species than any other habitat within the main channel (Sandheinrich and Atchison, 1986).

In Chapter 5, statistical analysis was performed to find the relationship between dike parameters (DL, DE, DS, CW, and RC) and dike pool surface area change (CA). However, it is necessary to know how dike pool surface area change is actually related to change in aquatic habitat for fish living in the dike field, in order to accept the dike pool area as a surrogate for measuring aquatic habitat. In this study, the PHABSIM model was used to predict the usable habitat area of each life stage of the representative fish (referred to as *target species*) within the dike field.

Traditionally, PHABSIM, the software package used in the Instream Flow Incremental Methodology (IFIM), has been used to predict the minimum flow requirements to maintain biota in cases where reservoir manipulation or irrigation diversion and abstraction are potential disturbances. IFIM is a series of concepts, techniques, and computer programs used to combine channel morphology, characteristics of flow, and biological preferences of target organisms in order to predict gains or losses

in physical habitat under new or modified flow regimes (Bovee, 1982). Recently, non-traditional applications of IFIM have been used to assess other flow-related concerns in riverine ecosystems. Gore and Hamilton (1996) used PHASIM to evaluate stream enhancement activities on small and large rivers with low head weirs. They concluded that PHASIM can be a useful tool to evaluate the benefit of certain restoration activities, and in the case of weir-like structures, indicated that similar structures impart similar benefit, regardless of scale of application. Shuler and Nehring (1993) also demonstrated that PHASIM can be used to evaluate stream enhancement activities. Gore *et al.* (1998) predicted the habitat value of the riffles for benthic macroinvertebrates using PHASIM. They concluded that PHASIM can be an aid in demonstrating the value of certain restoration structures during rehabilitation planning process.

In this study, the PHASIM model was used to verify whether the dike pool surface area change (CA) can represent the aquatic habitat change for fish living in the dike field. Additionally, the cross-section geometry data calculated from the HEC-6 model were used as input geometry data for the PHASIM model, to test whether the cross-section geometry data from the HEC-6 model can be used to predict change in aquatic habitat for fish.

## **6.2 METHOD**

The final output of PHASIM is the habitat-discharge relationship. The habitat is usually expressed as the Weighted Usable Area (WUA). This relationship is based on the assumption that the amount of physical habitat suitable for use changes with discharge.

This model consists of two basic components: (1) hydraulic simulation models, and (2) habitat simulation models. Hydraulic simulation models calculate changes in

water surface and velocity patterns with discharge. Simulation is carried out by dividing the cross section into vertical cells of smaller areas to more finely describe the distribution of physical habitat. The measured velocity versus discharge relationship for each vertical cell within each cross section is used to determine the distribution of roughness (Manning's  $n$ ) across the channel. Once the flow distribution has been calibrated at all verticals across the cross section for the discharge at which the velocity versus discharge relationship is constructed, the cell velocities are computed for other discharges by weighting the cell velocity based on conveyance (Ghanem *et al.*, 1996). Habitat simulation models combine these relationships with Habitat-Suitability Curves (HSC) to produce habitat-discharge relationships. Therefore, the WUA is calculated as a summation of the individual cells using the following equation (Nestler *et al.*, 1989):

$$WUA = \sum_{i=1} F[f(v_i), g(d_i), h(s_i)] a_i \quad (6.1)$$

where,

$v_i$  = flow velocity in the subsection area  $a_i$ ;

$d_i$  = water depth over the subsection area  $a_i$ ;

$s_i$  = channel index of subsection area  $a_i$ ;

$f(v_i)$  = function that transforms velocity into a measure of value for a life stage of target species;

$g(d_i)$  = function that transforms depth into a measure of value for a life stage of target species;

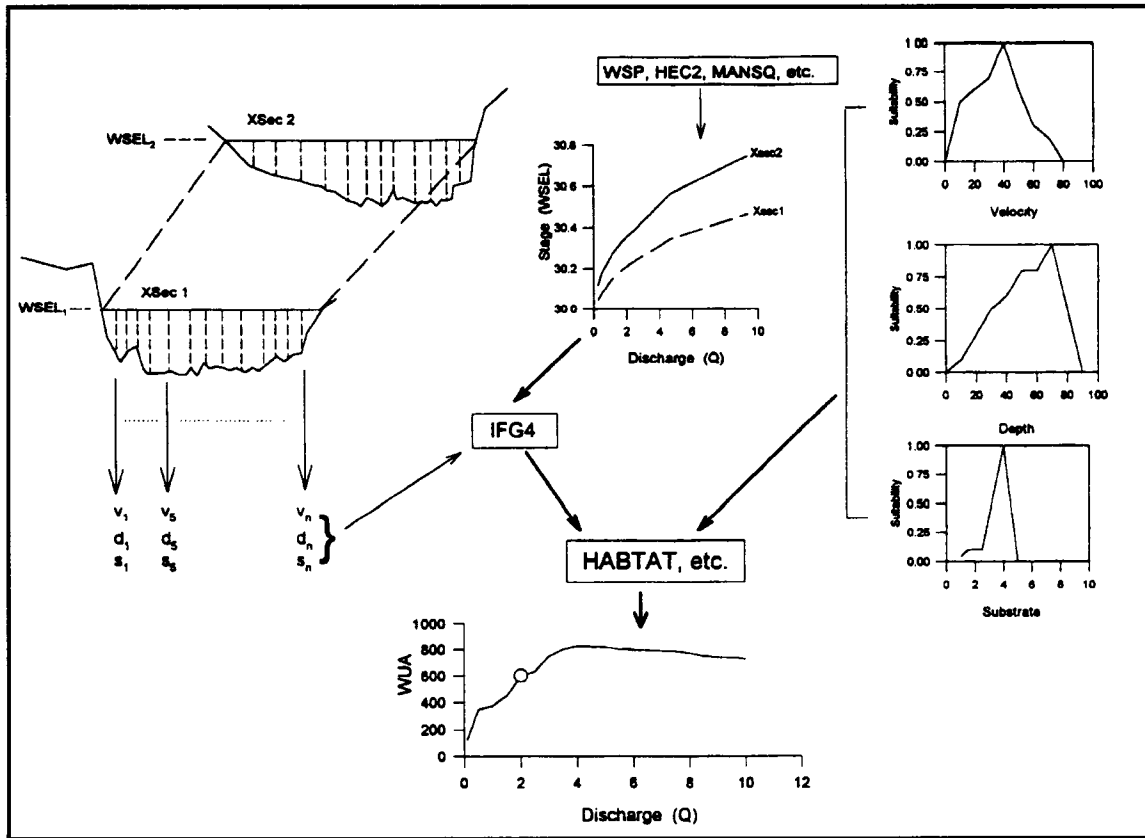
$h(s_i)$  = function that transforms channel index into a measure of value for a life stage of target species; and

$$\begin{aligned}
F[f(v), g(d), h(s)] &= \text{function that combines information on } v, d, \text{ and } s \text{ into a} \\
&\quad \text{single composite value for a life stage of target species.} \\
&= \text{multiplication: } f(v) \times g(d) \times h(s) \\
&= \text{geometric mean: } (f(v) \times g(d) \times h(s))^{0.333} \\
&= \text{minimum: minimum of } f(v), g(d) \text{ or } h(s)
\end{aligned}$$

In Equation (6.1), preference factors ( $f(v)$ ,  $g(d)$ , and  $h(s)$ ) are obtained from each of the HSC, which are the relationships between depth, velocity, and channel index (cover, substrate, or a combination of cover and substrate) and the corresponding suitability values that vary from 0.0 to 1.0. Sometimes the lack of well-defined HSC limits the use of this model. Some researchers also insist that these curves may not be transferable from one stream to another and site-specific curves are preferable (Vismara *et al.*, 2001). However, the problem is that the development of these HSC is costly (Gordon *et al.* 1995).

The general procedures in PHABSIM are as follows (Figure 6.1):

- Survey every cross section to get the velocity, depth, and channel index for each vertical cell;
- Calculate the stage-discharge relationship using several models within PHABSIM, or using HEC-2 or HEC-RAS;
- Calculate the cell-by-cell velocities over a range of discharges, using this calculated stage-discharge relationship; and
- Calculate the WUA by combining the depth, velocity, and channel index with selected HSC.



**Figure 6.1: Diagrammatic representation of the PHABSIM evaluation (Gore and Hamilton, 1996)**

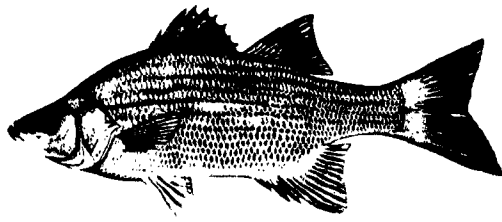
The Bondurant Towhead and Baleshed Landing dike fields, which were selected for the HEC-6 analysis, were also selected for the PHABSIM analysis. Because the calibration data measured for vertical cells across the cross section were not available for these two dike fields, the velocity at each vertical cell was calculated using the flow depth of each cross section, and channel index was assumed to be same for all cross sections; i.e., sand bed was assumed for all cross sections of both dike fields.

### 6.3 SELECTION OF TARGET SPECIES

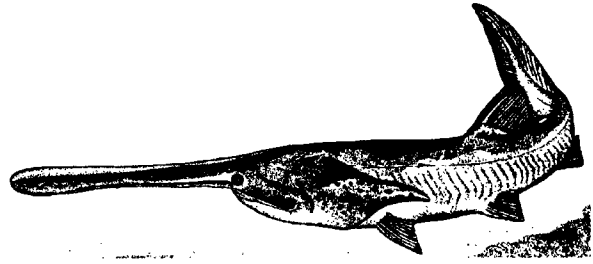
As mentioned above, the lack of well-defined HSC limits the use of this model. For this reason, only two criteria were considered for the selection of the target species: (1) species living in the Mississippi River and (2) availability of HSC.

In the Mississippi River, carp, gizzard shad, small mouth buffalo, white bass, and channel catfish comprise 75.6 percent of the catch in pooled areas of the upper river (Environmental Science and Engineering, Inc., 1983). Pennington *et al.* (1980) found ten species unique to dike fields in the Lower Mississippi River: stoneroller, steelcolor shiner, express minnow, pugnose minnow, spotfin shiner, creek chub, black buffalo, black stripe topminnow, longear sunfish, and spotted bass. At low river stages, dike pools bordered by middle bars are formed in the Lower Mississippi River, where three generalized fish communities are present: the lentic community consisting of pooled habitats, includes shortnose gar, American eel, skipjack herring, common carp, gizzard shad, paddlefish, striped bass, sunfishes, sauger, and tripped mullet; the shallow water community on either side of the sandbar includes cyprinids, clupeids, and atherinids; and the lotic community includes flathead catfish, blue catfish, and blue sucker (Nailon and Pennington, 1984).

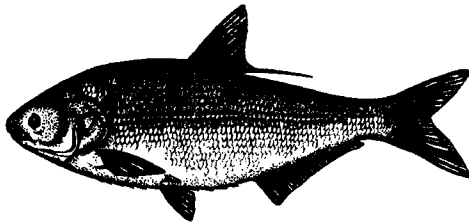
Among the species listed above, HSC were available for five species: white bass, paddlefish, gizzard shad, spotted bass, and striped bass, which were selected as the target species. The white bass (*Morone chrysops*) (Figure 6.2 (a)) is an excellent game fish in large reservoirs and has been introduced from coast to coast (Hamilton and Nelson, 1984). HSC of the white bass exist for fry and juvenile stages. The paddlefish (*Polyodon spathula*) (Figure 6.2 (b)) supported a large commercial fishery in the Mississippi River



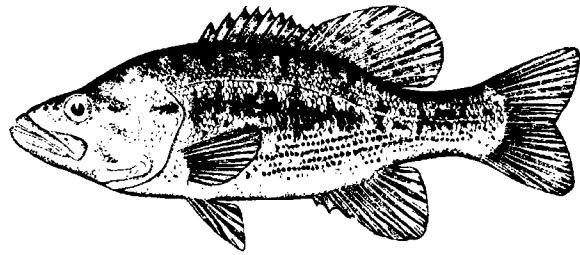
**(a) white bass**



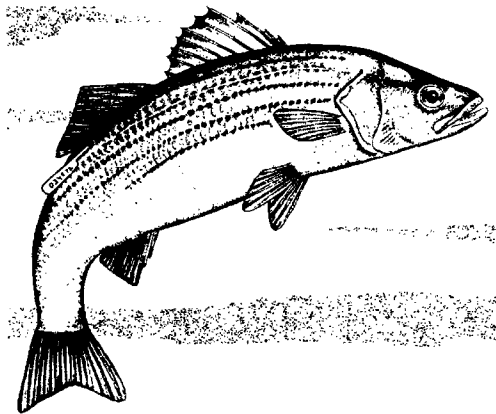
**(b) paddlefish**



**(c) gizzard shad**



**(d) spotted bass**



**(e) striped bass**

**Figure 6.2: Target species – (a) Hamilton and Nelson, 1984; (b) Hubert *et al.*, 1984; (c) Williamson and Nelson, 1985; (d) McMahon *et al.*, 1984; (e) Crance, 1984**

basin in the early 1900s (Carlson and Bonislavsky, 1981). The paddlefish is primarily a large river species and travels extensively throughout a variety of riverine habitats (Hubert *et al.*, 1984). HSC of the paddlefish exist only for adult stage. The gizzard shad (*Dorosoma cepedianum*) (Figure 6.2 (c)) is an open-water species, living at or near the surface (Becker, 1983). The gizzard shad have no life stages that are obligate riverine. If the major objective of the PHABSIM analysis is to protect the indigenous biota in a given area, the gizzard shad may not be the best candidate for a target species. However, the gizzard shad is important as forage in many areas and investigators may want to predict impacts on forage species resulting from alteration of the flow regime (Williamson and Nelson, 1985). HSC of the gizzard shad exist for spawning, egg incubation, fry, juvenile, and adult stages. The spotted bass (*Micropterus punctulatus*) (Figure 6.2 (d)) is primarily a stream species and generally fares poorly in reservoirs except those having deep, clear, relatively infertile water and steep, rocky shorelines (McMahon *et al.*, 1984). HSC of the spotted bass exist for spawning, egg incubation, fry, juvenile, and adult stages. However, HSC for spawning and egg incubation stages were not used, because the suitability index of those stages is zero for the sand, which is the substrate for all cross sections of both dike fields. The striped bass (*Morone saxatilis Walbaum*) is tolerant of a variety of environmental conditions. It is found in marine, estuarine, and lacustrine habitats, depending on individual stocks, life stage, environmental variables, transplantations, and access to suitable spawning areas (Crance, 1984). HSC of the spotted bass exist for spawning, egg incubation, and larval stages.

## 6.4 RESULTS

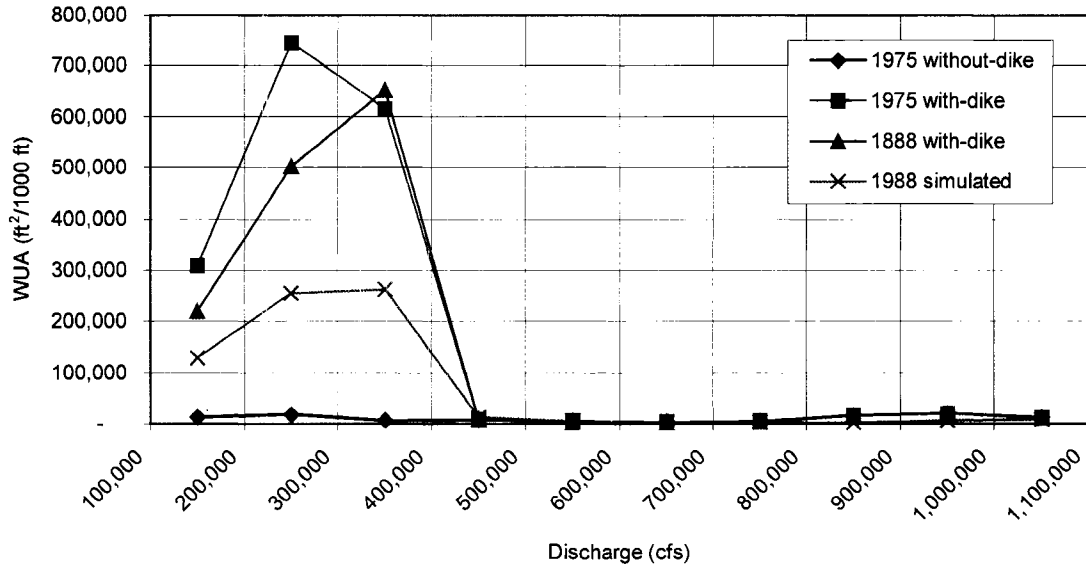
### 6.4.1 BONDURANT TOWHEAD DIKE FIELD

As explained in the HEC-6 analysis of Section 5.4, the Bondurant Towhead dike field has hydrographic survey data for three years (1964, 1975 and 1988). Therefore, the PHABSIM model with two dikes (Dikes 1 and 2), which were constructed in 1975, was run for each of the following four cross-section geometric conditions: 1) measured in 1975 and without dikes (referred to as *1975 without-dike condition*); 2) measured in 1975 and with dikes (referred to as *1975 with-dike condition*); 3) measured in 1988 and with dikes (referred to as *1988 with-dike condition*); and 4) simulated from the HEC-6 model and with dikes (referred to as *1988 simulated condition*).

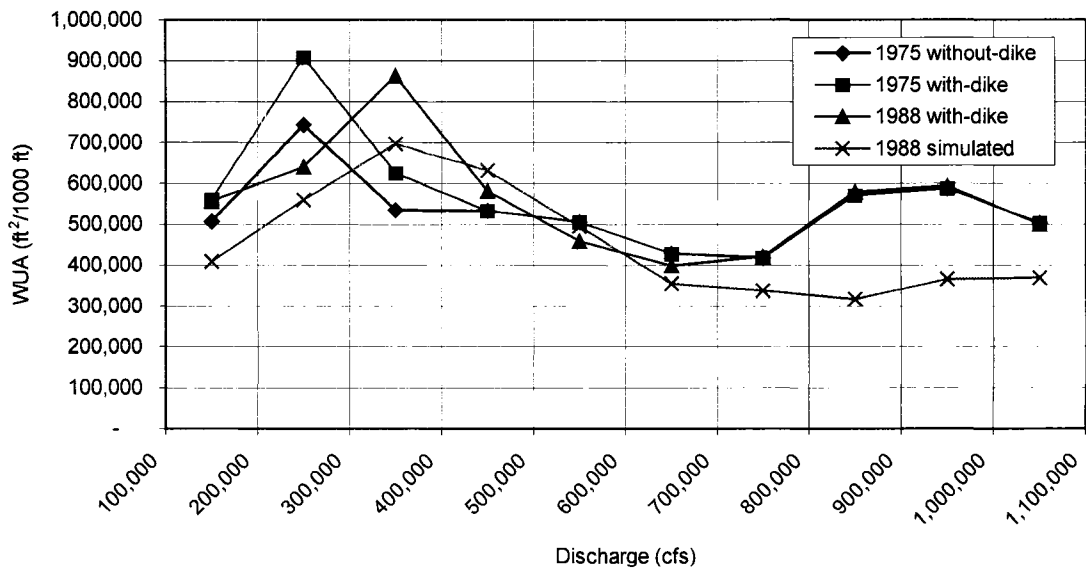
The PHABSIM model was run for the section between RM 392.8 and 395, which includes all the cross sections affected by the dike field. The stage of each discharge was calculated using the HEC-RAS model. The expansion and contraction ratios determined in the HEC-6 analysis were also used in the HEC-RAS and PHABSIM models to consider the effect of ineffective flow area; expansion ratio of 3:1, and contraction ratio of 1:1. In the PHABSIM model, ineffective flow area was represented by setting Manning's  $n$  of ineffective area of each cross section as high as 1,000, which made the velocity of ineffective flow area zero. For the discharges overtopping the dikes, the cross-section data without ineffective area were used. The model was run for the discharges ranging from 150,000 cfs to 1,050,000 cfs with 100,000 cfs interval, where 1,050,000 cfs was the approximate bankfull discharge of this dike field.

