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Using Multi-Criteria Decision Analysis to Support Ecosystem Restoration Planning

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PURPOSE: This technical note describes multi-criteria decision analysis and demonstrates its utility in the selection and prioritization of potential restoration sites for ecosystem restoration initiatives.

BACKGROUND: Planners in the U.S. Army Corps of Engineers (Corps) are constantly challenged to incorporate disparate and often conflicting physical, environmental, economic, and societal evidence into the ecosystem restoration decision-making process. Although the Corps' goal is to restore ecosystem function, structure, and dynamic processes in a resilient and sustainable manner, oftentimes recommended plans are met with skepticism when the decisions are based on highly variable inputs with significant uncertainties that are subject to ever-changing political and social influences. What is needed is a tool or a suite of fundamental methodologies that can aggregate heterogeneous information in a transparent, meaningful manner that is scientifically rigorous, yet practical, and can be made ready for immediate Corps implementation. To address this concern, the ***Environmental Benefits Analysis (EBA) Research Program*** is developing a procedural framework to consistently evaluate environmental benefits across program lines, geographical regions, and ecosystem types. In practice, the EBA is focusing on the identification and development of science-based tools, methods, and procedures for evaluating and comparing the benefits resulting from ecosystem restoration at the project, District, Division, and national scales. Under this program, the authors advocate the use of Multi-Criteria Decision Analysis (MCDA), and herein they offer a focused literature review of ongoing applications in the ecosystem restoration arena to support this stance. To illustrate the utility of these methods, a case study is presented that employs a sieve-mapping GIS-based tool that employs MCDA to elicit expert information on the identification and priority of spatially explicit "siting" criteria to select potential restoration sites in an unbiased fashion. To conclude, the benefits of incorporating MCDA into ecosystem restoration planning are discussed and future research initiatives are proposed to test the veracity of such approaches in the Corps' decision-making process.

A ROAD MAP FOR THIS TECHNICAL NOTE: The purpose of this technical note is to provide a focused review of the peer-reviewed literature concerning the use of multi-criteria

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decision analysis (MCDA) as it has been used in ecosystem restoration studies outside of the purview of the Corps and to present a case study to illustrate the approach's utility in Corps ecosystem restoration planning. This technical note is not a "how to" manual on the specifics of MCDA techniques nor a comprehensive review of its potential use in ecosystem restoration studies, but rather presents the fundamental elements of MCDA that should be considered in the Corps planning process. As such, it is intended for Corps planners and resource managers that seek information on how to incorporate MCDA into their day-to-day activities.

This note is divided into four major sections:

1. ***What is the problem?***
2. ***What is MCDA?***
3. ***Where has it been used?***
4. ***Case study illustration.***

This organization is designed to lead the reader through an overview of the role of MCDA, related considerations that should be addressed by the Project Delivery Team (PDT), and concludes with a practical application of the technique. Finally, the advantages and disadvantages of MCDA are discussed and potential research initiatives are considered.

WHAT IS THE PROBLEM? Ecosystem restoration planning and management can be a complicated, socially contentious and uncertain undertaking. This is because planners and resource managers are continually challenged to answer questions such as:

- Do study objectives conflict? If so, how will the multiple objectives (oftentimes characterized by disparate methods) be evaluated?
- How can stakeholder and decision-maker interactions be structured to elicit value judgments concerning trade-offs in an unbiased manner that builds stakeholder confidence and promotes insight and consensus?
- How can performance measures be combined to arrive at an optimal solution to the problem at hand?

As such, planners in the Corps are regularly challenged to incorporate disparate and often conflicting physical, environmental, economic, and societal information into the ecosystem restoration decision-making process. Although the Corps' goal is to restore ecosystem function, structure, and dynamic processes in a resilient and sustainable manner, oftentimes the recommended plans are met with skepticism when the decisions are based on highly variable inputs with significant uncertainties subject to ever-changing political and social influences. What is needed is a tool or a suite of fundamental methodologies that can aggregate heterogeneous information in a transparent, meaningful manner that is scientifically rigorous, yet practical and easy to implement in the Corps. One such solution methodology is Multi-Criteria Decision Analysis (MCDA).

WHAT IS MULTI-CRITERIA DECISION ANALYSIS? Multi-criteria decision analysis is a set of procedures that analyze complex decisions based on disparate, conflicting criteria (Malczewski 1999), and as such is uniquely configured to address complex decision-making issues within the Corps. MCDA consists of a series of techniques (i.e., weighted summation, concordance, analysis, etc.) that facilitate the scoring, ranking, or weighting of decision-making criteria based on stakeholder preferences (Higgs 2006 and references therein). These techniques originated over three decades ago in the fields of mathematics and operations research and are well-developed and documented (see, for example, Hwang and Yoon 1981; Keeney and Raiffa 1993; Yoe 2002; Chee 2004; Linkov et al. 2004; Kiker et. al. 2005, Edwards et al. 2007). These techniques ideally operate within a transparent framework that encourages informed decision-making by providing opportunities for genuine, substantive participation in decision-making supported by the best available scientific knowledge that can also incorporate uncertainties in an honest, rigorous and consistent manner. MCDA typically involves five steps (Chee 2004):

1. Define the goals and objectives.
2. Identify decision options.
3. Select the criteria that measure performance relative to the objectives.
4. Determine the weights for the various criteria.
5. Apply the procedures and perform the mathematical calculations to rank options.

