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ENVIRONMENTAL AUDITING FOR NONPOINT SOURCE POLLUTION CONTROL IN A REGION OF NEW SOUTH WALES (AUSTRALIA)

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ABSTRACT

The concept of environmental auditing of point source pollution has been adapted to nonpoint source pollution in rural lands. Geographic Information Systems (GIS) and other information technologies provide an effective environmental management tool for characterising nonpoint source (NPS) pollution in a regional context and thereby can assist the environmental auditing process. Nonpoint source pollution problems of rural watersheds in Australia, particularly those in the state of New South Wales, and the role of the state's environment protection agency are outlined. A case study that applies an auditing methodology using GIS in a study area within the Lachlan River catchment is presented. The suitability of the approach for land condition evaluation and the review of land use controls for nonpoint source pollution is discussed.

KEYWORDS

Geographic information system; Lachlan River; remote sensing; vegetation clearance; nonpoint source pollution; water quality in Australia.

INTRODUCTION

Auditing for Nonpoint Source Pollution

Environmental auditing of activities that cause point source emissions has now become a routine procedure for the review of environmental policy. Determining the degree of compliance with pollution controls is a fundamental prerequisite to the assessment of the adequacy of these controls. Similarly, the degree of compliance with existing land use controls needs to be established before an evaluation of controls on nonpoint source (NPS) pollution can be carried out.

The auditing procedure also assists in identifying impediments to the practical implementation of NPS pollution control strategies as well as providing indicators of the performance of land managers and administrators.

Auditing Using GIS

In order to monitor and report on NPS pollution and its relationship with land use activities, a substantial environmental database and a diverse analytical capability to interrogate that information need to be

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established. There is a universal need to integrate catchment-based environmental and land use information with stream ecosystem information over both space and time in order to define these relationships.

Geographic Information Systems (GIS) are a useful tool to assist with this task. GIS provide a generic knowledge-based management tool for the analysis and interpretation of primary data being collected on land use activities and water quality. Moore (1990) has reviewed the functional advantages of using GIS for identifying and targeting areas susceptible to NPS pollution. The ability to develop knowledge-based watershed models of pollutant transport, using the analytical sub-systems of GIS, is seen as particularly useful in evaluating the performance of environmental protection strategies (Moore, 1990: Ethridge and Olsen, 1992).

Cully Hession and Shanholtz (1988) and Stanholtz et al. (1988b) selected GIS as the most logical approach to identifying agricultural land areas needing improved management for NPS pollution within Virginia's Chesapeake Bay catchment area. A regional-based GIS was also selected to allow the development of protocols for evaluating existing and alternate policies based on Best Management Practice strategies for effective NPS pollution control (Stanholtz et al., 1988a).

Such endeavours to geographically define source areas of NPS pollution are prompted by a recognition that small parts of watersheds often contribute a disproportionately large share of NPS pollutants. These areas need to be identified in order to target efforts in reducing overall watershed pollutant loadings (NWQEP, 1988; Baker, 1992). Empirical data of the quantity and quality used in the Chesapeake Bay program are often not available, and effective indicators of environmental condition and NPS pollution need to be identified and measured. Land cover change and other associated factors have been used as indicators of land degradation in a study by Garg and Harrison (1992) using a GIS approach.

The US EPA (1989) has stated the need to move beyond chemical monitoring to measures of ecological condition if NPS pollution, commonly occurring in conjunction with habitat alteration, is to be characterised adequately (Baker, 1992). For effective water quality management, Kinney and Omernik (1990) advocate a regional GIS approach, examining the spatial patterns of environmental resources and their associations with landscape characteristics or human impacts to assess their extent, status, or trends.

In 1982 a Parliamentary Select Committee, established by the State Government of New South Wales to inquire into land use and the state of natural resources of the Western Division of the State, recommended that more objective, ecologically-based data were required to make sound management decisions to control degradation, and adequately monitor the condition and trend of resources (Parliament of New South Wales, 1983). The following case study demonstrates efforts being made, using the GIS approach outlined above, to address these requirements.

BACKGROUND TO THE STUDY

The Murray-Darling Basin

The Murray and Darling Rivers drain the inland areas of south-eastern Australia. The watersheds of the two river systems combine to form the Murray-Darling Basin which covers more than a million square kilometres.

The Basin is vital to the Australian economy. The annual value of its primary and secondary production is about US$7000 million which accounts for one third of Australia's total production from natural resource-based industries (MDBMC, 1989).