As shown in Figure 6.3, the WUA of all life stages of all species with the exception of striped bass increased right after construction of the dikes (1975 with-dike

### White Bass-Fry

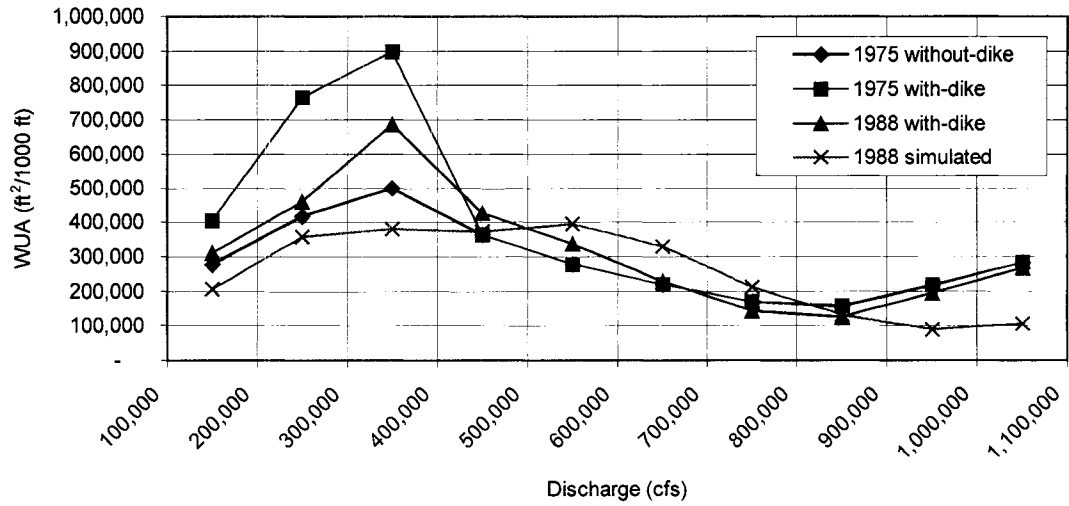


### White Bass-Juvenile



**Figure 6.3: Comparison of WUAs – Bondurant Towhead**

### Paddle Fish-Adult



### Gizzard Shad-Spawning & Egg Incubation

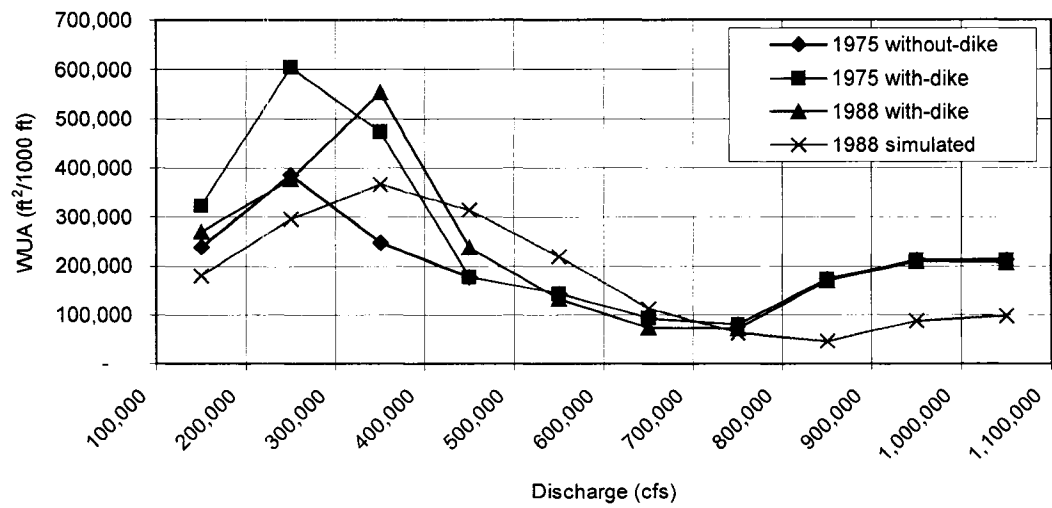
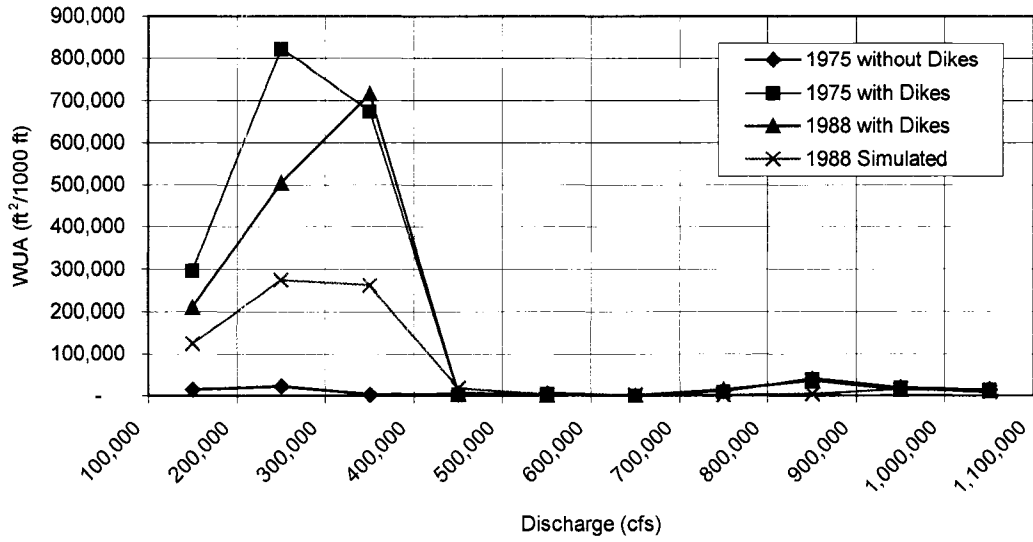


Figure 6.3 (Cont.)

### Gizzard Shad-Fry



### Gizzard Shad-Juvenile & Adult

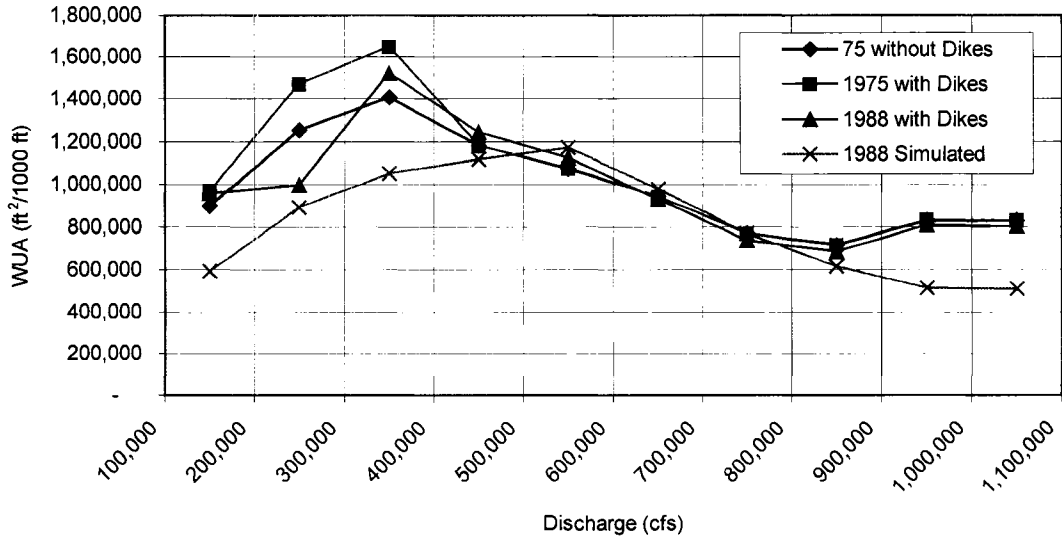
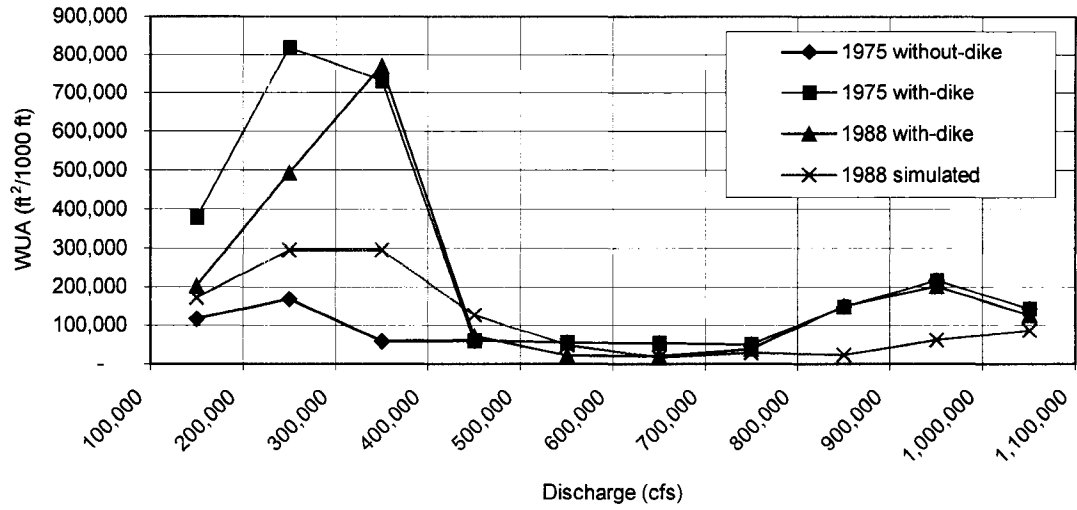


Figure 6.3 (Cont.)

### Spotted Bass-Fry



### Spotted Bass-Juvenile

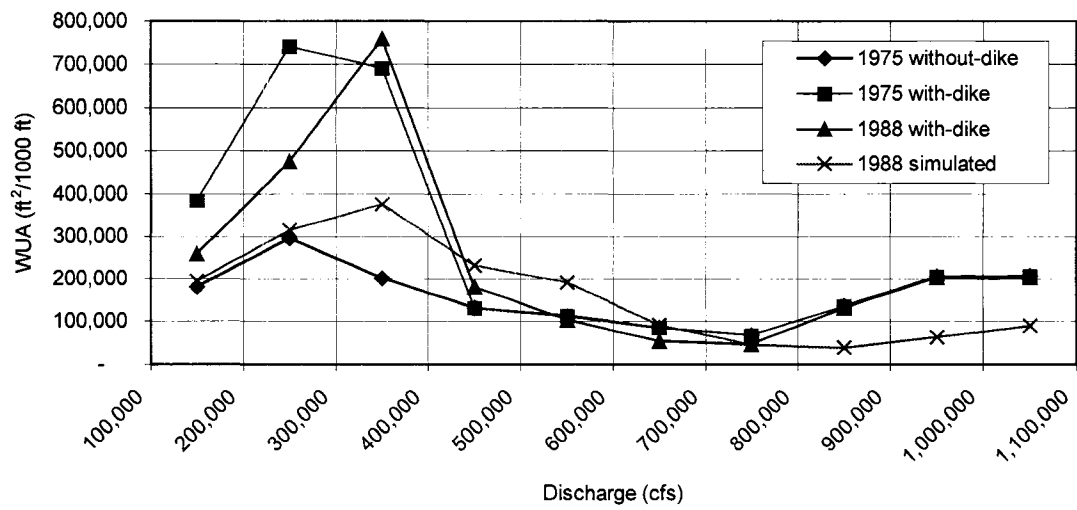
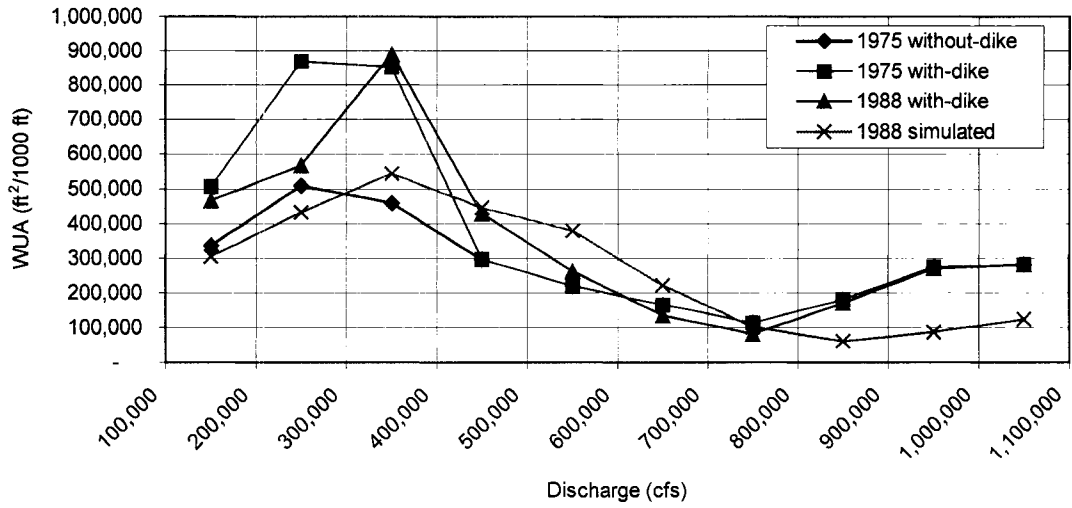


Figure 6.3 (Cont.)

### Spotted Bass-Adult



### Striped Bass-Spawning, Egg Incubation & Larval

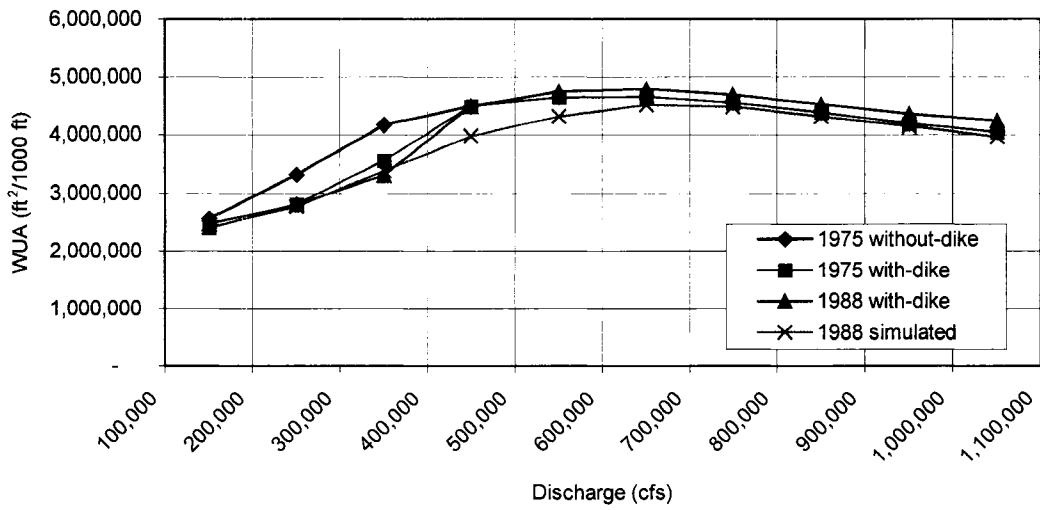
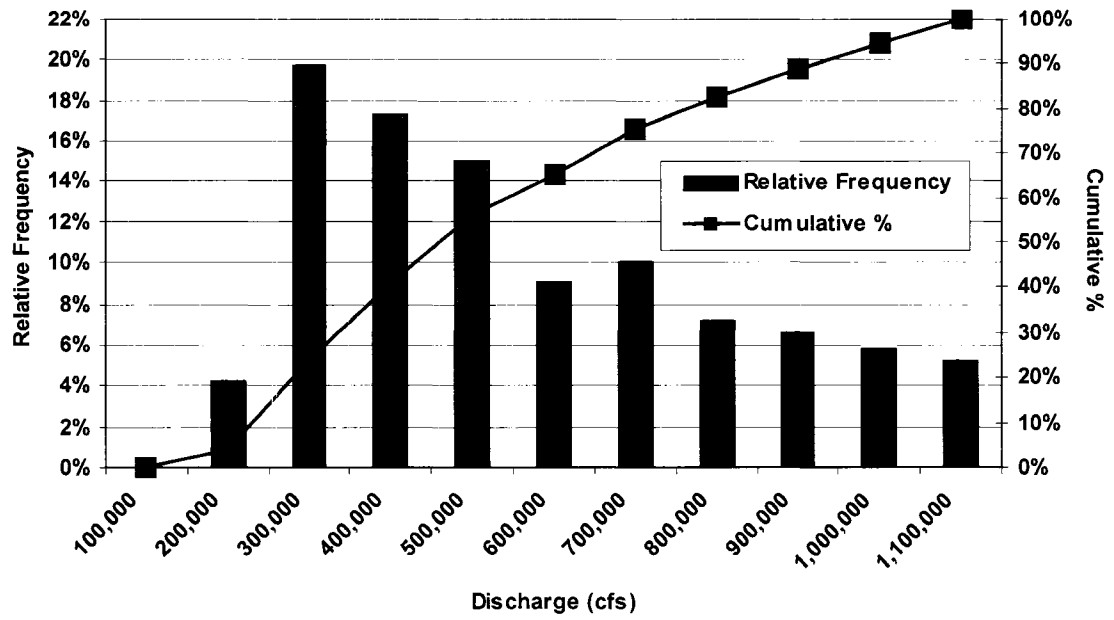


Figure 6.3 (Cont.)

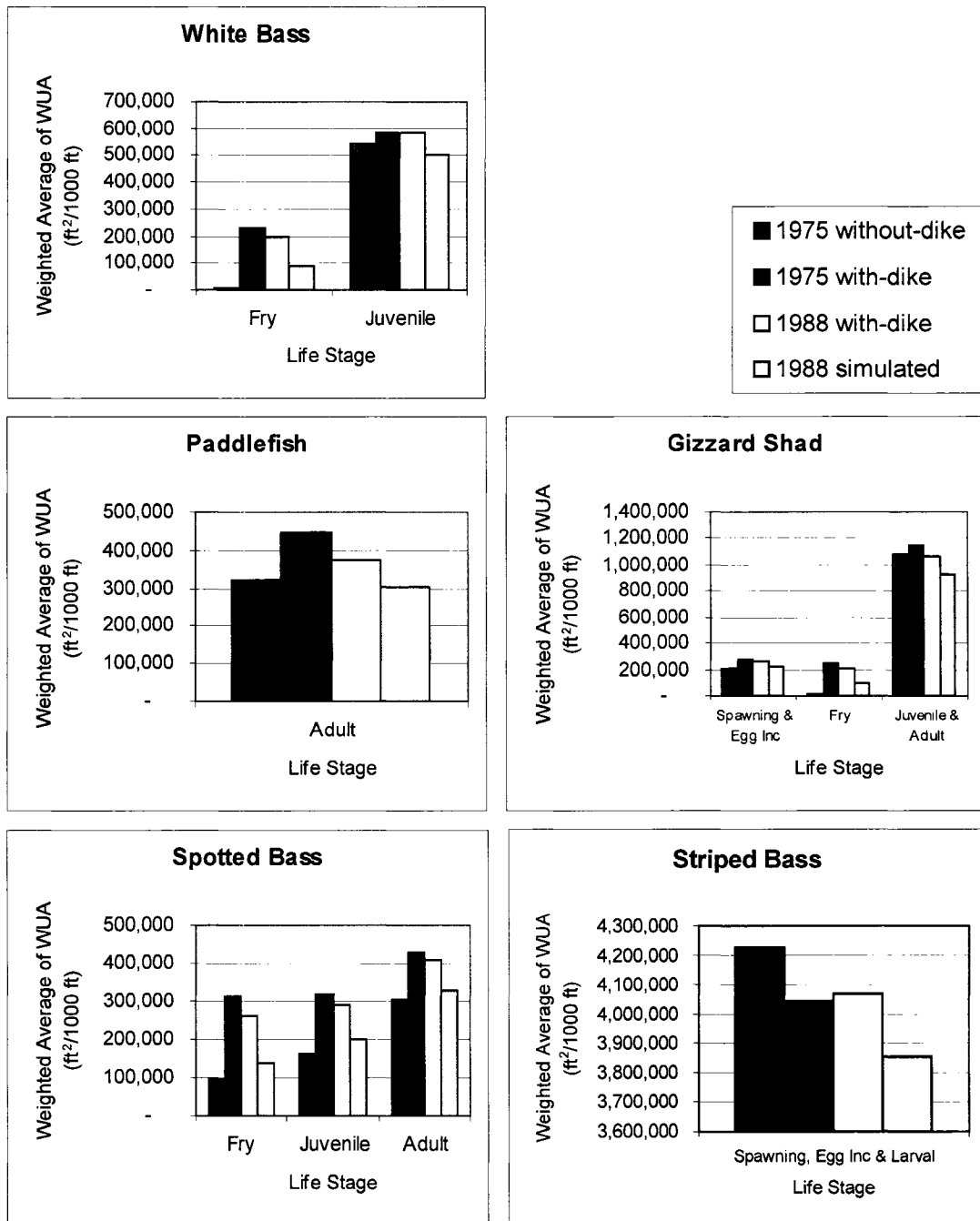
condition). Most of the increase in WUA occurred for discharges below 450,000 cfs, which is the boundary discharge at which all dikes are overtopped and, therefore, the dike pool areas are treated like the main channel. For most discharges, the WUA of all life stages of all species decreased in the 13 years after dike construction (1988 with-dike condition), and most of the decrease also occurred for discharges below 450,000 cfs. However, for some cases, the WUA of 1988 with-dike condition was larger than the WUA of 1975 with-dike condition even for discharges below 450,000 cfs. Figure 6.3 shows that, for most discharges, the WUA of all life stages of all species of the 1988 simulated condition was smaller than that of the 1988 with-dike condition.

As explained above, the overall trend in WUA change between four cross-section geometric conditions may be found using the WUA versus discharge relationship. However, if it is possible to represent change in WUA for the whole range of discharges by a single value, it will be a very useful tool, not only for the comparison of WUA between species with different life stages, but also for the comparison of change in WUA with percent change in dike pool surface area. For this purpose, the average of WUA weighted by the relative frequency of discharge (referred as to *weighted average of WUA*) was introduced. The same discharge data used in the HEC-6 analysis (measured at Vicksburg) were used for the histogram of discharge. Figure 6.4 shows the relative frequency of each discharge smaller than 1,100,000 cfs.