MCDA techniques include mechanisms for: (a) articulating visions about goals and objectives; (b) learning about the decision problem; (c) exploring system dynamics and potential outcomes associated with decision options; (d) assessing risk and analyzing uncertainty; (e) facilitating discussion, deliberation and negotiation about trade-offs; and (f) evaluating options in the search for compromise solutions (Howard 1991; Chee 2004). Sensitivity analysis can also be used within the MCDA process to explore the impact of some of these interactions (Yoe 2002; Proctor and Drechsler 2003; Linkov et al. 2004; Kiker et. al. 2005). In MCDA, criteria are scored on interval or ratio scales and then transformed to ensure commensurability before algorithms based on value or utility functions, goal programming, outranking or descriptive/multivariate statistical methods are applied to rank the options (Howard 1991; Stewart 1992). Stewart (1992) and Drechsler (2004) discuss factors to consider when choosing a ranking strategy. The MCDA process thus offers a methodology for combining multiple criteria and value judgments into a more concise set for decision making. However, one of the greatest challenges associated with MCDA is how to compare and combine dissimilar metrics. Often dissimilar criteria are transformed or normalized to a single scale such as zero to one. Transformation to this commensurable scale can be accomplished through multiple techniques reviewed elsewhere (Skaggs et al., in preparation). Following scale transformation, criteria and value are combined through aggregation algorithms, and alternatives are compared and ranked. Stewart (1992) and Drechsler (2004) discuss factors to consider when choosing a ranking strategy.

According to many researchers and practitioners, MCDA is well-suited for eliciting values and preferences and evaluating stakeholder interests (Yoe 2002; Chee 2004; Linkov et al. 2004; Kiker et. al. 2005 and references therein). However, having the right combination of people is an essential element in the MCDA process, and of course decision makers, stakeholders, scientists, and engineers all play important roles. The membership and function of these participants overlap or vary. Each participant has unique experiences and perceptions that lead to unique decision-making paradigms. Policy and decision-makers define the planning context and dictate overall constraints of a decision, and thus affect the selection of a recommended plan and its implementation. Stakeholders provide input in defining the problem, but they contribute the most when assisting in the formulation of evaluation criteria/performance metrics and making value judgments for weighting the various criteria. Depending on the problem and restoration context, stakeholders may have some responsibility in ranking and selecting the final option. The primary role of scientists and engineers is to provide the technical input necessary to inform the decision process, so their role is to provide the measurements of metrics that quantify the degree to which the various alternatives satisfy the objectives of the project. Scientists and engineers also may play a secondary role as stakeholders or decision-makers.

WHERE HAS IT BEEN USED? Decisions must be based on the results of scientific data or physical modeling. To date, little effort has been applied to engaging and understanding stakeholder perspectives or to providing for potential learning among stakeholders. Stahl (2003) found that decision processes can be improved by more effectively encouraging stakeholder participation, integrating information, exploring new potential alternatives, and developing a consensus.

MCDA can guide decision-making in a transparent, collaborative manner where conflicting data and interests threaten to overwhelm the planning process. Over the last several years, the Corps has developed approaches and guidance for implementing MCDA approaches for planning (Yoe 2002; Linkov et al. 2004; Kiker et. al. 2005). These suggest comprehensive decision analytic approaches that consider a broad array of objectives and criteria/metrics (Clemen 1995) including those associated with ecosystem restoration (Males 2002). Guidance contained in *Trade-Off Analysis Planning and Procedures Guidebook* (Yoe 2002) provides a multi-criterion decision analytic approach for comparing and deciding between alternative plans.

Studies offering insight into MCDA applications and the state of the science have been published in the open literature (see Higgs 2006 and references therein; Kiker et al. 2005 and references therein; Malczewski 2004 and references therein). Site selection studies using Geographic Information System (GIS)-based mapping, expert elicitation, and automated decision-support systems have demonstrated practical applications of MCDA in the field (Carlon et al. 2006; Shrier et al. 2008; Sullivan et al. 2008; Malczewski 1999). For example, Carlon et al. (2006) used MCDA in their DESYRE decision support system to plan the rehabilitation of contaminated megasites. DESYRE contains six interrelated modules (e.g., site characterization, risk, socio-economic factors, technological analysis, residual risk analysis, and decision making) to address complex contaminant management concerns. Similarly, Sullivan et al. (2008) developed the Decision Evaluation for Complex Risk Network Systems (DECERNS) software tool to select remedial and abatement solutions based on radionuclide distribution data and value judgment on the efficiency of various management alternatives. Shrier et al. (2008) developed a systematic approach to integrate different objectives (e.g., the suitability for groundwater recharge vs. wildlife habitat) and captured the decision processes employed by local experts to address seasonal flooding problems. As such, the development of the approach was intended to create a better understanding of the site evaluation process, yet identify demands for additional databases and future research. Malczewski (2006) developed an approach to incorporate fuzzy (linguistic) quantifiers (a form of MCDA) into a GIS-based land suitability analysis. Fuzzy logic derived from the theory of approximate reasoning facilitated the translation of natural language specifications into formal mathematical expressions and led to the formulation of weighting judgments in his study.

In these instances, multi-criteria approaches reduced the costs and time involved in locating and prioritizing potential ecosystem restoration alternatives based on pre-defined criteria and weights — all within a highly visual, spatially explicit environment. Techniques coupling GIS and MCDA have proven to be particularly useful in situations where there are large numbers of sites under consideration, where numerous criteria are important, or where subjective judgments by opposing stakeholders are inevitable. Yet until now, these techniques have not been actively employed in Corps' ecosystem restoration activities with any degree of regularity.

CASE STUDY: MISSOURI RIVER COTTONWOOD RESTORATION SITE SELECTION: In the mid 1900's, the Corps constructed six dams on the mainstem of the Missouri River for the purposes of flood control, navigation, hydroelectric power generation, and water storage for irrigation in an attempt to bring stability and prosperity to the region in the midst of the Great Depression. The ecological ramifications of these activities continue today:[1]

- Nearly 3 million acres of natural riverine and floodplain habitat have been altered through land-use changes, inundation, channelization, and levee building.
- The amplitude and frequency of the river's natural peak flows have been dramatically reduced.
- Cottonwood forest reproduction (historically the most abundant and ecologically significant species on the river's extensive floodplain) has largely ceased.
- Several species (the least tern, piping plover, and pallid sturgeon) have been placed on the federal Endangered Species List.

