Marys River Watershed Restoration Planning by Using a Multiple-Objective Decision-Support Tool, RESTORE

by

Kimitake Nishioka

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ABSTRACT

Effective watershed restoration planning and prioritization is often very difficult because decision making typically involves a large number of alternatives evaluated on the basis of multiple and often conflicting technical, social, economic, and environmental objectives and criteria. In order to solve such complex decision making problems, multi-objective decision making (MODM) models in conjunction with a geographic information system (GIS) have lately attracted considerable attention. The combination of MODM techniques and GIS capabilities allows watershed managers to determine high priority areas and the best restoration alternatives under the presence of diverse goals, objectives, and criteria. As my internship project, I was asked by the Marys River Watershed Council (MRWC), at the west side of the Willamette Valley in northwestern Oregon, for methods to develop restoration projects for Marys River watershed. I used an integrative GIS-based multi-objective decision support software, RESTORE, to generate and examine restoration prioritization plans at accomplishing different sets of objectives. In this project, I examined several different information obtained from RESTORE, including the most and second preferred restoration plans, priority areas, and similarity areas. Through the visualization and analyses of these data, RESTORE proved to be a powerful and operational tool for watershed restoration planning. The results also suggested, however, that we need more information and evaluative models to use RESTORE more effectively for Marys River watershed restoration planning and prioritization.

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1. INTRODUCTION

1.1 Background

In the vast majority of watersheds in the United States, population growth and natural resource development have altered characteristics and functions of land and water ecosystems. According to the National Research Council (1999), most watersheds in the U.S. have been altered, with only five percent of the surface area still in its original natural condition, and about 2.5 percent in designated wilderness areas. In case of the wetlands, over the past 200 years, 53 percent of the wetlands in the conterminous U.S. have been lost, with some states losing up to 80 percent of their wetlands (Dahl, 1990). These losses were caused by draining and filing of wetlands primarily for agricultural uses and urban development (Kubasek and Silverman, 2001). While the rate of wetland loss in the U.S. has significantly decreased in the past decade, wetlands have still been lost at a rate of about 58,500 acres per year (Dahl, 2000).

Watershed management is becoming beneficial for many reasons including the protection of fish and wildlife habitat, recreation, and use of water and other natural resources in a sustainable manner. Effective watershed restoration planning and prioritization often involve choices or selections of alternative management plans and scenarios, which should be consistent with stakeholder goals and objectives (Thill, 1999). It is often the case, however, that the decision making for watershed restoration planning is very difficult for a number of reasons. One problem is the search for consensus among various interested decision makers (DMs) and interest groups (Malczewski, 1996). In many instances each person has a different background associated with educational, professional, and personal experience, so that they usually represent unique preference with respect to the relative importance of criteria on the basis of which the alternatives are evaluated. In addition, the decision making typically involves a large number of alternatives evaluated on the basis of multiple and often conflicting technical, social, economic, and environmental objectives and criteria (Diamond and Wright, 1988). For example, a proposed site and restoration option that is best with respect to one objective, such as water quality improvement, may not be best with respect to another objective based on, for instance, minimizing cost. As Brooks et al. (1997) point out, watershed management not only depends solely on the topographical and landscape characteristics of watersheds, but also needs to fully integrate institutional, social, economic factors into viable solutions that meet environmental and socioeconomic objectives. In order to solve such complex decision making problems, therefore, some systematic method of dealing effectively with multidisciplinary, multiobjective, and multistakeholder aspects of watershed restoration planning is required.

Many scientists and researchers have studied and developed systematic procedures for analyzing complicated decision problems for several decades in the variety of fields (Thill, 1999). As a useful method, multiple-objective decision-making (MODM) models in conjunction with a geographic information system (GIS) have attracted considerable attention recently (Heywood et al., 1995). The general objective of MODM is to help DMs design restoration alternatives and search for the best alternative under the presence of diverse DMs objectives, priorities, and criteria (Jankowski, 1994). Because the alternatives that are defined by variable spatially explicit data depend on landscape features, taking advantage of GIS is necessary for effective modeling. Thus, an approach that integrates GIS into MODM can allow watershed managers not only to gather and display large amount of spatial data, but also to analyze and make decisions in a context of the landscape and restoration alternative characteristics (Malczewski, 1996).

Considering the brief background of GIS-based MODM mentioned above, let me explain my internship project. As the internship project, I was asked by the Marys River Watershed Council (MRWC), in western Oregon, for methods to develop restoration projects for Marys River watershed. MRWC had been working with the U.S. Environmental Protection Agency (EPA) to finalize the first version of a watershed restoration priorities map created mainly based on a Cutthroat Habitat Suitability Index Model developed by the U.S. Fish and Wildlife Service. The priorities map would be evaluated in the field to validate the priorities and to recommend restoration actions appropriate for the site. Since the challenge commonly faced with watershed councils is how to effectively identify and prioritize restoration activities, using another approach for watershed restoration planning might assist MRWC evaluate validity or effectiveness of their restoration priorities. For this reason, I used an integrative GIS-based multi-objective decision-support software, RESTORE, to generate restoration prioritization plans appropriate for the Marys River watershed. As mentioned before, since many researchers suggest that effective watershed restoration strategies require several options for meeting potentially conflicting restoration objectives, using a tool like the RESTORE may be useful for prioritizing problems and identifying areas for restoration activities. The purpose of this study for the Marys River watershed is to create the preferred restoration plans by using the RESTORE model to assess different sets of objectives and examine a variety of output data from RESTORE. The results will help the Marys River Watershed Council prioritize and analyze their restoration options.

1-2 Overview of RESTORE Tool

RESTORE is a GIS-based multiple-objective decision-support software tool for conducting watershed restoration planning and prioritization. It has been developed by Oregon State University (OSU) in conjunction with two watershed councils - the Long Tom and South Santiam watersheds in Oregon's Willamette Valley (Lamy et al., 2002). The combination of MODM techniques and GIS capabilities allows DMs to determine high priority areas for focusing restoration activities that meet their restoration goals under a variety of site conditions. In other words, RESTORE incorporates a set of rules and constraints associated with different restoration alternatives with site-based information and DMs goals and objectives for creating a watershed restoration plan.

Application of RESTORE involves a number of steps. First, a set of feasible restoration alternatives, DMs objectives and subobjectives, and criteria (constraints and rules) for evaluating the alternatives are identified and established. The feasibility of alternatives is determined upon the satisfaction of the set of constraints imposed on the decision criteria and scores of the set of rules. The decision criteria may be quantitative or qualitative and they relate to specific restoration alternatives, DMs objectives, and site conditions. Second, RESTORE requires that a watershed of interest be divided into many discrete parcels (cells) of land on GIS. A cell is a smallest spatial unit which is a candidate for evaluation, and associated with each cell are a variety of spatial data such as area, land use, and soil. Spatial query language and spatial analysis operation such as overlay and proximity available in the GIS are used to prepare the spatial data. Then, the alternatives are ranked for each cell, based on their achievement of the criteria and DMs preferences. RESTORE uses the weighted summation approach in which each objective is assigned a weight according to their importance. The evaluation of the alternatives are run from a common geographical user interface (GUI) and the final output of RESTORE is a spatially explicit preferred proposed landscape composed of the best alternatives for the cells. The GUI can allow DMs to perform visual evaluations of the proposed landscapes, to look at different combinations of information layers, to examine a detailed score for each cell, and so forth.

According to Lamy et al. (2002), results of applying RESTORE in the two watersheds suggest that multiple-objective methods can provide a valuable tool in the analysis of complex watershed management issues. Bolte et al. (2001) also point out, during the course of developing and applying RESTORE for the watersheds, that RESTORE was well received by the stakeholder groups for several reasons, including: the capability of visually evaluating their watersheds from numerous perspectives; easily interpreted and understandable decision process because of its rule-based approach; the availability of easily setting and understanding objective weights which allows them to feel 'in control' of the process. For these reasons, I think that using RESTORE for Marys River watershed restoration planning and prioritization can help MRWC evaluate validity or effectiveness of their restoration priorities.

1-3 Study Area

The Marys River watershed, shown in Figure 1-1, is located on the west side of the Willamette Valley in northwestern Oregon. Its 310 sq mile watershed is the largest watershed in Benton County and small edges of the watershed fall into Lane, Lincoln, and Polk counties. The elevation within thirteen 7.5-min USGS quadrangles covering the area ranges from 4,200 feet above mean sea level at Marys Peak to 250 feet at the city of Corvallis. The Marys River watershed encompasses a geomorphically complex region that includes mountainous areas of the Oregon Coast Range and broad flats of the valley floor (Glasmann, 2000). Viewed in terms of land use, hydrology, and landscape, the watershed might be further divided into three distinct areas: an upland forest area, a valley agricultural area, and a downstream urban area (Ecosystems Northwest, 1999). Figure 1-2 illustrates the land use and land cover data for the watershed. Several

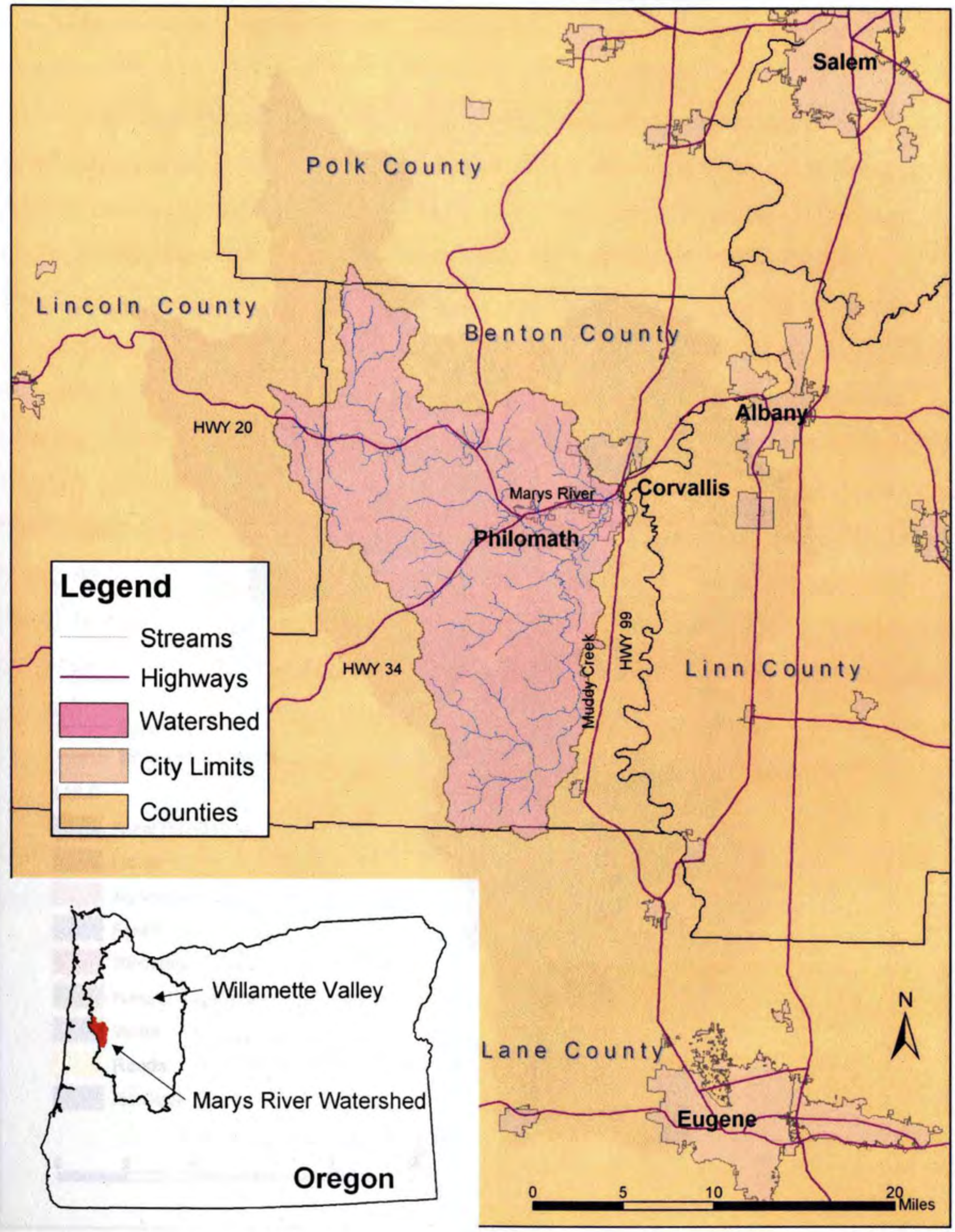

Figure 1-1. Location of the Marys River watershed within Oregon

Figure 1-2. Land use and land cover (LULC) and 303d-listed streams for Marys River watershed.

headwater streams from the upland forest area enter the main channels and then flow thorough the agricultural area and into the Willamette River at the downstream urban area. In the following, I would like to explain more detailed characteristics of these three areas.

