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Using Spatial Systems To Establish Priorities For Catchment Management

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ABSTRACT

Priorities for catchment management can be established based on either, an objective assessment of relative priorities throughout the catchment, or by simply responding to crises associated with particular land uses and their sectional interests. While the latter method can have advantages in terms of establishing community good will, team cohesion, and a sense of achievement for particular sectional interests, it may have shortcomings in terms of a more objective and rational assessment of the relative magnitude and hence priority of land management problems. Spatial modelling using GIS can form the basis for developing a catchment-wide understanding of the relative importance of land management problems.

Spatial models have been successfully used to estimate water and pollution generation rates internationally, and to identify phosphorus-loss hot-spots in the Leschenault and Swan catchments locally. Land capability assessment, based on soil and landform information, has been well established as a basis for defining, together with an assessment of planning considerations such as demand, infrastructure and services, the suitability of the land for particular land uses. Land capability information can also be used to prioritise and target catchment management activities.

Situations where land management practices need to be improved can be readily identified by combining current land use information, land capability information and the results of spatial models describing water, nutrient, sediment or salt generation using GIS. For example, an intersection between existing landuse, land capability and a nutrient generation model would flag annual horticulture as being inappropriate on leaching sands adjacent to fragile wetlands. Such an intersection would not flag this particular landuse where it had been established at a site with a higher land capability rating. These types of intersections can also help identify priority areas for rehabilitation or conservation of riparian corridors. An example of the use of these types of intersections in catchment management prioritisation is presented.

INTRODUCTION

The development of appropriate policies to reverse land and waterway degradation has traditionally been hampered by poor understanding of the relationships between numerous complex biophysical processes. The need to identify specific areas where improved land management practices are required is becoming increasingly important as greater emphasis is placed upon the interactions of social and economic forces with natural resource management (Mallawaarachchi, 1996). In approaching this problem, however, there needs to be a recognition that small parts of the catchment often contribute a disproportionately large share of nonpoint source pollutants. These areas need to be identified in order to target reductions of total nutrient loadings (Turner and Ruffio, 1993). Experimental field studies of phosphorus transport over large areas are usually not feasible due to time and financial constraints, hence the requirement to identify 'hot spots' within the landscape.

Historically the Swan River has been a highly valued asset to the Perth community. An increasing number of potentially harmful phytoplankton blooms occurring in the upper Swan (Hosja and Deeley, 1994), has met with considerable community concern, and through the Swan Canning Cleanup Program Action Plan (SRT 1998), attention has been focused on the relationships between land use and runoff quality from the Swan Coastal Plain. Ellenbrook has been identified as a major source of phosphorus to the Swan River estuary (Deeley *et al*, 1993, Donohue *et al*, 1994). The hydrological characteristics of this sub-catchment have been extensively modified by the filling and draining of natural wetlands and extensive clearing for agricultural and urban development. This has resulted in an increase in the pollutant carrying capacity of runoff reaching the estuary each year. Fertilisers applied to the very sandy soils (Yeates *et al*, 1984, Deeley, 1989) of the sub-catchment are transported to the river system. While a diverse range of land uses now exist across the Ellenbrook sub-catchment, some activities located in particularly vulnerable regions have contributed a disproportionately large share of the annual nutrient load (Sharma *et al*, 1994).

Investigations into nutrient export estimation have utilised a variety of approaches ranging from highly complex to very simple, empirical models. The early development of empirical models tended to ignore the spatial variation of dominant parameters, and the more complex process-based models have been limited in their use by intensive data requirements (Poiani & Bedford, 1995). Sophisticated modelling techniques have generally had more success when confined to small,

well-defined catchments and for fine-resolution time-scales (hours, days). A good model can be expected to produce a collection of predictions which reflect the general physical and temporal scales of the problem at hand (Walters, 1993).

Detailed modelling procedures may be more representative of the natural processes occurring within a catchment, yet the large resources required to undertake process-based modelling for the required space and time scales are often prohibitive. Increasing the complexity of models may be accompanied by decreasing cost-effectiveness, and complex models with a narrow focus on particular aspects of the environment may not provide results appropriate for assisting broader management processes. The nature of many reductionist studies tends to mirror the fragmentation of the ecosystems which are being studied, rather than drawing together a holistic understanding of the dominant processes (Hobbs & Saunders, 1990).

