2 The LUIM framework

In this section we describe the current framework used in the LUIM. During its development the fundamental approach has not changed, nor have the data and knowledge requirements. However, in the earlier applications the risk framework was not so explicitly defined and some terms were used differently. Differences in the usage and the framework are explained in the individual case studies.

In the LUIM, maps of soil, land, hydrology, vegetation and land use are interpreted with respect to threatening processes such as soil structure decline, erosion, and vegetation loss. The LUIM has aspatial and spatial components. The aspatial component incorporates knowledge of relationships between threatening processes, landscape characteristics and land management practices. These relationships are formulated as rules and ratings. The spatial component uses a GIS to apply these rules and ratings in the landscape and map their occurrence. The outputs of the LUIM are maps that rank the likelihood and level of risk associated with a particular threatening process. The ranking of likelihood and risk can then be used to guide investment to the areas of greatest risk.

2.1 The Risk Assessment Framework

Risk, as outlined in the Australian Standard (Standards Australia 1995) is the chance of a specified event occurring (likelihood) and the magnitude of the likely consequences (consequence).

LIKELIHOOD × CONSEQUENCE = RISK

In a landscape context, threats are generally broad-scale landscape processes rather than discrete catastrophic events. The risk is not so much whether or not a process will occur, but whether the process will be of a sufficient magnitude to cause concern. Thus the definition of risk has been adapted to suit the specific purpose of LUIM. The LUIM uses data on land qualities and management to populate values for likelihood and consequence in the risk framework (Figure 1).

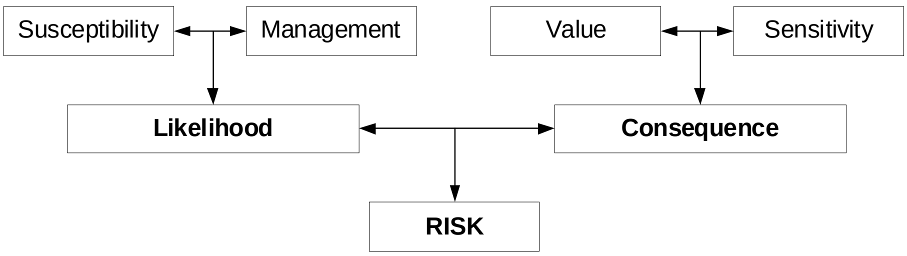

Figure 1 Schematic representation of the LUIM components in a risk assessment framework.

Definition of terms

Likelihood, consequence and risk terminology has been modified from the Australian Standards for Risk Management (Standards Australia 1995) to suit the LUIM.

Risk: The product of the likelihood that degradation will occur to an asset and the consequence suffered if it happens.

Likelihood: The likelihood that degradation will occur depends on the susceptibility of the asset and the role that land use practice may play in causing, aggravating or moderating degradation (management). Hence likelihood is a product of the asset's inherent susceptibility to degradation and the imposed land use and associated practices.

SUSCEPTIBILITY × MANAGEMENT = LIKELIHOOD

Consequence: The consequence of degradation depends on how incapacitated or dysfunctional the asset becomes (sensitivity) and on the productive and ecological qualities of the asset (value). Consequences may also exist for offsite assets.

SENSITIVITY × VALUE = CONSEQUENCE

The additional terms used in the LUIM framework (Figure 1) are:

Susceptibility: the chance (%) of a threatening process reaching a threshold rate or magnitude at a given point in the landscape, based on fundamental landscape characteristics.

Management: management actions that influence the susceptibility of the landscape to specific threatening processes.

Sensitivity: the level of response of an environmental asset to a specific threatening process of a threshold rate or magnitude. Sensitivity could also be considered as the degree of resilience or ability to recover from disturbance as a result of a threatening process.

Value: the assumed worth of a biophysical or built asset based on environmental, social and economic services provided by that asset.

2.2 Data Requirements

Key data required for an application of the LUIM to assess land degradation issues at any scale are:

1. Threat identification. List the threatening processes to be assessed (water erosion, sedimentation, etc.).
2. Identification of assets. Identify and map the assets to be assessed for risk from threatening processes.
3. Asset susceptibility. Determine or rate the susceptibility of assets to each threatening process.
4. Land use and land management practices. Compile the spatial data and expert knowledge on the land use management practices for the region. This requires and inventory of practices, their spatial distribution and knowledge of their potential impact on each threatening process.
5. Asset sensitivity. Identify the sensitivity of the assets to each threatening process.
6. Asset value. Classify the assets for their economic, social and environmental value.