Figure 6.5 shows the comparison of the weighted average of WUA between four cross-section geometric conditions. The weighted average of WUA increased right after construction of the dikes (1975 with-dike condition) for all life stages of all species with the exception of striped bass, which showed a decrease in all life stages. However, the



**Figure 6.4: Histogram of discharge – Bondurant Towhead**



**Figure 6.5: Comparison of weighted average of WUA – Bondurant Towhead**

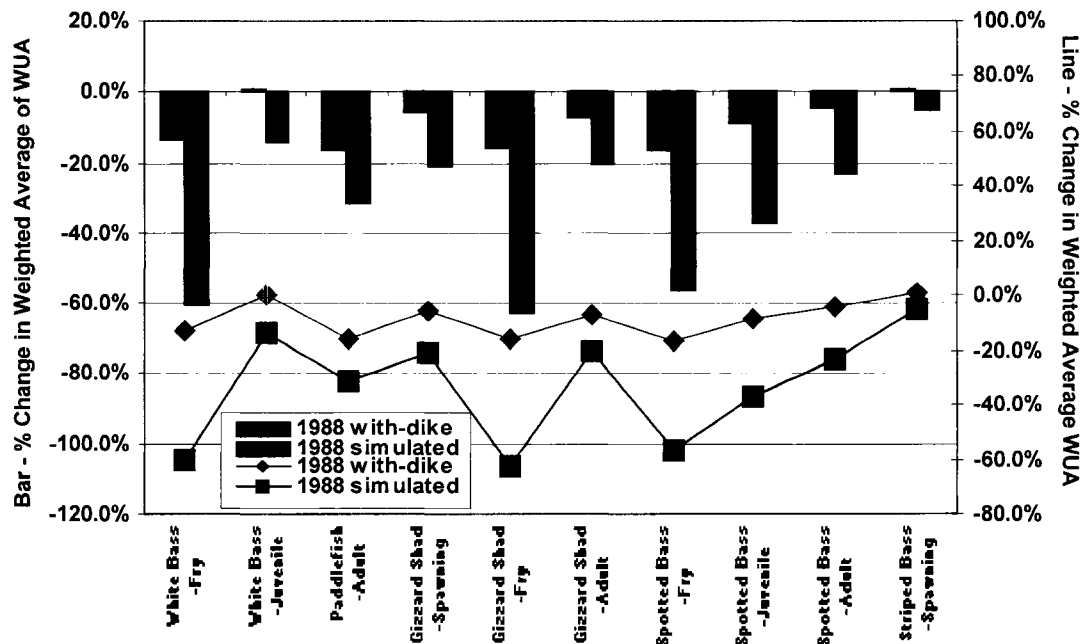
amount of increase in weighted average of WUA of each life of each species was much different from each other, ranging from 7.1% up to more than 2,000% (Table 6.1). The weighted average of WUA decreased in the 13 years after dike construction (1988 with-dike condition) for all life stages of all species with the exception of juvenile stage of white bass and all stages of striped bass. The amount of decrease ranged from -4.2% to -16.5% (Table 6.1). The weighted average of WUA of all life stages of all species of the 1988 simulated condition was smaller than that of the 1988 with-dike condition, which means that using the cross-section geometry data simulated from the HEC-6 model underestimates the WUA or, in other words, overestimates the decrease in WUA in the 13 years after dike construction. However, as shown in Figure 6.6, both conditions showed similar relative change in weighted average of WUA between species with different life stages. Therefore, it can be concluded that the PHABSIM results using the cross-section geometry data simulated from the HEC-6 model tend to underestimate the WUA for most species, but can be used in place of the measured data in case where it is necessary to predict the relative change in WUA between species with different life stages.

As shown in Table 6.1, the average value of percent change in weighted average of WUA of the 1988 with-dike condition was -8.3%, whereas that of the 1988 simulated condition was -29.4%. In the meanwhile, according to measured data (ERDC data set), the percent change in total pool surface area within the dike field of 1989 relative to 1975 ranged from -39.7% measured at 0 foot LWRP to -8.0% measured at 15 feet LWRP (Table 6.2). This comparison shows that the percent change in weighted average of WUA (-8.3%) matches well with the percent change in total pool surface area measured

**Table 6.1: Percent change in weighted average of WUA relative to previous cross-section geometric condition – Bondurant Towhead**

Species	Life Stage	% Change in Weighted Average of WUA Relative to Previous Geometric Condition			
		1975 Without -dike	1975 With -dike	1988 With -dike	1988 Simulated
White Bass	Fry	-	2212.1%	-13.3%	-60.5%
	Juvenile	-	7.5%	0.5%	-14.0%
Paddlefish	Adult	-	38.6%	-16.2%	-31.5%
Gizzard Shad	Spawning & Egg Incubation	-	36.3%	-5.6%	-20.9%
	Fry	-	2034.2%	-15.9%	-62.6%
	Juvenile & Adult	-	7.1%	-7.3%	-20.1%
Spotted Bass	Fry	-	230.9%	-16.5%	-56.3%
	Juvenile	-	95.0%	-8.8%	-37.3%
	Adult	-	41.0%	-4.2%	-23.3%
Striped Bass	Spawning, Egg Incubation & Larval	-	-4.4%	0.7%	-4.7%
Average*				-8.3%	-29.4%

\*Average was calculated from the averages of each species.



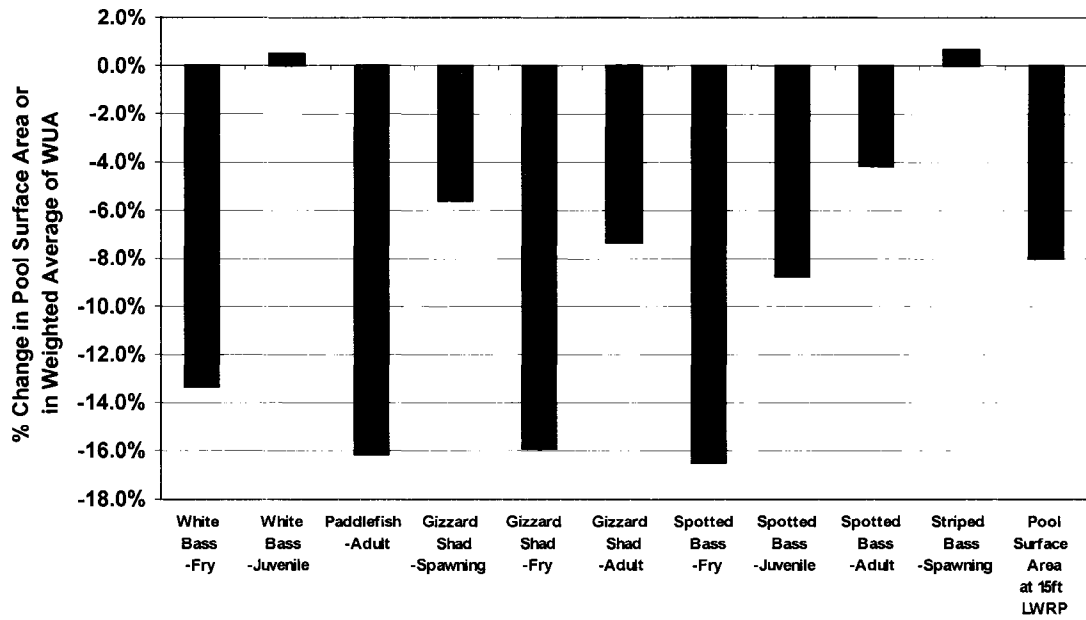
**Figure 6.6: Comparison of percent change in weighted average of WUA between the 1988 with-dike and 1988 simulated conditions – Bondurant Towhead**

**Table 6.2: Percent change in total pool surface area and volume of 1989 relative to 1975 – Bondurant Towhead**

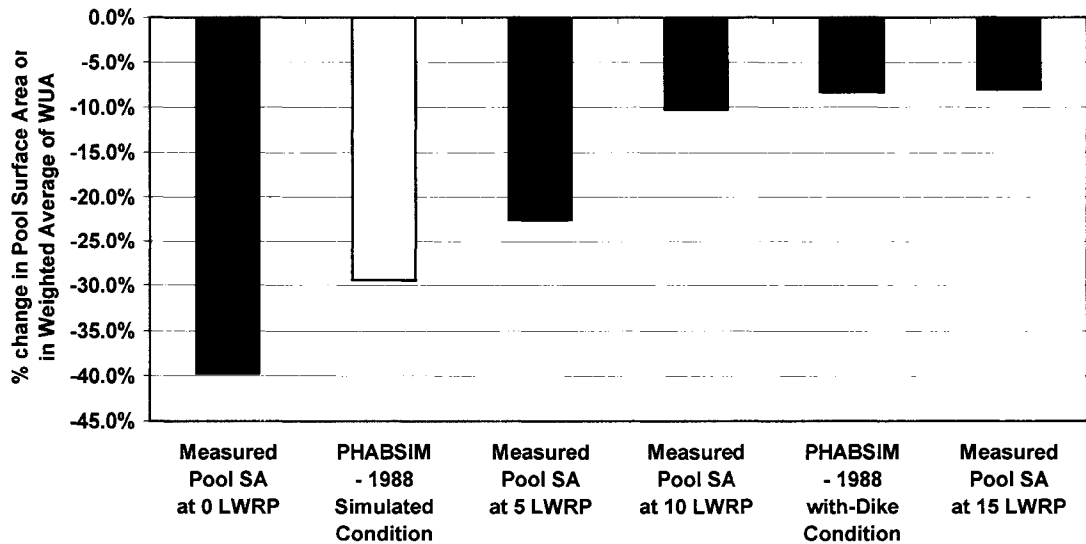
Stage	% Change in Pool Surface Area & Volume of 1989 Relative to 1975			
	0 foot LWRP	5 feet LWRP	10 feet LWRP	15 feet LWRP
<b>Total Surface Area</b>	-39.7%	-22.6%	-10.1%	-8.0%
<b>Total Volume</b>	-63.8%	-54.1%	-43.2%	-35.1%

at 15 feet LWRP (-8.0%) during the similar period. As mentioned in the statistical analysis of Section 5.3, the statistical analysis was performed using the percent change in pool surface area measured at 15 feet LWRP, because it was most highly correlated with other parameters. Therefore, based on this comparison, it can be concluded that the dike pool surface area change can represent the aquatic habitat change for fish living in the dike field. However, as shown on Figure 6.7, the percent change in WUA of each life stage of each species is much different from the percent change in pool surface area measured at 15 feet LWRP. It suggests that the PHABSIM model needs to be used to evaluate the effect of the dike field on the aquatic habitat of each life stage of each species selected as target species, even though the percent change in pool surface area can be used instead of the percent change in weighted average of WUA in terms of average value.

Figure 6.8 represents the comparison of percent change in pool surface area at various stages with the percent change in weighted average of WUA of the 1988 with-dike and 1988 simulated conditions. It shows that the percent change in weighted average of WUA using the cross-section geometry data simulated from the HEC-6 model is between the percent change in pool surface area measured at 0 foot LWRP and at 5 feet LWRP. Therefore, it can be said that the cross-section geometry data calculated from the HEC-6 model can be used as input geometry data for PHABSIM, to predict change in aquatic habitat for fish, although there is a tendency to underestimate the WUA.



**Figure 6.7: Comparison of percent change in pool surface area at different stages and percent change in weighted average of WUA of different species with different life stage – Bondurant Towhead**



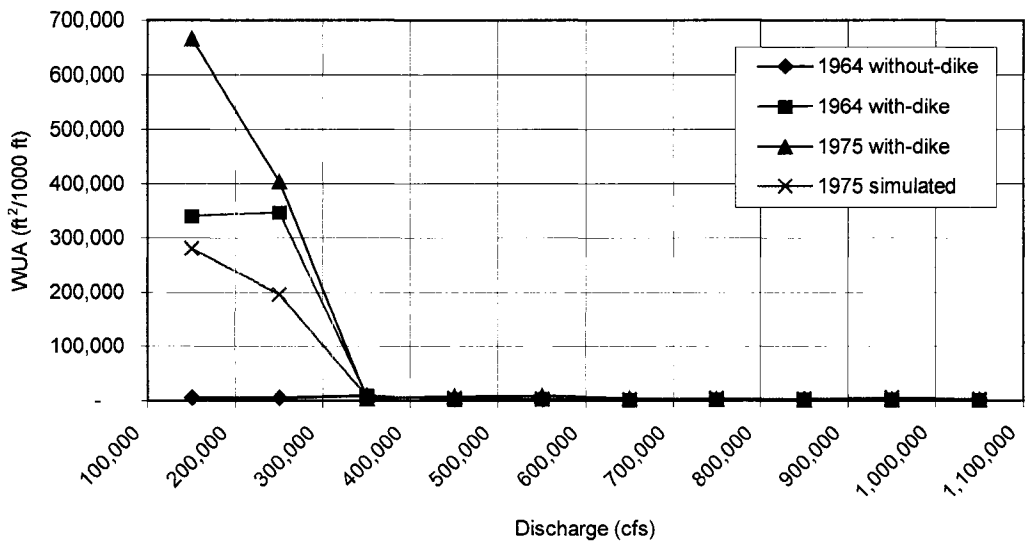
**Figure 6.8: Comparison of percent change in pool surface area at different stages and percent change in weighted average of WUA of different conditions – Bondurant Towhead**

#### **6.4.2 BALESLED LANDING DIKE FIELD**

For the Balesled Landing dike field, the PHABSIM model with five dikes (Dike 1 through 5) which were constructed in 1965, was run for each of the following four cross-section geometric conditions: 1) measured in 1964 and without dikes (referred to as *1964 without-dike condition*); 2) measured in 1964 and with dikes (referred to as *1964 with-dike condition*); 3) measured in 1975 and with dikes (referred to as *1975 with-dike condition*); and 4) simulated from the HEC-6 model and with dikes (referred to as *1975 simulated condition*).

The PHABSIM model was run for the section between RM 490.8 and 494.4, which includes all the cross sections affected by the dike field. For input data, the same procedure used in the Bondurant Towhead dike field was used. As shown in Figure 6.9, the WUA of all life stages of all species with the exception of striped bass increased right after construction of the dikes (1964 with-dike condition). Most of the increase in WUA occurred for discharges below 350,000 cfs, which is the boundary discharge at which all dikes are overtopped and, therefore, the dike pool areas are treated like the main channel. For most discharges, the WUA of all life stages of all species increased in the 11 years after dike construction (1975 with-dike condition). Most of the increase in WUA also occurred for discharges below 350,000 cfs, but in some cases, the decrease in WUA occurred. Figure 6.9 shows that, for most discharges, the WUA of all life stages of all species of the 1975 simulated condition was smaller than that of 1988 with-dike condition.

### White Bass-Fry



### White Bass-Juvenile

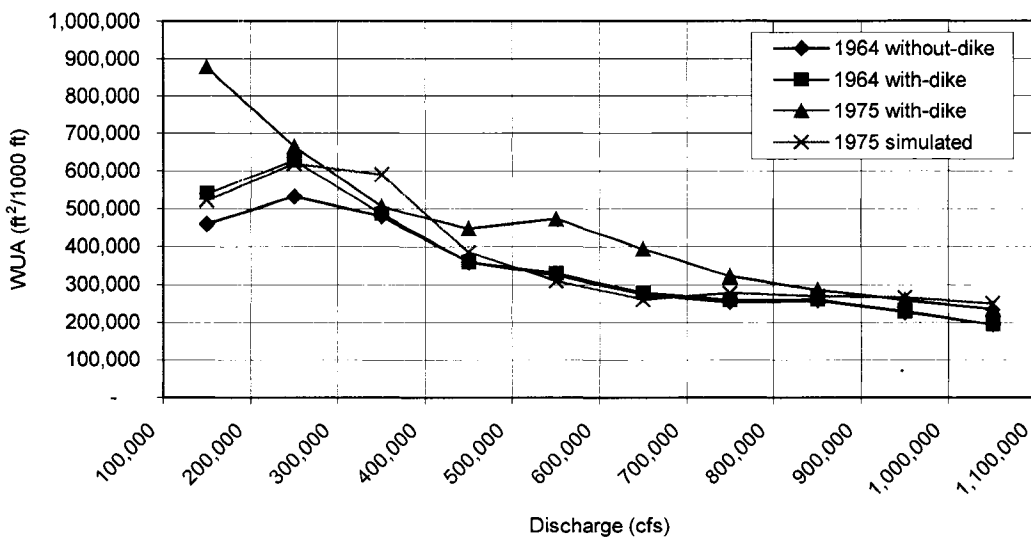
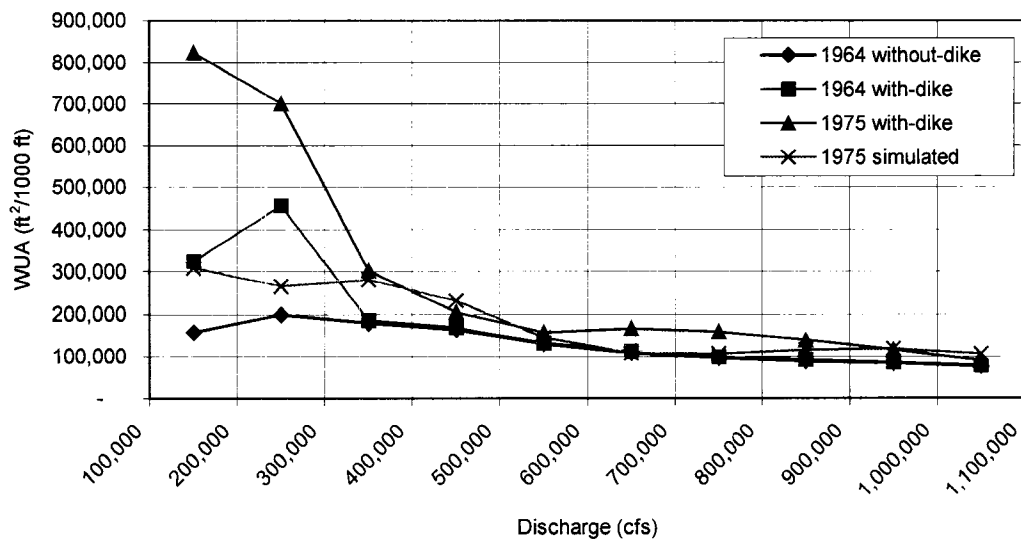


Figure 6.9: Comparison of WUAs – Baleshed Landing

### Paddle Fish-Adult



### Gizzard Shad-Spawning & Egg Incubation

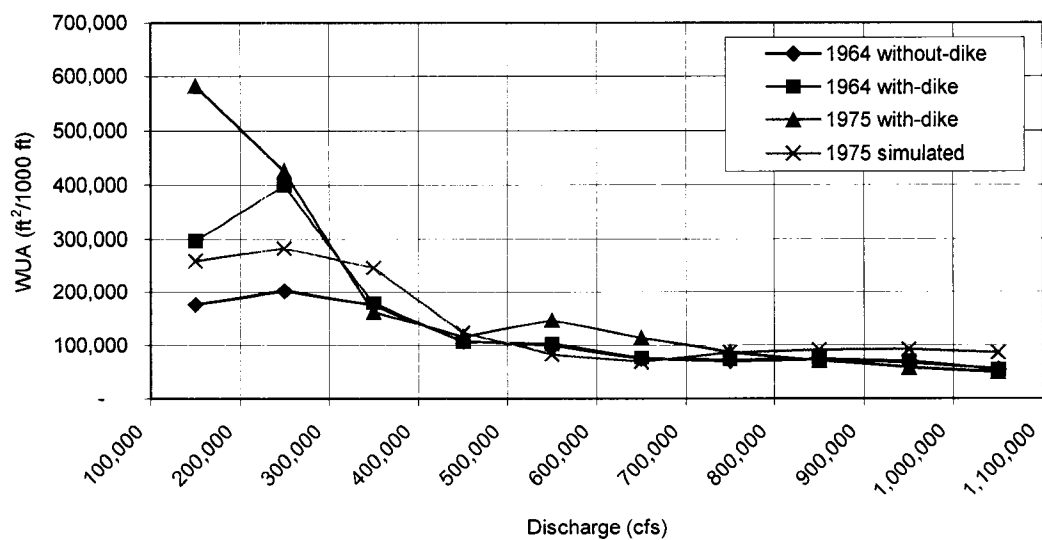
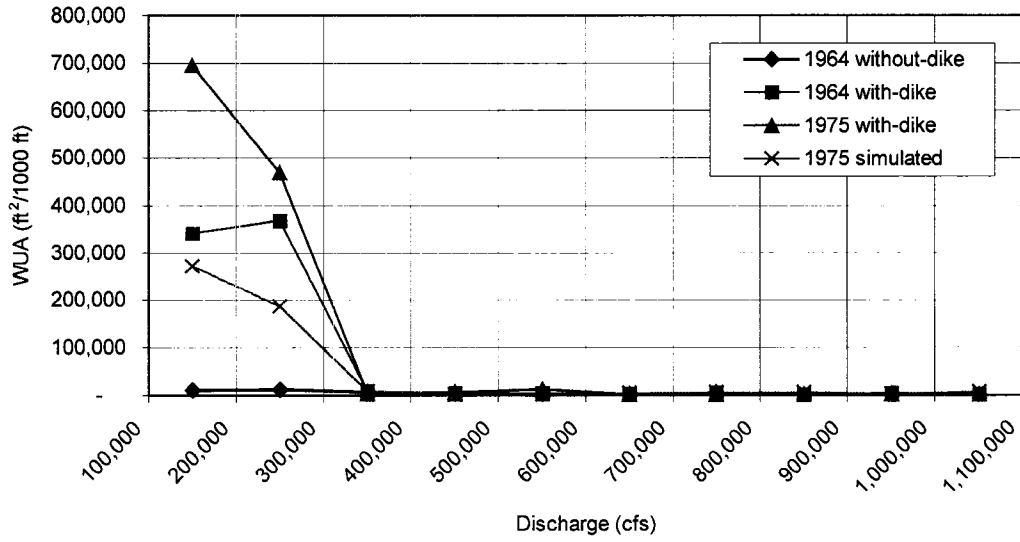


Figure 6.9 (Cont.)