In 2000, in response to additional flood control initiatives proposed by the Corps, the U.S. Fish and Wildlife Service issued a Biological Opinion (BiOp) (later amended in 2003) directing the Corps to conduct collaborative, long-term planning efforts to restore critical ecosystem functions, mitigate for habitat losses, and recover native fish and wildlife populations, while seeking to enhance social, economic, and cultural values for future generations along the Missouri River (U.S. Fish and Wildlife Service (USFWS) 2000, 2003). Several working groups were then established to address each of the species of concern, and a separate team was established to develop a Cottonwood Management Plan with the purpose of planning and implementing restoration initiatives for cottonwood forest communities across the basin (Figure 1).

[1] National Academies of Science report entitled, "The Missouri River Ecosystem: Exploring the Prospects for Recovery," online at *http://www.nap.edu/catalog.php?record_id=10277*.

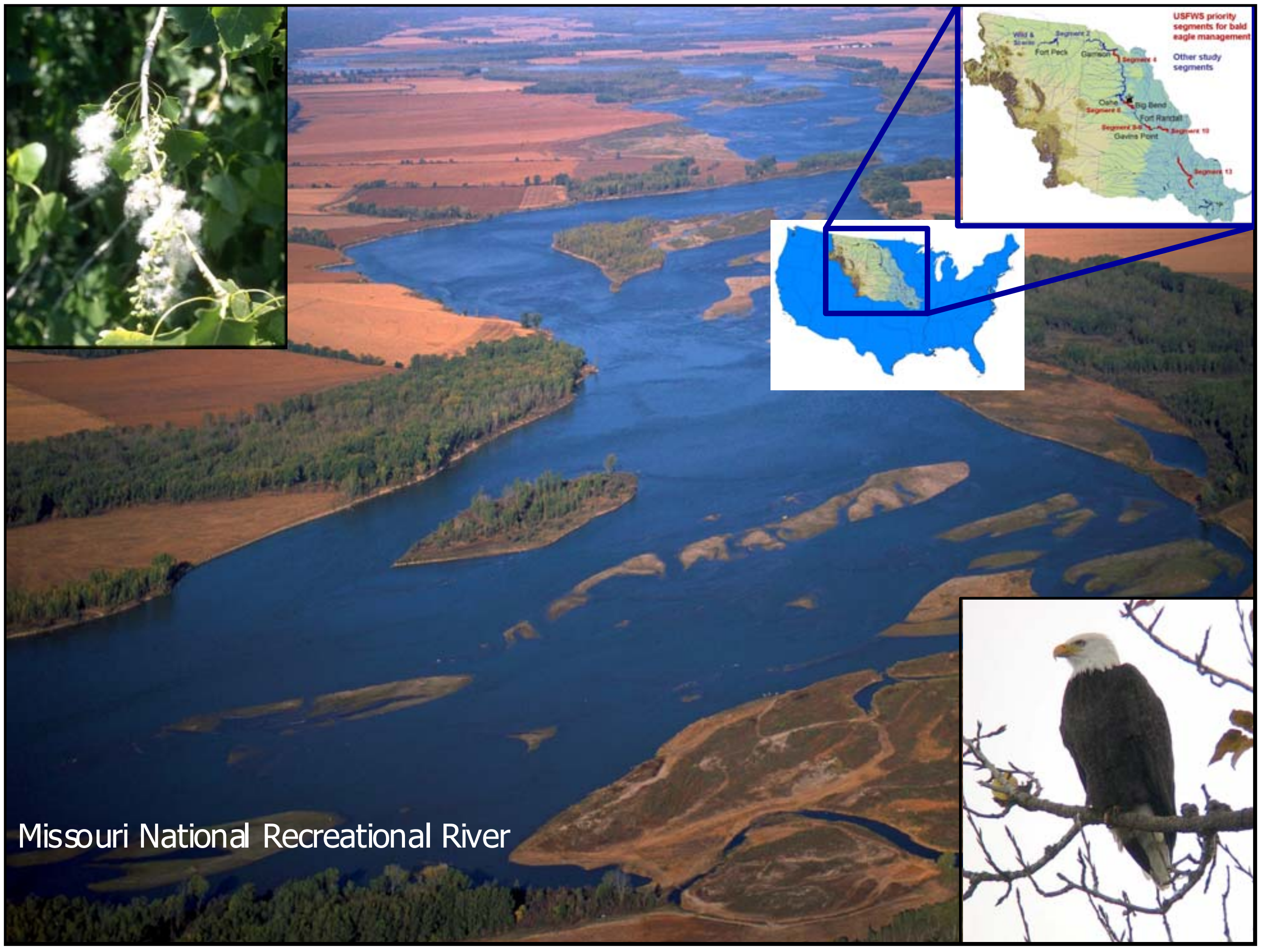

Figure 1. Location of the Missouri River Basin and identification of the priority segments addressed under the Cottonwood Management Plan at the direction of the USFWS Biological Opinion regarding bald eagle habitat restoration. Priority Segment 10 (located between Gavins Point Dam and Ponca State Park in southeastern South Dakota, USA) is the focus of this case study.

