

A Simple, Portable, Spatial Multi-Criteria Analysis Shell – MCAS-S

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Keywords: *Multi criteria analysis, spatial decision support, natural resource management, coupled human-environment systems*

EXTENDED ABSTRACT

Multi-criteria approaches to analysis of complex issues in coupled human-environment systems have found wide application across business, government and communities around the world. Increased attention has been paid to spatial implementations of multi-criteria analysis. Spatial capability is available in several GIS, such as IDRISI and ArcView, and is often customised for particular problems in spatially explicit decision tools. However, simple, flexible multi-criteria shells are not readily available, particularly without a programming requirement, and with easy adaptability to any problem. The ASSESS (A System for Selecting Suitable Sites) multi-criteria interface in ArcInfo GIS has been applied widely over a number of years - most recently in analysis of tensions in Australian rangelands. However, there is now a need for a completely portable and flexible spatial multi-criteria shell to assist in exploration of a wide range of science-policy issues at government and community level.

This paper describes a multi-criteria analysis shell for spatial decision support (MCAS-S) constructed in C and C++. The key constructs that characterize the shell are: 1) the combination of cognitive mapping and actual map display and manipulation in the workspace window; 2) automatic association of menu panes with map types; and 3) live update of layers in the workspace when changes are made to classification of primary layers. The user can select grids, drag them into the display window, manipulate them, then create composites and do two-way comparisons forming a cognitive flow diagram of maps and arrows on the screen. Another important feature is the automatic update of available functions when the user accesses maps of different types such as raw input data, composite indicators, and two-way and multi-way comparisons. This makes the interface very intuitive to use. The shell requires basic GIS pre-processing of data to the same grid resolution,

spatial extent and projection. The shell provides the following key functions:

- reads grid data in several formats; calculates histograms and enables grid classification in a variety of ways;
- provides for two-way comparisons;
- provides multi-way analysis of multiple grids with graphical representation as radar plots;
- provides for pixel interrogation using radar plot and two-way matrix graphics;
- allows creation of binary inclusion zones from radar plots;
- allows creation of scaled (0 – 1) floating point multi-way summary index using various methods of combination.

The conceptual model for use of the software by policy clients and stakeholders involves:

- desktop access for policy makers with project constructed by consulting experts;
- projects distributed to clients with online participatory analysis;
- iterative updating and re-working of project with alternative map assessments.

However, the tool enables clear visualization of the relationship between the decision, the science, other constraints and the spatial data. This paper provides a full description of the shell and gives some operational examples using data from analysis of tensions in Australia's rangelands. The paper discusses the further development and application of the shell to aid policy and community decision-making.

1. INTRODUCTION

Multi-criteria approaches to analysis of complex issues in coupled human-environment systems have found wide application across business, government and community sectors. Increased attention has been paid to spatial implementations of multi-criteria analysis (Jankowski, 1995). Spatial science and information needs to be translated into the language of the political and economic decision-making sectors of society (Grant et al., 2002). Spatial capability is available in several GIS, such as IDRISI and ArcView, and is often customised for particular problems in spatially explicit decision tools. Project specific software for spatial multi-criteria analysis (MCA) has been developed (Store and Jokimaki, 2003; Mazzetto et al., 2003; Guipponi et al., 2004). However, simple, flexible multi-criteria shells are not readily available, particularly without a programming requirement, and with easy adaptability to any problem. The ASSESS (A System for selecting Suitable Sites; Veitch, 1997) multi-criteria interface in ArcInfo GIS has been applied widely over a number of years (Bui, 1999; Walker and Veitch, 2001; Walker et al, 2002; Hill et al., 2005a) - most recently in analysis of tensions in Australian rangelands (Hill et al., 2005b). However, this system was limited by some of the structural constraints imposed by GIS, and by specific software dependence and limited portability. A key requirement of a multi-criteria analysis shell is utility for participatory processes and use in workshop situations. For this purpose, the interface needs to be flexible, and provide transparency between any overall spatially explicit assessments, the input data, and classification and combination rules used to generate them. In this paper we describe a flexible, spatial multi-criteria analysis shell that attempts to provide the visual cognitive links between the participatory process and the spatially explicit input data.

