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GIS AND WATER RESOURCE PROTECTION IN SOUTH AFRICA

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1. INTRODUCTION

This paper focuses on the use of geographic information systems (GIS) to support the application of resource protection legislation in South Africa, through new developments as well as more traditional methods of information presentation. All developments and presentations are done using various modules of the ESRI suite of software.

South Africa is essentially a semi-arid country. The average annual rainfall is about 500mm per year with about 35% of the area receiving less than 300mm per year (the western parts of the country) and only 7% receiving more than 800mm per year (mostly in the east) [1]. In most of the country less than 10% of the rainfall is converted into runoff. The areas of lower precipitation are also those with the highest evaporation rates. Average annual evaporation ranges from approximately 1300mm in the east to more than 3000mm in the far northwestern parts of the country [1]. In 1996 South Africa had a population of approximately 40.5 million people. This number is increasing by approximately 2% every year, resulting in increasing pressures on the environment and natural resources [2].

The sustainable use of water resources is therefore imperative in ensuring an adequate supply for future generations and the protection of the aquatic ecosystem has an important role in this sustainability. The new water legislation introduced in South Africa in 1998 lays great emphasis on resource sustainability, and it is the responsibility of the Department of Water Affairs and Forestry to develop the procedures needed to implement this legislation.

2. SOUTH AFRICAN WATER LAW

The new National Water Act (NWA) (Act 36 of 1998) is aimed at providing sufficient water of adequate quality and quantity for both human and ecological needs – summarized by the statement: “Some, for all, forever” [3].

According to the National Water Act the first step required in the protection of the resource is the classification of all water resources based on the amount of protection required for long-term sustainability. Once the class of a water resource has been determined, the quantity and quality of water required to satisfy basic human needs (referred to as the Basic Human Needs Reserve) and to protect aquatic ecosystem sustainability (referred to as the Ecological Reserve) is determined. The procedures necessary to assess aquatic ecosystem health for classification and set the Ecological Reserve include several that rely on GIS: ecoregion delineation (1), river geomorphological classification (2) and river habitat assessment (3). Fig. 1 shows a brief outline of the steps followed and where the GIS-based procedures (numbered 1 – 3) discussed in this paper fit into the process.

