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Creating a Wetland Restoration Decision Support System Using GIS Tools

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PURPOSE: This technical note is a product of the Ecosystem Management and Restoration Research Program (EMRRP) work unit titled "Development of a Spatially Explicit Decision Support System for Prioritizing wetland Restoration Areas." This technical note discusses the potential development and application of a generalized, GIS-based wetland restoration decision support system (DSS) using ArcView ® ModelBuilder. The discussion includes the general steps needed in creating a wetland restoration DSS, the types of digital data that can be useful in performing these types of evaluations, and an example of a specific restoration DSS created using ModelBuilder (Figure 1).

Figure 1. Former agricultural land in the Mississippi alluvial plain that was identified for restoration into bottomland hardwood forest using a wetland restoration GIS-based decision support system. The site was selected based on factors such as the presence of hydric soils, being located in the 2-year floodplain, and proximity to public natural lands.

BACKGROUND: Wetlands provide an array of ecological and environmental benefits, such as carbon cycling, flood control, water quality improvement, and wildlife habitat (Richardson 1994). There have been many ongoing efforts by Federal, State, local, and private agencies to restore wetlands and compensate for past and present loss of this natural resource. Selection of potential restoration sites can be based on a variety of factors. However, in the past, the availability of the land could often be the driving factor in determining which areas were to be restored (O'Hara et al. 2000), and restoration projects usually occurred on a site-specific basis in response to regulatory requirements, with limited success (Kentula et al. 1992). Currently, though, there is growing interest in considering and implementing wetland restoration at a watershed scale (NRC 2001).

When planning wetland restoration, it has become much easier to take into account watershed-level considerations because a variety of spatially explicit, digital, landscape level data (such as landuse, soil, floodplains, vegetation, etc.) have become readily obtainable, and can often even be downloaded for free from public websites. Furthermore, desktop geographic information system (GIS) programs such as ESRI's ArcGIS ® have become more ubiquitous, and current versions of the software are relatively user friendly. Therefore, using GIS tools, a planner can integrate a variety of spatial data, screen and evaluate potential sites, prioritize restoration efforts across a large regional scale, and undertake wetland restoration efforts at the landscape level. Site-specific fieldwork efforts can then be narrowly focused on areas that meet a given set of criteria.

Some examples of this sort of broad-scale approach to wetland restoration are demonstrated in O'Neill et al. (1997) for the Upper Arkansas River Basin in Colorado, Russell et al. (1997) for the San Luis Rey River Basin in Southern California, White and Fennessy (2005) for the Cuyahoga River watershed in Ohio, the Maryland Department of Environment (2004) for the state's coastal bays, and O'Hara et al. (2000) for a large area in the Mississippi Delta. O'Hara et al. (2000), for instance, produced a GIS-based decision support system (DSS) software for prioritizing forested wetland restoration in the region. The DSS allows planners to select the most desirable areas for potential restoration, based on multiple variables. Although this project developed a useful tool, it is limited in that it is "hardwired" to the particular area being studied (as is the case with the other studies listed above), and therefore cannot be transferred for use in other regions. Optimally, a similar type of DSS would be developed that was flexible enough so that it could be easily modified (even by those without any specific programming knowledge) and applied to almost any type of wetland in any area of the country.

However, the major difficulty in creating a restoration DSS that is generally applicable is that there is not one universal type of wetland to which a single restoration template can be applied. Obviously, the details of selecting a site for bottomland hardwood forest restoration in the Mississippi Delta are different than those for selecting a site for salt marsh restoration in coastal North Carolina. Also, selection criteria may differ based on the primary reason for restoration (improving water quality versus creating waterfowl habitat, for instance). Another difficulty in developing a universal DSS is that the availability of different forms of GIS data differs greatly throughout the country, so that necessary or helpful data may not be available for a specific area of interest. Therefore, a useful, general restoration DSS would be one that provides an ample amount of structure and guidance for restoration planning, but is still flexible enough to be modified by end-users in order to account for their planning needs, specific data requirements, and data availability. ESRI's ArcView® ModelBuilder is a potential tool for creating such a DSS.

ArcGIS ModelBuilder: ModelBuilder is an ArcGIS tool that provides a graphical modeling framework for designing and implementing geoprocessing models. Model elements, data, and functions can be displayed and manipulated through a graphical interface that appears as a flowchart diagram (Figure 2).

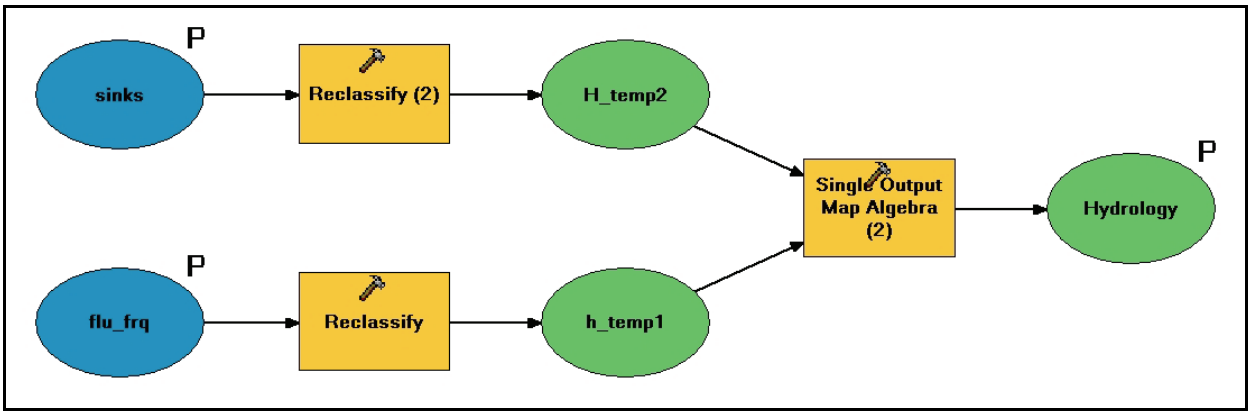

Figure 2. Example of a simple spatial model represented as a flowchart diagram in ModelBuilder.