European occupation of the Basin for over 150 years is associated with serious resource degradation. Changes in land use have increased turbidity, nutrient levels, bacterial pollution and pesticides in the Basin's rivers and groundwaters, creating major water quality problems for most users (MDBMC, 1989). Paralleling this decline in water quality throughout the Basin, native vegetation has been reduced to less than 50% of its pre-European extent and is now found mainly in the arid and semi-arid regions of the States of New South Wales (NSW) and Queensland (MDBMC, 1990). Losses due to poor water quality and other forms of land degradation occurring in the Basin have been estimated at over US$170 million per annum.

Water Quality in Inland NSW

The eastern river basins of NSW support most of the State's population and urban and industrial centres, while the western basins, contained within the Murray-Darling Basin and covering five-sixths of the State, support most of the rural and agricultural activities. This variation has led to different water quality problems (NSWWRC, 1991).

NPS pollution is a major cause of impairment to the State's inland waterways. The main source is agricultural activity, similar to the NPS pollution regime of surface waters in the USA (Baker, 1992). Clearing and cultivating land and over-stocking pastures with livestock has promoted soil erosion and land salinisation, with consequent impacts on water quality. Similarly, the use of pesticides and fertilisers associated with cultivation and grazing also introduces chemicals into water bodies (NSWWRC, 1991). Increasing levels of turbidity, nutrients and salinity have been identified as major pollutants of inland surface waters (DAHE, 1986; Garman et al., 1991). Pesticides also make a significant contribution to NPS pollution at specific locations (Garman, 1983; Garman et al., 1983).

Role of the NSW Environment Protection Authority

The NSW Environment Protection Authority (EPA) is responsible for ensuring that the environment of the state is protected, restored and enhanced. Environmental monitoring carried out by the EPA and other government agencies provides interpreted information on the condition of the environment, allowing for State of the Environment Reporting (a legal requirement) every two years. This process will assist in establishing a basis for integrated watershed management, through government- community programs such as Total Catchment Management.

As part of this monitoring program, a study is being undertaken by the EPA to assess the extent and nature of resource degradation caused by NPS pollution in an area within the Murray-Darling Basin (Fig. 1).

Nonpoint Source Pollution in the Study Area

The study area is located within the NSW Western Division, a State administrative region. It lies within the Lachlan River watershed, a tributary system of the Murray-Darling Basin. The lands are predominantly government-owned with leasehold tenure being held by most land users. It is one of several areas within the Western Division where agricultural activity has intensified over recent years.

Natural vegetation, predominantly mallee[1], has been cleared for grazing, broad-acre cropping and, in limited cases, irrigated farming, prompting public concern over possible environmental impacts within these marginal cropping lands. The potential problems which can arise if mallee areas are opened up to unrestricted clearing and cultivation have been experienced for over half a century or more in the low rainfall mallee lands of Victoria and South Australia (Hunt, 1980).

The Lachlan River, immediately downstream of the study area, has been reported as having a high median phosphorus level, exceeding proposed water quality standards for most uses. Moderate to high levels of turbidity have been recorded for the area, as in other NSW tributaries of the Murray-Darling Basin, despite the regulated nature of flows (Bek and Robinson, 1991).

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[1] Mallee commonly refers to *Eucalyptus* scrubs and shrubs having many stems arising from a large, underground woody swelling composed of stem tissue called a lignotuber. This term is also widely used to describe the plant communities and regions where these plants predominate (Parsons, 1981).

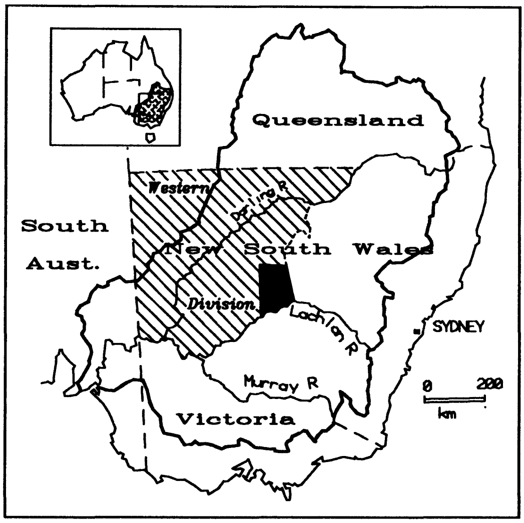

Fig. 1. Location of the Study Area within the Murray-Darling Basin.

