Site Selection and Suitability Modeling

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1.0 INTRODUCTION:

Land use planning has become more complex with a growing desire to integrate goals related to sustainable development. Thus, the modern planning process has evolved into a movement of conflicting and contradicting interests between environmental, economic, and social interests. Planners face new challenges as they attempt to design projects that maintain ecological systems, contribute to economic development, and create quality places. Under these circumstances, it becomes difficult to make decisions based upon rational behavior given numerous players. This complexity has been reduced by the development of geographic information systems (GIS) analysis and decision making tools that predict land use opportunity and illustrate future growth patterns given various assumptions.

With advancements in technology, spatial models have become tools to aid in land use decision making. "Decision analysis is a set of systematic procedures for analyzing complex decision problems. Decision problems … typically involve a large set of feasible alternatives and multiple conflicting and incommensurate evaluation criteria. GIS-based (or spatial) multi-criteria decision analysis can be defined as a collection of techniques for analyzing geographic events where the results of the analysis (decisions) depend on the spatial arrangement of the events" (Malczewski 1999, xi-xii). Choice models and suitability models both aid in the decision making process. A suitability model however can be regarded as a choice model that works for an entire study area and not just for specified locations, as in location choice models. Joerin et al (2001) explained that the land suitability assessment process is similar to the process of choosing an appropriate location with the exception that the goal of suitability is not to isolate the best alternative but to look at the suitability index that is mapped for the entire area.

Land use suitability techniques analyze interactions among three types of factors: location, development actions, and environmental elements to determine the most appropriate locations for land use action (Collins et al 2001). Two spatially-based decision analysis approaches are multi-criteria decision making (MCDM) and the Land Use Conflict Identification Strategy (LUCIS). The differences between these approaches are not only in generating the suitability index but differences exist in the procedure taken to reach the final objectives. MCDM evolved as a response to the observed inability of people to effectively analyze multiple streams of information, and evaluate and choose among alternatives using systematic analysis (Linkov et al 2004). LUCIS was developed in a response to a gap in existing land use suitability models for projecting future land-use alternatives. Based upon Eugene P. Odum's (1969) compartment model, LUCIS uses a three land use type classification system to emulate Odum's model "so that growth-type, steady-state, and intermediate-type ecosystems can be linked with urban and industrial areas for mutual benefit" (Carr and Zwick 2007, 10). The uniqueness of the LUCIS method is the prediction of land use conflict, which is a comparison of preference for each land use category with respect to the other land use categories for each piece of land (Carr and Zwick 2007).

The progression of GIS technologies over the past 40 years has made it an integral part of most decision support systems. The value of GIS is the capability to perform integrated analysis of spatial and attribute data (Malczewski 1999) in a problem-solving environment. The challenge of most decision models is to appropriately articulate workflow processes in a spatial environment. This can most easily be achieved by executing a series of individual spatial tools until the workflow has been completed. For simple decision problems, this can be an inconsequential task. For more complex decision problems, as those typically encountered in a physical planning environment, workflows can often be complex and involve numerous actors. For complex decisions the more automated processes included in the analysis, the more efficient the decision making process becomes.

The purpose of this paper is to present LUCIS as a method that addresses the spatial shortcomings of traditional MCDM methods. This paper will also present methodologies used to integrate MCDM with three aspects of the LUCIS approach suggesting automation procedures: 1) for use in generating suitability and conflict surfaces; 2) to generate alternative future scenarios; and 3) to allocate projected population and employment that advance basic GIS capabilities.

2.1 BACKGROUND:

There are two major approaches in the decision making process (Table 1). The first, alternative-focus approach, focuses on generating decision alternatives. The second, value-focused approach, uses the values (evaluation criteria) as the fundamental element of the decision analysis (Malczewski 1999). According to Malczewski, the differences between these two approaches "are related to the question of whether alternatives should be generated first and then the value structure should be specified, or conversely, the alternatives are derived from the value structure. The general principle for structuring the decision-making process is that the decision alternatives should be generated so that the values specified for the decision situation are best achieved. This implies that the order of thinking focuses first on what is desired and then on alternatives to obtain it. It is argued that values are more fundamental than alternatives to a decision problem (Malczewski 1999, 95).

Table 1: Comparing sequences of activities for the value- and alternative-focused approaches

Step	Value Focused Approach	Alternative-Focused Approach
1	Decision problem recognition	Decision problem recognition
2	Specify values	Identify alternatives
3	Generate alternatives	Specify values
4	Evaluate alternatives	Evaluate alternatives
5	Select an alternative	Select an alternative
6	Recommendation	Recommendation

(Source: Based on Keeny 1992; Malczewski 1999, 49)

In MCDM and LUCIS there are four main components to the decision making process: 1) evaluate existing conditions (suitability); 2) assign utility (weighting) for a distinct purpose; 3) measure values (community values) that represent parameters or standards for organizing suitability criteria; and 4) distribute population and employment (allocation).

GIS and Decision Analysis

Cowen describes "GIS as a decision support system involving the integration of spatially referenced data in a problem-solving environment. The basis of geospatial decision support is the GIS technology. The basic decision aids of GIS include data management to extend human memory, graphic display to enhance visualization, and spatial analysis functions to extend human computing performance. Beyond these common GIS decision aids, special features include modeling, optimization, and simulation functions required to generate, evaluate, and test the sensitivity of computed solutions" (Nyerges and Jankowski 2010, 7). The flexibility of GIS plays an integral role in its appeal to spatial decision modelers. Application programming interfaces (API) within a GIS toolbox allow the enhancement of the decision support function by adding models that support various capabilities (Nyerges and Jankowski 2010). MCDM is one example of a decision-aiding tool that links environmental models with methods that incorporate decision-makers' preferences within land-use allocation and suitability analysis (Collins et al 2001; Linkov and Steevens 2005). LUCIS is another example of a strategy used to analyze multi-objective decisions.

Generally, in GIS-based multicriteria decision analysis (MCDA)[1], a choice of one or more alternatives is made from a set of geographically defined alternatives (events) with respect to a given set of evaluation criteria. "The alternatives are defined geographically in the sense that results of the analysis (decisions) depend on their spatial arrangement" (Malczewski 1999, 90). Malczewski describes the six components of MCDM problems as: (1) a *goal* or set of goals the decision maker (interest group) attempts to achieve; (2) the *decision maker* or group of decision makers involved in the decision-making process along with their preferences with respect to evaluation criteria; (3) a set of evaluation criteria (*objectives* and/or *attributes*) on the basis of which the decision makers evaluate alternative courses of action; (4) the set of decision *alternatives*, that is, the decision or action variables; (5) the set of uncontrollable variables or *states of nature* (decision environment); and (6) the set of *outcomes* or consequences associated with each alternative – attribute pair (Malczewski 1999, 82).

According to Eldrandaly et al (2005), GIS and MCDM tools suffer from serious shortcomings when used in decision-making problems involving spatial data.

> While GIS possess ideal capabilities for performing spatial searches based on mappable criteria, they are of limited use when multiple criteria with conflicting objectives are considered in the analysis. GIS also have limited capabilities for integrating geographical information with subjective values and preferences imposed by decision makers. Likewise, MCDM techniques possess ideal capabilities for analyzing decision problems, generating useful alternative

[1] The terms multicriteria decision making (MCDM) and multicriteria decision analysis (MCDA) are used interchangeably in decision analysis literature (Malczewski 1999) and in this paper.

> solutions, and evaluating alternatives based on values and preferences imposed by decision makers. However, these techniques assume a spatial homogeneity within the study area, which is unrealistic for many spatial decision-making situations. Malczewski (2005) suggested that there is a serious need for an explicit representation of geographical dimension in the MCDM techniques. (Eldrandaly et al 2005, 163).

MCDA analyze multiobjective decisions through the use of optimization approaches (i.e., numerical scores), which define a relationship between the input maps and the output map by communicating the merit of each option on a single scale. "Scores are developed from the performance of alternatives with respect to individual criteria and then aggregated into an overall score. Individual scores may be simply summed or averaged, or a weighting mechanism can be used to favor some criteria more heavily than others" (Linkov and Steevens 2005, 816). The criteria evaluations in MCDA are conflicting in their nature. This conflict can be resolved by applying the decision of experts or communities using a weighting procedure such as linear weighting or analytical hierarchy process (AHP).

Eldrandaly et al believe that integration of the capabilities of the GIS and MCDM would eliminate explicit shortcomings and could improve the complex decision making ability. The LUCIS methodology accommodates for these shortcomings. LUCIS can be summarized as a five steps workflow: (1) define *goals and objectives* that become the criteria for determining suitability; (2) identify *data resources* potentially relevant to each goal and objective; (3) analyze data to determine *relative suitability* for each goal; (4) combine the relative suitabilities of each goal to determine *preference* for the three major land-use categories; and (5) compare the three land-use preferences to determine likely areas of future *land-use conflict* (Carr and Zwick 2007, 12). Although the structure of the MCDM and LUCIS methods seem similar, significant differences exist between the two methods.

Version 1 of the LUCIS strategy ("LUCIS v1"), based on methods described in "Smart Land Use Analysis: The LUCIS Model" (Carr and Zwick 2007), compiles GIS ESRI ModelBuilder Modules and dynamically aggregates them to obtain a GIS raster surface that spatially illustrates preferred locations of future land use. With the ability to place GIS data and geoprocessing tools in a visual program, "the GIS analyst can create complex programs without having to learn a programming language," according to Carr and Zwick (2007, 26). LUCIS v1 required user input at each tool within the model, including several steps at which the user would have to perform separate calculations outside of the GIS environment.

Land Use Suitability & Overlay

Land use suitability analysis is an analytical process that combines inventory information to determine whether the requirements of a land use are adequately met by the characteristics of the land. The result is either tabular data, a single map or a series of composite maps that display the relative suitability [or appropriateness] for a specific use (in siting studies) or a number of uses (in comprehensive planning) (Randolph 2004, 591). As landscape architects in the late 1800s, Charles Eliot and Warren Manning used suitability analysis in their environmental planning pursuits to measure the relative degree lands in Boston were fit for integration into the Boston Metropolitan Park System. Central to this process was developing a systematic approach to inventory site resources and, through the use of overlay mapping, analyze the natural fitness of the land (Carr 2008, 5).

Suitability techniques have evolved quickly during the twentieth century. In the 1960s Ian McHarg included an ecological inventory process into suitability analysis. During the late 1960s and early 1970s the advent and use of computers in land use suitability marked the beginning of a revolution expanding the capabilities of suitability analysis. With computers, large amounts of information could be combined and overlays became more accurate. The most significant technological advance was the use of the computer to make simple grid maps. The grid cell allowed more precise analysis of map factors between multiple maps. In the 1980s map algebra was developed which allowed mathematical computation among several grid maps. In the early 1990s, GIS became a formal technology. GIS technologies "store, analyze, and display spatial and nonspatial data and are capable of creating new data through automated overlays and spatial searches" (Collins et al 2001, 614).

LUCIS illustrates the next era of suitability modeling. LUCIS is organized in a hierarchical structure of goals, objectives, and sub-objectives (Figure 1), similar to Alexander and Manheim's procedural tree (Alexander and Manheim 1962). For each respective objective and/or sub-objective, a GIS model is developed. Each model is a sequence of spatial data and geoprocessing tools that first assign an estimate of utility and then assigns a suitability value for that utility. In the higher orders of the hierarchy, suitability assignments are made for the development of land uses (i.e., agriculture, conservation, and urban) which are then combined in a single raster to identify the conflict between the land use preferences.

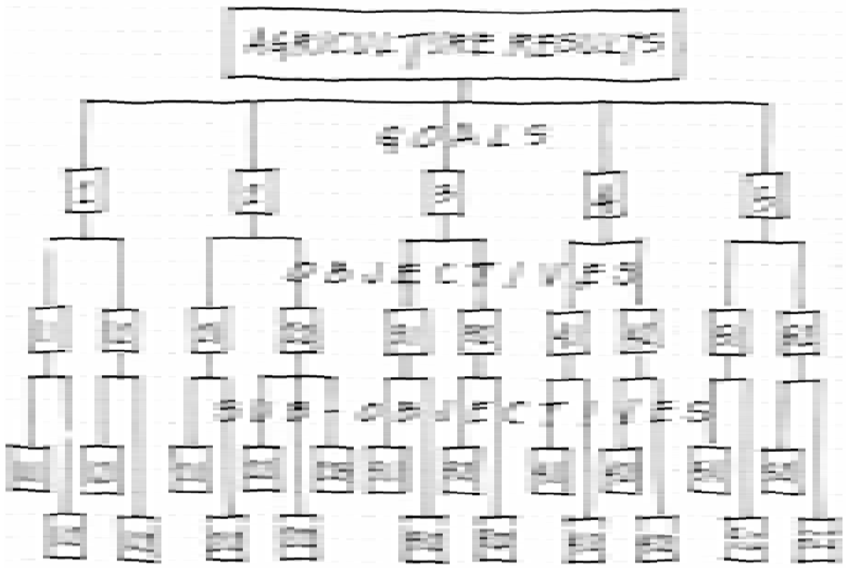


Figure 1: Example LUCIS hierarchical relationships of goals, objectives and sub-objectives for agricultural land use suitability analysis. (Source: Carr and Zwick 2007, 231)

The suitability index is a value that represents the relative usefulness for a particular land use. In the LUCIS model values ranging from one to nine are assigned, where one represents the lowest suitability and nine the highest suitability value (Carr & Zwick, 2007). Classification into these value ranges occur using various methods depending upon the nature of the criteria to be evaluated or according to the utility to be classified as a suitability surface. Some of the procedures are simple (binary methods) and some of them have higher complexities. Regardless of whether the model measures a qualitative or quantitative process, the output of the LUCIS model employ at least two values, 1 and 9.