The upland forest area of the Marys River watershed covers the western and northwestern portions of the area. While forestry is the main land use in the area, small scattered residences, agriculture, and farms are observed especially along the highway 20 and 34. Approximately 70 percent of the upland area is owned by private or non-governmental industries, and the rest of the area is owned by public such as United States Department of Agriculture (USDA) Forest Service, Bureau of Land Management (BLM), and the State of Oregon. The valley agricultural area is located eastern portion of the watershed. In addition to extensive agricultural activity, the area is characterized by a mix of forests, prairies, and seasonal wetlands, mainly along the Muddy Creek, the main stream of the area. Ownership in the valley area is largely private, though a small portion around the mid-Muddy Creek is designated a national wildlife refuge. The downstream urban area corresponds closely to urban growth boundaries of Philomath and Corvallis. The urban area is a mix of residences, businesses, and industries and is owned by mostly private owners. Since the Marys River flowing into these urban areas is influenced by a variety of urban and agricultural activities including urban storm runoff, wastewater effluent, and soil erosion, the Marys River in this area has been placed on the 303(d) list of impaired waters, meaning that the river does not meet specific water quality standards regulated by the Oregon Department of Environmental Quality (ODEQ).

2. METHODOLOGY

The methodology section is composed of three parts. First, several key components for implementing RESTORE tool and processing data are described. Second, the method used in RESTORE for ranking restoration options to create a preferred proposed landscape that reflects stakeholder goals is outlined. Finally, because RESTORE was implemented by assigning different weights to each objective, the setting of RESTORE for my project is illustrated.

2-1 Components of RESTORE

The application of RESTORE for watershed restoration planning requires four main components: (1) a set of objectives and subobjectives DMs attempt to achieve; (2) a set of restoration options, that is, alternative courses of action; (3) spatial data set relevant to restoration decision-making; (4) a series of rules and constraints on the basis of which DMs evaluate restoration alternatives. In the following, I would like to describe each component in detail.

2-1-1 Objectives and Sub-objectives

The first component required to develop a preferred watershed restoration is a set of objectives. Objectives are statements about the desired state of watersheds. In multiple objective decision-making situations, therefore, there should be several statements reflecting DMs goal. A well-defined set of objectives often exhibits a hierarchical structure where objectives at lower level are more specific and more operational than those at higher level (Chankong et al., 1983). Thus, in RESTORE, five standard objectives were identified, and then more specific sub-objectives were chosen toward fulfilling these objectives (Table 2-1). Since it is important to make goal setting a community-based planning in sound watershed restoration planning (Good, 1999), objectives and sub-objectives in RESTORE were originally developed in cooperation with the two watershed councils described earlier. The degree to which these objectives are met is the basis for comparing restoration options.

Table 2-1. Objectives and sub-objectives used in RESTORE

Objectives	Sub-objectives
Water Quality	Nitrogen Phosphorus Sediments Dissolved Oxygen Fecal Coliform Temperature Pesticides
Water Quantity	Low Summer Flows Winter Flooding
Habitat Quality	Shrub Users Grass Users Conifer Forest Users Hardwood Forest Users Stream Invertebrates Riparian and Wetland Invertebrates Aquatic and Riparian Vertebrates Cool Water Fish Insect Eating Predators Other Predators
Social Issues	Perceived Benefit Cost Ratio Protect Private Property Rights Public Education Public Support Voluntary Action Aesthetics Fairness Low Impact Recreation High Impact Recreation Scientific Merit
Economic Issues	Minimize Cost

2-1-2 Restoration Options

Restoration options are alternative courses of action among which DMs can choose. These actions are land-base activities or modifications that cause intervention in the existing conditions and result in movement toward a desired target based on management goals and objectives. For the project, I used a standard set of 19 restoration options presently used in RESTORE (Table 2-2). These alternatives were identified and developed in consultation with two watershed councils, based on feasibility of using management options for addressing environmental problems (Bolte, 2001).

Table 2-2. Restoration options used in RESTORE

Restoration Options
Agricultural Riparian Buffer
Urban Riparian Buffer
Forest Riparian Buffer
Wetland Conservation
Wetland Construction
Wetland Restoration
Create Conditions Favorable to Native Species
Enhance Stream Complexity
Increase Late Summer Flows
Streambank Stabilization
Creekside Management
Heterogeneous Development Patterns
Nonriparian Filter Strips
Field Borders
Agricultural Soil and Water BMPs
Agricultural Chemical BMPs
Agricultural Habitat BMPs
Forest Harvest Type and Scale Modification
No Action

As Heathcote (1998) points out, in theory, potential watershed management actions can contain four types of practices, including structural options, nonstructural options, vegetative approaches, and "do nothing" option. All four types of restoration options were considered in RESTORE. First, structural options require construction activities, such as "wetland construction" and fencing for "creekside management," for improving water quality and quantity. Second, nonstructural options, often called best management practices (BMPs), are sometimes more efficient than structural measures. BMPs are methods that have been determined to be the most effective and practical means of preventing or reducing pollutions (Peterson et al., 1998). For my project, nonstructural measures included three types of agricultural BMPs for soil erosion, wastewater treatment, and habitat. Third, vegetative approaches are practices that alter vegetative cover of land to stabilize eroding areas or to treat runoff. Vegetative options are widely used in agricultural applications and in urban setting. Most of the restoration options for the project belonged to this type, for instance, "urban riparian buffer," "nonriparian filter strips," and "forest harvest type and scale modification." Finally, a "do nothing" alternative was included in RESTORE. No action option is to keep the existing state of an area where change is not necessary at the present time. This option is sometimes viable, because it is often inexpensive.

2-1-3 Spatial Data

From the MODM perspective, spatial data can be viewed as information sources available to DMs for achieving their objectives and generating feasible restoration plans based on site-specific data. As mentioned earlier, within RESTORE, a map of a study area is first made into small discrete parcels (cells) that are considered the smallest spatial land unit. That is, the watershed is a contiguous collection of a large number of cells on which DMs can make a decision as the basis for model input. The cells were developed by spatially overlaying three GIS polygon coverages for land use and land cover, soils, and subbasin. For the Marys River watershed, there were approximately 12,000 cells whose average area was 6.5 hectares. Once the cells were defined, other required spatial data were added to each cell. GIS procedure for these processes will be described later.

Spatial data preparation for the study area was accomplished using ArcView3.2 and ArcGIS 8.1 commercially supported by the Environmental Systems Research Institute, because RESTORE requires that the spatial data be represented by shapefiles (.shp) spatial data format. Shapefiles are a basic vector file structure for storing the location and attribute information of points, lines, and polygons (ESRI, 1998). I mainly used the ArcGIS for data analysis and used the ArcView for only running some scripts that allow users to extend the capabilities of the system beyond those provided in the standard package.

The spatial data requirements for the project were extensive, though most of the data were readily available from the following three web sites. Ownership, urban growth boundaries (UGB), 303d streams, and wetlands data were downloaded from the State Service Center for GIS (SSCGIS), land use and land cover (LULC) data was derived from the Pacific Northwest Ecosystem Research Consortium (PNW-ERC) web site, and hydric soil data was obtained from the Soil Survey Geographic (SSURGO) data base web site of the Natural Resources Conservation Service (NRCS). A subbasin coverage and stream network coverage with arc-node topology for the Marys River Watershed, which were delineated from Digital Elevation Models (DEMs), were obtained from Kellie Vache, graduate student of Bioengineering Department at OSU. Erosion potential coverage and slope coverage were also created by Kellie. Refer to the appendix A for a complete listing of GIS data for the project.

Since data retrieved from different sources were in different map projections and coordinate systems, all data layers had to be projected into a consistent spatial coordinate system in order for them to overlay correctly when they were used for spatial analysis. In this project, all data were presenting using the Universal Transverse Mercator (UTM) coordinate system zone 10 (from 126W to 120W) as a standard coordinate system. The UTM system is conformal and maintains shape with accurate representations and minimal distortion of any location within the zone. Another advantage is that many organizations project their topographic maps using UTM, thus it is easy to obtain UTM coordinates from maps for input to data sets. Converting data layers into the UTM, if necessary, was done with ArcToolbox Project Wizard before the data layers were further analyzed and modified. In the following section, I would like explain the required spatial data and GIS procedure for each data.

Cells

To generate the cells, three spatial data layers including LULC, soils, and subbasin were clipped to the extent of the Marys River basin using GeoProcessing Wizard in ArcMap. Then, using union overlay tool in GeoProcessing Wizard could overlay three data to create a new shapefile containing a set of integrated polygons. Since new features of the output shapefile do not have their area and perimeter calculated automatically in ArcMap, they have to be recalculated after the union operation. Thus, I used Field Calculator in ArcView with Visual Basic for Applications (VBA) statements "[shape]. ReturnArea" and "[shape]. ReturnPerimeter" to recalculate area and perimeter, respectively. The resulting shapefile had updated features. Figure 2-1 shows this process for creating the cells. Now that individual cell is homogeneous with respect to LULC, soil, and subbasin, next step is to add other site information into the cells.

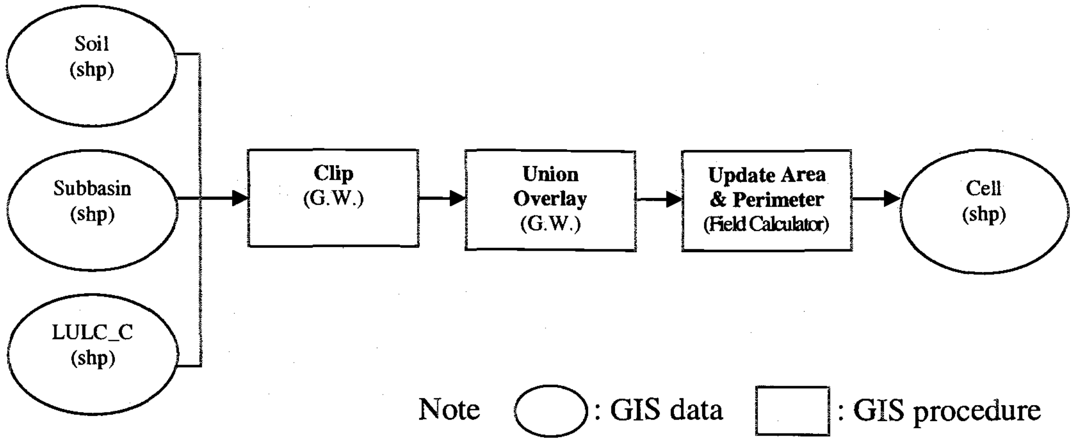

Figure 2-1. Process for creating cells

Land Use and Land Cover (LULC)

The LULC data from the PNW-ERC is a 30m gridded dataset created by TM imagery analysis, describing the vegetation, water, natural surface, and cultural features on the land surface across the Willamette River Basin for approximately 1990. The LULC data is classified by the PNW-ERC land use classification system in three different level of articulation. At the top level, LULC_A, there are nine distinct categories which are the coarsest articulation LULC classes. LULC_B categories are sub-divisions of LULC_A, and the LULC_B categories are further subdivided into LULC_C to reflect greater detail, such as light duty loads, rural service center, and so forth. For more detail about these classes, refer to the Appendix B. These LULC classes were used to define the land use and land cover characteristics of the cells. It should be noted that, since wetlands appears to be under-represented in the LULC data due to their small size and the relatively dry year (1992) used for analysis (Adamus et al., 2000), the 1990 existing wetlands condition data from PNW-ERC was overlaid on the LULC data for reasonably revising wetland areas and distribution.

