PART TWO

THE MANUAL

List of acronyms

AEAM	Adaptive environmental assessment and management
ANSWERS	Areal nonpoint source watershed environment response simulator
APS	Adaptive policy simulation.
ARC/INFO	Proprietary name – commercial GIS plotting package
ARS	Agricultural research service (USDA)
CAD	Computer aided design
CE-QUAL	a series of river water quality simulation models (US Corps of Engineers)
CREAMS	Chemical, run-off, and erosion from agricultural management systems
CRSM	Colorado river simulation model (US Bureau of Reclamation)
DSS	Decision support system
DSS-SLM	Decision support system for the sustainable management of sloping lands in Asia
DTM	Digital terrain model
EPIC	A soil loss prediction model
ESCAP	Economic and Social Commission for Asia and the Pacific
EXIS	A commercial expert systems shell program
GenaMap	A commercial GIS plotting package
GIS	Geographical information system
GLEAMS	Groundwater loading effects of agricultural management systems
GMS	A marine observation satellite system (Japan)
GPS	Global positioning system
HEC-series	A set of simulation models developed at the Hydrologic Engineering Centre, US Corps of Engineers
HSPF	Hydrologic simulation package (FORTRAN)
IBSRAM	International Board for Soil Research and Management
IRS	Indian remote sensing
IWM	Integrated watershed management
MIKE 11	A Danish river water quality model
MSS	Multi-spectral scanner
MOS	Marine observation satellite (Japan)
MOUSE	Modelling of urban sewers (Danish model)
NGO	Non-governmental organization
PC	Personal computer
QUAL Series	A set of water quality simulation models (US Corps of Engineers)
SALMON-Q	A river water quality model (Wallingford, UK)
SOILOSS	An erosion prediction model (NSW Soil Conservation Service).
SPANS	Spatial analysis system (commercial GIS package).
SPOT	Système probatoire d'observation de la terre
SSAR	Streamflow synthesis and reservoir management model
SWMM	Storm water management model
SWRRB	Simulator for water resources in rural basins

SYMPTOX 3	Simplified method program – variable complex stream toxins model
TERRA	TVA environment and river resource aid
TNT mips	Map and image processing system; a commercial GIS package
TR series	USDA run-off prediction models
USBR	US Bureau of Reclamation
USDA	US Department of Agriculture
USLE	Universal soil loss equation
WASP 5	Water quality analysis simulation program
WEPP	Water erosion prediction project (USDA)
WMO	World Meteorological Organization
WSC	Watershed classification

V. DATA COLLECTION AND EVALUATION FOR WATERSHED MANAGEMENT AND NATURAL HAZARD ASSESSMENT

A. Information needs for watershed management and disaster reduction

The occurrence of water-related natural disasters in the ESCAP region is increasing as burgeoning populations make it more and more necessary to occupy locations subject to high hazard. Such disasters are usually accompanied by massive destruction of life, property and infrastructure. The economic costs associated with them can amount to a significant proportion of the national economy for many developing countries. Economic losses of such magnitude can have the effect of preventing advances in living standards and retarding overall economic development.

Natural hazards which can culminate in disasters have been discussed in Chapter III and include cyclones, floods, landslides and droughts. Areas which are at risk of experiencing such disasters can be identified and mapped. The potential impact of these hazards can be increased by watershed degradation, including deforestation, overstocking and soil erosion. Fortunately, the susceptibility of an area to natural hazards can be reduced by the introduction of appropriate land-use planning and practices, which modify land use and promote the implementation of control measures.

The incidence of watershed degradation can be substantially reduced by the adoption of practices which involve the concept of integrated watershed management. Before these principles can be implemented, it is first essential to prepare an inventory of the watershed's natural resources and a survey of its environmental characteristics. This information provides a basis from which to define the potential impact of likely hazards and identify hazard-prone areas. The assessment and mapping of hazards is an essential element in disaster prevention and mitigation. All of these tasks rely upon the availability of basic data about the topography, climate, soils, geological, environmental and land-use characteristics of the watershed. It is the purpose of this chapter to indicate the nature of such data and outline the procedures and techniques employed for hazard assessment, resource and environmental inventory and the effective implementation of the integrated watershed management approach.

B. Data for watershed management

1. Resource information requirements

Integrated watershed management involves the coordinated management of the land resources of a watershed or river basin, undertaken in such a way as to optimize the long-term productivity of these resources whilst at the same time maintaining or enhancing the quality of the watershed environment.