Threat identification.

The scope of the risk assessment needs to be defined by listing the threatening processes to be assessed. Threats that have been previously assessed using the LUIM have focussed on soil, wetland and native vegetation assets:

Threats to soil: wind erosion, water erosion, land slips, soil structure decline, soil acidification. [Victorian Catchment Indicators, Corangamite, West Gippsland and Mallee case studies]

Threats to wetlands: increased groundwater input, increased surface water input, increased wetting frequency, increased wetting duration, and salinisation. [Wetland Tool case study]

Threats to remnant native vegetation: weed invasion, loss of regeneration capacity, total grazing pressure, increased nutrients, changed hydrological regime. [Goulburn Broken and Lower Murray case studies]

A LUIM 'case' is set up for each threatening process and populated with the data and rules specific to assessing each threat. Examples in the case studies illustrate the selection of specific rules. Asset value and land use are independent of the threatening process and do not require special rules for different threats.

Asset description.

Asset definition depends on the project objectives and is therefore determined by the user. An asset may be any spatially definable element and can be based on a natural feature, enterprise or infrastructure. The asset forms the basis for the map units that will be used in the LUIM. The final resolution of the map output is based on the asset rather than the input data, which may have a range of resolutions.

The assets are described according to attributes relevant to each threatening process and have usually been identified in catchment strategies. In past studies these attributes have included:

- soil attributes such as soil type, texture, pH, structure and top soil depth,
- land form type and position in the landscape,
- geology,
- remnant vegetation attributes such as vegetation type, conservation status, isolation and patch size and shape,
- surface and groundwater characteristics, and
- climatic factors.

Figure 2 illustrates a patch of remnant native vegetation sited in an agricultural landscape. The patch is a good example of a mappable biodiversity asset. The perimeter of the patch will form the map unit boundary.

Figure 2 An example of a remnant patch of vegetation defined as an asset

The impact of the agricultural land management practices, both adjacent to and within the patch, on biodiversity values may be the focus of the risk assessment. The attributes collected for the vegetation asset will depend on the threats being assessed, but might include patch size and shape, vegetation type, landform and soil type.

Data sources

This information may be sourced from a number of spatial data sets including: geomorphology, land systems, soil surveys, ecological vegetation classes, bioregions, rainfall, land use, wetlands, rivers, and digital elevation models (DEM).

Asset susceptibility

Classification of the asset's susceptibility to a threatening process is based on how the inherent characteristics affect the potential for degradation. For example, a site with a steep slope and a light-textured dispersive soil has a higher potential for gully erosion than a site with a very gentle slope and heavy soils. Susceptibility to soil erosion has traditionally been considered important to include in soil surveys and land capability assessments.

Data sources

General methods or rules for assessing the susceptibility to some degradation issues are available in the literature but may need to be modified to suit the specific regional context. Susceptibility ratings can also be derived using empirical data or they can be based on the opinion of experts where other methods are unavailable. The LUIM is flexible and can accommodate rules regardless of their derivation.

Land use and land management practices:

The required land use and management practice data are:

- a land use map,
- an inventory of land management practices for each land use category, and
- estimates of distribution of each of the practices for the region.

Practices or combinations of practices then need to be rated or ranked for their influence on each threatening process (influence may be positive or negative). In the earliest application of the LUIM (the Victorian Catchment Indicators project) the experts who rated the practices also assigned their level of confidence to the rating. In the LUIM the classification information is used to derive degradation likelihood ratings for each map unit, taking into account its inherent 'susceptibility' to a degradation issue, and specific land management regime.

Data sources

Much of Victoria has detailed land use maps derived from interpreted satellite imagery. These data are nominally at 1:100 000 scale, but actually have paddock scale resolution. Every parcel of land and natural or built feature is classified using the Bureau of Rural Sciences (BRS) Australian Land Use and Management (ALUM) classification. Currency of the maps depends on when they were created. This can be particularly important in areas where land use change has been rapid (conversion of grazing to cropping) and in areas where rotational grazing/cropping systems are common.

Agricultural census information, collected from individual farmers every five years, is one source of land management information. The data are at a very coarse scale, being presented for Statistical Local Areas (SLA) as the smallest spatial unit. However, the agricultural statistics can be used to inform the probability of particular practice occurring within a specific map unit. Expert knowledge from land managers, agronomists and extension staff provides a basis for understanding the distribution of management practices.