Since the original LULC data is Tagged Image File Format (TIFF) which is not intended for cell-by-cell analysis in ArcGIS, as a first step, I used Image to Grid Tool in ArcToolbox to convert the image data to a grid format. The grid for the entire Willamette River Basin needed to be clipped to the extent of the Marys River basin, so that this was done by an ArcView Avenue script, "Grid.ClipToPoly". Then, the clipped grid was converted to a polygon coverage using Grid to Polygon Coverage tool in ArcToolbox because a coverage format is best applied to discrete objects with defined shapes and boundaries. In this process, however, it is likely that there are any gaps or small areas, probably the result of errors known as slivers, caused by unmatched nodes along two lines (Clarke, 2001). For this reason, polygons smaller than a grid size (900 m^2) was eliminated using ELIMINATE script that can merge the slivers into the neighboring polygons and create a new polygon shapefile as an output data. The original data downloaded from the web site was classified by only LULC_C categories, the most detailed land use classification, so that I edited attribute information of the output shapefile according to the land use classes (Appendix B) and created three distinct shapefiles, LULC_A, LULC_B, and LULC_C.

The final step of the process was to put the three LULC data into the cells, which means that each cell should own a specific land use characteristic. The idea here is to overlay the LULC data and the cells and then to query a land use characteristic in which each cell has its center. This process was done by the Select By Location dialog with "have their center in" option available from ArcMap. Consequently, the attribute information for the three LULC data were added to three new fields in the attribute table of the cells. The same process was done for the 1990 existing wetlands data, then a cell under the 1990 wetlands category was classified as a wetland regardless of its original land use category assigned by the LULC data. Figure 2-2 shows the flowchart of this LULC data process.

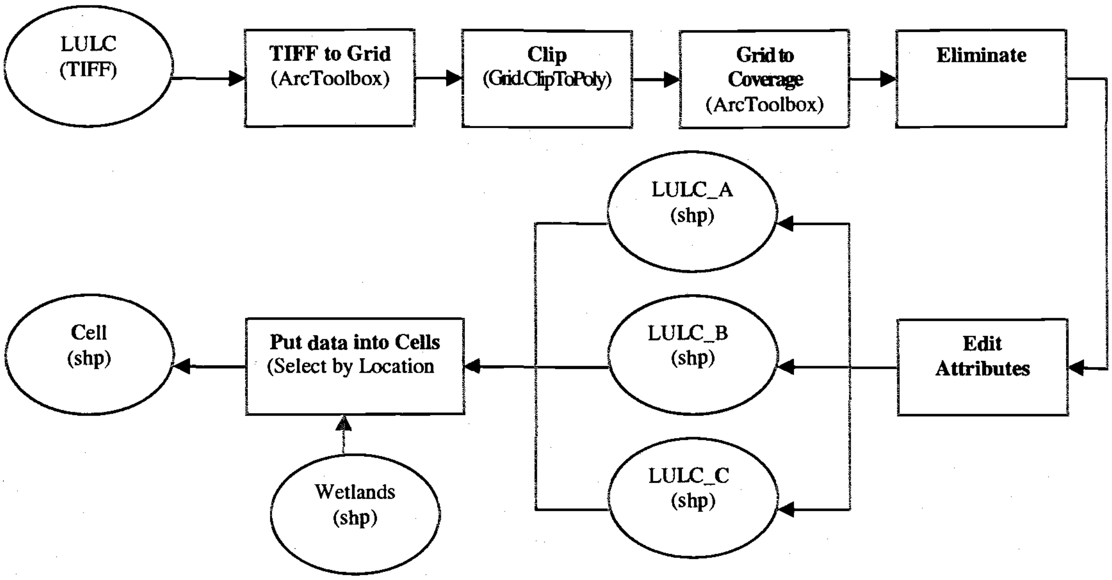

Figure 2-2. Process for adding three LULC data and wetlands data into the cells.

Hydric Soil

Most regulated wetlands are widely recognized as consisting of three main components: hydric soils, hydric vegetation, and wetland hydrology (Hurt and Carlisle, 2001). Thus the hydric soil attribute is generally used to assign wetland conservation, construction, and restoration. The hydric soils are defined by the U.S. Department of Agriculture's National Resources Conservation Service (NRCS, 2003) as "soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part of the soil." It generally corresponds to hydric soil group D in the SSURGO data set that gives the proportionate extent of the component soils and their properties, so that I used this data set for the study area to identify the hydric soils.

The original SSURGO map data were available in Arc interchange file formats (E00) and needed to be clipped to the extent of the study area. Therefore, the data was converted to a polygon coverage and then converted to a shapefile using ArcToolbox, so that it could be used as the clipping shapefile. After the shapefile was clipped by the GeoProcessing Wizard, all polygons assigned by hydric soil group D were coded as 1 and all other polygons were coded as 0 in the attribute table. Finally, using the previously mentioned procedure, the resulting hydric soil data was added into the cells with a new field. The flowchart of the process appears in the Figure 2-3.

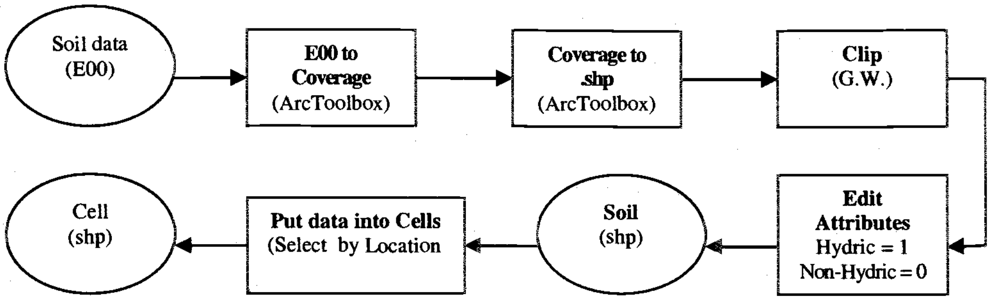

Figure 2-3. Process for adding hydric soil data into the cells.

Ownership

Given the wide range of privately owned lands and the diversity of land ownership in the Marys River Watershed, opportunities to restore the watershed might differ by ownership. In other words, understanding of land ownership patterns can help understand the current capability of landscape and also assist in setting priorities for watershed restoration and protection in terms of landowner permission. In addition, it is often the case that private lands are more at risk of ecological functions than public lands, hence ownership information is necessary to be incorporated into the decision rules. The land ownership data for Oregon was created by SSCGIS in 1992 and 1993. The data contain 14 ownership codes, the information about particular agencies responsible for lands.

The original ownership data was available on a shapefile so that there was no need to convert it to other data formats. After the data was directly clipped to the extent of the watershed by using GeoProcessing Wizard, the ownership codes in the attribute table was reclassified for the project. Oregon and California lands administered by BLM were coded as 1, private or non-governmental lands were coded as 2, and other lands were coded as 3. Finally, the data was put into the cells in the same way as before. The flowchart of the process is shown in the Figure 2-4.

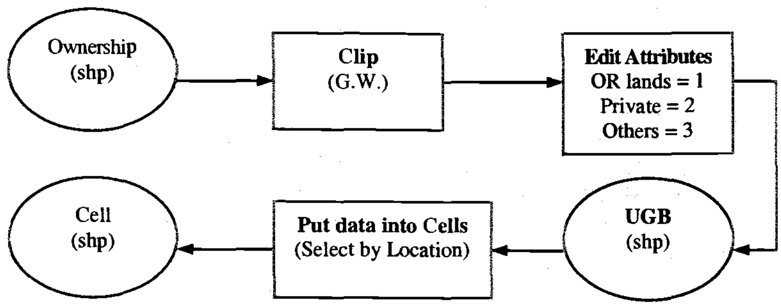

Figure 2-4. Process for adding ownership data into the cells.

Urban Growth Boundaries (UGB)

The rules developed in the project involve social and economic issues, thus it was essential to incorporate political boundaries. I used data on UGB in Oregon that was created by Oregon Department of Transportation (ODOT), Metro Regional Council of Governments (METRO), and SSCGIS in 1996. UGB is a zoning tool that separates urban and urbanizable lands from rural lands for every city in the state. Since Oregon Land Use laws limit development outside of UGB, most of the lands outside the UGB will continue to be used for farming, forestry, or low-density residential development. In the same way as the land ownership, therefore, restoration opportunities and priorities might vary by region inside or outside the UGB.

The original UGB data was a shapefile, so that it was directly clipped on the extent of the watershed. To reclassify the attribute information for the project, the lands inside and outside the UGB were coded 1 and 0, respectively. Then the data was put into the cells. The flowchart in Figure 2-5 illustrates the process.

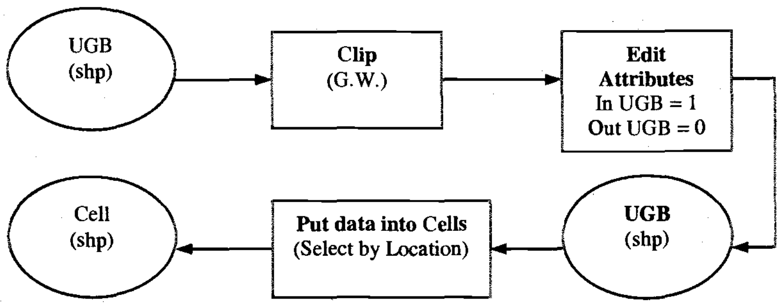

Figure 2-5. Process for adding UGB data into the cells.

Stream Order

Leopold (1994) defines stream order as "a measure of the position of a stream in the hierarchy of tributaries." Thus it is widely used to describe relative stream size where small order streams are considered to be small in size. Stream order for the project was determined by the Strahler stream ordering system (Strahler, 1964). The idea of the system is that the smallest permanent streams are called first order and stream order only increase when streams of the same order intersect. Streams of smaller order joining a higher order stream retain the order of the higher order upstream segment. Stream order is used in a number of the rules, because it is considered due to its importance to water and habitat qualities. For instance, leaching of pollutants or degradation of streambanks from overland runoff along a first order stream is assumed to have more serious effect on water quality than similar process occurring along a forth order stream. Therefore, lower order streams tend to be more critical for watershed restoration than higher order streams.

To calculate the Strahler stream order for all arc features in the stream network coverage created by Kelly, I used an ArcView Avenue script "Create Strahler Stream Order" downloaded from the ESRI script library. This script generates a stream order value for each arc and adds it to a new column "Strahler" in the attribute table. After running the script, stream order data was put into the cells. The largest stream order for the project was 5^{th} order. The figure 2-6 shows the flowchart of the process.

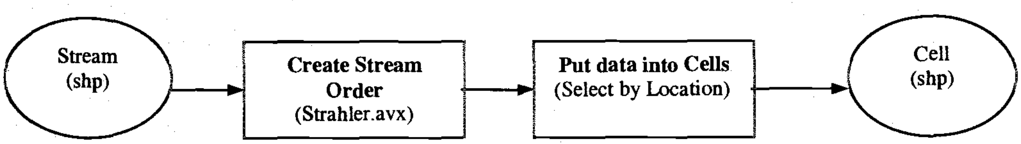

Figure 2-6. Process for creating and adding stream order data into the cells.

Stream Length per cell

In the same way as the stream order, stream length per cell is used in a large number of the rules and constraints. Morphological characteristics like stream order and length within each cell need to be determined especially to expect effects of the different restoration options on water and habitat qualities.

To calculate the stream length per cell, intersections of the streams and the cells were computed using an ArcView Avenue script called "View.IntersectThemes" created by ESRI. This script computes the intersection line shapefile from an intersection theme (streams) and an overlay theme (cells), and the output file has all the attribute of both themes for each intersection. The result of each intersection should be the length of a stream per cell, though the script does not have the length of a stream calculated automatically. As a result, it was necessary to calculate the stream length by using Field Calculator in ArcView with a VBA macro "[Shape].ReturnLength". The updated stream length were then put into the cells. The figure 2-7 shows the flowchart of this process.

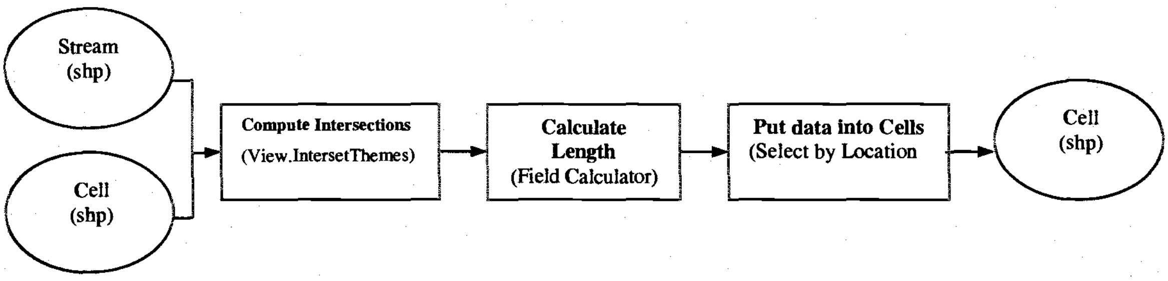

Figure 2-7. Process for calculating and adding stream length data into the cells.