ModelBuilder allows for multiple functions to be strung together and executed in a specific order. Once the required data layers are input into the model, the various functions are run automatically and sequentially in order to create the desired output. Therefore, a single model can be applied to multiple data sets. Models can also be edited by adding, deleting, and changing relationships among the various parameters and processes.

DATA CATEGORIES: Although the specific datasets needed for a wetland restoration DSS will vary depending on the wetland type and area of interest, certain categories of data will usually be applicable for use across all regions and wetland classes. Regardless of the type of wetland to be restored, an optimal restoration site would generally be one that is in close proximity or connected to other natural areas, and has the proper hydrology and hydric soils already in place. This section discusses several variables, based on commonly available digital data layers, that can be used in creating a wetland restoration DSS. Not all of the variables listed in this section will necessarily be used in a particular DSS, and additional layers that are not listed can still be used in the DSS, if they are available. However, it is essential that the DSS developer/user have at least the following three digital spatial layers, which will be applicable in nearly any wetland restoration scenario, and from which many other layers can be generated (also listed are potential on-line sources for obtaining these data):

- Digital Elevation Map (DEM), preferably 10 m or less
  Potential source:
  http://edc.usgs.gov/geodata/
- Landuse/Land cover layer
  Potential source:
  http://edc.usgs.gov/products/landcover/lulc.html

- Soils layer
  Potential sources:
  http://www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/
  http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/

The SSURGO soils layer is preferable to the STATSGO layer. A STATSGO layer is only appropriate if the scale of the project is at the state or multi-state level, or if no other data are available.

The website below provides a fairly comprehensive collection of links to various state GIS data clearinghouses, which will generally have the data layers listed above as well as many additional useful layers.

http://libraries.mit.edu/gis/data/datalinks/statedataweb.html

These links were working as of June 2006.

Pre-Screening Variables/Layers. The purpose of the DSS is to compare sites that are potential candidates for wetland restoration. Certain areas, for various reasons, will not be under consideration for restoration and thus do not need to be evaluated. This section discusses some variables/layers that can be used to screen out areas that do not need to be evaluated further.

- Urban areas. Commercial, industrial, and residential areas typically offer little practical potential for extensive wetland restoration, and therefore can usually be screened out of consideration.

- Existing wetlands. Technically speaking, existing wetlands do not need to be restored, and therefore will generally be screened out of consideration. However, a comparable DSS could also be created to target areas for preservation or enhancement, in which case the existing wetlands layer would be integral to the analysis.

Hydrologic Variables/Layers. Since hydrology is the dominant factor in determining the functioning of a wetland, the hydrology of a site will be integral to the success of almost any wetland restoration effort (Kusler and Kentula 1990). Selecting a restoration site where the proper hydrologic regime is already in place or can easily be restored is preferable, as it saves the time, effort, expense, and uncertainty of altering a site in order to obtain the desired hydrology. Therefore, one or more hydrologic variables should be used in any wetland restoration DSS. Useful variables/GIS coverages in this category are:

- Flood frequency. Flood frequency is a useful variable for any wetland system (such as riverine wetlands) that relies on flooding as a major part of the hydrologic regime. Areas that are inundated more frequently will generally be more likely to sustain a wetland. Although 100-year FEMA flood frequency maps are available for most areas, maps depicting more frequently flooded areas (2 years and less, for instance) may be harder to come by depending on the region of interest. In many cases, these maps may need to be newly generated, either from historical aerial photos or using hydrologic models.

- Topographic depressions. Topographic depressions are areas in the landscape where water is likely to pond. If there is no outlet from which the water can drain, it will remain in the depression until it evaporates or groundwater seepage occurs, thus sustaining the wetland hydrologically while also providing potential floodwater storage and water quality benefits. If a topographic depression map is not available for the area of interest, it can be generated using a high-resolution digital elevation map (DEM) and the ArcGIS ® software. Aerial photographs may also be used to show areas where water ponds. Pre-drainage aerial photos can be especially helpful in this regard.

- Wetness/Saturation index. As an alternative to the flood frequency and depressions layers, a wetness or saturation index layer can be used as an indicator of a site's hydrologic suitability (see Russell et al. (1997), O'Neill et al. (1997), and White and Fennessy (2005) for examples). The wetness index, as detailed in Phillips (1990), is a relative measure of the potential for saturation (wetness) of an area as compared to its surrounding landscape. The index is calculated based on surface slope, upslope drainage area, and soil transmissivity, although soil transmissivity can be left out of the equation if it is not available. Sites with large drainage areas and low slopes will have a higher wetness relative to sites with smaller drainages or higher slopes.

Soil Variables/Layers. Existing soil properties are another important consideration when selecting sites for restoration. Useful variables/GIS coverages in this category are:

- Hydric soils. By jurisdictional definition, a wetland must contain hydric soils (Environmental Laboratory 1987). Since it can take several years for hydric soils to develop naturally, it is preferable to restore a site where these soils already exist. It is likely that a hydric soil GIS layer will not exist for the area of interest, but one can easily be created by selecting out the hydric soils (using a hydric soil list) from a digital soil layer.

- Soil class. The actual soil class or soil type may also be of interest when selecting an area for restoration. When restoring certain wetlands, for instance, it might be optimal to select restoration areas with a pre-existing organic/peaty soil. Other features of the soil may also be of direct interest or can be used as indicators of the site's hydrology and topography. This information is generally available from a SSURGO digital soil layer.

Distance Variables/Layers. This data category refers to map layers that depict the distance between the potential restoration site and various other natural or man-made areas. These variables for the most part will be important in rating the habitat potential of the restoration areas. The layers will usually need to be newly generated using the ArcGIS Spatial Analyst extension, but the base layers needed to generate the distance layers generally are easily obtainable. Useful coverages in this category are:

- Distance to natural seed source. Depending on its proximity to the restoration area, a seed source has the potential to naturally regenerate the vegetation at a site (Middleton 1999). The appropriate seed source may be a forested or herbaceous area, based on the type of wetland being restored. For instance, in bottomland hardwood systems, restoration areas that are near

existing mature forest tend to have much higher species diversity than areas that are far away from existing mature stands (Allen 1990). Similarly, Reinartz and Warne (1993) found that for herbaceous depressional wetlands, diversity and number of native wetland plant species increased significantly as distance to the nearest seed source decreased.