The sheer magnitude of this task (> 530,000 square-mile drainage area; > 2,300 river miles flowing through seven states) forced the Corps to develop a planning strategy to efficiently and effectively assess the system's integrity at a landscape level. The USFWS BiOp assisted in this endeavor by dividing the river into manageable units, and assigning priorities based on species of concern. However, continuity of planning strategies across reaches has been difficult to maintain in the absence of standardized procedures. In response, the Cottonwood Management Team decided to develop a standard assessment approach that could be flexibly applied to address each segment's unique concerns. The approach was meant to be principled, yet flexible in practice. The intent was to develop tools that were sufficiently adaptive so that they could be tailored to address each segment's unique concerns. The approach included an assemblage of baseline inventory metrics, ecosystem assessment tools, planning techniques, and implementation/monitoring procedures to address ongoing adaptive management initiatives. The first task called for the selection of targeted restoration sites for the cottonwood community. The Cottonwood Management Team required a collaborative, spatially explicit technique to find, prioritize, and select sites for restoration – one that encouraged collaborative decision-making in a scientifically defensible forum.

In response, the Cottonwood Management Team sought the expertise of the U.S. Army Engineer Research and Development Center (ERDC) to develop the Cottonwood Restoration Integrated Site Identification System (CRISIS), a participatory GIS-based, sieve-mapping system that employs expert elicitation to identify spatially explicit "siting" criteria within an MCDA framework that in turn screens for potential restoration and preservation targets. As described earlier, MCDA offers an approach to scoring, weighting, and/or ranking disparate criteria elicited from participants' perceptions of importance with regard to criteria in making decisions. When conducted in a controlled setting (using, for example, anonymous polling of experts or stakeholders), this elicitation is completed with as little bias as possible, thereby avoiding concerns of "group think" as well as problems with subject anchoring.

Sieve mapping is a commonly used multi-criteria, GIS-based planning approach that allows participants to assess the value of an area's contribution (land availability, ecosystem integrity, land use conflicts, etc.) toward attainment of overall goals and objectives fulfilling the project purpose – in this case, the objective was to locate and prioritize sites that were suitable for cottonwood restoration activities. Each constraint or opportunity (i.e., criterion) 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 intended use (Figure 2). A spatial overlay procedure offers participants the opportunity to assign ratings and weightings of importance to the criterion in combination, and conducts thorough "what-if" scenario analyses in an iterative fashion. The GIS platform proved to be visually engaging, thereby promoting a straightforward assimilation of criteria in a spatially meaningful manner.

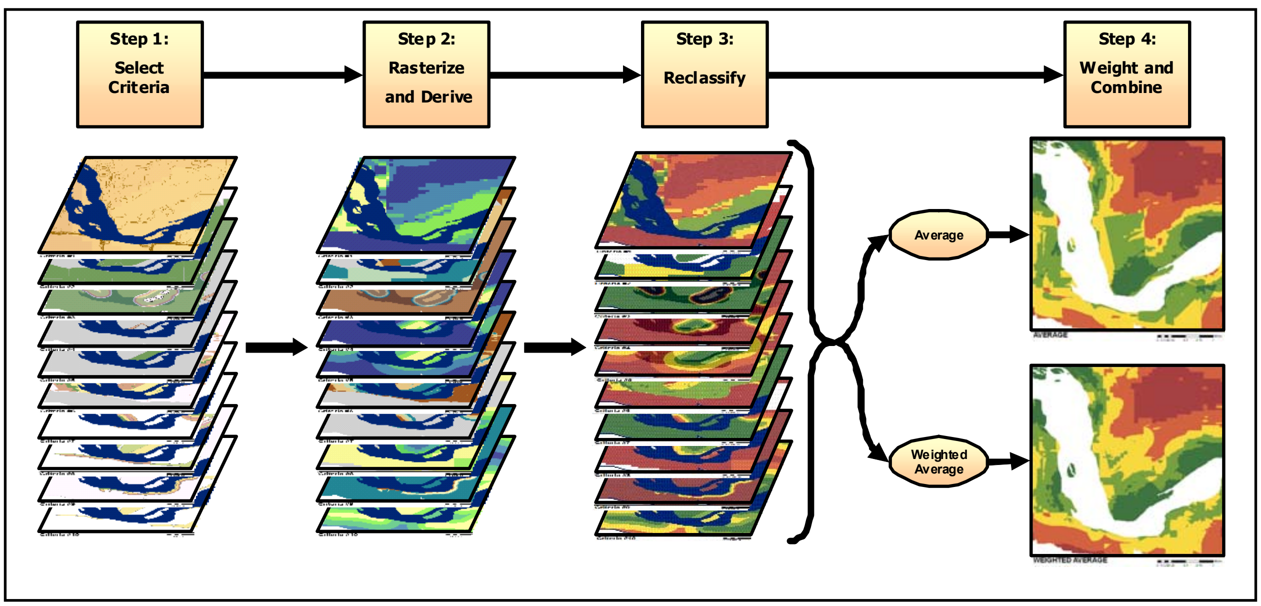

Figure 2. Sieve mapping is a multi-step process that involves the selection, derivation, and reclassification of expert-derived suitability criteria. When overlaid in a GIS environment, this mapping "sieves" the conditions and determines plausible solutions given opportunities and constraints.

Generating Criteria. The Cottonwood Management Team first hosted a series of brainstorming workshops to generate a list of potential criteria that could be used to "sieve" potential restoration sites. Team members spanned multiple areas of expertise (i.e., hydrology, ecology, natural resource management, etc.) and affiliations (Table 1).

Table 1. Experts involved in the MCDA exercise to identify, prioritize and select restoration targets for the Cottonwood Management Plan.