Distances from the cells

The final data required for the project were distances of a cell to the following seven features: the nearest stream, the nearest wetland, and the nearest 303(d) listed stream impaired by various sources including temperature, sediment, bacteria, dissolved oxygen, and toxin.

Stream and wetland features are considered to be an important for environmental issues such as water quality improvement and habitat restoration. For this reason, I used the stream network data and the Willamette Valley Natural Wetlands data created by the Nature Conservancy of Oregon in 1996 to calculate the proximity to streams and existing wetlands. In addition, features proximity to 303(d) listed streams were also required in the decision rules because water quality is an important issues for the watershed restoration. I used the data on Streams on Oregon's 1998 303(d) List of Water Quality Limited Waterbodies developed by Oregon Department of Environmental Quality (DEQ). This data provides a comprehensive inventory of streams that do not meet an applicable state water quality criterion for all sources. In the attribute table of the data, a stream segment subject to the 303(d) list is coded 1 and a stream not subject to the list is coded 0 for each source. As mentioned above, the rules take into account only five sources for the 303(d) list.

All data were available on shapefiles, so firstly they were clipped to the extent of the watershed. Using ArcView Avenue script "Nearest Feature", distances to the nearest feature in the 'To' theme (e.g. streams) were calculated for each feature in the 'From' theme (cells). The output of running the script was a new table containing a distance to the nearest feature field, so that this table was joined to the cells table. The flowchart in figure 2-8 illustrates this process.

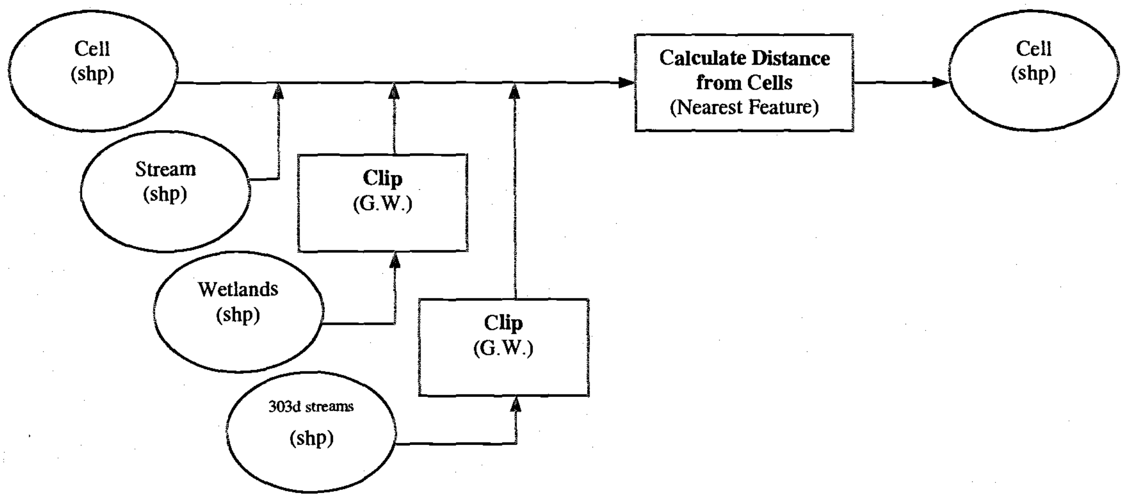

Figure 2-8. Process for calculating and adding distance data into the cells

2-1-4 Constraints and Rules

The next important components of RESTORE are constraints and rules which provide an overall assessment of the restoration alternatives at meeting different restoration objectives under various site conditions. Constraints and rules in RESTORE are based on the knowledge of domain expert's interpolation of existing data, and are expressed by deterministic relations in IF-THEN format. Two notable characteristics of this method, called "rules of combination" originally proposed by Hopkins (1977), is firstly the use of explicit rules to assign suitabilities to sets of combinations of environmental and socioeconomic factors. In RESTORE, the suitability is described by a positive or negative impact of a specific restoration option at addressing an objective, which is expressed by scores ranging from - 4 to 4, high negative impact to high positive impact. Secondly, rules of combination are expressed in terms of verbal logic rather than numbers and arithmetic. Since verbal rules are natural way of coding expertise, DMs can readily understand (Pereira et al., 1993).

Constraints and rules should be distinguished. Constraints represent restrictions imposed on the decision space, indicating that they can be used to identify the set of feasible alternatives at a specific site based on a site-scale characteristic. If a particular alternative does not meet constraints imposed on a site, it is excluded from further consideration. Application of constraints is, therefore, the step in which infeasible alternatives are eliminated and remaining alternatives will be subjected to detail scrutiny. As an example, for a "wetland construction" option, RESTORE assigns the following constraint: "Wetland construction for a cell is considered only IF a soil type is hydric and a land use is not wetland or road" (Appendix C). On the other hand, rules can be used to facilitate an ordering of the remaining alternatives according to their performance with respect to the set of evaluation criteria. These rules relate different restoration alternatives to objectives and subobjectives as a function of site-based information. For example, the following rules assesses the efficacy of a "wetland construction" for meeting the water quality objective: "IF a soil erosion potential for a cell is equal or less than 5 tons per acre, THEN effectiveness of a wetland construction at reducing sediment transport into a stream is considered high, a score of 4."

RESTORE currently contains a set of approximately 350 rules developed through cooperation with the two watersheds mentioned previously. I used these standard criteria for the project. For each objective and restoration option, a set of constraints and rules should be stored in the Microsoft® Excel file format. These constraints and rules were listed on an Excel spread sheet with restoration options in columns and objectives and subobjectives in rows. The file allows us to view, edit, or update if reconsideration is necessary.

2-2 Theory of Ranking Restoration Options

To prioritize the restoration options, finally, each alternative is evaluated relative to others for each cell in terms of the set of decision rules and DMs preferences used to rank the available alternatives, while taking into account the specific constraints of the area. The process of ranking the restoration options in RESTORE involves two interrelated steps: first, the objectives are weighted by DMs according to their relative importance; then, the scores resulting from the set of rules and associated weights are combined.

To deal with situations where multiple objectives are involved, information about DMs preferences, the relative importance of the objectives, is required. This is achieved by assigning to each objective a weight that indicates the objective importance relative to the other objective under consideration. The weights of 'relative importance' are rated by directly assigning numbers between 0 and 1 for each objective, where 0 is least important and 1 is most important. There is a slider bar for each objective available on RESTORE user screen, so that what DMs have to do to assign or change the weights is just move the slider right or left. Major advantages for assigning weights of 'relative importance' are to allow for a rough measure of relative difference among the importance of objectives and to make it easy to change weights if reconsideration is necessary (Eschenbach, 2003).

To rank the restoration options, then the Simple Additive Weighted Method (SAW) is used in RESTORE. This method is the most popular among the basic multiple criteria evaluation techniques (Blank and Targuin, 1998), because this is simple, easy to understand, and powerful. A rating is simply calculated for each restoration option by multiplying single objective score with the associated normalized weight of the objective, and then summing. For each restoration option (*i*), RESTORE uses the following equations to calculate the total weighted score (*S*).

$$S_i = \sum_{j=1}^{n} w_j r_{ij} \qquad (1)$$

$$\sum_{j=1}^{n} w_j = 1 \qquad (2)$$

In the equations, (*r*) indicates the scores resulting from the decision rules' output at reaching a specific objective ($j = 1, 2, \ldots, n$). (*w*) is the normalized weight where each weight of 'relative importance' described previously is divided by the total of all the weights. Thus, sum of all the normalized weights equals 1. Once the total weighted scores are calculated, the alternative with the highest score is chosen for preferred restoration option.

Figure 2-9 provides an example of how RESTORE can rank the restoration options and determine the best option for a cell (No. 6983) by using ASW. Each weight of 'relative importance' should be rated on a 0-to-1 scale. In this case, objectives for "water quality," "water quantity," "habitat quality," "social issues," and "economic issues" are assigned weights of 0.8, 0.8, 0.6, 0.2, and 0.3, respectively. The total for all weights (2.7) is divided into each weight to compute the normalized weights (w_j) in the second row of the Figure. Each restoration option has scores from the decision rules' output for each objective. For instance, the wetland construction option obtains scores of 2.31, 1.75, 3.00, 0.00, and 3.64, respectively, for the five objectives. There are some restoration options with no score, however, indicating that the cell 6983 does not meet the constraints imposed on the options, so that these options are eliminated from further process. Total weighted scores for rest of the options are then calculated by using the equation (1). Figure 4 shows the calculation for wetland restoration option as an example. In this scenario, wetland restoration option having the highest overall score (2.29) would be the preferred restoration option.

2-3 Application of RESTORE with Different Sets of Objectives

I described the components of RESTORE and the theory of ranking restoration options so far, then the final output of RESTORE is a preferred restoration plan at meeting DMs objectives. In this project, I examined three different sets of objectives including; (1) environmental emphasis, (2) balanced emphasis of environmental and socioeconomic objectives, and (3) socioeconomic emphasis. Specific weights assigned for each set of objectives appear in Table 2-3. In case of the environmental emphasis, "water quality," "water quantity," and "habitat quality" are among five primary concerns and are assigned a maximum weight (1.0). "Social issues" and "economic issues" are lowest concerns and are assigned a minimum weight (0). On the other hand, the

Cell No. 6983

Restoration Options	Water Quality	Water Quantity	Habitat Quality	Economic	Social	Scores
	Objectives					
Weights (relative Importance)	0.8	0.8	0.6	0.2	0.3	
Normalized Weights	0.30	0.30	0.22	0.07	0.11	
Agricultural Riparian Buffer	–	–	–	–	–	–
Urban Riparian Buffer	–	–	–	–	–	–
Forest Riparian Buffer	–	–	–	–	–	–
Wetland Conservation	–	–	–	–	–	–
Wetland Construction	2.31	1.75	0.77	-4.00	3.53	1.77
Wetland Restoration	2.31	1.75	3.08	0.00	3.64	**2.29**
Create Conditions Favorable to Native Species	0.00	0.00	2.50	-1.00	2.88	0.88
Enhance Stream Complexity	–	–	–	–	–	–
Increase Late Summer Flows	–	–	–	–	–	–
Streambank Stabilization	–	–	–	–	–	–
Creekside Management	–	–	–	–	–	–
Heterogeneous Development Patterns	–	–	–	–	–	–
NonRipiarian Filter Strips	1.81	0.00	2.82	-1.00	2.21	1.41
Field Borders	1.00	0.00	2.82	-2.00	2.21	1.17
Agricultural Soil and Water BMPs	2.75	0.00	2.40	-1.00	1.46	1.51
Agricultural Chemical BMPs	2.50	0.00	3.00	-1.00	1.46	1.57
Agricultural Habitat BMPs	2.75	0.00	2.72	-1.00	1.46	1.58
Forest Harvest Type and Scale Modification	–	–	–	–	–	–

$$S_i = \sum_{j=1}^{n} w_j r_{ij}$$

$$= 0.30*2.31 + 0.30*1.75 + 0.22*3.08 + 0.07*0 + 0.11*3.64$$

$$= 2.29$$

Figure 2-9. Example of how RESTORE can calculate scores and rank the restoration options for a cell no. 6983.

socioeconomic emphasis has a completely opposite weight for each objective. The balanced emphasis is given the same weights (0.5) for all objectives.

Table 2-3. Conditions for three different sets of objectives

		Conditions		
		(1) Environmental Emphasis	(2) Mixed Emphasis	(3) Socioeconomic Emphasis
Objectives	Water Quality	1	0.5	0
	Water Quantity	1	0.5	0
	Habitat Quality	1	0.5	0
	Social Issues	0	0.5	1
	Economic issues	0	0.5	1

3. RESULTS AND DISCUSSION

I ran the RESTORE for the Marys River watershed to meet the three different sets of objectives mentioned before. Using several data available for the output of RESTORE, I would like to do some analyses of patterns and structure of the watershed restoration plans proposed by RESTORE and to examine differences, characteristics, and problems in the following sections.