- Distance to roads. Roads can limit movements and be a potential source of disturbance and hazard to certain animals (Roe et al. 2006, Herrmann et al. 2005), making the restored wetland less than optimal for wildlife habitat. It may also be useful to use two separate distance layers, one for primary roads, which are a greater and constant disturbance, and one for secondary roads.

- Distance to public lands. Public lands can include such things as wildlife refuges, conservation areas, special management areas, and state and federal parks. Restoring close to these lands can create larger contiguous patches of habitat or add connections and corridors between patches that are beneficial for the movement of wildlife (Semlitsch and Bodie 2003).

- Distance to streams. Wetlands in close proximity to or buffering a stream can provide both water quality (Mitsch et al. 2005) and flood attenuation benefits (Mitsch and Gosselink 1993). A nearby stream can also potentially serve as aquatic habitat for wildlife in the wetland.

Size/Shape Layers. This category refers to data layers that contain information on the size and shape of contiguous areas that are possible locations for restoration sites. This is another group of variables that can be useful for evaluating the wildlife habitat potential of potential restoration sites.

- Block size. For many species, having a few large contiguous patches of suitable habitat is preferable to numerous small, unconnected or isolated patches (Wigley and Roberts 1997, Pearlstine et al. 1997)). Therefore, it may be desirable to select areas that allow for a large contiguous wetland to be restored.

- Core area ratio. This variable is the ratio between core area (the area within a patch beyond some specified edge distance or buffer width) and the total patch area. In forested ecosystems, for example, having a high ratio increases the amount of habitat interior space, thereby increasing species diversity in the interior (Ohman and Eriksson 1998).

STEPS FOR CREATING A RESTORATION DSS: There are four general steps that can be used in creating an appropriate wetland restoration DSS:

- Determine goal(s) of restoration
- Determine which variables will be used as inputs in the DSS
- Determine the weighting and scoring of individual variables
- Determine how the variables will interact with each other

Determine Goal(s) of Restoration. Wetland restoration can have a number of goals, each with their own considerations (Natural Resources Conservation Service (NRCS) 1997). Therefore, the first step is to determine the goals of the restoration effort, as these will largely dictate what variables are used in the DSS. If the only goal is flood attenuation, for instance, then variables relating to habitat quality will not need to be considered.

Determine Which Variables Will Be Used as Inputs in the DSS. The variables listed in the "Data Categories" section of this technical note can be used as a starting point in developing the DSS. More variables can be added based on their relevance to the wetland type being considered and availability of the necessary spatial data. Beyond availability, the decision of which variables to include in the DSS can be based on the existing literature, or local expertise and best professional judgment.

Determine the Scaling/Scoring of Individual Variables. Individual variables will need to have their raw value scaled/converted into a numerical index score that can then be input into the DSS. The scaling can be based on some combination of restoration priorities, existing literature, and professional judgment. Certain variables may be deemed more influential than others for selecting restoration sites; this consideration can be reflected in the way individual variables are scored.

Determine How the Variables Will Interact With Each Other. Once the index scores for the variables are calculated, they can be aggregated together in some manner to produce a score that rates/ranks a potential site's restoration suitability, based on the goals outlined in step 1. Usually, the aggregation will just be a simple addition of the index scores, although other methods can be used with proper justification.

The index score, weightings of variables, and aggregation methodology may be determined using a team of local experts, perhaps in the context of a workshop. Regardless of the method of determining ratings, one of the advantages of this system is that it makes the process transparent to all involved natural resource managers and the influences of the effect of index scores can be tested in an iterative fashion.

EXAMPLE OF A RESTORATION DSS CREATED WITH ModelBuilder: This section illustrates how a restoration DSS can be created using ModelBuilder. It also demonstrates the procedure following the four steps described earlier. This example DSS is based on the logic and model developed in O'Hara et al. (2000). A large amount of digital data is available for the study area used in the O'Hara report, but this section will also demonstrate alternative ways of creating the DSS if all of the same data were not available. The purpose of this section is not to provide a step-by-step tutorial on creating a ModelBuilder-based DSS, but to demonstrate the capabilities of the software and give examples of some of the possible outputs.

Study Area. The study area is Sharkey County, MS, which is a 435-mile^2 area within the Mississippi alluvial plain. The area consists of cultivated land, dominated by cotton, soybeans, and corn crops. Part of the county is an extensive bottomland hardwood forest, contained within the Delta National Forest. There are very few urban areas (Figure 3).