### Gizzard Shad-Fry



### Gizzard Shad-Juvenile & Adult

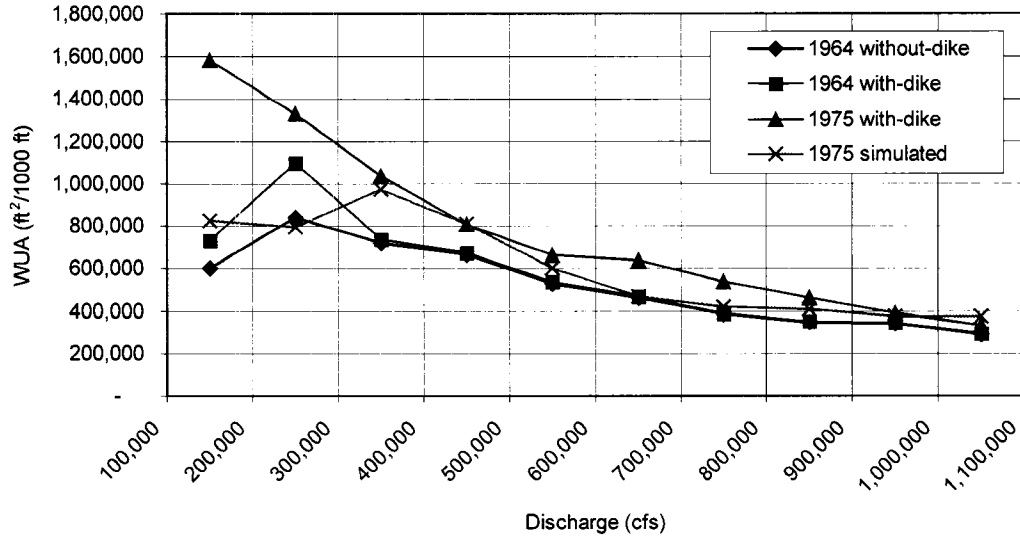
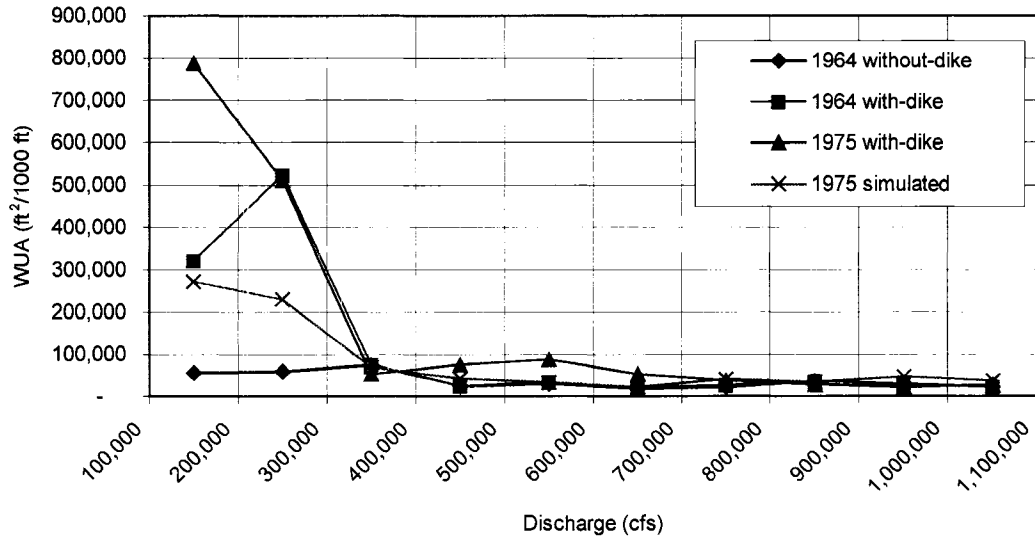


Figure 6.9 (Cont.)

### Spotted Bass-Fry



### Spotted Bass-Juvenile

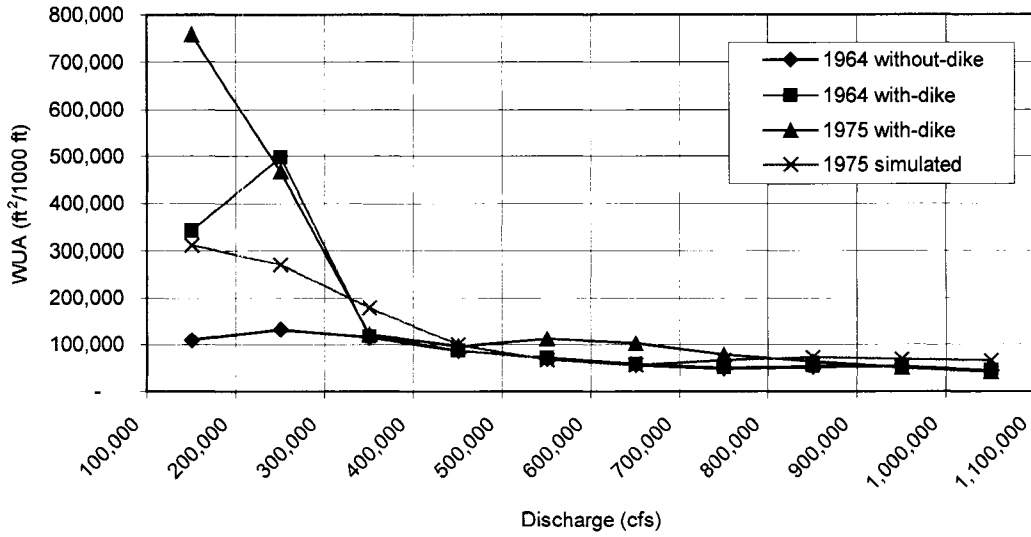
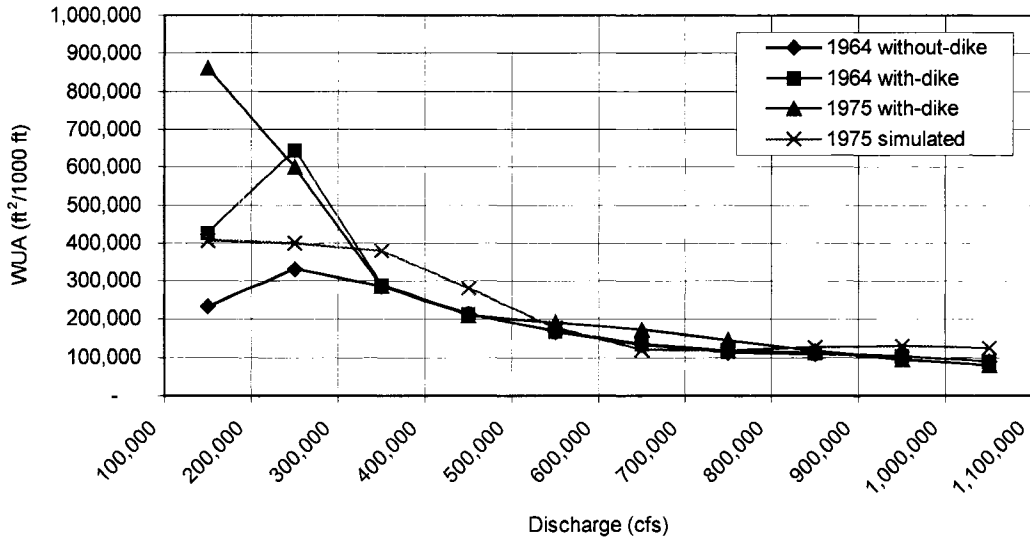


Figure 6.9 (Cont.)

### Spotted Bass-Adult



### Striped Bass-Spawning, Egg Incubation & Larval

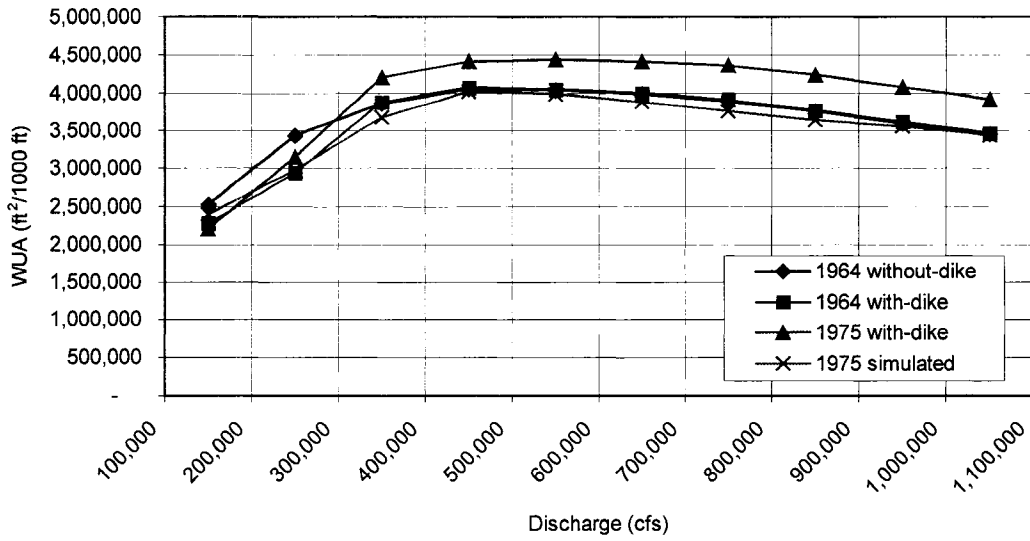


Figure 6.9 (Cont.)

For the same reason explained in Section 6.4.1, the weighted average of WUA was calculated for the comparison between different cross-section geometric conditions. The discharge data measured at Arkansas City were used for the histogram of discharge. Figure 6.10 shows the relative frequency of each discharge smaller than 1,100,000 cfs.

Figure 6.11 shows the comparison of the weighted average of WUA between four cross-section geometric conditions. The weighted average of WUA increased right after construction of the dikes (1975 with-dike condition) for all life stages of all species with the exception of striped bass, which showed a decrease in all life stages. However, the amount of increase in weighted average of WUA of each life of each species was much different from each other, ranging from 6.7% up to 1,786% (Table 6.3). The weighted average of WUA increased in the 11 years after dike construction (1975 with-dike condition) for all life stages of all species. The amount of increase ranged from 5.5% to 54.5% (Table 6.3). The weighted average of WUA of all life stages of all species of the 1975 simulated condition was much smaller than that of the 1975 with-dike condition, which means that using the cross-section geometry data simulated from the HEC-6 model underestimates the WUA in the 11 years after dike construction. This appears to result from periodic dredging of the Baleshed Landing dike field after construction, according to Franco's (1982) record during the period of 1968 to 1975, as mentioned in the HEC-6 analysis of Section 5.4. Therefore, as shown in Figure 6.12, the 1975 with-dike and 1975 simulated conditions showed different relative change in weighted average of WUA between species with different life stages, unlike the Bondurant Towhead dike field.

As shown in Table 6.3, the average value of percent change in weighted average of WUA of the 1975 with-dike condition was 25.8%, whereas that of the 1975 simulated

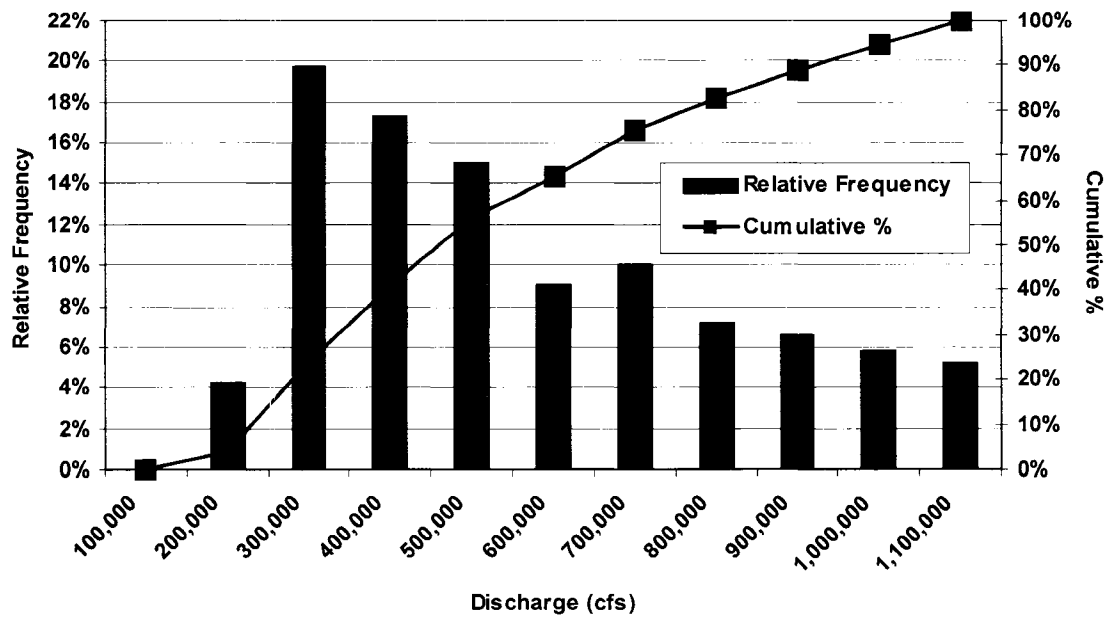
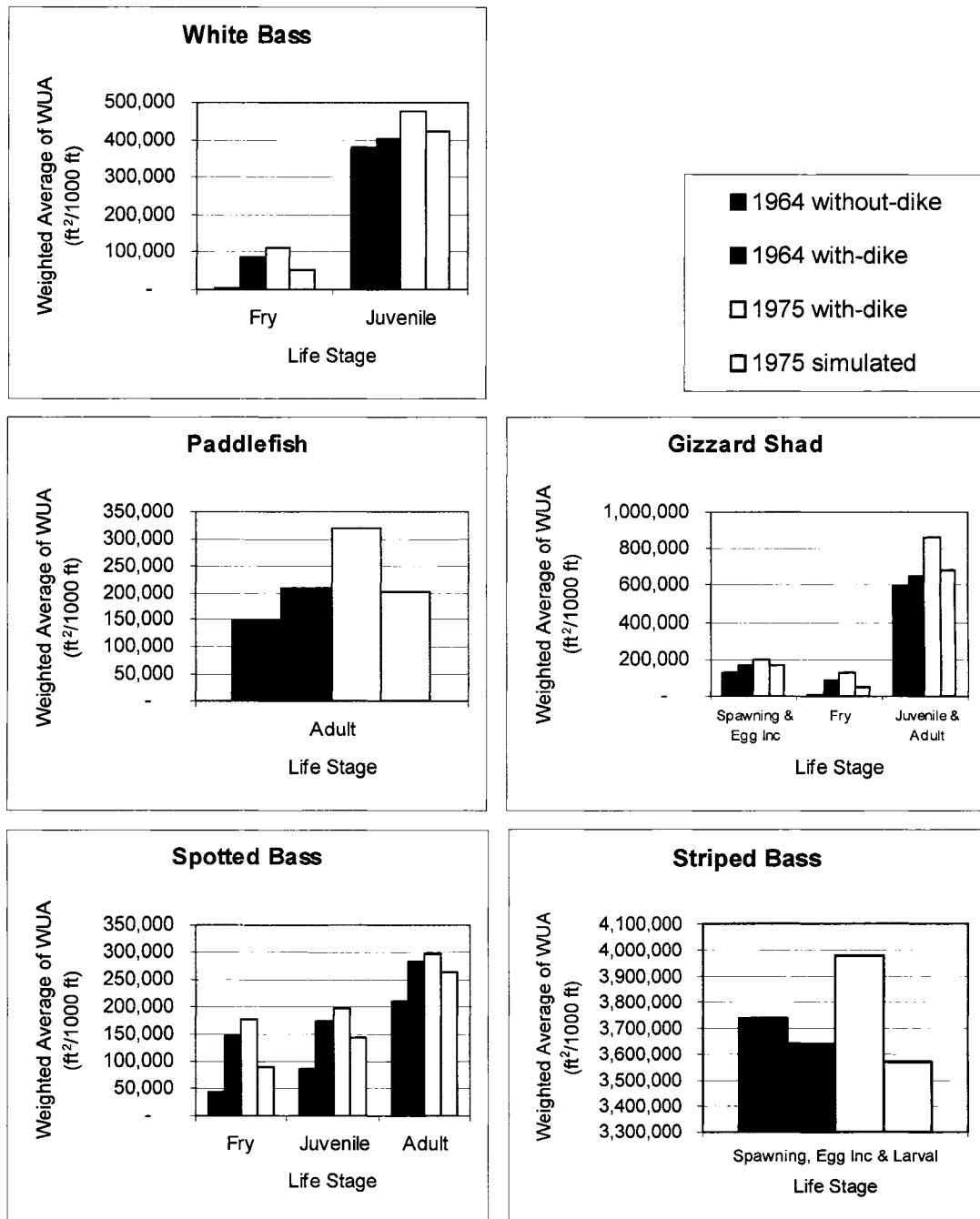


Figure 6.10: Histogram of discharge – Baleshed Landing

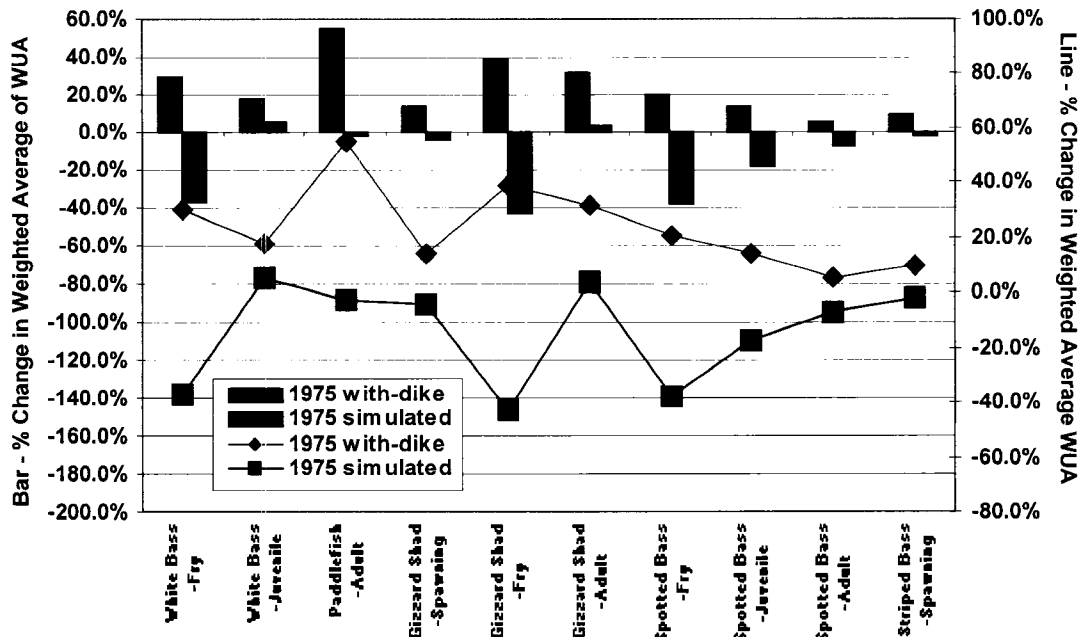


**Figure 6.11: Comparison of weighted average of WUA – Baleshed Landing**

**Table 6.3: Percent change in weighted average of WUA relative to previous cross-section geometric condition – Baleshed Landing**

Species	Life Stage	% Change in Weighted Average of WUA Relative to Previous Geometric Condition			
		1964 Without -dike	1964 With -dike	1975 With -dike	1975 Simulated
White Bass	Fry	-	1786.0%	29.8%	-37.3%
	Juvenile	-	6.7%	17.9%	5.5%
Paddlefish	Adult	-	41.4%	54.5%	-2.6%
Gizzard Shad	Spawning & Egg Incubation	-	35.5%	13.8%	-4.2%
	Fry	-	1420.9%	38.9%	-43.1%
	Juvenile & Adult	-	10.7%	31.1%	3.5%
Spotted Bass	Fry	-	247.2%	20.3%	-37.6%
	Juvenile	-	94.5%	13.7%	-17.4%
	Adult	-	33.8%	5.5%	-7.0%
Striped Bass	Spawning, Egg Incubation & Larval	-	-2.6%	9.3%	-1.9%
Average*				25.8%	-11.2%

\*Average was calculated from the averages of each species.