Asset sensitivity

Asset sensitivity to degradation is one of the hardest data sets to develop. There is a lack of empirical data and past applications of the LUIM have had to rely on expert judgement. As an example, regional soil experts chose depth of top soil as a criterion for sensitivity assessment in a soil erosion risk assessment in the West Gippsland region (Dortmans *et al.* 2006). Thinner topsoils were considered by the experts to be less resilient to erosion.

Asset value

There is no standard method for assessing asset value, although there are many techniques and methods in the literature. The method will depend entirely on the purpose of the assessment, the people who are involved, and the assets that are being assessed. There is no right or wrong way of valuing the assets, but it is important that there is adequate documentation of the process used and of any assumptions that are made. It is also of key importance that the purchasers or users of the assessment are comfortable with, and understand, the way in which value has been assigned to the assets.

2.3 Likelihood, Consequence and Risk

Each component of the risk framework is mapped separately then combined into a single data layer using a Geospatial Information System (GIS). The spatial data are combined with expert knowledge of land management and landscape processes to produce a spatially explicit output, rating the risk to land assets from various forms of degradation. Figure 3 summarises the modelling process.

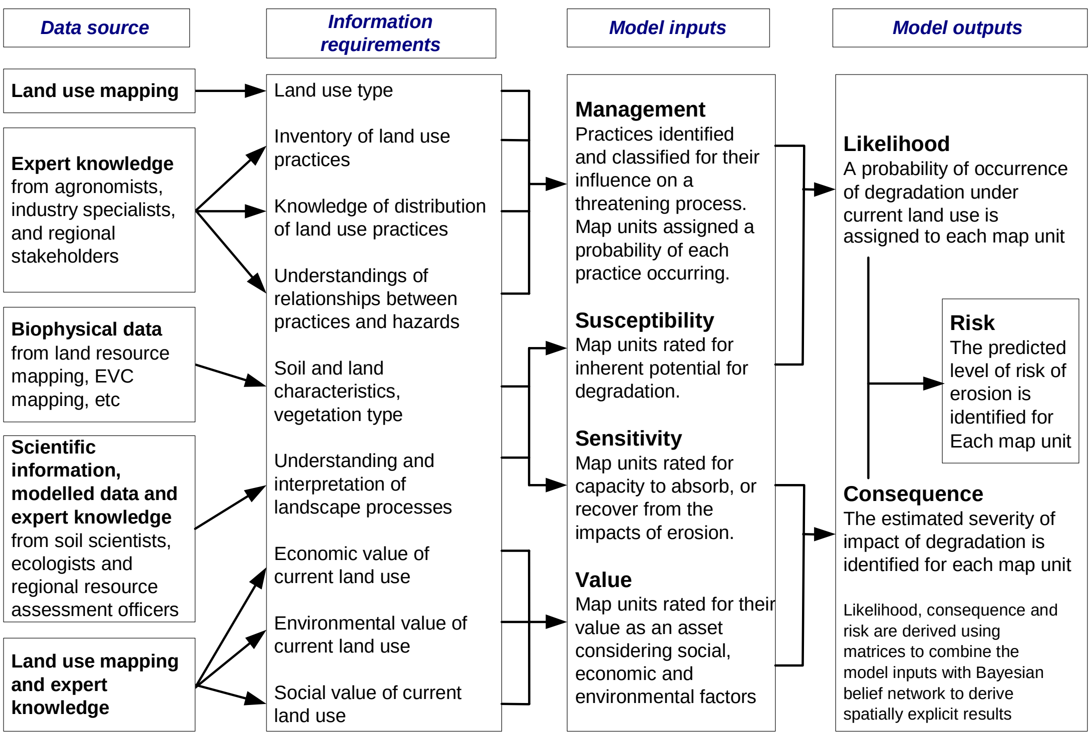

Figure 3 Chart showing the generic LUIM components, data inputs and model outputs.

Expert knowledge is used to set the parameters or 'rules of assessment' within the LUIM framework. Likelihood of occurrence of degradation under specific land management regimes is rated using a matrix (Table 1) adapted from the Australian Standard risk management (Standards Australia 1995). This matrix combines the land management practice classifications with the susceptibility ratings.

