Using GIS and Multi Criteria Decision Analysis to Select Restoration and Preservation Sites for the Missouri River Cottonwood Management Plan

Kelly A. Burks-Copes[1], Lisa A. Rabbe[2], Suzanne Boltz[3], Kristine Nemec[4], Antisa C. Webb[1], and Greg Kiker[5]

[1]Environmental Laboratory, US Army Engineer Research and Development Center, Vicksburg, MS., [2] US Army Corps of Engineers, Alaska District, [3] EA Engineering, Science and Technology, [4] US Army Corps of Engineers, Omaha District, and [5]Agricultural and Biological Engineering Department, University of Florida

Research Theory and Case Study

1. Introduction

Today, the US Army Corps of Engineers (Corps) is faced with the "wicked problem" of carrying out engineering and construction activities while balancing competing social, environmental and economic demands in highly developed and highly controlled large river systems across the country (Figure 1). The Corps' challenge is to employ an integrated, risk-informed approach to decision making that encourages collaborative stakeholder participation from conception to implementation. The problem is one of transparency – negotiating trading offs of disparate information proffered by numerous stakeholders and interests groups in a holistic, yet adaptive manner. Expert-based sieve mapping offers one solution to integrating diverse attitudes and knowledge of system-wide drivers and stressors within a highly engaging visual medium that informs decision making in a cost effective and timely manner.

Figure 1. Engineering and construction activities on large river systems like the Missouri River (shown here) pose "wicked" challenges to Corps planners and resource managers faced with an impossible mission – solving dynamic environmental resource problems based on oftentimes incomplete or contradictory information, and balancing the interests of numerous stakeholders and interest groups transparently and in real-time.

2. Sieve Mapping - What is it?

Sieve mapping is a multi-criteria, GIS-based planning approach that allows participants to relatively value contributions of an area (land availability, ecosystem integrity, land use conflicts, etc) to the obtainment of goals and objectives fulfilling the project purpose. Each constraint or opportunity (i.e., criteria) is mapped as a rasterized "sieve," and the area of concern is "passed through" the "sieves" systematically in a definitive sequence to reveal areas suitable for the use contemplated (Figure 2). A spatial overlay procedure offers participants the opportunity to assign ratings and weightings of importance to the criteria in combination and conduct thorough "what if" scenario analyses.

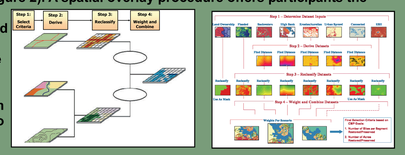


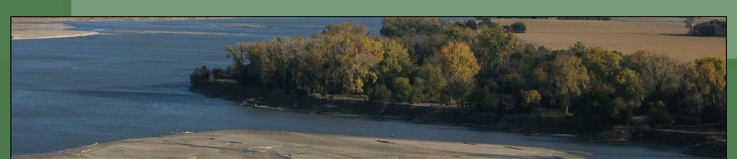
Figure 2. Sieve mapping is a multi-step process that involves the selection, derivation, and reclassification of expert-derived suitability criteria that when overlaid in a GIS environment "sieves" the conditions and determine plausible solutions given opportunities and constraints.

3. Case Study: 2009 Missouri River Cottonwood Management Plan

In response to the US Fish and Wildlife Service's Biological Opinion (BiOp) rendered in 2000 (and amended in 2003) on impacts to the cottonwood riparian zones supporting bald eagles along the Missouri River (Figure 3a), the Corps has initiated a planning-level effort to study, select and construct restoration sites along six priority segments in seven Midwest states (Figure 3b). However, the sheer magnitude and potential controversial aspects of the effort has led the planning team to streamline their ad hoc site selection procedures and adopt a more transparent, collaborative, spatially explicit approach to locating, prioritizing and selecting targets for restoration and preservation with impetus placed on sustainability and cost/time savings.

Figure 3. The Cottonwood Management Plan targets sites within the Missouri River Basin spanning seven states in the middle of the country.

Here we introduce CRISIS: Cottonwood Restoration Integrated Site Identification System – a participatory GIS-based planning decision support system developed by the U.S. Army Engineer and Research Development Center (ERDC) that employs expert elicitation to identify spatially-explicit "siting" criteria within a Multi-Criteria Decision Analysis (MCDA) framework to screen for potential restoration and preservation targets. MCDA offers an approach to scoring, weighting, and ranking disparate criteria relating to a particular issue using experts, stakeholders and interest groups who contribute their perceptions of importance with regard to criteria in making decisions. When conducted in a controlled setting (using anonymous polling packages), this expert elicitation is completed with as little bias as possible, thereby avoiding concerns with "group think." The GIS platform offers a visually engaging medium that promotes straightforward assimilation of criteria in a spatially meaningful manner. The team's ultimate goal was to produce a standardized, yet adaptive decision support tool that could be implemented and "ported" to each of the priority segments up- and downstream with relative ease. It was assumed that a standardized approach would save time and money, and that a flexible or adaptive tact would provide a transparent decision making forum to stakeholders and interest groups alike, reducing conflict and controversy throughout the process.