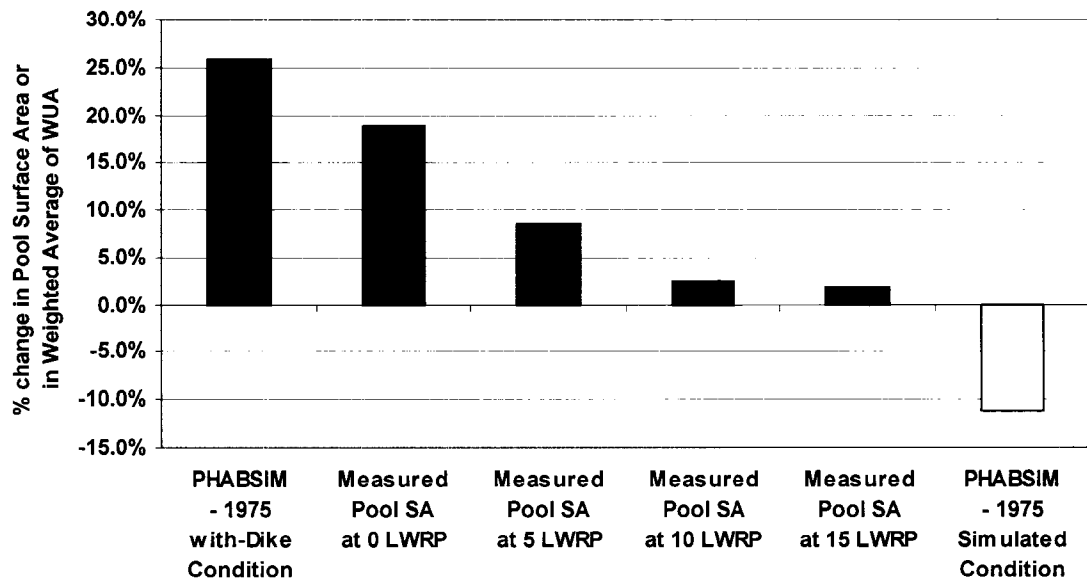


**Figure 6.12: Comparison of percent change in weighted average of WUA between the 1975 with-dike and 1975 simulated conditions – Baleshed Landing**

condition was -11.2% for the reason explained above. According to measured data (ERDC data set), the percent change in total pool surface area within the dike field of 1976 relative to 1965 ranged from 18.9% measured at 0 foot LWRP to 1.8% measured at 15 feet LWRP (Table 6.4). Figure 6.13 represents the comparison of percent change in pool surface area at various stages with percent change in weighted average of WUA of the 1975 with-dike and the 1975 simulated conditions. It shows that the percent change in weighted average of WUA of 1975 with-dike condition is a little larger than the percent change in pool surface area measured at 0 foot LWRP. Therefore, in this case, it can be said that the dike pool surface area change underestimated the increase in aquatic habitat for fish, considering that the percent change in pool surface area measured at 15 feet LWRP was used in the statistical analysis. However, when considering that only 23% of the data used in the statistical analysis have greater than 1% change in pool surface area, the percent change in pool surface area still can be considered as a surrogate to predict change in WUA.

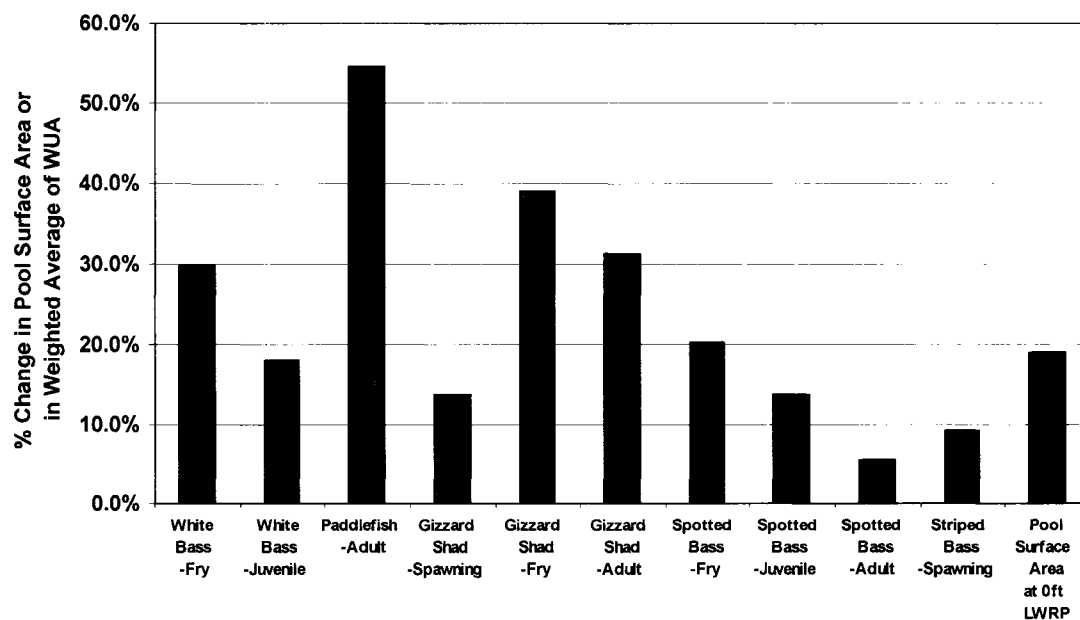
**Table 6.4: Percent change in total pool surface area and volume of 1976 relative to 1965 – Baleshed Landing**

Stage	% Change in Pool Surface Area & Volume of 1976 Relative to 1965			
	0 foot LWRP	5 feet LWRP	10 feet LWRP	15 feet LWRP
<b>Total Surface Area</b>	18.9%	8.5%	2.5%	1.8%
<b>Total Volume</b>	65.3%	43.4%	31.7%	24.4%



**Figure 6.13: Comparison of percent change in pool surface area at different stages and percent change in weighted average of WUA of different conditions – Baleshed Landing**

In Figure 6.14, the percent change in WUA of each life stage of each species was compared with the percent change in pool surface area measured at 0 foot LWRP. It also suggests that the PHABSIM model needs to be used to evaluate the effect of the dike field on the aquatic habitat of each life stage of each species selected as target species, even when the percent change in pool surface area can be used instead of the percent change in weighted average of WUA in terms of average value.

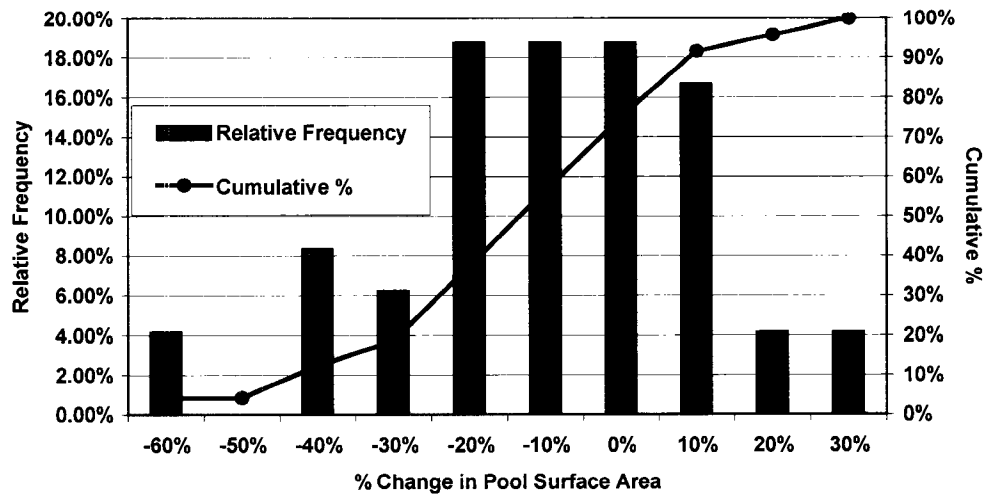


**Figure 6.14: Comparison of percent change in pool surface area at different stages and percent change in weighted average of WUA of different species with different life stage – Baleshed Landing**

## 7 DIKE DESIGN PROCEDURE

Based on the results obtained from analyses in Chapters 5 and 6, the following steps are suggested for environmental dike design for the Lower Mississippi River. These can be used, not only to maintain dredging-free navigation channels, but also to secure the minimal aquatic habitat within the dike pool area to maintain existing aquatic habitat.

- Step 1) Determine the width and draft of the navigation channel, based on the master plan for the waterway project, and set a goal for the minimum percent change in pool habitat area formed between the dikes. When setting a goal, the histogram of the percent change in pool surface area change (CA) shown in Figure 7.1 can be used as design criteria; e.g., -10% change in pool surface area corresponding to 56% of the cumulative relative frequency. Using the cumulative relative frequency, the relative levels of percent change in pool surface areas targeted as a goal can be compared.
- Step 2) Develop several scenarios about the location and number of dikes to maintain the planned waterway alignment.
- Step 3) Run the HEC-6 model for each scenario, to evaluate each scenario, and determine the dimension and location of each dike by considering the minimum navigation requirement and economy. When running the HEC-6

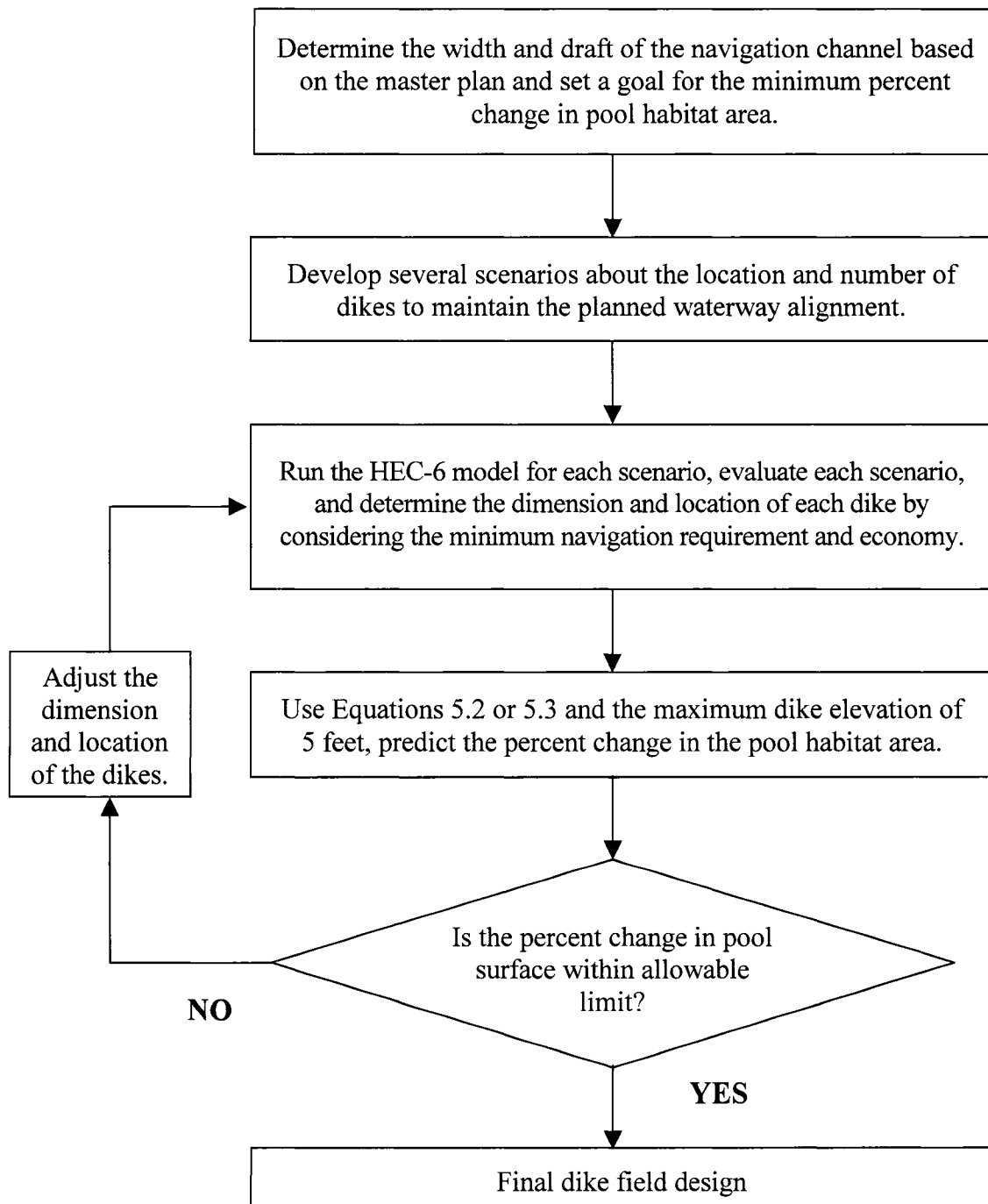


**Figure 7.1: Histogram of percent change in pool surface area**

model, a hydrograph period of 10 to 15 years is recommended, which is considered the period that the dike field reaches equilibrium state.

- Step 4) Using Equations (5.2) or (5.3) and the maximum dike elevation of 5 feet obtained from the statistical analysis for the dike pool surface area, predict change in the pool habitat area, and according to the result, adjust the dimension of the dikes determined in Step 3 to meet the goal set in Step 1.
- Step 5) Repeat Step 3 and Step 4 until the acceptable result is obtained.
- Step 6) Additionally, if possible, use the PHASIM analysis to estimate the available habitat area for each life stage of each species living in the project reach, for conditions of before, right after, and long after dike construction. For calculation of the available habitat area long after construction of the dikes, the cross-section geometry data obtained from HEC-6 analysis can be used.

A flow chart of these dike design steps is presented in Figure 7.2.



**Figure 7.2: Flow chart of dike design procedure**

## **8 CONCLUSIONS AND RECOMMENDATIONS**

### **8.1 SUMMARY AND CONCLUSIONS**

The data set collected for this study incorporates the ERDC data set, which includes surface area, volume, and depth measurements for each dike field, and the following: dike length, dike elevation, dike slope, dike angle with the bank, construction year, dike location, dike type, etc.

Lamb and Ethridge's (1991) conveyance design line was applied to the updated ERDC data set to examine whether it could be used as a dike design criterion, because it has been most widely used in dike design for the Lower Mississippi River. To determine if dredging occurred, changes in main channel volume were investigated. The investigated results from main channel volume records for the Memphis and Vicksburg Districts were compared with the results from Lamb and Ethridge's design line (Tables 4.1 and 4.2, respectively). With the exception of three cases, the separation by Lamb and Ethridge's design line matched well with that of main channel volume record. However, according to Franco's (1982) records during the period of 1968 to 1975, many dike fields were dredged after dike construction, although most of them were classified as 'No Dredging' in Tables 4.1 and 4.2. Additionally, Lamb and Ethridge's design line used side conveyance of individual dikes to decide whether the dike field was dredged, but the degree of main channel volume change within the dike field is affected by all dikes

within the dike field as well as hydraulic conditions of the reach. Therefore, it must be recognized that there is a limit to using Lamb and Ethridge's design line for dike design.

Simple and multiple linear regression analyses were performed, to find relationships between dike geometric parameters (DL, DE, SD, RC, CW, etc.) and pool habitat parameter (CA). The analysis was performed for the percent change in pool surface area (CA) measured at 15 feet LWRP, because it was most highly correlated with other parameters. CA was inversely proportional to DL with a  $R^2$  value of 0.5296, and was also inversely proportional to DE with a  $R^2$  value of 0.2232. Therefore, it can be concluded that the shorter and the lower the dike, the less the pool surface area decreases, thereby preserving more habitat area. In the plot of DE versus CA (Figure 5.2(b)), DE data points were separated into two groups by the 5-foot dike elevation line. From the two-sample t-test of CA data, it was concluded that the 5-foot dike elevation can be approximately regarded as the maximum dike elevation to keep the dike pools maintained without sedimentation, and then it can be used as the environmental design guideline for the dike elevation.

Multiple linear regression analysis was performed for two groups of parameters: a group of the measured parameters and a group of the dimensionless parameters. The backward elimination method was used for the selection of the variables (Tables 5.4 and 5.5). Using this method, the model with two parameters, DL and DE, was selected for the group of measured parameters, and the model with two parameters, DL/CW and RC/CW, was selected for the group of dimensionless parameters. From multiple linear regression analysis for the group of measured parameters (DL and DE), Equation (5.2) was developed ( $R^2 = 0.5687$ ), and from multiple linear regression analysis for the group

of dimensionless parameters ( $DL/CW$  and  $RC/CW$ ), Equation (5.3) was developed ( $R^2 = 0.5464$ ). Both Equations (5.2) and (5.3) can be used to predict the pool habitat area change represented by the pool surface area change for the given geometry of the dikes (dike length and elevation) and the channel (radius of curvature). Because Equation (5.3) consists of dimensionless parameters and is independent of the units, it is recommended to use Equation (5.3) with the consideration of the maximum 5-foot dike elevation to keep the dike pools maintained without sedimentation.

HEC-6 model was used, to find relationships between dike geometric parameters and main channel parameters. Two dike fields were selected for the application of the HEC-6 model: the Bondurant Towhead and Baleshed Landing. On the assumption that bed elevation change is affected only by the main current, it was necessary to predict the angle of the flow diverted by the dike, to determine the movable bed portion of the cross sections in the dike field. From the model calibration, the expansion ratio of 3:1 and contraction ratio of 1:1 were selected for the base and plan tests (Table 5.8).

In the Bondurant Towhead dike field, the measured cross-section areas were compared with those simulated from the base condition using the expansion ratio of 3:1 (Figure 5.19). The simulated cross-section areas at all cross sections except one matched relatively well with the measured areas with average error of 8.9%. The simulation result showed that thalweg elevation decreases within the dike field as dike length increases (Figure 5.21), and it is necessary to install an additional dike between two existing dikes (Figure 5.20). The simulation result also predicted that thalweg elevation decreases within the dike field as dike elevation increases (Figure 5.23), but the degree of decrease in thalweg elevation is very small compared to the dike length change. When the

elevation of dikes was decreased to 5 feet, which was suggested as the maximum elevation to keep the dike pools maintained without sedimentation, the simulation result showed that average thalweg elevation increases only by 0.24 foot, less than 0.37-foot decrease by increasing the dike length by 10%. Thus, it can be an environmental design example to increase the dike length by less than 10% instead of decreasing the dike elevation of both dikes to 5 feet. The effect of decreasing the dike spacing by half is less than that of 10% increase in dike length. The HEC-6 model for Baleshed Landing showed similar results as Bondurant Towhead for dike length and elevation change (Figures 5.29 and 5.31, respectively). When dike elevation was decreased to 5 feet, the simulation result showed that the average thalweg elevation increases only by 0.05 foot, less than 0.17-foot decrease by increasing dike length by 10%.

The simulation results explained above are several examples demonstrating that the HEC-6 model can be used as a tool for dike design. The HEC-6 model also can be used to evaluate the scenarios established at the initial stage of dike design, which are possible combinations of the dike geometric parameters satisfying the master plan for the waterway project. After running the HEC-6 model for each scenario, the dimension and location of each dike within the dike field can be determined by considering the minimum navigation requirement and economy.

The PHABSIM model was used to verify whether the dike pool surface area change (CA) could represent the amount of aquatic habitat for fish living in the dike field. Additionally, the cross-section geometry data calculated from the HEC-6 model were used as input geometry data for the PHABSIM model, to test whether cross-section geometry data from the HEC-6 model can be used to predict change in aquatic habitat for

fish. The Bondurant Towhead and Baleshed Landing dike fields were also selected for the PHABSIM analysis. Five species were selected as target species: white bass, paddlefish, gizzard shad, spotted bass, and striped bass. The expansion (3:1) and contraction (1:1) ratios determined in the HEC-6 analysis were also used in the PHABSIM model to consider the effect of ineffective flow area.

For the Bondurant Towhead dike field, the PHABSIM model was run for four cross-section geometric conditions. To represent change in WUA for the whole range of discharges by a single value, the average of WUA weighted by the relative frequency of discharge (weighted average of WUA) was introduced. The weighted average of WUA increased right after construction of the dikes (1975 with-dike condition), and decreased in the 13 years after dike construction (1988 with-dike condition) compared to the 1975 with-dike condition (Figure 6.5). The weighted average of WUA of the 1988 simulated condition was smaller than that of the 1988 with-dike condition, but both conditions showed similar relative change in weighted average of WUA between species with different life stages (Figure 6.6). Therefore, it can be concluded that the PHABSIM results using cross-section geometry data simulated from the HEC-6 model tend to underestimate the WUA for most species, but can be used in place of the measured data, in cases where it is necessary to predict the relative change in WUA between species with different life stages. The average of percent change in weighted average of WUA (-8.3%) matches well with the percent change in total pool surface area measured at 15 feet LWRP (-8.0%) during the similar period. Considering that the statistical analysis was performed using the percent change in pool surface area measured at 15 feet LWRP, it can be concluded that the dike pool surface area change can represent the aquatic habitat

change for fish living in the dike field. However, as shown in Figure 6.7, the PHABSIM model needs to be used to evaluate the effect of the dike field on the aquatic habitat of each life stage of each species, even though the percent change in pool surface area can be used instead of the percent change in weighted average of WUA in terms of average value. Figure 6.8 suggests that the cross-section geometry data calculated from the HEC-6 model can be used as input geometry data for the PHABSIM model, to predict change in aquatic habitat for fish, although there is a tendency to underestimate the WUA.

