

# **Tutorial: Using SAGA for Multi-Criteria Evaluation**

Developed by Vern W. Cimmery

May 2016

Updated December 2018

## **1. Overview**

This tutorial explores the application of SAGA functions and tools that support Multi-Criteria Evaluation (MCE), in particular, using Boolean, Weighted Linear Combination (WLC), Analytical Hierarchy Process (AHP) and Ordered Weighted Average (OWA) techniques. The AHP is treated in this tutorial as a variant of WLC, specifically designed for the development of factor weights.

This tutorial does not spend a lot of time analyzing outputs from MCE techniques. The emphasis is on how you can apply SAGA to create the grid maps to support MCE.

The desire for developing this tutorial came from a professional interest in these procedures and several questions submitted to the SAGA GIS User Forum. The scenario loosely follows a 1997 exercise developed by Ron Eastman:

Eastman, J. Ronald. Idrisi for Windows: User's Guide, Version 2.0, January 1997. Clark University, USA. Tutorial Exercises: Multi-Criteria Evaluation – Boolean Analysis, Multi-Criteria Evaluation – Weighted Linear Combination, and Multi-Criteria Evaluation – Ordered Weighted Average.

I have included some technical references at the end of many of the sections. My access to a university research library is very limited. The references listed in this tutorial are easily located on various Internet websites.

The first part of the tutorial describes the scenario involving MCE methods for identifying land areas suitable for residential development. The constraint and factor grid data layers are introduced that provide spatial data for 2 constraints and 6 factors. The hypothetical rationale behind the use of each constraint and factor is described. The preparation of each constraint and factor is described in some detail. At the end of this section a summary is given of the grid maps prior to their application with the three MCE methods.

Each of the three methods of MCE explored in this tutorial, Boolean aggregation, Weighted Linear Combination, and Ordered Weighted Average, is developed and presented in its' own section. The first part of each section describes the requirements the method has for standardizing the data values for the constraint and factor grid maps. Once the input layers have been prepared, a description is provided as to how the method processes the standardized constraints and factors to produce a grid map containing data values describing suitability for residential development. The Analytical Hierarchy Process is introduced as a weight development technique in the discussion of the WLC method.

It is not the purpose of this tutorial to explain how to use the results. The primary purpose of the tutorial is to describe how tools and functions in SAGA can be used to produce suitability grid maps using MCE techniques. The tutorial provides a mixture of how to use tools in SAGA for accomplishing MCE as well as technical information related to the MCE methods.

Here is an alphabetical list of the SAGA tools applied in this tutorial.

*Grid – Analysis/Accumulated Cost*  
*Grid – Analysis/Analytical Hierarchy Process*  
*Grid – Analysis/Ordered Weighted Averaging (OWA)*  
*Grid – Calculus/Fuzzify*  
*Grid – Calculus/Grid Calculator*  
*Grid – Filter/Filter Clumps*  
*Grid – Tools/ Proximity Grid*  
*Grid - Tools/Create Grid System*  
*Grid – Tools/Grid Buffer*  
*Grid - Tools/Grid Masking*  
*Grid - Tools/Reclassify Grid Values*  
*Grid -Gridding/Shapes to Grid*  
*Shapes - Polygons/Polygon Clipping*  
*Shapes - Polygons/Polygon Dissolve*  
*Shapes - Polygons/Polygon Properties*  
*Shapes - Tools/Create New Shapes Layer*  
*Table - Calculus/Field Calculator (Shapes)*  
*Terrain Analysis – Morphometry/Slope, Aspect, Curvature*

The tutorial is developed using the System for Automated Geoscientific Analysis (SAGA), version 2.2.4, 64-bit operating on a laptop. As you go through this tutorial, if you encounter mistakes please let me know. My e-mail contact address is kapcimmery at hotmail dot com.

The following guides may be useful to understanding SAGA and are available in the download section at the SAGA website [sourceforge.net/projects/saga-gis/Files](http://sourceforge.net/projects/saga-gis/Files):

Cimmery, Vern (2010). User Guide for SAGA(Version 2.0.5), Vol. 1. 393 pp.

Cimmery, Vern (2010). User Guide for SAGA(Version 2.0.5), Vol. 2. 336 pp.

Cimmery, Vern (2015). SAGA: Basic Table and Vector Support. 275 pp.

### **Conventions**

Input, output, and option tool parameters are one of two types: mandatory or optional. A parameter including "<<" or ">>" in the field is mandatory and one that includes "<" or ">" is optional. Rather than repeat this information when describing tool parameters I am providing this explanation at the beginning.

Many parameters are what I call "toggle check box" parameters. That is, the value field to their right contains a check box used to toggle between an on and off condition. Move the mouse pointer into the check box and press the left mouse button and it toggles the status of the box between on and off. A check mark in the box indicates, normally, that the parameter is toggled on while the lack of a check mark indicates the parameter is toggled off. Again, rather than repeat this explanation every time a check box parameter is encountered, I will most often indicate that it is a toggle check box type parameter and assume the reader understands how they operate. I may occasionally repeat the explanation as a reminder.

Grid maps are members of a specific grid system defined by a spatial extent and cell size. When a grid map is loaded into a SAGA work session, if the grid system it is a member did not already exist for the session, it is now listed along with any other loaded grid systems. Grid tools generally have a grid system parameter that must be chosen first before a member grid map can be selected for a grid input parameter. In this tutorial, a specific grid system is defined for the project area and referred to as the project area grid system.

A grid map or shapes data layer must be loaded into the current work session in order to be available for use with any SAGA function or tool. Layers can be loaded into a work session as members of a defined project, as part of the most recent work session (selected when a SAGA session is first initiated), or by using the "Load" command in the drop-down list of options for the File option of the Menu Bar.

Many tools are executed using an 'Okay' button that is on of the tool parameters window. Many dialog windows include buttons like 'Okay', 'Yes', and 'No'. You move the mouse pointer over the 'Okay' button and press the left mouse button. The tool then executes using the current parameter settings or returns a response to the GUI. This explanation may not be repeated for every tool description or dialog window. Sometimes I will refer to clicking on the 'Okay' button to execute the tool as a reference to this more detailed procedure. This same convention is true for 'Yes' and 'No' buttons.

The default for mandatory output parameters is often "<create>". The tool produces the expected data layer or table output. The name of the output may follow from the name of the input data layer, a combination of the input data layer name plus the tool process, or from the parameter name, for example "Result" or "Filter". Another option that is often available on the drop-down list is "<not set>". The tool executes but does not produce an output. When an existing data layer is chosen for the output parameter from the drop-down list of options, the output from the tool overwrites the current data values of the chosen data layer for output.

The coordinate system used for the project area of this tutorial is the Washington State Plane Coordinate System, south zone.

Every grid map has a no data value. The most common no data values is -99999 followed

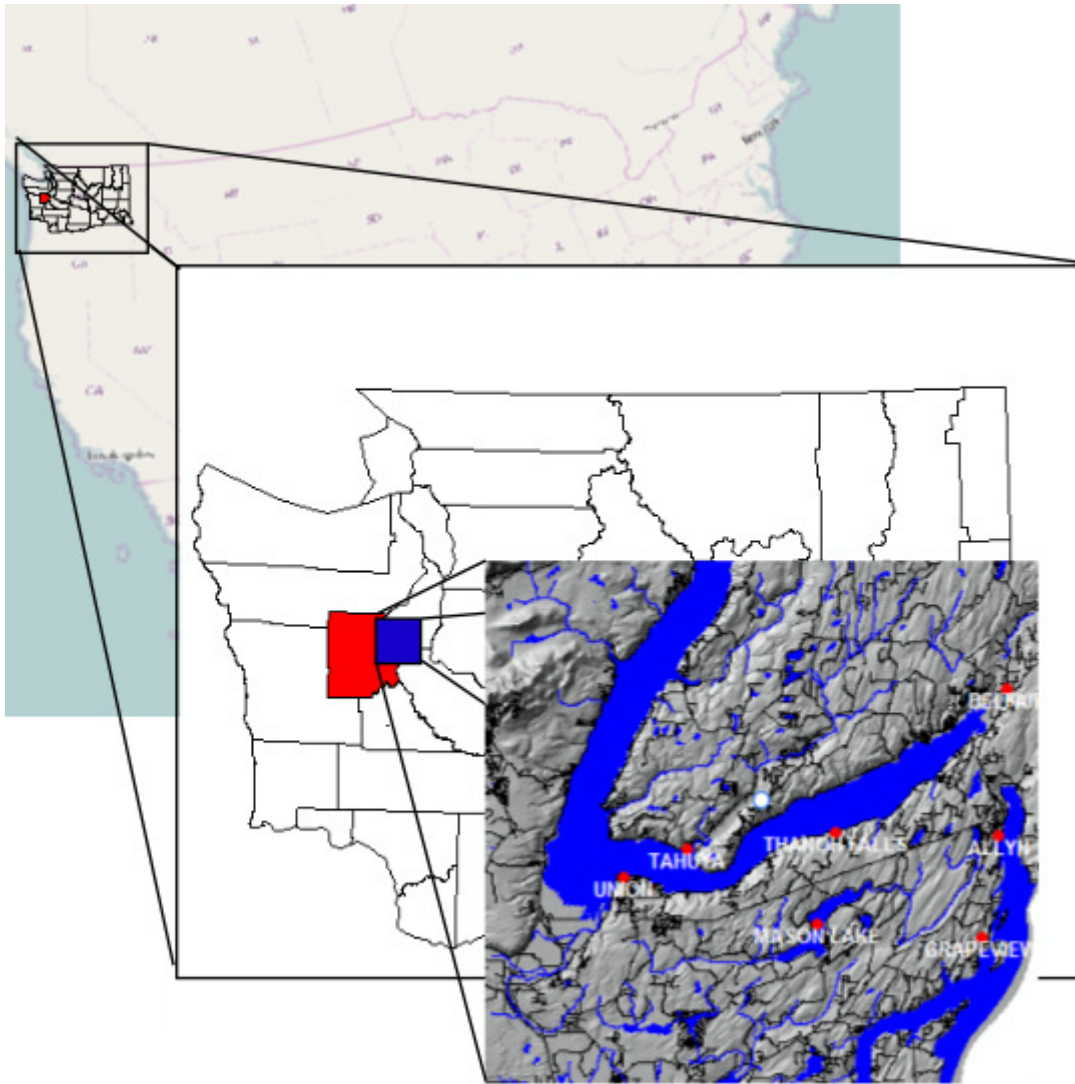
by -1 and 0. Often, grid cells outside of an irregular shaped project area but within the spatial extent contain the no data value. In other cases, the grid cells for features of a grid map, for example, roads, contain valid data values and all non-road grid cells of the map contain the no data value. If you have a question about what the no data value is for a grid map you can display the settings for the grid map in the 'Object Properties' window. Navigate to the 'Data' tab area of the Manager Window and click on the grid map of interest to make it active. The entries for the settings of the active grid map are now displayed in the 'Settings' tab area of the 'Object Properties' window. Near the top of the display, in the "General" section, is a setting named "No Data". The no data value for the grid map displays in the value field to the right of this setting.

The no data value used in a grid map is stored as part of the grid map. When you load the grid map into a work session, the no data value is part of the data included. SAGA tools that create grid map output have a no data value used for the output as part of the tool program. It is possible that depending on a tool option, that one option supports the use of -99999 for an output grid map and another option supports the use of 0 for an output grid map. For example, the 'Output Values' parameter of the *Grid - Gridding/Shapes to Grid* tool supports the 0 no data value for the "data / no data" option and -99999 for the "index number" and "attribute" options.



## II. Background

The objective is to find the most suitable areas for residential development within a project area that includes the south portion of Hood Canal and a portion of Case Inlet (part of the South Puget Sound). This is the general area referred to as North Mason (NM), i.e., North Mason County.



**Figure II-1. Location map for the project area.**

Developers have been pressuring the county commissioners to have land areas that best suit their requirements allocated to residential development. On the other hand, and often in conflict with developer goals, environmental groups would like to see areas preserved for wildlife purposes and not developed. Mason County has some specific regulations already in place that limit the availability of land for development. All these considerations must be incorporated into the decision making process.

This problem fits well into a MCE scenario. The goal is to explore possible suitable areas for residential development for NM: areas that best meet the needs of all groups involved. The county commissioners are working with both developers and environmentalists and together they have identified eight criteria to assist in the decision making process. This is the first step in the MCE, identifying and developing criteria.

### **Defining a Project Area**

The Mason County GIS Department, located in Shelton, Washington, maintains the County ESRI ARC-INFO GIS database. Many of the GIS data layers they maintain can be downloaded from the county website. These layers are the source of much of the data used in this tutorial.

One of the first tasks is to define a project area for NM. The NM project area boundary is used to limit the county-wide data layer coverage to the project area. A project area grid system is defined using a 30-foot grid cell size; i.e., cells are 30 feet on each side.

The map view window in Figure II-2 displays the project area with a topographic relief background (shades of gray), the transportation network (in black), stream drainage (blue), and bodies of water (blue). The towns of Grapeview and Allyn are on the western boundary of Case Inlet. Belfair is located at the head of Hood Canal. Also on Hood Canal you can see Thanoh Falls, Tahuya, and Union. Mason Lake is just below the center of the map view window.

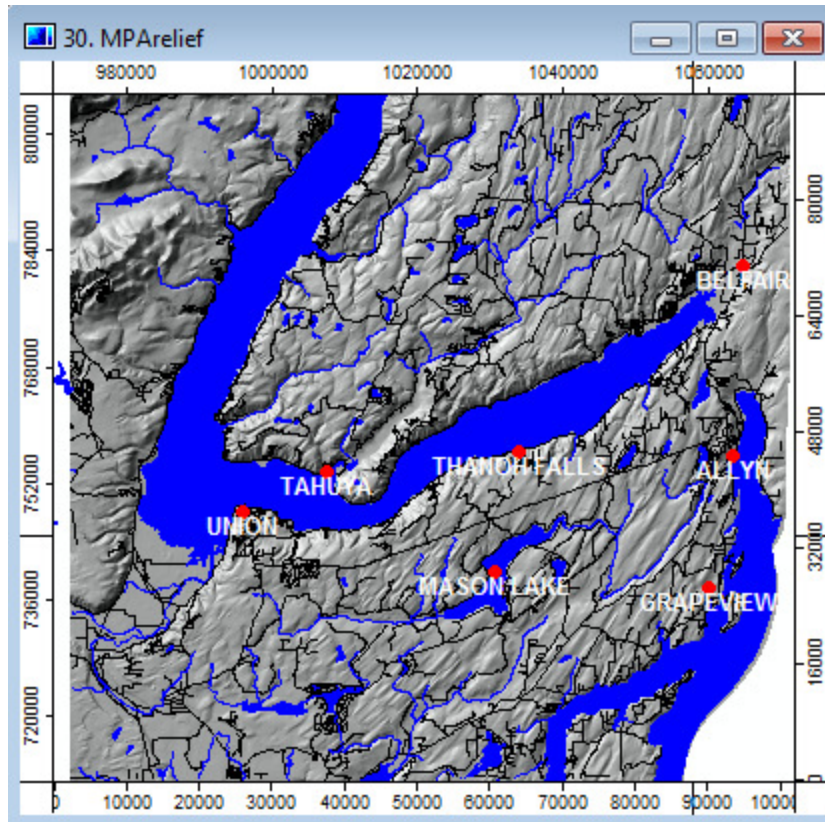


Figure II-2. The tutorial project area.

A polygon shapes data layer for the project area is created by the *Shapes - Tools/Create New Shapes Layer* tool and on-screen digitizing. Figure II-3 displays the parameters window for this tool.

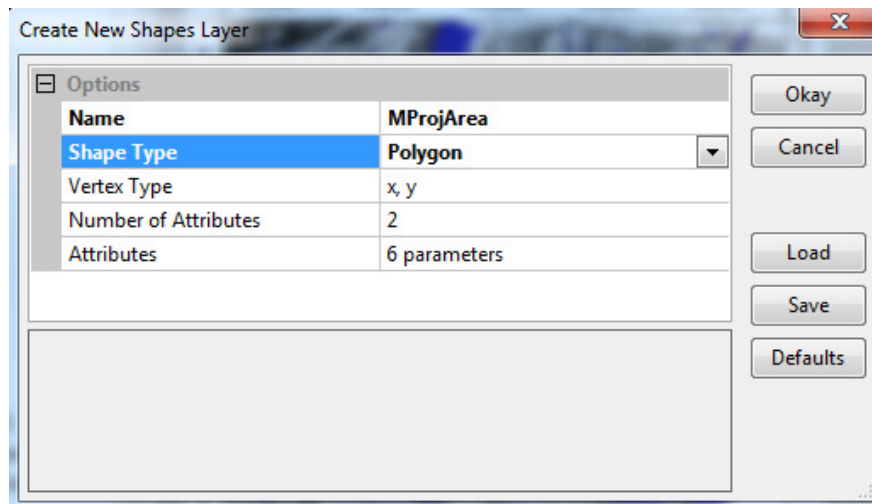

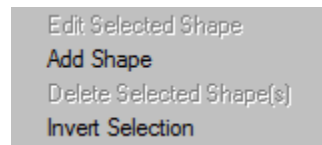


Figure II-3. The *Shapes - Tools/Create New Shapes Layer* tool parameters window.

The name for the new data layer, 'MProjArea', is entered for the 'Name' parameter. There are four choices for the 'Shape Type' parameter: Point, Multipoint, Lines, Polygon. I am creating a polygon shapes data layer so I choose the "Polygon" option. I click the mouse pointer on the 'Okay' button and the tool executes.

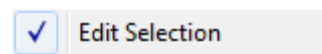
The new data layer 'MProjArea' does not contain any polygon objects. I display the new data layer in the same map view window displayed in Figure II-2. I use on-screen digitizing tools available with shapes data layers to on-screen digitize a polygon object defining the project area boundary starting with the 'Action' tool. First I click with the mouse pointer on the new data layer name 'MProjArea' in the 'Data' tab area of the Manager Window making it the active data layer.

I choose the 'Action' tool (  ) on the toolbar and move the mouse pointer within the map view window. The appearance of the mouse pointer in the map view window looks like a small blue circle with the letter "i" added to the pointer icon. I press the right mouse button and a pop-up list of edit options displays (Figure II-4).



**Figure II-4. Pop-up list of options.**

I choose the second one in the list, "Add Shape". I move the mouse pointer to where I want to start my polygon definition and start defining boundary points by pressing the left mouse button for each boundary point. When I am done defining the polygon boundary, I press the right mouse button to terminate the point digitizing process. I press the right mouse button a second time and the "Edit Selection" option displays (Figure II-5).



**Figure II-5. The "Edit Selection" option.**

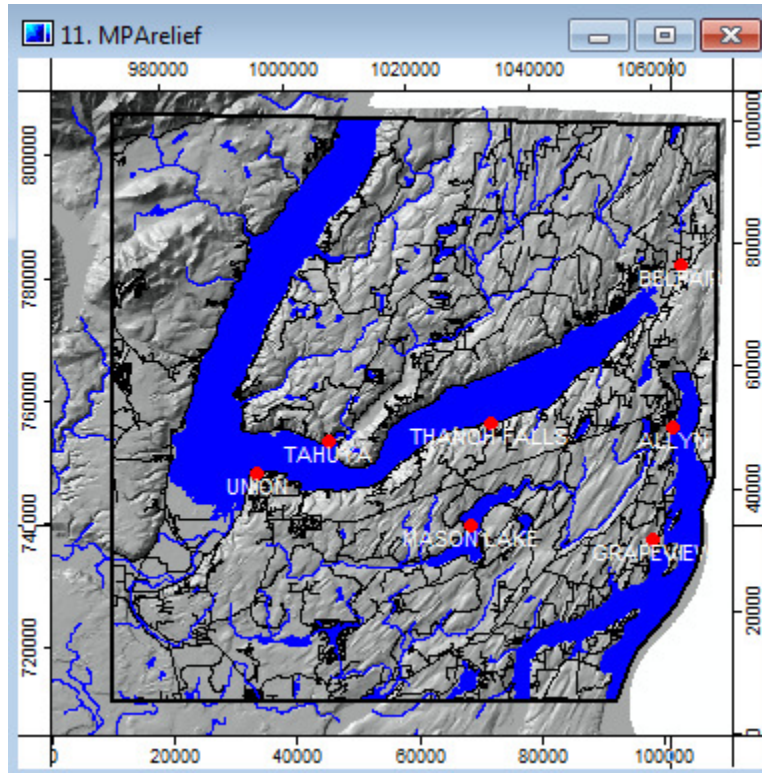
A check mark is displayed to the left of the phrase indicating the option is active. I can press either the left or right mouse buttons and a dialog window displays with the question: "Apply Changes?". There are two choices, selected with the "Yes" or "No" buttons. I choose "Yes" and the object is saved.

At this point, the new polygon object is selected. If I want to make adjustments to the project area boundary polygon I can edit the polygon and re-save it or if I want to add more objects I could start the digitizing process over by right-clicking with the mouse button within the map view window.

The attribute table linked to the new layer contains one attribute. It is named "ID". I open the attribute table in the work area. I go to the 'Data' tab area of the Manager Window and

click on the data layer name 'MProjArea'. A pop-up list of options displays. I position the mouse pointer over the "Attribute" option and choose the "Show" option on the list. The table displays in the work area. I change the 0 that is stored for the "ID" attribute for the one polygon to 1 and re-save the data layer.

The polygon object for the project area displays in Figure II-6.



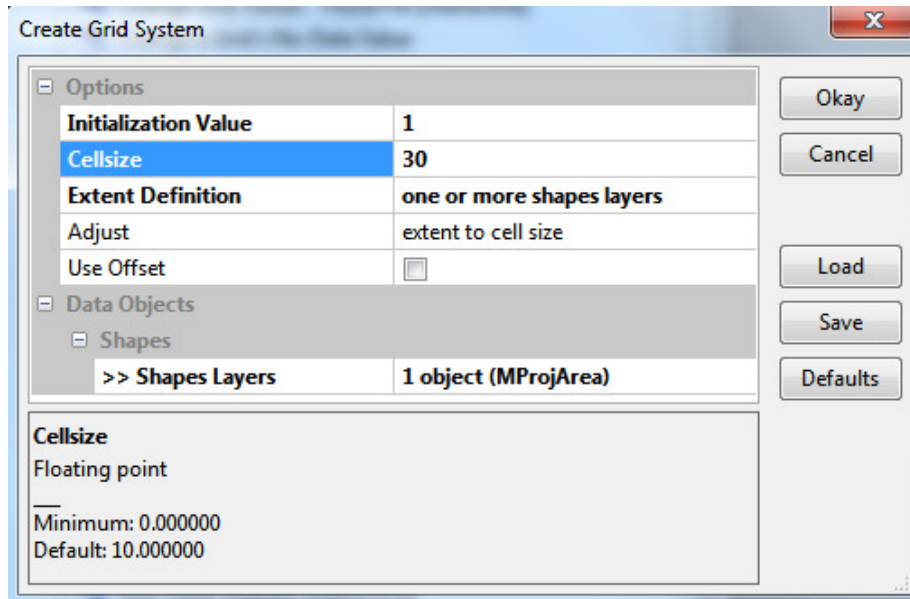
**Figure II-6. The project area polygon.**

The map view windows in Figures II-2 and II-6 are the same with the exception of the 'MProjArea' layer displayed in Figure II-6, the project area boundary (a polygon object) displayed with a heavy black line. Notice that the project area has an irregular shape.

### **Defining a Grid System**

I use the 'MProjArea' polygon shapes data layer to define a grid system for the project area. The *Grid -Gridding/Shapes to Grid* or the *Grid - Tools/Create Grid System* tools can define a new grid system based on the 'MprojArea' polygon shapes data layer. Because the *Grid - Tools/Create Grid System* tool is specifically designed for that purpose it is the tool I use. The parameters window for the tool is displayed in Figure II-7.





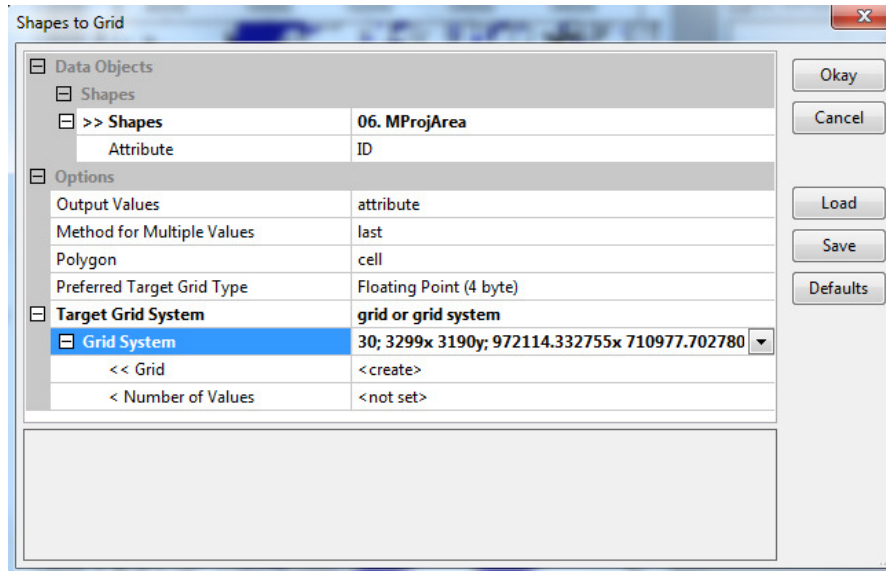
**Figure II-7. The *Grid - Tools/Create Grid System* tool parameters window.**

This tool supports several approaches for creating a new grid system. I choose "one or more shapes layers" for the 'Extent Definition' parameter. I want to base the new grid system on the 'MProjArea' polygon shapes data layer. This option lets me choose the 'MProjArea' polygon shapes data layer for the input parameter '>> Shapes Layers'. The spatial extent of this layer (a rectangle sized to encompass the polygon object defining the project area boundary) is used to define a new grid system. I edit the entry for the 'Initialization Value' from 0 to 1 and for the 'Cellsize' parameter I enter 30 representing a 30 foot square grid cell for the grid system. The new grid system definition is:

30;3299x 3190y; 972114.332755x 710977.70280y.

A dummy grid map is created as a member of the new grid system. The 'Dummy Grid' is listed as the single grid map for the grid system in the 'Data' tab area of the Manager Window. In order to make sure I don't accidentally lose the grid system definition when I exit the work session I save the 'Dummy Grid' grid map, otherwise if I exit the work session without saving any grid map as a member of the grid system I lose the new grid system definition.

I expect to need a grid map of the project area using the *Grid -Gridding/Shapes to Grid* tool to create this grid map. Figure II-8 displays the parameters window for the tool.



**Figure II-8. The parameter entries for the *Grid -Gridding/Shapes to Grid* tool to create a grid map.**

I select the 'MProjArea' polygon shapes data layer for the input parameter '>> Shapes'. The 'MProjArea' data layer contains a single polygon object defining the project area boundary. This shapes data layer has only one attribute in the linked attribute table: "ID". A data value of 1 is entered for the single object.

Three choices are available for the 'Output Values' parameter: data / no data, index number, and attribute. I believe any of the three choices would work although the results may have to be further processed. I notice that the "data / no data" and "index number" choices result in output grid maps that use 0 as the no data value. The "attribute" option produces a grid map using -99999 for the no data value. I am going to use the "attribute" option. Once I choose this option, the 'Attribute' parameter becomes visible and available in the parameters window. I choose the "ID" attribute that is the only attribute in the attribute table linked to the input shapes data layer.

The 'Polygon' parameter has two choices: node or cell. The center of a grid cell is referred to as a "node". If the "node" of a grid cell falls within the polygon object boundary, the grid cell is assigned a data value otherwise it receives a no data value. When the "cell" option is selected, whenever a grid cell falls within a polygon object boundary, the grid cell receives a data value. I use the "cell" option.

There are two choices available for the 'Target Grid System': user defined, grid or grid system. If I choose "user defined" the tool defines a new grid system based on a default set of parameters that can be edited as needed. I choose the "grid or grid system" option because I want to create a project area grid map that is a member of the grid system I created using the *Grid - Tools/Create Grid System* tool earlier. I choose the already existing project area grid system, "30;3299x 3190y; 972114.332755x 710977.70280y ", for the 'Grid System' parameter.

The "<create>" option is used for the output parameter '<< Grid'. I click on the 'Okay' button and the tool executes. The default name for the output grid map is 'MProjArea [ID]'. I re-name it 'MProjAreaGR' and save it to a storage folder.

The 'MProjArea' shapes data layer is used often in this tutorial to "clip" shapes objects of input data layers that fall outside of the project area polygon boundary. For example, the *Shapes - Polygons/Polygon Clipping* tool is applied for this purpose during the development of grid maps for constraints and factors. Also, the 'MProjAreaGR' grid map acts as a masking layer to discard data values in grid cells of grid maps that are within the spatial extent of the grid system but outside of the irregular shape of the project area. Some of the tools used in the tutorial generate data values for all grid cells within the spatial extent of the selected grid system. The *Grid - Tools/Grid Masking* tool is applied using the 'MProjAreaGR' grid map for this purpose in the development of constraint and factor grid maps.

#### References

Mason County Government, Washington. Public Works Department, Geographic Information Systems Department, [www.co.mason.wa.us/gis/index.php](http://www.co.mason.wa.us/gis/index.php)



### **III. Constraints and Factors**

As part of the MCE process for identifying land areas to consider for residential development, county commissioners have focused on three themes of criteria: county regulations that limit where development can occur, financial considerations important to developers, and wildlife concerns important to environmentalists.

County building regulations are constraining criteria that limit areas for residential development. The most significant of these regulations prohibits new development, including residential, from taking place within 180 feet of open water bodies, major streams, or wetlands. This is the first constraint.

The second constraint is that new residential development cannot occur in areas that are already developed. As you will see, this constraint is specific to land use classes characterized as "developed" land use classes versus land use classes considered as not developed.

Having determined these two constraints, the more challenging process for the county commissioners is to identify the factors that describe the relative suitability of remaining areas. These criteria do not absolutely constrain development as the two constraints, but are factors that enhance or detract from the relative suitability of a land area for residential development.

The developers consider four factors that contribute to the cost of building new homes. These factors are current land use type, distance from roads, slope gradient, and distance from city centers. The cost of new development is lower on land that is inexpensive to acquire and clear for housing, nearer to roads and on low slopes. High building costs might be offset by building lots closer to a city center; areas where home buyers are often willing to pay more to purchase due to proximity to urban amenities.

Important factors for the environmentalists are ones that determine the quality of available wildlife habitat for remaining land areas. The environmentalists believe that new residential development should occur away from water bodies, major streams and wetlands and should be as near as possible to existing development.

The above criteria are of two types, constraints and factors. Constraints are those Boolean criteria that, regardless of the MCE method, constrain or limit the analysis to particular geographic areas. In this case, the constraints differentiate areas, that can be considered potentially suitable for residential development versus other areas that are not suitable under any condition.

Factors, however, are different from constraints. Factors define some degree of suitability for all geographic areas. They define areas or alternatives in terms of a continuous measure of suitability and in fact enhance or detract from the alternatives under consideration outside the areas that have been constrained.

Here is the list of constraints and factors.

Open Water and Wetlands Constraint  
Land Use Constraint  
Land Use Factor  
Distance from Roads Factor  
Travel Time from Town Centers Factor  
Slope Factor  
Distance from Water Factor  
Distance from Developed Land Factor

The remainder of this section describes how the initial grid maps representing the constraints and factors are developed in SAGA.

### **The Open Water and Wetlands Constraint**

This first of the two constraints is for the county regulation prohibiting development within 180 feet of water bodies, major streams, and wetlands. Residential development cannot occur in these areas or within 180 feet of these features under any conditions. The grid map for this constraint must include grid cells considered not available that are water body, major stream and wetland features plus grid cells defining a 180 foot protection zone around these features. All other grid cells of this grid map are in the available category.

Here is a summary of how this grid map is created.

There is a polygon shapes data layer named 'MWater' that contains polygon objects for all water areas, ponds, and lakes in Mason County. There is also a line shapes data layer named 'Mmajorstrms6' that has line objects for all major streams in Mason County up to and including streams of Strahler Order 6.

The U.S. Fish and Wildlife Service maintains a National Wetland Inventory mapping system. One of the components of that system is a data layer of all wetlands in Washington state. A similar data layer exists for Mason County named 'MwetlandsAll'. This data layer has 1617 polygon objects for 7 classes of wetlands present in Mason County: estuarine and marine deepwater, estuarine and marine wetland, freshwater emergent wetland, freshwater forested/shrub wetland, freshwater pond, lake and riverine. The wetland inventory map does not include all open waters and streams.

These three county-wide shapes data layers, 'MWater', 'Mmajorstrms6', and 'MwetlandsAll' are the basis of the features for the project area open water and wetlands constraint layer.

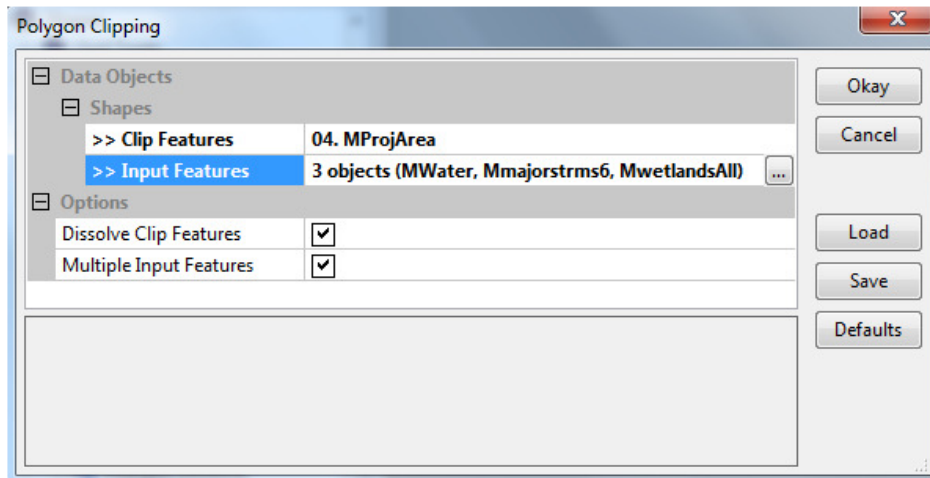
There is spatial overlap between features on these layers. This is not a problem as the last processing step is producing a single constraint grid map of the features. On this grid map any occurrence of a water body, major stream or wetland is considered a feature of the constraint layer.

### Processing Steps for the Open Water and Wetlands Constraint Grid Map

1. Create project area grid maps of the county-wide shapes data layers for water ('MWater'), major streams ('Mmajorstrms6'), and wetlands ('MwetlandsAll').
2. Convert the three project area shapes data layers for water, major streams, and wetlands to grid maps.
3. Combine the three grid maps for water, major streams, and wetlands into a single grid map.
4. Convert the data value range of the single grid map for water, major streams, and wetlands into 1's for features and 0's for non-feature grid cells.
5. Define a 180' buffer zone surrounding water, major streams, and wetlands features.
6. Convert the data range for features and the buffer zone to 1's and all other grid cells to 0's.

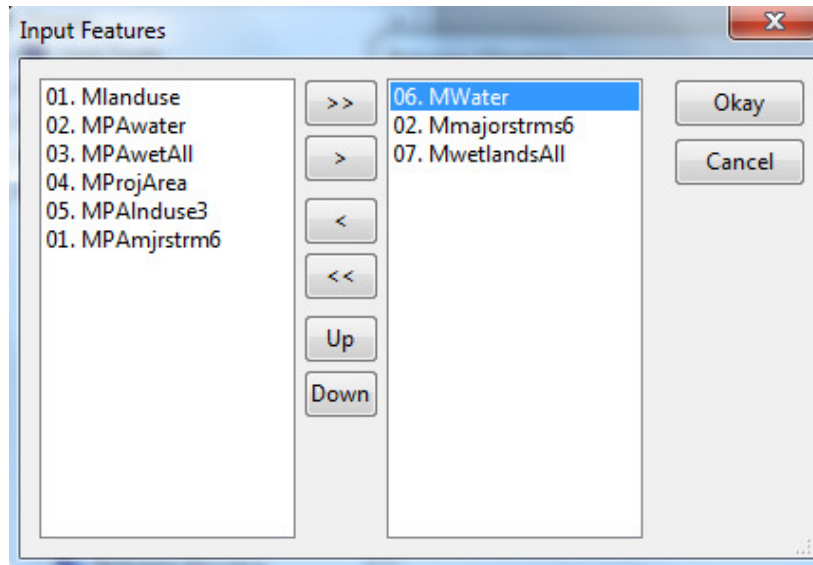
1. Create project area map layers of the county-wide shapes data layers for water ('MWater'), major streams ('Mmajorstrms6'), and wetlands ('MwetlandsAll').

The first step in developing the grid map for this constraint is to create project area data layers from the county-wide shapes data layers for water areas, major streams and wetlands. The *Shapes - Polygons/Polygon Clipping* tool is used to "clip" the three county-wide layers 'MWater', 'Mmajorstrms6' and 'MwetlandsAll' with the project area polygon data layer 'MProjArea'. This step discards data that falls outside of the project area. The *Shapes - Polygons/Polygon Clipping* tool parameters window displays in Figure III-1.



**Figure III-1. The parameters window for the *Shapes - Polygons/Polygon Clipping* tool.**

The project area polygon shapes data layer 'MProjArea' is chosen for the input parameter '>> Clip Features'. This layer contains a single polygon object for the project area. Shapes data layers are selected for the '>> Input Features' parameter by clicking the mouse pointer in the value field to the right of the parameter name and then clicking on the ellipsis that appears. The 'Input Features' window in Figure III-2 displays.



**Figure III-2. The 'Input Features' parameter window.**

The list of shapes data layers on the left is from the 'Data' tab area of the Manager Window. A data layer in the list on the left is chosen by moving the mouse pointer over the name and pressing the left mouse button. The name becomes highlighted. If you move the pointer over another name and press the left mouse button again, the first layer is un-highlighted and the new one is highlighted. You can select and highlight multiple layers by keeping the Ctrl key depressed as you click on your selections.

When one or more data layers are selected, they are moved to the right side of the window by clicking on the button that displays the '>' symbols in the center of the window. You can move layers from the right side back to the left side by selecting and using the '<' symbols button. You can also move data layers back and forth between the two lists by double-clicking with the mouse pointer positioned on the file you want to move. The 'Up' and 'Down' buttons can be used to move layers up or down in the list. The list order for the selected layers is important for some tools, for example the *Grid - Calculus/Grid Calculator* tool, but it is not important for how *Shapes - Polygons/Polygon Clipping* tool executes.

You can see in Figure III-2 that the three layers 'MWater', 'Mmajorstrms6', 'MwetlandsAll' have been selected and moved to the right side panel. I click on the 'Okay' button to return to the tool parameters window.

The default entries for the two toggle box options parameters are accepted. The toggle box parameter 'Dissolve Clip Features' makes a difference if the data layer chosen for the '>> Clip Features' parameter has two or more polygon objects with internal common boundaries. When the option is off, the aggregate coverage of the two or more polygons acts as a cookie cutter on the input features and internal common boundaries define boundaries of intersection on the output data layer. When the option is on, the internal common boundaries do not create new polygons on the output data layer. The 'Multiple

Input Features' toggle box option is automatically turned on (a check mark is in the toggle box) if two or more data layers are entered for the '>> Input Features' input parameter. If this option is turned off, I can only select one data layer for the input parameter '>> Input Features'.

I click on the 'Okay' button and the tool executes, creating three new shapes data layers, one for each of the three layers chosen for the '>> Input Features' parameter. The default names for the output shapes data layers are: 'MWater [clipped]', 'Mmajorstrms6 [clipped]', and 'MwetlandsAll [clipped]'. The three new clipped layers are re-named 'MPAwater', 'MPAmjrstrm6', and 'MPAwetAll' and saved to the project area storage folder.

2. Convert the three project area shapes data layers for water, major streams, and wetlands to grid maps.

This is the first step of three leading to the definition of a buffer zone around water, major streams, and wetlands features. SAGA has several tools that create buffer zones either for features defined on grid maps or for objects of shapes data layers. After exploring the shapes tool *Shapes - Tools/Shapes Buffer* it is decided to use a grid buffer tool. In anticipation of this process, before continuing, the *Grid - Gridding/Shapes to Grid* tool is going to be applied to convert the three new shapes layers to grid maps.

The *Grid - Gridding/Shapes to Grid* tool is executed three times, once for each of the three shapes data layers. In the first execution, the 'MPAwater' polygon shapes data layer is chosen for the input parameter '>> Shapes'. A number of choices are available for the 'Output Values' parameter: data / no data, index number, and attribute.

The three grid map layers created by the *Grid - Gridding/Shapes to Grid* tool are going to be combined into a single grid map using an addition equation with the *Grid - Calculus/Grid Calculator* tool. When this tool processes 1 or more grid maps with a formula, any grid cell of any grid map containing a no data value produces a no data value for the corresponding grid cell of the output grid map. The exception is if the 'Use NoData' parameter is turned on. If this parameter is turned on, a no data value is treated by the tool as if it is a valid data value by the formula.

The "data / no data" and "index number" choices for *Shapes to Grid* tool result in output grid maps using 0 as the no data value. This means that if the 'Use NoData' parameter is turned on as a *Grid Calculator* tool parameter, the formula would use these 0 values to produce a valid grid cell output. The "attribute" option uses -99999 as the output no data value. If -99999 was used as a valid data value through the 'Use NoData' parameter, the results would not be acceptable even though the output values are valid.

The "data/no data" option is going to be used. This means that where data exist on the input shapes data layer the tool outputs a data value of 1 for the grid cells. Grid cells with no data are coded with the no data value 0.

The 'Polygon' parameter has two choices: node or cell. The center of a grid cell is referred to as a "node". If the "node" of a grid cell falls within the polygon object boundary, the grid cell is assigned a data value otherwise it receives a no data value. When the "cell" option is selected, whenever a grid cell falls within a polygon object boundary, the grid cell receives a data value. I use the "cell" option.

There are two choices for the 'Target Grid System': user defined, grid or grid system. If the "user defined" option is used, the tool defines a new grid system based on a default set of parameters. The "grid or grid system" option is used so that the project area grid system can be selected. The intent is that the new grid map be a part of the project area grid system created using the *Grid - Tools/Create Grid System* tool. I choose the existing project area grid system, "30;3299x 3190y; 972114.332755x 710977.70280y ", for the 'Grid System' parameter.

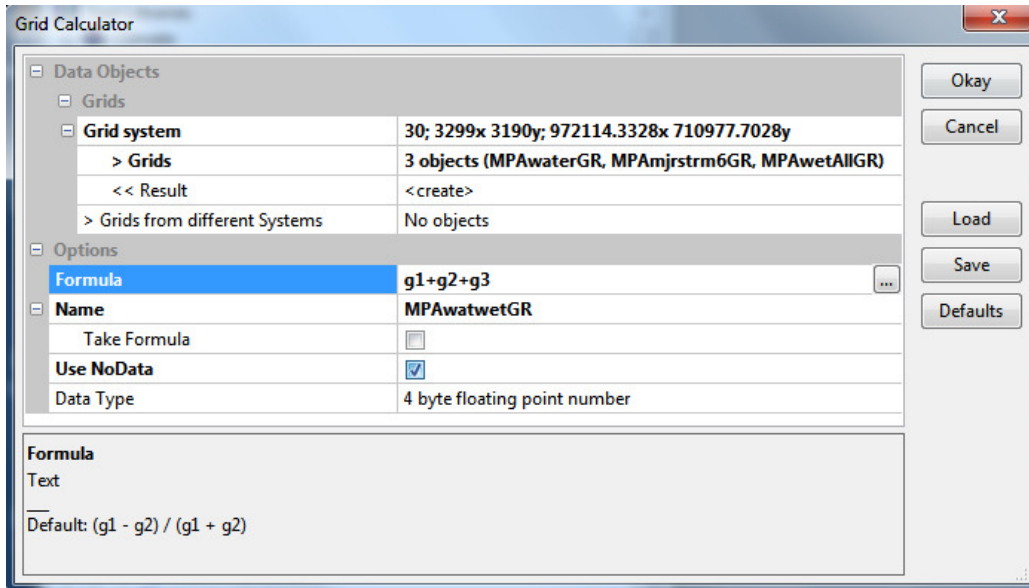
The "<create>" option is used for the output parameter '<< Grid'. I click on the 'Okay' button and the tool executes. The default name for the output grid data layer is 'MPAwater [ID]'. I re-name it to 'MPAwaterGR' and save it.

The *Grid - Gridding/Shapes to Grid* tool is executed two more times, once for the line shapes data layer 'MPAmjrstrm6' and the second time for the 'MPAwetlandsAll' data layer. The three new grid maps are named 'MPAwaterGR', 'MPAmjrstrm6GR', and 'MPAwetallGR' and all are saved. The water-related features on each grid map are coded with 1's. All non-water grid cells contain the no data data value 0.

3. Combine the three grid maps for water, major streams, and wetlands into a single grid map.

This step adds (combines) the three grid map layers for water, major streams and wetlands into a single grid map. The data values on the output grid map will be 0, 1, 2, and 3. If the same grid cell on each of the three input grid maps is a feature grid cell, the corresponding grid cell of the output grid map contains a 3. If only two of the three grid cells of the input grid maps are feature grid cells, the output grid maps contains a 2, and so on. When no feature exists for the grid cell on any of the three grid maps, the output to the corresponding grid cell on the output layer is 0. This is because the 'Use NoData' parameter is turned on for the tool execution. Turning on this option means the "0" no data value is treated as a valid data value by the formula. "0" is used as the no data value for each of the three input grid maps.

The parameters window for the *Grid – Calculus/Grid Calculator* tool displays in Figure III-3.



**Figure III-3. The *Grid – Calculus/*Grid Calculator tool parameters that create the ‘MPAwatwetGR’ grid map.**

The 'MPAwaterGR', 'MPAmjrstrm6GR' and 'MPAwetAllGR' grid maps are entered for the input parameter '> Grids'. The data values on each of these three layers are 1's and the no data value for each is 0.

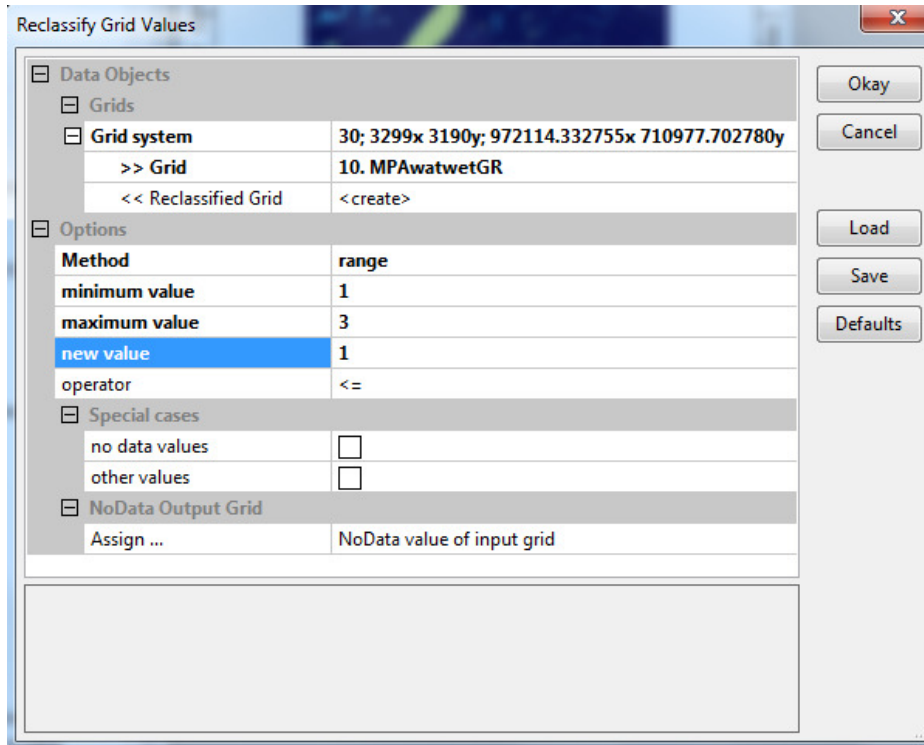
The entry for the 'Formula' parameter is "g1+g2+g3", a simple layer addition equation. The references are variables that refer to each of the three input layers in the order they are listed. The default entry "<create>" is used for the output parameter '<< Result'. The output grid map is named 'MPAwatwetGR'. This name is entered for the 'Name' parameter. I click on the 'Okay' button and the tool executes. The output grid map as named 'MPAwatwetGR' and saved.

The data values on the 'MPAwatwetGR' grid map are 0, 1, 2 and 3. The *Grid – Calculus/*Grid Calculator tool uses -99999 for no data values on grid maps produced.

4. Convert the data value range of the single grid map for water bodies, major streams, and wetlands into 1's for features and 0's for non-feature grid cells.

The 'MPAwatwetGR' grid map has data values of 0, 1, 2, and 3. The data values 1, 2, and 3 identify three different features (water bodies, major streams, and wetlands) of the grid map. The goal is for all features to be coded with the data value 1. Grid cells containing the data value 0 are non-features.

The *Grid - Tools/Reclassify Grid Values* tool is used to recode data values 2 and 3 to 1's. The new grid map has two valid data values: 1 and 0. The parameters window is displayed in Figure III-4 for the *Grid - Tools/Reclassify Grid Values* tool.



**Figure III-4. Parameters for reclassifying the 'MPAwatwetGR' grid map to create the 'MPAwatwetRcGR' grid map.**

The project area grid system "30; 3299x 3190y; 972114.332755x 710977.702780y" is chosen for the 'Grid system' parameter. The 'MPAwatwetGR' grid map, produced by the *Grid – Calculus/Grid Calculator* tool, is chosen for the input parameter '>> Grid'. The default "<create>" option is accepted for the output parameter '<< Reclassified Grid'.

There are several options for the 'Method' parameter depending on recoding needs. The need is to recode a data range 1, 2, 3 to 1 so the "range" option is chosen for the 'Method' parameter. A 1 is entered for the 'minimum value' parameter and 3 for the 'maximum value' parameter. The new value 1 is entered for the 'new value' parameter. Less than or equal, "<=", is chosen for the operator. The name used for the default output grid map is the same name as the input layer with "\_reclassified" added as a suffix. The tool is executed using the parameters in the parameters window in Figure III-4.