Extensive clearing of mallee vegetation and subsequent cropping on shallow loamy red earths in the study area during the last twenty years has potentially left a considerable portion of this low rainfall, marginal cropping region susceptible to water erosion. In a soil stability study carried out within the area, Hunt (1980) found clearing and cultivation resulted in a significant decrease in water stable aggregates (ranging from 23 to 62 per cent), with a major part of the decline occurring in the first year of cultivation.

The increased clearing and cropping, with associated accelerated soil erosion and addition of soil conditioners, has been implicated with NPS pollution incidents of algal blooms, fish kills and high levels of turbidity. There is, however, a distinct lack of information on the quantitative relationships between pollution causes (or sources) and effects. There is also a lack of inventory information regarding the extent and nature of these sources.

METHODS

Data Requirements

The intention of the study is to report on the condition of the environment in the study area. A key objective is to identify the nature and sources of NPS pollution, and determine their impacts on water quality.

Vegetation clearance and cropping patterns were selected as source indicators. Vegetation clearance serves as an index to water quality impacts caused by soil loss and nutrient run-off. The intensity of subsequent cropping practices, including soil tillage and addition of fertilizers, adds to the understanding of the spatial relationship between pollution sources, stream turbidity and nutrients.

In addition to the clearing and cropping monitoring data, the following information was required to investigate the nature of NPS pollution sources:

Existing land use controls on clearing and cropping, to enable the monitoring data to be matched as a compliance check.

Water quality data, to derive spatial and temporal trends for correlation with land use activity.

Other environmental data layers, including land systems[2], soil erosion hazard and Digital Elevation Models (DEM), to facilitate the interpretation of the NPS pollution regime.

Data Sources

The required GIS database was developed from data obtained from a variety of sources.

For vegetation clearance, a time series of satellite images were classified and loaded into the GIS, presenting a sequence of "snapshots" of land cover change over the last twenty years.

Information on recent cropping intensities was supplied by the Western Division Resource Monitor program, an inter-agency co-operative project established in 1986 to routinely monitor cropping in these marginal lands on an annual basis. The extent of cropping for each year between 1986 and 1991 was entered into the GIS.

Cultivation and clearing approval licences were entered as another GIS layer. The data were supplied in digital format by the agency responsible for administering lands in the area.

Available water quality data for the last twenty years from sampling stations upstream, downstream and within the study were acquired as attribute data for the GIS from water administration agencies.

For resource management purposes, land systems can be considered homogeneous ecological response units. This concept is similar to the Biophysical Land Units (BLU) approach used in the U.S.A. for assessing and monitoring spatial and temporal impacts on the existing environment and assisting in evaluating and improving land management methods. Land systems for the study area were digitized and entered into the GIS from maps compiled from aerial photograph interpretation.

Soil erosion hazard information was digitized into the GIS from maps supplied by the agency responsible for soil conservation.

To further qualify the geography of land use activities, a terrain model was required to determine slope angles, proximity to surface drainage systems, and general landsurface features. Contours and spot heights were digitized from topographic maps, to enable a Digital Elevation Model to be built.

Discussion of Methods of Analysis

Land cover status maps were produced from satellite imagery for the years 1973, 1980, 1989 and 1991. Figure 2 shows the land cover status for 1991 as an example. The cleared areas give an indication of the location and spatial extent of potential NPS pollution source areas. An estimate of the accuracy of the interpreted land cover was determined through ground-truthing procedures. The location of sampling stations for water quality data used in the study are shown in the inset of Figure 2.

The data layers established in the GIS, combined with spatial and temporal trends identified in the water quality analysis, can be analysed extensively to characterise the nature of the NPS pollution source areas. For example, overlaying various combinations of the four clearing layers has enabled the production of maps showing the geography of changes in clearing regime over time. Figure 3 shows the amount and direction of change in clearing status for the period 1980-91 in a sub-area of the study. Using the GIS, combining the land status layers of different years identifies new cleared areas. Overlaying the new clearing with clearing licence approvals can flag areas where breaches may have occurred. It is not essential for these data layers to register perfectly to each other as potential breaches would require further investigation. Also shown in Figure 3 is an example of the "address matching" of new clearing with licences granted for a portion of the study area. As mentioned earlier, determining the degree of compliance with existing land use

[2]a land system is an area or group of areas throughout which there is a recurring pattern of topography, soil and vegetation (Christian, 1958). It is widely used for land classification in the Australasian region.

controls is an important first step in the audit process, before the efficacy and performance of control policies and prescription standards implemented to control NPS pollution (and other degradation) can be judged.