Criteria Selection and Multi-Criteria Decision Analysis (MCDA)

4. Selecting and Integrating Criteria

In 2006, an Ecosystem Evaluation Team (E-Team) was convened to oversee the development of a Cottonwood Management Plan for the Missouri River. Over the course of several iterative workshops, researchers from ERDC led a consensus-based expert elicitation process to develop the critical site selection criteria for the project. All told, 10 criteria were advanced for site selection in this study:

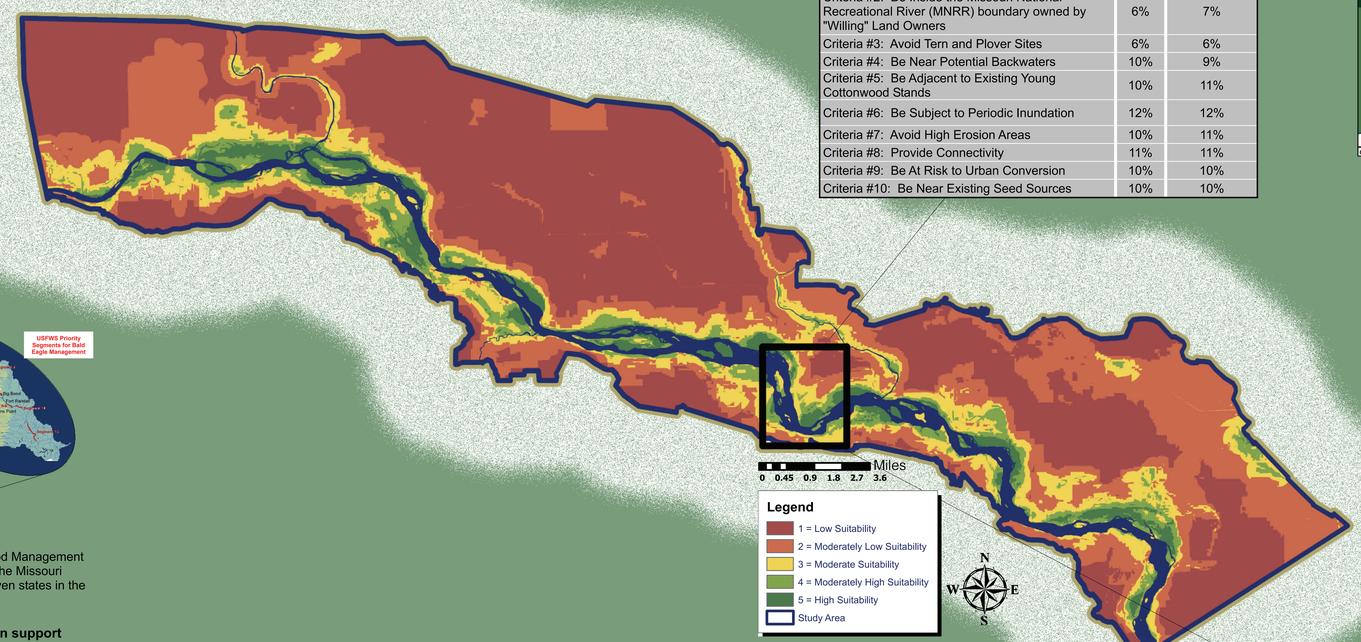
The sites must:

1. Have Suitable Groundwater Depths
2. Be Inside the Missouri National Recreational River (MNRR) boundary owned by "Willing" Land Owners
3. Avoid Tern and Plover Sites
4. Be Near Potential Backwaters
5. Be Adjacent to Existing Young Cottonwood Stands
6. Be Subject to Periodic Inundation
7. Avoid High Erosion Areas
8. Provide Connectivity
9. Be At Risk to Urban Conversion
10. Be Near Existing Seed Sources

ERDC-EL then surveyed the E-Team using MCDA asking each member to rank and score the 10 criteria on the basis of importance with regards to site selection (n = 16). These results were then combined to generate composite weights for each criterion (Table 1).

Table 1. Sixteen E-Team members were polled using MCDA to rank the selection criteria. These votes were then compiled into a single weighting factor per criterion and incorporated into a mathematical algorithm to generate the final site selection map.