Name	Affiliation
Bowen, Dan	Benedictine College
Bristol, Trent	ND Forest Service
Cowman, Tim	Missouri River Institute, University of South Dakota
Dixon, Mark	University of South Dakota
Gilbert, Mike	USACE - Omaha District
Hinners, John	South Dakota Dept. of Agriculture, Div. of Resource Conservation
Jacobson, Robert	US Geological Survey - CERC
Johnson, Carter	South Dakota State University
Lepisto, Paul	Izaak Walton League of America
Nemec, Kristine	USACE - Omaha District
Phingsten, Richard	EA Engineering
Rabbe, Lisa	USACE - Kansas City District
Scott, Mike	U.S. Geological Survey
Skold, Jason	The Nature Conservancy
Smydra, Theresa	Missouri River Futures/NRCS
Wilson, Steve	National Park Service, Missouri National Recreational River

Over the course of several months, the list of criteria was refined and 10 independent criteria were ultimately selected for use in the analysis. Appendix A provides a rationale for why the following 10 criteria were selected and how they relate to the objective of restoring ecosystem health.

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

A GIS-based thematic map was developed for each criterion (in vector format). These maps were then rasterized and reclassified to indicate the relative suitability of each cell with respect to each criterion at the direction of the team's scientific experts. A normalized scale of 1 to 5 was adopted to capture the range of conditions ("5" = optimal conditions; "1" = unsuitable conditions) (Figure 3). See Appendix A for more details.

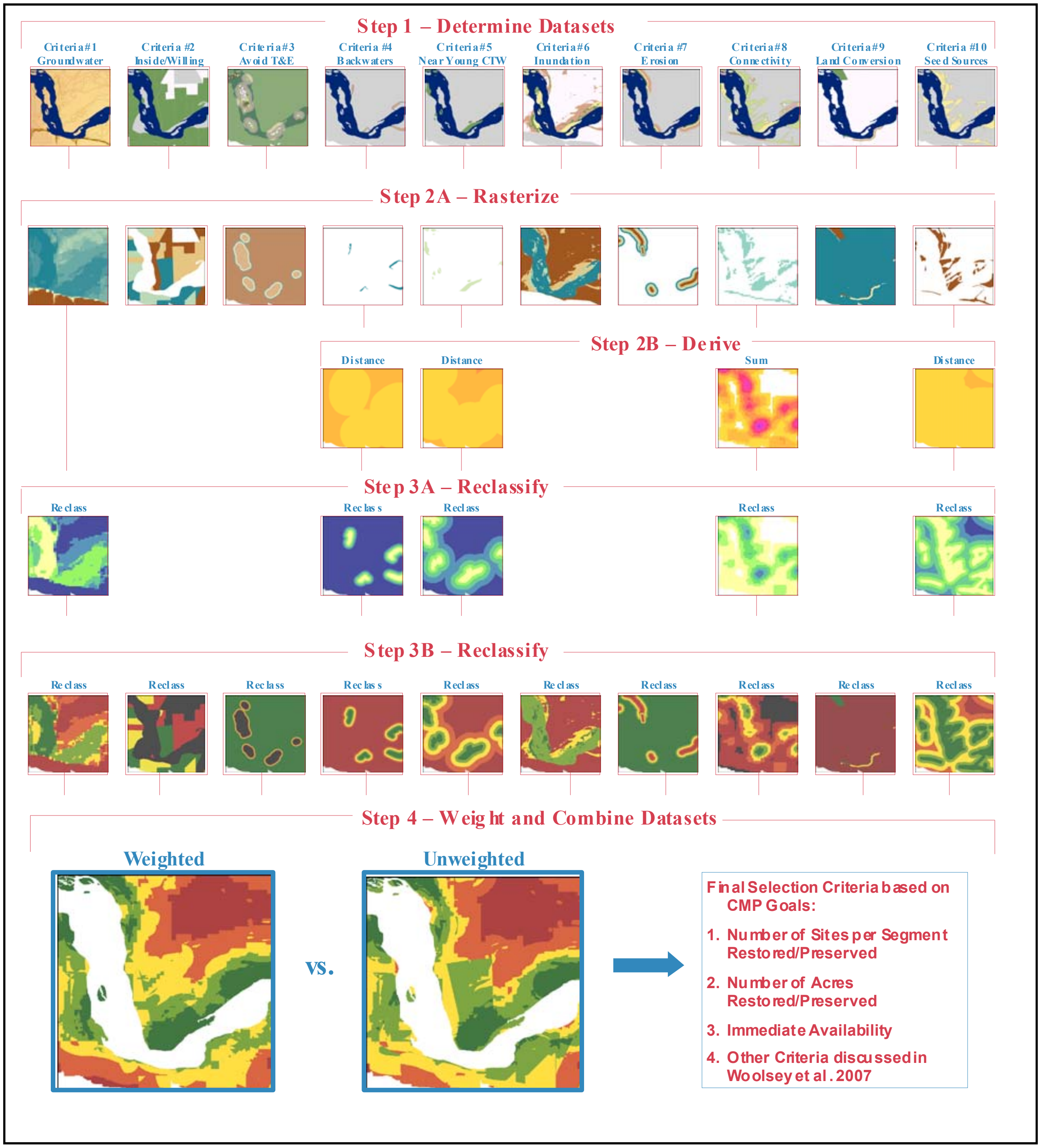

Figure 3. The original data gathered for the case study originated from several different sources and were acquired in several different formats (polygon, line, point, and raster) that required processing to generate a series of layers wiith similar scaling for proposed aggregation.

Applying MCDA. ERDC then facilitated a blind balloting procedure to elicit each member's opinion as to which criteria were the most useful in site selection. A Microsoft Excel spreadsheet was distributed to the team, and the members were asked to rank the criteria from highest (most important) to lowest (least important). These values were averaged across the team on a criterion-by-criterion basis, and converted to ranks using rank sum transformation (Malczewski 1999). In rank sum, the rank position is weighted and then normalized by the sum of all weights (Table 2). This ranking method is simple and provides an approach to weight assessment. However, it is limited by the number of criteria to be ranked and is not appropriate for a large number of criteria since it becomes very difficult to straight rank as a first step (Malczewski 1999).