In the Baleshed Landing dike field, the weighted average of WUA increased right after dike construction (1975 with-dike condition), and increased in the 11 years after dike construction (1975 with-dike condition) compared to the 1964 without-dike condition (Figure 6.11). The weighted averages of WUA were smaller than those of the 1975 with-dike condition. This appears to result from periodic dredging of the Baleshed Landing dike field after construction. The average of percent change in weighted average of WUA of the 1975 with-dike condition (25.8%) is a little larger than the percent change in pool surface area measured at 0 foot LWRP (18.9%). Therefore, it can be said that the dike pool surface area change underestimated the increase in aquatic habitat for fish, considering that the percent change in pool surface area measured at 15 feet LWRP (1.8%) was used in the statistical analysis. However, when considering that only 23% of the data used in the statistical analysis have greater than 1% change in pool surface area, the percent change in pool surface area can still be considered as a surrogate to predict change in WUA.

Finally, based on the results gained from the above analyses, the procedures for environmental dike design were suggested (Figure 7.2).

## 8.2 RECOMMENDATIONS

As mentioned in Chapter 5, the ERDC data set used in this study is not for each individual dike, but for a dike field or dike system. Therefore, the statistical analysis could not be used for the main channel analysis, because it was difficult to separate the main channel parameters for each dike. Therefore, if the main channel area and volume data measured for each dike are available, it is possible to predict the relationships between dike geometric parameters and main channel parameters using the statistical analysis. It is thus recommended that the ERDC data set will include the main channel area and volume data separated for each dike.

In the model calibration of the HEC-6 model, the expansion ratio of 3:1 and contraction ratio of 1:1 were selected. It is recommended to improve the model accuracy by predicting the expansion and contraction ratios around the dike using the physical modeling combined with 2-D or 3-D numerical modeling, although the predicted ratios might be varied according to the discharge. Additionally, for 2-D or 3-D numerical modeling, it is necessary to collect more detailed data, such as velocity and bed material distribution across the cross section.

As mentioned in Section 6.2 of the PHABSIM analysis, the calibration data measured for vertical cells across the cross section were not available for both dike fields, so the velocity at each vertical cell was calculated using the flow depth of each cross section. However, it is recommended to measure the velocities at vertical cells across the cross section to be able to calibrate the cell velocities and increase the accuracy of the model.

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## **APPENDIX A: DIKE SUMMARY TABLES**

**Table A.1: Dike summary table for Memphis District**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Map Year (Latest)	Location (RM)	Side of River* (L or R)	Construction Type* (1, 2 or 3) (Initial)	Construction Type* (1, 2 or 3) (Latest)	Dike Type* (1, 2 or 3)	Notes
<b>Island 1</b>	1U	1992		2001	949.3	L	1		1	
	1	1967	1992	2001	948.5	L	1		2	
	2	1966		1967	947.9	L	1		1	
	3	1966		1967	947.3	L	1		1	
	4	1969		1970	945.7	L	1		1	
	5	1969		1970	945.2	L	1		1	
	6	1969		1969	944.6	L	1		1	
	7	1969		1969	944.2	L	1		1	
<b>Pritchard</b>	1U	1969		1970	945	R	1		1	
	1	1959	1970	1970	944.5	R	2	3	1	
	2	1959		1968	944	R	2		1	
	2.5	1970	1985	1985	943.8	R	1		1	
	3	1959		1968	943.4	R	2		1	
<b>Wrights Point</b>	1	1962	1985	1986	822.1	R	2	1	2	
	2	1962	1985	1986	821.8	R	2	1	1	
	3	1962	1968	1969	821.5	R	2	3	1	
	4	1962	1968	1969	821	R	2	3	2	
	5	1962	1968	1969	820.5	R	2	3	1	
	5A	1968		1969	820.3	R	1		3	
	5B	1968		1969	820	R	1		3	
	5C	1968		1969	819.6	R	1		3	
	5D	1970		1971	818.8	R	1		3	
	6	1974		1975	818.7	R	1		1	
	6A	1989		1988	817.8	R	1		2	
	6B	1982	1989	1988	817.4	R	1		2	
	7	1974	1982	1983	816.7	R	1		2	Need a new map. This dike was raised and extended in 1994.
8	1985		1987	816.1	R	1		2		
9	1985		1987	815.6	R	1		1		
<b>Island 25</b>	1	1969	1974	1978	804.4	R	1		1	
	2	1969	1975	1978	803.7	R	1		1	

**Table A.1 (cont.)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Map Year (Latest)	Location (RM)	Side of River* (L or R)	Construction Type* (1, 2 or 3) (Initial)	Construction Type* (1, 2 or 3) (Latest)	Dike Type* (1, 2 or 3)	Notes
Forked Deer	1	1964		1965	800	L	1		1	
	2	1964		1965	799.6	L	1		1	
	3	1968		1969	798.8	L	1		L-head	
	4	1968		1969	797.7	L	1		1	
	5	1968		1969	797.1	L	1		1	
Densford	1	1965	1967	1969	757.3	L	3		1	
	2	1965	1967	1969	756.9	L	3		1	
	3	1965		1966	756.3	L	1		1	
Randolph Point	1U	1961	1966	1968	748.3	L	2	3	1	
	2U	1961		1968	748.1	L	2		1	
	3U	1961	1967	1968	747.7	L	2	3	1	
	4U	1961		1968	747.4	L	2		1	
	1	1960	1986	1986	746.4	L	2	3	1	
	2	1960		1968	746	L	2		1	
3	1960	1986	1986	745.6	L	2	3	2		
Above Loosahatchie	1	1968		1969	743.6	L	1		1	Need a new map. This dike was raised and extended in 1994.
	2	1968		1969	743	L	1		1	Need a new map. This dike was raised and extended in 1994.
	3	1968	1985	1985	742.4	L	1		1	
	4	1968	1992	1995	741.9	L	1		1	
	5	1968	1992	1995	741.3	L	1		1	
	6	1970		1970	740.8	L	1		1	
Redman Point	1.5R	1958		1969	743.3	R	2		1	
	2AR	1958	1967	1969	743	R	2	3	1	
	3R	1958	1960	1966	742.7	R	2		1	
	4R	1958	1967	1969	742.4	R	2	3	1	Need a new map. This dike was raised in 1984.
Sycamore Chute	1	1992		1995	741.2	R	1		2	
	2	1992		1995	740.8	R	1		2	
	3	1992		1995	740.4	R	1		2	
	4	1992		1995	740	R	1		2	
Robinson Crusoe	1	1963	1974	1975	740.2	R	2	1	2	
	2	1963		1966	739.6	R	2		1	

**Table A.1 (cont.)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Map Year (Latest)	Location (RM)	Side of River* (L or R)	Construction Type* (1, 2 or 3) (Initial)	Construction Type* (1, 2 or 3) (Latest)	Dike Type* (1, 2 or 3)	Notes
Dismal Point	IU, IUT	1965		1974	725.6	R	1		2	
	1	1961		1964	725.3	R	2		1	
	2	1961		1964	724.6	R	2		1	Need a new map. This dike was raised and extended in 1972.
	3	1962	1965	1967	723.8	R	2		1	
	4	1962	1965	1967	722.9	R	2		1	
	5	1962	1965	1967	722.2	R	2		2	
	5T	1966		1967	721.4	R	1		3	
	6	1984		1985	720.9	R	1		2	
Armstrong	1	1963	1970	1971	720.1	R	2	3	2	
	2	1963	1968	1969	719.4	R	2		2	
	3	1969		1970	718.5	R	1		2	
	3A	1969		1970	718.5	R	1		3	
	3B	1969		1970	718.3	R	1		3	
	3C	1969		1970	718	R	1		3	
	4	1969		1970	717.3	R	1		1	
Cat Island	1									Map for this dike does not exist.
	2	1932	1965	1967	712	R	2	3	1	
	3A	1958		1967	711.6	R	2		1	
	4A	1958	1990	1991	710.9	R	2	3	2	
	4AT	1958	1991	1991	710.4	R	2	3	3	
	4B	1970		1971	710.1	R	1		1	
	5	1958		1967	710	R	2		1	
	6	1958	1962	1967	709	R	2		2	
Seyppel	1	1963	1991	1991	706.4	R	2	1	2	
	2	1963		1968	705.8	R	2		1	
	3	1963	1966	1968	705.3	R	3	2	1	
	4	1997		1996	704.9	R	1		2	
	5	1997		1996	704.2	R	1		2	

**Table A.1 (cont.)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Map Year (Latest)	Location (RM)	Side of River* (L or R)	Construction Type* (1, 2 or 3) (Initial)	Construction Type* (1, 2 or 3) (Latest)	Dike Type* (1, 2 or 3)	Notes
<b>Pickett</b>	1U	1997		1996	704.9	L	1		2	
	1	1965	1997	1996	704.5	L	1		2	
	2	1965	1997	1996	704	L	3	1	2	
	3	1965	1997	1996	703.6	L	3	1	2	
<b>Island 62</b>	1	1963	1968	1969	640	R	2	3	1	
	2	1963	1965	1967	639.7	R	2		1	
	3	1963	1965	1967	639.4	R	2		1	
	4	1969		1970	638.1	R	1		1	
	4A	1969		1970	638	R	1		3	
	4B	1969		1970	637.7	R	1		3	
	4C	1969		1970	637.5	R	1		3	
	4D	1970	1977	1979	637	R	1		3	
	4.5	1974		1978	637.4	R	1		1	
	5	1974		1975	636.2	R	1		2	
<b>Island 63</b>	1									Map for this dike does not exist.
	2									Map for this dike does not exist.
	3									Map for this dike does not exist.
	4A	1960	1969	1970	640.4	L	2	3	1	
	5A	1960		1966	640	L	2		1	
	6	1959	1974	1975	639.4	L	2	1	1	
<b>Island 63 Bar</b>	1	1974		1975	639.4	L	1		2	
	2	1974		1975	639.2	L	1		2	

\*Side of River: L = Left Bank  
R = Right Bank

\*Construction Type: 1 = Stone Dike  
2 = Pile Dike  
3 = Stone-filled Pile Dike

\*Dike Type: 1 = Transverse  
2 = L-Head  
3 = Vane

**Table A.2: Dike summary table for Vicksburg District**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Map Year (Latest)	Location (RM)	Side of River* (L or R)	Construction Type* (1, 2 or 3) (Initial)	Dike Type* (1, 2 or 3)	Notes
Island 70	1								Map for this dike does not exist.
	2								The file is unreadable.
	3								The file is unreadable.
	4								The file is unreadable.
	5	1990		1990	606.4	L	1	1	
	6	1990		1990	606.3	L	1	1	
	7	1990		1990	605.8	L	1	1	
	8								The file is unreadable.
	9	1993		1993	605.3	L	1	1	
	10	1993		1993	605	L	1	1	
	1L								Map for this dike does not exist.
Catfish Point	1								The file is unreadable.
	2								The file is unreadable.
Chicot Landing	1	1968		1969	565.5	R	1	1	
	2	1968		1969	564.8	R	1	1	
	3	1967	1986	1986	564	R	1	1	
	3A	1967	1986	1986	563.8	R	1	3	
	3B	1967	1986	1986	563.4	R	1	3	
	3C	1974		1986	563	R	1	3	
	4	1995		1996	563.8	R	1	1	
	5								The file is unreadable.
Ashbrook Cutoff	1								The file is unreadable.
	2								The file is unreadable.
	3								The file is unreadable.
	4	1962	1969	1969	548.3	L	3	1	

**Table A.2 (cont.)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Map Year (Latest)	Location (RM)	Side of River* (L or R)	Construction Type* (1, 2 or 3) (Initial)	Dike Type* (1, 2 or 3)	Notes
Ashbrook-Miller Bend	2UL								The file is unreadable.
	1UL	1983		1982	547.3	L	1	1	
	1L	1965		1966	546.81	L	1	1	
	2L								The file is unreadable.
	3L	1965	1966	1966	545.72	L	1	1	
	1R								The file is unreadable.
	2R	1965		1966	547.66	R	1	1	
	3R	1965		1966	547.09	R	1	1	
	4R	1965		1966	546.54	R	1	1	
Island 82-Miller Bend	1L	1966		1966	545.9	L	1	1	
	2L								The file is unreadable.
	3L								The file is unreadable.
	4L								The file is unreadable.
	1R								The file is unreadable.
	2R								The file is unreadable.
	3R								The file is unreadable.
		4R							The file is unreadable.
Island 86	1								The file is unreadable.
	2	1970	1988	1991	519.8	R	1	2	
	3								The file is unreadable.
	4								The file is unreadable.
	4chute								The file is unreadable.
	5	1994		1995	517.1	R	1	1	
Lower Cracraft	1	1970		1991	510.25	R	1	2	Need a new map. This dike was raised and extended in 1991.
	2	1970		1991	509.7	R	1	2	Need a new map. This dike was raised and extended in 1991.
	3	1971		1991	508.9	R	1	2	Need a new map. This dike was raised and extended in 1991.
Carolina	1								The file is unreadable.
	2	1974		1991	509	L	1	1	Need a new map. This dike was raised and extended in 1992. (?)
Wilson Point	1	1969		1991	500.6	R	1	1	
	2	1969		1991	500	R	1	2	
	3	1992		1992	498.2	R	1	1	

**Table A.2 (cont.)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Map Year (Latest)	Location (RM)	Side of River* (L or R)	Construction Type* (1, 2 or 3) (Initial)	Dike Type* (1, 2 or 3)	Notes
<b>Baleshed Landing</b>	1	1965		1987	494.6	L	1	1	
	2	1965	1997	1997	493.8	L	1	1	
	3	1965	1997	1997	493.0	L	1	1	
	4	1965	1997	1997	492.2	L	1	1	
	5	1965	1989	1990	491.2	L	1	1	
	6	1992		1992	489.8	L	1	1	
<b>Ben Lomond</b>	1								The file is unreadable.
	2								The file is unreadable.
	2A	1968		1969	487.8	L	1	3	
	2B	1967		1969	487.4	L	1	3	
	2C								The file is unreadable.
	2D								The file is unreadable.
	3	1970	1987	1987	486.3	L	1	1	
	3A	1970	1987	1987	486.2	L	1	3	Need a new map. This dike was raised in 1988.
	3B	1974	1975	1975	485.8	L	1	3	
	3C	1974	1975	1975	485.4	L	1	3	
4	1978	1987	1987	485.3	L	1	1		
<b>Forest Home Towhead</b>	6U	1997		1998	452.6	L	1	1	
	5U	1991	1992	1992	452	L	1	1	
	4U	1991	1994	1994	451.4	L	1	1	
	3U	1991	1994	1994	450.8	L	1	1	
	2U	1991	1994	1994	450.2	L	1	1	
	1U	1994		1995	449.7	L	1	1	
	1	1980	1997	1997	449.2	L	1	1	
	2	1980	1997	1997	448.6	L	1	1	
	3	1980	1997	1997	448.1	L	1	1	
<b>Marshall Cutoff</b>	1	1978		1978	448.2	R	1	1	
	2	1978		1978	447.2	R	1	1	

**Table A.2 (cont.)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Map Year (Latest)	Location (RM)	Side of River* (L or R)	Construction Type* (1, 2 or 3) (Initial)	Dike Type* (1, 2 or 3)	Notes
Bondurant Towhead	1U	1991	1998	1998	395.5	R	1	1	
	1	1974	1991	1991	394.8	R	1	1	
	2	1973	1991	1991	394	R	1	1	
Waterproof	1U	1989	1994	1994	380.6	R	1	1	
	1	1963	1994	1994	379.9	R	1	2	
	2	1963		1991	379.5	R	2	2	
	3	1963	1994	1994	379.1	R	1	2	
	4	1964		1991	378.8	R	2	2	
	5	1963	1965	1991	378.4	R	3	2	Need a new map. This dike was raised and extended in 1976.

\*Side of River: L = Left Bank  
R = Right Bank

\*Construction Type: 1 = Stone Dike  
2 = Pile Dike  
3 = Stone-filled Pile Dike

\*Dike Type: 1 = Transverse  
2 = L-Head  
3 = Vane

## **APPENDIX B: DIKE GEOMETRIC DATA TABLES**

**Table B.1a: Dike geometric data table for Island 1, Pritchard, Wrights Point, Island 25, and Forked Deer for the Memphis District (columns 1 through 14)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Location (RM)	Side of River	Dike Type	LWRP (ft, NGVD)	Bank Head Position			Main Body Position		
								Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)
Island 1	1U	1992		949.3	L	Transverse	278	80	291	13			
	1	1967	1992	948.5	L	L-head	278	220	312	34	280	301	23
	2	1966		947.9	L	Transverse	278	225	297.4	19.4	470	292.4	14.4
	3	1966		947.3	L	Transverse	277	255	296	19	550	289.8	12.8
	4	1969		945.7	L	Transverse	276	340	295.9	19.9	500	292	16
	5	1969		945.2	L	Transverse	276	410	293	17	460	292	16
	6	1969		944.6	L	Transverse	276	445	291.6	15.6	700	286.6	10.6
	7	1969		944.2	L	Transverse	276	178	292	16	300	289	13
Pritchard	1U	1969		945	R	Transverse	276	297	296	20	450	292	16
	1	1959	1970	944.5	R	Transverse	276	294	311.5	35.5	500	291	15
	2	1959		944	R	Transverse	275	307	314	39	463	291.7	16.7
	2.5	1970	1985	943.8	R	Transverse	275	473	290	15	550	288	13
	3	1959		943.4	R	Transverse	275	460	313	38	610	291.5	16.5
Wright's Point	1	1962	1985	822.1	R	L-head	228	320	244	16			-228
	2	1962	1985	821.8	R	Transverse	228	120	242.5	14.5			-228
	3	1962	1968	821.5	R	Transverse	227	210	244	17	220	239	12
	4	1962	1968	821	R	L-head	227	460	240	13			-227
	5	1962	1968	820.5	R	Transverse	227	515	237	10			-227
	6	1974		818.7	R	Transverse	226	570	245	19	810	240	14
	6A	1989		817.8	R	L-head	226	745	246	20	845	243	17
	6B	1982	1989	817.4	R	L-head	225	286	242	17	360	240	15
	7	1974	1982	816.7	R	L-head	224	1130	259	35	1200	242	18
	8	1985		816.1	R	L-head	223	320	245	22	325	243	20
	9	1985		815.6	R	Transverse	222	120	242	20			-222
Island 25	1	1969	1974	804.4	R	Transverse	217	340	240	23			-217
	2	1969	1975	803.7	R	Transverse	216	150	239	23	200	234	18
Forked Deer	1	1964		800	L	Transverse	216	219	233	17			-216
	2	1964		799.6	L	Transverse	216	23	234	18	250	227	11
	3	1968		798.8	L	L-head	216	340	250	34	400	231	15
	4	1968		797.7	L	Transverse	215	390	251	36	470	233	18
	5	1968		797.1	L	Transverse	215	368	231	16			-215

**Table B.1b: Dike geometric data table for Island 1, Pritchard, Wrights Point, Island 25, and Forked Deer for the Memphis District (columns 15 through 30)**

Dike Field	Dike No.	Downhill Slope Position			Dike End Position			Length (ft)	Representative Elevation		Slope (ft/ft)	Notch*		dike angle (deg)	
		Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)		(ft)	(ft, LWRP)			Features		
Island 1	1U	1800	280	2	1890	259.5	-18.5	1720	284	6	0.0000	x		90.00	
	1	2600	283	5	2700	263	-15	2380	293	15	0.0019	x		90.00	
	2	3547	275	-3	3578	264	-14	3322	292.4	14.4	0.0000	x		89.50	
	3	3500	276.8	-0.2	3520	266	-11	3245	289.8	12.8	0.0000	x		81.50	angled D/S
	4	2450	283	7	2520	278	2	2110	290.9	14.9	0.0000	x		82.73	angled D/S
	5	2050	282	6	2100	274	-2	1640	288.8	12.8	-0.0004	x		84.95	angled D/S
	6	1420	282	6	1500	265	-11	975	286.6	10.6	0.0000	x		86.08	angled D/S
Pritchard	7	1020	281	5	1120	260	-16	842	287.5	11.5	0.0000	x		79.85	angled D/S
	1U	1552	280.7	4.7	1620	270	-6	1255	290.7	14.7	0.0000	x		88.70	angled D/S
	1	2453	282	6	2500	274	-2	2159	288	12	0.0004	x		88.70	angled D/S
	2			-275	2160	288.7	13.7	1853	291.7	16.7	0.0000	x		88.68	angled D/S
	2.5	2650	281	6	2705	266	-9	2177	289	14	-0.0007	x		88.70	angled D/S
Wright's Point	3			-275	1978	289.5	14.5	1518	291.5	16.5	0.0000	x		88.70	angled D/S
	1	1600	242	14	1645	231	3	1280	242	14	0.0000	x		87.00	angled D/S
	2	1000	234	6	1045	225	-3	880	241	13	0.0000	x		86.50	angled D/S
	3	2010	223	-4	2100	174	-53	1800	239	12	0.0000	x		86.98	angled D/S
	4			-227	1050	224	-3	590	225	-2	0.0271	x		82.50	angled D/S
	5	3100	229	2	3130	216	-11	2585	237	10	0.0000	x		102.48	angled U/S
	6			-226	6330	252	26	5760	240	14	0.0000	x		87.22	angled D/S
	6A	1650	243	17	1775	218	-8	905	243	17	0.0000	x		82.18	angled D/S
	6B	2200	230.2	5.2	2300	211	-14	1914	236	11	0.0002	x		83.40	angled D/S
	7	9522.6	228	4	9582.6	217	-7	8392.6	236	12	0.0000	x		107.95	angled U/S
Island 25	8	1600	240	17	1680	225	2	1280	241	18	0.0000	x		67.00	angled D/S
	9	1000	233	11	1055	223	1	880	239.5	17.5	0.0000	x		82.50	angled D/S
	1	2000	224	7	2140	192	-25	1660	233	16	0.0043	x		97.00	angled U/S
	2	3200	223	7	3250	200	-16	3050	231	15	0.0000	x		72.00	angled D/S
Forked Deer	1	1600	225	9	1620	210	-6	1381	225	9	0.0000	x		103.25	angled U/S
	2	2400	226	10	2410	221	5	2377	227	11	0.0005	x		103.25	angled U/S
	3	2350	222	6	2366	217	1	2010	228	12	0.0022	x		92.98	angled U/S
	4	1550	217	2	1660	202	-13	1160	219	4	0.0148	x		90.25	
	5	1500	216	1	1545	199	-16	1132	216	1	0.0133	x		90.25	