GIS layer overlay is the core of suitability analysis. Even suitability analysis undertaken at the time of hand drawn maps was dependent on map overlay (Collins et al 2001; McHarg 1969). The overlay procedure in GIS raster analysis depends upon three logical spatial overlay rules: enumeration, dominance, contributory and interaction. According to Carr and Zwick, enumeration "preserves all attribute values from multiple input layers. Enumeration creates an output layer that combines all attributes from the spatial input layers to provide a clear and distinct set of unique attribute combinations from the input. The dominance rule depends on the selection of a single value that is preferred over all other values found at the same spatial location. The selection is defined or governed by external rules, not simply the combination of values. The contributory rule is applied by performing a group of operations [which are] values from one input contributing to the results without regard for the values from other inputs. Lastly, the interaction rule, unlike the contributory rule, considers the interaction between factors. However, to consider interactions between factors, the factors must be translated into the same standard intervals." (Carr and Zwick 2007, 50-57). These rules represent logical operations that can be translated into equivalent functions in land use modeling such as layer weighting and the combination of different utility surfaces into a suitability layer.

The dynamic relationship between land characteristics and land use illustrates the complexity of land use suitability analysis (Driessen & Konijn 1992). Through interaction, utility is combined to create suitability. Single utility assignments (SUA), which are the assignment of utility values within an individual raster layer, are combined using weights to create multiple utility assignments (MUA) (Carr & Zwick 2007). However, utility is a measurement of human satisfaction and thus if applied to land use could mean how much a person can be satisfied by the land characteristics. This explains why utility is used in choice models while suitability is used in criterion evaluation models or land suitability models. The various approaches to suitability analysis "offer alternative perspectives in understanding the interactions between human and natural processes. Some are innovative and sensitive to the future, while others are the repackaging of the same approaches under different names or refinements of tools and techniques" (Ndubisi 2002, 138).

The GIS overlay techniques for the MCDM method can be divided into two main methods: the multi-objective method and the multi-attribute method. The multi-objective method depends on two or more objectives to be combined using a set of constraints. This is always solved by standard linear programming methods. The problem in this method is that adding constraints will help the planner in decision making but will add computational complexity making it difficult to apply in a GIS environment. The multi-attribute method is applied using GIS map algebra techniques. It uses weighted linear combination (WLC) and the Boolean operations "AND" and "OR" in the overlay process. However, this process gives the same weight despite the geographic location, as the WLC is based on the concept of a weighted average. In this method relatively more importance is given to the attributes because it is assumed that the importance of location is taken into account in generating each layer to be combined by the Boolean operator. Ordered weighted averaging (OWA) has also been used to overcome the disadvantages of WLC. The OWA method involves two set of weights, one is the criterion importance weight which is constant for the criterion at all locations and the other is the order weight which is associated with the criterion on a location by location weight (geographic or spatial weights). AHP, used in MCDM, is a method that incorporates the generation of the linear combination weights by aggregating the priority for each level in the hierarchy process. AHP is also used as a consensus building tool in situations involving group decision making (Malczewski 2004).

LUCIS and MCDM Comparison – Weighting & Community Values

Programmed and automated procedures as well as community participation using Delphi or pairwise comparison methods (i.e., AHP), are used in ranking and ordering procedures to assess the importance of weights (Carr & Zwick, 2007; Malczewski, 1999, 2004). The pairwise comparison technique, developed by Thomas Saaty in the 1970s and 1980s in the context of AHP multiple criteria evaluation methods, represent the relative importance of criteria. “Weights are not assigned directly but represent a ‘best fit’ set of weights derived from the eigenvector of the square reciprocal matrix used to compare all possible pairs of criteria. The advantage of this technique is that information can be used from handbooks, regression output, or decision modelers/experts can be asked to rank order individual factors” (Nyerges and Jankowski 2010, 140-141). Malczewski defines weight as, “a value assigned to an evaluation criterion that indicates its importance relative to other criteria under consideration. The larger the weight, the more important is the criterion in the overall utility” (Malczewski 1999, 177).

Both MCDM and LUCIS integrate weights into their methods. MCDM provide four methods for assessing criterion weights: ranking, rating, pairwise comparison, and trade-off analysis. “Which method to use depend on the trade-offs one is willing to make between ease of use, accuracy, the degree of understanding on the part of the decision maker, and the theoretical foundation underlying a given method; the availability of computer software; and the way the method can be incorporated into GIS-based multicriteria decision analysis” (Malczewski 1999, 189).

Carr and Zwick (2007) calculate community preference using the more advanced pairwise comparison method of AHP. In the AHP procedure, a model is created and the project goal is stated. The goal for pairwise comparison is a statement defining pair comparisons. The objectives and sub-objectives are treated as components of the overall goal. Then, each unique pair is compared for their usefulness in supporting the goal. All components are compared using Saaty’s 1 to 9 scale, ranging from *equally important/useful* to *extremely more important/useful* (Table 2). Next, the pairwise comparisons are evaluated within a matrix for all pairs of values to produce final pairwise utility values (Table 3). Finally, the final pairwise utility values are transformed into single utility assignment values ranging from one to nine (Carr and Zwick, 2007). After completing the pairwise comparisons, the weight for each layer is calculated according to an eigenvalue / eigenvector procedure.

Table 2: Scale for pairwise comparison (Source: Saaty 1980).

Definition	**Intensity of Importance**
Extremely more important	9
Very strongly to extremely more important	8
Very strongly more important	7
Strongly to very strongly more important	6
Strongly more important	5
Moderately to strongly more important	4
Moderately more important	3
Equally to moderately more important	2
Equally important	1

Table 3: Pairwise comparison matrix for LUCIS conservation land use.

	Goal 1: Native Biodiversity	Goal 2: Protection of Water Quality	Goal 3: Ecological Processes	Goal 4: Enhancing Existing Conservation Areas	Goal 5: Resource Based Recreation
Goal 1: Native Biodiversity					
Goal 2: Protection of Water Quality					
Goal 3: Ecological Processes					
Goal 4: Enhancing Existing Conservation Areas					
Goal 5: Resource Based Recreation					

LUCIS v1 (Carr & Zwick, 2007) uses software packages external to the ArcMap environment to calculate the AHP layer combining weights.

LUCIS and MCDM Comparison – Decision Rules

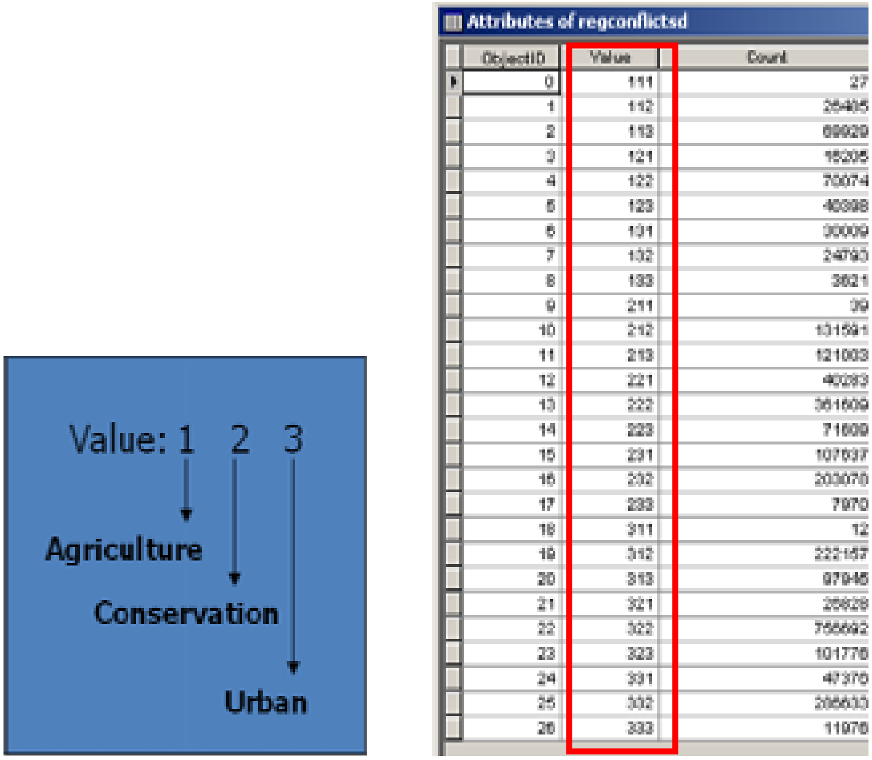
MCDA uses layer combination according to the outcomes of AHP and the consensus of Delphi panels. The combination is mainly layer weighting using an interaction rule. However some of the weighting is done in the suitability assignment level in the hierarchy structure. A similar technique is utilized in the LUCIS model. The primary and most important difference is that MCDA uses alternative scenarios and the weights generated by AHP to evaluate the suitability for each scenario while LUCIS uses a conflict surface, which is a matrix that preserves the original preference values. This matrix consists of three or four digits, according to the number of preference surfaces combined to create the conflict surface.

Preference applies community values to the cumulative suitability of land fitness. The aggregation of relative suitability surfaces for a goal can be seen as an opportunity surface even if it has some conflicting aspects. For example, an opportunity surface for urban suitability contains the complex MUA grids for commercial, industrial, multi-family and single family. The generated opportunity surface identifies the conflict between the components of an urban environment yet maintains the original suitability for each individual component. The interaction between sets of goals within each land use, illustrated at the highest level of the hierarchy, demonstrates conflict while preserving the suitability of the generating surfaces (Carr & Zwick 2005).

The purpose of the conflict surface is to generate a suitability matrix. Individually, suitability is determined and weights are assigned from AHP values exercises to create a complex MUA for each respective land use. Next, these land use opportunity surfaces are transformed from suitability into preference, which places each land use opportunity surface on the same scale – from one (low preference) to three (high preference) (Table 4). Using map algebra, each respective preference surface is combined to create a single conflict surface. The conflict surface is a suitability matrix of twenty-seven values (Figure 2); given three possible preference values for three land use types (3^3) the result is twenty-seven values.

Table 4: Preference value descriptions.

Cells with a value of:	Indicate:
1	low preference
2	medium preference
3	high preference



ObjectID	Value	Count
0	111	27
1	112	25405
2	113	69929
3	121	15205
4	122	70074
5	123	40398
6	131	30009
7	132	24793
8	133	3621
9	211	39
10	212	131591
11	213	121003
12	221	40283
13	222	351609
14	223	71609
15	231	107637
16	232	203070
17	233	7970
18	311	12
19	312	222157
20	313	97945
21	321	25628
22	322	755692
23	323	101776
24	331	47370
25	332	205633
26	333	11976

Figure 2: a) Order of conflict value. b) Conflict matrix.

The generation of the conflict surface is performed by multiplying the first preference by one hundred, the second preference by ten, and the third preference by one (Table 5). The surfaces are then combined using additive sum. Multiplication is not performed according to the importance as a weight but only to generate a two decimal index for identifying the conflict.

Table 5: Conflict score matrix (conservation and urban).

Surface		Urban		
Conservation	Preference	1 (Low)	2 (Medium)	3 (High)
	1 (low)	1 *10 + 1 = 11	12	13
	2 (medium)	2* 10 + 1 = 21	22	23
	3 (high)	31	32	33

There are three conflict classifications in LUCIS. No conflict is when a single land use type has the highest preference value and the other land uses in the conflict value have a lower value(s). Minor conflict is when two land use types have the same preference value and no other land use type has a higher value. Major conflict is when all land use types have the same preference values. Therefore, if you have created a conflict surface for three land use types (i.e., agriculture, conservation, and urban) and the conflict values were arranged as the first, second and third digit, respectively (Figure 2a), in the conflict matrix then if given a conflict value of 113 these specified lands would be highly preferred for urban. Whereas, if given a conflict value of 221 this would be a minor conflict between agriculture and conservation as they both have the same preference for the specified lands and urban prefers the land at a lower value.

LUCIS Allocation

The value of LUCIS is two-tiered. The first tier consists of the process to determine land use conflict. As described above, the process includes 1) determining land use suitability based upon the pre-determined goals and objectives; 2) determining land use preference; and 3) identifying conflict. The second tier illustrates alternative futures through the allocation of population and/or employment.