Table 2. Results of the MCDA process. The weighted criteria were used in the GIS sieve-mapping application.

Description	Average Vote Across All Participants[1]	Rank[2]	Rank Sum Weight (Normalized).
Criterion #1: Have Suitable Groundwater Depths	0.83	1	0.18
Criterion #2: Be Inside the Missouri National Recreational River (MNRR) boundary owned by "Willing" Land Owners	0.35	9	0.04
Criterion #3: Avoid Tern and Plover Sites	0.32	10	0.02
Criterion #4: Be Near Potential Backwaters	0.54	8	0.05
Criterion #5: Be Adjacent to Existing Young Cottonwood Stands	0.59	4	0.13
Criterion #6: Be Subject to Periodic Inundation	0.68	2	0.16
Criterion #7: Avoid High Erosion Areas	0.55	7	0.07
Criterion #8: Provide Connectivity	0.63	3	0.15
Criterion #9: Be At Risk to Urban Conversion	0.58	5	0.11
Criterion #10: Be Near Existing Seed Sources	0.56	6	0.09

[1]The higher the score, the more important (inverse ranking).
[2]The most important = 1, second important = 2, etc.

The resultant weights were entered into ESRI's Raster Calculator to perform the map algebra for the analysis using a weighted arithmetic average (Equation 1). In the interest of comparison and sensitivity analysis, an unweighted arithmetic average applying equivalently weighted criteria was also applied (Equation 2)

$$S_w = 0.18c_1 + 0.04c_2 + 0.02c_3 + 0.05c_4 + 0.13c_5 + 0.80*0.16c_6 + 0.07c_7 + 0.15c_8 + 0.11c_9 + 0.09c_{10} \quad (1)$$

$$SS_u = 0.10c_1 + 0.10c_2 + 0.10c_3 + 0.10c_4 + 0.10c_5 + 0.80*0.10c_6 + 0.10c_7 + 0.10c_8 + 0.10c_9 + 0.10c_{10} \quad (2)$$

where SS_w is weighted site suitability, SS_u is unweighted site suitability, and c_i is criterion number i as defined in Table 2.

Finally, the results were reclassified on a scale of 1 to 5 using natural breaks and then presented in a Red:Amber:Green pattern to communicate the results in a spatial context. ESRI's Cut/Fill tool was used to generate a "difference" map indicating where the weighted vs. unweighted maps differed. The results of the reclassification are presented below.

Results of the Application. Overall, about 219,000 acres of MO River floodplain were evaluated using this methodology. As indicated in Figure 4, MCDA allowed the team to refine their prioritization process and place more emphasis on areas that address three specific criteria of concern, namely depth of groundwater (Criterion #1), periodic inundation (Criterion #6), and connectivity (Criterion #8). The result of the weighting yielded more habitat that was considered "less desirable," and more focus along the tributaries coming into the mainstem. As a result of implementing this process, 13 sites have been selected to date for further consideration in terms of restoration and preservation activities in this segment of the river. Additional sites will be considered in future years to offset ongoing degradational conditions, and it is clear that the ***CRISIS*** program can be used to target these additional acres for the team.

Discussion. The primary goal of the decision process for the project 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 the inherent flexibility of the approach would provide a transparent decision-making forum for stakeholders and experts, reducing conflict and controversy throughout the decision-making process. The ***CRISIS*** met these goals and advanced returns on the team's investments that included the following:

1. It separated facts (from individual criteria scores) from stakeholder preferences (the weights).
2. It allowed value judgments of the various stakeholders to be incorporated into the analysis (via weighting factors) according to their perceived importance.
3. It allowed complex trade-offs to be performed on multiple and varied "siting" factors and engaged numerous yet diverse scientists, decision makers, and stakeholders in the process.
4. It provided a semi-objective and transparent framework for analysis.
5. It possessed inherent advantages associated with GIS-based constructions including automated, technically advanced processing that produced visually interactive maps that were easily ported to new locations and promoted technology transfer across multiple stakeholders and partners.

CRISIS was particularly useful in screening large numbers of alternative sites where numerous criteria needed to be considered and where subjective judgment by different stakeholders was needed to reach an objective consensus in the final decision-making process. The result was a transparent, accountable, and portable tool that cost-effectively evaluated the diverse siting alternatives and offered decision makers visually engaging results.

