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Ranking Restoration Alternatives for the Lower Mississippi River: Application of Multi-Criteria Decision Analysis

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PURPOSE: There are a variety of engineering techniques available for restoring aquatic habitat in rivers. These include, but are not limited to: reconnecting backwaters and other off-channel features (Hoover et al. 2000; Fischenich and Morrow 2000); enhancement of borrow pits near levees (Hoover and Killgore 2002); creation and preservation of gravel bars (Miller 2006); removal and management of sediment (Killgore et al. 2008). Most could be used at numerous sites along the Lower Mississippi River, but choosing one is the challenge, since an objective method of selecting the best overall technique does not exist. This study describes the creation of a decision support model that ranks river restoration categories for projects identified by the Lower Mississippi River Conservation Committee (LMRCC). Resulting decision scores for different categories represent a consensus of experts participating in model development. High-ranking categories provide greatest benefit for the Mississippi River Conservation Initiative.

BACKGROUND: The LMRCC (*www.LMRCC.org*), a group of twelve state wildlife and environmental member agencies and five federal cooperating agencies, conducted state-level planning meetings from 2001 - 2004 to identify aquatic habitat restoration projects on the Lower Mississippi River (LMR). Referred to as the Mississippi River Conservation Initiative, a total of 220 projects were selected over the four years by the states bordering the LMR: Arkansas, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee (Figure 1). The Habitat Restoration Technical Section of the LMRCC was established to develop long-term strategies to implement the restoration projects identified during these state meetings (Nassar et al. 2006). The extensive spatial scale, large number of sites, and diversity of proposed projects necessitated some level of “information reduction” so that simple recommendations could be made from the available information that would be of use to the large number of Initiative participants. Multicriteria decision analysis (MCDA) was used as a means of objectively identifying the “best” category (i.e., the type of restoration project) based on collective judgment of local experts with experience on the LMR.

In 2006, participants of the Habitat Restoration Technical Section discussed and identified specific criteria for prioritizing projects identified during state meetings. Based on these discussions, categories were formed to classify each individual project based on the type of habitat being restored. A draft Decision Support Model (DSM) was developed using MCDA to rank the categories. The MCDA used input from participants about habitat characteristics of each category, and how they should be weighted. The analysis was presented at subsequent LMRCC meetings. Decision scores generated by the model indicate those categories which result in

Figure 1. Aerial view of Mississippi River at Vicksburg, MS (Hoover, 07 November 2005).

appreciable environmental benefits at reasonable costs (i.e., a high benefit: cost ratio). MCDA is commonly used in the business community to identify the best course of action (e.g., Power 2003) but has recently been used by the Corps of Engineers to assess risks associated with management of aquatic invasive species (Suedel et al. 2005).

APPROACH: Commercial software was used to generate the model and analyze data. Criterium Decision Plus (CDP, Version 3) was used in this study due to its quantitative capabilities in biological research decision making in small group settings. Terminology is important in the understanding of the decision-making process. A goal is defined, followed by primary criteria and sub-criteria. The primary criteria and the sub-criteria are the important factors — determined by the group — needed to make an informed decision. Weights are assigned to the primary criteria and sub-criteria to calculate total scores of all the options or alternatives.

MCDA begins with the brainstorm step, which involves creating a decision tree. Group members provide input for the goal, criteria, sub-criteria and alternatives to the problem. From there, MCDA generates a hierarchy of options to be weighted. The software uses two different types of methodologies: Analytical Hierarchy Process (AHP) and Simple Multiattribute Utility Technique (SMART). AHP assumes a standardized scale of zero to one and does not work well when future additions to the model are necessary. SMART allows the user to set varying scales and adding to the model does not affect the robustness of the results. SMART was the method of choice for this study since habitat restoration is an ongoing procedure involving multiple partners with different objectives. After a method is selected, DSS then calculates scores for the alternatives. This calculation is simple multiplication of weighting factors derived by group members for each level of the model (Murphy et al. 2005).

IDENTIFICATION OF RESTORATION CATEGORIES: The 220 projects were categorized and defined according to the type of habitat being restored (Figure 2). The result was ten alternatives that represented the principal types of restoration projects identified by the Mississippi River Conservation Initiative (*www.LMRCC.org*). Three alternatives were for main channel habitats: notched dikes, islands, and chevrons. Four alternatives were for channel margins: hard points, gravel bars, tributary mouths, and secondary channels. Three alternatives were for floodplains: lakes and backwaters, borrow pits, and batture land (Figure 3A-F). Physical characteristics and restoration techniques varied among the alternatives (Appendix I). Restoring secondary channels and restoring lakes and backwaters were the most frequently suggested project type (N=73 and N=68, respectively), followed by notching dikes in the main channel (N=38). The seven other project types were suggested infrequently (N < 15).