Table 1 Example likelihood matrix

Management practices	Susceptibility				
	Very low	Low	Moderate	High	Very high
Strongly negative	Very low	Moderate	High	Very high	Very high
Moderately negative	Very low	Low	Moderate	High	Very high
Weakly negative	Very low	Low	Low	Moderate	High
Neutral	Very low	Very low	Very low	Low	Low
Beneficial	Very low	Very low	Very low	Low	Low

Similar matrices are used to combine sensitivity and asset value to provide a measure of consequence, and to combine likelihood and consequence to derive risk. The user has complete control over the ratings in the matrices.

2.4 Bayesian belief networks are used to deal with data uncertainty

Spatial data have uncertainties associated with the scale and type of information available. We can readily compile an inventory of land uses and land use practices, but it is often impossible to precisely map these. Consequently the map units have some uncertainty associated with them. Bayesian belief networks (BBN) are a useful way to account for these uncertainties. The LUIM framework (Figure 1) provides the structure for a BBN, each component being represented by a 'node' in the BBN (Figure 4). The probability distributions for management practices are then contained in the 'management' node of the network. BBNs provide several advantages to the LUIM as they:

- allow all knowledge relevant to an issue to be explicitly represented,
- enable sensitivity analysis to identify the influence of individual model inputs on a result, and
- can integrate different types of scientific and expert knowledge.

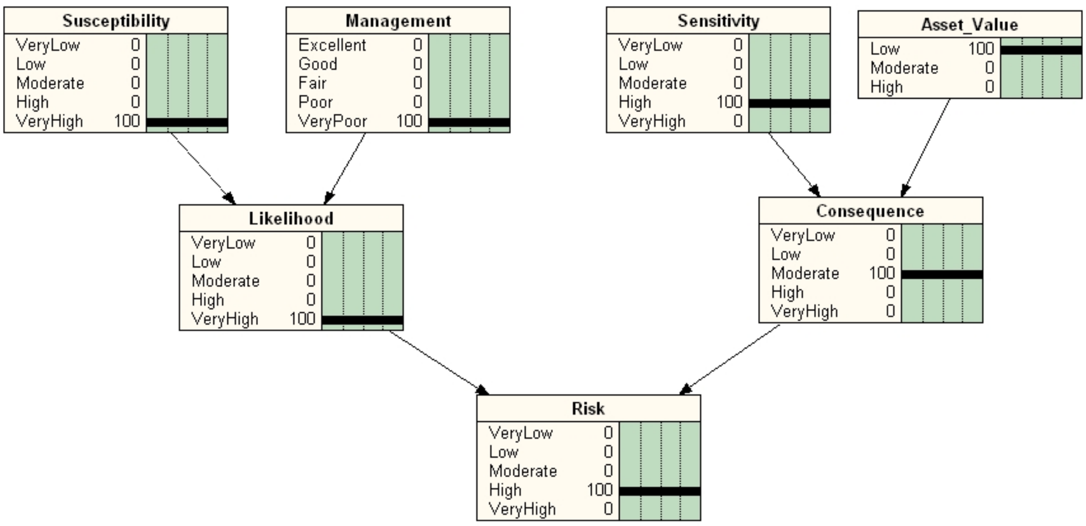

Figure 4 The basic structure of the Bayesian belief network within the LUIM.

The LUIM uses the software Netica V1.05 (Norsys, 1997) to compile the BBNs. Through the LUIM user interface, each node, is populated using the methods, matrices and data described earlier for the risk framework ie. the likelihood node in the BBN is linked to the matrix described in Table 1 and the consequence and risk nodes are linked to similar matrices.

Likelihood and risk results have associated probability scores that represent the uncertainty in the outcome for any map unit. Map outputs for likelihood and risk maps use the highest probability score for each map unit.

Currently, only uncertainties associated with land management practice information are tracked explicitly through the model network but uncertainties in any element of the framework could be incorporated. The example in Figure 5 shows the basic BBN structure (Figure 4), expanded to include the data inputs for susceptibility, management, sensitivity and value to assess a cropping management scenario for sheet and rill erosion. Actual values represent the attributes and ratings for a single map unit.

The nodes in Figure 5 (establishment, stubble management, stubble grazed) that connect to the management node, show the management options and associated probabilities of each practice occurring within that map unit. These probabilities influence the management classification and subsequently the likelihood and risk result.

All the other inputs, such as data used to assess susceptibility, can also be identified in the BBN (Figure 5) and their influence on the outcome can be measured. In this example, five factors have been used to assess susceptibility to sheet and rill erosion. Each node connecting to the susceptibility node, is informing the BBN of the combination of attributes particular to the map unit being assessed. As there is no uncertainty represented in the BBN for these factors each is given a 100% probability score.

