Reprinted from Proceedings of the Conference
Rivers '83, Waterway, Port, Coastal and Ocean Division
ASCE/New Orleans, LA
October 24-26, 1983

ENVIRONMENTAL GUIDELINES FOR DIKE FIELDS

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ABSTRACT

Dikes have been used to stabilize and train long sections of the Missouri, Mississippi, and other major meandering rivers. Design criteria for dike fields have usually been limited to flood control and navigation objectives. However, recently completed biological field studies have made possible formulation of general dike design criteria based on ecological considerations. As long as dike fields remain aquatic they provide extremely valuable habitat for fish and macroinvertebrates. The crux of the environmental design problem, therefore, is to design dike fields which do not fill with sediment yet still meet river training objectives.

Methods for controlling dike field sediment accretion include varying basic design parameters such as dike length and crest elevation, constructing gaps or notches in dikes, and using dikes which are not attached to the bank. Additional techniques which may be employed to manage existing dike fields include selective repair of failures, dredging deposited sediments, using dredged material to modify habitat, and placing additional rock or other structures underwater to develop aquatic habitat.

Dike notching is presently the most widely employed environmental feature. Although there is some controversy regarding notch effectiveness, the preponderance of presently available biological data favors notching. Most existing notches have been designed based on intuition, but a compilation of experience allows formulation of a more rational approach. A standard notch design should not be used; instead, a range of notch sizes and configurations should be constructed to provide spatial and temporal habitat diversity. Primary design parameters for notches include location (both within a dike field and along the crest of a given dike), shape, width, and depth.

Introduction

Dikes are longitudinal structures placed in waterways to develop and stabilize channels in desirable alignments. Series of dikes are often used to constrict low flows, thus scouring deeper channels and reducing dredging requirements. Dikes have been used widely on major alluvial rivers throughout the United States. Early training works were mainly single or multiple rows of piling clusters connected by stringers, but almost all structures built in the last 20-30 years have

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been continuous embankments of stone. Training works on most U.S. rivers are nearly complete, and most ongoing work is limited to maintenance and relatively minor additional construction. Dike designs are described by several writers (3, 14, 11). This paper synthesizes available information regarding environmental aspects of dike design. A more extensive treatment is presented by Burch et al. (3).

Hydraulic Effects

Effects of dike field construction on river morphology and hydraulics vary greatly from location to location. For example, the combined effects of reservoirs and training works have converted the lower Missouri river from an extremely dynamic, braided stream with many islands to a single channel with gently sinuous, almost uniform bends. Water surface area has been reduced by 50-70 percent (12, 20). Most of this reduction has been in ecologically valuable backwater and off-channel areas. On the other hand, dikes have caused much smaller change in water surface area along the lower Mississippi (21). The effects of dikes on middle Mississippi River widths and stages have been the topic of lively debate (30 with discussions). Bearing in mind, then, that the nature and magnitude of dike field effects vary from river to river, the following is a cumulative list of effects: bed degradation, increased thalweg depths (32), decreased widths and water surface area at normal and low stages (12, 20, 21, 28), lower stages for low flows, and higher stages for high flows. These effects may be offsetting -- for example, reduction in channel width reduces flow conveyance, but the resultant scour increases conveyance.

On a more local scale, dike fields produce complex patterns of flow and sediment transport. Greatest turbulence occurs in the vicinity of the riverward tips of spur dikes, and teardrop-shaped scour holes develop. When flows just overtop dikes, deep scour also occurs along the downstream faces. Velocities just downstream of dikes are reduced during normal to low flows, allowing finer sediments to be deposited. Bars often form between dikes. When river stage falls below the dike crest elevation, quiescent and near-quiescent conditions develop within and nearby dike fields.

Biological Effects

Dike fields - as long as they remain aquatic - provide habitat in short supply in the "economy" of the riverine ecosystem. Dike structures provide stable, stony, substrate which is rare in most large alluvial rivers, and the resulting density and diversity of benthic macroinvertebrates (fish food organisms) is indeed impressive, especially relative to the adjacent sediments. One lower Mississippi River dike was found to support 2 to 10 times as many taxa of macroinvertebrates with a density of 3 to 4 orders of magnitude greater than adjacent sediments or nearby channel areas (2, 19). Similar findings have been reported for the Missouri and upper Mississippi Rivers (16, 15).