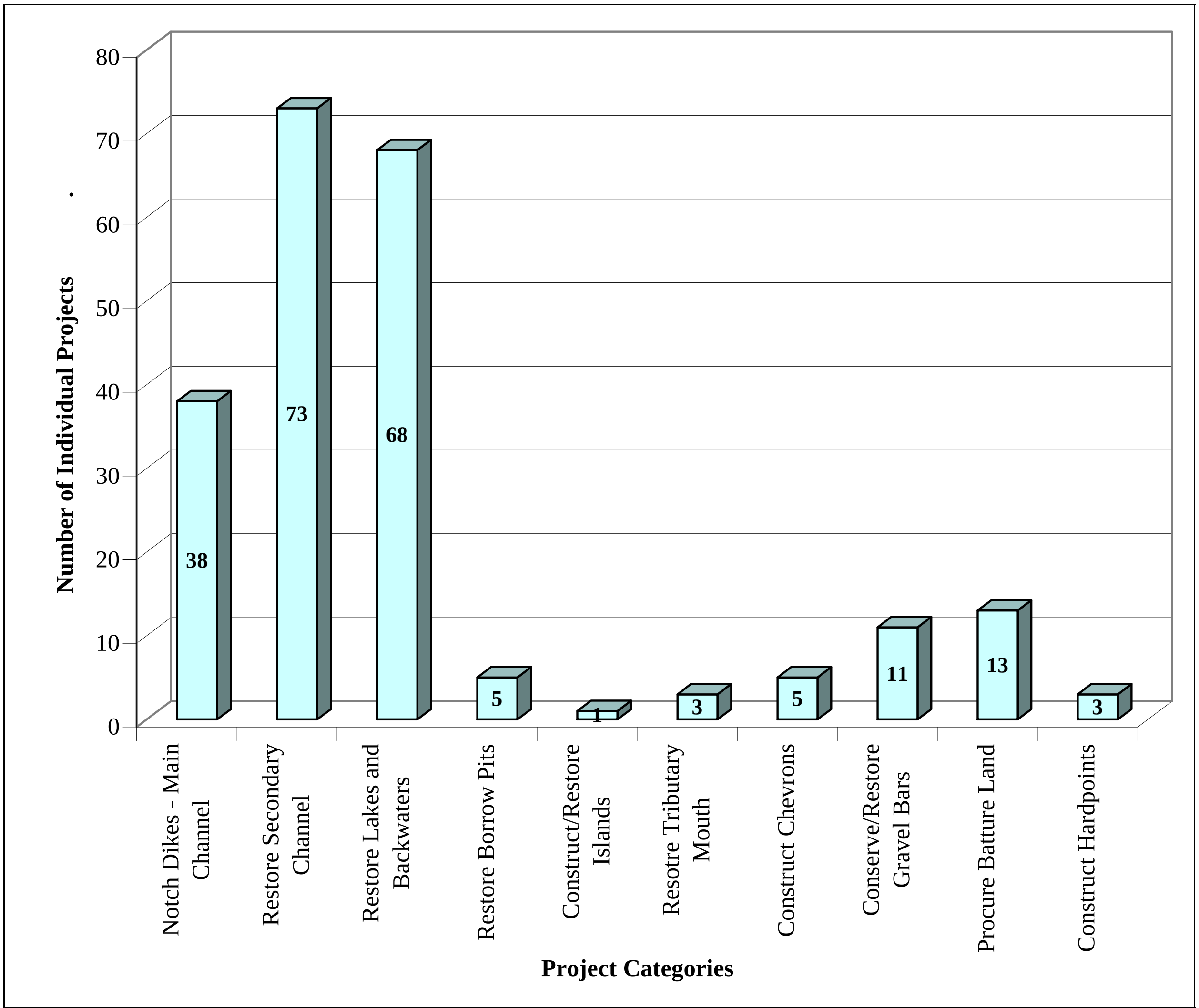

Figure 2. Number of the total 220 projects placed into categories; the categories were identified during state meetings.

Figure 3. Aerial photos of some of the six project alternatives including: secondary channel (A), lakes/backwater (B), borrow pit (C), islands (D), batture land (E) and hardpoints (F) (Hoover, 07 November 2005).

APPLICATION OF MCDA: The goal was to rank the alternatives using CDP. The criteria and sub-criteria were selected from participants in the Habitat Restoration Technical Section meetings. Two criteria were selected and written in the model that represented the most influential criteria in habitat restoration:

- Significance of the habitat
- Cost

Sub-criteria that define each criterion were also selected. Sub-criteria for Significance of Habitat was analogous to variables used in habitat assessment techniques, such as Habitat Evaluation Procedure (HEP) (USFWS 1980).