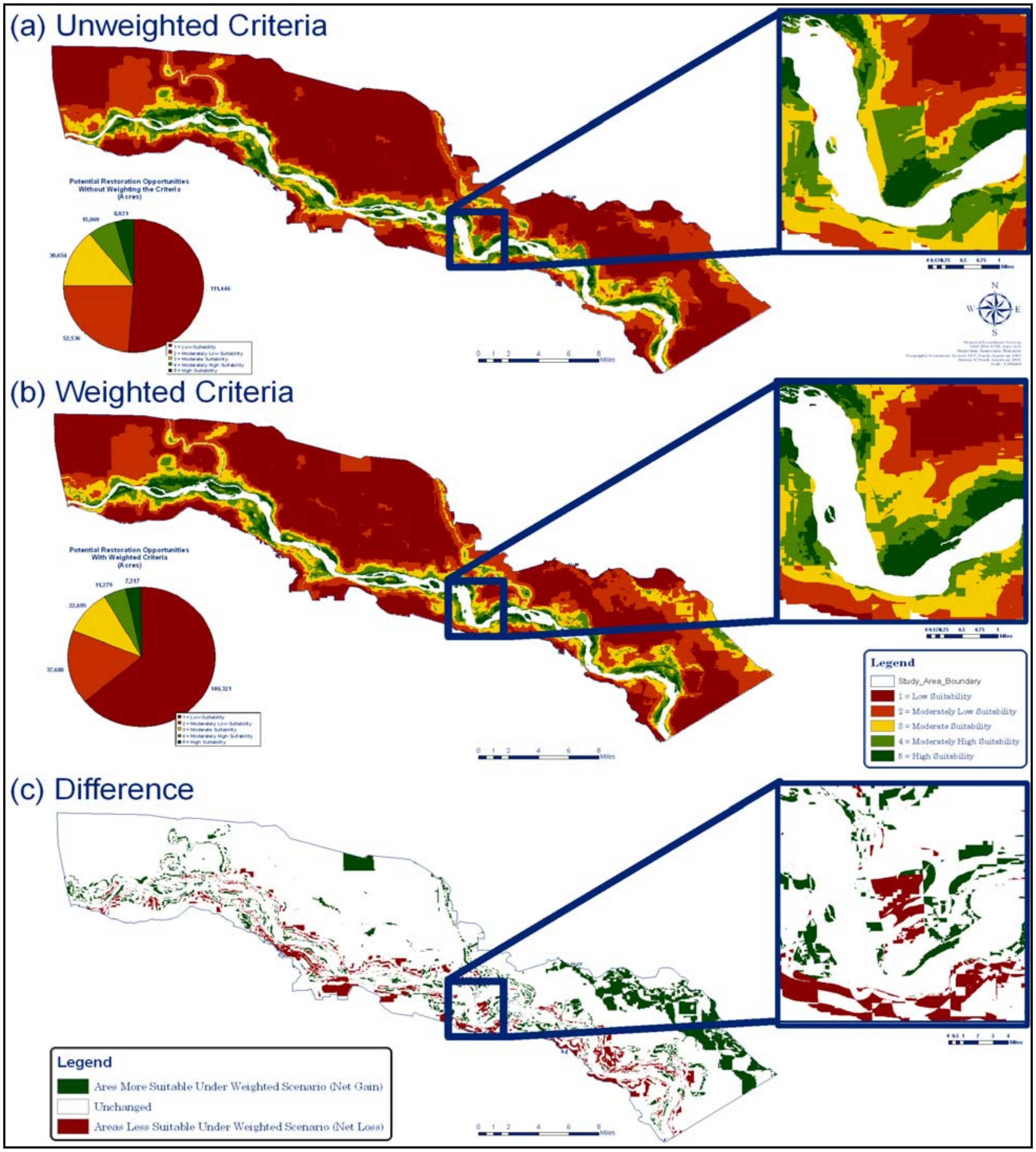

Figure 4. Results of the sieve mapping application. Areas of “low” suitability are indicated in red and transform to a red-amber-green coding scheme that indicates “high” suitability in the darkest green areas. In Panel (a), the results are displayed under a non-weighted scenario (as if all the criteria were considered equally important). Panel (b) displays the results of the weighted values applied to these same criteria. Note in the square pop-out windows significant areas are no longer considered “optimal” for acquisition under the “weighted” scenario. In this case, groundwater depth, periodic inundation, and connectivity play a much heavier role in site suitability. Panel (c) shows the difference between the two maps. Areas in green are elevated in status under the weighted scenario, and areas in red are now considered less suitable for acquisition and restoration.

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS: As the case study illustrated, the potential for MCDA to actively, yet objectively engage stakeholders in the process of collaborative decision making is substantial. GIS-based decision support systems such as ***CRISIS*** provide a usable platform to engage stakeholders in a visually stimulating decision-making environment that allows rapid communication of complex and obscure concepts. Effective environmental decision-making requires a basic structure for simultaneous consideration of the environmental, ecological, technological, economic, and socio-political factors relevant to evaluating and selecting ecosystem restoration alternatives. Integrating this heterogeneous information demands a systematic and understandable framework to organize people, processes, and tools for making a structured and defensible decision. MCDA achieves these goals in a way that facilitates decision-making processes that involve risk, multiple criteria, and conflicting interests. As demonstrated using the Missouri River case study, MCDA systematically structures the decision process multiple ways, including:

- Helping decision makers think systematically about the problem by providing a logical framework for defining options and comparing performances on criteria.
- Displaying tradeoffs among performance so that project managers and stakeholders alike can understand the relative advantages and disadvantages of management alternatives.
- Helping decision makers and stakeholders reflect upon, articulate, and apply explicit and developed value judgments concerning conflict criteria and uses.
- Demonstrating which options are most preferred and should be screened out.
- Helping people evaluate risk and uncertainty more consistently and rationally.
- Documenting how decisions are made and negotiated.

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APPENDIX A: RATIONALE FOR SELECTING CRITERIA FOR ANALYSIS

Table A1. Ten criteria were developed by experts to locate, select, and prioritize cottonwood restoration sites along Segment 10 of the Missouri River under the Cottonwood Management Plan initiative. This table summarizes the reasoning behind the selection of each criterion and the scaled map outputs for each (scale = 1 – 5, where 1 is minimum and 5 is optimum condition).