In addition to providing productive substrate, at normal and low stages dikes create areas of low velocity which are valuable habitat for fish, macroinvertebrates, and some wildlife species. Naturally occurring low-velocity habitats such as chutes, sloughs, floodplain lakes, and abandoned channels are extremely diverse and productive, but are often eliminated as rivers are leveed and channelized. Beckett (1) noted the similarity of macroinvertebrate communities found in lower Mississippi River dike fields at low flow (quiescent conditions) to those found in backwaters. Several Missouri River investigators have noted the ecological importance of quiescent waters associated with training structures (25, 31). Studies of several habitat types found along the Missouri and Mississippi Rivers have shown more adult and larval fish species inhabitat dike fields than any other habitat type (5, 7, 22, 33). Dike fields may thus, in a sense, replace the natural backwaters lost due to channelization.

As noted above, long-term effects of river training on riverine hydraulics and morphology in some cases include reductions in total water surface area and backwater area due to stabilization of the channel and sediment accretion around the dikes. Declines in game fishery, commercial fish harvest, fish diversity, and wildlife populations along the Missouri River have been attributed to the construction of training works (12, 13, 18, 20, 26). The effects of dike construction on ecology of other major rivers have not been thoroughly investigated. Investigation is hampered by the lack of pre-dike data and unaltered reaches for comparison and to provide a control.

Environmental Features

Despite the difficulty of quantifying benefits of dike field environmenral features, incorporation of environmental considerations into river engineering projects and testing of environmental features is a worthwhile endeavor. Recent findings concerning river ecology, biological responses to environmental features, and the habitat requirements of various fish and wildlife species make possible a more rational, less intuitive approach to environmental feature design. In addition, the advanced stage of most river training projects means that opportunities for modification of river training practices are rapidly diminishing.

Variation of Design Parameters

Dike designers normally must select dike field location, dike plan, crest elevation, crest profile, dike length, the angle of dike with the channel and the sequence of construction for a given reach. Of these parameters, dike field location is probably the greatest determinant of the rate and extent of sediment accretion within the dike field (and thus its lifetime as aquatic habitat), but is less easily manipulated than the other parameters because of constraints imposed by engineering objectives. There is little information presently available regarding the effects of dike design parameters on scour and deposition within the dike field relative to the amount of information available regarding main channel processes.

Franco (1967) reported results of a series of physical model tests of dike design parameter variations. The physical model was a sand-bed model similar to a reach of the lower Mississippi River. Dike fields tested each had three dikes. Although the purpose of the study was to evaluate the ability of various dike designs to develop the navigation channel, it was reported that dike fields with crests sloping riverward and fields with crest elevations stepped up at each successive dike downstream experienced lower within-field deposition than level crested or stepped-down fields.

Franco's work was preliminary and he cautioned against indiscriminate application of his findings to river training design. His results do indicate potential for achieving environmental objectives by varying basic design parameters. In addition to the results noted above, Franco also mentioned the effects of crest elevation and L-heads on within-dike field deposition.

Low Elevation Dikes

Franco observed that the area covered by deposition downstream of the model dikes generally increased with a decrease in length-weighted average dike elevation. Effects of a wide range of crest elevation on the elevation of dike field sediment deposits were not reported. Considerable prototype experience with low elevation dikes is available because of the wide variation in crest elevations employed. Dikes on the upper Mississippi are almost all continuously submerged (impoundments were constructed after the dikes), while some of the dikes on the Missouri River are lower than normal due to degradation or design. In general, lower Mississippi River dikes are overtopped more than middle Mississippi or Missouri River dikes. In some cases, low elevation dikes are built and then raised in subsequent years if necessary to meet river training objectives. Most of the continuously submerged dikes along the upper Mississippi have not filled with sediment, and several investigators have noted their habitat value to fish (10, 23).