- Habitat Scarcity/Rarity: Naturally occurring habitat that has been or could be altered by water resource development, agricultural development, or other types of human-induced impacts. This sub-criterion is comparable to areal extent in habitat assessment techniques.
- Degree of Connectivity/Area of Influence: Physical connection of two or more naturally occurring habitats. Habitats can be the same type (e.g., tracts of bottomland hardwoods) or different types (e.g., connecting a backwater with the main channel). This sub-criterion is analogous to a period of occurrence (i.e., temporal) and can be used in habitat assessment techniques.
- Special Status Species: Federal- and state-listed invertebrates (e.g., fat pocketbook mussel), fishes (e.g., pallid sturgeon, paddlefish, blue sucker), and birds (e.g., wood stork, least tern) that will directly benefit from the project. Invasive species (e.g., silver carp) were not considered since they are nearly ubiquitous and there are no effective techniques to exclude them from restored habitats. This sub-criterion is analogous to habitat quality or suitability in habitat assessment techniques.

Sub-criteria for Cost represented total project costs (short-term, long-term) and project lifetime. This enabled users to evaluate respective cost/benefit ratios of different alternatives when selecting a project.

- Construction Costs: Factors to consider include materials, labor, existing funding, access during construction period, and authority (e.g., cost-shared).
- Duration of Benefits: Project life; short term (<10 years) vs. long term (> 10 years)
- Operations and Maintenance costs: Short term (1-time cost) vs. long term (life of project)

The alternatives (i.e., habitats) were clearly defined (Appendix I) based on descriptions in Baker 1991. Relationships between all factors in the model are represented by the “brainstorm” diagram (Figure 4).

The hierarchy step of MCDA completes the appropriate connections based on the brainstorm diagram, which includes the goal, criteria, and sub-criteria (Figure 5). Qualitative or quantitative weights are assigned to these connections. Verbal scores are converted by MCDA to quantitative scores. Qualitative weights were chosen in this exercise. The group of biologists were comfortable and had previous experience with implementing unique descriptors in MCDA.

DECISION SCORES: During a preliminary meeting, a score sheet was prepared (Appendix II) and distributed to each participant in the Habitat Restoration Technical Section. Participants were asked to assign a value of high, medium, or low with regard to the relative importance of the two criteria and six sub-criteria in the decision-making process. A total of 22 participants, representing 10 state and federal agencies, provided input. Habitat was rated a more significant criterion than cost. For the sub-criteria, habitat scarcity was most important, followed by connectivity and special status species in terms of significance of the habitat (Figure 6).