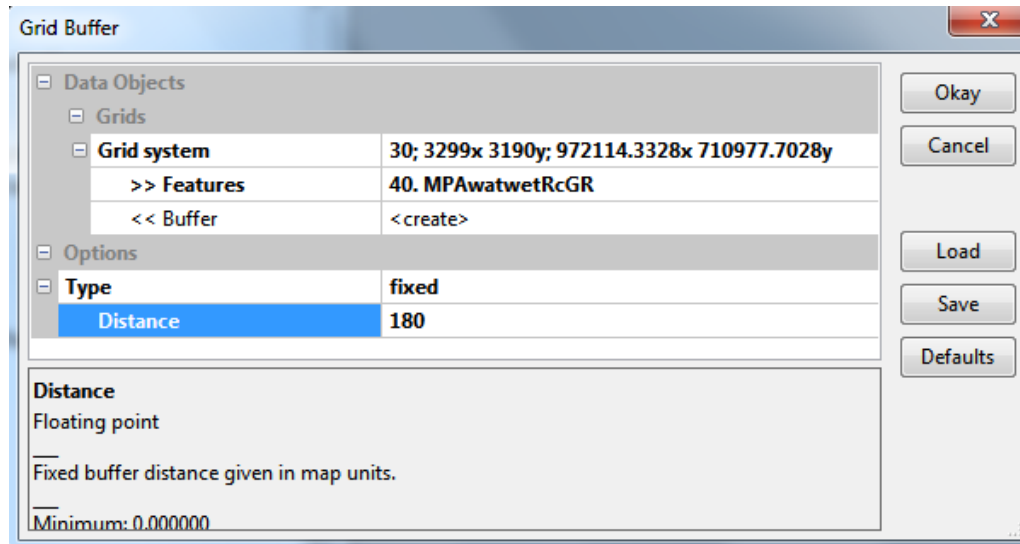
I rename the output grid map 'MPAwatwetRcGR' and save it.

5. Define a 180' buffer zone surrounding water bodies, major streams, and wetlands features.

The protected area zone is a 180-foot buffer surrounding each feature. The *Grid – Tools/Grid Buffer* tool is used to define this buffer zone around the features of the 'MPAwatwetRcGR' grid map.



The parameters window for the *Grid – Tools/Grid Buffer* tool is displayed in Figure III-5.



**Figure III-5. The *Grid – Tools/Grid Buffer* tool parameters window.**

The 'MPAwatwetRcGR' grid map is chosen for the '>> Features Grid' input parameter. The "<create>" option is selected for the output parameter '<< Buffer Grid'. There are two options for the 'Buffer Distance' parameter: Fixed or Cell. The "Fixed" option is used. When this option is used, the entry for the 'Distance' parameter defines the buffer width. A value of 180 (feet) for the buffer width is entered in the value field to the right of the 'Distance' parameter. When the "Cell" option is chosen the value you enter is for the number of cells wide for the output buffer.

The output from this tool is a grid map containing water bodies, major streams and wetlands features (grid cells) coded with the data value 2. Surrounding each feature cell or group of feature cells is a buffer zone, 180' wide (6 grid cells wide) coded with the data value 1.

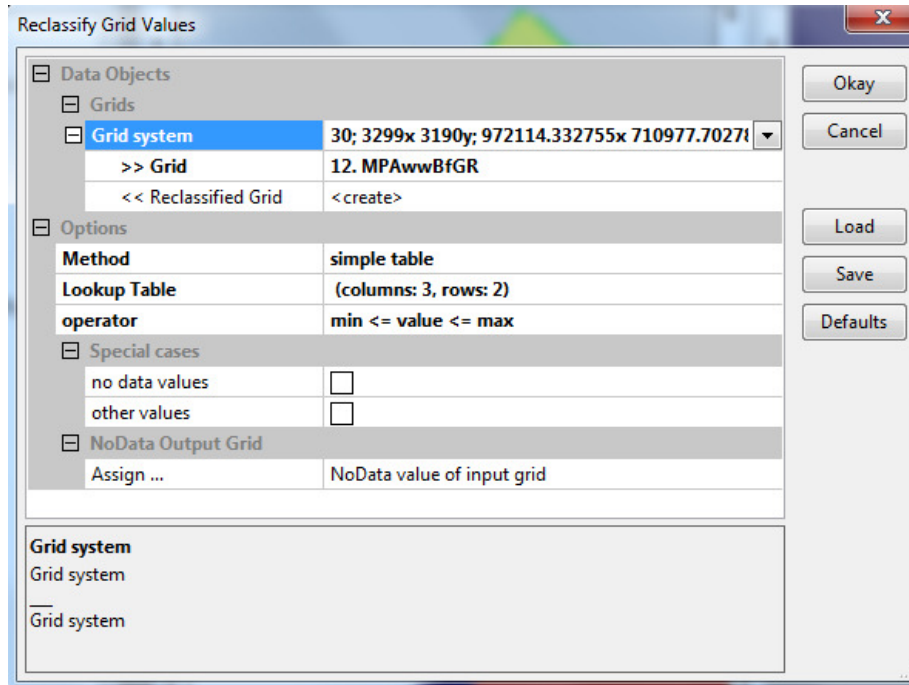
I click on the 'Okay' button and the tool executes. The default name for the output grid map is 'Buffer Grid'. It is re-named 'MPAwBfGR' and saved.

6. Convert the data range for features and the buffer zone to 1's and all other grid cells to 0's.

On the 'MPAwBfGR' grid map, unavailable areas are represented by the feature grid cells and the buffer grid cells surrounding the feature grid cells. Buffer grid cells contain 1's and feature grid cells contain 2's. All other grid cells contain 0's. The requirement is that grid cells for available areas contain 1's and grid cells in not available areas contain 0's. Thus, the values on the 'MPAwBfGR' need to be recoded so that grid cells containing 1's and 2's contain the data value 0 (representing areas not available) and grid cells containing 0's contain 1's (representing areas available). The *Grid –*

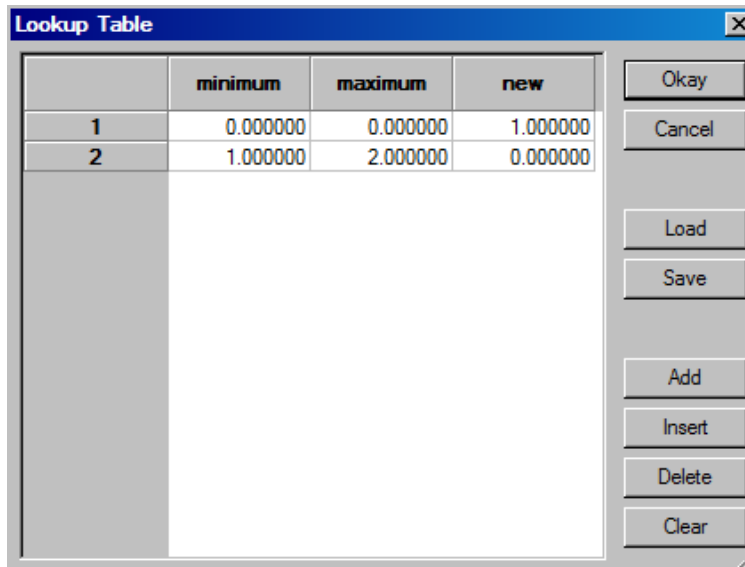
*Tools/Reclassify Grid Values* tool is applied to reclassify these values. The output grid map is named 'MPAwCo1'. Here is how it is created.

Figure III-6 displays the *Reclassify Grid Values* parameters window.



**Figure III-6. Parameters to reclassify the 'MPAwwBfGR' grid map.**

The 'MPAwwBfGR' grid map is chosen for the '>> Grid' parameter. The "simple table" option is selected for the 'Method' parameter. The default "<create>" option is used for the output parameter '<< Reclassified Grid'. The "min <= value <= max" choice is chosen for the 'operator' parameter. Figure III-7 displays the data values entered for the "simple table".

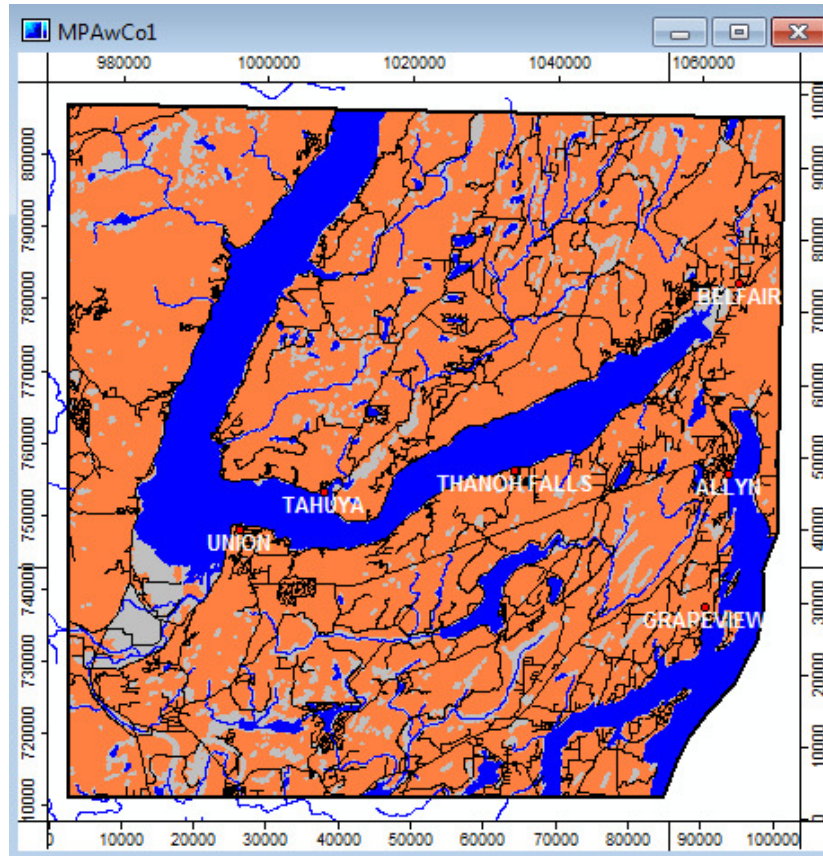


**Figure III-7. The “simple table” for reclassifying data values.**

The lookup table in Figure III-7 shows that grid cells currently containing 0's are recoded to contain 1's and grid cells containing 1's and 2's are recoded to contain 0's. I click on the 'Okay' button and return to the tool parameters page. I click on the 'Okay' button on the parameters window and the tool executes producing the default grid map layer 'MPAwwBfGR\_reclassified'.

Before re-naming and saving the output layer, the *Grid - Tools/Grid Masking* tool is applied. This tool is used to discard extraneous data values that exist in grid cells located outside of the irregular shape of the project area boundary but within the spatial extent of the grid system. The project area grid map is 'MProjAreaGR' and is chosen for the '>> Mask' input parameter and the 'MPAwwBfGR\_reclassified' layer for the input parameter '>> Grid'. The "<create>" option is used for the output parameter '< Masked Grid'. I click on the 'Okay' button and the tool executes.

The output grid map 'Masked Grid' is re-named 'MPAwCo1' and saved. Figure III-8 displays the 'MPAwCo1' constraint data layer.



**Figure III-8. The Open Water and Wetlands Constraint grid map.**

The areas tinted orange are the available areas and gray is used for not available land areas. Blue is used for water.

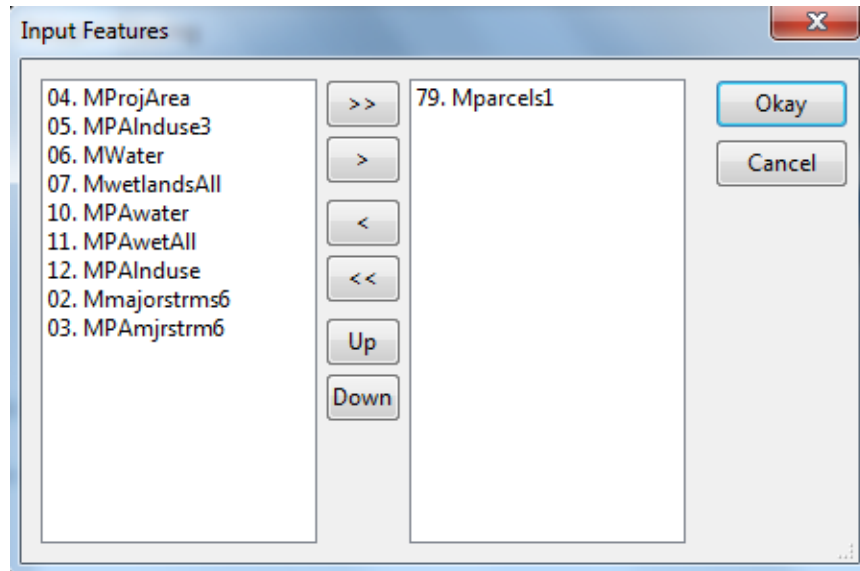
### **The Land Use Constraint**

The land use category for land parcels in the county is identified in the "LANDUSE" attribute of the attribute table linked to the county parcels data layer ('Mparcels1'). There are 60650 parcels (polygon objects) in Mason County in 62 unique land use classes. The land use constraint differentiates land use classes that are available for development from land use classes that are not available for development.

The 'Mparcels1' layer is clipped to create a parcel data layer for the project area. The land use class attribute provides the data values needed to create a land use data layer for the project area. The county-wide parcel data layer is clipped using the *Shapes - Polygon/Polygon Clipping* tool. This step discards polygon objects and portions of polygon objects that falls outside of the project area boundary. If parcels are split by the project area boundary, the portions within the project area are retained along with parcel polygon objects fully contained by the project area.

The project area polygon shapes data layer 'MProjArea' is selected for the input parameter '>> Clip Features' in the *Shapes - Polygon/Polygon Clipping* tool parameters

window. This layer contains a single polygon object for the project area. Shapes data layers are selected for the '>> Input Features' parameter by clicking the mouse pointer in the value field to the right of the parameter name and then clicking on the ellipsis that appears. The 'Input Features' window in Figure III-9 displays.



**Figure III-9. The 'Input Features' window for the *Shapes - Polygon/Polygon Clipping* tool.**

A data layer in the list on the left is chosen by moving the mouse pointer over the name and pressing the left mouse button. The name becomes highlighted. If you move the pointer over another name and press the left mouse button again, the first layer is un-highlighted and the new one is highlighted. You can select and highlight multiple layers by keeping the Ctrl key depressed as you click with the mouse on the file names.

Once one or more data layers are selected, they are moved to the right side of the window by clicking on the button that displays the '>' symbols in the center of the window. You can move layers from the right side back to the left side by selecting and using the '<' symbols button. You can also move data layers back and forth between the two lists by double-clicking with the mouse pointer positioned on the file you want to move. The 'Up' and 'Down' buttons can be used to move layers up or down in the list. The list order for the selected layers can be important for some tools, for example the *Grid - Calculus/Grid Calculator* tool, but it is not important for how this tool executes.

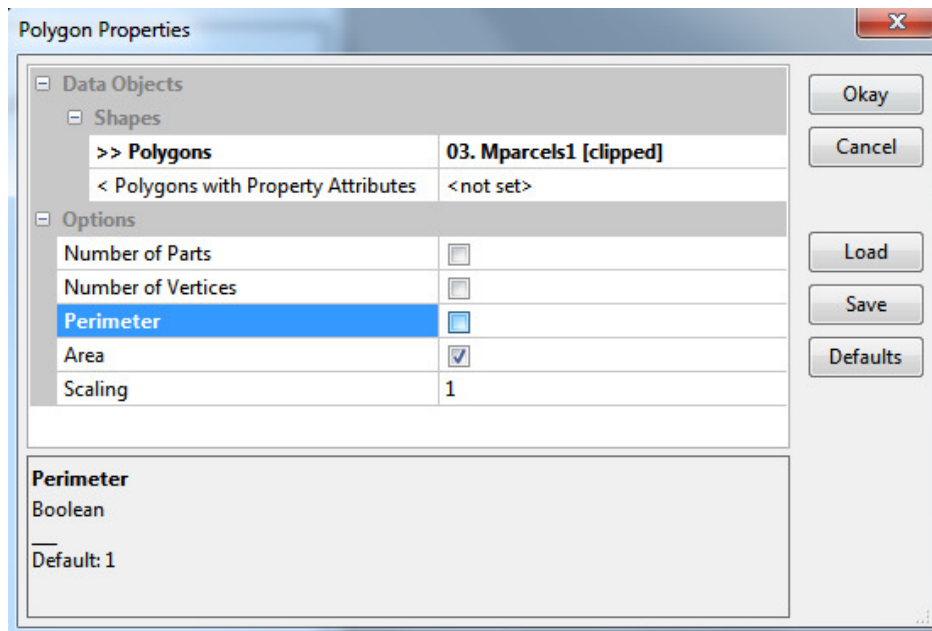
You can see in Figure III-9 that the 'Mparcels1' data layer has been selected and moved to the right side panel. This is the county-wide parcels data layer. I click on the 'Okay' button to return to the main tool window.

The default entries for the two toggle box options parameters 'Dissolve Clip Features' and 'Multiple Input Features' are accepted. Both are turned on. This status is indicated with a check mark in the toggle boxes. I click on the 'Okay' button and the tool executes creating

a new shapes data layer containing parcel polygon objects occurring within the project area.

Polygon objects, split by the project area boundary during the clipping process, result in two or more "new" polygon objects. The portion of the split polygon outside of the project area is discarded and the portion within the project area retained. Numeric attribute data of the original polygon object is not updated as part of the clipping process. Thus numeric data that changes due to the new polygons is now in error and needs to be updated. For example, data for the "SHAPE\_AREA" attribute in the attribute table linked to the 'Mparcels1' data layer identifies the area of the polygon object in square feet. When a polygon is split into two or more new polygons the entry for "SHAPE\_AREA" does not also get split. This means the square feet entry for "SHAPE\_AREA" for split polygons in the new data layer is inaccurate since the data is for the original polygon object size. This is easy to fix.

First the attribute table linked to the output data layer 'Mparcels1 [clipped]' is displayed in the work area. In the table view window the "Delete Fields" table support tool is chosen and the "SHAPE\_AREA" attribute is deleted from the table. Next the *Shapes - Polygons/Polygon Properties* tool is executed. The parameters window for this tool is displayed in Figure III-10.



**Figure III-10.** The parameters window for the *Shapes - Polygons/Polygon Properties* tool.

The [clipped]' data layer is used for the input parameter '>> Polygons'. The "<not set>" option for the output parameter '< Polygons with Property Attributes' is chosen. Rather than create a new copy of the input data layer, using this option will update the attribute table linked to the input data layer. The toggle box for the toggle box parameter 'Area' is

toggled to on. The tool is executed and an attribute with the default name "AREA" is output to the attribute table linked to the 'Mparcels1 [clipped]' data layer.

The output layer is re-named 'MPAInduse1' and saved. The new land use shapes data layer contains 33113 polygon objects. The attribute table linked to the new data layer has almost the same attribute structure as the input 'Mparcels1' data layer with the addition of the "AREA" attribute. The "LANDUSE" attribute in the attribute table linked to the 'MPAInduse1' has 58 unique land use classes and the "AREA" attribute in the attribute table contains updated area information for each polygon object.

The "LANDUSE" attribute, with its unique land use classes, can be used to create a new polygon shapes data layer where all polygon objects having the same land use class become part of a multi-polygon object for the land use class. Polygon objects having the same land use class are merged with other polygon objects having the same land use class. Two or more adjacent polygons with the same land use class having a common boundary are merged into a single polygon. The common boundary, in this case, is eliminated. There is an option you can use if you want to retain the common boundary for mapping/display purposes.

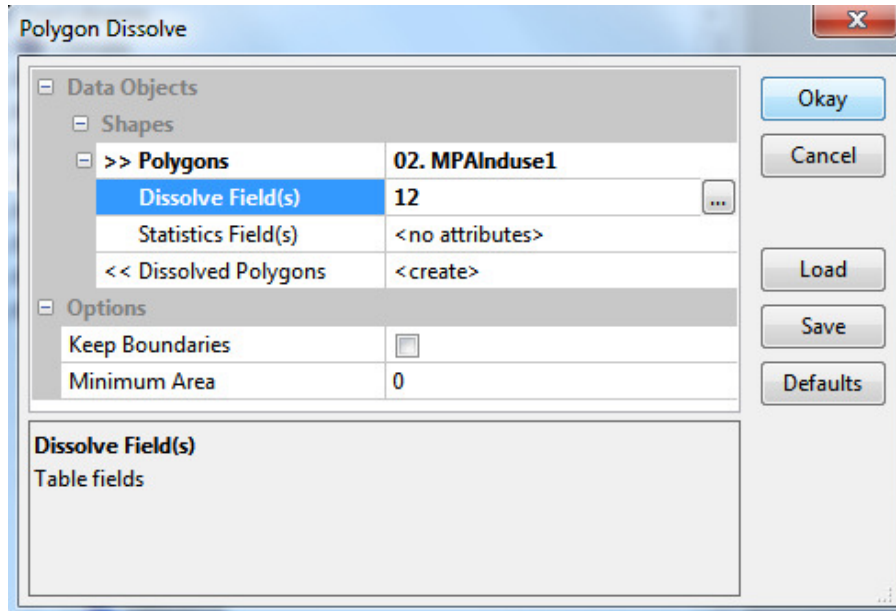
The *Shapes - Polygons/Polygon Dissolve* tool supports this merging process. Adjacent polygons of the same land use class in the "LANDUSE" attribute will have their common polygon boundary dissolved forming a larger polygon. Resulting merged polygons, regardless of adjacency, in the same land use class become one polygon of a multi-polygon object for the land use class.

For example, there are 30 parcels for an imaginary land use class named Blue. Each parcel is a unique parcel but four of them are adjacent to each other and share common boundaries. The common boundaries between the four would be dissolved, merging the four into a single larger polygon object. The other 26 parcels of Blue land use class are not neighbors or touching. The 26 parcel polygon objects with the Blue land use and the new merged Blue polygon would become part of a new single multi-polygon object for the land use class Blue. The multi-polygon is defined by the 27 single polygons.

Another feature of the *Shapes - Polygons/Polygon Dissolve* tool is the ability to calculate statistics for aggregated numeric attribute data values. The market value for all of the parcels in the same land use class needs to be totaled. The tool allows for one or more numeric attributes to be chosen and for up to 9 statistics to be calculated for each chosen attribute. The 'Statistics' parameter supports the calculation of up to 9 statistics: sum, mean, minimum, maximum, range, deviation, variance, listing, and count.

Figure III-11 displays the parameters window for *Shapes - Polygons/Polygon Dissolve* tool.



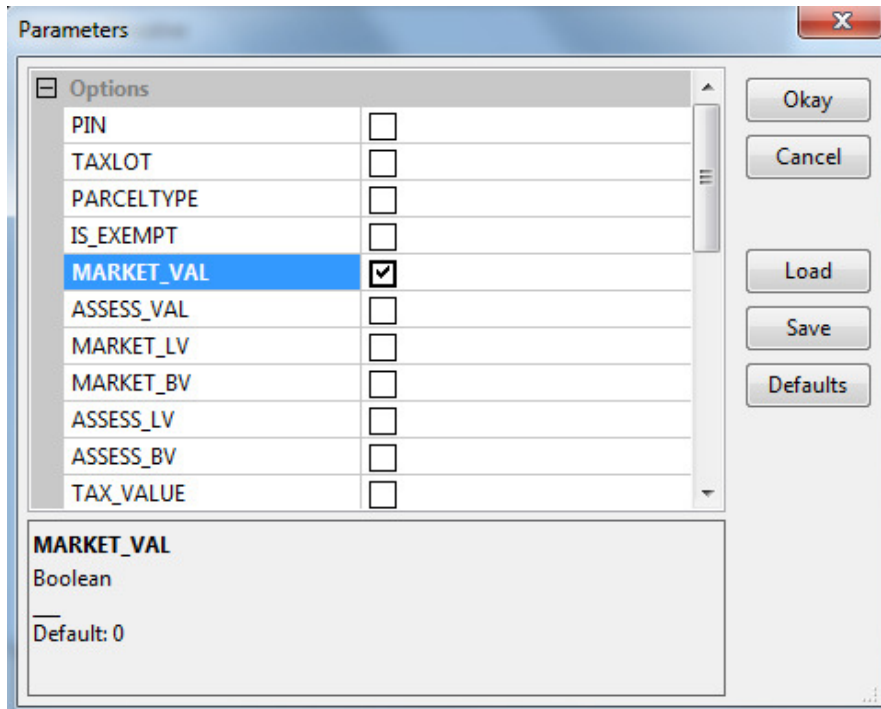


**Figure III-11. The *Shapes - Polygons/Polygon Dissolve* tool parameters window.**

The new 'MPAInduse1' polygon shapes data layer is chosen for the input parameter '>> Polygons'. The "LANDUSE" attribute in the attribute table linked to the input data layer is chosen as the attribute for merging polygon objects. This is the 12th attribute in the attribute table. I see that "12" appears for the 'Dissolve Field(s)' parameter. Note that this parameter supports multiple entries.

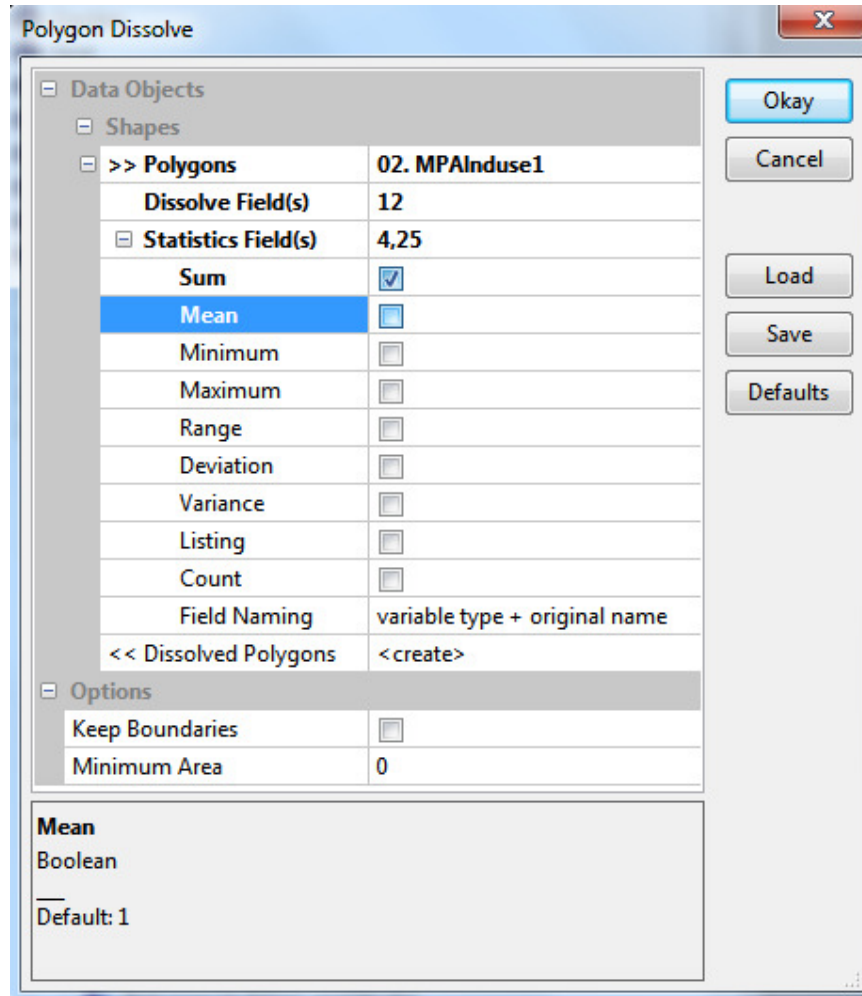
The default for the 'Statistics' parameter is "<no attributes>". When the default is used no statistics are calculated for any attributes in the attribute table linked to the input shapes data layer. I move the mouse pointer into the value field to the right of the 'Statistics' parameter and click. An ellipsis appears on the right. I click the mouse pointer on the ellipsis. The 'Parameters' window in Figure III-12 displays.





**Figure III-12.** The 'Parameters' page for the *Shapes - Polygons/Polygon Dissolve* tool.

The 'Parameters' window is where I choose one or more attributes in the attribute table for which you want the tool to produce statistics. This is a scrollable window and the attributes are toggle box parameters. I select an attribute by moving the mouse pointer into the toggle box and pressing the left mouse button. A check mark appears in the box. The 'MARKET\_VAL' attribute (parameter) is chosen as is the 'AREA' attribute near the bottom of the list (the scroll bar is used to scroll down to the bottom of the list and choose the 'AREA' attribute). The window is exited by clicking on the 'Okay' button. The 'Polygon Dissolve' parameters window in Figure III-13 displays again.



**Figure III-13.** The parameters window for the *Shapes - Polygons/Polygon Dissolve* tool.

The parameters window has changed appearance because two attributes are selected for statistics. The attributes are "MARKET\_VAL", attribute number 5 in the attribute table list, and "AREA", attribute 26 in the table list (note that the attribute numbering in the tool starts with 0). You can see that these attribute locations are listed in the value field to the right of the 'Statistics' parameter, "4,25".

The parameter window now includes a list of statistics options the tool supports. These are also toggle box parameters. Sum is the only statistic needed for the two attributes. The mouse pointer is clicked in the toggle box for the 'Sum' parameter. The tool sums the numeric entries for the "MARKET\_VAL" and "AREA" attributes for each polygon object and produces a total. It is expected that each unique land use multi-polygon will have attributes for total value for market value and the total number of square feet.

The default "<create>" option is used for the output parameter '<< Dissolved Polygons'. At the bottom of the parameters window is the toggle check box option 'Keep boundaries'. This is the parameter mentioned earlier that is used if you want the dissolved

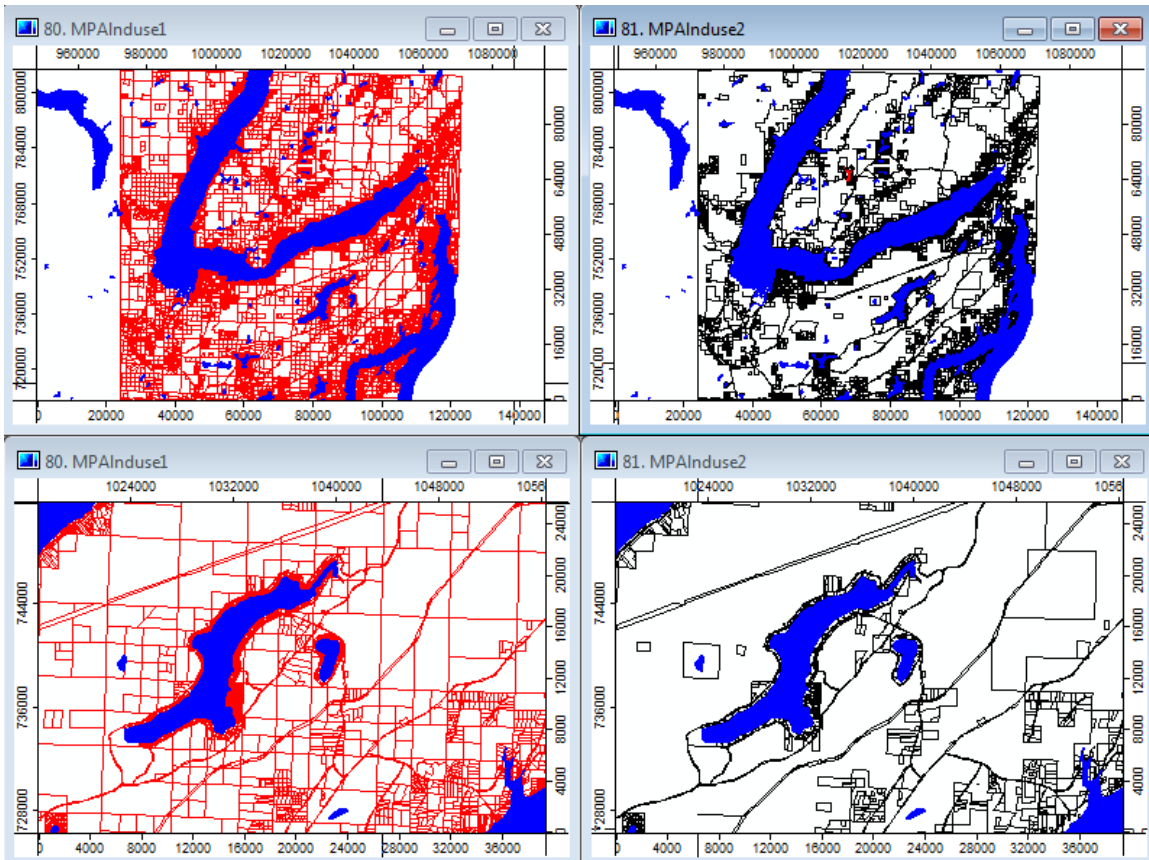
polygon boundaries to remain for mapping or display purposes. The tool is executed by clicking on the 'Okay' button with the mouse pointer.

The default name for the output is 'MPAInduse1 [Dissolved: LANDUSE]'. I re-name it to 'MPAInduse2' and save it.

There are 58 polygon objects in the new, condensed version of the input data layer. The polygon objects in the 'MPAInduse2' layer are single, multi-polygon polygon objects, one for each unique land use class. All of the polygon objects having the same land use class have been merged into a single multi-polygon object.

The attribute table linked to the 'MPAInduse2' data layer contains three attributes: LANDUSE, SUM\_MARKET\_VAL, and SUM\_AREA.

The second constraint, land use categories not available for development, can now be created. This constraint is derived from the land use polygon shapes data layer 'MPAInduse2'. As noted above, this layer includes 58 multi-polygon objects, each multi-polygon object representing one of 58 land use categories. Figure III-14 compares the 'MPAInduse1' and 'MPAInduse2' polygon shapes data layers; the 'MPAInduse1' data layer the one the multi-polygon 'MPAInduse2' is based on.



**Figure III-14. Comparing the 'MPAInduse1' (on the left) and 'MPAInduse2' polygon shapes data layers.**

Comparing the map view windows in Figure III-14 you can easily discern that the multi-polygon objects on the 'MPAInduse2' data layer (on the right in the figure) are aggregations of the parcel polygon objects of the 'MPAInduse1' data layer (the layer on the left). In particular, it is noticeable looking at the zoomed in area around Mason and Benson Lakes near the middle of the lower map view windows.

The "LANDUSE" attribute in the attribute tables linked to the 'MPAInduse1' and 'MPAInduse2' polygon shapes data layers lists the most detailed level land use classification for the parcels. For example, there are nine classes related to residential land use ranging from "11 - Residential - Single Family" to "19 - Residential - Vacation and Cabin". Two new attributes are to be added to the 'MPAInduse2' attribute table related to a more generalized land classification scheme. The attributes are named "GENNAME" and "GENUSE". The first one is for text entries and the second for numeric entries. The intent is to collapse the more detailed land use classes into a more general one. For example, the nine classes of residential land use are generalized into a single class named "Residential". A numeric code for the generalized classification is entered for the attribute named "GENUSE". For the "Residential" class this numeric code is 10. Please note that the detailed land use class information does not go away.

The detailed land use categories are collapsed into nine general land use categories. These are Residential (10), Commercial (20, 30), Transportation (40), Trade (50), Services (60), Recreation (70), Resource (80), and Undeveloped (90). The numbers in parentheses are the numeric codes used in the "GENUSE" attribute. Two of these general classes are going to retain some of the more detailed categories that are related to land use constraints.

The Resource (80)

Resource - Other [Resource - Fishing (84), Resource - Mining (85)]

Resource - Agriculture (81)

Resource - Agriculture Activities (82)

Resource - Agriculture Current Use (83)

Resource - Designated Forest Land (88).

The Undeveloped (90)

Undeveloped - Other (90) [Undev. - Open Space (94), Undev. - Water Areas (93)]

Undeveloped - Land (91)

Undeveloped - Noncommercial Forest (92)

Undeveloped - Timberland (95)

Unclassified (99).

In the list above you can see more detailed land use classes are being retained for the Resource and Undeveloped general land use class.

Using the built-in table support functions, the two new attributes are created in the attribute table linked to the 'MPAInduse2' data layer. They are named "GENNAME" and "GENUSE" as described above. The "GENNAME" contains the names for the generalized land use classes. "GENUSE" is for a numeric equivalent of the land use class name. A third attribute named "AVAILSTATUS" is also added. This attribute is used for identifying the availability for development or not available for development status. A 1 entered for this attribute means the parcel polygon objects in this land use class are available for development and a 0 means they are not available for development. Here is a description of how the changes to the 'MPAInduse2' attribute table are implemented.

Display the attribute table for the 'MPAInduse2' data layer in a table view window. Use the table column "Add Field" tool. In the "Add Field" dialog window enter "GENNAME" for the 'Name' parameter, "string" for the 'Field Type' and insert it as the second attribute of the table (after the "LANDUSE" attribute). Enter the second new attribute naming it "GENUSE". Use "signed 8 byte integer" for the 'Field Type' and insert it as the third attribute of the table, after the "GENNAME" field. The characteristics for the "AVAILSTATUS" attribute are the same as used for the "GENUSE" attribute.

An attribute for storing acres is going to be added named "AREA(ACRES)". The *Table - Calculus/Table Calculator (Shapes)* tool is used to enter the acre figures. The "AREA(ACRES)" attribute uses "8 byte floating point number" for the 'Field Type' and is added as the last attribute following the "SUM\_AREA" attribute.

The data for the "GENNAME", "GENUSE", and "AVAILSTATUS" is manually entered. The text and numeric entries for "GENNAME" and "GENUSE" generally follow from the text already available for the "LANDUSE" attribute in the table. I rely on copy and paste for most of the entries.

Available for development parcels are in land use classes: Resource - Agriculture (81), Resource - Agriculture Activities (82), Resource - Agriculture Current Use (83), Resource - Designated Forest Land (88), Undeveloped - Land (91), Undeveloped - Noncommercial Forest (92) and Undeveloped - Timberland (95). A 1 is entered for the "AVAILSTATUS" attribute for these land use classes.

Not suitable for development areas include: Residential (10), Commercial 1 (20), Commercial 2 (30), Transportation (40), Trade (50), Services (60), Recreation (70), Resource - Other (80), Undeveloped - Other (90) and Undeveloped - Unclassified (99). A 0 is entered for the "AVAILSTATUS" attribute for these land use classes.

You will notice above that the land use class numbers used in the "GENUSE" attribute in the attribute table linked to the 'MPAInduse2' data layer are shown within the parentheses after the land use class names.

The 'MPAInduse2' attribute table contains 58 records. Figure III-15 displays a portion of the attribute table records.

	LANDUSE	GENNAME	GENUSE	AVAILSTATUS
42	72 - Recreational - Public assembly	Recreation	70	0
43	74 - Recreational - Rec. Activities	Recreation	70	0
44	75 - Recreational - Resorts & Group Camps	Recreation	70	0
45	76 - Recreational - Parks	Recreation	70	0
46	79 - Recreational - Other Recreational	Recreation	70	0
47	84 - Resource - Fishing	Resource - Other	80	0
48	85 - Resource - Mining	Resource - Other	80	0
49	81 - Resource - Agriculture	Resource - Agriculture	81	1
50	82 - Resource - Agriculture Activities	Resource - Agriculture Activities	82	1
51	83 - Resource - Agriculture Current Use	Resource - Agriculture Current Use	83	1
52	88 - Resource - Designated Forest Land	Resource - Designated Forest Land	88	1
53	93 - Undeveloped - Water areas	Undeveloped - Other	90	0
54	94 - Undeveloped - Open Space	Undeveloped - Other	90	0
55	91 - Undeveloped - Land	Undeveloped - Land	91	1
56	92 - Undeveloped - Noncommercial Forest	Undeveloped - Noncommercial Forest	92	1
57	95 - Undeveloped - Timberland	Undeveloped - Timberland	95	1
58	99 - Undeveloped - Unclassified	Undeveloped - Unclassified	99	0

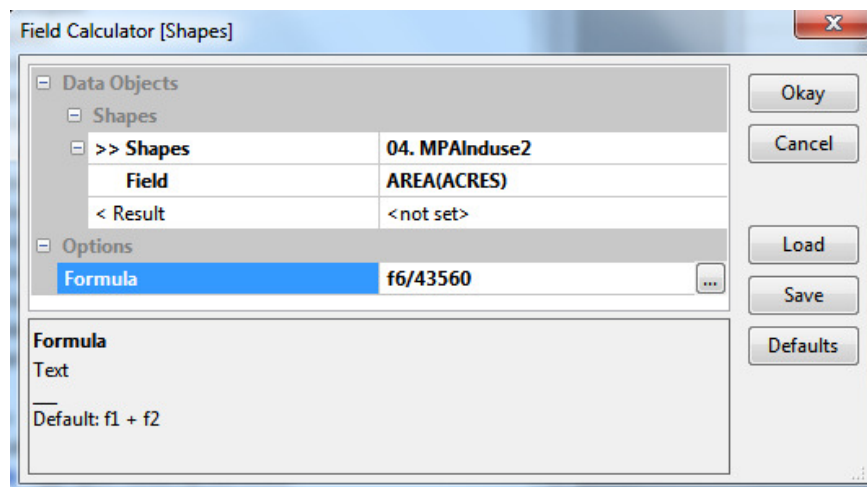
**Figure III-15. A portion of the attribute table linked to the 'MAInduse2' data layer.**

The portion of the attribute table displayed in Figure III-15 illustrates how the more detailed land use categories are aggregated and it also shows where more detailed land use categories are retained for the purposes of this constraint. You can see in rows 42 through 46 of the table an example of the how the more detailed land use categories for recreation are handled. Notice how they are aggregated into a more general land use class

70 in the "GENNAME" and "GENUSE" attributes. Viewing records 47 through 58 you can see how the two general land use classes 80 and 90 are handled and where the more detailed land use classes are retained.

The square feet area entries for the "SUM\_AREA" attribute are converted to acres by dividing by 43560 (the number of square feet in an acre). The "SUM\_AREA" data values are total square feet for the land use multi-polygon object. The attribute for this calculation is named "AREA(ACRES)" and was added earlier. The *Table - Calculus/Table Calculator (Shapes)* tool is used to calculate acres.

The parameters window for the *Table - Calculus/Table Calculator (Shapes)* tool is displayed in Figure III-16.



**Figure III-16.** The parameters window for the *Table - Calculus/Table Calculator (Shapes)* tool.

The equation "f6/43560" divides the square feet data values stored in the "SUM\_AREA" attribute (referred to by "f6" in the equation) and outputs the acre values to the new attribute "AREA(ACRES)". The default "<not set>" entry is used for the output parameter '< Result'. Using this option means the tool does not create a new version of the data layer but outputs the new data into the "AREA(ACRES)" attribute in the existing attribute table. I click on the 'Okay' button and the tool executes. I use the Excel spreadsheet program to summarize the acres by the land use classes.

Table III-1 displays a summary of the land use classes for the "GENNAME", i.e., Class, and "GENUSE", i.e., Class Number, attributes.

**Table III-1: Summary of the General Land Use Classes**

Class	Class Number	Avail/Not Avail (1)/(0)	Project Area Acres
Residential	10	0	20376.53
Commercial 1	20	0	51.88
Commercial 2	30	0	22.96
Transportation	40	0	2386.93
Trade	50	0	221.85
Services	60	0	4343.76
Recreation	70	0	2232.37
Resource - Other	80	0	167.05
Resource - Agriculture	81	1	8.52
Resource - Agriculture Activities	82	1	21.52
Resource - Agriculture Current Use	83	1	1516.97
Resource - Designated Forest Land	88	1	75692.09
Undeveloped - Other	90	0	33725.63
Undeveloped - Land	91	1	21700.08
Undeveloped - Noncommercial Forest	92	1	39833.67
Undeveloped - Timberland	95	1	2679.95
Unclassified	99	0	3256.76

The last step in developing this constraint layer is to create a grid map for land use classes available for development (grid cells containing 1's) and land use areas not available (grid cells containing 0's). The 'MPAInduse2' shapes data layer attribute "AVAILSTATUS" is the source of data values used by the *Grid - Gridding/Shapes to Grid* tool to create this new grid map. The column titled "Avail/Not Avail" in Table III-1 displays the data values for the "AVAILSTATUS" attribute.

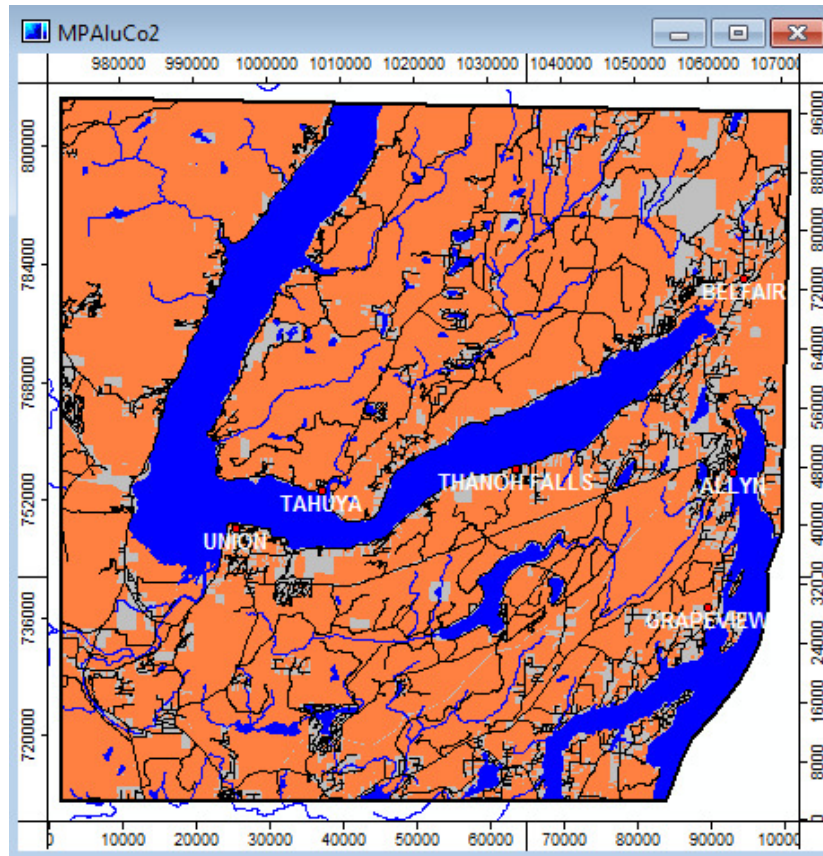
In the parameters window for the *Grid - Gridding/Shapes to Grid* tool the 'MPAInduse2' polygon shapes data layer is chosen for the input parameter '>> Shapes'. A number of choices are available for the 'Output Values' parameter. The "attribute" option is going to be used. Once this option is chosen, the 'Attribute' parameter becomes available in the parameters window for the tool. The "AVAILSTATUS" attribute is selected from the drop-down list of available attributes. This attribute uses a 1 for land use classes that are available and 0 for land use classes not available.

The 'Polygon' parameter has two choices: node or cell. The "cell" option is used. There are two choices available for the 'Target Grid System': user defined, grid or grid system. The "grid or grid system" option is selected because the output grid map is to be a member of the project area grid system. The already existing project area grid system, "30; 3299x 3190y; 972114.332755x 710977.70278y", is chosen for the 'Grid System' parameter.

The default "<create>" option is entered for the output parameter "<< Grid". I click on the 'Okay' button and the tool executes. The output grid map is named 'MPAInduse2



[AVAILSTATUS]'. It is re-named 'MPAluCo2' and saved. Figure III-17 displays the 'MPAluCo2' grid map.



**Figure III- 17. The Land Use Constraint grid map.**

The areas tinted orange are the available areas and gray is used for not available land areas. Blue is used for water.

This completes development of the two Boolean constraint grid maps. It is now time to look at the development of the factor grid data layers. Of the six factors, the first four are related to residential building costs while the last two relate to wildlife habitat preservation.

### **The Land Use Factor**

Land developers want to prioritize land use classes available for development. Remember, these land use classes are considered not already developed. The developers want to prioritize the available land use classes according to average per acre market value for each land use class. The lower the average per acre market value the more desirable an area in the land use class is for residential development.

You will recall that when the *Shapes - Polygons/Polygon Dissolve* tool was used for merging parcel polygons of the 'MPAlnduse1' data layer based on having the same land

use class and sharing a common boundary that two new attributes, one for market value and the other for area, were output. More specifically, the sum of the "MARKET\_VAL" and "AREA" attributes for the input polygon shapes data layer 'MPAInduse1' were totaled for all parcels within each land use class. The attribute table for the output shapes data layer 'MPAInduse2' contains the two new attributes named "SUM\_MARKET\_VAL" (the fifth field in the attribute table) and "SUM\_AREA" (the sixth field in the table). The units for the "SUM\_AREA" attribute are square feet.

The *Table - Calculus/Table Calculator (Shapes)* tool was used earlier to compute acres from the square feet area totals of the "SUM\_AREA" attribute and output the new data to the "AREA(ACRES)" attribute. The same tool uses the "SUM\_MARKET\_VAL" and "AREA(ACRES)" attribute to calculate a per acre market value for each land use class.

The "Add field" table tool is used to add a new attribute, "MKTVA(ACRE)", to the attribute table linked to the 'MPAInduse2' attribute table. I choose the "8 byte floating point number" data type for the attribute. The new attribute is added as the last attribute for the table.

The *Table - Calculus/Table Calculator (Shapes)* tool is applied to calculate the per acre market value for each land use class. The formula is "f5/f7" or "SUM\_MARKET\_VAL" divided by "AREA(ACRES)". The variable "f5" refers to the fifth attribute in the table, "SUM\_MARKET\_VAL", and the "f7" variable refers to the seventh attribute in the table, "AREA(ACRES)". The output is sent to the new attribute "MKTVA(ACRE)". This attribute is identified for the 'Field' parameter. The "<not set>" option is chosen for the output parameter '< Result''. I click on the 'Okay' button to execute the tool with these parameter settings.

Figure III-18 displays a portion of the updated attribute table linked to the 'MPAInduse2' polygon shapes data layer.