An alternative approach has been the use of a coupled model-GIS to provide estimates of loading rates or export coefficients in order to evaluate catchment-wide nutrient contributions to non-point pollution (Heidke & Auer, 1993; Poiani & Bedford, 1995). Such models can produce reliable estimates of loads providing sufficient local monitoring data is available for calibration, together with an accurate description of the various combinations of geographic attributes within the catchment (Heidke & Auer, 1993). Empirical loading functions are now commonly used to derive representative nutrient export coefficients using long-term averaged rainfall data (Allanson, Moxey & White, 1993; Heidke & Auer, 1993; Negahban *et al*, 1995; Poiani & Bedford, 1995; Poiani, *et al*, 1996). These applications allow for rapid determination of the average non-point nutrient loads within large and highly varied catchments. The unit load models reflect the mass of a pollutant generated per unit area per unit time, and are typically based on variables such as land use, soil texture and topography (Heidke & Auer, 1993). These models can be easily used to evaluate potential impacts of land use changes, and most avoid the extensive resource requirements of the more sophisticated non-point pollution models such as HSPF and AGNPS (Heidke & Auer, 1993).

Environmental managers have traditionally relied on written records and manually produced maps, yet Geographic Information Systems (GIS) allow nonspatial data to be combined with spatial information, providing simultaneous analysis of both data sets (Le Maitre, *et al*, 1993). Geographic Information Systems have been used for some years to map surface characteristics of the landscape, and are now being incorporated into management regimes due to the effective integration of multiple spatial data sets. The integration of pollution models within GIS provides a relatively simple summary of the non-point pollution potential within a catchment, although the ability to make predictions through time is sacrificed because of the spatial rather than temporal nature of the GIS framework (Poiani & Bedford, 1995). This may not be an impediment when identifying the need for improved management measures, but may need to be accompanied by effective trend detection once the success of implementation strategies needs to be evaluated.

The ability to produce the results of model simulations within a spatial format provides a number of advantages for management and policy development. The presentation of spatial information using thematic maps increases the ability to communicate concepts and relationships that may be drawn from integrating spatial data. This increases the opportunity for broad community input into the development of alternative management policy choices guided by model predictions.

In this paper we describe the use of a spatial model of land capability combined with landuse to provide a land capability audit for existing landuses in a section of the Ellenbrook catchment as a first step toward identifying nutrient-loss hotspots.

METHODS

A central portion of the Ellenbrook sub-catchment was used in this study (Figure 1a). A range of spatial data representing landform, soils and landuse were assembled, and assessed for suitability prior to the design of the model. Landuse was determined using unsupervised image analysis of Landsat TM satellite data merged with information describing cadastre and tenure. Groundtruthing, a SPOT/TM merge image (Figure 1b) and a two-way validation was used to refine the landuse coverage. The SPOT/TM merge image shows Ellenbrook running approximately north-south with the largely cleared central portion of the catchment. Remnant vegetation shown as the darker patches remains on the western portion of the sub-catchment toward the Gnangarra mound and to the east covering parts of the Darling scarp. The town of Muchea is located in the lower left of the image. The settling ponds of the TiWest mineral sand processing plant can be seen located in the upper left of the image. A block of annual horticulture can be seen in the upper left of the image.

Preliminary information from soil landscape mapping undertaken by Agriculture Western Australia (Figure 1c) was used to define land capability for a range of potential landuses using standard methods (Wells, 1989). This coverage is intended to illustrate the heterogeneous nature of soil types in the region rather than provide information on the extent of individual soil units. The landuse coverage was simplified to represent the landuse classes covered in the land capability assessment (Figure 1d). The results of the land capability assessment undertaken by Agriculture WA together with Land Assessment Pty Ltd are presented in Figures 2a to 2d.