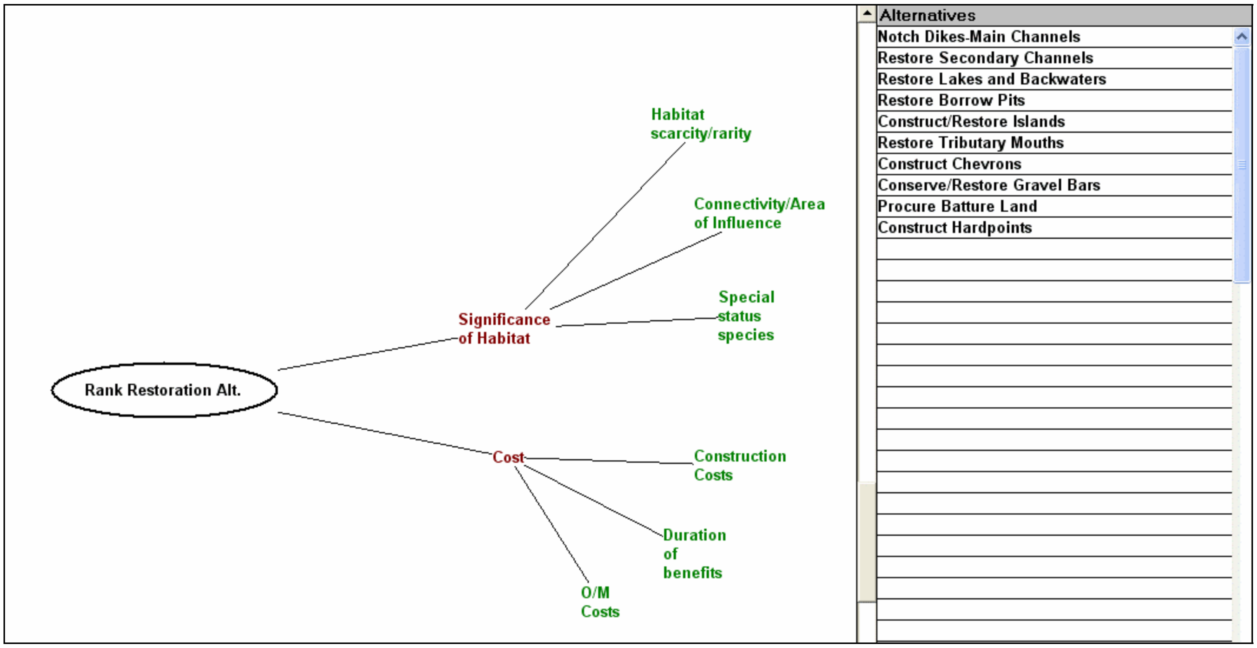

Figure 4. Brainstorm/Decision Tree.

Goal Criteria Sub- Alternat

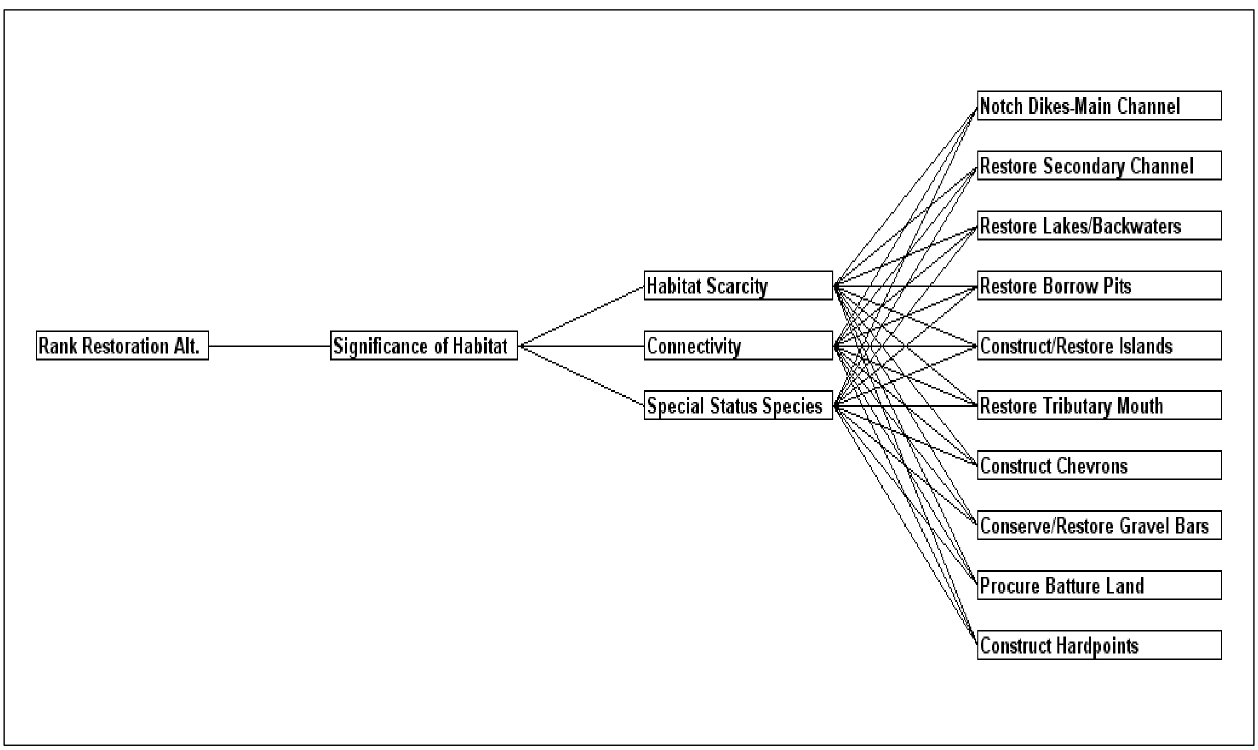

Figure 5. Hierarchy.