	LANDUSE	GENNAME	GENUSE	AVAILSTATUS	SUM_MARKET_VAL	SUM_AREA	AREA(ACRES)	MKTVA(ACRE)
41	71 - Recreatio	Recreation	70	0	2976495.000000	305672.115051	7.017266	424167.321178
42	72 - Recreatio	Recreation	70	0	2027420.000000	3585445.675164	82.310507	24631.363351
43	74 - Recreatio	Recreation	70	0	17946935.000000	15143704.821000	347.651626	51623.331136
44	75 - Recreatio	Recreation	70	0	50193405.000000	34733978.153919	797.382419	62947.719726
45	76 - Recreatio	Recreation	70	0	76338220.000000	40169629.015897	922.167792	82781.268950
46	79 - Recreatio	Recreation	70	0	398400.000000	3303452.150976	75.836826	5253.384401
47	84 - Resource	Resource - Pther	80	0	5281050.000000	2641816.128020	60.647753	87077.422066
48	85 - Resource	Resource - Other	80	0	950655.000000	4634556.034680	106.394767	8935.166926
49	81 - Resource	Resource - Agriculture	81	1	20670.000000	371149.216374	8.520414	2425.938572
50	82 - Resource	Resource - Agriculture Activities	82	1	1127920.000000	937458.574847	21.521088	52409.990711
51	83 - Resource	Resource - Agriculture Current Use	83	1	17514465.000000	66079145.253230	1516.968440	11545.701635
52	88 - Resource	Resource - Designated Forest Land	88	1	337803905.000000	3297147522.138913	75692.091876	4462.869193
53	93 - Undevelo	Undeveloped - Other	90	0	92175.000000	1413206399.890920	32442.754818	2.841158
54	94 - Undevelo	Undeveloped - Other	90	0	69914650.000000	55882210.990303	1282.879040	54498.240138
55	91 - Undevelo	Undeveloped - Land	91	1	393156165.000000	945255546.270383	21700.081411	18117.727650
56	92 - Undevelo	Undeveloped - Noncommercial Forest	92	1	116930860.000000	1735154453.260692	39833.665135	2935.478310
57	95 - Undevelo	Undeveloped - Timberland	95	1	51818910.000000	116738590.543430	2679.949278	19335.780131
58	99 - Undevelo	Undeveloped - Unclassified	99	0	0.000000	141864461.360454	3256.759903	0.000000

**Figure III-18. The updated attribute table linked to the 'MPAInduse2' data layer.**

The eight attributes in the attribute table linked to the 'MPAInduse2' data layer are displayed in the table view window in Figure III-18. Eighteen of the 58 records for the 58 multi-polygon objects are visible. It happens that this portion of the table includes the records for the 7 land use classes that are available for development. These classes are identified by 1's in the attribute "AVAILSTATUS".

The developers easily arrange the available land use classes from preferred to least preferred according to lowest per acre market value to highest per acre market value. See Table III-2 below. The per acre market value for each land use class is exploited later in the process sections.

**Table III-2: Preferred to Least Preferred Land Use Class List**

GENNAME	GENUSE	MKTVA(ACRE)
Resource - Agriculture	81	2425.94
Undeveloped - Noncommercial Forest	92	2935.48
Resource - Designated Forest Land	88	4462.87
Resource - Agriculture Current Use	83	11545.70
Undeveloped - Land	91	18117.73
Undeveloped - Timberland	95	19335.78
Resource - Agriculture Activities	82	52409.99

This criterion is developed by isolating all areas that are available for development. However, unlike with the 'MPAluCo2' constraint layer, where all available land use classes are 1's and not available land use classes are 0's, the land use class numeric designations are retained as data values for the seven available land use classes. The "GENUSE" attribute in the attribute table linked to the polygon shapes data layer 'MPAInduse2' is the source for data values for a land use class grid map. The *Grid - Gridding/Shapes to Grid* tool is applied converting this shapes data layer to a grid map.

The polygon shapes data layer 'MPAInduse2' is chosen for the input parameter '>> Shapes' in the parameters window for the *Grid - Gridding/Shapes to Grid* tool. The "attribute" option is selected for the 'Output Values' parameter and the "GENUSE" attribute entered for the 'Attribute' parameter. This attribute contains general land use class entries, e.g, 10 for residential land use, 40 for transportation, etc.

There are two choices available for the 'Target Grid System': user defined, grid or grid system. The "grid or grid system" option is used because the output grid map is to be a member of the project area grid system. I choose the existing project area grid system, "30; 3299x 3190y; 972114.332755x 710977.70278y ", for the 'Grid System' parameter.

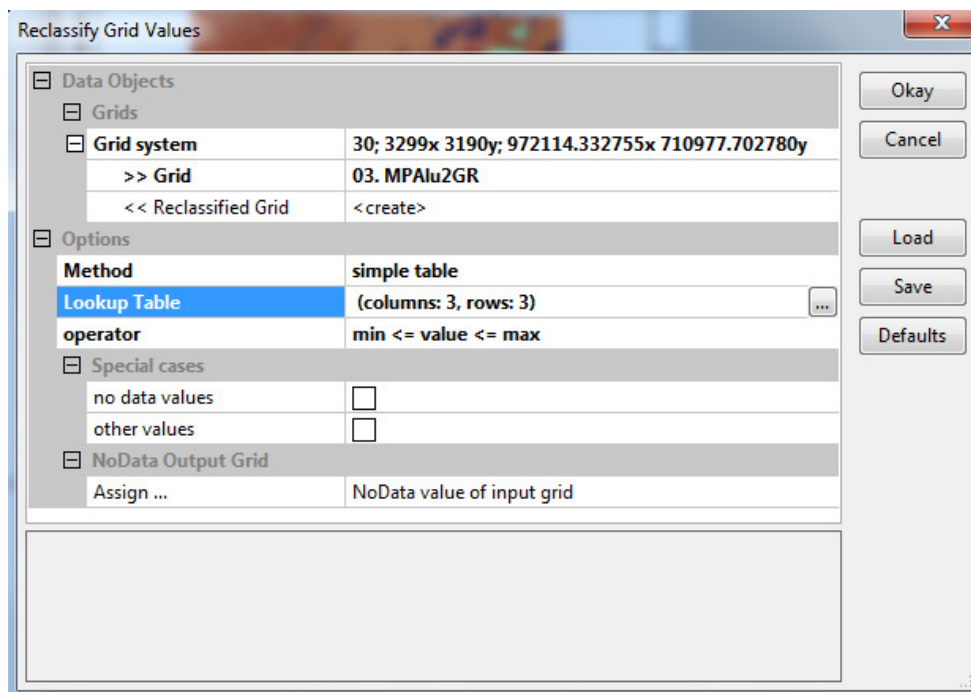
The default "<create>" option is accepted for the output parameter '<< Grid'. The tool is executed by clicking on the 'Okay' button. The default name for the output grid map is 'MPAInduse2 [GENUSE]'. It is re-named 'MPAlu2GR' and saved.

The data range for the 'MPAlu2GR' grid map is from 10 to 99. The data values are the same ones used in Table III-1 listed for the "Class Number" column. The "Avail/Not

Avail" column of Table III-1 defines suitable for development areas as land use classes Resource - Agriculture (81), Resource - Agriculture Activities (82), Resource - Agriculture Current Use (83), Resource - Designated Forest Land (88), Undeveloped - Land (91), Undeveloped - Noncommercial Forest (92) and Undeveloped - Timberland (95). Not suitable for development areas include land use classes Residential (10), Commercial 1 (20), Commercial 2 (30), Transportation (40), Trade (50), Services (60), Recreation (70), Resource - Other (80), Undeveloped - Other (90) and Unclassified (99).

The *Grid – Tools/Reclassify Grid Values* tool is used to reclassify the unsuitable categories to the data value 0 on the 'MPAlu2GR' grid map. The unsuitable classes use the data values 10, 20, 30, 40, 50, 60, 70, 80, 90, and 99. The remaining suitable land use classes are not recoded and their current data value is copied to the output grid map.

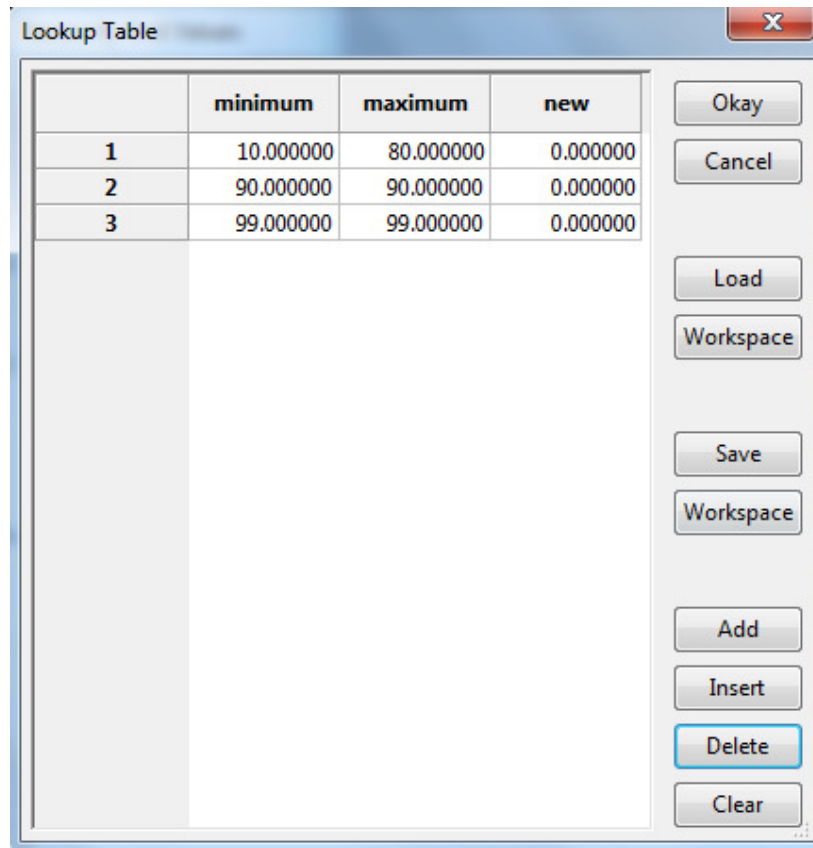
The *Grid – Tools/Reclassify Grid Values* tool parameters page is displayed in Figure III-19.



**Figure III-19. The reclassify parameter entries for the 'MPAlu2GR' grid map.**

The 'MPAlu2GR' grid map, produced by the *Grid - Gridding/Shapes to Grid* tool from the 'MPAlnduse2' shapes data layer, is chosen for the input parameter '>> Grid'. The default "<create>" option is used for the output parameter '<< Reclassified Grid'.

Several options are available for the 'Method' parameter. The "simple table" option is going to be used. The lookup table for this option identifies the grid cell data values to be recoded and the new values to use. If a particular grid cell data value is not going to be recoded that data value does not need to be included in the lookup table. Figure III-20 displays the simple table with the data values for recoding to the new data value 0.

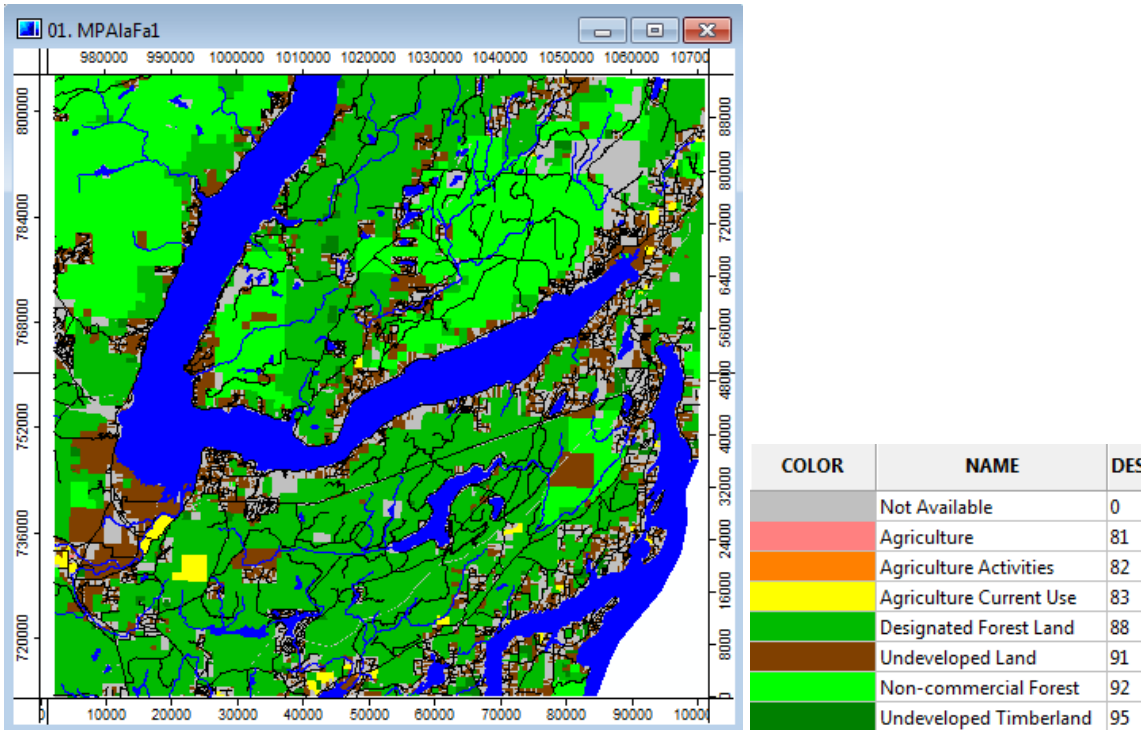


**Figure III-20. The "simple" lookup table for recoding the 'MPAlu2GR' grid map.**

Existing data values from 10 to 80 and data values 90 and 99 are recoded to the new data value 0. Since all other data values of the input grid data layer are not to change, they are not listed in this table.

I finish keying in data values for the lookup table and click with the mouse pointer on the 'Okay' button. This returns me to the parameters window displayed in Figure III-19. I choose the option "min <= value <= max" for the 'operator' parameter and execute the tool.

The default output grid data layer is named 'MPAlu2GR\_reclassified'. I re-name it 'MPAlaFa1' and save it. Figure III-21 displays the Land Use Factor grid map.



**Figure III-21. The Land Use Factor grid map.**

The 'MPA1aFa1' has data values of 0, 81, 82, 83, 88, 91, 92, and 95. The non-zero data values represent available land use classes. The legend for the land use classes is displayed on the right. Blue areas are water and the black lines are the road network.

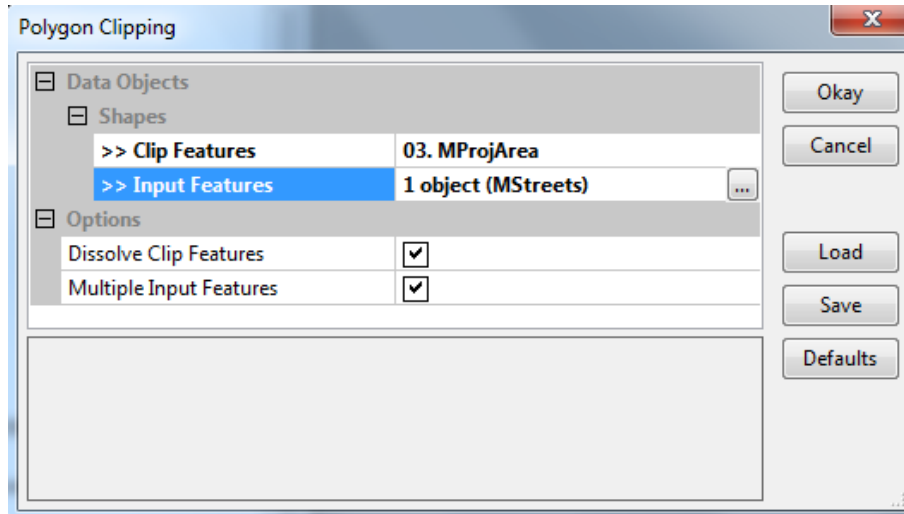
### **The Distance from Roads Factor**

Distance from roads is one of the more important cost considerations for developers. Poor road access can be very expensive for a construction project. Grid cells of this factor grid map identify the distance each grid cell is from the nearest road.

The *Grid – Tools/Proximity Grid* tool is used for calculating distance from roads. A grid map of the road network is input to the tool. Since a grid map for the road network does not exist, one must be created from the road network line shapes data layer. A county-wide grid map of roads is not needed; one is needed for the project area. The *Shapes - Polygons/Polygon Clipping* tool is used to clip the county road network line shapes data layer with the project area polygon object in the 'MProjArea' data layer. The line shapes data layer of roads for the project area is then converted to a grid map.

Figure III-22 displays the parameters window for *Shapes - Polygons/Polygon Clipping* tool.





**Figure III-22.** The parameters for clipping the 'MStreets' line shapes data layer.

The project area polygon shapes data layer 'MProjArea' is chosen for the input parameter '>> Clip Features' in the parameters window for the *Shapes - Polygons/Polygon Clipping* tool. This layer contains a single polygon object for the project area. The county road network shapes data layer 'MStreets' is selected for the '>> Input Features' parameter by clicking the mouse pointer in the value field to the right of the parameter name and then clicking on the ellipsis that appears. This displays the 'Input Features' double-panel window in which you choose one or more shapes data layers with features to be clipped. In this case the 'MStreets' line shapes data layer is chosen.

The polygon object boundary of the 'MProjArea' data layer is used to discard all line objects or parts of line objects that fall outside of the project area in the line shapes data layer 'MStreets'. The default name for the output line shapes data layer is 'MStreets [clipped]'. This layer is re-named 'MPAstreets' and saved. This new data layer contains 2904 line objects for the project area road network.

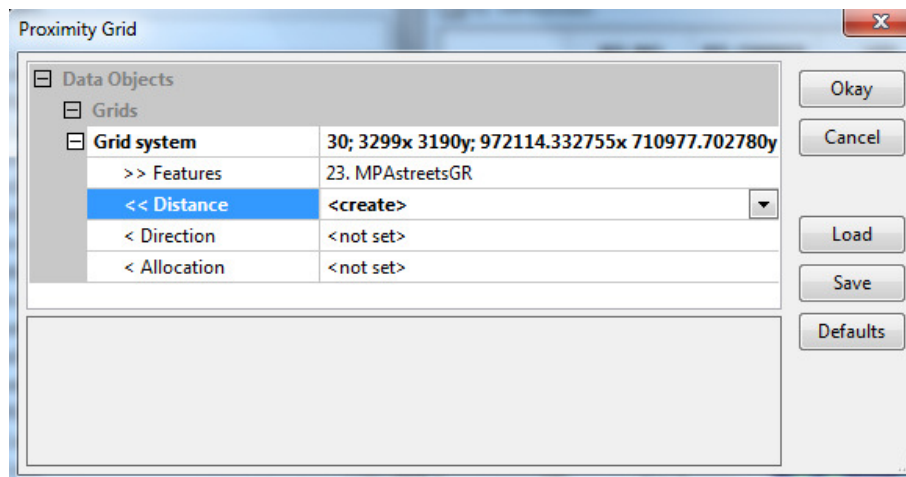
The shapes to grid map conversion tool, *Grid – Gridding/Shapes to Grid*, is used to create a grid map version of the project area line shapes road network, 'MPAstreets'. This data layer is chosen for the input parameter '>> Shapes'. This tool can use an attribute in the attribute table linked to the input data layer 'MPAstreets' as a source for data values for the output grid map.

A consideration for the development of a road network grid map is that the Travel Time from Town Center Factor requires a road network grid map using speed limit for road data values. One of the attributes in the attribute table linked to the 'MPAstreets' data layer is for street speed limit, "CTYSPD". The "attribute" option is chosen for the 'Output Values' parameter and the "CTYSPD" attribute used for the input parameter 'Attribute'. This is the attribute that is going to provide data values for the road grid cells of the output grid map. The speed limits used for streets and roads in the project area are 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, and 60.

The "grid or grid system" option is chosen for the 'Target Grid System' parameter and the project area grid system for the 'Grid System' input parameter. The default "<create>" option is used for the output parameter '<< Grid'.

The default name for the output grid map is 'MPAstreets [CTYSPD]'. The tool is executed by clicking on the 'Okay' button. The output is re-named 'MPAstreetsGR' and saved.

The grid map for distance from roads is created with the *Grid – Tools/Proximity Grid* tool using the 'MPAstreetsGR' grid map as the input layer. Figure III-23 displays the parameters page for the *Grid – Tools/Proximity Grid* tool.



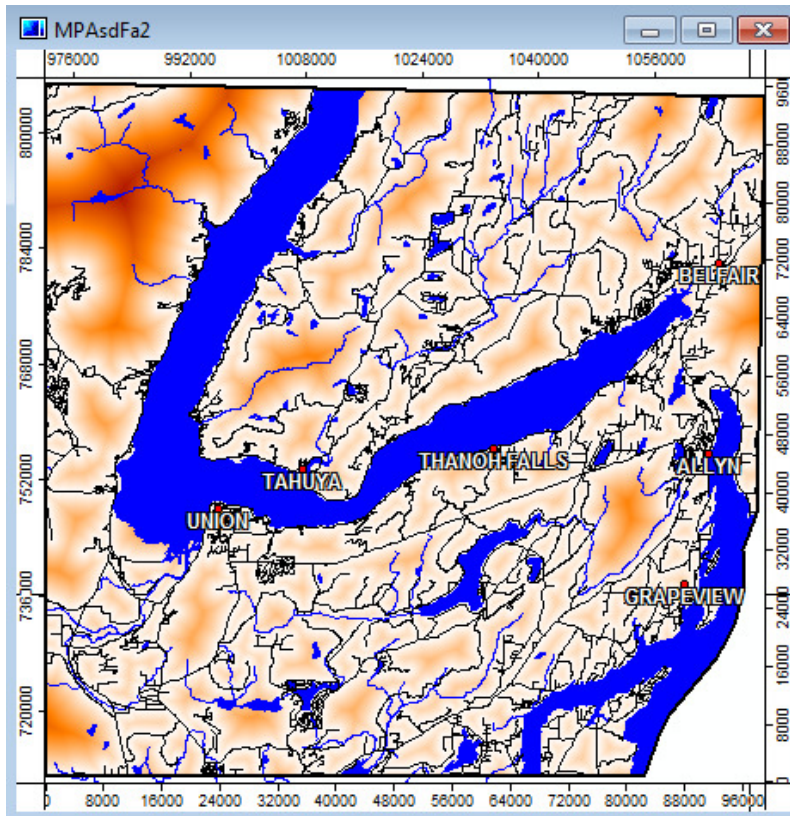
**Figure III-23. The parameters page for the *Grid – Tools/ Proximity Grid* tool.**

I click on the 'Okay' button and the tool executes outputting the default grid map 'Distance'.

Prior to saving the output data layer 'Distance', the *Grid - Tools/Grid Masking* tool is applied to discard data values occurring outside of the irregular shape of the project area. The project area grid system is selected for both 'Grid system' input parameters because both the 'Distance' and 'MProjAreaGR' data layers are members of this system. The 'MProjAreaGR' grid map is the grid version of the polygon shapes data layer 'MProjArea'. The 'Distance' grid map produced by the *Proximity Grid* tool is entered for the input parameter '>> Grid' and the 'MProjAreaGR' layer for the input parameter '>> Mask'. I click on the 'Okay' button and the tool executes.

The output grid map is re-named 'MPAsdFa2' and saved. The grid cell data values on this layer represent the distance each cell is to the nearest road.





**Figure III-24. The *Distance from Roads Factor* grid map.**

In the map view window in Figure III-24, grid cells nearer to roads have a lighter tone while grid cells more distant from roads have more of a reddish tint.

### **The Travel Time from Town Centers Factor**

Distance is often a cost factor as in the previous factor. New residents may want to be near the services provided by an urban center and willing to pay more for homes located closer to a town center. In the case of this factor, distance is not a ground measurement but a travel time measurement.

A cost surface can be a friction surface representing the relative frictions, or barriers to movement, associated with travel through a cell. I am going to create a friction surface defined by travel time for road and off-road grid cells. Travel time for a vehicle on a road grid cell is the designated speed limit for the road. A hypothetical speed is applied for off-road speed.

The project area grid cell size is 30' by 30'. Table III-3 displays the travel time, in fractions of minutes, for a vehicle at the specified speed limit to travel through a 30' by 30' grid cell.

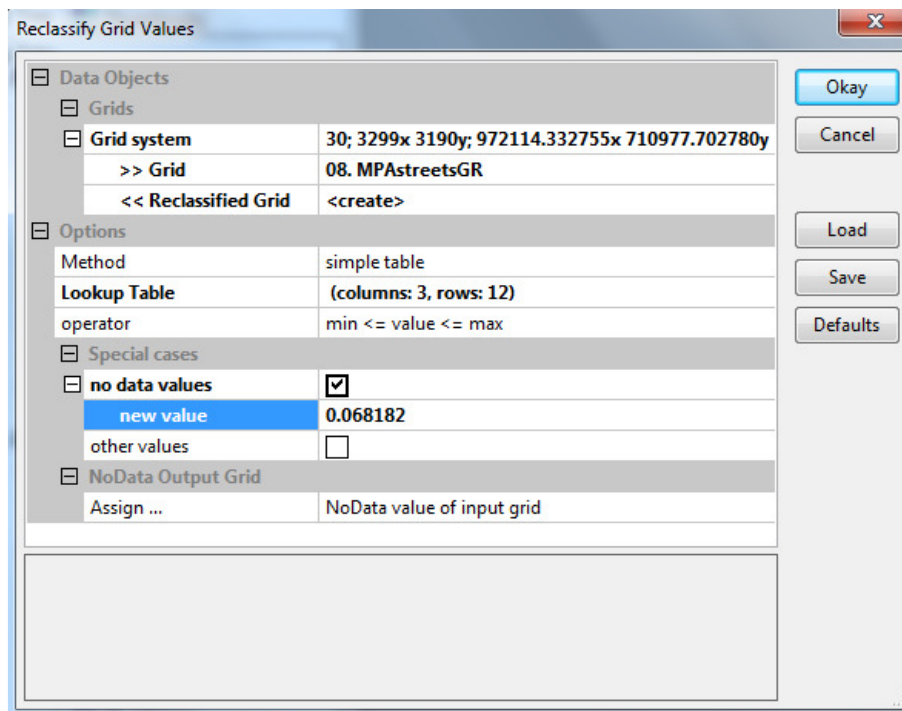
**Table III-3: Travel Time (in minutes) to Travel Across a 30' by 30' Grid Cell**

Speed Limit	Travel Time	Speed Limit	Travel Time	Speed Limit	Travel Time
5	.068182	25	.013630	45	.007576
10	.034091	30	.011364	50	.006818
15	.022727	35	.009740	55	.006198
20	.017045	40	.008523	60	.005682

The travel speed for off-road travel is going to be 5 MPH for a travel time of .068182 minutes per grid cell. Travel through a non-road grid cell assumes construction of an access road.

A new layer, using travel time data values, is created with the *Grid – Tools/Reclassify Grid Values* tool. Recall in the previous section describing the development of the Distance from Roads Factor grid map, one of the steps was to apply the *Grid - Gridding/Shapes to Grid* tool to produce the 'MPAstreetsGR' grid map. The data values for features of this grid map are for road speed limits.

Table III-3 lists the speed limit for a road and the travel time for a vehicle to cross a 30' by 30' road grid cell at that speed. The information in Table III-3 is used with the *Grid – Tools/Reclassify Grid Values* tool to create a new grid map for travel time. Figure III-25 displays the parameters page for the tool.



**Figure III-25. The parameter entries to reclassify the 'MPAstreetsGR' grid map.**

The road grid cells on the 'MPAstreetsGR' grid map identify the speed limit for the road grid cells. The data values are 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, or 60. The no data value is -99999. On this grid data layer, 'no data values' are off-road grid cells. The default "<create>" is used for the output parameter '<< Reclassified Grid'. The "simple table" method for recoding these values is chosen. Figure III-26 displays the simple table used for recoding the grid data layer speed limit data values.

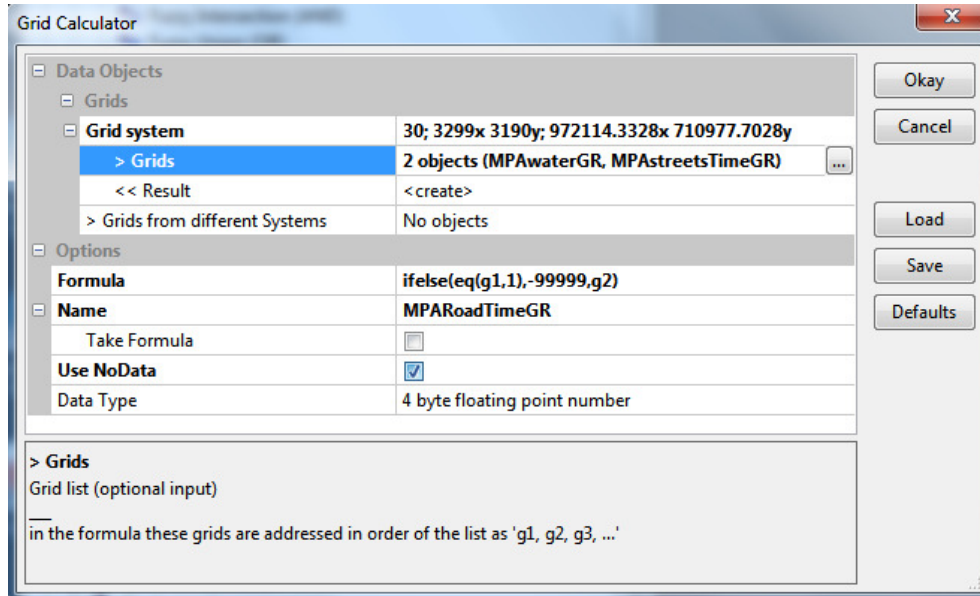
	minimum	maximum	new
1	5.000000	5.000000	0.068182
2	10.000000	10.000000	0.034091
3	15.000000	15.000000	0.022727
4	20.000000	20.000000	0.017045
5	25.000000	25.000000	0.013630
6	30.000000	30.000000	0.011364
7	35.000000	35.000000	0.009740
8	40.000000	40.000000	0.008523
9	45.000000	45.000000	0.007576
10	50.000000	50.000000	0.006818
11	55.000000	55.000000	0.006198
12	60.000000	60.000000	0.005682

**Figure III-26. The simple table used to recode speed limit data values.**

The entries for the "new" column are the travel times for a vehicle traveling at the speed entered for the "minimum" and "maximum" columns to cross a 30' by 30' grid cell. The grid cells are road grid cells. After making my entries in the simple table, I click on the 'Okay' button and return to the tool parameters window.

Off-road area grid cells contain the no data value -99999. The toggle box for the 'no data values' parameter is checked to indicate that the current no data value of -99999 is to be recoded. When the toggle box 'no data values' parameter is turned on, a 'new value' parameter appears in the parameters window for the data value. The value 0.068182 is entered for the 'new value' parameter value field just below the 'no data values' parameter. The "min <= value <= max" option is chosen for the 'operator' parameter. Once these entries are made the tool executes when you click on the 'Okay' button. The default name for the output grid data layer is 'MPAstreetsTimeGR'.

Every grid cell of the 'MPAstreetsTimeGR' grid map has a data value related to travel time. This includes grid cells that are actually water bodies. Water bodies should not be included as part of the travel time grid map. The *Grid - Calculus/Grid Calculator* tool is used to convert the travel times falling in water body grid cells to no data values of -99999. The parameters window for the *Grid - Calculus/Grid Calculator* tool is displayed in Figure III-27.



**Figure III-27. The *Grid - Calculus/Grid Calculator* tool parameters to produce the 'MPARoadTimeGR' grid map.**

The 'MPAwaterGR' grid map is chosen as one of the two inputs for the '> Grids' input parameter. This grid map uses the data value 1 to represent water bodies. All other grid cells contain the no data value 0. The second input grid map is 'MPAstreetsTimeGR'. This is the grid map produced by the *Grid - Tools/Reclassify Grid Values* tool. Every grid cell of this map contains a data value for travel time based on either the speed limit for a road, if it is a road grid cell, or if it is an off-road grid cell a time based on a speed of 5 miles per hour. This is the grid map that includes travel times for water bodies.

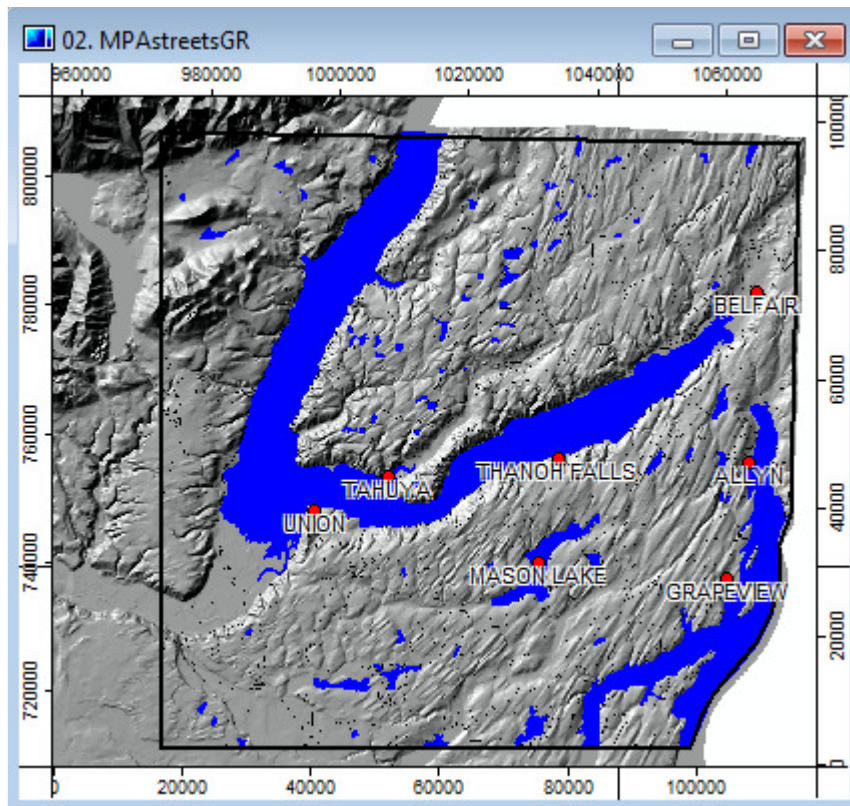
The equation entered for the 'Formula' parameter is: `ifelse(eq(g1,1),-99999,g2)`. The variable "g1" refers to the 'MPAwaterGR' grid map. All water bodies on this layer contain the data value 1. All other grid cells contain the no data value 0. The equation checks to see if a grid cell of this layer contains a 1. If it does contain a 1 it means it is a water body grid cell. The no data value -99999 is output to the corresponding grid cell of the output grid map. If the check of the grid cell shows a value of 0, it means it should contain a travel time data value from the "g2" variable grid map, 'MPAstreetsTimeGR'. In that case, the data value for the travel time grid map is output to the corresponding grid cell of the output grid map.



The name for the new grid map produced by the tool is 'MPARoadTimeGR' and is entered for the 'Name' parameter. The no data value 0 is going to be considered as a valid data value. The 'Use NoData' toggle box parameter is toggled to on for that purpose.

The tool is executed and the output grid map 'MPARoadTimeGR' is saved. This new grid map contains travel times for all grid cells that are not water body grid cells. Water body grid cells contain the no data value -99999.

A grid map is needed that identifies a grid cell for each of the six city centers. Travel times are calculated from each of the six city centers. One of the shapes data layers in the map view window in Figure III-28 is a point shapes data layer ('NMTowns') displaying the approximate locations of the six towns of Union, Thanoh Falls, Tahuya, Grapeview, Allyn and Belfair. Note that Mason Lake is not included as a town. These are all "unincorporated" towns. This means they do not have a city limits as an incorporated area does and they are administered by the county commissioners rather than a town city council or similar authority.



**Figure III-28. The six unincorporated towns of NM.**

There will be six grid cells on a new grid map containing the data value 1 representing the estimated centers for each of the six unincorporated towns. The travel time for grid cells from the nearest city center is calculated from these city center cells. The 'NMTowns' point shapes data layer serves as the basis for the city center locations.

It is usually important that the city center point objects fall on a road, in order for a travel time layer to be created by the *Grid – Analysis/Accumulated Cost* tool for the road network. Because travel time for this factor also considers off-road grid cells, it may not be an issue. Regardless, I am going to locate the city center locations on a road. The point objects of the 'NMTowns' data layer representing the town locations don't always fall on a road. After I make necessary adjustments of the city center locations on a new point shapes data layer I use the *Grid - Gridding/Shapes to Grid* to create the grid map for towns.

Here is a short summary of how this grid map for town center locations is created.

1. Create a new empty point shapes data layer.
2. On-screen digitize centers for the six towns.
3. Edit the "ID" attribute in the attribute table linked to the point shapes data layer.
4. Convert the point shapes data layer to a grid map.



1. Create a new empty point shapes data layer.

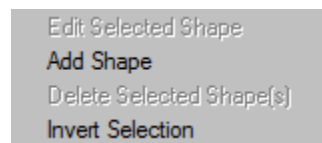
I create an empty point shapes data layer named 'MPACentPnt' using the *Shapes – Tools/Create New Shapes Layer* tool. I enter a name for the new layer, "MPACentPnt", for the 'Name' parameter in the parameters window. There are four choices for the 'Shape Type' parameter. I choose "Point". I accept the defaults for the remaining parameters.

2. On-screen digitize centers for the six towns.

Using on-screen digitizing tools, new point objects representing the town centers are defined as point objects on this new layer.

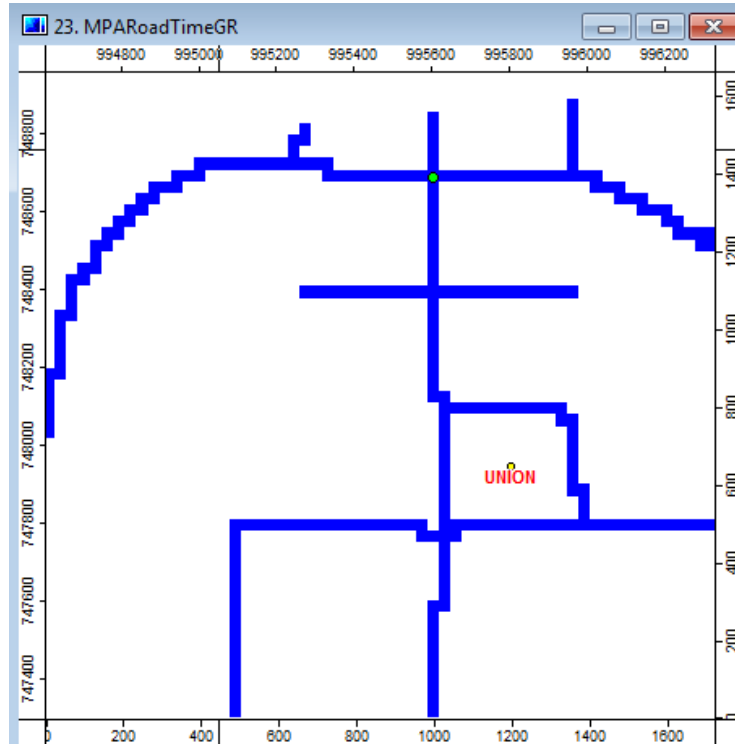
A new map view window is displayed in the work area for the 'MPAstreetsGR' grid map and the 'NMTowns' and 'MPACentPNT' point shapes data layers. I move the mouse pointer onto the 'MPACentPNT' layer name in the 'Tab' area of the Manager Window and click the left mouse button to make it the active layer. The layer must be active in

order for point objects to be added. I use the  zoom tool on the toolbar and zoom in on the central area of the town of Union in the map view window. Then I choose the  'Action' tool on the toolbar and move the mouse pointer within the map view window and click the right mouse button. The pop-up menu displayed in Figure III-29 appears.



**Figure III-29. Pop-up menu of options.**

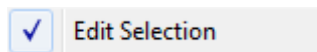
On the pop-up menu I choose the “Add Shape” option and move the mouse pointer within the map view window to where I want to on-screen digitize the town center point. I want this point to fall on a road. This is why the 'MPAstreetsGR' grid map is displayed as a backdrop in the map view window.



**Figure III-30. Onscreen digitizing a “town center”.**

The green circle displayed in Figure III-30, near the top of the map view window, is my point object defining the city center for Union. This location is an estimate only. Notice that the location falls on a road (roads are displayed in blue). The location of Union on the 'NMtowns' point shapes data layer is displayed with a yellow circle and labeled "Union". You can see that the point does not fall on a road.

Press the right mouse button and the option in Figure III-31.



**Figure III-31. The "Edit Selection" option.**

A check mark is displayed to the left of the phrase indicating a tool is active. When I click with the mouse pointer on the option, another dialog window displays: "Apply Changes?". There are two choices, selected with the "Yes" or "No" buttons. I choose "Yes".

Following the same on-screen digitizing process point objects are defined for the other 5 towns in the project area. The 'MPACentPNT' point shapes data layer now has six point objects, one for each town center.

3. Edit the "ID" attribute in the attribute table linked to the point shapes data layer.

The attribute table linked to the 'MPACentPnt' data layer is displayed in the work area. The data value 1 is manually keyed in as the data value for the "ID" attribute for each point object record. Once the entries are made the data layer is saved. This attribute is going to be the source for data values when the point shapes data layer is converted to a grid map. The other opportunity for entering data values for this attribute would have been during the on-screen digitizing process. I chose to wait until I had completed identifying the points and then entered the data directly into the attribute table.

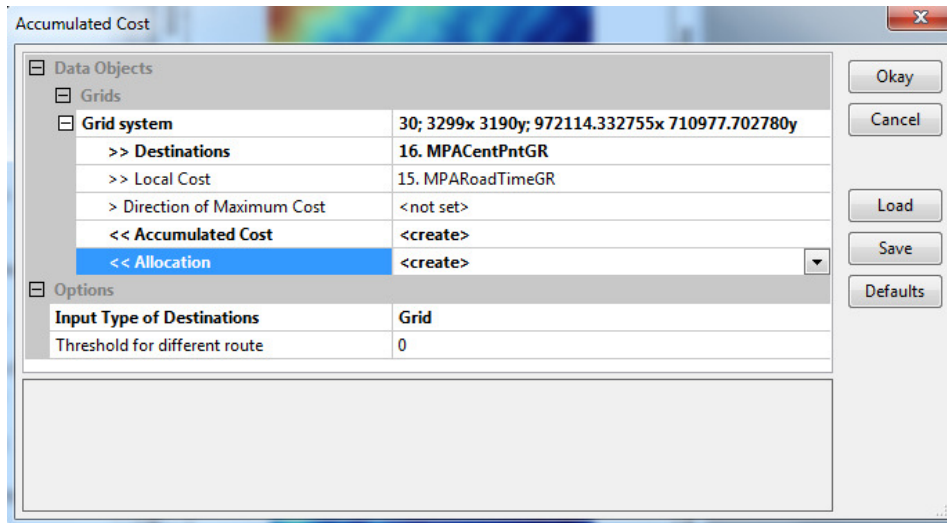
4. Convert the point shapes data layer to a grid map.

The *Grid – Gridding/Shapes to Grid* tool is used to convert the 'MPACentPnt' point shapes data layer to a grid map. The 'MPACentPnt' point shapes data layer is selected for the input parameter '>> Shapes'. The "attribute" option for the 'Output Values' parameter is chosen. Once this option is chosen, the 'Attribute' parameter becomes visible and available in the parameters window. The "ID" attribute is selected as the source of grid cell data values for the output grid map. The "grid or grid system" option is used for the 'Target Grid System' and the project area grid system chosen for the 'Grid System' parameter. The defaults for the other parameters are accepted and the tool executed.

The output default grid map is named 'MPACentPnt [ID]'. It is re-named 'MPACentPntGR' and saved to the project area storage folder. This grid map is one of the two input grid maps for the *Grid – Analysis/Accumulated Cost* tool.

The *Grid – Analysis/Accumulated Cost* tool is applied to develop what is called an accumulated cost grid map.





**Figure III-32. The *Grid – Analysis/Accumulated Cost* tool parameters window.**

The *Grid – Analysis/Accumulated Cost* tool parameters window (Figure III-32) displays the parameter entries for creating an accumulated cost grid map with the default name 'Accumulated Cost'. Grid cell data values of this map are travel times the grid cells are from the nearest of the six unincorporated towns of NM.

The 'MPARoadTimeGR' grid map is selected for the input parameter '>> Local Cost'. Recall that the water bodies of this grid map contain the no data value of -99999. This means that the water bodies of the output grid maps produced by this tool also contain the no data value -99999. Each road grid cell in the input layer contains a data value for the travel minutes it takes a vehicle to traverse the grid cell moving at the road speed limit. The value .068182 is the travel time in minutes, at 5 miles per hour, for off-road grid cells.

This tool supports grid map or point shapes data layer inputs for the '>> Destinations' input parameter. The type of input is chosen in the 'Input Type of Destinations' parameter. There are two options: Grid or Points. The "Grid" type of input is selected. The input parameter '>> Destinations' appears in the "Grids" section of the parameters window. The 'MPACentPntGR' grid map is entered for the parameter. This is the grid map containing the six town center points. All the grid cells in the layer contain no data values (-99999) except for the six single cells for the town centers and they each contain a 1 that identifies the grid cell locations of the six unincorporated towns in the project area.

When the "Points" option is chosen for the 'Input Type of Destinations' parameter', a "Shapes" section appears in the parameters window that includes an input parameter '>> Destinations'. The value field to the right of it would be for choosing a point shapes data layer for destinations.

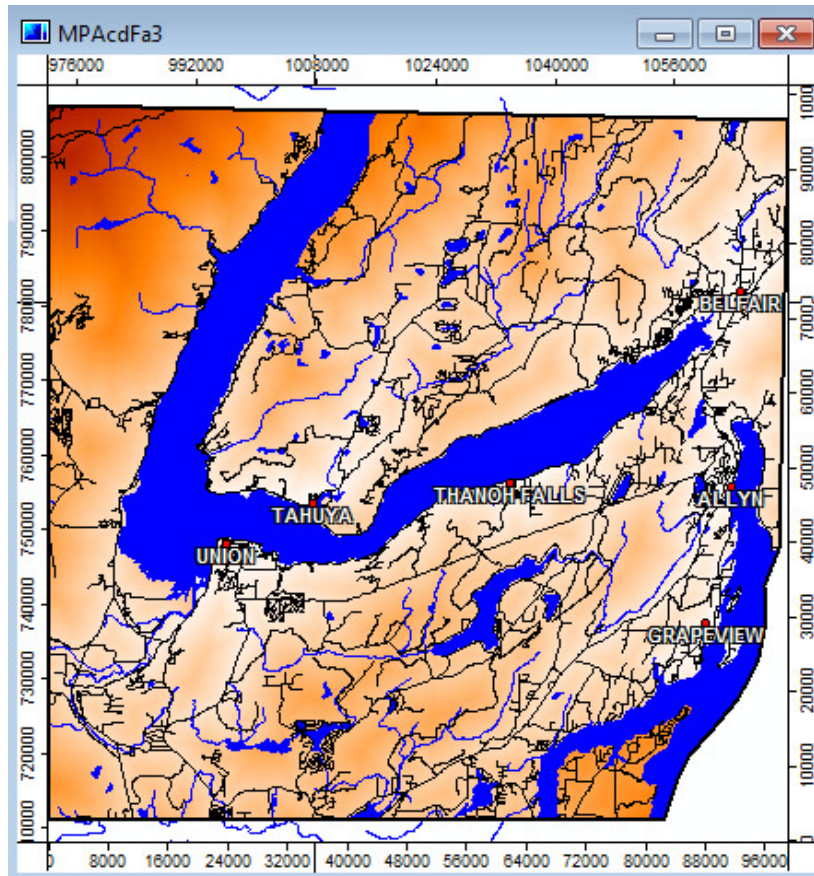
The input parameter '> Direction of Maximum Cost' is used when the "anisotropic" approach for calculating an accumulated cost grid map is needed. This approach is used when a directional factor is considered along with the data of the local cost grid map. The "<not set>" default option is used for this parameter when the "isotropic" approach is used.

The default entry for the output parameter '<< Accumulated Cost' is "<create>". The data values of this output grid map are accumulated times, in minutes, from the nearest town center. The other output grid map created by this tool ("Allocation") is for identifying the nearest point (city center) to each grid cell. This output is created, by default using the "<create>" option since there is not a "<not set>" option available for the parameter. Since it is not needed, once the grid map is created it is deleted.

Once the parameter entries are made the 'Okay' button is clicked on and the tool executes producing the default grid maps 'Accumulated Cost' and 'Allocation'. As the 'Allocation' grid map is not needed I delete it. The water body grid cells of the 'Accumulated Cost' grid map contain the no data value -1.

Prior to saving the output data layer 'Accumulated Cost', the *Grid - Tools/Grid Masking* tool is applied to discard data values occurring outside of the irregular shape of the project area but within the spatial extent of the grid system. The project area grid system is chosen for both 'Grid system' input parameters as both the 'Accumulated Cost' and 'MProjAreaGR' data layers are members of this system. The 'MProjAreaGR' grid map is the grid version of the polygon shapes data layer 'MProjArea'. I choose the output grid data layer from the *Grid - Analysis/Accumulated Cost* tool, 'Accumulated Cost', for the input parameter '>> Grid' and the 'MProjAreaGR' layer for the input parameter '>> Mask'. I click on the 'Okay' button and the tool executes. The no data value -1 is replaced on the output grid map with the no data value -99999.

The output 'Masked Grid' grid map is re-named 'MPAcFa3' and saved. Figure III-33 displays the 'MPAcFa3' grid map.



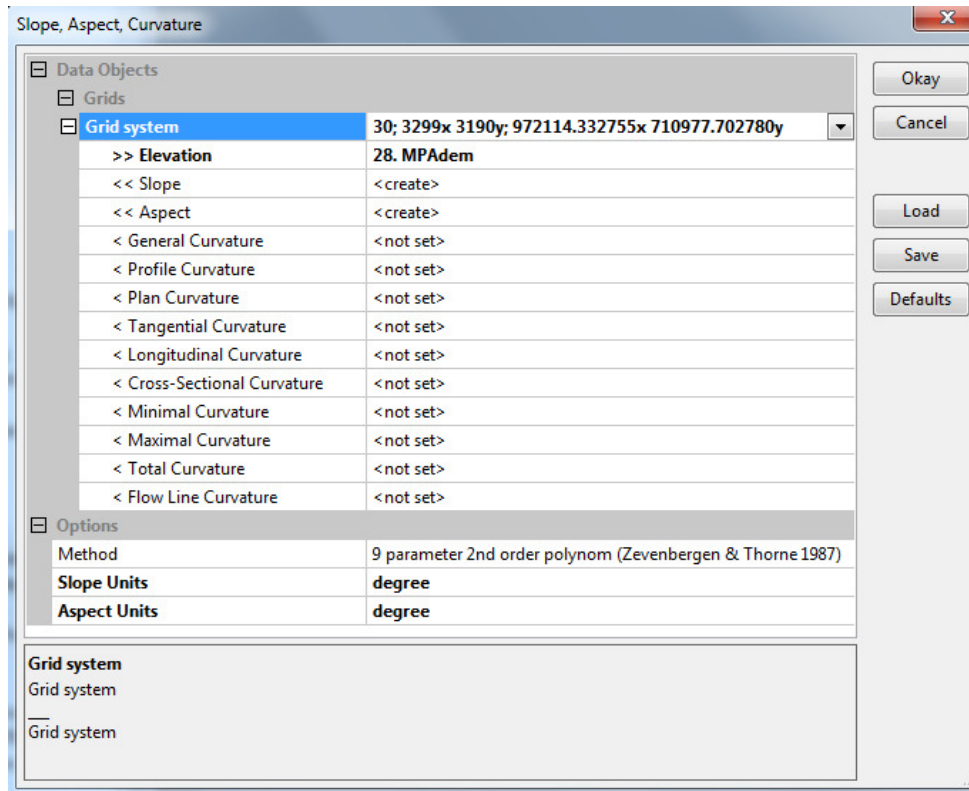
**Figure III-33. The ‘MPAcFa3’ travel time grid map.**

Grid cells in the map view window in Figure III-32 that are nearer city centers have a lighter shade compared to grid cells more distant. Distance from city centers is determined by travel time.