In this context, land resources can be defined as including all the elements of the physical environment which influence the potential for land use. They therefore refer not only to the soil or earth mantle but also to relevant features of geology, geomorphology, landforms, climate, hydrology, vegetation and fauna.

To manage such resources in an integrated and effective manner, it is clearly essential that detailed information regarding the nature, quantity and quality of these resources be available. The collection and presentation of such information is the purpose of natural resources survey or resource inventory activities. For effective management of these resources it is essential also to have information about the uses to which the land is put, requiring the collection of data in the form of a land-use survey. The effects of past human activity in the watershed, such as vegetation clearing or accelerated erosion, form an important component of such a survey, because they impact strongly on the quality of the available land resources.

The integrated watershed management approach requires an assessment of the appropriateness of existing forms of land use and, if considered desirable or necessary, the introduction of improved or more beneficial forms of land use. In this context, land uses include productive uses, such as cropping, livestock production or forestry, along with uses that provide services or other benefits, such as use for water catchment purposes, recreation, tourism, wildlife conservation, or the improvement of environmental quality.

Watershed management decision-making must therefore depend upon an assessment of the potential of the land resources for alternative kinds of use and where appropriate, the introduction of modified or improved forms of land use. The assessment of the potential of the land is what is called land evaluation. Its basic feature is a comparison of the requirements of land use with the resources offered by the land. Its fundamental purpose is to predict the consequences of land-use change, as a basis for the planning of such change.

Land evaluation depends upon basic information from three major sources: land resources, land use and economics. In making integrated watershed management planning decisions, which should be based upon agreed multiple objectives, additional information is needed from other sources, which should include environmental, social and political considerations.

Resource inventory requires the collection, analysis and presentation of data relating to all the land resources of the watershed, which can be expected to include the following components:

- Topography and landform
- Geology and geomorphology
- Soils
- Climate, including data relating to rainfall, temperature, evaporation, wind, insolation etc.
- Hydrology, including the quantity and quality of available surface and sub-surface water resources
- Vegetation cover, vegetation associations
- Native fauna, including habitat survey

The collection of resource data can be greatly facilitated through the use of aerial photography and other forms of remote sensing. These techniques are discussed in further detail in Section V.C.3 below. The analysis and presentation of such data can be greatly facilitated through the use of geographical information systems technology, which provides for the computer storage and manipulation of large quantities of data and the presentation of these data in a variety of formats which include comprehensive transparent overlay mapping. These techniques are also discussed in further detail in Section V.B.3 below. Finally, the availability of such data in computer-compatible form allows the development of computer models of watersheds, in which a variety of hypothetical land-use changes and policy initiatives can be explored and assessed through the medium of computer simulation. These techniques are discussed in further detail in Section V.F below.

The mapping of land resources for land evaluation purposes can be greatly facilitated by organizing the survey programme on the basis of land mapping units. These are areas of land which exhibit a substantial degree of homogeneity in terms of their physical characteristics, the scope of which has been defined as a preliminary to the mapping programme. Typical land mapping units might include soil associations, soil series or phases, geomorphological units of various kinds, soil-landform associations, or vegetation communities. The most effective approach for watershed management purposes is to map on the basis of land systems. A land system is an area of land showing a recurring pattern of topography, soils and vegetation and subject to comparatively uniform climatic conditions. Within each land system unit there may be a number of land facets, which are smaller areas having essentially uniform environmental characteristics. Land systems and land facets can be recognized as distinctive patterns on aerial photographs, so that mapping according to land systems depends heavily upon remote sensing techniques. The land systems approach is discussed in further detail in Section V.B.2 which follows.

2. The land systems approach

From the point of view of integrated watershed management, the key feature of the land systems approach is that it is itself an integrated survey approach, allowing all the significant factors of the physical environment of the watershed to be mapped simultaneously. Normally these factors will include topography, landform, soils, geology, hydrology, climate, vegetation and land use. The approach has the advantage that, being based on the interpretation of remotely sensed resource information, it can be undertaken rapidly and cheaply over a large land area. Further, it is readily amenable to computer representation, so that geographical information systems and watershed simulation models can readily be based upon it. Originally devised as a technique for rapid resource appraisal and land evaluation over large areas of empty or sparsely-settled country in undeveloped nations, it offers very considerable potential as a basic mapping tool for integrated watershed management purposes.