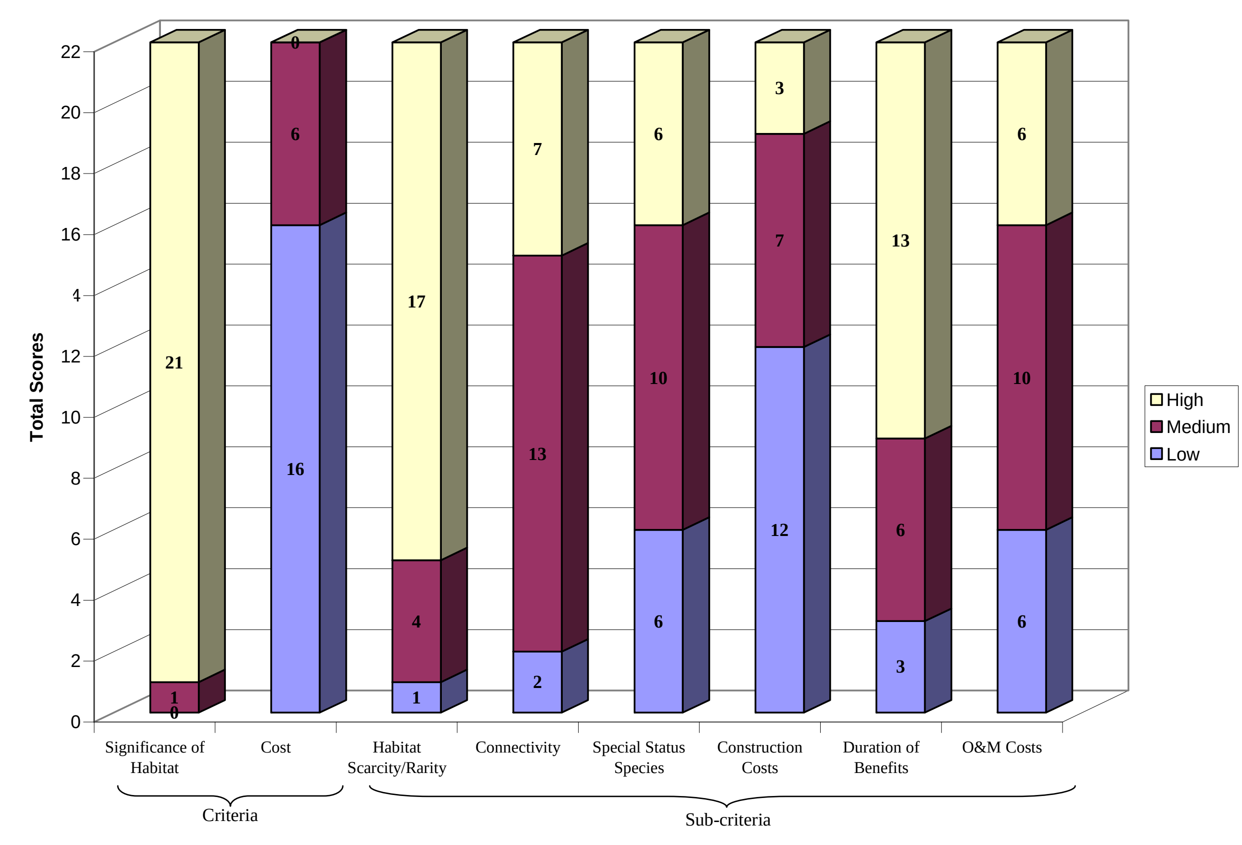

Figure 6. The results from assigning relative importance to criteria and sub-criteria by the Habitat Technical Section.

The final step was to assign relative values between the sub-criteria and each alternative (Table 1). In this step, qualitative descriptions were assigned to each sub-criteria and alternative. For significance of habitat, biologists at ERDC provided the descriptive values for guidance (i.e., rare, common, abundant, permanent, seasonal, never, high benefits, medium benefits, low benefits). For cost, it became apparent to the participants more detailed knowledge was necessary from experts in that field. It was also decided that cost should be excluded from the model because: 1) its impact would always rank lower than the other criterion (i.e., significance of habitat) nullifying its utility; 2) during the initial phase of restoration, cost should not be a factor in decision making; 3) long-term (project costs were unavailable (or inapplicable to many of the alternatives)). Once data are available for individual restoration projects, cost can be reincorporated into the DSM. The highest ranked alternative was restoring secondary channels, followed by notching dikes in main channel and restoring borrow pits (Figure 7). Addition of the sub-criteria mean rankings contributed to the overall score of the categories (Figure 8).

HIGH-SCORING ALTERNATIVES: Four alternatives, representing different riverine habitats, scored highly (decision score > 0.600), indicating a stronger likelihood of environmental benefits than other alternatives (decision score < 0.500).

Table 1. Example of ranking of the sub-criteria to each alternative by a meeting attendee.