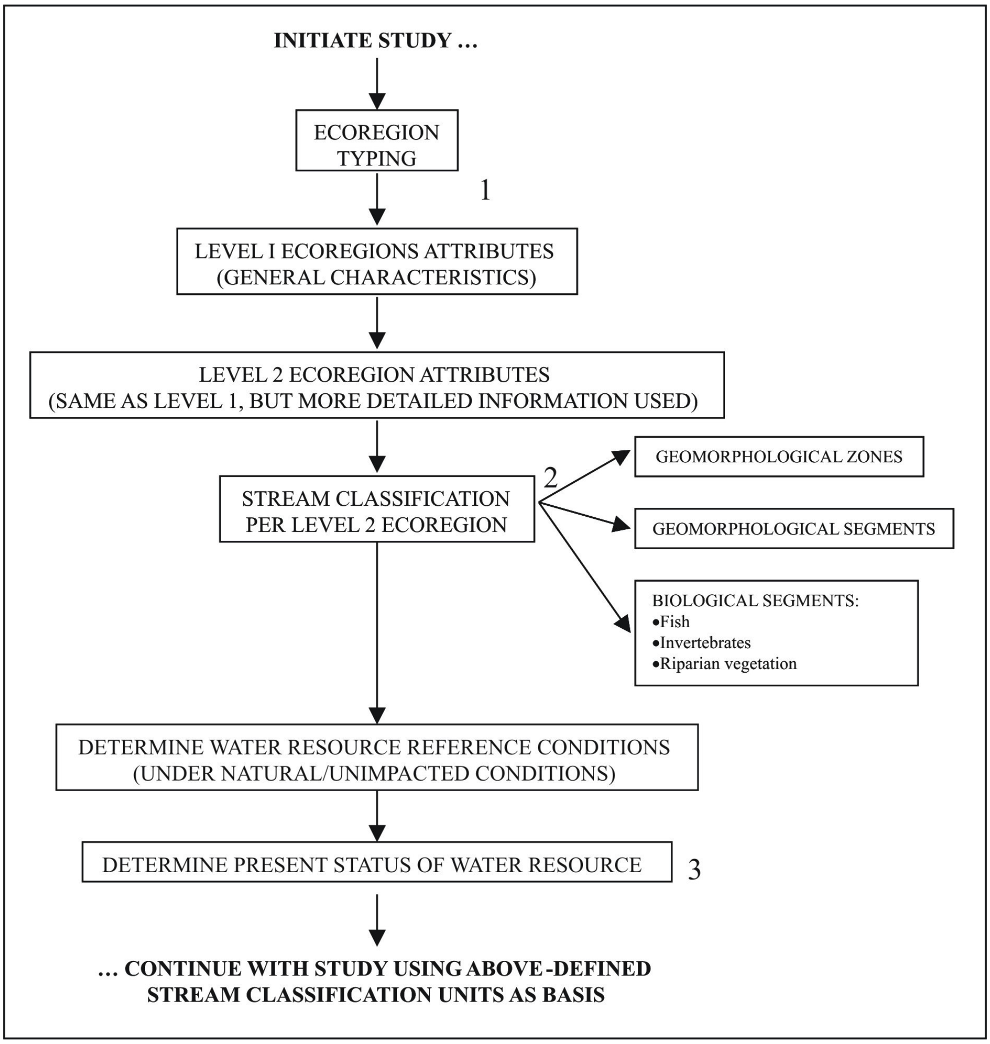

Fig. 1 Abbreviated generic procedure for Ecological Reserve Determination

3. ECOREGION DELINEATION

A national-scale ecological classification of South Africa will allow the grouping of rivers according to similarities. This will simplify assessments of ecological water quantity and quality requirements by making it possible to make predictions about the kind of ecosystem that can be expected to occur under natural or unimpacted conditions. It will also allow the extrapolation of information from data rich rivers to data poor rivers within the same ecoregional context.

The regional patterns observed in ecosystems are a reflection of the spatial variations in factors such as climate, mineral availability (soils and geology), vegetation and physiography. Ecological regions (ecoregions) can be described as regions of relative homogeneity in ecological systems (1 in fig. 1). This paper describes how maps of the geographic phenomena reflecting spatial differences in ecosystems are used to identify areas of ecological similarity, ultimately to produce a map showing the ecoregion classification of the country. Although the classification at its highest level (Level 1) is terrestrial, it will eventually, at lower levels, be used in river classification.

Ecoregions for the whole of South Africa are currently being delineated according to hierarchical levels of detail, based on an approach proposed by Omernik [4]. This approach is based on a qualitative evaluation of the various input maps, to take into account differences in generality, accuracy, and the particular classifications of each mapped characteristic. Furthermore, the characteristics that are more or less important can vary from one place to another. Based on these evaluations regional boundaries are drawn using expert judgement [5]. These arcs are then translated into a GIS coverage describing the various contributing attributes of each region. A preliminary broad scale Level 1 ecoregion classification has been done for the whole of South Africa. Twenty Level 1 ecoregions have eventually been delineated, based primarily on terrain morphology and vegetation. Altitude, rainfall, runoff variability, air temperature, geology and soils were also taken into consideration in the initial delineation.

A more detailed Level 2 classification has been undertaken by DWAF in the northeastern part of South Africa, and is systematically being extended to the rest of the country as required by Ecological Reserve determinations. Each subsequent level uses the same attributes as the previous level, but in more detail; for example, physiography can be broken down to be examined in terms of terrain morphological classes, slope, relief, altitude, etc [6]. Once ecoregions have been identified at least to Level 2, it is possible to link these through to the stream channel through stream classification (2 in fig. 1). Geomorphological classification followed by biological classification of streams forms the basis for the assessment and estimation of Ecological Reserve requirements. One of the inputs for geomorphological classification of streams is the channel slope.

4. RIVER CHANNEL SLOPES

Identifying longitudinal river channel slope is part of the stream classification process. Understanding the longitudinal variation of physical and geomorphological characteristics and associated biological distributions down the length of the river provides a framework for classification that can be used to describe similar streams, while retaining the idea of longitudinal change down the system. Channel slope is also needed for determining the current river habitat integrity – slope provides a broad indicator of habitat types (such as pools and rapids) in a river section, providing some indication of the biota (e.g. fish species) that may be expected to be present.

Traditionally river channel profile and slope is determined from the contours on 1:50 000 scale topographical paper maps [7]. This paper describes how this process is performed using river profiles and slopes obtained using a Digital Elevation Model (DEM) by applying a methodology for slope determination which is more rapid, automated and can be applied in any part of South Africa using readily available data. This DEM-based procedure has already been applied to 84 South African rivers, including the Orange River, which is the longest river in the country.