2. CONCEPTUAL APPROACH

Our original goal was to create a very portable and easy to use exploratory shell with generic functionality that was completely independent of data and project type. We sought to build upon the simplicity of the ASSESS approach, but remove the GIS-based barriers to flexibility and interactive use. In the design process, the first key construct was the means of coupling the human cognitive process with the display and interrogation of spatial data so that the origins of complex summary indices of condition, suitability or some other query goal were transparent. Cognitive

mapping (Bisdorff, 1999) provides a chart-based means for visualizing the inter-linkages and dependencies between elements in a decision process including the factors, the drivers, and the criteria. In cognitive mapping, the arrows between elements indicate a direction of causality. In MCAS-S, they simply indicate contribution to a combined layer of some type. The second key construct was the automatic update of available functions according to the nature of the user-selected data layers. These two features make the interface highly intuitive and easy to use. The third key construct was the maintenance of a live link between the primary data and all of the subsequent indicator, composite and analysis layers. This allows the user to make adjustments to treatment of primary data and immediately see the consequence in the derived layers.

3. MCAS-S

The structure of MCAS-S is shown in Figure 1. The software is written in C++ and C and is compliant with Microsoft.Net 1.0 Protocols. The software requires the user to prepare the raw spatial data for any project in a consistent geographical extent, pixel resolution and projection. The data can then be imported in BIL, ArcInfo float, GEOTIFF and IDRISI raster formats. The imported data are then available in a menu under the heading of Primary Input Data. The primary data can be selected from the menu and dragged into the display workspace. An example of the interface showing the drop-down menu for primary input data, the histogram and classification option for input data, and the workspace is shown in Figure 2. The primary data can be classified into a maximum of 10 classes using equal interval, equal area and user-defined classification. The data can be truncated from both the top and bottom, and the rankings reversed.

The classified layer can be saved when the user is satisfied with the classification. The saved layer then appears in a list under the Classified Data menu item (Figure 2). The classified data may be assigned to themes or groups according to the project needs. Once all of the individual indicators have been created, the user can use them in weighted combinations to construct composite indicators. A new map window is dragged from the menu button "Composite" into the workspace – the interface for creating a composite will automatically appear. The interface has a series list of indicator layers available for construction of the composite.