As stated earlier, the conflict surface is a suitability matrix using the cumulative suitability of the goals within each land use. Early applications of LUCIS allocated people and employment according to a general "urban" category. The development of the conflict surface does not manipulate the original preference values, therefore a conflict surface can also be generated between goals for a more detailed analysis of land use preference. Therefore, allocation of urban uses has evolved from areas generally classified as urban to allocating projected residential populations into areas with high multi-family and single family preference. Future employment is now allocated into areas with high commercial, service, and industrial preference, allowing for specific employment types to be allocated in areas designated for that particular use. Any conflicts that may arise between goals, indicating possible competition of uses, can be resolved using an AHP procedure, panel consensus, or other method as performed in MCDM.

Allocation in LUCIS is multi-dimensional, meaning allocation can occur generally where a given future employment or population figure is satisfied within a given area of urban preference or allocation can occur at variable densities across the landscape in areas with high urban or goal-level preference. The allocation process in LUCIS is flexible and accommodates most land use planning demands.

The MCDA scenario building approach takes different alternatives and calculates the suitability for the model alternatives, which inherits a selection of the more appropriate scenario. However, in the LUCIS structure and the LUCIS allocation procedure, scenario building is performed on multiple levels. The first opportunity is when changing the weights upon combining suitability surfaces for each hierarchical level, which is the same analysis used in MCDA. The second opportunity is in the flexible allocation scenario where the conflict and suitability assignment are used in a combined grid and the population allocation is performed according to priorities specified according to different scenarios. The combine grids join conflict and suitability values and preserve the attributes for these grids in the overlay. The tool is also useful for scenario building and testing of policies.

In the allocation process, Carr & Zwick (2007) identified six general steps to visualize future land use which are:

1. Allocation starts in the area that does not include conflict and where urban preference dominates.
2. Allocation continues if needed in moderate conflict and major conflict, if necessary, where the normal values for urban are highest.
3. Creating a "remaining lands" mask to account for the cells allocated in steps 1 and 2.
4. Allocate remaining cells for future agricultural land where it is not in conflict and the preference is greater than conservation or urban.
5. Allocate remaining cells for future conservation land where it is not in conflict and the preference is greater than agricultural or urban.
6. Allocate remaining cells that are in conflict between agriculture and conservation according to the greater preference.

(Carr and Zwick 2007, 167)

Generally, the LUCIS method accommodates for many of the shortcomings in a traditional MCDM method. For the processes for which MCDM is best known, LUCIS provides a decision analysis framework for land use planners and modelers with knowledge of GIS technologies. Although the role of land use planners is shifting to include more physical and spatial planning analysis skills, LUCIS can facilitate this role change by automating key procedures in the conflict identification and allocation process.

2.2 LUCIS V2 AND LUCISPLUS

The evolution of suitability analysis has required that current methods be "more accurate, legally defensible, technically and ecologically sound, and open to public scrutiny" (Ndubisi 2002, 142). In suitability analysis soundness can be measured through incremental yet significant improvements in available tools and in automation, which also improves validity and reliability. LUCIS Version 2[2] (LUCIS v2) integrates LUCISplus[3], a set of automation tools for the LUCIS method.

[2] LUCIS v2 is an update of the original methods presented in "Smart Land-Use Analysis: The LUCIS Method" by Peggy Carr and Paul Zwick, ESRI Press 2007. Methods for LUCIS v2 will be documented in the upcoming book by Paul Zwick and Iris Patten, ESRI Press 2012 (anticipated).

LUCISplus is composed of four tools for use in the LUCIS model, but can be adapted for any spatial analysis method performed within a GIS environment. These tools have been developed to automate standard processes imperative to developing a LUCIS conflict surface and in the allocation process. The first, the *A4Suitability* tool, is a utility reclassification tool that reclassifies a utility surface according to a reclassification table or according to statistics based on geographic zones (i.e., zonal statistics). The second tool, the *A4Community Values Calculator* integrates pairwise comparison calculations into the ArcMap environment as a VBA program. The third automation tool is the *A4Layer Weighting* tool. This tool uses the output table generated by the A4Community Values Calculator to execute a map overlay.

The fourth and final toolset, the *A4Allocation* tools, is a set of three tools in the LUCISplus toolbox. This toolset allocates population and employment using three different methods. The first method, illustrated in the *Trend Allocation* tool, uses the enumeration rule to maintain the attribute values of a combined grid. The tool then allocates all available land iteratively; land identified by the conditions or constraints defined by suitability values or conflict scores. The second method is executed in the *Allocation by Table* tool. This tool is also described as a planning table or scenario builder. Using the LUCIS conflict value as a condition, the planner enters the condition(s) for an allocation. This tool enables the planner to allocate population and employment for a particular year or for several years simultaneously. The final tool within the A4Allocation Toolset is the *A4Detailed Allocation* tool. The previous tools in the A4Allocation Toolset allow eight masks and/or conditions for allocation. The A4Detailed Allocation Tool is an allocation procedure with up to twelve different masks and/or additional conditions. This tool can also handle iterative procedures. The application of each tool as well

[3] In LUCISplus, the term ‘plus’ stands for “processing land use scenarios”.

as the logic behind the tool functions are demonstrated in the example described in section 3.0 below.

The automated allocation process uses priorities to determine where future urban development should occur. These priorities depend upon growth patterns, proposed densities, transportation masks, etc. Manual allocation, especially across multiple jurisdictions is a complex procedure. The needed accuracy and the time spent in the allocation process necessitates an automated procedure that can perform the allocation in a more reasonable and flexible fashion.

3.0 ILLUSTRATIVE EXAMPLE:

During a graduate level land use course the LUCIS method was used to determine land use suitability for Pima County, Arizona. LUCIS was used to identify growth opportunities for this region. The following section describes the use of the LUCISplus tools in determining future land use patterns for eastern Pima County through the year 2040.

The first step in LUCIS, determining land use suitability, is a systematic assessment of the environment according to three aspects:

- *Impact Variables*: Identifying components of the environment that are important (e.g. water quality)
- *Impact Indicators*: Measures that indicate change in an impact variable (e.g. dissolved oxygen)
- *Impact Thresholds or Standards*: Values of impact indicators above or below which there is a problem; used to evaluate the impact (e.g., 6 ppm minimum of dissolved oxygen)

(Source: Randolph 2004, 613)

Impact Variables are analogous with the LUCIS hierarchical goals, objectives, and sub-objectives. The students modeling Pima County identified statements representing what should be accomplished (goals). The goals and objectives used in modeling were based upon those identified by Carr and Zwick but modified to reflect the ecoregions present across the Sonoran landscape. To measure these goals students then created process models to understand how the landscape operates with respect to two general functions: economic and physical. These process models served as the framework for the sub-objectives.

Students then identified an inventory of available data that best demonstrate the suitability of the feature(s) identified in their process model. For example, to identify soils suitable for row crop production we use a GIS layer that spatially illustrates the location of various types of soils, including attributes relating to soil composition and soil yield. This represents Impact Indicators within the systematic assessment process.

1. **The A4Suitabilty Tool:**

Proximity based indicators of change are probably the most important in land use analysis as they integrate transaction costs in determining land use opportunity. Prior to the introduction of the A4Suitability Tool the planner would take the mean (MEAN), standard deviation (STD), and minimum (MIN) or maximum (MAX) statistics generated from Zonal Statistics to manually calculate the suitability intervals for non-binary classifications. Once the values for each interval were determined these values would be manually input into the Reclassify tool. This method proved to be time consuming, cumbersome, and prone to error.

The A4Suitability tool functions as a standalone tool available within a custom ArcToolbox or can be seamlessly integrated into a model facilitating a continuous automation procedure. Additionally, the A4Suitability tool automatically generates the reclassification table and output raster.

The reclassification table is a listing of the LUCIS suitability index assignments and a count of cells that have been assigned a specific utility value. To determine this utility value, either 1) the average of the mean values for all zones acts as the baseline for suitability and one-quarter standard deviation ranges; or 2) data from a table introduced by the user is used to determine the remap ranges. The user can manually modify the remap table produced by the A4Suitability tool and use the modified table for subsequent model analysis. The A4Suitability tool output raster is based upon the suitability index values listed within the reclassification table.

LUCIS employs two possible suitability index classification value ranges: increasing suitability (ranging from one to nine) or decreasing suitability (ranging from nine to one). Increasing suitability is best described as the further away a feature (i.e. noise sources) is from its objective (i.e. residential development) the more suitable the land. Decreasing suitability is best described as the closer a feature (i.e. roads) is to its objective (i.e. residential development) the more suitable the land. The A4Suitability tool allows the user to indicate the suitability index as decreasing or increasing within the A4Suitability tool interface. If the user chooses the decreasing suitability option, the tool will use the mean and a one-quarter standard deviation to compose ranges that correspond to the suitability index values from nine to one starting with a suitability index of nine for all values up to the MEAN value and decreasing by one-quarter standard deviation increments for eight intervals between the MEAN and MAX value (Figure 3). Since the suitability index one is the last value calculated this value range may be larger or smaller than the other eight suitability index ranges. If the one-quarter standard deviation value is less than the cell size then the suitability index values will be divided into equal intervals between the MEAN and MAX value.

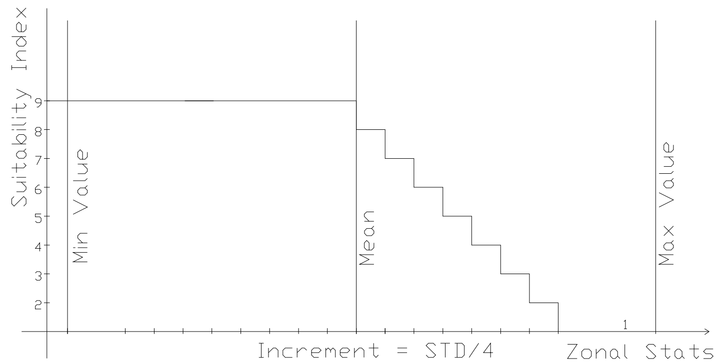


Figure 3: Decreasing suitability indexing.

Increasing suitability is calculated in a similar manner. If the user chooses the increasing suitability option, the tool will prepare suitability index values from one to nine, starting with a suitability index of nine for all values above the MEAN and decreasing by one-quarter standard deviation increments for eight intervals between the MEAN and MIN (Figure 4). Since a suitability index of one is the last value calculated this value range may be larger or smaller than the other eight suitability index ranges. If the one-quarter standard deviation value is less than the cell size then the suitability index values will be divided into equal intervals between the MEAN and MIN.

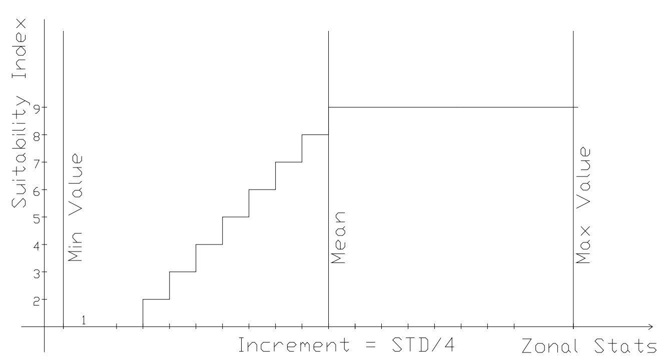


Figure 4: Increasing suitability indexing.

Figure 5 below illustrates the agricultural suitability model for the proximity of row crops to markets. The statistical relationship of existing row crop locations, lu_crops1, and city boundaries, dist_azcitites, is determined using the Zonal Statistics tool. The result of this calculation is illustrated in Figure 6. The A4Suitability tool (Figure 7) is used to measure what could be an increasing transactional cost the further away row crop fields are from the markets to which they sell. This planning concept is measured spatially using the Decreasing Suitability option within the A4Suitability tool. Therefore, distances up to the mean have a high suitability (i.e. low transaction cost) but the further you are from the mean the higher the transaction costs and the suitability of those lands decreases. Figure 8 illustrates the reclassification table listing the values for each suitability interval and Figure 9 illustrates the output raster, both generated by the A4Suitability tool.