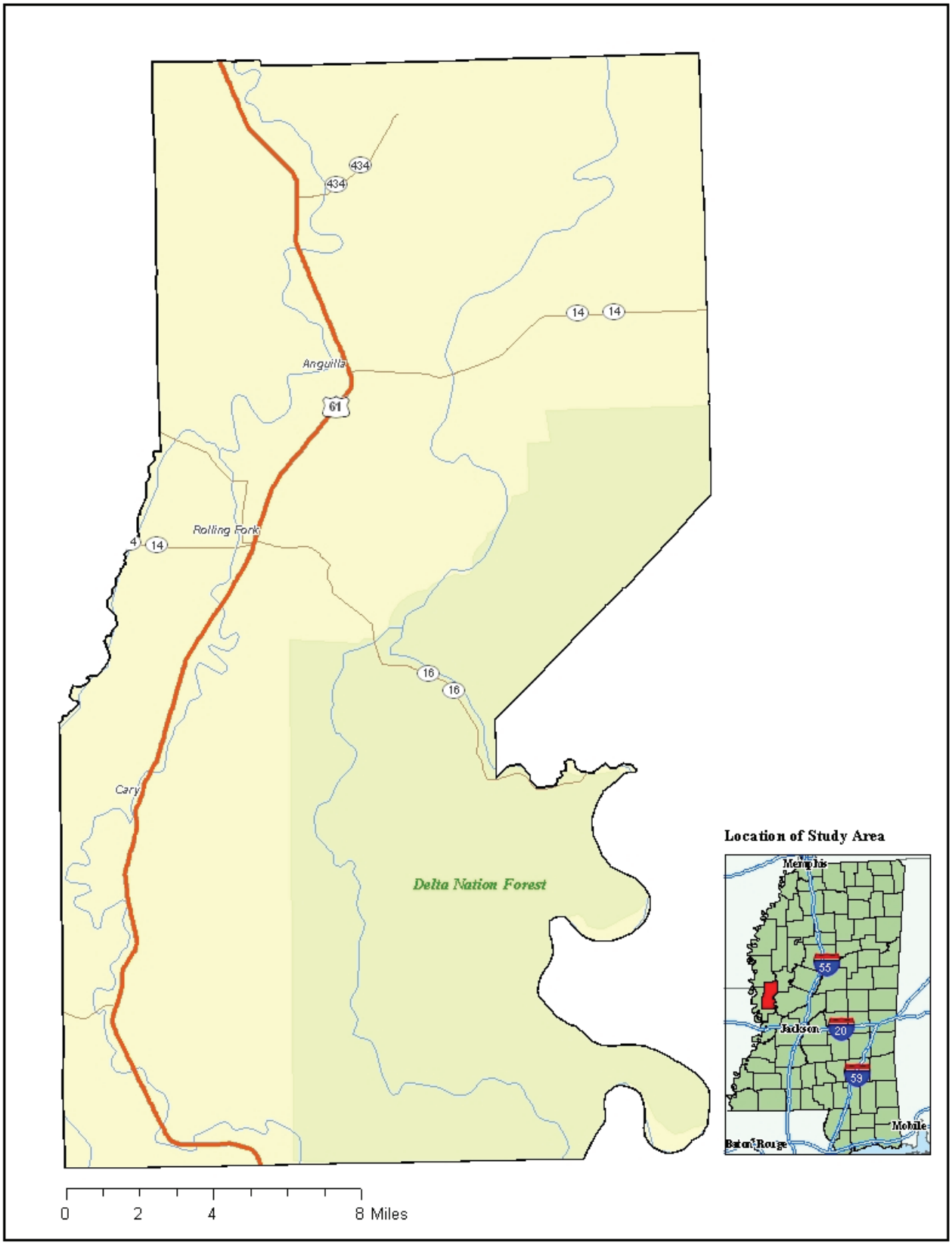

Figure 3. Sharkey County, MS.

Pre-Screening. Existing forested areas were not considered as potential restoration areas and were not included in the analysis.

Step 1. Determine Goals of Restoration and Step 2. Determine Which Variables Will Be Used as Inputs in the DSS. The goal is to prioritize the areas that will be restored to bottomland hardwood forest. Prioritization will be determined based on two general factors/functions: restorability and habitat. The restorability function assesses the ability of a location to sustain a functional wetland and is based on geomorphology, hydric soils, regeneration distance, existence of farmed wetlands, and hydrologic (flood frequency and depressions) variables.

The habitat function considers how well an area can support a wildlife population typical of a healthy bottomland hardwood forest ecosystem, and is based on proximity to wildlife management and conservation areas, distance from roads, permanent water bodies, and forest block size and core area.

The restorability function combines six variables: environment of deposition, soils, regeneration distance, NRCS farmed wetlands, flood frequency, and topographic depressions.

Step 3. Determine the Scaling/Scoring of Individual Variables. The scoring of the variables used in this example is the same as that used in O'Hara et al. (2000); i.e., variables are scored categorically. For example, the 'soils' variable in the restorability function is scored as a 10 if the soil is hydric and a 1 if it is non-hydric. The 'forest block size' variable in the habitat function is scored as a 10 if it is greater than 320 acres, a 5 if it is between 10 and 320 acres, and a 1 if it is between 1 and 10 acres. Overall, variable scores in the restorability function range from 0-20, and scores in the habitat function range from 0-10, although not all variables are scored within that range.

Step 4. Determine How Variables Will Interact with Each Other. Scaled variable scores will be aggregated for each function using a simple summation:

- **Habitat Ranking** = (Distance to WMA) + (Distance to Conservation Areas) + (Distance to Primary Roads) + (Distance to Secondary Roads) + (Distance to Permanent Water) + (Forest Block Size) + (Core Area Ratio).

- **Restorability Ranking** = (Environment of Deposition) + (Soils) + (Regeneration Distance) + (Farmed Wetlands) + (Flood Frequency) + (Topographic Depressions).

Output. The final output is a map showing a combination of the restorability and habitat scores for each cell in the raster (Figure 4) which can then be used as a guide for prioritizing areas for wetland restoration. Maps can also be created showing scores for just the habitat (Figure 5) and restorability (Figure 6) functions.

Benefits of Using ModelBuilder. Several features of ModelBuilder make it well-suited for creating a restoration DSS, especially one that can be applied universally. For instance, data layers can be easily reclassified (Figure 7) in order to change the scaling of individual variables. This feature could be very useful when developing the DSS in a group setting and local expert opinion is being used to determine the variable values.