As indicated above, a land system is an area of land having a recurring pattern of topography, soils and vegetation and a comparatively uniform climate. These areas are first identified from aerial photography, viewed stereoscopically, and their boundaries are sketched directly onto the photographic prints. For broad-scale, reconnaissance-level survey black and white photography at scales of 1:40,000-1:50,000 is normally used as the basis for mapping at 1:250,000 and 1:100,000 scales. For integrated watershed management purposes, mapping at larger scales, e.g. 1:50,000 or larger, might be desirable. Limited field survey, generally based on vehicular traverses along selected transect lines, is used to verify the airphoto interpretation.

Each land system is given a distinctive name, generally based on the geography of the locality. Within each land system unit, a number of land facets will be identified. Land facets are areas having essentially uniform characteristics and represent the smallest areas that can be recognized and delineated on standard-scale aerial photographs. The land facets are usually geomorphological features that are causally related to the broader features of the land system of which they form a part. They will be given names which are descriptive of their landform character. By way of example, within an upper watershed land system which is composed of steep sided hills and ridges with incised river valleys between them, the land facets may include ridge crests, side slopes, cliffs and crags, footslope terraces, valley bottoms, floodplains and main river channel sections.

The results of a land system survey are presented in an integrated set of documents which will usually comprise:

(a) A map showing the land systems, with an extended legend detailing the principal environmental and climatic features of the area surveyed;

(b) A description of each land system, including details of the principal features of each of the land facets identified within the system;

(c) A textual account of each of the key factors of the environment surveyed, including geomorphology, climate, hydrology, soils and vegetation;

(d) If appropriate, an evaluation or interpretation of the system in terms of its development potential or management possibilities.

As has already been indicated, the nature of the data relevant to this approach is such that it is readily amenable to preparation and presentation in a computer-based, geographical information systems format. This facilitates the cartographic process of transferring system and facet boundaries from airphotos to the base map, using graphical digitizing equipment, and permits the preparation of comprehensive land system base maps using a range of overlay techniques to display topographic, environmental and climatic features. It also greatly facilitates the collation and display of the land system description information, which is usually presented in several components, graphic and tabular, including a schematic diagram of the system and its facets, a listing of the key characteristics of the system amplifying the legend of the base land systems map, and a detailed tabular description of the individual land facets of the system. The latter mighty be accompanied by sketches of typical facet cross-sections and/or small maps illustrating facet features.

The detailed account of the key environmental factors of the system is presented in a document comprising several chapters giving systematic accounts of the geomorphology, climate, hydrology, soils and vegetation of the system. This should be accompanied by a set of related maps presented at smaller scales than the system base map, which might include special maps presenting such features as arable soils, vegetation associations, areas of erosion or slope stability hazard, etc.

The detail presented in the final section of the survey report, the evaluation section, will depend upon the purposes for which the survey was undertaken and the extent to which it will itself form the basis for a much more comprehensive land evaluation, land capability or land suitability study. Normally, a land systems survey report will include at least one chapter presenting an evaluation or interpretation of the system under study for specific uses or management needs, which might for example be an evaluation of potential for cropping, livestock production or forestry production; an assessment of engineering factors relevant to water resources development, road construction, railway construction or urban development; an assessment of natural hazard risk from flooding, cyclone or land instability; or an assessment of watershed management constraints and opportunities.

For integrated watershed management purposes, however, the land systems survey is best treated as an essential preliminary to further and more detailed studies aimed at specific land capability and land suitability classification for a variety of catchment land uses. The techniques used for the undertaking of such assessment are discussed in further detail in Section V.C below.

3. Remote sensing and geographical information systems

Remote sensing techniques have become an essential feature of data collection systems for integrated watershed management over the past decade. These techniques are invaluable for the rapid collection of data and for the study of extensive areas, particularly in developing countries for which conventional resource mapping sources are limited They are particularly suited for reconnaissance studies associated with large-scale soil and vegetation mapping programmes.

The most useful forms of remote sensing involve the collection of images generated by the reflection of radiation emitted from the earth's surface. The various kinds of imagery detected by sensors carried aloft by aircraft or satellites are all referred to under the general term "remote sensing". Each form of remote sensing relates to a specific band of wavelengths on the electromagnetic spectrum. In passive systems which rely on the detection of reflected energy, the sensors used are capable of recording the range of wavelengths from visible through to thermal radiation. Active remote sensing systems generate their own form of energy, which is transmitted from an aircraft or spacecraft and detected as a signal reflected from the earth's surface. This type of system is categorized as radar.