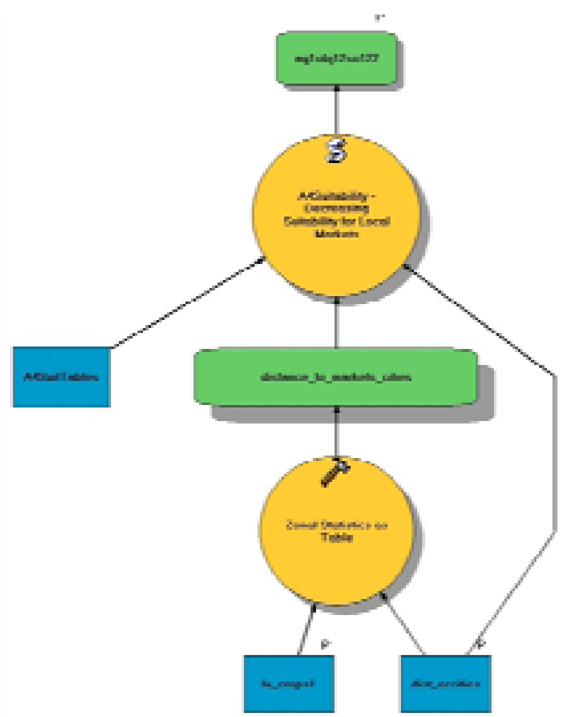


Figure 5: LUCIS Model - Agriculture Stakeholder, Row Crop Goal, Physical Objective, Proximity to Markets Sub-objective.

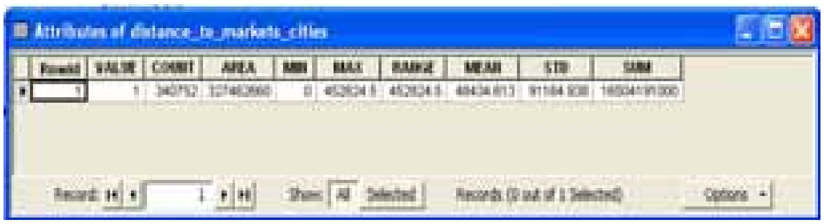


Figure 6: Output table of Zonal Stats tool.

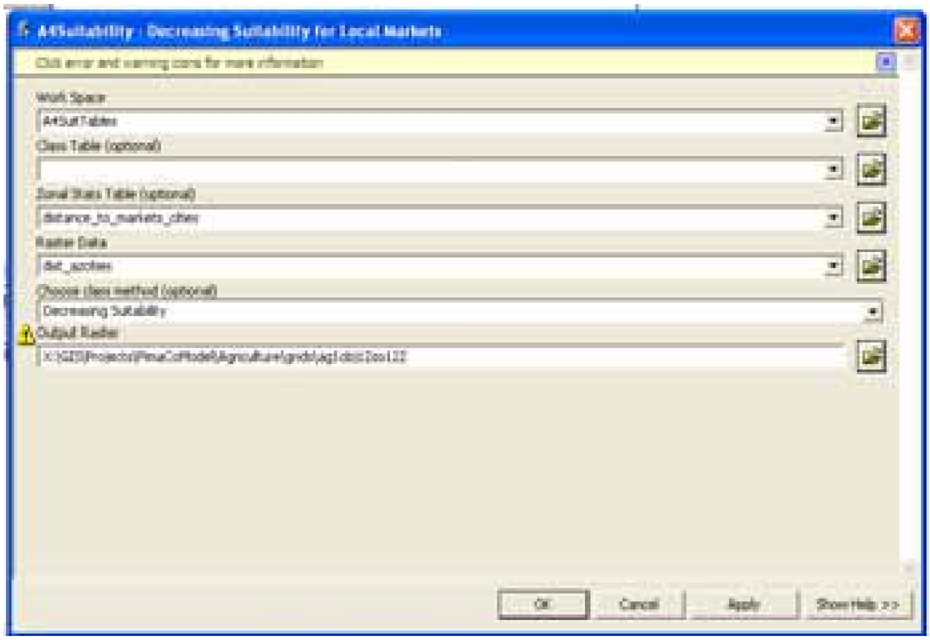


Figure 7: A4Suitability Tool Interface.

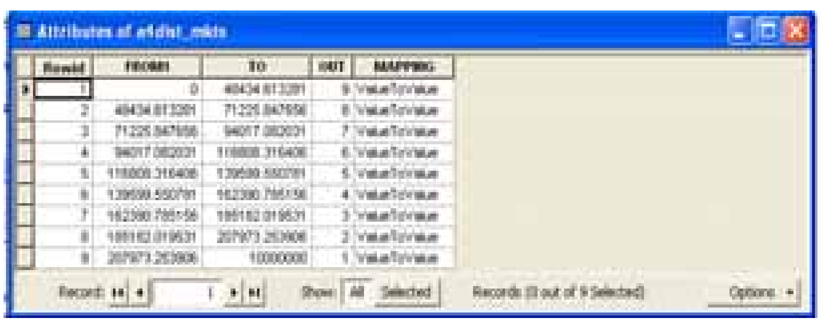


Figure 8: Output table of A4Suitability Tool.

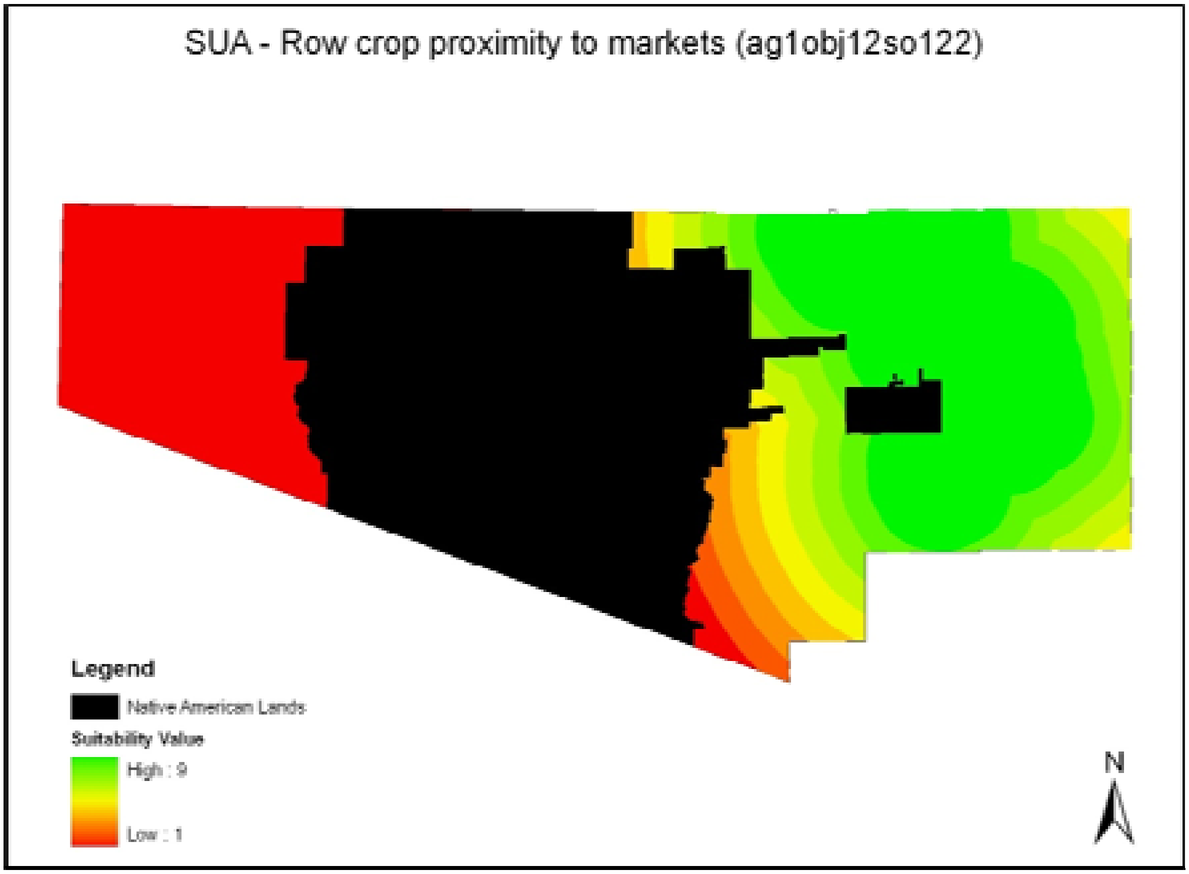


Figure 9: Final row crop proximity SUA.

2. The A4 Community Values Program

The following goals and objectives were used in the Pima County model for the Conservation stakeholder:

Conservation Goals and Objectives – Pima County Model

Goal 1 Native Biodiversity
- **Objective 1.1** Identify lands important for protecting native focal species
  - **Sub-objective 1.1.1** Identify areas important for protecting wide-ranging species & habitats
- **Objective 1.2** Identify areas important for protecting natural communities
- **Objective 1.3** Identify areas important for protecting or restoring intact landscapes

Goal 2 Protection of Water Quality
- **Objective 2.1** Identify areas important for protecting surface water bodies
  - **Sub-objective 2.1.1** Identify all riparian systems, lakes, and ponds as well as special and unique surface water features
  - **Sub-objective 2.1.2** Identify floodplains
  - **Sub-objective 2.1.3** Identify wetlands and wetland buffers
- **Objective 2.2** Identify areas important for protecting groundwater resources
  - **Sub-objective 2.2.1** Identify recharge zones for groundwater
  - **Sub-objective 2.2.2** Identify unconfined aquifers (springs) and sinkholes

Goal 3 Ecological Processes
- **Objective 3.1** Identify land important for the maintenance of the process of flooding and flood storage in the landscape
  - **Sub-objective 3.1.1** Identify lands near wetlands that are more prone to flooding
  - **Sub-objective 3.1.2** Identify areas that are within floodplains
  - **Sub-objective 3.1.3** Identify surface waters and associated buffers of a size sufficient to protect their flood storage function

Goal 4 Enhancing Existing Conservation Areas
- **Objective 4.1** Identify lands proximal to existing conservation lands
- **Objective 4.2** Identify areas of continuous native vegetation most likely to facilitate functional connections between existing conservation lands

Goal 5 Resource Based Recreation

- **Objective 5.1** Identify potential areas used for resource based recreation
  - **Sub-objective 5.1.1** Identify existing and potential trail systems
  - **Sub-objective 5.1.2** Identify cultural and historic sites potentially compatible with outdoor recreation
  - **Sub-objective 5.1.3** Identify areas that provide access to resource based recreation
- **Objective 5.2** Identify all surface water features with the potential for outdoor recreation use
- **Objective 5.3** Identify areas more suitable for wilderness based experiences and hunting

Once the suitability of each objective and/or sub-objective is determined, they are combined according to their hierarchical level using utility values (i.e. weights) that equal 1.0 (100%). The weights at the objective and sub-objective level are citizen-driven; meaning the weights obtained at this level reflect localized knowledge of community values. These weights are obtained from existing plans, community meetings, or focus groups. Often surveys are used to gauge community values. For determining the importance of the future location of growth - exercises such as visioning sessions, which link questions about personal preference for future growth to a solid connection with the landscape through either maps or other visual aids, encourage participants to think realistically about their goals and how to achieve them. Weights at the goal level are derived from experts; individuals or stakeholder groups that understand the combined value of individual processes.

Community values, if existing policy is not used as a guide, can often introduce bias into the larger suitability process. Who defines the assumptions used for suitability weighting results in achieving different ends? "On one end of the gradient is an approach that looks to citizen stakeholder groups to define internally consistent narrative assumptions about how future land [use] will unfold. The citizen-driven approach produces alternative futures that typically have the advantages of integral citizen involvement, greater political plausibility and increased likelihood of institutional acceptance" (Hulse et al 2004, 326). The disadvantage of this approach is that it is difficult to statistically aggregate their preferences into a smaller number of values. According to Hulse et al, "At the other end of the gradient is an expert-driven approach, with experts in the bio-physical and social sciences or planning professions defining a set of decision or transition rules, often with input from other groups, that determine future land [use] conditions. The decision rules are generally constructed to optimize for particular endpoints or illustrate focal policy options (e.g., improved water quality, better wildlife habitat, lower infrastructure costs, less highway congestion, etc.). Alternative futures produced using this approach typically have the advantages of quantifiable statistical likelihood and the disadvantages of unclear political plausibility, which may be due to the encoded decision or transition rules lying outside the political processes actually governing land [use] in the study area" (Hulse et al 2004 326).

To determine the numeric weight, particularly between goals, the A4Community Values Calculator was developed. The A4Community Values Calculator is initiated by installing the program as an ArcMap macro in VBEditor. Based upon pairwise comparison methods, this program blurs the line between planner and land use modeler. A planner with minimal experience in modeling can easily use this program within a GIS environment to complete a values survey among stakeholders. When evaluating the importance between objectives/alternatives the A4Community Values Calculator integrates any number of objective and/or sub-objective raster suitability surfaces as inputs. The A4Community Values Calculator interface prompts the user to specify the usefulness of each pair of raster surfaces and dynamically compares the raster pair. As the user indicates values for each pair, the A4Community Values Calculator automatically populates a pair-wise comparison matrix. The calculator then outputs a parameter table of the raster names and their corresponding relative weights. As a way to reflect community participation, the tool also uses an algorithm to update the weights based on the different pair-wise comparison assignments for a group of people or a panel meeting. The result is a table of weights reflecting group values which is then used as an input for the A4 Layer Weighting Tool, the tool used to create a complex multiple utility assignment (MUA). Although there are many multi-criteria decision support tools available, having this tool available within the GIS saves time, eliminates the expense of purchasing a third-party software package, and reduces error when inputting values from a standalone software package.