A 400m x 400m coverage of elevation points is available for the whole of South Africa from the South African Department of Land Affairs: Directorate Surveys and Land Information. In steep, more mountainous areas and dense urban areas the points are 200m apart. The river profile generation methodology involves the generation of a Digital Elevation Model from the elevation data using the ArcInfo TOPOGRID module, followed by analysis using a combination of ArcInfo commands, Microsoft Excel data processing, and Arc Macro Language (AML) data processing. A data file containing the distances and heights required to create a smoothed longitudinal profile of the river is produced and then processed to generate a slope for every 50m drop in height along the channel. This paper will describe the procedures used and the issues of resolution affecting the generation of a smoothed river profile. Issues of scale influencing the accuracy of the original elevation data, as well as the accuracy of the river arc being used, also affect the procedure.

To check the accuracy of the method a comparison was made between river channel profiles produced using the DEM and profiles produced using the manual method based on the contours on a 1:50 000 scale map sheet [8]. The analysis included nineteen river profiles. Thirteen of these rivers showed an altitude success rate of more than 70% of the points per river occurring within 30m of the height measured on a 1:50 000 map. Thirteen rivers also had more than 70% of the DEM calculated slopes being within 2% of the contour measured slopes.

Ecologists at the IWQS use these final slopes to identify river geomorphological zones and are satisfied that the discrepancies are within acceptable limits. Therefore, although the resolution of the original data is rather coarse, it is readily available for the entire country at a reasonable cost and the final product is considered sufficiently accurate for the task at hand.

5. RIVER RIPARIAN HABITAT ASSESSMENT

Video images filmed from a helicopter flying along the length of the river provide information to make qualitative assessments of the river habitat integrity, as do digital or scanned photographs taken at biological and chemical monitoring points. GIS functionality and customised Arcview extensions [9] make it possible to link videos and photographs to actual locations along a channel, providing a rapid visual assessment of riparian habitat (3 in fig. 1). Changes in vegetation over time (seasonally, or over a period of years) can also be monitored in this way, as demonstrated using videos and photographs taken in the Crocodile River catchment of South Africa. Altogether, videos have been flown of the main rivers of 16 catchments in South Africa.

Aerial video coverage of a river, however, is not always available and is expensive to obtain. A supplementary data source is a land cover classification based on 1994 / 1995 Landsat Thematic Mapper satellite imagery at 1:250 000 scale, available for the whole of South Africa [10]. Knowing the land cover within a certain distance (e.g. 1km) of a river provides valuable insight into river habitat integrity and the present ecological status of the river. An AML procedure is used to clip the available land cover data within the required distance from a river, and then automatically calculate the area of each land cover class within each ecoregion intersecting the river. This information is used to identify areas of high and/or low water use impacts along the channel.

6. CONCLUSIONS

The Ecological Reserve defines the water required to protect the aquatic ecosystem of a river. Much of the background information needed to determine this Reserve is spatial in character and scientists at the Institute for Water Quality Studies of the Department of Water Affairs and Forestry in South Africa are using the functionality provided by GIS to get further insight and answers required to make Ecological Reserve assessments. As better quality input data becomes available, the methodologies and approaches described in this paper will be able to produce even better answers than at present.

Digital Elevation Models of 20m x 20m resolution and 50m x 50m resolution are available for South Africa, at a much higher cost than the 400m x 400m resolution DEM. Studies are being undertaken to investigate the level of improvement in outputs using these higher resolution inputs. A more detailed DEM will provide the river geomorphological relationships (e.g. pool-riffle relationships) required to refine the stream and ecological relationships.

The national land cover project is also currently being extended from data available at 1:250 000 to 1:50 000 scale. Habitat integrity and present ecological status assessments will benefit greatly from this new data once it becomes available.

The application of GIS in providing support to the information required for the implementation of the NWA is also not limited to that described in this paper. The provision of good quality data to facilitate and enhance the NWA implementation in South Africa is of top priority and, therefore, the review and improvement of current methodologies and the development of new ones, is an essential, ongoing process.

7. ABBREVIATIONS

AML – Arc Macro Language
DEM – Digital Elevation Model
DWAF – Department Of Water Affairs And Forestry
GIS – Geographic Information System
IWQS – Institute for Water Quality Studies
NWA – National Water Act

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