The different types of imagery available possess certain special attributes, depending upon the nature of the image. which fit them for different applications in resource surveys. Black and white photography, standard panchromatic photography, near infra-red monochrome photography, true colour photography and false colour photography all involve the collection of light rays focused onto a sensitive base, usually film. Other types of remote sensing system, such as multi-spectral scanners (MSS), thermal scanners and radar, record reflected radiation as an electronic signal which is subsequently converted into quasi-photographic images.

Each of these techniques is best suited for specific tasks, some of which are useful for watershed management applications such as soil, terrain and vegetation surveys. The utility of a specific technique will depend upon the level of clarity and accuracy with which natural features such as landforms, vegetation types, land use, the existence and extent of water bodies and so on can be distinguished.

Normal aerial photography has so far proven to be the most useful technique for watershed management purposes, because of the high degree of resolution obtainable and the ability of this technique to show the spatial distribution of ground characteristics. The ability to view adjacent pairs of photographs stereoscopically very significantly enhances their utility for the discrimination of ground features. Large areas can be accurately mapped by assembling mosaics from individual photographs. The amount of detail discernible depends upon the map scale employed.

By comparison with conventional aerial photography, satellite imagery has the major advantage of low cost, enabling a much larger area to be covered by a small number of prints. Unfortunately, the ground resolution capability of this form of imagery is much lower than that achievable with aerial photography, which limits the scope of its application to reconnaissance-level mapping.

The most widely used category of remote sensing for water resources management and hazard assessment purposes is black and white or panchromatic vertical aerial photography. Prints are normally available in 23-cm^2 format, flown in parallel strips with stereoscopic overlap to facilitate stereoscopic viewing and permit the making of photogrammetric measurements in three dimensions. Enlargements to various scales are readily obtainable, as well as mosaics and orthophotographs, all of which are widely used as map substitutes for survey and reconnaissance purposes.

The photography scales used in resource assessment and watershed management commonly range from 1:5,000 to 1:50,000. Large-scale prints at 1:5,000 and 1:10,000 are particularly suitable for detailed soil and vegetation surveys as well as base maps for such purposes as the planning and design of erosion control schemes and flood plain zoning. Scales of 1:20,000 or 1:25,000 are particularly useful for soil and vegetation surveys or land capability and terrain evaluation surveys. A scale of about 1:40,000 is most suitable for reconnaissance surveys of large areas.

As an indication of the scope of the various scales suggested above, it mighty be noted that with a large-scale photograph at 1:5,000 the area covered by a single picture is 1.3 km^2 and resolution to less than 1 m on the ground is possible. At a scale of 1.40,000 the area covered by a single picture is 84 km^2 and resolution to about 10 m is possible.

The most widely used MSS satellite imagery is obtained from the Landsat Series (USA) and the SPOT system (France). Countries within the ESCAP region which operate remote sensing satellite systems include Japan (MOS, GMS), India (IRS) and China. Images are available from these sources as computer-compatible tapes or disks, waveband-specific quasi-photographs in black-and-white or false colour, or false colour composites. By comparison with aerial photographs, satellite images cover a large area and are available principally in small-scale formats. Landsat images, for example, cover a ground area of 185 km x 185 km, or 34,000 km^2 and offer nominal ground resolution of about 80 m. More detailed information is obtainable from the SPOT satellite images, which have a swath width of 80 km and offer 10 m resolution. Scales available from MSS sources range from 1:200,000 to 1:1,000,000, the commonest for large surveys being 1:1,000,000. The SPOT system uses adjacent pairs of images from which stereoscopic viewing is possible.

Compared with aerial photography, satellite imagery has two advantages; firstly, its ready availability and relative cheapness, and secondly, its ability to provide coverage of a large area of land on a small number of prints. On the other hand, it has the disadvantages of poor ground resolution and limited stereoscopic capability. Satellite imagery has been widely used, however, for rapid, large-area reconnaissance-level surveys of extensive land areas and in some cases, of whole countries. It also serves as a valuable preliminary to more detailed larger-scale, airphoto-based surveys. Another advantage of satellite imagery, from both a resource monitoring viewpoint and a disaster monitoring and management viewpoint, is the frequency with which imagery is repeated. The Landsat satellites, for example, are in continuous polar orbit with a return period of 16 days, allowing the progression of a major flood or the passage of a major drought event to be closely monitored.