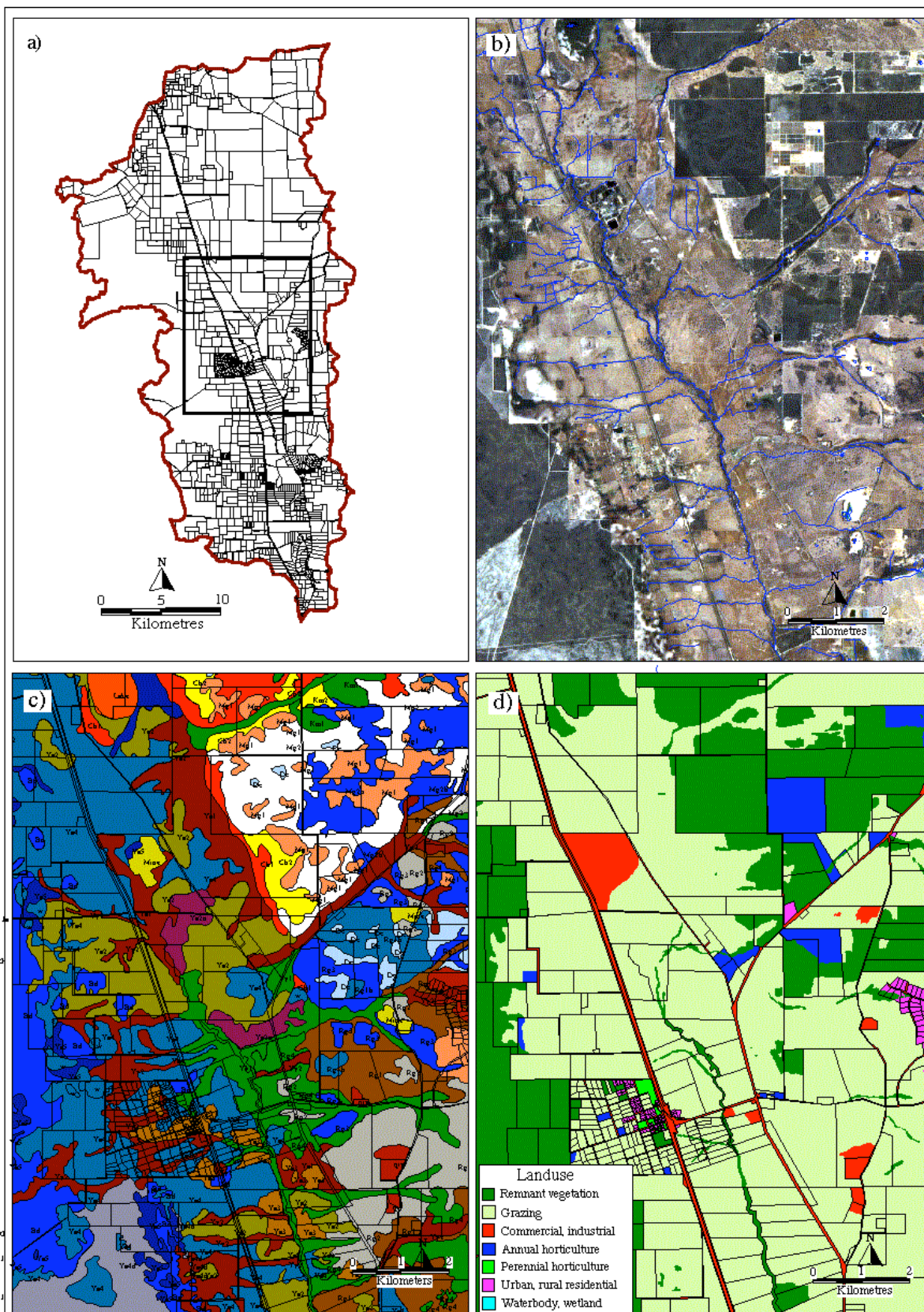


Figure 1a Location of study area within the Ellenbrook catchment.
 Figure 1b Spot TM merge image (1992) with streamlines.
 Figure 1c Preliminary Agriculture WA soil landscape mapping.
 Figure 1d Landuse and cadastre.