For the Pima County project, students were considered the experts. For the conservation land use goals listed above, the goal grids were added to the A4Community Values program in sequential order. Students then identified their value preference between the paired comparisons. The A4Community Values Calculator lists which grids are being compared and the planner selected the importance categories using Saaty's 1 to 9 scale (Table 2). The 2 through 9 values above the 1 indicate that the grid listed at the top of the preference scale is more important to the degree identified by the student. The 2 through 9 values below the 1 indicate that the grid listed at the bottom of preference scale is more important to the degree identified by the student. For example, Figure 10 illustrates the A4Community Values program for the conservation landuse. This particular student is comparing the importance between ecological processes and enhancing existing conservation areas. The student feels that enhancing existing conversation areas is moderately to strongly more important than ecological processes.

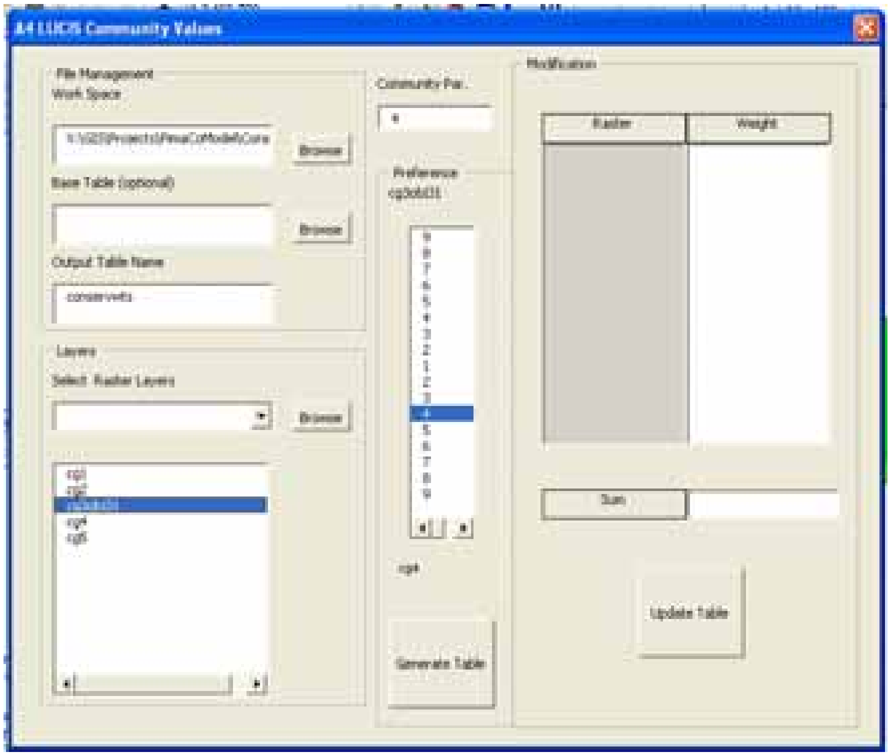


Figure 10: A4LUCIS Community Values interface.

Once the values survey is completed the A4Community Values Calculator generates a table. The values visible in the A4Community Values Calculator interface (Figure 11) are the same as those in the table saved at the location identified in the File Management section of the interface (Figure 12).

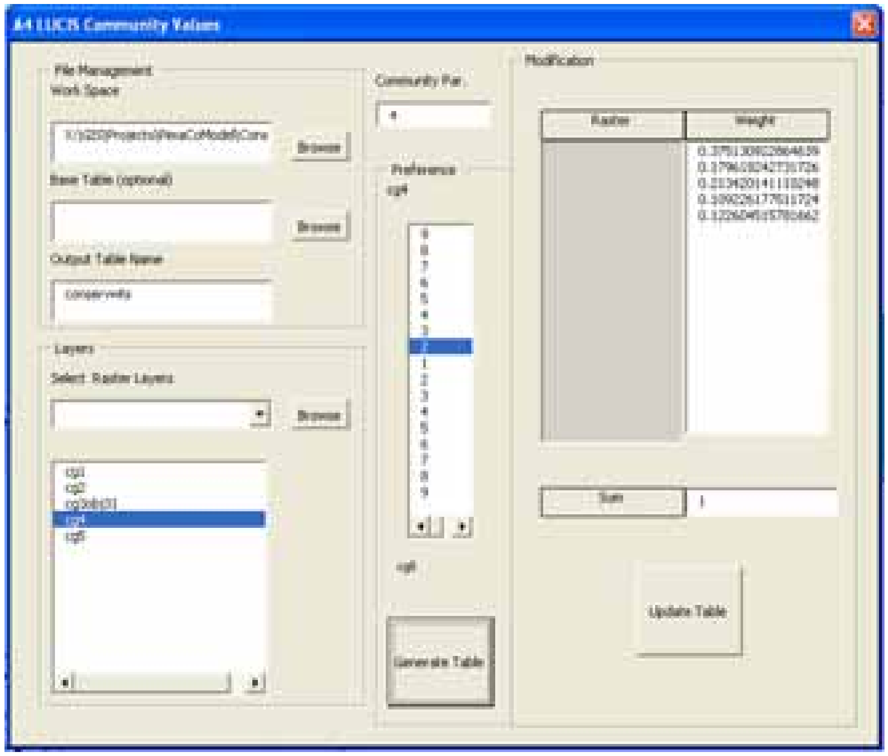


Figure 11: Calculation of the weights for conservation goals.

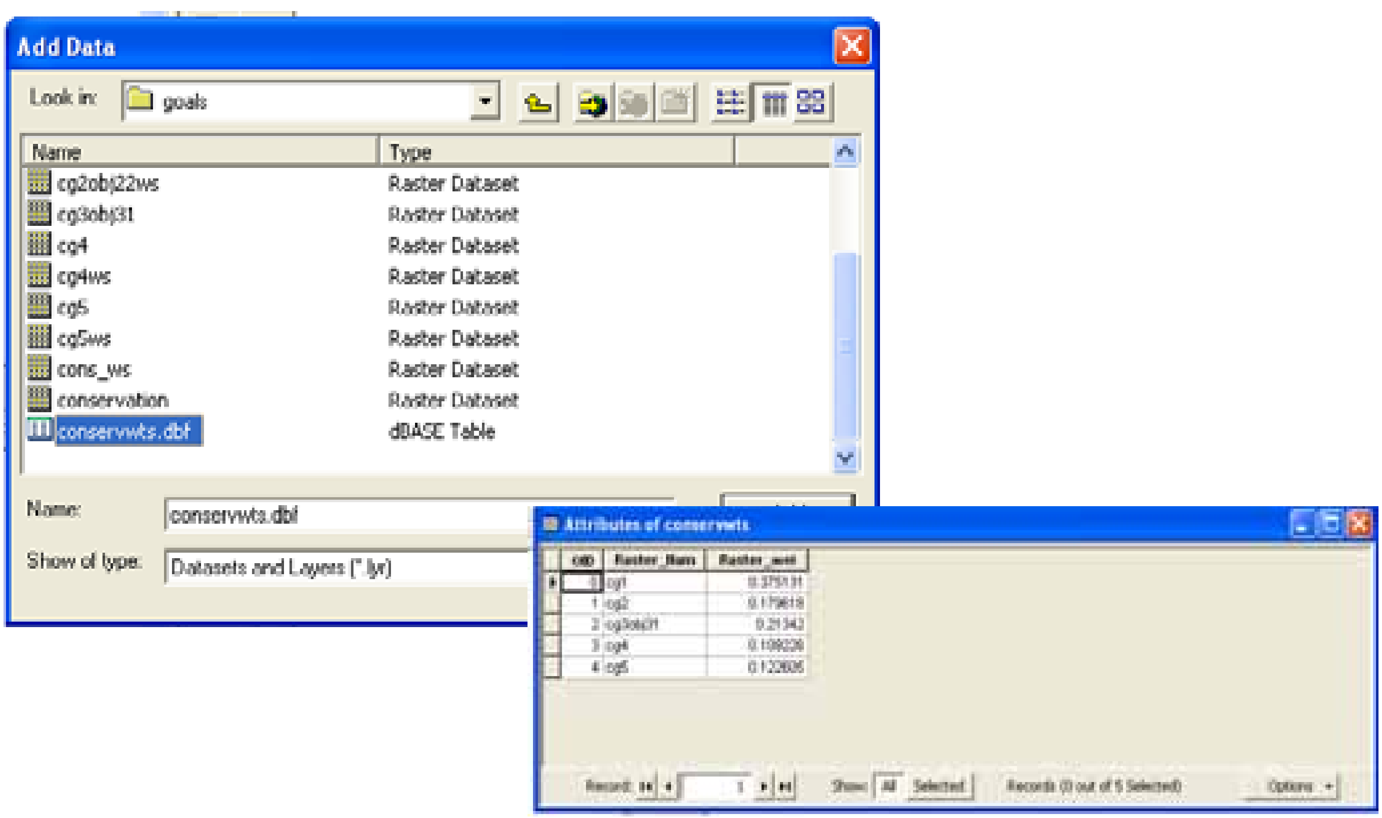


Figure 12: A4Community Values output table listing calculated weights.

3. The A4Layer Weighting Tool

When determining the final suitability for each land use, the degree of interaction between each goal MUA is measured by the weights generated from the A4Community Values program. The A4Layer Weighting Tool is similar to the Weighted Sum tool (Figure 13) available in the Spatial Analyst toolbox. Both tools can multiply multiple raster surfaces (Figure 14) by a specified weight then sum the surfaces together. Instead of manually entering the weights for each goal surface, the A4Layer Weighting Tool uses the parameter table generated from the A4Community Values program or a table of similar structure generated outside the A4Community Values program as an input to the A4Layer Weighting tool (Figures 15 and 16).

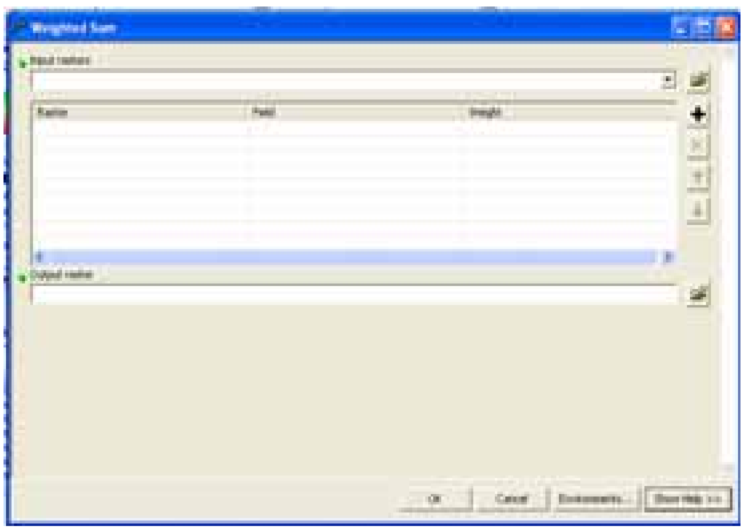


Figure 13: ESRI ArcToolbox Weighted Sum tool.

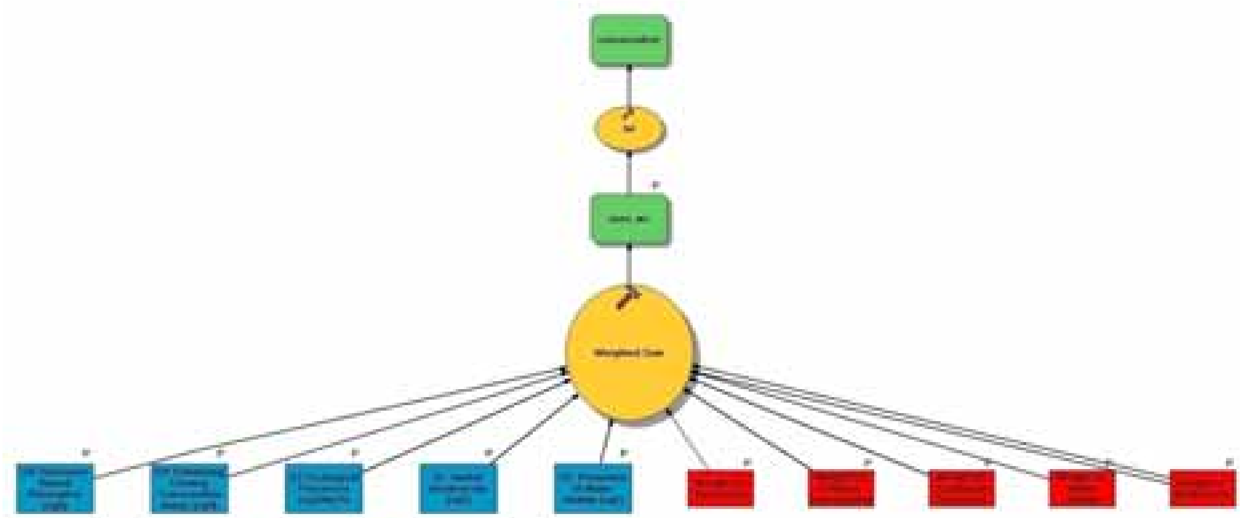


Figure 14: Conservation land use model using Weighted Sum tool.