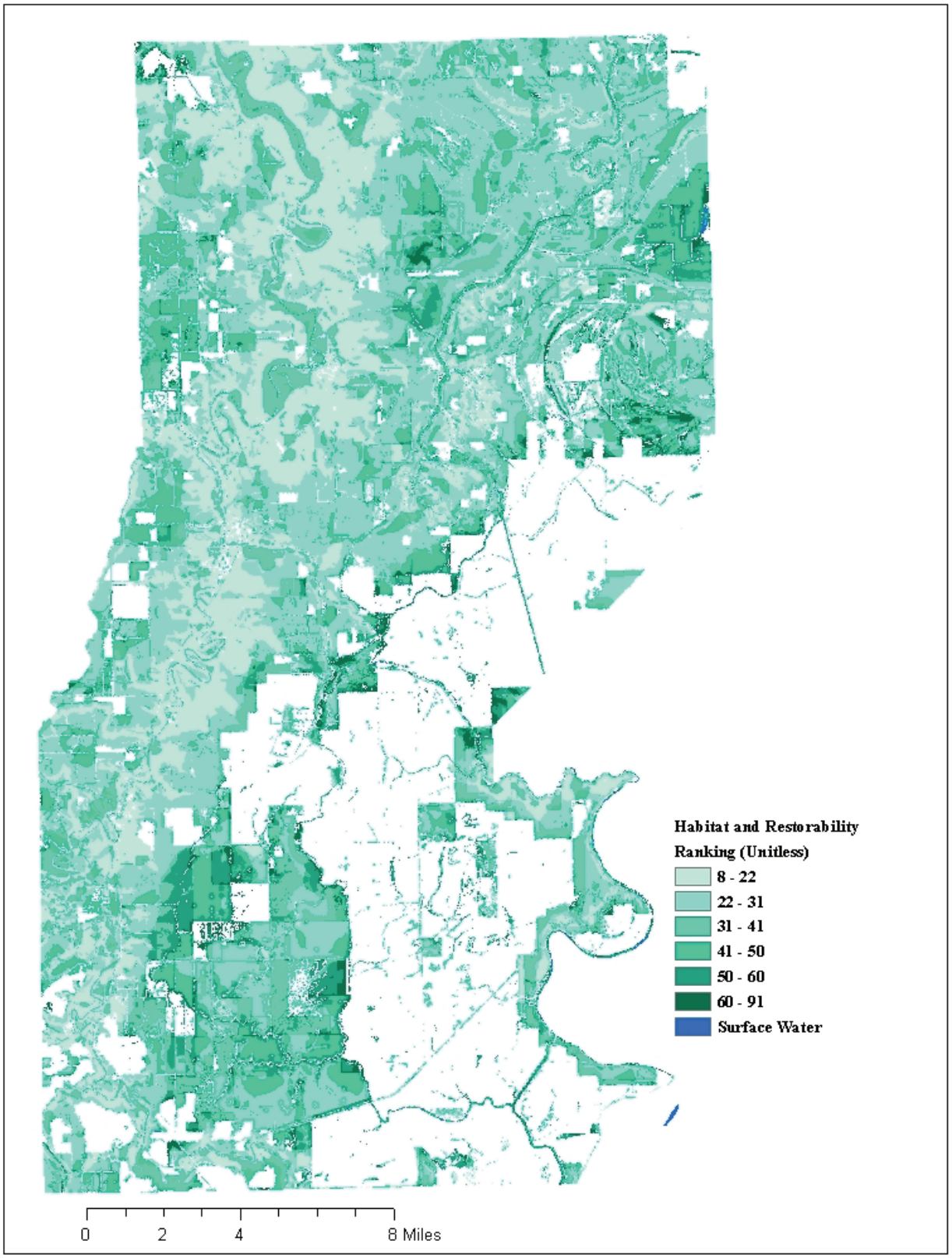

Figure 4. Combined habitat and restorability ranking for Sharkey County. The higher the ranking (darker color), the more suitable an area is for restoration, based on its ability to sustain a functional wetland and to provide adequate wildlife habitat.