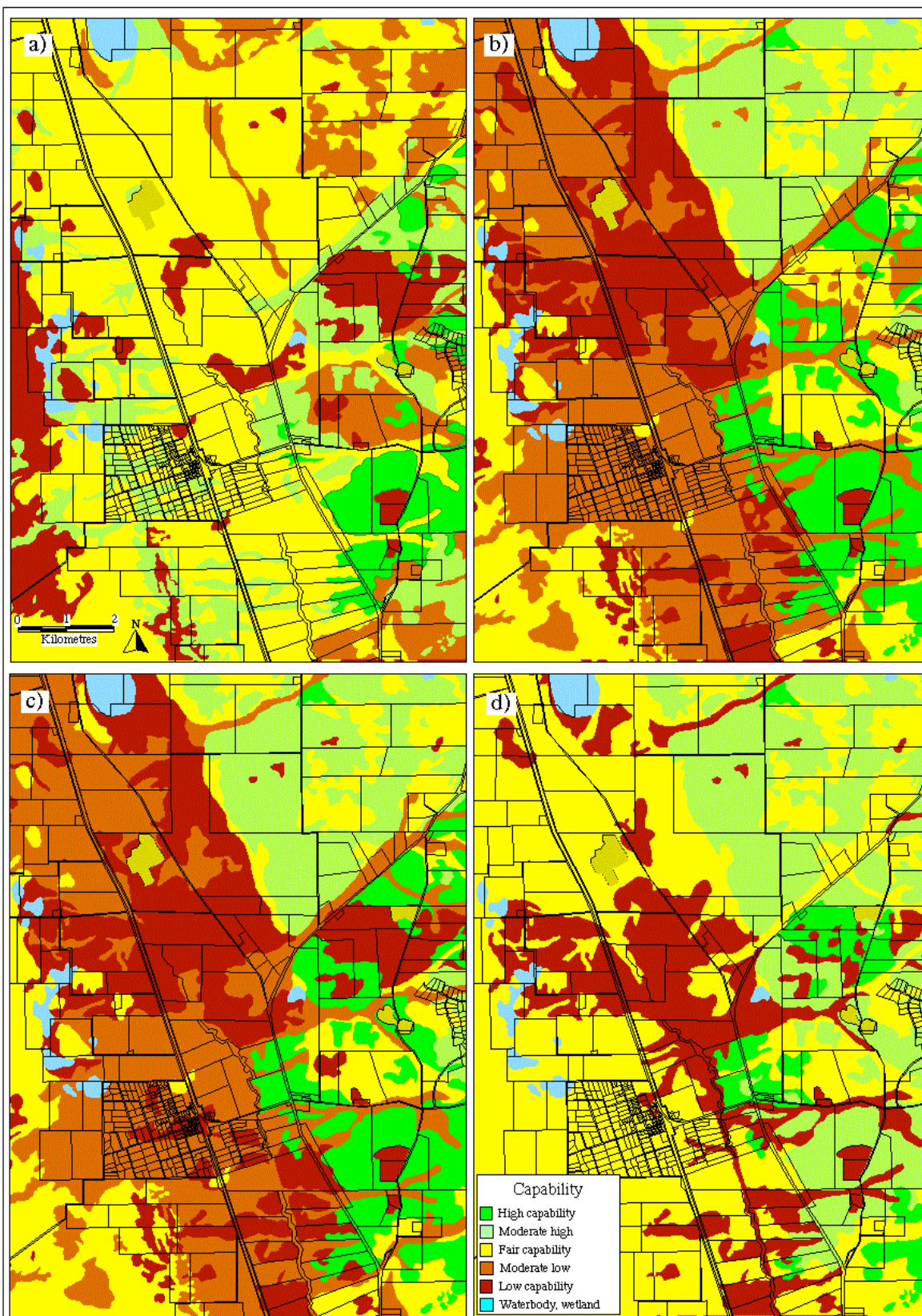


Figure 2a Land capability for grazing.

Figure 2b Land capability for urban (sewered residential).

Figure 2c Land capability for on-site effluent disposal (rural residential, commercial, industrial).

Figure 2d Land capability for annual horticulture.



Data source: Preliminary soil landscape mapping by AgWA, capability assessment with Land Assessment Pty Ltd.

