WATER RESEARCH COMMISSION

GEOGRAPHIC INFORMATION SYSTEMS (GIS) AND THE INTEGRATED ENVIRONMENTAL MANAGEMENT (IEM) PROCEDURE IN THE PLANNING AND MANAGEMENT OF WATER RESOURCES

TASK 4: ENVIRONMENTAL ATLAS FOR THE SABIE RIVER CATCHMENT

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INTRODUCTION

The ATLAS concept was developed by the Department of Environment Affairs, and was formulated because of the following factors, all of which have a pronounced influence felt by both the Department and others.

- Large amounts of geographically related environmental data is in existence.
- This environmental information is widely disseminated between many different organisations.
- The information has been captured on a variety of media, in a variety of formats which are not always compatible.
- Access to all this information is difficult, and it can take literally months to gain access to, or acquire, certain information.

It was realised that these problems not only affected the Department, but all users and potential users of geographically represented environmental information. This led to the idea of an atlas wherein geographically represented environmental information could be contained in a user-friendly manner.

Modern computer technology made the implementation of this idea possible. By using computers, primary data sets can be processed to secondary and tertiary information levels, which then hold great benefits for users with complex needs.

The CSIR was commissioned in 1991 to conduct a feasibility study for the ATLAS concept. They found that a definite need for ATLAS existed with a wide spectrum of users.

Based on the findings of the feasibility study, the University of Pretoria was appointed to do the first pilot project. The Durban Functional Region (DFR) was chosen for this project, and resulted in the release of ATLAS for the DFR to users.

It is envisaged that the ATLAS concept would greatly contribute to increasing environmental awareness through its expanding user base, and assist in solving some of the environmental problems associated with the dramatic and expanding growth in and around the metropolitan areas of South Africa.

The goal of ATLAS is to provide decision makers across the spectrum of the public and private sectors including authoritative bodies, developers, planners, and interested and affected parties concerned with development in metropolitan areas, with a decision-support system based on environmental considerations in order to facilitate holistic and environmentally sound decision making.

For the purpose of this study, the ATLAS concept was adapted and applied to the Sabie River catchment study. When reference is thus made to ATLAS, we are referring to the Sabie River and related GIS data.

PHASE ONE: DEVELOPMENT

The utilisation procedure is based on the adapted IEM procedure developed earlier as well as the ATLAS concept.

The terminology used is important and will lead to an understanding of the procedural functioning of the atlas. Each heading is related to a sequential step in a process used to develop the atlas and then used in reverse order during utilisation of the atlas.

The development of geographic information systems (GIS) has made the establishment of a digital atlas such as ATLAS possible, and a good background understanding of GIS concepts will greatly enhance understanding of ATLAS concepts. The advantages of GIS have led to the realisation that an atlas such as ATLAS can be both functional and practical. The use of GIS tools such as ARCVIEW™ forms the basis to the approach followed in the development of the ATLAS procedure.

Step one: Problem Analysis

The problems of the environmental effects of changes in catchment basins and the effects of engineering structures initiated to solve these problems have been discussed previously. Generally these problems are found to occur at three basic positions in the catchment basin and at three different scales.

- **Water retention structures**
  These are the most obvious environmental impacts and they are caused by direct physical construction activities or inundation by water after the structure has been completed. These impacts are normally permanent and direct.

- **Upstream catchment basin**
  The second problem is initiated in the catchment basin upstream from any proposed water retention structure. These changes in land-use patterns can affect the success of the water retention structure.

- **Downstream catchment basin**
  The third problem is the environmental impact of the water retention structure on the ecology of the downstream reaches of the river. These impacts are related to the immediate physical environments of the stream reaches below the structures and can stretch for the total length of the river.

Step two: Development Proposal

Although many legal and administrative requirements are involved in developing proposed solutions for the sake of this atlas we have followed the proposed adapted IEM procedure and have attempted to link GIS capabilities to the implementation of this proposal.

Step three: Project Alternatives

For the Sabie river three basic water retention structures have been selected from the catchment basin study conducted by Chunnett & Fourie (1990) which discusses numerous other possible dam sites. They have been described in greater detail in the previous chapters (see project alternatives).

Step four: Environmental Atlas

Atlas Type

The natural environment functions as an integrated whole with the various components contributing to the development of systems termed by ecologists as ecosystems. These systems can function at various levels leading from macro continental systems to micro systems such as small coastal dune systems.

To develop an understanding of these systems and how they function, the systems are normally subdivided and classified under separate headings. The sequence of these subdivisions is important to an understanding of each category since knowledge of each contributes to an understanding of the next category.