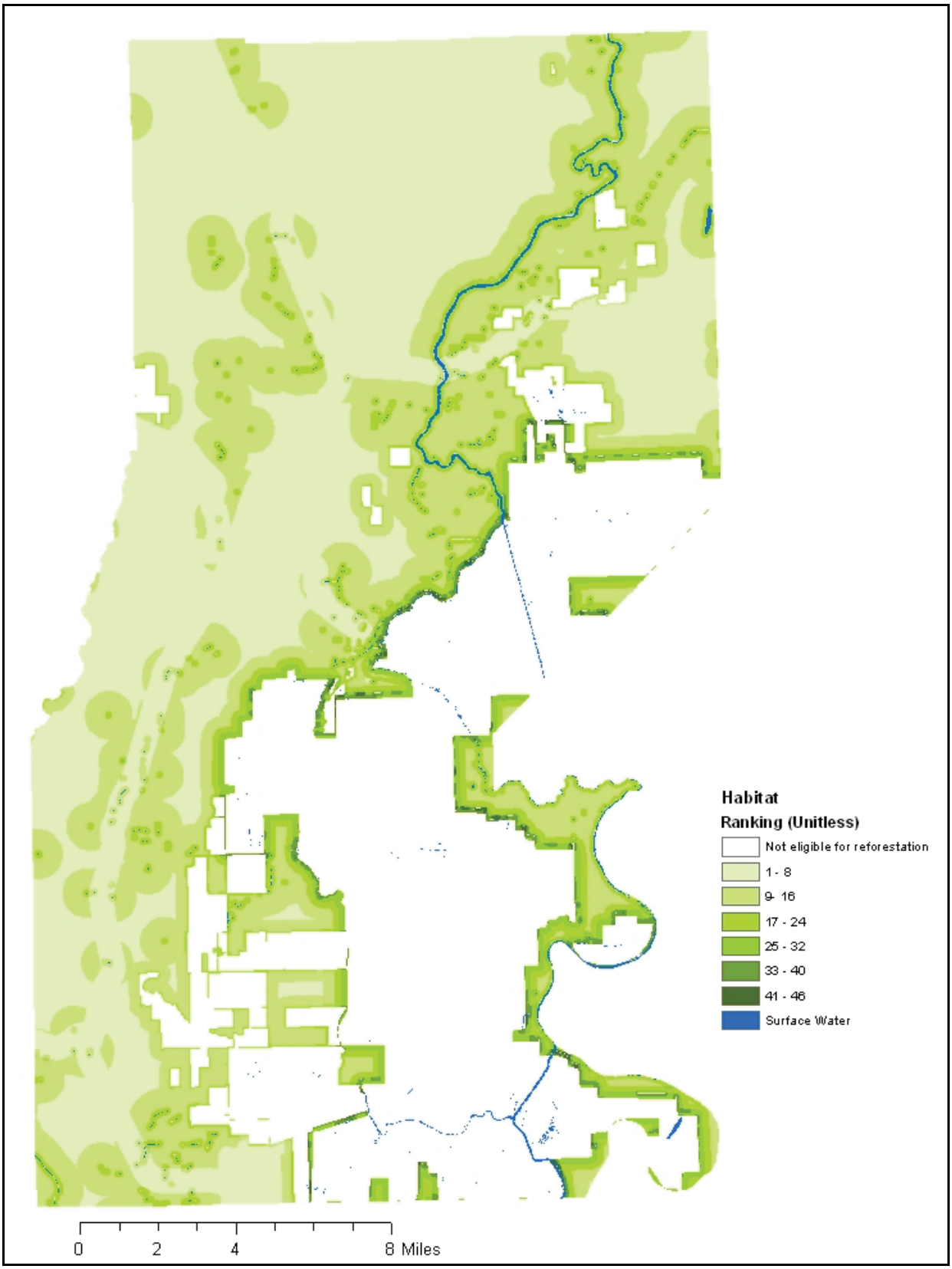

Figure 5. Habitat scores for Sharkey County. Darker green areas indicate areas more suitable for restoration, based on their ability to provide adequate wildlife habitat.

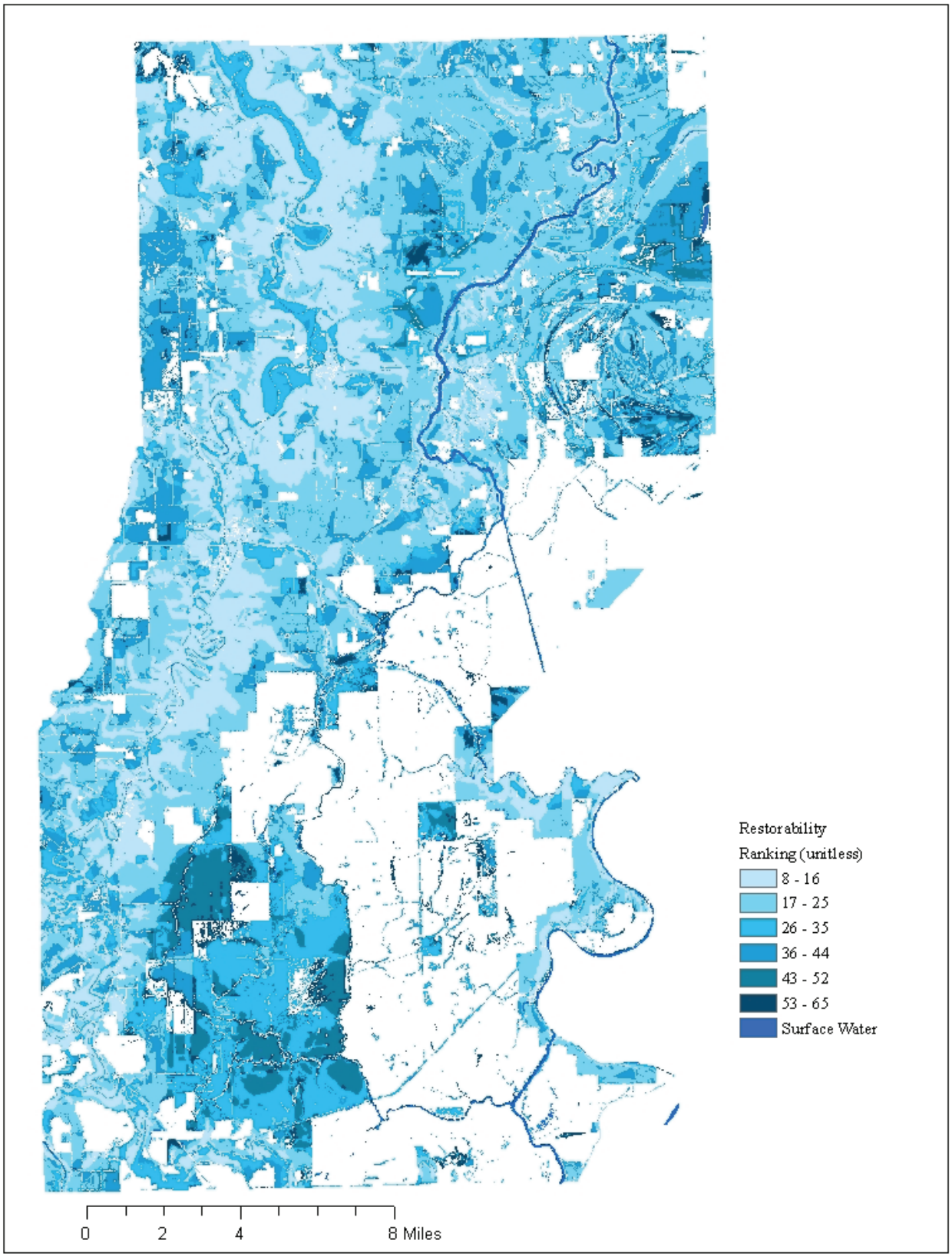

Figure 6. Restorability scores for Sharkey County. Darker blue areas indicate areas more suitable for restoration, based on their ability to sustain a functioning wetland.