Selection Criterion	Logic for Inclusion	Reclassification
Criterion #1: Have Suitable Groundwater Depths	Cottonwoods are phraetophytes - dependent upon water for survival. Depth to groundwater has been shown to be a good indicator of functioning and sustainable cottonwood ecosystems in the Missouri River Basin.	1 = >3 m 2 = 2-3 m 3 = 1-2 m 4 = 0-1 m 5 = <0 m
Criterion #2: Be Inside the Missouri National Recreational River (MNRR) boundary owned by "Willing" Land Owners	Locating sites within the Missouri Natural Recreational River boundary that are owned by landowners interested in working with the Federal government to restore cottonwoods in the basin is assumed to be a priority, given current funding opportunities in the region.	0 = Sites are outside the MNRR boundary or in the river 1 = Sites are inside the MNRR boundary, but landowners are unwilling to participate 3 = Sites are inside the MNRR boundary, but the landowner participation status is unknown 5 = Sites are inside the MNRR boundary, and landowners are willing to participate
Criterion #3: Avoid Tern and Plover Sites	Direct competition for resources (in this case land) among Federally Threatened and Endangered species under the Missouri River Bi-Op (in particular the terns and plovers) should be avoided. A specific avoidance buffer (300 m) can be utilized to remove areas along the river near the tern and plover habitats, and sandbars with active nests in the river have been omitted entirely. A preference is given to restoration/preservation initiatives along the banks outside the avoidance zones.	0 = Sites within the 600-ft buffer surrounding tern and plover existing restoration sites (or known nesting sites) 1 = Sites are 600-700 ft from tern & plover existing restoration sites (or known nesting sites) 2 = Sites are 700-800 ft from tern & plover existing restoration sites (or known nesting sites) 3 = Sites are 800-900 ft from tern & plover existing restoration sites (or known nesting sites) 4 = Sites are 900-1000 ft from tern & plover existing restoration sites (or known nesting sites) 5 = Sites are >1000 ft from tern & plover existing restoration sites (or known nesting sites)
Criterion #4: Be Near Potential Backwaters	It is desirable to select sites that overlap with ongoing backwater restoration initiatives to optimize mobilization and planning costs/efforts, and restore cottonwood riparian ecosystems to their full functionality. By definition, these ecosystems should contain multi-aged stands of cottonwoods, willow shrublands, wet meadows, marsh wetlands, backwater channels, and open water areas spread across the landscape in a dynamic mosaic. Biotic legacies from preceding cottonwood forests, propagules from adjacent cottonwood stands, forest structuring processes, and the generation of spatially diverse complexes combine to produce both overall compositional diversity and patch diversity (habitat breadth).	1 = >400 m 2 = 300-400 m 3 = 200-300 m 4 = 100-200 m 5 = <100 m

Selection Criterion	Logic for Inclusion	Reclassification
Criterion #5: Be Adjacent to Existing Young Cottonwood Stands	Young stands indicate areas where accretion is occurring, a condition that is favorable to the establishment of cottonwood stands as well.	1 = 0-100 m 2 = 100-300 m 3 = 300-600 m 4 = 600-1000 m 5 = >1000 m+
Criterion #6: Be Subject to Periodic Inundation	Cottonwoods required periodic inundation in order to establish. Flow regulation and channelization substantially changed the Missouri River's historic hydrologic and geomorphic regimes and the natural variability in flows along many rivers has been modified by water management activities. The primary change was that extreme high and extreme low flows were lost from the hydrograph downstream of each mainstem dam. Not only have high flows been reduced in many areas, but low flows have increased considerably. Therefore, the current annual hydrograph exhibits far less flow variability, specifically, in the reaches directly below the dams where the spring and summer rises no longer occur in many stretches. The post-regulation flow pattern has been reversed compared to pre-dam (historic) conditions, with peak flows now occurring in winter (February and March) and minimum flows occurring mainly early and late in the growing season (May and September). The post-dam floodplain environment is severely missing overbank flooding, which only occurs on the lowest terraces.	1 = Rarely Flooded 2 = Infrequently Flooded 3 = Frequently Flooded 4 = Moderately Flooded Must multiply this by 0.8 to evenly weight the outcome in the composite formula
Criterion #7: Avoid High Erosion Areas	Sustainability is key to successful restoration initiatives, and as such, locating areas with low erosion potential suggests resilience in the face of large episodic flooding events.	1 = Areas likely to erode in the next 20 yrs 2 = Areas likely to erode in the next 40 yrs 3 = Areas likely to erode in the next 60 yrs 4 = Areas likely to erode in the next 80 yrs 5 = Areas not likely to erode
Criterion #8: Provide Connectivity	Landscape connectivity involves the linkage of habitats, species, communities and ecological processes at multiple spatial and temporal scales. Human activities can reduce connectivity by creating artificial barriers to species dispersal, leading to isolated populations that become vulnerable to extinction due to reduced access to resources, genetic deterioration, increased susceptibility to environmental catastrophes and demographic accidents, and other problems. Disturbances periodically make portions of the landscape uninhabitable. Corridors fulfill an "escape" function by permitting animals to flee disturbance. Corridors also aid in recolonization of the recovering site by plants and animals. Habitat patches that are isolated from similar habitat patches by great distances or inhospitable terrain are likely to have fewer species than less isolated patches because relatively few individuals of a given species will immigrate into the isolated patch, and fewer mobile species will visit isolated patches because it is inefficient to do so.	1 = Offers Low Connectivity 2 = Offers Moderately Low Connectivity 3 = Offers Moderate Connectivity 4 =Offers Moderately High Connectivity 5 = Offers High Connectivity
Criterion #9: Be At Risk to Urban Conversion	In an effort to capture the potential landuse conversion trends in the reach over the course of the next 100 years (2006 – 2110), the E-Team devised a series of spatially explicit heuristics (rules-based decisions) to identify critical changes in coverage, with the intent of developing a series of trend maps on a target-year basis to better illustrate these changes. Drivers of change included urban sprawl, erosion, agricultural conversions, protected lands, and cottonwood succession. Restoration initiatives would regard these areas as "threatened" and would therefore target these areas for protection and restoration.	1 = High Risk 2 = Moderately High Risk 3 = Moderate Risk 4 = Moderately Low Risk 5 = Low Risk
Criterion #10: Be Near Existing Seed Sources	There is a higher likelihood that there will be a heavier seed fall on the area (i.e., less work to restore the sites) if sites are positioned close to existing seed sources.	1 = 0-100 m 2 = 100-300 m 3 = 300-600 m 4 = 600-1000 m 5 = >1000 m+