The climatic component of the environment and the physical component interact and combine with the biological component to create a framework within which a variety of processes operate at a variety of scales. To assist in understanding these systems the atlas is segmented into the following types:

- **Climatic (Air)**
- **Landscape (Land)**
- **Hydrological (Water)**
- **Biological (Life)**
- **Land use (Use)**

These five headings are used to create a classification system for the environmental data inherent to the establishment of the ATLAS.

Data Categories

Various categories of information are grouped within each of the above atlas types. These information types are basic to the ATLAS concepts as they determine the type of data which will be collected and entered into the GIS on which the atlas will be based.

The following data categories are involved:

Atlas type: Air
- Temperature
- Rainfall
- Wind

Atlas type: Land
- Geology
- Landscape
- Soils

Atlas type: Water
- Catchments
- Rivers
- Wetlands

Atlas type: Life
- Vegetation
- Wild life

Atlas type: Land use
- Land use
- Infrastructure

Category Attributes

Each of the data categories listed above has certain descriptive characteristics or attributes. Geographic features are stored in the computer as polygons (area features such as geology or land use), lines (line features such as roads and rivers) or points (point features such as wells and boreholes). The descriptive or non-geographic data is stored in database files referred to as attribute tables.

The geographic features and their attributes are combined or merged through a GIS overlay procedure to create a landscape facet database. The landscape facet database constitutes the heart of the atlas, containing the necessary geographic and non-geographic information required. Updating of this database is a prerequisite to its successful implementation and will ensure an ever increasing and improving information base.

Attribute Values

The attributes represent characteristics of the environment and as such represent values when examining environmental information. Ecological value of a particular attribute might be that it maintains the health of the ecosystem and as such has ecological benefits. Social attribute values may include aesthetic or cultural advantages of certain characteristics. Economic attribute values may point to benefits related to construction cost or the presence of raw materials. The existence of infrastructure is an example of an attribute value which has a bearing on the cost of development.

Attribute values considered for ATLAS are listed below:

- Life-supporting processes
- Biological diversity
- Sustainable resources
- Aesthetic features
- Cultural features
- Cost of construction
- Existing facilities

Attributes are evaluated through established database procedures and the results are transferred to the GIS attribute table. Re-evaluation becomes a relatively simple operation and can be performed repeatedly during later stages when larger volumes or higher quality information becomes available. In this manner the value component of the atlas can be updated or upgraded at various stages.

When the various values are grouped it becomes clear that in the list above, the first three values are linked to *ecological values.* The second two are *social values.* The last two are *economic values.* The evaluation of these attributes results in the grouping of values for the following classes.

- Ecological: Life-supporting, biological diversity and sustainable resource values

- Social: Aesthetic and cultural feature values

- Economic: Construction costs and existing facilities values

Step five: Proposal Classification

The previously discussed water retention structures are now classified for their effects on the environment. The classification can be completed for the proposed project but also for each individual subcatchment. As for this particular exercise, we have assumed that, as we are not sure of the severity of these environmental impacts, according to the proposals contained in the previous chapter an initial assessment has been conducted. In accordance with proposals related to an initial assessment impacts will be determined as follows.

Impacts resulting from the upstream catchment basin

For this purpose the dam catchment is illustrated and the ecological/economical/social impact is shown through ARCVIEW™ from the PROJECT.AV views. The user can also access the catchments PAT (Polygon Attribute Table) and see % sediment yield and % MAR. The user may now compile his own views according to his needs.

Impacts resulting from the proposed dam

This too shows ecological/economical/social impacts and includes a direct physical impact which can all be seen through ARCVIEW™ from the PROJECT.AV views.

Impacts resulting from the proposed dam on the downstream reaches

Again ecological/economic/social impacts are shown. The user can access the PAT and view % MAR and % sediment yield. The volumes of these can also be seen as Mm^3 per annum for MAR and tones for sediment yield. Impacts on future land-use can also be seen, as conservation/development/and agricultural zones. The user can create his own views as required.

These impacts will be classified as

Impacts on features

This is the direct physical impact (inundation)

Impacts on values

This is the impact on ecologic/economic/social values.

Impacts on opportunities for land-use

This is the impact on possible conservation/agriculture/development zones.

PHASE TWO: UTILISATION PROCEDURE

The development procedure represented by phase 1 allows for two completely different methods of utilisation. Firstly, ATLAS can be utilised as a series of printed maps representing impacts occurring in each of the three basic impact regions, the upstream, dam basin and downstream reaches. Secondly, the ATLAS can be utilised as a full GIS database accessed through the use of GIS viewing tools such as ARCVIEW™ through which complex queries and analyses can be performed. These two methods are discussed below.

Step one: Opportunities and Constraints Maps

In this instance three separate map sets representing impacts on features, values and land-use opportunities, can be made available at a scale not larger than 1:50000, according to user requirements. In this format the user would simply identify a project on a standard map and after locating the atlas data set identify the number of environmental impact categories. This method is low key in nature and does not require a computer platform or any knowledge of GIS. It is envisaged that this method of using ATLAS could be popular, although the user will be responsible for the cost of printing.

