GIS-BASED LAND USE SUITABILITY MODELING FOR OPEN SPACE PRESERVATION IN THE TIJUANA RIVER WATERSHED

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by

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GIS-Based Land Use Suitability Modeling for Open Space

in the Tijuana River Watershed

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ABSTRACT OF THE THESIS

GIS-Based Land Use Suitability Modeling for Open Space
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by
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Master of Science in Geography
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Public participation is becoming increasing important in the decision-making process as decision-makers are looking for ways to gain support from various stakeholder groups. Open spaces, or primarily undeveloped areas, are valued for their environmental, economic, and recreational benefits. Because limited resources are available to protect these areas, an efficient and effective method is needed to identify and prioritize these areas for preservation. This study, based in the binational Tijuana River Watershed, examined a stakeholder-driven approach for prioritizing open space areas for preservation. A GIS-based land use suitability analysis was conducted using environmental, economic, and recreational factors gathered from existing literature and expert opinion. The Analytic Hierarchy Process (AHP) was used as a means for incorporating stakeholder preferences as weights for the input factors. The results provide an indication of which areas in the watershed are most valuable to stakeholders. In addition, results were compared to a 2004 biological study to identify overlapping areas of value to both biologists and stakeholders.

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CHAPTER 1

INTRODUCTION

Open spaces, or primarily undeveloped, natural areas, offer a wealth of human and natural benefits. Economic, environmental, ecological, social, and recreational advantages can result from the preservation of these natural areas (Arendt, 1996). However, urban expansion and increased population growth have destroyed or threatened natural areas around the world. In the Tijuana River Watershed, the proportion of urbanized areas has steadily increased from 0.18% in 1938 to 6.8% in 1994 (Ojeda Revah, 2000). Although urban land uses represent only a relatively small portion of the watershed, no part of the watershed has escaped the impact of human activities. Population figures in the watershed are also climbing, indicating that urban development is continuing to expand. This growth will create a further loss of access to open spaces and a decrease in the quality of life for residents in the watershed.

Stakeholders in the watershed have shown concern for these issues. At the 2003 Tijuana River Watershed stakeholder meetings, a variety of action items were identified by participants that included “creating and protecting green areas (áreas naturales protegidas),” “creating natural parks to address social problems,” “creating binational conservation areas,” and “restricting development to create green areas” (The Tijuana River Watershed Binational Vision Project, 2003).

In order to protect these areas of ecological and environmental significance, an effective and efficient method is needed to identify and prioritize open space areas for preservation. This method should incorporate stakeholders' concerns and priorities, as well as expert opinion. This research seeks to employ a GIS-based approach to fill this methodological gap and address the following research questions:

1. Based on a survey of Tijuana River Watershed stakeholders, what are the emerging concerns and priorities related to open space preservation?
2. What specific areas result from a raster-based suitability analysis designed to represent these priorities?

3. How do areas resulting from this analysis compare to areas identified in the 2004 Las Californias Binational Conservation Initiative report?

CHAPTER 2

LITERATURE REVIEW

This review of the existing literature begins with an overview of the Tijuana River Watershed as a geographical unit of study, followed by a discussion of some of the most pressing environmental issues and a description of stakeholder groups in the region. The next section addresses the nature of open space and benefits associated with the preservation and restoration of these areas. Finally, a discussion of GIS-based suitability analysis is included to provide background information on the technique to be used in this study.

2.1 Tijuana River Watershed

A Mediterranean climate with cool, wet winters and dry, hot summers characterizes the southwestern coast of California and the adjoining area of Baja California. This Mediterranean-type ecosystem is home to a wide variety of plant and animal species and has been identified as a hotspot for biodiversity (Conservation International, 2004). The Tijuana River Watershed covers an area of 1,750 square miles within a portion of this region (see Figure 2.1). Because of the rough and varied terrain, three sub-climates have also been identified in the watershed: a semi-arid climate in the lower altitudes near the coast, a temperate climate in the higher altitudes and a cooler, humid climate in the highest peaks (Ojeda Revah, 2000).

The basin is dissected by the U.S.-Mexican border, with two-thirds of the catchment area in Mexico and the other third in the United States (Wright, 1996). The largest populations are concentrated in the urban areas of San Diego, Tijuana, and Tecate. Population projections in these areas in 2000 totaled nearly 4.1 million, with 2.8 million in San Diego, 1.2 million in Tijuana, and 78,000 in Tecate (Peach and Williams, 2003). As these numbers continue to rise, severe environmental consequences will result in the watershed (Brown, 1998).

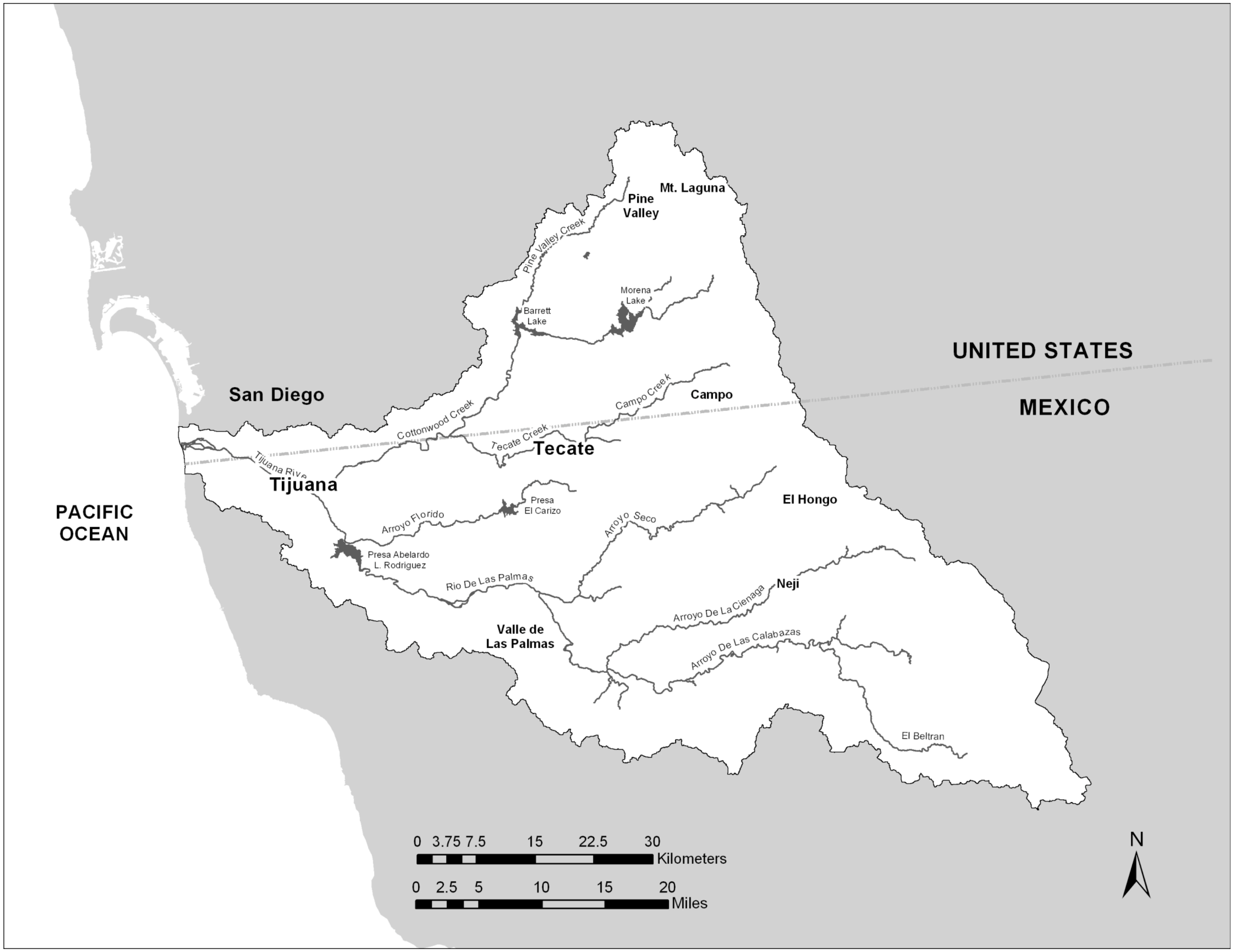


Figure 2.1. The Tijuana River Watershed.

2.1.1 Watershed Approach

A watershed can be defined as a region in which water and sediment drain into a common outlet. It is a region delineated by hydrologic processes rather than political or cultural boundaries (Lal, 2000). A watershed management approach focuses on the entire watershed as a system of physical and biological processes that forms the basis for decision-making (Montgomery et al., 1995). Within a watershed framework, decisions are made based on impacts to an entire ecosystem rather than a single political entity. When hydrologic processes are taken into account, ecosystem management and land use decisions will offer more ecologically sound and sustainable solutions (Brooks et al., 1997).

Because an international boundary runs through the basin, a disparate set of jurisdictions and organizations with conflicting goals and priorities is present. Many management decisions in the United States are made at a relatively decentralized level with organizations existing at the state, county, and regional levels. However, it is difficult to identify corresponding Mexican organizations because of Mexico's centralized government and administration (Spalding, 2000; Van Schoik, 2003). The two countries have a history of making management decisions independently, despite the environmental implications on both sides of the border. A more logical approach to management is a watershed framework that incorporates stakeholder groups from both sides of the border (The Good Neighbor Environmental Board, 2000).

2.1.2 Stakeholder Groups

One of the inherent difficulties in identifying stakeholders in a binational watershed is the sheer diversity of interests involved. If decisions are to be truly collaborative, all community interests need to be represented (Committee on Watershed Management, 1999). Because of its international nature, the involvement of both U.S. and Mexican citizens is crucial to the success of any planning efforts in the Tijuana River Watershed. Any watershed-wide approach will also incorporate upstream and downstream interests, as well as ground water and surface water users, because of their differing and often conflicting needs. Urban and rural inhabitants also may have dissimilar viewpoints because of their different lifestyles and working environments. An equally important, but often ignored, group includes the native tribes and indigenous people of the region. In the Tijuana River Watershed, the

Campo and La Posta tribes of San Diego County and the Kumiai of northern Baja California are included in this group of stakeholders (The Tijuana River Watershed Binational Vision Project, no date). Lastly, government officials are often the individuals with the ultimate power in decision-making, and their involvement is crucial to the success of any planning efforts (Heathcote, 1998). It is important to involve all of these groups.

2.1.3 Environmental Issues

Poor water quality, flooding, air pollution, and biodiversity loss are just some of the environmental issues being faced in the Tijuana River Watershed. These problems stem in large part from the rapid population growth and associated conversion of land to urban uses in the region. San Diego's population is growing at a rate of 2.8% per year, while Tijuana's population is growing even faster, at an annual rate of 4.9%. According to population projections for the region, the watershed could grow to 6.3 million by 2030 (Peach and Williams, 2003).

Because of this growth, the quality of freshwater and groundwater in the region has been significantly degraded. Urban, industrial, and agricultural uses on both sides of the border have given the State Water Resources Control Board reason to classify the Tijuana River Watershed as a Category I (impaired) watershed (Project Clean Water, no date). Problems with wastewater treatment and non-point sources of pollution have contributed to degraded water quality in the border region (Michel, 2000). High levels of population growth and increased urbanization, combined with recent drought conditions, have also impacted water quantity (Nitze, 2003). Decreases in water supplies can be attributed to aquifer depletion, lack of conservation and reclamation, and improper diversions of natural flows (Herzog, 2000). New conservation plans are needed to increase the available water supply and make better use of existing local resources.

Not only has water been a contentious subject in the region, but air quality is also a major issue of concern. Most all of the counties along the border are in a state of non-attainment for air quality standards, meaning that they have exceeded National Ambient Air Quality Standards for major pollutants such as ozone, carbon monoxide and lead (Alegría, 2000). According to the California Air Resources Board, when pollutants exceed these levels, the public's health is potentially in danger (California Air Resources Board, 2005).

Some of these air-related problems can be attributed to weak enforcement of environmental laws, long-distance transport of pollutants, and lack of absorption due to deforestation (Spalding, 2000).

A major cause of the decrease in biodiversity in the region is habitat fragmentation, a process in which a landscape is perforated or broken up by land use changes. As a result of this fragmentation, ecosystems become increasingly isolated with less interior habitat space (Forman and Gordon, 1986). Lina Ojeda Revah's research in the Tijuana River Watershed illustrates fragmentation that has occurred within the coastal sage scrub, chaparral, and riparian vegetation communities (Ojeda Revah, 2000). Species such as the Big Horn sheep and the Arroyo toad have also been listed as endangered or threatened as a result of this fragmentation (The Tijuana River Watershed Binational Vision Project, no date).

2.2 Open Space

Open space areas, sometimes referred to as greenbelts, greenspaces, or greenways, can be defined in a variety of ways. Some definitions of open space may incorporate golf courses, cemeteries, or agricultural land, while others may exclude these land uses. Land ownership is also an issue as certain definitions state that open areas must be publicly owned while others do not distinguish between public and private spaces. The Environmental Protection Agency (EPA) defines open space as “a portion of a site which is permanently set aside for public or private use and will not be developed. The space may be used for passive or active recreation, or may be reserved to protect or buffer natural areas” (Environmental Protection Agency, 2002). The National Park Service (NPS) similarly defines open space as an area that “includes public and private land that is retained as primarily undeveloped. This could include lands devoted to active or passive recreational use or lands retained for visual or natural resource protection purposes” (National Park Service, 2004). An alternative definition that emphasizes the ecological significance of these areas is offered by Smart Growth, an organization funded and coordinated by the EPA. It defines open space as “natural areas both in and surrounding localities that provide important community space, habitat for plants and animals, recreational opportunities, farm and ranch land (working lands), places of natural beauty and critical environmental areas (e.g. wetlands)” (Smart Growth, 2004). For the purpose of this research, these definitions have been combined to designate an open space area as **a primarily undeveloped space, publicly or privately owned, that is permanently reserved because of its recreational, visual, or ecological significance**.

2.2.1 Need for Open Space

Research has consistently shown that open space areas provide a variety of benefits that improve a community's quality of life; however, demands for continued growth have made preservation of these areas difficult. The executive director of The Endangered Habitat League in San Diego was quoted in 1998 as saying,

> "The time to fight all growth is past. California will grow. Our job is to develop policies for smart growth-smart enough to preserve critical resources and valuable open space, smart enough to make our cities attractive places to live, and smart enough to provide housing and a high quality of life for all Californians" (Center for Continuing Study of the California Economy, 1998).

This statement can be applied to regions throughout the watershed where growth is just as pervasive. Clearly, methods are needed to address these conflicting goals of development and preservation and provide a balanced solution.

2.2.2 Benefits of Open Space Preservation

The advantages of preserving open space are numerous. In the Tijuana River Watershed, these benefits directly address, and in some cases, provide solutions to the aforementioned environmental issues in the region. This section outlines some of these benefits in the following categories: environmental and ecological, economic, and social and recreational.

2.2.2.1 Environmental and Ecological Benefits

As previously described, the Tijuana River Watershed is facing a myriad of environmental issues related to water, air and habitat loss. By investing in the preservation of open space areas in the region, some of these problems can be mitigated. Depending on where open space is preserved, benefits can be seen related to water quality and quantity. If buffer zones are preserved around water features, water can be filtered by natural vegetation that reduces pollutants before it flows into lakes and reservoirs. Runoff is also reduced by these buffer zones causing more water to infiltrate into underground aquifers making it accessible to local users (Arendt, 1999).

One of the most obvious ecological benefits resulting from open space preservation is the protection of local vegetation and wildlife. In riparian habitats, these benefits are even more substantial due to the abundance of significant organisms and processes that exist in these regions (Committee on Watershed Management, 1999). One method that protects local habitat is the creation of natural corridors or narrow zones of contiguous open space that connect larger natural areas. By providing organisms with this mobility, some of the fragmentation issues, such as those in the Tijuana River Watershed, can be relieved (Committee on Watershed Management, 1999). With careful selection of areas for preservation, significant habitat can be protected and restored.

2.2.2.2 ECONOMIC BENEFITS

Open spaces provide distinct economic benefits for nearby and surrounding communities. Businesses and workers are drawn to regions in which parks and open spaces are abundant and accessible (Lerner and Poole, 1999). A study published in 1997 revealed that recreation, parks and open spaces were particularly important to small businesses' decisions regarding location (Crompton et al., 1997). It has also been shown that property values of homes increase with views of open space or natural areas (Kaplan and Kaplan, 1989).

Another economic advantage of open space preservation is the increase in economic activity resulting from a boost in tourism. Tourists are attracted to the outdoor recreational opportunities, as well as natural and scenic views provided by open space areas (Arendt, 1996). The travel and tourism industry is integral to the economies of both the United States and Mexico, making open spaces in the Tijuana River Watershed even more valuable for sustainable tourism (Herzog, 2000).

The protection of floodplain areas can have a positive economic impact in a region because flood damages are diminished downstream. A survey done in 1993 by the Illinois State Water Survey revealed that for every additional 1% of land along a stream corridor that is protected, there is a 3.7% decrease in peak stream flows (Lerner and Poole, 1999). As flooding is mitigated, recurring flood damage costs and disaster assistance decrease significantly (Lerner and Poole, 1999). In the Tijuana River Watershed, flooding is an issue of concern as many communities are impacted by seasonal floods (Dresler and Woods, 2000).

There are also direct economic benefits from preserving open spaces in riparian zones. Because runoff is reduced, more water infiltrates into underground aquifers, becoming available for human consumption. Consequently, less infrastructure and funding are needed to import, store, and treat drinking water (Lerner and Poole, 1999).

2.2.2.3 Social and Recreational Benefits

Research has consistently shown that natural areas have a positive impact on the quality of life in a region. People with access to nearby natural areas have lowered levels of stress and higher levels of relaxation and satisfaction with their lives (Kaplan and Kaplan, 1989). In 1995, approximately 2,000 people were polled about quality of life issues by the Regional Plan Association and the Quinnipac College Polling Institute. It was reported that low crime rates and access to open space areas were the major factors in determining quality of life (Leinberger and Berens, 1997).

There is a great demand for the recreational benefits that result from preserving open space areas (Smith and Hellmund, 1993; Fleischer and Tsur, 2003). However, with population growth and increased development, accessibility to these types of activities is decreasing. In the Tijuana River Watershed, preserved open space areas could provide opportunities for hiking, camping, biking, fishing, hunting, wildlife watching, and photography. In turn, this would increase the quality of life for residents and visitors to the region.

2.2.3 Identification and Prioritization of Open Space Areas

With limited resources available in the Tijuana River Watershed, a method is needed to identify and prioritize open space areas to maximize the benefits of preservation. It is important to determine which areas provide which types of benefits and how these will best meet the needs of stakeholders in the region. This is the approach that many institutions have used to select areas with the most potential. In Clark County, Washington, a land suitability analysis was conducted using GIS technologies to create a map of optimal open space locations based on a variety of criteria (Bohard, 1992). A similar GIS-based suitability analysis done in Prescott Valley, Arizona, focused on wildlife habitat, recreation, and riparian corridors as criteria to identify potential sites for greenway development (Miller et al., 1998). The focus of the current research project was to develop a comparable technique for use in the Tijuana River Watershed.

2.3. GIS-Based Land-Use Suitability Analysis

Land-use suitability analysis is a method for identifying the most appropriate future land uses according to a set of constraints, preferences, or predictors (Malczewski, 2004). Initially, these techniques were conducted with hand-drawn overlay maps; however, now GIS technology is integral to analyzing and mapping large datasets (McHarg, 1969; Whitley and Xiang, 1993). The premise of this type of analysis is that a number of overlay maps, or maps representing various criteria (e.g., slope, distance to nearest road, soil type), are combined to yield a final overall suitability map of the study area (Hopkins, 1977; Tomlin, 1990; Malczewski, 2004).

2.3.1 Multicriteria Decision-Making (MCDM) Techniques

The framework of land-use suitability analysis is built upon the concept of multicriteria evaluation. Multicriteria decision-making (MCDM) or multi-attribute decision-making (MADM) techniques involve the evaluation of several criteria or attributes to meet a specific objective (Eastman et al., 1995; Jankowski, 1995). These techniques have been used in a variety of scenarios and research situations. For example, in Switzerland, MCDM techniques and GIS were used to identify suitable land for housing (Joerin, et. al, 2001). In South Africa, a study was done using multicriteria analysis to evaluate areas for development based on four specific land use categories, each with its own set of criteria (der Merwe and Hendrik, 1997).

MCDM techniques can be divided into two categories: compensatory and noncompensatory (Jankowski, 1995). Compensatory techniques evaluate alternatives in a manner so that high performance on one criterion can compensate for low performance on another. With a noncompensatory approach, there are no such trade-offs (Jankowski, 1995).

One of the most commonly used MCDM procedures representing a compensatory approach is weighted summation or weighted linear combination (WLC), in which criteria are multiplied by a weight and summed together (Eastman et al., 1995). Because weighted summation is sufficiently straightforward to use with raster data in GIS, it will be incorporated into the land-use suitability analysis for this research (Eastman et al., 1995).

2.3.2 Methods, Techniques, and Software

The key principle behind land-use suitability analysis is the cartographic modeling approach in which a set of map operations is performed on input maps of a study area to create a spatial model (Tomlin, 1990; Malczewski, 2004). One example of this approach is a model used in Argonne, Illinois, to identify potential sites for wetland mitigation. Input maps of land use, hydrology, soil, vegetation, historic wetlands, and historic depressions were processed and combined to create an output map illustrating the most suitable wetland areas (Kuiper, 1999).

In Malczewski's 2004 overview of GIS-based land-use suitability analysis, he outlines a three-step technique for conducting a suitability analysis from a cartographic modeling approach (Malczewski, 2004):

1. Preprocessing Stage-datasets are collected at the same resolution and scale, and then transformed/projected into the same coordinate system
2. Flowchart Stage-the land-use suitability model is depicted as a flowchart showing all weighting and combining processes
3. Execution Stage -the model is executed using GIS operations

The three steps delineated above were incorporated into the suitability model used in this research.

Suitability analyses can be conducted in GIS using a vector data model or a raster data model. The raster-based, or grid-based, method is usually preferred when the input data vary over a continuous surface such as vegetation, elevation, or soil (Chang, 2004). The GIS layers used in this study are of this nature and, therefore, the raster-based approach was used.

One of the most common raster-based techniques for generating land suitability maps is Map Algebra, a language based on matrix algebra. Each raster grid, or input map, functions like a matrix variable in an algebraic equation. Selected operators and/or functions are available to apply to these variables to create output maps (Tomlin, 1990; DeMers, 2002;

Malczewski, 2004). Because of its robust capabilities, Map Algebra was used as the means of completing step three of the process outlined above.

There are a variety of GIS software packages available with raster-based modeling capabilities. The Environmental Sciences Research Institute's (ESRI) ArcGIS 9 provides a graphical user interface called ModelBuilder in which models can be designed and run using a flow chart format. A variety of built-in tools and scripts are available with inherent Map Algebra functionality. All input and intermediate data, as well as any processes and output data, are represented as components of a flow chart (ESRI, 2004b). ModelBuilder was used to create a flow chart of the suitability model for this research. In addition, the cartographic tools built into ArcGIS 9 were also used to generate the final suitability maps.

2.3.3 Incorporating Stakeholder Input

Because stakeholder input is becoming increasingly important in the decision making process, a method is needed to incorporate the public's opinions and preferences regarding land use decisions (Committee on Watershed Management, 1999). An integral part of the suitability analysis involves weighting each of the input maps or factors relative to its importance in the final outcome of the model (Lyle and Stutz, 1983). It is in the selection of these weights that stakeholder input can be effectively integrated.

In his 1999 book, GIS and Multicriteria Decision Analysis, Malczewski compares four methods of criterion weighting: ranking, rating, pairwise comparison, and trade-off analysis (Malczewski, 1999). While ranking (arranging in rank order) is the simplest method to use, the results can only be viewed as an approximation of the true weights (Malczewski, 1999). The rating method in which weights are estimated based on a predetermined scale is also a relatively simple method, yet is often criticized because of its lack of theoretical foundations (Malczewski, 1999). The pairwise comparison and trade-off analysis methods offer much more precision in terms of calculating weights and both have underlying theoretical bases; however, research has shown that the pairwise comparison technique is simpler to use and just as effective as trade-off analysis (Malczewski, 1999).

The method that introduced the use of pairwise comparison for determining factor weights is the Analytic Hierarchy Process (AHP) (Saaty, 1980). In this process, all of the factors in the suitability analysis are grouped into categories such as economic, social, and environmental to create a hierarchy. Stakeholders are asked to make comparisons between each possible pair of factors and determine which is more important using a 9-point scale to indicate degree of preference. The process is then repeated between each pair of categories. The scores are synthesized using matrix algebra calculations to generate factor weights (Whitley and Xiang, 1993; Malczewski, 1999). In addition, a consistency index can be calculated to assess an individual's consistency across all judgments (Saaty, 1980; de Steiguer et al., 2003). Because of its relative ease of implementation and its theoretical and empirical foundations, the AHP was used as a framework for gathering input from stakeholders in the Tijuana River Watershed for this study (Malczewski, 1999).

CHAPTER 3

METHODOLOGY

The primary objective of this study is to design a raster-based model and apply it to a suitability analysis of open space areas for preservation in the context of an international watershed. A survey instrument was employed for gathering data from stakeholders in the Tijuana River Watershed. The Analytic Hierarchy Process (AHP) was used to structure the surveys and calculate the weights used in the model. After the weights were calculated, the model was run to generate potential preservation areas. A sensitivity analysis was conducted to determine the stability of the assigned weights. Finally, each of these areas was qualitatively compared with open space areas targeted in a previous study. Figure 3.1 illustrates the order in which these steps were completed.

3.1 Suitability Analysis

The GIS-based land-use suitability analysis in this study was designed using the cartographic modeling approach previously described in Section 2.3.2. The preprocessing was done using GIS data from the Tijuana River Watershed Data Clearinghouse at http://typhoon.sdsu.edu/Facilities/Data/Clearinghouse/trw.html. Table 3.1 delineates the GIS datasets used in this study.

Based on the existing GIS datasets for this region, along with published literature and expert opinion, eight factors were identified for inclusion in this model (see Figure 3.2). In a suitability analysis, a factor is a criterion used to measure the suitability of the land for a specific objective (der Merwe and Hendrik, 1997). For example, in this model "distance to business and residential areas" was used as a factor to measure the economic value of an area. These factors have been grouped into three categories as shown in level two of the hierarchy: environmental, social, and economic (see Figure 3.2). For each factor in the analysis, a capability class or rating scale has been employed. The scale used follows the Food and Agriculture Organization's (FAO) guidelines for land capability evaluations.

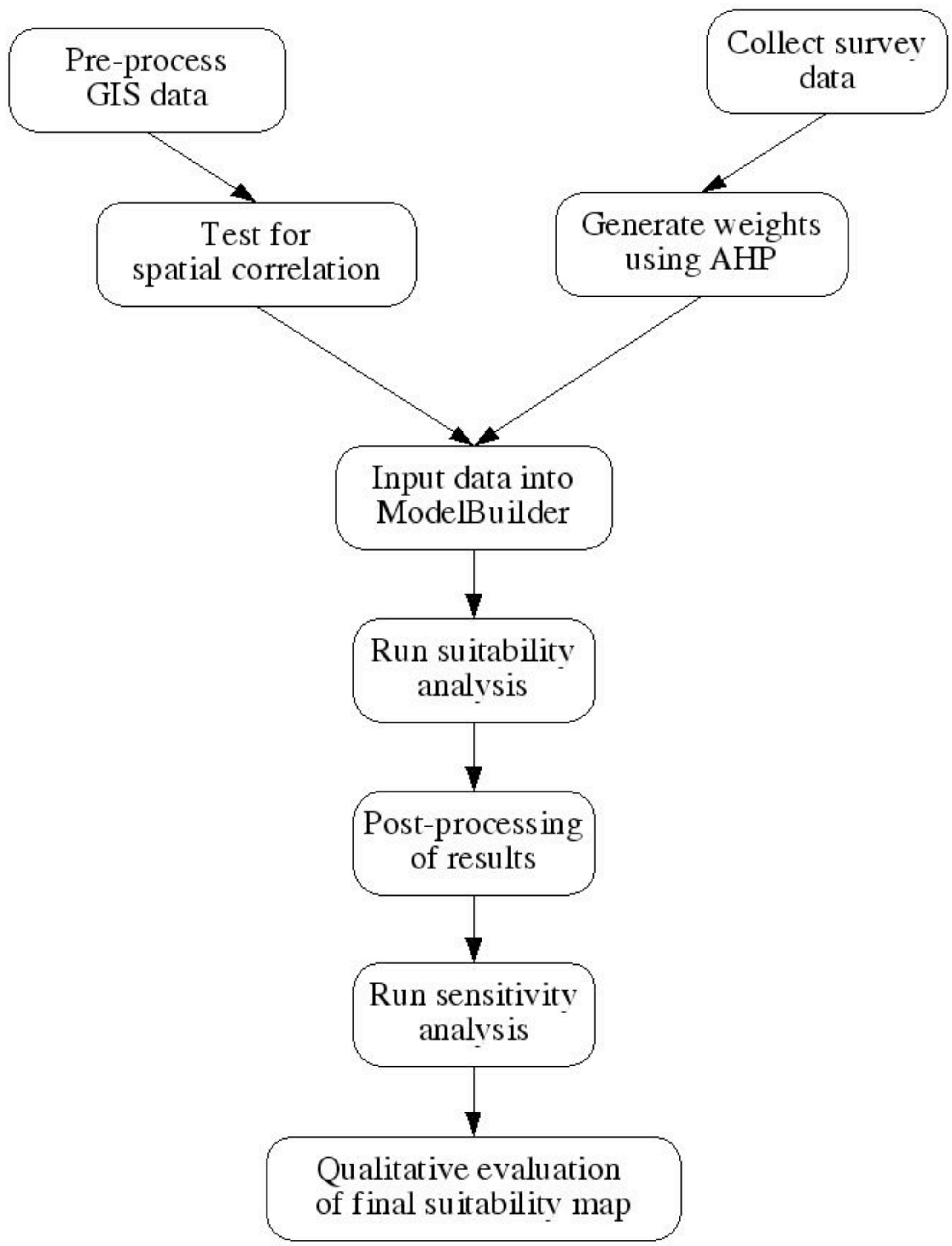


Figure 3.1. Flow of methodology.