\*x = no notch and O = notch

**Table B.1c: Dike geometric data table for Island 1, Pritchard, Wrights Point, Island 25, and Forked Deer for the Memphis District (columns 31 through 42)**

Dike Field	Dike No.	1st deflection angle (deg)		2nd deflection angle (deg)		3rd deflection angle (deg)		Side Conveyance (x 10 <sup>6</sup> ) - one side only	Side Conveyance (x 10 <sup>6</sup> ) - both sides of bank		Width of Main Channel at 0 LWRP (ft)
										Jointed dike	
Island 1	1U							0.36			3740
	1	14.50	angled U/S					0.21			4921
	2							0.40			5643
	3							0.43			6037
	4							0.24			4823
	5								0.35	Pritchard 1U	4823
	6								0.40	Pritchard 1	4626
Pritchard	6								0.24	Pritchard 2	4331
	1U								0.35	Island 1 5	3675
	1								0.40	Island 1 6	5052
	2								0.24	Island 1 7	5315
	2.5							0.28			4987
Wright's Point	3							0.11			4987
	1	18.50	angled D/S					0.07			3707
	2							0.06			3904
	3							0.20			4626
	4	18.43	angled U/S					0.10			5085
	5							0.29			5577
	6							0.36			9383
	6A	7.00	angled U/S								
	6B	45.00	angled U/S								
	7	29.08	angled D/S					0.63			10827
Island 25	8	18.50	angled D/S								
	9										
Forked Deer	1							0.15			4626
	2							0.38			6201
Forked Deer	1							0.23			4068
	2							0.34			4888
	3	25.75	angled D/S					0.26			4724
	4							0.20			3806
	5							0.21			3806

**Table B.2a: Dike geometric data table for Densford, Randolph Point, Above Loosahatchie, Redman Point, Sycamore Chute, Robinson Crusoe, and Dismal Point for the Memphis District (columns 1 through 14)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Location (RM)	Side of River	Dike Type	LWRP (ft, NGVD)	Bank Head Position			Main Body Position		
								Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)
Densford	1	1965	1967	757.3	L	Transverse	195	360	209	14	400	207	12
	2	1965	1967	756.9	L	Transverse	195	230	218	23	400	211	16
	3	1965		756.3	L	Transverse	194	470	216	22	500	213	19
Randolph Point	1U	1961	1966	748.3	L	Transverse	190	383	222	32	500	206.1	16.1
	2U	1961		748.1	L	Transverse	189	511	223	34	630	205.7	16.7
	3U	1961	1967	747.7	L	Transverse	189	589	223	34	700	205	16
	4U	1961		747.4	L	Transverse	189	419	223	34	523	205	16
	1	1960	1986	746.4	L	Transverse	188	814	211	23	950	204	16
	2	1960		746	L	Transverse	188	457	222	34	1090	204	16
	3	1960	1986	745.6	L	L-head	188	820.66	219	31	850.66	207	19
Above Loosahatchie	1	1968		743.6	L	Transverse	187	-	-	-	-	-	-
	2	1968		743	L	Transverse	187	-	-	-	-	-	-
	3	1968	1985	742.4	L	Transverse	186	520	205.5	19.5			-186
	4	1968	1992	741.9	L	Transverse	186	360	208.5	22.5			-186
	5	1968	1992	741.3	L	Transverse	186	430	200	14			-186
	6	1970		740.8	L	Transverse	185	196	203	18			-185
Redman Point	1.5R	1958		743.3	R	Transverse	187	255	216	29	370	204.3	17.3
	2AR	1958	1967	743	R	Transverse	187	310	207	20	350	201	14
	3R	1958	1960	742.7	R	Transverse	187	35	218	31	140	203.8	16.8
	4R	1958	1967	742.4	R	Transverse	186	-	-	-	-	-	-
Sycamore Chute	1	1992		741.2	R	L-head	186	210	206.2	20.2	400	202	16
	2	1992		740.8	R	L-head	185	420	204	19	740	201	16
	3	1992		740.4	R	L-head	185	85	199	14			-185
	4	1992		740	R	L-head	185	130	197	12	400	185	0
Robinson Crusoe	1	1963	1974	740.2	R	L-head	185	320	201	16			-185
	2	1963		739.6	R	Transverse	185	739	216	31	845	202	17
Dismal Point	1U	1965		725.6	R	Transverse	179	220	202	23	250	200	21
	1	1961		725.3	R	Transverse	179	209	212	33	330	194.5	15.5
	2	1961		724.6	R	Transverse	179	-	-	-	-	-	-
	3	1962	1965	723.8	R	Transverse	179	280	202	23	320	194	15
	4	1962	1965	722.9	R	Transverse	178	279	210	32	410	193.3	15.3
	5, 5T	1962	1966	722.2	R	L-head	178	125	200	22	215	193	15
	6	1984		720.9	R	L-head	177	4350	199	22	4460	198	21

**Table B.2b: Dike geometric data table for Densford, Randolph Point, Above Loosahatchie, Redman Point, Sycamore Chute, Robinson Crusoe, and Dismal Point for the Memphis District (columns 15 through 30)**

Dike Field	Dike No.	Downhill Slope Position			Dike End Position			Length (ft)	Representative Elevation		Slope (ft/ft)	Notch*		dike angle(deg)	
		Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)		(ft)	(ft, LWRP)			features		
Densford	1			-195	1750	184	-11	1390	206	11	0.0008	x		100.50	angled U/S
	2	3340	194	-1	3380	179	-16	3110	207	12	0.0017	x		100.50	angled U/S
	3	3400	194	0	3460	169	-25	2930	211	17	0.0004	x		73.00	angled D/S
Randolph Point	1U			-190	1351	206	16	968	206	16	0.0001	x		88.82	angled D/S
	2U			-189	1885	205.7	16.7	1374	205.7	16.7	0.0000	x		89.00	angled D/S
	3U	2500	195	6	2640	169	-20	1911	205.6	16.6	-0.0003	x		89.00	angled D/S
	4U			-189	2200	204.6	15.6	1781	204.6	15.6	0.0000	x		89.02	angled D/S
	1			-188	4050	196.7	8.7	3236	205	17	0.0000	x		102.00	angled U/S
	2			-188	3559	213	25	3102	204	16	0.0000	x		97.02	angled U/S
	3	4600	194	6	4700	175	-13	3779.34	204	16	-0.0006	x		52.08	angled D/S
Above Loosahatchie	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	2200	189	3	2255	177	-9	1680	202	16	0.0040	O	6' crown	86.68	angled D/S
	4	1850	198	12	2080	152	-34	1490	198	12	-0.0012	x		83.30	angled D/S
	5	1500	194	8	1680	158	-28	1070	198	12	0.0021	x		78.67	angled D/S
	6	1500	188	3	1530	179	-6	1304	198	13	0.0000	x		95.30	angled U/S
Redman Point	1.5R			-187	855	217	30	600	204.3	17.3	0.0000	x		83.02	angled D/S
	2AR	1800	192	5	1810	188	1	1490	201	14	0.0000	x		82.98	angled D/S
	3R			-187	2692	197.8	10.8	2657	203.8	16.8	0.0000	x		81.53	angled D/S
	4R	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sycamore Chute	1	1200	202	16	1340	172	-14	990	202	16	0.0000	x		84.27	angled D/S
	2	2250	200	15	2380	176	-9	1830	200	15	0.0014	x		101.93	angled U/S
	3	2300	200	15	2400	180	-5	2215	200	15	-0.0005	x		138.70	angled U/S
	4	1250	195.3	10.3	1340	176	-9	1120	195.3	10.3	0.0000	x		105.48	angled U/S
Robinson Crusoe	1			-185	4250	211.5	26.5	3930	200	15	0.0006	x			
	2			-185	4907	235	50	4168	201.5	16.5	0.0001	x			
Dismal Point	1U			-179	2512	191	12	2292	191	12	0.0017	x		90.00	
	1			-179	2230	194.5	15.5	2021	194.5	15.5	0.0000	x		74.03	angled D/S
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3			-179	3690	194	15	3410	194	15	0.0000	O	destroyed**		
	4			-178	2697	193.3	15.3	2418	193.3	15.3	0.0000	O	destroyed	100.27	angled U/S
	5, 5T	9360	185	7	9460	163	-15	9335	193	15	0.0000	x		64.65	angled D/S
	6			-177	7450	183	6	3100	186	9	0.0039	x		43.50	angled D/S

\*x = no notch and O = notch; \*\*destroyed: destroyed naturally, and not recovered

**Table B.2c: Dike geometric data table for Densford, Randolph Point, Above Loosahatchie, Redman Point, Sycamore Chute, Robinson Crusoe, and Dismal Point for the Memphis District (columns 31 through 42)**

Dike Field	Dike No.	1st deflection angle (deg)		2nd deflection angle (deg)		3rd deflection angle (deg)		Side Conveyance (x 10 <sup>6</sup> ) – one side only	Side Conveyance (x 10 <sup>6</sup> ) – both sides of bank		Width of Main Channel at 0 LWRP (ft)
									Jointed dike		
Densford	1							0.20			3740
	2							0.42			5381
	3							0.32			5643
Randolph Point	1U							0.08			4823
	2U							0.12			5020
	3U							0.20			5381
	4U							0.16			4921
	1							0.30			5938
	2							0.25			6529
	3	45.00	angled U/S					0.36			6496
Above Loosahatchie	1	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-
	3								0.47	Redman Point 3R	4396
	4							0.16			3904
	5								0.22	Sycamore Chute 1	4003
	6								0.38	Sycamore Chute 2	3740
Redman Point	1.5R										
	2AR										
	3R								0.47	Above Loosahatchie 3	
	4R	-	-	-	-	-	-	-	-	-	-
Sycamore Chute	1	24.92	angled U/S						0.22	Above Loosahatchie 5	
	2	27.92	angled U/S						0.38	Above Loosahatchie 6	
	3	70.00	angled D/S					0.23			
	4	8.00	angled D/S					0.22			
Robinson Crusoe	1	33.95	angled D/S								
	2										
Dismal Point	1U							0.29			5381
	1							0.21			5315
	2	-	-	-	-	-	-	-	-	-	-
	3							0.39			6824
	4							0.28			7218
	5, 5T	26.47	angled U/S	50.50	angled D/S			0.48			
	6	21.00	angled U/S				0.29				

**Table B.3a: Dike geometric data table for Armstrong, Cat Island, Seyppel, Pickett, Island 62, Island 63, and Island 63 Bar for the Memphis District (columns 1 through 14)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Location (RM)	Side of River	Dike Type	LWRP (ft, NGVD)	Bank Head Position			Main Body Position		
								Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)
Armstrong	1	1963	1970	720.1	R	L-head	176	225	203	27	320	193	17
	2	1963	1968	719.4	R	L-head	175	110	209	34	205	192.2	17.2
	3	1969		718.5	R	L-head	175	260	198	23	550	192	17
	4	1969		717.3	R	Transverse	174	430	194	20	435	191	17
Cat Island	1	-	-	-	-	-		-	-	-	-	-	-
	2	1932	1965	712	R	Transverse	172	405	179.2	7.2			-172
	3A	1958		711.6	R	Transverse	172	367	206	34	510	187	15
	4A	1958	1990	710.9	R	L-head	172	300	192	20			-172
	4B	1970		710.1	R	Transverse	172	200	204	32			-172
	5	1958		710	R	Transverse	172	290	204	32	390	186.6	14.6
Seyppel	6	1958	1962	709	R	L-head	171	210	211	40	410	186.3	15.3
	1	1963	1991	706.4	R	L-head	170	300	203	33	430	192	22
	2	1963		705.8	R	Transverse	169	124	196	27	225	185	16
	3	1963	1966	705.3	R	Transverse	169	180	179.5	10.5			-169
	4	1997		704.9	R	L-head	168	190	179.9	11.9			-168
	5	1997		704.2	R	L-head	168	343	179.2	11.2			-168
Pickett	1U	1997		704.9	L	L-head	168	120	180.1	12.1			-168
	1	1965	1997	704.5	L	L-head	168	310	182	14	357	178.5	10.5
	2	1965	1997	704	L	L-head	167	320	182	15			-167
	3	1965	1997	703.6	L	L-head	167	240	193	26			-167
Island 62	1	1963	1968	640	R	Transverse	137	80	166	29	160	152	15
	2	1963	1965	639.7	R	Transverse	136	54	171	35	190	152.5	16.5
	3	1963	1965	639.4	R	Transverse	136	239	167	31	335	152.2	16.2
	4	1969		638.1	R	Transverse	135	170	155	20			-135
	4.5	1974		637.4	R	Transverse	135	350	156	21	540	149	14
	5	1974		636.2	R	L-head	133	120	153	20	320	148	15
Island 63	1	-	-	-	-	-		-	-	-	-	-	-
	2	-	-	-	-	-		-	-	-	-	-	-
	3	-	-	-	-	-		-	-	-	-	-	-
	4A	1960	1969	640.4	L	Transverse	137	140	148	11			-137
	5A	1960		640	L	Transverse	137	245	165	28	330	150.7	13.7
	6	1959	1974	639.4	L	Transverse	136	55	153	17			-136
Island 63 Bar	1	1974		639.4	L	L-head	136	-785.27	171.7	35.7			-136
	2	1974		639.2	L	L-head	136	216	164	28			-136

**Table B.3b: Dike geometric data table for Armstrong, Cat Island, Seyppel, Pickett, Island 62, Island 63, and Island 63 Bar for the Memphis District (columns 15 through 30)**

Dike Field	Dike No.	Downhill Slope Position			Dike End Position			Length (ft)	Representative Elevation		Slope (ft/ft)	Notch*		dike angle (deg)	
		Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)		(ft)	(ft, LWRP)			features		
Armstrong	1	5800	185	9	5900	165	-11	5575	192	16	0.0015	x		80.75	angled D/S
	2	4725	205	30	4730	199	24	4615	192.2	17.2	-0.0003	x		75.00	angled D/S
	3	3500	187	12	3530	181	6	3240	192	17	0.0000	x		85.00	angled D/S
	4	1900	186	12	1940	162	-12	1470	186	12	0.0000	x		84.00	angled D/S
Cat Island	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	850	179.2	7.2	885	166	-6	445	179.2	7.2	0.0000	x		59.33	angled D/S
	3A			-172	1780	182	10	1413	187	15	0.0000	x		85.98	angled D/S
	4A	4500	175	3	4560	158	-14	4200	192	20	0.0000	x		85.90	angled D/S
	4B	2750	179	7	2850	158	-14	2550	186	14	0.0084	x		90.00	
	5			-172	2212	191.6	19.6	1922	186.6	14.6	0.0000	x		90.00	
Seyppel	6			-171	1840	186.3	15.3	1630	186.3	15.3	0.0000	x		65.93	angled D/S
	1			-170	2899.14	193	23	2599.14	188	18	0.0000	x		90.00	
	2			-169	3913	185	16	3789	185	16	0.0000	x		84.27	angled D/S
	3			-169	2985	179.5	10.5	2805	179.5	10.5	0.0000	x		73.00	angled D/S
	4	2300	179.9	11.9	2422	155	-13	2110	179.9	11.9	0.0000	O	26' crown	73.39	angled D/S
Pickett	5	1630	179.2	11.2	1745	155.7	-12.3	1287	179.2	11.2	0.0000	x		99.52	angled U/S
	1U	1250	180.1	12.1	1390	151.5	-16.5	1130	180.1	12.1	0.0000	x		87.62	angled D/S
	1	1860	179.5	11.5	1965	158	-10	1550	179.5	11.5	-0.0007	x		101.98	angled U/S
	2	2900	179.1	12.1	3030	153	-14	2580	179.1	12.1	-0.0003	x		104.00	angled U/S
Island 62	3	4250	178.2	11.2	4403	148	-19	4010	178.2	11.2	0.0023	O	35' crown	110.47	angled U/S
	1	1400	154	17	1450	149	12	1320	152	15	0.0000	x		90.00	
	2			-136	3200	144	8	3146	152.5	16.5	0.0000	x		84.02	angled D/S
	3			-136	3200	146.2	10.2	2961	152.2	16.2	0.0000	x		93.00	angled U/S
	4			-135	2000	129	-6	1830	149	14	0.0000	x		96.52	angled U/S
	4.5			-135	2410	149	14	2060	149	14	0.0000	x		80.97	angled D/S
Island 63	5	4400	154.5	21.5	4430	132	-1	4280	148	15	0.0000	x		86.07	angled D/S
	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4A	2180	144	7	2320	107	-30	2040	149	12	-0.0008	x		84.78	angled D/S
	5A			-137	1845	155.7	18.7	1600	150.7	13.7	0.0000	x		84.80	angled D/S
Island 63 Bar	6			-136	1875	171.8	35.8	1820	154	18	0.0000	x		90.00	
	1			-136	1160	150	14	1945.27	171.1	35.1	0.0000	x		74.83	angled D/S
	2	800	153	17	1000	99	-37	584	153	17	0.0188	x		70.98	angled D/S

\* x = no notch and O = notch

**Table B.3c: Dike geometric data table for Armstrong, Cat Island, Seyppel, Pickett, Island 62, Island 63, and Island 63 Bar for the Memphis District (columns 31 through 42)**

Dike Field	Dike No.	1st deflection angle (deg)		2nd deflection angle (deg)		3rd deflection angle (deg)		Side Conveyance (x 10 <sup>6</sup> ) - one side only	Side Conveyance (x 10 <sup>6</sup> ) - both sides of bank		Width of Main Channel at 0 LWRP (ft)
										Jointed dike	
Armstrong	1	45.00	angled U/S	45.00	angled D/S			0.53			6693
	2	26.57	angled U/S	26.57	angled D/S			0.38			6693
	3	20.00	angled D/S					0.30			6562
	4										4593
Cat Island	1	-	-	-	-	-	-	-	-	-	-
	2							0.10			2165
	3A							0.15			4068
	4A	20.68	angled D/S	13.40	angled U/S	41.60	angled U/S	0.37			6660
	4B							0.17			
	6	25.17	angled U/S								
Seyppel	1	30.17	angled D/S	4.58	angled U/S	4.58	angled D/S	0.12			7021
	2							0.34			7054
	3							0.41			7021
	4	22.00	angled D/S						0.32	Pickett 1U	6430
	5	22.00	angled D/S						0.28	Pickett 1	5052
Pickett	1U	10.00	angled U/S						0.32	Seyppel 4	5118
	1	10.00	angled U/S						0.28	Seyppel 5	5118
	2	20.00	angled U/S					0.24			5774
	3	20.00	angled U/S					0.27			6562
Island 62	1								0.46	Island 63 4A	5709
	2							0.32			6037
	3								0.30	Island 63 Bar 2	6660
	4							0.23			
	4.5							0.23			
	5	11.00	angled D/S					0.33			5249
Island 63	1	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-
	4A								0.46	Island 62 1	5052
	5A										4593
	6										
Island 63 Bar	1	13.07	angled U/S								
	2	12.00	angled D/S						0.30	Island 62 3	

**Table B.4: Dike geometric data table for the Memphis District (vane dikes)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Location (RM)	Side of River	LWRP (ft)	Dike Start Position			Dike End Position			Length (ft)
							Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	
Wrights Point	5A	1968		820.3	R	223.5	0	237	13.5	1000	237	13.5	1000
	5B	1968		820	R	223.5	1550	236	12.5	2550	237	13.5	1000
	5C	1968		819.6	R	223.5	3050	235	11.5	4050	235	11.5	1000
	5D	1970		818.8	R	222.7	450	244	21.3	2600	238	15.3	2150
Dismal Point	1UT	1965		725.6	R	181.5	2512	191	9.5	4012	186	4.5	1500
Armstrong	3A	1969		718.5	R	176.7	0	193	16.3	500	192	15.3	500
	3B	1969		718.3	R	176.5	1200	191	14.5	2200	191	14.5	1000
	3C	1969		718	R	176.3	3050	189	12.7	4050	189	12.7	1000
Cat Island	4AT	1958	1991	710.4	R	173.9	0	187	13.1	2800	205	31.1	2800
Island 62	4A	1969		638	R	136.6	0	150	13.4	800	150	13.4	800
	4B	1969		637.7	R	136.6	1200	147	10.4	2000	149	12.4	800
	4C	1969		637.5	R	136.6	2450	149	12.4	3000	148	11.4	550
	4D	1970	1977	637	R	135	200	161	26	3578	149	14	3378