Step two: GIS Viewing method

The second method of using ATLAS is more complex but much more powerful and will allow the user access to the GIS database through the use of GIS viewing software such as ARCVIEW™. In this specific method two approaches in the utilisation of the GIS database can be followed.

The first approach will be that the user will extract information pertaining to an identified project in terms of the three atlas land use types. Through this query procedure the user will be able to extract:

- all the attributes of each of the data categories
- the number of environmental impacts for each of the three impact regions
- a description of reasons for the allocation of environmental impact.

Through the use of the GIS viewing software, users would be able to produce their own maps for further use.

DATABASE DESCRIPTION

GIS Data format

The ATLAS GIS database is based on the micro computer (PC) version of ARC/INFO™ release 3.4D from Environmental Systems Research Institute (ESRI), Redlands California, USA. Although the ultimate objective remains to provide ATLAS on a wide variety of hardware and software platforms, this option was selected due to the wide user base of ARC/INFO™ in the field of natural resources management, and the subsequent release of a low cost viewing program for ARC/INFO™ data called ARCVIEW™. Releases of ATLAS on other hardware and software platforms are envisaged for the near future, based on demand.

ARCVIEW™ operates in the Microsoft Windows™ operating system and a working knowledge of both will be a prerequisite to successful utilisation of ATLAS.

GIS Data structure

The GIS database consists of a series of ARC/INFO coverages residing in a dedicated ATLAS subdirectory called WNKSABIE. There is DEVELOP.AV and a PROJECT.AV file under ATLAS. The DEVELOP.AV file covers the social and environmental data and includes views on values and proposed land uses. The PROJECT.AV file covers project alternatives and shows the impacts of each dam site. Both data sets must be viewed through ARCVIEW™.

Description of database item (field) names

A detailed description of item or field names in the attribute (non-geographic) data file is included in this document as Appendix A and B.

Geographic mapping parameters

Scale

All geographic data was collected and captured at a scale of 1:50000 with the exception of geology and soils which was performed at a scale of 1:10000 and 1:250 000 respectively. The ATLAS as a whole, however, is designed for use at scale not larger than 1:50000.

Survey system and map projection

All geographic data is represented in the Gauss Conformal projection system (also known as Transverse Mercator) with central meridian 31 degrees East, units expressed in meters with zero offsets in Y and X co-ordinates, positioned in the South-Eastern global quadrant. Limitations of the GIS database software to cater for the display of Southern Survey co-ordinates as commonly used in South Africa, necessitates the display thereof as Cartesian co-ordinates which simply means that X and Y co-ordinates are swopped and their numerical signs reversed. This is not a serious limitation and is not expected to pose any problems to users.

Hardware and software requirements

Hardware

The minimum hardware requirement for running ATLAS is an 80386-based micro computer with a minimum of 8Mb random access memory (RAM), a mathematical co-processor, 1.44 Mb 3.5" floppy disk drive and free hard disk space in excess of 50 Mb, excluding space needed for the operating system. It is, however, seriously recommended that ATLAS be based on an 80486 DX micro computer due to the size of the database and its resultant demands on the system.

Software

Software required for ARC/INFO™ based ATLAS would be PC ARCVIEW™ based on the Microsoft Windows™ operating system.

Copyright and Database serial numbers

The Department of Water Affairs and Forestry will effect distribution of ATLAS to users at very low cost. Copyright vests with the Department of Water Affairs and Forestry and no part of ATLAS may be reproduced, except for own use and data backup purposes, sold or given away to anyone for any purpose whatsoever without prior consent from the Department. Baseline data used for the production of ATLAS must be acquired from their original sources if needed. The Department of Water Affairs and Forestry can be contacted for more information in this regard.

DATABASE INSTALLATION

Data backup

Before attempting to install the ATLAS database on a microcomputer hard disk, it is advisable to make a backup copy of the diskettes in order to protect the data. Use the duplicate copies for installation and store originals in a safe place.

Installation procedure

Installing the ATLAS database on hard disk is simple. The entire database is stored in compressed format on four 1.44 Mb 3.5" floppy disks through the PKZIP™ compress utility from PKWARE™. The steps to install ATLAS are as follows and are also repeated in a READ.ME file located on disk 1 of the data set.