Description	Rank	Percentage
Criteria #1: Have Suitable Groundwater Depths	15%	13%
Criteria #2: Be Inside the Missouri National Recreational River (MNRR) boundary owned by "Willing" Land Owners	6%	7%
Criteria #3: Avoid Tern and Plover Sites	6%	6%
Criteria #4: Be Near Potential Backwaters	10%	9%
Criteria #5: Be Adjacent to Existing Young Cottonwood Stands	10%	11%
Criteria #6: Be Subject to Periodic Inundation	12%	12%
Criteria #7: Avoid High Erosion Areas	10%	11%
Criteria #8: Provide Connectivity	11%	11%
Criteria #9: Be At Risk to Urban Conversion	10%	10%
Criteria #10: Be Near Existing Seed Sources	10%	10%



6. Evaluation of the Application:

To date, thirteen sites have been selected for serious consideration in terms of restoration and preservation activities. Additional sites are being considered in the out years to offset ongoing degradational conditions. The CRISIS technique will continue be used over the life of the project to highlight potential action areas as needed.

The CRISIS project carries with it a series of 4 specific returns on this investment:

1. It allows complex trade-offs to be performed on multiple and varied "siting" factor by multiple, diverse scientists, decision makers and stakeholders.
2. It allows value judgments to be incorporated into the analysis by weighting factors according to their perceived importance.
3. It provides a semi-objective framework for analysis
4. It has all the advantages associated with GIS-based construction including automated technically advanced processing that produces visually interactive maps that can be easily ported to new locations and promotes technology transfer across multiple stakeholders and partners via ArcGIS toolboxes.

CRISIS has been particularly useful in screening large numbers of alternative sites where there are large numbers of potential criteria to be taken into consideration or where subjective judgment by different stakeholders are needed to reach an objective consensus in the final decision making process. The result is a transparent, accountable, and portable tool to cost-effectively sift the varied choices and offer decision makers results in a visually engaging medium.

Applications and Results

5. Mapping the Results

A GIS-based thematic map was developed for each criterion (vector format). These maps were then rasterized and reclassified to indicate the relative suitability of each cell with respect to the criterion. A normalized scale of 1 to 5 was adopted to capture the range of optimal conditions (5's) and unsuitable conditions (1's). Map algebra was used to combine the reclassified grids into a single composite map based on the MCDA composite scores and ranks. A Red:Amber:Green map was produced highlighting the areas of Low:Medium:High restoration/preservation potential (map in center).

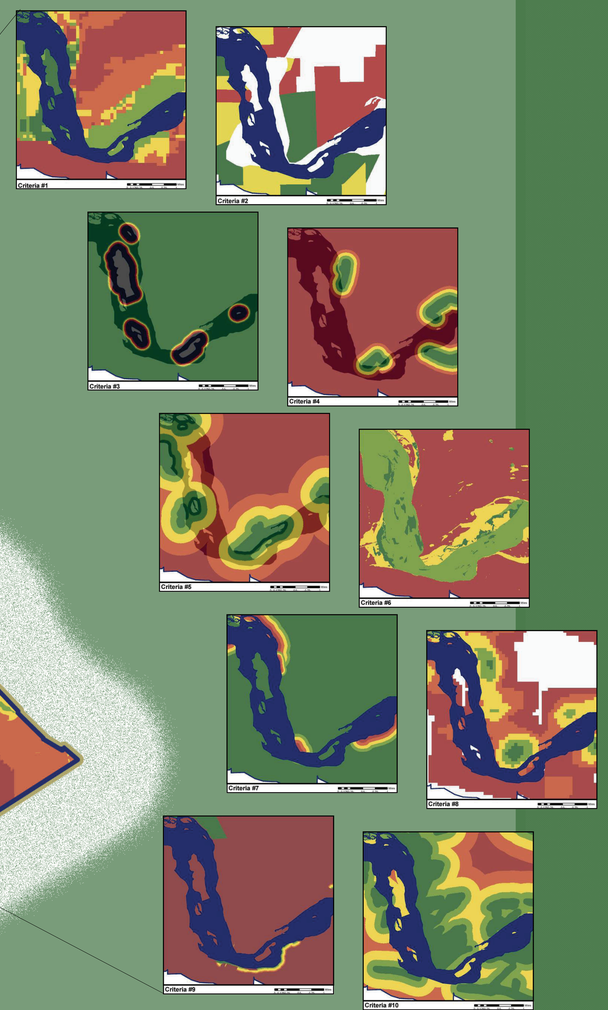


Figure 5. The selection criteria were mapped across the study are and reclassified to capture the suitability within each theme. Here, suitable sites are shown in green, moderately suitable sites are yellow, and poorly suited sites are shown in red on a criteria-by-criteria basis. The map in the center graphically illustrates the results of combining the criteria sieves under the MCDA protocol to generate a composite site recommendation map for the study.

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