3-1. Most Preferred Watershed Restoration Plans

Figure 3-1 shows the most preferred restoration plans for the Marys River watershed at accomplishing the three different sets of objectives. Each cell is color coded to a specific restoration option in the legend. The ratio of restoration options that were applied in the three sets of preferred proposed landscapes are represented in figure 3-2. The ratio was calculated based on areas in which each restoration option was applied, not based on the number of cells applied in the watershed. Note that actual numbers of the ratio are added to several restoration options that were applied in small areas and were not made clear in the histograms. Based on these figures, I would like to examine the differences and characteristics of three sets of restoration plans.

First, based on visual evaluation of the proposed landscapes, the socioeconomic emphasis proposed landscape was considerably different from the environmental and mixed emphasis proposed landscapes, especially in the upland forest area. "Forest harvest type and scale modification (FHTSM)" were the dominant restoration options and applied to approximately 52 percent of the watershed in both environmental and mixed emphasis plans. "Create conditions favorable to native species (CCFNS)" was the main restoration option and applied to 73.4 percent of the watershed in the socioeconomic emphasis plan. Before considering this difference, it should be noted that, according to the constraints of restoration options in RESTORE (Appendix C), restoration options available to apply to the forest area except riparian zone are only two. The constraints say that "CCFNS" is considered only if land use is not road and "FHTSM" is considered only if detailed land use is forest closed mixed or forest closed conifer 41 to 200 years. The reason why only socioeconomic emphasis proposed landscape had a different restoration

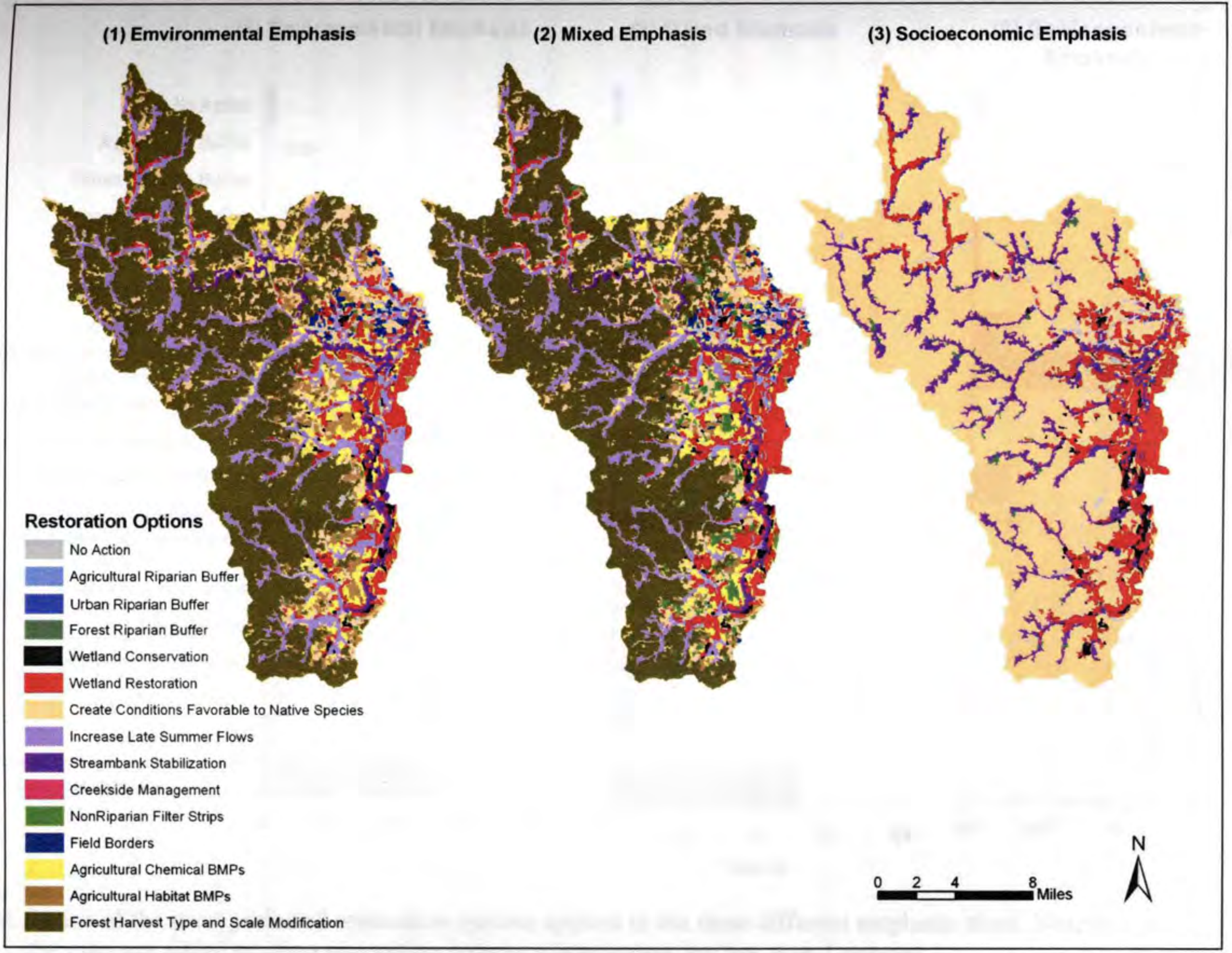

Figure 3-1. Most preferred restoration plans at accomplishing the three different sets of objectives.

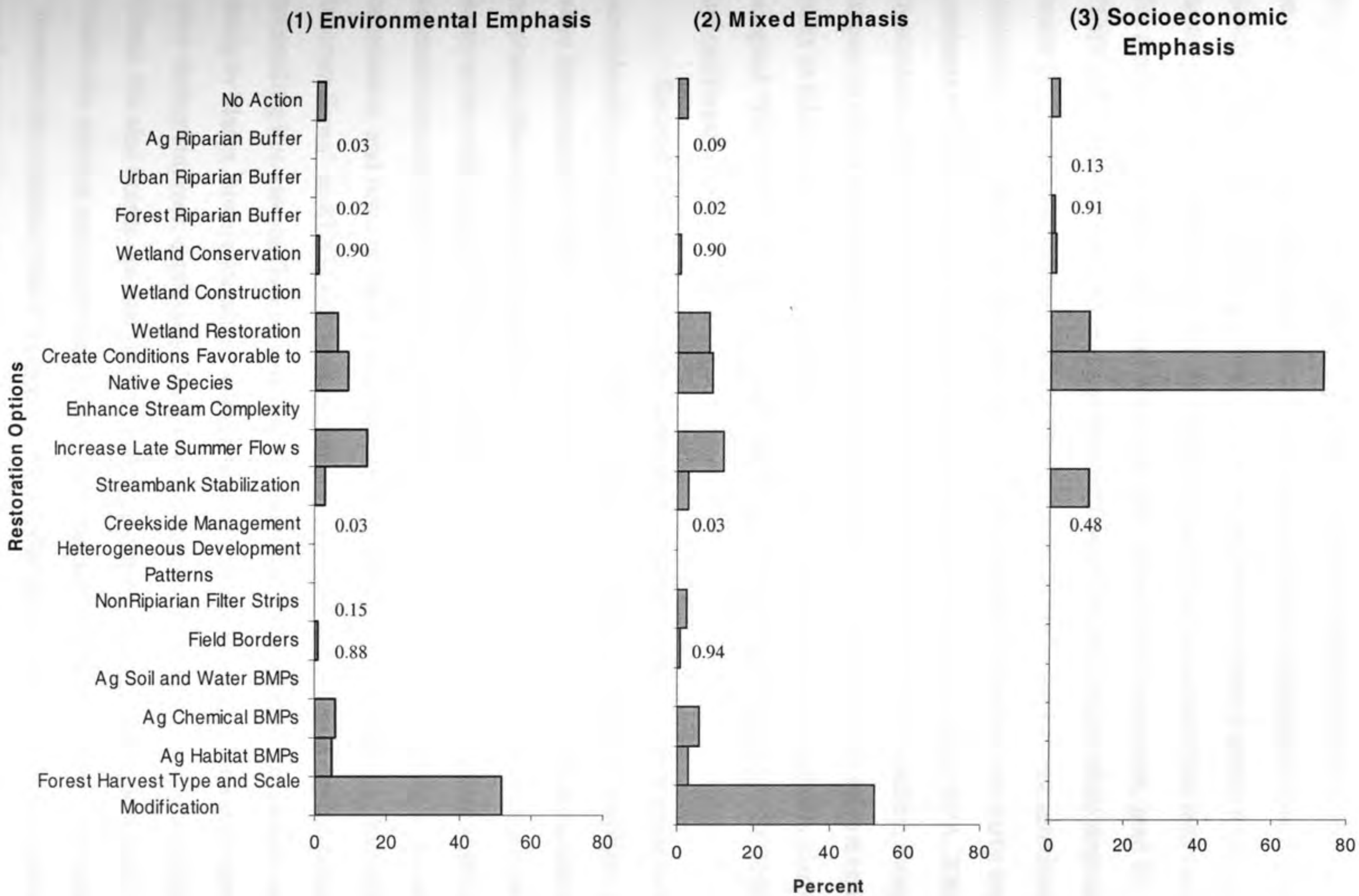

Figure 3-2. Ratios of the most preferred restoration options applied in the three different emphasis plans. Note that actual numbers of the ratio are added to some restoration options whose scores are less than 1 percent.

option in the upland area is made clear when we compare definitions and decision rules of these two restoration options. "CCFNS" is defined in RESTORE as managing plant succession horizontally as well as vertically to benefit desired wildlife or living resources. Since the main goal of this restoration option is to maintain and increase wildlife and natural habitat quality, it does not necessarily have a positive impact on water quality and water quantity. In fact, there is no rule or score of the restoration option for meeting the water quality and water quantity objectives. In contrast, goal of "FHTSM" option is to manage forest harvest operations that might cause degradation of water quality and habitat impairment. For instance, some forest harvest activities including poorly designed landings, skid trails, and stream crossing can carry large amounts of sediment into streams, reducing water and habitat quality (EPA, 2004). This restoration option is useful for improving water quality and habitat quality, though social impact of the option seems to be lower than that of "CCFNS" option according to the rules in RESTORE. For these reasons, environmental and mixed emphasis plans mainly adopted "FHTSM" and socioeconomic emphasis plans mainly adopted "CCFNS" in the upland forest area.

Second, I would like to pay attention to riparian areas. The first point to be considered is, in upland riparian areas, both environmental and mixed emphasis plans were dominated by "increase late summer flows" option, while the socioeconomic emphasis plan was mainly applied to "streambank stabilization" option. Also for riparian areas in the valley agricultural and downstream urban areas, "streambank stabilization" seemed to be the main restoration option for all three plans. Consider now the definitions, constraints, and rules of these two restoration options. The definition of "Increase late summer flows" in RESTORE is manipulation of watershed features for the purpose of controlling low stream flow in summer. As Pearcy (1999) states in his stream temperature study in Marys River watershed, water temperatures are too warm for native species of trout during summer, especially along main channels of the Marys River and Muddy Creek. He also points out that rates of warming during summer were most rapid in headwater reaches and decreased greatly downstream. Thus, one of the constraints of "increase late summer flows" is that a stream order must be less than four, relatively small streams in size. In addition, this option is quite effective for improving water quantity and habitat quality, which is reflected in the rules. For the environmental and mixed emphasis plans, above two factors should be the reason why "increase late summer flows" was applied in the upland riparian area and was not applied along the lower main channel of the Marys River and Muddy Creek whose stream orders are more than four. On the other hand, "streambank stabilization" is defined as stabilization and protection of stream banks against scour and erosion using vegetation or structural techniques. Taking the rules into consideration, overall positive environmental impact of "streambank stabilization" is smaller than that of "increase late summer flows", while positive socioeconomic impact seems to be higher. As a result, "streambank stabilization" instead of "increase late summer flows" was mainly adopted in the upland riparian areas for the socioeconomic emphasis plan.