Table 3.1. Tijuana River Watershed GIS Data

GIS Data	Format	Date
Sub-Basins	Polygon	2000
Land Use	Polygon	1995
Vegetation	Polygon	1995
Roads	Line	1994
DEM	Raster	2000
Lakes	Polygon	2000
Streams	Line	2000
Communities	Point	2000

Spatial Reference Information:
Universal Transverse Mercator, zone 11
North American Datum of 1983
GRS 80

Data Sources: Center for Earth Systems Analysis Research and El Colegio de la Frontera Norte

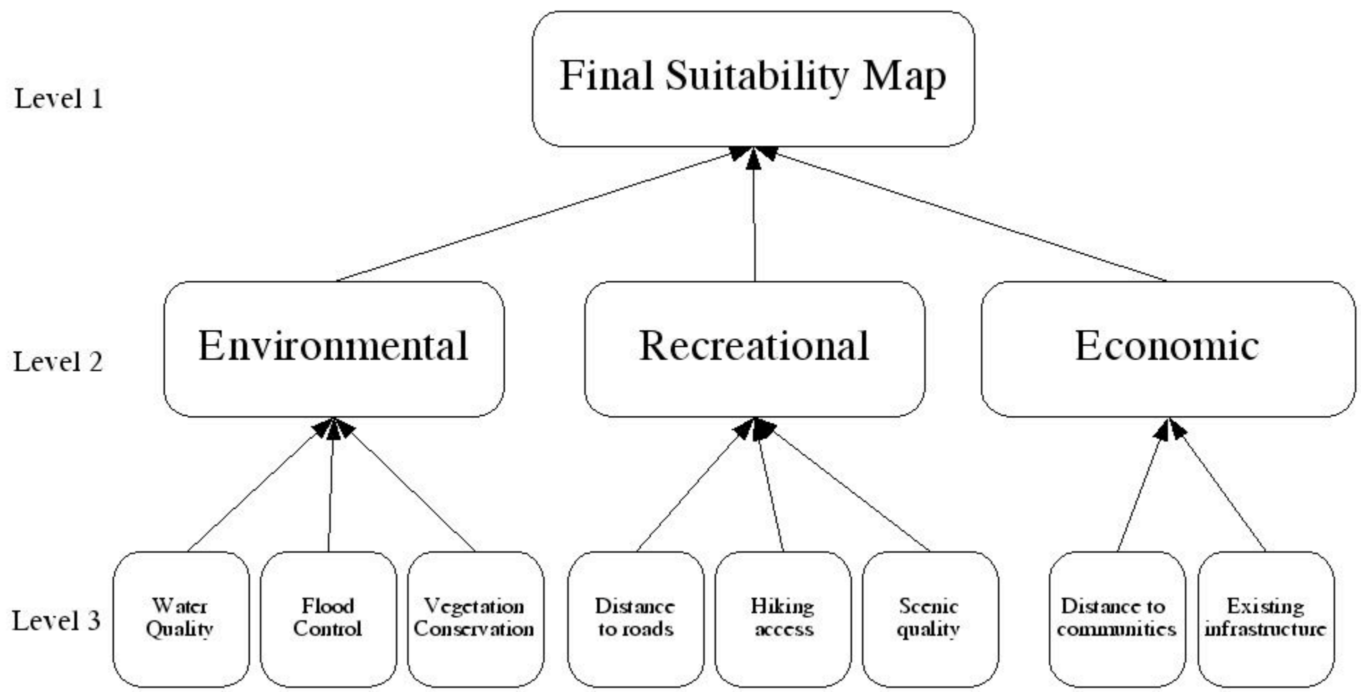


Figure 3.2 Suitability analysis hierarchy.

Values of zero to three are applied, with higher values indicating the most suitable areas and zero reserved for unsuitable areas (der Merwe and Hendrik, 1997).

3.1.1 Environmental Factors

Previous academic studies have identified various methods for measuring the environmental value of an area. Land, surrounding water features, that can be used to protect water quality, is one of the most common indicators of environmental value (Thrall et al., 1998; Kramer and Dorfman, 2000; Mahon and Miller, 2003). When preserved, land that is steeply sloping or erodible is valuable in preventing flooding in a region (Kramer and Dorfman, 2000). Areas that provide habitat for rare, endangered, or sensitive species are also highly valued, especially when these areas connect existing habitats (Smith and Theberge, 1986; Noss, 1987; Arendt, 1999). Vegetation is another measure of a region's environmental value. If an area contains endemic or rare plant species it is often valued above other areas (Sargent and Brande, 1976; Smith and Theberge, 1986). For this model, three of the above factors were selected to measure environmental value (see Table 3.2). Wildlife habitat was not chosen as a factor because data related to native or significant species are not available in the Tijuana River Watershed.

Table 3.2. Environmental Factors

Factor	Capability Class	Class Description
	3	Water body
Water Quality	3	Within 100 feet of water body
	1	More than 100 feet away from water body
	3	> 25% slope
Flood Control	2	15% - 25% slope
	1	< 15% slope
	3	High conservation priority
Vegetation	2	Medium conservation priority
	1	Low conservation priority

For each environmental factor in the suitability analysis, a capability class was created with values ranging from one to three. In the case of water quality, this class is based on Wenger's 1999 review of literature related to riparian buffers. It was shown that a vegetated buffer of 100 feet (30 meters) is adequate in most cases for preventing sediment runoff by trapping pollutants before they enter the water (Wenger, 1999). Therefore, all water bodies (lakes and higher order streams), as well as any land located within a 100-foot buffer received a value of three, indicating the highest level of value. All other areas were assigned a value of one. ArcGIS tools were used to create the raster representation of this factor. The vector data for streams and lakes were buffered at 100 feet and these polygons were converted into a grid with a value of three. A mask of the entire watershed was used to assign a value of one to the remaining cells within the region. Appendix A depicts the raster data created for the water quality factor.

The capability class for the flood control factor is calculated based on the percentage of slope in an area. In Randall Arendt's 1999 workbook, *Growing Greener*, he claims that regions with slopes greater than 25% are at a high risk of severe erosion if not left in their natural state (Arendt, 1999). He states that areas with slopes between 15% and 25% should also be avoided for development if possible (Arendt, 1999). To prevent erosion, silting, and flooding, the City of San Diego Progress Guide and General Plan also discourages development on slopes greater than 25% (The City of San Diego, 1989). For this model, areas with slopes greater than 25% are given a value of three, indicating that if preserved, they are of the highest value for preventing flooding. Those with slopes of 15% to 25% receive a two and those less than 15% are given a one. Using the DEM for the entire watershed, a slope surface was created and reclassified to represent this capability class. Appendix A illustrates the areas that received values of one, two, and three.

Researchers at San Diego State University have classified vegetation in the Tijuana River Watershed based on its conservation priority (The Tijuana River Watershed Binational Vision Project, 2004). High priority is given to vegetation such as Coastal Sage Scrub and Oak Woodland that is native to the region and in need of conservation. Medium and low priorities are assigned to vegetation categories that offer less value or are considered to be invasive species. For the vegetation capability class, these high, medium, and low categories were translated into values of three, two, and one, respectively. The vector data were directly converted into raster format using these values (see Appendix A).

3.1.2 Recreational Factors

Passive recreation or recreation that requires little development and has a minimal impact on the environment (e.g., hiking, biking, picnicking, etc.) is the focus of this suitability analysis (Thrall et al., 1988). Measuring the value for this type of recreation has been done using a variety of techniques in different research studies. In a 2003 suitability study, the recreational value of an area was considered high if it was adjacent to and accessible from existing trails, had the potential for diverse recreational opportunities, was located in a region currently needing increased recreational opportunities, and was publicly accessible (Mahon and Miller, 2003). The City of San Diego recognizes areas of high recreational potential as "areas particularly suited to recreational activities, such as those containing streams and trails" (The City of San Diego, 1989). Some studies have identified scenic quality as important to the overall recreational value of an area (Kramer and Dorfman, 2000). For this analysis, three factors were selected: scenic quality, hiking access, and distance to roads (see Table 3.3). Analysis at the level of hiking trails cannot be conducted in the Tijuana River Watershed because no GIS dataset representing trails is available; therefore roads, most of which are unpaved, are used as a proxy for trails in this study.

Table 3.3. Recreational Factors

Factor	Capability Class	Class Description
Distance to Roads	3	< = 100 meters from roads
	2	100 – 200 meters from roads
	1	> 200 meters from roads
Hiking Accessibility	3	< = 5% slope
	2	6% - 15% slope
	1	15% - 25% slope
	0	> 25% slope
Scenic Amenity	3	High to very high scenic amenity
	2	Moderate to moderately high scenic amenity
	1	Low to moderately low scenic amenity

The capability class for the distance to roads factor is designed to give highest priority to areas that are most accessible from roads. In the dataset used, roads include major highways and interstates, as well as arterial and unpaved streets. Those areas that lie within a 100-meter buffer from the roads received a value of three indicating that they are the most accessible. Areas within 100 to 200 meters from the road are somewhat accessible and are valued at two. All other areas are the least accessible from existing roads and were assigned a one. Appendix A illustrates these road buffers in raster format.

Slope is used as a factor in this analysis to measure the accessibility of an area for hiking or other general passive recreation. The capability class values range from one to three and are based on Xiang's 1996 GIS-based trail alignment study in which slope was used as a measurement of suitability for hiking trails (Xiang, 1996). These slope values were taken from Xiang's study and assigned an appropriate capability class value (see Table 3.3). A slope surface was created and this grid was reclassified corresponding to the capability class values (see Appendix A).

3.1.2.1 Scenic Value

Techniques for measuring the scenic quality of a landscape vary greatly from study to study. In 1994, researchers created equations to predict the scenic beauty of a landscape in Oregon using video recorded segments and GIS layers (Bishop and Hulse, 1994). Another study published in 2004 used photographs, GIS, and spatial metrics to predict the scenic perception in Massachusetts (Palmer, 2004). However, the resulting equations from these studies are specific to the land cover and vegetation in the regions and are not generalizable. What can be noted are some of the similarities that emerge from the results of these studies. Two of the most common indicators of scenic beauty appear to be the naturalness of the landscape and the amount of water visible (Bishop and Hulse, 1994; Palmer, 2004). These two factors were used to determine the areas in the Tijuana River Watershed that have the most scenic value.

To account for the naturalness of the landscape in the Tijuana River Watershed, a classification scheme used in a 1997 study of visual attributes was employed (Ayad and Guenet, 1997). The existing land use dataset was reclassified using a scale of one to three such that artificial landscapes including urban, industrial, commercial, and residential areas received a one. Areas that retain some natural character of the land, but have been modified, such as agricultural, dispersed residential, and recreational were assigned a two. All natural and near-natural regions were assigned a three. The activities present in these areas are most similar with the natural character of the land (see Appendix B). This classification is illustrated, in raster format, in Figure 3.3.

In addition to naturalness, the existence of water was used as a factor in determining scenic preference. To approximate the areas where water could potentially be visible, two buffers of 200 meters each were created around lakes and streams. Water bodies (lakes and streams) and the first buffer zone were assigned a value of three ("high"). The next buffer zone was given a two ("medium") and the remaining areas in the watershed received a one ("low"). These buffers were converted into raster format and shown in Figure 3.4. To create the final scenic preference map, the two previous grids (see Figures 3.3 and 3.4) were added together to produce a surface of values from two to six. This grid was then reclassified assigning a value of one to cells containing a two or three, a two for all cells containing a four, and a three to the remaining cells (see Figure 3.5).

3.1.3 Economic Factors

Two economic factors were selected for inclusion in this model: proximity to communities and existing infrastructure (see Table 3.4). There are other factors that contribute to the economic value of an area; however, they have already been accounted for in other parts of the suitability analysis. Recurring flood damage is costly for government agencies, as well as residents and businesses (Lerner and Poole, 1999). By preserving open space areas, flooding can be diminished and in some cases, prevented. These benefits have already been incorporated in the environmental factors of this model. Recreational benefits contribute to the economic value of a region as they boost tourism and attract new residents. These benefits are also already incorporated through the recreational factors in this model.

The economic value of an open space area most often increases with proximity to businesses and residential areas. This value is greatest when homes or businesses are within a quarter of a mile from the open space area (Thrall et al., 1988; Kramer and Dorfman, 2000). This distance measure was used to assign values to the capability class for this factor. All areas within a one-quarter mile buffer zone of major communities in the watershed were assigned a value of three indicating that they are the most valuable. All other areas received a one. Appendix A depicts the raster representation of this factor.

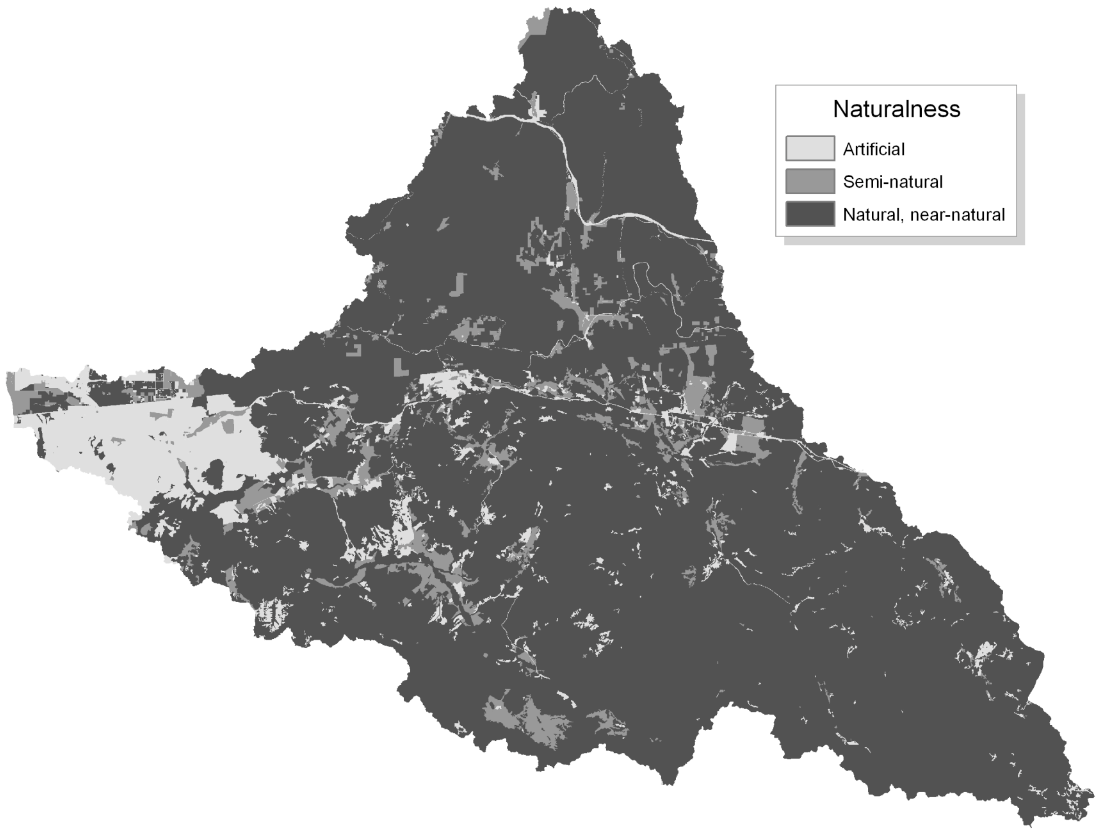


Figure 3.3. Naturalness grid.

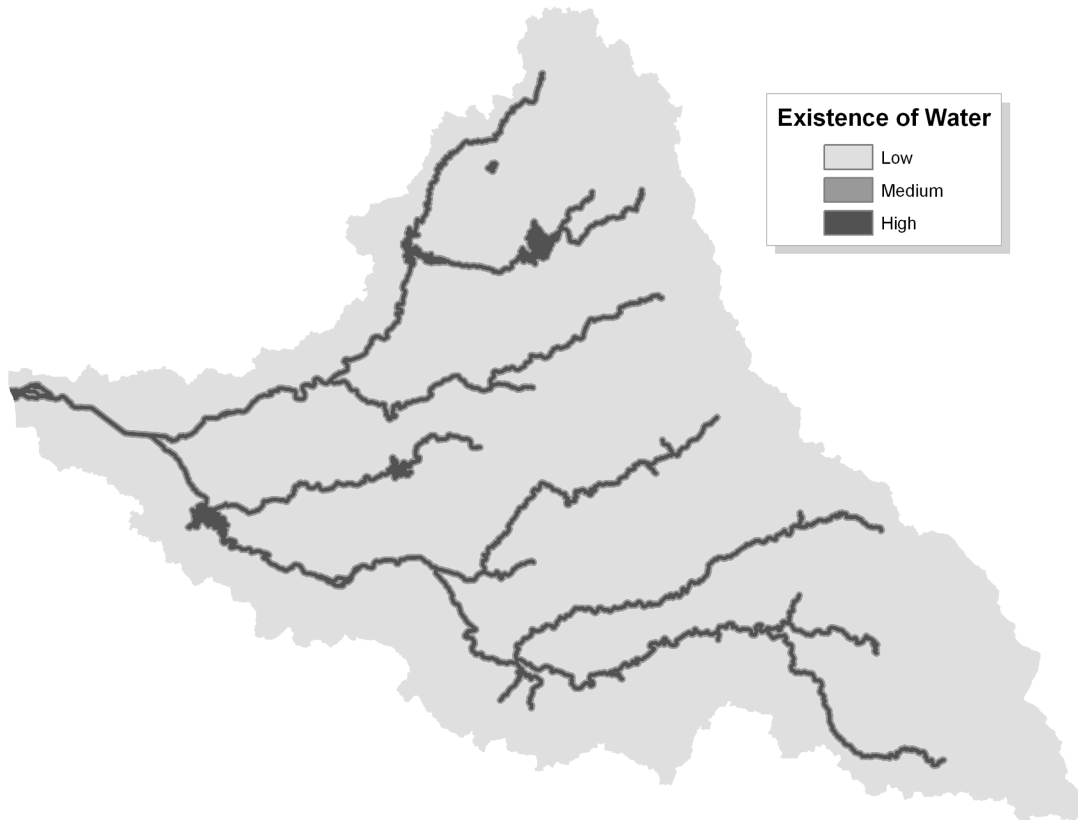


Figure 3.4. Existence of water grid.

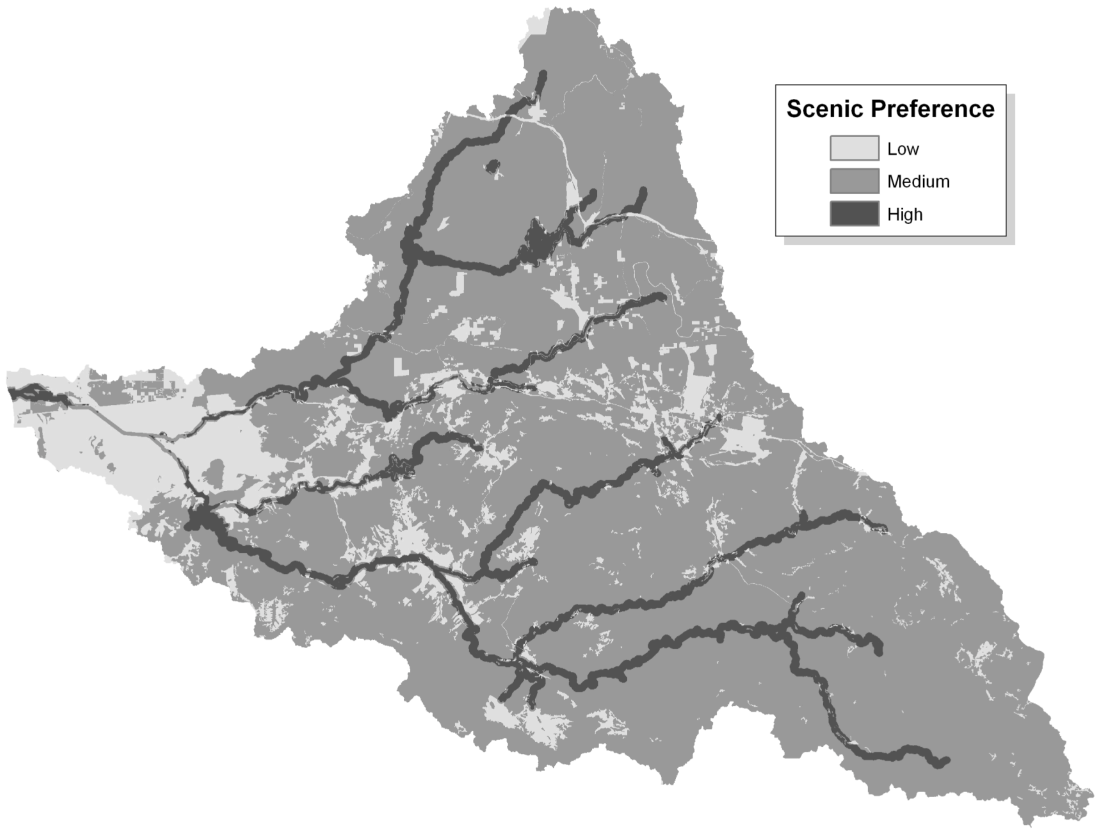


Figure 3.5. Scenic preference grid.

Table 3.4. Economic Factors

Factor	Capability Class	Class Description
Distance to Communities	3	Within 0.25 miles of a community
	1	> 0.25 miles of a community
Existing Infrastructure	3	High density of roads
	2	Medium density of roads
	1	Low density of roads

Infrastructure costs also play a role in the economic value of an open space area. Existing infrastructure, which provides access to an area, can lower initial maintenance and recreation costs because there is no need to create access roads or trails. Road density, the length of roads per unit of area, is an indicator of existing infrastructure and in turn, the economic value of an area (Millward, 2000). To assign values to areas in the Tijuana River Watershed, the line density tool in ArcGIS was used with the roads dataset to create a density grid across the watershed. This grid was reclassified into three categories (high, medium, and low) using the natural breaks method in ArcGIS. Cells were then assigned values from the capability class as shown in Table 3.4. Appendix A displays this final grid.

3.1.4 Factor Independence

When using the weighted linear combination approach (see Section 2.3.1), the input map layers or factor maps should be uncorrelated or preferentially independent of each other (Hopkins, 1977; Malczewski, 1999 and 2000). If input factors in a suitability analysis are found to be correlated, the resulting output may not correctly represent stakeholders' or decision makers' preferences. For example, high performance on one factor (e.g., cost) may be dependent on the performance of another factor (e.g., vegetation). If categorical data exist in this situation, a combination of factor values may become more important than simply the positive performance on one or more of these factors. In this case, redundant factors should be removed from the analysis to prevent misleading results. This assumption, however, is often difficult to meet in spatial decision problems (Hopkins, 1977; Malczewski, 1999 and 2000).

To prevent errors in this study associated with redundant input datasets, factor maps were deductively selected so that factor dependence would be minimized. For example, the scenic value factor is dependent on the presence of water and natural landscapes, but in theory, not on the hiking accessibility factor (slope) or the distance to roads factor. Likewise, the classifications used in the water quality factor are dependent on proximity to water, but not on the conservation value of vegetation or on the classifications used to assess flood control value (steepness).

Statistical tests were examined as methods for exploring dependency among the input factors. However, because each of the grids was classified at the coarse level of high (3), medium (2), or low (1), many traditional tests for correlation could not be used. A difference of proportions test was investigated as one means for determining the existence of factor independence. The relationship between the scenic value factor and the distance to roads factor was examined with this test, yet the results did not provide a conclusive answer. While they did offer some insight into the relationships between the different classifications, it was not possible to determine if the factors were correlated enough to impact the model results. Therefore, deductive reasoning was used to assess potential dependence among the input factors (Hopkins, 1977). Further details regarding the results of statistical tests are provided in Appendix C.

3.2 QUESTIONNAIRES

The questionnaire (see Appendix D) for this study was designed using the Analytic Hierarchy Approach (AHP) published by Thomas Saaty in 1980 and is discussed further in Section 3.2.3. Two demographic questions were used to identify a respondent's stakeholder group. A question regarding occupation was used to determine if a stakeholder is associated with a governmental or non-governmental agency. Respondents were asked to list the city or town they live in, as well as demarcate the location on map as a means of verification. From this question, stakeholder group affiliation was inferred regarding U.S./Mexican residence, urban/rural residence, upstream/downstream use, and ground water/surface water use. The ten pairwise comparisons asked the respondents to analyze the importance between two factors or categories in the hierarchy (see Figure 3.2). A box was checked corresponding to the relative importance of one attribute over another. A Spanish version was provided to Spanish-speaking stakeholders (see Appendix D).

3.2.1 Sample Group

Stakeholders living in many areas of the watershed were asked to participate in this study. Survey data were collected on four occasions in which members of the Binational Watershed Advisory Council (BWAC) and the Environmental Protection Agencies' Border 2012 Water Task Force for the Tijuana River Watershed, stakeholders attending the 2004 Tijuana River Watershed Stakeholder Meeting, and local residents in Tecate served as the sample group for this study. Because many of these respondents act as decision-makers within the Tijuana River Watershed, they are ideal for inclusion in this sample. Their opinions and input provide realistic and valuable results.

This sample of respondents consisted of stakeholders from both sides of the border, with 35 respondents from Mexico, 26 from the United States and 14 that did not answer this question. More specifically, these stakeholders claimed to live as far east as Campo and Tecate, and as far south as Ensenada. Many of the respondents came from the San Diego and Tijuana regions. While a variety of stakeholders were present, the most underrepresented group appeared to be the indigenous population. One representative of this group completed a questionnaire, yet it proved to be difficult to obtain any more responses from this group. Stakeholders' occupations were classified into three major categories: academic, governmental, and non-governmental (NGO's). Only two respondents worked in the private sector so they were categorized as "other," along with any blank responses. A wide variety of jobs were represented including land use planners, biologists, students, engineers, and secretaries.

The BWAC quarterly meeting on November 4, 2004, was the first event in which questionnaires were distributed. This meeting was held at the Hotel Pueblo Amigo near the border in Tijuana. This location provides easy access for stakeholders on either side of the border. The BWAC is an organization consisting of academics, private sector employees, government officials, non-governmental organizations, and other researchers and practitioners interested in the sustainability of the Tijuana River Watershed. Funding to support the meetings of this council is provided by the State of California, the County of San Diego, and San Diego State University (The Tijuana River Watershed Binational Vision Project, 2005). One of the major goals of these quarterly meetings is to prepare a binational vision for the Tijuana River Watershed. This vision document will reflect the stakeholders' views for an ideal state of the watershed and strategies to achieve these goals.

Immediately following the BWAC meeting on November 4, 2004, at the same location, was the Border 2012 Water Task Force meeting in which the second set of questionnaires was distributed. Border 2012 is a grass roots partnership between U.S. and Mexican governmental agencies, as well as other stakeholders. The mission of the Border 2012 program is to "protect the environment and public health in the U.S.-Mexico border region, consistent with the principles of sustainable development" (Border 2012 Water Task Force, 2004). Members of the Task Force represent a wide variety of the stakeholders in the Tijuana River Watershed. Meetings are open to the public and are often comprised of representatives from governmental, non-governmental, and educational institutions, as well as residents from either side of the border. These meetings are intended to assist the BWAC in implementing the Binational Vision for the Tijuana River Watershed.

On November 18, 2004, the questionnaire was administered to stakeholders in the Tecate region. These respondents are employees at the Tecate Fire Department, a local government agency, and Comisión Estatal de Servicios Públicos de Tecate (CESPTe). This group of stakeholders consisted of secretaries, cartographers, architects, fire fighters, water authority employees, and environmental educators.

The final application of questionnaires took place at the TRW Stakeholder Meeting on December 3, 2004 at the Hotel Pueblo Amigo in Tijuana. This meeting was open to the public and invitations were sent to all stakeholders that had previously expressed interest in the watershed. Notices were also posted in public places and on appropriate Web sites to draw as large a crowd as possible. Attendees at this meeting came from areas across the watershed and represented a diverse group of stakeholders.

3.2.2 Data Collection

To facilitate the survey process, a PowerPoint presentation was prepared and given prior to the distribution of the questionnaires at the first two meetings on November 4, 2004. An introduction to the issue of open space preservation along with an explanation of the factors used in this study was presented. The presentation provided respondents with a brief overview of the suitability analysis and a description of the hierarchy to be used. An example question was explained to illustrate use of the scale on the questionnaire. Translation for this presentation was also provided to accommodate all stakeholders. A combined total of 29 questionnaires were obtained from these two meetings.

Because the questionnaires distributed in Tecate were given on an individual basis, it was not feasible to use the presentation given at the first two meetings. Instead, each respondent was given a brief introduction to the study, the questionnaire was explained, and any questions were answered at that the time. The respondents were given as much time as needed to complete the questionnaires and a Spanish speaker was on hand to translate any instructions and questions. This distribution yielded 16 questionnaires.

A similar process was followed at the Stakeholder Meeting on December 3, 2004. Because it was not possible to give a presentation at this meeting, stakeholders were contacted on an individual basis and asked to complete the questionnaire. Spanish speakers were available to translate instructions and answer questions for Spanish-speaking stakeholders. Thirty respondents completed questionnaires at this meeting, making the total sample size 75.

3.2.3 Generation of Weights

Once the testing phase was completed, results were translated into weights using the Analytic Hierarchy Process (AHP), explained below (Saaty, 1980). This approach requires that each decision maker complete a series of pairwise comparisons between the factors at each level in the hierarchy (Saaty, 1980). Each comparison is a two-part question determining 1) which criterion is more important and 2) how much more important. For this study, respondents completed ten pairwise comparisons that were translated into numerical values using the scale shown in Figure 3.6.

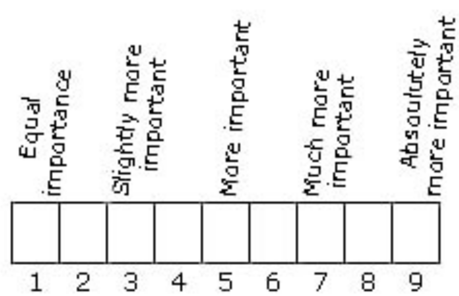


Figure 3.6. AHP scale.

To record these preferences, four comparison matrices could be generated for each respondent. These would represent preferences related to 1) environmental value, 2) recreational value, 3) economic value, and 4) overall value. For example, Figure 3.7 illustrates one stakeholder's preferences related to the environmental value of open space in the watershed. The numbers as translated from the questionnaire correlate to the degree of preference for one attribute over another. In this case, "Flood Control" was viewed as "Slightly more important" than "Vegetation" and was assigned a 3. In each case, the reciprocal value is automatically placed in the matrix to represent the reverse preference. The value of 1/3 in Figure 3.11 correlates to the reciprocal value of 3 and the importance of "Vegetation" over "Flood Control."

Environmental Value	**Vegetation**	**Flood control**	**Water quality**
Vegetation	1	1/3	1/8
Flood control	3	1	1/5
Water quality	8	5	1

Figure 3.7. Sample AHP matrix.

To calculate the weights from these matrices, each matrix is multiplied by its eigenvector which corresponds to the largest eigenvalue of the matrix. This standardizes the values into a ratio scale so that all components sum to one (Saaty, 2000). Using the eigenvalue technique with a sample size of 75, 300 matrices would need to be generated and converted. Because these calculations are time-intensive, a computer program was used to assist in the process. In a 2002 study that used AHP methodology to incorporate stakeholder input, the computer software, Expert Choice, was used to calculate criterion weights (Soma, 2003). An equivalent computer application, Criterium Decision Plus 3.0, was used to calculate the weights in this study (see Figure 3.8). Once the weights were calculated for each respondent, they were summed and averaged to determine the overall weights to be used in the suitability analysis (see Table 3.6).

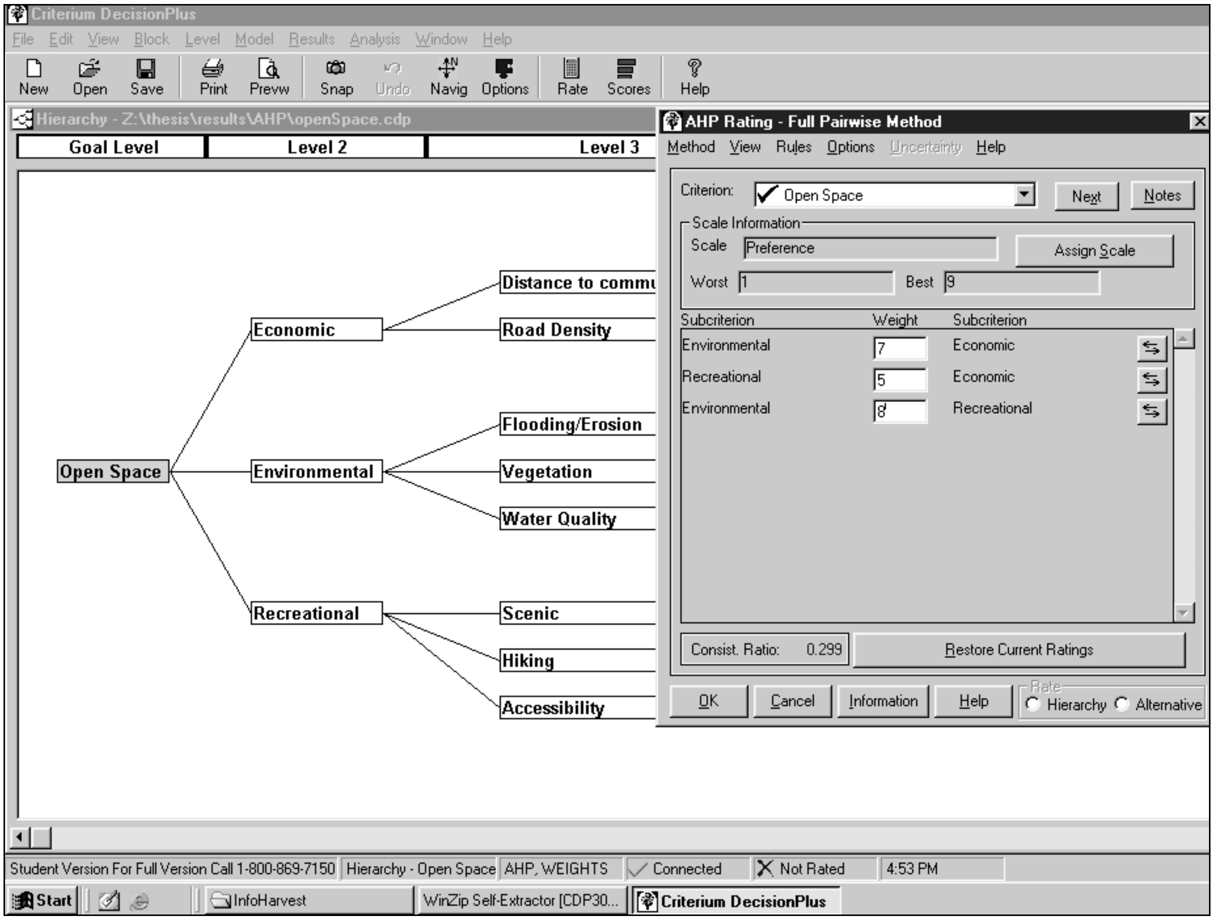


Figure 3.8. Criterium DecisionPlus 3.0.

Table 3.6. Model Weights Derived From Questionnaires

Factor	Weight
Environmental (2)	0.616
Economic (2)	0.174
Recreational (2)	0.210
Vegetation (3)	0.357
Water quality (3)	0.430
Flood control (3)	0.213
Distance to communities (3)	0.496
Existing infrastructure (3)	0.504
Scenic amenity (3)	0.438
Hiking accessibility (3)	0.313
Distance from roads (3)	0.249

(2) and (3) indicate the level in the hierarchy (see Figure 3.2)

3.3 Modeling Procedure

After the input raster maps were created and the weights were generated, ArcGIS 9 ModelBuilder was used to create the suitability model. A sub-model was created for each level two factor (environmental, economic, and recreational) and the output from each of these three sub-models was used as input for the final open space model. Breaking the model down in this manner improved overall efficiency and made the process of incorporating the weights simpler. Some post-processing was done on the final output and a sensitivity analysis was conducted to assess the stability of the selected weights.

3.3.1 Sub-Models

A flow chart, created in ModelBuilder, is provided for each of the sub-models, illustrating the necessary steps in the modeling process. Figure 3.9 depicts the environmental sub-model and Figure 3.10 shows the resulting grid surface. The economic and recreational sub-models are shown with their outputs as well (see Figures 3.11 - 3.14). All input datasets, both raster and vector, are shown as dark blue ovals. The yellow boxes are processes implemented as tools in ArcGIS and any datasets resulting from these processes are shown as green ovals. The lighter blue ovals represent variables used as inputs to processes in the models. In each of these models, the variables are weights used in the weighted overlay. Objects with the letter *P* next to them are model parameters and can be changed by the user. This allows the model to be run with different weights and datasets. Figure 3.15 provides a flow chart of the final model that integrating the three sub-models.

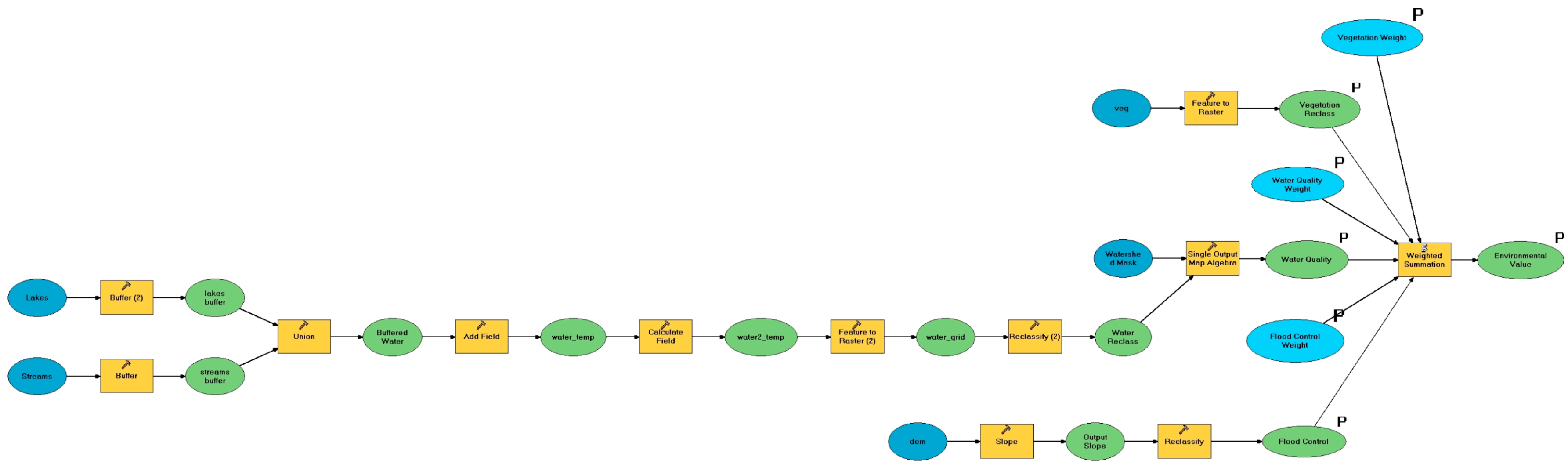


Figure 3.9. Environmental sub-model.

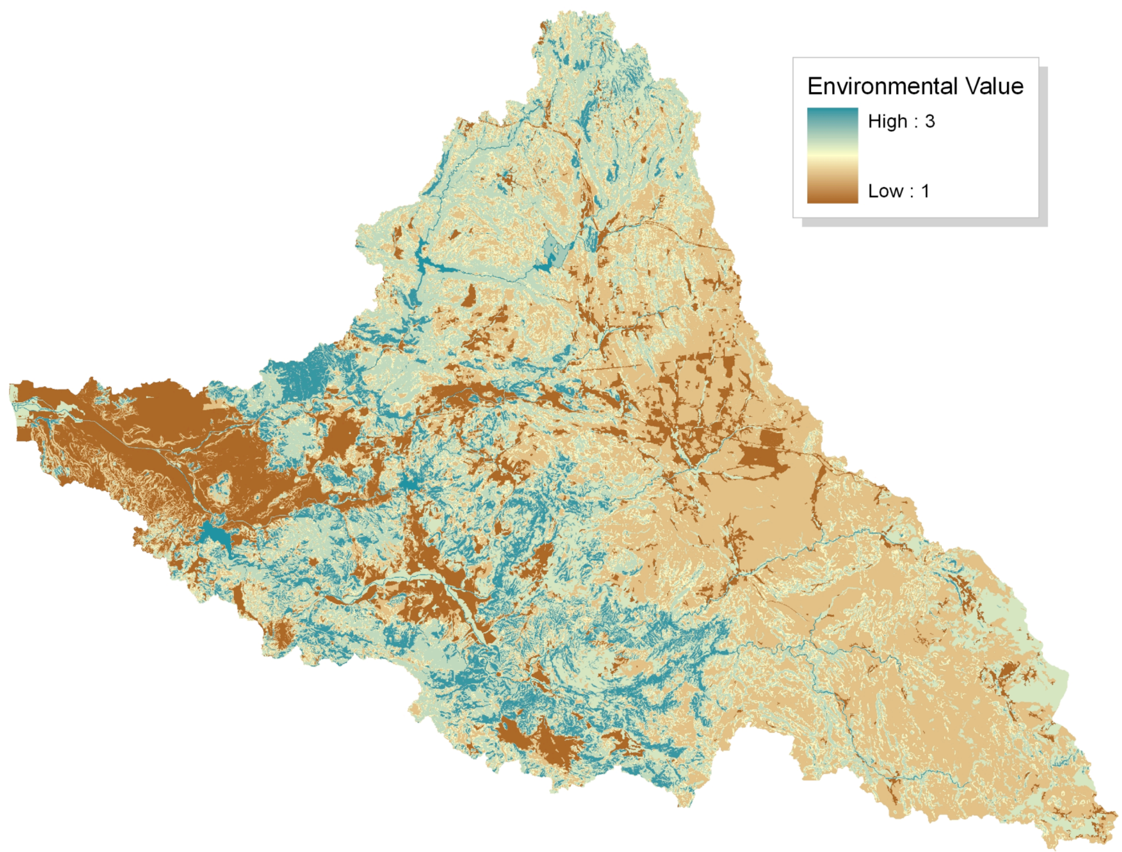


Figure 3.10. Environmental value grid.

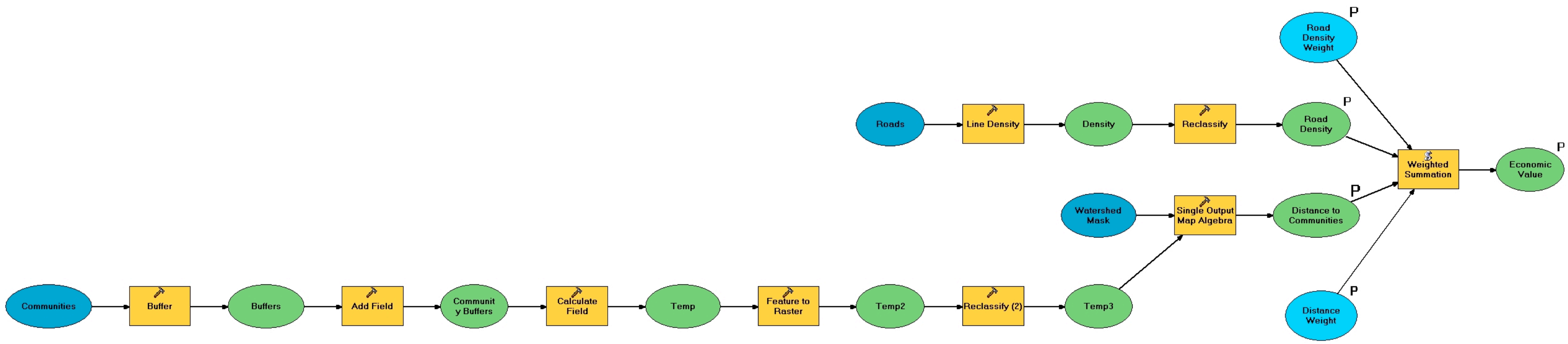


Figure 3.11. Economic sub-model.

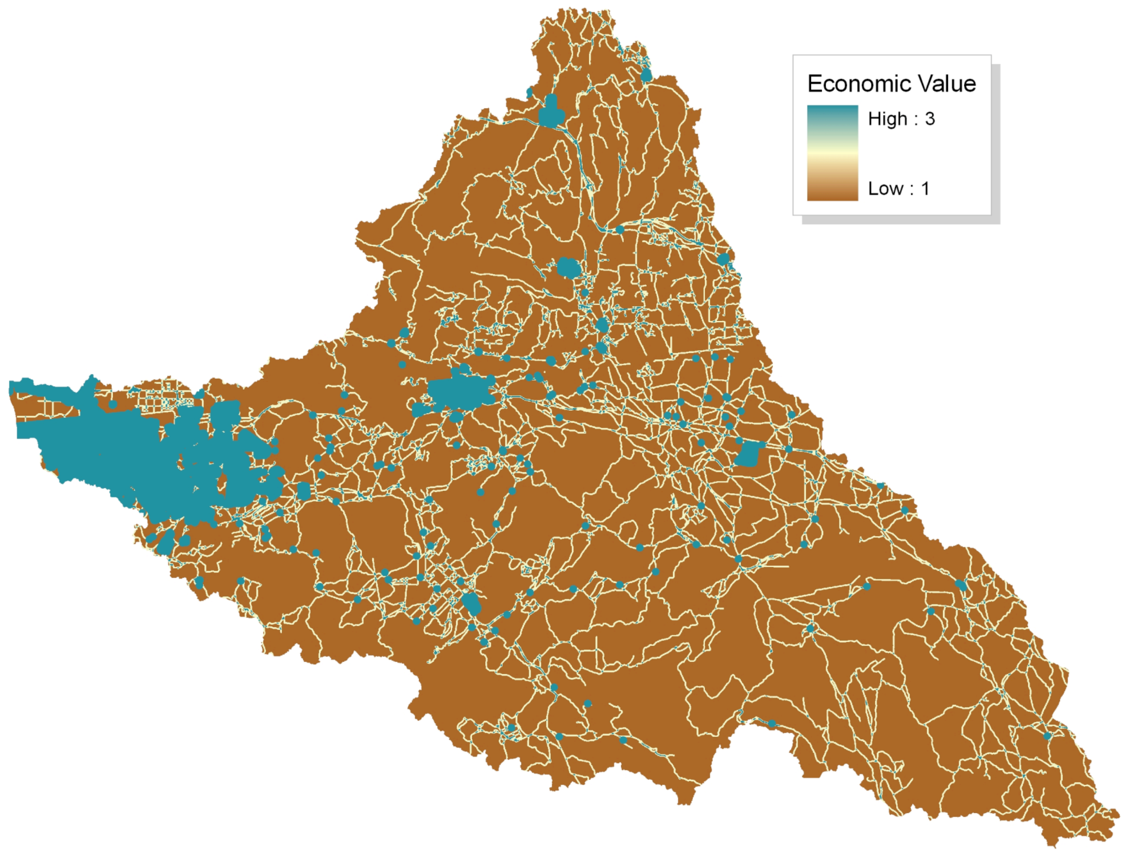


Figure 3.12. Economic value grid.

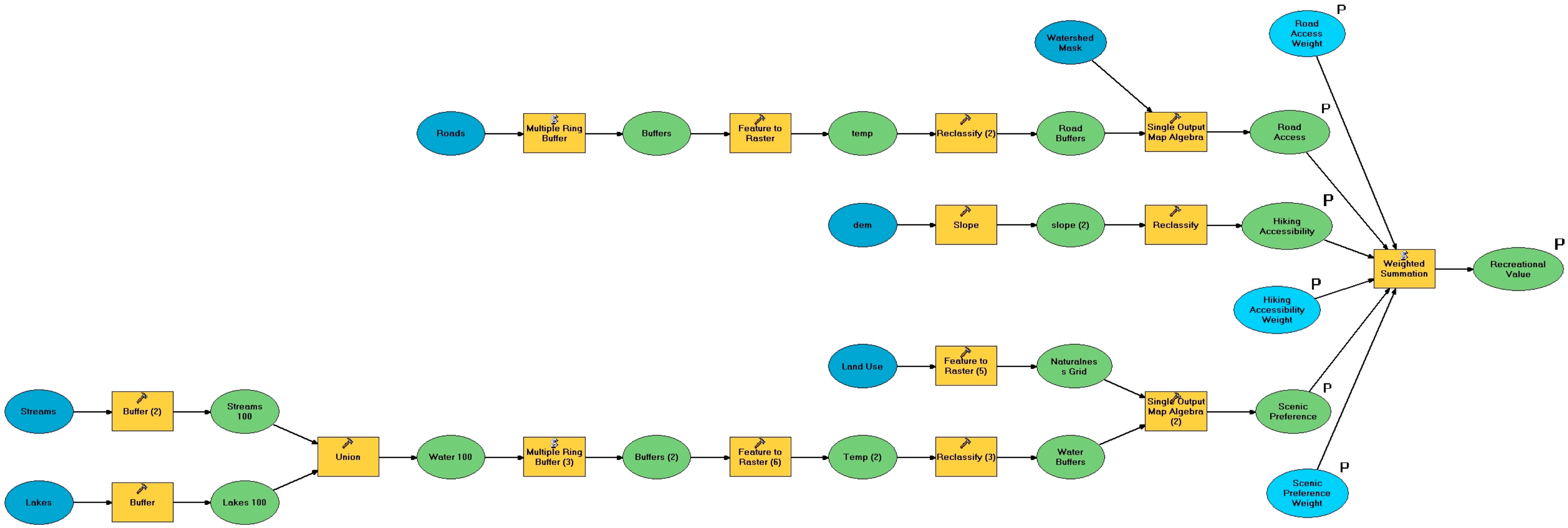


Figure 3.13. Recreational sub-model.

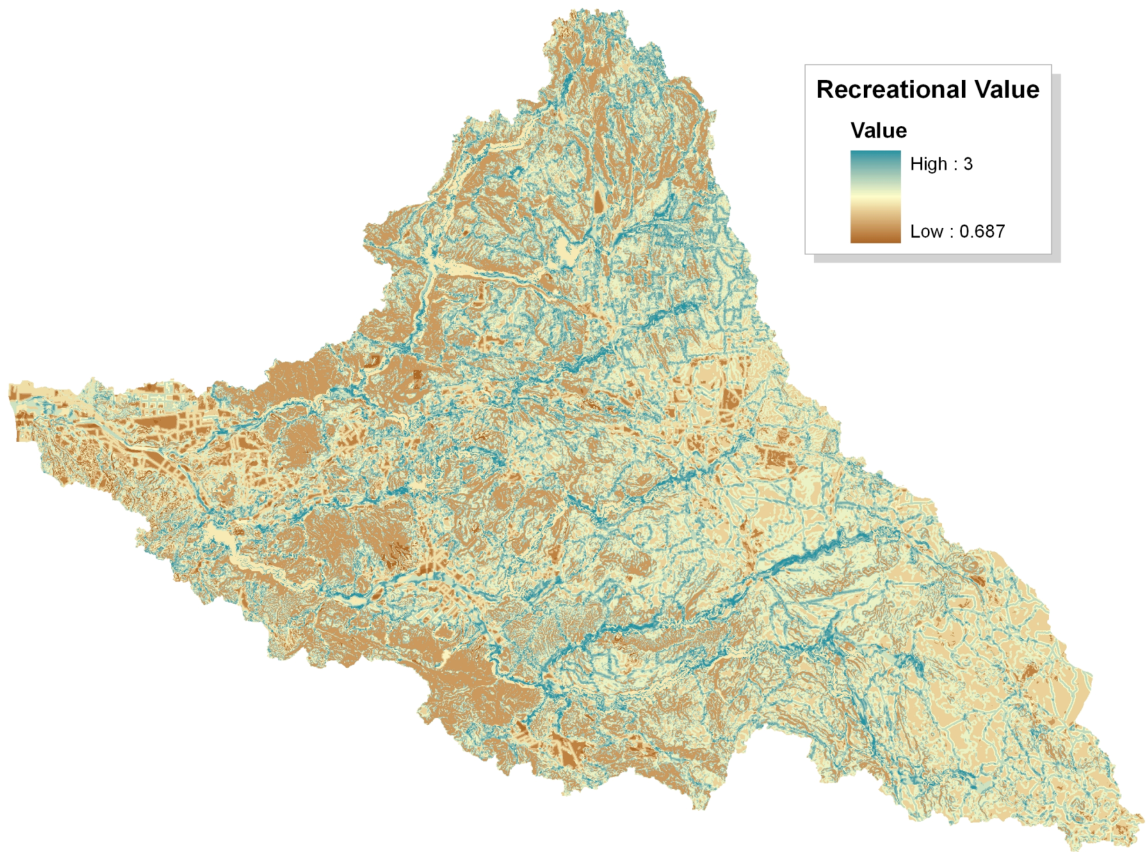


Figure 3.14. Recreational value grid.

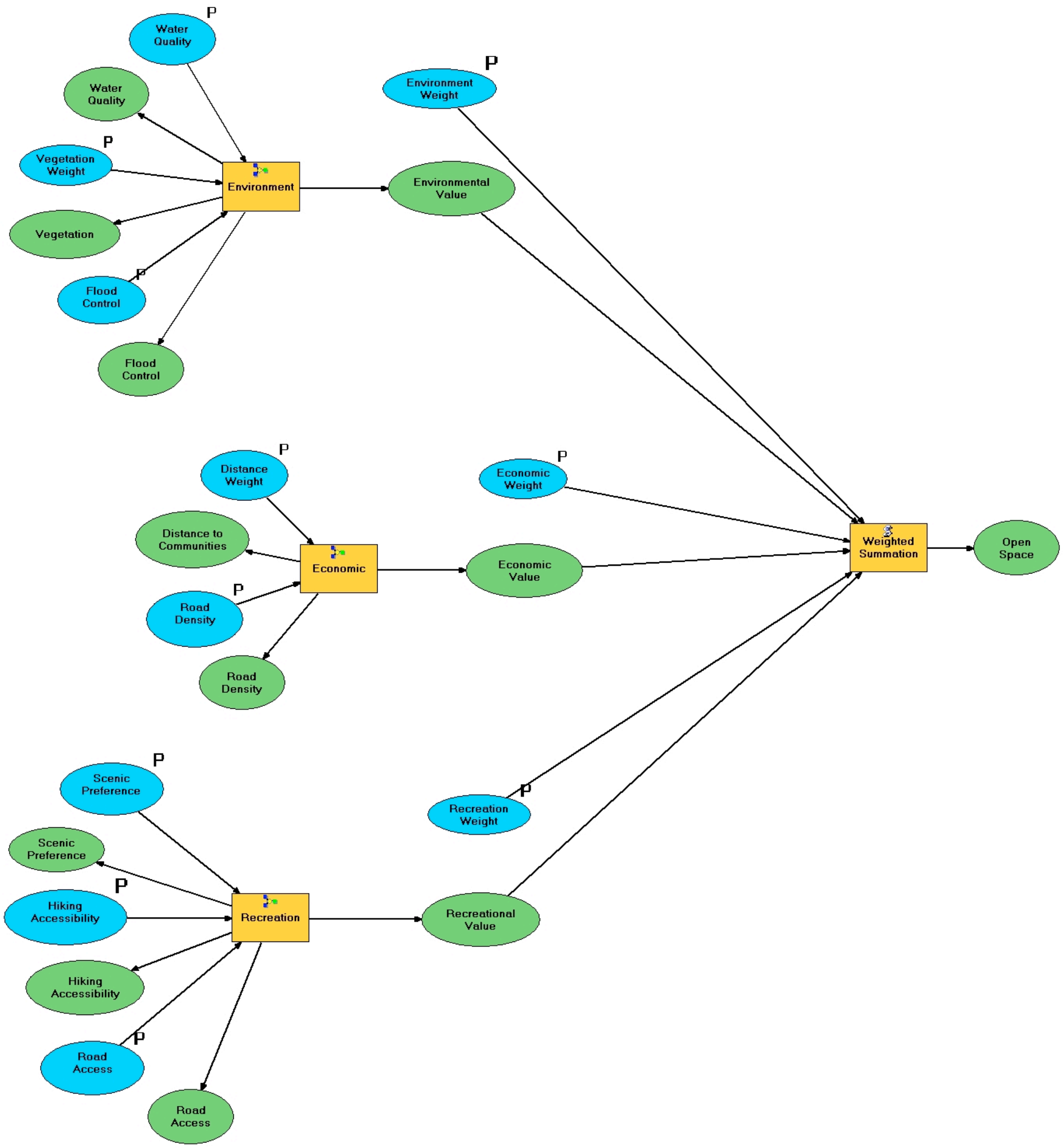


Figure 3.15. Open space model.

3.3.2 Sensitivity Analysis

A sensitivity analysis was conducted on the model to assess the stability of the selected weights. At level two in the hierarchy, each weight (environment, recreation, and economic) was varied with a 20% increase and decrease while the other two weights were adjusted equally to keep the total at 1.0 (see Table 3.5). For example, to increase the environment weight by 20%, an additional 0.1232 was added to the original weight of 0.6160. To keep the total of the weights at 1.0 before running the model, the economic and recreation weights were each decreased by .0616 (half of 0.1232).

To determine the effects of these different sets of weights, a count was conducted to record the number of high, medium, and low cells each time the model was run. Because each set of output needed to be categorized, the classification scheme used for the original set of weights was employed. Because the breaks were the same, it was easy to see how the values of the cells changed for each run of the model.

When examining the counts for the “high” cells, it appears that the environmental weight was the most sensitive to change. A difference of 454,217 cells was observed between the lowest and highest weights. The economic factor was similarly sensitive and revealed a change of 416,987 cells. However, fluctuations in the recreational weight caused relatively little change among the “high” cells (36,367 cells). Upon closer examination, the “low” and “medium” counts were also stable.

All of the factors at level three in the hierarchy were also examined and the results can be found in Appendix E. Among the environmental factors, vegetation appeared to be the most sensitive and water quality the least sensitive. The economic factors were relatively stable and among the recreational factors, scenic quality showed the most change.

3.3.3 Post-Processing

Running the model resulted in a raster containing values ranging from 0.934270 to 2.868792. The natural breaks classification method was used to reclassify the raster values into three categories of low, medium, and high (see Figure 3.16). Because this technique emphasizes natural groupings that already exist in the data by minimizing variation within classes and maximizing variation between classes, it is ideal for displaying the results from this model (Plumb, 1988, Slocum et al., 2005).

Table 3.5. Level Two Sensitivity Analysis Results

	Original Weights	Environment + 20%	Environment - 20%	Economic + 20%	Economic - 20%	Recreation + 20%	Recreation - 20%
Environment	0.6160	0.7392	0.4928	0.5986	0.6334	0.5950	0.6370
Economic	0.1740	0.1124	0.2356	0.2088	0.1392	0.1530	0.1950
Recreation	0.2100	0.1484	0.2716	0.2542	0.2274	0.2520	0.1680
COUNTS							
Low	1854610	1840063	2365361	905613	1788040	1731646	1875641
Medium	2126736	1969253	1898142	2658746	2119474	2221582	2113954
High	961656	1133686	679499	1378643	1035488	989774	953407

Counts based on classification derived from original weights:

Low	0 - 1.340841
Medium	1.340842 - 1.578346
High	1.578347 - 3

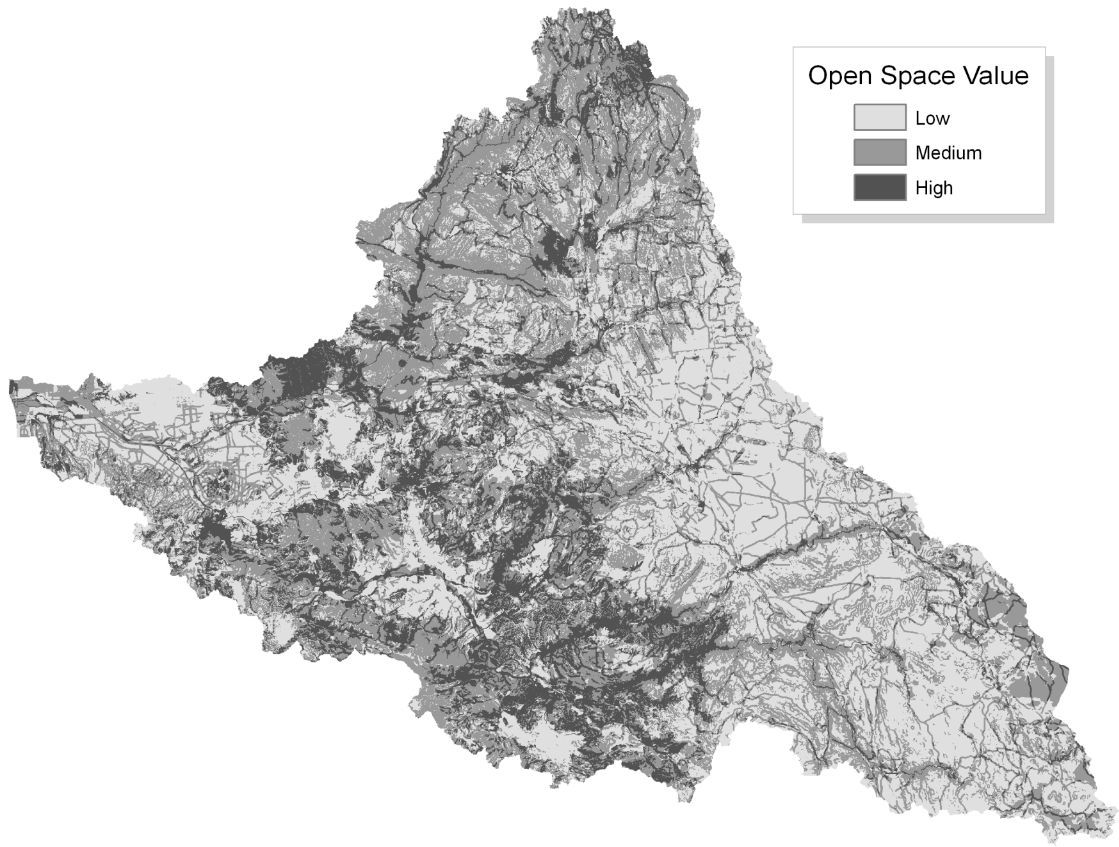


Figure 3.16. Classified model output.

This model was run with 30-meter resolution data and the final classified output contained many isolated cells and groupings of cells too small for analysis. While it is difficult to identify a size threshold, much of the existing literature emphasizes the importance of size as a factor because larger preservation areas are less vulnerable and more valuable for conservation (Smith and Theberge, 1986; Noss, 1987). In Noss's 1987 study, "Protecting Natural Areas in Fragmented Landscapes," areas up to a few thousand acres are considered small to moderately sized (Noss, 1987). For this study, areas less than 25 acres were dissolved into larger regions so that the results would illustrate a more generalized picture of open space in the watershed. Map generalization techniques are often used in post-processing to clean up raster data and remove unnecessary detail. To remove these isolated cells in this output, several ArcGIS generalization tools were used.

Initially, the Majority Filter was used to remove the smallest groups of isolated cells. This filter utilizes a function to replace the value of a cell based on the values of its neighboring cells. For example, in Figure 3.17, values of isolated cells were replaced. The cell containing -3 was replaced with 7 because four of its five neighbors contained this value. However, if the neighboring cells are varied and there is not a consistent value held by either half of the cells or a majority of the cells, the cell will remain untouched. This filter was used with a replacement threshold of MAJORITY, indicating that a majority of the neighboring cells must contain the same value for replacement to occur. It was also run with FOUR as the number of neighbors meaning that the four immediate neighboring cells were considered. The Majority Filter was run five times until the grid was stabilized and no further changes could be made. To further smooth the boundaries between the three classes and create more usable regions, the Boundary Clean function was utilized. This tool expands and shrinks the boundaries of zones so that any group of less than three horizontally or vertically contiguous cells will be taken into a larger zone. In this function, cells of a larger value have higher priority. In this model, this will give priority to open space areas of high value causing them to take in smaller groups of cells, creating a slightly less fragmented surface.

Because a region of 25 acres will contain approximately 112 cells (30 meter resolution), further generalization was needed to remove areas of 25 acres or less. The Region Group function was applied to the grid resulting from the Boundary Clean. This tool will identify any contiguous set of cells (using all eight cells as neighbors) as its own region

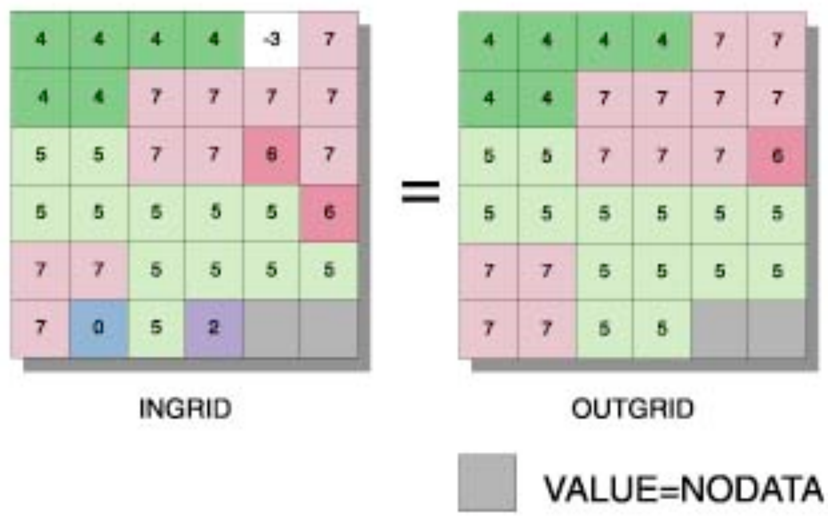


Figure 3.17. Majority filter example. Source: Environmental Systems Research Institute, Redlands, CA.

with a unique identifying number. The Extract by Attributes tool was then used to select regions containing 112 or fewer cells.

The Nibble function takes two grids as inputs: an input raster and an input raster mask. Any cells identified in the mask are replaced in the input raster with values of their nearest neighbors. The cells resulting from the previous Extract by Attributes were used as the input raster mask and were nibbled from the grid resulting from the Region Group function. This grid was then reclassified to replace all regions with values of high, medium, or low from the original classification. Figure 3.18 shows the final output grid after all post-processing.

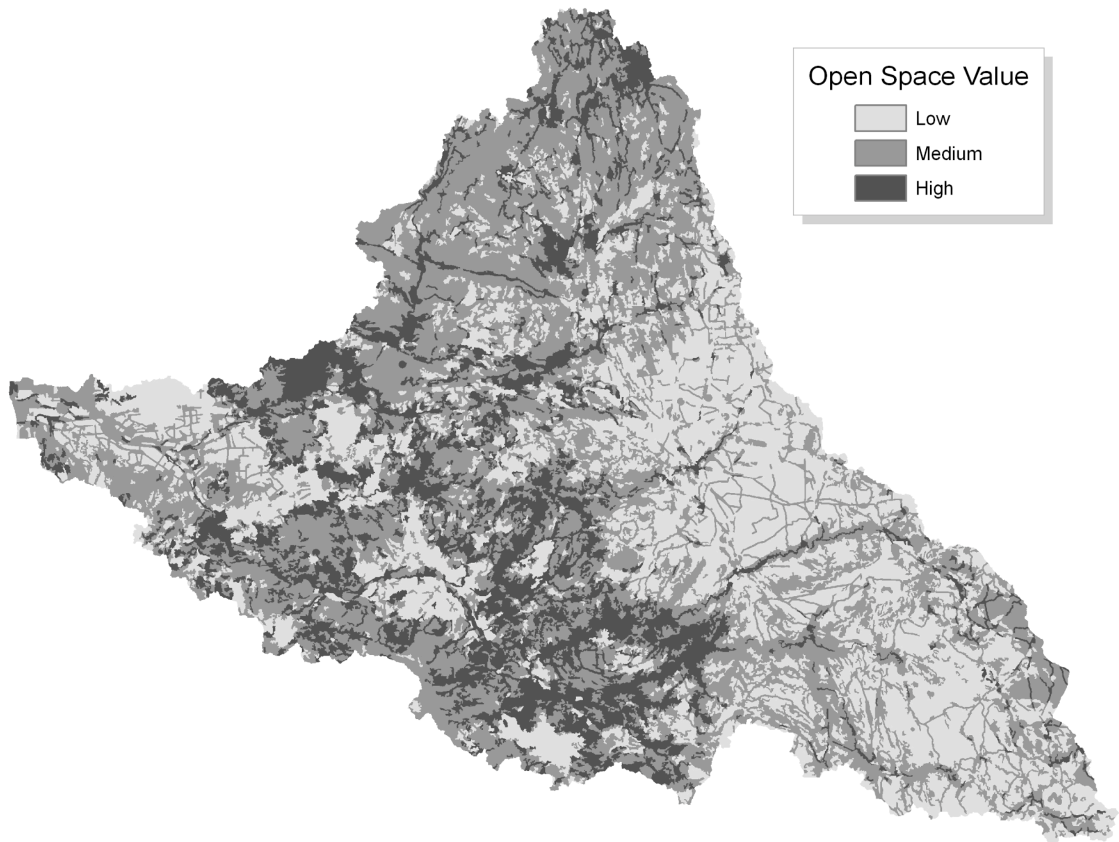


Figure 3.18. Cleaned model output.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter begins by presenting the results of the questionnaires broken down by stakeholder sub-group. The next section includes a description of the areas resulting from the application of the open space suitability model, followed by a comparison of these areas with those highlighted in the Las Californias Report.

4.1 QUESTION ONE

Based on a survey of Tijuana River Watershed stakeholders, what are the emerging concerns and priorities related to open space preservation?

To answer question one, results were complied from 75 questionnaires completed by stakeholders. The responses to these questionnaires were recorded and average values were calculated for the entire sample, as well as for various sub-groups of respondents (e.g., U.S. residents and Mexican residents). The Difference of Means *t*-test was used to determine if the variance between the groups was statistically significant. As a part of the AHP process, consistency ratios were calculated for all responses and averaged to indicate an overall consistency level.

4.1.1 Data Processing

Table 4.1 shows the average priority weights for the factors at the second and third levels in the hierarchy. The weights are shown for the entire sample, as well as for different groups of stakeholders. The first column shows the weights averaged for the entire sample of 75 respondents. These were the weights employed in the model for this study. Each of the following columns depicts the weights for the same factors, but based on an average for a specific group of stakeholders. For example, U.S. residents placed a weight of 0.603 on the environment factor, compared to a weight of 0.616 for the entire sample. A sample size of *n* is given for each sub-group to indicate the portion of the sample represented. Not all respondents provided answers to the demographic questions and were excluded from the sub-groups as necessary. Fourteen respondents did not indicate a place of residence and were

Table 4.1. Factor Priorities by Stakeholder Sub-Group

Factor	Complete Sample (n=75)	U.S. Residents (n=26)	Mexican Residents (n=35)	Academic Community (n=16)	Government Officials (n=28)	Non-Governmental Organizations (n=10)
(2) Environment	0.616	0.603	0.612	0.605	0.632	0.587
(3) Vegetation	0.357	0.367	0.353	0.398	0.402	0.319
(3) Water quality	0.430	0.445	0.389	0.410	0.378	0.416
(3) Flood control	0.214	0.189	0.258	0.192	0.220	0.265
(2) Economic	0.174	0.203	0.178	0.181	0.178	0.187
(3) Distance to communities	0.496	0.497	0.464	0.510	0.514	0.270
(3) Existing infrastructure	0.504	0.503	0.536	0.490	0.486	0.730
(2) Recreation	0.209	0.194	0.211	0.214	0.190	0.226
(3) Scenic value	0.438	0.474	0.420	0.472	0.450	0.444
(3) Hiking accessibility	0.313	0.301	0.298	0.312	0.262	0.390
(3) Distance from roads	0.249	0.225	0.281	0.216	0.288	0.166

(2) and (3) indicate the level in the hierarchy (see Figure 3.2)

removed from the U.S. and Mexican resident categories. Of the 75 questionnaires, 21 did not contain a classifiable occupation, either because the respondent left the question blank or the response did not fit into one of the three major categories.

The overall weights used in the suitability model appear to provide an acceptable representation of the interests of the different groups of stakeholders, as there are no major differences that can be observed between the preferences of the sub-groups compared with the entire sample. Only minor distinctions have surfaced and will be discussed in the following sections.

4.1.2 Results by Country of Residence

Of the three factors in level two of the hierarchy (environment, economic, and recreation), environment was clearly the highest priority among all stakeholders. This emphasis on environmental value was not surprising because of the high level of environmental awareness among stakeholders, particularly among those attending the watershed meetings. A report published in 1995 asked Tijuana River Watershed workshop participants to identify the most important planning and educational issues in the region. Some of the most frequently mentioned issues were flood management, water availability and water quality (Wright et al., 1995). Clearly, this awareness of and concern for environmental issues is still prevalent, at least among the groups sampled.

When looking at each of these environmental factors, a similar pattern was observed. Both the U.S. and Mexican sub-groups demonstrated preferences very similar to those of the overall sample. Both groups considered water quality to be the most valuable environmental factor. Many of the concerns expressed by stakeholders on either side of the border deal with available drinking water and related contamination issues. One stakeholder commented that, "before thinking of economic value, one should first understand the problems related to vegetation, fauna, and above all, water." Other stakeholders mentioned the immediacy of water issues in the region and the need to educate residents about water conservation. Next to water quality, vegetation was the most important environmental factor among these two groups. Both the U.S. and Mexican sub-groups agreed that the importance of conserving vegetation species in the watershed surpassed the importance of flood control.

U.S. and Mexican stakeholders differed in their valuation of economic versus recreational factors. Mexican residents agreed with the overall sample and ranked recreational factors slightly higher than economic factors, whereas the opposite was true for U.S. residents. These differences, however, were not statistically significant. Table 4.2 shows the results of a Difference of Means *t*-Test for the U.S. and Mexican weightings of all factors. Differences in weights for economic factors were significant only at the level of 0.173 and recreation factors at 0.487. None of the differences between U.S. and Mexican stakeholders can be considered statistically significant (p=0.05).

Table 4.2. Difference of Means *t*-Test for U. S. and Mexican Respondents.

Factor	*t* - value	DF	p-value (2-tailed test)
(2) Environment	-0.442	72	0.660
(3) Vegetation	0.241	57	0.810
(3) Water quality	1.031	57	0.307
(3) Flood control	-1.620	57	0.111
(2) Economic	1.377	72	0.173
(3) Distance to communities	0.399	57	0.691
(3) Existing infrastructure	-0.399	57	0.691
(2) Recreation	-0.699	72	0.487
(3) Scenic value	0.879	57	0.383
(3) Hiking accessibility	0.057	57	0.955
(3) Distance from roads	-1.020	57	0.312

(2) and (3) indicate the level in the hierarchy (see Figure 3.2)

Within the category of economic factors, U.S. and Mexican residents' values followed the overall trends and weighted "existing infrastructure" slightly better than "distance to communities." However, the weights between these factors were very close (not more than 0.072). Either stakeholders do not feel strongly regarding one factor over another, or they did not have a complete understanding of these factors and therefore, ranked them as equally important. While stakeholders indicated very little difference in preference between economic factors, the recreational factors revealed a distinct trend. Both sets of residents agreed with the overall sample in their ranking of "scenic value" as the most important recreational factor, followed by "hiking accessibility," and then, "distance from roads."

4.1.3 Results by Occupation

Like the U.S. and Mexican sub-groups, the occupational sub-groups showed only minor deviations from the overall weights. All of the weights for the factors at level two in the hierarchy were very similar among the sub-groups and followed the overall pattern, indicating environment as significantly most important. Within the level three factors, some differences can be noted.

The stakeholders working for non-governmental organizations (NGO's) were the only sub-group that specified the same rank ordering as the overall sample for the environmental factors with "water quality" being most important, followed by "vegetation conservation," and then "flood control." Those working in academic institutions or governmental agencies indicated that "vegetation conservation" was the most important factor, followed by "water quality" and "flood control."

While the NGO stakeholders' preferences aligned with the overall sample for the level two factors, their weighting of economic factors deviated greatly. The other sub-groups ranked the two economic factors very close to each other (around 0.5 for each), yet the NGO sub-group believed the "existing infrastructure" factor to be substantially more important than the "distance to communities" factor (0.730 compared to 0.270). Table 4.3 displays the results of a Difference of Means *t*-Test for the weights among these sub-groups, and the differences among the economic weights prove to be statistically significant. Between the government and NGO employees the differences are significant at the 0.051 level and at the 0.049 level between the academics and NGO employees. One possible explanation might be that stakeholders working for an NGO are more concerned with the cost of potential preservation projects because they are working on tighter budgets than government employees and academics. The size of the NGO sub-group was also smaller than the other two sub-groups and additional surveys could potentially present a more accurate depiction of this group's preferences.

Among the recreational factors, all sub-groups' preferences aligned with the complete sample except for one small difference. Government officials ranked "distance from roads" as slightly more important than "hiking accessibility," whereas the other sub-groups preferred the opposite. Overall, the difference in weights between these two factors was not large. For the NGO sub-group, there was a variance of 0.224, which was the largest among

Table 4.3. Difference of Means *t*-Test for Occupational Sub-Groups.

	Academic-Government			Government-NGO			Academic-NGO		
Factor	***t* - value**	**DF**	**p-value (2-tailed test)**	***t* - value**	**DF**	**p-value (2-tailed test)**	***t* - value**	**DF**	**p-value (2-tailed test)**
(2) Environment									
(3) Vegetation	-0.061	41	0.952	0.995	34	0.327	0.896	23	0.380
(3) Water quality	0.521	41	0.605	-0.514	34	0.610	-0.077	23	0.939
(3) Flood control	-0.575	41	0.568	-0.755	34	0.456	-1.116	23	0.276
(2) Economic									
(3) Distance to communities	**-0.041**	41	0.967	2.025	34	**0.051**	2.080	23	**0.049**
(3) Existing infrastructure	**0.041**	41	0.967	-2.025	34	**0.051**	-2.080	23	**0.049**
(2) Recreation									
(3) Scenic value	0.295	41	0.769	0.058	34	0.954	0.314	23	0.756
(3) Hiking accessibility	0.967	41	0.339	-2.446	34	**0.020**	-0.994	23	0.331
(3) Distance from roads	-1.059	41	0.296	1.445	34	0.157	0.784	23	0.441

(2) and (3) indicate the level in the hierarchy (see Figure 3.2)

all the sub-groups, indicating that these stakeholders felt most strongly about the "hiking accessibility" factor compared to the "distance from roads" factor.

4.1.4 Presentation Differences

As described in section 3.2.2, some stakeholders were provided with a presentation prior to completing the questionnaire and because of logistics, others were not. To determine if this inconsistency impacted the outcome of the questionnaires, results were separated for these two groups and examined (see Tables 4.4 and 4.5). There are some distinctions that can be made between the two sub-groups; however, both appear to follow the major trends represented by the average weights resulting from the overall sample and there are no statistically significant differences.

Among the level two factors, both sub-groups appeared to be in agreement with each other. Although both sub-groups ranked the "recreation" factor as more important than the "economic" factor however, the stakeholders that did not receive the presentation prior to completing a questionnaire placed even more emphasis on this difference. While the stakeholders receiving the presentation indicated a difference of only 0.004 between these two factors, the other sub-group weighted the "recreation" factor 0.054 higher than the "economic" factor. Although this difference is not statistically significant, one possible explanation might be that a respondent may be able to comprehend the idea of recreational value easily, whereas economic value may require a more detailed explanation for complete understanding. For example, a stakeholder may be readily familiar with recreational uses of open space land (e.g., hiking, camping, bicycling), but not accustomed to thinking about open space in terms of potential maintenance costs or increased revenues. Therefore, stakeholders that did not receive the presentation may have weighted the "recreation" factor more strongly because they had a better understanding of what it referred to.

When looking at the level three factors, there are some minor differences. Among the environmental factors, stakeholders that heard the presentation prioritized "vegetation" as only slightly more important than "water quality," yet stakeholders that did not hear the presentation felt the opposite and the difference between the weights was greater. Again this difference is not statistically significant, but it might be explained by the idea that respondents not hearing the presentation had an inherent notion of what benefits would result

Table 4.4. Factor Priorities Distinguished by Presentation

Factor	Received Presentation (n=29)	Did Not Receive Presentation (n=46)
(2) Environment	0.594	0.630
(3) Vegetation	0.403	0.331
(3) Water quality	0.394	0.450
(3) Flood control	0.203	0.219
(2) Economic	0.201	0.158
(3) Distance to communities	0.429	0.537
(3) Existing infrastructure	0.571	0.463
(2) Recreation	0.205	0.212
(3) Scenic value	0.418	0.450
(3) Hiking accessibility	0.319	0.309
(3) Distance from roads	0.263	0.241

(2) and (3) indicate the level in the hierarchy (see Figure 3.2)

Table 4.5. Difference of Means *t*-Test for Respondents Receiving a Presentation Prior to Completing a Questionnaire.

Factor	*t* - value	DF	p-value (2-tailed test)
(2) Environment	-0.802	72	0.425
(3) Vegetation	1.403	70	0.165
(3) Water quality	-1.086	70	0.281
(3) Flood control	-0.412	70	0.681
(2) Economic	1.342	72	0.184
(3) Distance to communities	-1.424	69	0.159
(3) Existing infrastructure	1.424	69	0.159
(2) Recreation	-0.186	72	0.853
(3) Scenic value	-0.570	71	0.571
(3) Hiking accessibility	0.207	71	0.837
(3) Distance from roads	0.440	71	0.661

(2) and (3) indicate the level in the hierarchy (see Figure 3.2)

from protecting and improving water quality, but were not as familiar with the benefits of conserving vegetation. Clearly, both sub-groups felt that these two factors were of greater importance than controlling floods in the region. At the time the questionnaire was distributed, the watershed had not recently experienced heavy precipitation. Because of this, stakeholders may not have been as immediately concerned about the flood control factor.

Both sets of stakeholders weighted the two economic factors close to “equal importance,” yet the importance of factors was reversed for the two sub-groups. Stakeholders that received the presentation found “existing infrastructure” to be more important and those not receiving the presentation found “distance to communities” to be more important. The underlying recreation factors were ranked the same by both sub-groups with very similar priority weights.

4.1.5 Inconsistency Ratios

The idea of inconsistency within the AHP framework refers to rankings made by respondents that are contradictory or inexact. For example, a consistent set of responses might weight a > b, b > c, and then a > c. Inconsistency could arise if instead, the respondent ranks a > b and b > c, and then ranks c > a. Logically, this is an inconsistent set of responses. The AHP methodology provides a means for measuring this inconsistency with a consistency ratio (CR). To determine the CR, a consistency index (CI) is calculated for a set of judgments and compared to a randomly index (RI). This ratio (CR) represents the departure of the actual judgments from a randomly generated set of weights (Saaty, 1980). According to Saaty, CR’s of 10% or less are acceptable because some element of inconsistency is necessary to inspire change and the rethinking of existing preferences and opinions (Saaty, 1980).

As each set of weights was generated in CriteriumDecision Plus, a CR was also calculated. These ratios were summed and averaged for all sets of weights. The results revealed a high level of inconsistency among the respondents’ judgments. Among the weights for the factors at level two in the hierarchy, an average CR of 27% was calculated. The environmental factors at level three generated a 40% CR and the recreational factors, 45%. The economic factors had a CR of 0% because only two factors were compared, making inconsistency impossible. These high levels of inconsistency may be a result of respondents’ lack of understanding regarding the factors or they may be due to a quick and cursory completion of the questionnaire. This problem could have been avoided by providing stakeholders with an interactive computer questionnaire in which they would be forced to rethink their responses until an acceptable level of consistency was met. However, this type of data collection was not feasible for this study, so inconsistency was accepted as an inherent limitation.

To determine the impact that this inconsistency might have on the resulting weights, all responses with CR's greater than 10% were removed from the sample and weights were calculated from the remaining responses. The new weights were then compared to the original weights and a measure of variance was calculated (see table 4.6). While this caused slight changes in the weights, none were significant. The variance between the original weights and those without the inconsistent responses was less than 0.100 in all cases. This can be explained by the way that Criterium DecisionPlus calculated weights in situations of high inconsistency. If a set of judgments were intransitive or inconsistent, the resulting weights were equal or close to equal to account for the lack of clear preferences. Therefore, these equal weightings had very little impact on the overall weights when the averages were calculated.

Table 4.6. Consistency of Weights

Factor	Original weights	Weights with inconsistent responses removed	Variance
Economic	0.182	0.174	0.008
Environment	0.626	0.616	0.010
Recreation	0.192	0.209	0.017
Vegetation	0.357	0.372	0.015
Flood control	0.214	0.219	0.005
Water quality	0.430	0.410	0.020
Scenic amenity	0.422	0.438	0.016
Distance to roads	0.192	0.249	0.057
Hiking accessibility	0.387	0.313	0.074

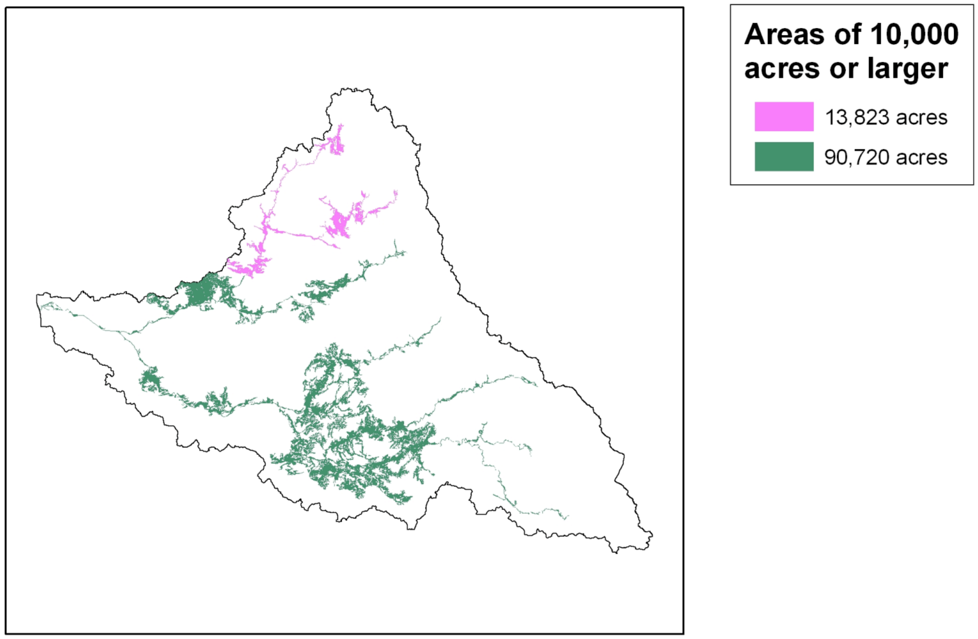
4.2 QUESTION TWO

What specific areas result from a raster-based suitability analysis designed to represent the priorities of Tijuana River Watershed stakeholders?

Because extracting specific areas or regions requires an underlying set of assumptions (e.g., size and shape), this question could potentially be answered in a variety of ways. To illustrate this, Figure 4.1 depicts two maps based on different size requirements. Both maps are based on data in vector format and during conversion, all contiguous sets of cells containing a value of high (3) were converted into polygons. In one map, a minimum size areas. Both of these maps provide valid results, but are based on the application of different assumptions. The selected classification method can also impact the final output. As previously discussed in Section 3.3.3, the natural breaks classification method was used in this study. However, other classification methods such as equal interval, standard deviation, or quantile could be employed. Because this study is intended to provide generalized results that can be constrained later to meet decision-makers' needs, no specific size or shape restrictions were imposed on the resulting maps. The natural breaks method was utilized and data were left in raster format (see Figure 3.18). The following discussion will explore some of the different areas that contain concentrations of cells with values of "high" and what implications might emerge.

4.2.1 Mount Laguna Area

One area that appeared to have a concentration of "high" cells is located in the northern portion of the watershed in the Mount Laguna area (see Figure 4.2). This area contains some of the highest elevations in the watershed (1,500 to 2,000 meters) and is mostly found in the Upper Cottonwood sub-basin. The general relief in this area mimics the hydrography, with many eroded valleys and steep slopes. This region also contains a large amount of high conservation priority vegetation, including Black Oak woodland, Jeffrey Pine forest, and mountain meadows. This area is part of the Cleveland National Forest and consists almost entirely of undeveloped lands with a few small regions set aside for recreational purposes. The Sunrise Highway and many arterial roads provide public access to this area and make it a popular spot for passive recreation. Figure 4.3 contains photographs of the forested areas in this region.



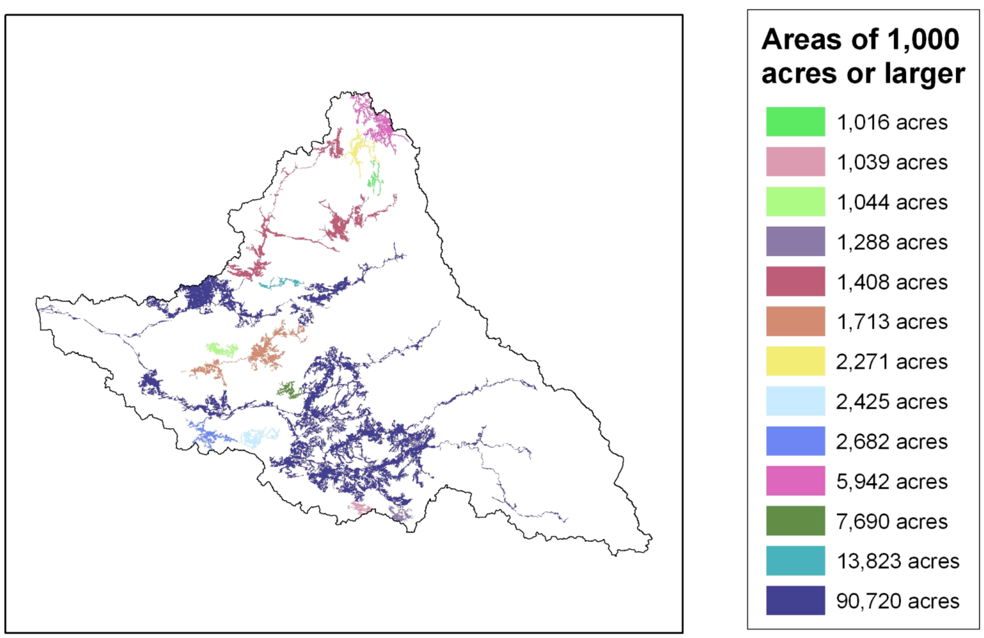


Figure 4.1. Potential size requirements.

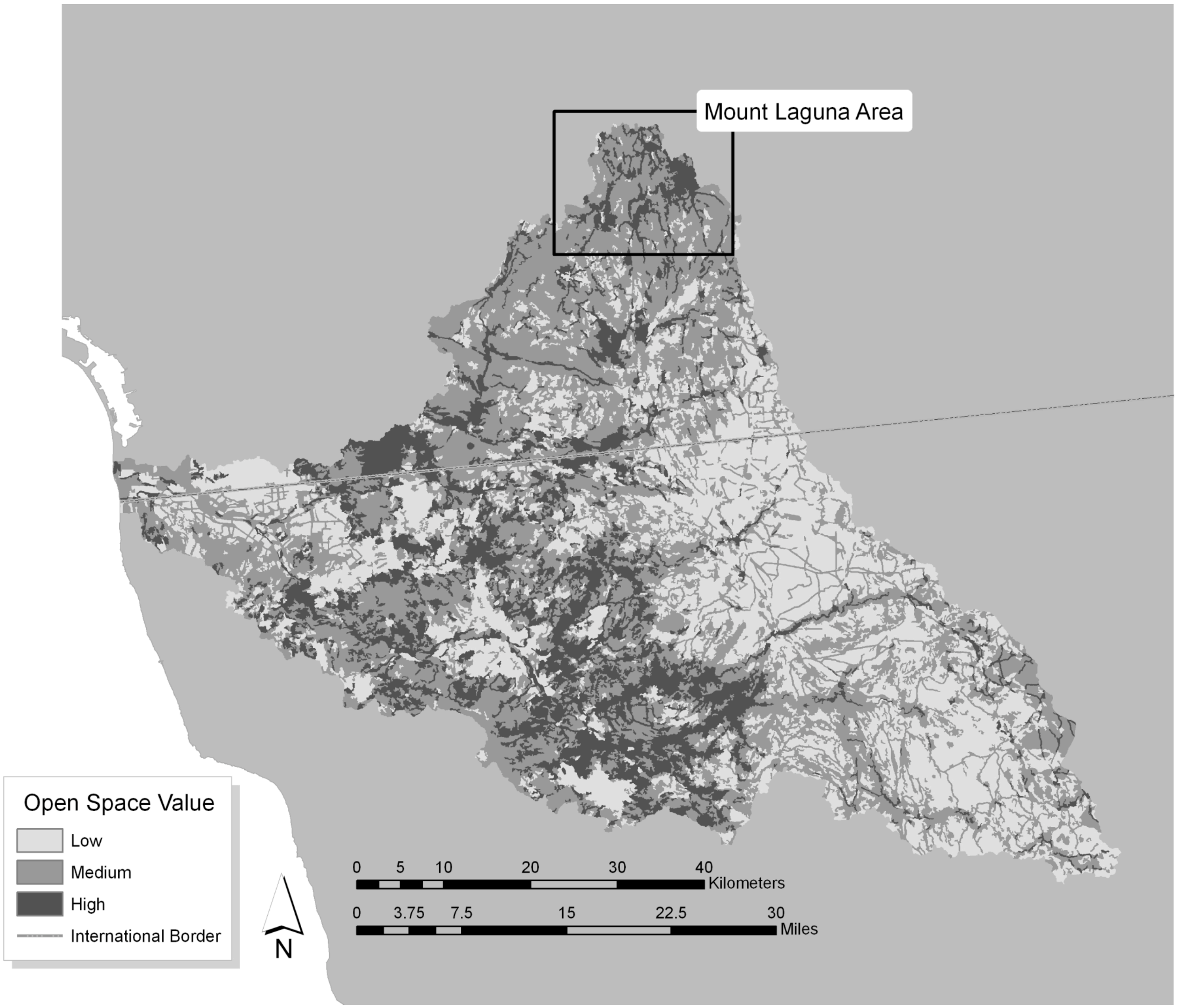


Figure 4.2. Mount Laguna area.

Figure 4.3. Photographs of the Mount Laguna area. Source: Paul Ganster.

4.2.2 South Central Zone

The central and southern portion of the watershed also contains a concentration of cells valued "high" (see Figure 4.4). This large and isolated area tends to follow the rivers and riparian vegetation in the region. The riparian zones along Arroyo La Ciénega and Arroyo Las Calabazas consist mainly of Riparian Scrub and Oak Riparian forest. The rest of the region is comprised mainly of Coastal Sage Scrub with a few patches of grassland. The overall elevation is significantly lower than the Mount Laguna area with values in the range of 500 meters to 1,000 meters. The terrain is varied with a range of gently sloping to very steep slopes and portions of four of the sub-basins can be found in this area. Figure 4.5 illustrates some of the natural areas in this region, as well as a Rancho Viejo, a privately owned ranch, that provides camping and recreational opportunities for tourists.

4.2.3 Otay Region

Figure 4.6 highlights a group of "high" cells located near the international border in the central portion of the watershed. This area contains some of the steepest slopes in the watershed (greater than 25%) and a great deal of relative relief. The Lower Cottonwood/Río Alamar sub-basin completely encompasses this area and some streams run through the region. The vegetation in this area consists almost entirely of Coastal Sage Scrub with some small patches of Southern Interior Cypress Forest. This area is completely undeveloped and has very limited road access. The Bureau of Land Management (BLM) designated this region a wilderness area in 1999, indicating that it is preserved under federal law (Bureau of Land Management, 2003), at least on the U.S. side of the border. Small portions of this area extend into Mexico and are not protected under federal law. Figure 4.7 includes two photographs taken in the Otay region of the watershed that depict the general character of the landscape in this area.

4.3 Question Three

How do areas resulting from this analysis compare to areas identified in the 2004 Las Californias Binational Conservation Initiative report?

To answer the third research question, a qualitative comparison was conducted between the results from this study and the Las Californias study. The methodological

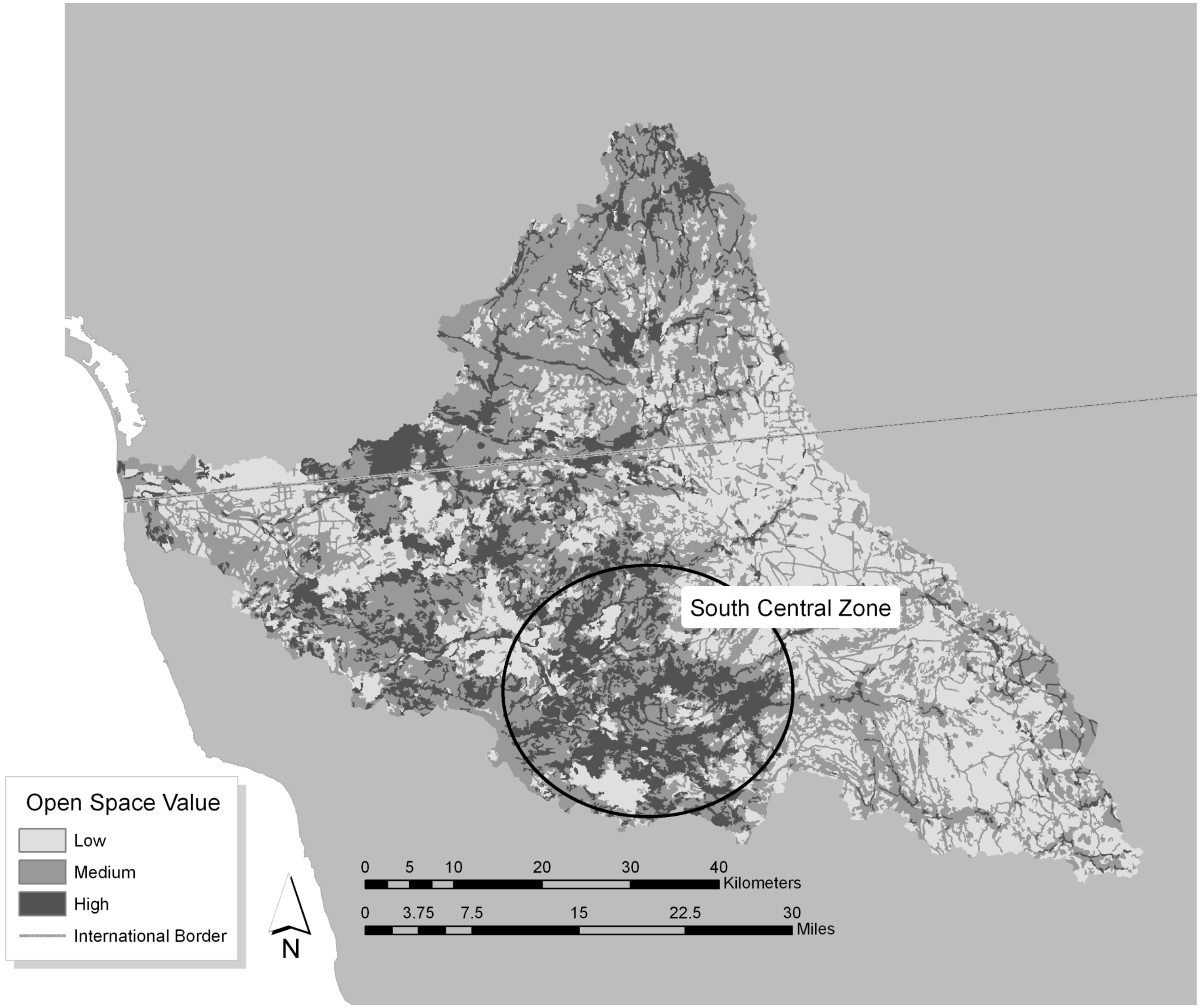


Figure 4.4. South central zone.

Figure 4.5. Photographs of the South central zone. Source: Paul Ganster.

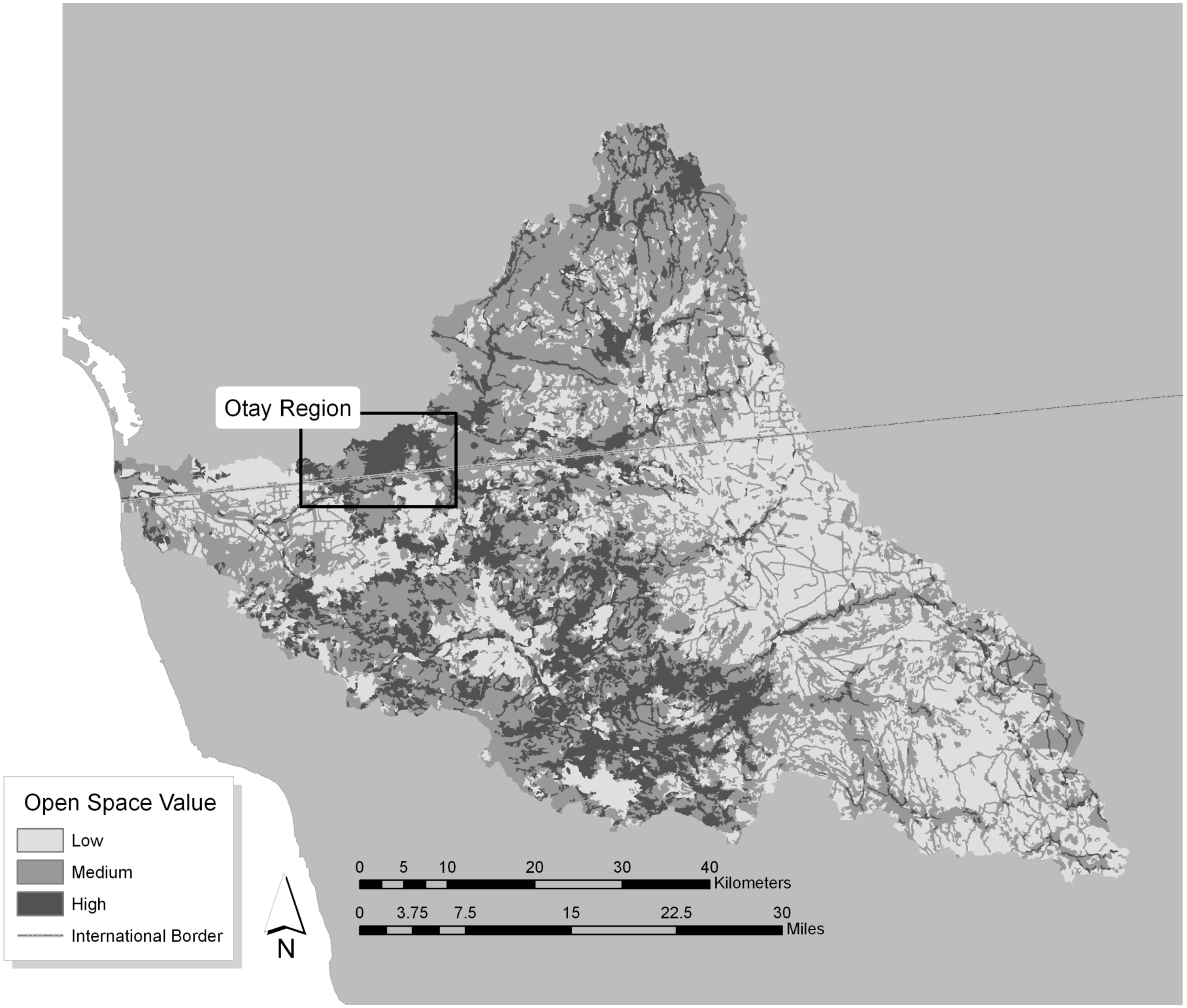


Figure 4.6. Otay region.

Figure 4.7. Photographs of the Otay region.

approach used in the Las Californias study was examined and compared, as well as the resulting conservation areas.

The Las Californias Binational Conservation Initiative is a partnership between three nonprofit conservation organizations: Pronatura (Mexico), The Nature Conservancy (U.S.), and the Conservation Biology Institute (U.S.). These groups partnered together to conduct studies on natural resources in the California-Baja California border region. In 2004, this work was published as “A Vision for Habitat Conservation in the Border Region of California and Baja California” (Pronatura et al., 2004). The San Diego State University Geography Department provided a portion of the database used in this project. The study area identified in the report completely encompasses the Tijuana River Watershed (see Figure 4.8) so targeted areas can be easily compared to resulting areas from this study.

A major component of the Las Californias report focuses on identifying biogeographically valuable areas that represent the diversity of the region. While this thesis research focuses on stakeholder values rather than specifically on ecological and biological systems, both studies attempt to identify the most valuable conservation areas in the region. Because of these similar goals, the Las Californias report is ideal for comparison with this study. Areas coincidental to both studies are highlighted in the following discussion and differing regions are further analyzed to determine their value to different groups.

4.3.1 Methodological Comparison

The methodology employed in the Las Californias study differs from the suitability modeling approach used in this research. While this thesis evaluated areas based on stakeholders’ assessments of environmental, economic, and recreational value using a GIS-based suitability analysis, the Las Californias study focused specifically on identifying areas that fit the following criteria using a technical approach (Pronatura et al., 2004):

a. Contain high ecosystem integrity,
b. Represent local diversity,
c. Contain irreplaceable resources, and
d. Can support human use

To identify areas meeting these criteria, the Spatial Portfolio Optimization Tool (SPOT) was used along with a GIS database containing both raster and vector datasets.

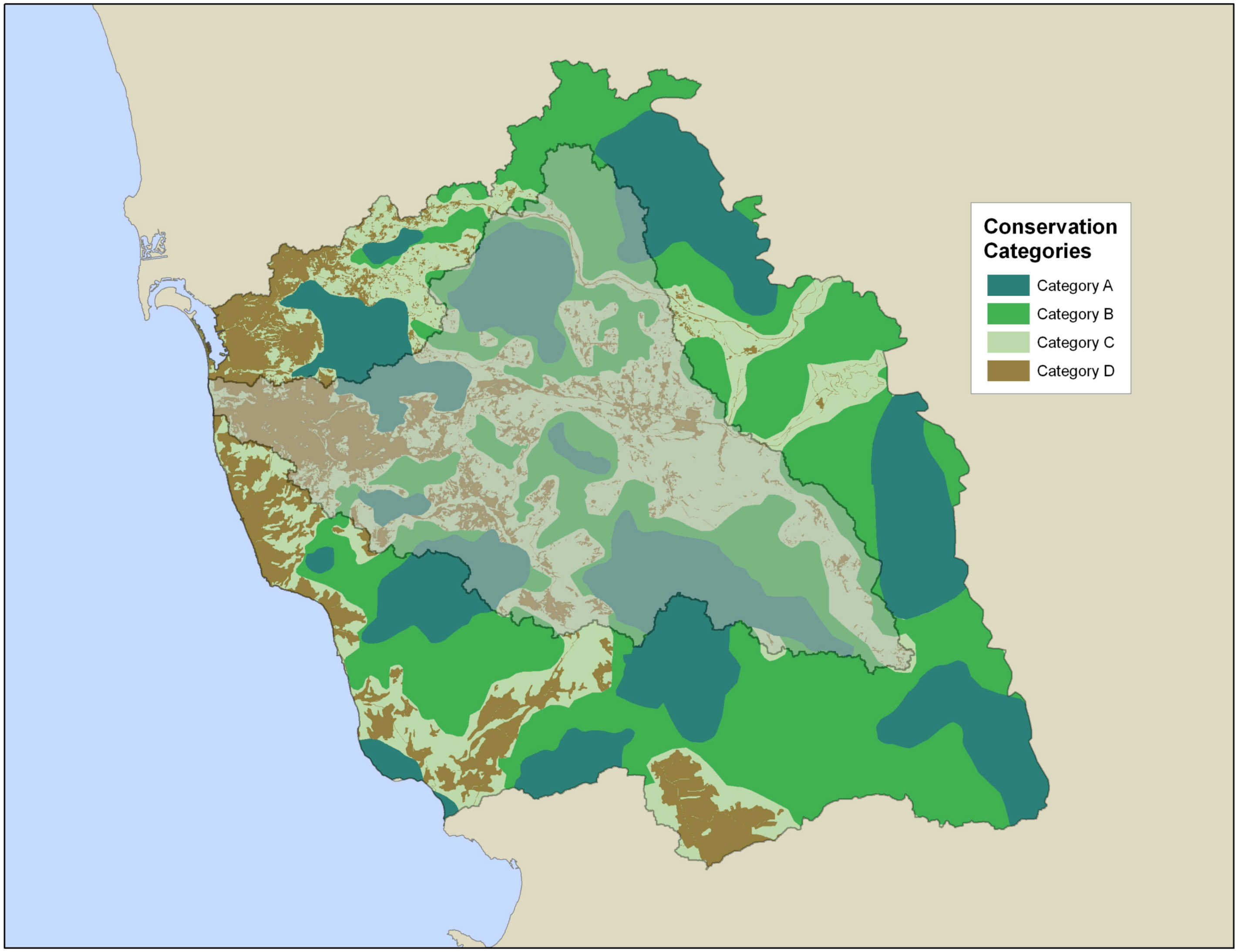


Figure 4.8. Las Californias results.

SPOT uses digital datasets as inputs to identify areas that best meet specified conservation goals. For the Las Californias study, these conservation goals were delineated as percentages of various vegetation communities. SPOT used a vegetation dataset, as well as a cost surface layer (representing areas most impacted by human modification), to identify conservation portfolios that met the conservation goals with minimum fragmentation and cost (Pronatura et al., 2004). Output from the SPOT model was then refined and categorized based on its ability to meet the above four criteria. The categorized output is shown in Figure 4.8. The output from the allocation of SPOT differs from the output in this study in how it has been classified. This thesis uses a high, medium, and low classification to indicate overall value to stakeholders, while the Las Californias study classifies areas based on what type of conservation approach should be implemented. However, comparisons can still be made based on the overall value assigned to different geographic regions throughout the watershed.

4.3.2 Geographical Comparison of Results

All of the regions discussed in Sections 4.2.1 to 4.2.4 have characteristics in common with areas highlighted in the Las Californias report. In the following section, each of the previously discussed areas will be compared with the biological resources and conservation objectives in the Las Californias report.

The Laguna Mountains region that emerged in this study was classified as Category A in the Las Californias report (see Figure 4.9). As described in the report, Category A areas are relatively large and contain intact habitat. Protecting these areas is crucial to maintaining \the biodiversity and natural processes that occur in the region (Pronatura et al., 2004). Stakeholders surveyed in this study appeared to appreciate this area because of both its environmental and recreational value. The Las Californias report described this area as home to the Peninsular bighorn sheep and as a transition zone between the montane and desert vegetation communities. Stakeholders also valued the conservation of vegetation in this region as mentioned previously in Section 4.2.1. Clearly, both studies found the Laguna Mountains region to be of environmental importance and worthy of conservation. While stakeholders also valued its recreational opportunities, it would be advantageous to promote passive recreation that would not interfere with the preservation of important ecological communities in this region.

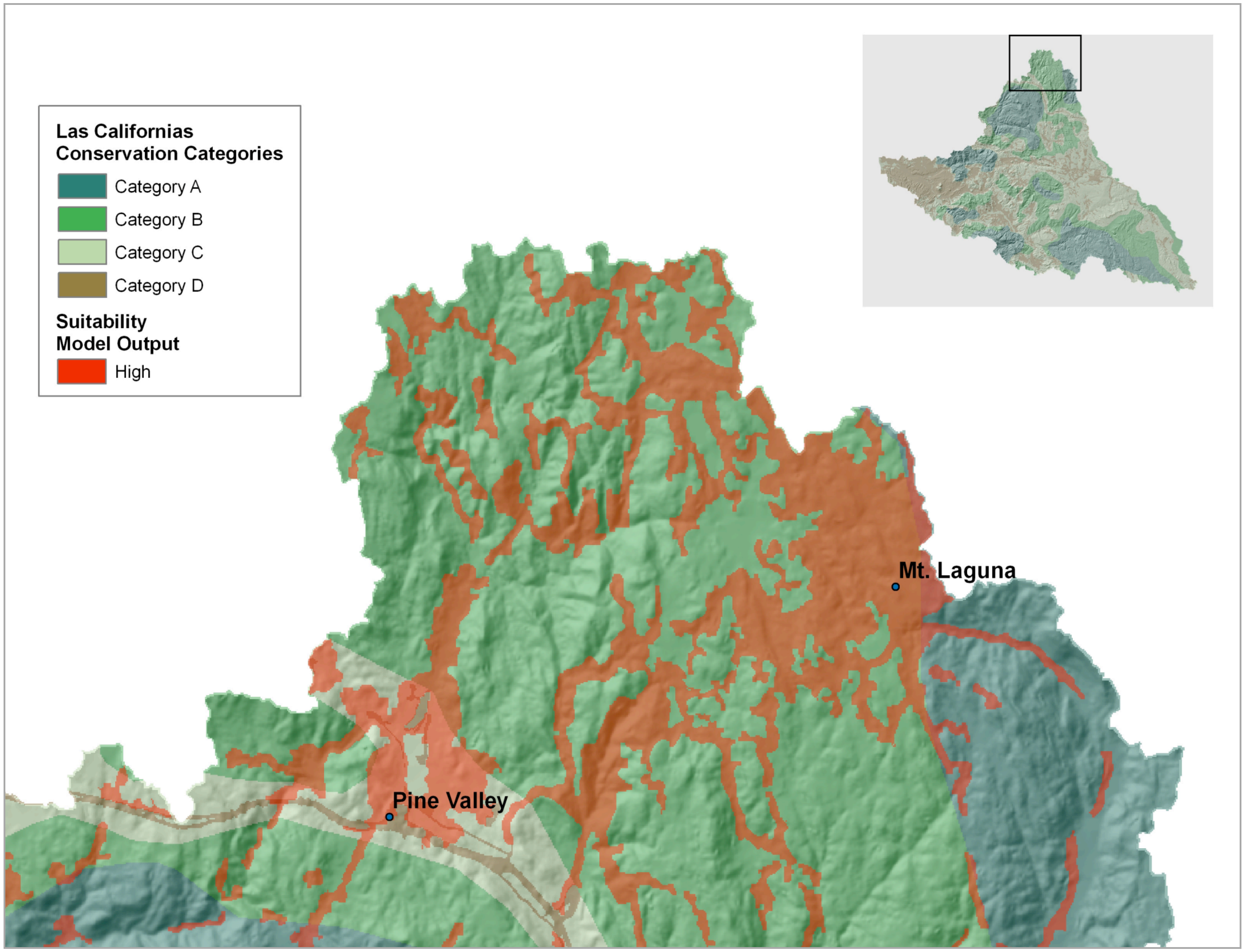


Figure 4.9. Mount Laguna area.

The Otay region highlighted in this study aligns with the Category A San Ysidro unit in the Las Californias study (see Figure 4.10). While the San Ysidro region also encompasses lands north of the watershed, it completely contains the Otay area from this study. The model implemented in this study identified this area as important because of its vegetation and its potential for controlling flooding in the region. The Las Californias report found this area to be a home to populations of California Gnatcatchers and coastal cactus wrens, as well as many other endemic and sensitive flora and fauna (Pronatura et al., 2004).

The areas described in the South Central zone do not overlap with a single region in the Las Californias results, as the last two did. However, it appears that the South Central zone encompasses some of the El Pinal Category A region as well as other Category B and Category C lands (see Figure 4.11). According to the Las Californias report, the El Pinal region is home to a variety of vegetation types, including Jeffrey pine forest and red shank chaparral. The endangered Arroyo toad has also been seen living in this area (Pronatura et al., 2004).

Category B lands are designated as such because they contain valuable habitat and vegetation, but not to the degree of Category A areas. Likewise, Category C regions contain natural areas, but are characterized by fragmentation from human use. They are described as areas containing residential and agricultural uses that can still promote sustainable land uses such as parkland and open space (Pronatura et al., 2004). The Category C lands that overlap with the South Central zone appear to lie mainly in the riparian areas. Because the model used in this study placed high importance on riparian areas for their scenic and environmental value, these areas emerged in the final output. These overlapping regions may offer opportunities to provide passive recreational areas, as well as protection for riparian habitats in ponds and streams.

The water bodies and riparian zones identified as being of “high” value in this study overlap with all categories of conservation in the Las Californias study. Many of these regions are labeled as Category D indicating that they can support human uses while protecting isolated resources and wildlife (Pronatura et al., 2004). These overlapping Category D areas would be ideal for developing river parks for residents in the watershed. These parks would not only enhance the quality of life in the region, but would provide

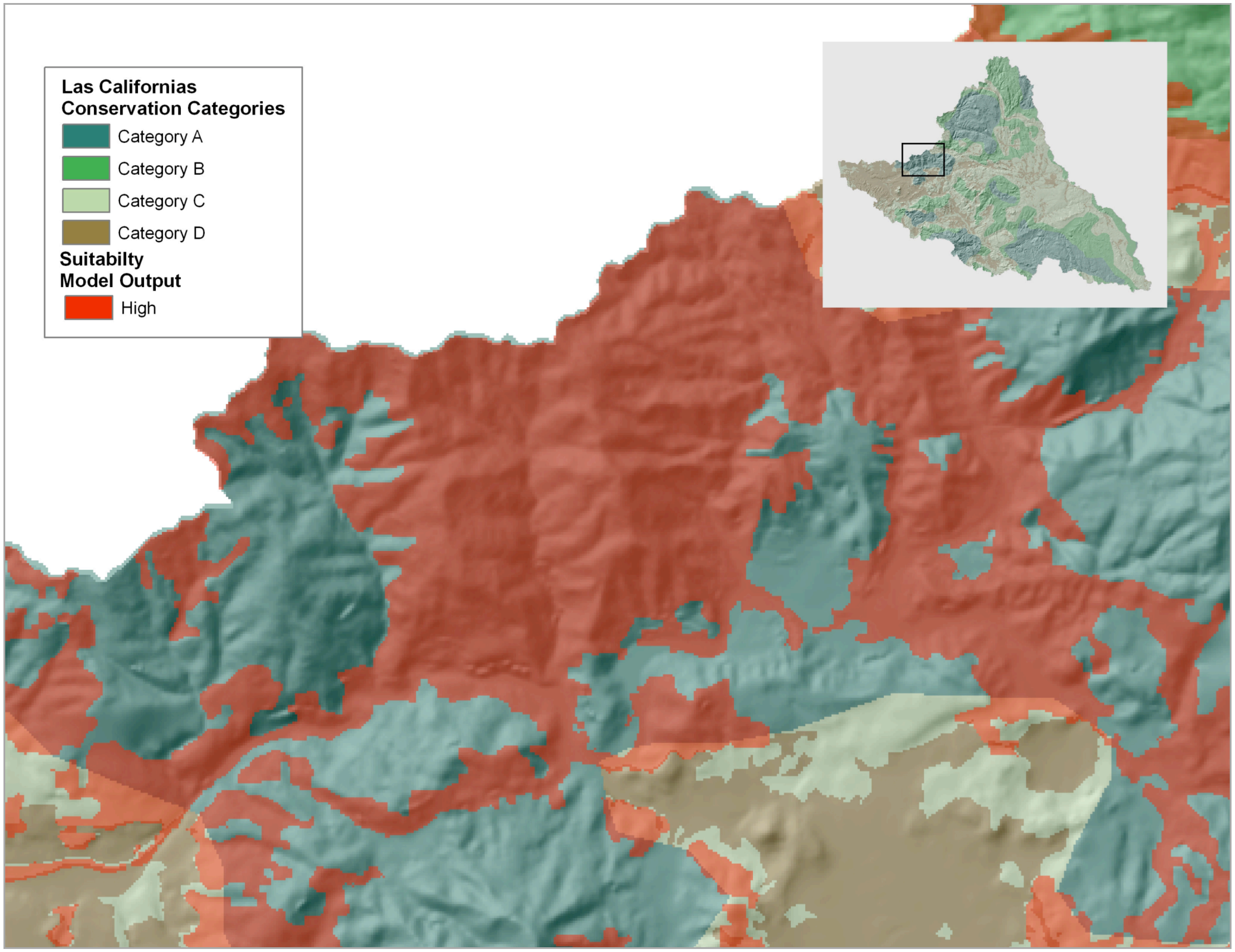


Figure 4.10. Otay region.

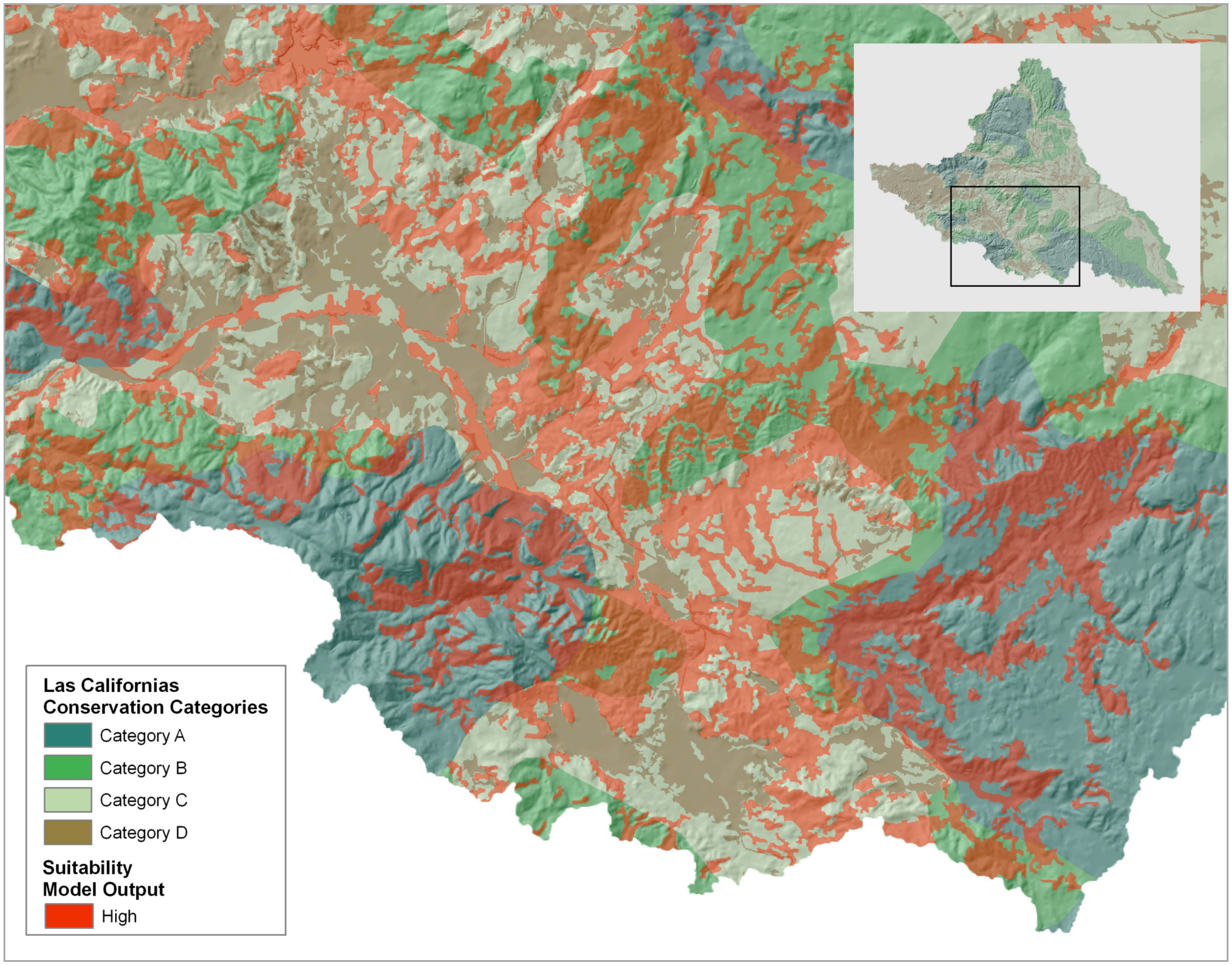


Figure 4.11. South central zone.

opportunities for repairing and preserving some of the damaged habitat and creating more corridors to connect larger natural areas.

Clearly, the biological approach used in the Las Californias report differs from the stakeholder-driven methodology used in this study, yet both sets of results appear to highlight similar geographic regions. Areas valued “high” in this study often emerge as Category A lands in the Las Californias results. By focusing on these regions of overlap, decision-makers can justify their selections as highly valuable areas that are not only biologically important, but are of great concern and priority to watershed stakeholders.

CHAPTER 5

CONCLUSIONS

The suitability model used in this thesis provides a framework for identifying open space areas in the Tijuana River Watershed that are most valuable to stakeholders. The application of the methodology described herein helps to determine areas that are of the greatest importance to stakeholders. An examination of the model inputs can explain why these areas were highlighted. The model created for this study provides researchers with a foundation to improve upon and modify as necessary. The weights used in this study can be adjusted if further stakeholder research is conducted, and each of the factors can be modified to represent new or improved data. The methods used in this study also offer approaches for handling sparse and incongruent datasets often found in international border regions. They may be useful to researchers conducting GIS-based land-use suitability analyses in binational areas.

5.1 Key Findings

One of the objectives of this study was to identify the concerns and priorities of Tijuana River Watershed stakeholders regarding the preservation of open spaces. The responses from the questionnaires administered to stakeholders indicate that the environmental value of the watershed is of primary importance. Recreational and economic values were both considered to be far less important than environmental concerns. Many of the comments written by stakeholders further emphasized their desires for implementing sustainable development to protect the flora, fauna, and water in the region. One comment seemed to summarize the general concern held by most stakeholders: "Preservation of open spaces is of the utmost importance to our region."

The second objective was to determine which specific areas met the identified priorities. This proved to be somewhat difficult, as highly valued areas exist throughout the watershed. This study focused on the regions that contained larger concentrations of "high" cells and three separate areas were identified: the Mount Laguna area, the Otay region, and a south central zone. These specific areas vary in terms of elevation, slope, and relative relief, but all contain sensitive vegetation and some riparian habitat. These areas are comprised mostly of undeveloped lands and have varying degrees of road access.

While these areas have great value for stakeholders, they are also of value to the biologists and researchers at the Nature Conservancy, Conservation Biology Institute, and Pronatura that conducted the Las Californias study. The third objective was to compare the areas found in this study with those identified in the Las Californias report. Many of the areas that were ranked as having "high" value in this study were classified as Category A in the Las Californias study. These Category A lands are described as "large, intact habitat blocks" with "irreplaceable resources and natural ecological processes, such as fire and stream flow regimes" indicating that they are of high conservation priority (Pronatura et al., 2004).

5.2 Limitations

One of the major limitations in this study was the lack of GIS data available for the Tijuana River Watershed. Because of its binational nature, there is a scarcity of continuous data in the watershed. In many cases, data collection efforts stop at the border and datasets must be merged together, often creating unwanted artifacts. This section concludes with a discussion of some of the specific datasets that could greatly improve the results in this study. If these datasets were to become available in the future, they could be incorporated into the existing model to further improve the output.

Because this model assessed the recreational value of an area, data regarding hiking trails would have been useful in determining a region's accessibility, yet these data do not exist for the entire watershed. In this study, a roads dataset was used in place of trail data because the dataset included unpaved roads. In many cases, dirt roads can provide a reasonable approximation of how accessible an area is for passive recreational purposes. However, if hiking trail data are generated in the future, it should replace or supplement the "distance to roads" factor used in this study to improve overall accuracy.

Another data gap that, if addressed, could improve the results of this model is the lack of comparable soils data across the watershed. Soils data are collected differently in the United States and Mexico. U.S. soils data are classed according to the Seventh Approximation and exist at a scale of 1:24,000. In Mexico, soils data are mapped and classified according to the FAO system and are at a scale of 1:250,000. These two classification systems are inherently incompatible. If comparable soils data were available, the water quality factor used in this analysis could be greatly enhanced. Instead of a simple 100-foot buffer around water bodies, a variable buffer that accounts for spatial variations in physical landscape and human land use could be incorporated to provide a more realistic depiction of environmental values in the region. Because the models that delineate these variable-width buffer zones require detailed soil data as input parameters, it is not possible to run these models in the Tijuana River Watershed (Xiang, 1993). If detailed and comparable soils data become available in the future, more realistic preservation zones can be modeled to better depict environmental valuse in the region.

Data regarding cultural resources in the region, such as prehistoric and historic sites, would allow for the inclusion of an additional factor for analysis in the economic and recreational values portions of this model. The addition of species-specific data would allow for more accurate modeling of the most valuable habitats in the watershed. Because there are no data regarding the distribution of specific plant or animal species available at this time, their locations can only be estimated based on the existing vegetation and land uses. These data could also be easily incorporated as an environmental factor in this model.

Finally, an accurate land ownership dataset would allow decision-makers to target areas that are not only valuable to stakeholders and researchers, but are reasonable to acquire and maintain. Land ownership data could be incorporated into the model as a constraint, such that only cells in available areas are selected in the final output. This would allow for a more efficient decision-making process and would give a better illustration of how the watershed is currently maintained.

The questionnaires developed for this study were administered with the caveat that a high level of inconsistency could potentially result because stakeholders would not have the opportunity to amend their responses. Additional information could be obtained by using an interactive process for administering the questionnaires that allows stakeholders to respond to and revise highly inconsistent responses. This would not only improve resulting Consistency Ratios, but it would provide respondents with feedback and compel them to think critically about their choices.

5.3 Future Research

Aside from additional data collection and generation, further research should be conducted to improve the scenic quality factor in this model. A study involving photographic analysis, similar to the studies described in Section 3.1.2.1, could be performed to assess stakeholders' preferences regarding landscape and vegetation in the Tijuana River Watershed. An inventory of scenic observation points could be conducted, along with extensive viewshed analysis, to determine the most visible scenic areas in the watershed. This would not only improve the scenic quality factor in this model, but the recreational value factor as well.

Another area in which future research should occur is in the methods for ranking the cells in the final suitability map. Parameterized region-growing is one technique that would allow decision-makers to impose specific size and shape restrictions based on their particular needs (Brookes, 1997). The output would then let them explore clustered areas or zones that best meet these requirements. Linear programming, Bayesian modeling, fuzzy set theory, and various artificial intelligence (AI) approaches offer additional techniques that could also be explored for generating optimal regions (Chuvieco, 1993; Eastman et al., 1995; Malczewski, 2004).

The results from this study offer decision-makers with a stakeholder-driven approach for selecting open spaces for preservation. However, because of binational complexities in the region, difficulty lies in the application of these findings. Further research might explore trans-border agencies or organizations that could implement the preservation of identified open space areas. The Tijuana River Watershed Binational Vision Project is currently investigating the idea of a trans-border mechanism that would incorporate participation from agencies and organizations from both sides of the border, and provide a means for addressing environmental, economic, and social issues in the region (The Tijuana River Watershed Binational Vision Project, 2004). This type of mechanism would be ideal for utilizing the findings in this study to promote preservation and sustainable development in the Tijuana River Watershed.

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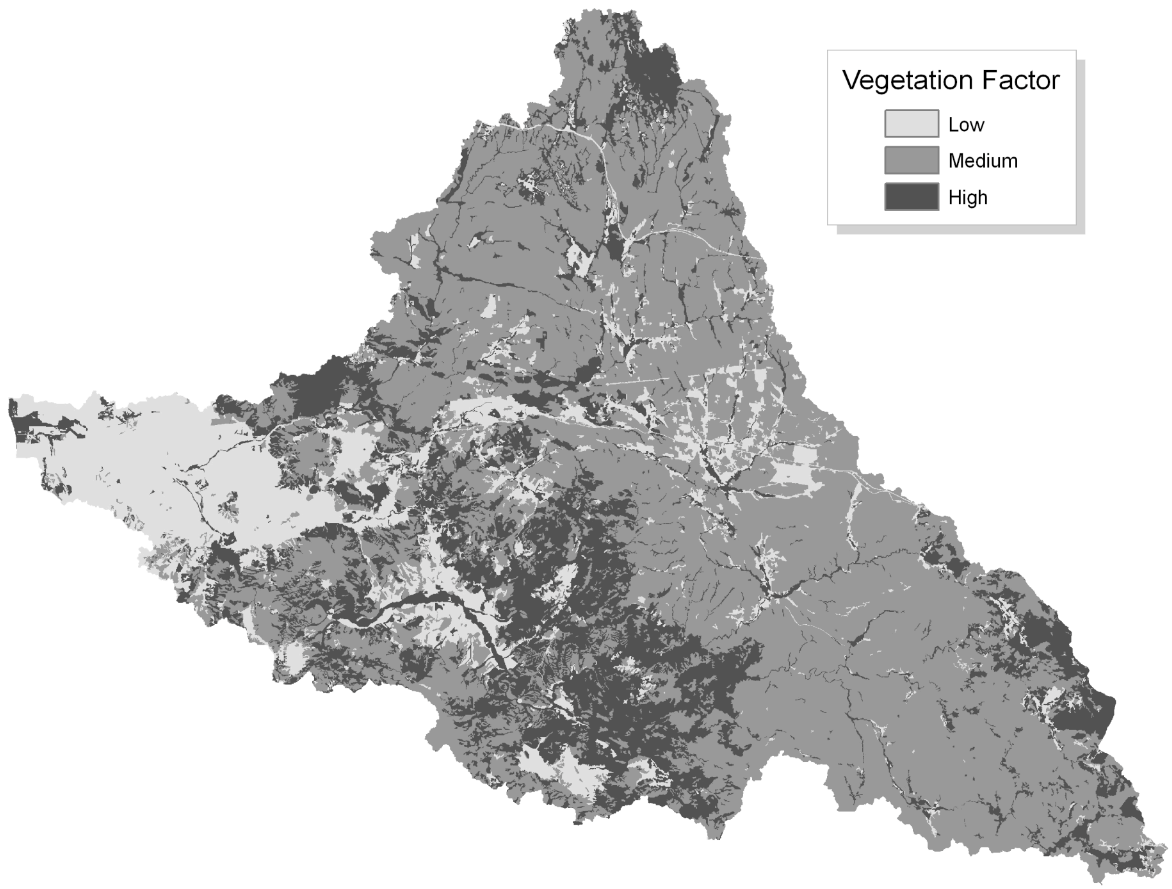
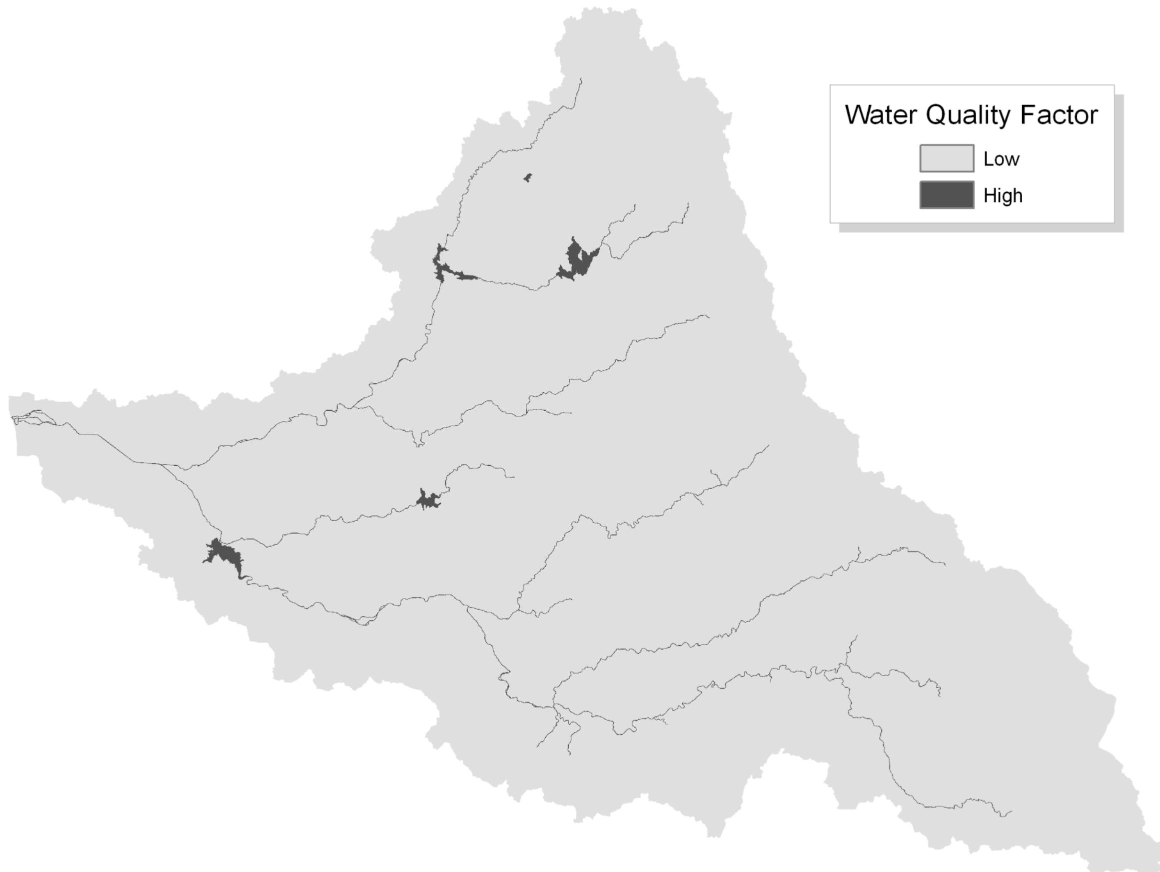
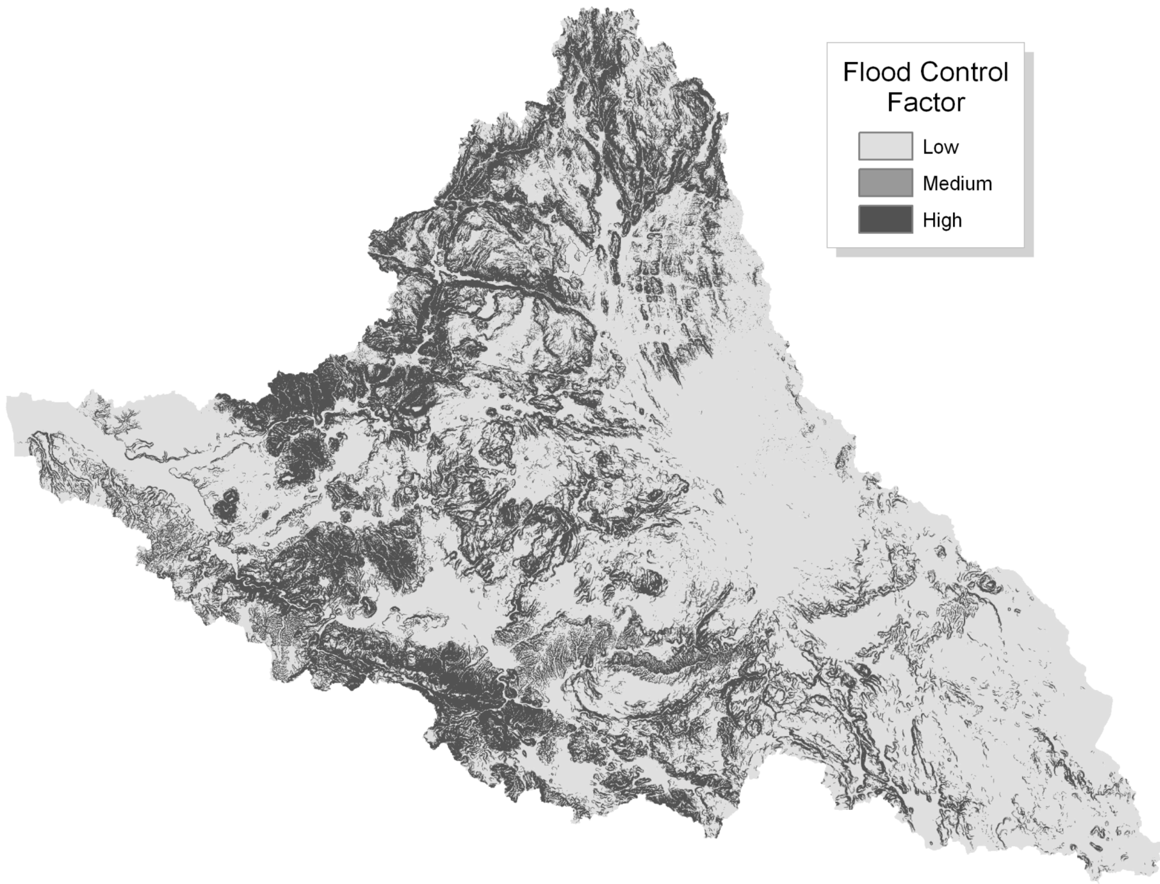
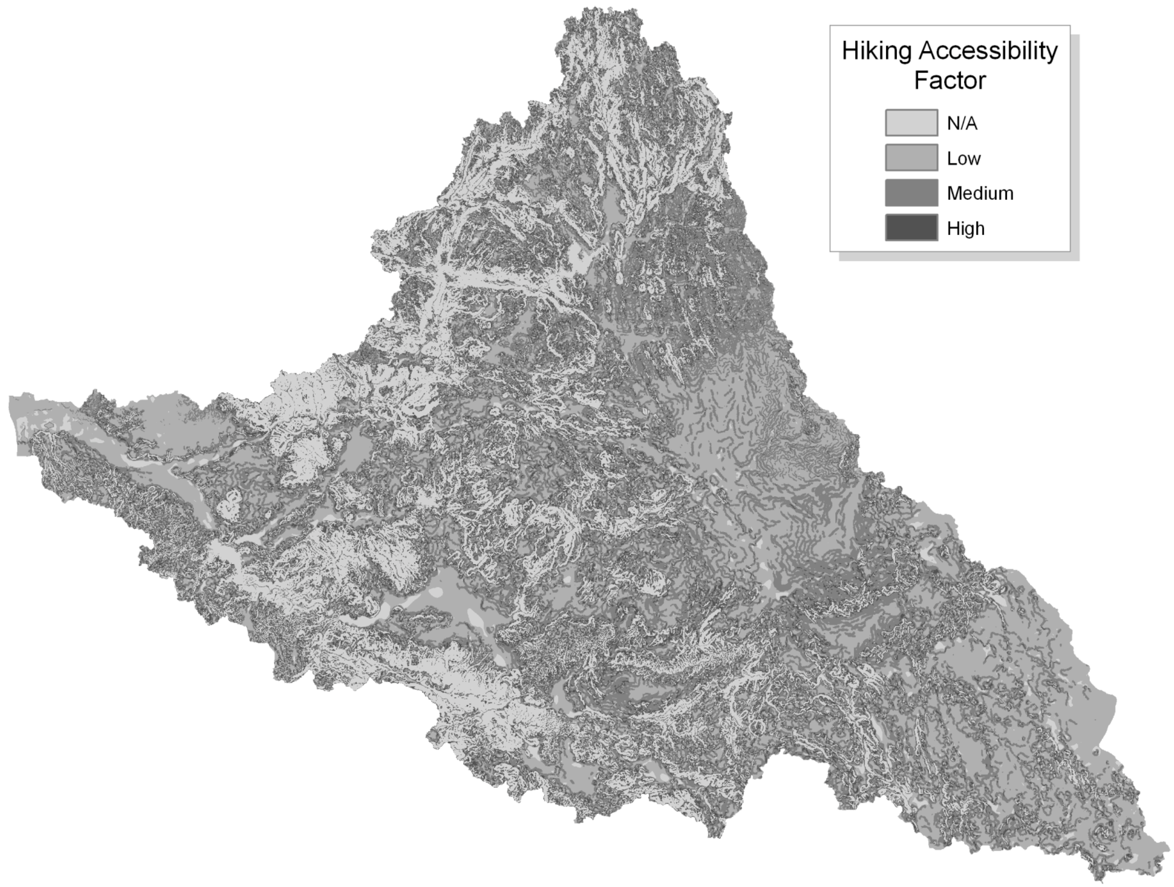
APPENDIX A

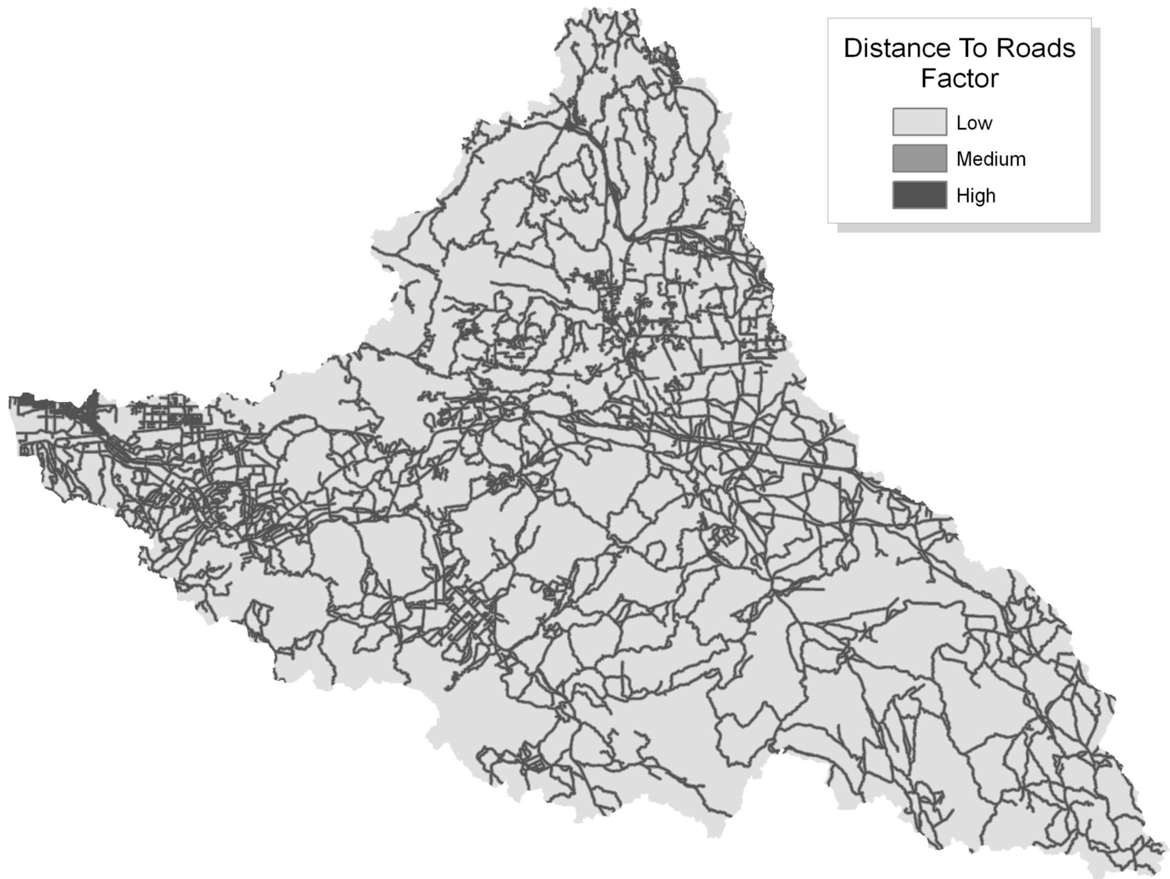
INPUT FACTOR MAPS

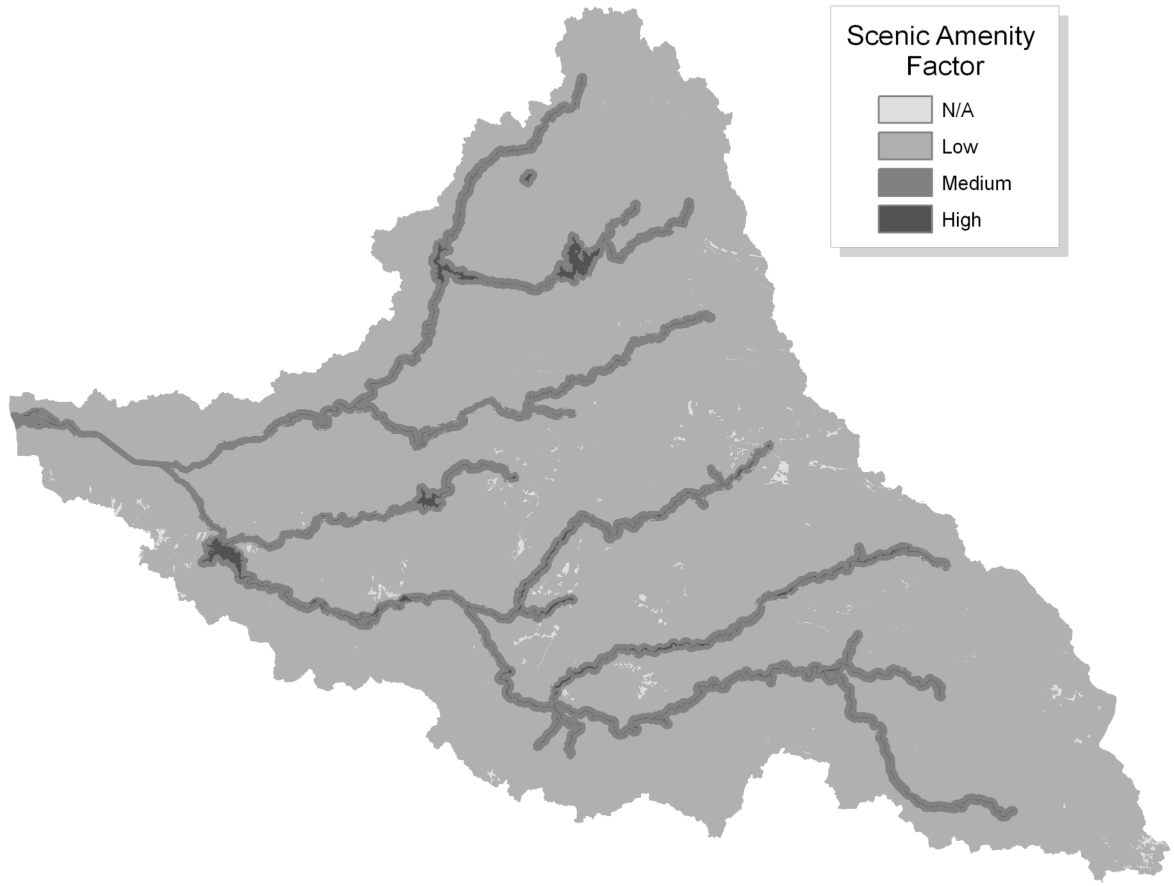

Vegetation Factor
Low
Medium
High

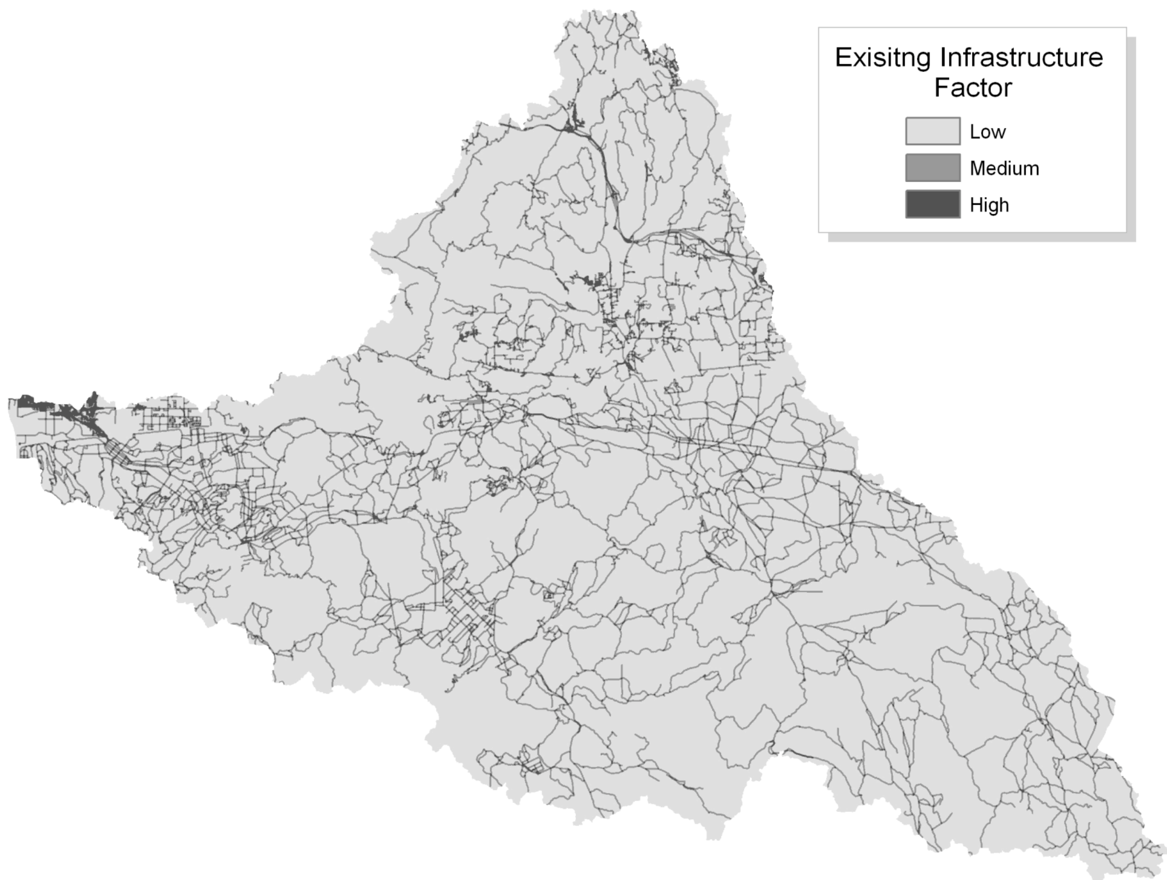

Water Quality Factor
Low
High

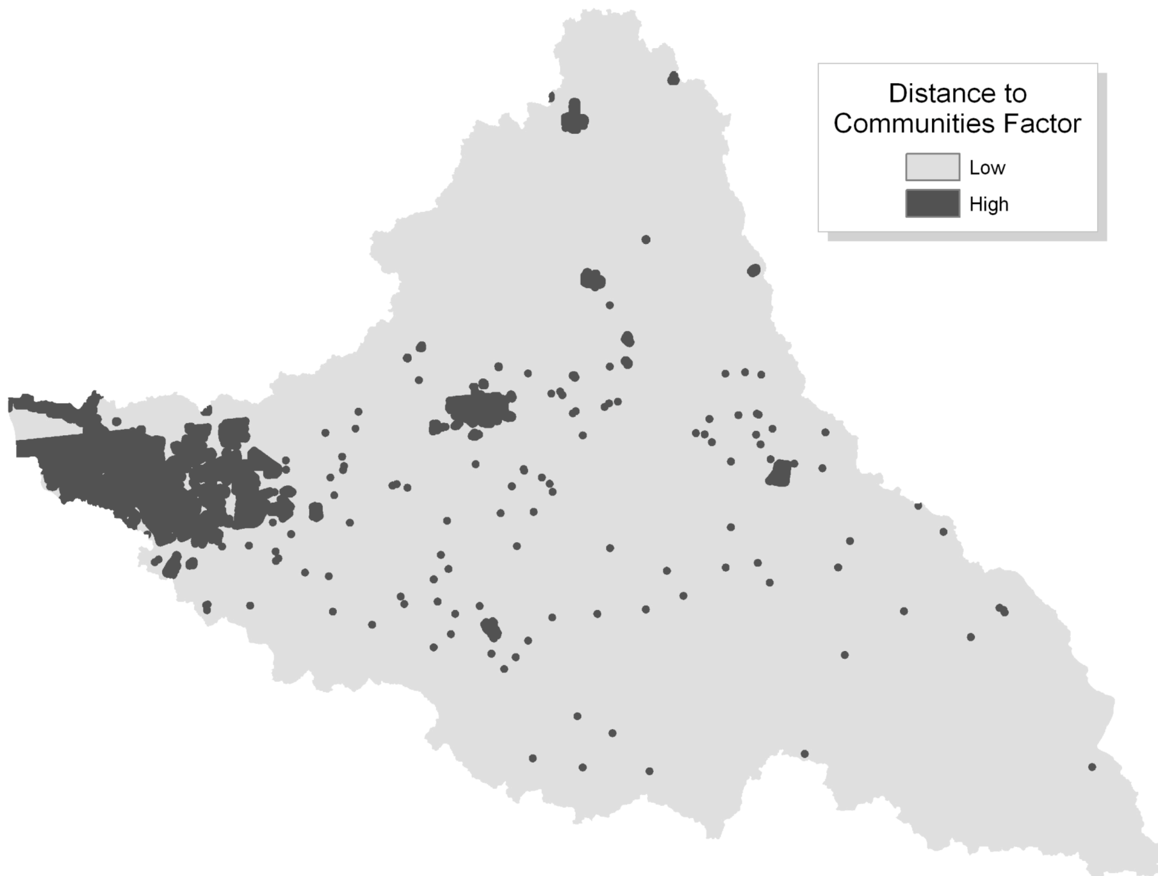

Flood Control Factor
Low
Medium
High


Hiking Accessibility Factor
N/A
Low
Medium
High


Distance To Roads Factor
Low
Medium
High


Scenic Amenity Factor
N/A
Low
Medium
High


Exisitng Infrastructure
Factor
Low
Medium
High


Distance to
Communities Factor
Low
High

APPENDIX B

NATURALNESS CLASSIFICATION

Land Use	Naturalness Classification
Agriculture	2
Industrial	1
Institutional	1
Landfills/Junkyards	1
Non-developed	3
Recreation	2
Residential	1
Transportation	1
Disturbed/Under construction	1
Water body	3
Row crops	2
Tree crops	2
Viticulture	2
Improved pasture	2
Open grazeable land	3
Commercial	1
Dispersed residential	2
Extractive industry	1

1 = Artificial
2 = Semi-natural
3 = Natural, near-natural

APPENDIX C

FACTOR INDEPENDENCE TEST

To explore the possibility of relationships between the input factors, a Kolmogorov-Smirnov (K-S) Goodness-of-Fit Test was used because of its ability to compare an observed distribution to a theoretical distribution using cumulative frequencies of ordinal data (McGrew, Jr. and Monroe, 2000). Once the cumulative expected and observed frequency distributions are determined, the K-S test statistic, D, can be calculated with the following formula:

$$D = \text{maximum } |CRF_o(X) - CRF_e(X)|$$

where:

$CRF_o(X)$ = cumulative relative frequencies for the observed distribution

$CRF_e(X)$ = cumulative relative frequencies for the expected distribution

This D value can then be compared to a critical value to determine if the observed distribution is statistically different from the expected distribution.

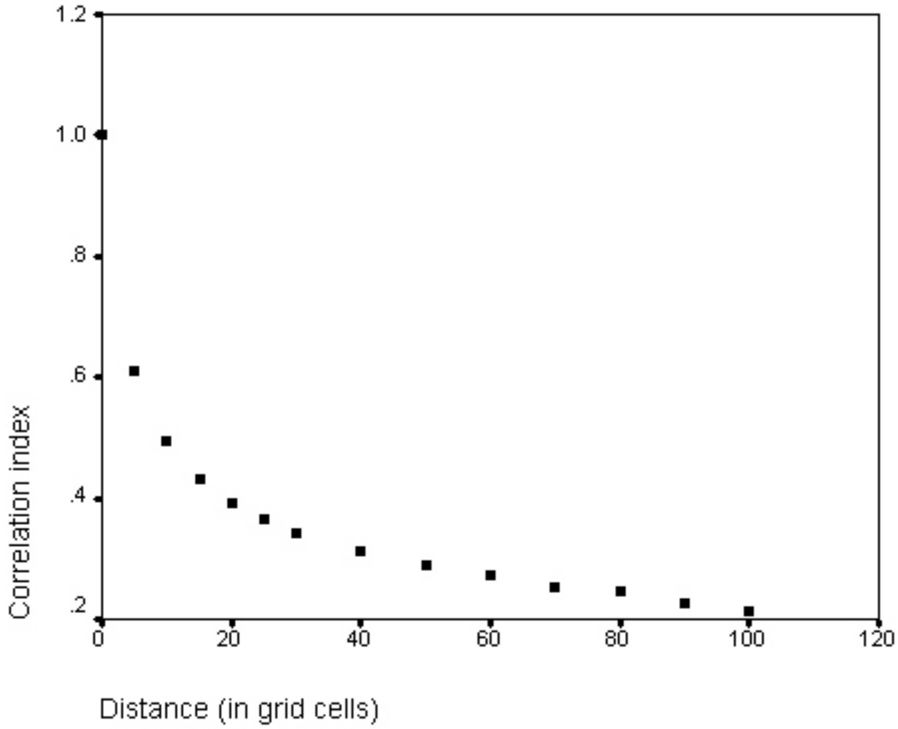
In this study, the theoretical, or expected, distribution is normal, indicating no correlation between the overlaid input factors, but rather a distribution occurring by random chance. To determine the cumulative frequencies for the normal (expected) distribution, proportions of values were calculated from the original input grids. For example, in the original grid, depicting scenic value, a proportion of 0.1364 cells contain a value of one. In the distance to roads factor, the cells containing a value of three represent a proportion of 0.2005 of the grid. This would result in an expected proportion of 0.0273 (derived from 0.1364 * 0.2005) of cells containing a one (scenic value) and a three (distance to roads) in an overlaid grid. Each expected proportion was calculated and is shown in cumulative form in the table below.

The observed proportions were calculated in the same way, but from cells sampled from the actual grid resulting from the overlay. To remove the effects of any possible spatial autocorrelation in these comparisons, grids were sampled at every 40th cell (1,200 meters). This interval was determined after examining the eight graphs shown below. Each grid was repeatedly compared to itself at an offset distance and a correlation index was calculated using the formula shown in the figure below. These graphs illustrate the changes in correlation (y-axis) against the offset distance (x-axis). The distance at which the correlation value begins to stabilize provides a value of spatial variation where the effects of spatial autocorrelation are minimized (Shine and Wakefield, 1999). For the hiking and existing infrastructure factors, it appears that the correlation index flattens out around 20 cells, while for most of the other factors, this value is closer to 40 cells. Therefore, a spatial variation value of 40 cells was selected as a sampling distance so that spatial autocorrelation would be removed in all grid comparisons.

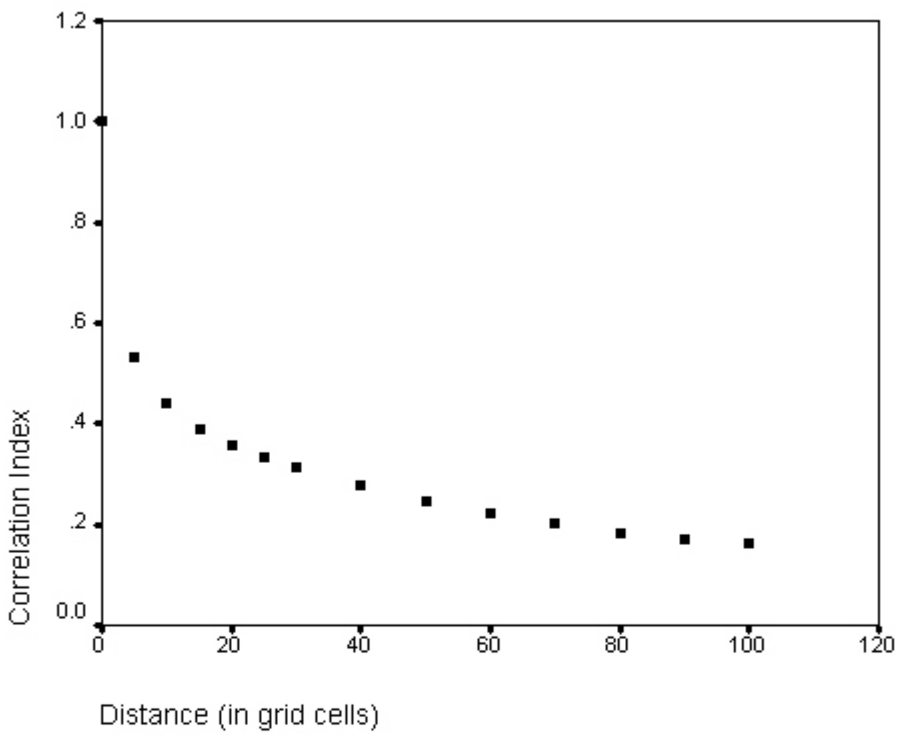
The D values were then calculated for each set of proportions using the formula outlined above and compared to the critical value of 0.0244 for n=3089 and p=0.05. In the two cases that are shown in bold in the following table, the D value exceeded the critical value, indicating that these proportions are significantly different from the expected (normal) distribution. This difference may be the result of interactions between the two factors, but the overall extent and impact of this correlation on the actual model results is difficult to determine.

K-S Values Comparing Expected and Observed Proportions.

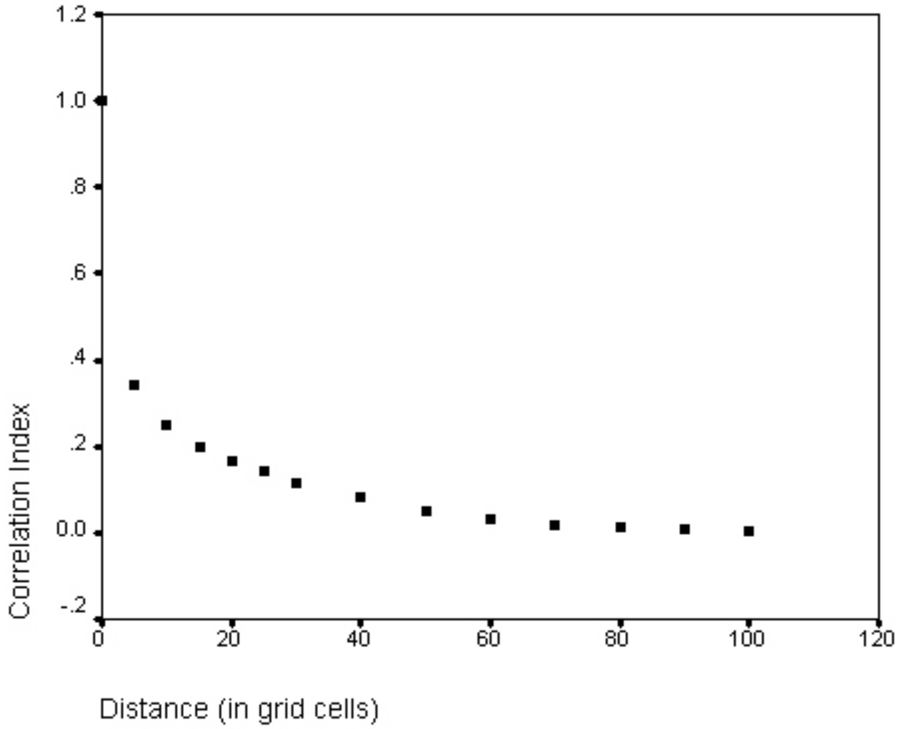
Distance to Roads Value	Scenic Value	Expected Proportions (cumulative)	Observed Proportions (cumulative)	D Value
1	3	0.0530	0.0431	0.010
3	1	0.0803	0.0531	**0.027**
3	2	0.2371	0.2600	0.023
2	1	0.2576	0.2710	0.013
2	3	0.2700	0.2804	0.010
1	2	0.7780	0.7097	0.013
2	2	0.8955	0.8597	**0.037**
1	1	0.9840	0.9753	0.009
3	3	1.0000	1.0020	0.002



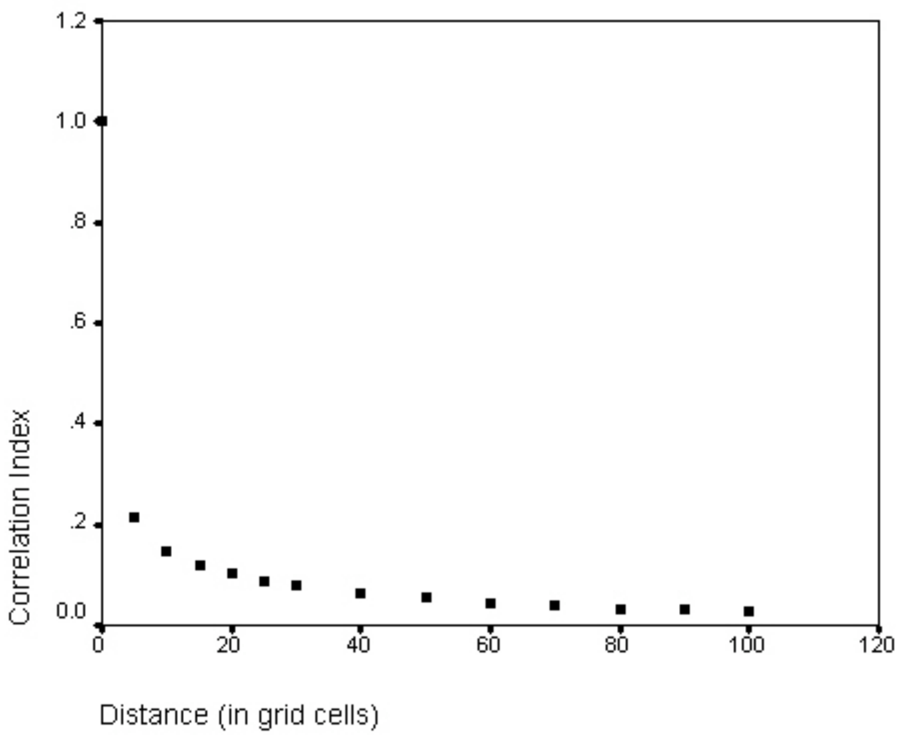
Vegetation Factor



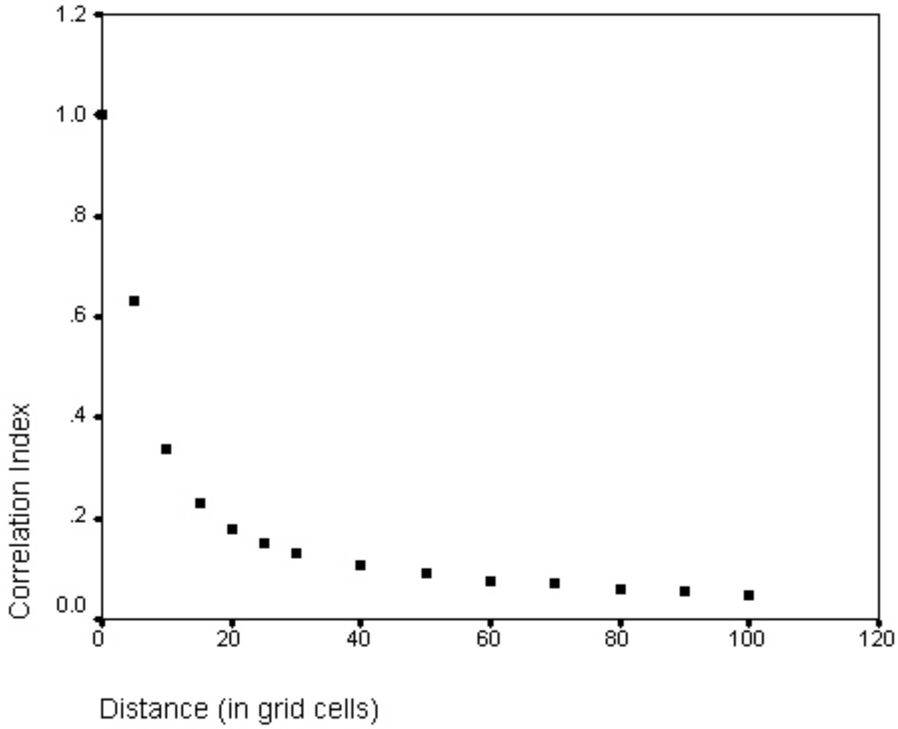
Flood Control Factor



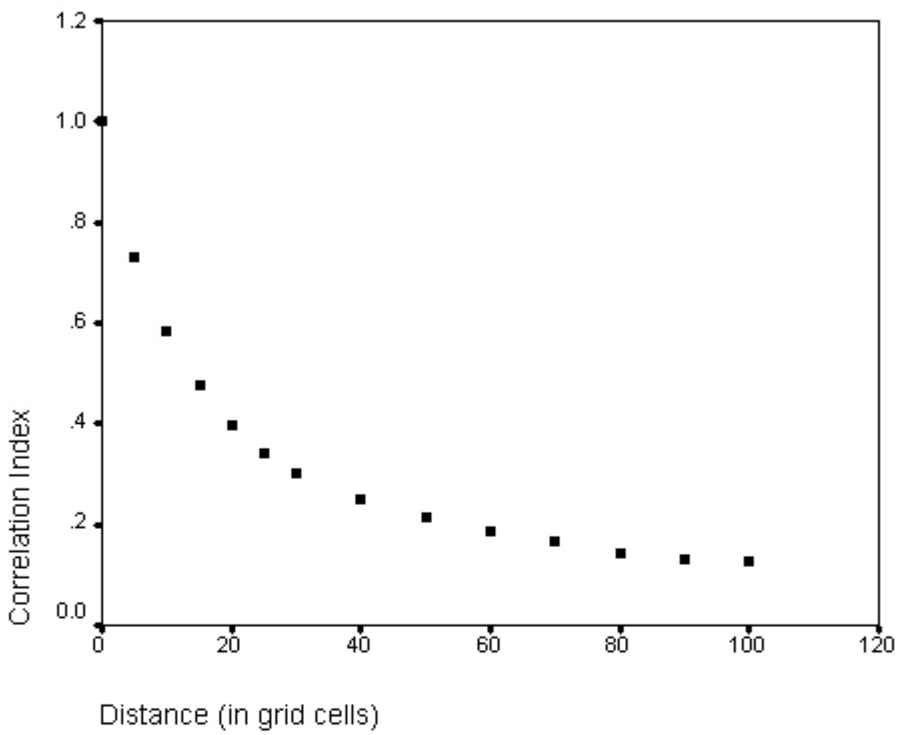
Water Quality Factor



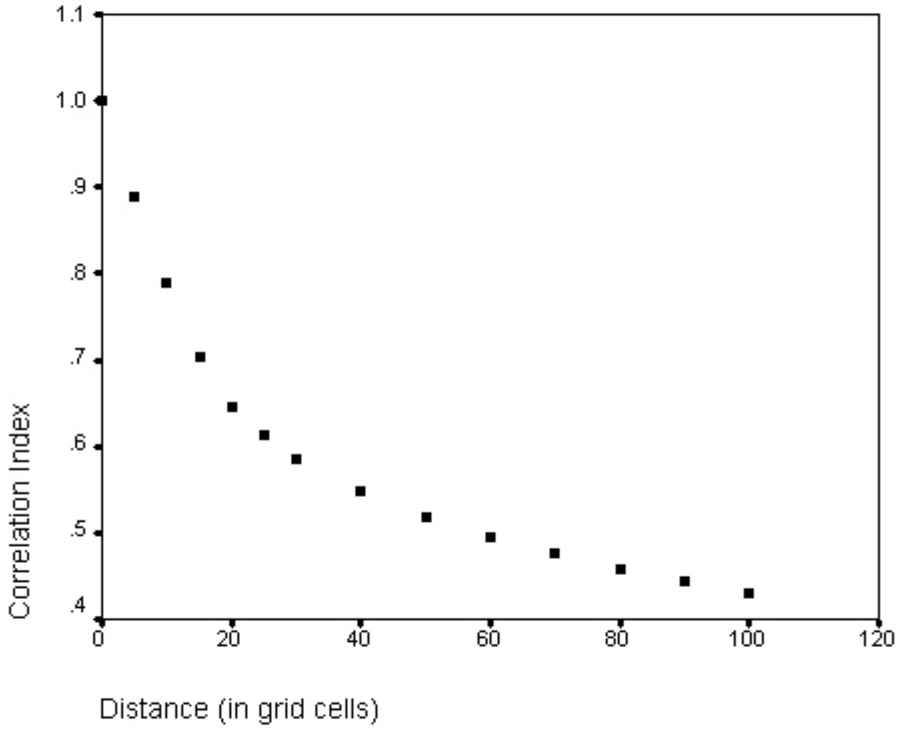
Hiking Factor



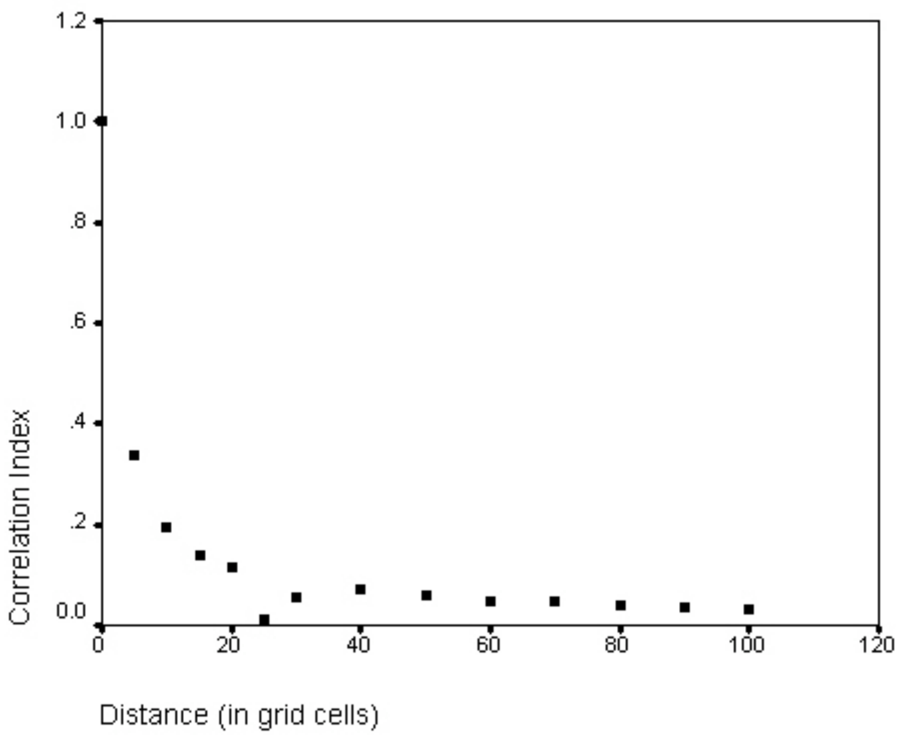
Distance to Roads Factor



Scenic Factor



Distance to Communities Factor



Existing Infrastructure Factor

The general notation used in correlation formulas and their GRID interpretation are the following:

n - the total number of cells in a grid: NROWS * NCOLS

i - any cell on the first input grid

j - any cell on the second input grid that is offset from i's location by the specified x-, y-offset

z_i -the value of the attribute of cell i

z_j -the value of the attribute of cell j

$\bar{z}_i$ -the mean value of the attribute of the first grid

$\bar{z}_j$ -the mean value of the attribute of the second grid

c_{ij} -the similarity of i's and j's attributes: $(z_i - \bar{z}_i) * (z_j - \bar{z}_j)$

In the terms of the above notation, spatial autocorrelation is simply a measure of the attribute similarities in the set of c_{ij} with the locational similarities, and then summing the results into a single coefficient (Goodchild, 1986).

The formula for calculating the CORRELATION index is:

$$c = \sum_{k}^{n} c_{ij} / (\mathrm{sqrt}(\sum_{k}^{n} (z_i - \bar{z}_i)^2) \times \mathrm{sqrt}(\sum_{k}^{n} (z_j - \bar{z}_j)^2))$$

Source: Environmental Systems Research Institute, Redlands, CA.

APPENDIX D

QUESTIONNAIRE (ENGLISH AND SPANISH VERSIONS)

Tijuana River Watershed Open Space Questionnaire

Thank you for your assistance in this research project. As a Master's student in geography at San Diego State University (SDSU), I am completing my thesis research in the Tijuana River watershed (TRW). Because of the rapid loss of open spaces or natural areas in the watershed, I will be conducting a study to identify and prioritize open space areas for preservation. A major component of this research involves stakeholder input regarding these issues. Because you have been identified as a TRW stakeholder, your responses to the following questions will be used to identify open space areas most valuable to stakeholders.

Your participation in this study is voluntary. If you decide to participate, your responses will be anonymous - that is, recorded without any identifying information that is linked to you. If you have any questions regarding this survey, please contact me at 619-594-0404 or willough@rohan.sdsu.edu. You may also contact the Institutional Review Board at SDSU 619-594-6622 to report problems or concerns related to this study.

This questionnaire should take only 10 minutes to complete and your responses will remain anonymous. Results of this study will be made available for you via e-mail, as well as at the Tijuana River Watershed Web site at http://www.trw.sdsu.edu

Thank you,
Merrilee Willoughby

What is your occupation? ______________________________

What city or town do you live in? ______________________________

Please mark the area with an X on the map below.

The Tijuana River Watershed/La Cuenca del Río Tijuana

Each of the following questions asks you to compare two attributes of open space and determine which is more important and to what degree.

****

For example:

*Is **wildlife** or **vegetation** more important to the environmental value of an open space in the Tijuana River watershed? Place an X in the appropriate box.*

	Absolutely more important	Much more important	More important	Slightly more important	Equal importance	Slightly more important	More important	Much more important	Absolutely more important	
Wildlife		**X**								**Vegetation**

If wildlife were "much more important" than vegetation, an X would be placed here.

****

1. Is the **environmental** value or **economic** value of an open space in the Tijuana River watershed more important? Place an X in the appropriate box.

	Absolutely more important	Much more important	More important	Slightly more important	Equal importance	Slightly more important	More important	Much more important	Absolutely more important	
Environmental Value										**Economic Value**

2. Is the **economic** value or **recreational** value of open space in the Tijuana River watershed more important? Place an X in the appropriate box.

	Absolutely more important	Much more important	More important	Slightly more important	Equal importance	Slightly more important	More important	Much more important	Absolutely more important	
Economic Value										**Recreational Value**

3. Is the **environmental** value or **recreational** value of open space in the Tijuana River watershed more important? Place an X in the appropriate box.

	Absolutely more important	Much more important	More important	Slightly more important	Equal importance	Slightly more important	More important	Much more important	Absolutely more important	
Environmental Value										Recreational Value

4. Is **vegetation conservation** or **flood control** more important to the **environmental value** of open space in the Tijuana River watershed? Place an X in the appropriate box.

	Absolutely more important	Much more important	More important	Slightly more important	Equal importance	Slightly more important	More important	Much more important	Absolutely more important	
Vegetation Conservation										Flood Control

5. Is **flood control** or **water quality** more important to the **environmental value** of open space in the Tijuana River watershed? Place an X in the appropriate box.

	Absolutely more important	Much more important	More important	Slightly more important	Equal importance	Slightly more important	More important	Much more important	Absolutely more important	
Flood Control										Water Quality

6. Is **vegetation conservation** or **water quality** more important to the **environmental value** of open space in the Tijuana River watershed? Place an X in the appropriate box.

	Absolutely more important		Much more important		More important		Slightly more important		Equal importance		Slightly more important		More important		Much more important		Absolutely more important	
Vegetation Conservation																		**Water Quality**

7. Is an **increase in the economic value of nearby communities** or a **minimum financial investment for construction and maintenance** more important to the **economic value** of open space in the Tijuana River watershed? Place an X in the appropriate box.

	Absolutely more important		Much more important		More important		Slightly more important		Equal importance		Slightly more important		More important		Much more important		Absolutely more important	
Increase in the economic value of nearby communities																		**Minimum financial investment for construction and maintenance**

8. Is **scenic value** or **hiking access** more important to the **recreational value** of open space in the Tijuana River watershed? Place an X in the appropriate box.

	Absolutely more important		Much more important		More important		Slightly more important		Equal importance		Slightly more important		More important		Much more important		Absolutely more important	
Scenic Value																		**Hiking Access**

9. Is **scenic value** or **distance to roads** more important to the **recreational value** of open space in the Tijuana River watershed? Place an X in the appropriate box.

	Absolutely more important		Much more important		More important		Slightly more important		Equal importance		Slightly more important		More important		Much more important		Absolutely more important	
Scenic Value																		Distance to Roads

10. Is **hiking access** or **distance to roads** more important to the **recreational value** of open space in the Tijuana River watershed? Place an X in the appropriate box.

	Absolutely more important		Much more important		More important		Slightly more important		Equal importance		Slightly more important		More important		Much more important		Absolutely more important	
Hiking Access																		Distance to Roads

Please use this space to provide any additional comments.

____

____

____

____

____

____

Espacios Abiertos de la Cuenca del Río Tijuana Cuestionario

Gracias por su ayuda al participar en este proyecto de investigación. Como estudiante de la Maestría en Geografía en la Universidad Estatal de San Diego (SDSU), estoy preparando mi tesis de investigación sobre la Cuenca del Río Tijuana (conocida como TRW por sus siglas en inglés). En vista de la pérdida rápida de espacios abiertos o de áreas naturales en la cuenca, conduciré un estudio para identificar y para dar la prioridad a las áreas de espacios abiertos con fines de preservación. Las observaciones de las personas interesadas en TRW a este respecto son un componente muy importante de la investigación. Usted ha sido identificado(a) como persona interesada en la TRW, y por lo tanto, sus respuestas a las preguntas incluidas serán utilizadas para identificar las áreas de espacios abiertos más valiosas para las personas interesadas.

Su participación en este estudio es voluntaria. Si usted decide participar, sus respuestas serán anónimas - es decir, serán registradas sin ninguna información que se identifique con usted. Si usted tiene cualquier pregunta con respecto a esta encuesta, por favor comuníquese conmigo al 619-594-0404 o al willough@rohan.sdsu.edu. También podrá comunicarse con el Comité Examinador Institucional en SDSU (619-594-6622) para reportar cualquier problema o inquietud relacionada con este estudio.

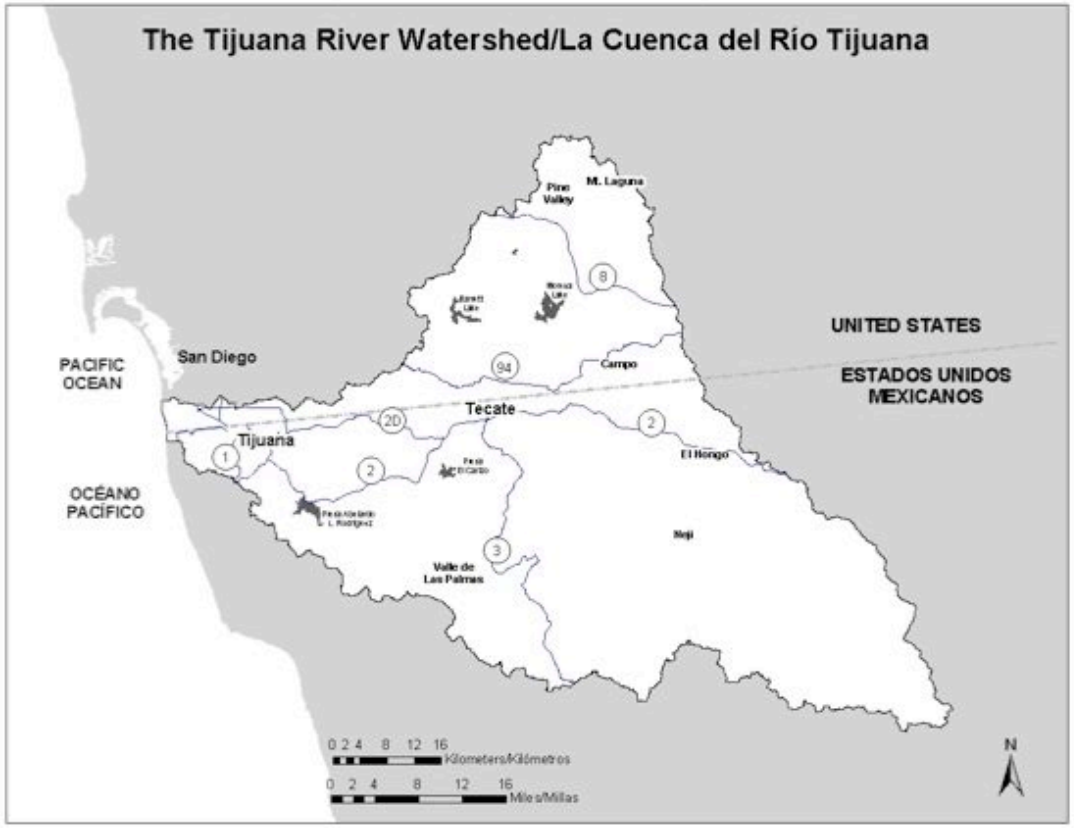
Este cuestionario se puede contestar en aproximadamente 10 minutos y sus respuestas permanecerán anónimas. Los resultados de este estudio se distribuirán a través de la lista de correos electrónicos del BWAC y estarán disponibles en el sitio del Internet de la Cuenca del Río Tijuana a http://www.trw.sdsu.edu

Muchas gracias,
Merrilee Willoughby

¿A qué se dedica? ____

¿En qué ciudad o población vive? ______________________________

Por favor, marque el área con una X en el mapa a continuación.



Cada una de las siguientes preguntas le pide que compare dos atributos de los espacios abiertos y determine cuál es más importante y a qué grado.

****

Por ejemplo:

*En los espacios abiertos de la Cuenca del Río Tijuana, ¿qué es más importante para el medio ambiente: **la fauna** o la **vegetación**?*

	Absolutamente más importante	Mucho más importante	Más importante	Ligeramente más importante	De igual importancia	Ligeramente más importante	Más importante	Mucho más importante	Absolutamente más importante	
fauna		X								**vegetación**

Si considera que la fauna es "mucho más importante" que la vegetación, deberá colocar una X aquí.

****

1. ¿Qué es más importante para los espacios abiertos de la Cuenca del Río Tijuana, el valor **ambiental** o el valor **económico**? Coloque una X en la casilla más apropiada.

	Absolutamente más importante	Mucho más importante	Más importante	Ligeramente más importante	De igual importancia	Ligeramente más importante	Más importante	Mucho más importante	Absolutamente más importante	
valor ambiental										**valor económico**

2. ¿Qué es más importante para los espacios abiertos de la Cuenca del Río Tijuana, el valor **económico** o el valor **recreativo**? Coloque una X en la casilla más apropiada.

	Absolutamente más importante	Mucho más importante	Más importante	Ligeramente más importante	De igual importancia	Ligeramente más importante	Más importante	Mucho más importante	Absolutamente más importante	
valor económico										**valor recreativo**

3. ¿Es el valor **ambiental** o el valor **recreativo** más importante para los espacios abiertos de la Cuenca del Río Tijuana? Coloque una X en la casilla más apropiada.

	Absolutamente más importante	Mucho más importante	Más importante	Ligeramente más importante	De igual importancia	Ligeramente más importante	Más importante	Mucho más importante	Absolutamente más importante	
valor ambiental										**valor recreativo**

4. ¿Qué es más importante para el **valor ambiental** de los espacios abiertos de la Cuenca del Río Tijuana, la **conservación de la vegetación** o el **control de inundaciones**? Coloque una X en la casilla más apropiada.

	Absolutamente más importante	Mucho más importante	Más importante	Ligeramente más importante	De igual importancia	Ligeramente más importante	Más importante	Mucho más importante	Absolutamente más importante	
conservación de la vegetación										**control de inundaciones**

5. ¿Qué es más importante para el **valor ambiental** de los espacios abiertos de la Cuenca del Río Tijuana, el **control de inundaciones** o la **calidad del agua**? Coloque una X en la casilla más apropiada.

	Absolutamente más importante	Mucho más importante	Más importante	Ligeramente más importante	De igual importancia	Ligeramente más importante	Más importante	Mucho más importante	Absolutamente más importante	
control de inundaciones										**calidad del agua**

6. ¿Qué es más importante para el **valor ambiental** de los espacios abiertos de la Cuenca del Río Tijuana, la **conservación de la vegetación** o la **calidad del agua**? Coloque una X en la casilla más apropiada.

	Absolutamente más importante	Mucho más importante	Más importante	Ligeramente más importante	De igual importancia	Ligeramente más importante	Más importante	Mucho más importante	Absolutamente más importante	
conservación de la vegetación										**calidad del agua**

7. ¿Qué es más importante para el **valor económico** de los espacios abiertos de la Cuenca del Río Tijuana, **aumento en el valor económico de terrenos** o **poca inversión financieria para la construcción y el mantenimiento**? Coloque una X en la casilla más apropiada.

	Absolutamente más importante	Mucho más importante	Más importante	Ligeramente más importante	De igual importancia	Ligeramente más importante	Más importante	Mucho más importante	Absolutamente más importante	
aumento en el valor económico de terrenos										**poca inversión financieria para la construcción y el mantenimiento**

8. ¿Qué es más importante para el **valor recreativo** de los espacios abiertos de la Cuenca del Río Tijuana, la **vista panorámica** o el **acceso a veredas**? Coloque una X en la casilla más apropiada.

	Absolutamente más importante	Mucho más importante	Más importante	Ligeramente más importante	De igual importancia	Ligeramente más importante	Más importante	Mucho más importante	Absolutamente más importante	
vista panorámica										**acceso a veredas**

9. ¿Qué es más importante para el **valor recreativo** de los espacios abiertos de la Cuenca del Río Tijuana, la **vista panorámica** o la **distancia a caminos y carreteras**? Coloque una X en la casilla más apropiada.

	Absolutamente más importante	Mucho más importante	Más importante	Ligeramente más importante	De igual importancia	Ligeramente más importante	Más importante	Mucho más importante	Absolutamente más importante	
vista panorámica										**distancia a caminos y carreteras**

10. ¿Qué es más importante para el **valor recreativo** de los espacios abiertos de la Cuenca del Río Tijuana, el **acceso a veredas** o la **distancia a caminos y carreteras**? Coloque una X en la casilla más apropiada.

	Absolutamente más importante	Mucho más importante	Más importante	Ligeramente más importante	De igual importancia	Ligeramente más importante	Más importante	Mucho más importante	Absolutamente más importante	
acceso a veredas										**distancia a caminos y carreteras**

Por favor utilice este espacio para proporcionar comentarios adicionales.

APPENDIX E

SENSITIVITY ANALYSIS RESULTS

Level Three (Environmental Factors) Sensitivity Analysis Results

	Original Weights	Vegetation + 20%	Vegetation - 20%	Water quality + 20%	Water quality - 20%	Flooding + 20%	Flooding - 20%
Vegetation	0.357	0.4284	0.2856	0.314	0.40	0.3357	0.3783
Water quality	0.430	0.3943	0.4657	0.516	0.344	0.4087	0.4513
Flood control	0.213	0.1773	0.2487	0.170	0.256	0.2556	0.1704
COUNTS							
Low	2368507	787080	2368507	2424956	2368507	3966619	2424956
Medium	1969599	3551026	2164610	2108161	1969599	1577101	1913150
High	605038	605038	410027	410027	605038	399424	605038

Counts based on classification derived from original weights:

Low	0 - 1.421875
Medium	1.421876 - 1.921875
High	1.921876 - 3

Level Three (Economic Factors) Sensitivity Analysis Results

	Original Weights	Distance + 20%	Distance - 20%	Infrastructure + 20%	Infrastructure - 20%
Distance	0.496	0.5952	0.3968	0.3952	0.5968
Infrastructure	0.504	0.4048	0.6032	0.6048	0.4032
COUNTS					
Low	3863077	3863077	3863077	3863077	3863077
Medium	853354	691012	853354	853354	691012
High	229943	392285	229943	229943	392285

Counts based on classification derived from original weights:

Low	0 – 1
Medium	1.000001 – 2.007813
High	2.007814 - 3

Level Three (Recreational Factors) Sensitivity Analysis Results

	Original Weights	Roads + 20%	Roads - 20%	Hiking access + 20%	Hiking access - 20%	Scenic + 20%	Scenic - 20%
Dist. to roads	0.249	.2988	.1992	.2177	.2803	.2052	.2928
Hiking Access	0.313	.2881	.3379	.3756	.2504	.2692	.3568
Scenic	0.438	.4131	.4629	.4067	.4693	.5256	.3504
COUNTS							
Low	1173491	1173491	1272994	1203447	1173491	1173491	1923522
Medium	2154964	2088997	2268110	2372582	2147199	2147199	1338966
High	1614983	1680950	1402334	1367409	1622748	1622748	1680950

Counts based on classification derived from original weights:

Low	0 - 1.373672
Medium	1.373673 - 1.870605
High	1.870606 - 3

ABSTRACT OF THE THESIS

GIS-Based Land Use Suitability Modeling for Open Space
in the Tijuana River Watershed
by
Merrilee Renee Willoughby
Master of Science in Geography
San Diego State University, 2005

Public participation is becoming increasing important in the decision-making process as decision-makers are looking for ways to gain support from various stakeholder groups. Open spaces, or primarily undeveloped areas, are valued for their environmental, economic, and recreational benefits. Because limited resources are available to protect these areas, an efficient and effective method is needed to identify and prioritize these areas for preservation. This study, based in the binational Tijuana River Watershed, examined a stakeholder-driven approach for prioritizing open space areas for preservation. A GIS-based land use suitability analysis was conducted using environmental, economic, and recreational factors gathered from existing literature and expert opinion. The Analytic Hierarchy Process (AHP) was used as a means for incorporating stakeholder preferences as weights for the input factors. The results provide an indication of which areas in the watershed are most valuable to stakeholders. In addition, results were compared to a 2004 biological study to identify overlapping areas of value to both biologists and stakeholders.