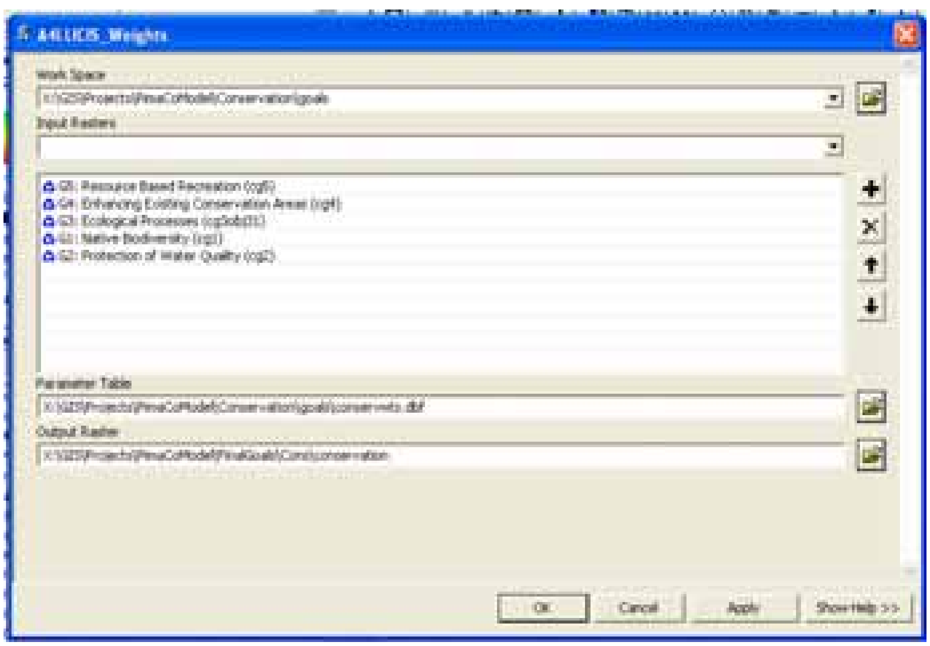


Figure 15: A4Layer Weighting tool interface.

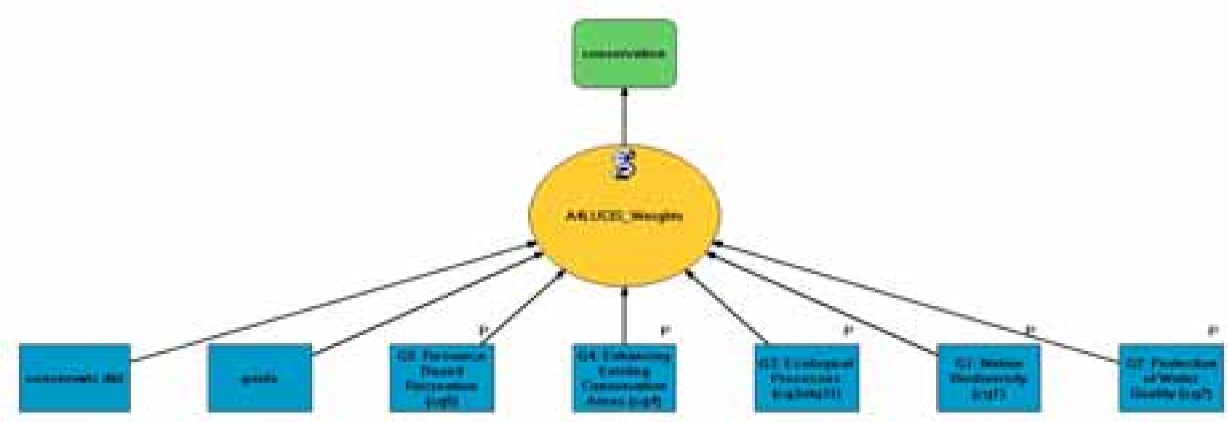


Figure 16: Conservation land use model using A4Layer Weighting tool.

Suitability for land use MUAs (i.e., agriculture, conservation, and urban) are normalized to create preference. In the case of our conservation example, the result is a single raster layer illustrating the final conservation preference. As Carr and Zwick describe, “A subtly but important difference exists between suitability and preference. Rather than asking what is most suitable, to determine preference the question becomes, ‘Which of the contributing suitability criteria are most important?’ (Carr and Zwick 2007, 128)” This importance is measured by the expert weighting process described above. Once a preference surface has been generated, lands restricted from development are removed from the preference grid. In the case of Pima County, these lands included major roads, Native American reservation lands, existing conservation areas, washes, and federal park lands (Figures 17-19).

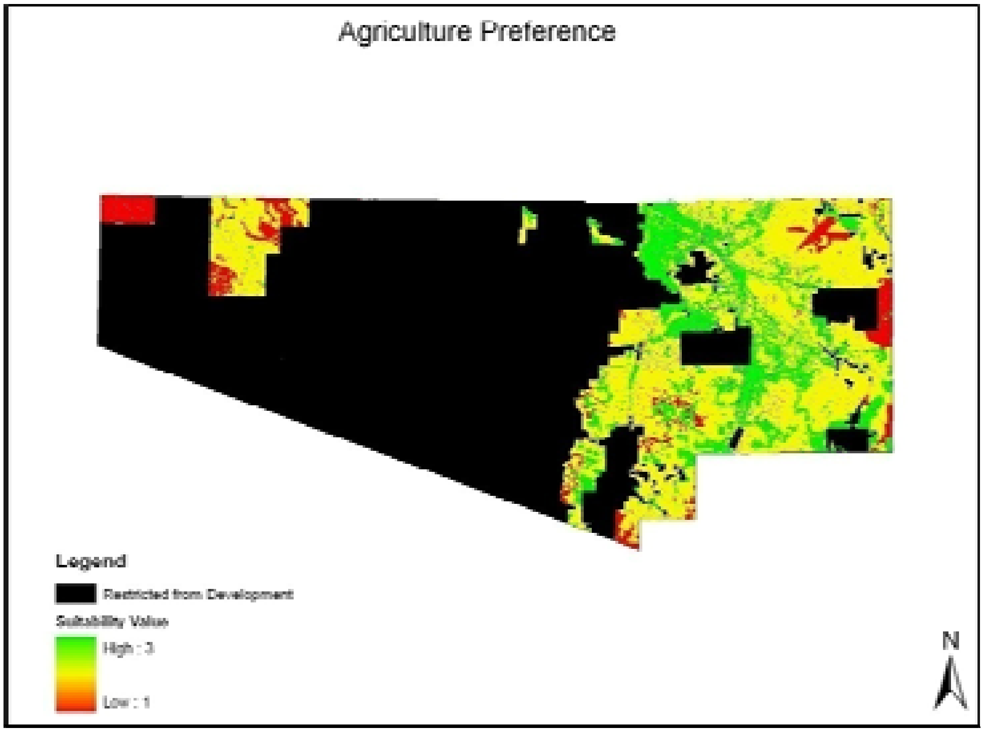


Figure 17: Agriculture preference grid for Pima County, Arizona.

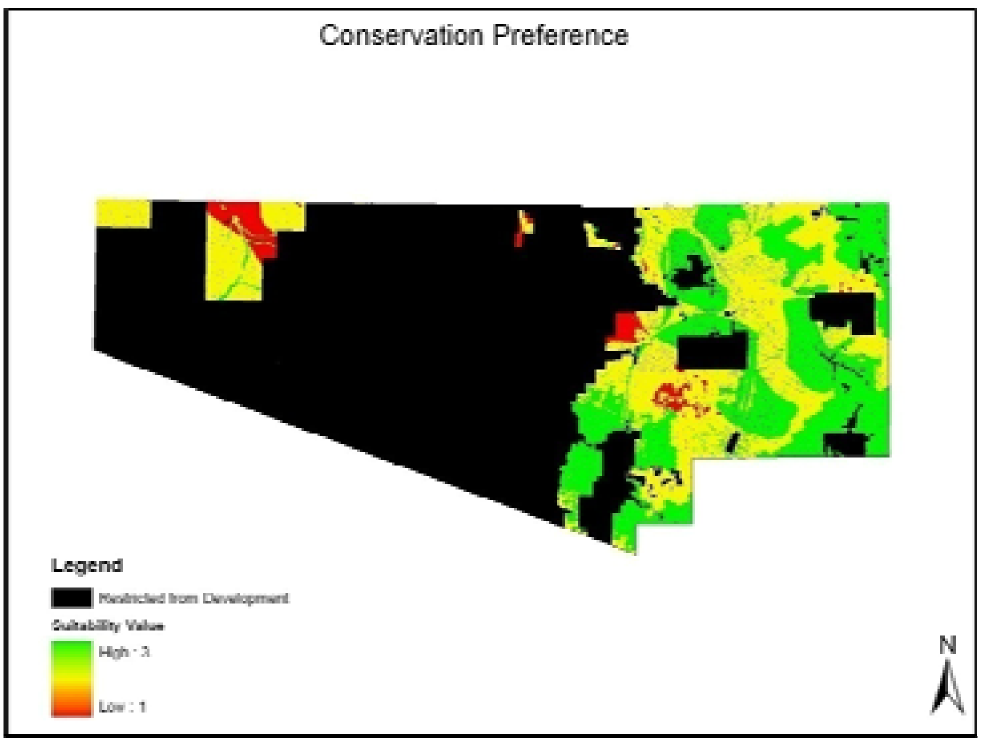


Figure 18: Conservation preference grid for Pima County, Arizona.

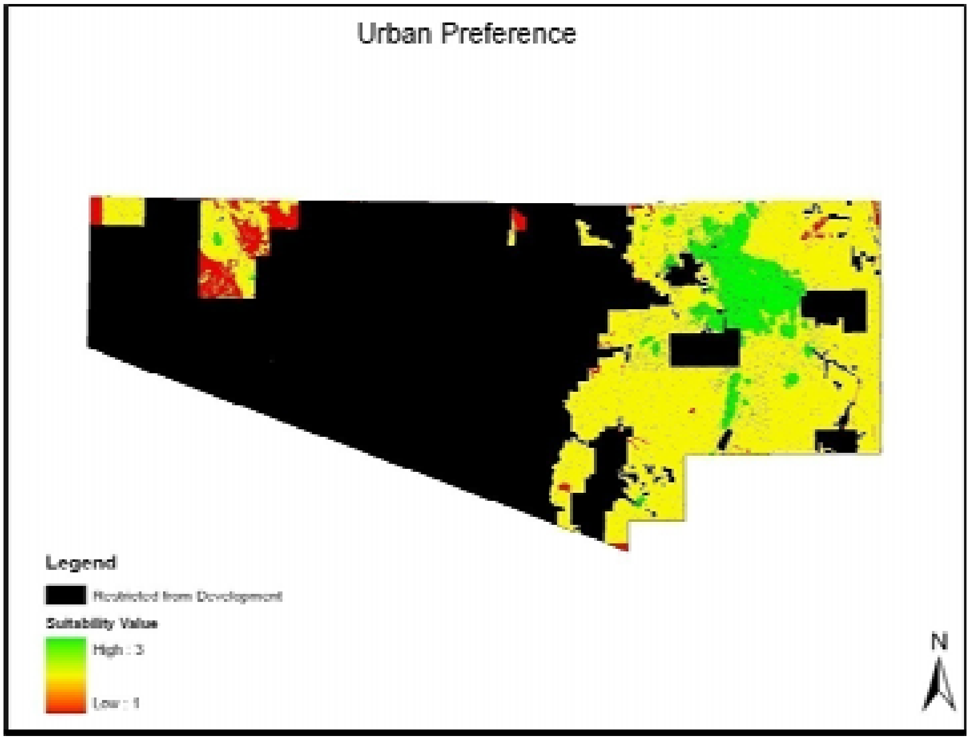


Figure 19: Urban preference grid for Pima County, Arizona.

The weights for overlay can be also taken from trends and policy initiatives. Sometimes the AHP approach and the pairwise comparisons are difficult to apply because the planner is not familiar with the comparison inputs. In this case the weight can be assigned by a trend study or threshold values or by using statistical analysis or regression to capture existing relationships between utility variables.

From the three land use preference surfaces the conflict surface is developed (Figure 20). As described in the methodology section, the three land use grids are combined using map algebra. The attribute table for the conflict surface indicates the land area associated with each conflict value (Figure 21).