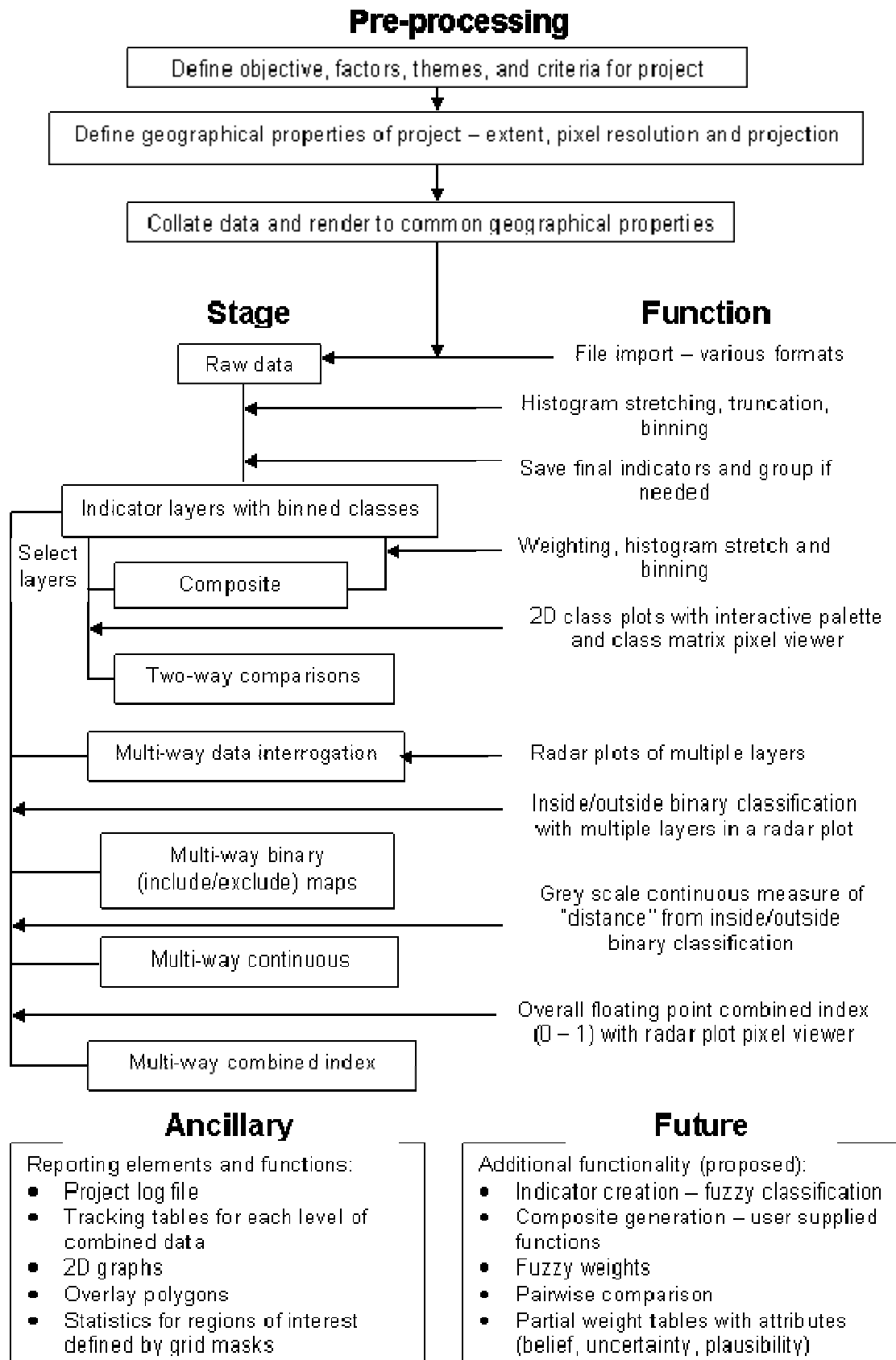


Figure 1. Flow chart for MCAS-S showing stages and functionality

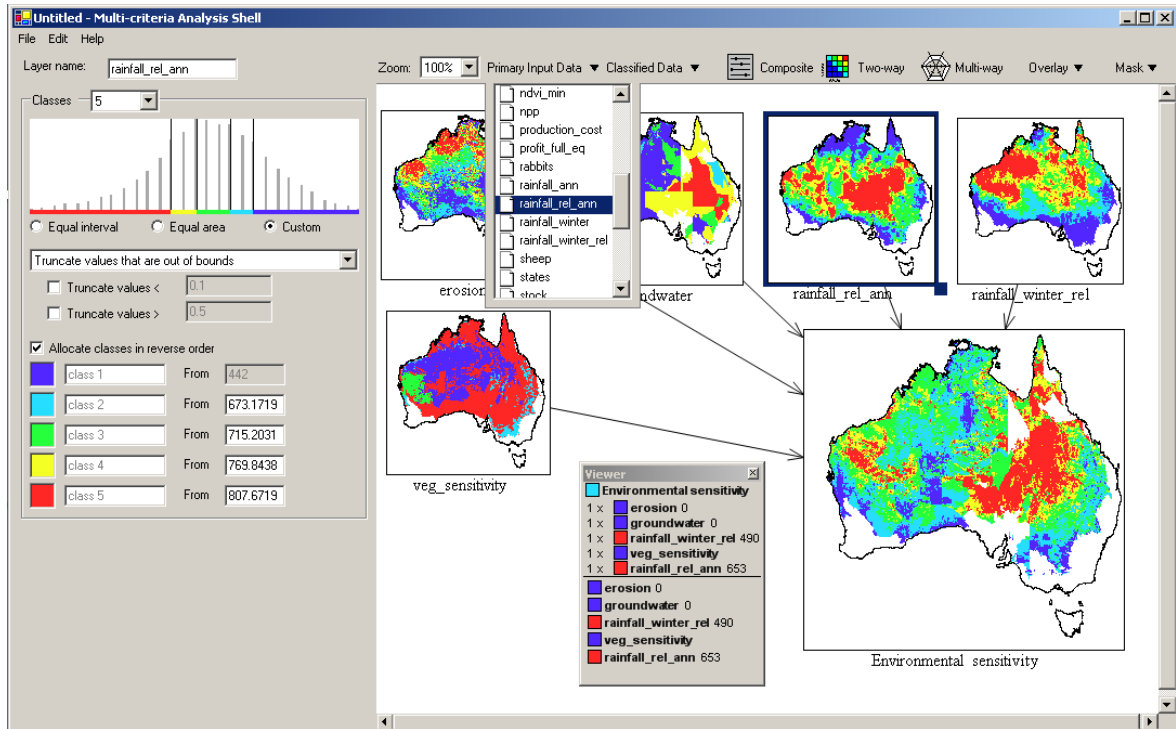


Figure 2. MCAS-S interface showing the drop down menu with the list of primary input data layers. The left panel displays the histogram and classification intervals for the highlighted primary data layer. The workspace displays a composite indicator for environmental sensitivity based on five binned indicator layers with the pixel viewer recording the weighting of layers and individual input layer values for a single pixel.

Each layer has a slider bar and entry box where the weighting of contribution to any composite can be set. The composite map dynamically updates as the user changes the weightings on the input layers. An example composite indicator, “environmental sensitivity” is shown as the product of five individual indicator layers in Figure 2. Composites may also be created using simple user-supplied functions. Pre-defined simple combinatory or algebraic models can then be used to create sophisticated and integrative composite indicators.

At this stage the user will have a number of individual and composite indicators grouped by the main themes of the project. Under each theme the user can visualize in the workspace a hierarchical, cognitive “map” of indicator development all the way through to a final summary indicator for the whole theme. For example, in a study on the Australian rangelands (Hill et al., 2005), indicators were grouped under three themes: natural resource base; production base, and; threatening processes. A combinatorial approach was used to create a hierarchy of indicators. Domestic (DGP) and feral animal (FGP) grazing pressure was combined to form

total grazing pressure (TGP). TGP was then combined with environmental sensitivity (ES; Figure 2) to produce grazing impact (GI). Finally, GI was combined with mining and fire layers to produce a total impact indicator for threatening processes (Hill et al., 2005).

The relationships between themes, specific views and particular indicators may be examined using several methods. Two-way comparison enables the user to create a two-way comparison map, explore the association between input classes, and define a particular colour ramp and value scale to highlight association of high or low values, or feature a particular geographical region. When the user clicks the two-way menu button and drags another map window into the workspace, the two-way panel interface appears at the left (Figure 3). The two-way response space is visualized in a dynamic two-dimensional colour palette linked to the map display in the workspace. The user can manually move the focus of the colour ramp to any point within a graphical array (up to 10 x 10) and dynamically change the corresponding map colour pattern. The two-way class values can also be examined for each pixel in a dynamic pixel viewer.