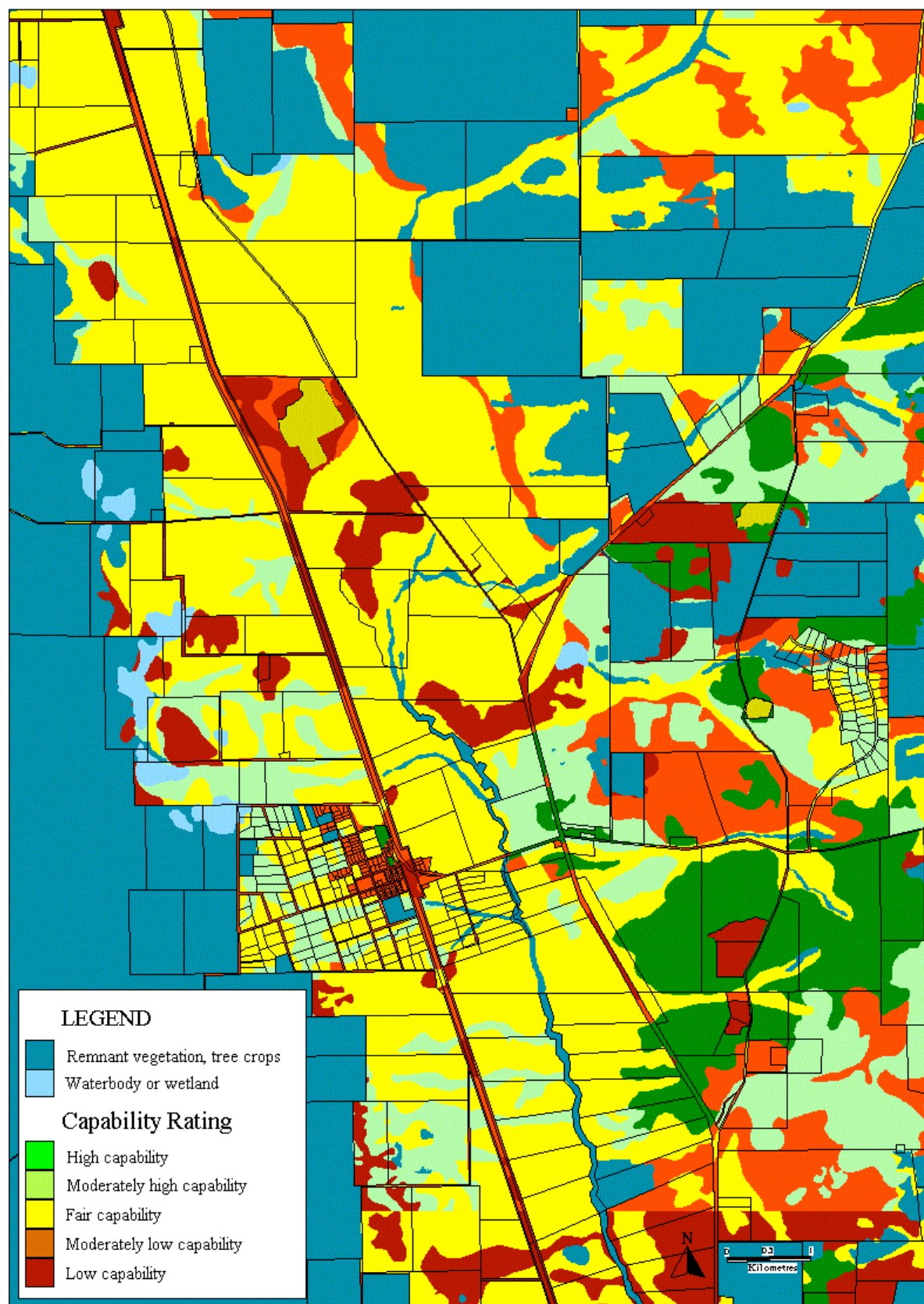


Figure 3 Capability audit for existing landuses.