Third, I would like to focus attention on "no action" option. Areas assigned by "no action" were all the same for the three plans and accounted for 2.5 percent of the watershed. According to the constraints of all restoration options (Appendix C), there is no restoration option available to apply in areas whose land use are roads. In other words, although "no action" does not have any rule and constraint in RESTORE, it is considered if land use is road. It is reasonable to suppose that "no action" is considered at areas dominated by roads where any restoration option used in this project is hard to perform. I would suggest, however, that we make more positive use of "no action" option. It is often useful to incorporate this option in watershed management, because it is usually inexpensive, it is easy for DMs and lay people to understand, and it provides a useful basis of comparison with other intervention-based options (Heathcote, 1998). For example, in case of an area where soils are contaminated with past discharge, just keeping the existing state of the area might lead to some improvement through natural process. Consequently, we might need to incorporate rule sets or other factors for "no action" option, so that it is considered in restoration planning even if land use is not road.

Finally, I would briefly mention other characteristics. In terms of diversity of restoration options applied to the watershed, a glance at the figure 3-2 will reveal that 13 out of 19 restoration options were applied for both environmental and mixed emphasis plans, while only 7 out of 19 restoration options were applied for the socioeconomic emphasis plan. Seven restoration options among them were only applied to the environmental and mixed emphasis plans, while "urban riparian buffer" was the restoration option that was applied only in the socioeconomic emphasis plan. Another important point is that there were four restoration options that were not proposed in any plans, including "wetland construction", "enhance stream complexity", "heterogeneous development patterns", and "agricultural soil and water BMPs". In the following sections, I will further examine the three proposed landscapes from the different points of view.

3-2 Similarity Areas

The map in figure 3-3 shows areas where the same restoration option is suggested for each of the three plans. A cell applied to this case is shaded with a color that corresponds to a specific restoration option in the legend. The pie chart illustrates the percentage of each restoration option against the watershed area. There were 7 restoration options satisfying this condition, which made up 19.6 percent of the watershed. The dominant restoration options, except for "no action", were "create conditions favorable to native species", "wetland restoration", and "streambank stabilization", which accounted for 9.2, 6.3, and 1.7 percent of the watershed, respectively. From visual evaluation of the map, most of the proposed restoration options appeared to be concentrated along the main channels of the Marys River and Muddy Creek.

From an MODM perspective, choice of preferred restoration option depends not only on geographic features of events but also on diverse range of objectives that are often in conflict in the decision making process. However, the fact that the areas identified under the similarity map simultaneously satisfy a range of different perspectives on goals for restoration suggests that restoration options in the areas are determined solely by their site condition or geographic features, regardless of goals and objectives. Alternatively, it could be argued that the proposed site location and restoration options appear robust in terms of relatively positive impact on both environmental and socioeconomic qualities. In my opinion, the information derived from the similarity map is seen to be of great value for DMs in performing evaluations of the preferred watershed restoration plan.

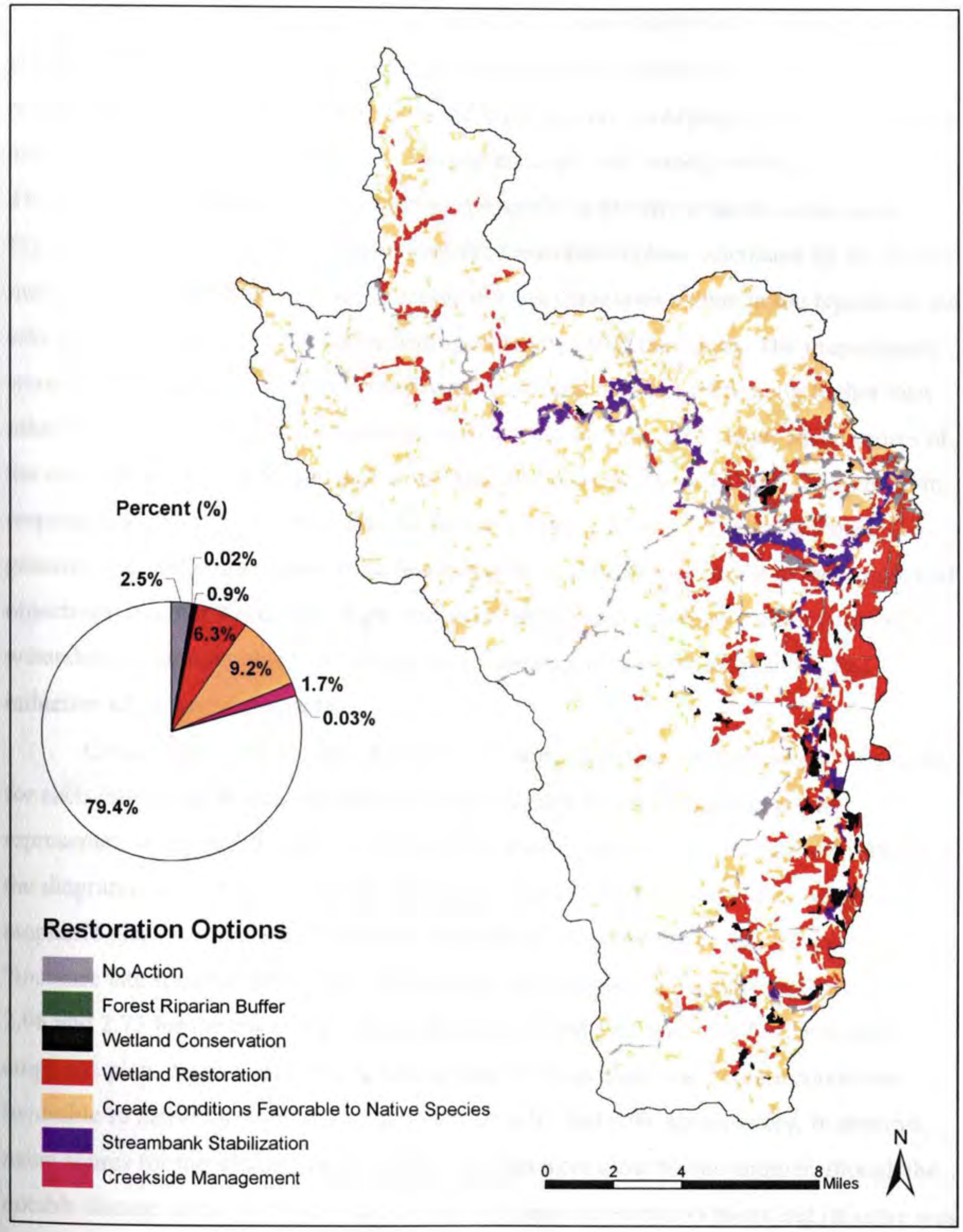

Figure 3-3. Similarity areas where the same restoration options are proposed for each of the three different emphasis plans. Pie chart illustrating the ratio of each proposed restoration option.

3-3 Priority Areas

Priority areas for restoration can be identified with RESTORE by evaluating how effective a restoration plan is at accomplishing restoration objectives. A preferred restoration option proposed in a cell has the highest score according to the decision rules and DMs priorities, though degree of the scores might vary widely within the watershed. Thus, areas with higher scores should be considered as priority areas for restoration. Figure 3-4 shows scores for the three preferred restoration plans calculated by the SAW method mentioned earlier. I divided scores into six categories shown in the legend for the sake of convenience, so each cell is distinguished by using the colors. The maps clearly show that overall score of the environmental emphasis plan is significantly higher than other two plans whose overall scores are sufficiently close to each other. Mean scores of the environmental, mixed, and socioeconomic emphasis plans were 2.00, 1.42, and 1.46, respectively. From the result, it may be presumed that the Marys River watershed generally has the proper geographic features or sites conditions to achieve environmental objectives. In other words, we might encounter difficulties when we plan or perform a watershed restoration plan that focuses on an enhancement of social qualities and reduction of economic impacts.

Consider now the overall attractiveness of each restoration option. A mean score for each restoration option proposed in the three preferred restoration plans are represented in figure 3-5. The ratios of the restoration options (fig. 3-2) are also shown in the diagrams as a reference. Trends of mean scores for the environmental and mixed emphasis plans were relatively similar. The highest two restoration options were "increase late summer flows" and "streambank stabilization" whose mean scores were 2.98 and 2.77 for the environmental emphasis plan and 1.82 and 1.94 for the mixed emphasis plan, respectively. The lowest option for both plans was "create conditions favorable to native species" whose scores were 0.91 and 0.94, respectively. In contrast, mean scores for the socioeconomic emphasis plan were close to one another, though the notable feature is that the lowest option was the same as other two plans and its score was 1.44. Although "create conditions favorable to native species" was the dominant restoration option for the socioeconomic emphasis plan and also in the similarity map

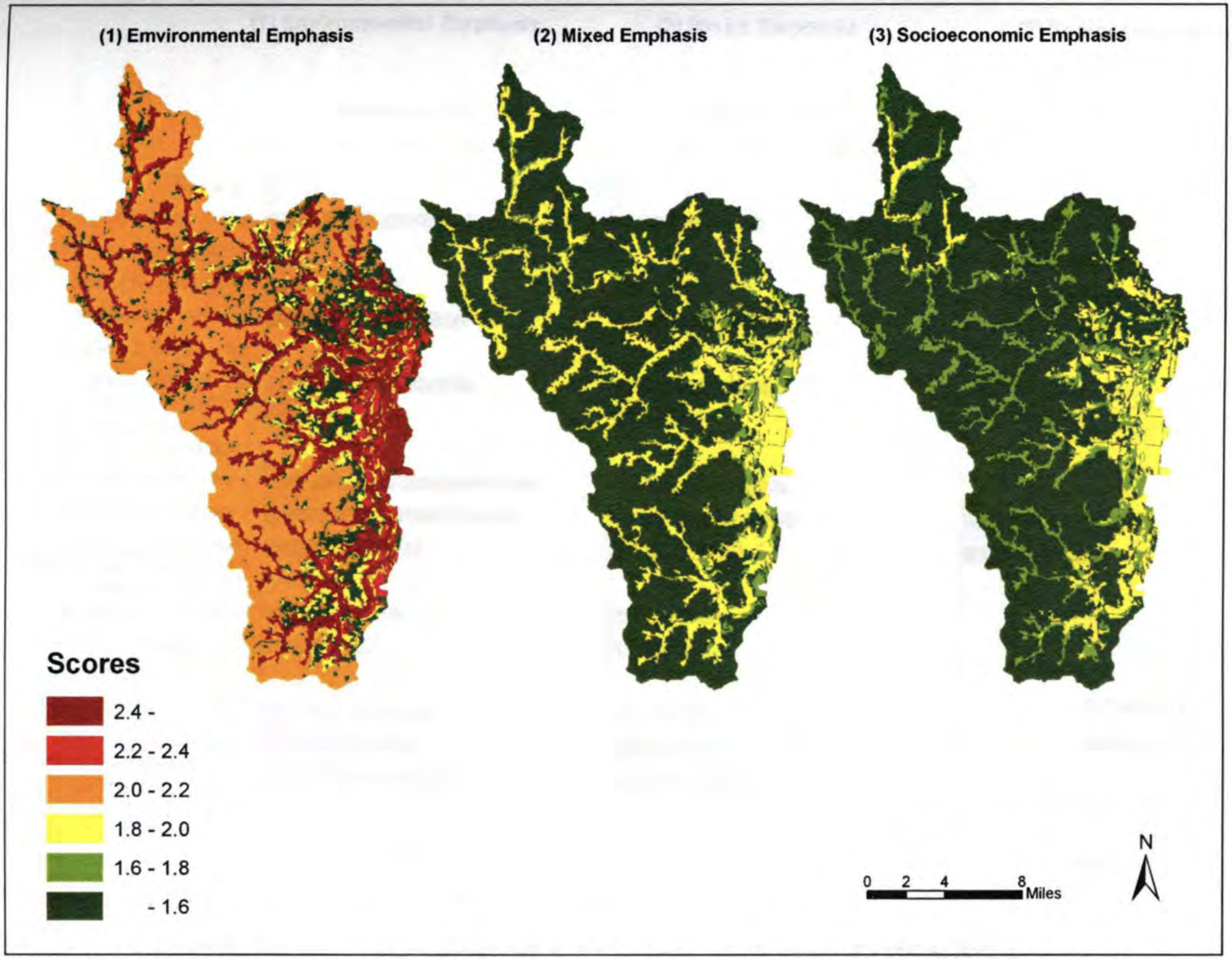

Figure 3-4. Scores for the most preferred restoration plans at accomplishing the three different sets of objectives.