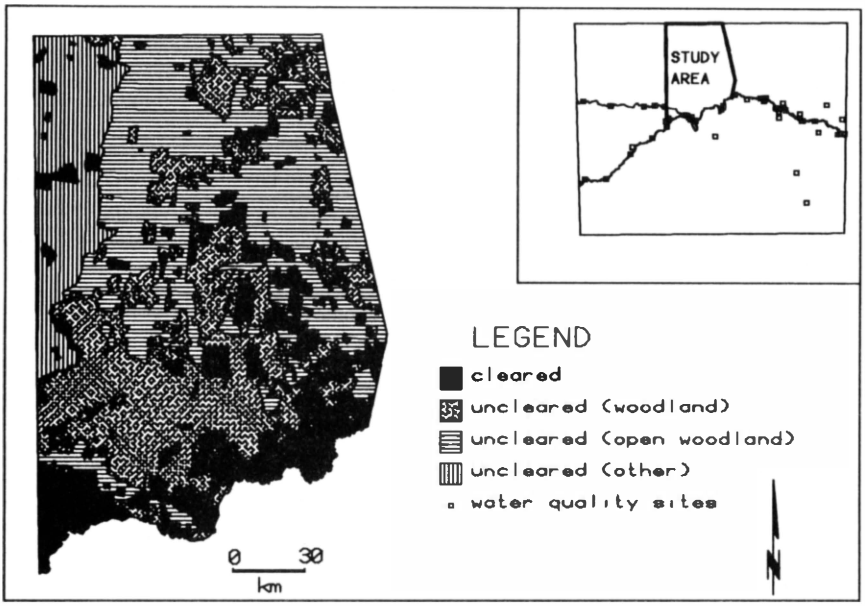

Fig. 2. Landcover Status in 1991. Water Quality Monitoring Stations used in the study are shown in inset.

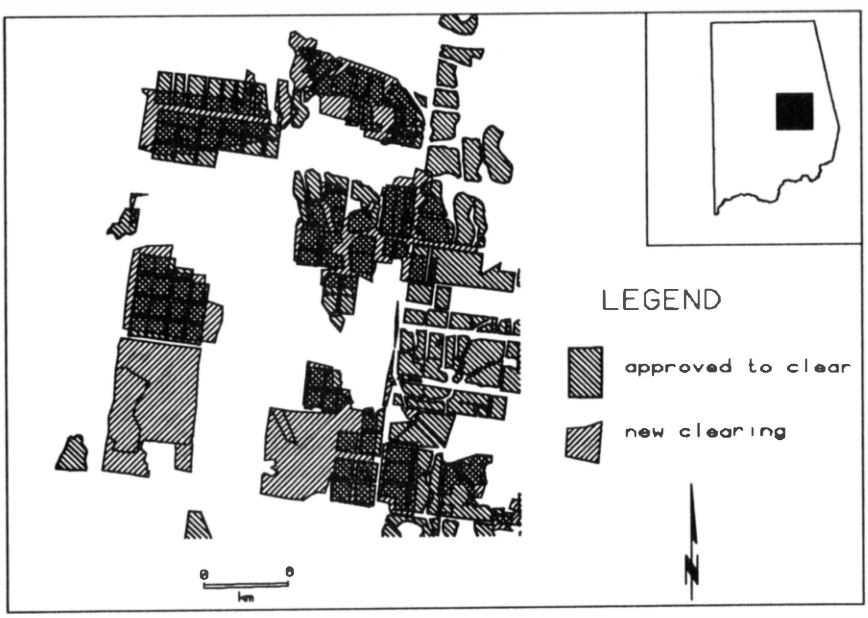

Fig. 3. Example of new clearing between 1980-1991 v. existing Clearing Approvals for part of the study area.

The GIS can be used to analyse the cropping data to provide an indication of land use intensity and NPS pollution hazard, particularly turbidity and eutrophication emanating from accelerated soil erosion, loss of organic matter in topsoil and nutrient runoff from fertilizer applications. For example, Figure 4A shows areas cropped at least three years out of six during the period 1986-1991. The dimensions of this type of GIS analysis can be varied to show higher or lower intensities or consecutive cropping cycles. The cropping intensities can also be overlain with other layers such as soil erosion hazard (Figure 4B) to further qualify NPS pollution risk or facilitate interpretation of observed spatial trends in water quality.