### **The Slope Factor**

The last of the factors related to residential building costs is slope. Home building costs are lower on low slope gradient. A slope gradient grid map can easily be created from a digital elevation model using the SAGA tool *Terrain Analysis – Morphometry/Slope, Aspect, Curvature*. The digital elevation model grid data layer for the project area is named 'MPAdem'. This grid map is chosen for the '>> Elevation' input parameter.

Figure III-34 displays the parameters page for this tool.



**Figure III-34.** The parameters page for the *Terrain Analysis – Morphometry/Slope, Aspect, Curvature* tool.

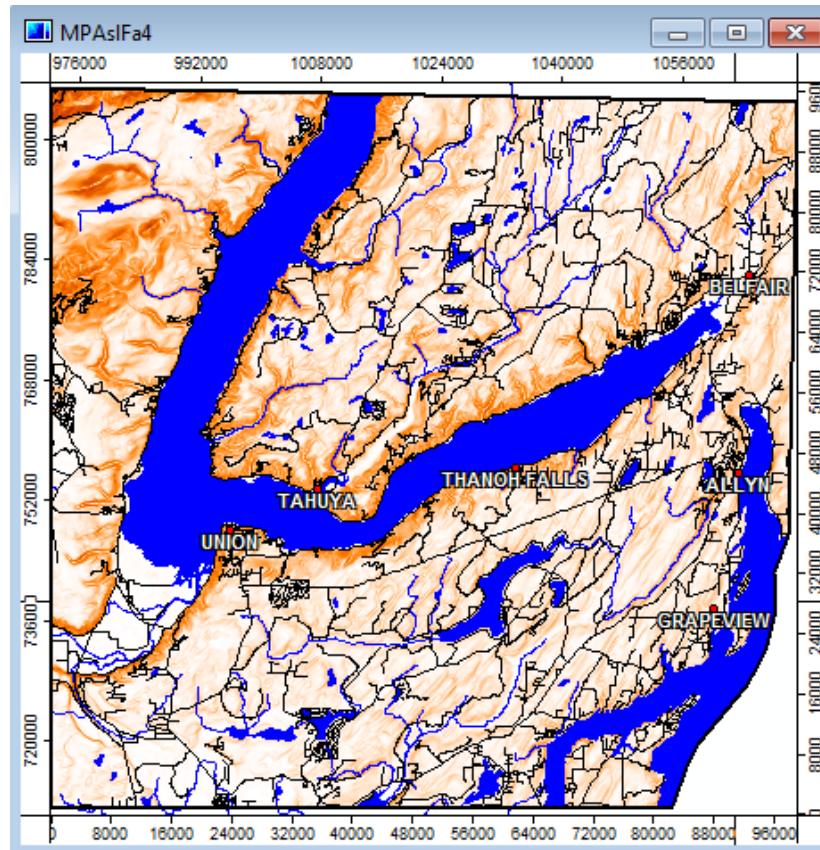
This tool supports the creation of twelve types of output grid maps from a DEM. Two of the outputs are required: slope and aspect. Their default entries are “<create>”. The other nine outputs are optional. I accept the default choices for the '<< Slope' and '<< Aspect' and the other output parameters.

In the 'Options' section, near the bottom of the parameters window, you see three option parameters. The default "9 parameter 2nd order polynom (Zevenbergen & Thorne 1987)" is identified for the 'Method' parameter. There are three choices for the 'Slope Units' parameter : radians, degree, and percent. The "degree" option is chosen. The aspect output will not be used so it makes no difference which units option is used for it. The default for aspect is "radians". The default name for the slope output grid map is 'Slope'. I click on the 'Okay' button and the tool executes.

Before re-naming the 'Slope' grid map, the *Grid - Tools/Grid Masking* tool is going to be applied to discard any data values in grid cells that fall outside of the irregular boundary of the project area. This tool has been used several times in the tutorial for this purpose.

The 'Slope' grid map is chosen for the '>> Grid' input parameter and the 'MProjAreaGR' layer used for the '>> Mask' input parameter. I click on the 'Okay' button and the tool executes.

The new masked grid map is named 'Grid Mask'. I re-name it 'MPAslFa4' and save it to the project area storage folder. Figure III-35 displays the 'MPAcdFa3' grid map.



**Figure III-35. The Slope Factor grid map.**

Grid cells in the map view window in Figure III-35 having a lower slope are displayed in a lighter shade compared to grid cells on steeper slopes.

### **The Distance from Water Factor**

Groundwater contamination from waste disposal systems and other residential non-point source pollution is a major concern for residents near the Puget Sound and in Mason County in Washington state. Groundwater data is not available. Open water, major streams and wetlands can be used as surrogates for the groundwater concern. Distance from these features is one of the two remaining factors.

Environmentalists argue that new residential development should occur as far as possible from the already protected open water and wetland areas. Distance away from the established protected areas around open water, major streams and wetland areas can be calculated using the *Grid – Tools/Proximity Grid* tool.

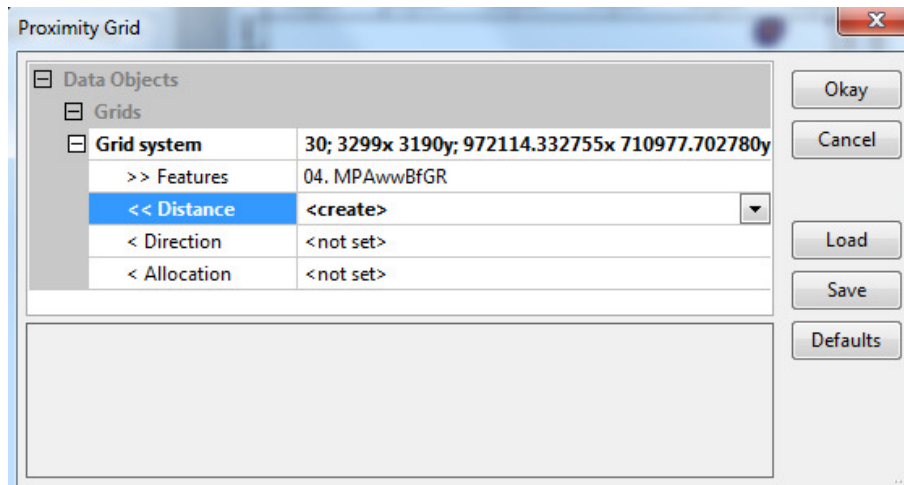
Earlier, a grid data layer for a 180-foot wide buffer around all bodies of water, major streams and wetlands was created named 'MPAwwBfGR'. Water, major streams and wetlands are features of this grid map with grid cells containing the data value 2. The



180-foot buffer areas are coded with 1's. All other grid cells of the map, grid cells that are not features or in the buffer area, contain the no data value 0.

The grid map 'MPAwwBfGR' is the input grid map to the *Grid – Tools/Proximity Grid* tool. Grid cell data values on the output grid map produced by the tool identify how far the grid cell is to the nearest buffer areas of protected water body, major stream or wetland. Thus, the grid cells on the 'MPAwwBfGR' grid map containing the no data value 0, will on the output grid map have data values for how far the grid cell is from the buffer area surrounding features.

Figure III-36 displays the parameters window for the *Grid – Tools/Proximity Grid* tool..



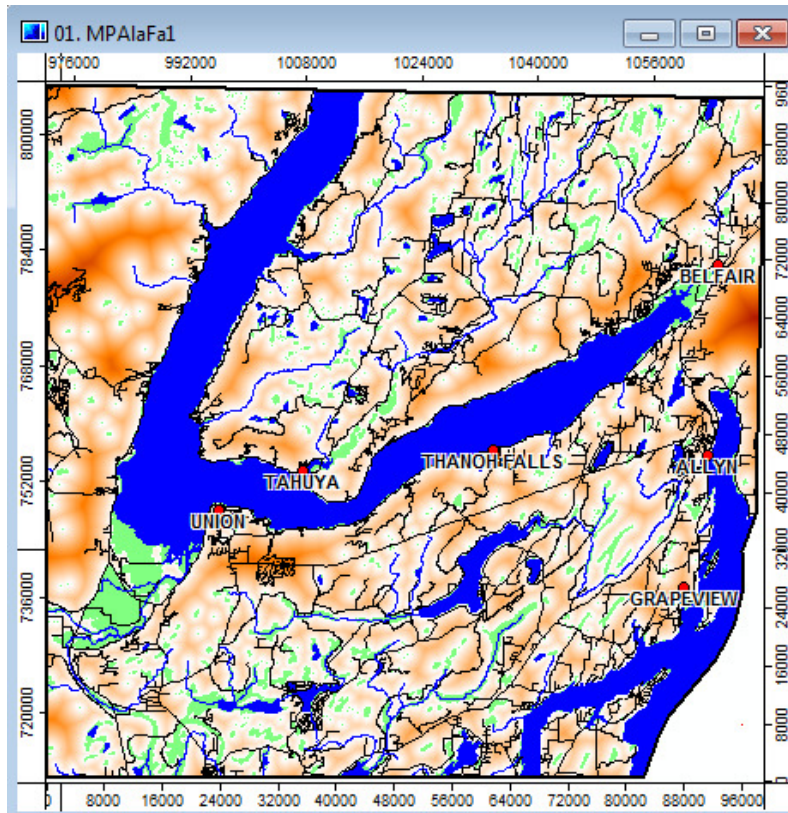
**Figure III-36. The *Grid – Tools/Proximity Grid* tool parameters for producing the 'MPAwwBfGR' grid map.**

The 'MPAwwBfGR' grid data layer, created earlier in this process with the *Grid - Tools/Grid Buffer* tool, is chosen for the input parameter '>> Features'. The default "<create>" option is used for the output parameter '<< Distance'. The default name for the output grid data layer is 'Distance'. I click on the 'Okay' button with the mouse pointer and the tool executes.

The 'Distance' grid map includes valid data values in grid cells outside of the irregular outline of the project area but within the spatial extent of the grid system. Before saving the 'Distance' grid map, the *Grid - Tools/Grid Masking* tool is going to be applied to discard any data values in grid cells that fall outside of the irregular boundary of the project area. The *Grid - Tools/Grid Masking* tool is used to replace these valid data values with the no data value -99999.

The 'Distance' grid map is chosen for the '>> Grid' input parameter and the 'MProjAreaGR' layer used for the '>> Mask' input parameter. I click on the 'Okay' button and the tool executes.

The new masked grid map is named 'Grid Mask'. It is re-named 'MPApdFa5' and saved to the project area storage folder. Each grid cell on this layer that is not a feature or a buffer area for a feature contains a distance value for how far the grid cell is from the nearest buffer area around a water, major stream, or wetlands feature. Figure III-37 displays the 'MPApdFa5' grid map.



**Figure III-37. The *Distance from Water Factor* grid map.**

In the map view window in Figure III-36, grid cells nearer to water (water bodies, major streams and wetlands) are displayed in a lighter tone while grid cells more distant from these features have more of a reddish tint. Water is displayed in blue and wetlands in green.

#### **The Distance from Developed Land Factor**

The last of the factors is also an environmental concern. The county commissioners prefer that new residential development occur near currently developed land. This would keep isolated, remote areas that are good for wildlife, distant from any development.

Earlier a polygon shapes data layer for land use in the project area named 'MPAInduse2' was created. The *Distance from Developed Land Factor* grid map is going to be created from a new version of this data layer named 'MPAInduse3'. Here is how I create this new data layer.

In the 'Data' tab area of the Manager Window, I click on the data layer name 'MPAInduse2'. A pop-up list of options displays. The "Save as..." option is chosen on the list. I navigate to the project area storage folder and enter the new data layer name "MPAInduse3" in the "File name:" data entry box and click on the 'Save' button. This saves the new version of the 'MPAInduse2' data layer. The 'MPAInduse2' data layer still exists and is available in the work session. I use the "Load" function available from the "File" Menu Bar list of options to load the new 'MPAInduse3' polygon shapes data layer into the current work session.

Like the data layer it is copied from, this new data layer contains 58 multi-polygon polygon objects, each one representing a unique land use class. A new attribute named "DEVSTATUS" is needed in the attribute table linked to this data layer. This attribute identifies whether a land use class is a developed land use class (coded with 1) or not (contains a 0).

The attribute table linked to the 'MPAInduse3' data layer is displayed in the work area. Using the column tool "Add Field" the new attribute "DEVSTATUS" is added following the existing "AVAILSTATUS" attribute. The "signed 8 byte integer" data type is chosen for the 'Field Type' parameter. I click on the 'Okay' button and the new attribute is added into the attribute table and is populated by integer 0's.

I manually key in 1's for the "DEVSTATUS" attribute for "GENUSE" classes 10 through 80, 81, 82, and 83. These are the land uses considered to be developed land uses. Land use classes 88, 90, 91, 92, 93, 95, and 99 contain 0's. These are the land uses considered to be not developed. Once the entries are made the data layer is re-saved.

The *Grid - Gridding/Shapes to Grid* tool is used to create a new grid map that contains 1's for grid cells in land use classes considered as developed land uses and 0's for grid cells in land uses considered as not developed. The 'MPAInduse3' polygon shapes data layer is chosen for the input parameter '>> Shapes' in the parameters window for the *Grid - Gridding/Shapes to Grid* tool. After choosing the "attribute" option for the 'Output Values' parameter, the "DEVSTATUS" attribute is selected from the list of available attributes for the 'Attribute' parameter. This attribute is the source of data values on the output grid map.

The "grid or grid system" option is identified for the 'Target Grid System' parameter and the project area grid system "30: 3299x 3190y; 972114.332744x 710977.702780y" is chosen. The default "<create>" is used for the output parameter '<< Grid'. I click on the 'Okay' button and the tool executes. I re-name the default output 'MPAInduse3 [DEVSTATUS]' grid map 'MPAdevGR' and save it.

This new grid map is going to provide the features from which to calculate distance to no data grid cells. The *Grid - Tools/Proximity Grid* tool calculates distance from features to grid cells containing the no data value, in this case, a no data value of -99999. There are two data values for the 'MPAdevGR' grid map, 1's and 0's. The data value 1 identifies land areas considered to be in a developed land use class. These areas would be the



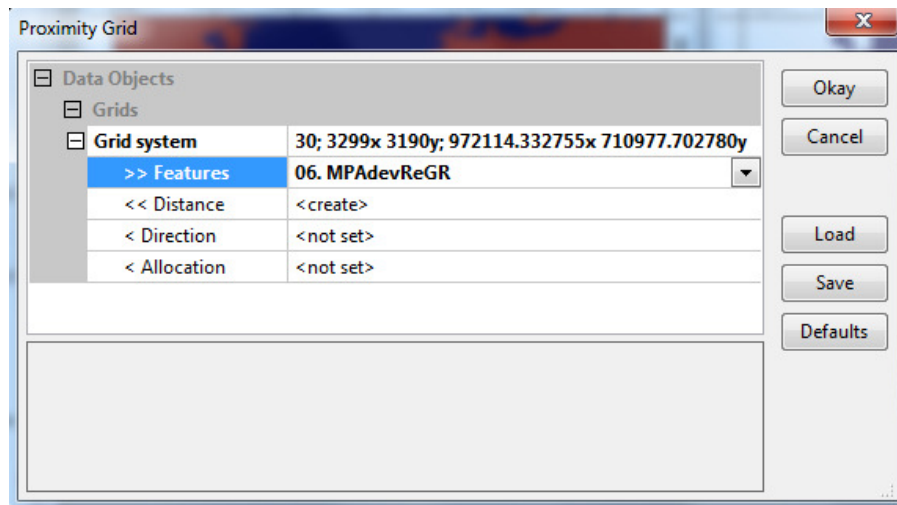
"features" for the *Grid – Tools/Proximity Grid* tool. The data value 0 identifies grid cells in a land use considered not developed.

This factor identifies distance from already developed land areas. The tool calculates from the features (land uses coded with 1's) to no data value grid cells. Since 0 on this grid map is a valid data value and is not a no data value it needs to be converted to a no data value of -99999. Therefore, in order for the *Grid – Tools/Proximity Grid* tool to properly calculate distances from already developed land uses (grid cells containing the data value of 1), the grid cells containing 0 representing not developed must be recoded from 0 to the no data value -99999 using the *Grid - Tools/Reclassify Grid Values* tool.

The 'MPAdevGR' grid map is chosen for the input parameter '>> Grid' in the parameters window for the *Grid - Tools/Reclassify Grid Values* tool. The default "<create>" option is accepted for the output parameter '<< Reclassified Grid'. A single data value, 0, is to be changed on the input grid map. The "single" option is used for the 'Method' parameter. I type in 0 for the value field to the right of the 'old value' parameter and -99999 for the 'new value' input parameter. The default "=" is accepted for the 'operator' parameter. I click on the 'Okay' button and the tool executes using my entries.

The default name for the output grid map is 'MPAdevGR\_reclassified'. It is re-named 'MPAdevReGR' and saved.

The *Grid – Tools/Proximity Grid* tool is executed using the 'MPAdevReGR' grid map as the feature grid map and the output grid map is to be named 'MPAddFa6'. Figure III-38 displays the parameters page for the *Proximity Grid* tool.



**Figure III-38. The parameter entries for creating the interim distance from developed land grid map.**

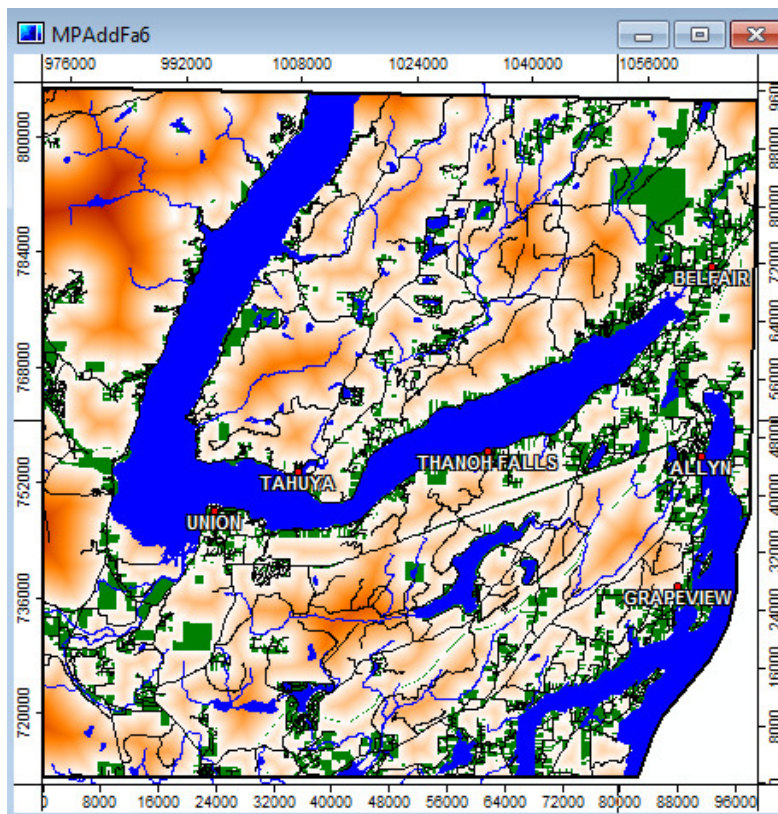
The 'MPAdevReGR' grid map is chosen for the input '>> Features' parameter. The default "<create>" option is accepted for the output parameter '<< Distance' and the defaults ("<not set>") for the remaining parameters. I click on the 'Okay' button and the tool

executes. The default name for the output grid map is 'Distance'.

As with several other factor grid maps, the *Grid - Tools/Grid Masking* tool is going to be applied to the 'Distance' grid map to discard data values occurring in grid cells outside of the irregular outline of the project area. These valid data values are converted to no data values.

The grid system for the project area is chosen for the 'Grid system' parameter in the parameters window for the *Grid Masking* tool. The default output from the *Grid - Tools/Proximity Grid* tool, 'Distance' grid map, is chosen for the input parameter '>> Grid'. The "<create>" option is used for the output parameter '< Masked Grid'. The 'MProjAreaGR' grid map identifies grid cells within the irregular shape of the project area. This map is chosen for the input parameter '>> Mask'. I click on the 'Okay' button and the tool executes.

I re-name the default 'Masked Grid' to 'MPAddFa6' and save it. Figure III-39 displays the 'MPAddFa6' grid map.



**Figure III-39. The *Distance from Developed Land Factor* grid map.**

Grid cells in the map view window in Figure III-39 displaying in green identify developed land class areas. Grid cells that are nearer to the developed land class areas have a lighter shade compared to grid cells more distant. Water areas are displayed in blue and the road network is in black.

### **Summary of the Constraint and Factor Grid Maps**

The eight criteria grid data layers used as inputs to the land allocation process for residential development have now been developed. The first two are constraints that represent county development restrictions and land that is currently developed which cannot be considered for residential development. The remaining criteria are factors, four related to building costs and two related to wildlife habitat concerns. These factors will determine the suitability of non-constrained land.

The treatment of the six factors varies depending on the MCE approach. For example, in the Boolean approach, the factors are applied in the same manner as constraints using 1's for identifying suitable areas and 0's for not suitable areas. The constraints are rescaled to value ranges representing degrees of suitability for the WLC and OWA techniques.

Here is a brief summary of these eight constraint and factor grid data layers.

#### **Open Water and Wetlands Constraint, MPAwCo1**

A county development restriction. Residential development cannot occur in these areas or within 180' of these features. "Open Water and Wetlands" are defined as bodies of water and major streams plus wetlands. A 180' buffer is delineated around these features. Available areas, that is areas that are not features and within 180' of features, are coded with 1's. Unavailable areas are coded with 0's. These areas are features and land within 180 feet of the features.

#### **Land Use Constraint, MPAluCo2**

A county development restriction. Land use classes not available for development (because they are already developed) are Residential (10), Commercial 1 (20), Commercial 2 (30), Transportation (40), Trade (50), Services (60), Recreation (70), Resource - Other (80), Undeveloped - Other (90), and Unclassified (99). These classes are coded with 0's.

Note that Undeveloped - Other (90) includes water areas and open space areas and Resource - Other (80) includes Resource - Fishing (84) and Resource - Mining (85).

Land use classes available for development (because they are not considered to be developed) are Resource - Agriculture (81), Resource - Agriculture Activities (82), Resource - Agriculture Current Use (83), Resource - Designated Forest Land (88), Undeveloped - Land (91), Undeveloped - Noncommercial Forest (92), Undeveloped - Timberland (95). These classes are coded with 1's.

#### **Land Use Factor, MPAlaFa1**

Related to residential building costs. Land use classes representing available lands are coded with their specific land use class code. These codes are:

Resource - Agriculture (81)

Resource - Agriculture Activities (82)

Resource - Agriculture Current Use (83)  
Resource - Designated Forest Land (88)  
Undeveloped - Land (91)  
Undeveloped - Noncommercial Forest (92)  
Undeveloped - Timberland (95)

All other land use classes are coded with 0's.

Distance from Roads Factor, MPAsdFa2

Related to residential building costs. Grid cells of this factor grid map identify the distance each grid cell is from the nearest road.

Travel Time from Town Centers Factor, MPAdFa3

Related to residential building costs. Grid cells of this factor grid map identify the travel time each grid cell is from the nearest town center.

Slope Factor, MPAslFa4

Related to residential building costs. Grid cell data values are slope in degrees.

Distance from Water Factor, MPApdFa5

Related to wildlife preservation. Grid cell data values identify the distance in feet each grid cell is from the 180' buffer surrounding water bodies, major streams, and wetlands.

Distance from Developed Land Factor, MPAddFa6

Related to wildlife preservation. Grid cells in a land use class considered developed contain the data value 1. These are the following land use classes:

Residential (10)  
Commercial 1 (20)  
Commercial 2 (30)  
Transportation (40)  
Trade (50)  
Services (60)  
Recreation (70)  
Resource - Other (80)  
Resource - Agriculture (81)  
Resource - Agriculture Activities (82)  
Resource - Agriculture Current Use (83)

Note that in the Resource - Other (80) are developed areas for fishing and mining.

Grid cells in land use classes considered as not developed contain the no data value - 99999.

References

U.S. Fish and Wildlife Service, National Wetland Inventory mapping system.

#### **IV. Boolean Aggregation Method**

Let's explore the Boolean aggregation method of multi-criteria evaluation. This approach is widely used and forms the basis of many GIS supported spatial analyses. It is often referred to as constraint mapping. Before criteria can be combined and compared with each other in any MCE, they need to be standardized to some scale of suitability.

In order to differentiate from the original grid maps prepared in section **III. Constraints and Factors**, Boolean factor data layers created in this section have the letter "B" as a prefix to the layer name.

##### **Factor, Constraint Grid Map Standardization**

Standardization, in the Boolean case, means that all factor grid maps must be converted to Boolean or binary grid maps of areas suitable (coded with 1's) and not suitable (coded with 0's).

The previous tutorial section described the preparation of two constraint and six factor grid maps. Constraints are Boolean criteria that constrain, or limit the spatial solution to particular geographic regions. In this case, the two constraints relate to county regulations prohibiting development within 180 feet of water, major streams and wetlands and in land uses considered as already developed.

Factors are criteria that define some degree of suitability for all geographic regions. They define areas or alternatives in terms of a continuous measure of suitability that enhances or detracts from the alternatives under consideration outside the areas that have been constrained, e.g., proximity to some feature such as a road and major stream or steepness of slope. However, due to how the Boolean approach is applied, i.e., binary 1 or 0, Boolean factor grid maps behave in the same manner as and have the same consequence as constraint grid maps.

All of the factor grid maps are converted into constraints. Converting all criteria to Boolean grid maps containing 1's and 0's allows them to be easily aggregated into a final solution using basic Boolean algebra supported in the *SAGA Grid – Calculus/Grid Calculator* tool.

The constraint grid maps previously created, 'MPAwCo1' and 'MPAluCo2', are applied as they exist. Areas coded with 1's on these two layers are suitable and areas with 0's are not suitable. The factor grid maps need to be converted to Boolean maps where the data value 1 means suitable and the data value 0 means not suitable. The factor grid maps have the same effect as the two constraint layers.

Converting the factor maps to Boolean format involves making hard decisions related to the guidelines presented earlier for their creation. These decisions differentiate areas suitable for development and areas not suitable for development.

The following discussion describes the decision rules for our criteria.

## **Criteria Decision Rules**

### **Land Use Factor**

Parcels in seven land use classes are available for development. These land use classes have been ranked by developers in terms of suitability: Resource - Agriculture (81), Resource - Agriculture Activities (82), Resource - Agriculture Current Use (83), Resource - Designated Forest Land (88), Undeveloped - Land (91), Undeveloped - Noncommercial Forest (92) and Undeveloped - Timberland (95).

A decision is needed as to which of the land use classes available for development are considered suitable for residential development by developers and which are not suitable. Developers want to use the average per acre market value for each land use class for this determination. The lowest average per acre market value is most suitable and the highest value is least suitable and the other land use classes are ranked in between accordingly.

Table III-2 displays a list of land uses available for development ordered from lowest average per acre market value to highest average per acre market value. The average per acre market values for Resource - Agriculture (81), Undeveloped - Noncommercial Forest (92), and Resource - Designated Forest Land (88) are the lowest and least expensive for the seven land use classes. Of the seven available land use classes, these three are considered suitable for residential development by developers. The 'MPAlaFa1' grid map is used as input to create a new grid map containing only these three land use classes. The grid cells in the grid map for the three land use classes contain 1's representing suitable; cells in other land uses that are available for development contain 0's representing not suitable.

### **Distance from Roads Factor**

The cost for residential development increases the further you are from existing roads. Thus, areas closer to roads are more suitable than those that are distant. However, for a Boolean analysis the suitable grid cells of a factor grid map involving distance from roads must be delineated by a definite distance value. I reclassify my grid map of distance from roads such that areas within 1200 feet of any road are suitable (coded with 1's) and those beyond 1200 feet are not suitable (coded with 0's). The 'MPAsdFa2' grid map is used to create this new layer.

### **Distance to Town Centers Factor**

The developers assume that most residents want to be close to the amenities offered by town centers. Homes close to the six town centers may produce higher revenue for developers. Distance from town centers is a function of travel time on area roads and on future constructed access roads in off-road areas. Developers are most interested in areas within 10 minutes driving time of town centers, so I will reclassify the travel distance grid map ('MPAcFa3') such that any grid cell is suitable if it is within 10 minutes travel time of one of the six town centers. Grid cells further than 10 minutes travel time are not suitable and those grid cells contain 0's.

### Slope Factor

Because low slope gradient reduces home and road construction costs, I reclassify my slope data layer so that grid cells with slopes less than or equal to 8 degrees are suitable (grid cells will contain 1's) and those greater than 8 degrees will be considered unsuitable (grid cells will contain 0's). The 'MPAslFA4' grid map is the input layer for creating this factor.

### Distance from Water Factor

Local groundwater is at risk from septic system pollution and runoff. Environmentalists have pointed out that areas further from water bodies, major streams and wetlands are more suitable for residential development than those that are close. A 180-foot buffer already protects areas close to water bodies, major streams and wetlands. However, environmentalists would like to see the protection buffer extended another 180 feet. In this case, suitable areas have to be at least 360 feet from any water body, major stream or wetlands feature of the 'MPAwatwetRcGR' grid map. This particular grid map was developed during the creation of the 'MPApdFa5' grid map for the Distance from Water Factor.

### Distance from Developed Land Factor

Grid cells within 1200 feet of developed land are considered best for new development by environmentalists interested in preserving isolated wildlife habitat. Eleven land use classes are considered as developed land. These classes are Residential (10), Commercial 1 (20), Commercial 2 (30), Transportation (40), Trade (50), Services (60), Recreation (70), Resource - Other (80), Resource - Agriculture (81), Resource - Agriculture Activities (82) and Resource - Agriculture Current Use (83). Distances on the 'MPAddFa6' factor grid map are reclassified so that grid cells within 1200 feet of developed land use classes are suitable and have data values of 1. Grid cells further than 1200 feet from developed land use classes are unsuitable and have the data value 0.

The 'MPAddFa6' grid map is used for developing this factor grid data layer.

The layer naming structure for the new Boolean data layers along with the corresponding factor data layer names and decision rules are displayed in Table IV-1.

**Table IV-1: Boolean Factor Maps and Decision Rules**

Factor Data Layer	Boolean Data Layer	Decision Rule
MPAlaFa1	BlaSuit	Forest and Open Undeveloped
MPAsdFa2	BsdRoads	Within 1200 feet of roads
MPAcdfFa3	BcdTime	Within 10 minutes of town center
MPAslFa4	BslSlope	< than 8 degree slope
MPAwatwetRcGR	BpdWater2	> than 360 feet from water, major streams and wetlands
MPAddFa6	BpdDev	< than 1200 feet from developed areas

The two constraint layers, ‘MPAwCo1’ and ‘MPAluCo2’, retain their original names. These two layers are used as constraint layers in each method discussed in this tutorial.

### **Land Use Factor**

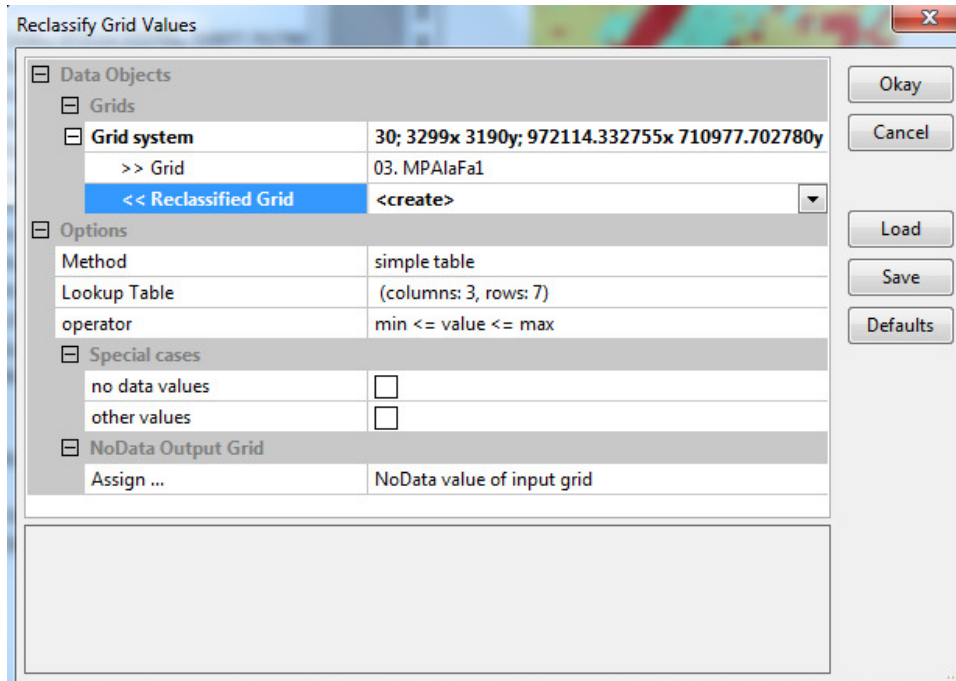
Parcels in seven land use classes are available for development. These land use classes are considered available for development: Resource - Agriculture (81), Resource - Agriculture Activities (82), Resource - Agriculture Current Use (83), Resource - Designated Forest Land (88), Undeveloped - Land (91), Undeveloped - Noncommercial Forest (92) and Undeveloped - Timberland (95). The numbers in parentheses are the data values used for the land use classes on the ‘MPAlaFa1’ grid map.

Developers have made a hard decision as to which of the seven available land use classes are most suitable for residential development and which are not suitable. Of the seven categories of available land, three are considered most suitable by developers. They base suitability on the average per acre market value of parcels in each land use classification (see Table III-2 earlier in this document). The three land use classes with the lowest average per acre market value are Resource - Agriculture (81), Undeveloped - Noncommercial Forest (92), and Resource - Designated Forest Land (88).

The Resource - Agriculture (81), Undeveloped - Noncommercial Forest (92), and Resource - Designated Forest Land (88) data values of 81, 92, and 88 on the ‘MPAlaFa1’ grid map are reclassified as 1’s to indicate suitability. All other grid cells will have 0 values.

The *Grid – Tools/Reclassify Grid Values* tool is used to develop the Boolean suitable and unsuitable grid maps for available land use classes. Figure IV-1 displays the parameters page for the tool.





**Figure IV-1. The reclassify parameter entries for the 'MPAlaFa1' grid map.**

The input grid map for the '>> Grid' parameter is the factor grid map 'MPAlaFa1'. This layer has seven data values: 81 for Resource - Agriculture, 82 for Resource - Agriculture Activities, 83 for Resource - Agriculture Current Use, 88 for Resource - Designated Forest Land, 91 for Undeveloped - Land, 92 for Undeveloped - Noncommercial Forest and 95 for Undeveloped - Timberland. The data value 0 is used for all other land uses.

The grid map to be developed from 'MPAlaFa1' has 2 data values: 1 for suitable and 0 for not suitable. The suitable category consists of the land use classes Resource - Agriculture, Undeveloped - Noncommercial Forest, and Resource - Designated Forest Land. These land use class data values (81, 92 and 88) are recoded to 1's. The other four land use classes Resource - Agriculture Activities, Resource - Agriculture Current Use, Undeveloped - Land, and Undeveloped - Timberland with data values 82, 83, 91, and 95 are recoded as not suitable with new data values of 0.

I choose the "simple table" option for the 'Method' parameter. Figure IV-2 displays the simple table used.

	minimum	maximum	new
1	81.000000	81.000000	1.000000
2	82.000000	82.000000	0.000000
3	83.000000	83.000000	0.000000
4	88.000000	88.000000	1.000000
5	91.000000	91.000000	0.000000
6	92.000000	92.000000	1.000000
7	95.000000	95.000000	0.000000

**Figure IV-2. The simple table to recode land use classes.**

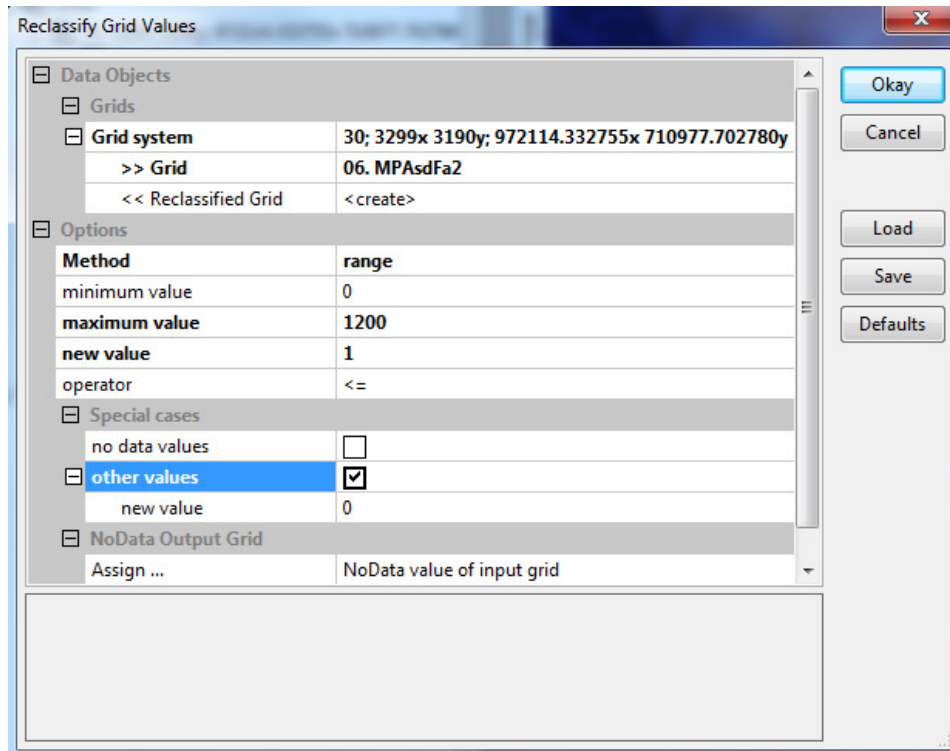
The simple table clearly displays how the seven land use codes are reclassified to 1's and 0's by the "new" column entries. I click on the 'Okay' button and return to the parameters window in Figure IV-1. The "<= value <= max" option is chosen for the 'operator' parameter. All of my parameter entries are done and I click on the 'Okay' button and the tool executes.

The default name for the output grid map is 'MPAlaFa1\_reclassified'. I re-name it 'BlaSuit' and save it to the project area storage folder. Suitable areas for residential development on the 'BlaSuit' grid map are coded with 1's, not suitable areas with 0's.

### **Distance from Roads Factor**

Residential development costs can be lower when development happens on or near existing roads. Thus, areas closer to roads are more suitable than distant areas.

The *Grid – Tools/Reclassify Grid Values* tool is applied to reclassify the grid map for distance from roads ('MPAsdFa2') such that grid cells within 1200 feet of any road are suitable (using data value 1) and those beyond 1200 feet are not suitable (using data value 0). The parameters page for this execution of the *Reclassify Grid Values* tool is displayed in Figure IV-3.



**Figure IV-3. The parameters window for reclassifying the distance from roads grid map.**

The input grid map for the '>> Grid' parameter is the factor grid map 'MPAsdFa2'. This is a distance grid map created with the *Grid – Tools/Grid Proximity Buffer* tool. Distances were calculated from the road features grid cells on the layer to all non-feature grid cells.

The "range" option is selected for the 'Method' parameter. The data range for recoding is defined by data values 0 and 1200 entered for the 'minimum value' and 'maximum value' parameters. A 1 is entered in the value field to the right of the 'new value' parameter. The "<=" option is chosen for the 'operator' parameter. Data values greater than 1200 are considered "other values". I check the box to the right of the 'other values' parameter and enter 0 for the 'new value' parameter in the next row below. I click on the 'Okay' button and the tool executes.

The default output grid map is named 'MPAsdFa2\_reclassified'. The output grid map from the *Grid – Tools/Reclassify Grid Values* tool uses 1's for suitable areas and 0's for not suitable area. I re-name it to 'BsdRoads' and save it.

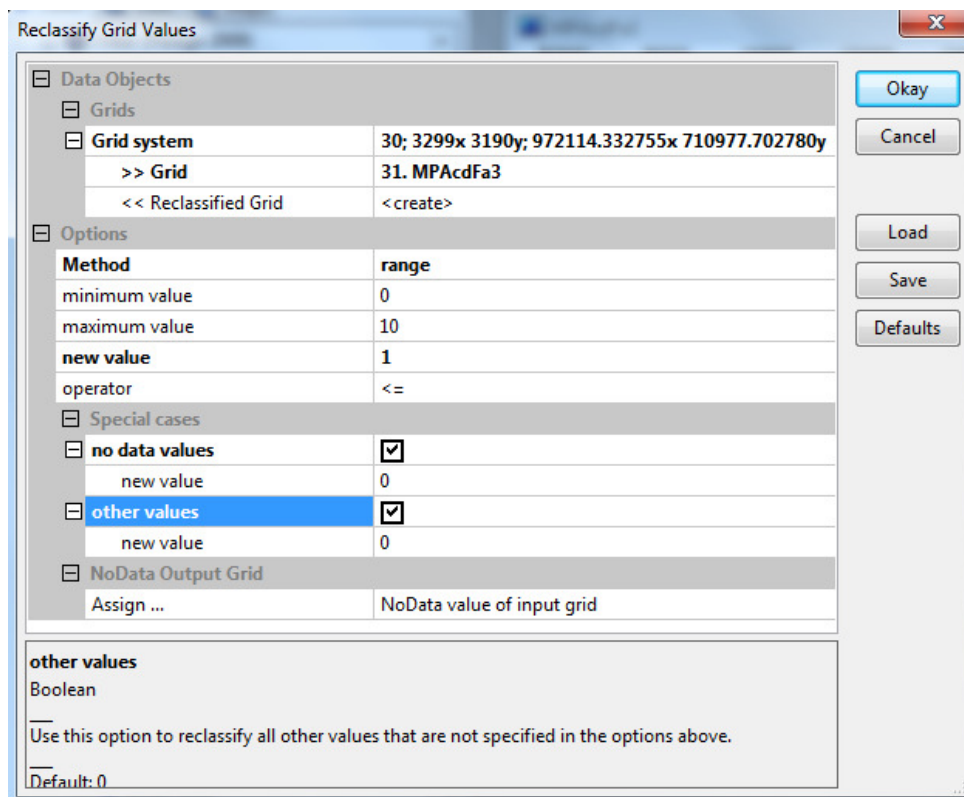
### **Distance to Town Centers Factor**

Distance to the six town centers is measured by travel time on roads and potential new access roads. Developers are most interested in areas within 10 minutes driving time of the six town centers.

Data values for grid cells in the 'MPAcdFa3' grid map identify the accumulated driving time, in minutes, each cell is from the nearest town center. The designated road speed limit is the travel speed used for calculating travel time for each road grid cell. Off-road grid cells (potential new access roads) assume a speed of 5 miles per hour. It takes .068182 minutes, at 5 miles per hour, to cross a 30' grid cell. Table III-3, earlier in this document, identifies the fractional minutes for traversing a 30' grid cell at the various posted speeds.

The *Grid – Tools/Reclassify Grid Values* tool is used to reclassify the travel time grid cells of the 'MPAcdFa3' factor grid map into 0's and 1's. All accumulative times of 10 minutes or less are recoded with the value 1 for suitable areas. Times greater than 10 minutes are reclassified with the value 0 for not suitable areas. Water bodies are coded with the no data value -99999 on the 'MPAcdFa3' grid map. These grid cells are recoded to 0.

The parameters page for the *Grid – Tools/Reclassify Grid Values* tool is displayed in Figure IV-4.



**Figure IV-4. The *Grid – Tools/Reclassify Grid Values* tool parameters window for creating the 'BcdTime' grid map.**

The input grid map is 'MPAcdFa3'. The "<create>" option is chosen for the '<< Reclassified Grid' parameter and the "range" method is used for the 'Method' parameter. The data range is defined as 0 to 10 by a 0 for the 'minimum value' parameter and a 10

for the 'maximum value' parameters. A 1 is entered for the 'new value' parameter. The option "<=" is chosen for the 'operator' parameter.

No data values (-99999) are recoded to the value 0 entered in the 'new value' parameter. This toggle box is turned on; a check appears in the box. All other values are greater than 10 and are to be recoded to 0's. You can see that the box to the right of the 'other values' toggle box parameter is checked and the value 0 is entered for the 'new value' parameter. This means that all values outside of the 0 to 10 range are recoded to 0. I click on the 'Okay' button and the tool executes. The name for the default output grid map is 'MPAcFa3\_reclassified'.

Before the 'MPAcFa3\_reclassified' grid map is re-named and saved, the *Grid - Tools/Grid Masking* tool is applied to discard data values occurring outside of the project area irregular boundary but within the spatial extent of the grid system.

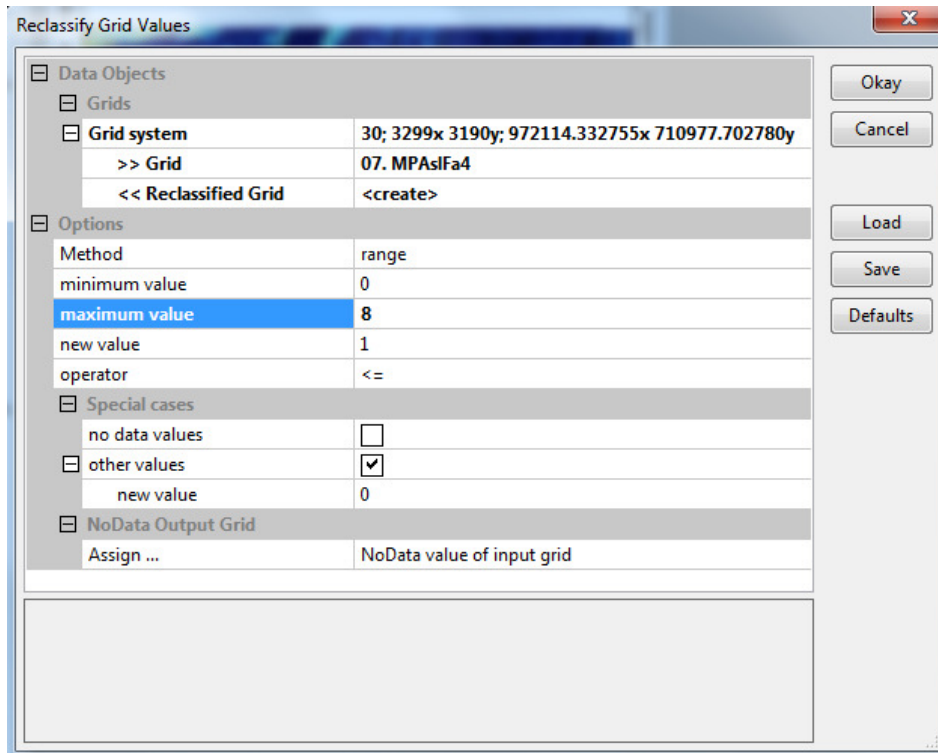
This tool uses the project area grid map 'MProjAreaGR' to mask out grid cells occurring outside of the irregular shaped project area boundary but within the spatial extent of the grid system. The data values in these grid cells are converted to no data values. The 'MProjAreaGR' is chosen for the '>> Mask' input parameter and the 'MPAcFa3\_reclassified' layer is used for the input parameter '>> Grid'. The "<create>" option is used for the output parameter '< Masked Grid'. I click on the 'Okay' button and the tool executes.

I re-name the default 'Masked Grid' to 'BcdTime' and save it. Data values of 1 on this layer are areas suitable for residential development. These areas are within 10 minutes driving time of the town centers. Data values of 0 are areas not suitable. These are areas further than 10 minutes driving time from the town centers.

### **Slope Factor**

Housing and road construction on low slopes is relatively less expensive compared to on steeper slopes. I reclassify the slope grid map so that slopes less than or equal to 8 degrees are considered suitable (coded with 1 values) and greater than 8 degrees are considered not suitable (coded with 0 values). The 'MPAsIFa4' grid map is used for developing this factor layer with the *Grid - Tools/Reclassify Grid Values* tool.

Figure IV-5 displays the *Grid - Tools/Reclassify Grid Values* tool parameters page.



**Figure IV-5. The parameters window for the *Grid – Tools/Reclassify Grid Values* tool.**

The 'MPAsIFa4' grid map is derived from a DEM using the *Terrain Analysis – Morphometry/Slope, Aspect, Curvature* tool. Grid cells contain continuous data values representing slope in degrees. The 'MPAsIFa4' grid map is chosen for the input parameter '>> Grid'. The "<create>" option is chosen for the output '<< Reclassified Grid' parameter. The "range" approach is used for the 'Method'. The option "<=" is chosen for the 'operator' parameter.

The "range" method recodes slope angles between 0 and 8 degrees with 1's and cells with slope angles greater than 8 degrees with 0's. The 'minimum value' and 'maximum value' parameters are set to 0 and 8. All slope values between 0 and 8 are recoded with the value 1 that is entered for the 'new value' parameter. All other values, i.e., values greater than 8, are recoded to 0's. The 'other values' parameter box is checked and the value 0 entered for the 'new value' parameter. I click on the 'Okay' button and the tool executes. The output grid map default name is 'MPAsIFa4\_reclassified'.

I re-name the output factor grid map 'BsISlope'. On this grid map, grid cells containing 1's identify areas suitable for residential development and cells containing 0's are areas not suitable for residential development.