In the Figure 5 example, the moderate risk rating would be mapped as the risk result for the map unit as it has the highest probability score. The moderate probability score is 58%, which means that there is a 42% probability of the risk result being other than moderate for that map unit.

Our primary sources for understanding Bayesian probability have been Cain (2001) and Ames (2002).

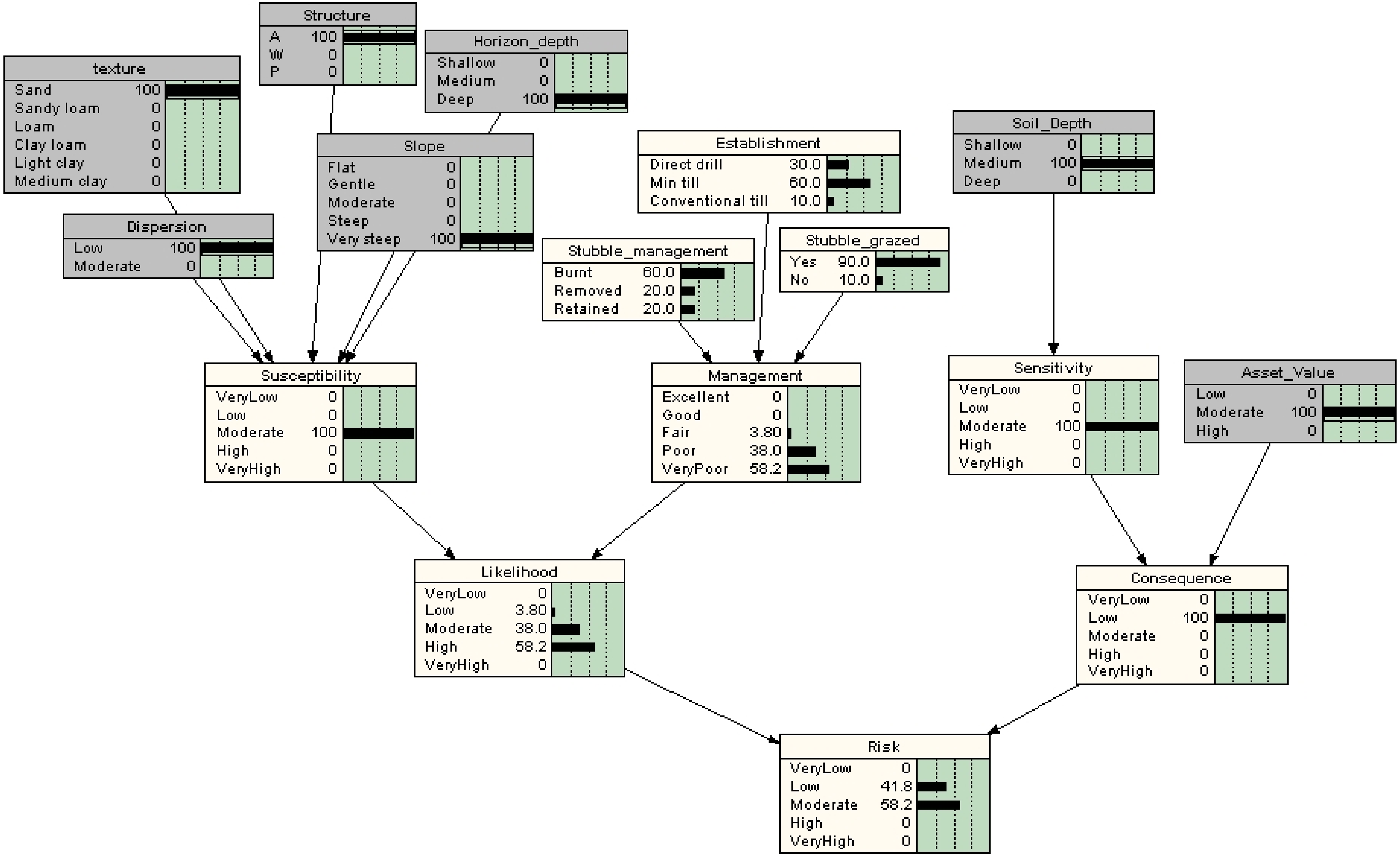

Figure 5 LUIM Bayesian Belief Network for sheet and rill erosion risk under a cropping land management regime, showing an example of results for a single map unit.