It needs to be appreciated that, regardless of the category of remote sensing employed, field verification or "ground truthing" of the imagery is essential for the effective application of these techniques in watershed management. During the past five years this activity has been greatly facilitated by the readily availability of low-cost satellite-based navigational or "Global Positioning System" (GPS) equipment. For less than $1,000 US anybody can now purchase a hand-held GPS instrument which utilizes signals from five of a set of twenty-four navigational satellites to give an instantaneous reading of latitude, longitude and height above sea level to a degree of resolution of better than 100 m. With more sophisticated equipment, particularly where differential transmitter stations have been established or where the agency undertaking the survey can obtain access to military-quality signals, resolution to a level of 1 m is obtainable. With such equipment, the location of any sampling site and a wide range of distance, area and height measurements can be made rapidly and accurately, greatly reducing the cost and time-requirements of field survey and ground truthing activities.

Over the past twenty years, the enormously increased amount of resource evaluation and assessment data available from the various types of remote sensing system, much of it available directly in computer-accessible format, and the increasingly widespread availability of low-cost computer equipment, has greatly encouraged the development of techniques for the archiving, analysis, mapping and presentation of such data. Where these techniques relate to the collection, analysis and presentation of geographical data and information, they are called geographical information systems (GIS).

Geographical information systems utilize geographical data and information with respect to three components: spatial data, which pertain to the locational aspects of geographical features, along with their spatial dimensions, attribute data, which pertain to the description, measurement and classification of geographical features; and time, which is particularly important in natural hazard assessment because of the rapidity with which geographical features may alter during the occurrence of disaster events. As has been indicated above, the collection of such data has been greatly facilitated by the availability of various kinds of remote sensing systems. Its incorporation into a computer-compatible format, and its ability to be manipulated within the computer for rapid data analysis, classification and presentation, has been further facilitated by the ready availability of digital mapping devices and software programmes, which allow the ready transformation of analogue data from maps or remote sensing images into computer-usable format.

A GIS has four functional components, which comprise:

(a) A data input subsystem, which collects and processes spatial data from sources such as existing maps and remote-sensing imagery;

(b) A data storage and retrieval sub-system, which organizes data in a structured form and allows it to be retrieved in various forms for subsequent manipulation, analysis or display;

(c) A data manipulation and analysis sub-system allowing the modification or reorganization of data according to given rules and providing a basis for the preparation and manipulation of models of the geographic area;

(d) A data-reporting sub-system capable of displaying all or selected parts of the data base in chosen tabular or cartographic formats.

A key advantage of the GIS approach is that it permits the integration of a wide range of categories of data and the merging or overlaying of various groupings of data, which greatly facilitates the use of the data for design, planning or policy-implementation purposes. By way of example, plans of urban and industrial development can be superimposed on topographic maps and plans of communication systems and the whole overlain by maps of major flood level contours to provide a basis for floodplain zoning rules. A further key advantage is that the GIS system permits the aggregation of spatial and attribute data into models of the land or resource system under study and provides a basis for the simulated operation of such models according to a variety of scenarios as a basis for planning and design problem-solving. In integrated catchment management, the data-integrating and model-forming capabilities of GIS packages are of very substantial potential value for management purposes, particularly as a basis for optimizing models, decision support systems and expert systems. The use of such models and decision-support systems is discussed in further detail in Sections V.F and V.G below.

A wide range of commercial software packages and systems for GIS is now readily available, usually in association with related Remote Sensing (RS) packages. Some of the proven commercial systems now in wide use include GenaMap, TNTmips, SPANS and ARC/INFO, all of which are available from organizations located within the ESCAP region. The use of GIS technology is now widespread throughout the region, and has been strongly fostered by World Bank and United Nations agencies for use in developing countries. ESCAP has been very active in the promotion of GIS as a key tool for natural resources development and planning throughout Asia and the Pacific and should be contacted for further information in this regard.

C. Land resource evaluation

1. Land evaluation

Land evaluation is the process of assessing the potential of land for various alternative uses. These may include productive uses, such as arable farming, livestock production or forestry, and uses that provide services or other kinds of benefits, such as water supply catchment, wildlife conservation, recreation or tourism.