### **Distance from Water Factor**

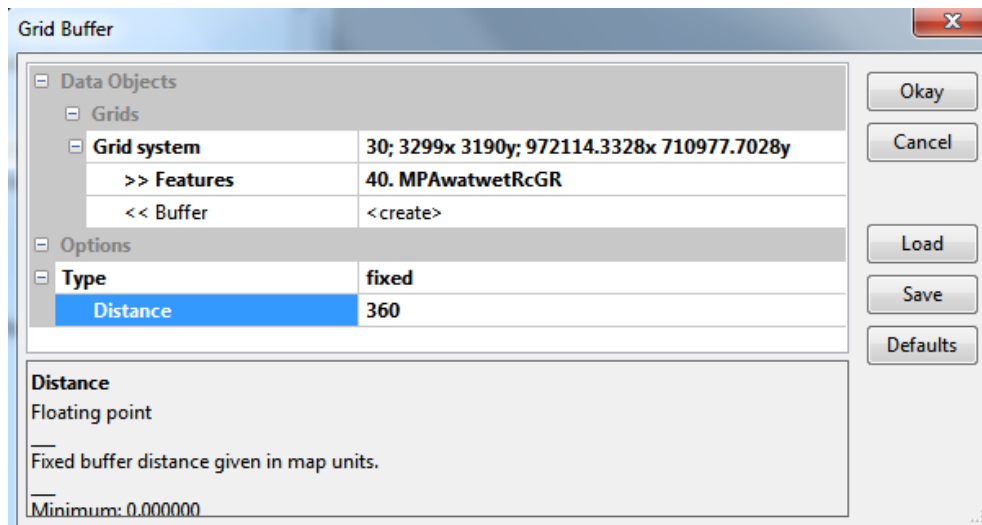
Local groundwater is at risk from septic system pollution and runoff. Due to this risk, environmentalists have pointed out that areas further from water bodies, major streams

and wetlands are more suitable for development than areas that are close. A 180-foot buffer already protects these areas but environmentalists would like to see this protection extended another 180 feet. Suitable areas will then have to be at least 360 feet from any water body or wetland feature, i.e., 180 feet from the existing protected areas (including the 180' protection buffer already delineated).

During the development of the constraint grid map 'MPAwCo1' (for Open Water and Wetlands Constraint), an interim grid map was created named 'MPAwatwetRcGR'. This layer includes all water bodies, major streams, and wetlands features. Feature grid cells are coded with the data value 1. All other grid cells contain 0's. This grid map can be used as input for the *Grid - Tools/Grid Buffer* tool and a 360' buffer around the grid map features can be delineated. One requirement for the *Grid Buffer* tool is that data values for features of an input grid map be greater than 0. The 'MPAwatwetRcGR' grid map meets this requirement.

As noted above, feature grid cells of the 'MPAwatwetRcGR' grid map for water bodies, major streams, or wetlands are coded with 1's. All other grid cells contain 0's. The *Grid - Tools/Grid Buffer* tool is used to create a 360' wide buffer around the grid map features.

Figure IV-6 displays the parameters page for the *Grid - Tools/Grid Buffer* tool.



**Figure IV-6. The parameter entries for the *Grid - Tools/Grid Buffer* tool creating the 'BpdWater1' grid map.**

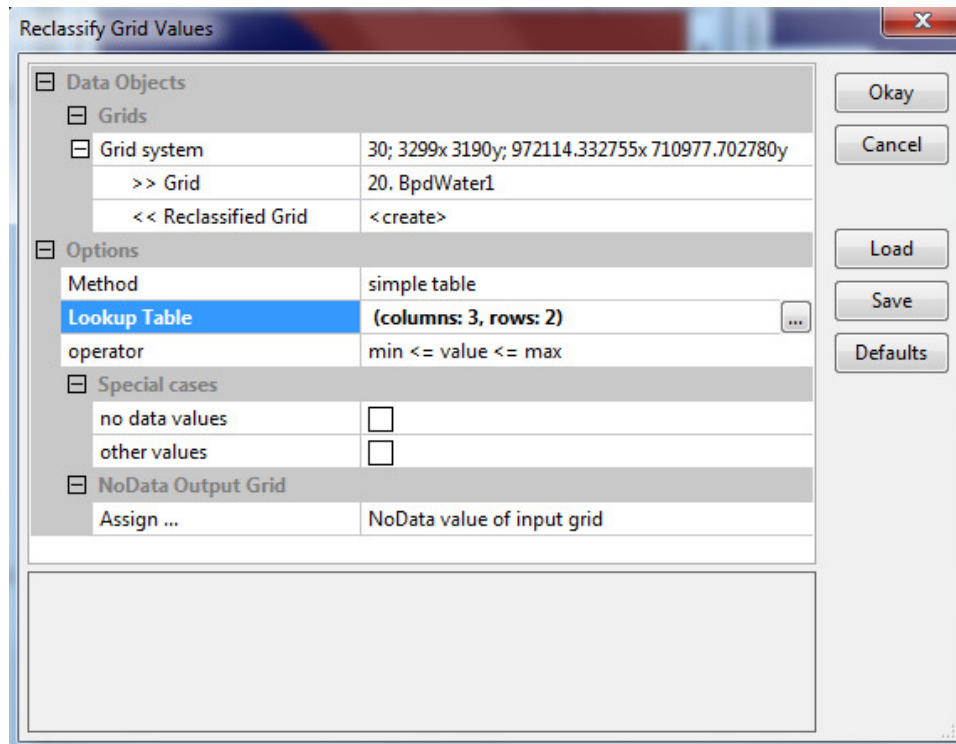
The 'MPAwatwetRcGR' grid map is chosen for the '>> Features Grid' parameter and '<create>' is chosen for the output '<< Buffer Grid' parameter. The buffer 'Distance' parameter is set to 360. I click on the 'Okay' button and the tool executes. The default name for the output grid map is 'Buffer Grid'.



I re-name the output grid map 'BpdWater1'. The output layer uses the data value 1 for the 360-foot buffer and 2's for the features from the 'MPAwatwetRcGR' input layer. All other grid cells contain the no data value 0.

I need to apply a reclassify step to the 'BpdWater1' output layer to create a binary layer containing 1's for areas suitable for residential development and 0's for not suitable areas. The areas that are coded with the no data value 0 on the 'BpdWater1' layer are areas beyond 360 feet from water bodies, major streams and wetland features. These areas for this factor are, therefore, suitable for residential development. These grid cells should, however, contain 1's and not 0's. The areas coded with 1's and 2's, on the other hand, should be coded with 0's. These represent areas unsuitable for residential development.

I use the tool *Grid – Tools/Reclassify Grid Values* to convert the data values 1 and 2 used for the buffer and features to 0's and the areas coded with 0's to 1's. Figure IV-7 displays the parameters page for the *Grid – Tools/Reclassify Grid Values* tool.



**Figure IV-7. The parameter entries for the *Grid – Tools/Reclassify Grid Values* tool to reclassify the 'BpdWater1' grid map .**

The 'BpdWater1' layer output from the *Grid Buffer* tool is chosen for the input parameter '>> Grid'. The option chosen for the output parameter '<< Reclassified Grid' is '<create>'. The "simple table" option is selected for the 'Method' parameter. The data values I enter for the "simple table" are displayed in Figure IV-8. The option "min <= value <= max" is chosen for the 'operator' parameter.

	minimum	maximum	new
1	0.000000	0.000000	1.000000
2	1.000000	2.000000	0.000000

**Figure IV-8. The data values used in the “simple table” to recode the 'BpdWater1' grid map.**

The values used in the “simple table” create an output layer containing 1’s for suitable areas and 0’s for unsuitable areas. The default output grid map is named 'BpdWater1\_reclassified'.

Before the 'BpdWater1\_reclassified' grid map is re-named and saved, the *Grid - Tools/Grid Masking* tool is applied to discard data values occurring in grid cells outside of the project area irregular boundary but within the spatial extent of the grid system.

The project area grid map 'MProjAreaGR' is used with the *Grid Masking* tool. Data values for grid cells not falling within the project area are converted to no data values. The 'MProjAreaGR' is chosen for the '>> Mask' input parameter and the 'BpdWater1\_reclassified' layer is used for the input parameter '>> Grid'. The "<create>" option is used for the output parameter '< Masked Grid'. I click on the 'Okay' button and the tool executes.

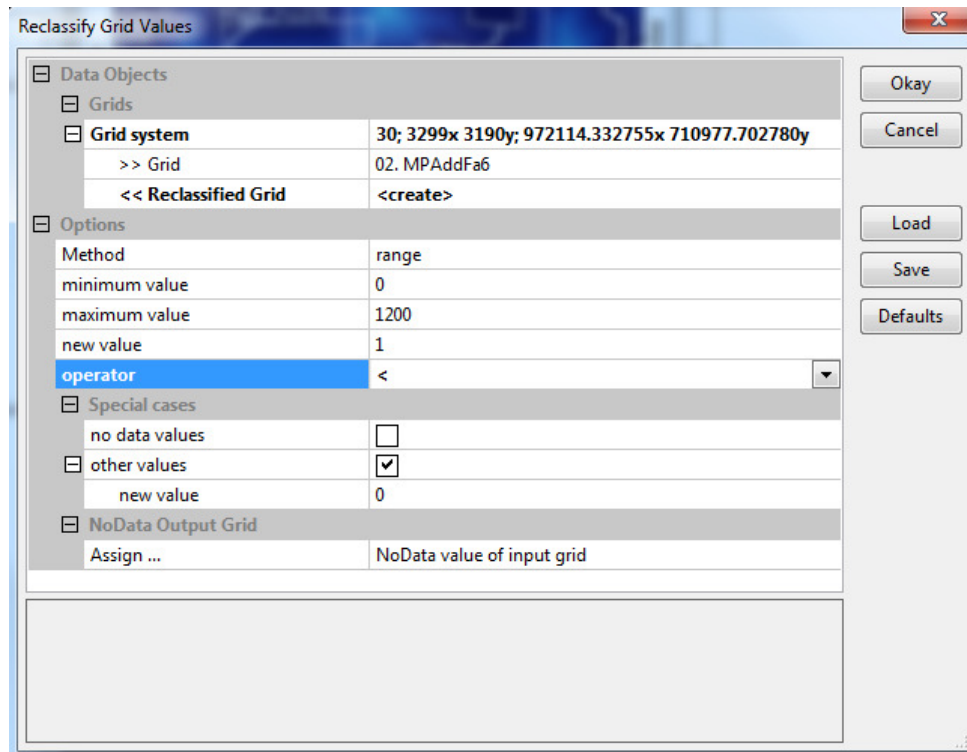
I re-name the output grid map 'Masked Grid' to 'BpdWater2' and save it.

### **Distance from Developed Land Factor**

Areas within 1200 feet of developed land are considered best for new development by environmentalists interested in preserving isolated wildlife habitat. The 'MPAddFa6' grid map is used for developing this factor. The tool *Grid - Tools/Proximity Grid* created the 'MPAddFa6' layer. Grid cell data values on this layer are distances, in feet, from each

cell to the nearest developed land. Developed land is defined as land use classes Residential (10), Commercial 1 (20), Commercial 2 (30), Transportation (40), Trade (50), Services (60), Recreation (70), Resource - Other (80), Resource - Agriculture (81), Resource - Agriculture Activities (82) and Resource - Agriculture Current Use (83).

The *Grid – Tools/Reclassify Grid Values* tool is used to recode distance values greater than 0 and less than 1200 to 1's and distances greater than 1200 to 0's. Figure IV-9 displays the parameters page for this tool.



**Figure IV-9. The parameters page for The *Grid – Tools/Reclassify Grid Values* tool parameter entries for 'BpdDev' grid map.**

The grid map 'MPAddFa6' is chosen for the '>> Grid' input parameter and "<create>" is selected for the output '<< Reclassified Grid' parameter. The 'Method' parameter option selected is "range". The operator chosen is "<".

The grid cell values are distances in feet. Distances greater than 0 and less than 1200 are recoded as 1's. This range is chosen by entering 0 for the 'minimum value' and 1200 for the maximum value parameters and choosing the "<" operator. The 'other values' parameter box is checked and 0 is entered for the 'new value' parameter. This instructs the tool to recode all other values outside of the defined range as 0's. I click on the 'Okay' button and the tool executes.

The default name of the output grid map is 'MPAddFa6\_reclassify'. The output grid map contains 1's to represent areas suitable for residential development and 0's for unsuitable

areas. I re-name the default output factor grid map 'MPAddFa6\_reclassified' to 'BpdDev' and save it to a storage folder.

### **Boolean Grid Map Summary**

#### Constraint Grid Data Layers

##### MPAwCo1

A county development restriction. Water features are defined as bodies of water, major streams, and wetlands. A 180' buffer is delineated around the water features. Suitable areas, areas beyond the 180' buffer, are coded with 1's and unsuitable areas are water features and the 180 foot wide buffer surrounding them. These grid cells are coded with 0's.

##### MPAluCo2

A county development restriction. Available land use classes are Resource - Agriculture (81), Resource - Agriculture Activities (82), Resource - Agriculture Current Use (83), Resource - Designated Forest Land (88), Undeveloped - Land (91), Undeveloped - Noncommercial Forest and Undeveloped - Timberland (95). These land use classes are coded with 1's.

Not available land use classes are Residential (10), Commercial 1 (20), Commercial 2 (30), Transportation (40), Trade (50), Services (60), Recreation (70), Resource - Other (80), Undeveloped - Other (90), and Unclassified (99). These classes are coded with 0's.

#### Factor Grid Data Layers

##### Land Use Factor, BlaSuit

Related to building costs. Land use classes Resource - Agriculture (81), Undeveloped - Noncommercial Forest (92), and Resource - Designated Forest Land (88) with data values of 81, 92, and 88 on the 'MPAlaFa1' grid map are reclassified as 1's to indicate suitability. All other grid cells contain 0 values.

##### Distance from Roads Factor, BsdRoads

Related to building costs. Grid cells within 1200 feet of roads are recoded to 1's and those beyond 1200 feet recoded with 0's.

##### Distance to Town Centers Factor, BcdTime

Related to building costs. Grid map road features and off-road grid cells contain data values representing travel time from the six town centers. Grid cells within 10 minutes of the six town centers are recoded with 1's. Areas further than 10 minutes are recoded with 0's.

##### Slope Factor, BslSlope

Related to building costs. Input grid cell data values are slope in degrees. Slopes 8 degrees and less are recoded with 1's and slopes greater than 8 degrees are recoded with 0's.

Distance from Water Factor, BpdWater2

Related to wildlife preservation. Grid cell data values represent distance in feet from buffer areas around water bodies, major streams, and wetlands. Grid cells representing features and areas with-in 360 feet of features are recoded with 0's. Grid cells in areas beyond 360 feet of features are recoded with 1's.

Distance from Developed Land Factor, BpdDev

Related to wildlife preservation. Input grid cell data values represent distance in feet from developed land use areas. These are areas in land use classes Residential (10), Commercial 1 (20), Commercial 2 (30), Transportation (40), Trade (50), Services (60), Recreation (70), Resource - Other (80), Resource - Agriculture (81), Resource - Agriculture Activities (82) and Resource - Agriculture Current Use (83). Grid cells within 1200 feet of developed land use areas are recoded with 1's. Developed land use areas and areas beyond 1200 feet recoded with 0's.

### **The Boolean Aggregation Approach**

All of the factor grid maps have been standardized into Boolean grid maps, i.e., all suitable areas are coded with 1's and not suitable areas are coded with 0's for each grid map. Now they can be combined using the Boolean approach. The SAGA *Grid - Calculus/Grid Calculator* tool is used to accomplish this combining.

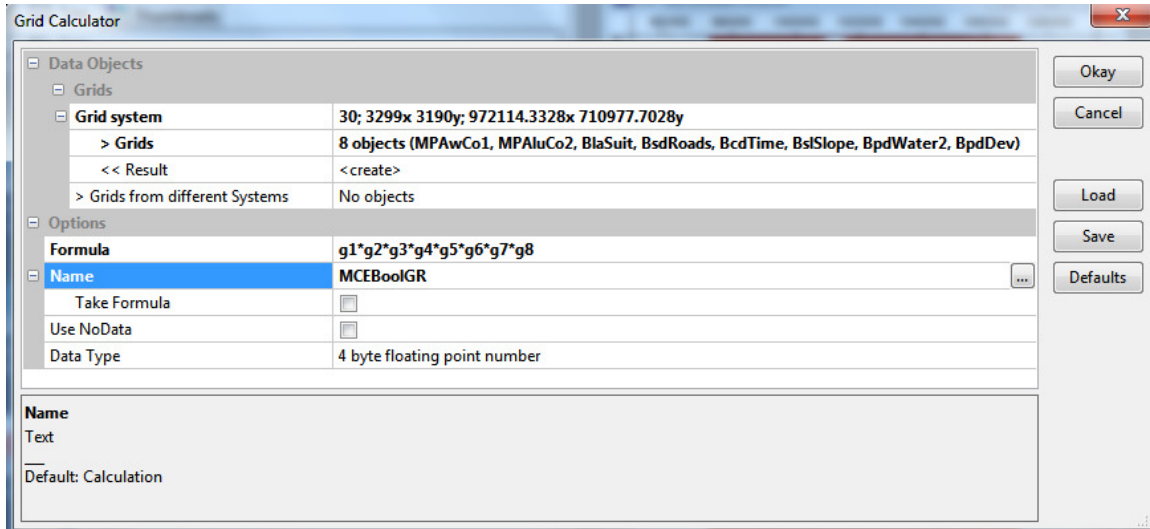
The 8 grid maps representing the constraint and factor layers are multiplied together to produce a single grid data layer of suitable and not suitable. The output grid map consists of 1's and 0's. A data value of 1 in a grid cell on the output grid data layer means that all 8 of the corresponding grid cells of the input layers had data values of 1. A data value of 0 in an a grid cell on the output layer means that at least 1 of the 8 input layers had a data value of 0 for the corresponding cell.

The input grid maps are:

Constraints: MPAwCo1, MPAluCo2

Factors: BlaSuit, BsdRoads, BcdTime, BslSlope, BpdWater2, BpdDev

The *Grid - Calculus/Grid Calculator* tool allows input of any number of grid maps (constraints and factors). They are multiplied together to produce a single grid data layer of suitability. The parameters window for the tool is displayed in Figure IV-10.



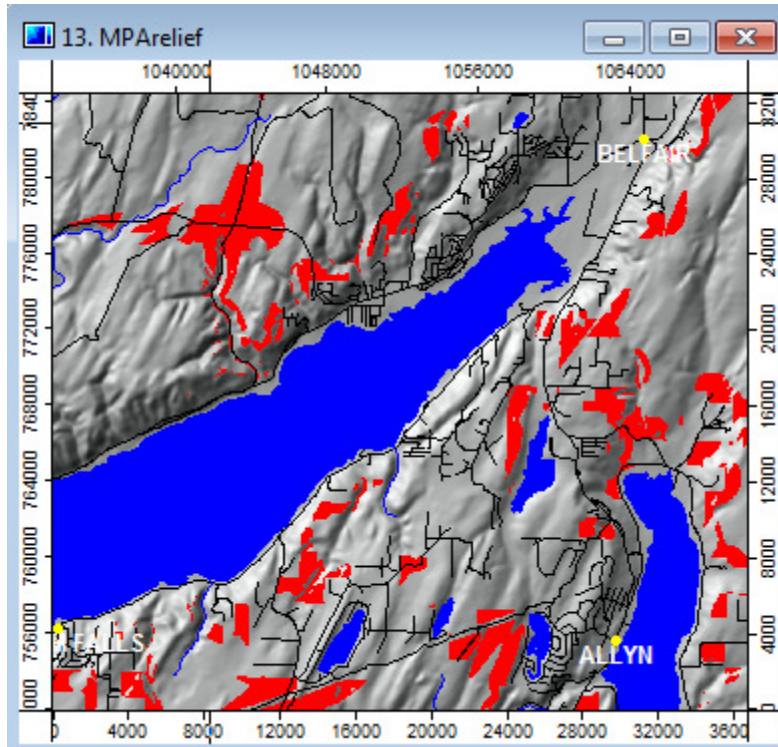
**Figure IV-10. The *Grid – Calculus/Grid Calculator* tool parameters for creating the 'MCEBoolGR' grid map.**

The two constraint and six factor grid maps are chosen for the '> Grids' parameter. All of these layers use the Boolean binary format with 1's representing suitable areas and 0's representing unsuitable areas. The "<create>" option is chosen for the output '<< Result' parameter.

The equation entered for the 'Formula' parameter is:  $g1 * g2 * g3 * g4 * g5 * g6 * g7 * g8$ . The variables "g1" through "g8" represent the 8 input layers in the order they are listed; e.g., "g1" represents 'MPAwCo1', "g2" represents 'MPAluCo2', and so on. The equation is a basic multiplying equation. The name for the output grid map, "MCEBoolGR", is entered for the 'Name' parameter. This is the name used for the interim output grid map.

I click on the 'Okay' button and the tool executes.

The output grid map, 'MCEBoolGR' has the value 1 where all areas of suitability intersect for all criteria and the value 0 for all areas that are unsuitable for one or more of the criteria. Suitability in one criterion cannot compensate for a lack of suitability in any other layer. They do not trade off. By meeting all criteria, the result is the best location possible for residential development.



**Figure IV-11. A zoomed in area of the ‘MCEBoolGR’ grid map.**

The zoomed in portion of the output ‘MCEBoolGR’ grid map (see Figure IV-11) displays suitable areas in red. Topography is displayed in gray, roads in black, and water in blue. You can observe quite a few suitable for residential development grid cells (in red).

### **Applying the 50 Acre Spatial Requirement**

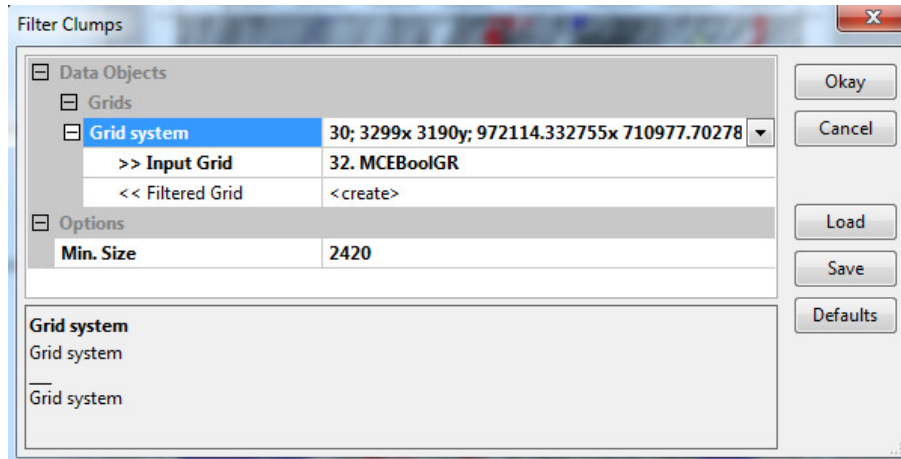
The last step in the scenario, using the ‘MCEBoolGR’ output grid map, is to identify suitable areas that are 50 acres or smaller and delete them. Developers do not consider residential projects smaller than 50 acres as feasible. Viewing the ‘MCEBoolGR’ grid map you can discern areas of contiguous suitability that might not meet the residential developer criteria of feasibility for a development project.

A grid cell is 30' by 30' in size or 900 square feet in area. An acre is 43560 square feet in size. Fifty acres is 2,178,000 square feet or 2420 grid cells (2,178,000 divided by 900).

I use the *Grid – Filter/Filter Clumps* to identify all groups of grid cells less than 50 acres (2420 grid cells) in size. When the tool identifies a clump of grid cells less than 2420 grid cells in size, the data value for each grid cell in the group is recoded to the no data value - 99999. I name the output grid map ‘MCEBoolSubGR’.

The tool parameter page is displayed in Figure IV-12.



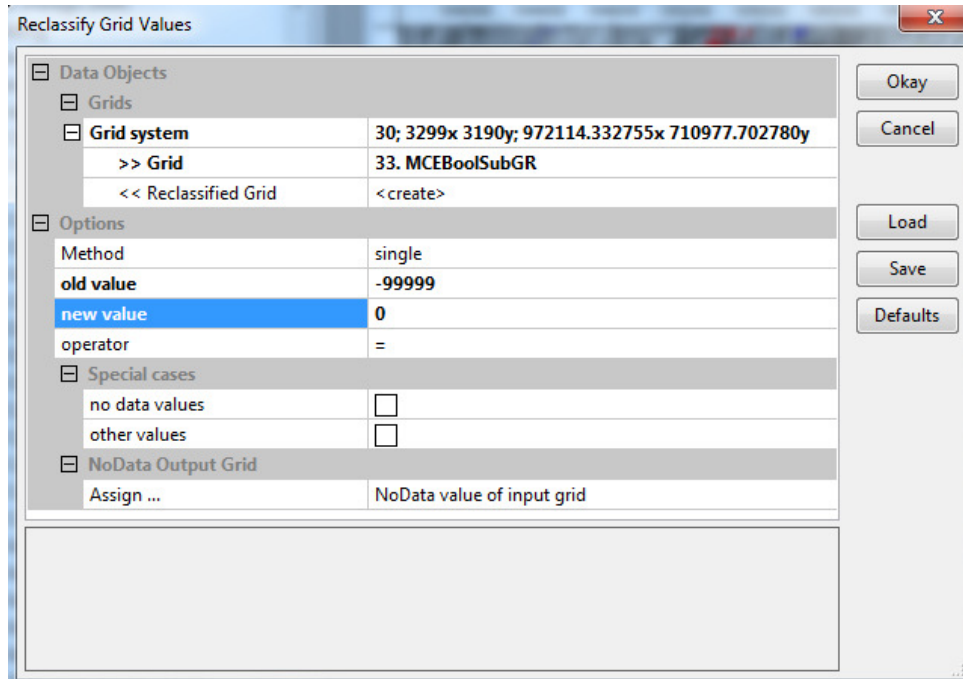


**Figure IV-12. The *Grid – Filter/Filter Clumps* tool parameters page.**

The 'MCEBoolGR' grid data layer is chosen for the '>> Input Grid' parameter. The "<create>" option is chosen for the output parameter '<< Filtered Grid'. I have entered 2420 as the minimum number of cells for a group or clump of cells. The default name of the output is 'Filtered Grid'. I re-name the output 'MCEBoolSubGR' and save it.

As I noted above, the contiguous grid cells not meeting the 2420 cell threshold have their data values changed to -99999. These grid cells are in the unsuitable category. The *Grid – Tools/Reclassify Grid Values* tool is used to change these no data values to 0.

The parameters page for the *Grid – Tools/Reclassify Grid Values* tool is displayed in Figure IV-13.



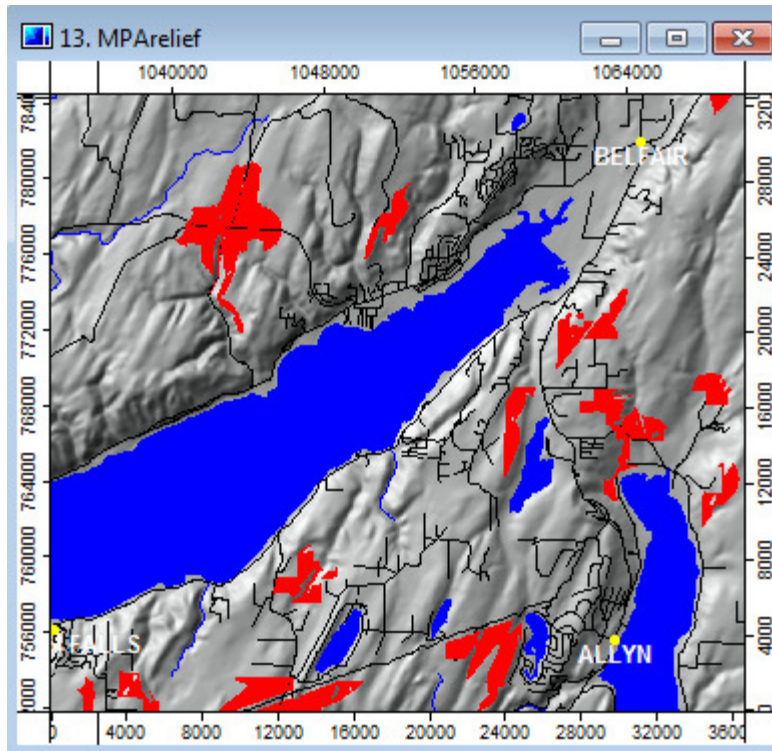
**Figure IV-13. Parameter entries for reclassifying the 'MCEBoolSubGR' grid map.**

The input grid map is the 'MCEBoolSubGR' layer with clumps of contiguous cells smaller than 2420 cells containing the no data value of -99999. I use the "single" method to change the single value -99999 where it occurs on the grid map to the new value of 0. I click on the 'Okay' button and the tool executes. The default name of the output grid map is 'MCEBoolSubGR\_reclassified'.

Before re-naming and saving the 'MCEBoolSubGR\_reclassified' grid map, the *Grid - Tools/Grid Masking* tool is going to be applied to discard data values in grid cells that fall outside of the irregular boundary of the project area. This tool has been used with several constraint and factor grid maps for the same purpose earlier in this tutorial.

The 'MCEBoolSubGR\_reclassified' grid map is chosen for the '>> Grid' input parameter and the 'MProjAreaGR' layer used for the '>> Mask' input parameter. I click on the 'Okay' button and the tool executes.

The new masked grid map is named 'Grid Mask'. I re-name it 'MCEBoolDivGR' and save it to the project area storage folder.



**Figure IV-14. A zoomed in area of the ‘MCEBool50’ grid map.**

Figure IV-14 displays the same zoomed in area as in Figure IV-11 for the ‘MCEBoolDivGR’ grid map. You can see that groups of suitable grid cells smaller than 50 acres in size have dropped out.

The areas in red are areas larger than 50 acres in size, suitable for residential development. Included in the map display window are shapes data layers for roads, streams, and bodies of water. The backdrop is the grid map for relief.

When you use the Boolean aggregation method, there is no possibility for criteria to trade off with each other. If a location is not suitable for all criteria, then it could not be suitable on the final map. The next approach, weighted linear combination (WLC), allows us to use the full potential of our factors as representing varying degrees of suitability and making trade off between factors possible.

#### *Discussion*

Boolean aggregation is often described as conservative. The factor grid maps are binary in nature, 1’s or 0’s. A land area is either in or out, it is either suitable or not suitable. There is no in-between, no varying degree. Despite what might be interpreted as disadvantages of this method, Boolean aggregation is the most popular approach for suitability analysis.

Developing alternatives can be accomplished by making adjustments to hard decisions related to factor grid data layers. The only “weight” for suitability is “1”. The spatial area for the data value of 1 can be adjusted, however, by changing the criterion for the factor.

As an example, Table IV-1 describes the hard decisions used for each of the six factor grid data layers. Changing any one of these decisions potentially changes the spatial solution either decreasing or increasing the area in the suitability category. Instead of defining suitability for proximity to roads as 1200’ it might be justified to change this to 600’. This might be a change you would make dependent on the average topography in the study area. Or maybe you want to increase the travel time criterion from 10 minutes to 12 minutes. Making any change to criterion the Boolean factor grid data layers are based on will potentially change the spatial coverage of the suitability category in the output.

The Boolean approach described in this tutorial is often called the “AND” approach. If you have 6 Boolean factor grid data layers (each containing 1’s for suitable and 0’s for not suitable), the suitability category on the final suitability map is based on “a” AND “b” ... AND “f”. A grid cell on the final suitability map is only suitable if the cell has a 1 for each of the input Boolean factor grid data layers. On the other hand, there is the “OR” approach.

Using the “OR” approach, the suitability category on the final suitability map is based on “a” OR “b” ... OR “f”. A grid cell on the final suitability map is suitable if the cell has a 1 for any one of the input Boolean factor grid data layers. Using this approach, the final suitability map has 6 levels of suitability ranging from low (1) to high (6). Depending on the factors involved, alternatives could be developed using levels. You could have a rule where certain factors are mandatory and any additional factors are enhancements to the decision space.

I think you can see that a lot of different scenarios can be developed utilizing the Boolean aggregation approach.

#### References

Hott, Rebecca, Ron Santini, and Jeffrey Brownson. “GIS-Based Spatial Analysis for Large-Scale Solar Power and Transmission Line Issues: Case Study of Wyoming, U.S.”, presentation at Empowering the World with Renewable Energy, Denver, Colorado, May 13-17, 2012.

Ozdemir, Perihan Sezisli. “Comparison of GIS-Based Land Use Suitability Analysis Tools: A Case Study in Coyote Valley, California” (M.Sc. thesis, San Jose State University, 2011), p. 69.

## **V. Weighted Linear Combination**

The second method of multi-criteria evaluation addressed in this tutorial is Weighted Linear Combination (WLC). In this method, factor grid maps are not reduced to simple Boolean or binary constraints, i.e., 1's for suitable and 0's for not suitable as in the Boolean approach. Instead the factor grid maps are standardized to a continuous scale of suitability from 0 (the least suitable) to 1 (the most suitable).

Rescaling factor grid maps to a standard continuous scale allows for comparisons between factors and combining them, as in the Boolean case. However, in the continuous scale case, the hard decision Boolean method of defining any particular area as absolutely suitable or not is avoided. The line between suitable and unsuitable is not absolute as in 1 or 0. With WLC, a soft or “fuzzy” concept is used to define those areas that are suitable and the boundary between suitable and unsuitable for the factors.

The constraints, open water and wetlands ('MPAwCo1') and suitable and unsuitable land use classes ('MPAluCo2') retain their hard Boolean character. These two constraints are based on regulatory absolutes and are applied as a mask in one of the last steps of the WLC.

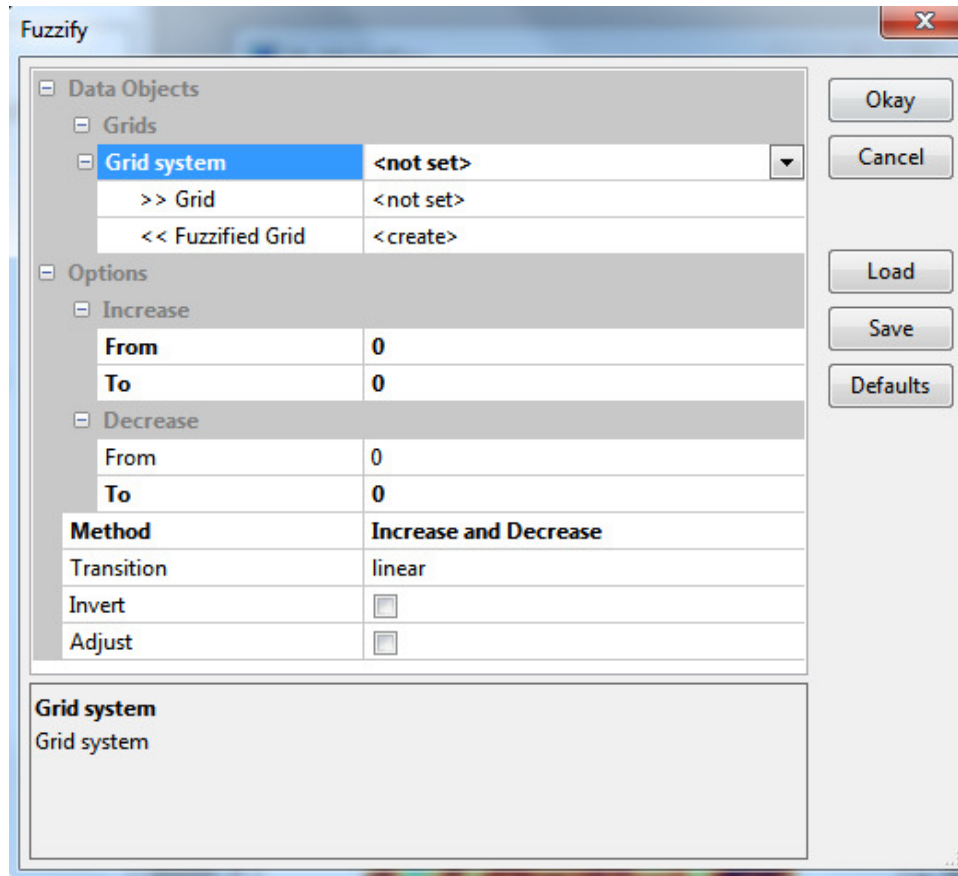
As we will see, WLC allows for the variability of continuous type data to be considered and it also gives us the ability to have factors trade off with each other. This means, for example, an area with a low suitability value for one factor can be compensated for by a high suitability score of another factor. How factors trade off with each other is determined by a set of factor weights applied to each grid map. The factor weights indicate the relative importance of each factor.

### **The Fuzzy Standardization Process**

Before standardizing our factors, let's take a brief look at applying the fuzzy concept using the SAGA *Grid – Calculus/Fuzzify* tool.

The SAGA *Grid – Calculus/Fuzzify* tool is a data standardization procedure used to rescale factor grid map values into continuous values between 0 and 1. Thus, rather than the factor map data values being distinct, either 1's or 0's (binary) as in the Boolean approach, the values are continuous ranging between 0 and 1.

Figure V-1 displays the parameters page for the SAGA *Grid – Calculus/Fuzzify* tool.



**Figure V-1. The parameters page for the SAGA Grid – Calculus/Fuzzify tool.**

The key parameters in the tool that guide the rescaling process are the ‘Transition Type’ parameter options and the Increase and Decrease 'From' and 'To' parameters in the Options section. An earlier version of the *Fuzzify* tool equated the variables "A" to "Increase To", "B" to "Increase From", "C" to "Decrease To", and "D" to "Decrease From".

The ‘Transition’ parameter has three options: linear, sigmoidal, and j-shaped. Each choice is a specific curve function used to rescale a range of data values belonging to a grid map.

The 'Method' parameter has three options: "Increase", "Decrease", and "Increase and Decrease". In Figure V-1 the "Increase and Decrease" option is showing. This option supports entry of values defining both increase and decrease re-scaling methods. The other two options support one or the other, i.e., either decrease or increase but not both. An option not chosen, i.e., either "Increase" or "Decrease", will have its 'From' and 'To' entries automatically default to 0's when the tool executes.

The "Increase" option is used when you want to re-scale a range to increase from 0 to 1. The "Decrease" option is applied when I want to re-scale a range decreasing from 1 to 0.

The table below explains how the tool interprets the data values for the entries to the "From" and "To" parameters.

**Table V-1: Fuzzify tool parameter settings**

Increase

- From Values less than "From" will be set to 0.
- To Values between "From" and "To" increase from 0 to 1.

Decrease

- From Values between [Increase] "To" and "From" are set to 1; values between "From" and "To" decrease from 1 to 0.
- To Values greater than "To" will be set to 0.

Each of the three methods is described graphically and in text. Four curve forms are explored for each method. The curves are: a) a monotonically increasing curve, b) a monotonically decreasing curve, and c) and d) are symmetric curves. A set of trial values for the control points is developed for each of the graphs. The values are used as input for an execution of the *Grid – Calculus/Fuzzify* tool. Based on the 'Membership Function Type' parameter option and the values entered for control points, the output is described.

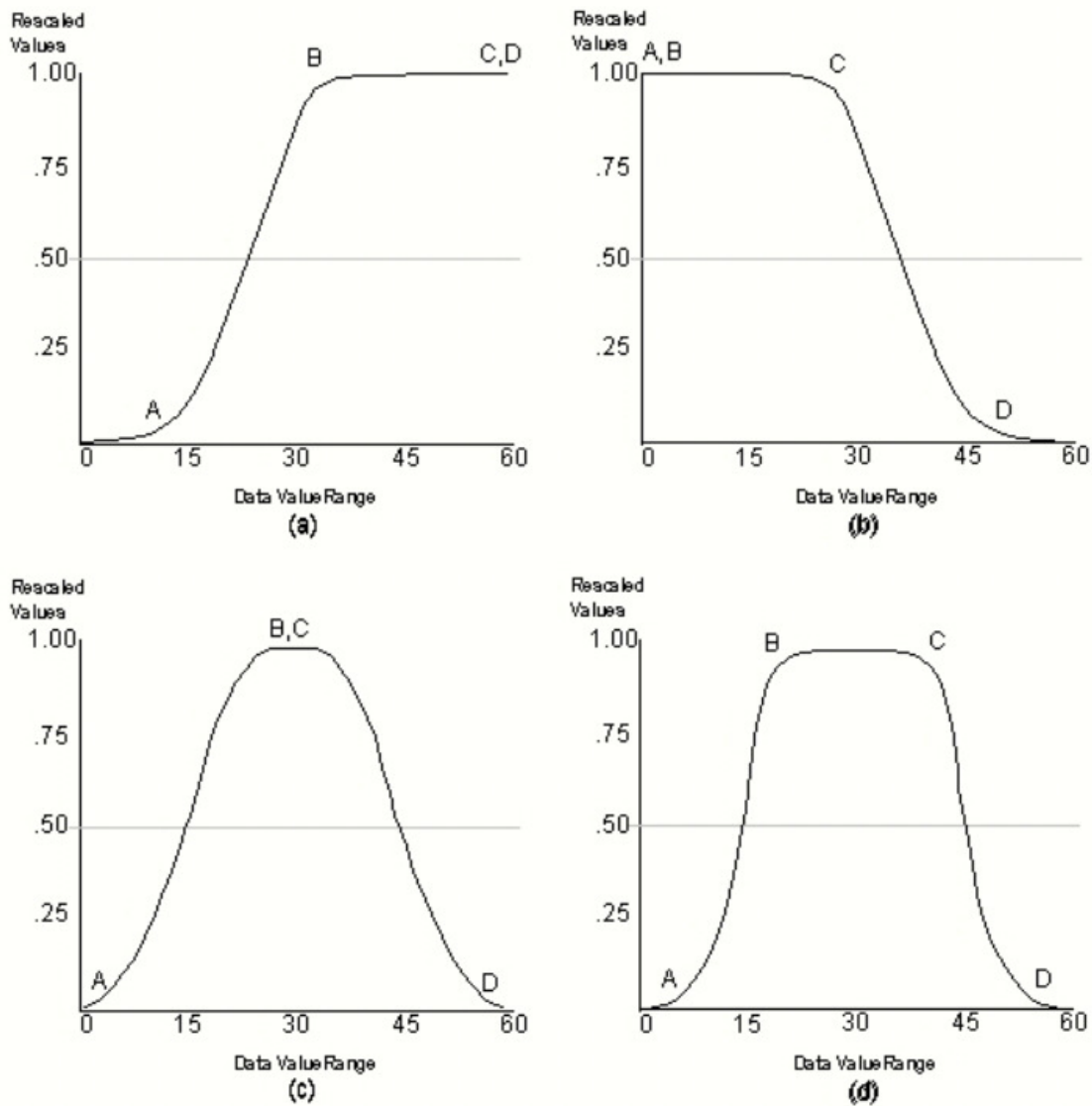
The y-axis in each graph is the rescaled data range, 0 to 1. The x-axis is a hypothetical data range for a grid data layer, from 0 to 60. You may want to refer back to Table V-1 when reading through the following examples.

The following graphs were created for an earlier version of the *Fuzzify* tool that referred to control points A, B, C, and D. As noted earlier, these control points equate to the Increase and Decrease 'From' and 'To' parameters in the current *Fuzzify* version. Rather than re-create the graphs I am choosing to cross-reference the control points and the parameters as they represent the same variables. If this proves to be confusing, please let me know and I will re-create the graphs and replace this version of the tutorial.

**Sigmoidal, Linear, and j-Shaped Curves**

Sigmoidal or s-shaped is the most commonly used function. The four control points govern the shape of the curve. You can see in the figures below that the four control points A (Increase From), B (Increase To), C (Decrease From), and D (Decrease To) represent the inflection points of the curve.





**Figure V-2. Sigmoidal or s-shape curves.**

Figure V-2a shows a monotonically increasing curve and V-2b a monotonically decreasing curve. Figures V-2c and V-2d represent two symmetric curves.

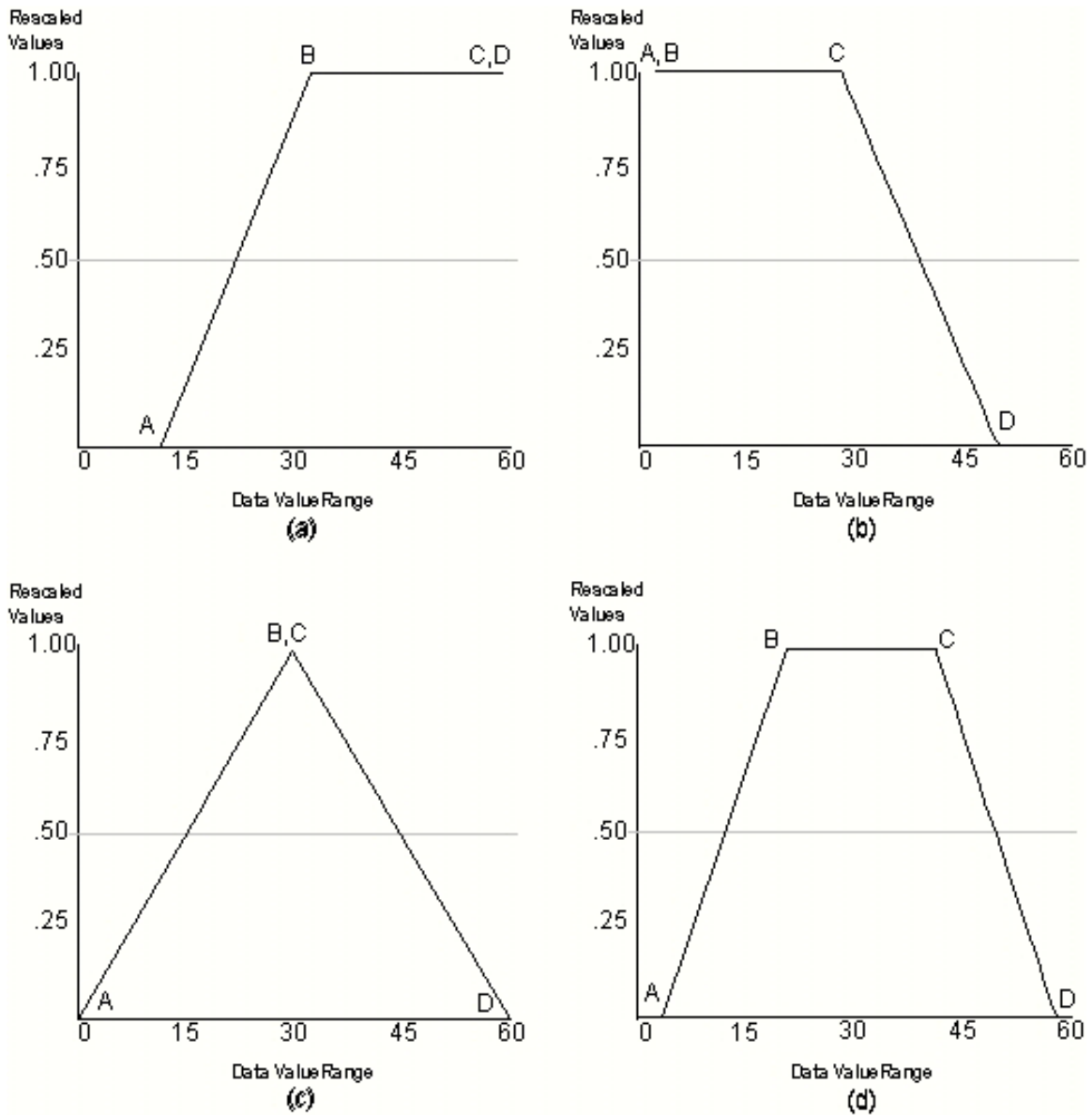
In Figure V-2a, the data value entered for control point A (Increase From) is 10, for point B (Increase To) the data value is 30. The maximum data value of 60 is entered for points C (Decrease From) and D. When the *Grid – Calculus/Fuzzify* tool is executed with these control point values and using the ‘Membership Function Type’ parameter option “sigmoidal”, the output is original data values from 0 to 10 are rescaled to 0, values from 10 to 30 are rescaled increasing from 0 to 1. Values greater than 30 are rescaled to 1. Remember in this hypothetical dataset there are no values greater than 60.

In Figure V-2b, this is a decreasing curve. The data value entered for control points A (Increase From) and B (Increase To) is 0. The values for points C (Decrease From) and D (Decrease To) are 25 and 50. The output from the tool is data values from 0 to 25 are rescaled to 1 and values from 25 to 50 rescaled decreasing from 1 to 0. Values greater than 50 are rescaled to 0.

Figures V-2c and V-2d represent symmetric curves. In Figure V-2c the data value entered for control point A (Increase From) is 0, for points B (Increase To) and C (Decrease From) the value is 30 and for point D (Decrease To) the value is 60. The result is data values from 0 to 30 are rescaled increasing from 0 to 1 and values from 30 to 60 are rescaled decreasing from 1 to 0 at the data value 60.

In Figure V-2d the data value entered for control point A (Increase From) is 4, for point B (Increase To) the value is 15 and for C (Decrease From) the value is 45. The value entered for point D (Decrease To) is 56. The result is data values from 0 to 4 rescaled to 0. Values between 4 and 15 are rescaled increasing from 0 to 1. Values from 15 to 45 rescaled to 1 and values from 45 to 56 rescaled decreasing from 1 to 0 at 56. Values greater than 56 rescaled to 0.

Using the sigmoidal method, these inflection points define a rounded transition at a boundary rather than a sharp boundary. In the above examples, transition is a gradual one unlike in the case of a linear curve relationship. Figure V-3 displays a similar set of curves using the linear function.



**Figure V-3. Linear curves.**

Figure V-3 shows similar curves as displayed in Figure V-2 except for a linear curve function. Figure V-3a is a monotonically increasing curve, V-3b a monotonically decreasing curve. Figures V-3c and V-3d represent two symmetric curves.

In Figure V-3a, the data value entered for control point A (Increase From) is 10 and for point B (Increase To) the data value is 30. The maximum data value of 60 is entered for both points C (Decrease From) and D. The output from the *Grid – Calculus/Fuzzify* tool is data values from 0 to 10 are rescaled to 0, values from 10 to 30 are rescaled increasing from 0 to 1. Values greater than 30 are rescaled to 1.