Habitat Scarcity **How rare are the following habitats types in the LMR?**		
Rare **(<1 per 10RM)**	**Common** **(2-3 per 10 RM)**	**Abundant** **(>3 per 10 RM)**
Restore Secondary Channels	Conserve/Restore Gravel Bars	Restore Borrow Pits
Restore Lakes and Backwaters	Construct/Restore Islands	Notch Dikes – Main Channel
Restore Tributary Mouth	Procure Batture Land	
Construct Hard points		
Construct Chevrons		
Connectivity **Which project(s) create a connection between macro-habitats (main channel, secondary channel, and floodplain waterbodies)?**		
Permanent **(360 Days/year)**	**Seasonal** **(Stage-dependent)**	**Never** **(No connection made)**
Procure Batture Land	Restore Secondary Channels	Conserve/Restore Gravel Bars
	Restore Lakes and Backwaters	Construct Chevrons
	Restore Tributary Mouth	Construct/Restore Islands
		Restore Borrow pits
		Construct Hard points
		Notch Dikes – Main Channel
Special Status Species **Will the project benefit a state or federally listed species?**		
High Benefits **(Survival and Reproduction)**	**Medium Benefits** **(Feeding and Preferred Habitat)**	**Low Benefits** **(Transient Habitat Utilization)**
Conserve/Restore Gravel Bars	Restore Secondary Channels	Construct Chevrons
Construct/Restore Islands	Restore Lakes and Backwaters	Construct Hard points
	Restore Borrow pits	Notch Dikes – Main Channel
	Restore Tributary Mouth	
	Procure Batture Land	

Borrow pits and tributary mouths (decision scores = 0.625) are floodplain and channel margin habitats, respectively, and are inhabited by distinctive assemblages of small, slackwater fishes (Baker et al. 1991) with special morphological and physiological adaptations to these critical wetland habitats (Hoover and Killgore 1997). They are critically important as surrogate habitats for species characteristic of small floodplain pools, such as pirate perch, taillight shiner, topminnow, pygmy sunfish, and bantam sunfish (Baker et al. 1991). They are also important as nurseries for many main-channel species, such as buffalo and paddlefish. These habitats can also serve as important amphibian habitat and are feeding grounds for wood storks. Mississippi Valley Division (MVD) and Vicksburg District (MVK) have studied, assessed, and developed restoration guidelines for these habitats (Sabo and Kelso 1991).

Notched dikes (decision score = 0.625) are main channel border habitats inhabited by swift water species. Notched dikes increase scour of sediments and diversify depths and velocity, thus making the water suitable for a variety of fish species. Characteristic fishes found in habitats such as this include blue catfish, shovelnose sturgeon, and pallid sturgeon. Notched dikes also function as surrogate habitats for natural scour holes and erosional features. MVD and Memphis District have actively promoted the creation and assessment of these habitats since 1990 (www.LMRCC.org).

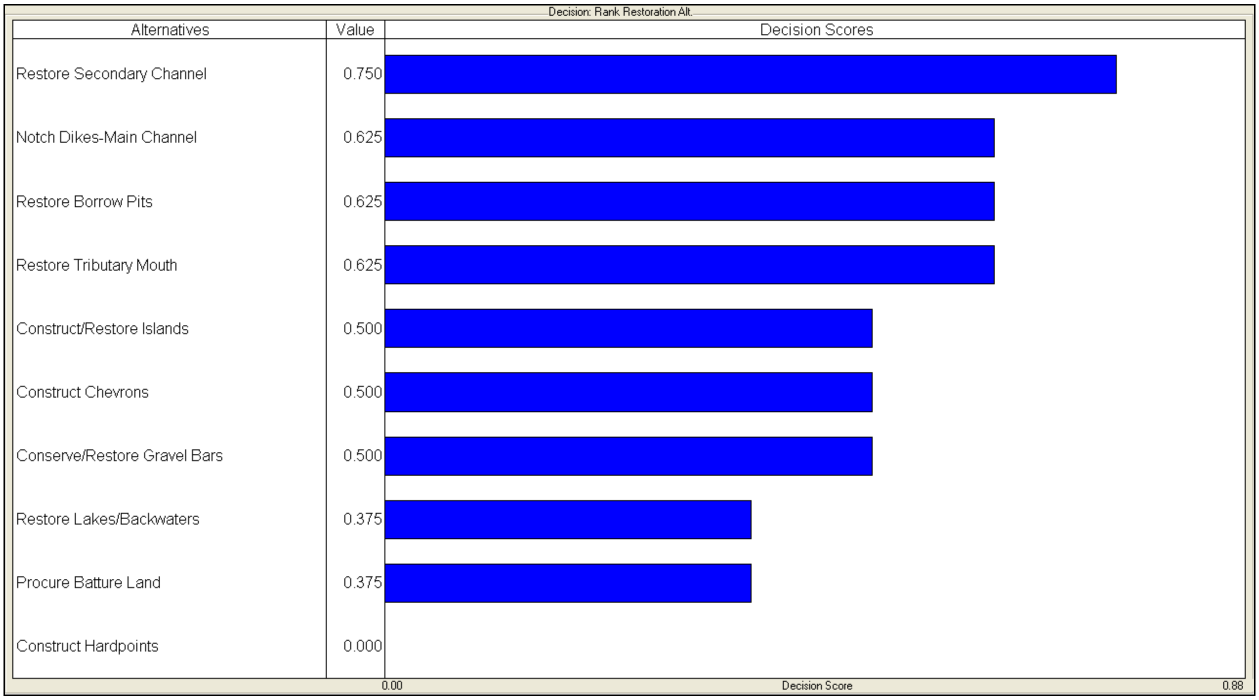

Figure 7. Final decision scores after entire ranking process.