L-heads

Franco also tested L-head dikes. The L-heads restricted sediment-carrying bottom currents from moving into the area between the dikes. Flow over the L-head produced scour along the landward face of the trail portion of the dike. The L-head dikes reduced maximum scour at the ends of the dikes and the elevation of deposition between the dikes, compared to the other dike systems modeled. Biological studies along the Missouri River have revealed that small backwaters behind L-head dikes support dense and diverse aquatic communities (5, 27).

Notches

Notches are gaps or indentations in the crests of dikes. Notches may be constructed in new dikes, excavated in existing dikes, or allowed to remain after failure of a portion of a dike. The purposes of designed notches is to allow water to flow through the dike field at intermediate stages to develop or maintain side channels and chutes and prevent additional sediment accretion. Over 1600 dike notches have been constructed along the Missouri River and about 64 have been built in middle Mississippi River dikes. A few notches have been built in upper Mississippi River dikes (some to allow passage of recreational boats), while notches on the lower Mississippi are limited to unrepaired failure notches (3).

Typically, flow through a notch causes a scour hole to develop immediately downstream, and a small bar may form below the scour hole. Missouri River notches have been generally effective in halting or slowing sediment accretion in dike fields. Morphology of the area behind a notched dike is highly variable with time, and thus long periods of observation are required to properly evaluate notch effects. Scour and deposition occur erratically through time depending on hydrographic variations (31). Where notches cause significant increases in dike field current velocities, substrates tend to be coarser and less stable above and below the notch (1, 8, 29).

Most investigators have concluded that dike notches have had beneficial effects on aquatic habitat, either by creating small chutes, submerged bars, and additional aquatic edge or by halting or reducing sediment deposition. However, notch effects are subject to great spatial and temporal variations. Hydrographic variations, dike field design, dike design, and notch design affect performance of notches. Table 2 summarizes biological studies of habitats adjacent to notched dikes.

Notched L-heads

Some of the references in Table 2 report conflicting results of notching L-head dikes. The four notched L-heads in the Missouri River miles 160-179 study area provided more aquatic habitat than similar, unnotched structures but the quality of the habitat was marginal. Habitat diversity was poor and species richness and catch rates were low. Conversely, notched L-heads and revetments in the Missouri River mile 530-565 area provided better habitat than notched spur dikes. Jennings (17) reported the Missouri River notched L-head dikes he studied provided marginal habitat for zooplankton, benthos and fish that was inferior to areas adjacent to notched spur dikes but superior to main channel border. Smith et al. (29) noted that bed samples taken downstream of notched dikes contained more sand than unnotched dikes, but samples taken downstream of notched L-heads contained less sand than those from notched spur dikes. Beckett et al. (1) reported a deep failure notch in a lower Mississippi River L-head dike created undesirable high velocity conditions within the dike field. A shallower notch might have provided more desirable results.

Rootless and Vane Dikes

A few low-elevation rootless dikes have been built between existing dikes in Missouri River dike fields, and there are a few rootless structures along other rivers because of flank failures or increased water levels due to impoundment. Vane dikes are found in some reaches of the Missouri and lower Mississippi. No quantitative information is available regarding effects on habitat. Burke and Robinson (4) reported that inspections and hydrographic surveys around Missouri River rootless dikes indicated the structures have been effective in developing habitat diversity and preventing sediment accretion.