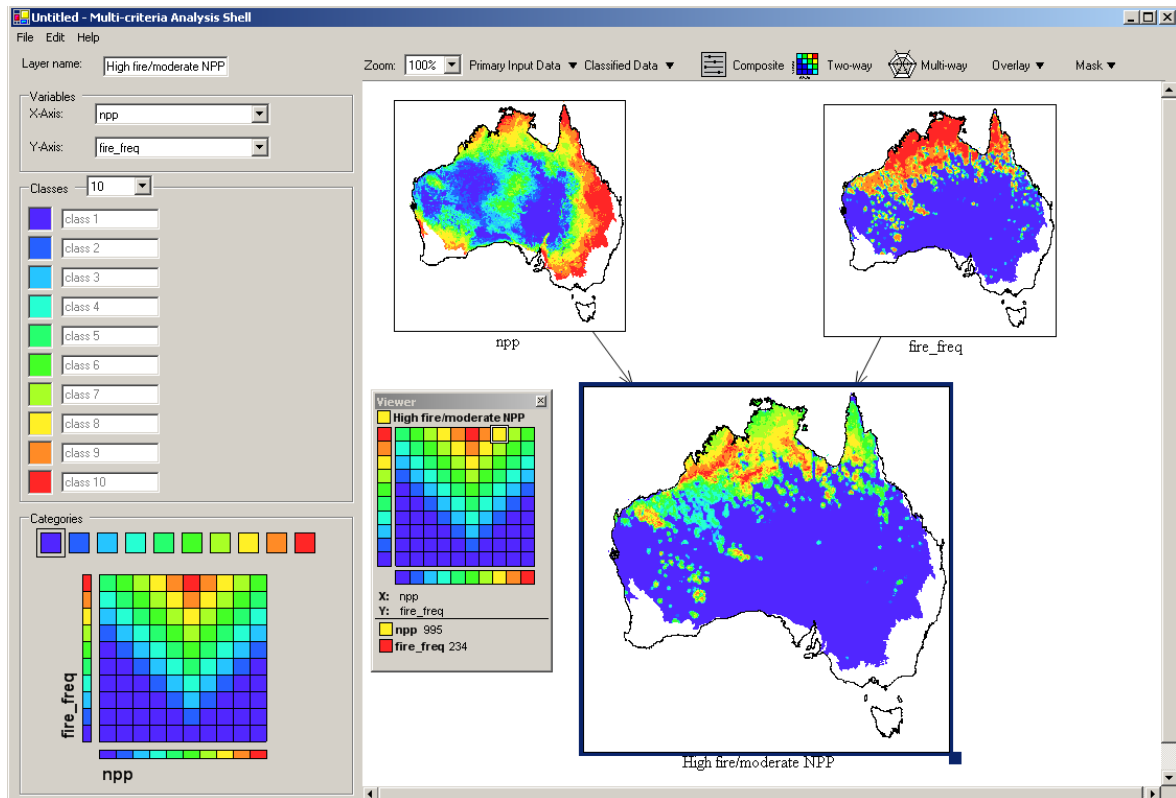


Figure 3. The interface for exploration and categorization of two-way comparisons includes a dynamic two-dimensional colour palette and two-way matrix pixel viewer. The two-way map shows the relationship between net primary productivity (NPP) and fire frequency. The colour palette is set to highlight high fire frequency and moderate NPP.

Multi-way comparison provides both dynamic and procedural approaches to analysis. The multi-way analysis uses the radar plot as the basis for visualization (Figure 4). A radar plot can be thought of as a histogram that has been bent into a circle with each individual spoke representing a variable (EPA, 2005). The user can create radar plots with spokes representing indicators or themes. The radar plot is available through a viewer function for dynamic data interrogation. The user can select layers and get dynamic feedback of values for all layers represented in the radar plot as they move the mouse over the surface of a selected map. The multi-way analysis also enables the user to create a binary layer that defines the area either inside or outside the limits of the radar plot, i.e. the area that meets or does not meet certain criteria levels (Figure 4). The user is able to drag the boundary value on each vector in the radar plot to any level. The multi-way map is updated to show the region satisfying the criteria values; the user may define whether values inside or outside the boundary are highlighted in the map. The example in Figure 4 shows a region where

grazing pressure from sheep, goats and kangaroos is high. The multi-way may also be displayed as a grey-scale surface showing “distance” from selected criteria values.

The multi-way analysis can also use numerous thematic indicators to produce a single floating-point index layer scaled from 0 – 1 as a final combined and standardized index. For example, if ecosystem services were being evaluated, there may be many individual and composite indicators listed under each of a number of themes such as biodiversity, carbon, water quality, water yield, economic return, amenity value, agricultural productivity etc. Each theme could have a single overall composite indicator, and these could be combined to form an overall assessment of ecosystem services.

The software has a number of ancillary features particularly related to reporting (Figure 1). These include generation of statistics for regions of interest from user-supplied layers and creation of two-dimensional graphs for exploration of the relationships between input data layers.