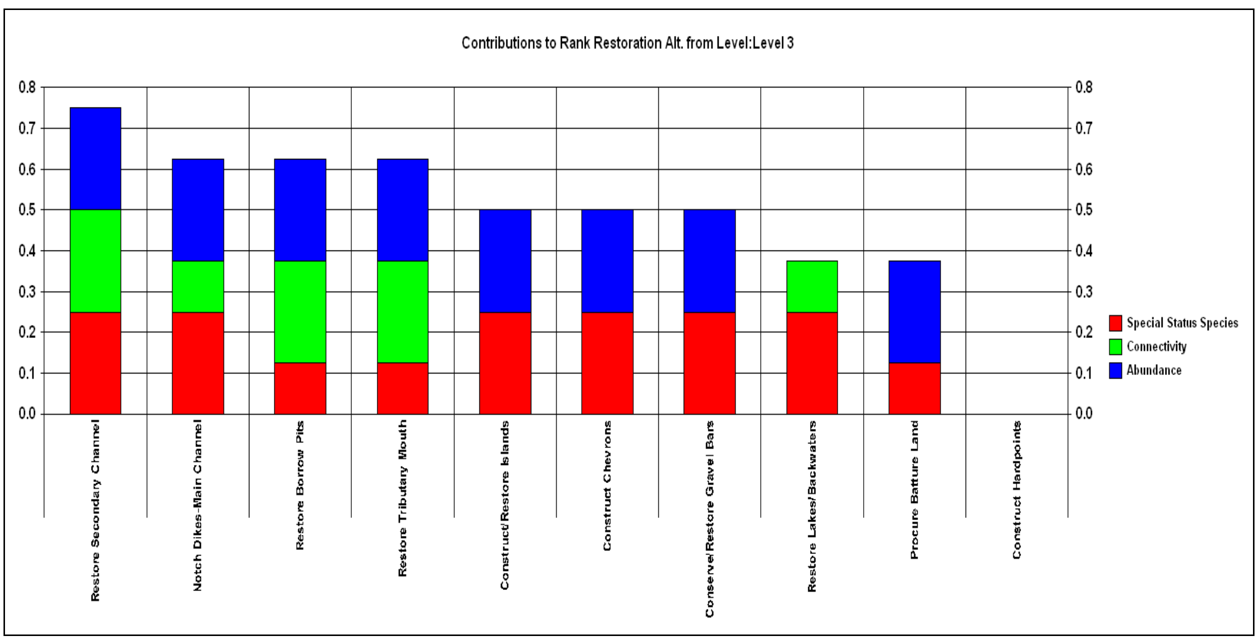

Figure 8. Mean contributions of criteria for each project category.

Secondary channels scored highest (decision score = 0.750). Secondary channels — also referred to as chutes — are usually associated with islands along the margin of the main channel. Secondary channels are relatively rare compared to other habitat categories, and are inhabited by a mix of main channel and backwater species. Zonation within the habitat is pronounced, with lotic species like sturgeon and carpsuckers predominating near the head- and tail-waters. Lentic species such as channel catfish and sunfishes, are abundant in the middle. The abundance of planktivorous fishes like buffalo is high, and insectivorous minnows are common. These habitats are restored by removing or notching closure dikes that were constructed to shunt more flow into the main channel during low water periods. Notching increases flow, scours sediment that has accumulated over time, and increases period of connectivity to the main channel.

APPLICATION OF THE MODEL: The results of the decision model can be used to establish goals — or expected outputs — of restoration, provide a summary of all alternatives for planning purposes, and identify alternatives that should provide higher benefits than others. In fact, the prioritization of categories became guidance when choosing projects for restoration. Historically, secondary channel habitat has been modified greatly by the Mississippi River and Tributaries Project and is nearly absent downstream of Baton Rouge (Baker et al. 1991). An example of a restoration project classified as a secondary channel is Island 63 (RM 640, Coahoma County, MS). Construction for this project began after intensive planning (i.e., engineering, cost calculation, authorization, etc.) took place. Monitoring efforts pre- and post-project found a net gain of 21% in habitat units at a relatively low cost ($36,000), but without restoration, it was predicted that up to 70% of the habitat value of the secondary channel would be lost due to long-term sedimentation. Island 63 demonstrates application of prioritization to better focus efforts on particular projects with a high benefit to cost ratio. The next step is to rank the value of all secondary channels in the lower Mississippi River — choosing those with a high benefit to cost ratio — and to continue restoring flows into these relatively rare, but biologically important riverine habitats. Overall, the decision-support model has made it possible to develop meaningful guidance to meet the goals and objectives of the Mississippi River Conservation Initiative.