Land systems, which identify areas of similar environmental type (and thus similar land capability), are used extensively by resource managers as policy criteria for approving land use activities such as clearing and cropping. It is therefore important as part of the auditing process to quantify the distribution of existing NPS pollution hazards such as clearing and cropping intensities with respect to the policy standards. This can be achieved within the GIS by combining the land system layer with the land use activity layers. The results can be displayed in map form, or tables can be generated to list the proportion or rate that each land system has been cleared or cropped. This information can facilitate management decisions such as approval for new clearing on environmentally sensitive land systems. With further study the ecological response of each environmental type to NPS pollution- generating activities can be modelled.

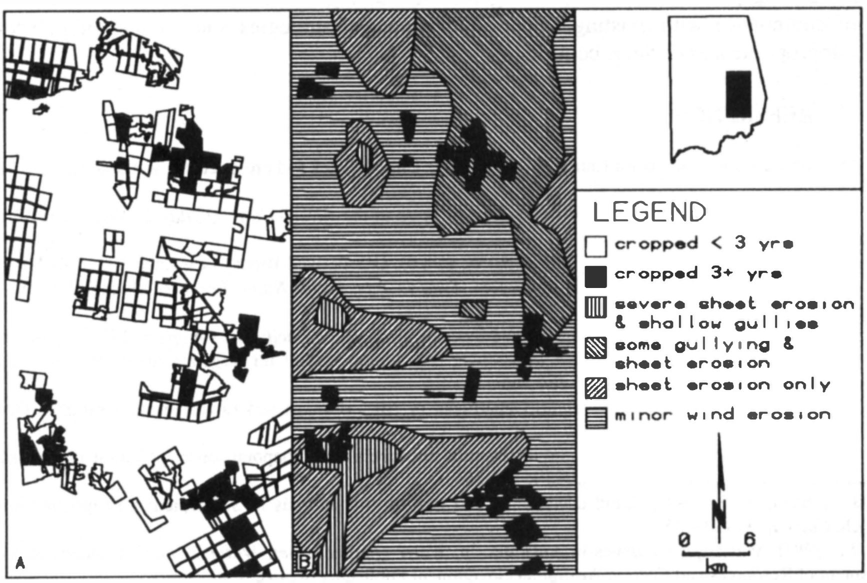

Fig. 4. Example of cropping intensity v. soil erosion hazard for part of the study area.

Combining the clearing and cropping layers with the DEM yields information such as the distribution of land use activities with respect to different slope classes, or their proximity to surface drainage features. The terrain-modelling functionality of the GIS permits the generation of a three-dimensional surface model as a graphic display to the operator. Draping other georeferenced GIS layers, such as land use activity, over this surface display allows a catchment perspective of the concentration and general distribution of land use activities. In addition, combining the clearing regime and soil erodibility layers with the DEM facilitates the identification of cleared areas such as those situated on steep, highly erodible soils and close to high order streams within the drainage network.

Preliminary results from an analysis of water quality data have identified spatial and temporal trends in the water quality regime of the area. Further statistical analysis is currently being undertaken to establish a higher degree of rigour in the trends. Tests for spatial and temporal correlation between the water quality trends and the NPS pollution hazards delineated by the GIS analysis will follow.

This correlation can be seen as the final step of the audit process where an assessment of the performance of current land use control policies aimed at minimising NPS pollution can be completed. The GIS approach has advantages in producing environmental management information for decision support at various stages throughout the audit process. As well, the establishment of a regional GIS provides an on-going information base to which contemporary information can be regularly and routinely added. Building the temporal and spatial extent of the GIS database will facilitate future policy review.

CONCLUSION

The advent of advanced information technologies, such as remote sensing and GIS, is assisting environmental managers in better understanding the relationships between land use activities and their resultant impacts upon natural resources. Monitoring the distribution and development of NPS pollution should be implemented in a more capable and effective manner. Decisions on land use development can be made with an improved awareness about the sustainability, from an ecological perspective, of the proposed activities, as well as with a greater confidence in predicting the nature of impacts.

Environmental auditing procedures, incorporating these technologies, provide an ideal mechanism for the surveillance of compliance with existing NPS pollution control strategies and, as part of policy review, evaluating the appropriateness of those controls.

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