Land evaluation is a key process in land-use planning and an essential feature of integrated watershed management practice. Effective land-use planning can best be undertaken on the basis of a detailed assessment of the qualities of the land, a systematic evaluation of its potential for alternative uses and a rational set of decisions regarding the best uses for it Such planning is essential for effective watershed management, which is concerned with the prediction of the environmental effects of various forms of land use, the application of management practices to control the effects of adverse uses, and planning for the introduction of beneficial changes in land use.

Land evaluation is essentially concerned with a comparison between the available resource qualities of the land and the requirements of different kinds of land use. Such evaluation requires information inputs from three sources: the land itself, the needs and effects of land uses, and economics. A comprehensive resource inventory is necessary to establish the qualities of the existing land resources. Information about the requirements of possible land uses, including their adverse effects, comes from a variety of technical, ecological and environmental sources. In order to determine the best uses, or to rank alternative land uses as a basis for decision-making, economic data relating to the costs and benefits associated with alternative uses and their consequences are also required.

The resource inventory requires an integrated collection of data relating to topography and landform, geology and geomorphology, soil types and associations, climate, hydrology, vegetation, wildlife, and existing land uses. A soils survey is of central importance to land evaluation, because almost all forms of land utilization depend upon the soil as a medium for plant growth or as an engineering material. Whilst a soil survey might provide the basis for more detailed and comprehensive resource inventory, the resource survey needs to be undertaken on a comprehensive, "land systems" basis using some form of land mapping unit as its key structural feature. Where the survey is undertaken for integrated watershed management purposes, as distinct from evaluation for more specific production purposes such as agriculture or forestry, the land systems approach described in Section VI.B.2 above should certainly be employed. Application of the remote sensing and GIS techniques described in Section V.B.3 will greatly facilitate the undertaking of such an inventory and also facilitate the making of the evaluation itself and the presentation of its results.

Information about the resource requirements of various forms of land use, as well as their environmental consequences, adverse and otherwise, can be obtained from a variety of technological and scientific sources. Soil science, agronomy, forestry, ecology, civil and agricultural engineering and related disciplines are the basic sources of such information. Economic data are required for land evaluation to permit an assessment of the costs and benefits associated with alternative forms of land use and allow them to be ranked on a quantitative, dollar basis for purposes of comparison and decision-making. Whilst the disciplines associated with such assessment and ranking are principally those of economics, agricultural economics and resource economics, much detailed information about the costs and benefits associated with specific land uses is held by the technological and scientific disciplines previously mentioned. Comprehensive land evaluation requires not only the consideration of direct monetary costs and benefits from specific land-use practices, but also the assessment of shadow costs and direct and intangible benefits. This must also involve the determination of environmental and social costs and benefits; whilst these might not easily be expressible in terms of monetary values, there are now many techniques available for doing so.

The results of a land evaluation need not necessarily be expressed in dollar terms; evaluation may be qualitative, quantitative in physical terms, or quantitative in monetary terms. A qualitative evaluation is one in which the suitability of land for various alternative purposes is expressed in a qualitative way, using such terms as "highly suitable", "marginally suitable", "not suitable", etc. This may be an appropriate approach for broad-scale, reconnaissance surveys, particularly in the evaluation of undeveloped or sparsely settled areas, or as a preliminary to a more detailed survey. A particular advantage of this approach, which can be offset against its lack of precision, is that it permits the ready expression and comparison of a wide range of costs and benefits, encompassing environmental and social aspects as well as economic aspects. It is also appropriate where decision-makers, such as planners and politicians, have limited economic and technological expertise.

A quantitative physical evaluation is one which provides numerical estimates of the quantities of inputs and outputs associated with various land-use alternatives. Inputs may include resources, labour and capital; outputs will largely comprise quantitative expressions of land-use products, such as tonnes of wheat or rice, quantities of logs produced, volumes of water yielded or recreational and tourist visitor numbers. Such an approach is particularly useful for the expression of the environmental costs and benefits associated with land-use alternatives, as well as the social costs and benefits. Environmental costs and benefits, in particular, are most readily expressed in such terms as water and air quality parameters, tonnes of soil lost by erosion or areas of vegetation cleared. Economic costs and benefits can also be expressed in physical terms in such units as numbers of jobs lost or created. Whilst this approach is particularly useful from the point of view of environmental