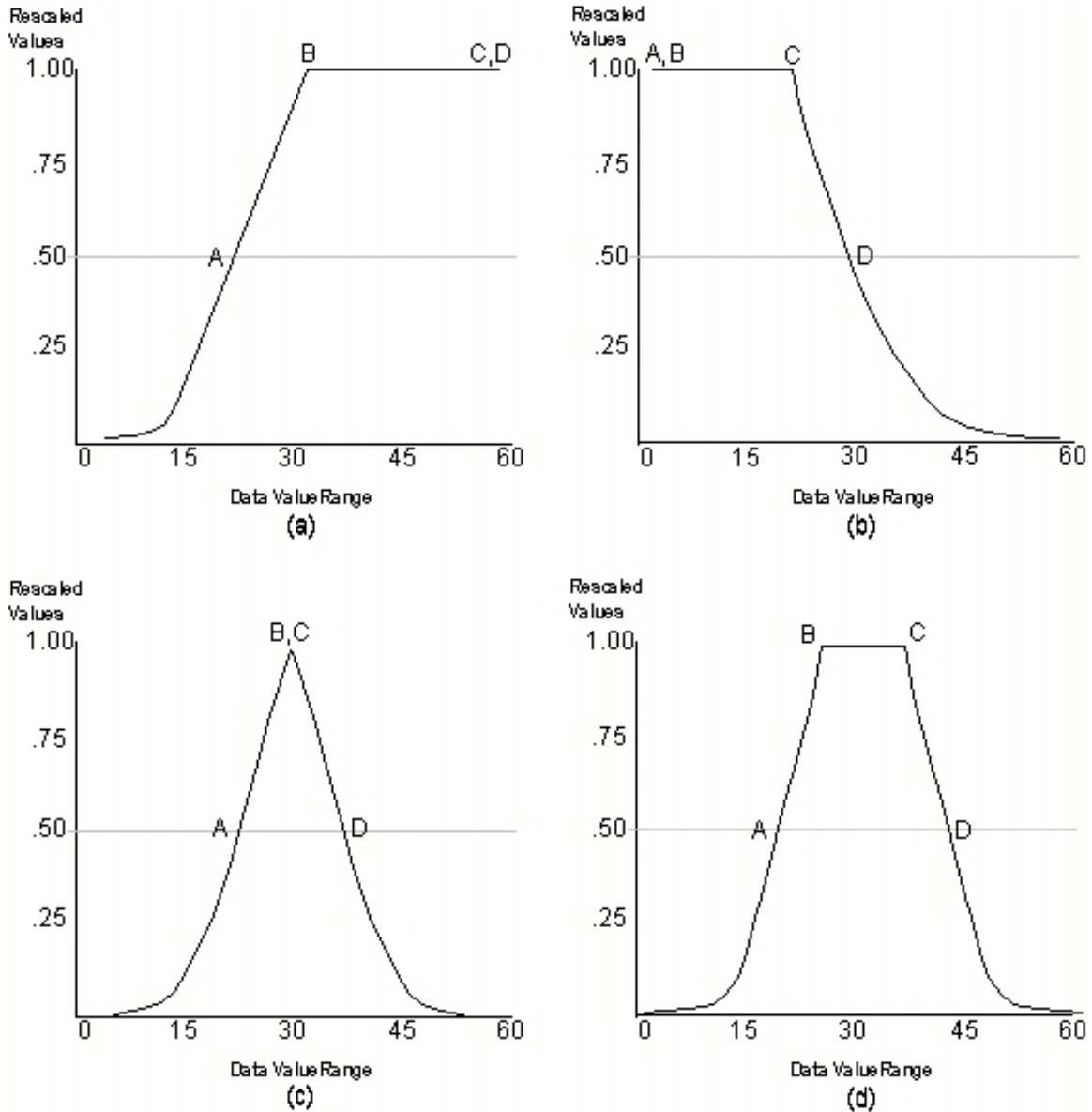
In Figure V-3b, this is a decreasing curve. The data value entered for points A (Increase From) and B (Increase To) is 0. The value entered for C (Decrease From) is 30 and for D (Decrease To) a 50 is used. The result is that data values between 0 and 30 are rescaled to 1 and values from 30 to 50 rescaled decreasing from 1 to 0. Values greater than 50 are rescaled to 0.

Figures V-3c and V-3d represent symmetric curves. In Figure V-3c the data value entered for control point A (Increase From) is 0, for points B (Increase To) and C (Decrease From) the value is 30 and for point D (Decrease To) the value is 60. The output is data values from 0 to 30 rescaled increasing from 0 to 1 and values from 30 to 60 rescaled decreasing from 1 to 0 at the data value 60.

In Figure V-3d the data value entered for control point A (Increase From) is 4, for point B (Increase To) the value is 17 and for C (Decrease From) the value is 44. The value entered for point D (Decrease To) is 57. The tool output is values from 0 to 4 are rescaled to 0. Values between 4 and 17 are rescaled increasing from 0 to 1. Values from 17 to 44 are rescaled to 1 and values from 44 to 57 are rescaled decreasing from 1 to 0 at 57. Values greater than 57 are rescaled to 0.

These inflection points define a sharp transition at a boundary rather than a gradual boundary as is the case with the sigmoidal curve function.

The third option for the 'Membership Function Type' parameter is j-shaped. The rescaling using the j-shaped function is different in that the A (Increase From) and D (Decrease To) inflection points indicate the points at which the function reaches 0.5 rather than 0. Figure V-4 displays four examples of this function.



**Figure V-4. The j-shaped function curves.**

Figure V-4 shows similar curves as Figures V-2 and V-3 except for a j-shaped curve function. Figure V-4a is a monotonically increasing curve, V-4b a monotonically decreasing curve. Figures V-4c and V-4d represent two symmetric curves.

In Figure V-4a, the data value entered for control point A (Increase From) is 20, for point B (Increase To) the data value is 30. The maximum data value of 60 is entered for both points C (Decrease From) and D. The tool rescales data values less than 20 to 0. Values from 20 to 30 are rescaled increasing from .5 to 1. Values greater than 30 are rescaled to 1.

In Figure V-4b, this is a decreasing curve. The value entered for points A (Increase From) and B (Increase To) is 0. The value entered for point C (Decrease From) is 25 and for point D (Decrease To) a 30 is used. Data values less than 25 are rescaled to 1 and data values between 25 and 30 are rescaled decreasing from 1 to .5. Data values greater than 30 are rescaled to 0.

Figures V-4c and IV-4d are symmetric curves. In Figure V-4c the data value entered for control point A (Increase From) is 20, for points B (Increase To) and C (Decrease From) the value is 30 and for point D (Decrease To) the value is 37. The result is that data values less than 20 and greater than 37 are rescaled to 0. Values from 20 to 30 are rescaled increasing from .5 to 1 and values from 30 to 37 rescaled decreasing from 1 to .5 at the data value 37.

In Figure V-4d the data value entered for control point A (Increase From) is 18, for point B (Increase To) the value is 26 and for C (Decrease From) the value is 36. The value entered for point D (Decrease To) is 42. The result is data values less than 18 and greater than 42 are rescaled to 0. Values from 18 to 26 are rescaled increasing from .5 to 1. Values between 26 and 36 are rescaled to 1 and values from 36 to 42 rescaled decreasing from 1 to .5.

This has been a brief introduction to fuzzy standardization and how it is implemented in the *Grid – Calculus/Fuzzify* tool.

### **Factor Standardization**

#### Land Use Factor

In the Boolean MCE approach the three available land use classes suitable for development are recoded as suitable with data values of 1. These classes are identified based on having low per acre market values. The three land use classes and their per acre market value are:

Land Use Class	Per Acre Market Value
Resource - Agriculture (81)	\$2425.94
Undeveloped - Noncommercial Forest (92)	\$2935.48
Resource - Designated Forest Land (88)	\$4478.34

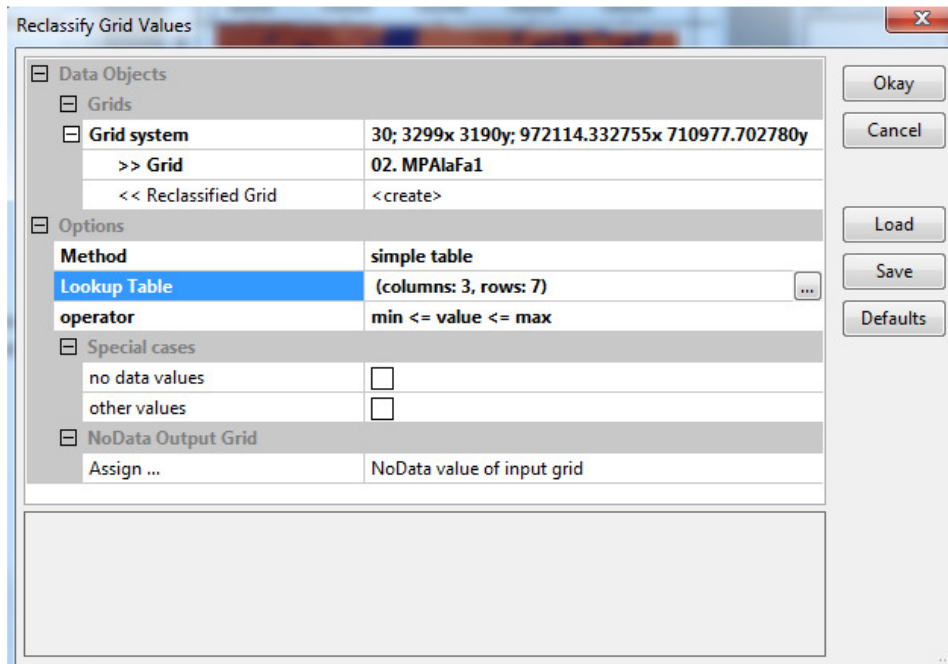
All other land use types are unsuitable. According to developers, the three available land use classes represent different levels of suitability for residential development based on the average per acre market value for land areas in each class. Knowing the relative suitability of each category, the three can be rescaled into the 0-1.0 data value range.

On the 0-1.0 scale the suitability rating of 1 is assigned to Resource - Agriculture (81) land areas, .66 to Undeveloped - Noncommercial Forest (92), and .33 to areas in land use class Resource - Designated Forest Land (88). These data values are based on their per acre rankings where the lowest per acre market value is the most suitable. The *Grid – Tools/Reclassify Grid Values* tool is used to change the category identifiers in the feature

grid map ‘MPAlaFa1’ to the new relative suitability scores. All other land use classes have a data value of 0.

The new standardized factor map derived from the land use layer ‘MPAlaFa1’ is named ‘WLClaSuit’.

I execute the *Grid – Tools/Reclassify Grid Values* tool. The tool parameters window is displayed in Figure V-5.



**Figure V-5. The *Grid – Tools/Reclassify Grid Values* tool parameter entries for reclassifying the land use grid map.**

The ‘MPAlaFa1’ grid map is chosen for the ‘>> Grid’ input parameter. On this layer, Resource - Agriculture land use is coded with the data value 81, Undeveloped - Noncommercial Forest with 92, and Resource - Designated Forest Land with 88. The remaining land use classes Resource - Agriculture Activities (82), Resource - Agriculture Current Use (83), Undeveloped - Land (91) and Undeveloped - Timberland (95) are not suitable and coded with 0's. I choose the “<create>” option for the output parameter ‘<< Reclassified Grid’. The “simple table” choice is selected for the ‘Method’ parameter. This means the replacement values for existing values are provided in a simple table. The data values I enter for the simple table are displayed in Figure V-6.



	minimum	maximum	new
1	81.000000	81.000000	1.000000
2	92.000000	92.000000	0.660000
3	88.000000	88.000000	0.330000
4	82.000000	82.000000	0.000000
5	83.000000	83.000000	0.000000
6	91.000000	91.000000	0.000000
7	95.000000	95.000000	0.000000

**Figure V-6. The replacement values in the “simple table” for the land use grid map.**

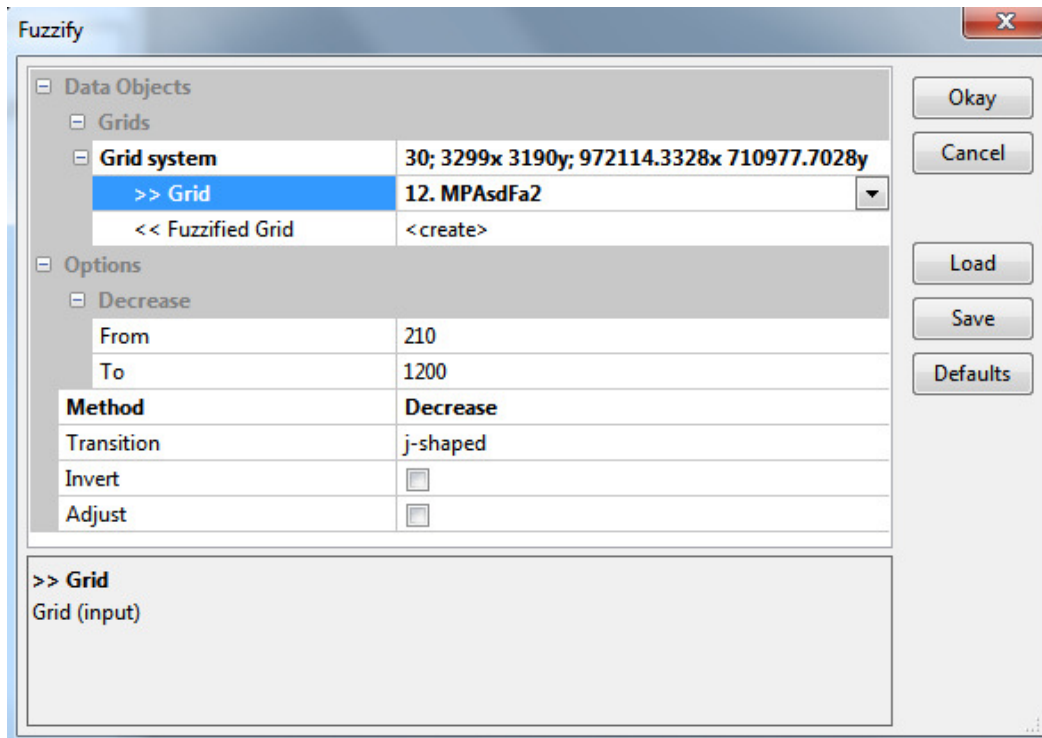
The “simple table” shows that grid cells currently coded with the data value 81 are recoded with 1, data value 92 is recoded with .66, and data value 88 with .33. You can see that all other land use class values 82, 83, 91, and 95 are recoded to 0’s. I click on the 'Okay' button and am returned to the parameters window displayed in Figure V-5. I execute the tool and the default output grid map 'MPAlaFa1\_reclassified' is created.

I re-name the output grid map ‘WLClaSuit’ and save it to the project area storage folder.

#### Distance to Roads Factor

Distance from roads is continuous data to be rescaled to the 0-1 range. Residential developers using the Boolean approach identified areas within 1200 feet of roads as suitable for development. However, given the ability to determine a range of suitability, areas within 210 feet of roads are the most suitable and areas beyond 210 feet to 1200 feet have a continuously decreasing suitability that approaches 0. This strategy is implemented using the *Grid – Calculus/Fuzzify* tool, the “j-shaped” option for the ‘Membership Function Type’ parameter, and entering control point values for a decreasing J-shaped curve.

Figure V-7 displays the parameters page for the tool. The ‘MPAsdFa2’ grid map is chosen as the input grid map.



**Figure V-7. The parameter entries for the *Grid – Calculus/Fuzzify* tool to create the ‘WLCsdRoads’ grid map.**

The grid cell data values in the ‘MPAsdFa2’ grid map are distances the cells are from the nearest road. The “j-shaped” option is chosen for the ‘Membership Function Type’ parameter. Control points Increase To and Increase From have values of 0. Control point Decrease To is the value for rescaling decreasing from 1. This value is 210. Control point Decrease From identifies the data value for the minimum rescale value of .5. This value is 1200. Data values between 0 and 210 are rescaled to 1. This describes the closest 210 feet near a road as most suitable. Note that the value 210 is approximately the side dimension of an acre. Values between 210 and 1200 are rescaled decreasing from 1 to .5 for the data value 1200. Values greater than 1200 are rescaled to 0. I click on the ‘Okay’ button and the tool executes using these parameter entries.

The default output grid map name is ‘MPAsdFa2 [Fuzzified]’. I name the output grid map ‘WLCsdRoads’ and save it to a storage folder.

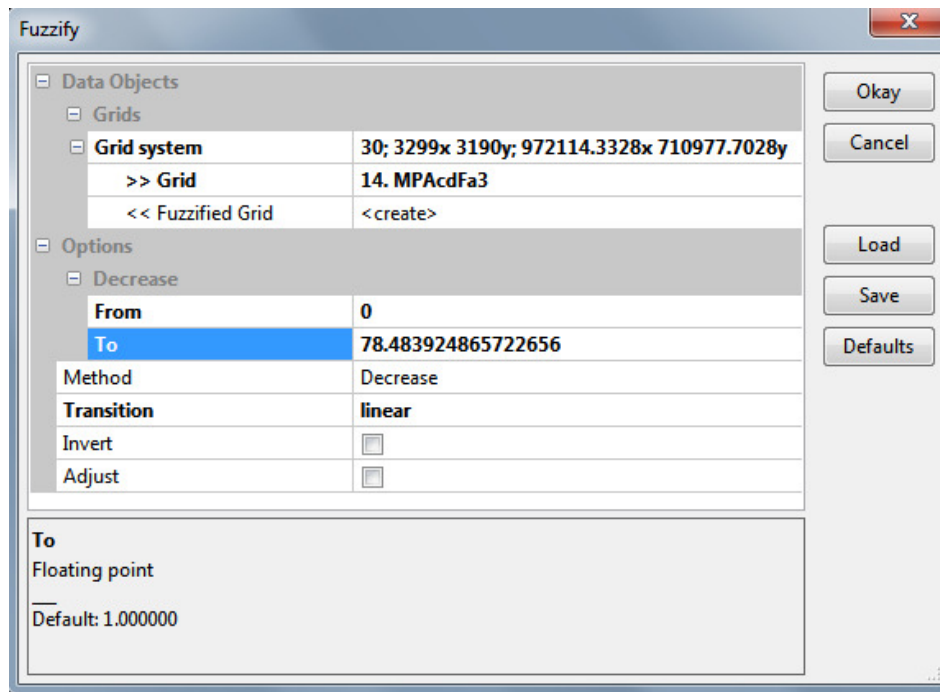
#### Distance to Town Centers Factor

The most common standardization or rescaling function takes an original range of data and performs a simple linear stretch. For example, measures of travel time from the six town centers, an important determinant of potential profit for developers, are rescaled to a range of suitability where the greatest travel time has the lowest suitability score (0) and the least travel time has the highest suitability score (1.0). A simple linear distance decrease function is used for this criterion, i.e., as travel time to the town center decreases its suitability increases.

The SAGA *Grid – Calculus/Fuzzify* tool is used. Data values must be entered for control points that reflect the linear decreasing function and decreasing suitability as travel time increases from the town centers. In this case, the control points are the end points on the linear curve, the minimum and maximum travel time data values for the ‘MPAcFa3’ grid map.

The minimum distance value for travel time from town is 0 minutes and the maximum value is 78.483925 minutes. The 0 value is a town center. The value 78.483925 is the maximum travel time calculated. The two values 0 and 78.483925 are used as control points.

The *Grid – Calculus/Fuzzify* tool is applied using the ‘MPAcFa3’ grid map for the input parameter. The linear function type is chosen to rescale the data. Figure V-8 displays the parameters page for the tool.



**Figure V-8. The *Grid – Calculus/Fuzzify* tool parameter entries for creating the 'WLCcdTime' grid map.**

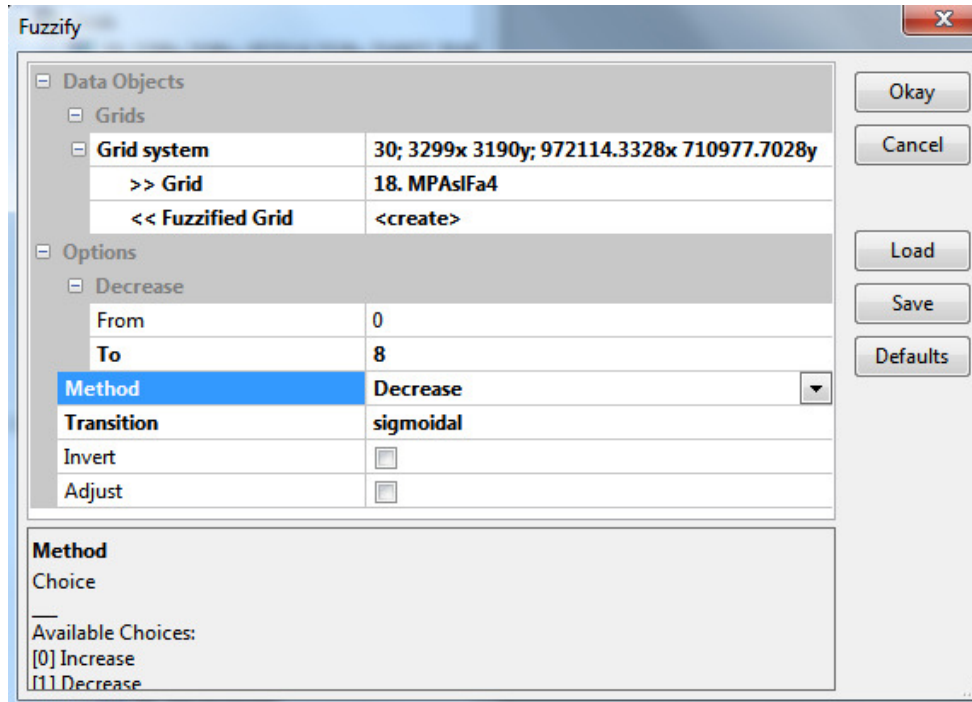
The “linear” method is chosen for the ‘Membership Function Type’ parameter. The maximum data value 78.483925 is keyed in for Decrease To (control point ‘D’). The value of 0 is entered for Increase From, Increase To, and Decrease From (control points ‘A’, ‘B’, and ‘C’). Data values between the values entered for Decrease From (‘C’) and Decrease To (‘D’) are rescaled decreasing from 1 to 0.

The default name of the output grid map is 'MPAcFa3 [Fuzzified]'. I re-name it ‘WLCcdTime’ and save it.

### Slopes Factor

Slope gradients less than 8 degrees are the most cost effective for residential development. However, the lowest slope values are the best and any slope above 8 degrees is equally unsuitable. The sigmoidal function is chosen to rescale the slope data to the 0-1 data range.

The *Grid – Calculus/Fuzzify* tool is applied using the 'MPAslFa4' grid map for the '>> Grid' input parameter. The parameters page for the tool is displayed in Figure V-9.



**Figure V-9. The parameter entries for the *Grid – Calculus/Fuzzify* tool to produce the 'WLCslSlope' grid map.**

The value 0 is entered for control points Increase From ('A'), Increase To ('B'), and Decrease From ('C') and 8 is entered for Decrease To (control point D). Data values between the values entered for Decrease From ('C') and Decrease To ('D') are rescaled decreasing from 1 to 0. This means that the data value 0 is rescaled to 1 and values increasing to 8 degrees are rescaled decreasing from 1 to 0 for the slope value 8. Slope values greater than 8 are rescaled to 0. The "sigmoidal" function is chosen for the 'Membership Function Type' parameter.

The tool outputs a grid map with the default name 'MPAslFA4 [Fuzzify]'. The grid map is re-named 'WLCslSlope' and saved.

### Distance to Open Water Factor

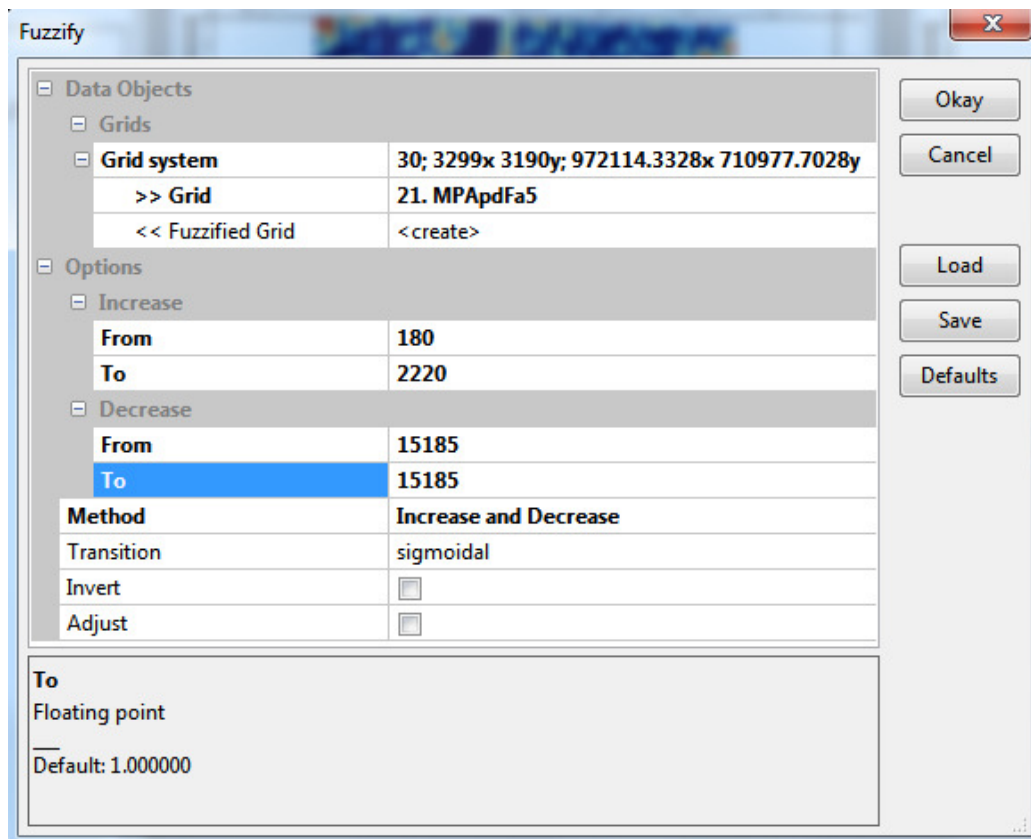
Other factors, such as the one for distance from water bodies, do not have a constant decrease or increase in suitability based solely on a specific distance or time. We know, for example, county regulations require residential development to be at least 180 feet

from open water and wetlands, and environmentalists prefer to see residential development even further from these water bodies. However, a distance of 2400 feet might be just as good as a distance of 3000 feet. Suitability doesn't increase with distance in a constant fashion.

In this example, suitability is very low within 360 feet of water as seen in the Boolean example. Beyond 360 feet, everyone agrees that suitability increases with distance. Environmentalists, however, point out that the benefits of distance level off to a maximum suitability at approximately 2400 feet. Beyond 2400 feet suitability is again equal. This function is best described by an increasing sigmoidal curve.

The sigmoidal function option in the *Grid – Calculus/Fuzzify* tool is chosen to recode the distance from protected features on the grid map 'MPApdFa5'. Remember, the water bodies, major streams and wetland features on this layer have a 180-foot protection buffer around each feature.

I run the *Grid – Calculus/Fuzzify* tool using the 'MPApdFa5' grid map as the input map (see Figure V-10).



**Figure V-10.** Using the *Grid – Calculus/Fuzzify* tool to create the 'WLCpdWater' grid map.

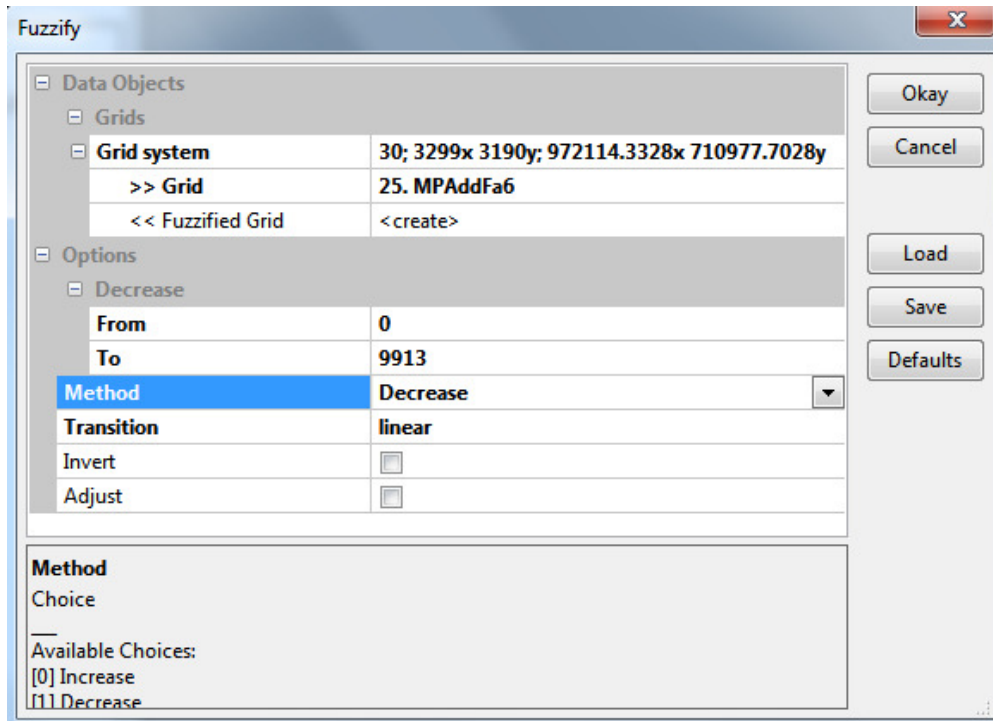
The “sigmoidal” option is chosen for the ‘Membership Function Type’ parameter. To accommodate the two thresholds of 360 and 2400 feet in the function, the control points are no longer the minimum and maximum of the input values. In the case of an increasing function, the Increase From value (A) is the value at which suitability begins to rise sharply above zero and the Increase To value (B) is the value at which suitability begins to level off and approaches a maximum of 1.0. The value 180 is entered for the Increase From control point (‘A’). When 180 feet is added to the already existing 180-foot protected area buffer, the result is a 360-foot protected area around the features. I enter a value of 2220 for the Increase To control point (B). The value 2220 takes into consideration the already existing 180-foot protected area buffer on the ‘MPApdFa5’ layer (2400 feet minus 180 feet equals 2220 feet). Values between 0 and 180 are rescaled to 0. Values between 180 and 2220 are rescaled increasing from 0 to 1.0. Data values between 2220 and 15185 are rescaled to 1. Note that 15185 is the maximum distance found on the 'MPApdFa5' grid map. I click on the 'Okay' button and the tool executes.

The default name for the output grid map is 'MPApdFa5 [Fuzzify]'. I re-name the output grid map ‘WLCpdWater’ and save it.

#### Distance from Developed Land Factor

The last factor is important to environmentalists. It is rescaled using a linear distance decay function. Areas closer to currently developed land are more suitable for residential development than areas farther away, i.e., suitability decreases with distance.

The *Grid – Calculus/Fuzzify* tool is executed using the ‘MPAddFa6’ grid map for the ‘>> Grid’ parameter. The data values in the ‘MPAddFa6’ grid map are distances with a data range from 0 to 9913. Figure V-11 displays the parameters page for the *Grid – Calculus/Fuzzify* tool.



**Figure V-11. The parameter entries for the *Grid – Calculus/Fuzzify* tool to create the 'WLCpdDev' grid map.**

The “linear” option is used for the ‘Membership Function Type’ parameter. The values entered for the control points are such that the suitability decreases from 1.0 to 0 at the maximum distance from developed land. I use the minimum distance value, 0, for the Decrease From control point ‘C’ and the maximum distance, 9913, for the Decrease To control point ‘D’. I name the output file ‘WLCpdDev’.

### **Weighted Linear Combination Grid Data Layer Summary**

#### **Constraint Grid Data Layers**

##### **MPAwCo1**

This constraint is based on a county restriction on development near open water and wetlands. This is open water defined as bodies of water, major streams and wetlands. A 180’ buffer is delineated around the water areas. This features and the 180’ buffer surrounding the features are unavailable for development and coded with 0’s. Available areas, areas outside the 180’ buffer, are coded with 1’s.

##### **MPAluCo2**

A county development restriction. Land use classes not available for development (because they are already developed) are Residential (10), Commercial 1 (20), Commercial 2 (30), Transportation (40), Trade (50), Services (60), Recreation (70), Resource - Other (80), Undeveloped - Other (90), and Unclassified (99). These classes are coded with 0's.

Note that Undeveloped - Other (90) includes water areas and open space areas.

Land use classes available for development (because they are not considered to be developed) are Resource - Agriculture (81), Resource - Agriculture Activities (82), Resource - Agriculture Current Use (83), Resource - Designated Forest Land (88), Undeveloped - Land (91), Undeveloped - Noncommercial Forest (92), Undeveloped - Timberland (95). These classes are coded with 1's.

#### Factor Grid Data Layers

##### WLClaSuit

This factor relates to building costs. Resource - Agriculture (81) land use class grid cells are recoded to 1's, grid cells in .66 to Undeveloped - Noncommercial Forest (92) are recoded to .66 and .33 becomes the data value for land use class Resource - Designated Forest Land (88) grid cells. All other land use classes are coded with 0's.

##### WLCsdRoads

This is a second factor that relates to building costs. Grid cell data values represent distance in feet a cell is from the nearest road. Distances from 0 to 210 feet are rescaled to 1's and values between 210 feet and 1200 feet rescaled decreasing from 1 to 0.

##### WLCcdTime

This factor relates to building costs. Road and off-road grid cell values represent travel time from the town center. A linear distance decay function is applied to travel time values from the minimum 0 to maximum 75.15 minutes. The rescale range is 1 for data value 0 decreasing to 0 for data value 75.15.

##### WLCslSlope

This factor is a building cost factor. Input grid cell data values are slope in degrees. Values rescaled decreasing from 1 to 0 for slopes 0 to 8 degrees with 0 degree slope coded 1 and 8 degree slopes coded 0.

##### WLCpdWater

This is one of two factors related to wildlife preservation. Input grid cell data values represent distance in feet from water bodies, stream network, and possible wetlands. Values rescaled; values less than 180 feet set to 0's; values 180 feet to 2220 feet increasing from 0 to 1. Values greater than 2220 are set to 1's.

##### WLCpdDev

This is a wildlife preservation factor. Input grid cell data values represent distance in feet from developed land use areas. These are areas in land use classes Residential (10),



Commercial 1 (20), Commercial 2 (30), Transportation (40), Trade (50), Services (60), Recreation (70), Resource - Other (80), Resources - Agriculture (81), Resources - Agriculture Activities (82), and Resources - Agriculture Current Use (83). Distance values are rescaled decreasing from 1 (for 0 feet) to 0 (for the maximum distance of 9913').

### **Applying the Weighted Linear Combination and Factor Weights**

Applying the WLC aggregation method involves three steps.

1. Identify a weight of relative importance for each factor grid map. This is referred to as a factor weight.
2. Create a factor weight grid map by multiplying each factor grid map by its specific factor weight.
3. Add the factor weight grid maps together.
4. Apply the Boolean constraint layers to mask out areas not suitable to any degree.

Once factor weights are determined, each standardized factor grid map is multiplied by its factor weight and the “weighted” factor maps are added together creating a composite with values for a continuous surface of suitability. Next, the Boolean constraint layers ‘MPAwCo1’ and ‘MPAluCo2’ are applied as masks to the composite layer to mask out areas not suitable to any degree.

Generally, a set of factor weights is developed around a theme or viewpoint. Multiple sets of weights can be developed to reflect varying viewpoints and alternatives. Viewpoints can relate to issues, citizen groups, special interest groups, etc.

A factor weight is the relative importance of the factor layer relative to other factor layers for determining suitability based on a perspective view. The factor weights for a set of layers must sum to one. The composite or suitability map has the same range of values as the standardized factor grid maps that are used (providing the grid map standardization data value range is the same range as the factor weights). The constraint grid maps (‘MPAwCo1’ and ‘MPAluCo2’) mask out unsuitable areas by multiplying the two layers times the composite layer.

Factor weights are often referred to as “trade off” weights. Because they indicate a factor’s importance relative to all other factors, they control how factors compensate for each other. In the case of WLC, where factors fully trade off, factors with high suitability in a given location can compensate for other factors with low suitability in the same location.

The use of factor weights is one of the advantages of the WLC method. As noted above, different sets of factor weights can be developed based on differing perspective viewpoints or alternatives. For example, in this tutorial six factors are used. One set of factor weights representing the residential developers perspective and a second set from the wildlife preservationist perspective are hypothesized. I can compare the outputs to see

where there is common agreement and areas of significant contrast. This approach was not possible with the Boolean aggregation process described earlier.

I consider the *Grid – Analysis/Analytical Hierarchy Process* tool as a variant of the WLC approach. AHP is a specific approach to developing a set of factor weights using a pair-wise comparison technique. However, the WLC method is not dependent on one particular weight development scheme versus another. I will discuss AHP later. For now, the focus is solely on the WLC process.

The factors of more importance to the residential developer perspective are: land availability, distance from roads, travel time from the city center, and ground slope. The two factors more important to the wildlife preservationist perspective are distance from water and wetland features and distance from developed land.

Table V-2 displays the two sets of weights, one from the perspective of the developer and one from the environmentalist.

**Table V-2: Hypothetical Weights for Two Perspectives**

Factor	Layer	Weights Developer	Weights Preservationist
Land Use	WLClaSuit	0.2000	0.1333
Distance from Roads	WLCsdRoads	0.2667	0.0667
Distance to Town Center	WLCcdTime	0.0667	0.1333
Slope	WLCslSlope	0.2000	0.2667
Distance from Water	WLCpdWater	0.0667	0.2000
Distance from Developed Land	WLCpdDev	0.2000	0.2000
	TOTAL	1.000	1.000

There are a number of weight development schemes that can be applied. The weights listed in the table are developed using a process similar to the one described in the 2011 USDA Forest Service Guide titled "Multi-Criteria Evaluation and Geographic Information Systems for Land-Use Planning and Decision Making". Using this approach, the question I asked myself, for each factor, was: How important is this factor from the perspective of a residential developer (or from an environmental preservationist) compared to another factor? The process for developing these factor weights is described in Appendix A of this tutorial.

Comparing the weights in the “Weights Developer” and “Weights Preservationist” columns in Table V-2 you can see differences on levels of importance relative to the perspective views.

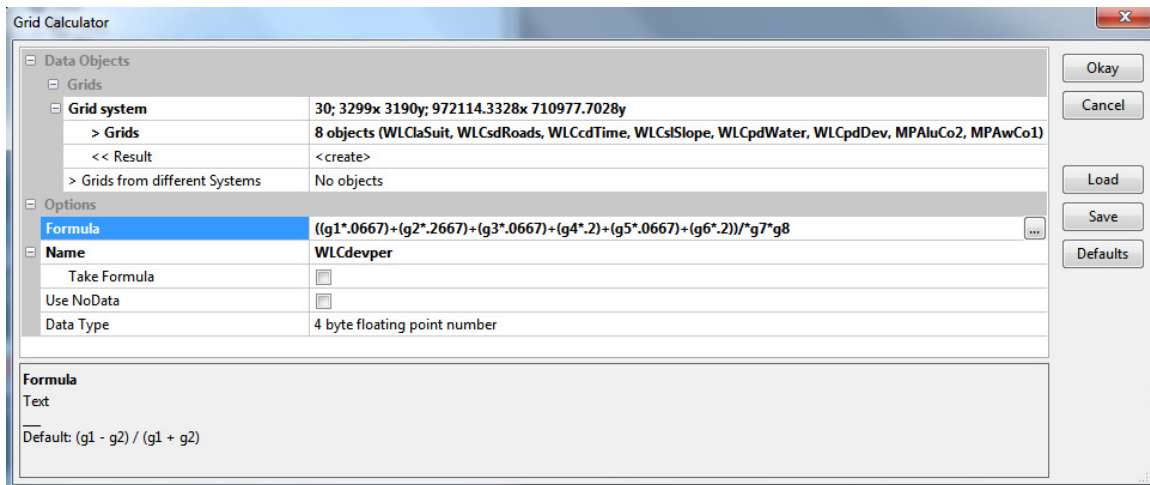
The *Grid – Calculus/Grid Calculator* tool is used to develop a WLC suitable/not suitable grid map. Below is a summary of the steps involved.

1. Multiply each layer by its factor weight. This output grid map can be referred to as a weighted factor grid map.

2. Add the six weighted factor grid data layers together creating a grid map where the cell values are the totals for all the weighted factor grid maps.
3. Multiply the grid map with the totals by the two constraints. This produces a composite with values representing varying degrees of suitability and 0's for not suitable.

You will see that the three steps can be accomplished in a single execution of the *Grid – Calculus/Grid Calculator* tool.

Figure V-12 displays the parameter window for developing a composite grid map for the residential developer perspective.



**Figure V-12. The *Grid – Calculus/Grid Calculator* tool parameter window for the developers perspective.**

The six factor and two constraint grid data layers are chosen for the ‘> Grids’ parameter. The input grid maps are referred to as variables “g1” through “g8” in the equation entered for the ‘Formula’ parameter. The equation entered is:

$$((g1*.2000)+(g2*.2667)+(g3*.0667)+(g4*.2000)+(g5*.0667)+(g6*.2000))*g7*g8$$

Briefly, this equation accomplishes three steps: applying a factor weight to each factor layer to create the weighted factor layers, adding the weighted factor grid maps together, and multiplying the composite by the two constraint layers.

In more detail, the equation instructs the tool to multiply each grid cell data value for layer “g1”, in this case the factor grid map ‘WLClaSuit’, by the weight .2000. This result is then added to the result of multiplying each grid cell data value for layer “g2” by the weight .2667, and so on through grid map “g6”. The constraint layers (they do not have factor weights), variables “g7” and “g8”, are then multiplied by the summation of the weighted factor layers. The effect of applying the two Boolean constraint layers is to

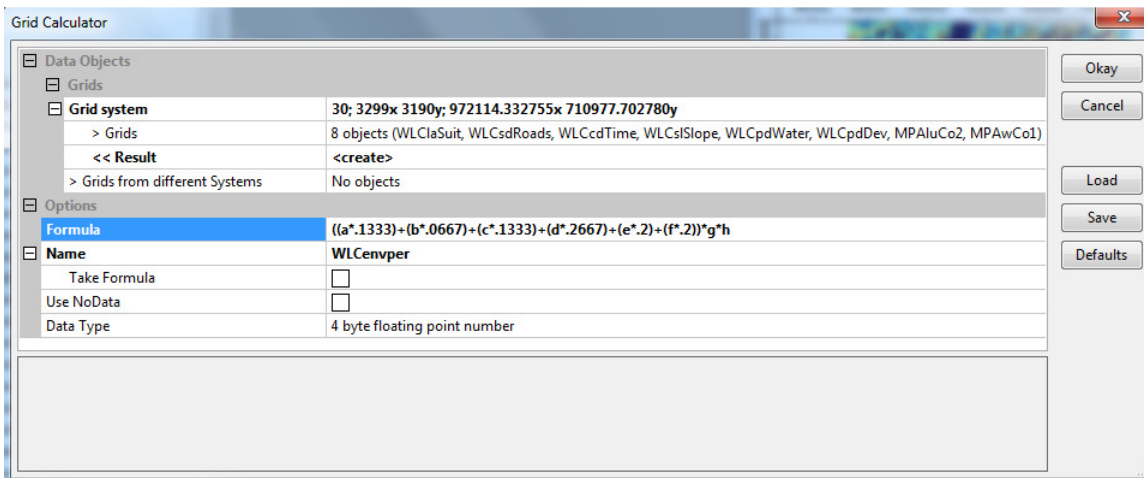
mask out areas that are not suitable to any degree (coding with 0's). The output from the equation is a composite or suitability grid map that is named 'WLCdevper'.

The 'WLCcdTime' grid map, chosen as one of the entries for the '> Grids' input parameter, uses the no data value -99999 for water bodies. Consequently, the water bodies on the output grid map 'WLCdevper' are also coded with the no data value -99999. Unless the no data value is identified as a valid data value using the 'Use NoData' parameter, a no data value in any grid cell produces a no data value for the corresponding grid cell of the output grid map. Water bodies are not suitable for residential development and the water body grid cells of the 'WLCdevper' grid map need to be recoded to 0 data values.

The *Grid - Tools/Reclassify Grid Values* tool is used to recode the no data value -99999 used on the 'WLCdevper' grid map to 0. The tool is executed using the 'WLCdevper' grid map for the input '>> Grid' parameter, "<create>" for the output parameter '<< Reclassified Grid', "single" for the 'Method' parameter, -99999 for the 'old value' parameter, 0 for the 'new value' parameter, and "=" for the 'operator' parameter. The default name for the output grid map is 'WLCdevper\_reclassified'.

The recode process applied resulted in data values occurring outside of the irregular outline of the project area so the *Grid - Tools/Grid Masking* tool is used to convert the data values in those grid cells to the no data value -99999. The 'WLCdevper\_reclassified' grid map is chosen for the input parameter '>> Grid', "<create>" for the output parameter '< Masked Grid', and 'MProjAreaGR' for the input parameter '>> Mask'. The default name for the output grid map is 'Masked Grid'. I re-name this grid map 'WLCdevper' and save it.

Figure V-13 displays the parameter values used with the *Grid - Calculus/Grid Calculator* tool to develop the output layer for the environmentalist perspective.



**Figure V-13. The *Grid – Calculus/Grid Calculator* tool parameter window for the environmentalist perspective.**

The parameters window used for applying the environmentalist perspective (see Figure V-13) is quite similar to the one for the developer perspective in Figure V-12. The factor weights change and there is a different name for the output grid map, 'WLCenvper'.

As with the 'WLCdevper' grid map, the 'WLCenvper' grid map also has water bodies coded with the no data value -99999. These no data values are handled in the same manner as explained for the 'WLCdevper' grid map.

1. Apply the *Grid - Tools/Reclassify Grid Values* tool to recode the -99999 no data value to 0.
2. Apply the *Grid - Tools/Grid Masking* tool to discard data values outside of the irregular outline of the project area but within the spatial extent of the project grid system.

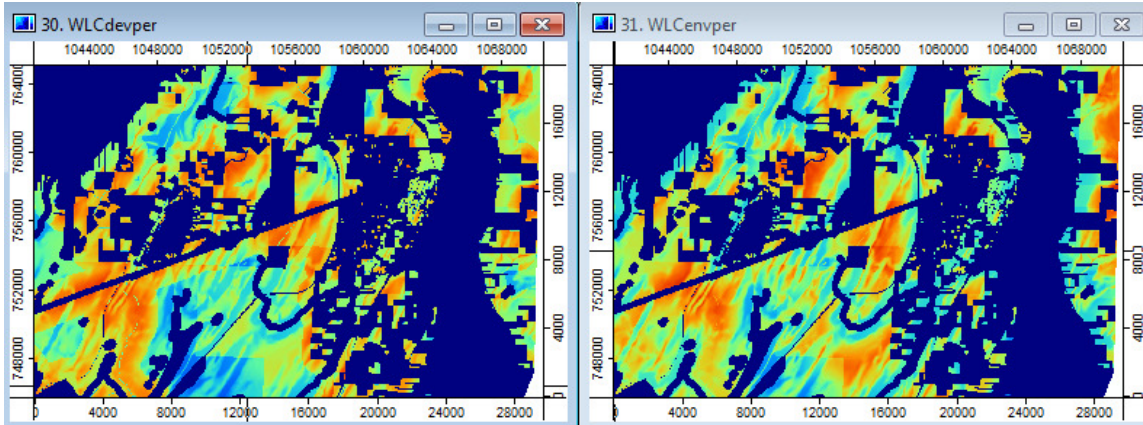
I re-name the output grid map 'Masked Grid' from the *Grid - Tools/Grid Masking* tool to 'WLCenvper' and save it.

### **Applying the 50 Acre Spatial Requirement**

As with the Boolean method explored earlier, a final processing step is to eliminate clumps of suitable cells smaller than 50 acres in size. This requirement also exists with the methods involving AHP and OWA in this tutorial. Applying the 50-acre spatial requirement for the WLC, AHP and OWA methods is different than for the Boolean method. The *Grid - Filter/Filter Clumps* tool identifies clumps of grid cells having the same grid cell data value.

The Boolean method deals with binary data for the factor grid maps while the WLC, AHP and OWA outputs contain continuous data values ranging between 0 and 1.0. Applying the 50 acre spatial requirement as a step in the Boolean method involved contiguous groups or clumps of grid cells all containing the data value 1. The grid cell data values involved in the WLC, AHP and OWA methods are continuous data values in the range 0 through 1. A detailed explanation of applying the 50-acre spatial requirement is provided in this section and is referred to in discussion of other methods in later sections.

The developer believes land areas smaller than 50 acres are infeasible for residential development projects. The 'WLCdevper' and 'WLCenvper' grid maps are displayed in Figure V-14.



**Figure IV-14. The ‘WLCdevper’ and ‘WLCenvper’ grid maps.**

Looking at the zoomed in views of the ‘WLCdevper’ and ‘WLCenvper’ output grid data layers in the map view windows in Figure V-14, you notice that a range of continuous data values exist and you can see many clumps of cells that appear to be smaller than 50 acres or 2420 grid cells. Most of these clumps are visible because they are surrounded by dark blue. The dark blue in the layer represents not suitable areas.

The *Grid – Filter/Filter Clumps* tool is used to find all contiguous areas of suitability smaller than 50 acres (2420 grid cells) in size. This tool works well with discrete data values, integer values like 0, 1, 2, 3, etc. For example, with the Boolean suitability layer, it worked well because the data was discrete, in that case, a data value of 1. Cells are identified as part of a clump if they are contiguous and if they all have the same data value. The data values for my two WLC suitability layers are continuous rather than discrete and range in value from 0 to 1.0. The 50-acre criterion is related to area and not to the data values in the clumped grid cells. I can still use the *Filter Clumps* tool but a couple extra steps will be involved including creating an interim version of the continuous data as binary data.

Another consideration regarding the application of the *Grid – Filter/Filter Clumps* tool is that the data value 0 is a valid data value. The data value 0 on the ‘WLCdevper’ and ‘WLCenvper’ grid maps identifies land areas not suitable for development. It does not make sense that these areas (grid cells with data values 0) should have the 50-acre rule applied. This can be taken into account in the first step below using -99999 (a no data value) as the output data value for 0 values of the input grid map 'WLCdevper'. The *Grid – Filter/Filter Clumps* tool is not applied to no data grid cells.

Here is a quick summary of how the ‘WLCdevper’ layer (the residential developer perspective) is processed to apply the requirement of a minimum 50-acre size.

1. The first step is to recode all values in the WLC suitability grid map greater than 0 to 1's. The *Grid – Calculus/Grid Calculator* tool is used for this purpose. The output layer is named ‘WLCdevperBIN1’. All grid cells with data values greater than 0 in the

'WLCdevper' grid map contain 1's on the 'WLCdevperBIN1' layer. Grid cells coded with 0's on the 'WLCdevper' are recoded as -99999 or no data values.

2. The *Grid – Filter/Filter Clumps* tool is executed using the 'WLCdevperBIN1' grid map as the input layer. Clumps of grid cells identified by the tool as smaller than 50 acres (2420 cells) have their grid data values replaced with the no data value of -99999. The output is named 'WLCdevperBIN2'.