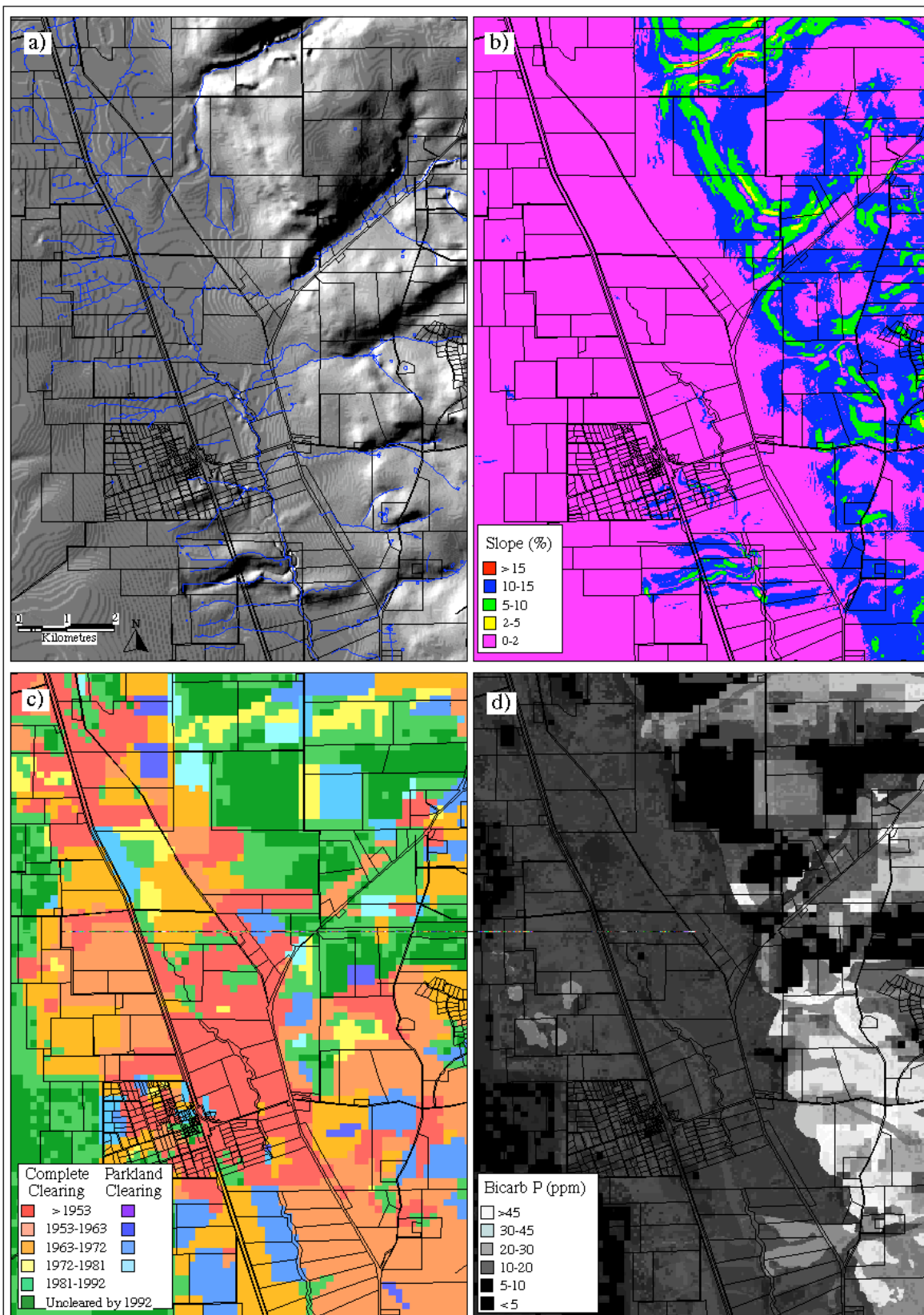


Figure 4a Digital elevation model with cadastral and streamlines.

Figure 4b Slope class.

Figure 4c Clearing history.

Figure 4d Simulated bicarbonate extractable phosphorus.

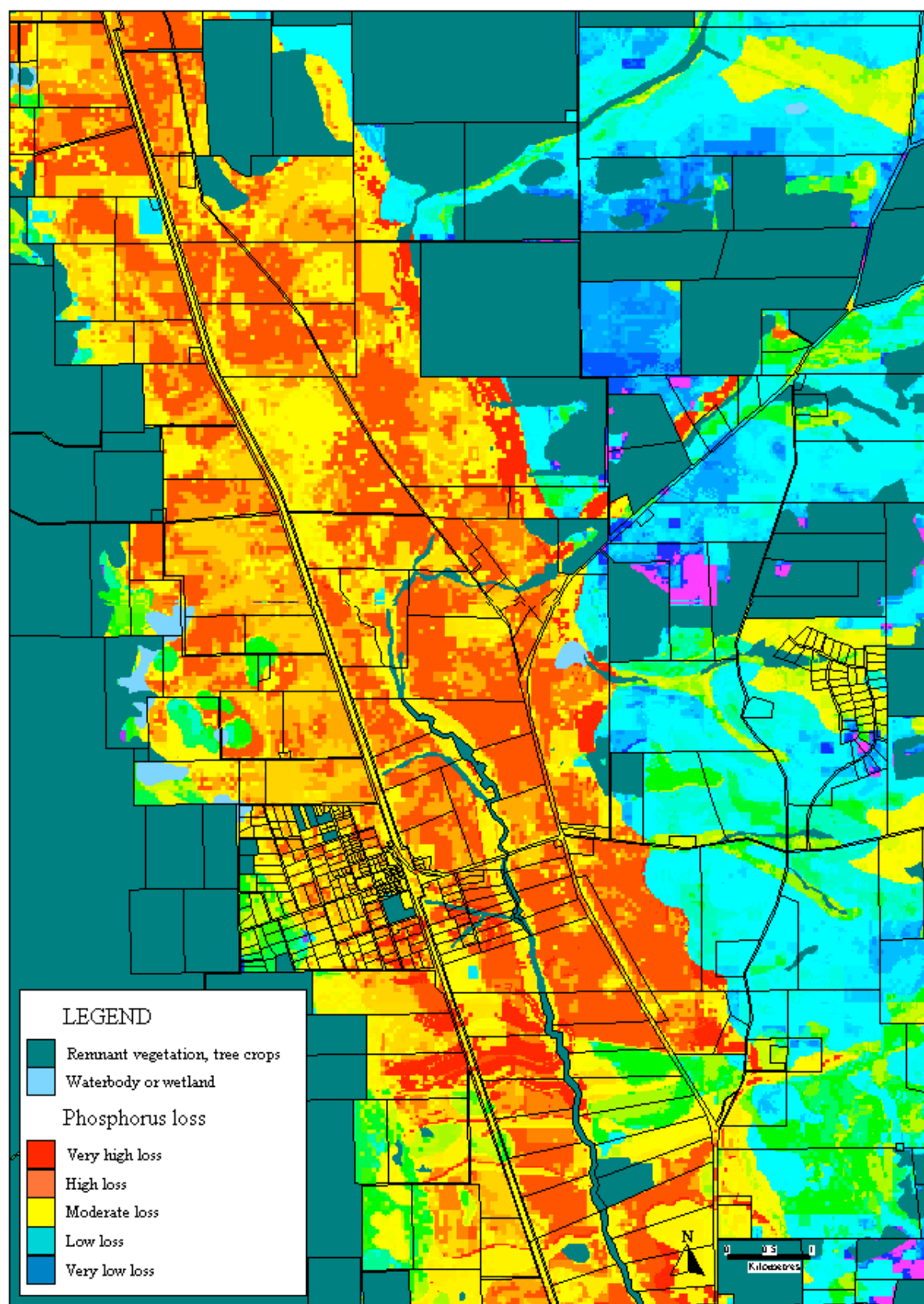


Figure 5 Simulated phosphorus loss.