TABLE 2. Results of Biological Studies of Notched Dikes

Survey Area	Effect of Notches[1/]	Major Findings and Conclusions	Reference
Missouri River. Channelized and unchannelized reaches in South Dakota, Nebraska, and Iowa. Notched and unnotched dikes.	+	Largest fish catches in the channelized reach came from habitats created at these structures and were similar to catches from backwater and chutes in the unchannelized reach.	18
Missouri River, Missouri. Spur dikes, L-heads, parallel revetments. (All notched.)	+	Chutes below the spur dikes provided better habitat than L-heads. Enclosed pools behind revetments provided valuable habitat.	17
Missouri River miles 168-186. Notched, rootless, or low elevation dikes and high unnotched dike.	0	Most species and number and weight of fish collected at high unnotched dike in slack water. Habitat favorable for fish at all dikes.	25
Missouri River miles 160-179. Notched spur dikes, notched L-heads, notched revetments.	+	Notches maintained and enhanced chute habitats downstream of spur dikes and enclosed pools behind revetments.	24
Missouri River miles 462-476. Notched L-heads and notched revetments.	+	Structures provided habitat for adult fish and nursery areas for young fish. Preservation of low velocity habitat important.	24
Missouri River miles 530-565. Notched spur dikes, notched L-heads, notched revetments.	+	Best habitat in dike fields with diverse depths and velocities, large areas of still water. Notched spur dikes less valuable than other notched structures.	24

(Continued)

1/ + = Beneficial, 0 = No Effect, - = Detrimental

TABLE 2 (Concluded)

Survey Area	Effect of Notches[1/]	Major Findings and Conclusions	Reference
Missouri River miles 712-704. Notched spur dikes, notched L-heads, notched revetments.	-	Spur dike notches created only high velocity habitat. Revetment notches beneficial by connecting pools behind revetments to the river, allowing fish to enter, spawn, and leave before winter. However, they may increase the rate of sediment deposition.	24
Upper Mississippi River Pool 13. Notched and unnotched spur dikes (submerged). Data before and after notch construction.	-	Benthic macroinvertebrates increased in main-channel border area after notching. No change in side channel benthos or fish. Negative effects (increase in deposition and removal of rock substrate) outweighed positive.	8
Middle Mississippi River miles 95-115. Spur dikes and L-heads (notched and unnotched).	+	Benthic macroinvertebrate diversity higher at notched dikes. No significant difference in fish diversity. Smaller fish at notched dikes. Notches provided habitat diversity.	29
Lower Mississippi River miles 506-566. Unnotched spur dikes and a notched L-head.	-, +	High velocities and sandy, unstable substrate in vicinity of notch. Less benthic macroinvertebrates in vicinity of notch than in other dike fields. Fish diversity slightly greater in dike field with notch.	1, 22

A chute usually develops between a rootless dike and the bank and a low sand bar develops downstream. In some cases rootless dikes have resulted in erosion of the adjacent bankline.

Minimum Maintenance

Flood flows sometimes result in minor damage to dikes such as crest degradation, unraveling channel ends, breaching, or flanking. The lowered and/or irregular crest profiles which result may cause complex flow patterns within the dike fields and improve habitat. If damaged structures remain functionally adequate, it may be advantageous to postpone all or part of the repairs, thus saving money and improving habitat. Some structures (such as old pile dikes) have been routinely allowed to deteriorate and several biological investigators report they are valuable as cover for fish.

Design of Environmental Features

A comprehensive approach to riverine habitat management is recommended over intensive concentration at isolated locations, except when prototype testing is conducted. A comprehensive program should be initiated by conducting a habitat mapping study (6). Goals may then be set for the temporal and spatial distribution and composition of habitat. Composition refers to the breakdown of total acreage among various habitat types (dike field, main channel, natural bank, slough, etc.).

If the results of mapping and goal setting indicate dike field aquatic habitat should be enhanced and/or preserved, the following steps may be followed when designing dike fields:

(1) Evaluate the long-term potential of the dike field as aquatic habitat. The location of dike structures with respect to the thalweg influences the size gradation of sediment deposits and the sediment accretion rate and pattern more than the type or location of notches or other types of structural modification. Location has been observed to be even more important than basic design parameters. Dike fields located in natural depositional zones such as convex bank point bars tend to fill rapidly, while dike fields subject to direct current attack tend to remain open.

(2) Based on the above evaluation, determine if design modifications or environmental features are in order. Dike fields prone to fill rapidly are probably poor candidates for environmental work. However, the preference of many important species for still or slowly-moving water indicates that "depositional" dike fields may provide valuable habitat prior to filling. An ecologically "ideal" dike field would provide still or slowly moving water connected with the main channel at low and intermediate stages, but would scour at high stages.