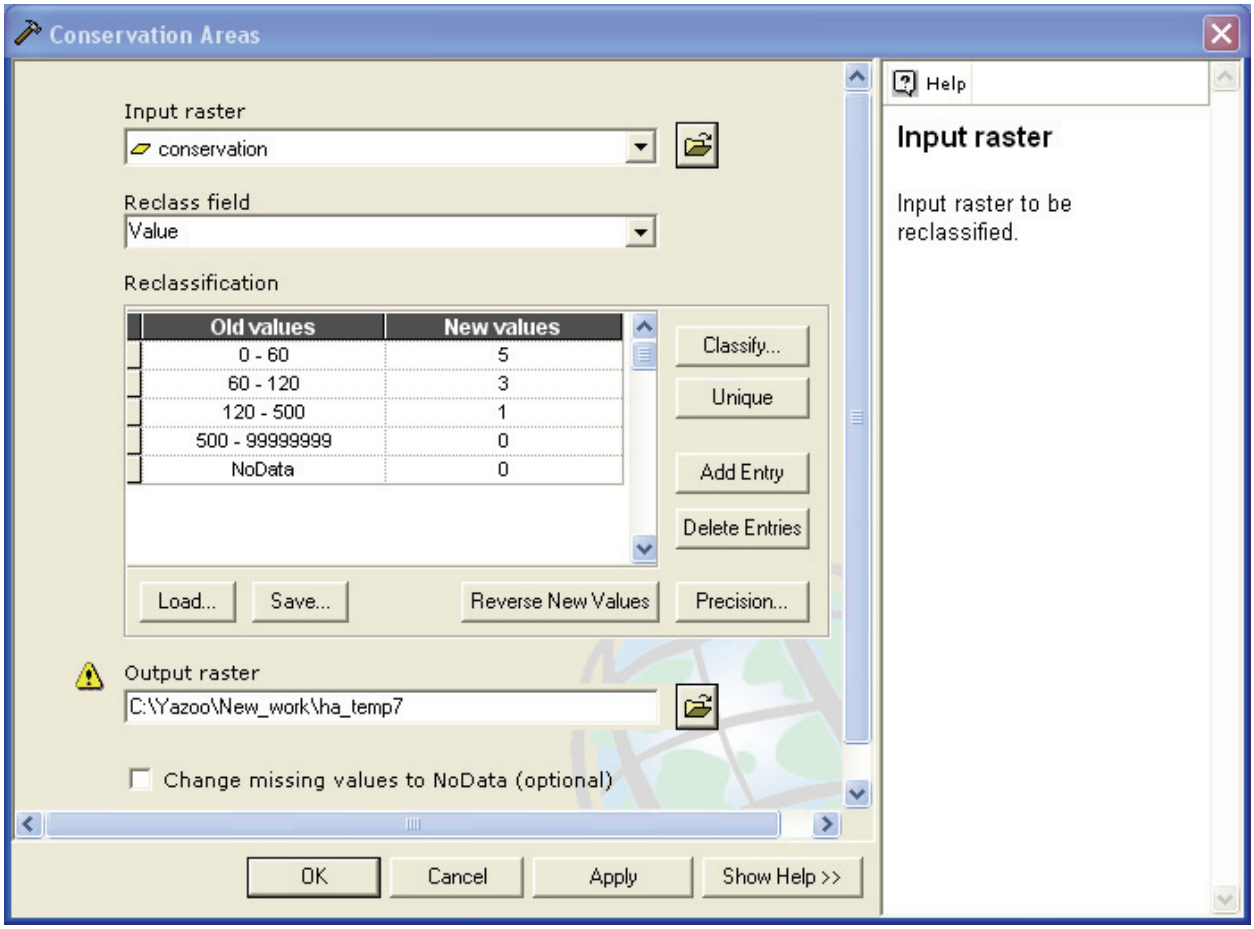

Figure 7. Screen showing how an input raster can be reclassified in order to change variable scaling.

In a universal DSS, variable layers can be excluded from the model if the data are not available. For example, in the restorability function, if an "environment of deposition" layer is not available, it can be "turned off" and not included in the analysis (Figure 8).

Similarly, alternative layers may be substituted in and out of the model. For instance, a wetness index layer can be used instead of flood frequency and depression layers. Figure 9 compares the restorability map created using the wetness index with that created using the flood frequency and depression layers.

CONCLUSION: The wide availability of digital, spatially explicit data and advancements in desktop GIS applications have made the development of a decision support system a practical and easily applicable method for prioritizing wetland restoration efforts at a landscape or watershed level. The ArcGIS ModelBuilder tool is a flexible and user-friendly method of developing such a DSS, particularly one that can be customized and applied nationally. Future efforts proposed within the EMRRP will further develop these ideas and seek to develop and distribute a ModelBuilder-based template that can be universally used by natural resources and wetland managers to aid in wetland restoration planning.