A series of intersections of landuse and each of the land capability coverages was undertaken as an audit of the capability of each existing landuse. The series of intersected coverages were then combined to provide a single coverage (Figure 3) describing an audit of the capability of existing landuses.

A phosphorus-loss model was developed (Deeley *et al*, 1997) by combining coverages of landuse, P application, soils, slope and clearing history. Simple empirical relationships were used with lookup tables containing class data for each coverage. Contours were used to develop a digital elevation model (Figure 4a) thus defining slope classes (Figure 4b). Clearing history (Figure 4c, Hammond and Mauger, 1985) was combined with estimates of phosphorus application rate for various landuses to generate a coverage of accumulated available P (Bicarbonate extractable P) in the soil (Figure 4d). It has been shown (Daniel *et al*, 1993, Sharpley *et al*, 1993, Sharpley, 1995) that there is a significant correlation between accumulated available soil P and runoff quality for a range of soils. The accumulated available soil P coverage was used together with slope and soil P-binding to generate a coverage of P-loss for the area (Figure 5).

RESULTS AND DISCUSSION

The landuse capability audit (Figure 3) shows how existing landuses at particular locations fit within their particular land capability rating for that location. Landuses that are situated on soils having a very low capability for that particular landuse are clearly identified. These situations are those most likely to be experiencing some form of land degradation or excessive loss of nutrients or sediments offsite. Alternatively, landuses situated on soils having a very high capability for that particular landuse are least likely to be experiencing land degradation or pollutant exports. This type of assessment is essential for farmers and land managers who are struggling to prioritise their restorative efforts. It is also essential for policy makers who must identify for which particular locations various development conditions must apply for particular landuses.

The P-loss model (Figure 5) identifies those areas which may have excessive nutrient export based on soil and geomorphological information but also based on the length of time that particular landuse had been in existence. In addition to flagging nutrient-loss hotspots, this type of assessment can also form a basis for the evaluation of alternative restorative measures such as riparian revegetation, tree crops, perennial crops, detention structures and slow release fertilizer applications (Weaver *et al*, 1994). This type of analysis also promotes involvement and participation by farmers and other land managers.

A number of studies have highlighted the potential for using GIS systems to assess nonpoint pollution loads from a wide variety of land uses in a similar manner to the auditing of point source industrial pollution (He *et al*, 1993, Summer *et al*, 1990, Julien *et al*, 1995). The integration of NPS models with GIS systems enabled Engel *et al* (1993) to produce simulations of catchment responses to rainfall events. Results of the simulations produced in this study were comparable to measurements of sediment and runoff levels measured on the ground. Reiche (1994) integrated existing rainfall and nitrogen modelling techniques with GIS to enable the Catchment related Water & Substance Simulation system (CWSS) to produce nitrogen simulations in small catchment areas. GIS information such as soil type, land use and elevation were combined with simulations of ground water and runoff movement, soil heat budget and organic nitrogen processes. The CWSS technique was used to simulate nitrogen export from the Lake Belau catchment of North Germany. The results of this study indicated that the average groundwater nitrogen levels already exceeded the legal limit, a fact supported by ground measurements, and allowed a specific annual reduction target to be set in order to maintain safe levels for drinking water.

Adaptability has been a central feature of some models developed in order to maximise the relevance of results to environmental management. LOADSS (Lake Okeechobee Agricultural Decision Support System) was developed to help address problems created by phosphorus runoff in Lake Okeechobee (Negahban *et al* 1995). It was designed to allow regional planners to alter land uses and management practices in the Lake Okeechobee Basin, and then view the environmental and economic effects resulting from changes. The information incorporated into the system includes land uses, soil associations, weather regions, management practices, hydrologic features and political boundaries. The system has the capacity to call external hydrologic models and display historical water quality and quantity data. LOADSS was originally developed for coarse resolution regional planning but was adjusted to incorporate hydrologic models for more detailed field-level analysis of management practices on dairies. The system also has the capacity to evaluate the cost effectiveness of management controls by allowing economic parameters to be included.