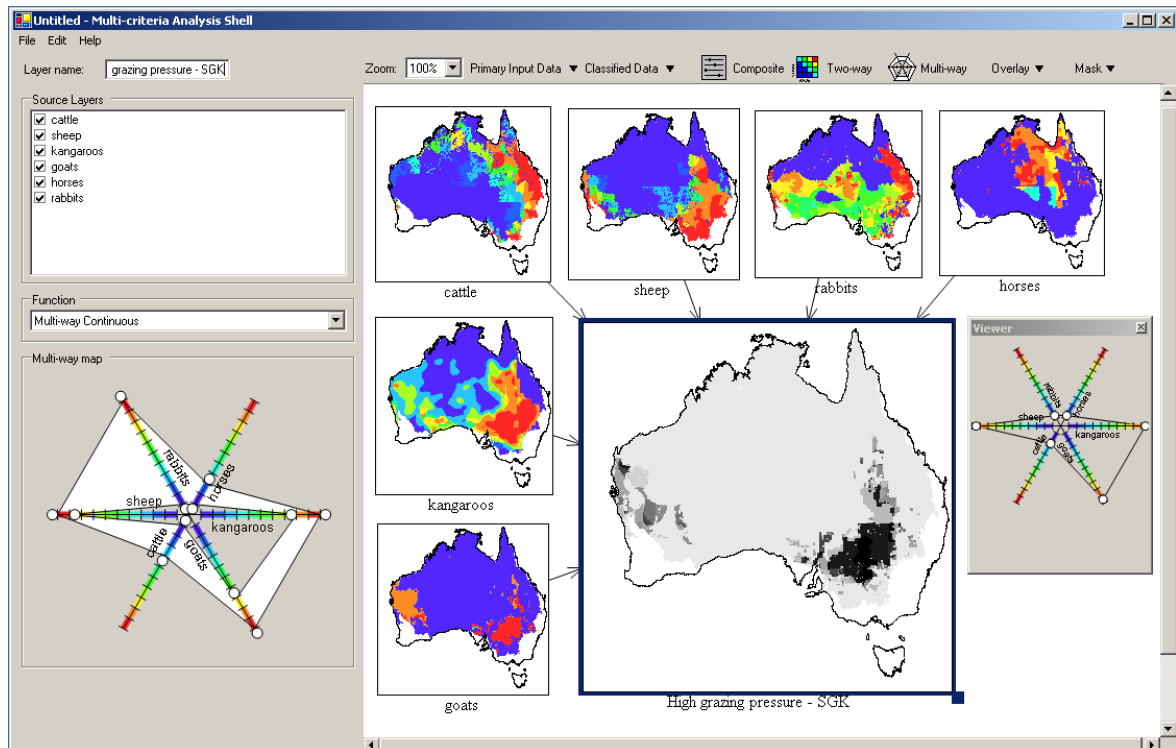


Figure 4. Multi-way analysis to create a continuous “distance” surface. The left panel lists the data layers visible in the workspace with check boxes for inclusion in the analysis. The radar plot shows a binary region analysis with the area inside the white area of the web mapped in black and other regions in a grey-scale of decreasing criteria satisfaction. The example shows a region where grazing pressure from sheep, goats and kangaroos is high, pressure from rabbits is variable, and pressure from cattle and horses is low. The pixel viewers values for a single pixel in a dynamic radar plot.

Additional functionality will be added in the near future. Definition of fuzzy membership functions will be available for initial classification of raw data into indicators. Facilities for incorporation of multiple expert opinions, and multiple stakeholder views will be added through provision of fuzzy weighting, pair-wise comparison (analytical hierarchy process; Ramanathan, 2001) and creation of partial weight tables to capture soft attributes such as belief, commonality and plausibility (Beynon, 2005).

The software is likely to be made available to collaborating agencies throughout the Australian government sector on a single user, not-for-distribution, licensing basis. An Internet-enabled version will be prepared.

4. POLICY APPLICATION AND FUTURE DEVELOPMENTS

The development of MCAS-S has been driven by a demand from policy clients. We see the model being applied as follows:

1. The software is available on the policy-makers desktop.
2. A suite of national datasets is available for rapid initial exploration.
3. Experts provide advice and develop problem-specific projects with data from science, economic and social domains.
4. In consultation with policy clients, an expert or science panel constructs the classified indicator layers and composite indicators to capture complex system functions and behaviours.
5. The project database is distributed to the stakeholders.
6. The software is used in a workshop, or distributed participatory process via the Internet, to explore the problem, develop two way and multi-way comparisons and

establish agreed or alternative final assessment indicators.

7. The database may be updated or augmented and the analysis revisited through iterative participatory processes.
8. The policy clients and decision stakeholders make as much or little use of the analysis as they need.
9. However, the tool enables clear visualization of the relationship between the decision, the science, other constraints and the spatial data.

MCAS-S is a shell with wide functionality. The tool provides a framework for exploration of issues and problems, and for assisting communication among stakeholders. A project at any scale and resolution can be constructed. MCAS-S is designed for use with expert advice and results are dependent upon the data, assumptions and actions of the user.

5. ACKNOWLEDGMENTS

The MCAS-S system was developed for the Natural Resource Management Division of the Department of Agriculture, Fisheries and Forestry with funding from the Natural Heritage Trust.

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