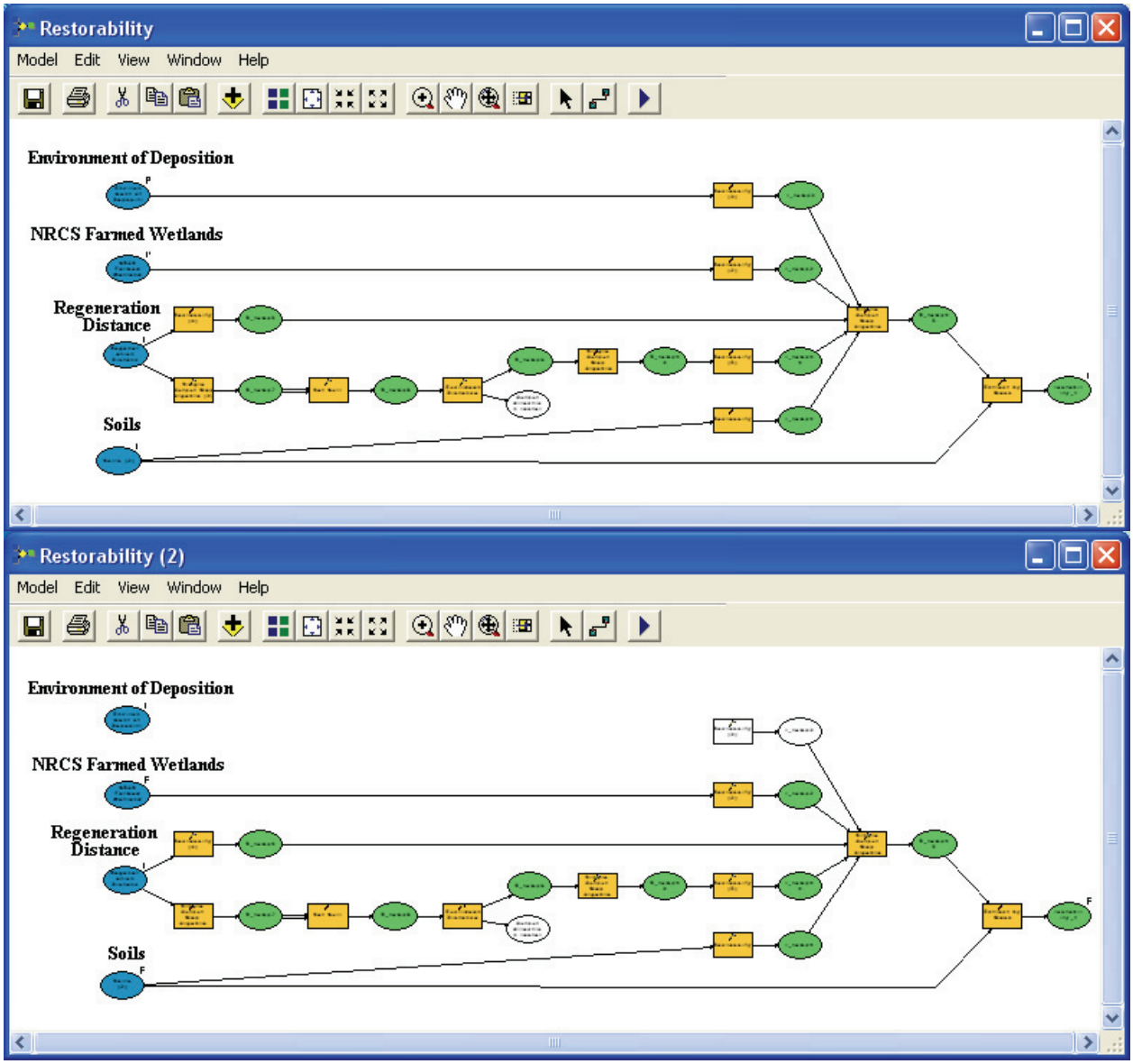

Figure 8. Screens showing “environment of deposition” layer being used (top) and not used (bottom) in the habitat function analysis.

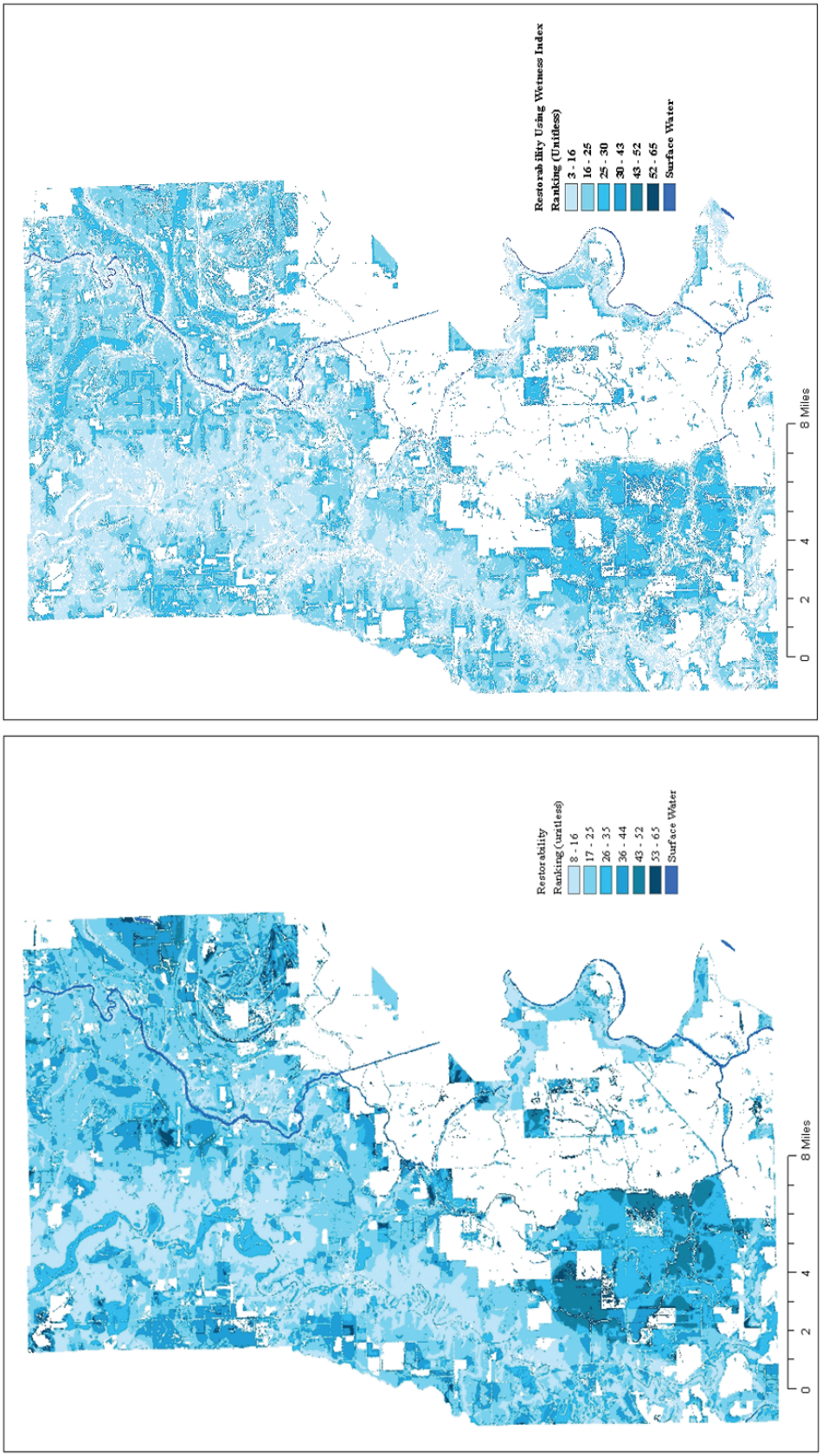

Figure 9. Restorability functional ranking maps. Map on the left was created using flood frequency and depression layers to address hydrologic suitability, map on the right used a wetness index layer for the same purpose.

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