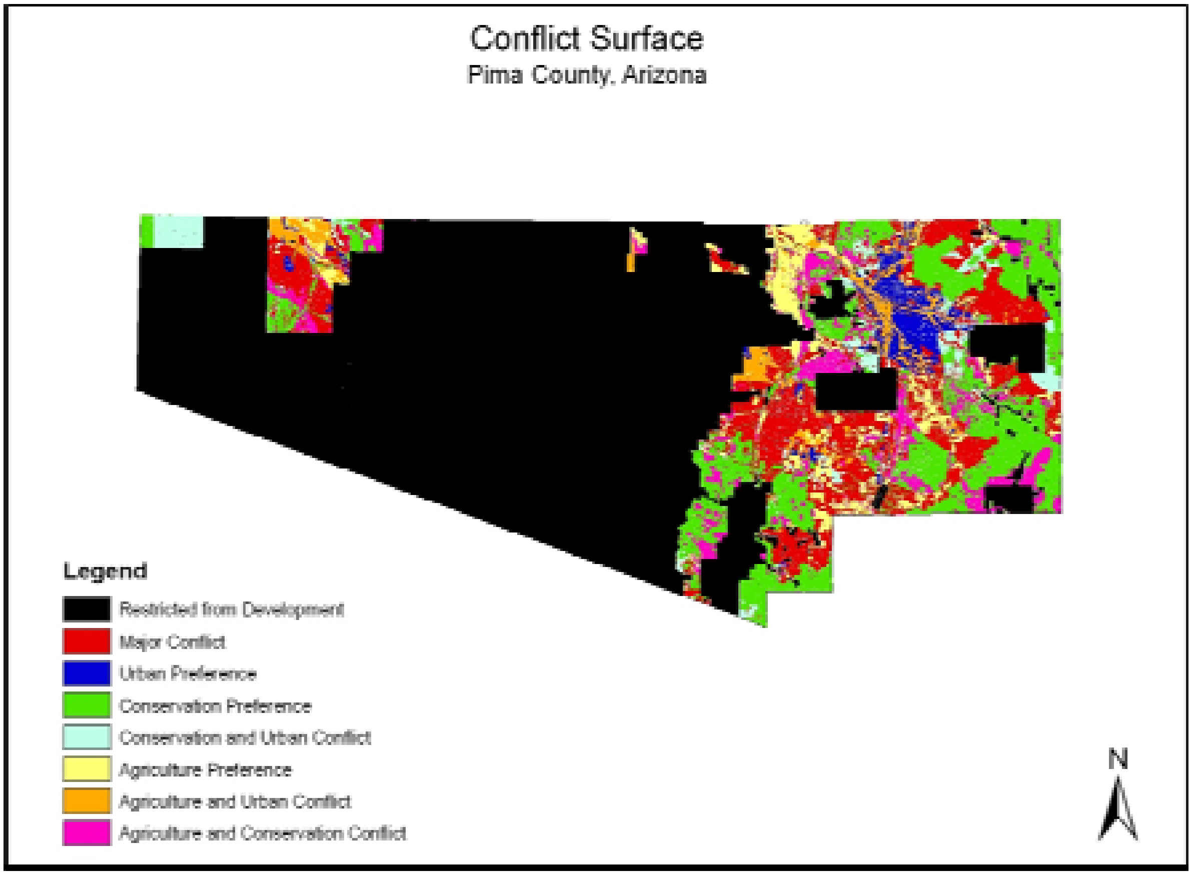
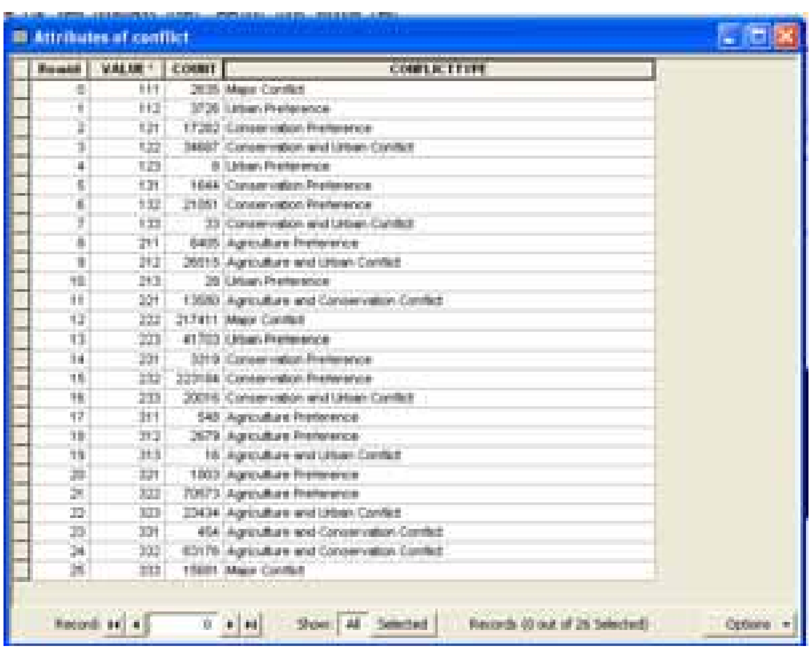


Figure 20: Conflict raster for Pima County, Arizona.



Attributes of conflict

Rowid	VALUE	COUNT	CONFLICTTYPE
0	111	2635	Major Conflict
1	112	3726	Urban Preference
2	121	17282	Conservation Preference
3	122	34697	Conservation and Urban Conflict
4	123	8	Urban Preference
5	131	1644	Conservation Preference
6	132	21051	Conservation Preference
7	133	33	Conservation and Urban Conflict
8	211	6405	Agriculture Preference
9	212	26515	Agriculture and Urban Conflict
10	213	28	Urban Preference
11	221	13580	Agriculture and Conservation Conflict
12	222	217411	Major Conflict
13	223	41703	Urban Preference
14	231	3319	Conservation Preference
15	232	223184	Conservation Preference
16	233	20016	Conservation and Urban Conflict
17	311	548	Agriculture Preference
18	312	2679	Agriculture Preference
19	313	16	Agriculture and Urban Conflict
20	321	1803	Agriculture Preference
21	322	70673	Agriculture Preference
22	323	22434	Agriculture and Urban Conflict
23	331	454	Agriculture and Conservation Conflict
24	332	63176	Agriculture and Conservation Conflict
25	333	15881	Major Conflict

Record: 0 Show: All Selected Records (0 out of 26 Selected) Options

Figure 21: The conflict matrix for the Pima County, Arizona conflict grid.

4. The A4 Allocation Tools

The new allocation procedures in the LUCIS model adopt automation tools for the future allocation of population and employment, scenario building, and testing of policies. There are three main categories associated with the allocation process: infill, redevelopment and Greenfield. Generally, and for our Pima County example, infill is defined as "development that occurs on vacant or abandoned lots, in spaces between buildings, or through the redevelopment of existing lots in an urban area, rather than on previously undeveloped land outside of developed area boundaries" (Housing Virginia 2010[4]). Redevelopment is defined as placing new development on a site with a pre-existing use. The third and last category is Greenfield development. These are lands whose previous use, if any, was agricultural in nature. The tools within the A4Allocation Toolset allocate urban uses within each of these categories.

The first tool in the allocation toolset is the Trend Allocation Tool. Due to the nature of development in and around the Pima County redevelopment doesn't occur at a significant rate. Therefore, the most likely locations of new populations (Table 6) will be in infill and Greenfield areas. The A4Allocation toolset provides tools for an automated allocation of these new urban populations and accommodates for spatial constraints and variable density allocations. The foundation of the allocation tools is a combine table. The combine grid (Figure 22) is prepared by an enumeration rule that combines all of the grids needed in the allocation process while maintaining their attribute values. Table 7 illustrates the basic fields used in the combine grid[5].

[4] http://www.housingvirginia.org/T1.aspx?PID=80#i
[5] The names of the combine grid fields are at the GIS operator's discretion and are subject to change.

Table 6: Population Projections for Pima County, Arizona

Year	Projected Population	New Population	% Change
2010	1,070,723		
2015	1,175,967	105,244	9.8%
2020	1,271,912	95,945	8.2%
2025	1,360,157	88,245	6.9%
2030	1,442,420	82,263	6.0%
2035	1,517,839	75,419	5.2%
2040	1,585,983	68,144	4.5%

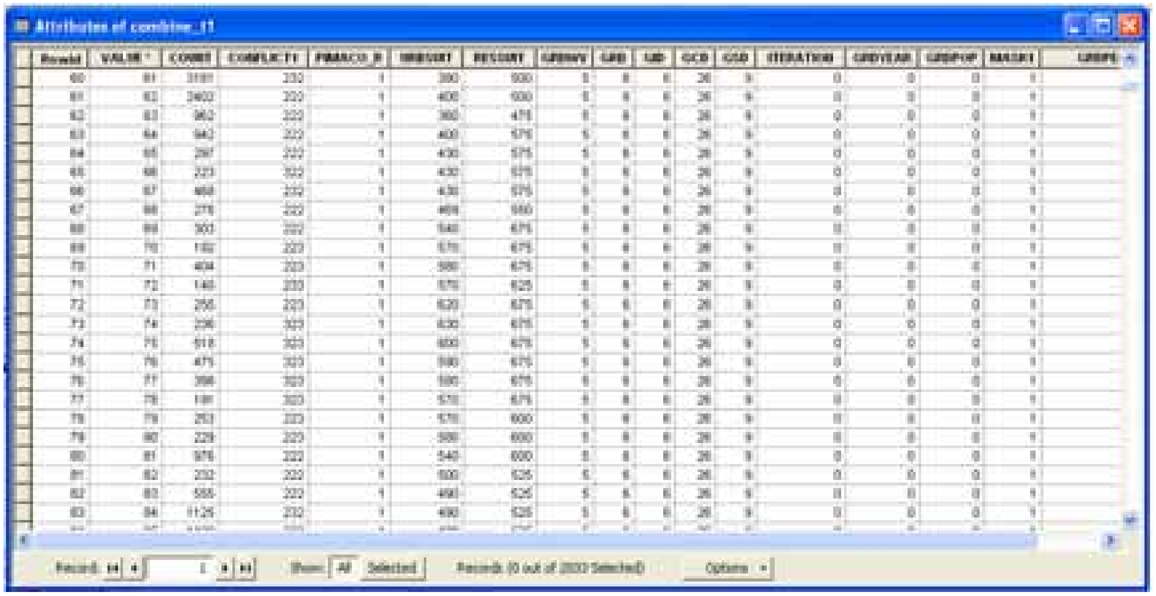


Figure 22: Allocation combine grid for Pima County, Arizona.

Table 7: Combine table field descriptions.

Field Name	Description
GFCONFLICT	Conflict grid
REGION	County number.
VACANT	Anything with land use code 100 or classified as vacant in the property appraiser data. 100 may be vacant residential, 101 may be vacant retail, etc. Values of 0 represent non-vacant land.
URBSUIT	The weighted sum urban suitability grid. Since the field is a float, the grid is multiplied by 100.
RESSUIT	The weighted sum residential suitability grid. Since the field is a float, the grid is multiplied by 100.
GRDWV	Gross residential density with vacant parcels
GRD	Gross residential density without vacant parcels
GID	Gross industrial density
GCD	Gross commercial density
GSD	Gross service density
GRDYEAR	Gross residential density without vacant parcels, year.
GRDWVYEAR	Gross residential density with vacant parcels, year.
GCDYEAR	Gross commercial density parcels, year.
GIDYEAR	Gross industrial density parcels, year.
GSDYEAR	Gross service density parcels, year.
GRTDYEAR	Gross retail density parcels, year.
GRDPEOP	Gross residential density people.
GRDWVPEOP	Gross residential density people, without vacant.
GCDPEOP	Gross commercial density people.
GIDPEOP	Gross industrial density people.
GSDPEOP	Gross service density people.
GRTDPEOP	Gross retail density people.
GUDYEAR	Gross urban density year of allocation.
MASK1	
Iter	Iteration
GRDyearG	

Generally, the allocation logic in the Trend Allocation Tool is as follows:

1. Allocation is prioritized according to the following conditions:

- Land use preference (e.g., urban) according to the conflict surface AND within an allocation area (i.e., Greenfield, infill, redevelopment) mask AND goal suitability value.

Therefore, in Pima County, for the year 2015, which is the first allocation interval, it is expected that there will be an additional 105,244 new residents. The conditions for allocation are:

- There are three iterations of allocations. If conditions in the first iteration don't satisfy the population demand then the conditions of the second iteration are compiled then the third, so on and so forth. The first iteration for Pima County is within areas of urban preference. Urban preference is represented in the conflict grid with values of 112, 123, 213, and 223. The second iteration occurs in areas where there is a conflict between urban and agriculture.
- Since redevelopment isn't a significant issue in Pima County, the allocation area mask is defined as all of Pima County.
- Determining where urban populations will locate can be handled from a gross- or micro-scale. At the gross scale projected populations can be placed in areas suitable for urban development in general, represented by areas of high suitability in the urban land use surface. At the micro-scale projected population can be accommodated specifically in areas appropriate for residential development by applying a condition that refers to the suitability grid of specific goals (i.e., residential, commercial, industrial, etc.).