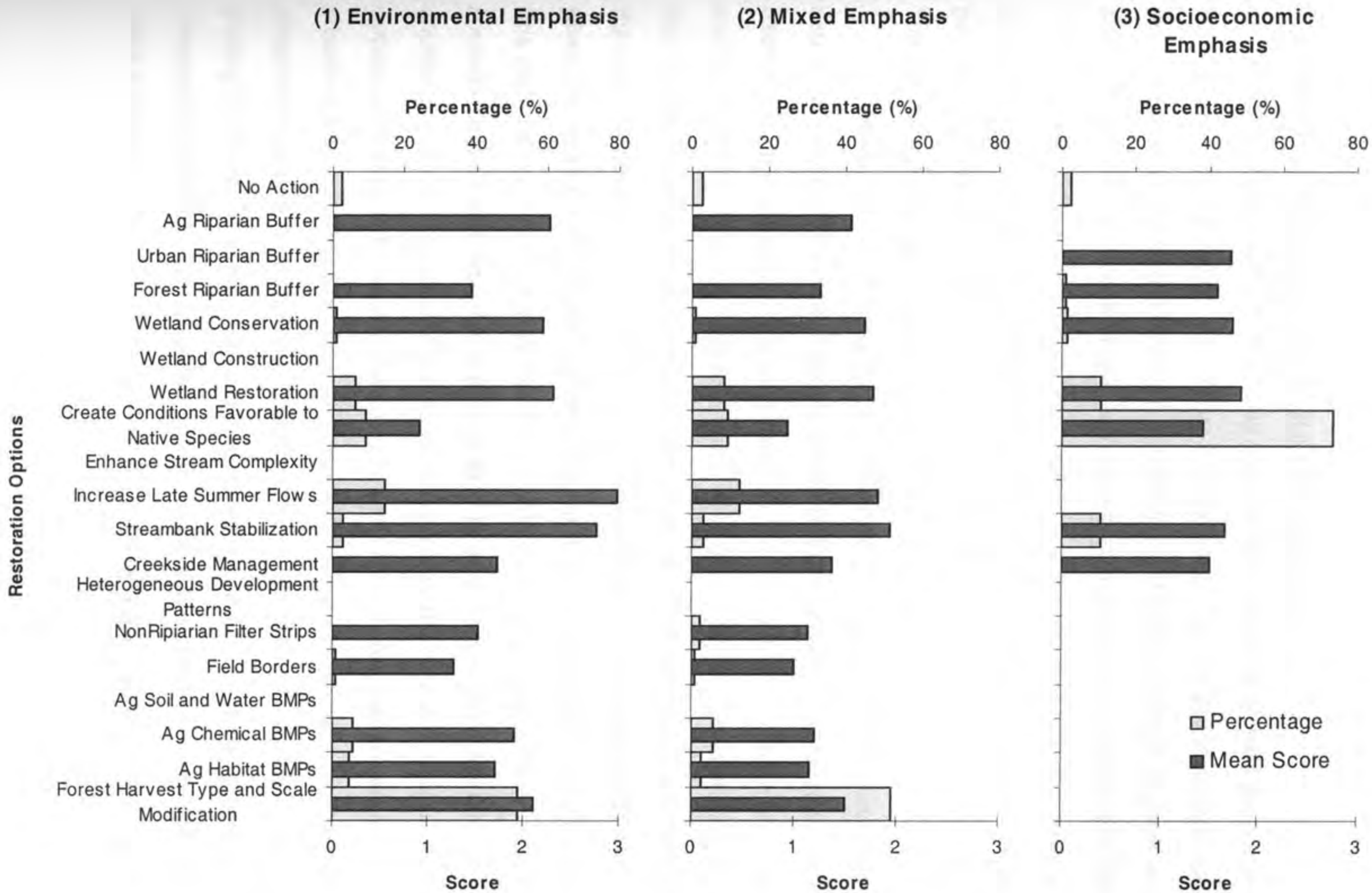

Figure 3-5. Mean score for each restoration option proposed in the three different emphasis plans. Ratios of the restoration options are also shown as a reference.

(fig. 3-3), the fact of its lowest effectiveness for any plans implies that the magnitude of its expected restoration benefit may be very small for the Marys River watershed.

3-4 Second Preferred Watershed Restoration Plans

Finally, I would like to briefly mention the second preferred proposed landscapes for the three sets of objectives. Figure 3-6 shows the second preferred restoration plans, meaning that a proposed restoration option in a cell has the second highest score. The ratios of the first and second preferred restoration options are compared in figure 3-7. It should be noted that "no second best" option is proposed to a cell, if a score of the second preferred restoration option in the cell is less than 10 percent of its score of the most preferred restoration option. This option is also proposed to the cells that are assigned by "no action" option in the most preferred restoration plans.

I think that considering the second or maybe third preferred restoration option in a cell is very useful for sound watershed restoration planning in some reasons. For example, an interesting thing is that ratios of "no second best" for the second preferred environmental and mixed emphasis plans were 87.0 and 74.2 percent, respectively, while that for the socioeconomic emphasis plan was only 24.6 percent. In my understanding, the more areas that are proposed for "no second best" in the second preferred restoration plans, the more the most preferred restoration plans (fig. 3-1) are likely to be reliable. On this assumption, I suggest that the overall most preferred restoration options for the socioeconomic emphasis plan are less likely to be reliable than other two plans. As another significant point, it is interesting to consider the case that several restoration options are proposed in a cell and some of their scores are close to one another. In the situation, because their priorities for restoration are very similar, a most preferred proposed restoration option with highest score might not be the best option. Before putting the restoration plan into practice, therefore, it is essential to carefully examine the potential impacts of each proposed option on the stated objectives in the field, or use other methods or models for evaluating their validity and effectiveness.

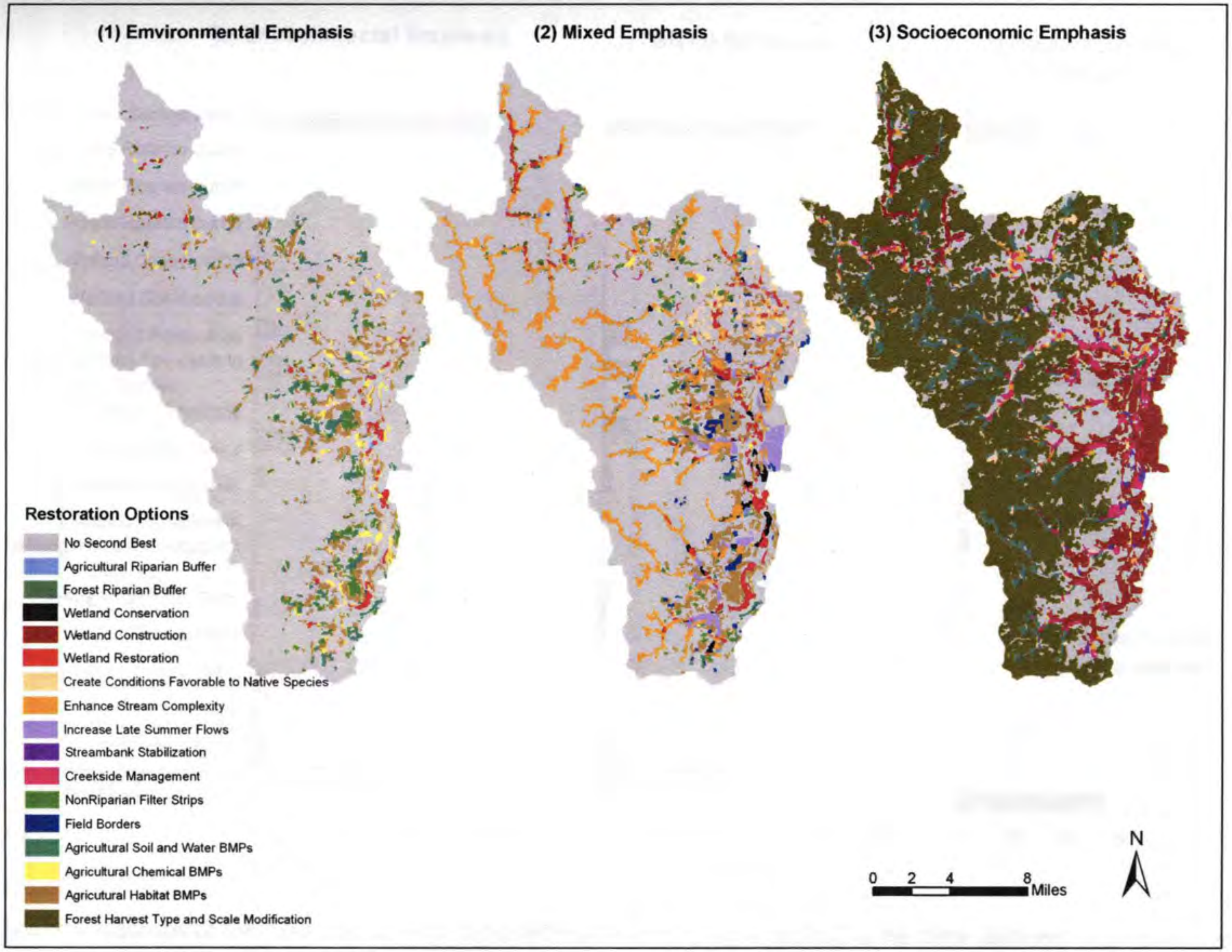

Figure 3-6. Second preferred restoration plans at accomplishing the three different sets of objectives.

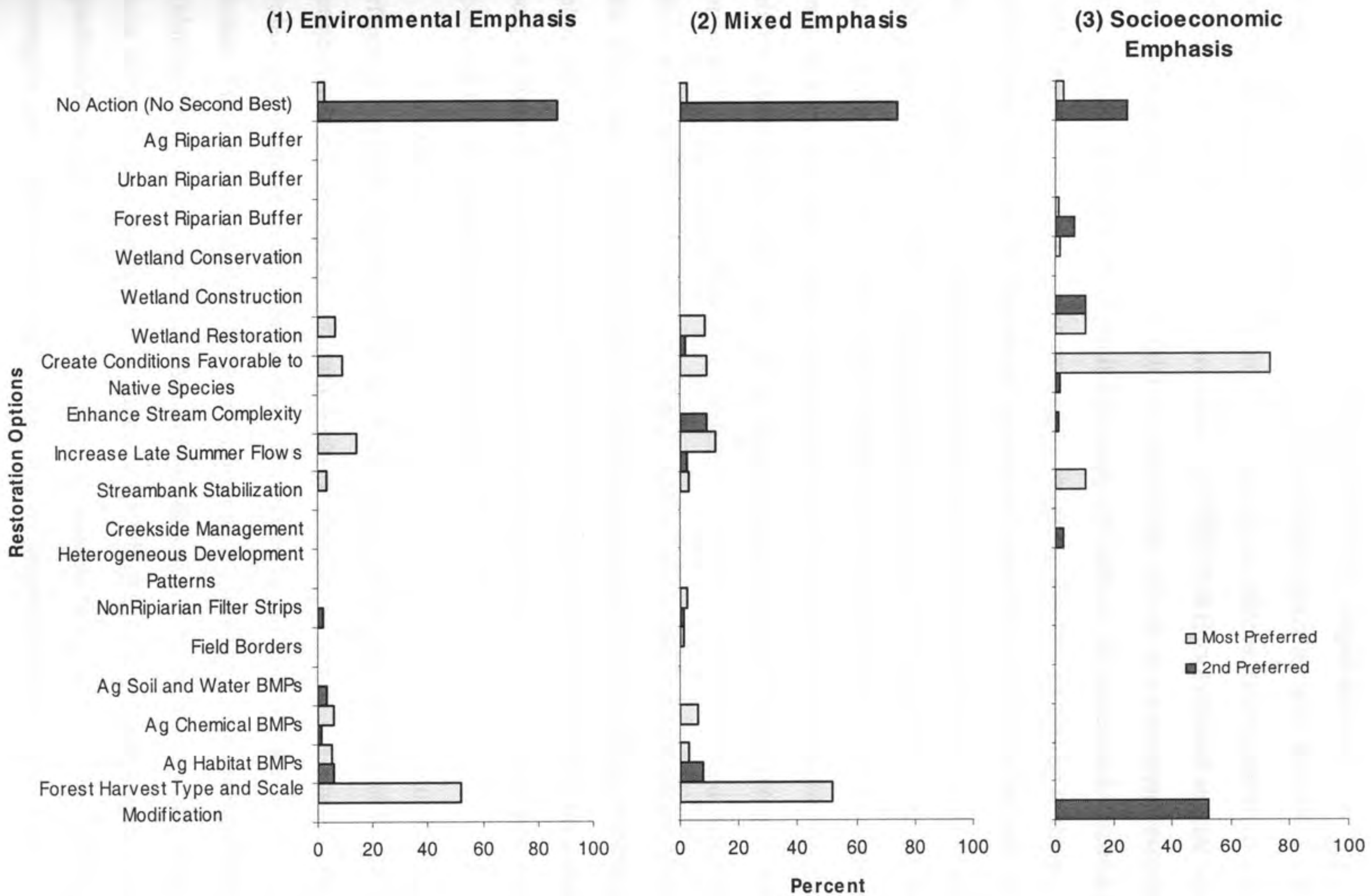

Figure 3-7. Ratios of the most and second preferred restoration options applied in the three different emphasis plans.