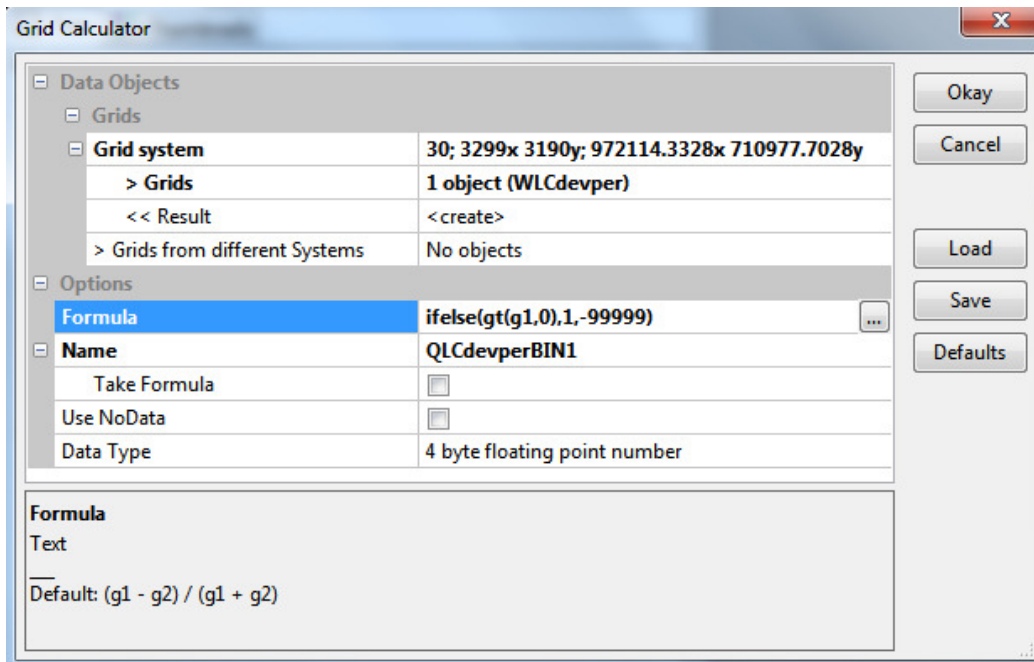
3. Since the clumps smaller than 50 acres are now unsuitable, the no data value -99999 on the 'WLCdevperBIN2' layer needs to be reclassified to the unsuitable data value of 0 using the *Grid – Tools/Reclassify Grid Values* tool. The output layer is named 'WLCdevperBIN3'. This layer is used to update the 'WLCdevper' grid map replacing data values for clumps of grid cells smaller than 50 acres with 0 data values.

4. Last, the *Grid – Calculus/Grid Calculator* tool is executed using the 'WLCdevperBIN3' and 'WLCdevper' as inputs. The equation for the execution checks the 'WLCdevperBIN3' for 0 values. The data values of corresponding grid cells of the 'WLCdevper' grid map are replaced with 0 data values. Thus, the clumps of grid cells 50 acres or less than size, on the 'WLCdevper' grid map, have had their data values replaced with 0's.

Here are details for what is outlined in the four steps above.

The first step is to recode all values in the grid map, 'WLCdevper', greater than 0 to 1's and all 0 values to the no data value -99999. The *Grid – Calculus/Grid Calculator* tool is used for this purpose.

The *Grid – Calculus/Grid Calculator* tool parameters page is displayed in Figure V-15.

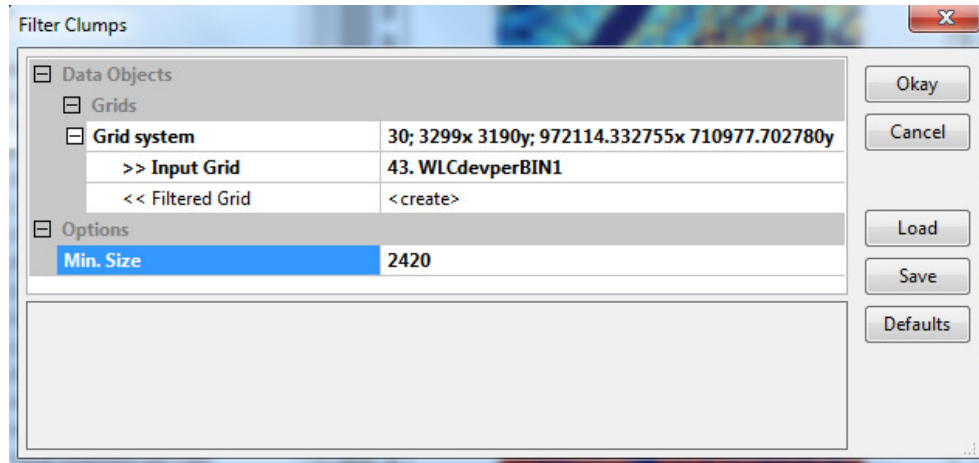


**Figure V-15. The *Grid – Calculus/*Grid Calculator tool parameters used to create the interim 'WLCdevperBIN1' grid map.**

The grid map 'WLCdevper' is chosen for the input '> Grids' parameter. The equation entered for the 'Formula' parameter checks the grid cell value on the input grid map (the input layer 'WLCdevper' is represented by the variable "a" in the formula) to see if it is greater than 0. If it is greater than 0, a 1 is placed in the corresponding cell of the output grid map otherwise the no data value -99999 goes to the output cell. The output grid map from this execution is named 'WLCdevperBIN1'. All grid cells with data values greater than 0 on the 'WLCdevper' grid map contain 1's on the 'WLCdevperBIN1' layer and all grid cells with 0's on the input grid map contain the no data value -99999.

The *Grid – Filter/Filter Clumps* tool is executed using the 'WLCdevperBIN1' grid map as the input grid map. Figure V-16 displays the parameter window for this tool showing the 'WLCdevperBIN1' grid map entered for the '>> Input Grid' parameter.





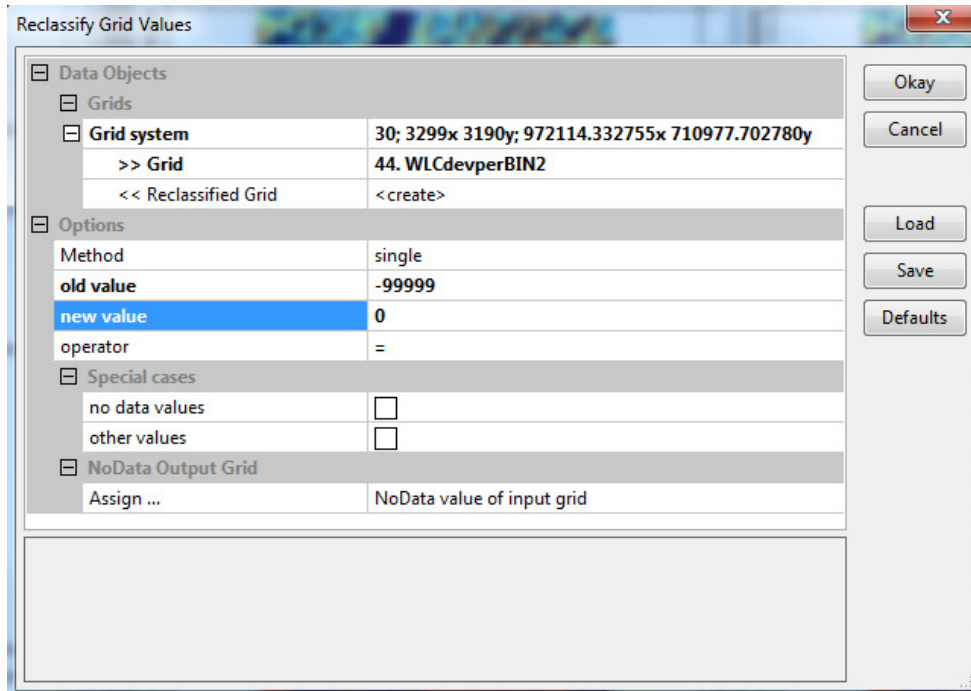
**Figure V-16. The *Grid – Filter/Filter Clumps* tool parameter entries producing the 'WLCdevperBIN2' grid map.**

Based on a 30-foot grid cell size, it takes 2420 grid cells to define 50 acres. When the tool identifies a clump of contiguous grid cells smaller in number than 2420 the no data value is output to each of the corresponding contiguous grid cells on the output grid map. I click on the 'Okay' button and the tool executes.

The default output grid map is named 'Filtered Grid'. This output grid map is re-named 'WLCdevperBIN2' and saved to the project area storage folder.

The clumps of cells smaller than 50 acres should be in the unsuitable category and coded with 0's. The *Grid – Tools/Reclassify Grid Values* tool is used to reclassify the -99999 no data values on the interim layer 'WLCdevperBIN2'. The -99999 data values are replaced with 0's. Remember that the grid cells with -99999 data values are the grid cells containing 0's on the 'WLCdevper' grid map. The new grid cells containing -99999 are clumps of grid cells less than 50 acres in size. They are to be added into the 0 data value grid cells of the 'WLCdevper' grid map.

Figure V-17 displays the tool parameter page for the *Grid – Tools/Reclassify Grid Values* tool using the 'WLCdevperBIN2' as the input layer.

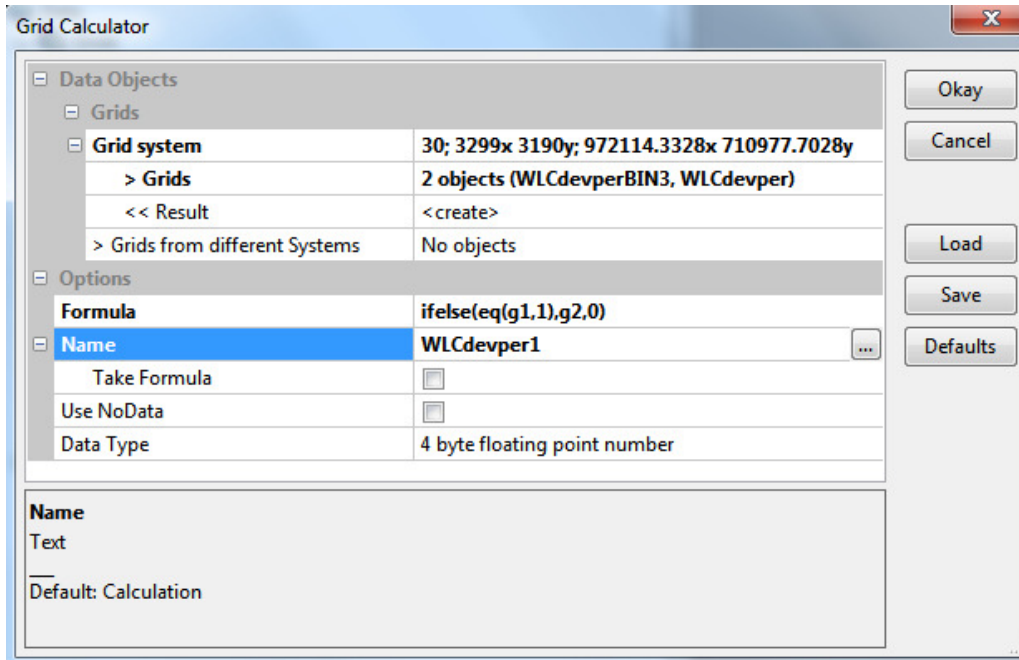


**Figure V-17. The parameter entries for reclassifying the 'WLCdevperBIN2' grid map.**

The 'WLCdevperBIN2' grid map is chosen for the '>> Grid' input parameter. The "single" option is chosen for the 'Method' parameter. This is used when you want to change a single grid data value to a new one. I enter -99999 for the 'old value' parameter and 0 for the 'new value' parameter. The operator used is "=". I click on the 'Okay' button and the tool executes creating the output grid map 'WLCdevperBIN2\_reclassified'.

I rename the output grid map 'WLCdevperBIN3' and save it. This output serves as a mask in the final step.

The *Grid – Calculus/Grid Calculator* tool is used to apply the 'WLCdevperBIN3' layer to update grid cells on the 'WLCdevper' data layer. The same grid cells of the 'WLCdevperBIN3' grid map that contain the data value 0 should also contain the data value 0 on the 'WLCdevper' grid map. The parameter page for the *Grid Calculator* tool using the 'WLCdevper' and 'WLCdevperBIN3' layers for the input '> Grids' parameter is displayed in Figure V-18.

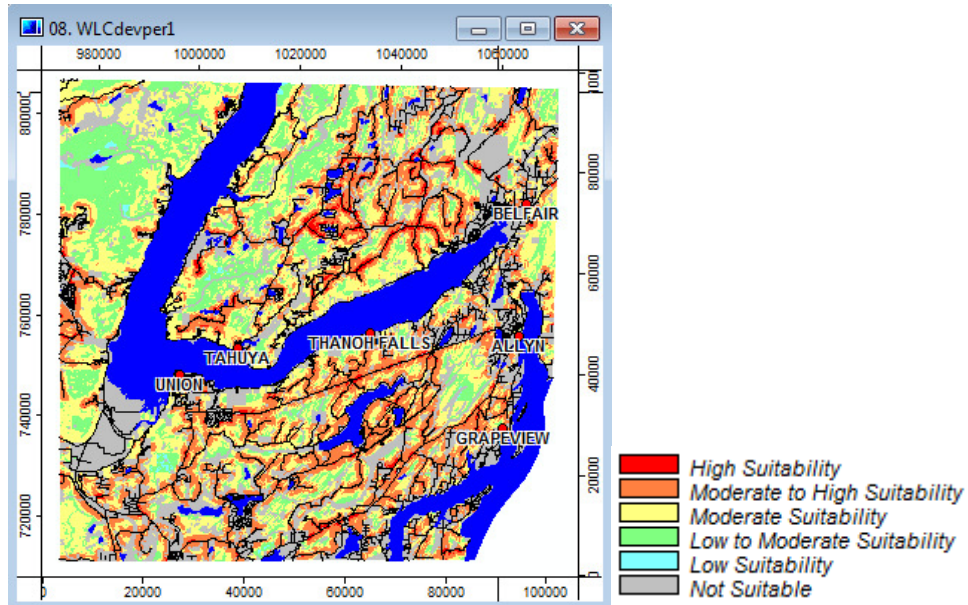


**Figure V-18. Using the *Grid – Calculus/Grid Calculator* tool to create the 'WLCdevper1' grid map.**

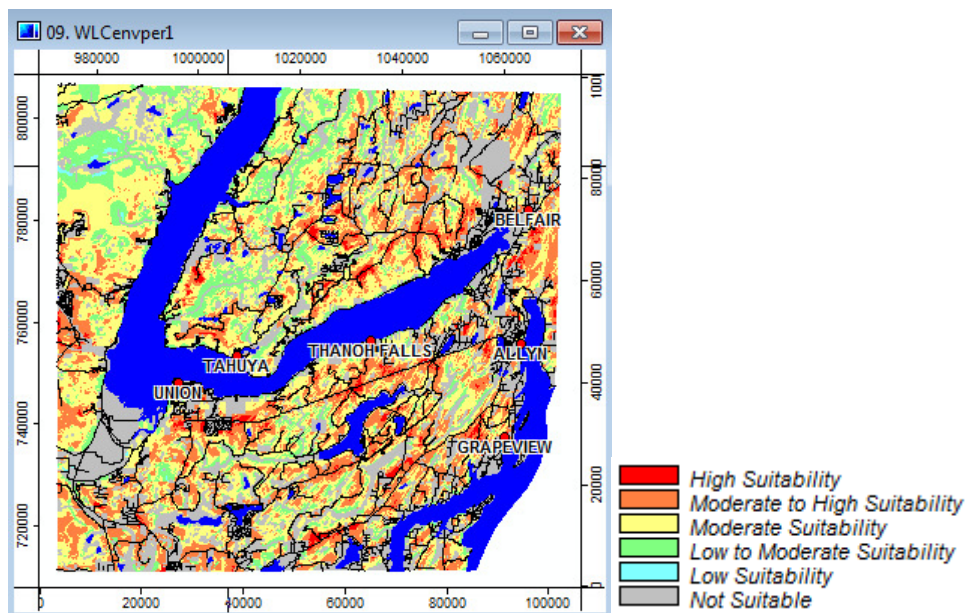
The equation treats the 'WLCdevperBIN3' layer as a mask. The layer is referred to as variable "g1" in the equation. The equation directs the tool to check a grid data value in the 'WLCdevperBIN3' layer to see if it is a 1. If the value is a 1, then the data value in the corresponding cell in the 'WLCdevper' layer is output to the corresponding cell of the output grid map. When the value is a 0, a 0 is output to the corresponding cell of the output grid map. The output grid map contains data values from the 'WLCdevper' layer for any grid cell containing a 1 on the 'WLCdevperBIN3' layer. I name of the output grid map is 'WLCdevper1' (entered for the 'Name' parameter). I save the new data layer.

I repeat the above process with the 'WLCenvper' layer. Interim layers named 'WLCenvperBIN1', 'WLCenvperBIN2', and 'WLCenvperBIN3' are created. The final output grid map is named 'WLCenvper1' and saved.

Figure V-19 displays the 'WLCdevper1' grid map and Figure V-20 displays the 'WLCenvper1' layer.



**Figure V-19. The developer ('WLCdevper1') grid map.**



**Figure V-20. The environmentalist perspective ('WLCenvper1') grid map.**

I created a lookup table for displaying the suitability data with 6 display classes. The classes each use the same class interval of .2. Included in the map are shapes data layers for roads, streams, and bodies of water.

The patterns for the two perspective grid maps are quite similar. Zooming in on areas helps to notice where differences occur. An easy way to quantify differences is to reclassify the two grid maps using the class intervals used for their display. Then the

*Spatial and Geostatistics - Grids/Zonal Grid Statistics* tool can be used to quantify numbers of grid cells in each class.

There are no acre differences for no data grid cells and unsuitable acres. Each grid map has 9472 acres of no data values and 90335 acres of unsuitable. These two categories should not differ between the two layers. The table below displays a comparison of the two suitability solutions.

**Table V-3: Comparing the Development and Environmental Perspectives**

Name	Class	Development		Environmental	
		Cell Count	Acres	Cell Count	Acres
No Data		458445	9472	458445	9472
Not Suitable (0)	1	4372199	90335	4372199	90335
0 - .2	2	22005	455	14771	305
.2 - .4	3	1221661	25241	917166	18950
.4 - .6	4	2300593	47533	2776705	57370
.6 - .8	5	1981154	40933	1822566	37656
.8 - 1.0	6	167753	3466	161958	3346

Displaying quantitative data related to the two perspective solutions provides obvious insights into differences between the two solutions. SAGA has other tools that can be applied for data analysis.

### *References*

Ayalew, Lulseged, Hiromitsu Yamagishi, and Norimitsu Ugawa. "Landslide Susceptibility Mapping Using GIS-Based Weighted Linear Combination, the Case in Tsugawa Area of Agano River, Niigata Prefecture, Japan" in *Landslides*, Vol. 1, 2004, pp. 71-81.

Basnet, B. B. and A. A. Apan. "Degree of Site Suitability Measurement in a GIS: The Effect of Standardization Method",

Djenaliev, Akjol. "Multicriteria Decision Making and GIS for Railroad Planning in Kyrgyzstan." M.Sc. Thesis, School of Architecture and the Built Environment, Royal Institute of Technology, Sweden. 2007. 60 p.

Drobne, Samo and Anka Lisec. "Multi-attribute Decision Analysis in GIS: Weighted Linear Combination and Ordered Weighted Averaging", *Informatica*, Volume 33, 2009, pp. 459-474. Covers WLC and ORA.

Eastman, J. Ronald. *Idrisi for Windows: User's Guide, Version 2.0*, January 1997. Clark University, USA. Tutorial Exercises: Multi-Criteria Evaluation – Boolean Analysis, Multi-Criteria Evaluation – Weighted Linear Combination, and Multi-Criteria Evaluation– Ordered Weighted Average.

Jiang, Hong, J. Ronald Eastman. “Application of fuzzy measures in multi-criteria evaluation in GIS”, *International Journal Geographical Information Science*, 2000, Vol. 14, No. 2, pp. 173-184. Also covers OWA.

Mahini, A. Salman and M. Gholamalifard. “Siting MSW landfills with a weighted linear combination methodology in a GIS environment”, *International Journal of Environmental Science Tech.*, 2006, Volume 3, Number 4, pp. 435-445. Also covers AHP.

López-Marrero, T.; González-Toro, A.; Heartsill-Scalley, T.; Hermansen-Báez, L.A. 2011. *Multi-Criteria Evaluation and Geographic Information Systems for Land-Use Planning and Decision Making*. [Guide]. Gainesville, FL: USDA Forest Service, Southern Research Station. 8 p.

### **The Analytical Hierarchy Process - Weights**

The SAGA tool *Grid – Analysis/Analytical Hierarchy Process* tool integrates three tasks. First, using a pair-wise comparison input matrix, the tool calculates a factor weight for each input factor grid data layer. Second, a weighted factor grid map is calculated by multiplying each input factor grid data layer by its’ factor weight determined by the input matrix. And, last, the weighted factor grid maps are added together to create a composite suitability grid map.

The second task listed above is assumed, as the tool does not produce weighted factor grid maps. Conceptually it is easiest hypothesizing that the tool goes through a step of multiplying each factor grid data layer by its “weight” as this is the process if one is to manually replicate this step. A manual process for creating weighted factor grid data layers is used in the OWA section of this tutorial.

Factor weights are calculated using a popular pair-wise comparison technique. The comparisons involve the relative importance of a pair of factors in determining their suitability to the stated objective. Appendix B of this tutorial describes, in a little more detail, the process I used for building the input pair-wise comparisons table for the *Grid – Analysis/Analytical Hierarchy* tool. The mathematics used by the tool to calculate layer weights are also explored in the appendix.

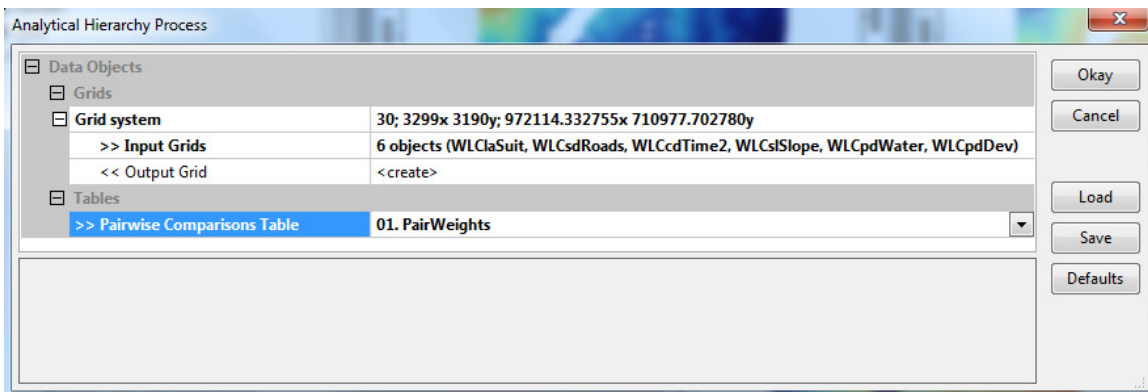
My initial execution of the *Grid – Analysis/Analytical Hierarchy Process* tool produced an output grid map containing an extreme negative data value for water bodies on the map. Please recall that on the 'WLCcdTime' grid map water bodies are coded with the no data value -99999. If no data values are included in a calculation they can cause problems. For example, this has been discussed related to the *Grid - Calculus* tool. It is possible something similar occurs with the *Grid – Analysis/Analytical Hierarchy Process* tool. I did a test by reclassifying the no data values on the 'WLCcdTime' grid map and the negative data values produced on the output were replaced with data values within the correct data range. We know that water bodies, major streams, and wetlands are considered not suitable and are handled with the Open Water and Wetland Constraint grid map 'MPAwCo1'. I can recode the no data values on the 'WLCcdTime' grid map as a work-around and the final results will not be affected.



Before executing the *Grid – Analysis/Analytical Hierarchy Process* tool I apply the *Grid - Tools/Reclassify Grid Values* tool to the 'WLCcdTime' grid map. The 'WLCcdTime' grid map is entered for the '>> Grid' input parameter, "<create>" is used for the output parameter '<< Reclassified Grid', "single" used for 'Method', -99999 is entered for the 'old value' parameter, 0 is entered for the 'new value' parameter, and "=" is used for the 'operator'. The output grid map is named 'WLCcdTime\_reclassified'.

There are data values occurring outside of the project area that I discard. These grid cells are actually recoded to the no data value -99999 by using the *Grid - Tools/Grid Masking* tool. The output grid map from this tool is named 'Masked Grid'. I re-name it 'WLCcdTime2' and save it. This is my corrected version of the grid map.

Figure V-21 displays the parameters window for the *Grid – Analysis/Analytical Hierarchy Process* tool.



**Figure V-21.** The parameters window for the *Grid – Analysis/Analytical Hierarchy Process* tool.

The input factor grid maps are the grid layers created as part of the WLC method. They are: WLClaSuit (LandFac), WLCsdRoads (RoadFac), WLCcdTime2 (TownFac), WLCslSlope (SlopeFac), WLCpdWater (WaterFac), and WLCpdDev (DevFac). The reference in the parentheses identifies the factor column reference used in Figure V-22. Notice that the grid data layers entered for the '>> Input Grids' parameter are in the same order as the grid data layer columns in the 'PairWeights' table displayed in Figure V-22. It is extremely important that the order of the factor grid maps in the input list match the order for the rows and columns of the pair-wise comparison table.

	LandFac	RoadFac	TownFac	SlopeFac	WaterFac	DevFac
1	1.000000	1.000000	5.000000	0.143000	3.000000	7.000000
2	1.000000	1.000000	7.000000	1.000000	3.000000	0.333000
3	0.200000	0.143000	1.000000	0.333000	3.000000	0.143000
4	7.000000	1.000000	3.000000	1.000000	5.000000	0.200000
5	0.333000	0.333000	0.333000	0.200000	1.000000	1.000000
6	0.143000	3.000000	7.000000	5.000000	1.000000	1.000000

**Figure V-22. The ‘PairWeights’ table of pair-wise comparisons.**

The tool uses the data provided in the table chosen for the ‘>> Pairwise Comparisons Table’ parameter to calculate an importance weight, i.e., a factor weight, for each of the input grid maps. This is the only input to this tool other than choosing the input factor grid maps. Once the factor weights are determined by the tool, the factor grid map is multiplied by its factor weight. The factor weight grid maps are added together producing a suitability layer. Recall that factor weight grid maps are not an output.

The six factor weights for the layers sum to 1.0. Each individual weight indicates the relative importance of any one factor relative to the others. The set of weights used in this tutorial was developed for a residential developers perspective for suitability for residential development. This tool allows for an iterative process of exploration where the user or group of users can experiment with a variety of weighting schemes to reflect different perspective views.

The weight developed for an input factor grid map is used as a multiplier for each grid cell data value in the factor grid map. Once the weights have been applied to their respective layer, the weighted grid maps are added together to produce the composite output grid map for the tool. Once I make the entries for the tool parameters I click on the 'Okay' button and the tool executes. The name for the default output grid map is 'Output Grid'. I re-name it 'WLCahp\_orig' and save it to a storage folder.

I want to verify a couple of the grid cell values on the output by manually calculating an output value using the input factor grid map cell values times the factor weights and summing.

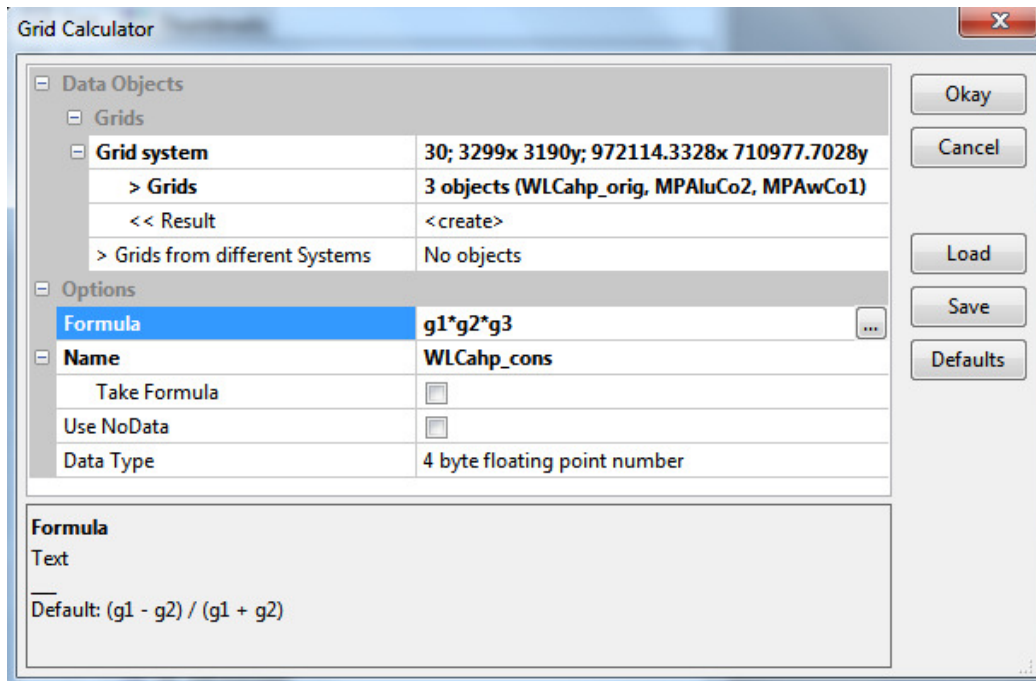
The "Cell 1" and "Cell 2" rows below list data values for the same grid cell for factor layers 1 through 6. The weights for each factor layer are listed in the "Wts." rows. The results of multiplying the grid cell data value by the weight is showing below the "Wts." rows.



	Layer Number					
	1	2	3	4	5	6
Cell 1	.33	.57	.90	.67	1.0	.94
Wts.	.234	.152	.055	.245	.049	.266
[Cell 1 * Wts]	.077	+.086	+.050	+.164	+.049	+.250 = .676
Cell 2	.33	1.0	.88	.96	0	.88
Wts.	.234	.152	.055	.245	.049	.266
[Cell 1 * Wts]	.077	+.152	+.049	+.236	+0	+.234 = .746

The check with the two grid cells verifies that the output data values are being calculated correctly.

After the factor weights are applied and the composite output layer produced, the next step is to multiply the composite by the Boolean constraints ('MPAwCo1' and 'MPAluCo2') to mask out areas that are not suitable to any degree. The resulting layer is a measure of aggregate suitability with data values ranging between 0 and 1.0. This masking is accomplished easily using the *Grid – Calculus/Grid Calculator* tool. Figure V-23 displays the parameters page for the tool.



**Figure V-23. The *Grid – Calculus/Grid Calculator* tool parameter entries for creating the 'WLCahp\_cons' grid map.**

The input parameter, '> Grids', has three entries. The first one in the list is the 'WLCahp\_orig' grid map that was created by the *Grid – Analysis/Analytical Hierarchy Process* tool. The 'MPAwCo1' and 'MPAluCo2' layers are the Boolean constraint layers. These three input layers are referred to as variables "g1a", "g2", and "g3" in the equation

entered for the 'Formula' parameter. Recall earlier that multiplying the layers in this manner means that when one or more of the layers have a cell containing a 0 value the product for the corresponding output layer cell will be 0. The output layer is named 'WLCahp\_cons'.

### Applying the 50 Acre Spatial Requirement

As with the Boolean and WLC methods explored earlier, a final step in the scenario is to eliminate clumps of suitable cells smaller than 50 acres. A more detailed explanation of applying the 50 acre spatial requirement is available in the description of the weighted linear combination method.

The 'WLCahp\_cons' grid map is displayed in Figure V-24.

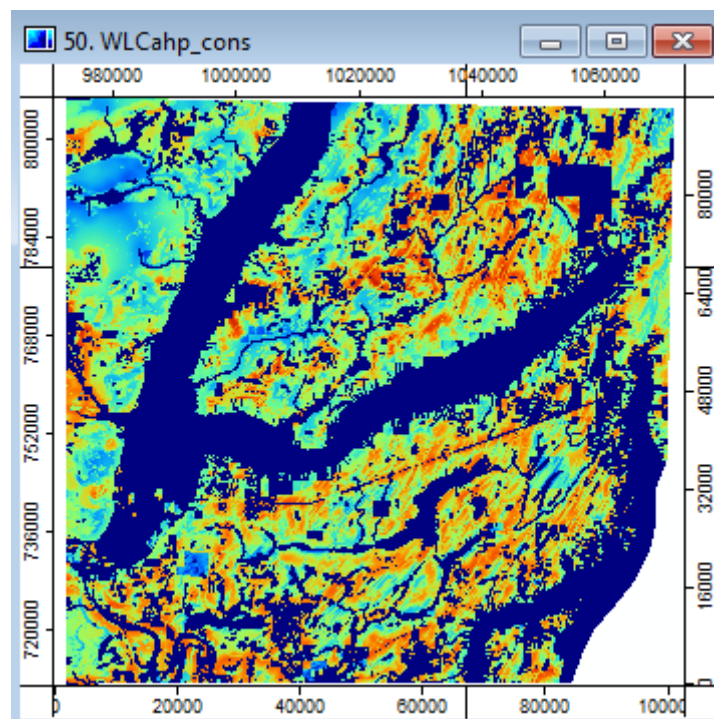


Figure V-24. The 'WLCahp\_cons' grid map.

Looking at the 'WLCahp\_cons' output grid map in Figure V-24, you can see many clumps of cells that appear to be smaller than 50 acres or 2420 grid cells. The dark blue in the layer represents not suitable areas.

The *Grid – Filter/Filter Clumps* tool is used to find all contiguous areas of suitability smaller than 50 acres (2420 grid cells) in size. This tool works well with discrete data values, integer values like 1, 2, 3, etc. For example, with the Boolean suitability layer, it worked well because the data was discrete, in that case, a data value of 1. Cells are identified as part of a clump if they are contiguous and if they all have the same data value. The data values for the 'WLCahp\_cons' suitability layer are continuous and range in value from 0 to 1.0. The 50-acre criterion is related to area and not to the data values in

the clumped grid cells. I can still use the *Filter Clumps* tool but a couple extra steps will be involved including creating an interim version of the continuous data as binary data. Below is a quick summary of how the 'WLCahp\_cons' layer is processed to apply the requirement of a minimum 50-acre size.

1. The first step is to recode all values on the 'WLCahp\_cons' grid map greater than 0 to 1's and all 0 values to the no data value -99999. The *Grid – Calculus/Grid Calculator* tool is used for this purpose. The output from this execution is named 'WLCahpperBIN1'. All grid cells with data values greater than 0 on the 'WLCahp\_cons' data layer contain 1's and all 0 data values of the 'WLCahp\_cons' grid map contain the no data value -99999 on the 'WLCahpperBIN1' layer.

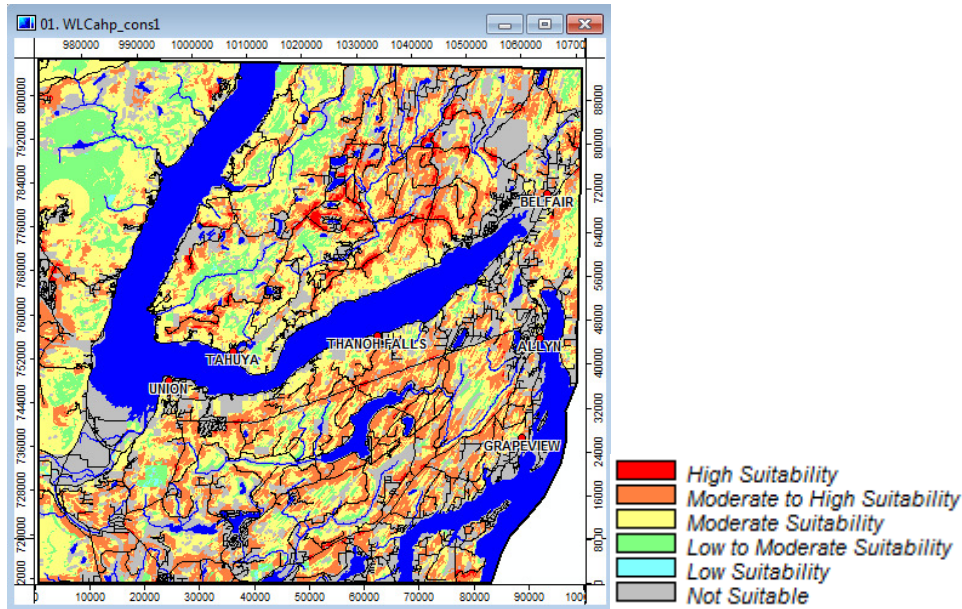
2. The *Grid – Filter/Filter Clumps* is executed using the 'WLCahpperBIN1' layer as the input layer. Clumps of grid cells identified by the tool as smaller than 50 acres (2420 cells) have their grid cell values replaced with the no data value of -99999. This output layer is named 'WLCahpperBIN2'.

3. Because the clumps smaller than 50 acres are now unsuitable, the *Grid – Tools/Reclassify Grid Values* tool is used to convert the -99999 values on the 'WLCahpperBIN2' layer to 0's. The output layer is named 'WLCahpperBIN3'. This layer is used as a mask in the final step.

4. I use the *Grid – Calculus/Grid Calculator* tool with the 'WLCahpperBIN3' and 'WLCahp\_cons' as inputs. The equation treats the 'WLCahpperBIN3' layer as a mask. The output grid map contains data values from the 'WLCahp\_cons' layer for any grid cell containing a 1 on the 'WLCahpperBIN3' layer. I name the output grid map 'WLCahp\_cons1'.

The steps described above are quite similar to the same process described in the WLC section of this tutorial. Please refer back to that section for more details.

Figure V-25 displays the output 'WLCahp\_cons1' grid map produced using the process outlined above in the four steps.



**Figure V-25. The ‘WLCahp\_cons1’ grid map.**

The suitability data for the layer is displayed using a lookup table with 6 class levels (this is the same table used for displays in Figures V-19 and V-20). Included in the map view window are shapes data layers for roads, streams, and bodies of water.

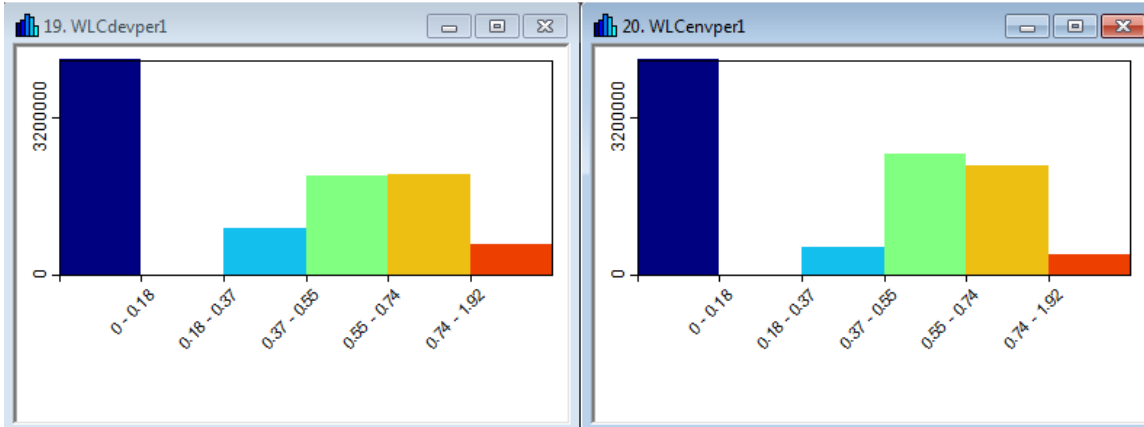
The AHP process provides a procedure for determining factor weights using a pair-wise comparison method. Appendix B of this tutorial gives an overview of the basic mathematics of how the pair-wise comparison table is developed and used to calculate the factor weights. Thus, if you do not want to use the *SAGA Grid – Analysis/Analytical Hierarchy Process* but want to use the AHP to calculate factor weights, Appendix B gives you the information needed to “manually” determine factor weights using a spreadsheet program. The other value of the information in Appendix B is it allows you to find out exactly what the weights are that the tool calculates. There is no output from the tool documenting what the calculated weights are that are used or a consistency ratio for the weights.

### **Discussion**

This section of the tutorial demonstrated how SAGA tools are used for supporting the WLC method of multi-criteria evaluation. Two very subjective sets of factor weights are developed and listed in Table V-2. The differences between the two sets is that one set represents a land development perspective and the other bias toward an environmental protection perspective. Keep in mind that these sets of factor weights are hypothetical and only for the purposes of this tutorial. The capability to develop factor weights and to adjust the weights is quite powerful in that it allows for a spectrum of “viewpoints” to produce a spatial image of suitability alternatives.

The AHP tool supports a subjective approach to factor weighting but in a more systematic manner using a pair-wise comparison process. Personally I favor the application of a systematic process rather than one that is purely subjective.

Unlike with the Boolean aggregation method, the WLC method produces a degree of suitability ranging from 0 (fully not suitable) to 1 (fully suitable) with values in between representing increasing degrees of suitability. Figures V-19 and V-20 display the two solutions for the developer and environmental perspective. Viewing the histograms for the two perspective grid maps the solutions look similar (Figure V-26).



**Figure V-26. Comparing histograms for the ‘WLCdevper1’ and ‘WLCenvper1’ perspective suitability grid maps.**

A six-class lookup table was used for each grid map to get a visual comparison between the two alternatives. The histogram form looks the same for both. The most suitable class for the development perspective includes more land area compared to the same class for the environmental perspective. Figures V-27 and V-28 display the tabular data for the two histograms.

	CLASS	AREA	Acres	COUNT	CUMUL	NAME	MIN	CENTER	MAX
1	1	3934979100.000000	90334	4372199	4372199	0	0.000000	0.000000	0.000000
2	2	11229300.000000	257	12477	4384676	0 - 0.18	0.000010	0.092419	0.184828
3	3	873172800.000000	20045	970192	5354868	0.18 - 0.37	0.184828	0.277243	0.369657
4	4	1819203300.000000	41763	2021337	7376205	0.37 - 0.55	0.369657	0.462071	0.554485
5	5	1839642300.000000	42232	2044047	9420252	0.55 - 0.74	0.554485	0.646900	0.739314
6	6	580601700.000000	13328	645113	10065365	0.74 - 1.92	0.739314	1.331728	1.924142

**Figure V-27. The histogram data for the ‘WLCdevper1’ grid map.**

	CLASS	AREA	Acres	COUNT	CUMUL	NAME	MIN	CENTER	MAX
1	1	3934979100.000000	90334	4372199	4372199		0.000000	0.000000	0.000000
2	2	7667100.000000	176	8519	4380718	0 - 0.18	0.000010	0.092419	0.184828
3	3	514935000.000000	11821	572150	4952868	0.18 - 0.37	0.184828	0.277243	0.369657
4	4	2213720100.000000	50820	2459689	7412557	0.37 - 0.55	0.369657	0.462071	0.554485
5	5	2004508800.000000	46017	2227232	9639789	0.55 - 0.74	0.554485	0.646900	0.739314
6	6	383018400.000000	8792	425576	10065365	0.74 - 1.92	0.739314	1.331728	1.924142

**Figure V-28. The histogram data for the ‘WLCenvper1’ grid map.**

I added a new field named "Acres" to the table and used the *Table – Calculus/Table Calculator* tool to calculate acres for the two histogram tables. The tables provide a quantitative basis for comparing the two alternatives.

The land area in the most suitable class for the environmental perspective is about 65% of the size for the same class in the development perspective. Other numeric and statistical comparisons could be used to better understand the differences.

#### *References*

Alias, Mohamad, Siti Zaiton Mohd Hashim and Supiah Samsudin. “Using Fuzzy Analytic Hierarchy Process for Southern Johor River Ranking.” International Journal of Advanced Software Computing Applications, 1:1 (July 2009): 62-76.

Al-Shalabi, Mohamed, Shattri Bin Mansor, Nordin Bin Ahmed, and Rashid Shiriff. “GIS Based Multicriteria Approaches to Housing Site Suitability Assessment.” Shaping the Change XXIII FIG Congress, Munich, Germany, October 8-13, 2006 p. 17.

Berry, Joseph K. “Analytical Hierarchy Process (AHP): Applying AHP in Weighting GIS Model Criteria.” GeoWorld, September, 2003.

Coyle, Geoff. “The Analytic Hierarchy Process (AHP).” Practical Strategy, Open Access Material, Pearson Education Limited, 2004, 11 p.

Farooq, Waqqas. “AHP (Analytical Hierarchy Process): Tutorial.” Waqqasfarooq.com, 2012. 7 p.

Forman, Ernest H. “Analytical Hierarchy Process.” Decision by Objectives, [mdm.gwu.edu/Forman/DBO.pdf](http://mdm.gwu.edu/Forman/DBO.pdf), 6 p.

Jabr., W. M. and F. A. El-Awar. “GIS and Analytic Hierarchy Process for Siting Water Harvesting Reservoirs.” Beirut, Lebanon, 2003, 8 p.

Kordi, Maryam. “Comparison of Fuzzy and Crisp Analytic Hierarchy Process (AHP) Methods for Spatial Multicriteria Decision Analysis in GIS”, M.Sc. Thesis in Geomatics, 2008, 55 p.

Liu, Dahai, Ram R. Bishu, and Lotfollah Najjar. "Using the Analytical Hierarchy Process as a Tool for Assessing Service Quality" in IEMS, Vol. 4, No. 2, pp. 129-135.

Nataraj, Sam. "Analytic Hierarchy Process as a Decision-Support System in the Petroleum Pipeline Industry" in Issues in Information Systems, Volume 6, No. 2, 2005, pp. 16-21.

Nonis, Colin N., Koshy Varghese, and K. S. Suresh. "Investigation of an AHP Based Multi Criteria Weighting Scheme for GIS Routing of Cross Country Pipeline Projects." 24<sup>th</sup> International Symposium on Automation and Robotics in Construction (ISARC 2007), Construction Automation Group, I.I.T. Madras, 2007, pp. 397-403.

Saaty, Thomas L., "Decision Making With the Analytic Hierarchy Process" in International Journal Services Sciences, Vol. 1, No. 1, 2008, pp. 83-98.

Vahidnia, M.H., A. Alesheikh, A. Alimohammadi, and A. Bassin. "Fuzzy Analytical Hierarchy Process in GIS Application" in The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. 37: Part B2. Beijing 2008, pp. 593-596.



## VI. The Ordered Weighted Averaging Method

The last method for aggregating criteria in our MCE tutorial is Order Weighted Average (OWA). This technique has some similarity to the WLC method.

The standard approach with OWA is to first apply a set of factor weights in a similar manner as described for WLC. These weights reflect the relative importance of a set of factor grid maps. I will use the same factor grid maps created in the WLC section and the factor weights developed with the AHP process.

The input grid maps for the OWA process are the factor grid data layers described in the "Factor Standardization" section of the WLC section of this tutorial. The WLC factor grid maps are: WLClaSuit, WLCsdRoads, WLCcdTime2, WLCslSlope, WLCpdWater, and WLCpdDev. A description of each of these grid maps is provided in the section "Weighted Linear Combination Grid Data Layer Summary".

A weighted factor grid map is created by multiplying the factor grid map by its' factor weight. I hypothesized earlier that a weighted factor grid map is an interim step as part of the computation steps for the *Grid – Analysis/Analytical Hierarchy Process* but that actual weighted factor grid maps are not produced as output. In addition, the calculated factor weights are not identified as part of the output.

Appendix B describes in detail how the *Grid – Analysis/Analytical Hierarchy Process* tool processes the input pair-wise matrix for calculating factor weights. Using this information I can manually calculate the factor weight for each factor grid map and use the *Grid – Calculus/Grid Calculator* tool to create the input weighted factor grid maps for the *Grid – Analysis/Ordered Weighted Averaging (OWA)* tool.

I am choosing here to use the factor weights created with the AHP tool to develop the weighted factor grid data layers that illustrate the OWA method. As an alternative, I could have chosen to use either of the sets of weights displayed in Table V-2 or developed a new set of weights.

The OWA process uses a second set of weights called order weights. These are not the same weights we have referred to as factor weights used to develop the weighted factor grid data layers. Order weights are applied to the weighted factor grid data layers. Order weights provide a greater degree of control over the overall level of trade off between factors for determining suitability. Just as the factor weights must sum to 1.0, so must the order weights sum to 1.0.

The order weights are applied according to the rank order of grid cell data values for the input factor grid maps at every grid cell. The order weights govern the degree to which factor weights influence the aggregation procedure.

Once weighted factor grid maps are available, the grid cell data values (i.e., the data values for the same grid cell across the grid maps) are ranked from low to high suitability across the grid maps. The factor with the lowest grid cell value is then multiplied by the



first order weight, the factor with the next lowest grid cell value is multiplied by the second order weight, and so on. This has the effect of applying weighting factors based on the data value rank from minimum to maximum value for each grid cell. The weighted values for a grid cell are totaled and the total is output to the corresponding grid cell in the output grid map.

Applying the OWA tool in SAGA, the number of order weights entered matches the number of input weighted factor grid maps. The order weights are entered in a single column. The first order weight in the column is applied to the minimum data value for the grid cell for the same grid cell of all the weighted factor grid maps. A value is calculated for an output cell by multiplying the minimum cell value of the input layers by the first order weight, the next larger factor grid map data value above the minimum value is multiplied by the second order weight in the column, etc., and the maximum factor grid map cell value by the last order weight in the column.

Below are a couple examples using three weighted factor grid input layers. The data value for the same grid cell for three grid maps is 0.1570, 0.0786, and 0.1805.

Order Weights	*	Sorted Factor Cell Data Value	=	Calculated Value		Output Value
0.2	*	0.0786	=	0.0157		
0.5	*	0.1570	=	0.0785		0.1484
0.3	*	0.1805	=	0.0542		

Example 1

Factor grid data layer 1 has a value of .1570 for the cell, factor grid data layer 2 has a value of .0786 for the cell and the third factor has a value of .1805 for the cell. The “Sorted Factor Cell Data Value” column displays these factor layer values sorted from minimum to maximum; the first row displays the minimum and the last row the maximum. The “Order Weights” column displays the order weights entered in the *Grid – Analysis/Ordered Weight Averaging (OWA)* tool. The weights are .2, .5, and .3. The weights are applied to the factor grid cell values from minimum to maximum. The first order weight is applied to the minimum factor cell value, the next order weight to the next higher cell value and the last order weight is applied to the maximum cell value. The product of the order weights and the cell data values is displayed in the “Calculated Value” column. These products are totaled and the total is output to the corresponding cell of the output grid data layer. In this example, the total is .1484. Let’s look at another example.