  For Pima County, a condition was included to find areas that had suitability values over 7 in the residential suitability grid.

A primary concern by planning professionals of land use models is the ability to accommodate new vacant lands and not treat infill as a separate allocation procedure. Both of these issues is addressed in the LUCISplus tools. All of the tools in the A4Allocation Toolset allocate in areas identified as infill, Greenfield, and redevelopment simultaneously. For example, there is a field within the combine grid entitled "Vacant". The values in this field are 100, 200, 300, and 400. The values represent vacant residential, vacant commercial, vacant industrial, and miscellaneous vacant (i.e., state lands), respectively. During allocation, urban populations are distributed according to the conditions specified by the user. After allocation the user can identify lands in which future population and employment have been placed and if the vacant field has a non-zero value then those are lands in which infill will occur.

Generally, the Trend Allocation Tool works as follows:

1. The Trend Allocation tool prompts the user to identify which fields within the combine grid correspond to the conditions and information necessary for allocation. The most important fields (Figure 23) in the interface are the Year Field, the Output Table field, and People Limit. The user specifies the allocation year (Year Field) and the number of new people to be allocated (People Limit). A grid is produced with the distribution of the allocation (Output Table). Within the original combine grid the cells used for each iterative year are identified as well as during what iteration those cells were allocated.

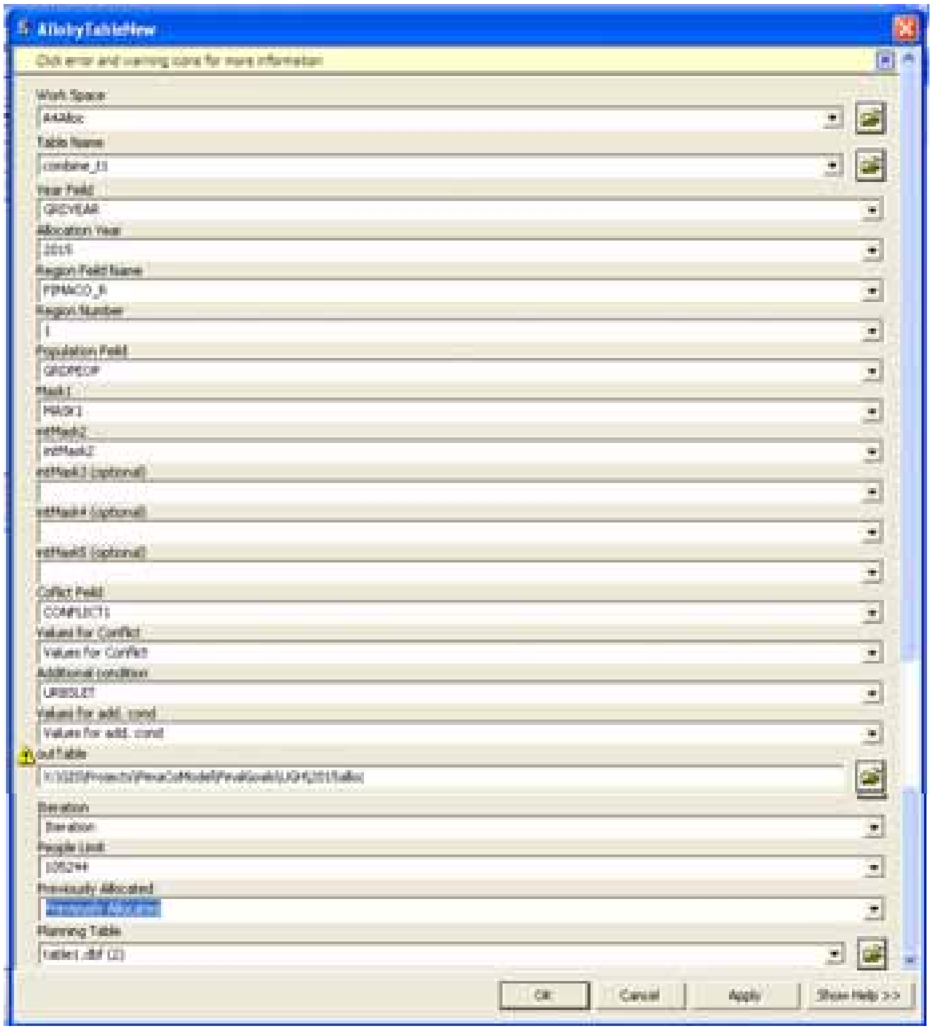
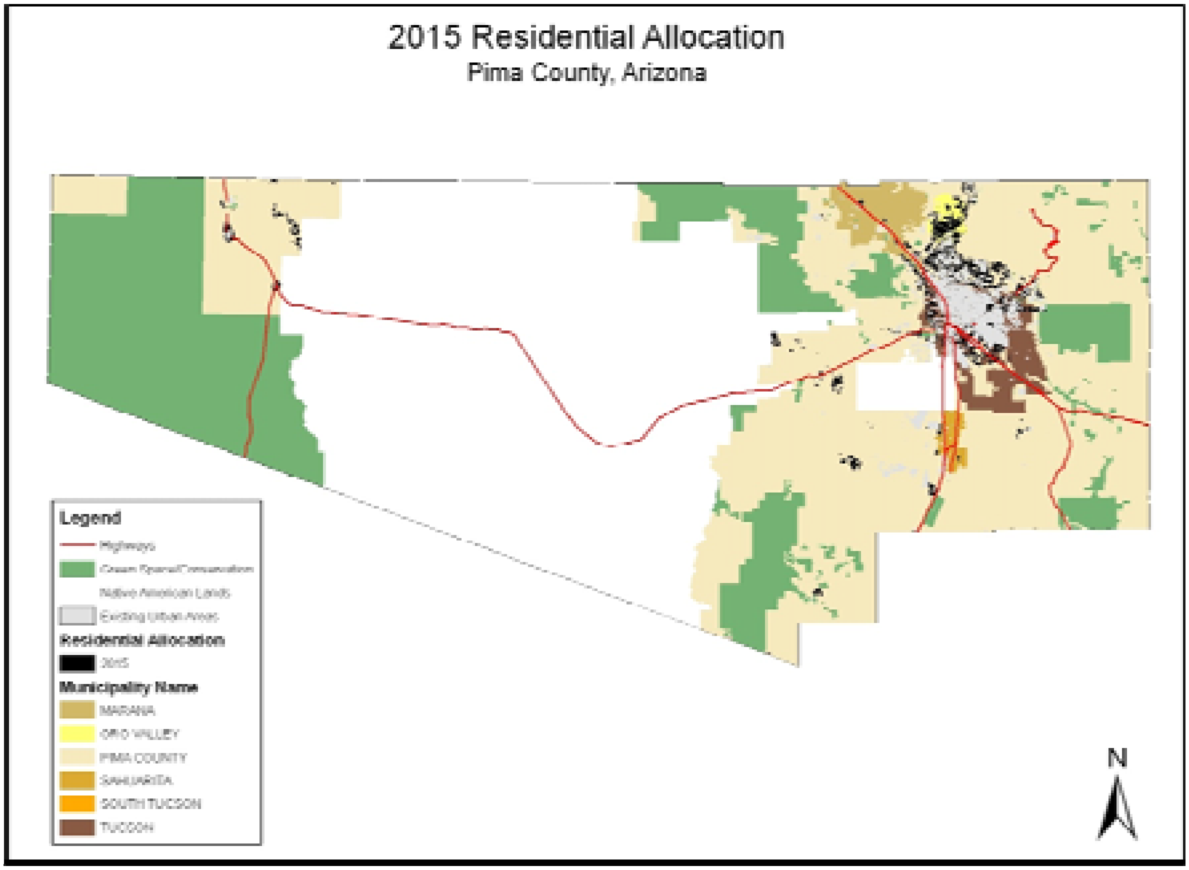


Figure 23: Trend Allocation tool interface.

Urban development is allocated at the densities specified within the combine grid (GRD, GID, GCD, GSD, etc. fields). Pima County has a significant natural resource inventory that includes Organ Pipe Cactus National Monument, Cabreza Prieta National Wildlife Refuge, Saguaro National Park East, and the five mountain ranges that surround Tucson. These lands were included in the mask of lands restricted for development. In addition to these natural resource lands there are almost 2.5 million acres of American Indian reservation, lands also included in the mask of lands restricted for development. Given current development densities

(6 ppl/acre), when the Trend Allocation Tool was executed according to the allocation conditions, lands with urban preference, agriculture and urban conflict, and a substantial amount of agriculture preferred lands were needed to satisfy 2015 population demand.



Several options exist to address the deficit in land available to satisfy the 30 year population demand. First, planners and policy makers can determine whether redevelopment should be considered in Pima County. If maintaining the current density of development is important to Pima County decision makers, they need to determine how far into the conflict matrix they would like to allocate population. Conflict values through agriculture preference were used to accommodate 2015 population demand, is Pima County willing to also allocate population in lands preferred for conservation? The last option is to increase densities.

Therefore, instead of allocating populations at the current density of 6 people/acre in infill and Greenfield areas, additional masks (MASK1 field) can be identified within the tool to allocate at higher or lower densities within designated areas (REGION field). The Trend Allocation tool can accommodate up to eight masks.

The Allocation by Table tool can also be seen as a planning table or a scenario builder where the planner enters the conditions for an allocation depending on each conflict score or on multiple sets of score. Using this tool the planner can perform the allocation for a specified year or for multi-year intervals simultaneously. Figure 24 shows a sample planning table used for an allocation process as well as the Planning by Table Tool interface.

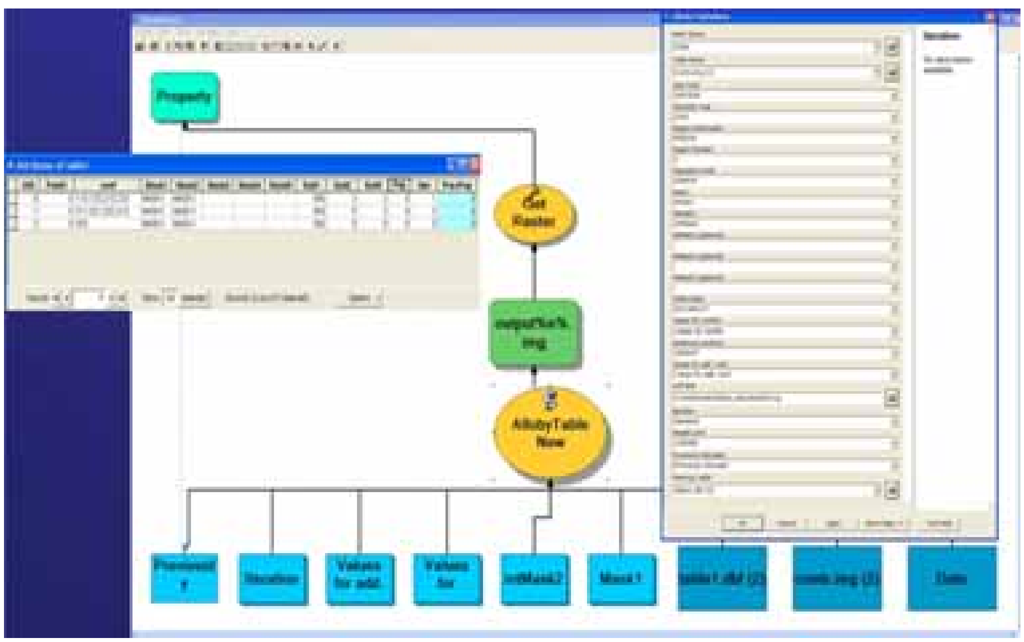


Figure 24: Planning by Table tool

The previous tools work for eight masks and/or conditions for an allocation. A detailed tool is also used in the allocation process. This detailed allocation can work on twelve different masks and/or additional conditions for an allocation procedure and can also be incorporated into a model that has iterative procedures.

4.0 CONCLUSION:

Hobbs et al (1992) state that MCDM techniques facilitate the decision making process by "making the process more explicit, rational, and efficient" (Zhao and Garner 2001, 1). Pairing these techniques with a spatial decision support model serves numerous ends, which include evaluating the importance of land use decisions. Important similarities between MCDM and LUCIS are the way complex problems are given structure in a hierarchical model, and as MCDM has evolved, the interaction between decision-makers and the computer-based system.

LUCIS integrates the four elements of problem solving activities (Malczewski 1999) (data, procedures, goals, and strategies) into a land use problem solving strategy. LUCISplus takes the LUCIS strategy a step further by creating an interactive scenario building environment that is flexible to the constraints of development and growth yet takes advantage of opportunities in the physical planning process. The most important function of the LUCISplus tools is the automation method, allowing land use decisions to be applied to landscapes within minutes. Although this paper has identified several shortcomings of the MCDM method in a spatial environment, when working with a spatial decision support system such as LUCIS MCDM is a very powerful methodology.

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