4. CONCLUSION AND RECOMMENDATION

Through the visualization and analyses of the output data obtained from the RESTORE, on the whole, the combination of GIS capability with MODM technique proved to be a powerful and operational tool for the Marys River watershed restoration planning. In the project, I became aware that RESTORE tool offered several advantages for restoration planning. First, the tool allows one to look at a watershed restoration plan as a spatially and visually explicit landscape throughout the watershed. Second, since DMs priorities can be changed as simply assigning weights according to their importance, it is easy to implement repeatable evaluations with different sets of objectives. As shown in the preferred restoration plans for the three sets of objectives, we could see the many differences and characteristics in the upland, riparian, and lowland areas of the watershed. I think that considering several sets of objectives is beneficial not only as a way to subjectively evaluate how proposed restoration options will change, but also to examine the watershed from numerous perspectives. Third, higher priority areas or relative importance of proposed restoration options can be identified with RESTORE by evaluating how effective a restoration option is at achieving restoration objectives. For the Marys River watershed, I found that overall priorities of the environmental emphasis plan were significantly higher than other plans, priority areas tended to be similar for any sets of objectives, and the dominant restoration option in the socioeconomic emphasis plan did not necessarily have higher priorities.

To sum up the results and discussion sections, let me make some comments on effective restoration planning for the Marys River watershed using RESTORE. In this project, while I just used the standard sets of objectives, restoration options, and decision rules, it is possible to use other options for reflecting our goal or specific watershed issues. For instance, as other restoration options are identified or other information relating a restoration option to DMs objectives and site-based information are provided, new decision rules can be readily added to RESTORE. Once creating several most preferred restoration plans, it is essential to evaluate these plans, which is often a complex task. Performing visual evaluations of several different combinations of information serves as a good starting point for evaluation process. I considered the several different output data including the ratio of proposed restoration options, second preferred restoration options, priority areas, and similarity areas, while it was not enough to assess how effective each of the proposed plans is at meeting the objectives. As the next step for evaluation process, therefore, using a set of evaluative models available for RESTORE will be an example to rationally solve this problem. For instance, a habitat evaluation model can evaluate the plans with respect to habitat quality, ranking breeding and feeding habitat for a variety of species. Based on such evaluation models, if we become aware any problems or doubt of effectiveness for the proposed plans, we might need to reconsider the decision rules, restoration plans, and so forth. It is also important to visit sites for comparing field conditions and examining the validity or effectiveness of the plans.

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APPENDICES

Appendix A. GIS data used in RESTORE

Theme Description	Scale	Type	Source	Acquired From
Land Use and Land Cover (LULC)	30m	TIFF	PNW-ERC	PNW_ERC
Wetlands	30m	TIFF	NWI, ODFW, and PNW_ERC	PNW_ERC
Soils	1:24,000	e00	Natural Resource Conservation Service	SSURGO
Ownership	1:100,000	shapefile	BLM and SSCGIS	SSCGIS
Urban Growth Boundaries (UGB)	1:24,000	shapefile	OR Dept. of Transportation and Dept. of Land Conservation and Development	SSCGIS
303d-Listed Streams	1:100,000	shapefile	OR Dept. of Env. Qual.	SSCGIS
Digital Elevation Models	1:24,000	e00	BLM, USGS, and USFS	SSCGIS

Theme Description	Metadata
Land Use and Land Cover (LULC)	http://www.fsl.orst.edu/pnwerc/wrb/metadata/ec90.html#TOC
Wetlands	http://www.fsl.orst.edu/pnwerc/wrb/access.html
Soils	http://www.ncgc.nrcs.usda.gov/branch/ssb/products/ssurgo/metadata/or606.html
Ownership	http://www.sscgis.state.or.us/data/metadata/k100/land_ownership.html
Urban Growth Boundaries (UGB)	http://www.sscgis.state.or.us/data/metadata/k24/ugb.html
303d-Listed Streams	http://www.sscgis.state.or.us/data/metadata/k100/98303.pdf
Digital Elevation Models	http://www.sscgis.state.or.us/data/baseline97/documents/metadata.pdf

Appendix B. PNW-ERC land use and land cover classification systems

LULC_A (Coarse-articulation LULC classes)

Class No.	Class Name
1	Rural Residential
2	Urban
3	Agriculture
4	Forest
5	Wetlands
6	Natural Vegetation
7	Water
8	Roads
9	No Data

LULC_B (Medium-articulation LULC classes)

Class No.	Class Name
1	Rural Residential
2	Residential
3	Urban Non Vegetated
4	Commercial Industrial
5	Civic Open Space
6	Rural Structure
7	Roads
8	Rural Non Vegetated
9	Water
10	No Data
11	Urban Vegetated
12	Forest Open
13	Forest Mixed
14	Forest Hardwood
15	Forest Semi Closed Conifer
16	Forest Closed Conifer < 60
17	Forest Closed Conifer > 60
18	Tree Berry Crops
19	Grass Seed
20	Annual Row Field Crops
21	Hay Pasture
22	Natural Vegetation
23	Wetlands

Appendix B. PNW-ERC land use and land cover classification systems (continued)

LULC_C (Fine-articulation LULC classes)

Class No.	Class Name	Class No.	Class Name
1	Residential 0-4 DU/ac	58	FCC 41-60 yrs
2	Residential 4-9 DU/ac	59	FCC 61-80 yrs
3	Residential 9-16 DU/ac	60	FCC 81-200 yrs
4	Residential > 16 DU/ac	61	FCC 200 yrs
5	Vacant	62	Forest Semi-closed hardwood
6	Commercial	66	Hybrid poplar
7	Comm/Industrial	67	Grass seed-grain-meadow foam
8	Industrial	68	Irrigated annual rotation
9	Industrial & Comm.	71	Grains
10	Residential & Comm.	72	Nursery
11	Urban non-vegetated unknown	73	Caneberries & Vineyards
12	Civic/open space	74	Double cropping
16	Rural structures	75	Hops
17	2 acre structure influence zo	76	Mint
18	Railroad	77	Radish seed
19	Primary roads	78	Sugar beet seed
20	Secondary roads	79	Row crop
21	Light duty roads	80	Grass
22	Other roads	81	Burned grass
24	Rural non-vegetated unknown	82	Field crop
25	Rural Service Center	83	Hay
26	Built high density	84	Late field crop
27	Built medium density	85	Pasture
28	Built low density	86	Natural grassland
29	Channel non-vegetated	87	Natural shrub
31	Stream orders. 1-4	88	Bare/fallow
32	Stream orders 5-7	89	Flooded/marsh
33	Water	90	Irrigated field crop
39	Topo. Shadow	91	Turfgrass/park
40	Snow	92	Orchard
42	Barren	93	Christmas trees
49	Urban tree overstory	94	Pasture/natural grass/xmas tr
51	Forest open	95	Woodlot
52	Forest Semi-closed mixed	96	Urban grass-shrub
53	Forest Closed hardwood	97	Hedgerow
54	Forest Closed mixed	98	Oak savanna
55	Forest Semi-closed conifer	99	Non-tree wetlands
56	Forest Closed Conifer 0-20 yr	100	Prairie
57	FCC 21-40 yrs		

Appendix C. Constraints for the restoration options used in RESTORE

Restoration Options	Constraints
Agricultural Riparian Buffer	LandUse = Agriculture and Stream_Length > 50 {meters}
Urban Riparian Buffer	LandUse = Urban and Stream_Length > 50 { meters}
Forest Riparian Buffer	LandUse = Forest and Stream_Length > 50 {meters}
Wetland Conservation	LandUse = Wetlands
Wetland Construction	LandUse $\neq$ Wetlands and LandUse $\neq$ Roads and Hydric_Soil = 1
Wetland Restoration	LandUse $\neq$ Wetlands and LandUse $\neq$ Roads and Hydric_Soil = 1
Create Conditions Favorable to Native Species	LandUse $\neq$ Roads
Enhance Stream Complexity	LandUse $\neq$ Roads and Stream_Length > 100 { meters }
Increase Late Summer Flows	LandUse $\neq$ Roads and Stream_Length > 10 { meters } and Stream_Order < 4
Streambank Stabilization	LandUse $\neq$ Roads and Stream_Length > 100 { meters }
Creekside Management	(LandUse = Agriculture or LandUse = RuralRes or LandUse = Urban) and Stream_Length > 10 { meters }
Heterogeneous Development Patterns	(LandUse = Agriculture or LandUse = Forest) and Ownership = Private and In_UGB = 1
NonRipiarian Filter Strips	LandUse = Agriculture and Detailed_LandUse $\neq$ DLU_Grass_Seed
Field Borders	LandUse = Agriculture or LandUse = RuralRes
Ag Soil and Water BMPs	LandUse = Agriculture
Ag Chemical BMPs	LandUse = Agriculture
Ag Habitat BMPs	LandUse = Agriculture
Forest Harvest Type and Scale Modification	Very_Detailed_LandUse = VDLU_Forest_Closed_Conifer_61_200_yrs or Very_Detailed_LandUse = VDLU_Forest_Closed_mixed

Appendix D. Status and trends of wetlands in the Marys River watershed

Wetland issues have become a major source of interest for watershed restoration efforts to the professional and the public, because wetland acreage has diminished significantly to the point where environmental and even socioeconomic benefits are now seriously threatened. The losses of wetlands compromise the important benefit provided by wetlands including maintaining hydrology and water quality, providing fish and wildlife habitats, protecting shorelines for erosion, and reducing flood damage (Dahl and Johnson, 1991). For these reasons, protection and conservation of these ecosystems are one of the key issues for watershed restoration planning.

The area and health of wetlands in the Marys River watershed appear to have declined significantly from historical levels. From the earliest settlement of the valley area about 1840, most of the losses of wetlands due to establishment of farms and channelization of streams seem to have occurred before the 1930's (Ecosystems Northwest, 1999). According to the Oregon Natural Heritage Program (ONHP) that performed wetland inventory in the Willamette Valley (Titus et al., 1996), Section 404 of the Clean Water Act, a permit for dredging and filling a wetland, appears to be violated everywhere, so that privately owned wetlands are worthy of protection from degradation and development. In the Marys River watershed, the Muddy Creek has been included in a conservation priority list for ONHP.

Some sense of distribution changes and historical wetland losses can be gained by comparing the 1850 historical conditions of wetlands with the 1990 existing conditions of wetlands in GIS (Appendix E). The 1850 historical condition map was created mainly through ONHP (Christy et al., 1998). The 1990 existing condition map was created by a compilation of available wetlands information, from the National Wetlands Inventory (NWI) where it was available, an Oregon Department of Fish and Wildlife (ODFW) vegetation map for the valley, and the Pacific Northwest Ecosystem Research Consortium (PNW-ERC) Landsat Thematic Mapper (TM) imaginary analysis (Adamus et al., 2000). As mentioned above, because privately owned wetlands should deserve increased protection, land ownership information is also included on the map in Appendix E. The ownership data was compiled by BLM and the State Service Center for

GIS (SSCGIS) in 1992 and 1993. Considering these data, it is estimated that in 1850 the Marys River watershed had 31.8 sq mi of wetlands, or approximately 10.6 percent of the watershed was considered wetlands. In contrast, it is now estimated that in 1990 the watershed has 4.3 sq mi of wetlands remaining, or about 1.4 percent of the watershed is considered wetlands. Consequently, from the earliest settlement, the watershed has lost an estimated 86 percent of their original wetlands. In addition, approximately 82 percent of current wetlands are owned by private owners.

Appendix E. Wetlands conditions in 1850 and 1990 with land ownership information