In this example, the same grid cell is evaluated having data values of 0.1570, 0.0786, and 0.1805 for the three grid maps. So the factor grid map data values do not change. The order weights are changed to the following: .45, .10 and .45.

Order Weights		Sorted Factor Cell Data Value	Calculated Value	Output Value
0.45	*	0.0786	= 0.0354	0.1323
0.10	*	0.1570	= 0.0157	
0.45	*	0.1805	= 0.0812	

Example 2

The second example uses two order weights that are identical. One is applied to the minimum cell data value for the cell and the other to the maximum cell value. The middle order weight is .10.

These two examples illustrate how the OWA process operates. Whether you have 3 or 6 or more input factor grid data layers, you must provide the same number of order weights in the input table for the 'Weights' parameter of the tool. Additionally, you can see that the order weights are applied to the input grid map grid cell values, on a cell-by-cell basis. The data values for the grid cell for the grid maps are sorted from minimum to maximum and the order weights from the first row of the input table to the last row are applied. The products of each factor grid map data value and order weight are summed and output to the corresponding cell in the output data layer.

This tutorial involves six factor grid maps. I will use six order weights. If I want to produce results similar to the WLC process, then I would specify the following order weights:

Order Weights:	0.16	0.16	0.16	0.16	0.16	0.16
Rank :	1st	2nd	3rd	4th	5th	6th

In the above example, weight is distributed or dispersed evenly between the six factor grid maps regardless of their rank position from minimum to maximum for any given location. Using the above weights produces an output grid map with patterns similar to one produced using the WLC method. If five factor grid maps were involved the individual weight would be .20.

I decide to place more importance on the minimum and maximum data values with the minimum data value twice as important as the minimum. The other four data values have an order weight ranging from .07 to .10. I am going to use the set of order weights below:

OrderWeights:	0.40	0.10	0.15	0.07	0.08	0.20
Rank :	1st	2nd	3rd	4th	5th	6th

I do not have a particular scenario supporting these weights other than to show how they are incorporated into the execution of the *Grid – Analysis/Ordered Weight Averaging (OWA)* tool. The input weighted factor grid maps are created using the AHP factor weights developed for the WLC example. The highest order weights are assigned to the minimum and maximum data values of the input weighted factor grid maps.

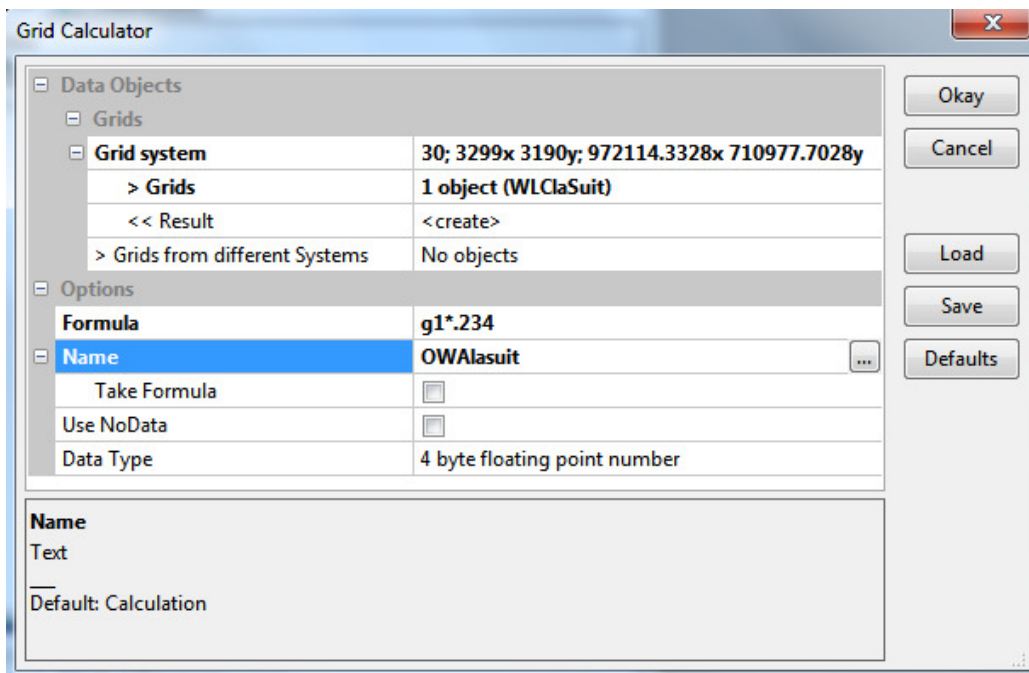
### Weighted Factor Grid Maps

As has been explained, the factor grid maps used in the WLC section and the weights developed by the *Grid – Analysis/Analytical Hierarchy Process* tool are used to create weighted factor grid maps. These WLC layer names with their weights are displayed in Table VI-1.

**Table VI-1: Factor Weights Produced by the AHP Process**

Factor	Layer	AHP Factor Weight
Land Use	WLClaSuit	0.234
Distance from Roads	WLCsdRoads	0.152
Distance to Town Center	WLCcdTime2	0.055
Slope	WLCslSlope	0.245
Distance from Water	WLCpdWater	0.049
Distance from Developed Land	WLCpdDev	0.266
	TOTAL	1

The *Grid – Calculus/Grid Calculator* tool is used to multiply the factor grid maps by their AHP factor weight. Figure VI-1 displays the parameter page for the tool.



**Figure VI-1. The *Grid – Calculus/Grid Calculator* tool parameters used to create the 'OWAlasuit' grid map.**

The settings displayed in Figure VI-1 produce the weighted factor grid map for the land factor. The input grid map for the '> Grids' parameter is 'WLClaSuit'. The equation entered for the 'Formula' parameter is "a\*.234". The character "a" is the variable representing the input grid map. The ".234" is the factor weight calculated by the *Grid – Analysis/Analytical Hierarchy Process* tool for the layer. The output weighted factor layer is named 'OWAlaSuit'.

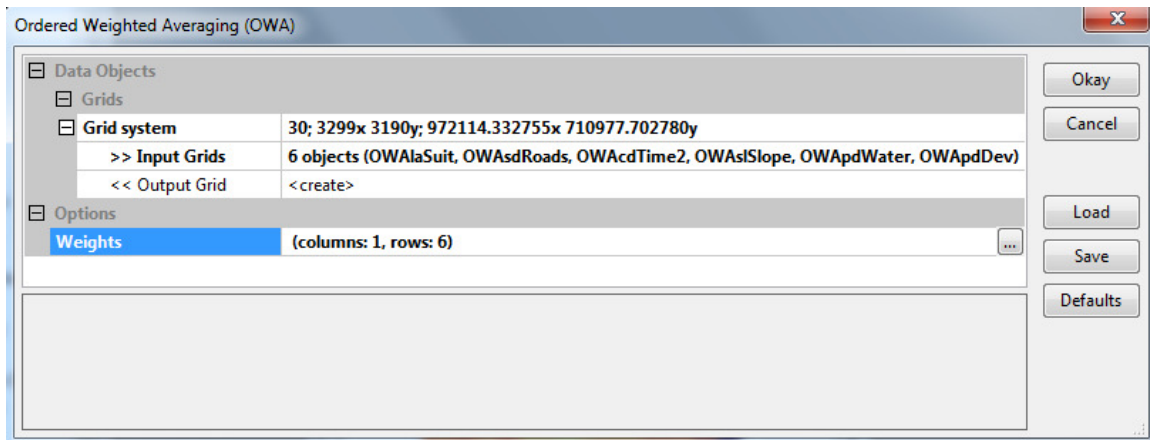
I executed the *Grid Calculator* tool once for each of the factor layers to create a set of weighted factor grid maps. These layers are the input layers for the *Grid – Analysis/Ordered Weighted Averaging (OWA)* tool. Table VI-2 displays a list of the input and output layers and the factor weight for each.

**Table VI-2. Weighted Factor Layers for the OWA Process**

Factor	Input Layer	Weighted Factor Layer	AHP Factor Weight
Land Use	WLClaSuit	OWAlaSuit	0.234
Distance from Roads	WLCsdRoads	OWAsdRoads	0.152
Distance to Town Center	WLCcdTime2	OWAcTime2	0.055
Slope	WLCslSlope	OWAslSlope	0.245
Distance from Water	WLCpdWater	OWApdWater	0.049
Distance from Developed Land	WLCpdDev	OWApdDev	0.266
		TOTAL	1.000

### Ordered Weights

The *Grid – Analysis/Ordered Weighted Averaging (OWA)* tool parameters window is displayed in Figure VI-2.



**Figure VI-2. The *Grid – Analysis/Ordered Weighted Averaging (OWA)* tool parameters window.**

The six weighted factor grid maps are chosen as the input layers for the '>> Input Grids' parameter. Note that the order the input grids appear in the value field for the '>> Input

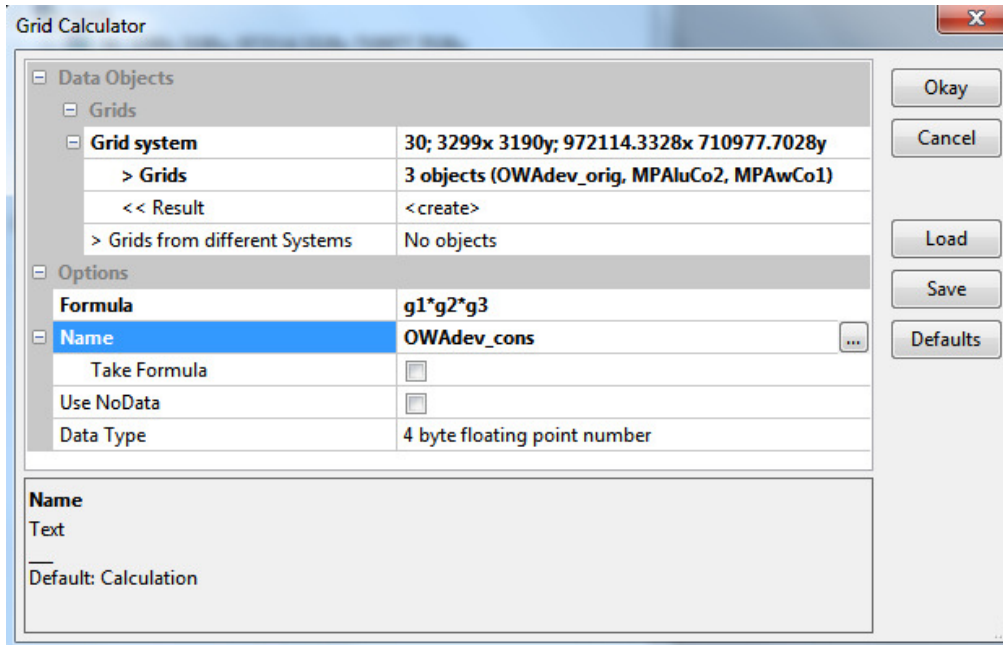
Grids' parameter does not matter because the tool sorts the data values of a grid cell for the weighted factor grid maps from low to high. I use the "<create>" option for the output parameter '<< Output Grid'. I enter order weights into the single column for the 'Weights' parameter. I click on the ellipsis with the mouse pointer and the 'Weights' window displays (Figure VI-3).

	Weight
1	0.400000
2	0.100000
3	0.150000
4	0.070000
5	0.080000
6	0.200000

**Figure VI-3. The ordered weight table for the 'Weights' parameter.**

The default name for the output grid map is 'Output Grid'. I re-name it 'OWAdev\_orig' and save it to the project area storage folder.

The next step is to use the *Grid – Calculus/Grid Calculator* tool to multiply the output grid map 'OWAdev\_orig' by the Boolean constraints 'MPAwCo1' and 'MPAluCo2' to mask out areas that are not suitable to any degree. The resulting layer is a measure of aggregate suitability that ranges in values between 0 and 0.131. Figure VI-4 displays the parameters page for the tool.

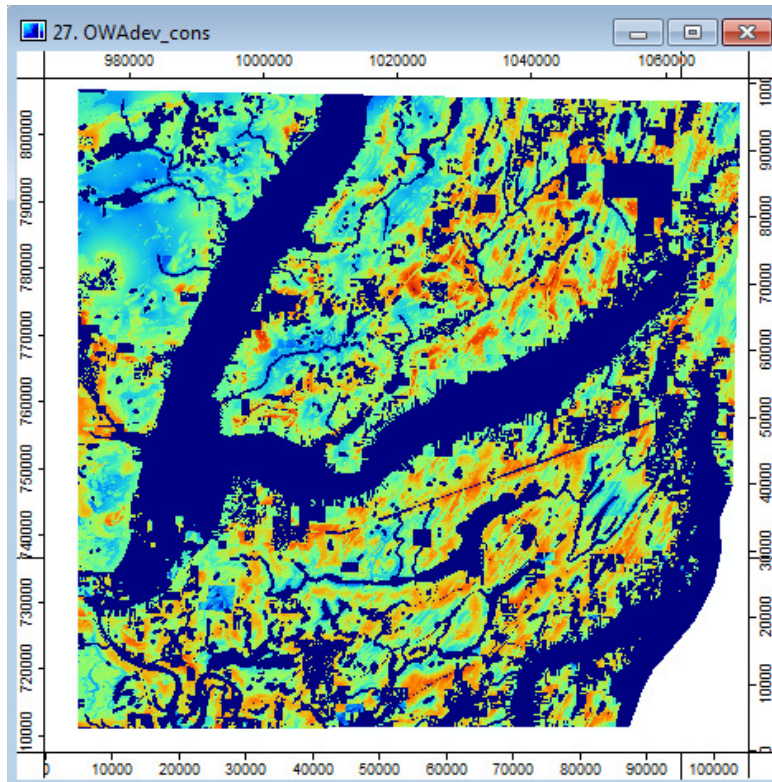


**Figure VI-4. The parameters window for creating the 'OWAdev\_cons' grid map.**

The input parameter, '> Grids', has three inputs chosen. The first one in the list is the 'OWAdev\_orig' grid map created by the *Grid – Analysis/Ordered Weighted Averaging (OWA)* tool. The 'MPAwCo1' and 'MPAluCo2' layers are the Boolean constraint layers. These three input layers are referred to as variables “g1”, “g2”, and “g3” in the formula entered for the 'Formula' parameter. Recall earlier that multiplying the layers in this manner means that when one or more of the layers have a cell containing a 0 value the product for the corresponding output layer cell is 0. The output layer is named 'OWAdev\_cons'. I click on the 'Okay' button and the tool executes. I save the 'OWAdev\_cons' grid map to a storage folder.

### **Applying the 50 Acre Spatial Requirement**

As with the Boolean and WLC methods explored earlier, a final step is to eliminate clumps of suitable cells smaller than 50 acres. The developer believes land areas smaller than 50 acres are infeasible for a residential development project. The 'OWAdev\_cons' grid map is displayed in Figure VI-5.



**Figure VI-5. The ‘OWAdev\_cons’ suitability grid map.**

Looking at the ‘OWAdev\_cons’ output grid map in Figure V-5, I can see many clumps of cells that appear to be smaller than 50 acres or 2420 grid cells. The dark blue in the layer represents not suitable areas.

The *Grid – Filter/Filter Clumps* tool is used to find all contiguous areas of suitability smaller than 50 acres (2420 grid cells) in size. This tool works well with discrete data values, integer values like 1, 2, 3, etc. For example, with the Boolean suitability layer, it worked well because the data was discrete, in that case, a data value of 1. Cells are identified as part of a clump if they are contiguous and if they all have the same data value. The data values for the ‘OWAdev\_cons’ suitability layer are continuous and range in value from 0 to 1.0. The 50-acre criterion is related to area and not to the data values in the clumped grid cells. I can still use the *Filter Clumps* tool but a couple extra steps are involved including creating an interim version of the continuous data as binary data. Below is a quick summary of how the ‘OWAdev\_cons’ layer is processed to apply the requirement of a minimum 50-acre size.

1. The first step is to recode all values on the ‘OWAdev\_cons’ grid map greater than 0 to 1’s and all 0 values to the no data value -99999. The *Grid – Calculus/Grid Calculator* tool is used for this purpose. The output from this execution is named ‘OWAdevperBIN1’. All grid cells with data values greater than 0 on the ‘OWAdev\_cons’ data layer contain 1’s and all 0 data values of the ‘OWAdev\_cons’ grid map contain the no data value -99999 on the ‘OWAdevperBIN1’ layer.



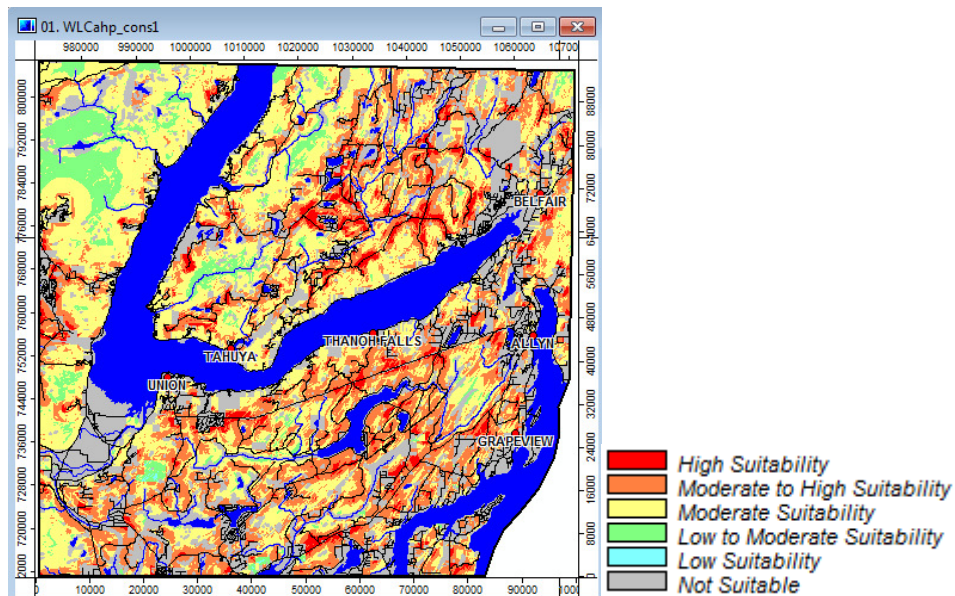
2. The *Grid – Filter/Filter Clumps* is executed using the ‘OWAdevperBIN1’ layer as the input layer. Clumps of grid cells identified by the tool as smaller than 50 acres (2420 cells) have their grid cell values replaced with the no data value of –99999. This output layer is named ‘OWAdevperBIN2’.

3. Because the clumps smaller than 50 acres are now unsuitable, the *Grid – Tools/Reclassify Grid Values* tool is used to convert the –99999 values on the ‘OWAdevperBIN2’ layer to 0’s. The output layer is named ‘OWAdevperBIN3’. This layer is used as a mask in the final step.

4. I use the *Grid – Calculus/Grid Calculator* tool with the ‘WLCahpperBIN3’ and ‘OWAdev\_cons’ as inputs. The equation treats the ‘WLCahpperBIN3’ layer as a mask. The output grid map contains data values from the ‘OWAdev\_cons’ layer for any grid cell containing a 1 on the ‘OWAdevperBIN3’ layer. I name the output grid map ‘OWAdev\_cons1’.

The process for applying the 50-acre requirement in the WLC section of this tutorial is very similar to its’ application for the OWA method. Please refer to that section for more detailed explanation.

Figure VI-6 displays the ‘OWAdev\_cons1’ grid map.



**Figure VI-6. The ‘OWAdev\_cons1’ suitability grid map.**

The suitability data for the layer is displayed using a lookup table for 6 class levels. Included in the map are shapes data layers for roads, streams, and bodies of water.



## Discussion

The mechanics related to applying the OWA process are described above. As part of the process a set of weighted factor grid data layers is created using the AHP generated factor weights. These layers and the factor weight used with each one are listed in Table VI-2. These layers are used in this discussion to explore the possibilities for the OWA process. This exploration is provided to encourage further research of available publications related to MCE, WLC, AHP, and OWA.

I am going to use order weights in the OWA tool to produce three outputs defining a minimum, maximum, and average solution using the weighted factor maps: OWA1aSuit, OWA5dRoads, OWAcdTime2, OWA5lSlope, OWApdWater, and OWApdDev. The 50-acre minimum requirement is not applied as a processing step for these three output grid maps. The three new grid maps are named 'OWAminORIG', 'OWAavgORIG', and 'OWAmaxORIG'.

It was noted earlier that a set of “average” weights for the order weights produces a suitability grid map similar in pattern to the WLC layer 'WLCahp\_cons' produced using the AHP pair-wise table factor weights. The average order weights used with the *Grid - Analysis/Ordered Weighted Averaging (OWA)* tool to create the 'OWAavgORIG' grid map are:

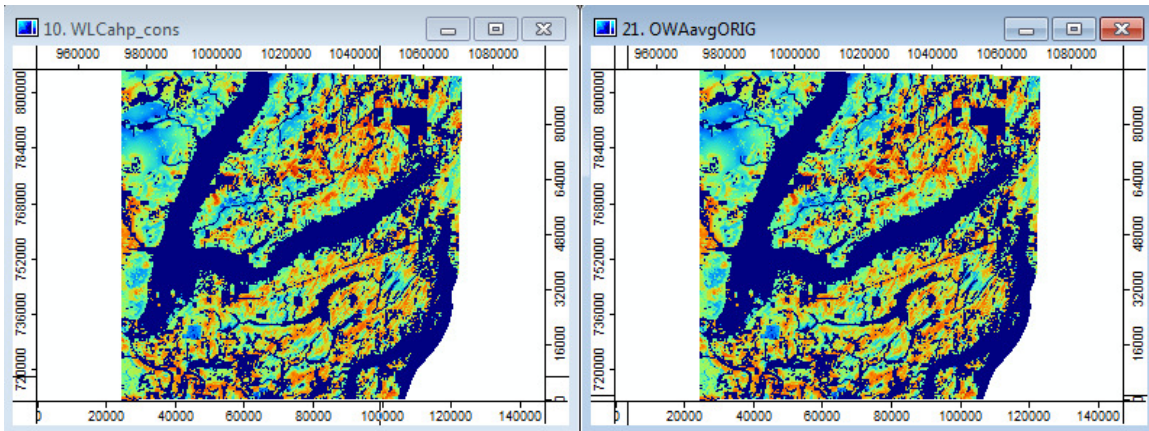
OrderWeights:	.16	.16	.16	.16	.16	.16
Rank :	1St	2nd	3rd	4th	5th	6th

You can see that weight is distributed equally among all the weight factor grid maps regardless of their rank order position from minimum to maximum for any given grid cell location. They are skewed neither to the minimum nor the maximum. No rank order position has a greater influence over another in the final result. There will be full trade off between the weighted factor grid maps allowing the factors weights to be fully employed.

The *Grid - Analysis/Ordered Weighted Averaging (OWA)* tool is executed using the six weighted factor grid maps (OWA1aSuit, OWA5dRoads, OWAcdTime2, OWA5lSlope, OWApdWater, and OWApdDev) are chosen for the input parameter '>> Input grids' along with "<create>" for the output parameter '<< Output Grid'. The weights listed above are entered for the 'Weights' parameter. I click on the 'Okay' button and the tool executes producing the default output grid map 'Output Grid'.

The constraint grid maps 'MPAwCo1' and 'MPAluCo2' are applied to the 'Output Grid' grid map using the *Grid - Calculus/Grid Calculator* tool. The three grid maps (MPAwCo1, MPAluCo2, and Output Grid) are chosen for the input parameter '> Grids'. The equation is "g1\*g2\*g3", a simple multiplication formula. The not suitable areas of the two constraint grid maps (grid cells containing the no data value -99999) define not suitable grid cells for the output grid map 'OWAavgORIG'. This grid map name is entered for the 'Name' parameter. I save the 'OWAavgORIG' grid map to a storage folder.

Figure VI-7 displays the WLC suitability layer 'WLCahp\_cons' (prior to applying the 50 acre requirement) and the output 'OWAavgORIG' produced by the OWA tool using the set of average order weights above.



**Figure VI-7. Visually comparing the WLC suitability layer to the OWA average suitability layer.**

The data ranges of the two layers are different; 0 to 0.9126 for the 'WLCahp\_cons' layer and 0 to 0.1522 for the 'OWAavgORIG' layer. The difference between the data ranges is due to the application of the order weights.

Now let's look at the two extremes aimed at producing low and high risk suitability grid maps.

I can produce a low risk suitability grid map ('OWAminORIG') that has some similarity to the output from the Boolean aggregation method. The Boolean solution is often referred to as the "risk averse" solution. The order weights I use to produce a low risk suitability layer are:

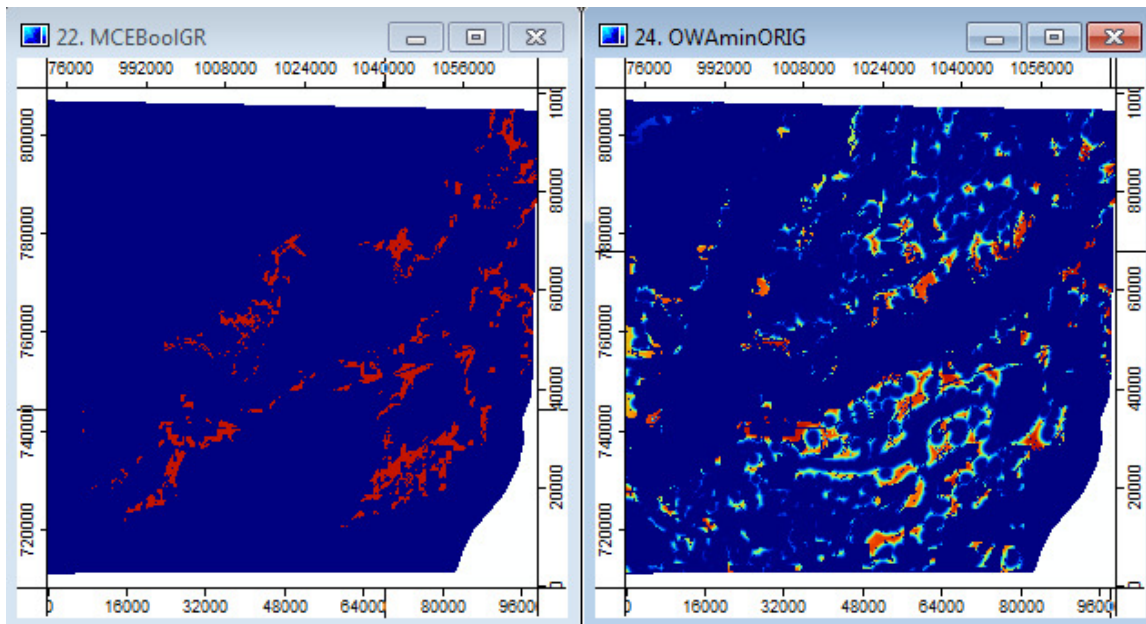
OrderWeights:	1	0	0	0	0	0
Rank :	1St	2nd	3rd	4th	5th	6th

I give the full weight to the single weight factor grid data layer with the minimum suitability value. No rank order position is given any weight. All the other order weights are set to 0. The result is that there is no trade off between factors. The order weights applied to the weighted factor grid data layers have no influence on the final suitability grid map. The minimum factor alone determines the final outcome.

The *Grid - Analysis/Ordered Weighted Averaging (OWA)* tool is executed using the six weighted factor grid maps (OWAlaSuit, OWAsdRoads, OWAcTime2, OWAslSlope, OWApdWater, and OWApdDev) are chosen for the input parameter '>> Input grids' along with "<create>" for the output parameter '<< Output Grid'. The weights listed above are entered for the 'Weights' parameter. I click on the 'Okay' button and the tool executes producing the default output grid map 'Output Grid'.

The constraint grid maps 'MPAwCo1' and 'MPAluCo2' are applied to the 'Output Grid' grid map using the *Grid - Calculus/Grid Calculator* tool. The three grid maps (MPAwCo1, MPAluCo2, and Output Grid) are chosen for the input parameter '> Grids'. The equation is "g1\*g2\*g3", a simple multiplication formula. The not suitable areas of the two constraint grid maps (grid cells containing the no data value -99999) define not suitable grid cells for the output grid map 'OWAminORIG'. This grid map name is entered for the 'Name' parameter. I save the 'OWAminORIG' grid map.

Figure VI-8 displays the Boolean suitability layer 'MCEBoolGR' in the map view window on the left and the output 'OWAminORIG' grid map in the right map view window that was produced by the OWA tool using the set of minimum order weights described above. The 50-acre limit requirement has not been applied to either grid map.



**Figure VI-8. Comparing the Boolean suitability layer to the OWA minimum suitability layer.**

The OWA low risk suitability solution layer includes the same suitability areas of the 'MCEBoolGR' grid map and expands beyond that solution.

Let's now look at a high risk suitability grid map. The order weights used to produce a high risk suitability layer are:

OrderWeights:	0	0	0	0	0	1
Rank :	1St	2nd	3rd	4th	5th	6th

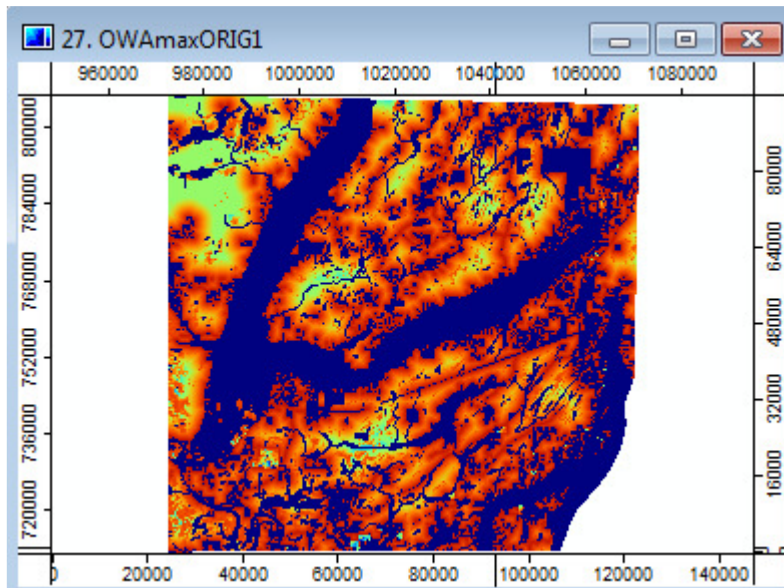
The full weight is assigned to the single weight factor grid map with the maximum suitability value. No rank order position is given any weight. All the other order weights are set to 0. The result is that there is no trade off between factors. The order weights

applied to the weighted factor grid data layers have no influence on the final suitability grid map. The maximum factor alone determines the final outcome.

The *Grid - Analysis/Ordered Weighted Averaging (OWA)* tool is executed using the six weighted factor grid maps (OWAlaSuit, OWAsdRoads, OWAcTime2, OWAslSlope, OWApdWater, and OWApdDev) are chosen for the input parameter '>> Input grids' along with "<create>" for the output parameter '<< Output Grid'. The weights listed above are entered for the 'Weights' parameter. I click on the 'Okay' button and the tool executes producing the default output grid map 'Output Grid'.

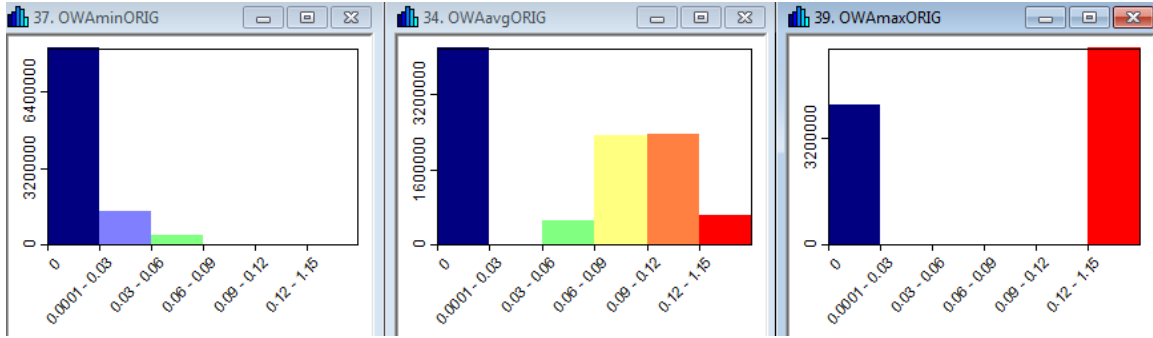
The constraint grid maps 'MPAwCo1' and 'MPAluCo2' are applied to the 'Output Grid' grid map using the *Grid - Calculus/Grid Calculator* tool. The three grid maps (MPAwCo1, MPAluCo2, and Output Grid) are chosen for the input parameter '> Grids'. The equation is " $g1 * g2 * g3$ ", a simple multiplication formula. The not suitable areas of the two constraint grid maps (grid cells containing the no data value -99999) define not suitable grid cells for the output grid map 'OWAmaxORIG'. This grid map name is entered for the 'Name' parameter. I save the 'OWAmaxORIG' grid map to a storage folder.

Figure VI-9 displays the 'OWAmaxORIG' layer produced by the above order weights.



**Figure VI-9. The OWA maximum risk grid map.**

The data histograms for the three OWA layers I just created are displayed in Figure VI-10.



**Figure VI-10. Data histograms for the minimum, average and maximum OWA grid maps.**

The histograms in Figure VI-10, starting on the left, are for the ‘OWAMinORIG’, ‘OWAavgORIG’ and ‘OWAMaxORIG’ grid maps. The first column in each histogram represents unsuitable data values (displayed in dark blue). The other 5 categories are for the same data classes on each layer. You can see that most of the data values in the ‘OWAMinORIG’ layer are in the first two data classes. This grid map is the low risk layer. The maximum risk layer (on the far right) has all of its data values in the highest data class. The average data layer has a distribution of data values across the upper four layers. The ‘OWAMinORIG’ layer sets the least risk or risk averse side of the solution space while the ‘OWAMaxORIG’ grid map sets the most risk side of the solution space. The OWA order weights can be mixed to output any level of risk within the solution space.

The order weights can be used to characterize a level of risk in a set of weighted factor grid maps. When there are six weights, as in this tutorial, if the sum of the first 3 is less than .5, the set of weights is skewed toward the maximum risk side of the scale. If the sum of first 3 is greater than .5, the weights are skewed to the minimum or less risk side of the scale.

This concludes this tutorial. The tutorial has explored three primary methods applied in the GIS environment for supporting multi-criteria evaluation. Two tools in SAGA, *Grid - Analysis/Analytical Hierarchy Process* and *Ordered weighted Averaging (OWA)*, are designed to support MCE. The lack of available user documentation can make attempts at applying them challenging. This tutorial should provide basic guidance on how they can be used. The *Grid - Calculus/Grid Calculator* and *Fuzzify* tools support basic grid map data standardization processes involved with MCE. In addition, other tools for more general GIS functions like data reclassifying, shapes to grid conversion, and clump identification (*Grid - Tools/Reclassify Grid Values*, *Grid - Gridding/Shapes to Grid*, *Grid - Filter/Filter Clumps*) have been used frequently in the tutorial. Once you have developed a set of constraint and factor grid maps SAGA has a variety of tool you can apply to accomplish MCE.

### *References*

Bell, Nathaniel, Nadine Schuurman, and Michael V. Hayes. "Using GIS-Based Methods of Multicriteria Analysis to Construct Socio-Economic Deprivation Indices." International Health Geography 6:17 (2007): 16.

Chen, Yun, Shahbaz Khan, and Zahra Padar. "Irrigation Intensification or Extensification Assessment: A GIS-Based Spatial Fuzzy Multi-Criteria Evaluation." Proceedings of the 8<sup>th</sup> International Symposium in Natural Resources and Environmental Sciences. Shanghai, P. R. China, June 25-27, 2008: pp. 309-318.

Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlita, L., Wehberg, J., Wichmann, V., and Boehner, J. (2015): System for Automated Geoscientific Analyses (SAGA) v. 2.1.4. Geosci. Model Dev., 8, 1991 - 2007, doi:10.5194/gd-8-1991-2015.

Fuller, Robert. "OWA Operators in Decision Making," in Exploring the Limits of Support Systems, ed: Carlsson, C. (TUCS General Publications, No. 3, Turku Centre for Computer Science, 1996), pp. 85-104.

Malczewski, Jacek. "Integrating multicriteria analysis and geographic information systems: the ordered weighted averaging (OWA) approach." International Journal of Environmental Technology and Management 6: ½ (2006): pp. 7-19.

Usunier, Nicolas, David Buffoni, and Patrick Gallinari. "Ranking with Ordered Weighted Pair-wise Classification." Proceedings of the 26<sup>th</sup> International Conference on Machine Learning, Montreal, Canada, 2009, 8 p.



**Appendix A: Development of WLC Weights.**

This is a summary of how the two sets of WLC weights have been developed for the developer and environmental perspectives. The procedure described is from the publication:

López-Marrero, T.; González-Toro, A.; Heartsill-Scalley, T.; Hermansen-Báez, L.A. 2011. Multi-Criteria Evaluation and Geographic Information Systems for Land-Use Planning and Decision Making. [Guide]. Gainesville, FL: USDA Forest Service, Southern Research Station. 8 p.

The six factors are arranged as a six by six matrix. The six columns are labeled across the top, from left to right, Land Use Factor, Distance from Roads Factor, Travel Time Factor, Slope Factor, Distance from Water Factor, and Distance from Developed Land Factor. The rows, starting in the row below the column labels, are labeled Land Use Factor, Distance from Roads Factor, Travel Time Factor, Slope Factor, Distance from Water Factor, and Distance from Developed Land Factor.

Due to the length of the labels and space limitations, the labels are somewhat abbreviated. Figure A-1 displays how a possible matrix would appear.

	Land Use Avail	Dist. Frm Roads	Travel Time Towns	Slope	Dist. Frm Water	Dist. Frm Dev. Land
Land Use Avail						
Dist. Frm Roads						
Travel Time Towns						
Slope						
Dist. Frm Water						
Dist. Frm Dev. Land						

**Figure A-1. A possible factor matrix for developing factor weights.**

Rather than use the labels I am going to refer to them as Factor 1, Factor 2, etc., keeping in mind from Figure A-1 the actual label.

Figure A-2 displays the matrix that will be used for developing the WLC factor weights.



	A	B	C	D	E	F	G	H	I
1									Factor
2		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Total	Weight
3	Factor 1								
4	Factor 2								
5	Factor 3								
6	Factor 4								
7	Factor 5								
8	Factor 6								
9							Sum:	0	0

**Figure A-2. The matrix used for developing WLC factor weights.**

The four factors displayed with the yellow fill are factors associated with residential building costs and the two factors with the green fill are associated with wildlife preservation. The objective is to compare pairs of factors. Relative to a specific perspective, which factor of the pair is more important. For example, comparing Factor 1 (Land Use Factor) and Factor 2 (Distance from Roads Factor) from the perspective of a residential developer. The developer decides that Factor 2 (Distance from Roads Factor) is more important and enters "Factor 2" into cell C3. Next, the developer compares Factor 1 (Land Use Factor) with Factor 3 (Travel Time Factor). The developer decides that Factor 1 (Land Use Factor) is more important and enters Factor 1 into cell D3.

This process continues until cells C3 through G3, D4 through G4, E5 through G5, F6 through G6, and G7 are filled in. The developer completes 15 paired comparisons. The factors used as entries in the matrix are counted and that count is entered in column H to the factor row. As an example, let's say that Factor 1 was chosen 2 times, Factor 2 chosen 3 times, Factor 3 chosen once, Factor 4 chosen 4 times, Factor 5 chosen 3 times, and Factor 6 chosen twice. These numbers would be entered, in the order listed, in column H starting in cell H3. The formula in cell H9 would total the numbers and the result is 15.

The factor weights are calculated and listed in column I. A factor weight is calculated by dividing the total number of times a factor was chosen by the total number of factors, i.e., 15. So if the factor was chosen twice, the weight is 2/15 or .1333. The second factor was chosen 3 times so its factor weight is 3/15 or .2000.

Figures A-3 and A-4 display two matrices. The matrix in Figure A-3 is used for calculating the factor weights from the perspective of the land developer and the matrix in Figure A-4 illustrates the perspective of the wildlife conservationist.

	A	B	C	D	E	F	G	H	I
1									Factor
2		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Total	Weight
3	Factor 1	1	Factor 2	Factor 1	Factor 4	Factor 1	Factor 1	3	0.2000
4	Factor 2		1	Factor 2	Factor 2	Factor 2	Factor 6	4	0.2667
5	Factor 3			1	Factor 4	Factor 3	Factor 6	1	0.0667
6	Factor 4				1	Factor 4	Factor 6	3	0.2000
7	Factor 5					1	Factor 5	1	0.0667
8	Factor 6						1	3	0.2000
9							Sum:	15	1

**Figure A-3. The land developer factor weight matrix.**

	A	B	C	D	E	F	G	H	I
1									Factor
2		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Total	Weight
3	Factor 1	1	Factor 1	Factor 1	Factor 4	Factor 5	Factor 6	2	0.1333
4	Factor 2		1	Factor 2	Factor 4	Factor 5	Factor 6	1	0.0667
5	Factor 3			1	Factor 3	Factor 3	Factor 6	2	0.1333
6	Factor 4				1	Factor 4	Factor 4	4	0.2667
7	Factor 5					1	Factor 5	3	0.2000
8	Factor 6						1	3	0.2000
9							Sum:	15	1

**Figure A-4. The wildlife conservationist factor weight matrix.**

The 1's in the diagonal cells identify non-pair intersections.

These are very hypothetical entries. The ideal would be to gather input from representatives of each participating group and average their results for final factor weights.

## **Appendix B: The AHP Pairwise Comparison Matrix**

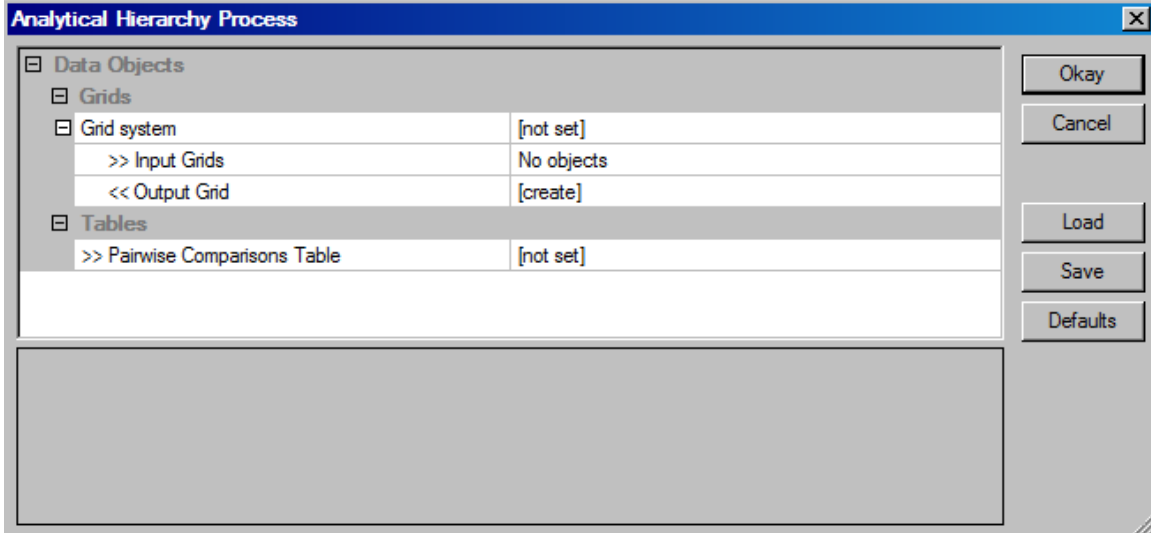
This appendix provides information on how to develop a pairwise comparison matrix to for use as an input table with the *Grid – Analysis/Analytical Hierarchy Process* tool. In addition, using the Excel spreadsheet program, I will explore the mathematics involved with calculating the set of factor weights. This particular example focuses on pairwise comparisons from the perspective of a land developer involved in residential developments. The same basic process can be applied for other perspectives using the same factors in which case some or all pairwise comparisons could change due to a differing perspective.

The Analytical Hierarchy Process (AHP) is used to prioritize alternatives. It is used in many different environments including GIS. A matrix of pairwise comparisons is constructed based on two questions for each paired comparison: Which of the two is more important with respect to the criterion? And, how strong is the level of importance?

There is a vast amount of literature available via the internet that explains in detail the theory and mathematics involved with applying the AHP. This appendix is a brief explanation of AHP and how it is implemented in the SAGA *Grid – Analysis/Analytical Hierarchy Process* tool.

The tool completes the calculations necessary using the table input for determining the relative preference weights for each input factor grid map. Next, each weight is used as a scaler or multiplying coefficient for the grid map data values to produce an interim layer. Once an interim layer has been calculated for each of the input grid map, the interim layers (they are now weighted factor grid maps) are added together to produce the output grid data layer. I am not sure if in fact the tool creates an interim “product” layer for each input layer but it is one way of interpreting the process. The tool does not output the weights that are calculated nor does it compute a consistency ratio. A consistency ratio is a statistic used to validate the pairwise comparison data.

The parameters window for the tool is displayed in Figure B-1.



**Figure B-1. The parameters for the *Grid – Analysis/Analytical Hierarchy Process* tool.**

The tool accepts a set of grid maps for the input parameter '>> Input Grids'. In this tutorial, these layers are factor grid maps. The factor grid maps represent the criteria that are rated by paired comparison in the AHP.

A table must be created for the input table parameter '>> Pairwise Comparison Table'. It is easy to create a blank table using the SAGA *Table – Tools/Create New Table* tool. In this pairwise comparison table, the number of columns must equal the number of input factor grid data layers, i.e., the number of criteria. The same will be true for the number of rows. I will use the “Add Record” option on the Table menu drop-down list of options to add the appropriate number of records. The Table menu option appears on the Menu Bar when you have a table open in the work area.

The pairwise comparison table should be viewed as a matrix. Each cell in the matrix is a comparison value representing the relative priority for the row and column intersection. Here is the pairwise comparison table I developed for this tutorial.

	LandFac	RoadFac	TownFac	SlopeFac	WaterFac	DevFac
1	1.000000	1.000000	5.000000	0.143000	3.000000	7.000000
2	1.000000	1.000000	7.000000	1.000000	3.000000	0.333000
3	0.200000	0.143000	1.000000	0.333000	3.000000	0.143000
4	7.000000	1.000000	3.000000	1.000000	5.000000	0.200000
5	0.333000	0.333000	0.333000	0.200000	1.000000	1.000000
6	0.143000	3.000000	7.000000	5.000000	1.000000	1.000000

**Figure A-2. The ‘PairWeights’ table.**

The abbreviated names for the factor grid maps are shown at the top of each column. The names correspond to the record numbers (1, 2, etc.) on the left. So the “LandFac” criterion is also represented by the number “1” in the list of record numbers. The values in the matrix represent “intensity of importance” using a 1 to 9 value system with 9 being “Extreme Importance”. Here is the standard AHP value ranking system.

- 1 Equal Importance
- 3 Moderate Importance
- 5 Strong Importance
- 7 Very Strong Importance
- 9 Extreme Importance

2, 4, 6, and 8 can be used for comparisons between the above values.

The diagonal values will always be 1 as these cells equate the same criteria. Let's look at the comparison between TownFac and 1 (LandFac). The row/column entry is 5.00000. This means that for this pair the distance from town criterion is “strong importance” compared to the LandFac criterion. Looking at the LandFac – 3 (TownFac) cell you will see that the reciprocal (1/5) for the “5” entry, .200000, is entered. The process I used to determine the ratings was to ask the question: Which of the pair is the more important criteria? How strongly more important?

The tool processes the table data and determines the weight is for each factor grid data layer. These are relative weights; the higher the weight the more important the criteria.

The Excel screen image below (Figure A-3) illustrates how the tool processes the pairwise comparison table and calculates the grid data layer weights.

	C	D	E	F	G	H	I	J	K
10		LU	RD	TD	SL	PD	DD		
11	LU	1.000	1.000	5.000	0.143	3.000	7.000		
12	RD	1.000	1.000	7.000	1.000	3.000	0.333		
13	TD	0.200	0.143	1.000	0.333	3.000	0.143		
14	SL	7.000	1.000	3.000	1.000	5.000	0.200		
15	PD	0.333	0.333	0.333	0.200	1.000	1.000		
16	DD	0.143	3.000	7.000	5.000	1.000	1.000		
17	Col. Sums	9.676	6.476	23.333	7.676	16.000	9.676		
18									
19	Normalize							Row	Weights
20		LU	RD	TD	SL	PD	DD	Sums	Rows/6
21	LU	0.103	0.154	0.214	0.019	0.188	0.723	1.402	0.234
22	RD	0.103	0.154	0.300	0.130	0.188	0.034	0.910	0.152
23	TD	0.021	0.022	0.043	0.043	0.188	0.015	0.331	0.055
24	SL	0.723	0.154	0.129	0.130	0.313	0.021	1.470	0.245
25	PD	0.034	0.051	0.014	0.026	0.063	0.103	0.292	0.049
26	DD	0.015	0.463	0.300	0.651	0.063	0.103	1.595	0.266
27	Col. Sums	1.000	1.000	1.000	1.000	1.000	1.000	6.000	1.000

**Figure A-3. The spreadsheet model.**

You can see that the upper portion is a duplicate of the “PairWeights” table displayed in figure A-2. This time, however, I have summed the columns (see row 17). The column sums are used to create the normalized data in rows 21 through 26. The value in cell D21 was calculated by dividing the value in D11 by the sum for the column in cell D17.

Column J contains row sums for the rows containing normalized data. Thus, the sum for cells D21 through I21 is 1.198. The weight that will be used with the criteria grid map is calculated in column K. For example, the sum for row 21 (1.198) is divided by the number of factors (6) and the weight is determined to be .200.

This is a quick explanation of how the relative weights are calculated by the tool for the input grid maps. The above explanation shows you how you can easily calculate the weights, using the AHP process. The weights can then be applied to their respective factor grid data layers using the *Grid – Calculus/Grid Calculator* tool to create weighted factor grid data layers if weighted grid maps are required for documentation.

Note that the weights for the six criteria sum to 1.000. This means you can also assess the relative importance of each weight by dividing by the lowest weight. For example, how much more important is the slope factor to a developer compared to the other factors? About 5 times more important than distance from water factor (.245 divided by .049). By going through the calculations it also will help you to develop pairwise comparisons for other viewpoints.