Specific objectives have been targeted with the aid of GIS based models in many areas of the world. Jurgens & Fander (1993) combined the Universal Soil Loss Equation (USLE) and GIS techniques to assess long term soil erosion in the Saar-valley, Germany. LANDSAT-TM information was used to map land use, soil type and slope classifications over the valley and the data was combined to create estimates of soil erosion from each pixel. Since highly eroded areas in the valley were considered to have a greater impact on surface water quality due to the transport of sediment bound nutrients, specific sites could be identified for precise prevention measures to improve runoff quality within the small catchment. GIS information

has also been used for the management of ground water pollution in the Beauce region of France. Hrkal & Trouillard (1994) identified pollution load, climatic conditions, and groundwater quality factors in a weighted system of classification which mapped areas where activities with a high polluting potential occurred over vulnerable regions of the aquifer, and contrasted these areas with those which occurred on low risk activities occurred on confined aquifers. The results of the analysis proved that the vulnerability of the local aquifers were such that no improvements in ground water quality could be made without improvements to agricultural activities. The scheme was particularly useful for catchment management since it was capable of accepting new information as well as preparing a number of scenarios, thus providing an adaptable and interactive technique.

Coarse resolution, regional based GIS models have had greatest success when dealing with large areas of heterogeneous land. Jordan et al (1994) simulated nitrate leaching to surface waters over a 10 by 10km grid within the Northern Ireland region. The system used spatially referenced information such as population numbers, meteorological data and leaching data from experimental catchments. The use of regional data rather than detailed catchment based information allowed minimum data storage requirements and allowed the use of PCs. It was possible to rapidly assimilate information describing the effects of increased fertiliser use, reduced vegetation coverage, or increased human population. The prediction of nitrogen losses from each catchment were also made to 25% accuracy, thus providing adequate information for catchment as well as regional-based management programs. Allanson, Moxey & White (1993) modelled nitrate emissions from the Tyne River catchment in England using GIS data. The results emphasised the importance of spatially and temporally differentiated prevention strategies to reduce nitrogen enriched runoff. Spatial distribution of nitrate emissions within the catchment were determined using a stepwise weighted system of land capability classifications. The simulation results indicated that the timing of emissions as well as cropping, soil and climatic factors all influenced the levels of nitrogen released from an area.

It can thus be concluded that significant progress in catchment management can be achieved by combining empirical relationships with spatial coverages in a GIS.

Future investigations

The capability audit completed as part of this investigation (Figure 3) will form the basis of a best management practices (BMP) evaluation action plan. Locations which have particular landuses situated on soils having a very low capability for that particular landuse can be readily identified. The Action Plan would flag those areas likely to be experiencing various forms of land degradation or excessive loss of nutrients or sediments off-site because of poor land capability.

The Ellenbrook Integrated Catchment Group have identified a need for this type of analysis to assist in developing a BMP evaluation matrix. Many farmers and land managers have moved some distance toward developing sustainable solutions to land degradation problems. Currently there is no available documentation describing what constitutes best practice for a particular combination of landuse and capability rating, even though there is considerable knowledge and experience available within the local farming community. A BMP evaluation matrix may need to be developed by EBICG representatives visiting managers of particular landuses across a range of capability ratings so as to undertake a qualitative assessment of the types of management practices being used. Innovative management practices could be identified for situations where some form of land degradation has been apparent because of poor capability. Although land degradation continues to occur in many of these locations, for some areas, farmers have developed highly innovative solutions for particular land degradation problems. A BMP evaluation matrix would help document best practice throughout the Ellenbrook catchment.

Identifying the environmental, economic and social linkages in a system or on a catchment is also vital. This is because land and water degradation occur usually as a result of the cumulative impacts of competitive production. Moreover, such production decisions are made at the fine or farm scale and if the adoption of BMPs results in economic winners and losers, then history shows that voluntary adoption rates are low. Legislative requirements for best practice are also rarely achieve success in Western Australia (cf. Clearing and drainage moratorium in the Peel-Harvey catchment).

Farmers and other land users will, however, be much more amenable to adopt a particular improved land management practice if the environmental, economic or social costs of implementing such a practice are readily articulated and can be equitably distributed. By establishing environmental, social and economic linkages, landowners can assess the cumulative impacts of various land use options in a wholistic context and work with Government agencies and scientists to develop the policies needed at a broad scale to favour the adoption of BMPs at fine scale. A robust wholistic process based on the principles of catchment management (Mitchell, 1991, Walters, 1993) is needed to handle such complexity and will “value add” to the various technical layers already discussed. Without it, the community that owns and manages the landscape will remain in fine scale competitive decision making and the prospect of improved water quality in the Ellen Brook and the Swan River in the short term, appears a remote prospect.

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