**Table B.5a: Dike geometric data table for Island 70, Catfish Point, Chicot Landing, Ashbrook Cutoff, and Ashbrook-Miller Bend for the Vicksburg District (columns 1 through 14)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Location (RM)	Side of River	Dike Type	LWRP (ft, NGVD)	Bank Head Position			Main Body Position			
								Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	
Island 70	1	-	-	-	-	-	-	-	-	-	-	-	-	
	2	-	-	-	-	-	-	-	-	-	-	-	-	
	3	-	-	-	-	-	-	-	-	-	-	-	-	
	4	-	-	-	-	-	-	-	-	-	-	-	-	
	5	1990		606.4	L	Transverse	112	3210	142	30				
	6	1990		606.3	L	Transverse	112	2765	137	25				
	7	1990		605.8	L	Transverse	112	425	153	41				
	8	-	-	-	-	-	-	-	-	-	-	-	-	-
	9	1993		605.3	L	Transverse	116	55	148	32	200	142	26	
	10	1993		605	L	Transverse	116	40	146	30	165	139	23	
11L	-	-	-	-	-	-	-	-	-	-	-	-	-	
Catfish Point	1	-	-	-	-	-	-	-	-	-	-	-	-	
	2	-	-	-	-	-	-	-	-	-	-	-	-	
Chicot Landing	1	1968		565.5	R	Transverse	99	185	145	46	220	131.5	32.5	
	2	1968		564.8	R	Transverse	99	140	144	45	205	123.5	24.5	
	3	1967	1986	564	R	Transverse	99	78	145.8	46.8	400	124	25	
	4	1995		563.8	R	Transverse	99	410	152	53	600	115	16	
	5	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	1995		563.4	R	Transverse	99	455	130	31	640	108	9	
Ashbrook Cutoff	1	-	-	-	-	-	-	-	-	-	-	-	-	
	2	-	-	-	-	-	-	-	-	-	-	-	-	
	3	-	-	-	-	-	-	-	-	-	-	-	-	
	4	1962	1969	548.3	L	Transverse	94	340	125	31	520	106	12	
Ashbrook-Miller Bend	2UL	-	-	-	-	-	-	-	-	-	-	-	-	
	1UL	1983		547.3	L	Transverse	93	420	118.5	25.5	700	97	4	
	1L	1965		546.81	L	Transverse	93	5165	124	31	5460	110.5	17.5	
	2L	-	-	-	-	-	-	-	-	-	-	-	-	
	3L	1965	1966	545.72	L	Transverse	93	3600	113.5	20.5				
	1R	-	-	-	-	-	-	-	-	-	-	-	-	
	2R	1965		547.66	R	Transverse	94	243	114	20	400	105	11	
	3R	1965		547.09	R	Transverse	93	340	113	20	550	104	11	
4R	1965		546.54	R	Transverse	93	240	112.5	19.5	400	104	11		

**Table B.5b: Dike geometric data table for Island 70, Catfish Point, Chicot Landing, Ashbrook Cutoff, and Ashbrook-Miller Bend for the Vicksburg District (columns 15 through 30)**

Dike Field	Dike No.	Downhill Slope Position			Dike End Position			Length (ft)	Representative Elevation		Slope (ft/ft)	Notch*		dike angle (deg)		
		Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)		(ft)	(ft, LWRP)			features			
Island 70	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	5	3940	105	-7	3975	93	-19	730	114	2	0.0188	x				
	6	3420	98	-14	3460	87	-25	655	103	-9	0.0266	x				
	7	2320	118	6	2580	93	-19	1895	118	6	0.0087	x				
	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	9	1500	103.5	-12.5	1520	99	-17	1445	119	3	0.0000	x				
	10	1300	98	-18	1330	92	-24	1260	118	2	0.0000	x				
	1L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Catfish Point	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Chicot Landing	1	2600	99	0	2625	89	-10	2415	117	18	0.0067	x		114.51	angled U/S	
	2	2945	114	15	3070	104	5	2805	114	15	0.0035	x		88.07	angled D/S	
	3				3725	116	17	3647	119	20	0.0024	O	peaked crown	98.29	angled U/S	
	4	1750	111	12	1820	101	2	1340	114	15	0.0035	x				
	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6				1360	103	4	905	105	6	-2.2200	x				
Ashbrook Cutoff	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	4				1300	108	14	960	106	12	0.0000	x		78.77	angled D/S	
Ashbrook-Miller Bend	2UL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	1UL				1220	72	-21	800	88	-5	0.0273	x				
	1L	6038	99	6	6075	92	-1	873	100.5	7.5	0.0199	x		89.23	angled D/S	
	2L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	3L	4695	101	8	4827	83	-10	1095	101	8	0.0114	x		85.88	angled D/S	
	1R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	2R	1280	70	-24	1310	57.5	-36.5	1037	96	2	0.0167	x		102.53	angled U/S	
	3R	1500	85	-8	1545	76.5	-16.5	1160	95	2	0.0106	x		74.41	angled D/S	
4R	1140	78	-15	1180	62	-31	900	97	4	0.0143	x		84.18	angled D/S		

\* x = no notch and O = notch

**Table B.5c: Dike geometric data table for Island 70, Catfish Point, Chicot Landing, Ashbrook Cutoff, and Ashbrook-Miller Bend for the Vicksburg District (columns 31 through 42)**

Dike Field	Dike No.	1st deflection angle (deg)		2nd deflection angle (deg)		3rd deflection angle (deg)		Side Conveyance (x 10 <sup>6</sup> ) - one side only	Side Conveyance (x 10 <sup>6</sup> ) - both sides of bank		Width of Main Channel at 0 LWRP (ft)
										Jointed dike	
Island 70	1	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-
	4	-	-	-	-	-	-	-	-	-	-
	5							0.15			
	6							0.16			
	7							0.05			
	8	-	-	-	-	-	-	-	-	-	-
	9							0.18			
	10							0.19			
	11L	-	-	-	-	-	-	-	-	-	-
Catfish Point	1	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-
Chicot Landing	1							0.11			4724
	2							0.18			5085
	3							0.23			5840
	4							N/A			
	5	-	-	-	-	-	-	-	-	-	-
	6							N/A			
Ashbrook Cutoff	1	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-
	4							N/A			
Ashbrook-Miller Bend	2UL	-	-	-	-	-	-	-	-	-	-
	1UL								0.43	Ashbrook-Miller Bend 3R	4199
	1L								0.25	Ashbrook-Miller Bend 4R	4757
	2L	-	-	-	-	-	-	-	-	-	-
	3L							0.12			5282
	1R	-	-	-	-	-	-	-	-	-	-
	2R							N/A			4035
	3R								0.43	Ashbrook-Miller Bend 1UL	4528
4R								0.25	Ashbrook-Miller Bend 1L	4265	

**Table B.6a: Dike geometric data table for Island 82-Miller Bend, Island 86, Lower Cracraft, Carolina, Wilson Point, Baleshed Landing, and Ben Lomond for the Vicksburg District (columns 1 through 14)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Location (RM)	Side of River	Dike Type	LWRP (ft, NGVD)	Bank Head Position			Main Body Position		
								Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)
Island 82-Miller Bend	1L	1966		545.9	L	Transverse	94	0	87.5	-6.5	117	84	-10
	2L	-		-	-	-	-	-	-	-	-	-	-
	3L	-		-	-	-	-	-	-	-	-	-	-
	4L	-		-	-	-	-	-	-	-	-	-	-
	1R	-		-	-	-	-	-	-	-	-	-	-
	2R	-		-	-	-	-	-	-	-	-	-	-
	3R	-		-	-	-	-	-	-	-	-	-	-
	4R	-		-	-	-	-	-	-	-	-	-	-
Island 86	1	-		-	-	-	-	-	-	-	-	-	-
	2	1970	1988	519.8	R	L-Head	80	200	118	38	250	111	31
	3	-		-	-	-	-	-	-	-	-	-	-
	4	-		-	-	-	-	-	-	-	-	-	-
	4chute	-		-	-	-	-	-	-	-	-	-	-
Lower Cracraft	5	1994		517.1	R	Transverse	78	435	109	31	620	93	15
	1	1970		510.25	R	L-Head	74	40	100.5	26.5			
	2	1970		509.7	R	L-Head	74	20	100	26	90	96	22
Carolina	3	1971		508.9	R	L-Head	73	60	98	25	390	90	17
	1	-		-	-	-	-	-	-	-	-	-	-
Wilson Point	2	1974		509	L	Transverse	74	200	105	31			
	1	1969		500.6	R	Transverse	72	170	106	34	200	97	25
Baleshed Landing	2	1969		500	R	L-Head	72	310	107	35	410	92.5	20.5
	3	1992		498.2	R	Transverse	72	430	102	30	700	80	8
	1	1965		494.6	L	Transverse	70	140	63	-7			
Ben Lomond	2	1965	1997	493.9	L	Transverse	69	300	79	10			
	3	1965	1997	493.1	L	Transverse	69	365	100	31	580	85	16
	4	1965	1997	492.3	L	Transverse	68	160	85	17			
	5	1965	1989	491.4	L	Transverse	68	870	103	35	1000	83	15
Ben Lomond	6	1992		490.1	L	Transverse	67	315	104	37	600	73	6
	1	-		-	-	-	-	-	-	-	-	-	-
	2	-		-	-	-	-	-	-	-	-	-	-
Ben Lomond	3	1970	1987	486.3	L	Transverse	65	122	80	15			
	4	1978	1987	485.3	L	Transverse	64	140	90.5	26.5	250	83	19

**Table B.6b: Dike geometric data table for Island 82-Miller Bend, Island 86, Lower Cracraft, Carolina, Wilson Point, Baleshed Landing, and Ben Lomond for the Vicksburg District (columns 15 through 30)**

Dike Field	Dike No.	Downhill Slope Position			Dike End Position			Length (ft)	Representative Elevation		Slope (ft/ft)	Notch*		dike angle (deg)	
		Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)		(ft)	(ft, LWRP)			features		
Island 82-Miller Bend	1L				697	87.5	-6.5	697	84	-10	-0.0299	x		85.88	angled D/S
	2L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4L	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1R	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2R	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3R	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Island 86	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	4980	83	3	5100	70	-10	4780	88	8	0.0015	x		117.46	angled U/S
	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4chute	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lower Cracraft	5	1540	93	15	1580	80	2	1105	94	16	-0.2400	x			
	1	1840	88	14	1890	49	-25	1800	90	16	0.0059	x		92.53	angled U/S
	2	3300	88	14	3460	68	-6	3280	89.5	15.5	0.0017	x		77.07	angled D/S
Carolina	3	4200	86	13	4345	61	-12	4140	86	13.0	0.0013	x		93.89	angled U/S
	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wilson Point	2	-	-	-	1310	40	-34	1110	75	1	0.0402	x		99.64	angled U/S
	1	1440	64.5	-7.5	1542	47	-25	1270	86	14	0.0119	x		102.54	angled U/S
Baleshed Landing	2	2520	68.5	-3.5	2530	64	-8	2210	85	13	0.0040	x		83.18	angled D/S
	3	4855	93	21	4865	91	19	4425	102	30	0.0004	O	5'crwon		
	1	580	52	-18	820	26	-44	440	52	-18	0.0393	x		76.47	angled D/S
	2	1300	67	-2	1340	56	-13	1000	70	1	0.0102	O		105.78	angled U/S
	3	2400	78.5	9.5	2500	70	1	2035	78.5	9.5	0.0037	O		106.10	angled U/S
Ben Lomond	4	2950	85	17	3060	73	5	2790	84	16	0.0000	O		96.62	angled U/S
	5	4140	74.5	6.5	4200	68	0	3270	77.5	9.5	0.0018	x		106.22	angled U/S
	6	4700	102	35	4705	96	29	4385	102	35	-0.0121	x			
Ben Lomond	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3				3710	77.1	12.1	3588	79	14	0.0400	x		72.08	angled D/S
	4	2600	78	14	2750	50	-14	2460	80.5	16.5	0.1600	x		97.94	angled U/S

\* x = no notch and O = notch

**Table B.6c: Dike geometric data table for Island 82-Miller Bend, Island 86, Lower Cracraft, Carolina, Wilson Point, Baleshed Landing, and Ben Lomond for the Vicksburg District (columns 31 through 42)**

Dike Field	Dike No.	1st deflection angle (deg)	2nd deflection angle (deg)	3rd deflection angle (deg)	Side Conveyance (x 10 <sup>6</sup> ) - one side only	Side Conveyance (x 10 <sup>6</sup> ) - both sides of bank		Width of Main Channel at 0 LWRP (ft)	
							Jointed dike		
Island 82-Miller Bend	1L								
	2L	-	-	-	-	-	-	-	
	3L	-	-	-	-	-	-	-	
	4L	-	-	-	-	-	-	-	
	1R	-	-	-	-	-	-	-	
	2R	-	-	-	-	-	-	-	
	3R	-	-	-	-	-	-	-	
4R	-	-	-	-	-	-	-	-	
Island 86	1	-	-	-	-	-	-	-	
	2	36.42	angled U/S	10	angled D/S	0.56		6857	
	3	-	-	-	-	-	-	-	
	4	-	-	-	-	-	-	-	
	4chute	-	-	-	-	-	-	-	
	5					0.09			
Lower Cracraft	1	34.34	angled U/S			0.09		3937	
	2	18.34	angled U/S					6168	
	3	13.48	angled U/S				0.62	Carolina 2 7940	
Carolina	1	-	-	-	-	-	-	-	
	2						0.62	Lower Cracraft 3 4265	
Wilson Point	1					0.14		2920	
	2	25.20	angled U/S			0.22		4560	
	3					0.11		7448	
Baleshed Landing	1					0.54		2625	
	2					0.20		4003	
	3					0.24		4593	
	4					0.26		6102	
	5					0.46		6037	
	6					0.39		7874	
Ben Lomond	1	-	-	-	-	-	-	-	
	2	-	-	-	-	-	-	-	
	3	11.61	angled U/S	8.83	angled D/S	89.57	angled D/S	0.37	6365
	4							0.16	5282

**Table B.7a: Dike geometric data table for Forest Home Towhead, Marshall Cutoff, Bondurant Towhead, and Waterproof for the Vicksburg District (columns 1 through 14)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Location (RM)	Side of River	Dike Type	LWRP (ft, NGVD)	Bank Head Position			Main Body Position		
								Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)
Forest Home Towhead	6U	1997		452.6	L	Transverse	54	150	90	36	400	68	14
	5U	1991	1992	452	L	Transverse	53	320	88	35	571	72	19
	4U	1991	1994	451.4	L	Transverse	53	455	79.5	26.5	620	68	15
	3U	1991	1994	450.8	L	Transverse	53	500	87	34	720	67	14
	2U	1991	1994	450.2	L	Transverse	53	430	94	41	700	69	16
	1U	1994		449.7	L	Transverse	53	470	89	36	660	67	14
	1	1980	1997	449.2	L	Transverse	52	180	91	39	460	66	14
	2	1980	1997	448.6	L	Transverse	52	220	90	38	325	72	20
	3	1980	1997	448.1	L	Transverse	51	300	86	35	480	65	14
Marshall Cutoff	1	1978		448.2	R	Transverse	51	910	80	29			
	2	1978		447.2	R	Transverse	51	1070	86.5	35.5	1400	77	26
Bondurant Towhead	1U	1991	1998	395.5	R	Transverse	34	216	72	38	780	33	-1
	1	1974	1991	394.8	R	Transverse	34	320	71	37	525	52	18
	2	1973	1991	394	R	Transverse	33	320	67	34	610	48	15
Waterproof	1U	1989	1994	380.6	R	Transverse	28	435	66	38	585	56.5	28.5
	1	1963	1994	379.9	R	L-Head	28	-65	58	30	200	44	16
	2	1963		379.5	R	L-Head	28	260	54	26	360	38	10
	3	1963	1994	379.1	R	L-Head	28	160	60	32	330	43	15
	4	1964		378.8	R	L-Head	27	370	58	31	450	38	11
	5	1963	1965	378.4	R	L-Head	27	420	50	23	700	22	-5

**Table B.7b: Dike geometric data table for Forest Home Towhead, Marshall Cutoff, Bondurant Towhead, and Waterproof for the Vicksburg District (columns 15 through 30)**

Dike Field	Dike No.	Downhill Slope Position			Dike End Position			Length (ft)	Representative Elevation		Slope (ft/ft)	Notch*		dike angle (deg)	
		Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)		(ft)	(ft, LWRP)			features		
Forest Home Towhead	6U	1480	69	15	1492	65.5	11.5	1330	74	20	-0.0019	O	40' crown	N/D	
	5U	-	-	-	1714	52	-1	1394	72	19	0.0010	O		N/D	
	4U	1720	56	3	1760	46	-7	1265	67	14	0.0010	O	fish notch	N/D	
	3U	1860	62	9	1920	48	-5	1360	67	14	0.0012	O	fish notch	N/D	
	2U	1900	56	3	1925	44	-9	1470	66	13	0.0047	O	fish notch	N/D	
	1U	1900	53	0	1915	45	-8	1430	69	16	0.0000	O	14' crown	N/D	
	1	-	-	-	1480	38	-14	1300	66	14	0.0018	O		96.07	angled U/S
	2	1700	40	-12	1720	33	-19	1480	66	14	0.0062	O		92.72	angled U/S
3	-	-	-	1885	21	-30	1585	66	15	0.0000	O		104.94	angled U/S	
Marshall Cutoff	1	2440	53	2	2480	42.5	-8.5	1530	60	9	0.0105	x			
	2	4220	47	-4	4255	41.5	-9.5	3150	56	5	0.0081	x			
Bondurant Towhead	1U	1680	16	-18	1720	11	-23	1464	34	0	0.0000	x			
	1	1940	11	-23	1985	-1	-35	1620	42	8	0.0093	x			
	2	2880	27.5	-5.5	2900	21	-12	2560	44.5	11.5	0.0017	O	fish notch		
Waterproof	1U	1960	11	-17	1995	2	-26	1525	38	10	0.0106	x			
	1	2700	30	2	2775	16	-12	2765	38	10	0.0034	x		92.34	angled U/S
	2				1330	38	10	1070	38	10	0.0000	x		87.60	angled D/S
	3	3240	35.5	7.5	3280	20	-8	3080	37	9	0.0026	x		94.38	angled U/S
	4				2120	38	11	1750	38	11	0.0000	x		93.35	angled U/S
	5				3250	38	11	2830	38	11	0.0000	x		95.51	angled U/S

\* x = no notch and O = notch

**Table B.7c: Dike geometric data table for Forest Home Towhead, Marshall Cutoff, Bondurant Towhead, and Waterproof for the Vicksburg District (columns 31 through 42)**

Dike Field	Dike No.	1st deflection angle (deg)		2nd deflection angle (deg)		3rd deflection angle (deg)		Side Conveyance (x 10 <sup>6</sup> ) - one side only	Side Conveyance (x 10 <sup>6</sup> ) - both sides of bank		Width of Main Channel at 0 LWRP (ft)
									Jointed dike		
Forest Home Towhead	6U							0.08			4068
	5U							0.09			4331
	4U							0.14			4199
	3U							0.12			4462
	2U							0.14			4396
	1U							0.14			4724
	1							0.18			3839
	2							0.19			4692
	3								0.42	Marshall Cutoff 1	4692
Marshall Cutoff	1								0.42	Forest Home Towhead 3	5118
	2							0.19			6430
Bondurant Towhead	1U							0.34			4068
	1							0.27			4724
	2							0.27			5446
Waterproof	1U							0.20			4265
	1	29.08	angled D/S					0.32			5315
	2	11.08	angled D/S					0.14			5217
	3	16.33	angled D/S					0.34			5840
	4	2.25	angled U/S					0.23			6201
	5	7.92	angled D/S					0.38			6562

**Table B.8: Dike geometric data table for Vicksburg District (vane dikes)**

Dike Field	Dike No.	Year of Construction	Year of Extension and/or Stone Fill (Latest)	Location (RM)	Side of River	LWRP (ft)	Dike Start Position			Dike End Position			Length (ft)
							Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	Station (ft)	Elevation (ft)	Elevation (ft, LWRP)	
Chicot Landing	3A	1967	1986	563.8	R	99	3725	116	17	4943	120	21	1218
	3B	1967	1986	563.4	R	99	5560	116	17	6760	119.5	20.5	1200
	3C	1974	1986	563	R	99	6760	119.5	20.5	12090	138	39	5330
Ben Lomond	2A	1968		487.8	L	66	-150	51	-15	1120	55	-11	1270
	2B	1967		487.4	L	66	0	79	13	1000	79	13	1000
	2C	-	-	-	-	-	-	-	-	-	-	-	-
	2D	-	-	-	-	-	-	-	-	-	-	-	-
	3A	1970	1987	486.2	L	65	0	77	12	1000	77.5	12.5	1000
	3B	1974	1975	485.8	L	64	0	78	14	1000	78	14	1000
	3C	1974	1975	485.4	L	64	0	78	14	1000	78	14	1000