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Appendix I - Restoration Project Categories and definitions

Notch Dikes – Main channel: Main Channel dike is a rip rap channel-training structure perpendicular to the bank adjacent to the main channel. Notches placed in main channel dikes increase habitat variability in dike pools.

Restore Secondary Channels: Secondary channels are side channels connected at both ends to the main channel; usually associated with islands. Restore by removing sediment deposition and/or notching dikes. Removing deposited sediment to re-establish flow within secondary channels. Notching secondary channel dikes will restore flow through existing secondary channels (1) or create secondary channels behind recently formed point bars (2). 1. Secondary channel closing structure maintains the majority of flow in the main channel. 2. Main channel dikes can overtime create point bars, which when dikes are notched form the island-secondary channel complex.

Restore Lakes and Backwaters: Lakes and backwaters include: 1. Oxbow Lakes (former channel bendway that has been isolated creating a large crescent shaped body of water) 2. Seasonal lake complex/floodplain pools (small permanent or semi-permanent isolated water bodies not associated with oxbow lakes) 3. Chutes (a long, narrow side channel connected at one end to the main channel or isolated by sediment deposition). Re-connect with river and/or restore habitat.

Restore Borrow Pits: Borrow Pits are manmade from the excavation of material to construct levees. Restore habitat within borrow pits by increasing depth, re-vegetating riparian zone, etc. Restore connectivity with river for isolated borrow pits.

Construct/Restore Islands: Islands are isolated, non-vegetated sandbars specifically utilized for least tern habitat. Retard vegetation; isolate bars from bank encroachment; etc.

Restore Tributary Mouth: Improve hydrology at mouth via sediment removal; weir construction; revetment; etc.

Construct Chevrons: Chevrons are large blocks or boulders in the medial area of the main channel forming a V-shape to scour channel and form a small island. Construct chevrons to create habitat diversity in channel.

Conserve/Restore Gravel Bars: Modify training structures to conserve exposed gravel or restore buried gravel

Procure Batture Land: Purchasing land for restoration; Improve access for fishing/boating.

Construct Hardpoints: Hardpoints are manmade structures in the main channel close to the bank, which create bank scallops and pool-type habitats. Construct hardpoints to create habitat diversity near shore.

Appendix II – Score sheet used to rank criteria and sub-criteria by the Habitat Technical Section of LMRCC

Ranking of Restoration Projects for LMRCC

Name:

Agency:

Address:

Phone:

e-mail:

Expertise:

STEP 1: Determine the relative importance of the following two criteria (i.e., criteria are the primary attributes in the decision matrix) in establishing the ranking of restoration projects. Check one.

Criteria: Significance of Habitat: ______ Low ______ Medium ______ High
Cost: ______ Low ______ Medium ______ High

Comments:

STEP 2: For each criteria, determine the relative importance of the sub-criteria in establishing the ranking of restoration projects. Check one.

Criteria: Significance of Habitat

Sub criteria: **Habitat scarcity/rarity**: ______ Low ______ Medium ______ High
DEFINITION: Natural occurring habitat that has been or could be altered by water resource development, agricultural development, or other types of human-induced impacts.

Comments:

Sub criteria: **Connectivity (Area of Influence**) : ______ Low ______ Medium ______ High
DEFINITION: Physical connection of two or more naturally occurring habitats. Habitats can be the same type (e.g., tracts of bottomland hardwoods) or different types (e.g., connecting a backwater with the main channel)

Comments:

Sub criteria: **Special Status Species**: ______ Low ______ Medium ______ High
DEFINITION: Federal and state listed invertebrates (e.g., mussels) and vertebrates (e.g., pallid sturgeon, paddlefish, blue sucker, alligator gar, fat pocketbook mussel, least tern) that will *directly* benefit from the project. DO NOT consider invasive species.

Comments:

Criteria: Cost

Sub criteria: **Construction Costs**: ______ Low ______ Medium ______ High
DEFINITION: Factors to consider include materials, labor, existing funding, and access during construction period and authority

Comments:

Sub criteria: **Duration of Benefits**: ______ Low ______ Medium ______ High
DEFINITION: Project life. Short term (<10 years) vs. long term
Comments:

Sub criteria: **O&M Costs**: ______ Low ______ Medium ______ High
DEFINITION: Short term (1-time cost) vs. long term (life of project)
Comments: