UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO

POSGRADO EN GEOGRAFÍA

CENTRO DE INVESTIGACIONES EN GEOGRAFÍA AMBIENTAL

Análisis multicriterio para la priorización de subcuencas y municipios para la aplicación de las políticas de conservación y aprovechamiento de los recursos naturales en la cuenca del lago de Cuitzeo

T E S I S

QUE PARA OBTENER EL GRADO ACADÉMICO DE

MAESTRO EN GEOGRAFÍA

(MANEJO INTEGRADO DEL PAISAJE)

P R E S E N T A

Daniel Iura González Terrazas

DIRECTOR DE TESIS: Dr. Manuel Mendoza Cantú

CIGA

CENTRO DE INVESTIGACIONES EN GEOGRAFÍA AMBIENTAL

MORELIA, MICHOACÁN. NOVIEMBRE 2008

Resumen

INTRODUCCIÓN
El objetivo del estudio es la identificación de áreas prioritarias para la implementación de políticas ambientales con intención de apoyar el desarrollo sustentable en la cuenca del lago de Cuitzeo. Este trabajo se enfoca en dos importantes políticas: Conservación y Uso sustentable. La identificación y priorización se basó en el uso de un proceso de toma de decisiones espacial multicriterio. Los criterios se refieren a los objetivos (definidos por las políticas ambientales) y los atributos (definidos por las características socio-ambientales de la cuenca). El proceso de análisis jerárquico (AJ) fue la herramienta que permitió analizar la aptitud de los municipios y subcuencas a partir de los datos espaciales. Durante la fase de definición del problema, los atributos para cada política fueron identificados y posteriormente utilizados en la fase de evaluación (diseño). La ordenación (fase de selección) se basó en la aptitud global de cada una de estas unidades espaciales con respecto a las políticas ambientales evaluadas. Para la validación de los resultados se generaron cuatro escenarios para cada una de las políticas ambientales. Se generó un mapa integrado que agrupa las unidades espaciales en función del desempeño de estas en los diferentes escenarios. Por último, se realizó un análisis de conflictos potenciales para la aplicación de las políticas ambientales para cada subcuenca y municipio. Se encontró que al utilizar la subcuenca, como unidad de análisis se tiene un 25 porciento más de superficie "sin conflicto", con respecto a la utilización de los municipios. Lo que apoya la idea de que la promoción de aplicación de recursos a programa de políticas a nivel de subcuencas generaría mayores consensos, minimizando los conflictos entre los sectores.

La cuenca del Lago de Cuitzeo (CLC), localizada en el Cinturón Volcánico Transmexicano, forma una unidad natural que en su mayoría presenta las condiciones de degradación ambiental que son comunes a otras regiones de México y de otros países de la región intertropical con economías en desarrollo. Debido a que la CLC carece de drenaje superficial al exterior (es una cuenca cerrada o endorreica), todos los procesos ambientales que ocurren en su interior tendrán un efecto en otros ecosistemas de la misma cuenca, lo cual facilita el análisis de la dependencia entre dichos procesos.
La degradación ambiental en el área de estudio tiene su principal expresión tanto en el deterioro de sus sistemas productivos como el de sus ecosistemas. Estos procesos negativos tienen sus principales causas en el impacto derivado del inadecuado manejo agropecuario y las deficiencias en el tratamiento de aguas residuales. Algunas áreas con alto valor biológico de la CLC se enfrentan al riesgo de perder su capital natural y equilibrio ecológico, mientras que otras áreas de la zona con alto potencial productivo para actividades forestales, de ecoturismo y agrícolas, entre otras, han sido mal aprovechadas debido a deficiencias en la evaluación de la aptitud de tierras (Mendoza, *et al*., 2001).

Es un hecho reconocido que las cuencas son la unidad natural más apropiada para hacer un análisis espacial de los componentes ambientales (Cotler *et al.,* 2004), pero a pesar de ello, los recursos

financieros destinados a programas ambientales son asignados a unidades económico administrativas: los municipios.

Como consecuencia, surge la necesidad de establecer un método racional y transparente para la asignación de recursos financieros para mejorar el aprovechamiento de los recursos naturales de la CLC. Es imperativo contar con mecanismos capaces de dar sustento tanto a las negociaciones entre los actores sociales como a la construcción de escenarios para la elección de las alternativas más adecuadas. Estas aproximaciones metodológicas deben de tomar en cuenta la totalidad de la complejidad de los aspectos espaciales de los procesos ambientales, al tiempo que constituyan una base sobre la cual se alcancen los objetivos de manejo del territorio a los distintos niveles administrativos.

Este trabajo se centra en desarrollar un procedimiento de identificación y agregación de áreas prioritarias en municipios y subcuencas para la aplicación de las políticas de conservación y aprovechamiento sustentable dentro de la CLC. Esto con la finalidad de establecer una jerarquía de la aptitud potencial de los municipios y subcuencas para la aplicación de estas políticas ambientales y de esa manera fortalecer el desarrollo sustentable de la CLC.

Localización y Generalidades

La cuenca cerrada del Lago de Cuitzeo se localiza en la región central de México dentro del Cinturón Volcánico Transmexicano, en el estado de Michoacán. Las coordenadas extremas son: 19° 30´, 20° 05´ LN y 100° 35´, 101° 30´ LO. Ocupa una superficie de aproximadamente 4, 000 km^2. Al fondo de la cuenca se localiza el segundo cuerpo de agua más grande de México, el cual se caracteriza por ser somero (entre 1 m y 2 m) y salobre. El área de estudio se ubica en una zona transicional, entre los climas templado seco y templado húmedo.

Las coberturas predominantes por superficie, para el año 1975, fueron cultivos de temporal, matorrales, bosques y cultivos de riego; mientras que en el año 2000 y 2003 fueron matorrales, bosques, cultivos de temporal y cultivos de riego. La cobertura de bosques templados se localiza en la porción sur de la cuenca, mientras que la cobertura de matorrales se presenta principalmente en la porción centro y norte de la misma. Proporcionalmente, el área ocupada por los asentamientos humanos creció al doble, lo que indica una alta tasa de transformación de otras coberturas hacia asentamientos humanos. El asentamiento urbano más importante dentro de la cuenca es la ciudad de Morelia, localizada en la sección central de la zona de estudio, seguida por la ciudad de Zinapécuaro. Dentro de la cuenca se encuentran total o parcialmente 28 municipios.

METODODOLOGIA

Análisis Espacial

El análisis espacial se enfocó en la identificación de los indicadores biofísicos o socioeconómicos más adecuados para evaluar y jerarquizar el potencial de los municipios y subcuencas para la aplicación de las políticas de conservación y aprovechamiento sustentable. La interpretación visual del arreglo de las curvas de nivel y el patrón de drenaje a escala 1:50,0000, permitió diferenciar 38 subcuencas que drenan o a la planicie del lago o directamente al lago.

El método utilizado incluyó cuatro fases:

1.Formulación del problema Esta es la fase de formulación del problema y que conduce a construir la estructura de los criterios para cada política con base en el AJ. La secuencia de actividades en esta fase fue: (1) Identificar los objetivos de la aplicación de las políticas de conservación y aprovechamiento sustentable con base en los requerimientos establecidos en las leyes ambientales locales; (2) Definir criterios apropiados para caracterizar cada objetivo principal y secundario, y (3) Definir las limitaciones de cada objetivo principal y secundario para establecer las áreas no aptas para las políticas de conservación y aprovechamiento sustentable.

2.Evaluación de la aptitud total de los municipios y subcuencas. En la fase de evaluación se obtienen los indicadores que pueden emplearse para la evaluación de la aptitud de los municipios y subcuencas de la CLC para la aplicación de las políticas de conservación y aprovechamiento sustentable. El objetivo principal de esta fase es ejecutar el Análisis Espacial Multicriterio (AEM) empleando la estructura de criterios y limitaciones definidos en la fase previa para obtener el mapa de aptitud para las políticas de conservación y aprovechamiento sustentable. En esa fase se define la importancia relativa de los criterios e indicadores con base en la elaboración de Matrices de Comparación Pareada (MCP).

3.Jerarquización de las unidades. Esta fase condujo a la evaluación y jerarquización de los municipios y subcuencas con base en su aptitud total para la aplicación de las políticas de conservación y aprovechamiento sustentable. Las actividades en esta fase son:

(1) Definición de una nueva estructura de criterios para la evaluación de las unidades espaciales para cada política ambiental.

(2) Definición de los escenarios decreto, demanda y oferta:

- (2.1.) Decreto, en el cual se le da mayor importancia a las estrategias y políticas decretadas en el programa de ordenamiento ecológico de la CLC.
- (2.2) Demanda, en el cual se le da mayor importancia a la demanda social inferida por el índice de marginación.
- (2.3) Oferta, en el cual se le da mayor importancia al índice de aptitud definido por el AEM.

(3) Elaboración del AEM con la nueva estructura de criterios, tomando en cuenta la generación de tres escenarios para cada política ambiental evaluada.

4.Análisis de sensibilidad y de conflictos**.** Los resultados son examinados con relación a diferentes escenarios con intención de verificar la robustez del método y reconocer la afinidad de las unidades analizadas para una cierta política ambiental.

RESULTADOS Y DISCUSION

Con base en los árboles multicriteriales representados en las Cuadros 1 y 2, se definió lo siguiente.

Política de conservación. Las unidades con los valores más altos del índice de aptitud se dividen en dos grupos. El primer grupo se distribuye en la parte alta de la cuenca en donde predomina un paisaje de montaña y lomeríos, la cubierta vegetal se constituye principalmente por bosque de pino, bosque mixto de pino-encino y en las partes más altas bosque de abies.

Política de uso sustentable. Las unidades con los valores más altos del índice de aptitud para la aplicación de esta política son las que se encuentran en las partes bajas de la cuenca en la planicie lacustre, y en la zona norte donde se desarrolla una intensa actividad agrícola de riego y de temporal.

Con base en la distribución de los valores del índice de aptitud de las unidades, se construyeron las clases de aptitud. La comparación del desempeño de cada unidad para cada política ambiental determina el tipo de conflicto presente

Se identifican tres distintas orientaciones en relación a las políticas ambientales: las subcuencas y municipios orientados a las actividades productivas ubicados en la parte baja de la cuenca sobre la planicie lacustre, las unidades territoriales orientadas a actividades de conservación localizados en las zonas de cabecera y las unidades territoriales con orientación mixta, comprendiendo los ambientes de transición entre las partes altas y bajas de la Cuenca

El tipo de conflicto más ampliamente distribuido en la CLC es el "Mixto 3er orden", es decir, la mayoría de las unidades territoriales, ya sean los municipios o las subcuencas, tienen al mismo tiempo un grado moderado de aptitud para las dos políticas.

La superficie total ocupada por afinidad para las políticas ambientales no cambia significativamente si se consideran los municipios o las subcuencas. Sin embargo, la superficie total "Sin conflicto 1er orden" aumenta considerablemente en la cuenca, tomando en cuenta una división territorial por subcuencas en relación a los municipios. Apoyando la idea de que la promoción de aplicación de recursos a programas de políticas a nivel de subcuencas generaría mayores consensos, minimizando los conflictos entre sectores.

CONCLUSIONES

La combinación del AMC y el AJ permiten la transformación de juicios lógicos cualitativos en valores cuantificables relacionados con los atributos seleccionados para el estudio. De esta manera se facilita la integración de los datos espaciales de acuerdo a los objetivos de cada una de las políticas ambientales analizadas.

El análisis de procesos de cambio en periodos múltiples, de corto y largo plazo, permite identificar las tendencias de cambio de uso del terreno. Este proceso puede incorporase al análisis de aptitud para la aplicación de políticas ambientales como un atributo del paisaje; lo anterior constituye un enfoque novedosos en la toma de decisiones espaciales en la CLC.

Los resultados del análisis de conflictos apoya la idea de que la aplicación de recursos a programas ambientales a nivel de subcuencas generaría mayores consensos, minimizando los conflictos entre los sectores involucrados.

Los resultados del presente estudio sugieren que puede optimizarse la asignación de recursos financieros por subcuencas y municipios, maximizando la eficiencia de un presupuesto limitado para las políticas de conservación y de uso sustentable.

Abstract

The objective of the present study is to identify areas with priority for the implementation of environmental policies to provide support to the sustainable development in the lake Cuitzeo basin. Two important environmental policies are focused in the present work: Conservation and Sustainable use.

The identification of priorities was based in a spatial multicriteria decision making process involving the evaluation of alternatives that minimize conflicts. The criteria relate to two concepts: 1) the objectives (defined by the environmental policies) and 2) the attributes (defined by the socio-environmental characteristics of the territory).

The attributes for the representation of the system were chosen considering their relevance for achieving the main objectives of the environmental policies evaluated in the present work. The spatial data were organized in a systematic and hierarchical manner in order to generate information for decision making at the level of municipality and sub-watershed. The process of hierarchical analysis allowed for the analysis of suitability of municipalities and sub-watersheds by means of spatial data. During the definition (intelligence) phase the problem is defined and the key factors identified and later incorporated in the evaluation (assessment) phase. The ranking (choice) phase allowed for the evaluation and ranking of municipalities and sub-watersheds based on total suitability for the implementation of each environmental policy considered here.

The present research demonstrated that change of landscapes along time is basic to understand the subjacent factors and their functional effects. The processes of change in vegetation cover and land use were compared in a long (1975-2003) and a short period (1996-2003).

In general, the municipalities located in the low portions of the basin on the lacustrine plain, hills and piedmonts have the highest suitability for sustainable use policy implementation. This is due to the fact that these areas fulfill the requirements needed for rain fed and irrigation agriculture and for cattle grazing. The municipalities in the higher portions of the basin have more total suitability for the application of the conservation policy, because they are characterized by having zones of well-preserved forest cover in high hills and mountain landscapes.

On the other side, the sub-watersheds with the higher values of the suitability indexes for the implementation of programs for sustainable development are those located in the lower parts of the basin near the limits of the lacustrine plain, where the dominant land cover, besides agriculture are grasslands in which most of the cattle grazing activity in the basin takes place. Evidently, the sub-watershed with the highest suitability is Tarímbaro - Queréndaro, mostly located on the lacustrine plain, having high suitability index values in over a 90 percent of its total surface. The sub-watersheds having a higher susceptibility of being incorporated to conservation programs are located in the higher portions of the lake Cuitzeo basin, where mountain and hill landscapes are predominant and the dominant land covers are pine forest, mixed pine-oak forest and, in higher

elevations, fir forest. A relevant feature of these higher areas is the presence, although isolated, of ravines with mesophytic conditions having a high biological value. Municipalities and sub-watersheds with well-preserved forest cover in hills and mountains are important due to the environmental services they provide (soil retention, aquifer recharge, biodiversity, among others).

Also, the sub-watersheds in the northern part of the basin in contact with Lake Cuitzeo are also relevant as a second group of territorial units with potential for the application of conservation programs. Some of the latter sub-watersheds are characterized by the recovery of the vegetation cover through a process of scrubland regeneration that is mainly caused by the abandonment of agricultural land during the past 30 years, diminishing the processes of soil erosion.

To validate the results of the present work, four scenarios were generated for each one of the environmental policies. For this goal, the relative importance of the main criteria was altered, i.e., a scenario of Supply was created favoring the suitability of the territorial unit; a second demand scenario favors social demand of terrain assessed by the marginality index by spatial unit; a third scenario of decree, favors the assignation of a given environmental policy to units of environmental management by the official environmental plan in the lake Cuitzeo basin; and finally, a fourth scenario without weighting of the main goals. The suitability index values for each of the four proposed scenarios were classified based on the frequency distribution histogram. Finally, the suitability for each scenario was integrated for each policy and an integrated map was generated aggregating the spatial units in terms of their performance in these scenarios.

As a part of the validation phase, an analysis was made of potential conflicts for the application of both environmental policies for each municipality and sub-watershed. Six conflict classes were defined. Three of these conflict classes group units with a certain degree of suitability for a given policy and unsuitable for the other one. The remaining three classes include “mixed” territorial units, i.e., units having a certain degree of suitability for both of the environmental policies. To each territorial unit an affinity for either environmental policy was assigned, except to units having the same suitability for the conservation and sustainable use policies.

One of the more relevant indicators resulting from the conflict analysis is the total surface within the lake Cuitzeo basin not showing conflict for the application of one or the other environmental policy. When municipalities and sub-watersheds were compared it was seen that using sub-watersheds as the unit of analysis the surface area (in Km^2) that does not present conflicts is of 34 percent of the total basin, while if municipalities are analyzed, the same area is of a 9 percent. Hence, if the sub-watersheds are used the areas without conflict are 25 per cent larger than if municipalities are analyzed. This finding supports the idea that promoting the assignment of resources for programs related to environmental policies at the level of sub-watershed would facilitate reaching a consensus, thus minimizing conflicts between sectors.

The approach and methodology applied in the present work are valuable tools for integrated watershed management and for ecological and territorial planning and regulation, in particular considering the scarcity of financial resources assigned to environmental programs derived from environmental policies resulting from territorial ecological planning and regulation programs. The organization of information may facilitate communication between environmental authorities at different levels and promote the assignation of financial resources to environmental and productive purposes.

Agradecimientos

Agradezco a la Universidad Nacional Autónoma de México (UNAM), particularmente al Centro de Investigaciones en Geografía Ambiental (CIGA) por abrir los espacios que permitieron desarrollar este trabajo dentro de la maestría “Manejo Integrado del Paisaje” del posgrado en Geografía.

De manera especial y sincera al director de la tesis Dr. Manuel Mendoza Cantú por su compromiso y apoyo de todas las maneras posibles para la realización de este trabajo. Te agradezco la intensa comunicación de trabajo, las ideas, correcciones y sugerencias creativas aportadas. Todo dentro de un marco de respeto. Gracias Manuel.

Al Dr. Davide Geneletti por sus valiosas contribuciones durante el desarrollo de la tesis que permitieron aumentar significativamente la calidad de esta.

A cada uno de los miembros del comité de revisión:
Al Dr. Davide Geneletti, al M. en C. Luis M. Morales Mancilla, al Dr. Manuel Bollo Manent y al Dr. Diego Pérez Salicurp por sus prontas y atinadas observaciones.

Agradezco a la DEGAPA por la beca otorgada durante la realización de la maestría. Así como por el apoyo en el transporte y seguros para la estancia en los Países Bajos.

A la UNAM a través de los proyectos PAPPIT, “Evaluación espacial y multitemporal de los cambios de cobertura y uso del terreno en la cuenca del lago de Cuitzeo: implicaciones para la sucesión forestal y el mantenimiento de la diversidad vegetal”, clave: IN304408 y Macroproyecto titulado “Manejo de Ecosistemas y Desarrollo Humano”, clave SDEI-PTID-02.

A los Fondos CONACYT-Estado de Michoacán a través del proyecto “Uso de técnicas de análisis multicriterio para la priorización de subcuencas para la conservación, restauración y el aprovechamiento de los recursos naturales en la Cuenca del Lago de Cuitzeo”, clave Michoacan-2005-C01-011.

Este trabajo se realizó parcialmente en el International Institute of Geo-Information and Earth Observation (ITC). Agradezco a este instituto el apoyo económico otorgado durante la estancia en los países bajos. Especialmente agradezco al Dr. Zoltan Vekerdy por el apoyo en la estructura y redacción de la tesis y sobre todo por el apoyo en la última etapa de la estancia. También agradezco al Dr. Ali Shariffi, sin duda, factor importante de este proceso de aprendizaje.

A todos mis maestros de la maestría ‘Manejo Integrado del Paisaje” del CIGA. Muchas gracias. .A todos mis compañeros de generación, va un abrazo de complicidad. Se les estima.

A la familia González Terrazas. Como siempre, su apoyo es razón de fortaleza.

Mónica Rueda: Te agradezco profundamente el apoyo en TODO. Gracias Moni, esto va para ti.

Table of content

List of figures

List of tables

List of equations

List of annexes

Acronyms and abbreviations

AHP	Analytic Hierarchy Process
SMCA	Spatial Multi-criteria Analysis
DSS	Decision Support System
EMPLCB	Environmental Management Plan of Lake Cuitzeo Basin
EMU	Environmental Management Units
LCB	Lake Cuitzeo Basin
LEEPAE	Law for the Ecologic Equilibrium for the Environmental Protection of Michoacán
LGEEPA	General Law for the Ecologic Equilibrium for the Environmental Protection
MCA	Multi-criteria analysis
MCDM	Multi-Criteria Decision Making
PCM	Pairwise Comparison method
SDSS	Spatial Decision Support Systems

1. Introduction

1.1. Problem statement

Environmental deterioration has been subject to analysis in the last decades, including its causes and consequences, because it affects directly the quality of the life of human population. Therefore, it is of high-priority to find an adequate distribution of land use that allows reducing the conflicts with the society and maintaining the ecological resources at the same time.

The watershed of the Lake Cuitzeo, located in the Mexican Volcanic Belt, is a natural unit that largely represents the conditions of degradation, which are also present in other regions of Mexico and in other countries with developing economies of the inter-tropical zone. The Lake Cuitzeo Basin (LCB) has no surface outflow, so all environmental processes have an effect on another part of the system within the basin, so it is easier to analyze the interdependencies. Moreover, this watershed has been surveyed recently and has a well developed data base that allows modeling the land suitability for several proposes (Mendoza, 2006).

Environmental degradation in the study area is expressed mainly in the deterioration of the productive systems and in ecological degradation. These negative processes are mainly due to an inadequate agricultural management and poor waste water treatment (Acosta, 2002). Some areas, originally with a high biological value have been seen in risk of losing their natural capital and ecological equilibrium, while other areas with a high potential for productive activities (forestry, eco-tourism, agriculture, etc) have been misused due to an inappropriate land suitability evaluation.

It is recognized that basins are the most appropriate natural units to analyze spatially the environmental components (Cotler et al., 2004). In spite of this, financial resources for environmental programs are distributed through economic administrative units, the municipalities.

There is a need for a clear rational method for the allocation of resources, because at the moment lobbying and other non-spatial aspects are more important in the allocation of resources. Therefore, a mechanism is needed which is able to support both the negotiation process with stakeholders and the scenario building to select the best alternative. This mechanism should take into account the spatial aspects of the environmental processes in their entire complexity and should support the implementation of the management objectives at different administrative levels

1.2. Research objectives

Due to its complexity, it is not possible to tackle this problem at all legislative and administrative levels in this study. Therefore, the aim is to generate information that helps the allocation of financial resources assigned to the environmental issues at a municipal and sub watersheds levels.

The budget assigned for the environmental programs are always insufficient, thus, it is important to recommend to the authorities which areas should have priority to invest in the conservation and productive programs.

1.2.1. General Objective

To identify the priority municipalities and sub watersheds for the implementation of selected environmental policies to support sustainable development in the Lake Cuitzeo Basin.

1.2.2. Particular objectives

- To develop a procedure to identify priority areas for the conservation and sustainable use policies within the LCB.
- To apply the developed procedure within the LCB.
- To establish a suitability ranking of the administrative (municipalities) and natural units (sub watersheds) of LCB according to their potential to the application of the conservation and sustainable use policies.

The spatial analysis will focus on the identification of the best biophysical indicators that allows evaluate and rank the municipalities and sub watersheds in terms of their potential for the application of environmental policies for conservation and sustainable use.

1.2.3. Research questions

What are the characteristics of the ideal area for the conservation and sustainable use policies?

How can these characteristics be measured and evaluated to achieve the objective of the conservation and sustainable use policies?

How should these characteristics be aggregated within the municipalities and the sub-watersheds to find out their relative importance to the conservation and sustainable use policies?

How should the overall results be validated?

1.3. Research method and structure of the thesis

This study is realized under the framework of the spatial decision support systems tools, in specific with the spatial multi-criteria analysis. The spatial information is analyzed under the principles of analytic hierarchy process.

This thesis discusses the study in the following chapters:

Chapter 1: Problem statement, general objectives, particular objectives, research questions and research method.

Chapter 2. Background; information based on the literature overview. Includes a general introduction to the spatial decision support systems, general framework of the spatial multi-criteria analysis and its principal components. Description of the principles of the analytic hierarchy process. An explanation of the environmental management plan of Lake Cuitzeo is realized, including its main environmental policies. Also the environmental management units are described.

Chapter 3. Description of the study area, localization and general characteristics. General description of the land cover and the spatial arrangement in municipalities and sub watersheds of the basin.

Chapter 4: Description of the analysis method focusing in the problem definition, assessment of the overall suitability of the spatial units and its correspondent ranking. Finally, the list of the source maps used through the study is given.

Chapter 5: Definition of the objectives and characteristics of the environmental policies. Description of the criteria structures, its indicators and veto factors.

Chapter 6: Assessment of the spatial units for each of the environmental policies. Partial valuation and relative importance of the criteria.

Chapter 7: Ranking of the spatial units. Aggregation procedure of the suitability indexes. Establish of the relative importance of the spatial units for each of the environmental policies.

Chapter 8: Asses the overall results of the previous phases through a sensitivity and conflict analysis.

Chapter 9: Discussion about the strength and weakness of the method. Which is the relevancy and the applicability of the method?

Chapter 10 Conclusions of the research. Final considerations and recommendation for the future research.

2. Background

This work has two main subjects: The integrated watershed management and the decision support systems, in particular spatial multicriteria analysis. Hufschmidt (1986) considered "watershed management as a planned system of management measures and implementation tools applied to a watershed through a set of institutional/organizational arrangements." In this sense the product of the present work should provide valuable information for the planning phase within the conceptual framework of integrated watershed management (Fig.1).

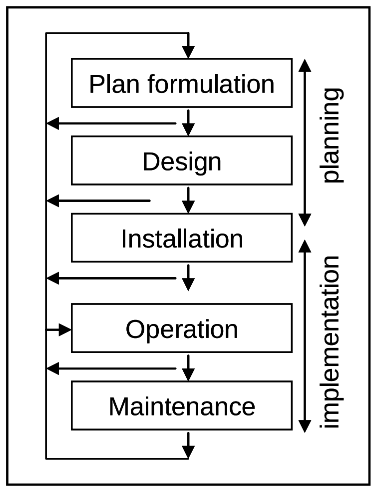


Figure 1 Five basic stage of IWM. Modified from Hufschmidt (1986)

2.1. Integrated watershed management

The concept of integrated watershed management (IWM) is not new, FAO (1986) reported that the first attempts to make an integral management were in the 40's of the past century, these first efforts were consequence of the blend of the land restoration methodology, derived from the rehabilitation of the Alps in the last quarter of the nineteenth century, and the techniques and concepts acquired in Europe and USA about soil and water conservation during the first half of the twentieth century. Although there is a increasing tendency to incorporate integrated watershed management in the academic outputs of natural resource management, the implementation of management plans having this approach are still seldomly used. This is understandable because the limits of economic-administrative units and of natural units, in this case the watersheds, almost never coincide in space. In this sense, to implement a successful plan there should be a high level of communication and common interests between the different sectors having interests within the watershed. Often, these interest are in conflict, creating one of the major barriers for the development and implementation of an integrated management plan having the watershed as its working unit (McDonald et al., 1988).

In Mexico, watershed management was institutionalized in the 50's of the past century, nowadays several governmental and no-governmental institution exist that administrate micro-watersheds with successful products. The efforts are focused in identifying the institutional, socioeconomic and environmental conditions that allow reaching the proposed objectives (INE, 2007).

The IWM concept has been shifting from being an isolated strategy for the conservation of a single resource (the water) to a concept that comprises the sustainable regional development.

Basics elements in a IWM plan are described by Heathcote (1998) :

- A watershed plan has to account for all the uses of the water system and others activities that affect water flow quality
- There has to be a good understanding of the hydrological regime.
- Management objectives for the watershed have to specified, with criteria for assessing management alternatives in an objective way.
- Public participation is essential in determining the objectives and managements decisions.
- There must be participation of all relevant regulatory institutions.

Even though it becomes quite difficult to design or propose integrated management alternatives to large watersheds due to: the complexity of the relations of its components, the poor availability and quality of data, and the heterogeneity of the territory; in medium and smaller watersheds it is possible to design a decision making plan considering local spatially-distributed parameters.

The IWM basic assumption is that the watershed is a dynamic, open system where energy and matter flow between the functional components of the systems, the National Institute of Ecology (INE, 2007) group and summarize these components in:

Hydrological function: recruitment, storage and discharge of the water.

Ecological function: interactions between the biological and physical elements of the unit.

Environmental Function: CO_2 storage, germplasm bank, maintenance of diversity, maintenance of soil, regulation of the biogeochemical cycle.

Socioeconomic Function: Supply the space for the cultural and social development of the inhabitants and the natural resources to satisfy the productivity activities. Figure 2 illustrates, in general way, the interplay of forces affecting IWM (Heathcote, 1998).

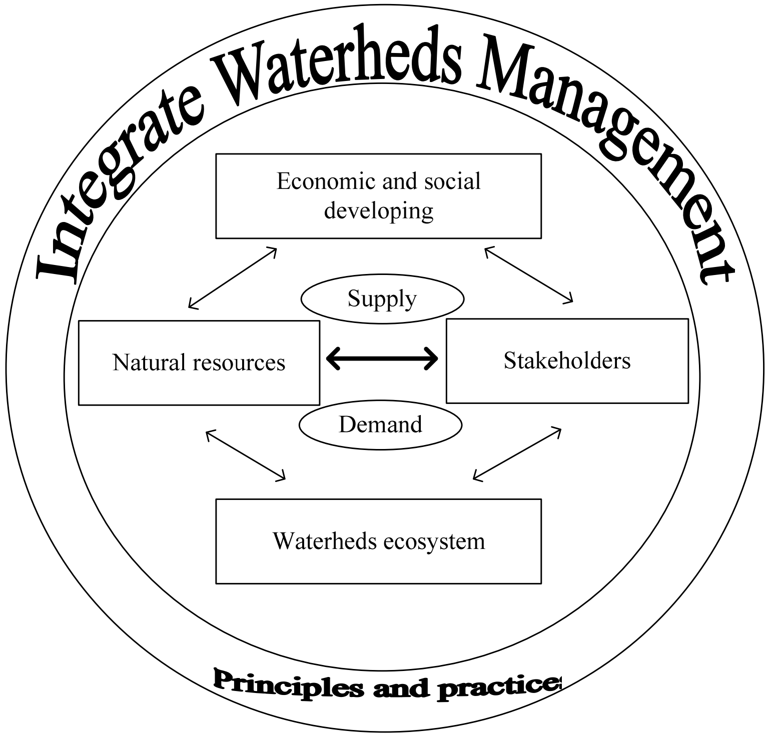


Figure 2 Forces affecting IWM. Modified from Heathcote, 1988

2.2. **Spatial Decision Support System**

The spatial decision support systems (SDSS) are management information systems that transform information into instructions that are intended to affect system behavior in such a way that they improve system performance (Sharifi *et, al.* 2004).

The main feature of SDSS is the capacity to make the problem more understandable. This goal is reached through the arrangement of the information in such a way that the decision makers can more easily explore the problem. Moreover, SDSS allows introducing appropriate models to the specific environmental decision. The alternatives can be evaluated in terms of the objectives proposed. As stated by Sharifi (2002): “These studies rely upon logic of mathematics and statistics and utilize the concept of utility related to the expression of preferences among alternatives options, while probability serves to evaluate the likelihood of these preference being utilized.”

Decision making involves sequences of processes that begins with the recognition of the problem to be solved and ends with a recommendation about how to solve that problem. The two main approaches are: the alternative-focused approach and the value-focused approach. The alternative focused approach begins with the development of the optional alternatives, and then, specifies the criteria and the value of these to evaluate and select the best predefined alternative(s). On the other hand, the value-focus approach uses the evaluation of the criteria as the fundamental element of the decision analysis. It assumes that the values are more fundamental than the alternatives to a decision problem, which means that the alternatives are achieved via the more fundamental values (Malczewski, 1999).

The general framework of the decision making process is based on a sequence of phases introduced by Simon (1960):

Intelligence: Identification of the problem, the difference between the desired state and the real state of the geographic system.

Assessment: Determination of the possibly alternatives, in such way as to achieve the established goals of the previous phase for reaching the desired state. This phase is related to the analysis of the possible courses of action.

Choice: The process of the selection of an alternative or a combination of them that represents the best option based on the previous statements.

2.3. Multicriteria analysis

The Multicriteria Decision Making (MDM) process is a decision support tool involving a set of alternatives that are evaluated on the basis of conflicts. The criteria refer to two concepts: the objectives (defined by the particular interest), and the attributes (defined by the characterization of the environment).

An objective is a statement about the desired state of the system under consideration. For any given objective, one or more different attributes are used to measure the performance in relation to that objective.

Broadly speaking, multicriteria analysis (MA) is divided in two main branches; the multi-objective decision making, and the multi-attribute decision making. The first one studies decisions in which the decision space is continuous, on the other hand, the multi-attribute decision making process concentrates on problems with discrete decisions spaces. In the latter problem, the set of decisions includes a finite number of predetermined alternatives (Triantaphyllou, 2000).

Before the integration with Geographic Information Systems (GIS) technology, the multicriteria analysis (MA) was typically aspatial, which means the assumption of a spatial homogeneity within the area in concern. This assumption is unrealistic because, usually, the evaluated characteristics vary across space. With the complementary relation between MA and GIS technology the decision maker has more information about the spatial distribution of the criterion values and of the spatial characteristics of the alternatives.

In the Spatial Multicriteria Analysis (SMA) geographical data are transformed into a decision. Using the words of Malczewski (1999): “spatial multicriteria analysis involves the evaluation of geographical events based on the criterion values and the decision maker's preference with respect to a set of evaluation."

According to Anselin and Meire (1989), "the MCA is viewed as a flexible decision tool in which the subjective aspects of the evaluation are made more explicit and the preferences, priorities and the judgments of the decision maker(s) or evaluator(s) are incorporated in a consistent and structured framework."

2.3.1. Components of a criteria tree

Constraints

A constraint is a criterion that determines which areas are included in or excluded from the suitability analysis; the excluded area will get a (0) null performance while the included area will have a suitability index between 0 and 1. Constraints are hard criteria that cannot be compensated with other constraints or factors.

Factors

A factor is a soft criterion that contributes to the suitability in a certain degree. There are two kinds of factors depending of the direction of the score (Voogd, 1983):

-Benefit-factors: contribute positively to the output; the more you have, the higher the values, the better it is.

-Cost-factors: contribute negatively to the output; the less you have, the lower the values, the better it is.

Contrary to the constraints, the factors could be compensated for other factors, in such a way that an area with high values of cost factor(s) can be compensated by the presence of high values of benefit factor(s), thus the overall suitability of this area represents the relations between these factors.

According to Sharifi (2003) the factors must gather attributes, as shown in Table 1.

Table 1 Attributes of criteria and indicators

Attribute	An indicator should:
Relevance	address key issues; be related to the assessment goal; and be sensitive and responsive to change in the system.
Analytic	be reliable; be theoretically founded; and provide an integrative measure.
Measurability	be easy to detect, record, and interpret; be cost effective; and be precisely-defined.

Group of factors

A group of factors contains a combination of criteria representing a sub-goal that allows to assess the main goal.

2.3.2. Partial valuation

Usually the criteria used in spatial multicriteria evaluations are of diverse nature, thus, are represented in different values and scales. Nevertheless, the multicriteria analysis requires the criteria to be comparable and/or combined; for this, the values of the various criteria have to be transformed to comparable units. This process is called normalization or standardization.

The most important standardization methods are summarized in Table 2.

Table 2 Summary of the most used standardization method

Standardization	Method
Maximum	Where the score is divided by the highest absolute score.
Interval	Linear function between absolute lowest score and the highest score.
Goal	Linear function between the real or hypothetical end point of the range and the lowest score.

2.4. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) developed by Saaty (1980), is an approach for multicriteria decision problems in which every problem has a decomposition process (analysis) and a hierarchical rearrangement of its main components. The overall decomposition of the decision problem is applied to create a hierarchy of clusters, in which each cluster is broken down in other clusters. The hierarchy arrangement has to respond to certain objectives. This arrangement is an abstraction of the system structure to understand the functional relations among the components and the impact of each of these on the system (Saaty, 1980). The process does not require numerical inputs to relate criteria of a cluster that represents an aspect of a problem, subjective judgments on which no scale of measurements exists can be used to determine the relative importance of the criteria according to the common objective. These judgments are used to derive the ratio scale priorities for the decision criteria and alternatives (Dyer et al., 1992).

2.4.1. Pairwise comparison

One of the main issues in the MCA is concerned with the derivation of weights which reflects the relative importance of the options in a multi-attribute judgment problem. The pairwise comparison matrix (PCM) method was developed in the context of the AHP by Saaty (1980). This method allows the decision maker to give a comparison judgment for every pair of criteria, the resulting output is the PCM constructed in a verbal scale basis and associated to a 1 – 9 ratio scale, see Table 3. A PCM is made to determine the relative importance of each element in each cluster with respect to the level in the hierarchy.

Table 3 Pairwise Comparison scale (Saaty, 1980)

Verbal scale (comparison between each pair of criteria)	Intensity of importance
Equally importance	1
Equal to moderate importance	2
Moderate importance	3
Moderate to strong importance	4
Strong importance	5
Strong to very strong importance	6
Very strong importance	7
Very to extremely strong importance	8
Extreme importance	9

The resultant comparison matrix presents reciprocity between the elements above and under the main diagonal. Table 4 shows an example to the inverse relation between these elements. In this sense the criterion A has a moderate importance in achieving the goal with respect to criterion B, that means that criterion A is 3 times preferred as criterion B, thus, criterion B receive a score of 1/3 of importance when is compared with criterion A.

Table 4 Pairwise Comparison Matrix (PCM)

	A	B	C
A	1	3	8
B	0.33	1	5
C	0.125	0.20	1

According to Malczewski (1999) one of the methods to define the criterion weights are as follows:

a. Sum the values in each column of the PCM.

b. Normalize the PCM by dividing each element in the matrix by its column total.

c. Calculate the average of the elements in each row of the normalized matrix by dividing the sum of the normalized scores for each row by the number of the criteria.

Table 5 shows the steps to determine the relative criterion weights using the values of the PCM example of Table 4.

Table 5 Steps to determine weights

Steps	a			b			c
Criterion	**A**	**B**	**C**	**A**	**B**	**C**	**Weights**
A	1	3	8	0.702	0.714	0.571	(0.702+0.714+0.571)/3= 0.662
B	1/3	1	5	0.211	0.238	0.357	(0.211+0.238+0.357)/3= 0.269
C	1/8	1/5	1	0.088	0.048	0.071	(0.088+0.048+0.071)/3= 0.069

When the number of elements to be compared in the PCM increases, the consistency in the judgments is more difficult to control, although the AHP does not demand perfect consistency and an inconsistency ratio of about 10 percent or less is considered acceptable. More details about the causes of inconsistency can be found in Sharifi and Herwinjen (2003) and about how the estimation of consistency ratio can be seen in Malczewski (1999).

For each level of the hierarchy an aggregation of the weights derived from the PCM has to be made, for this, the most often used method is the weighted linear combination or additive weighted values (Equation 1). An overall score is obtained for each alternatives by multiplying the importance weight assigned to each criterion by the scaled value given to the alternative of that attribute (Malczewski, 1999). Thus the overall score of the alternatives depends of the total sum of its rating in the different level of the hierarchy. Formally:

$$Vi = \sum_{j} w_j \; x_{ij}$$

Equation 1 Weighted linear combination

Where: *Vi* is the overall value of alternative *i*, w_j is the weight assigned to criterion *j* to reflect its importance related to other criterion and x_{ij} is the score of alternative *i* on criterion *j* (Belton, 1986).

2.5. Ecologic Management Plan of the watershed of Lake Cuitzeo

The territory is the physical space where the social, economic and cultural activities take place and interact with the natural environment. This process determines the characteristics of the landscape and represents the particular environmental history, a product of the human transformation of the ecosystem (EMPLCB, 2006).

The human activities are the main causes of the transformation of the natural habitats in terms of losses of biodiversity, ecological function and of alterations of the hydrologic cycle. In this sense, it is important to design planning strategies of the territory through tools that allow measuring the dynamic change in the environment due the human impact (SEMARNAT 2006). For this, in Mexico, the General Law of Ecologic Equilibrium and Protection of the Environment (LGEEPA, 2007) at federal level, and the Law of Ecologic Equilibrium and Protection of the Environment (LEEPAE, 2007) at state level, propose the Environmental Management Plan of Lake Cuitzeo

Basin (EMPLCB, 2006), to construct a strategy to planning the land uses related to the natural resources. The main objective of the EMPLCB is to assure the functionality and sustainability of the natural environment according to the necessity of the inhabitants and the productive activities realized in the LCB, in such a manner to achieve a balance between human transformation and conservation of the environment.

The EMPLCB determine the criteria of ecologic management for the preservation, protection, restoration, and sustainable use of the natural resources. This regional plan stipulates the rules for the environmental programs for its implementation and the evaluation of these. In this particular case, the regional environmental planning is coordinated by the environmental agency of the government of the State of Michoacán.

2.6. Environmental policies

The local environmental policies are designed to make the link between the national environmental strategies established in the federal government (LGEEPA, 2007) and the regional and local environmental properties at a local scale. In general terms, these policies regulate and establish the criteria for managing the natural resources.

In the state of Michoacán four environmental policies are recognized by the local legislation:

- Conservation
- Sustainable use
- Restoration
- Protection

2.6.1. Conservation

The main objective of this policy is to implement managements tools that allows maintaining the natural services of the system through the preservation of its landscape values (FAO, 2003):

- Ecological diversity
- Ecological stability
- Soil integrity
- Hydrological features
- Aesthetical character

The conservation policy implies the assumption that the structural functions of the landscape have priority over the productive and economic functions.

Conservation policy in the LCB

This policy is applicable in areas with a relevant ecological function. According to the EMPLCB, the areas that have to be preserved are those related to the maintenance of the recharge of aquifers, the ecological stability and the aesthetical characteristics of the landscape (EMPLCB, 2006).

2.6.2. Sustainable use

Sustainable use has its basis on the capacity of the system to support production activities without modifying the ecological balance (LGEEPA, 2007). It is applied in accordance with the actual or potential uses of the areas. The sustainable use policy recognizes the need to modify or even lose some environmental services, but without compromising the environmental stability of the area.

Sustainable use policy in the LCB

The policy is applicable in areas with a high potential for a type of land use involving one of the main productive activities developed in the LCB (EMPLCB, 2006). The areas with high erosion potential or with high potential flood and landslides hazards have to be avoided to minimize the risk of environmental degradation and avoid endangering the productive activities.

2.6.3. Restoration

This policy promotes programs and activities to stop or minimize the environmental deterioration due to incorrect management of the system. In this sense, areas with high rates of deforestation and erosion could be selected for the application of this policy to recuperate the environmental services. This policy designs restoration programs in degraded areas with the potential to be utilized in the short and medium terms (EMPLCB 2006).

2.6.4. Protection

This environmental policy promotes the permanency of the native ecosystems that, according to its extension, particularities and biodiversity attributes, deserve to be included in the natural protected areas system at the federal, state or municipal level.

The present study focuses on the conservation and sustainable use environmental policies. The main reason for this is that the restoration and protection policies are distributed in small areas of the basin due the restrictive parameters in which they are evaluated. Thus, these areas are taken as constraints in the evaluation for the conservation and sustainable use policies.

It is important to note that the restoration and the protection policies are going to be excluded of the prioritization process. This is because I consider that the restoration and the protection areas are defined by specific attributes and are not susceptible to be aggregated in a municipal and sub-watersheds levels.

2.7. Environmental management units

An environmental management unit (EMU) is the minimum area of the ecologic planning program where the environmental policies are applicable with specific rules and strategies to achieve the desired state of the area. An EMU is characterized according to the homogeneity in its biophysical, socioeconomic and potential use attributes. It represents the administrative unit of the EMPLCB. The definition of EMUs takes into account the potential land use and the conflicts between that and the present use.

The EMUs are based on the ecological regionalization of the LCB (Mendoza, 1997; 2001); where the geomorphological and edaphic characteristics, and the land cover types were integrated to generate systematic information about the landform units. The geomorphologic regionalization was the basis of the ecologic regionalization, were the selected hierarchy system was the geopedologic approach of Zinck (1988). In this sense the EMU correspond to the level of landforms.

The landforms are characterized by a particular modeled process determined by attributes like weather condition, type of rock, soil and land cover. In consequence, each of these units has an explicit distribution through the space and present particular ecologic function. The LCB is divided into 202 EMU derived from the above-mentioned ecological regionalization.

The importance of the EMUs to this study is related to the fact that each of these units has been assigned to an environmental policy corresponding to its bio-physics and social characteristics..Due the fact that the EMUs have a predefined environmental policy affinity assessed in the EMPLCB, these units are important elements to consider in measuring the relative importance of the municipalities and sub-watersheds for each of the environmental policies. Moreover, the EMUs play an important role in the construction of the scenarios, as well in the final ranking of each of the municipalities and sub-watersheds as is mentioned in section 7.2.3

3. Study area

3.1. Localization and general characteristics

The endorreic watershed of Lake Cuitzeo is localized in central Mexico within the Trans-Mexican volcanic belt, in the state of Michoacán. The extreme coordinates are: 19° 30´, 20° 05´ North latitude and 100° 35´, 101° 30´ West longitude see Figure 3. It is distributed in an area of approximately 4, 000 km^2.

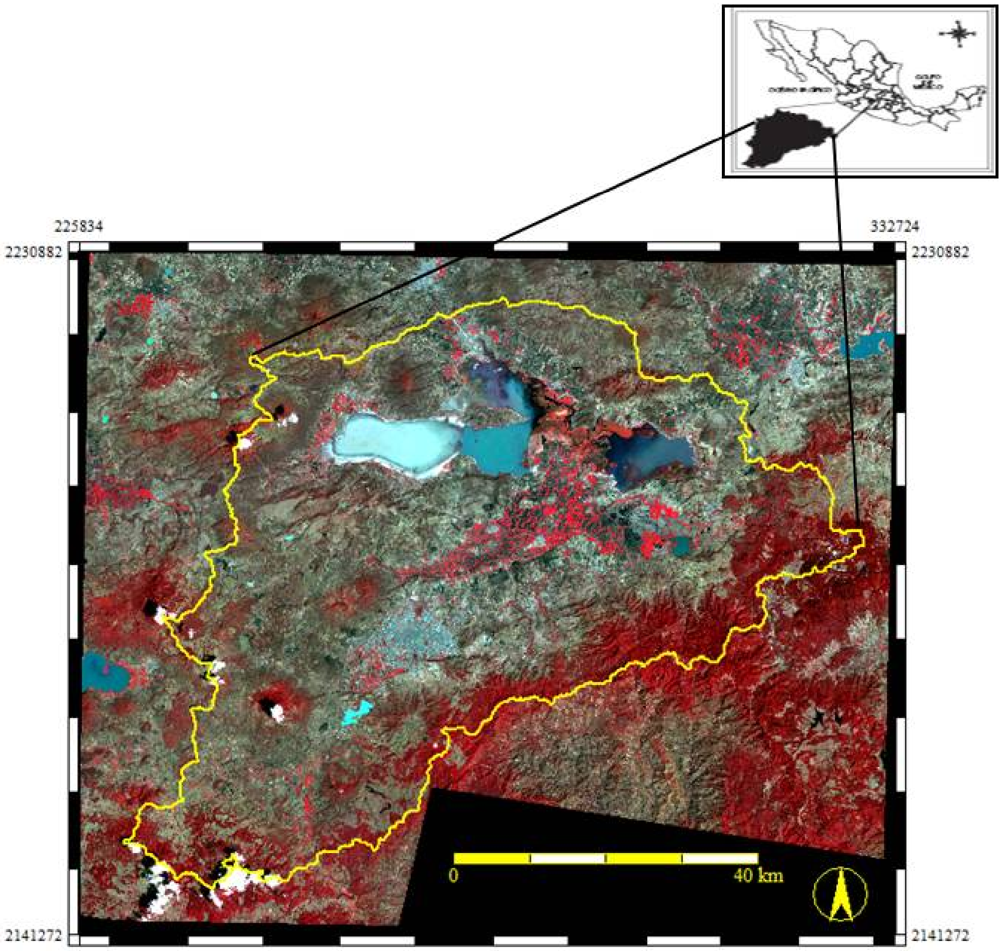


Figure 3 Localization of Lake Cuitzeo Basin. LANDSAT (Merge) 2003

The climate is temperate with seasonal summer rainfall, the average annual temperature is 17° C, and the annual rainfall is about 800 mm. The watershed is divided in 53 sub-watersheds.

The lower zone of the basin is the lake at 1,340 of altitude and the higher zone is about 3,600 meters above the sea level. It is developed over volcanic materials of Miocene–Quaternary age.

3.2. **Land cover**

The land cover represents the natural or artificial objects that cover the soil surface, these can be originated by natural environments through the ecologic evolution process or developed through artificial environments constructed and maintained by human beings (López et al., 2001).

In the Lake Cuitzeo basin, the temperate forest of pine and oak covers approximately a 20% of the basin, the sub-tropical scrubland, a 23%, grasslands, a 6% and rain-fed and irrigation agriculture is distributed over a 35% of the territory, see Table 6 and Figure 4**.**

Table 6 Land cover 2003 (Mendoza et al., 2006)

Land cover	Ha.	% of cover in the basin
Forest	80,278	19.6
Scrubland	94,956	23.7
Grassland	25,268	6.2
Rain-fed-agricultural land	74,385	18.5
Irrigated agricultural land	62,313	15.5
Forest Plantation	4246	1.1
Orchards	2935	0.7
Aquatic vegetation	5720	1.4
Lake	30,162	7.5
Human settlements	19,416	4.8
Eroded areas	1517	0.4

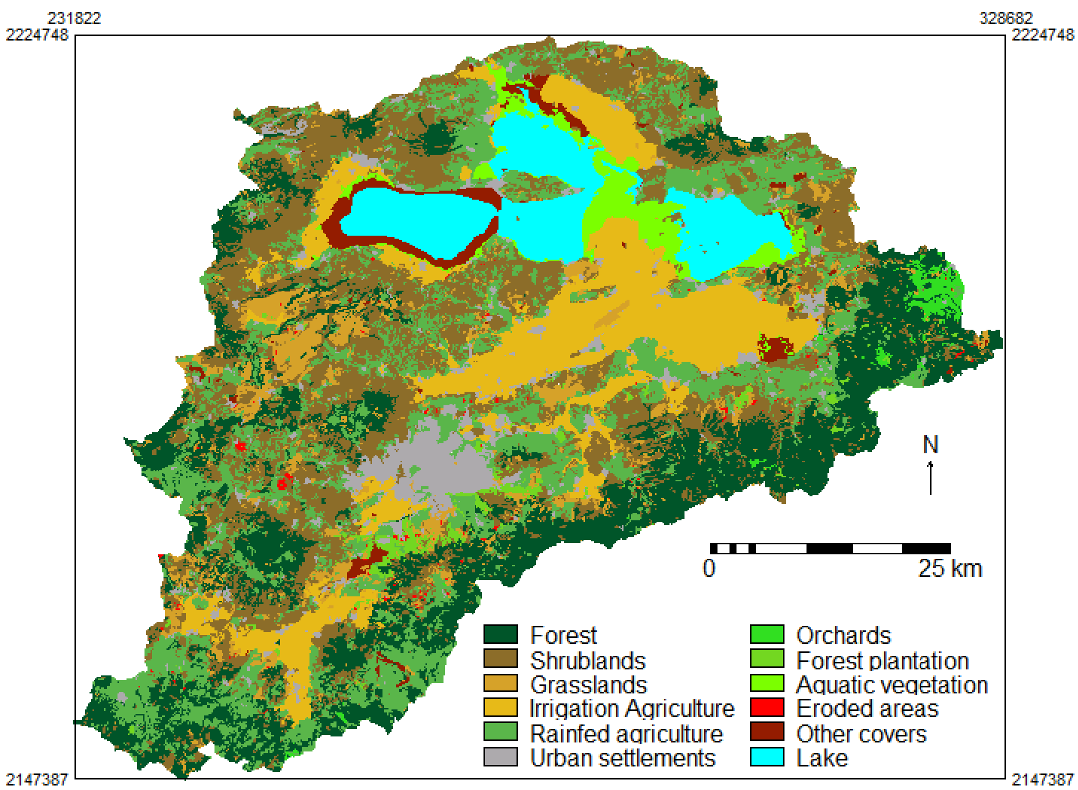


Figure 4 Generalized land cover 2003 (Mendoza et al., 2006)

The basin contains the Lake Cuitzeo with approximately 300 Km^2, being the second largest lake in Mexico. It is considered to have a high ecologic value, due the flora and fauna that develop in the wetland.

3.3. Municipality arrangement of the basin

One of the main features of the basin is the anthropogenic impact present in certain zones, in the central part, the capital city of Morelia is settled, with almost 1,000,000 inhabitants (INEGI, 2000), being the mayor urban core of the basin. Moreover, the city is undergoing an expansion process, thus, urbanization is one of the mayor impacts over the natural assets of the region. Another important social feature of the region is the high migration rate, excluding the capital, high levels of migration are present throughout the region, it is presumable that this high migration rates over the past years have had consequences in the land use change within the basin due to the abandonment of agricultural land.

Within the Lake Cuitzeo Basin territory 26 municipalities are totally or partially distributed (Figure 5 and Table 7), 20 of them belonging to the state of Michoacán and 5 to the state of Guanajuato.

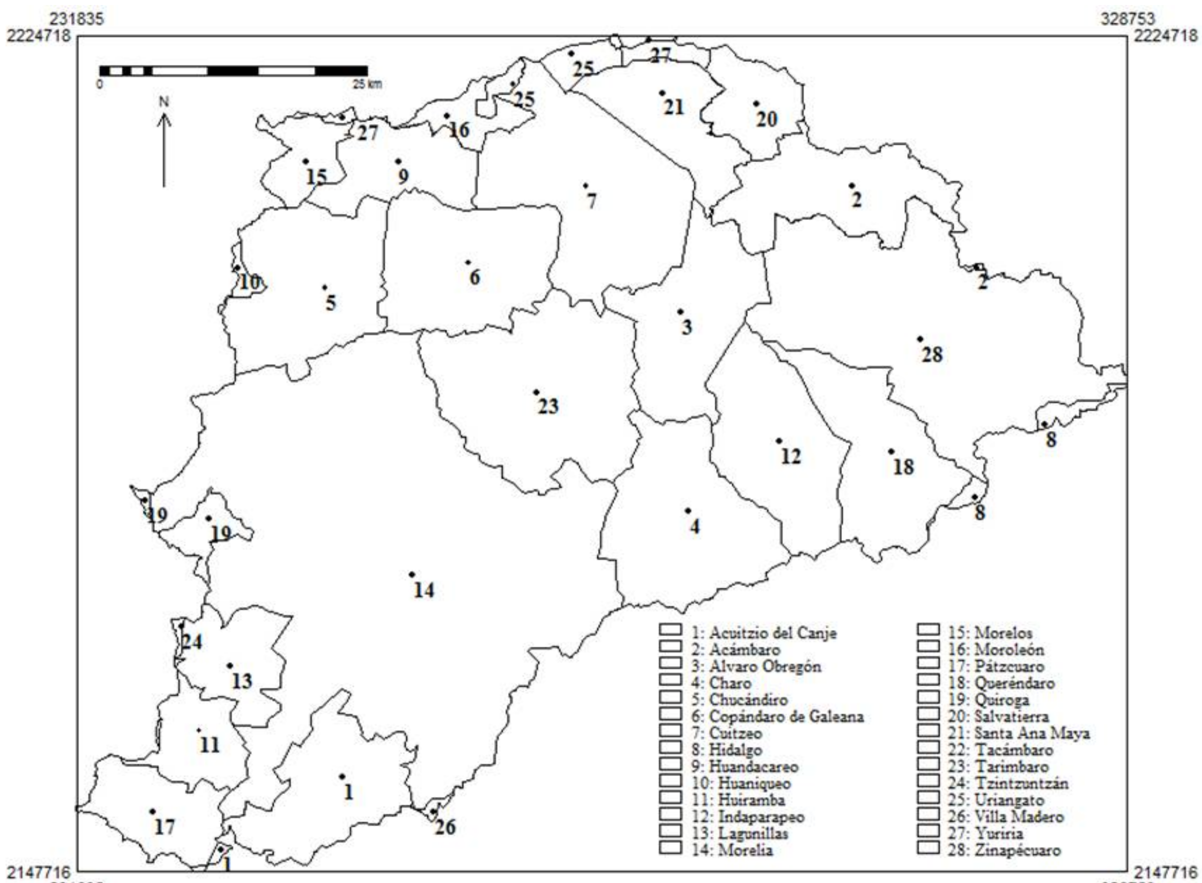


Figure 5 Distribution of municipalities within the Lake Cuitzeo Basin

Table 7 Municipalities within the Lake Cuitzeo Basin

Municipality	State	Area within the LCB Km^2	% of cover in the LCB	% of the municipality within the LCB.	Total Area
MORELIA	Michoacán	1058.5	26.3	100	1058.5
ZINAPÉCUARO	Michoacán	428.4	10.6	73.9	580
TARÍMBARO	Michoacán	262.4	6.5	100	262.4
CUITZEO	Michoacán	255.4	6.3	100	255.4
CHARO	Michoacán	200.1	5.0	62.1	322
CHUCÁNDIRO	Michoacán	183.5	4.6	95.5	192.2
COPÁNDARO	Michoacán	175.5	4.4	100	175.5
INDAPARAPEO	Michoacán	167.8	4.2	95	176.7
QUERÉNDARO	Michoacán	159.5	4.0	68	234.4
ÁLVARO OBREGÓN	Michoacán	157.0	3.9	96.6	162.6
ACUITZIO	Michoacán	140.6	3.5	78.1	180.1
SANTA ANA MAYA	Michoacán	103.7	2.6	100	103.7
HUANDACAREO	Michoacán	90.8	2.3	95.5	95.1
PÁTZCUARO	Michoacán	81.2	2.0	18.6	435.9
LAGUNILLAS	Michoacán	76.8	1.9	93.4	82.2
MORELOS	Michoacán	75.8	1.9	40.7	186.4
HUIRAMBA	Michoacán	65.6	1.6	82.7	79.3
QUIROGA	Michoacán	29.0	0.7	13.7	211.5
HIDALGO	Michoacán	16.1	0.4	1.5	1063
HUANIQUEO	Michoacán	6.9	0.2	3.4	201.1
VILLA MADERO	Michoacán	3.1	0.1	0.3	1019
ACÁMBARO	Guanajuato	145.7	3.6	16.8	867.6
SALVATIERRA	Guanajuato	64.2	1.6	11	581.8
MOROLEÓN	Guanajuato	31.9	0.8	20.3	156.9
URIANGATO	Guanajuato	29.0	0.7	25.5	113.8
YURIRIA	Guanajuato	17.4	0.4	2.6	664.1

3.4. Sub-watersheds arrangement of the basin

The visual interpretation of the contour lines arrangement and an the drainage pattern at a 1:50,000 scale produced by the INEGI , allows to differentiate 38 sub-watersheds that drain onto the lacustrine plain or directly into the lake (Figure 6 and Table 8).

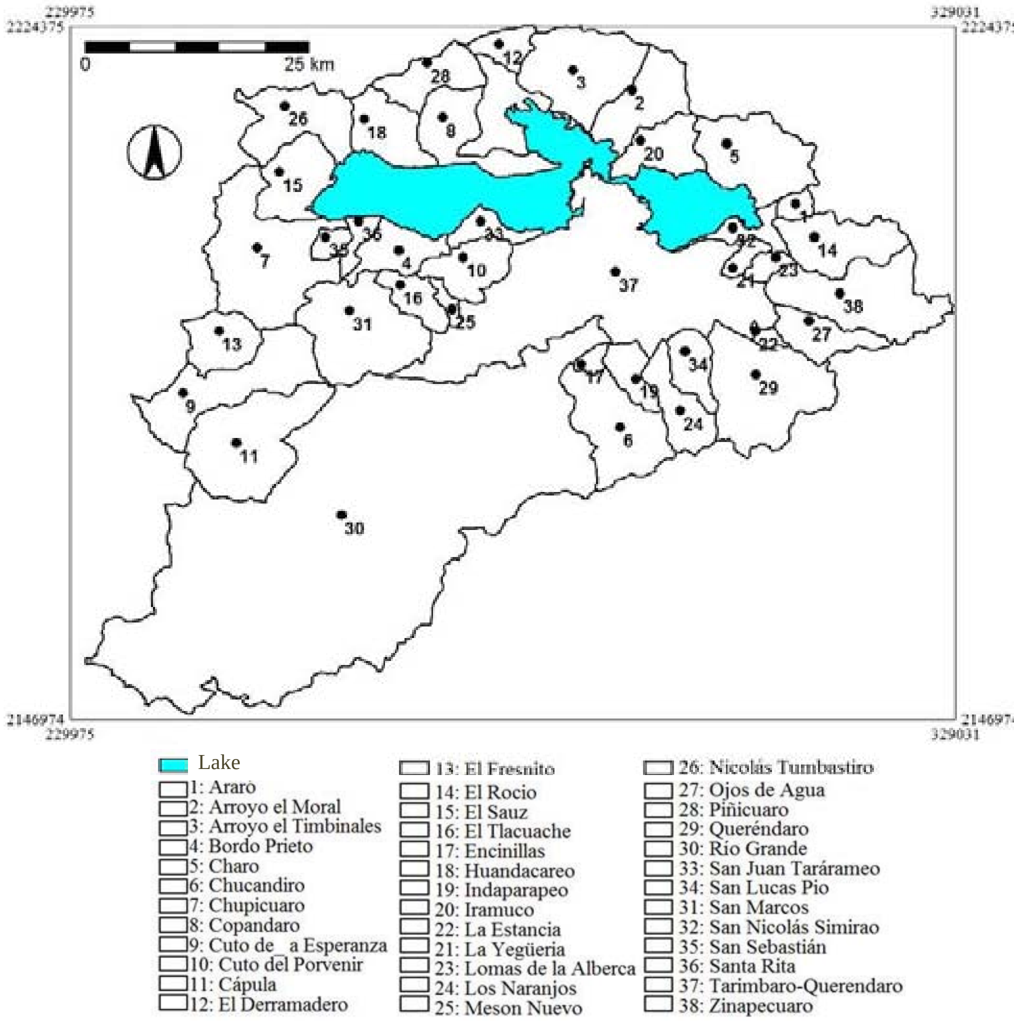


Figure 6 Sub-watersheds arrangement within the basin

Table 8 Sub-watersheds within the Lake Cuitzeo Basin

Sub watershed	% of cover in the LCB	Total area
ARARÓ	0.28	11.27
ARROYO EL MORAL	1.67	66.98
ARROYO EL TIMBINALES	2.64	105.56
COPANDARO	1.06	42.38
BORDO PRIETO	2.43	97.35
CHARO	2.42	96.67
CHUCANDIRO	3.98	159.45
CHUPICUARO	1.69	67.71
CUTO DE LA ESPERANZA	2.77	110.72
CUTO DEL PORVENIR	1.19	47.61
CAPULA	3.28	131.34

Continue (Table 8 Sub-watersheds within the Lake Cuitzeo Basin)

EL DERRAMADERO	0.58	23.39
EL FRESNITO	1.15	45.9
EL ROCIO	1.76	70.28
EL SAUZ	1.51	60.43
EL TLACUACHE	0.74	29.77
ENCINILLAS	0.2	8.14
HUANDACAREO	1.36	54.46
INDAPARAPEO	0.68	27.08
IRAMUCO	1.19	47.8
LA YEGÜERIA	0.29	11.78
LA ESTANCIA	0.17	6.69
LOMAS DE LA ALBERCA	0.3	11.86
LOS NARANJOS	1.18	47.08
MESON NUEVO	0.21	8.29
NICOLÁS TUMBASTIRO	1.94	77.64
OJOS DE AGUA	1.05	42.03
PIÑICUARO	1.19	47.68
QUERÉNDARO	3.34	133.71
RÍO GRANDE	29.2	1168.4
SAN MARCOS	3.11	124.5
SAN NICOLÁS SIMIRAO	0.55	22.05
SAN JUAN TARÁRAMEO	0.54	21.74
SAN LUCAS PIO	0.84	33.64
SAN SEBASTIÁN	0.29	11.62
SANTA RITA	0.37	14.95
TARI-QUERE	10.63	425.5
ZINAPECUARO	3	120.05
.FLOOD ZONE	1.48	59.03
.LAKE	7.75	310.12

4. Method and materials

There are a number of alternative ways to organize the sequence of activities in the decision making process. According to Keeney (1992) two main approaches are considered; the alternative-focused approach and the value-focused approach (see section 2.2). In this study, a value-focused approach was used. Although the alternatives, in this case the municipalities and sub-watersheds are previously established, the fundamental values needed to reach the objectives of each of the environmental policies are analyzed first.

The method is a three-phase process (Figure 7):

1. **Problem formulation "Intelligence phase"**

This is the phase in which the problem is formulated and that leads to the development of the criteria structure for each of the policies. The sequence of activities in this phase is as follow:

- Identify the objectives of the conservation and sustainable use policies based on the requirements of each of the policies stipulated in the local environmental laws.
- Define proper criteria to characterize each objective and sub-objective.
- Define the constraints of each objective and sub-objective to establish the unsuitable areas related to the conservation and sustainable use policies.

2. **Assessing the overall suitability of the municipalities and sub-watersheds. "Assessment"**

In the assessment phase the indicators that can be used for the assessment of the spatial units of the LCB for the conservation and sustainable use policies are defined. The main objective of this phase is to perform a spatial multicriteria evaluation using the criteria structure and constrains defined in the previous phase, in order to produce a suitability map for the conservation and sustainable use policies. For this it was necessary to:

- Construct the indicators for each of the defined criteria.
- Define the relative importance of the criteria and indicators.

3. **Ranking of the sub-watersheds and municipalities**

This phase led to the evaluation and ranking of the sub-watersheds and municipalities based on their overall suitability for the application of the conservation and sustainable use policies. The activities of this phase are:

Definition of new criteria structure for the evaluation of the spatial units for each of the environmental policies.

- Performing a spatial multicriteria evaluation using the new criteria structure.
- Aggregation in the spatial units of the suitability map of this phase to establish a ranked order of these for the conservation and sustainable use policies.
- Finally, a sensitivity and conflict analysis was carried out to validate the results.

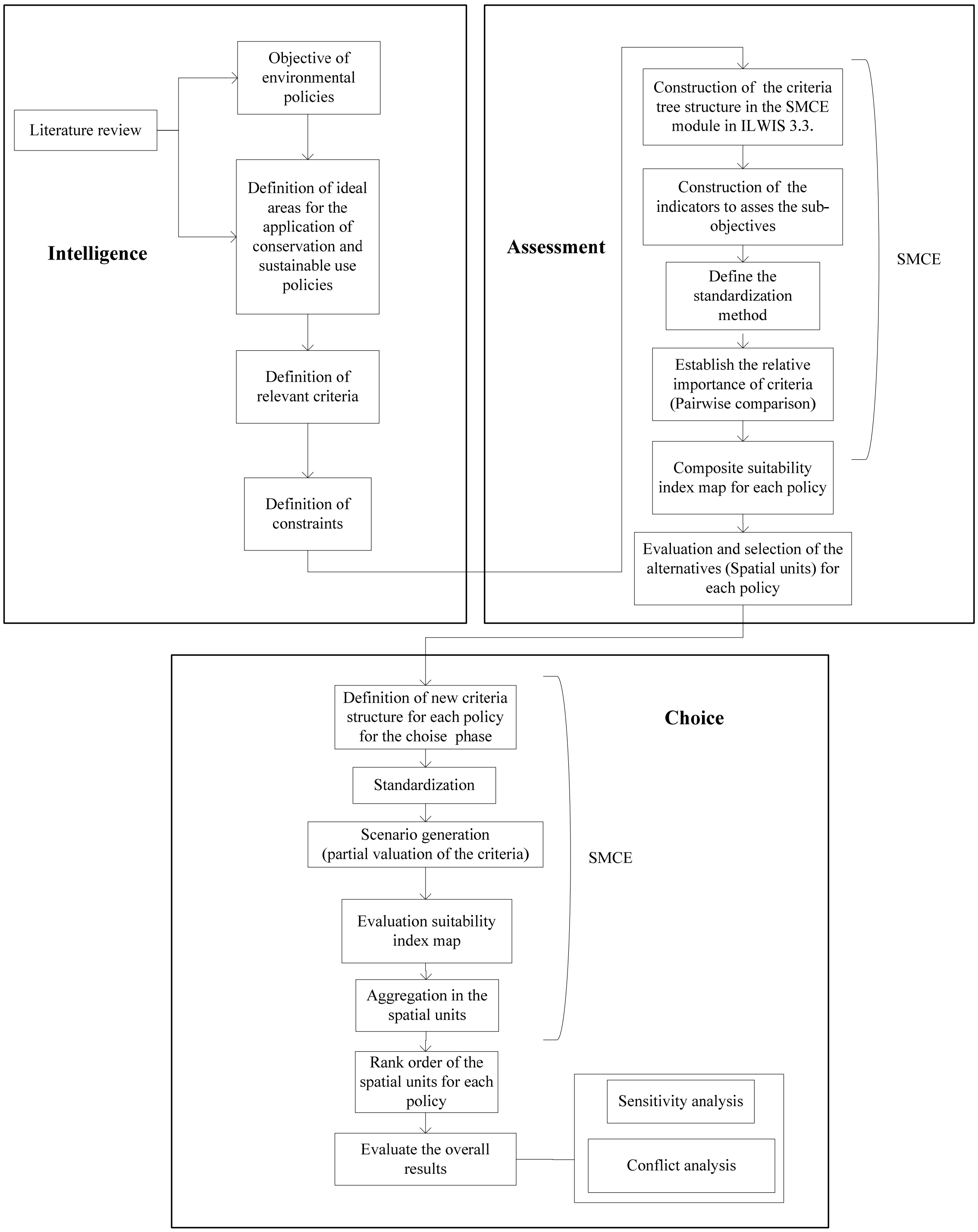


Figure 7 Simplified scheme of the three-phase process

Paths to evaluate the alternatives

In this spatial problem, the alternatives have to be described based on a set of maps providing information about each of the criteria. For this purpose, the problem can be visualized as an evaluation "table of maps" or "map of tables" that has to be transformed into a final ranking of the alternatives. For this, the aggregated process can be visualized in two different paths (Sharifi et al., 2004) : 1) aggregation in the spatial component and 2) aggregation of the criteria, see Figure 8. The difference between these two paths is the order in which the aggregation takes place. In Path 1, the effects of each criterion in the alternatives can be visualized in a map, and then all the information is aggregated in a non-spatial value for each criterion to derive the final utility for the alternatives. In Path 2, first an aggregation among the criteria is made to produce a suitability map for each of the alternatives. In a second step these suitability maps are aggregated into a non-spatial value to derive the final utility of each alternative

In the present study Path 2 is followed: the multicriteria analysis playing the main role, which means, that the criteria are aggregated first, and then the resulting suitability map is aggregated across the spatial units.

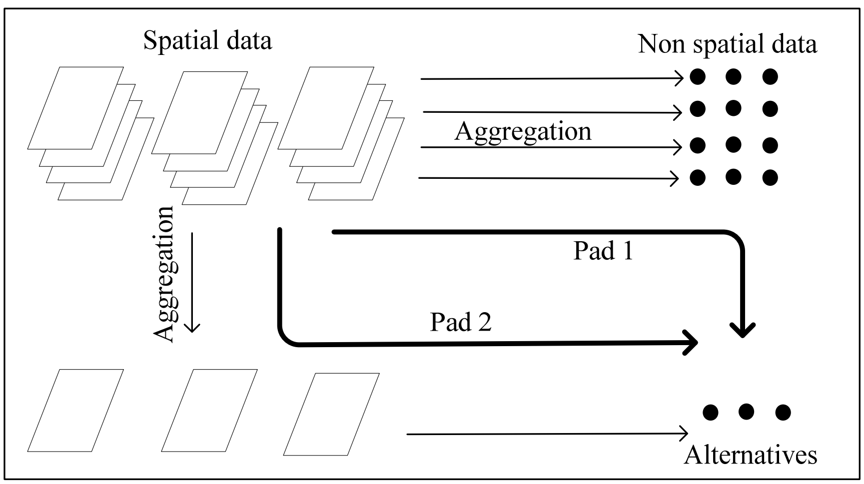


Figure 8 Two paths to evaluated the alternatives modified from Sharifi et al., 2004

4.1. Materials

All the analysis was carried out in a raster environment of the Spatial Multicriteria Evaluation module of the Integrated Land and Water Information System. ILWIS, version 3.3 (ITC, 2005).
The pixel size of all the raster maps was recalculated to 50 meters.

4.1.1. Spatial Data

The following maps were used and created in the preparation phase:

1. Land cover and land use digital maps, Scale 1: 50,000 of the following years:

-1975 (Lopez-Granados et al., 2001).
-1996 (Mendoza et al., 2005).
-2003 (Mendoza et al., 2005).

The 1975 map was based on the interpretation of panchromatic air photos at a 1:50,000 scale. For the 1996 map, digital orthophotos were interpreted with a 2x2 meters resolution. For the 2003 map an image interpretation of a 2003 LANDSAT7 ETM was made. Due to the fact that all the sources have different spatial resolutions; an area of 3 hectares was used as a minimal cartographic unit, adequate for all the image documents. The estimated accuracy for the land cover is 95 percent (Lopez et al., 2006).

2. Land suitability digital maps of the Lake Cuitzeo Basin (EMPLCB 2006):

-Rangeland use
-Rain-fed agriculture use
-Irrigation agriculture use
-Orchard use
-Forestry use

The land suitability maps compiled by Pulido *et al.*, (2001) are based on the land evaluation scheme proposed by FAO (1976). This spatial information is derived from the diagnostic phase of the EMPLCB (2006), and represents the physical evaluation for the most common land uses within the basin.

3. Distribution of suitable areas for restoration within the LCB (EMPLCB, 2006), Digital format. Scale 1:50,000.

4. Distribution of roads and communication infrastructure. 2002. Digital format. Scale: 1:50,000.

5. Distribution of human settlements. 2002. Digital Format. Scale: 1:50:000.

6. Functional zones of the Lake Cuitzeo basin, 2007. (Felipe, In preparation). Digital format. Scale: 1:50,000.

7. Topographic map series. 1999. Digital format. 1:50,000.

8. Hazard maps of the LCB, including:

- Erosion potential map (Mendoza et al., 2005), based in the Universal Soil Lost Equation (USLE). Digital map.

- Flood hazard within the Lake Cuitzeo Basin (Mendoza et al., 2005). Digital map.

- Land-slide hazard within the Lake Cuitzeo Basin (Mendoza et al., 2005). Digital map.

4.1.2. Non spatial data

1. Poverty index at municipal level in the LCB, 2005 (CONAPO, 2005).

5. Problem formulation "Intelligence phase"

To define the criteria structure for the identification of the suitable areas for conservation and sustainable use policies, it was necessary to identify the main objective of each of the policies and the ideal characteristics that the areas have to possess to be considered suitable.

5.1. Conservation policy: Objective and characteristics of ideal areas

The potential areas to conserve according to the EMPLCB (2006) are the ones where the vegetation cover is in a good state of preservation. In this aspect, the main environmental elements are the recharge of the aquifers, generation and conservation of the soils, and preservation of the biodiversity. The temperate dense (areas with more than 80 percent forest cover) and semi-dense forests (areas covered by 50 to 80 percent forest) fulfill this requirement in the LCB.

The potential areas where the conservation programs could be applied should have the minimal disturbance by human activities. The present land use has to be taken into account to minimize the conflicts between the productive activities and the conservation programs (LEEPAE, 2007).

Other important characteristics required by susceptible areas for conservation are the stability in terms of land cover change; i.e. reforestation, or degradation processes of the valuable forest cover. According to the state environmental law (LEEPAE, 2007), the areas for conservation have to be stable over time or present a positive process of regeneration of the vegetation cover. The conservation programs have to be focused on maintaining and promoting this valuable vegetation cover.

The main objective for the application of the conservation policy in the LCB according to the local environmental law (Mendoza et al., 2005; Mendoza, 2006; Michoacán, 2006; LEEPAE, 2007; LGEEPA, 2007) is to:

Preserve the environmental elements that allow to maintain the environmental services and at the same time minimize the conflicts between the productive activities and the conservation programs.

5.1.1. Definition of criteria for the conservation policy

Taking into consideration the main objective of the conservation policy in the LCB, and the characteristics that the ideal areas have to fulfill, it was necessary to identify the relevant criteria that allow assessing the suitability to apply the conservation programs. Thus, to achieve the main goal of the conservation policy, four main criteria were proposed, see Figure 9.

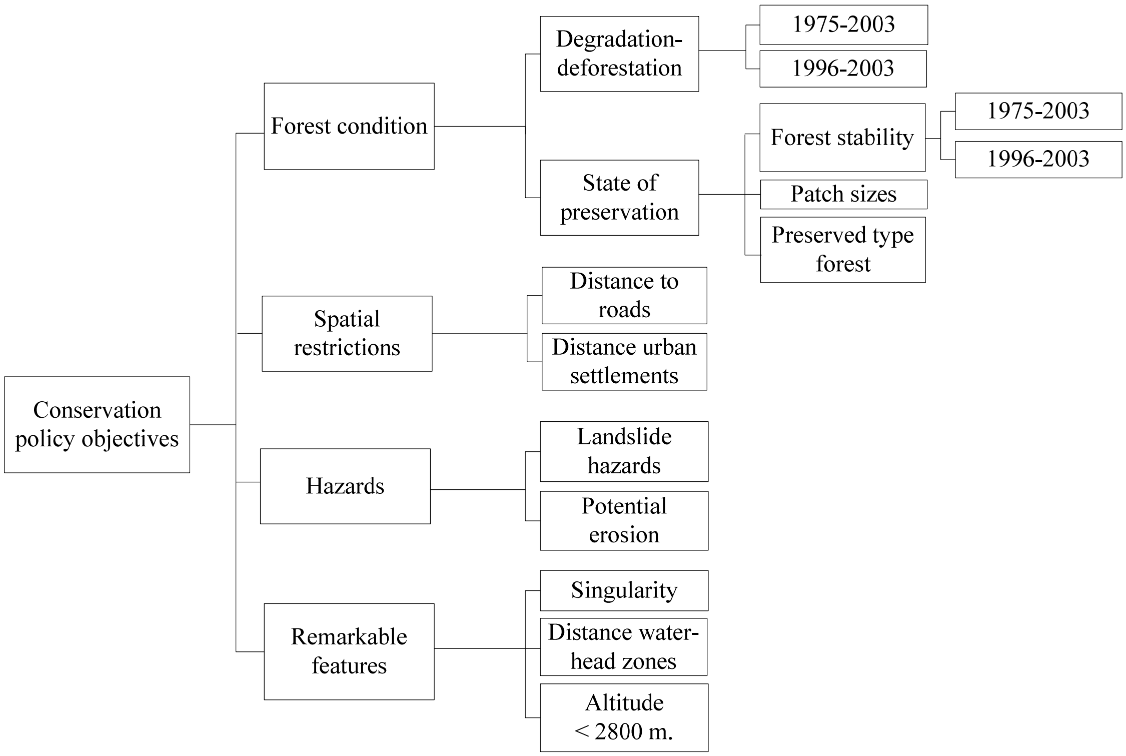


Figure 9 Criteria structure for assessing the suitability for the conservation policy in the LCB

Forest condition main criterion

This criterion is related to the distribution of the areas where the characteristics of the forest cover are suitable for the conservation policy, taking into account the process of change and the state of preservation of the forest. This main criterion is composed of two factor groups which are explained in the following paragraphs.

Forest degradation-deforestation: This sub criterion includes areas where the processes of degradation have occurred, which means the change from one category of forest to another category of forest with a lower state of preservation, i.e. shift of “dense forest” to “open forest”, furthermore, areas with deforestation, i.e. the change of any category of forest to another not forest category. Two periods were taken into account: 1975 to 2003 and 1996 to 2003. The first period includes the overall process of degradation-deforestation of the forest cover through almost 30 years; the second period allocate the most recent degradation-deforestation processes. In this last period only the areas with forest recovery between the years 1975 to 1996 were taken into account. This was made to avoid double counting and overestimation of the forest degradation-deforestation. The last period represents the land use change induced by the recent predominant productive activities. This factor has a negative relation with the application of the conservation policy. A pairwise verbal comparison was made giving a moderately more important judgment to the last period due that represent the localization of the recent degradation-deforestation process.

State of preservation: In this sub criterion, the present state of the forest cover is evaluated under the indicators of the type and size of the area covered with forest, also the trends of change are considered taking into account the reforestation process in the basin. This sub criterion is composed of three indicators:

a. Forest stability. This indicator is based on the areas with “dense forest” and “semi-dense forest”, which do not change through the period between 1975 and 2003. A second period between 1996 and 2003 is evaluated but taking into account only the areas where the forest cover showed recovery in the period between 1975 to 1996, and was preserved until 2003.

The total area of stable forest of the period between1975 to 2003 comprises 327 km^2. In the period between 1975 and 1996, the forest cover that was recovered and maintained until 2003 occupies an area of 440 km^2. Due to the dominance of this latter area, it is necessary to detect and promote this forest recovery process.

Taking into consideration the importance of the reforestation process in the basin, and that one of objectives of the conservation policy is to maintain and promote the reforestation process, the forest stability between 1996 to 2003 appears to be moderately more important than that during the period between 1975 to 2003 because it represents the areas where the recent environmental conditions allow for the recovery and maintenance of the forest cover.

b. Patch size. This indicator represents the patch size of “dense”, “semi-dense” and “open forest” of the general land cover of 2003. This is a benefit factor, the bigger the patch, the higher the value and the higher the score. According to (Villaseñor, 2005), a zone is considered “dense forest” when it is covered with more of the 80 percent of its area with forest cover, ‘semi-dense forest” are areas covered in a 50 to 80 percent and the “open forest” is covered in less than a 50 percent of the area.

c. Forest density. Represents the present density of the forest cover. This indicator is related to identifying the best-preserved type of forest due to its value in maintaining the ecologic stability in the basin. This indicator is derived from the reclassification of the land cover of 2003. The categories considered were “dense forest”, “semi-dense forest”, “open forest” and “not forest”; in this last category all non-forest categories were included. The relative importance was established through a pairwise comparison, where the “dense forest” appears to have more relative importance than the “semi-dense forest”, the “open forest” and the “no forest”, respectively. The values derived from the pairwise comparison were represented in an attribute table.

Spatial restrictions main criterion

This criterion aims at minimizing the disturbance produced by the infrastructure in areas suitable to the application of conservation programs. It is composed of two factors:

Distance to urban settlements: The areas suitable for the application of a conservation program have to be as far as possible from the disturbance of urban activities. An settlement in considered to be urban when it has more than 2,000 inhabitants (INEGI, 2001). A minimum distance of 3,000 meters is required (EMPLCB2006). The higher the distance to the urban cores the higher the score.

Distance to roads: This is based on the distribution of the paved and dirt roads. This criterion is based on the assumption that the road infrastructure is a disturbance factor for the areas with valuable characteristics for the conservation policy, specifically for the preserved forest cover. A minimum distance of 500 meters is required (Villaseñor, 2005). The higher the distance to the roads the higher the score is.

Special criterion (remarkable feature) main criterion

This criterion refers to particular conditions in the territory that enhance the value for the application of the conservation policy. This criterion is composed by the following factors:

Singularity: This factor is the combination of two attributes. First, the volcanic cones and lava flows are considered, because these areas represent high rates of groundwater recharge due the permeability of the rock and the presence of fissures where the water infiltrates to the aquifers. Furthermore, the traditional agriculture with terraces represents an ancient practice in the basin that allows breaking the length of the slope, and in this way reduces soil erosion. Due to this, these areas were considered singular for the hydrological and cultural values in the LCB. Thus, they are important to be considered in the conservation policy.

Distance of headwater zones: This factor is related to capturing and infiltrating the runoff due to the conditions of land cover and soil properties (Michoacán, 2006).

The LCB is divided in three basic functional zones that compose a hydrological basin. The headwater zone is distributed over 1,764 km^2 and comprises approximately a 40 percent of the total area of the basin, the transit zone comprises 1,352 km^2 and the emission zone covers 575 km^2, representing a 33 and 14 percent respectively. The remaining percentage is covered by the lake. The headwater zone in the LCB is mainly distributed in mountains of volcanic origin. The dominant type of soils are the Phaeozems and Leptosols, which support the temperate forest cover, the higher terrestrial biodiversity and the higher rates of water recharge (Cotler et al., 2004).

The degradation in the headwater zone has a consequence in the reduction of the water recharge capacity of the system, as well as in the increase of the transportation of sediments and nutrients to the downstream areas affecting the quality of water of the artificial and natural water bodies, including Lake Cuitzeo. In addition, the degradation in the higher zones of the basin reduces the life time of the dams due the accumulation of sediments. Thus, the headwater zones are valuable areas for the application of conservation programs. In this sense these factor have a negative relation: the higher the distance, the lower the score.

Altitude: Areas with altitudes greater than 2,800 m present particular geologic, edaphic, and climatic conditions, that have an influence on the establishment of particular vegetation covers, i.e.

fir (*Abies* spp.) forest (Villaseñor, 2005). Most of the primary forest cover is distributed within the higher areas of the basin. This gives more relative importance to the higher areas.

Hazards main criterion

This criterion is composed of two sub-criteria:

Landslide hazard: The use of these zones for productive activities is restricted due the potential hazard this represents; nevertheless, for the conservation policy, the associate characteristics of these zones that are mainly distributed in the headwater zone gives them a high value for the application of conservation programs. The classes of this indicator are represented and evaluated in an attribute table.

Erosion potential: The distribution of the erosion potential for the LCB (Mendoza et al., 2006) was estimated using the Universal Soil Loss Equation (USLE). According to this model, a 50 percent of the basin does not present erosion potential. These areas are distributed mainly in the most densely vegetated areas of the basin; i.e., in the “dense forest”, the “dense scrublands” and in the lacustrine plain where the slope is almost zero. The areas with “very low” erosion potential cover a 32 percent of the basin and are associated to the soft hillsides covered mainly with scrubland. The areas with “high potential” erosion represent less than a 3 percent of the basin, mainly distributed in the areas with rainfed agriculture. Finally, the “very high” erosion potential represents less than a 2 percent of the basin, distributed in the periphery of Morelia city and is prone to the change of the land use due to the urbanization process.

Erosion potential has a negative influence on the application of the conservation policy. The less the erosion potential the more suitable is the region for conservation policy. The classes of this indicator are represented and evaluated in an attribute table.

5.2. Sustainable use policy. Objective and characteristics of ideal areas

According to the EMPLCB (Michoacán, 2006) the ideal areas for the application of the sustainable use policy should be of high productivity capacity. These main productive activities in the LCB are: rain-fed agriculture, irrigation agriculture, rangeland, forest and orchard.

This policy promotes the present land use with production activities, but a set of consideration has to be taken into account; the areas with high erosion potential or with high potential flood and landslide hazard have to be avoided to minimize the risks for productive activities.

The sustainable use policy recognizes the necessity of modifying some ecologic elements (vegetation cover, properties of soil, for example) of the environment. It is regulated to protect the main environmental elements that support the functionality of the basin in terms of the environmental services (Ocampo., 2003). In this sense, the well-preserved areas of forest cover in the LCB are taken as a restriction to the application of the sustainable use policy.

Finally, taking into account the change of the land cover due the migration of the rural population in the basin, the areas that support productive activities over the years have priority to be assigned to the sustainable use policy. On the other side, the areas that present regeneration of the vegetation cover due to the abandonment of the parcels are more valuable for conservation programs.

Taking into account the previous considerations and according to the concept of the sustainable use policy of the federal environmental agency (SEMARNAT, 2006), the local environmental law (LEEPAE, 2007) and the EMPLCB (2006), the main objective of the sustainable use policy is to:

Define the areas where the productive programs can be developed according to the distribution of the land production capacity and at the same time minimize the deterioration of areas containing a well preserved natural capital.

5.2.1. Definition of criteria for the sustainable use policy

The criteria tree for the application of the sustainable use policy has a structure similar to that for conservation policies, but the distribution of the weights of criteria and factors are different, as well as the number of criteria. To achieve the principal goal of the sustainable use policy four main criteria were identified, see Figure 10.

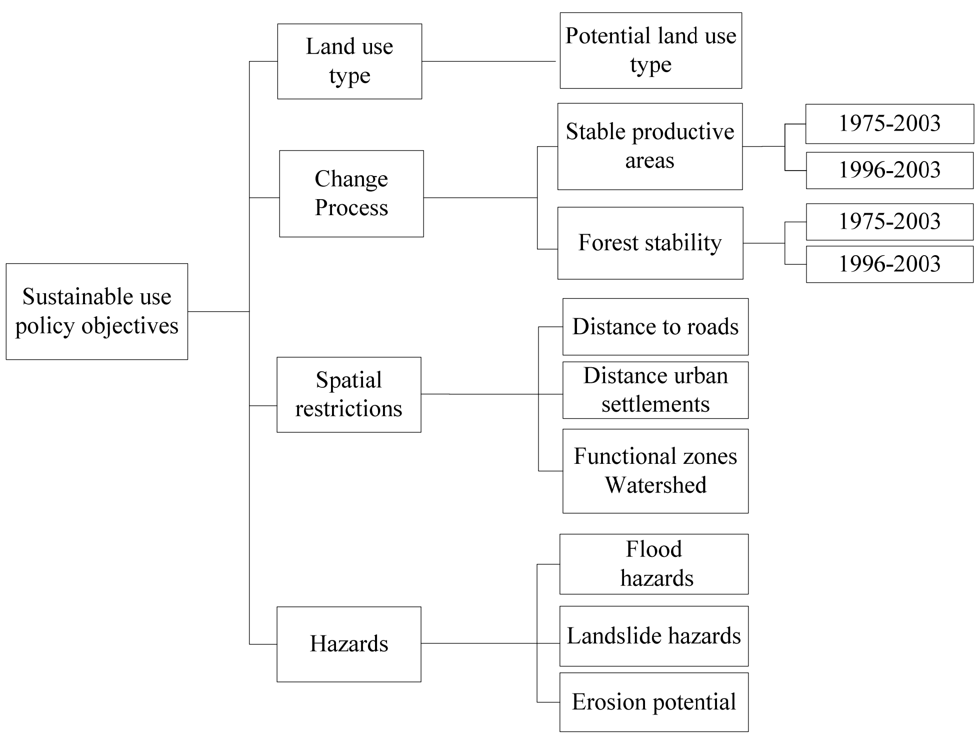


Figure 10 Criteria structure for assessing the suitability for the sustainable use policy in the LCB

Potential land use type main criterion

The land use types of the LCB Pulido *et al.,* (2001) are the product of the diagnosis stage of the Ecological Management Plan of the basin of lake Cuitzeo. This analysis was carried out to find the best potential productive land use, taking into account the relations between the biophysical factors and the productive projects of the region (EMPLCB 2006). This group of factors is composed by the most wide-spread potential uses in the basin, which are rain-fed agriculture, irrigated agriculture, orchards, forestry and rangeland. All the land use types present equal weights for this criterion.

At a lower level, a four-class suitability map represents each of the land use types. The classes are “High suitability”, “Moderate suitability”, “Low suitability”, “No suitable”, The areas with the best suitability for each potential land use have the higher relative importance with respect this criterion. The areas within the class “Moderate suitability” had the second relative importance, and so on. A pairwise verbal comparison was made among the suitability classes to determine their relative priorities.

Change process main criterion

This indicator considers the trend of the change of the most extended productive activities in the LCB. It takes into account those areas that have been used to a particular productive activity and the areas that changed to another productive activity in the most recent years. Furthermore, this indicator considers the recovery process of the forest vegetation and the type of forest to determine the suitability for the use of the territory for productive activities. This criterion is composed of three sub-criteria:

Stability of productive areas: This indicator represents the areas that are associated with the most widespread productive activities in the region: agriculture and rangeland. The land cover “dense scrub-lands”, “grass scrub-lands”, “dense grasslands” and “crops”, which did not change through the period between 1975 and 2003 have a good value for these productive activities. A second period is taken into account, between 1996 and 2003. In this period, only the areas that do not appear in the 1975 land cover as the classes mentioned before, and appear in the 1996 land cover and are maintained until the 2003 land cover are included. The last period represents the land use change induced by the recent predominant productive activities. A pairwise verbal comparison was made giving a moderately more important judgment to the last period, since that represents the recent predominant productive activities.

Forest stability: This indicator was calculated on the basis of the above-mentioned two periods: 1975-2003 and 1996-2003. These areas are not suitable to the productive activities. This indicator represents the areas with “dense forest” and “semi-dense forest” that did not change through the period between 1975 and 2003. In the same way as in the stability of productive areas factor, a second period between 1996 and 2003 was evaluated to take into account the areas where the forest cover recuperated in the period between 1975 and 1996, and was preserved until 2003. In order to create a buffer effect for these stable forest covers, two distance maps were generated, one per each period. A pairwise verbal comparison was made giving a moderately more important judgment to the last period due that it represents the localization of the recent recovery process of the forest cover.

Spatial restrictions main criterion

This criterion expresses the limiting factors of the productive activities in terms of time and costs of accessing the productive areas and the distribution of the watersheds functional zones.

Distance to urban settlements: It is considered that the areas where the productive activities can be applied have to be dense to the human settlements to minimize the cost of transportation of the workers and the derived products. The lower the distance to the urban centers the higher the score is.

Distance to roads: The areas to develop productive activities within the framework of the sustainable use policy are better if they have the necessary infrastructure to allow an adequate accessibility. In this sense, the costs in time and money are reduced, and at the same time it is a conditional to maintain the well preserved ecological zones that are further away from the pavements and bare transit roads. The lower the distance to the roads the higher the score is.

Distribution of the watershed functional zones: The discharge and transitional zones are the most suitable for the productive activities, on the opposite side, the headwater zone are less suitable due to the biophysical process having impact on the maintaining of environmental services such as recharge of aquifers, preservation of the biodiversity and soils. A pairwise verbal comparison was made among the watershed functional zone classes to establish the relative importance between them related to the sub-objective. The classes of this indicator are represented and evaluated in an attribute table.

Hazards main criterion

In order to minimize the lost of financial resources and to prevent the acceleration of degradation of suitable areas to an erosion process, the productivity activities have to be allocated taking into account the following hazards factors:

Landslides hazards: The usability of these zones for productive activities is restricted due to the potential of landslides. The less the landslide hazard the higher the value is. A pairwise verbal comparison was made to assign the relative importance of the hazard classes. The classes of this indicator are represented and evaluated in an attribute table.

Erosion potential: The areas that are of high erosion potential have to be discarded from the application of productive programs. These areas are more suitable to be incorporated in restoration programs to minimize the risk of erosion. The less the erosion potential the higher the value is to apply the sustainable use policy. The classes of this indicator are represented and evaluated in an attribute table.

Flood hazard: The areas susceptible to flood events have a low value for the application of the sustainable use policy, due to the risk these represent to productive activities. The classes of this indicator are represented and evaluated in an attribute table.

5.3. Constraints definition

The areas that are excluded for the suitability analysis for both of the criteria trees are those that are covered with:

- Restoration areas. The restoration areas identified in the EMPLCB have to have specific programs that achieve the objectives of this particular policy; neither the conservations nor the productive activities can be applied in these areas.

-Natural protected areas. These areas have the protection environmental policy assigned to them and neither the conservation nor the productive activities can be applied in these areas.

- Urban settlements. Neither of the environmental policies related to this analysis can apply environmental programs within the urban settlements.

- Water bodies. All the water bodies are excluded of the suitability analysis. Lake Cuitzeo was excluded because the productive activities realized in the lake are not considered in the present study. Moreover, as it being considered a discrete valuable ecologic unit of the landscape, environmental programs have been specifically designed for it.

6. Suitability assessment

This phase led to the characterization of the watersheds and municipalities based on the construction of a suitability index for each of the environmental policies. The criteria defined in the problem formulation phase for each of the environmental policies were converted into the branches and leaves of the criteria structures. The Spatial Multicriteria Evaluation module of the software package ILWIS® 3.3 was used to compute the final suitability index; the ILWIS SMCE trees are shown in Figure 11 for the conservation policy and in Figure 12 for the sustainable use policy.

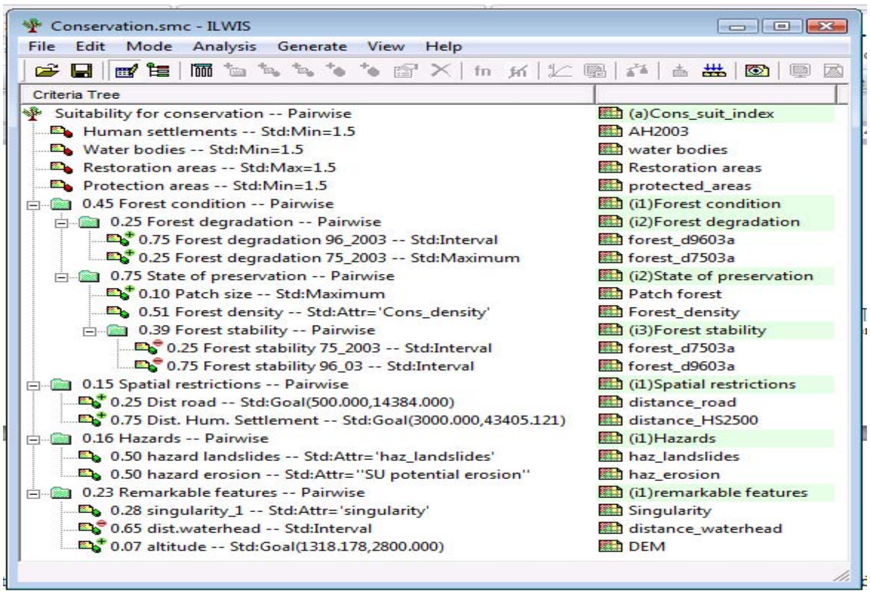


Figure 11 Conservation decision tree in the spatial SMCE module in the ILWIS interface

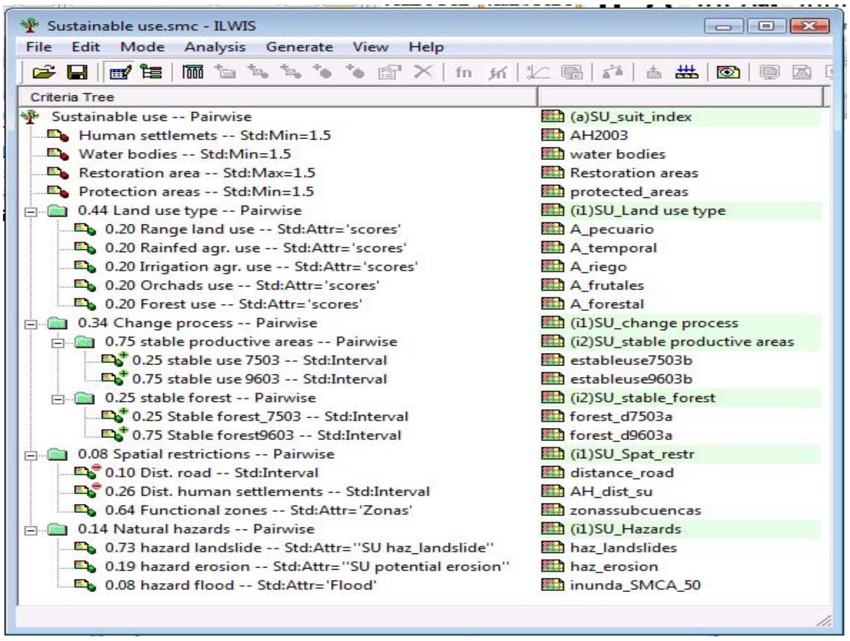


Figure 12 Sustainable use decision tree in the spatial SMCA module in the ILWIS interface

A summary of the main objectives, related criteria, factors and available source map used to represent the factors is shown in Table 9 for the conservation policy and in Table 10 for sustainable use policy.

Table 9 Criteria and related factors for Conservation policy

Main Objective	Criteria	Group of factors		Factor	Source data
Preserve the environmental elements that allow for the maintenance of the environmental services and at the same time the conflicts between the productive activities and the conservation programs are minimized.	Forest condition	Forest degradation		Distance to forest degradation 1975-2003	Map of change process 1975-2003
				Distance to forest degradation 1996-2003	Map of change process 1996-2003
		Forest stability		Dist. to area of forest stability 1975-2003	Map of change process 1975-2003
				Dist. to area of forest stability 1996-2003	Map of change process 1996-2003
		State of preservation	Patch size	Patch sizes forest vegetation	Land cover 2003
			Forest density	Presence of preserved type of forest	Land cover 2003
	Spatial restrictions			Dist. from roads	Road map
				Dist. from urban centers	Urban centre map
	Hazards			Landslide hazard	Map of landslide hazard
				Erosion hazard	Map of erosion potential
	Remarkable features			Singularity	Geology and land cover 2003
				Altitude greater than 2,800 m	DEM
				Dist. to headwater	Functional watershed zones

Table 10 Criteria and related factors for Sustainable use policy

Main Objective	Criteria	Group of factors	Factor	Source data
Find out the areas where the productive programs can develop according to the distribution of the land aptitude and at the same time the deterioration of areas containing a well preserved natural capital is minimized.	Potential land use type		Rain-fed agriculture	Potential land use type
			Irrigation agriculture	Potential land use type
			Orchards use	Potential land use type
			Rangeland use	Potential land use type
			Forestry use	Potential land use type
	Change process	Forest density	Presence of preserved type of forest	Land cover 2003
		Stable productive areas	Stability of agriculture and scrub-grassland areas 1975-2003	Map of change process 1975-2003
			Stability of agriculture and scrub - grassland areas 1996-2003	Map of change process 1996-2003
		Forest stability	Dist. to preserved forest cover	Map of change process 1975-2003
			Dist. to preserved forest cover	Map of change process 1996-2003
	Spatial Restrictions			Road map
				Urban centre map
				Watersheds functional zones
	Hazards		Landslide hazard	Map of landslide hazard
			Erosion hazard	Map of erosion potential
			Flood hazard	Map of flood hazard

6.1. Construction of indicators to assess the sub-objectives

Taking into account the developed conceptual framework of the intelligence phase, the indicators were designed in order to measure the degree of satisfaction of the sub-objectives. The next section shows how the factors were constructed, a brief explanation of the procedure is given and the product maps are showed and explained.

6.1.1. Forest degradation-deforestation

The input maps of the forest degradation-deforestation factor are the generalized land cover maps of the years 1975, 1996 and 2003. First it was necessary to identify the change process of the land cover between the selected dates by crossing the corresponding maps. The products were the change maps for the periods 1975-2003 and 1996-2003 showing the distribution of the deforestation, degradation, reforestation, the increment of the scrublands, and the urbanization process in the basin. Then, a reclassification of these products was made to identify only the areas where the deforestation and degradation process took place for the two periods. The latter two reclassified maps were crossed to identify the areas where recovery of the forest cover took place between 1975 and 1996 and then deforestation or degradation occurred in the period from 1996 to 2003. Finally, distance maps were calculated for each period, see Figure 13.

Between 1975 and 2003, forest degradation and deforestation occurred in the LCB on a total area of 264 km^2 (Figure 14). Ninety percent of the deforestation-degradation process took place between 1975 and 1996. After 1996, the rates of deforestation and degradation dropped drastically, only a 10 percent of it taking place from 1996 to 2003. Of the total degraded or deforested forest cover, a 70 percent was localized in lower and medium hills, in an altitude range between 2,000 and 2,400 meters above sea level and within the headwater zones of the basin.

Although nowadays the deforestation-degradation of the forest cover is not a generalized problem in the LCB, it has to be taken into account in the environmental planning. The deforestation-degradation process in the recent years appears to be concentrated in the higher and most isolated zones of the basin; in the high hills and in the mountains above 2,200 meters above sea level. Its seems, that illegal lodging is the main cause for the degradation-reforestation processes during the period from 1996 to 2003.

The legend used in the Figure 13 is the same for Figure 15 and Figure 17.

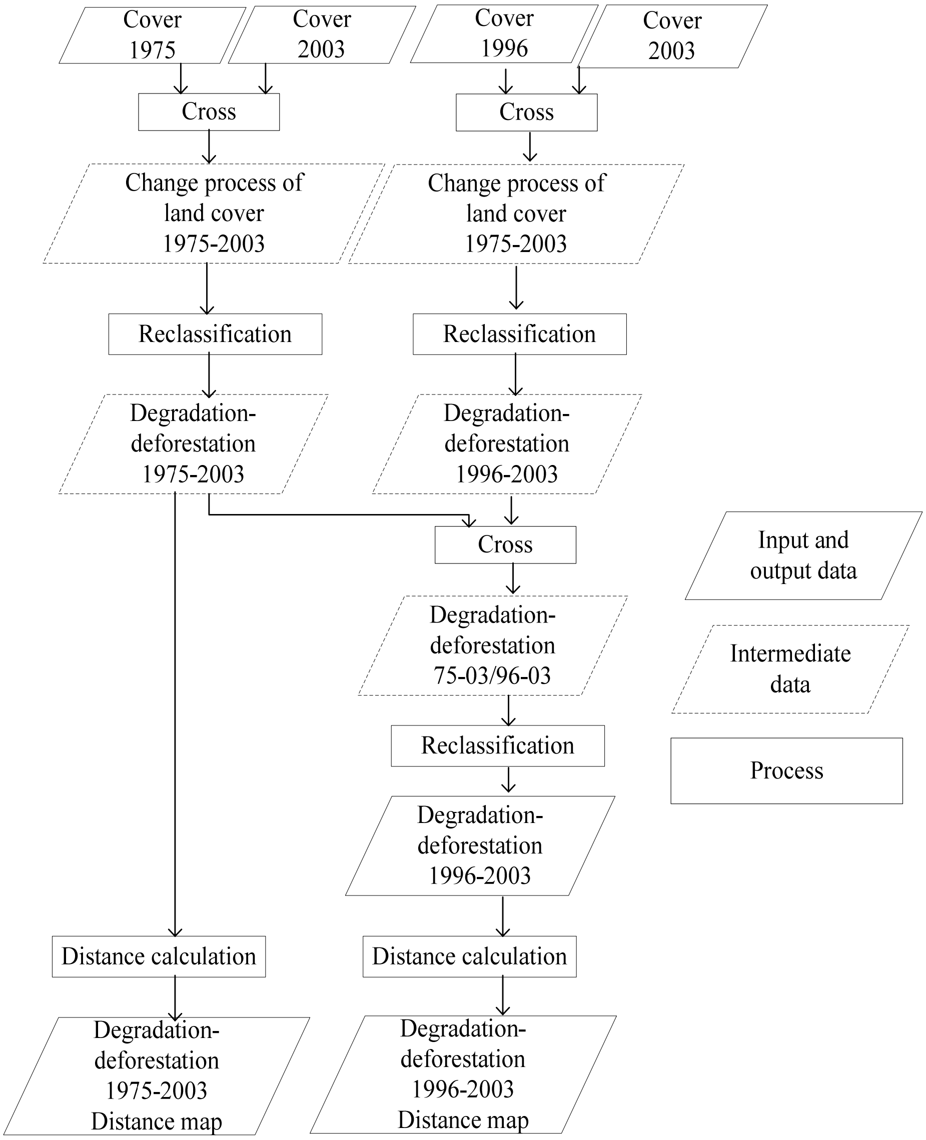


Figure 13 Forest degradation/deforestation factor. Flow chart and resulting maps

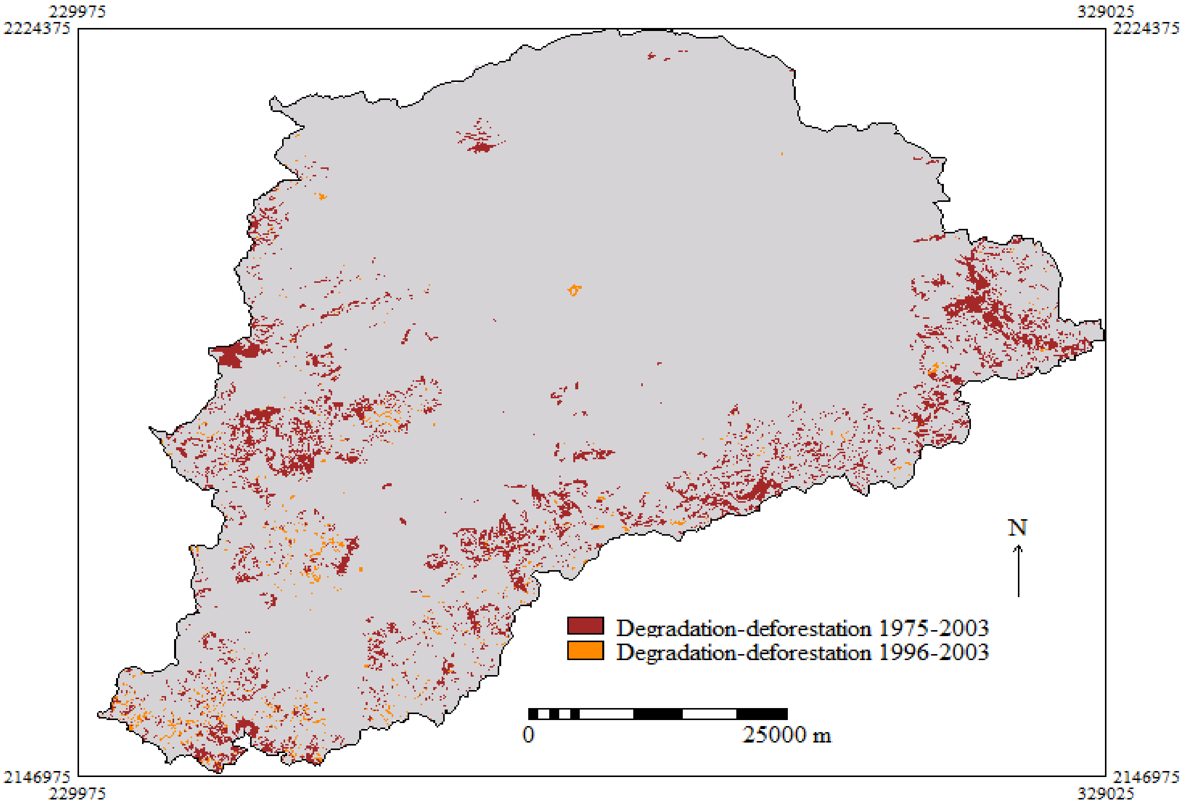


Figure 14 Forest degradation/deforestation map

6.1.2. Forest stability

The forest stability factor was computed along the same path as the forest degradation-deforestation factor. The generalized land cover maps of the years 1975, 1996 and 2003 were used as input. The derived land cover change maps for both periods were reclassified to identify the areas where the categories of “dense forest” and “semi-dense forest” did not change. Finally, these two products were crossed to exclude the stable forest of the 1975-2003 of the 1996-2003 stable forest map with the objective to avoid the double counting, and only take into account the recuperated forest cover during the period from 1975 to 1996, see Figure 15.

The forest stability factor is evaluated under the criterion “State of preservation” of the conservation policy decision tree and in the criterion “Change process” for the sustainable use decision tree.

This map (Figure 16) represents the forest stability in two different periods, corresponding to the forest that did not change between 1975 and 2003 and the forest that recuperated from 1975 to 1996 and is present in 2003. The forest cover present in 2003 covers a total area of 767 km^2, whilst 440 km^2 correspond to the reforestation process between 1975 and 1996, representing the 57 percent of the total forest cover. The reforestation process from 1996 to 2003 only represents one percent of the total forest cover.

The forest types included in the dense, and semi-dense forest cover are pine forest, oak forest, mixed forest (pine and oak), and fir (*Abies* spp.) forest in the higher zone of the basin.

A 75 percent of stable patches of forest distributed in the headwater zones, covering a total surface of 585 km^2. The remaining 25 percent is distributed in the transit zone. This distribution of the forest cover within the headwater and transit zones plays an essential role to maintain the capacity of recharge of ground water, prevent the loss of soil and the transportation of sediments to the depositional zones. In this sense, the distribution of the forest cover related to the hydrological functional zones of the basin is a valuable attribute that has to be taken into account in an environmental decision process.

70 percent of the forest cover present in the basin is distributed in the high hills and in the mountains. Nevertheless, the recovery process that took place between 1975 and 1996 was localized in all the landscape units above 2,000 meters of altitude; the rates being higher than above in the range from 2,000 to 2,400 meters above sea level. A 64 percent of the forest recovery was within this range, corresponding mainly to the low hills, medium hills and piedmont landscape units, on slopes ranging from 10 to 30 degrees. This trend of recovery of the cover led to reduce the soil erosion in areas that were earlier used for rain-fed agriculture.

The forest recovery process in the medium-high hills can be associated with a decrease in the misuse of this resource. This is due to a very strong population dynamics in the region, where the rural emigration to the urban settlements and to the United States of America play a main role in the land use and land cover change in the LCB . The lack of productive development programs in the rural zones during the last decades has prompted peasants to abandon relatively unproductive rain-fed agriculture zones, mainly in the transition between the plains and the high hills. A consequence of this abandonment of the rural environment is a reduction of the use pressure of the forest in the upper portions of the basin, having as a result the recovery of the forest cover. The class “Stable forest 1996–2003” represents the areas of that forest recovery.

The forest stability factor allows the spatial identification of the positive trends in terms of reforestation and permanence of the forest cover that play a main role in the support of the hydrological and ecological function of the basin. The continuity of the forest cover in the longer period has to be supported by the spatial identification of the trends of permanence and recovery of the forest cover.

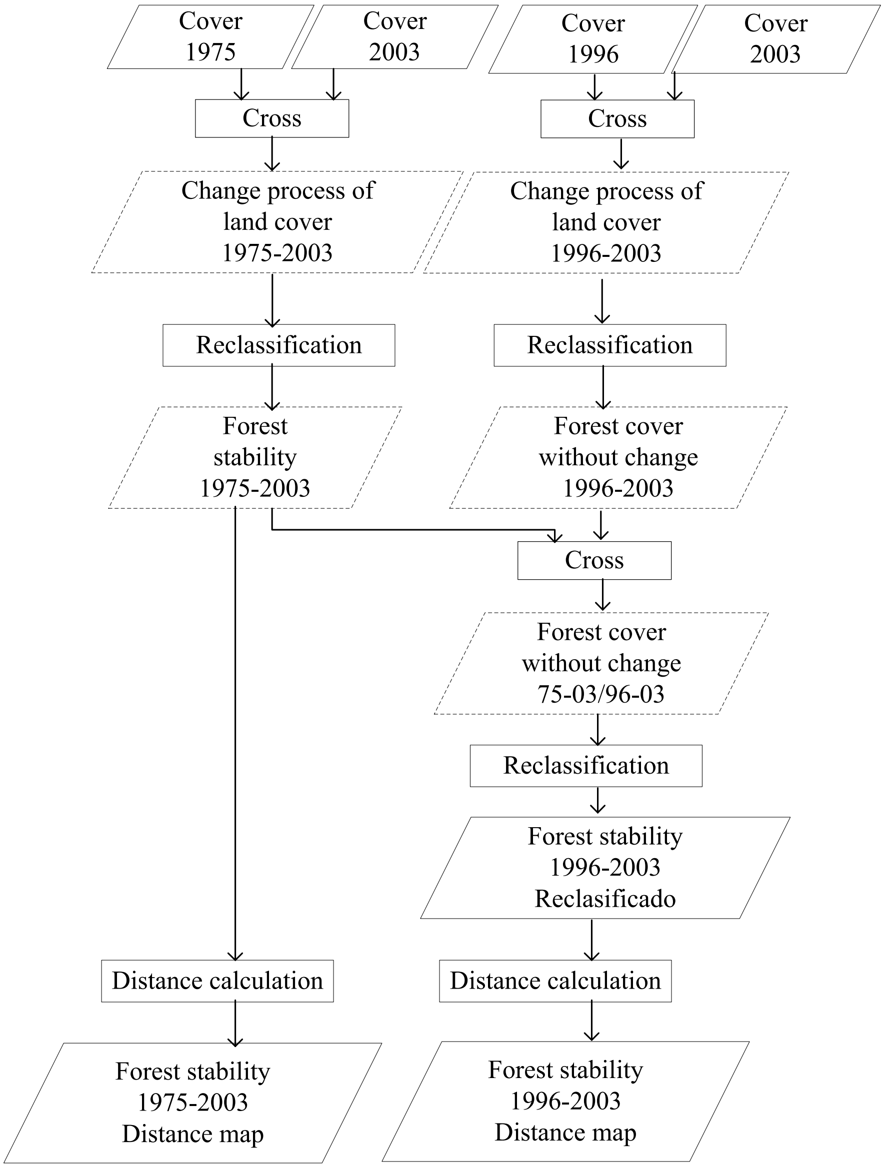


Figure 15 Forest stability factor. Flow chart and maps

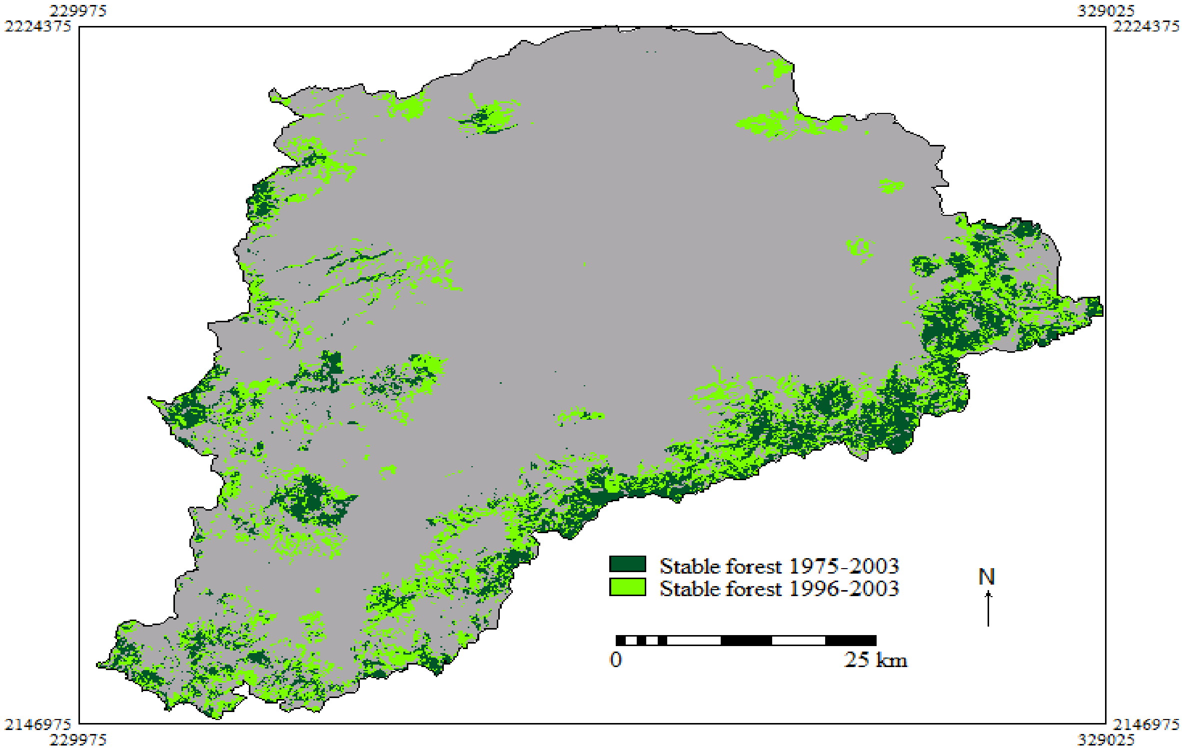


Figure 16 Forest stability map

6.1.3. Stable productive areas

The input maps for the stable productive areas factor were the generalized land cover maps of the years 1975, 1996 and 2003. The derived land cover change maps for both periods were reclassified to identify the areas where the agriculture and cattle grazing activities take place. The product maps were crossed to make another reclassification of the period from 1996 to 2003 in order to identify areas that change to productive activities in the period 1975-1996, and avoid double counting of the stable productive areas between 1975 and 2003, see Figure 17.

This indicator was evaluated for the main criterion "Change process" for the sustainable use criteria structure.

The stable productive areas (Figure 18) represent the areas that have been used for productive activities in the LCB. The most important productive activities are the rain-fed and irrigation agriculture and cattle grazing. The identification of the rain-fed and irrigation agriculture was made based on the general land cover of 2003. The cattle grazing is assumed to be realized in the grassland, in the mixed cover of grassland-scrubland and in the scrublands. This assumption is supported by field observations.

Two periods of stability of productive activities areas are taken into account, from 1975 to 2003 and from 1996 to 2003. The productive activity areas that are maintained during the longer period are mainly the rain-fed and irrigated agriculture, with 70 percent of the total stable productive areas. These areas are localized mainly in the plain of the basin on gentle slopes with less than 6 degree of steepness and in an altitude below 2,200 meters above sea level.

On the other hand, the stable productive areas from 1996 to 2003 are represented mainly by areas where cattle grazing is realized; a 78 percent of the stable productive areas during this period being covered with grassland and scrublands where cattle grazing is the dominant activity. A 45 percent of this area is developed over slopes of between 6 to 20 degrees, in altitudes between 2,000 and 2,400 meters above sea level.

The change in the patterns of the productive activities seems to respond to the abandonment of rain-fed agriculture land that led to an increase of the grassland and scrublands in the low and medium hills of the basin. This trend of land use is a valuable information that has to be taken into account in the design of productive programs related to cattle grazing activities. Nevertheless, at the same time, has to promote the regeneration of the vegetation cover that is taking place.

In the present study, the relative importance of the stable productive areas from 1996 to 2003 is assigned with the assumption that the permanence in the long term of the zones with ecological regeneration, depends on its incorporation to the sustainable productive activities. Otherwise, without a sustainable use management plan, these zones can be misused by overgrazing, having as a consequence the acceleration of the erosion process in these relatively steeper slopes.

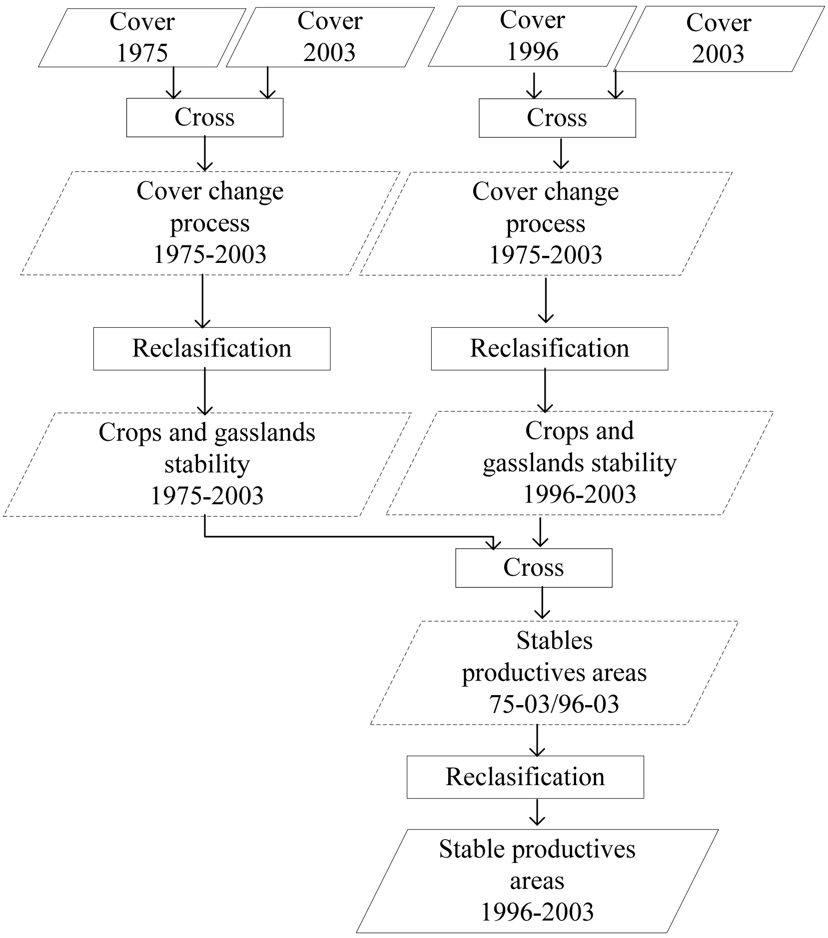


Figure 17 Stable productive areas factor. Flow chart

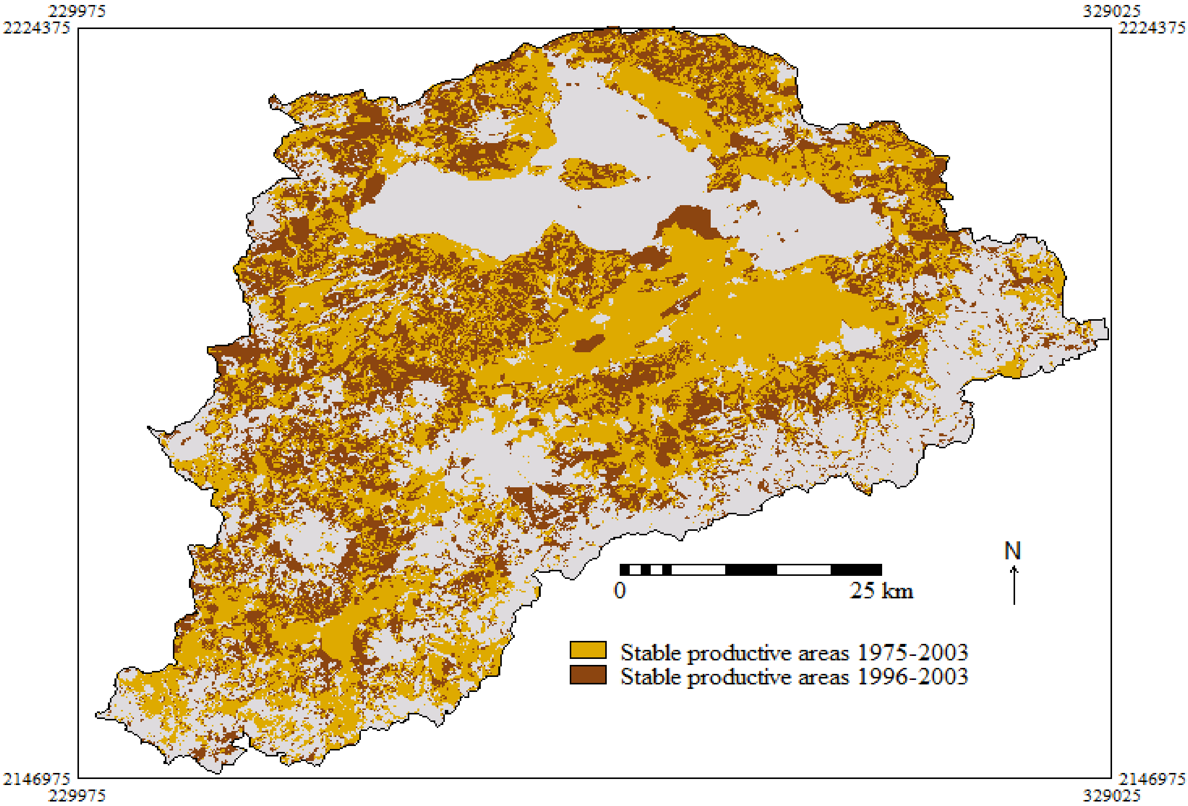


Figure 18 Stable productive areas map

All the indicators that are derived directly from the source map are evaluated based on their attribute tables. Annex 3 and Annex 4 show the classes of each of the attribute tables of the derived maps.

6.2. Partial valuation

As mentioned in section 2.3.2, the spatial multicriteria evaluation requires that the values of the criteria are transformed to comparable units in order to derive the final utility for each alternative. Through the standardization procedure, the variety of scales and units in which the attributes can be measured are made uniform. The method of standardization was selected according to the role of each criteria and indicator determined in the problem definition phase. In others words, the standardized method has to be in correspondence with the indicator, in order to achieve the overall objective.

In order to make the maps comparable, the values were standardized along a zero to one range. Boolean maps, such as the ones representing the stable productive areas used in the sustainable use criteria structure were standardized by assigning one to the presence of stable productive areas and zero where stable productive areas are not found.

For all the distance maps, an interval linear standardization function was used, in this function the minimum value of the input map is standardized to zero, the maximum value is standardized to one, and all the others input values are standardized to a value between zero and one. When distance is a benefit factor, for example, the distance of deforested areas in the conservation criteria structure, the interval normalization was applied by applying the following formula:

$$\text{Benefit factor} = \left(\frac{\text{value} - \text{minimum input value}}{\text{maximum input value} - \text{minimum input value}}\right)$$

Equation 2 Interval normalization for a benefit factor

If the criterion is expressing a negative relation, for example the relation of the distance to the areas of forest stability for the conservation policy structure, then the interval normalization was defined by applying the following formula:

$$\text{Cost factor} = 1 - \left(\frac{\text{value} - \text{minimum input value}}{\text{maximum input value} - \text{minimum input value}}\right)$$

Equation 3 Interval normalization for a cost factor

Another applied standardization method was the Goal function standardization that allows specifying the minimum or the maximum values that can be acceptable to have any utility. In the minimum goal value all the input map values smaller than the specified minimum value are standardized to zero. On the other side, in the maximum goal value, the specified value and the higher value of the input map are standardized to one.

The methods of standardization are shown in Table 11for the conservation policy, Table 12 for the sustainable use policy and in Table 13 for their constraints.

Table 11 Standardization methods. Conservation policy indicators

Indicator	Standardization
Distance to Forest degradation 1975-2003	Linear standardization, the further the distance the higher the score
Distance to Forest degradation 1996-2003	Linear standardization, the further the distance the higher the score
Distance to areas of forest stability 1975-2003	Linear standardization, the lower the distance the higher the score
Distance to areas of forest stability 1996-2003	Linear standardization, the lower the distance the higher the score
Patch size forest cover	Linear standardization, the bigger the patch the higher the score
Presence of preserved type of forest	Pairwise comparison among the preserved classes of forest
Distance from roads	Distance <3000 m. is set to 0, all other values the further the distance the higher the score
Distance to urban centers	Distance <500 m. is set to 0, all other values the higher the distance the higher the score
Landslide hazard	Pairwise comparison among landslides risk categories
Erosion potential	Pairwise comparison among erosion potential categories
Singular areas	Pairwise comparison among remarkable features categories
Altitude greater than 2800 meters	Goal. Altitude >2800 m. is standardized to 1, all others values the higher the distance the lower the score
Distance to Headwater zones	Linear standardization, the closest to the headwater zone the higher the score

Table 12 Standardization methods. Sustainable use policy indicators

Indicator	Standardization
Potential land use type. Range land	Pairwise comparison among suitability classes
Potential land use type. Rain-fed agriculture	Pairwise comparison among suitability classes
Potential land use type. Irrigation agriculture	Pairwise comparison among suitability classes
Potential land use type. Orchards use	Pairwise comparison among suitability classes
Potential land use type. Forestry use	Pairwise comparison among suitability classes
Presence of preserved type of forest	Pairwise comparison among the preserved classes of forest
Distance to areas of forest stability 1975-2003	Linear standardization, the higher the distance the higher the score
Distance to areas of forest stability 1996-2003	Linear standardization, the higher the distance the higher the score
Stable productive areas 1975-2003	Presence of stable productive areas is standardized to 1, all others to 0
Stable productive areas 1996-2003	Presence of stable productive areas is standardized to 1, all others to 0
Distance to urban centers	Linear standardization the lower the distance the higher the score
Distance from roads	Linear standardization the lower the distance the higher the score
Distribution of watershed functional zones	Pairwise comparison among the functional zones the preserved classes of forest
Landslide hazard	Pairwise comparison among landslides risk categories
Erosion potential	Pairwise comparison among erosion potential categories
Flood hazard	Pairwise comparison among flood risk categories

Table 13 Standardization methods. Constrains indicators

Indicator	Standardization
Restoration areas	Restoration areas are set to 0, others to 1
Protection areas	Protection areas are set to 0, others to 1
Lake Cuitzeo	The lake Cuitzeo areas are set to 0, others to 1
Urban centers	Urban centers areas are set to 0, others to 1

6.3. Relative importance of the criteria

Once all the maps were converted through the above-mentioned standardization methods to make them comparable, it was necessary to determine the relative importance for each factor and group of factors related to the main objective for each of the environmental policies. In this study, pairwise comparison (see section2.4.1) was chosen, because it allows making quality judgments of the relative importance of each pair of factors in relation to the objectives along the hierarchy.

The relative importance of the factors and groups of factors used in the present study was established on the basis of the assumptions explained in chapter 5. It is important to note that even though the objectives of each of the decision processes can be clear and concrete, in this case the objectives of the environmental the relative importance of the factors can change depending on who is making the judgment and on which are the intentions of the stake holders involved.

The relative importance of the factors was established and the overall composite suitability map was calculated through the combination of all the intermediate suitability maps of the criteria structures, using the weighted summation method (see section 2.4.1) to apply a weighted overlay of all the criteria maps in the decision structures.

Table 14 and Table 15 show the resultant weights for this process for the conservation and sustainable use policies respectively. The resultant pairwise comparisons matrixes for each level of the hierarchy can be consulted in Annex 1 and Annex 2.

Table 14 Assigned weights product of the PCM. Conservation multicriteria tree

Weight		Factor	Weight		Factor	Weight		Factor	Weight		Factor
Pairwaise	.45	Forest condition	Pairwaise	.25	Forest degradation -deforestation				Pairwaise	.25	Distance of forest degradation-deforestation 1975-2003
										.75	Distance of forest degradation-deforestation 1996-2003
				.75	State of preservation	Pairwaise	.39	Forest stability	Pairwaise	.25	Dist. to area of forest stability 1975-2003
										.75	Dist. to area of forest stability 1996-2003
							.10				Patch sizes of forest vegetation
							.51				Presence of preserved types of forest
	15	Spatial Restrictions							Pairwaise	.75	Dist. from urban settlements
										.25	Dist. from roads
	.16	Hazards							Pairwaise	.50	Landslide hazard
										.50	Erosion hazard
	.23	Remarkable features							Pairwaise	.65	Dist. to headwater zone
										.28	Singularity
										.07	Altitude above 2,800 m

Table 15 Assigned weights for each factor and groups of factors for the sustainable use policy

	Weight	Factor		Weight	Factor		Weight	Factor
Pairwaise	.44	Land use type	Pairwise	.20	Rain-fed agriculture			Distribution of potential land use
				.20	Irrigation agriculture			Distribution of potential land use
				.20	Orchard			Distribution of potential land use
				.20	Rangeland			Distribution of potential land use
				.20	Forestry			Distribution of potential land use
	.34	Change process	Pairwaise	.75	Forest stability	Pairwise	.75	Distance to area of forest stability 1996-2003
							.25	Distance to area of forest stability 1975-2003
				.25	Stable productive areas	Pairwise	.75	Presence of Scrub-grassland stability. 1996-2003
							.25	Presence of Scrub-grassland stability. 1975-2003
	.08	Spatial restrictions				Pairwaise	.10	Distance. from urban centers
							.26	Distance from roads
							.64	Distribution of watershed functional zones
	.14	Hazards				Pairwaise	.73	Landslide hazard
							.19	Erosion hazard
							.08	Flood hazard

6.4. Overall cell-based suitability assessment

The cell based suitability map shows a clearly distribution pattern of the best areas for the application of the conservation and the sustainable use policies.

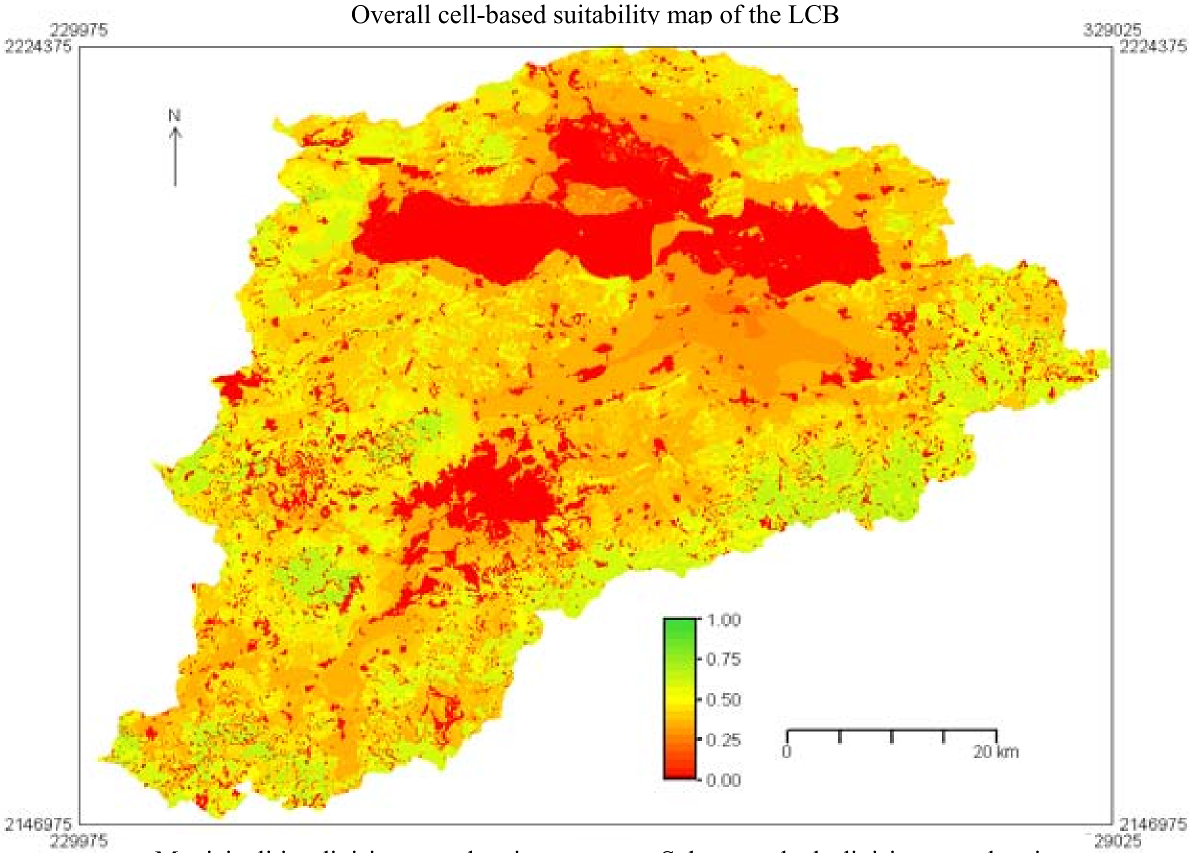
For the conservation policy, the areas with the best suitability values are distributed in the higher zones of the LCB, where the mountains and high hills are the dominate landscapes. In this landscapes the dominant vegetation cover are the dense forest, and the semi dense forest. It is important to note that in the north of the LCB there are anothers areas with high values of suitability, which correspond to the presence of dense scrubland, which probably express a recovery process triggered for the change in the land use in the last 30 years.

In the other hand the higher suitability values for the sustainable use policy are distributes in the lower zones of the LCB, mainly in the lacustrine plain and in the lower hills. In this landscape is where actually most of the productive activities, (rain-fed and irrigation agriculture and cattle grazing) take place.

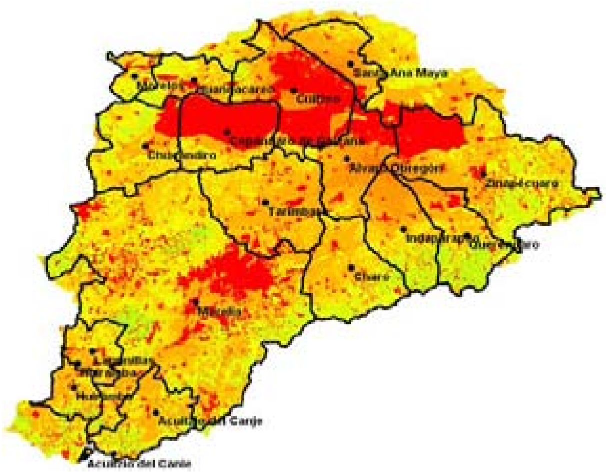
The overall cell based suitability maps within the LCB are shown in Figure 19 for the conservation policy and in Figure 20 for the sustainable use policy. The municipality and sub-watersheds divisions are shown only for illustrative and reference purposes.

Conservation policy

Overall cell-based suitability map of the LCB



Municipalities divisions overlapping



Sub-watersheds divisions overlapping

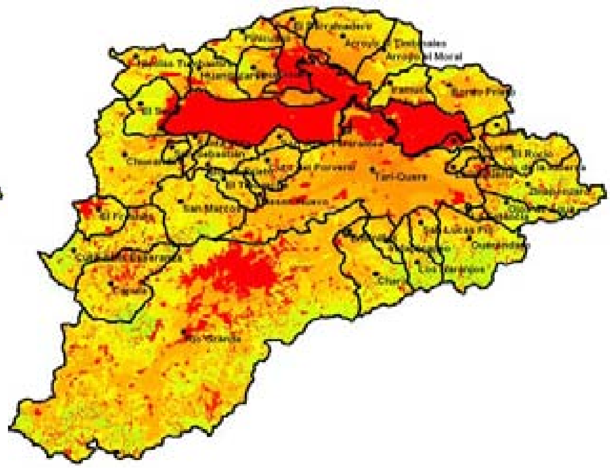
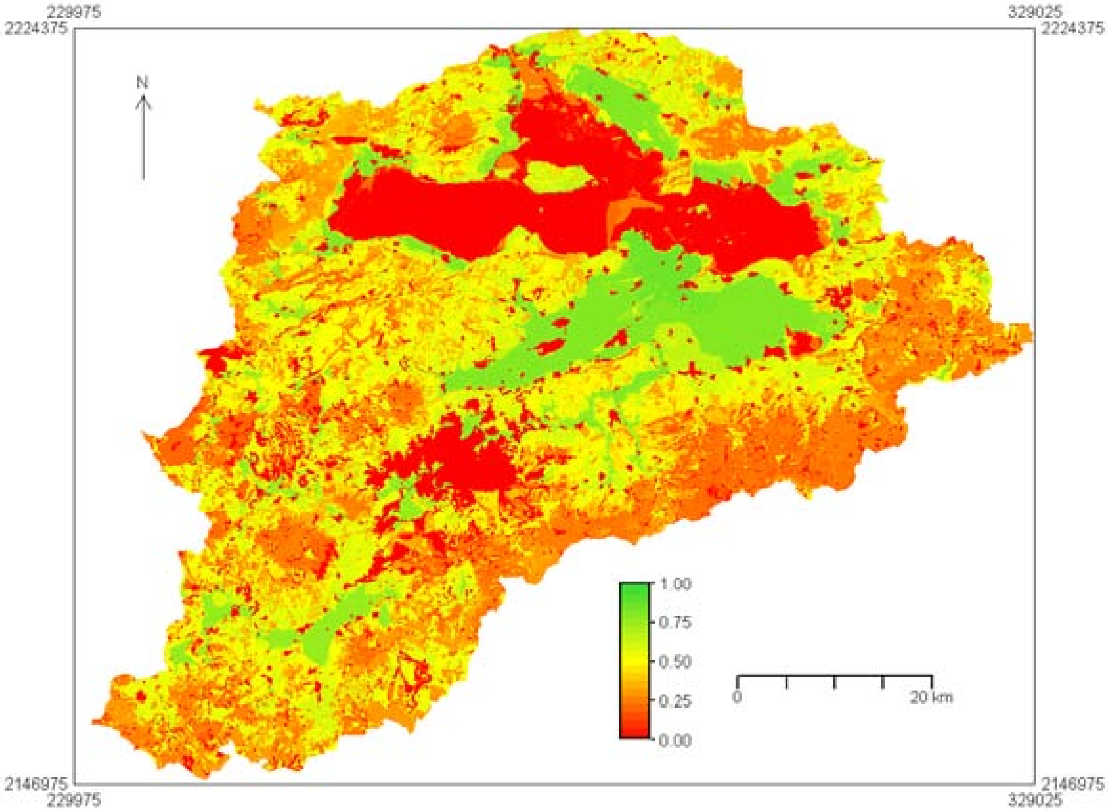


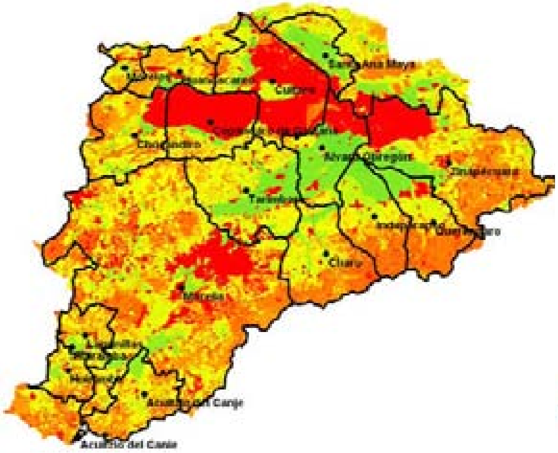
Figure 19 Conservation. Overall cell-based suitability map

Sustainable use policy

Overall cell-based suitability map of the LCB



Municipalities divisions overlapping



Sub-watersheds divisions overlapping

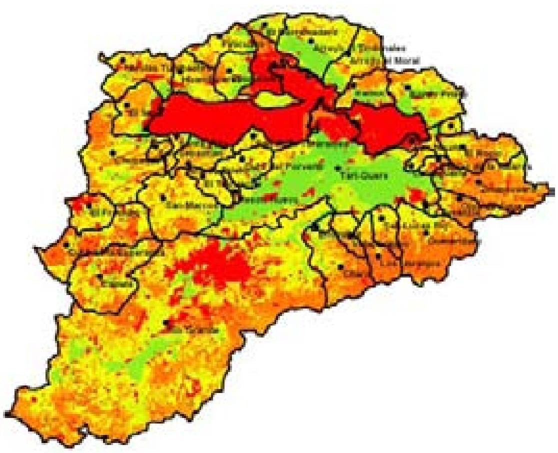


Figure 20 Sustainable use. Overall cell-based suitability map

6.5. Municipalities suitability assessment

First of all, the municipalities of the LCB that do not belong to the state of Michoacán were excluded, because they cover a negligible area. Furthermore, the environmental policies are part of the ecological management plan of Lake Cuitzeo, which is designed, implemented and financed by the state of Michoacán. Thus, the municipalities of the extreme north zone of the LCB that belong to the state of Guanajuato are excluded. In the same way, the municipalities with less than a 20 percent of their territories lying in the LCB, covering less than a 2 percent of the total area in the basin, were excluded for the choice phase of the present study because of the low impact they represent for the entire basin, and because most of its territory is outside the jurisdiction of the EMPLCB.

For the municipalities that are not in the previous excluded group, the overall suitability maps were used to evaluate them in order to identify the feasible alternatives for the application of the conservation and sustainable use policies.

For the definition of the alternatives, the values of the suitability maps for each of the policies were aggregated into the areas of the municipality. The average value, the sum of all the suitability values, the maximum value, and the percentage of cover of the most suitable 30 percent cells were calculated for each municipality. Table 16 shows the results of the evaluation for the conservation policy and Table 16 those for the sustainable use policy.

The average among all grids tends to smooth out the suitability among the municipalities and sub-watersheds. On the other hand, the maximum value where the municipality or the sub-watershed takes the value of its best performance cell tends to overestimate the suitability of the unit. The sums of all the suitability value tend to overestimate the larger units. Thus, since the municipalities and sub-watersheds have different areas and are not homogeneous units, the parameters of average, sum and maximum value of the suitability index do not represent the performance of these spatial units for each of the policies.

To define the best alternatives it is considered an intermediate parameter that takes into account the size of the unit and the relative cover of the most suitable cells within the unit. For this, the percentage of the total area of each unit that is cover with the better performance cells was taken to define the possible alternatives and to establish a first approach in the assessment of the municipality and sub-watersheds for the application of the conservation and sustainable use policies. The cells within the 30 percent best suitability values of the range were aggregated for this purpose. In this sense for each spatial unit the higher the percentage of cover of the best suitability values the better it is.

6.5.1. Conservation policy

The municipalities that appear to have the best utility for the conservation policy are distributed in the southeast margin of the LCB. These municipalities are characterized by the presence of forest cover in its territory. From municipality 1 to municipality 6 (see Table 16), the “dense” and “semi-dense” forest covers are occupying at least a 20 percent of the total area of each municipality. The municipality 1 (Queréndaro) presents the highest percentage of forest cover with almost a 40 percent, followed by municipality 2 (Acuitzo), municipality 3 (Charo), municipality 5 (Zinapécuaro), municipality 4 (Indaparapeo), and municipality 6 (Morelia), with a 33, 29, 26, 23 and 20 percent of forest cover, respectively.

Municipality 6 presents the highest rates of forestation in the basin during the period from 1975 to 1996, with a 36 percent of total forest recovery. The largest city in the basin; Morelia is located within this alternative too. Municipality 5 presents the second highest rate of forestation in this period with a 16 percent of the total forest recovery, followed by municipalities 2 and 3, each one with a 10 percent. In the same sense, municipality 6 presents the highest permanence of forest cover from 1975 to 2003. These results have to be weighted in the choice phase because the sizes of the alternatives have influence in the suitability values.

The high suitability values of municipalities 1, 3 and 4 are concentrated in the higher zone of the basin in a landscape composed mainly by high hills and mountains. On the other hand, for the municipalities 2, 5 and 6 the landscape units that concentrate the higher suitability values are the low and medium hills. It is interesting that in the municipalities 1, 3, and 4, have higher values of permanence of the forest cover from 1997 to 2003, and municipalities 2, 5 and 6 shows a recovery of the forest cover that took place from 1975 to 1996.

6.5.2. Sustainable use policy

The municipalities with highest values of suitability for the sustainable use policy (see

Table 17) are localized in the central and north zone of the LCB, along the shores of the lake. The predominant landscape unit is the lacustrine plain, followed by the low hills and piedmont units. These municipalities are characterized by extensive agricultural activities and huge areas of grassland and scrublands for the cattle grazing activities. Municipalities 1 and 4 (Tarímbaro and Álvaro Obregón respectively) are characterized by the permanence of irrigated agriculture. On the other hand, the municipalities localized at the north of the lake show change in the land use during the period from 1975 to 1996, shifting from rain-fed agriculture to grasslands and scrublands that have been used as cattle grazing areas.

Table 16 Results of the SMCE for the municipalities. Conservation policy

	Municipalities	Number of pixels	Average	Sum	Maximum value	**% of cover of the 30% most suitable cells**
Alt 1	Queréndaro	63700	0.56	34.77	0.87	**37.28**
Alt 2	Acuitzio	55933	0.54	28.3	0.83	**31.56**
Alt 3	Charo	79871	0.58	34.51	0.88	**26.71**
Alt 4	Indaparapeo	67032	0.56	33.03	0.87	**23.59**
Alt 5	Zinapécuaro	171084	0.52	31.67	0.84	**23.08**
Alt 6	Morelia	422919	0.56	32.2	0.85	**20.63**
Alt 7	Huiramba	26020	0.53	21.17	0.79	**20.29**
Alt 8	Morelos	17984	0.54	25.6	0.81	**17.65**
Alt 9	Lagunillas	31255	0.53	22.25	0.83	**17.5**
Alt 10	Chucándiro	73253	0.55	28.98	0.84	**13.69**
Alt 11	Huandacareo	36302	0.51	23.01	0.79	**12.07**
Alt 12	Cuitzeo	102324	0.47	21.76	0.8	**2.62**
Alt 13	Copándaro	70231	0.5	26.87	0.82	**1.41**
Alt 14	Tarímbaro	104898	0.51	24.24	0.81	**0.73**
Alt 15	Santa Ana Maya	41471	0.39	10.98	0.75	**0.39**
Alt 16	Álvaro Obregón	62764	0.37	12.33	0.55	**0**

Table 17 Results of the SMCE for the municipalities. Sustainable use policy

	Municipalities	Number of pixel	Average	Sum	Maximum. Value	**% of cover of the 30% most suitable cells**
Alt 1	Tarímbaro	104898	0.46	21.19	0.72	**83.8**
Alt 2	Santa Ana Maya	41471	0.49	23.03	0.73	**79.45**
Alt 3	Huandacareo	36302	0.45	21.2	0.71	**74.03**
Alt 4	Álvaro Obregón	62764	0.51	22.09	0.74	**70.19**
Alt 5	Lagunillas	31252	0.45	21.18	0.69	**68.24**
Alt 6	Chucándiro	73253	0.45	23.46	0.71	**65.75**
Alt 7	Huiramba	26020	0.45	21.62	0.69	**65.42**
Alt 8	Indaparapeo	67032	0.44	22.05	0.69	**63.97**
Alt 9	Morelos	17984	0.42	17.7	0.66	**63.05**
Alt 10	Charo	79870	0.44	22.25	0.69	**55.3**
Alt 11	Morelia	422918	0.45	22.75	0.7	**52.39**
Alt 12	Acuitzio	55929	0.45	21.84	0.69	**49.36**
Alt 13	Queréndaro	63696	0.46	24.18	0.72	**44.34**
Alt 14	Zinapécuaro	171083	0.46	24.91	0.73	**38.6**
Alt 15	Copándaro	70231	0.47	24.7	0.73	**30.81**
Alt 16	Cuitzeo	102324	0.47	24.7	0.73	**30.73**

6.6. Sub-watershed assessment

In this phase was possible to assess the totality of the lake Cuitzeo basin taking as a natural spatial unit the sub-watersheds The procedure used in this phase is similar in the assessment of the municipalities.

6.6.1. Conservation policy

Taking into account the aggregated values of the suitability index in the sub-watersheds, it was possible to identify two groups that present the best performance for this environmental policy (Figure 21)..

The first group includes the sub-watersheds that are distributed in the higher zones of the watershed where the mountain and high hills landscape prevail. The vegetation cover is composed by pine forest, mixed forest of pine and oak and in the higher zones are present patch of abies forest. It is important to note that in this altitudes are present isolates patches with mesophytic conditions that represent a remarkable feature in the landscape with a high value to the conservation policy. These sub-watersheds are characterized by its high percentage of forest cover related to its total area, the sub-watersheds of Queréndaro, Ojos de agua, Zinapécuaro and Los Naranjos are stand out over the others sub-watersheds in this valuable characteristic. In the same way, this sub-watersheds are the units that present the higher rates of permanence of the forest cover in the 1975-2003 period. As example, the Ojos de agua sub-watershed presents the 42.4 percent of its total area with a forest cover that does not change between the periods mentioned before. Queréndaro presents the 36 percent, Los Naranjos and Zinapécuaro the 32 and 28 percent respectively of the same indicator.

The other group of sub-watersheds that are susceptible to the incorporation of conservation programs are distributed in the north margin of lake Cuitzeo. Some of these units are characterized by the expansion of tropical scrubland areas as a consequence of the abandonment of the irrigated agriculture in poor soils, as a consequence These succession vegetation process in this units is related to the decrease of the erosion rates, for this represent a valuable characteristic for the application of the conservation environmental programs. The sub-watersheds that are in this group are: Huandacareo, Nicolás Tumbastío, El Sauz, Iramuco (Figure 21) . These last sub-watersheds present at the same time high suitability values for the conservation and sustainable use policies. For this, reason it is necessary to carry out an assessment that takes into account different scenarios to determine the best environmental policy to apply according to the capacity of the environment and the necessity of the stakeholders.

6.6.2. Sustainable use policy

The sub-watersheds with the higher suitability values for the application of the sustainable use programs are distributed in the lower zones of the basin in the lacustrine plain. In these units the irrigation and rain fed agriculture are the most distributed activities. The dominant cover is the grassland where takes place the activities mentioned before in addition with the cattle grazing. Clearly, the most suitable unit is the Tarímbaro – Queréndaro sector that has more than 90 percent of its total area within the better suitability values, this unit is distributed almost in its totality over the lacustrine plain (Figure 21). The units in the north portion on the basin, Arroyo el Timbinales, Arroyo el Moral, Iramuco y Bordo Prieto present a high performance for the application on the sustainable use policy, nevertheless as is mentioned before these units present a good performance for the conservation policy as well, and a conflict analysis carry out in the next chapters is essential to define the better environmental policy to apply.

As a first approach for the definition of the better units to apply one or another environmental policy it was necessary to aggregate the suitability values within the spatial units (municipalities and sub-watersheds). For each of the spatial units the average and the percentage of cover of the 30 percent best performance cells were calculated with other basic parameters. The Table 18 and Table 19 shows the results of this assessment phase for the conservation and sustainable use policy respectively.

In Figure 21 is shown the aggregation of the cell-based maps into watersheds and municipalities. For the aggregation the percentage of the total area of each spatial unit that is covered with the 30 percent most suitable cells was taking account. In the figure are represented the aggregation of the two policies analysed in this study

Table 18 Results of the SMCE for the sub watersheds. Conservation policy

	Sub watershed	NPix	Average	Sum	Maximum value	Area km.	% of cover of the 30% most suitable cells
Alt. 1	Araró	4503	0.39	8.26	0.55	11.3	**28.6**
Alt 2	Arroyo el Moral	26782	0.42	17.4	0.63	67.0	**23.7**
Alt 3	Arroyo el Timbinales	42199	0.40	17.63	0.62	105.5	**10.3**
Alt 4	Bordo Prieto	38896	0.43	14.52	0.6	97.2	**20.1**
Alt 5	Capula	52526	0.47	22.3	0.71	131.3	**23.6**
Alt 6	Charo	38634	0.48	19.8	0.69	96.6	**33.4**
Alt 7	Chucándiro	63737	0.47	19.69	0.69	159.3	**22.0**
Alt 8	Chupícuaro	27084	0.38	17.55	0.61	67.7	**10.7**
Alt 9	Copándaro	16952	0.44	16.4	0.64	42.4	**21.2**
Alt 10	Cuto de la Esperanza	44237	0.48	20.8	0.71	110.6	**38.7**
Alt 11	Cuto del Porvenir	19045	0.43	13.65	0.6	47.6	**8.9**
Alt 12	El Derramadero	9344	0.42	13.33	0.58	23.4	**14.6**
Alt 13	El Fresnito	18341	0.48	19.82	0.7	45.9	**11.2**
Alt 14	El Rocío	28096	0.43	14.24	0.6	70.2	**30.6**
Alt 15	El Sauz	24172	0.47	21.32	0.7	60.4	**39.4**
Alt 16	El Tlacuache	11909	0.43	15.14	0.62	29.8	**19.5**
Alt 17	Encinillas	3257	0.44	10.92	0.57	8.1	**8.1**
Alt 18	Huandacareo	21782	0.43	15.4	0.61	54.5	**24.0**
Alt 19	Indaparapeo	10833	0.47	18.72	0.67	27.1	**18.4**
Alt 20	Iramuco	19118	0.42	15.66	0.61	47.8	**28.3**
Alt 21	La Yegüeria	4710	0.40	10.8	0.55	11.8	**2.6**
Alt 22	La Estancia	2674	0.43	12.89	0.59	6.7	**12.5**
Alt 23	Lomas de la Alberca	4742	0.40	10.74	0.57	11.9	**5.0**
Alt 24	Los Naranjos	18807	0.48	21.07	0.7	47.0	**54.3**
Alt 25	Mesón Nuevo	3314	0.42	12.47	0.57	8.3	**19.7**
Alt 26	Nicolás Tumbastiro	30996	0.47	21.6	0.7	77.5	**35.3**
Alt 27	Ojos de Agua	16785	0.46	18.05	0.66	42.0	**51.2**
Alt 28	Piñicuaro	19057	0.45	17.95	0.66	47.6	**19.7**
Alt 29	Queréndaro	53420	0.48	21.07	0.7	133.6	**52.2**
Alt 30	Río Grande	467072	0.48	24.25	0.73	1167.7	**22.4**
Alt 31	San Marcos	49800	0.49	22.22	0.72	124.5	**25.7**
Alt 32	San Nicolás Simirao	8819	0.41	13.62	0.6	22.0	**10.9**
Alt 33	San Juan Tarárameo	8697	0.41	12.18	0.56	21.7	**21.1**
Alt 34	San Lucas Pío	13456	0.46	20.9	0.69	33.6	**22.5**
Alt 35	San Sebastián	4647	0.44	14.56	0.61	11.6	**30.1**
Alt 36	Santa Rita	5979	0.44	14.86	0.62	14.9	**17.1**
Alt 37	Tari Quere	170199	0.40	19.29	0.65	425.5	**2.0**
Alt 38	Zinapécuaro	47949	0.47	18.72	0.67	119.9	**38.1**

Table 19 Results of the SMCE for the sub watersheds. Sustainable use policy

	Sub watershed	NPix	Average	Sum	Maximum value	Area km.	% of cover of the 30% most suitable cells
Alt. 1	Araró	4505	0.47	20.02	0.78	11.3	**11.6**
Alt 2	Arroyo el Moral	26787	0.47	31.84	0.82	67.1	**32.1**
Alt 3	Arroyo el Timbinales	42219	0.49	31.35	0.83	105.6	**39.5**
Alt 4	Bordo Prieto	38932	0.47	32.14	0.81	97.4	**34.1**
Alt 5	Capula	52535	0.41	25.61	0.77	131.4	**16.0**
Alt 6	Charo	38660	0.43	28.37	0.78	96.7	**8.7**
Alt 7	Chucándiro	63763	0.45	31.74	0.8	159.5	**14.7**
Alt 8	Chupícuaro	27084	0.48	31.36	0.82	67.8	**40.1**
Alt 9	Copándaro	16952	0.43	26.21	0.8	42.4	**21.4**
Alt 10	Cuto de la Esperanza	44275	0.44	27.09	0.76	110.7	**7.3**
Alt 11	Cuto del Porvenir	19045	0.48	27.36	0.78	47.7	**12.4**
Alt 12	El Derramadero	9356	0.47	28.21	0.8	23.5	**21.9**
Alt 13	El Fresnito	18354	0.45	26.89	0.77	45.9	**11.5**
Alt 14	El Rocío	28111	0.46	26.68	0.78	70.3	**10.0**
Alt 15	El Sauz	24172	0.47	29.87	0.8	60.5	**12.5**
Alt 16	El Tlacuache	11909	0.39	18.76	0.63	29.8	**5.1**
Alt 17	Encinillas	3257	0.51	23.41	0.79	8.2	**38.8**
Alt 18	Huandacareo	21783	0.47	28.9	0.8	54.6	**14.9**
Alt 19	Indaparapeo	10833	0.38	20.27	0.77	27.1	**11.3**
Alt 20	Iramuco	19119	0.47	28.43	0.8	47.9	**28.3**
Alt 21	La Yegüeria	4710	0.43	23.3	0.8	11.8	**17.9**
Alt 22	La Estancia	2674	0.38	18.44	0.76	6.7	**17.4**
Alt 23	Lomas de la Alberca	4742	0.45	23.1	0.77	11.9	**9.2**
Alt 24	Los Naranjos	18823	0.36	19.71	0.63	47.1	**6.8**
Alt 25	Mesón Nuevo	3314	0.40	17.35	0.62	8.3	**8.8**
Alt 26	Nicolás Tumbastiro	31031	0.49	30.86	0.81	77.7	**13.7**
Alt 27	Ojos de Agua	16801	0.39	22.5	0.74	42.0	**2.9**
Alt 28	Piñicuaro	19068	0.47	29.85	0.81	47.7	**18.4**
Alt 29	Queréndaro	53470	0.36	18.98	0.62	133.7	**5.7**
Alt 30	Río Grande	467258	0.45	32.66	0.81	1168.2	**15.2**
Alt 31	San Marcos	49800	0.44	29.16	0.79	124.6	**9.3**
Alt 32	San Nicolás Simirao	8819	0.43	23.47	0.79	22.2	**12.8**
Alt 33	San Juan Tarárameo	8697	0.39	19.59	0.64	21.8	**14.3**
Alt 34	San Lucas Pío	13456	0.43	29.09	0.8	33.7	**8.2**
Alt 35	San Sebastián	4647	0.38	19.06	0.63	11.7	**2.2**
Alt 36	Santa Rita	5979	0.47	28.22	0.8	15.0	**18.2**
Alt 37	Tari Quere	170199	0.47	35.04	0.84	425.6	**66.7**
Alt 38	Zinapécuaro	47987	0.46	29.91	0.79	120.0	**6.5**

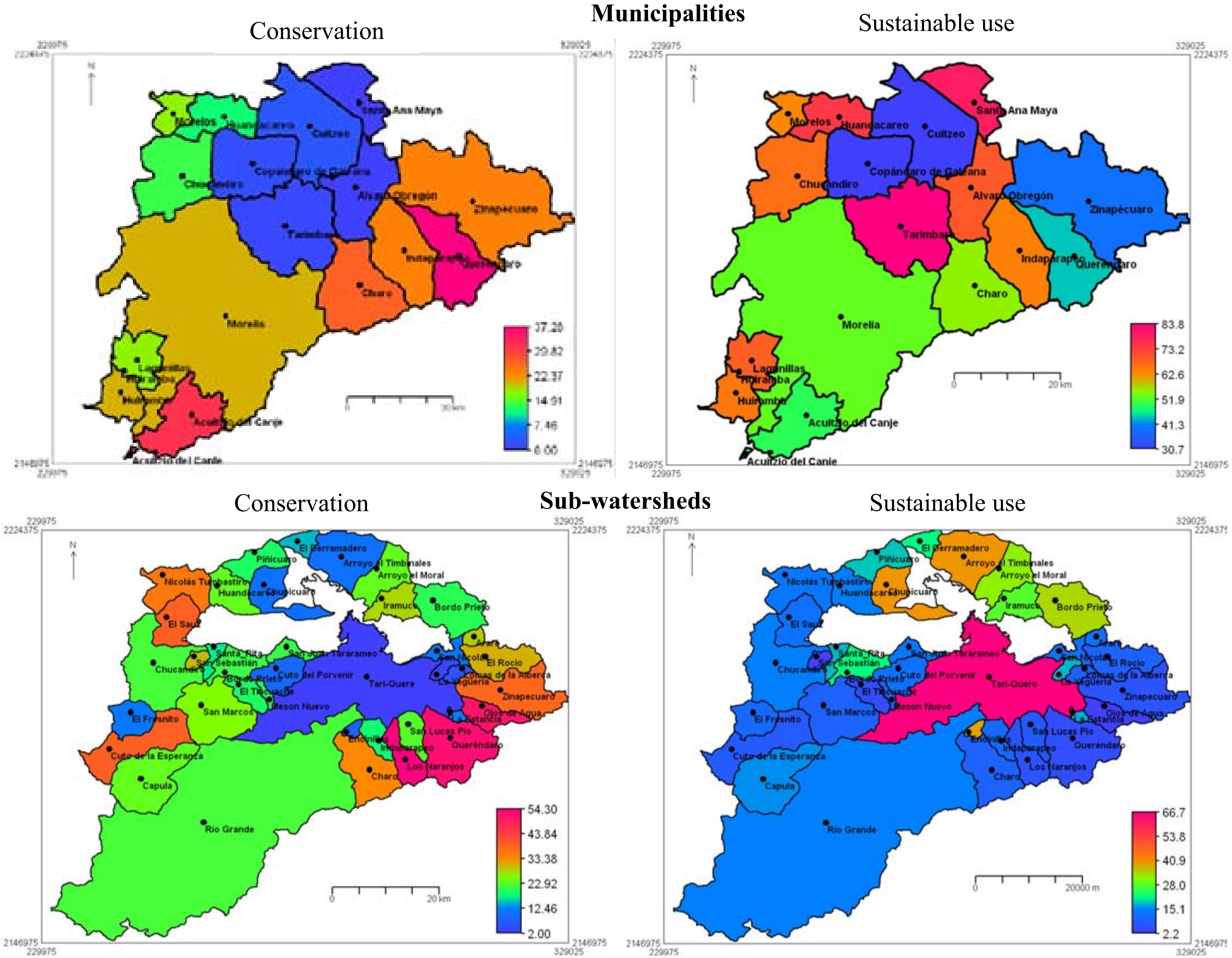


Figure 21Aggregation of the cell-based maps into watersheds and municipalities
Percentage of the total area covered with the 30 percent most suitable cells

7. Ranking of the work units “Choice phase”

The goal of this phase is to realize the ranking of the municipalities and watersheds with the best overall performance in the application of the environmental policies. To reach the objective of this phase it was necessary to carry out a new spatial multicriteria process. It is important to note that this phase was carried out in parallel for the conservation and sustainable use policy for both of the work units (conservation and sustainable use environmental policies).
The suitability maps cannot be used directly as input to calculate the final best alternatives for the application of the environmental policies. The suitability values have to be aggregated into the spatial units to establish their relative importance.

7.1. Distribution of the suitability indexes in the LCB

As a first approach for the spatial allocation of the values of the overall suitability index in the LCB a slicing process was carried out. Each of the suitability index maps was classified into suitability classes according to the distribution of the values of the frequency histogram in 4 suitability categories proposed for each of the policies (Figure 22 and Figure 23).

The sliced process for the suitability map for the conservation policy was easy to determine due the well defined four clusters in the distribution of the values. In the frequency histogram of the suitability map for the sustainable use policy, the values are distributed in two main clusters. Since the sustainable use suitability map did not show so clear clustering of the values, the class boundaries were selected by subdividing the larger cluster into three smaller groups using the break points of the curve aiming at an approximate histogram equalization.

The distribution of the suitability classes for the conservation policy (Figure 22) in the LCB is as follows:

- The best suitable class “S1” is distributed in the higher zones, in a landscape dominated by mountains, high hills and medium hills, where the majority of the permanent forests are located and the majority forest recovery took place. The main vegetation cover is represented by the dense forest. The best suitability class for the conservation policy covers the 12 percent of the total surface of the basin.
- The second best class “S2” is distributed also in the higher zones of the basin, nevertheless, it is represented mainly by the semi-dense forest and dense scrublands, it comprises less than an 8 percent of the total surface of the basin.
- The third and fourth suitability classes, “S3” and “S4”, cover a 61 percent of the basin. These classes are localized in the lower zones of the basin; mainly on the lacustrine plain, where the irrigated and rain-fed agriculture are the dominant land uses, followed by cattle grazing zones in the grassland and open scrublands.

- The unsuitable area covers a 19 percent and represents the constraints previously established.

The distribution of the suitability classes for the sustainable use policy in the LCB (Figure 23) is as follows:

- The most suitable class “S1” is mainly distributed in the lower zones of the basin in the lacustrine plain and in the lower hills just to the north of the lake. The predominant land cover is irrigated agriculture, followed by rain-fed agriculture and by cattle grazing. The best suitability class covers a 13 percent of the total area of the LCB.
- The second best class “S2” is distributed over the low and medium hills in the basin, the rain-fed agriculture and the dense scrubland being the most extended land cover within this class of suitability, and it comprises a 27 percent of the total surface of the basin.
- The “S3” class is represented manly by dense scrubland, scrub-grassland and rain-fed agriculture, covering 22 percent of the total area of the basin.
- The less suitable class; “S4” is distributed in the highest zones of the basin within the headwater zone. It is represented by the forest cover and by the patches of dense scrublands located above 2,400 meters altitude. This class covers a 17 percent of the total area of the basin.
- The unsuitable area covers 18 percent of the basin and is represented by urban settlements, eroded areas and the natural protected areas in the LCB.

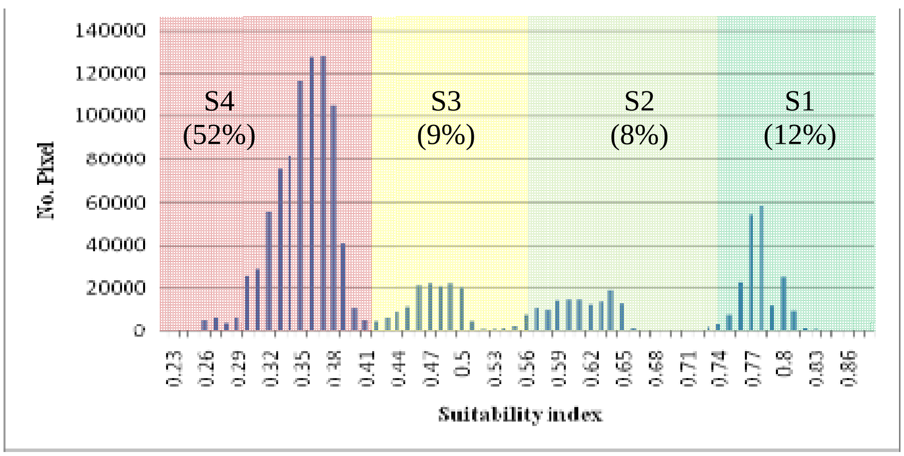


Figure 22 Frequency histogram of the conservation suitability map

.

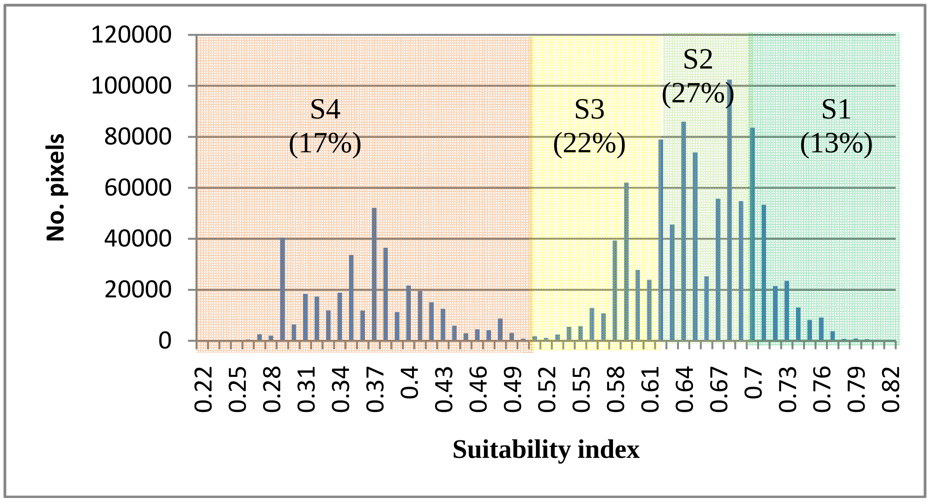


Figure 23 Frequency histogram for the sustainable use suitability map

7.2. Criteria structure for the ranking phase

The suitability index values, the information derived of the EMPLCB and the marginality index were aggregated in the spatial units and used to design the new criteria structures, one for each environmental policy

In these sense, the new criteria structure for the final evaluation phase is composed of three principal branches:

7.2.1. Supply

This term is referred to available areas with specific characteristics that match with the basic necessities to implement the environmental programs in the LCB. Integrates the distribution of the higher suitability index values derived of the biophysical attributes of the spatial units. For both criteria structure of the environmental policies evaluated in this work, this criterion is considered as a benefit factor. Is composed by two sub-criteria:

- **Connectedness of suitability classes per municipality**

This indicator represents how the best suitability values are distributed within the spatial units. It is considered that the areas that have a homogenous distribution of the higher suitability values are preferable than the areas that present a "salt and pepper" (scatter pattern) effect in its best performance cells. Thus, the size of the patch integrating the best 30 percent of the most suitable cells is taken as an indicator; the bigger the patch the better it is for the application of environmental programs. The connectedness of area with a certain suitability minimum threshold can be measured through an arithmetic average size of the different connected areas of that value (Sharifi, A. et, al. 2004), applying the following formula:

$$v1 = \left(\left(\left(\sum_{i=1}^{n} (size\ (i))^{\ p} \right)^{\ 1/p} \right) * 100/N \right) / n$$

Equation 4 Connectedness

Where: *v1*= connectedness

N= size of the spatial unit

n= number of connected areas per spatial unit

size (i) = size of connected area I

p = power; p =1 (straight average of the size of the connected areas)

For both criteria structure of the environmental policies this criterion is considered as a benefit factor.

- **Percentage of cover of the best performance cells per spatial unit.**

This criterion is a simple aggregate measurement of suitability per spatial unit.

The values of the suitability index map for each environmental policy were aggregated into the spatial units, to do this, only the best 30 percent of the best performance cells was taken into account. The premise is that the higher the percentage of cover with the best 30 percent most suitable cells within the spatial units, the better it is for the application of the environmental programs.

This criterion is considered as a benefit factor for both of the environmental policies

7.2.2. Demand

This criterion is based on the marginality index per locality. This index is a measure of exclusion of the social groups from the benefits of the development progress in the region. The marginality index was developed by the National Population Council of the Federal Government of Mexico. The index uses the information derived from the Second General Counting of Population and Housing by INEGI during October 4-29 of 2005. The index is presented as an aggregated value at a municipal and watershed level.

The marginality index allows making a differentiation between the spatial work units according to the intensity of the deprivation suffered by the inhabitants. This index is an aggregated value calculated through a principal component analysis using the nine following standardized socioeconomic indicators (Conapo, 2005):

- Percentage of illiterate 15 years or older population.
- Percentage of 15 years or older population without completed elementary education.
- Percentage of population living in a house without sewerage or W.C.
- Percentage of population living in a house without electric energy.
- Percentage of population living in a house without piped water.
- Percentage of households with some level of overcrowding.

- Percentage of population living in a house with dirt floor.
- Percentage of population in settlements with less than 5,000 people.
- Percentage of occupied population with an income of less than twice the minimum wage.

The marginality index is introduced in the decision process as a positive factor related to the sustainable use policy. The index shows that the less protected social groups are localized in the rural environment of the LCB. At higher dispersion level of the settlements the value of the index is higher. Therefore, the municipalities with high marginality index have to promote the sustainable productive programs to insert these marginal groups into the productive activities, in order to enhance their life quality and at the same time reduce the uncontrolled exploitation of the natural resources of the municipality.

The marginality index was used as a negative factor to evaluate the municipalities for the conservation policy. It is assumed that at less marginality index the population is not forced to over exploit the natural resources, so there is less risk in applying conservation policy. Furthermore, the population is less scattered in the rural environment and more concentrated in the urban settlements, depending less directly on the natural resources. In consequence, the municipalities with lower marginality index values mean less pressure on the valuable areas for conservation programs.

It is considered as a benefit factor for the application of the sustainable use policy in the spatial units. On the other side, it is considered as a cost factor in the criteria structure for the application of the conservation policy.

7.2.3. Decree

- **Percentage of area assigned to conservation and productive uses by the governmental decree in the EMPLCB per spatial unit.**

The third main criterion represents the percentage of area within the spatial units that is assigned to the conservation and productive activities uses by the EMPLCB. This criterion is introduced because the environmental management units (section 2.7) are the working units in which the environmental programs are applied in Mexico. Each EMU is assigned by decree to an environmental policy according to its biophysical and socioeconomic characteristics. Thus, it is important to take this into account for measuring the overall performance of the spatial units for each of the environmental policies.

In this sense, the higher the percentage of the total area of each spatial unit that is assigned by the EMPLCB to the conservation policy, the better it is for the application of the conservation policy. On the other hand, the higher the percentage of the total area of each spatial unit that is assigned to the sustainable use policy by the EMPLCB, the better it is for the application of the sustainable use policy.

This criterion is an aggregated value for each spatial unit and is considered as a benefit factor for both of the environmental policies

7.3. Partial valuation

In order to make the criteria comparable, the values of the maps were standardized from zero to one.

For all maps the maximum standardization method was used because it allows keeping the ratio between the actual and the standardized values for the maps that present the lower value different to zero. This standardized function was applied by dividing the actual value by the maximum value.

The only criterion that was considered to have a negative relation was the marginality index in the evaluation of the conservation criteria structure, the formula for the maximum standardized function for a cost factor according to Malczewski is:

$$\text{Cost factor} = 1 - \left(\frac{\text{actual value}}{\text{maximum input value}}\right)$$

Equation 5 Cost factor. Maximum standardization

7.4. Relative importance of the criteria. Scenario generation

For the evaluation phase four different scenarios were proposed aiming to subtract information about the response of the spatial units under different set of weights.

Scenario 1. **Supply**. This scenario gives more relative importance to the suitability index defined in the SMCE , the other two main criteria show the same relative importance among them.

Scenario 2. **Demand**. In this set of weight a higher relative importance is given to the social demand expressed by the marginality index. The other two main criteria show the same relative importance among them.

Scenario 3. **Decree**. This set of weights state a more relative importance to the strategies and environmental polices dictated by the EMPLCB.

Scenario 4. **Without trend**. Equal weights for the three main criteria.

The relative importance of the three main criteria was defined through the ranking ordering method; this technique consists of arranging the criteria in order of importance related to the proposed scenario, and then translates this order into a quantitative ranking.

In the annexes it can be observed the values of each main criterion for each of the proposed scenario. Also, the annexes shows the final utility of each spatial unit for the environmental policies for each of the scenario.

It is important to note that the scenarios were proposed to assess the responses of the spatial units to the manipulation of the relative importance of the main criteria. In this way this analysis allows to integrate in a final ranking different point of view of the stakeholders in the lake Cuitzeo basin.

Table 20 Different sets of weights for the four scenarios in the SMCE

Supply scenario

Weight		Criteria	Weight	Factor
Rank order	**.50**	Supply	.50	Connectedness
			.50	Best performance cells
	.25	Demand	1	Marginality index
	.25	Decree	1	Percentage of cover EMU per unit

Demand scenario

Weight		Criteria	Weight	Factor
Rank order	**.25**	Supply	.50	Connectedness
			.50	Best performance cells
	.50	Demand	1	Marginality index
	.25	Decree	1	Percentage of cover EMU per unit

Decree Scenario

Weight		Criteria	Weight	Factor
Rank order	**.25**	Supply	.50	Connectedness
			.50	Best performance cells
	.25	Demand	1	Marginality index
	.50	Decree	1	Percentage of cover EMU per unit

Without trend scenario

Weight		Criteria	Weight	Factor
Rank order	**.33**	Supply	.50	Connectedness
			.50	Best performance cells
	.33	Demand	1	Marginality index
	.33	Decree	1	Percentage of cover EMU per unit

8. Sensitivity and conflict analysis

8.1. Sensitivity analysis

With the objective of assess the consistency of the results of the multicriteria analysis for ranking municipalities and sub-watersheds, a sensitivity analysis was made to know the response of the spatial units to the change of weights in the main criteria within the multicriteria trees. For this goal, four scenarios were proposed (Supply, Demand, Decree, No trend). The former procedure allows knowing which municipalities and sub-watersheds behave consistently in their ranking, i.e., they do not change from suitability class when changing the relative importance of a given main criterion, and in consequence, which of these spatial units change their suitability class when relative importance of a given criteria is changed. At the same time, the sensitivity analysis allows comparing the used criteria, thus knowing which attributes of the territory are more relevant for defining the degree of suitability of the special units assessed in the present study.

In order to compare the ranking of the territorial units in relation to the scenarios, the following suitability classes were defined: “Suitable,” “Moderately Suitable,” and “Unsuitable.” The definition of suitability classes was based on the statistical distribution of the suitability index values in each scenario. For this, the normal distribution of data was first corroborated using the Saphiro-Wilk normality test. All suitability index values had normal distribution in all the scenarios.

The limits of the classes of the suitability index values were defined by means of the standard deviation values. By this statistical procedure, the class “Suitable” gather the spatial units having suitability index values beyond one time the standard deviation to the right of the mean value of the distribution; the class “Moderately Suitable” includes values within one standard deviation to the right and left of the mean value; and the class “Unsuitable” corresponded to suitability index values distributed beyond one standard deviation to the left of the mean value. As an example, Figure 24 shows the normal distribution of the scenario “Supply” in the sub-watershed analysis for suitability for implementation of the conservation policy.

Finally, the territorial units were aggregated in the three suitability classes defined above, considering the performance of each unit in the four proposed scenarios for the two environmental policies evaluated in the present study. The class aggregation criteria were:

Class 1 “Suitable:” Includes all units having the category “Suitable” in at least two scenarios, and not having the category of “Unsuitable” in any scenario.
Class 2 “Moderately Suitable:” In this class are grouped units having the category of “Moderately Suitable” in at least three scenarios.
Class 3 “Unsuitable:” Aggregates units having the category “Unsuitable” in two or more scenarios.

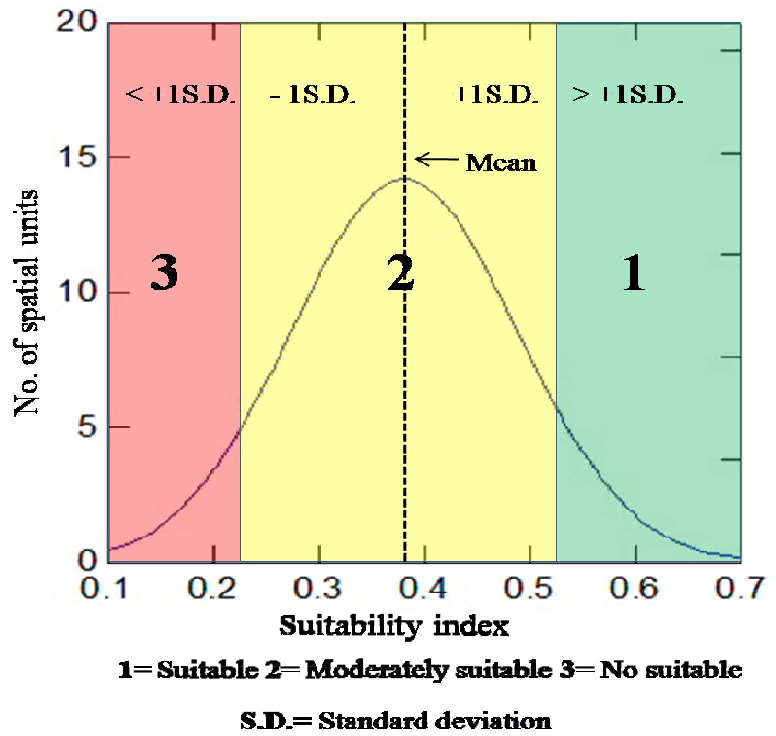


Figure 24 Construction of suitability classes based on the distribution of the suitability values
The example correspond to the scenario "Supply" in conservation policy

8.1.1. Conservation policy

Municipalities

The municipalities with a better performance for the application of environmental programs based on the conservation policy were Huandacareo and Queréndaro, both displaying an absolute consistency in suitability across the four proposed scenarios. In general, all municipalities behaved consistently in relation to the scenarios, none of the municipalities having changes of class of more than one order of magnitude in any of the scenarios; i.e., changes from class 1 to class 3, or the reverse, were not observed (see Table 21). The spatial distribution of the municipalities suitability for application of programs for the conservation of environmental assets and services, in accordance with each scenario and their integration, is presented in Figure 25.

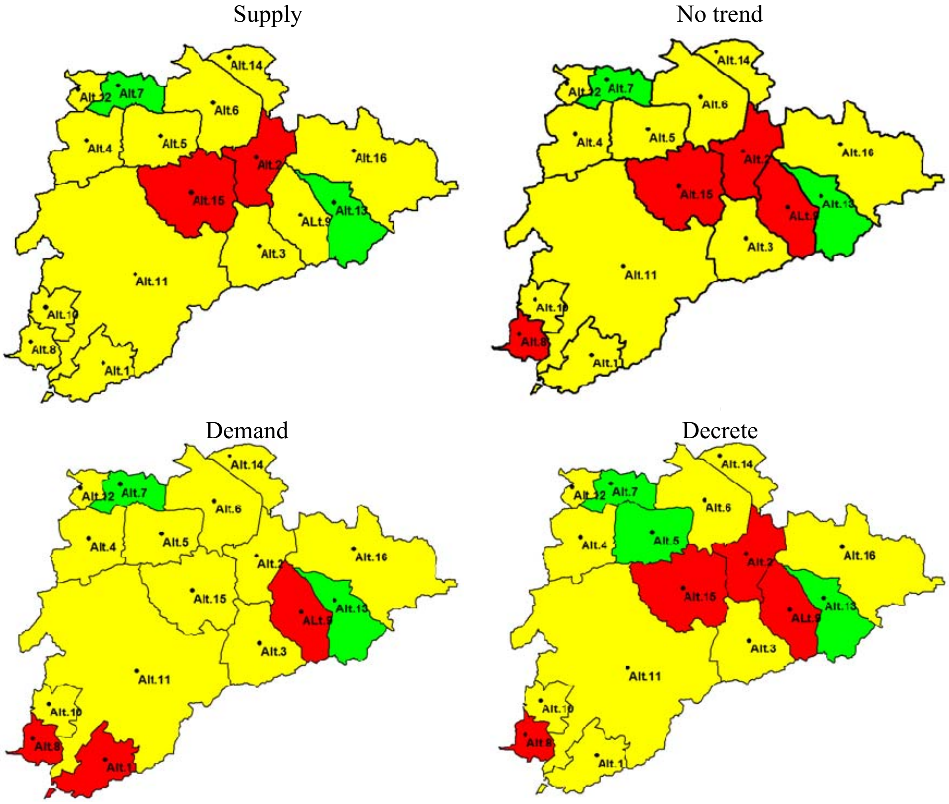
In the map of suitability of municipalities integrating the suitability index values in the four proposed scenarios, two municipalities are seen to present the highest suitability for the conservation policy, both belonging to the class "Suitable" but for different reasons. Queréndaro displays a high performance due to the criteria of quality and permanence of forest cover, characteristics shared by the municipalities in the mountainous areas adjacent to Queréndaro, although having lower suitability index values. In the case of Huandacareo, it belongs to the class "Suitable" because of the relative high value of the recovery of the vegetation cover, mainly due to the expansion of scrubland in the areas to the north of Lake Cuitzeo (Figure 25).

Regarding the distribution of municipalities by class of suitability for the conservation policy, two municipalities fall within the class "Suitable" covering a total extension of 250 km^2, representing a 7 percent of the total area of the LCB. In the class "Moderately Suitable" are 12 municipalities with a total area of 2698 km^2 (a 75 percent of the LCB), while in the class "Unsuitable" 2 municipalities are included adding to an extension of 652 $km^{2.}$ (corresponding to an 18 percent of the LCB).

Table 21 Suitability of municipalities by scenario for the policy of conservation

	Municipality\Scenario	Supply	No trend	Demand	Decree
Suitable	Huandacareo	1	1	1	1
	Queréndaro	1	1	1	1
Moderately Suitable	Copándaro de Galeana	2	2	2	1
	Charo	2	2	2	2
	Chucándiro	2	2	2	2
	Cuitzeo	2	2	2	2
	Lagunillas	2	2	2	2
	Morelia	2	2	2	2
	Morelos	2	2	2	2
	Santa Ana Maya	2	2	2	2
	Zinapécuaro	2	2	2	2
	Acuitzio del Canje	2	2	3	2
Unsuitable	Álvaro Obregón	3	3	2	3
	Huiramba	2	3	3	3
	Indaparapeo	2	3	3	3
	Tarímbaro	3	3	2	3

Priority of municipalities for the conservation policy. Scenarios.



Integrative map for the scenarios in the conservation policy

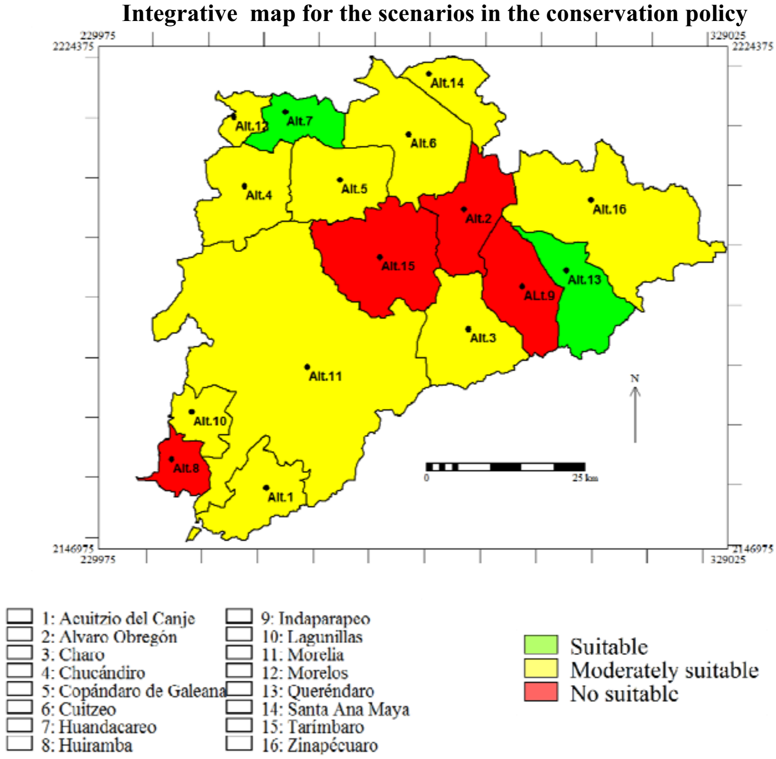


Figure 25 Prioritization of municipalities. Conservation policy

Sub-watersheds

The sub-watersheds having the best overall suitability for the application of environmental programs derived from the conservation policy are: Queréndaro, Zinapécuaro, Ojos de Agua and Capula; all four showing total consistency across the evaluated scenarios. The sub-watersheds Cuto de la Esperanza, Charo and San Juan Tararameo are also classed as "Suitable", however, in two of the proposed scenarios they were grouped in the class "Moderately Suitable." In the "Unsuitable" class high consistency is seen in all sub-watersheds in all scenarios; the only noticeable exception being the sub-watershed Mesón Nuevo included in the class "Moderately Suitable," but in the class "Suitable" for the "Demand" scenario and in the class "Unsuitable" for the "Decree" scenario (see Table 22). The spatial distribution of suitability of sub-watersheds for the application of environmental programs related to the conservation of environmental assets and services per scenario and their integration is shown in Figure 26.

The spatial distribution of suitability for conservation policy application by sub-watershed follows the same pattern as that for municipalities, i.e., higher suitability are located in the mountainous area to the south of the LCB; where sub-watersheds having larger proportion of their territory in high elevations are prominent. Also, a positive tendency was observed regarding some of the sub-watersheds to the north of Lake Cuitzeo, which is due to the above-mentioned process of scrubland expansion. Otherwise, the less suitable units for the implementation of the conservation policy are observed to correspond to those located in the central portion of the LCB, on the lacustrine plain where agriculture and cattle grazing are dominant activities.

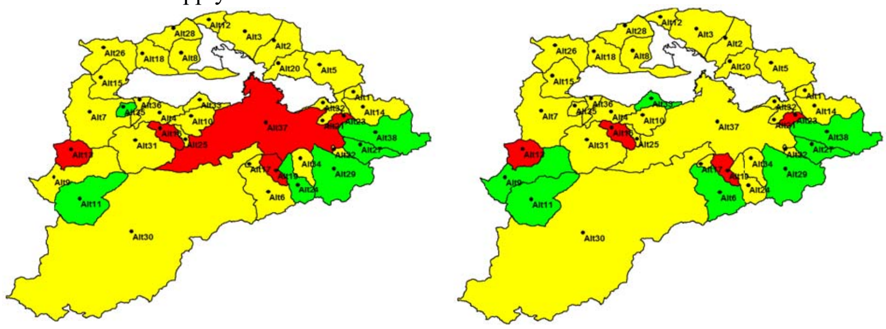
The distribution of suitability of sub-watersheds for the conservation policy is as follows: the class "Suitable" includes 7 sub-watersheds with an extension of 653 Km^2 corresponding to an 18 percent of the total area of the LCB; in the class "Moderately Suitable" 25 sub-watersheds are grouped with a surface area 2321 km^2, representing a 64 percent of the basin; and in the class "Unsuitable" 7 sub-watersheds are included adding to an area 645 km^2 corresponding to a 17 percent of the total extension of the LCB.

Table 22 Suitability for conservation policy application of sub-watersheds by scenario.

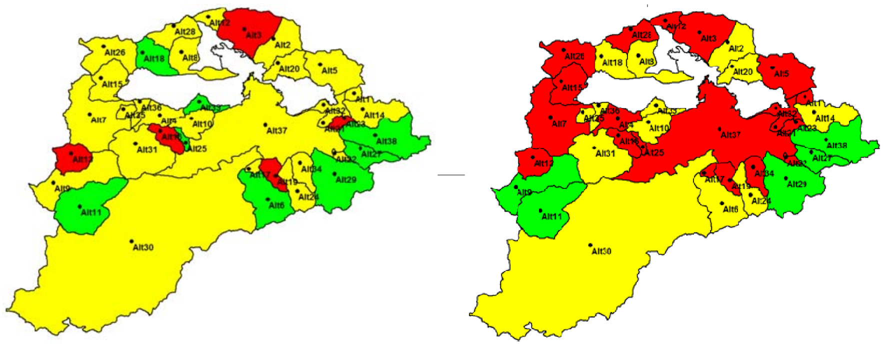
	Sub-watershed\Scenario	Supply	No trend	Demand	Decree
Suitable	Queréndaro	1	1	1	1
	Zinapécuaro	1	1	1	1
	Ojos de Agua	1	1	1	1
	Capula	1	1	1	1
	Cuto de la Esperanza	2	1	2	1
	Charo	2	1	1	2
	San Juan Tararameo	2	1	1	2
Moderately Suitable	Huandacareo	2	2	1	2
	Los Naranjos	1	2	2	2
	San Sebastián	1	2	2	2
	Arroyo el Moral	2	2	2	2
	Chupícuaro	2	2	2	2
	Cuto del Porvenir	2	2	2	2
	El Rocío	2	2	2	2
	Iramuco	2	2	2	2
	Mesón Nuevo	2	2	1	3
	Río Grande	2	2	2	2
	San Marcos	2	2	2	2
	Santa Rita	2	2	2	2
	Araró	2	2	2	3
	Bordo Prieto	2	2	2	3
	Chucándiro	2	2	2	3
	Copándaro	2	2	2	3
	El Derramadero	2	2	2	3
	El Sauz	2	2	2	3
	Encinillas	2	2	2	3
	La Yegüería	2	2	2	3
	La Estancia	2	2	2	3
	Nicolás Tumbastiro	2	2	2	3
	Piñícuaro	2	2	2	3
	San Nicolás Simirao	2	2	2	3
	San Lucas Pío	2	2	2	3
Unsuitable	Arroyo el Timbinales	2	2	3	3
	Tarimbaro-Queréndaro	3	2	2	3
	El Fresnito	3	3	3	3
	El Tlacuache	3	3	3	3
	Indaparapeo	3	3	3	3
	Lomas de la Alberca	3	3	3	3

Priority of subwatersheds for the coservation policy. Scenarios.

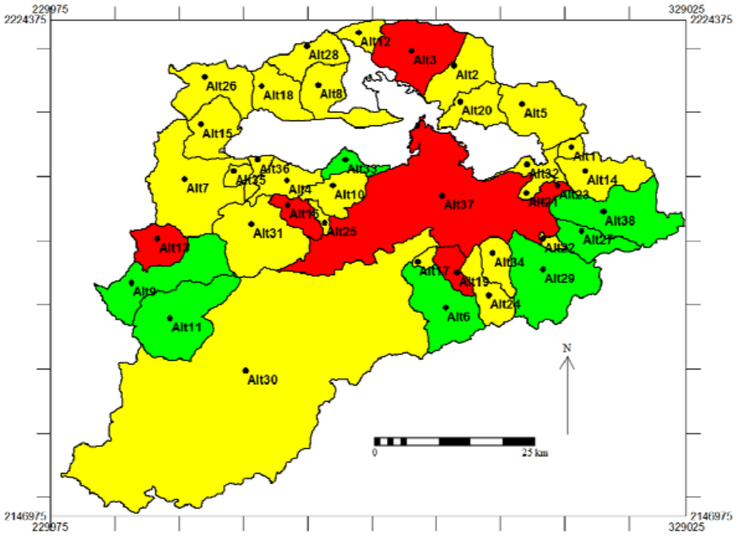
Supply	No trend



Demand	Decrete



Subwatersheds. Integrative map for the scenarios in the conservation policy



Alt1: Araró
Alt2: Arroyo el Moral
Alt3: Arroyo el Timbinales
Alt4: Bordo Prieto
Alt5: Charo
Alt6: Chucandiro
Alt7: Chupicuaro
Alt8: Copandaro
Alt9: Cuto de_ a Esperanza
Alt10: Cuto del Porvenir
Alt11: Cápula
Alt12: El Derramadero
Alt13: El Fresnito
Alt14: El Rocio
Alt15: El Sauz
Alt16: El Tlacuache
Alt17: Encinillas
Alt18: Huandacareo
Alt19: Indaparapeo
Alt20: Iramuco
Alt22: La Estancia
Alt21: La Yegüeria
Alt23: Lomas de la Alberca
Alt24: Los Naranjos
Alt25: Meson Nuevo
Alt26: Nicolás Tumbastiro
Alt27: Ojos de Agua
Alt28: Piñicuaro
Alt29: Queréndaro
Alt30: Río Grande
Alt33: San Juan Tarárameo
Alt34: San Lucas Pio
Alt31: San Marcos
Alt32: San Nicolás Simirao
Alt35: San Sebastián
Alt36: Santa Rita
Alt37: Tarimbaro-Querendaro
Alt38: Zinapecuaro

Suitable
Moderately suitable
No suitable

Figure 26 Prioritization of sub-watersheds. Conservation policy.

8.1.2. Sustainable use policy

Municipalities

The most suitable municipalities for the application of environmental programs derived from the policy of sustainable use are Álvaro Obregón and Indaparapeo, both displaying total consistency in suitability class across the four proposed scenarios. As in the case of the conservation policy, municipalities behave in a consistent manner in all scenarios, neither of the municipalities changing from classes by more than one order of magnitude in all scenarios (see Table 23). Figure 27 shows the spatial distribution of the suitability of municipalities for the application of programs related to the environmental policy of sustainable use for each of the four evaluated scenarios. It can be noticed that most of the municipalities within the class "Moderately Suitable" in the integrated map is due to administrative territorial limits and not to "natural" limits; which makes some of the municipalities to be mapped in the higher portion of the LCB, with forest cover, and the remaining of these administrative units to be located in the lacustrine plain where agricultural and cattle grazing are the dominant activities. Because of this, it is recommended to make intra-municipal studies in order to assign priorities to areas for particular environmental programs.

Regarding the distribution of municipalities for each suitability class for the implementation of programs derived from the sustainable use policy, 2 municipalities were included in the class "Suitable" adding to an extension of 324 km^2 representing a 9 percent of the total area of the LCB. In the class "Moderately Suitable" 12 municipalities were grouped with a surface area of 2845 km^2 (a 79 percent of the LCB total area). Finally, 2 municipalities were included in the class "Unsuitable" with a total extension 430 km^2, a surface area corresponding to a 12 percent of the extension of the LCB.

Table 23 Suitability of municipalities for the sustainable use policy by scenario

	Municipality\Scenario	Supply	No trend	Demand	Decree
Suitable	Álvaro Obregón	1	1	1	1
	Indaparapeo	1	1	1	1
Moderately Suitable	Acuitzio del Canje	2	2	1	2
	Morelos	2	2	2	1
	Charo	2	2	2	2
	Chucándiro	2	2	2	2
	Huandacareo	2	2	2	2
	Huiramba	2	2	2	2
	Lagunillas	2	2	2	2
	Queréndaro	2	2	2	2
	Santa Ana Maya	2	2	2	2
	Tarímbaro	2	2	2	2
	Morelia	2	3	2	2
	Zinapécuaro	2	3	2	2
Unsuitable	Copándaro de Galeana	3	3	3	3
	Cuitzeo	3	3	3	3

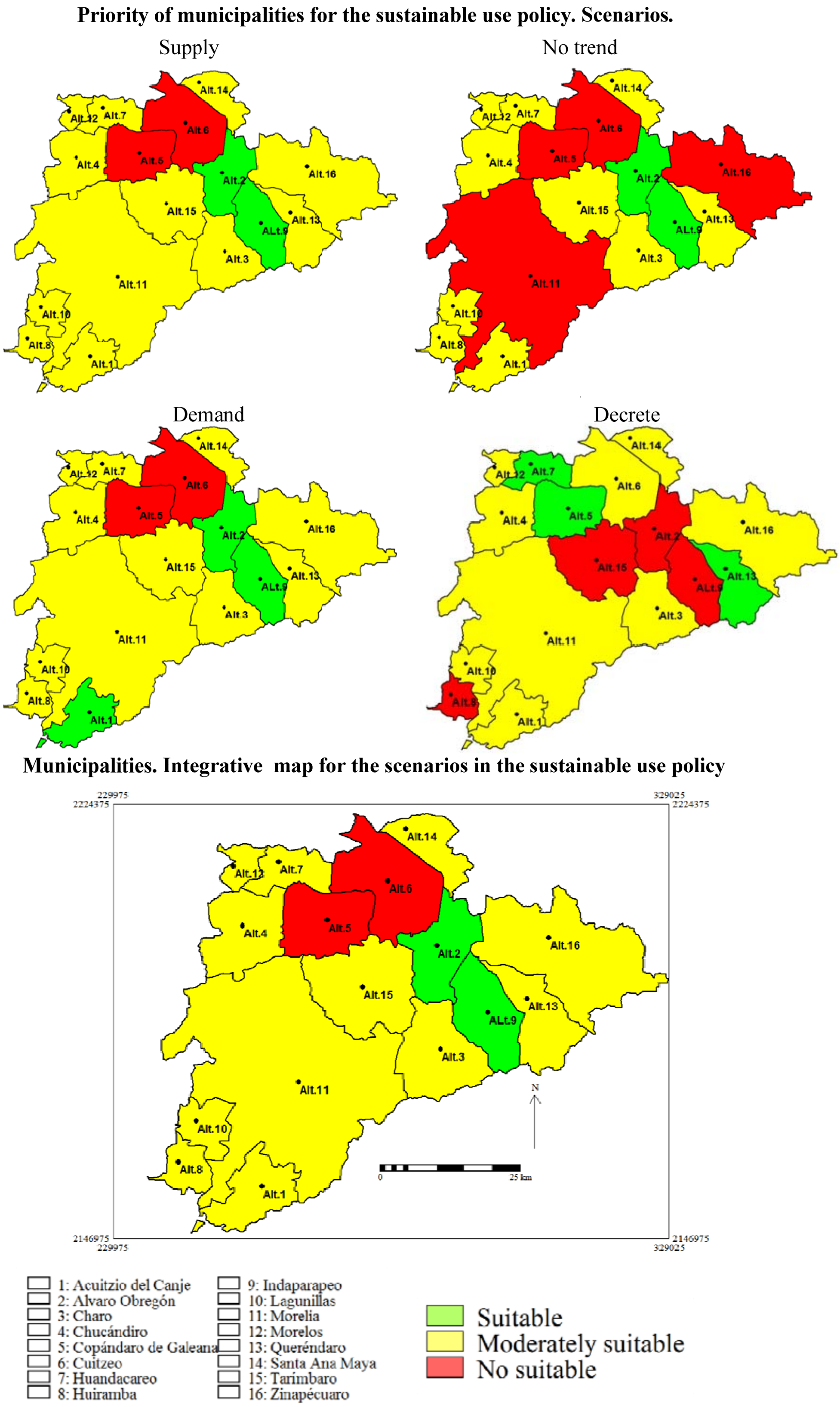


Figure 27 Prioritization of municipalities. Sustainable use policy

Sub-watersheds

Sub-watersheds with the better overall performance for the application of programs derived from the environmental policy of sustainable use are those totally or mostly included in the lacustrine zone of the LCB. The sub-watersheds with higher suitability and total consistency were El Tlacuache and Indaparapeo, followed by Arroyo el Timbinales, El Sauz, Encinillas and Lomas de la Alberca, sub-watersheds that in one scenario were classed as "Moderately Suitable;" finally, the Tarímbaro-Queréndaro sub-watershed was also in the most suitable group, however in two scenarios it classed as "Moderately Suitable." The sub-watersheds in the classes "Moderately Suitable" and "Unsuitable" showed high consistency, only presenting class changes of one order of magnitude in suitability class in one or in two scenarios (see Table 24). The spatial distribution of the suitability of sub-watersheds for sustainable use programs by scenario, and their integration are shown in Figure 28.

Regarding the evaluation of the suitability of sub-watersheds for the sustainable use policy, 8 sub-watersheds grouped in class "Suitable" over a total extension of 668 km^2, representing an 18 percent of the LCB total area. In the class "Moderately Suitable" were 22 sub-watersheds adding to an extension of 2,232 Km^2 corresponding to a 61 percent of the basin's area. Finally, 9 sub-watersheds classed as "Unsuitable" spreading over 732 km^2, a 20 percent of the total extension of the LCB.

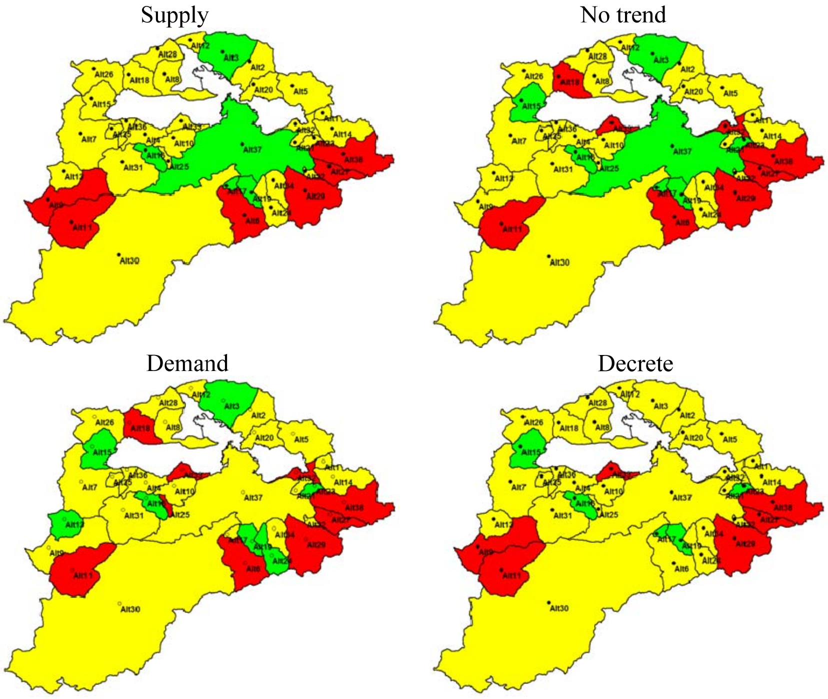
Table 24 Suitability of sub-watersheds for the sustainable use policy by scenario

	Municipality\Scenario	Supply	No trend	Demand	Decree
Suitable	El Tlacuache	1	1	1	1
	Indaparapeo	1	1	1	1
	Arroyo el Timbinales	1	1	1	2
	El Sauz	2	1	1	1
	Encinillas	1	1	2	1
	Lomas de la Alberca	2	1	1	1
	Tarímbaro-Queréndaro	1	1	2	2
Moderately Suitable	El Fresnito	2	2	1	2
	Los Naranjos	2	2	1	2
	Araró	2	2	2	2
	Arroyo el Moral	2	2	2	2
	Bordo Prieto	2	2	2	2
	Chucándiro	2	2	2	2
	Chupícuaro	2	2	2	2
	Copándaro	2	2	2	2
	Cuto del Porvenir	2	2	2	2
	El Derramadero	2	2	2	2
	El Rocío	2	2	2	2
	Iramuco	2	2	2	2
	La Yegüería	2	2	2	2
	La Estancia	2	2	2	2
	Nicolás Tumbastiro	2	2	2	2
	Piñícuaro	2	2	2	2
	Río Grande	2	2	2	2
	San Marcos	2	2	2	2

Continue (Table 24 Suitability of sub-watersheds for the sustainable use policy by scenario)

	San Lucas Pío	2	2	2	2
	San Sebastián	2	2	2	2
	Santa Rita	2	2	2	2
	Mesón Nuevo	2	2	3	2
Unsuitable	Cuto de la Esperanza	3	2	2	3
	Huandacareo	2	3	3	2
	San Nicolás Simirao	2	3	3	2
	Charo	3	3	3	2
	San Juan Tarárameo	2	3	3	3
	Capula	3	3	3	3
	Ojos de Agua	3	3	3	3
	Queréndaro	3	3	3	3
	Zinapécuaro	3	3	3	3

Priority of subwatersheds for the sustainable use policy. Scenarios.



Subwatersheds. Integrative map for the scenarios in the sustainable use policy

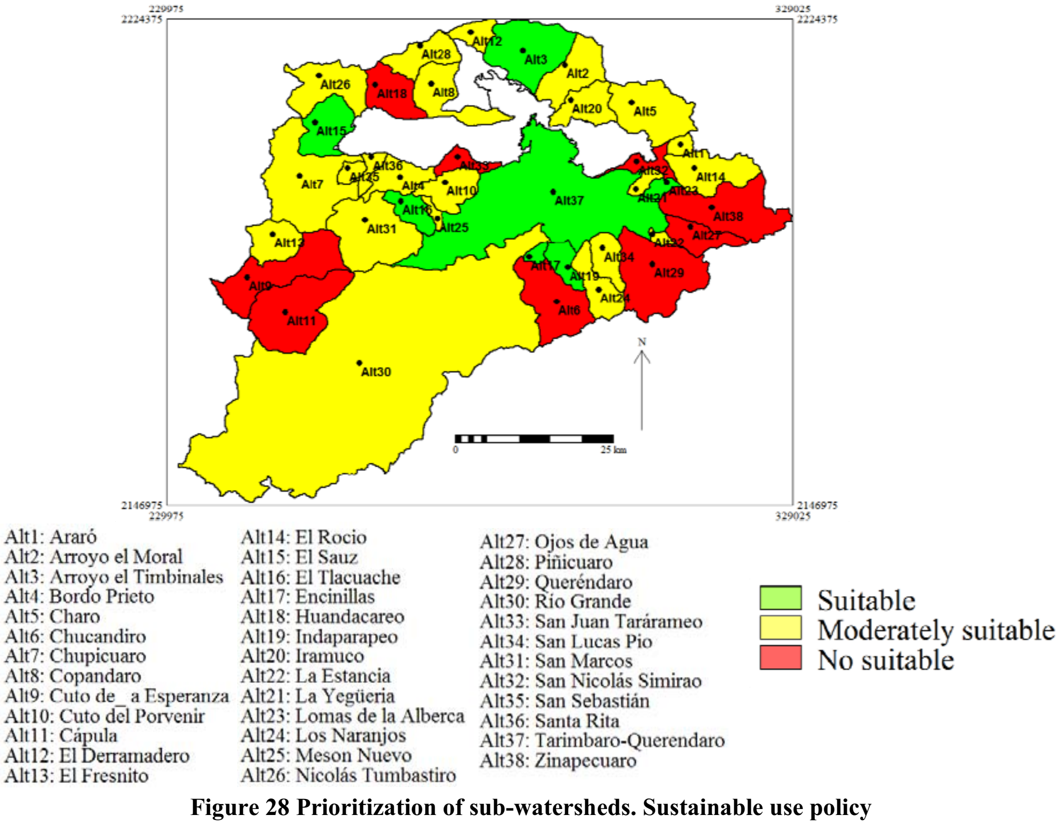


Figure 28 Prioritization of sub-watersheds. Sustainable use policy

8.2. Conflict Analysis

In this phase, potential conflicts in the application of the environmental policies in the territorial units are identified based on the comparison of suitability for conservation and sustainable use in each of the municipalities and sub-watersheds. The objective is to aggregate the spatial units in six conflict classes depending on their degree of conflict for the implementation of both environmental policies analyzed in the present study. The conflict classes are:

Without conflict first order: Units in the "Suitable" class for one of the policies and in the class "Unsuitable" for the other.

. **Without conflict second order**: Units in the class "Moderately Suitable" for one of the policies and in the class "Unsuitable" for the other.

Without conflict third order: Units in the class "Unsuitable" for both policies.

Mixed first order: Units in the class "Suitable" for both policies.

Mixed second order: Units in the class "Suitable" for one of the policies and in the class "Moderately Suitable" for the other.

Mixed third order: Units in the class "Moderately Suitable" for both policies.

The types of suitability conflicts for the implementation of the conservation and sustainable use policies of the territorial units are shown in Table 25

Table 25 Types of suitability conflict in territorial units

	Suitability classes	
Conflict class	**Territorial unit (conservation)**	**Territorial unit (sustainable use)**
Without conflict first order	"Suitable"	"Unsuitable"
Without conflict second order	"Moderately Suitable"	"Unsuitable"
Without conflict third order	"Unsuitable"	"Unsuitable"
Mixed first order	"Suitable"	"Suitable"
Mixed second order	"Suitable"	"Moderately Suitable"
Mixed third order	"Moderately Suitable"	"Moderately Suitable"

8.2.1. Municipalities

The municipalities of Queréndaro (Alternative 13) and Huandacareo (Alternative 7) are in the class "Without conflict first order" for the application of the conservation policy (see Table 26 and Figure 29). This result is interesting because of the different spatial distribution of both municipalities within the LCB; in Queréndaro, located in the southern part of the basin, the predominant landscapes are mountain and high hill, while Huandacareo, located to the north of lake Cuitzeo, is mainly characterized by low hills and lacustrine plain landscapes.

Regarding the sustainable use policy, none of the municipalities was classed as "Without conflict first order," meaning that none of the municipalities better suited for sustainable use was classified as

“Unsuitable” for applying the conservation policy. The municipalities with higher potential for environmental programs that were classified as “Without conflict second order” were Álvaro Obregón and Indaparapeo (alternatives 2 and 9, respectively); an interesting result because both municipalities have different geomorphological characteristics. Álvaro Obregón is located in the lacustrine plain where irrigation agriculture is dominant, while Indaparapeo is a Mixed unit having part of its territory in mountain landscape and another in the lacustrine plain, in this latter landscape intense agricultural activity taking place.

Eight municipalities classified as “Mixed third order” because of which they do not present potential for neither of the environmental policies here considered (Table 26). Finally, four municipalities classified as “Without conflict second order,” two of these being suitable for conservation (Copándaro de Galeana and Cuitzeo) and two, for sustainable use (Huiramba and Tarímbaro). Of these latter four municipalities, three are located in the limits of lake Cuitzeo, Huiramba being located in the southern part of the basin in the limit with the Pátzcuaro basin. None of the municipalities classified as either “Mixed third order,” i.e., in the “Suitable” category for both environmental policies considered, nor “Without conflict third order,” i.e., in the category “Unsuitable” for both considered environmental policies.

Table 26 Type of conflict and affinity by municipality

Municipality	Conflict	Affinity
Álvaro Obregón	**Without conflict first order**	Sustainable use policy
Indaparapeo	**Without conflict first order**	Sustainable use policy
Huandacareo	**Mixed second order**	Conservation policy
Queréndaro	**Mixed second order**	Conservation policy
Acuitzio del Canje	**Mixed third order**	No affinity
Charo	**Mixed third order**	No affinity
Chucándiro	**Mixed third order**	No affinity
Lagunillas	**Mixed third order**	No affinity
Morelia	**Mixed third order**	No affinity
Morelos	**Mixed third order**	No affinity
Santa Ana Maya	**Mixed third order**	No affinity
Zinapécuaro	**Mixed third order**	No affinity
Copándaro de Galeana	**Without conflict second order**	Conservation policy
Cuitzeo	**Without conflict second order**	Conservation policy
Huiramba	**Without conflict second order**	Sustainable use policy
Tarímbaro	**Without conflict second order**	Sustainable use policy

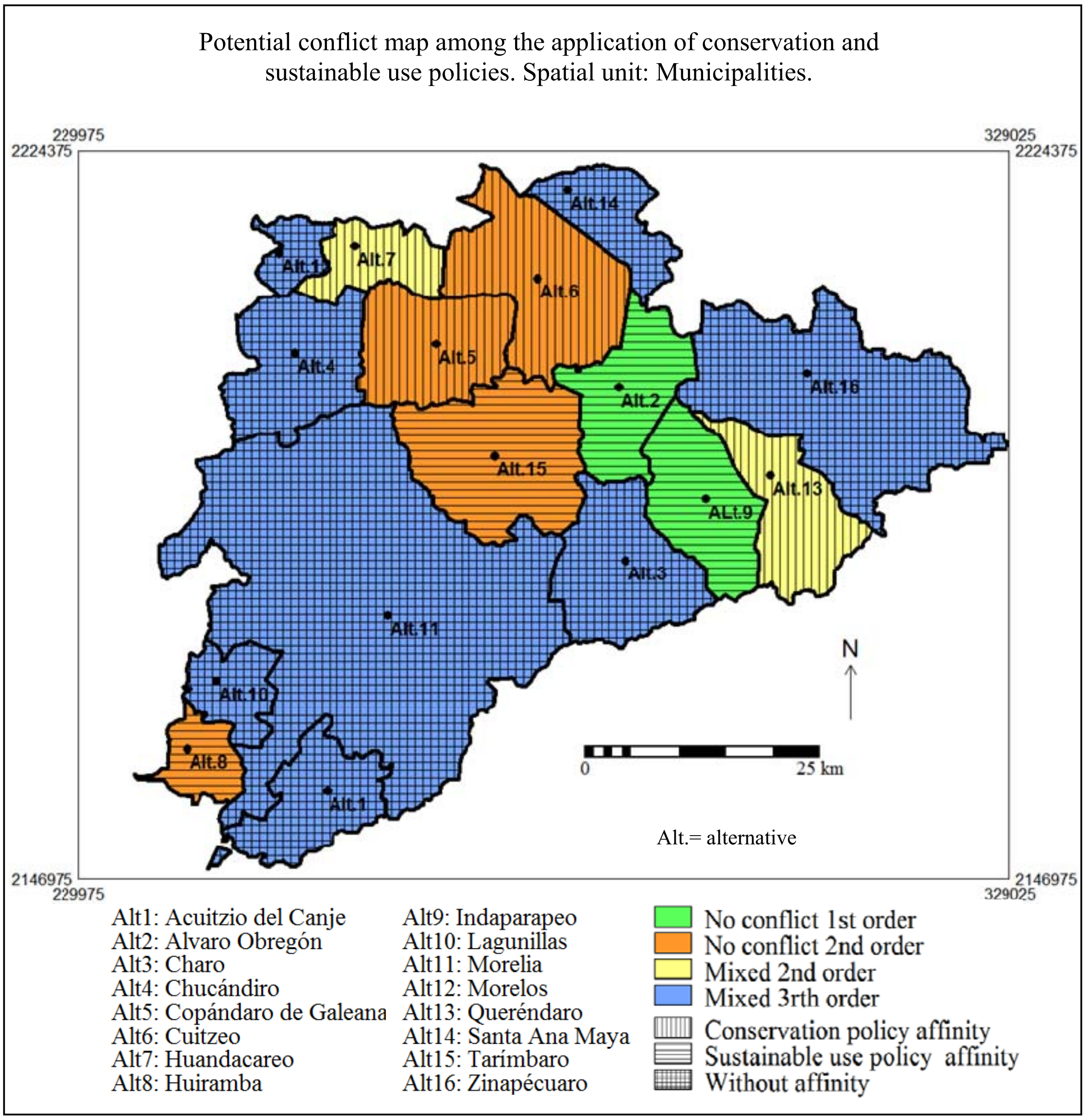


Figure 29 Map of potential conflicts among environmental policies by municipality

8.2.2. Sub-watersheds

The sub-watersheds having higher potential for the application of the conservation policy and that classified as “Without conflict first order” are: Charo, Cuto de la Esperanza, Capula, Ojos de Agua, Queréndaro, San Juan Tararameo and Zinapécuaro (alternatives 5, 9, 11, 27, 29 and 38 , respectively Table 27 and Figure 30). Most of these sub-watersheds are distributed in the mountainous zone in the southern portion of the basin, with the exception of the sub-watersheds Capula and Cuto de la Esperanza, located in the western part of the basin in the limits with the Pátzcuaro basin, having hills and low hill landscapes,

Regarding the sustainable use policy, the sub-watersheds in the category “Without conflict first order” are: Arroyo el Timbinales, El Tlacuache, Indaparapeo, Lomas de la Alberca, and Tarímbaro-Queréndaro (alternatives 3, 16, 19, 23 and 37, respectively, Table 27 and Figure 30). The location of these sub-basins in the integrated map of suitability for sustainable use programs is consistent with previous results in that the territories of all of them are located, entirely or largely, in the low part of the LCB over the lacustrine plain.

Only two sub-watersheds with high suitability for sustainable use were classified as “Without conflict second order:” El Sauz, and Encinillas. The class “Mixed second order” included 21 sub-watersheds, while the category “Without conflict second order” grouped three sub-watersheds: El Fresnito, Huandacareo and San Nicolás Simirao, the latter sub-watersheds classifying as suitable for sustainable use programs. None of the sub-watersheds was classified as “Mixed first order” (suitable for both environmental policies considered) or “Without conflict third order” (unsuitable for both analyzed environmental policies).

Table 27 Type of conflict and affinity by sub-watershed

Sub-watershed	Conflict	Affinity
Charo	Without conflict first order	Conservation policy
Cuto de la Esperanza	Without conflict first order	Conservation policy
Capula	Without conflict first order	Conservation policy
Ojos de Agua	Without conflict first order	Conservation policy
Queréndaro	Without conflict first order	Conservation policy
San Juan Tararameo	Without conflict first order	Conservation policy
Zinapécuaro	Without conflict first order	Conservation policy
Arroyo el Timbinales	Without conflict first order	Sustainable use policy
El Tlacuache	Without conflict first order	Sustainable use policy
Indaparapeo	Without conflict first order	Sustainable use policy
Lomas de la Alberca	Without conflict first order	Sustainable use policy
Tarímbaro-Queréndaro	Without conflict first order	Sustainable use policy
El Sauz	Mixed second order	Sustainable use policy
Encinillas	Mixed second order	Sustainable use policy
Araró	Mixed third order	No affinity
Arroyo el Moral	Mixed third order	No affinity
Bordo Prieto	Mixed third order	No affinity
Chucándiro	Mixed third order	No affinity
Chupícuaro	Mixed third order	No affinity
Copándaro	Mixed third order	No affinity
Cuto del Porvenir	Mixed third order	No affinity
El Derramadero	Mixed third order	No affinity
El Rocío	Mixed third order	No affinity
Iramuco	Mixed third order	No affinity
La Yegüería	Mixed third order	No affinity
La Estancia	Mixed third order	No affinity
Los Naranjos	Mixed third order	No affinity
Mesón Nuevo	Mixed third order	No affinity
Nicolás Tumbástiro	Mixed third order	No affinity
Piñícuaro	Mixed third order	No affinity
Río Grande	Mixed third order	No affinity
San Marcos	Mixed third order	No affinity
San Lucas Pio	Mixed third order	No affinity
San Sebastián	Mixed third order	No affinity
Santa Rita	Mixed third order	No affinity
El Fresnito	Without conflict second order	Sustainable use policy
Huandacareo	Without conflict second order	Sustainable use policy
San Nicolás Simirao	Without conflict second order	Sustainable use policy

Potential conflict map among the application of conservation and sustainable use policies. Spatial unit: Municipalities.

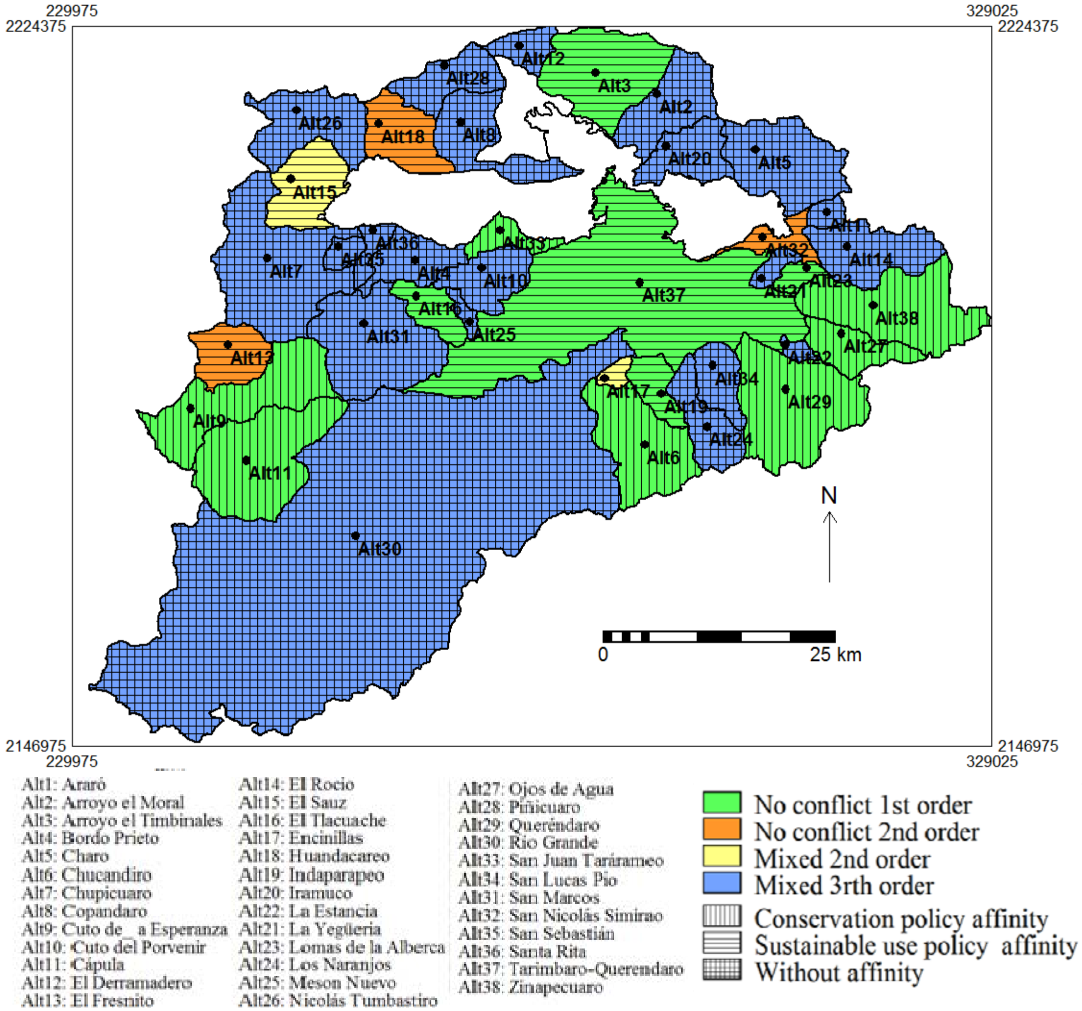


Figure 30 Map of potential conflicts among environmental policies by sub-watershed

From a general perspective, the type of conflict that was more frequently found in the LCB is “Mixed third order;” which means that most of the territorial units, both municipalities and sub-watersheds, are simultaneously moderately suitable for both environmental policies analyzed here. An interesting result is that the total surface occupied by the suitability for both environmental policies remains significantly the same if either the municipalities or the sub-watersheds are considered. However, the total area in the LCB of the class “Without conflict first order” is considerably more extended when sub-watersheds are the territorial units with respect to the same when municipalities are considered (Figure 31 ,Figure 32 and Table 28, Table 29). This latter result reinforces the idea that promoting the assignment of resources for environmental policies at the level of sub-watershed would more easily generate a consensus, thus minimizing conflicts between sectors.

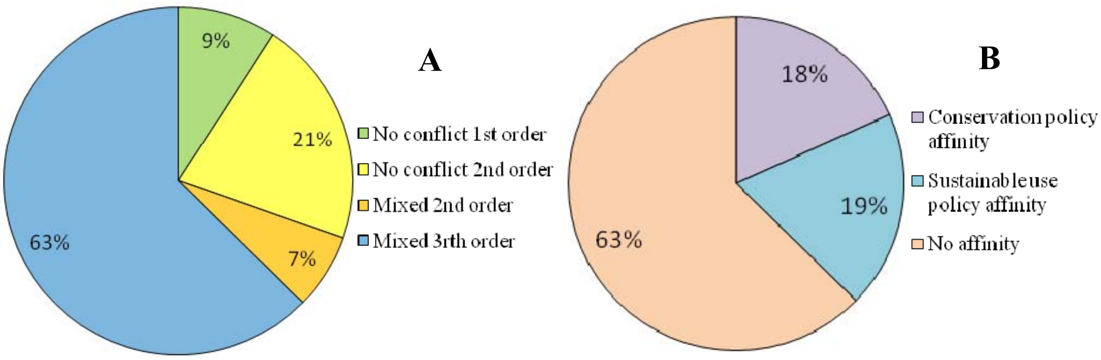


Figure 31 Aggregated surfaces by municipality in the LCB

Table 28 Aggregated surfaces in Km2 within the LCB by municipality
A: Type of conflict. B: Affinity for environmental policy

A

Type of conflict	Km^2
Without conflict first order	325
Without conflict second order	759
Without conflict third order	0
Mixed first order	0
Mixed second order	250
Mixed third order	2236

B

Type of suitability	Km^2
Conservation policy	652
Sustainable use	682
No affinity	2236

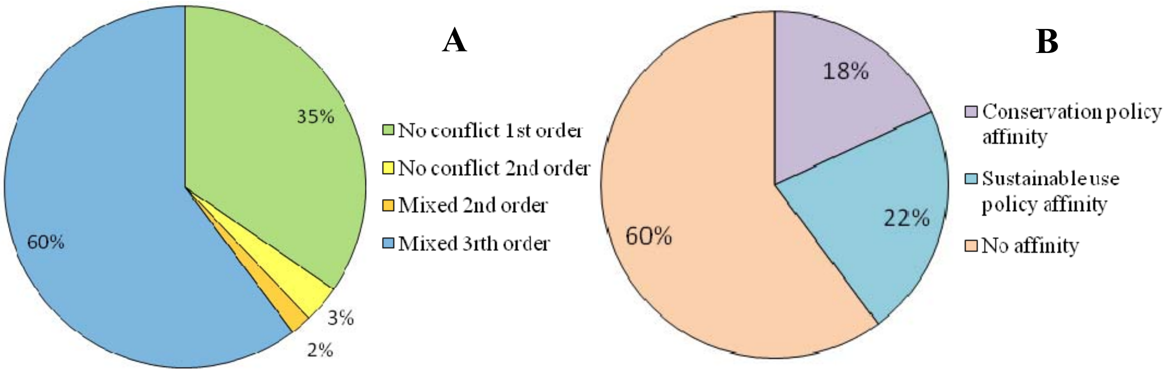


Figure 32 Aggregated surfaces by sub-watershed in the LCB

Table 29 Aggregated surface in Km2 within the LCB by sub-watershed
A: Type of conflict. B: Affinity for environmental policy

A

Type of conflict	Km^2
Without conflict first order	1256
Without conflict second order	122
Without conflict third order	0
Mixed first order	0
Mixed second order	68
Mixed third order	2186

B

Type of affinity	Km^2
Conservation policy	656
Sustainable use policy	790
No affinity	2186

9. Discussion

A specific methodology to evaluate the feasibility for the application of the environmental policies at a municipal level did not exist in the LCB; although, several studies have been done in the basin to evaluate the applicability of the conservation and sustainable use programs at a semi detailed scale. Those studies have considered landforms as the basic evaluation unit (Mendoza M. et al., 2001; Pulido, J. et al., 2001; Mendoza et al., 2006; Michoacán, 2006). In those previous studies, the biophysical attributes of the landforms and their relationship with social necessities where taken into consideration to delineate the environmental management units (EMUs), which are the basic unit for analyzing and applying the EMPLCB.

The present study focused on two important environmental policies. The conservation and sustainable use policies are designed for different objectives, but both aim at reaching a sustainable development of a region. In order to maintain the balance of the basin, it is necessary to allocate the most suitable areas for each purpose. In case of the implementation of the sustainable use policy, besides providing the sustainability of their use for the areas, environmental conflicts have to be also avoided. The implementation of the conservation policy can promote and maintain areas, which provide environmental services to the basin. That means that these discussed environmental policies are complementary. The attributes of the landscape that makes certain territory suitable for the conservation policy depend on the success and permanence of the implementation of the sustainable use policy, and vice versa. Both are focusing on improving the equilibrium between the upper zone of the basin (the most suitable for conservation) and the lower part (the most suitable for the productive practices). It is important to note that one of the main goals is to reach this complementary relation between conservation and sustainable use to maintain one of the most evident element of the landscape in this endorreic basin: the Cuitzeo Lake.

9.1. System design and criteria selection

The attributes selected to represent the system were chosen considering their relevance to the main objectives of each one of the environmental policies. The spatial information was organized in a systematic and hierarchical way in order to generate useful information in the decision making process at a municipal level. The analytic hierarchy process (AHP) was the tool to integrate the spatial information in a compensatory structure of criteria that represents the chosen attributes for each of the environmental policies in the LCB.

During the problem definition phase, the key factors were identified, which then were used in the assessment phase. Four main criteria were identified for each policy. The criteria structure for sustainable use includes: land use type (land stability), process of change, spatial restriction and hazards. The criterion structure for conservation policy is: forest condition, spatial restriction, hazards and remarkable features.

Several attributes from the landscape can be measured or surveyed using remote sensing techniques, for instance, lithology, landforms, soils, and especially, land cover, based on digital analysis of medium or high resolution imaginary, but some studies are still based on visual interpretation of aerial photographs (Mendoza et al., 2002). Most of the input data used in this thesis were interpreted by visual interpretation, in the framework of previous studies.

The spatial relationships between these attributes are important, such as coincidence, proximity, adjacency and accessibility (Morales, 1992). This was analyzed using GIS techniques (overlay, distance analysis, connectedness) (ILWIS, 2005), which were applied during the assessment and choice phases. For example, the patchiness of the forest cover was calculated and taken into account in the criteria structure.

In this SMCE, the dynamics of the landscape was a major feature taken into account for selecting the attributes that allow characterizing the ideal zones for the application of the environmental policies. It was demonstrated that the study of the temporal changes of spatial patterns in landscapes is important to understand the underlying factors and the functional effects. Analysis of land cover changes contributes to understand better how the land use trends evolve on both long and short terms, and this information was included in the decision making process. According to the knowledge of the author, the dynamics of the landscape has not been previously taken into account in such a direct manner in Mexico.

The land cover and land use change patterns were not homogenous through time. Therefore the identification of the trends of change by means of a multi-temporal analysis allowed localizing where that change is positive or negative for the application of the environmental policies. In the case of the conservation policy, the criterion *forest condition* was based on the dynamics of the forest cover, its permanence, forestation and deforestation trends through the analysis of two different periods of time: a larger one, of almost 30 years (1975-2003) and a shorter one of less than 7 years (1996-2003). In the same way, for the sustainable use policy the permanence and change of the productive activities were evaluated in the same periods through the criterion *change process*, where the permanence of the productive activities has a positive influence for the application of the sustainable use policy.

The most recent trends show a change process between rain-fed agriculture to scrublands that are associated with cattle grazing activity. These areas represent the recent predominant productive practice of the inhabitants of the lower zone of the basin, and are associated to a process of regeneration of vegetation cover. Due to this, these areas appear to be suitable to introduce productive programs that promote the regeneration of the vegetation cover.

It is evident that between the years 1975 to 1996 there is a drastic change in the use of the natural resources in the LCB, almost all the forestation process and the change from the agriculture practices to cattle grazing activities occur during this period of time. As is concluded in previous studies (López et al., 2006), the migration of inhabitants of the basin from the rural environments to the capital city of the state or to the Unites States, promote the change of land utilization patterns due the abandonment of the parcels. The reduction of the population density in the rural environment in the last 20 years of the past century (INEGI, 2000) can explain in part this phenomenon, but further studies have to be done to support this statement. The trends in the change of land cover related to both environmental policies lead to identifying valuable areas to the application of the environmental programs with more possibility of success in the medium and long term.

9.2. Relative importance of the criteria

The relative importance of the criteria were determined based in a verbal pairwise comparison, using the linguistic measurement of preference (Saaty, 1980). The method was selected because it allows making a qualitative judgment based on the reasoning assumptions of the relation between the criteria and the main objective of each of the environmental policies.

It is important to notice that the set of weights used in this study were established based on the opinion of experts involved in the construction of the EMPLCB. Nevertheless a sensitivity analysis was carried out, developing different scenarios in order to privilege stakeholder’s judgments having a different focus (productive oriented and conservation oriented).

In the last phase several aggregation methods were tested in order to get the proper result map. According to the objective of the present study the best aggregation methods were: average among all grid cells when percentage values of connectedness cover suitability classes and EMU’s were aggregated, and aggregation of sum among all grid cells for each suitability class per municipality. The first method is one of the most commonly used (Geneletti et al., 2008).

Although this approach can have some weaknesses, it has the advantage that it can be applied in different territorial units, such as eco-regions or watersheds at regional scale using different attributes with the basic structure of the model, especially in developing countries with similar environmental conditions.

In general, the spatial unit that are localized in the lower part of the basin, on the lacustrine plain, have the best overall suitability for the sustainable use policy. This is because the most extensive productive practices are carried out in this area: rain-fed and irrigation agriculture, and cattle grazing. It is important to notice that some units in the edges of the Lake Cuitzeo appears to have the lower overall suitability for this policy, even though there are within the zone where the best-ranked units are localized. This is explained because the Lake Cuitzeo, used as a constraint factor, is extended over the most part of the territory of this units. Thus, these units (the municipalities in this case) have to be treated considering the particular management plan for the Lake Cuitzeo.

In general, the spatial units that are localized in the upper section of the basin have the best overall suitability for the conservation policy. All of them are localized in the extreme south of the LCB. These units are mainly characterized by the presence of a well-preserved forest cover on high hills and mountainous areas. This areas are important because of the environmental services they supply to human beings (soil retention, water recharge, biodiversity, among others).

According to the presented ranking in Chapter 8, some municipalities and sub watersheds are clearly sustainable use or conservation oriented, nevertheless, the rest of the municipalities or the sub watershed are oriented to a mixed environmental policies. In the last case, environmental and non-environmental (productive oriented) agencies have to increase communication in order to reduce possible future conflicts for using natural resources.

9.3. Applicability of the method

In the present approach, the information from several sources was integrated in order to identify the biophysical attributes for the evaluation of the suitability of the municipalities and sub watersheds for the implementation of the conservation and sustainable use policies in the LCB, using SMCE and GIS-based decision support technologies. This approach not only provides information to prioritize the implementation of policies, but at the same time it can be used for the monitoring of the implementation of the policies.

The here-discussed method is a valuable tool considering the scarcity of financial resources assigned in the LCB for the design, implementation and monitoring of environmental programs. Moreover, this aggregated information facilitates the communication among the environmental authorities at different levels of the administrative structure, which are in charge of the allocation of the financial resources with environmental and productive proposes.

10. Conclusions

The analysis of the present work leads to the following conclusions:

- The identification of the suitable areas for both policies in the framework of the multicriteria evaluation was based on the use of a hierarchical analysis. This combination allows translating the qualitative logical judgments in relation of the chosen attributes into quantitative values, which allow integrating the spatial data according to the objectives of each environmental policy. One of the main advantages of this approach is the efficient structuring of the data available and the processing of large data sets of different types of data.

- The multi-temporal analysis through a long and a short period of time, allows identifying the trends of land use change that can be used as an essential attribute of the landscape for the application of the environmental policies. The incorporation of the landscape dynamics in an environmental spatial decision problem is an innovative approach in the Lake Cuitzeo Basin.

- The criteria were designed in order to respond to the environmental conditions of the LCB. Nevertheless the approach and the criteria structure can be adapted to other areas with similar environmental conditions, especially in the region of the Trans-Mexican volcanic belt, where the landscape dynamics, the biophysical and socioeconomic characteristics are similar to those present in the LCB.

- The aggregation at a municipal and watershed level of the biophysical spatial data used in the assessment of the overall suitability of the LCB for each of the policies allows integrating and making comparable the utility value of these spatial units for the application of the environmental programs. The final ranking of the was assessed based on the transformation of spatial information to a non-spatial dimension.

- The developed procedure allows identifying three different orientations related to the environmental policies: the units oriented to productive activities localized in the lower zone of the basin within the lacustrine plain, the units oriented to conservation activities localized within the headwater zones and the mixed oriented municipalities, which comprise a transitional environment between the higher and the lower zones of the basin.

- The prioritization of the municipalities could provide practical information that can be used to support planning of the implementation and monitoring of the environmental programs in the framework of the EMPLCB. Based on the results of this study, a better financial resource allocation can be done by municipality, maximizing the efficiency of a limited budget for the conservation and sustainable use policies. Because of that, the information generated in this study can be used in the improvement on the decision making in the EMPLCB.

11. Recommendations

The present study could address only a part of the issues related to the planning and implementation of environmental management actions. Based on the lessons learnt, the following recommendations can be made:

- There are municipalities without a clear orientation for either conservation or sustainable use policies. For those, it is recommendable to carry out a prioritization of environmental management units, in order to assign the financial resources to the most suitable areas for each of the policies.

- For the spatial units with a clear environmental policy orientation it is recommendable to carry out a prioritization based on the EMUs, in order to allocate the most suitable areas within the municipalities or the sub watersheds.

- It is necessary to incorporate the opinion of different sectors involved in the LCB through the realization of workshops, in order to generate equilibrium between the conservation and production scenarios. Different points of view of the relative importance of the criteria for each of the policies and consensus over them are essential for the successful management of the LCB.

- To put emphasis on the management of natural units instead of administrative units. The results promote the idea that this management orientation can increase the consensus and minimize the conflicts among the sector involved.

12. References

Acosta, A. (2002). Changes in water consume and land use patterns. The case of Lake Cuitzeo Basin, Morelia, Michoacán. Universidad Michoacana de San Nicolás de Hidalgo. Bachelor Thesis.

Anselin, A. and Meire, P. (1989). "Multicriteria techniques in ecological evaluation : an example using the analytical hierarchy process." reprinted from: Biological Conservation, 49 (1989), pp. 215-229.

Belton, V. (1986). "Comparison of the analytic hierarchy process and a simple multi - attribute value function." In: European Journal of Operational Research, 26(1986)1, pp. 7-21.

Cotler, H. and Priego, A. (2004). El análisis del paisaje como base para el manejo integrado de cuencas: el caso de la cuenca Lerma-Chapala. El manejo integral de cuencas en México. Estudios y reflexiones para orientar la política ambiental. Cotler H.. México, Instituto Nacional de Ecología: pp. 264.

Dyer, R. and Forman, E.(1992). "Group decision support with the Analytic Hierarchy Process." In: Decision Support Systems, 8 (1992), pp. 99-124.

FAO (1976). Esquema para la evaluación de tierras. Boletín de Suelos de la FAO. Organización de las Naciones Unidas para la Agricultura y la Alimentación. Roma, Italia. pp.66

FAO (1986). Strategies, approaches and systems in integrated watershed management. Rome. Italy pp. 97.

FAO (2003). FAO Conservation guides : guide 1(1977) - guide 34 (1999) full text in English, French and Spanish = Cahiers FAO conservation = Guías FAO conservación. FAO. Rome, Italy.

Felipe, H (In preparation). Evaluación del cambio de cobertura vegetal y uso de suelo en zonas funcionales de la cuenca del Lago de Cuitzeo. Biology. Morelia, Michoacan, Universidad Michoacana de San Nicolás de Hidalgo. Bachelor thesis.

Geneletti, D. and Van Duren, I. (2008). "Protected area zoning for conservation and use: A combination of spatial multicriteria and multiobjective evaluation" Landscape and Urban Planning 85(2): pp. 97 - 110.

Heathcote, I. (1998). Integrated watershed management : principles and practice. Wiley & Sons. New York. pp.414

Hufschidt, M (1986). A conceptual framework for analysis of watershed management activities. Strategies, approaches and systems in integrated watershed management. FAO. Rome: pp 102-113.

INE. (2007). Instituto Nacional de Ecología. "Conceptos." Retrieved 23 August 2007, from http://www.ine.gob.mx/dgoece/cuencas/conceptos.html

INE. (2007). Instituto Nacional de Ecología "Sistematización de casos exitosos de manejo integral de cuencas hídricas." Retrieved 22 August 2007 from http://www.ine.gob.mx/dgoece/cuencas/download/casos_exitosos.pdf

INEGI. (2000). "Censo Nacional de Poblacion y Vivienda." Retrieved 1 August 2007, from http://www.inegi.gob.mx/inegi/default.aspx

INEGI (2001). XII Censo General de Población y vivienda por localidad, 2000. Instituto Nacional de Geografía e Informática. CD . México.

ILWIS 3.3 (2005) Integrated Land and Water Information System ITC. Enschede. The Netherlands

Keeney, R. (1992). Value-focused thinking. Harvard University press. Cambridge

LEEPAE (2007). "Ley del Equilibrio Ecológico y Protección al Ambiente del Estado de Michoacán de Ocampo." Periódico oficial del gobierno de Michoacán de Ocampo.

LGEEPA. (2007). "Ley general de equilibrio ecológico y protección al ambiente." Retrieved 29 August 2007, from http://www.diputados.gob.mx/LeyesBiblio/pdf/148.pdf.

Lopez E. and Bocco G. (2001). Cambio de cobertura vegetal y uso de suelo. Regionalización ecológica, conservación de recursos y ordenamiento territorial de la cuenca de Cuitzeo. Mendoza M., Instituto de Ecología, UNAM. Informe final presentado del Programa SIMORELOS-CONACYT: pp. 266.

Lopez, E., Bocco, G., Mendoza, M., Velazquez, A. and Aguirre-Rivera, R. (2006). "Peasant emigration and land-use change at the watershed level: A GIS-based approach in Central Mexico." Agricultural Systems 90: pp. 62-78.

Malczewski, J. (1999). GIS and multicriteria decision analysis. Wiley & Sons. New York. 392.

McDonald, A. and Kay, D. (1988). Water resources: issues and strategies. Longman Scientific & Technical. London. pp. 284 .

Mendoza, J. and Etter, R. (2002). "Multitemporal analysis (1940–1996) of land cover changes in the southwestern Bogotá highplain (Colombia)." Landscape and Urban Planning 59(3): pp. 147-158.

Mendoza, M. (1997). Regionalización geomorfológica y de paisaje de la zona costera entre Guaymas y Agiabampo, Sonora, México. Centro de Conservación y Aprovechamiento de los Recursos Naturales (CECARENA), ITESM-Campus Guaymas. Tesis de Maestría en Ciencias**:** pp.147

Mendoza, M. (2005). Propuesta metodológica del proyecto "Uso de técnicas de análisis multicriterio para la selección de subcuencas para conservación, restauración y aprovechamiento de los recursos naturales en la Cuenca del Lago de Cuitzeo" UNAM.

Mendoza M., Lopez E. and G., Bocco (2001). "Regionalización Ecológica, Conservación de Recursos Naturales y Ordenamiento Territorial en la Cuenca del Lago de Cuitzeo, Michoacán."

Mendoza, M., López, E., Geneletti, D., Salinas, V. and Nenapace, G. (2006). "Segundo Informe Técnico. Uso de técnicas de análisis multicriterio para la priorización de subcuencas para la conservación, restauración y el aprovechamiento de los recursos naturales en la Cuenca del Lago de Cuitzeo." 52 pp.

EMPLCB. Ecologic Management Plan of Lake Cuitzeo Basin (2006) Ecologic Management Plan of Lake Cuitzeo Basin. Gobierno del Estado de Michoacán. México. pp. 170.

Michoacán, Gobierno del estado. (2003) Plan estatal de Desarrollo Michoacán 2003-2008, Periódico Oficial del Gobierno del Estado de Michoacán de Ocampo.

Morales, L. (1992). Search and space theory as the foundation for the design of an object - oriented geographyc information system. MSc Thesis. ITC. Enschede, The Netherlands.

SEMARNAT (2006). Manual del Proceso del Ordenamiento Ecológico, Secretaria del Medio Ambiente y Recursos Naturales.

CONAPO (2005) Índice de marginación a nivel municipal. Consejo Nacional de Población. Retrieved 24 March 2008, from http://www.conapo.gob.mx

Pulido, J. , Pérez, J. and Martínez, S. (2001). Los suelos de la cuenca de Cuitzeo. Regionalización Ecológica, Conservación de Recursos Naturales y Ordenamiento Territorial en la Cuenca del Lago de Cuitzeo, Michoacán. Mendoza, M. López, E. and Bocco, G.

Pulido, J., Pérez, J. and Martínez, S. (2001). Evaluación de tierras para fines agrícolas y Forestales. Regionalización ecológica, conservación de recursos y ordenamiento territorial, Informe Final presentado al Programa SIMORELOS - CONACyT. Departamento de Ecología de los Recursos Naturales, Instituto de Ecología, UNAM. México.

Saaty, T. L. (1980). The analytic hierarchy process. McGraw-Hill. New York . pp.165

Sharifi, A. and Herwinjen, M. van (2004). Spatial Decision Support Systems. ITC Lectures ITC: pp.64

Sharifi, M. A. (2002). "Integrated planning and decision support systems for sustainable watershed development : resource paper." Presented at a study meeting on watershed development organized by the Asian Productivity Organization & The Iranian Ministry of Agriculture, 12-17 October 2002, Tehran, Iran. pp. 32.

Simon, H. A (1960). The New Science of Management Decision. Harper & Brothers. New York. pp.201

Triantaphyllou, E. (2000). Multi-criteria Decision Methods: A Comparative Study. Kluwer Academic Publishers. The Netherlands.288 pp.

Villaseñor, G., Ed. (2005). La Biodiversidad de Michoacán; Estudio de Estado, CONABIO. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México.

Voogd, H. (1983). Multicriteria evaluation for urban and regional planning. Pion. London.pp.367

Zinck, J. (1988). Physiography and soil. Soil survey Course. ITC. Enschede , The Netherlands. pp 156

13. Annexes

Annex 1 Pairwise comparaison matrix. Conservation policy

Priorities respect to: Conservation / main goal

	Forest condition	Spatial restrictions	Remarkable features	Hazards	Normalized weights	**Weights**
Forest condition	1	5	5	3	1	**.450**
Spatial restrictions	1/5	1	1	1	.333	**.150**
Remarkable features	1/5	1	1	1	.511	**.230**
Hazards	1/3	1	1	1	.355	**.160**
Inconsistency= .02						

Priorities respect to: Conservation /Forest condition

	Forest degradation	State of preservation	Normalized weights	**Weights**
Forest degradation	1	1/3	.333	**.25**
State of preservation	3	1	1	**.75**
Inconsistency= .00				

Priorities respect to: Conservation / Forest condition / Forest degradation

	1975-2003	1996-2003	Normalized weights	**Weights**
1975-2003	1	1/3	.333	**.25**
1996-2003	3	1	1	**.75**
Inconsistency= .00				

Priorities respect to: Conservation/Forest condition/State of preservation

	Patch size	Forest density	Forest stability	Normalized weights	**Weights**
Patch size	1	1/7	1/3	.13	**.097**
Forest density	7	1	3	1	**.515**
Forest stability	3	1/3	1	.40	**.388**
Inconsistency=.08					

Priorities respect to: Conservation/Forest condition/State of preservation/Forest stability

	1975-2003	1996-2003	Normalized weights	**Weights**
1975-2003	1	1/3	.333	**.25**
1996-2003	3	1	1	**.75**
Inconsistency= .00				

Priorities respect to: Conservation/Forest condition/State of preservation/Forest density

	Dense scrubland	No forest	Dense forest	Open forest	Semi open forest	Normalized weights	**Weights**
Dense scrubland	1	9	1/3	5	3	.562	**.273**
No forest	1/9	1	1/9	1/5	1/7	.056	**.027**
Dense forest	3	9	1	5	5	1	**.486**
Open forest	1/5	1/5	1/5	1	1/3	.156	**.076**
Semi open forest	1/3	1/7	1/5	3	1	.284	**.138**
Inconsistency=.09							

Priorities respect to: Conservation/Remarkable features

	Singularity	Distance to water head	Altitude	Normalized weights	**Weights**
Singularity	1	1/3	5	.57	**.279**
Distance to water head	3	1	7	1	**.649**
Altitude	1/5	1/7	1	.11	**.072**
Inconsistency=.06					

Priorities respect to: Conservation /Remarkable features/Singularity

	Terrace-volcanic	Agriculture terrace	Volcanic	Normalized weights	**Weights**
Terrace-volcanic	1	3	3	1	**.600**
Agriculture terrace	3	1	1	.33	**.200**
Volcanic	1/3	1	1	.33	**.200**
Inconsistency=.00					

Priorities respect to: Conservation/ Hazards

	Erosion potential	Landslides	Normalized weights	**Weights**
Erosion potential	1	1	1	**.50**
Landslides	1	1	1	**.50**
Inconsistency= .00				

Priorities respect to: Conservation/ Hazards/ Erosion potential

	Very high	High	Low	Very Low	Without hazard	Normalized weights	**Weights**
Very high	1	1/3	1/5	1/7	1/9	.078	**.032**
High	3	1	1/3	1/5	1/7	.089	**.060**
Low	5	3	1	1/3	1/5	.227	**.120**
Very Low	7	5	3	1	1/5	.613	**.228**
Without hazard	9	7	5	5	1	1	**.560**
Inconsistency=.08							

Priorities respect to: Conservation/ Hazards/ Landslides

	Very high	High	Low	Very Low	Without hazard	Normalized weights	**Weights**
Very high	1	3	5	7	9	1	**.515**
High	1/3	1	3	5	7	.512	**.264**
Low	1/5	1/3	1	3	3	.229	**.118**
Very Low	1/7	1/5	1/3	1	3	.127	**.066**
Without hazard	1/9	1/7	1/3	1/3	1	.072	**.037**
Inconsistency=.05							

Annex 2 Pairwise comparison matrix. Sustainable use policy

Priorities respect to: Sustainable use / Main objective

	Potential land use type	Change process	Spatial restrictions	Hazards	Normalized weights	**Weights**
Potential land use type	1	1	3	3	1	**.440**
Change process	1	1	3	3	.735	**.340**
Spatial restrictions	1/3	1/3	1	1	.245	**.080**
Hazards	1/3	1/3	1	1	.227	**.140**
Inconsistency = .05						

Priorities respect to: Sustainable use/Potential land use type

	High suitability	Moderate suitability	Marginal suitability	No suitable	Normalized weights	**Weights**
High suitability	1	5	5	9	1	**.629**
Moderate suitability	1/5	1	3	5	.339	**.213**
Marginal suitability	1/5	1/3	1	4	.183	**.115**
No suitable	1/9	1/5	1/4	1	.069	**.044**
Inconsistency= .09						

Priorities respect to Sustainable use/Change process

	Forest stability	Stable productive areas	Normalized weights	**Weights**
Forest stability	1	1/3	.333	**.25**
Stable productive areas	3	1	1	**.75**
Inconsistency=.00				

Priorities respect to: Sustainable use/Change process/Stable productive areas

	1975-2003	1996-2003	Normalized weights	**Weights**
1975-2003	1	1/3	.333	**.25**
1996-2003	3	1	1	**.75**
Inconsistency= .00				

Priorities respect to: Sustainable use/Change process/Forest stability

	1975-2003	1996-2003	Normalized weights	**Weights**
1975-2003	1	3	.333	**.25**
1996-2003	1/3	1	1	**.75**
Inconsistency= .00				

Priorities respect to: Sustainable use/Change process/Density

	Dense scrubland	No forest	Dense forest	Open forest	Semi open forest	Normalized weights	**Weights**
Dense scrubland	1	1/9	3	1/5	1/3	.156	**.076**
No forest	9	1	9	5	7	1	**.486**
Dense forest	1/3	1/9	1	1/5	1/5	.056	**.027**
Open forest	5	5	5	1	3	.562	**.273**
Semi open forest	3	7	5	1/3	1	.284	**.138**
Inconsistency=.09							

Priorities respect to: Sustainable use/Spatial restrictions

	Distance to roads	Functional zones watershed	Distance to human settlements	Normalized weights	**Weights**
Distance to roads	1	1/5	1/3	.164	**.105**
Functional zones watershed	5	1	3	1	**.637**
Distance to human settlements	3	1/3	1	.405	**.258**
Inconsistency=.04					

Priorities respect to: Sustainable use/Spatial restrictions/Functional zones watershed

	Water head	Transit	Outlet	Normalized weights	**Weights**
Water head	1	1/3	1/5	.237	**.114**
Transit	3	1	1	.843	**.405**
Outlet	5	1	1	1	**.481**
Inconsistency= .03					

Priorities respect to: Sustainable use/Hazards

	Landslides	Erosion potential	Floods	Normalized weights	**Weights**
Landslides	1	3	7	1	**.730**
Erosion potential	1/3	1	5	.260	**.190**
Floods	1/7	1/5	1	.109	**.080**
Inconsistency= .06					

Priorities respect to: Sustainable use/ Hazards/Landslides

	Very high	High	Low	Very Low	Without hazard	Normalized weights	**Weights**
Very high	1	1/3	1/5	1/7	1/9	.078	**.032**
High	3	1	1/3	1/5	1/7	.089	**.060**
Low	5	3	1	1/3	1/5	.227	**.120**
Very Low	7	5	3	1	1/5	.613	**.228**
Without hazard	9	7	5	5	1	1	**.560**
Inconsistency= .08							

Priorities respect to: Sustainable use/ Hazards/ Floods

	Without hazard	Very Low	Moderate	High	Normalized weights	**Weights**
Without hazard	1	3	6	9	1	**.571**
Very Low	1/3	1	4	7	.489	**.279**
Moderate	1/6	1/4	1	5	.194	**.111**
High	2/9	1/7	1/5	1	.068	**.039**
Inconsistency=.08						

Priorities respect to: Sustainable use/Hazards/ Erosion potential

	Very high	High	Low	Very Low	Without hazard	Normalized weights	**Weights**
Very high	1	1/3	1/5	1/7	1/9	.078	**.032**
High	3	1	1/3	1/5	1/7	.089	**.060**
Low	5	3	1	1/3	1/5	.227	**.120**
Very Low	7	5	3	1	1/5	.613	**.228**
Without hazard	9	7	5	5	1	1	**.560**
Inconsistency=.08							

Annex 3 Main criteria, indicators, and related classes for the conservation policy

Main criterion	Indicator	Classes in the attribute table
Forest condition	Forest density	Dense scrubland
		Dense forest
		Semi open forest
		Open forest
		No forest
Remarkable features	Singularity	Agriculture in terrace
		Lava flows – Volcanic cones and Agriculture in terrace
		Lava flows –Volcanic cones
		Without singular areas
Hazards	Erosion potential	Very high
		High
		Low
		Very Low
		Without hazard
	Landslides	Very high
		High
		Low
		Very Low
		Without hazard

Annex 4 Main criteria, indicators, and related classes for the sustainable use policy

Main criterion	Indicator	Classes in the attribute table
Potential land use type	Grasslands	High suitability
		Moderate suitability
		Low suitability
		No suitable
	Rain fed agriculture	High suitability
		Moderate suitability
		Low suitability
		No suitable
	Irrigated agriculture	High suitability
		Moderate suitability
		Low suitability
		No suitable
	Orchards	High suitability
		Moderate suitability
		Low suitability
		No suitable
	Forestry	High suitability
		Moderate suitability
		Low suitability
		No suitable
Change process	Forest density	Dense scrubland
		Dense forest
		Semi open forest
		Open forest
		No forest
Hazards	Erosion potential	Very high
		High
		Low
		Very Low
		Without hazard
	Landslides	Very high
		High
		Low
		Very Low
		Without hazard

Continue Annex 4 Main criteria, indicators, and related classes for the sustainable use policy

Hazards	Floods	High
		Moderate
		Low
		Without hazard
Spatial restrictions	Functional zones of watershed	Water head
		Transit

Annex 5 Utilities for the scenarios by municipality

Conservation policy (a) = Criterion, (b) = relative importance

Scenario SUPPLY

Municipality	Supply (a)	.50 (b)	Demand (a)	.25 (b)	Decree (b)	.25(b)	**Utility**
Acuitzio del Canje	0.590	0.295	0.000	0.000	1.000	0.250	**0.545**
Alvaro Obregón	0.160	0.080	0.880	0.220	0.070	0.018	**0.318**
Charo	0.550	0.275	0.900	0.225	0.450	0.113	**0.613**
Chucándiro	0.560	0.280	0.670	0.168	0.180	0.045	**0.493**
Copándaro de Galeana	0.150	0.075	0.860	0.215	0.860	0.215	**0.505**
Cuitzeo	0.120	0.060	0.990	0.248	0.700	0.175	**0.483**
Huandacareo	1.000	0.500	1.000	0.250	0.440	0.110	**0.860**
Huiramba	0.390	0.195	0.590	0.148	0.220	0.055	**0.398**
Indaparapeo	0.510	0.255	0.470	0.118	0.270	0.068	**0.440**
Lagunillas	0.350	0.175	0.830	0.208	0.420	0.105	**0.488**
Morelia	0.340	0.170	0.610	0.153	0.730	0.183	**0.505**
Morelos	0.780	0.390	0.850	0.213	0.000	0.000	**0.603**
Queréndaro	0.900	0.450	0.770	0.193	0.620	0.155	**0.798**
Santa Ana Maya	0.210	0.105	0.730	0.183	0.780	0.195	**0.483**
Tarímbaro	0.130	0.065	1.000	0.250	0.150	0.038	**0.353**
Zinapécuaro	0.430	0.215	0.890	0.223	0.560	0.140	**0.578**

Scenario DEMAND

Municipality	Supply (a)	.25 (b)	Demand (a)	.50 (b)	Decree (b)	.25 (b)	**Utility**
Acuitzio del Canje	0.590	0.148	0.000	0.000	1.000	0.250	**0.398**
Alvaro Obregón	0.160	0.040	0.880	0.440	0.070	0.018	**0.498**
Charo	0.550	0.138	0.900	0.450	0.450	0.113	**0.700**
Chucándiro	0.560	0.140	0.670	0.335	0.180	0.045	**0.520**
Copándaro de Galeana	0.150	0.038	0.860	0.430	0.860	0.215	**0.683**
Cuitzeo	0.120	0.030	0.990	0.495	0.700	0.175	**0.700**
Huandacareo	1.000	0.250	1.000	0.500	0.440	0.110	**0.860**
Huiramba	0.390	0.098	0.590	0.295	0.220	0.055	**0.448**
Indaparapeo	0.510	0.128	0.470	0.235	0.270	0.068	**0.430**
Lagunillas	0.350	0.088	0.830	0.415	0.420	0.105	**0.608**
Morelia	0.340	0.085	0.610	0.305	0.730	0.183	**0.573**
Morelos	0.780	0.195	0.850	0.425	0.000	0.000	**0.620**
Queréndaro	0.900	0.225	0.770	0.385	0.620	0.155	**0.765**
Santa Ana Maya	0.210	0.053	0.730	0.365	0.780	0.195	**0.613**
Tarímbaro	0.130	0.033	1.000	0.500	0.150	0.038	**0.570**
Zinapécuaro	0.430	0.108	0.890	0.445	0.560	0.140	**0.693**

Scenario DECREE							
Municipality	Supply (a)	0.25 (b)	Demand (a)	0.25(b)	Decree (a)	.50 (b)	**Utility**
Acuitzio del Canje	0.590	0.148	0.000	0.000	1.000	0.500	**0.648**
Alvaro Obregón	0.160	0.040	0.880	0.220	0.070	0.035	**0.295**
Charo	0.550	0.138	0.900	0.225	0.450	0.225	**0.588**
Chucándiro	0.560	0.140	0.670	0.168	0.180	0.090	**0.398**
Copándaro de Galeana	0.150	0.038	0.860	0.215	0.860	0.430	**0.683**
Cuitzeo	0.120	0.030	0.990	0.248	0.700	0.350	**0.628**
Huandacareo	1.000	0.250	1.000	0.250	0.440	0.220	**0.720**
Huiramba	0.390	0.098	0.590	0.148	0.220	0.110	**0.355**
Indaparapeo	0.510	0.128	0.470	0.118	0.270	0.135	**0.380**
Lagunillas	0.350	0.088	0.830	0.208	0.420	0.210	**0.505**
Morelia	0.340	0.085	0.610	0.153	0.730	0.365	**0.603**
Morelos	0.780	0.195	0.850	0.213	0.000	0.000	**0.408**
Queréndaro	0.900	0.225	0.770	0.193	0.620	0.310	**0.728**
Santa Ana Maya	0.210	0.053	0.730	0.183	0.780	0.390	**0.625**
Tarímbaro	0.130	0.033	1.000	0.250	0.150	0.075	**0.358**
Zinapécuaro	0.430	0.108	0.890	0.223	0.560	0.280	**0.610**

Scenario NO TREND							
Municipality	Supply (a)	.33 (b)	Demand (a)	.33 (b)	Decree (a)	.33 (b)	**Utility**
Acuitzio del Canje	0.590	0.195	0.000	0.000	1.000	0.330	**0.525**
Alvaro Obregón	0.160	0.053	0.880	0.290	0.070	0.023	**0.366**
Charo	0.550	0.182	0.900	0.297	0.450	0.149	**0.627**
Chucándiro	0.560	0.185	0.670	0.221	0.180	0.059	**0.465**
Copándaro de Galeana	0.150	0.050	0.860	0.284	0.860	0.284	**0.617**
Cuitzeo	0.120	0.040	0.990	0.327	0.700	0.231	**0.597**
Huandacareo	1.000	0.330	1.000	0.330	0.440	0.145	**0.805**
Huiramba	0.390	0.129	0.590	0.195	0.220	0.073	**0.396**
Indaparapeo	0.510	0.168	0.470	0.155	0.270	0.089	**0.413**
Lagunillas	0.350	0.116	0.830	0.274	0.420	0.139	**0.528**
Morelia	0.340	0.112	0.610	0.201	0.730	0.241	**0.554**
Morelos	0.780	0.257	0.850	0.281	0.000	0.000	**0.538**
Queréndaro	0.900	0.297	0.770	0.254	0.620	0.205	**0.756**
Santa Ana Maya	0.210	0.069	0.730	0.241	0.780	0.257	**0.568**
Tarímbaro	0.130	0.043	1.000	0.330	0.150	0.050	**0.422**
Zinapécuaro	0.430	0.142	0.890	0.294	0.560	0.185	**0.620**

Sustainable use policy (a) = Criterion, (b) = relative importance

Scenario SUPPLY

Municipality	Supply (a)	.50 (b)	Demand (a)	.25 (b)	Decree (a)	.25(b)	**Utility**
Acuitzio del Canje	0.200	0.100	1.000	0.250	0.080	0.020	**0.370**
Alvaro Obregón	1.000	0.500	0.120	0.030	0.730	0.183	**0.713**
Charo	0.260	0.130	0.100	0.025	0.610	0.153	**0.308**
Chucándiro	0.170	0.085	0.330	0.083	0.850	0.213	**0.380**
Copándaro de Galeana	0.120	0.060	0.140	0.035	0.270	0.068	**0.163**
Cuitzeo	0.190	0.095	0.010	0.003	0.310	0.078	**0.175**
Huandacareo	0.220	0.110	0.000	0.000	0.600	0.150	**0.260**
Huiramba	0.300	0.150	0.410	0.103	0.740	0.185	**0.438**
Indaparapeo	0.630	0.315	0.530	0.133	0.770	0.193	**0.640**
Lagunillas	0.270	0.135	0.170	0.043	0.640	0.160	**0.338**
Morelia	0.110	0.055	0.390	0.098	0.360	0.090	**0.243**
Morelos	0.200	0.100	0.150	0.038	1.000	0.250	**0.388**
Queréndaro	0.270	0.135	0.230	0.058	0.480	0.120	**0.313**
Santa Ana Maya	0.670	0.335	0.270	0.068	0.290	0.073	**0.475**
Tarímbaro	0.430	0.215	0.000	0.000	0.880	0.220	**0.435**
Zinapécuaro	0.170	0.085	0.110	0.028	0.490	0.123	**0.235**

Scenario NO TREND

Municipality	Supply (a)	.33 (b)	Demand (a)	.33 (b)	Decree (b)	.33(b)	**Utility**
Acuitzio del Canje	0.200	0.066	1.000	0.330	0.080	0.026	**0.422**
Alvaro Obregón	1.000	0.330	0.120	0.040	0.730	0.241	**0.611**
Charo	0.260	0.086	0.100	0.033	0.610	0.201	**0.320**
Chucándiro	0.170	0.056	0.330	0.109	0.850	0.281	**0.446**
Copándaro de Galeana	0.120	0.040	0.140	0.046	0.270	0.089	**0.175**
Cuitzeo	0.190	0.063	0.010	0.003	0.310	0.102	**0.168**
Huandacareo	0.220	0.073	0.000	0.000	0.600	0.198	**0.271**
Huiramba	0.300	0.099	0.410	0.135	0.740	0.244	**0.479**
Indaparapeo	0.630	0.208	0.530	0.175	0.770	0.254	**0.637**
Lagunillas	0.270	0.089	0.170	0.056	0.640	0.211	**0.356**
Morelia	0.110	0.036	0.390	0.129	0.360	0.119	**0.284**
Morelos	0.200	0.066	0.150	0.050	1.000	0.330	**0.446**
Queréndaro	0.270	0.089	0.230	0.076	0.480	0.158	**0.323**
Santa Ana Maya	0.670	0.221	0.270	0.089	0.290	0.096	**0.406**
Tarímbaro	0.430	0.142	0.000	0.000	0.880	0.290	**0.432**
Zinapécuaro	0.170	0.056	0.110	0.036	0.490	0.162	**0.254**

Scenario DEMAND							
Municipality	Supply (a)	.25 (b)	Demand (a)	.50 (b)	Decree (b)	.25(b)	**Utility**
Acuitzio del Canje	0.200	0.050	1.000	0.500	0.080	0.020	**0.570**
Alvaro Obregón	1.000	0.250	0.120	0.060	0.730	0.183	**0.493**
Charo	0.260	0.065	0.100	0.050	0.610	0.153	**0.268**
Chucándiro	0.170	0.043	0.330	0.165	0.850	0.213	**0.420**
Copándaro de Galeana	0.120	0.030	0.140	0.070	0.270	0.068	**0.168**
Cuitzeo	0.190	0.048	0.010	0.005	0.310	0.078	**0.130**
Huandacareo	0.220	0.055	0.000	0.000	0.600	0.150	**0.205**
Huiramba	0.300	0.075	0.410	0.205	0.740	0.185	**0.465**
Indaparapeo	0.630	0.158	0.530	0.265	0.770	0.193	**0.615**
Lagunillas	0.270	0.068	0.170	0.085	0.640	0.160	**0.313**
Morelia	0.110	0.028	0.390	0.195	0.360	0.090	**0.313**
Morelos	0.200	0.050	0.150	0.075	1.000	0.250	**0.375**
Queréndaro	0.270	0.068	0.230	0.115	0.480	0.120	**0.303**
Santa Ana Maya	0.670	0.168	0.270	0.135	0.290	0.073	**0.375**
Tarímbaro	0.430	0.108	0.000	0.000	0.880	0.220	**0.328**
Zinapécuaro	0.170	0.043	0.110	0.055	0.490	0.123	**0.220**

Scenario DECREE							
Municipality	Supply (a)	.25 (b)	Demand (a)	.25 (b)	Decree (b)	.50(b)	**Utility**
Acuitzio del Canje	0.200	0.050	1.000	0.250	0.080	0.040	**0.340**
Alvaro Obregón	1.000	0.250	0.120	0.030	0.730	0.365	**0.645**
Charo	0.260	0.065	0.100	0.025	0.610	0.305	**0.395**
Chucándiro	0.170	0.043	0.330	0.083	0.850	0.425	**0.550**
Copándaro de Galeana	0.120	0.030	0.140	0.035	0.270	0.135	**0.200**
Cuitzeo	0.190	0.048	0.010	0.003	0.310	0.155	**0.205**
Huandacareo	0.220	0.055	0.000	0.000	0.600	0.300	**0.355**
Huiramba	0.300	0.075	0.410	0.103	0.740	0.370	**0.548**
Indaparapeo	0.630	0.158	0.530	0.133	0.770	0.385	**0.675**
Lagunillas	0.270	0.068	0.170	0.043	0.640	0.320	**0.430**
Morelia	0.110	0.028	0.390	0.098	0.360	0.180	**0.305**
Morelos	0.200	0.050	0.150	0.038	1.000	0.500	**0.588**
Queréndaro	0.270	0.068	0.230	0.058	0.480	0.240	**0.365**
Santa Ana Maya	0.670	0.168	0.270	0.068	0.290	0.145	**0.380**
Tarímbaro	0.430	0.108	0.000	0.000	0.880	0.440	**0.548**
Zinapécuaro	0.170	0.043	0.110	0.028	0.490	0.245	**0.315**

Annex 6 Utilities for the scenarios by sub watershed

Conservation policy (a) = Criterion, (b) = relative importance

Scenario SUPPLY							
Sub watershed	Supply (a)	.50 (b)	Demand (a)	.25 (b)	Decree (b)	.25(b)	**Utility**
Araró	0.360	0.180	0.790	0.198	0.050	0.013	**0.390**
Arroyo_el_Moral	0.250	0.125	0.380	0.095	0.660	0.165	**0.385**
Arroyo_el_Timbinales	0.100	0.050	0.210	0.053	0.520	0.130	**0.233**
Bordo_Prieto	0.200	0.100	0.590	0.148	0.180	0.045	**0.293**
Charo	0.380	0.190	0.650	0.163	0.620	0.155	**0.508**
Chucandiro	0.250	0.125	0.460	0.115	0.100	0.025	**0.265**
Chupicuaro	0.160	0.080	0.710	0.178	0.310	0.078	**0.335**
Copandaro	0.210	0.105	0.460	0.115	0.300	0.075	**0.295**
Cuto_de_la_Esperanza	0.390	0.195	0.310	0.078	0.970	0.243	**0.515**
Cuto_del_Porvenir	0.090	0.045	0.670	0.168	0.430	0.108	**0.320**
Cápula	0.230	0.115	0.640	0.160	1.000	0.250	**0.525**
El_Derramadero	0.160	0.080	0.520	0.130	0.220	0.055	**0.265**
El_Fresnito	0.150	0.075	0.190	0.048	0.320	0.080	**0.203**
El_Rocio	0.320	0.160	0.630	0.158	0.450	0.113	**0.430**
El_Sauz	0.550	0.275	0.390	0.098	0.070	0.018	**0.390**
El_Tlacuache	0.220	0.110	0.000	0.000	0.000	0.000	**0.110**
Encinillas	0.120	0.060	0.950	0.238	0.000	0.000	**0.298**
Huandacareo	0.260	0.130	0.730	0.183	0.570	0.143	**0.455**
Indaparapeo	0.220	0.110	0.200	0.050	0.080	0.020	**0.180**
Iramuco	0.300	0.150	0.410	0.103	0.560	0.140	**0.393**
La Yegüeria	0.050	0.025	0.810	0.203	0.000	0.000	**0.228**
La_Estancia	0.360	0.180	0.750	0.188	0.000	0.000	**0.368**
Lomas de la Alberca	0.110	0.055	0.270	0.068	0.060	0.015	**0.138**
Los_Naranjos	0.710	0.355	0.060	0.015	0.790	0.198	**0.568**
Meson_Nuevo	0.310	0.155	1.000	0.250	0.000	0.000	**0.405**
Nicolás_Tumbastiro	0.370	0.185	0.530	0.133	0.210	0.053	**0.370**
Ojos_de_Agua	0.880	0.440	0.510	0.128	0.940	0.235	**0.803**
Piñicuaro	0.200	0.100	0.610	0.153	0.240	0.060	**0.313**
Queréndaro	0.540	0.270	0.470	0.118	1.000	0.250	**0.638**
Río_Grande	0.210	0.105	0.330	0.083	0.760	0.190	**0.378**
San Marcos	0.240	0.120	0.410	0.103	0.820	0.205	**0.428**
San Nicolás Simirao	0.150	0.075	0.730	0.183	0.010	0.003	**0.260**
San_Juan_Tarárameo	0.290	0.145	0.610	0.153	0.800	0.200	**0.498**
San_Lucas_Pio	0.280	0.140	0.380	0.095	0.270	0.068	**0.303**
San_Sebastián	0.800	0.400	0.360	0.090	0.390	0.098	**0.588**
Santa_Rita	0.220	0.110	0.610	0.153	0.570	0.143	**0.405**
Tari-Quere	0.020	0.010	0.710	0.178	0.070	0.018	**0.205**
Zinapecuaro	0.430	0.215	0.570	0.143	0.970	0.243	**0.600**

Scenario NO TREND							
Sub watershed	Supply (a)	.33 (b)	Demand (a)	.33 (b)	Decree (b)	.33(b)	**Utility**
Araró	0.360	0.119	0.790	0.261	0.050	0.017	**0.396**
Arroyo_el_Moral	0.250	0.083	0.380	0.125	0.660	0.218	**0.426**
Arroyo_el_Timbinales	0.100	0.033	0.210	0.069	0.520	0.172	**0.274**
Bordo_Prieto	0.200	0.066	0.590	0.195	0.180	0.059	**0.320**
Charo	0.380	0.125	0.650	0.215	0.620	0.205	**0.545**
Chucandiro	0.250	0.083	0.460	0.152	0.100	0.033	**0.267**
Chupicuaro	0.160	0.053	0.710	0.234	0.310	0.102	**0.389**
Copandaro	0.210	0.069	0.460	0.152	0.300	0.099	**0.320**
Cuto_de_la_Esperanza	0.390	0.129	0.310	0.102	0.970	0.320	**0.551**
Cuto_del_Porvenir	0.090	0.030	0.670	0.221	0.430	0.142	**0.393**
Cápula	0.230	0.076	0.640	0.211	1.000	0.330	**0.617**
El_Derramadero	0.160	0.053	0.520	0.172	0.220	0.073	**0.297**
El_Fresnito	0.150	0.050	0.190	0.063	0.320	0.106	**0.218**
El_Rocio	0.320	0.106	0.630	0.208	0.450	0.149	**0.462**
El_Sauz	0.550	0.182	0.390	0.129	0.070	0.023	**0.333**
El_Tlacuache	0.220	0.073	0.000	0.000	0.000	0.000	**0.073**
Encinillas	0.120	0.040	0.950	0.314	0.000	0.000	**0.353**
Huandacareo	0.260	0.086	0.730	0.241	0.570	0.188	**0.515**
Indaparapeo	0.220	0.073	0.200	0.066	0.080	0.026	**0.165**
Iramuco	0.300	0.099	0.410	0.135	0.560	0.185	**0.419**
La Yegüeria	0.050	0.017	0.810	0.267	0.000	0.000	**0.284**
La_Estancia	0.360	0.119	0.750	0.248	0.000	0.000	**0.366**
Lomas de la Alberca	0.110	0.036	0.270	0.089	0.060	0.020	**0.145**
Los_Naranjos	0.710	0.234	0.060	0.020	0.790	0.261	**0.515**
Meson_Nuevo	0.310	0.102	1.000	0.330	0.000	0.000	**0.432**
Nicolás_Tumbastiro	0.370	0.122	0.530	0.175	0.210	0.069	**0.366**
Ojos_de_Agua	0.880	0.290	0.510	0.168	0.940	0.310	**0.769**
Piñicuaro	0.200	0.066	0.610	0.201	0.240	0.079	**0.347**
Queréndaro	0.540	0.178	0.470	0.155	1.000	0.330	**0.663**
Río_Grande	0.210	0.069	0.330	0.109	0.760	0.251	**0.429**
San Marcos	0.240	0.079	0.410	0.135	0.820	0.271	**0.485**
San Nicolás Simirao	0.150	0.050	0.730	0.241	0.010	0.003	**0.294**
San_Juan_Taráramero	0.290	0.096	0.610	0.201	0.800	0.264	**0.561**
San_Lucas_Pio	0.280	0.092	0.380	0.125	0.270	0.089	**0.307**
San_Sebastián	0.800	0.264	0.360	0.119	0.390	0.129	**0.512**
Santa_Rita	0.220	0.073	0.610	0.201	0.570	0.188	**0.462**
Tari-Quere	0.020	0.007	0.710	0.234	0.070	0.023	**0.264**
Zinapecuaro	0.430	0.142	0.570	0.188	0.970	0.320	**0.650**

Scenario DEMAND							
Sub watershed	Supply (a)	.25(b)	Demand (a)	.50 (b)	Decree (b)	.25(b)	**Utility**
Araró	0.360	0.090	0.790	0.395	0.050	0.013	**0.498**
Arroyo_el_Moral	0.250	0.063	0.380	0.190	0.660	0.165	**0.418**
Arroyo_el_Timbinales	0.100	0.025	0.210	0.105	0.520	0.130	**0.260**
Bordo_Prieto	0.200	0.050	0.590	0.295	0.180	0.045	**0.390**
Charo	0.380	0.095	0.650	0.325	0.620	0.155	**0.575**
Chucandiro	0.250	0.063	0.460	0.230	0.100	0.025	**0.318**
Chupicuaro	0.160	0.040	0.710	0.355	0.310	0.078	**0.473**
Copandaro	0.210	0.053	0.460	0.230	0.300	0.075	**0.358**
Cuto_de_la_Esperanza	0.390	0.098	0.310	0.155	0.970	0.243	**0.495**
Cuto_del_Porvenir	0.090	0.023	0.670	0.335	0.430	0.108	**0.465**
Cápula	0.230	0.058	0.640	0.320	1.000	0.250	**0.628**
El_Derramadero	0.160	0.040	0.520	0.260	0.220	0.055	**0.355**
El_Fresnito	0.150	0.038	0.190	0.095	0.320	0.080	**0.213**
El_Rocio	0.320	0.080	0.630	0.315	0.450	0.113	**0.508**
El_Sauz	0.550	0.138	0.390	0.195	0.070	0.018	**0.350**
El_Tlacuache	0.220	0.055	0.000	0.000	0.000	0.000	**0.055**
Encinillas	0.120	0.030	0.950	0.475	0.000	0.000	**0.505**
Huandacareo	0.260	0.065	0.730	0.365	0.570	0.143	**0.573**
Indaparapeo	0.220	0.055	0.200	0.100	0.080	0.020	**0.175**
Iramuco	0.300	0.075	0.410	0.205	0.560	0.140	**0.420**
La Yegüeria	0.050	0.013	0.810	0.405	0.000	0.000	**0.418**
La_Estancia	0.360	0.090	0.750	0.375	0.000	0.000	**0.465**
Lomas de la Alberca	0.110	0.028	0.270	0.135	0.060	0.015	**0.178**
Los_Naranjos	0.710	0.178	0.060	0.030	0.790	0.198	**0.405**
Meson_Nuevo	0.310	0.078	1.000	0.500	0.000	0.000	**0.578**
Nicolás_Tumbastiro	0.370	0.093	0.530	0.265	0.210	0.053	**0.410**
Ojos_de_Agua	0.880	0.220	0.510	0.255	0.940	0.235	**0.710**
Piñicuaro	0.200	0.050	0.610	0.305	0.240	0.060	**0.415**
Queréndaro	0.540	0.135	0.470	0.235	1.000	0.250	**0.620**
Río_Grande	0.210	0.053	0.330	0.165	0.760	0.190	**0.408**
San Marcos	0.240	0.060	0.410	0.205	0.820	0.205	**0.470**
San Nicolás Simirao	0.150	0.038	0.730	0.365	0.010	0.003	**0.405**
San_Juan_Tarárameo	0.290	0.073	0.610	0.305	0.800	0.200	**0.578**
San_Lucas_Pio	0.280	0.070	0.380	0.190	0.270	0.068	**0.328**
San_Sebastián	0.800	0.200	0.360	0.180	0.390	0.098	**0.478**
Santa_Rita	0.220	0.055	0.610	0.305	0.570	0.143	**0.503**
Tari-Quere	0.020	0.005	0.710	0.355	0.070	0.018	**0.378**
Zinapecuaro	0.430	0.108	0.570	0.285	0.970	0.243	**0.635**

Scenario DECREE							
Sub watershed	Supply (a)	.25(b)	Demand (a)	.25 (b)	Decree (b)	.50(b)	**Utility**
Araró	0.360	0.090	0.790	0.198	0.050	0.025	**0.313**
Arroyo_el_Moral	0.250	0.063	0.380	0.095	0.660	0.330	**0.488**
Arroyo_el_Timbinales	0.100	0.025	0.210	0.053	0.520	0.260	**0.338**
Bordo_Prieto	0.200	0.050	0.590	0.148	0.180	0.090	**0.288**
Charo	0.380	0.095	0.650	0.163	0.620	0.310	**0.568**
Chucandiro	0.250	0.063	0.460	0.115	0.100	0.050	**0.228**
Chupicuaro	0.160	0.040	0.710	0.178	0.310	0.155	**0.373**
Copandaro	0.210	0.053	0.460	0.115	0.300	0.150	**0.318**
Cuto_de_la_Esperanza	0.390	0.098	0.310	0.078	0.970	0.485	**0.660**
Cuto_del_Porvenir	0.090	0.023	0.670	0.168	0.430	0.215	**0.405**
Cápula	0.230	0.058	0.640	0.160	1.000	0.500	**0.718**
El_Derramadero	0.160	0.040	0.520	0.130	0.220	0.110	**0.280**
El_Fresnito	0.150	0.038	0.190	0.048	0.320	0.160	**0.245**
El_Rocio	0.320	0.080	0.630	0.158	0.450	0.225	**0.463**
El_Sauz	0.550	0.138	0.390	0.098	0.070	0.035	**0.270**
El_Tlacuache	0.220	0.055	0.000	0.000	0.000	0.000	**0.055**
Encinillas	0.120	0.030	0.950	0.238	0.000	0.000	**0.268**
Huandacareo	0.260	0.065	0.730	0.183	0.570	0.285	**0.533**
Indaparapeo	0.220	0.055	0.200	0.050	0.080	0.040	**0.145**
Iramuco	0.300	0.075	0.410	0.103	0.560	0.280	**0.458**
La Yegüeria	0.050	0.013	0.810	0.203	0.000	0.000	**0.215**
La_Estancia	0.360	0.090	0.750	0.188	0.000	0.000	**0.278**
Lomas de la Alberca	0.110	0.028	0.270	0.068	0.060	0.030	**0.125**
Los_Naranjos	0.710	0.178	0.060	0.015	0.790	0.395	**0.588**
Meson_Nuevo	0.310	0.078	1.000	0.250	0.000	0.000	**0.328**
Nicolás_Tumbastiro	0.370	0.093	0.530	0.133	0.210	0.105	**0.330**
Ojos_de_Agua	0.880	0.220	0.510	0.128	0.940	0.470	**0.818**
Piñicuaro	0.200	0.050	0.610	0.153	0.240	0.120	**0.323**
Queréndaro	0.540	0.135	0.470	0.118	1.000	0.500	**0.753**
Río_Grande	0.210	0.053	0.330	0.083	0.760	0.380	**0.515**
San Marcos	0.240	0.060	0.410	0.103	0.820	0.410	**0.573**
San Nicolás Simirao	0.150	0.038	0.730	0.183	0.010	0.005	**0.225**
San_Juan_Tarárameo	0.290	0.073	0.610	0.153	0.800	0.400	**0.625**
San_Lucas_Pio	0.280	0.070	0.380	0.095	0.270	0.135	**0.300**
San_Sebastián	0.800	0.200	0.360	0.090	0.390	0.195	**0.485**
Santa_Rita	0.220	0.055	0.610	0.153	0.570	0.285	**0.493**
Tari-Quere	0.020	0.005	0.710	0.178	0.070	0.035	**0.218**
Zinapecuaro	0.430	0.108	0.570	0.143	0.970	0.485	**0.735**

Sustainable use policy (a) = Criterion, (b) = relative importance

Scenario SUPPLY							
Sub watershed	Supply (a)	.50 (b)	Demand (a)	.25 (b)	Decree (b)	.25(b)	**Utility**
Araró	0.200	0.100	0.210	0.053	0.960	0.240	**0.393**
Arroyo_el_Moral	0.300	0.150	0.620	0.155	0.510	0.128	**0.433**
Arroyo_el_Timbinales	0.390	0.195	0.790	0.198	0.610	0.153	**0.545**
Bordo_Prieto	0.270	0.135	0.410	0.103	0.850	0.213	**0.450**
Charo	0.090	0.045	0.350	0.088	0.540	0.135	**0.268**
Chucandiro	0.110	0.055	0.540	0.135	0.920	0.230	**0.420**
Chupicuaro	0.360	0.180	0.290	0.073	0.770	0.193	**0.445**
Copandaro	0.240	0.120	0.540	0.135	0.780	0.195	**0.450**
Cuto_de_la_Esperanza	0.060	0.030	0.690	0.173	0.280	0.070	**0.273**
Cuto_del_Porvenir	0.190	0.095	0.330	0.083	0.680	0.170	**0.348**
Cápula	0.120	0.060	0.360	0.090	0.250	0.063	**0.213**
El_Derramadero	0.260	0.130	0.480	0.120	0.830	0.208	**0.458**
El_Fresnito	0.100	0.050	0.810	0.203	0.650	0.163	**0.415**
El_Rocio	0.080	0.040	0.370	0.093	0.650	0.163	**0.295**
El_Sauz	0.120	0.060	0.610	0.153	0.950	0.238	**0.450**
El_Tlacuache	0.080	0.040	1.000	0.250	1.000	0.250	**0.540**
Encinillas	0.820	0.410	0.050	0.013	1.000	0.250	**0.673**
Huandacareo	0.140	0.070	0.270	0.068	0.570	0.143	**0.280**
Indaparapeo	0.100	0.050	0.800	0.200	0.940	0.235	**0.485**
Iramuco	0.220	0.110	0.590	0.148	0.580	0.145	**0.403**
La Yegüeria	0.160	0.080	0.190	0.048	1.000	0.250	**0.378**
La_Estancia	0.180	0.090	0.250	0.063	0.990	0.248	**0.400**
Lomas de la Alberca	0.100	0.050	0.730	0.183	0.950	0.238	**0.470**
Los_Naranjos	0.070	0.035	0.940	0.235	0.410	0.103	**0.373**
Meson_Nuevo	0.160	0.080	0.000	0.000	1.000	0.250	**0.330**
Nicolás_Tumbastiro	0.120	0.060	0.470	0.118	0.800	0.200	**0.378**
Ojos_de_Agua	0.030	0.015	0.490	0.123	0.290	0.073	**0.210**
Piñicuaro	0.330	0.165	0.390	0.098	0.820	0.205	**0.468**
Queréndaro	0.050	0.025	0.530	0.133	0.250	0.063	**0.220**
Río_Grande	0.110	0.055	0.670	0.168	0.410	0.103	**0.325**
San Marcos	0.090	0.045	0.590	0.148	0.390	0.098	**0.290**
San Nicolás Simirao	0.130	0.065	0.270	0.068	0.600	0.150	**0.283**
San_Juan_Tarárameo	0.170	0.085	0.390	0.098	0.400	0.100	**0.283**
San_Lucas_Pio	0.080	0.040	0.620	0.155	0.800	0.200	**0.395**
San_Sebastián	0.020	0.010	0.640	0.160	0.710	0.178	**0.348**
Santa_Rita	0.180	0.090	0.390	0.098	0.580	0.145	**0.333**
Tari-Quere	0.530	0.265	0.290	0.073	0.860	0.215	**0.553**
Zinapecuaro	0.050	0.025	0.430	0.108	0.250	0.063	**0.195**

Scenario NO TREND							
Sub watershed	Supply (a)	.33 (b)	Demand (a)	.33 (b)	Decree (b)	.33(b)	**Utility**
Araró	0.200	0.066	0.210	0.069	0.960	0.317	**0.452**
Arroyo_el_Moral	0.300	0.099	0.620	0.205	0.510	0.168	**0.472**
Arroyo_el_Timbinales	0.390	0.129	0.790	0.261	0.610	0.201	**0.591**
Bordo_Prieto	0.270	0.089	0.410	0.135	0.850	0.281	**0.505**
Charo	0.090	0.030	0.350	0.116	0.540	0.178	**0.323**
Chucandiro	0.110	0.036	0.540	0.178	0.920	0.304	**0.518**
Chupicuaro	0.360	0.119	0.290	0.096	0.770	0.254	**0.469**
Copandaro	0.240	0.079	0.540	0.178	0.780	0.257	**0.515**
Cuto_de_la_Esperanza	0.060	0.020	0.690	0.228	0.280	0.092	**0.340**
Cuto_del_Porvenir	0.190	0.063	0.330	0.109	0.680	0.224	**0.396**
Cápula	0.120	0.040	0.360	0.119	0.250	0.083	**0.241**
El_Derramadero	0.260	0.086	0.480	0.158	0.830	0.274	**0.518**
El_Fresnito	0.100	0.033	0.810	0.267	0.650	0.215	**0.515**
El_Rocio	0.080	0.026	0.370	0.122	0.650	0.215	**0.363**
El_Sauz	0.120	0.040	0.610	0.201	0.950	0.314	**0.554**
El_Tlacuache	0.080	0.026	1.000	0.330	1.000	0.330	**0.686**
Encinillas	0.820	0.271	0.050	0.017	1.000	0.330	**0.617**
Huandacareo	0.140	0.046	0.270	0.089	0.570	0.188	**0.323**
Indaparapeo	0.100	0.033	0.800	0.264	0.940	0.310	**0.607**
Iramuco	0.220	0.073	0.590	0.195	0.580	0.191	**0.459**
La Yegüeria	0.160	0.053	0.190	0.063	1.000	0.330	**0.446**
La_Estancia	0.180	0.059	0.250	0.083	0.990	0.327	**0.469**
Lomas de la Alberca	0.100	0.033	0.730	0.241	0.950	0.314	**0.587**
Los_Naranjos	0.070	0.023	0.940	0.310	0.410	0.135	**0.469**
Meson_Nuevo	0.160	0.053	0.000	0.000	1.000	0.330	**0.383**
Nicolás_Tumbastiro	0.120	0.040	0.470	0.155	0.800	0.264	**0.459**
Ojos_de_Agua	0.030	0.010	0.490	0.162	0.290	0.096	**0.267**
Piñicuaro	0.330	0.109	0.390	0.129	0.820	0.271	**0.508**
Queréndaro	0.050	0.017	0.530	0.175	0.250	0.083	**0.274**
Río_Grande	0.110	0.036	0.670	0.221	0.410	0.135	**0.393**
San Marcos	0.090	0.030	0.590	0.195	0.390	0.129	**0.353**
San Nicolás Simirao	0.130	0.043	0.270	0.089	0.600	0.198	**0.330**
San_Juan_Tarárameo	0.170	0.056	0.390	0.129	0.400	0.132	**0.317**
San_Lucas_Pio	0.080	0.026	0.620	0.205	0.800	0.264	**0.495**
San_Sebastián	0.020	0.007	0.640	0.211	0.710	0.234	**0.452**
Santa_Rita	0.180	0.059	0.390	0.129	0.580	0.191	**0.380**
Tari-Quere	0.530	0.175	0.290	0.096	0.860	0.284	**0.554**
Zinapecuaro	0.050	0.017	0.430	0.142	0.250	0.083	**0.241**

Scenario DEMAND							
Sub watershed	Supply (a)	.25 (b)	Demand (a)	.50 (b)	Decree (b)	.25(b)	**Utility**
Araró	0.200	0.050	0.210	0.105	0.960	0.240	**0.395**
Arroyo_el_Moral	0.300	0.075	0.620	0.310	0.510	0.128	**0.513**
Arroyo_el_Timbinales	0.390	0.098	0.790	0.395	0.610	0.153	**0.645**
Bordo_Prieto	0.270	0.068	0.410	0.205	0.850	0.213	**0.485**
Charo	0.090	0.023	0.350	0.175	0.540	0.135	**0.333**
Chucandiro	0.110	0.028	0.540	0.270	0.920	0.230	**0.528**
Chupicuaro	0.360	0.090	0.290	0.145	0.770	0.193	**0.428**
Copandaro	0.240	0.060	0.540	0.270	0.780	0.195	**0.525**
Cuto_de_la_Esperanza	0.060	0.015	0.690	0.345	0.280	0.070	**0.430**
Cuto_del_Porvenir	0.190	0.048	0.330	0.165	0.680	0.170	**0.383**
Cápula	0.120	0.030	0.360	0.180	0.250	0.063	**0.273**
El_Derramadero	0.260	0.065	0.480	0.240	0.830	0.208	**0.513**
El_Fresnito	0.100	0.025	0.810	0.405	0.650	0.163	**0.593**
El_Rocio	0.080	0.020	0.370	0.185	0.650	0.163	**0.368**
El_Sauz	0.120	0.030	0.610	0.305	0.950	0.238	**0.573**
El_Tlacuache	0.080	0.020	1.000	0.500	1.000	0.250	**0.770**
Encinillas	0.820	0.205	0.050	0.025	1.000	0.250	**0.480**
Huandacareo	0.140	0.035	0.270	0.135	0.570	0.143	**0.313**
Indaparapeo	0.100	0.025	0.800	0.400	0.940	0.235	**0.660**
Iramuco	0.220	0.055	0.590	0.295	0.580	0.145	**0.495**
La Yegüeria	0.160	0.040	0.190	0.095	1.000	0.250	**0.385**
La_Estancia	0.180	0.045	0.250	0.125	0.990	0.248	**0.418**
Lomas de la Alberca	0.100	0.025	0.730	0.365	0.950	0.238	**0.628**
Los_Naranjos	0.070	0.018	0.940	0.470	0.410	0.103	**0.590**
Meson_Nuevo	0.160	0.040	0.000	0.000	1.000	0.250	**0.290**
Nicolás_Tumbastiro	0.120	0.030	0.470	0.235	0.800	0.200	**0.465**
Ojos_de_Agua	0.030	0.008	0.490	0.245	0.290	0.073	**0.325**
Piñicuaro	0.330	0.083	0.390	0.195	0.820	0.205	**0.483**
Queréndaro	0.050	0.013	0.530	0.265	0.250	0.063	**0.340**
Río_Grande	0.110	0.028	0.670	0.335	0.410	0.103	**0.465**
San Marcos	0.090	0.023	0.590	0.295	0.390	0.098	**0.415**
San Nicolás Simirao	0.130	0.033	0.270	0.135	0.600	0.150	**0.318**
San_Juan_Tarárameo	0.170	0.043	0.390	0.195	0.400	0.100	**0.338**
San_Lucas_Pio	0.080	0.020	0.620	0.310	0.800	0.200	**0.530**
San_Sebastián	0.020	0.005	0.640	0.320	0.710	0.178	**0.503**
Santa_Rita	0.180	0.045	0.390	0.195	0.580	0.145	**0.385**
Tari-Quere	0.530	0.133	0.290	0.145	0.860	0.215	**0.493**
Zinapecuaro	0.050	0.013	0.430	0.215	0.250	0.063	**0.290**

Scenario DECREE							
Sub watershed	Supply (a)	.25(b)	Demand (a)	.25 (b)	Decree (b)	.50(b)	**Utility**
Araró	0.200	0.050	0.210	0.053	0.960	0.480	**0.583**
Arroyo_el_Moral	0.300	0.075	0.620	0.155	0.510	0.255	**0.485**
Arroyo_el_Timbinales	0.390	0.098	0.790	0.198	0.610	0.305	**0.600**
Bordo_Prieto	0.270	0.068	0.410	0.103	0.850	0.425	**0.595**
Charo	0.090	0.023	0.350	0.088	0.540	0.270	**0.380**
Chucandiro	0.110	0.028	0.540	0.135	0.920	0.460	**0.623**
Chupicuaro	0.360	0.090	0.290	0.073	0.770	0.385	**0.548**
Copandaro	0.240	0.060	0.540	0.135	0.780	0.390	**0.585**
Cuto_de_la_Esperanza	0.060	0.015	0.690	0.173	0.280	0.140	**0.328**
Cuto_del_Porvenir	0.190	0.048	0.330	0.083	0.680	0.340	**0.470**
Cápula	0.120	0.030	0.360	0.090	0.250	0.125	**0.245**
El_Derramadero	0.260	0.065	0.480	0.120	0.830	0.415	**0.600**
El_Fresnito	0.100	0.025	0.810	0.203	0.650	0.325	**0.553**
El_Rocio	0.080	0.020	0.370	0.093	0.650	0.325	**0.438**
El_Sauz	0.120	0.030	0.610	0.153	0.950	0.475	**0.658**
El_Tlacuache	0.080	0.020	1.000	0.250	1.000	0.500	**0.770**
Encinillas	0.820	0.205	0.050	0.013	1.000	0.500	**0.718**
Huandacareo	0.140	0.035	0.270	0.068	0.570	0.285	**0.388**
Indaparapeo	0.100	0.025	0.800	0.200	0.940	0.470	**0.695**
Iramuco	0.220	0.055	0.590	0.148	0.580	0.290	**0.493**
La Yegüeria	0.160	0.040	0.190	0.048	1.000	0.500	**0.588**
La_Estancia	0.180	0.045	0.250	0.063	0.990	0.495	**0.603**
Lomas de la Alberca	0.100	0.025	0.730	0.183	0.950	0.475	**0.683**
Los_Naranjos	0.070	0.018	0.940	0.235	0.410	0.205	**0.458**
Meson_Nuevo	0.160	0.040	0.000	0.000	1.000	0.500	**0.540**
Nicolás_Tumbastiro	0.120	0.030	0.470	0.118	0.800	0.400	**0.548**
Ojos_de_Agua	0.030	0.008	0.490	0.123	0.290	0.145	**0.275**
Piñicuaro	0.330	0.083	0.390	0.098	0.820	0.410	**0.590**
Queréndaro	0.050	0.013	0.530	0.133	0.250	0.125	**0.270**
Río_Grande	0.110	0.028	0.670	0.168	0.410	0.205	**0.400**
San Marcos	0.090	0.023	0.590	0.148	0.390	0.195	**0.365**
San Nicolás Simirao	0.130	0.033	0.270	0.068	0.600	0.300	**0.400**
San_Juan_Tarárameo	0.170	0.043	0.390	0.098	0.400	0.200	**0.340**
San_Lucas_Pio	0.080	0.020	0.620	0.155	0.800	0.400	**0.575**
San_Sebastián	0.020	0.005	0.640	0.160	0.710	0.355	**0.520**
Santa_Rita	0.180	0.045	0.390	0.098	0.580	0.290	**0.433**
Tari-Quere	0.530	0.133	0.290	0.073	0.860	0.430	**0.635**
Zinapecuaro	0.050	0.013	0.430	0.108	0.250	0.125	**0.245**

The end