(3) Consider manipulation of the basic dike design parameters to control the elevation and areal extent of sediment deposition within the dike field. At some sites, longer, lower dikes, L-heads, or vane

dikes might achieve river training goals but produce lower sediment deposits.

(4) Qualitatively project the depths, velocities, and resulting habitat conditions likely to occur in the dike field. Examination of conditions at existing dike fields in similar locations may be helpful.

(5) Consider structural modifications such as notches or rootless dikes.

(6) Consider management techniques such as dredging accumulated sediments, placing dredged material to change flow patterns or form islands, relocation of notches, placing additional stone, constructing reefs and fish attractors, and minimum maintenance.

Notch Design

Although most existing notches were designed based on intuition and professional judgement, a compilation of experience indicates a more rational approach is now possible. A notch designer should first study the design and performance of notches in locations similar to the site in question. If no notches have been constructed in similar situations, perhaps there are a few failure notches. Next, he must determine which dikes to notch. Assuming that dike fields or river reaches that should contain notched structures have been identified during habitat mapping and goal setting, the following criteria should govern selection of specific structures (31):

(1) Notches should not be placed near structures where small amounts of bankline erosion or bed scour might cause problems.

(2) Notches in spur dikes are generally more effective in developing open water than notches in longitudinal dikes.

(3) Notching two adjacent dikes is frequently effective, with the upstream notch and backwater serving as a settling basin for downstream areas.

(4) L-head dikes constructed just upstream from tributary inflows may be notched to prevent sediment buildup at the tributary mouth.

(5) Both notched and unnotched structures provide habitat for distinct assemblages of fish. Therefore, not every dike should be notched.

(6) Experience on the Missouri River indicates selected dikes should be accessible by floating plant and free of sediment deposits, or with only recently accreted sediment deposits free of established vegetation.

(7) If a large number of notches are to be constructed, locations notched first should be those which tend to produce the best habitat. Along the Missouri River, greatest success has been experienced with notches in L-heads or crossing control dikes. Notches in these

locations tend to preserve or develop chutes and enclosed pools. Notches in spur dikes have demonstrated the next highest rate of effectiveness, with longitudinal dikes in the middle of bends third.

After the structures to be notched are identified, the notch should be located on the dike plan and notch dimensions determined. Notches should be far enough from the bankline to prevent flanking problems. The distance from the notch to the riverward tip should be varied from dike to dike to produce diversity. A variety of notch widths, shapes, and depths should be used throughout a reach to provide spatial and temporal habitat diversity. Notches may be either trapezoidal, triangular, or irregular stair-step or saw tooth shapes may be used to develop local habitat diversity. Flow through a triangular notch increases more rapidly with increasing depth than for a trapezoidal notch.

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

Two basic approaches should be used for selecting notch depth: choose a depth that will allow flow almost all the time, or choose a depth that will allow flow only at moderate and high stages, thus providing slack water at low stages. Notch depth should increase with the range of stage fluctuations. Extremely deep notches are effective at developing high velocities and a resultant downstream scour hole. However, once the scour hole is formed, lower velocities and resultant finer-grained substrate are more desirable from a habitat standpoint. In some cases, therefore, it may be advantageous to construct deep, wide notches at first and partially close them after some initial development.

Monitoring

Since there are so many unknowns associated with dike field environmental features and dike design in general, monitoring efforts associated with river stabilization programs should be extended to within dike field phenomena, particularly dike fields with environmental features. Such monitoring will allow estimation of maintenance costs and refinement of design criteria for environmental features. The response of dike field habitat to features such as notches are a function of the subsequent hydrologic record. Therefore, long periods of time (10-20 years) may be required to thoroughly evaluate effects of environmental features.

Conclusions

Dikes and dike fields provide important aquatic habitats along major alluvial rivers developed for navigation. There are several methods for managing, preserving, and enhancing these habitats as dikes are constructed and maintained. Application of recent research findings allows somewhat rational design of dike field environmental features; however, the primitive state of the art and magnitude of potential benefits warrant further investigation.

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