- Make sure that there is at least 35 Mb of free disk space on the destination hard disk drive.
- At the DOS prompt, insert disk 1 into your floppy disk drive, e.g. drive A
- Change the active drive to the floppy drive by typing A:<Enter>
- At the DOS prompt type PKUNZIP -d WNKSABIE.ZIP C:\ <Enter> where C is your destination hard drive letter.
- You will be prompted to insert the *last* disk (disk 4) into the floppy drive. This step is required by the compress utility. Insert disk 4 into the floppy drive and press <Enter>.
- You will now be prompted to insert disk 1 into the floppy drive again and to press any key to begin decompressing the database to the correct path on the destination hard disk. A sub directory called \WNKSABIE will be created along with the relevant ARC/INFO™ data coverages as well as a preset ARCVIEW™ file.
- Insert disks sequentially as prompted until complete.
- The database installation is now complete and can be viewed and queried through ARCVIEW™.

CONCLUSION

- The development of an environmental database for use in the GIS contributes successfully to the environmental planning of catchment basins.

PROJECT ALTERNATIVES

Dam Site	% S.Y.	% MAR	% t/100 Floods
Madras	Controls 24% of total	Controls 69% of total	Controls 52% of total
Dingleydale	Controls 5% of total	Controls 21% of total	Controls 23% of total

Upstream Catchment	Ecologic	Economic	Social
Madras	Medium impact, most areas show 1-5 opportunities	Low impact, most areas show only 1 constraint	Low impact, most areas show 1-3 opportunities
Dingleydale	Low impact, most areas show 1-3 opportunities	Low impact, most areas show only 1 constraint	Low impact, most areas show only 1 opportunity

Dam Site	Inundation
Madras	1391ha in total; 62ha irrigated land; 105ha cultivated land; section of main road to Paul Kruger Gate (KNP); numerous GAZANKULU homesteads; Sabie sands holiday resort; few settlements in RSA
Dingleydale	875ha in total; 65ha cultivated land; 195ha irrigated land; section of road to Lebowa

* See ARCVIEW™ PROJECT.AV files for visual maps of impacts.

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APPENDIX A

SML TEXT AND COMMANDS

The following is a text document showing all commands that drive the SML. The maps and other visuals should be viewed through ARCINFO™ as explained in the main report.

APPENDIX A

ATTRIBUTE DATA FILE ITEMS

ITEM NAME	ITEM TYPE	ITEM DESCRIPTION
AREA	Numeric	Area of land facet in m^2
PERIMETER	Numeric	Perimeter of land facet in m
ATLASATT_	Numeric	Internal system polygon ID
ATLASATT_ID	Numeric	User polygon ID
ZONE_TYPE	Alpha	Broad temperature zones
MAP_MM	Alpha	Mean annual rainfall in mm
EVAP_MM	Alpha	Mean annual evaporation in mm
STAGE	Alpha	Geologic stage
FORMATION	Alpha	Geologic formation
SUPER_GRP	Alpha	Geologic super group
SOIL_SYMBL	Alpha	Soil symbols as used in SRK report
DAM_SERIES	Alpha	Dominent soil series
GEOMORPHOL	Alpha	Geomorphology
CATCH_NAME	Alpha	River catchment name
MAR_CONTRI	Alpha	Main annual runoff of each catchment
MAR_P_TOT	Numeric	Percentage of runoff each catchment produces
MAR_SEQ	Numeric	Sequential runoff of catchments
FLOOD_T5	Numeric	Five year flood
FLOOD_T100	Numeric	One hundred year flood
FLOOD_PMF	Numeric	Possible maximum flood
MAR_P_SEQ	Numeric	Percentage of sequential runoff each catchment produces
RIVBUF_ID	Numeric	100m Buffered river zone
DAM_NAME	Alpha	Existing dam names
SED_YIELD	Alpha	Broad sediment yield patterns
SED_TOTSC	Numeric	Sediment yield for each subcatchment
SED_P_TOT	Numeric	Percentage sediment each catchment produces
POPDENSITY	Numeric	Population density figures
LANDUSE	Alpha	Broad land-use
MADDING_ID	Numeric	Proposed dams

APPENDIX B

VALUE DATA FILE ITEMS

ITEM NAME	ITEM TYPE	ITEM DESCRIPTION
AREA	Numeric	Area of land facet in m^2
PERIMETER	Numeric	Perimeter of land facet in m
ATLASVAL_	Numeric	Internal system polygon ID
ATLASVAL_ID	Numeric	User polygon ID
ECOLO_ATR	Alpha	Ecological opportunities for air atlas: temperature and reason
ECOND_ATR	Alpha	Development constraints
ECONA_ATR	Alpha	Agricultural constraints
SOCIA_ATR	Alpha	Social opportunities
ECOLO_ARR	Alpha	Ecological constraints for air atlas: rainfall and reason
ECOND_ARR	Alpha	Development constraints
ECONA_ARR	Alpha	Agricultural constraints
SOCIA_ARR	Alpha	Social opportunities
ECOLO_AER	Alpha	Ecologic opportunities for air atlas: evaporation and reason
ECOND_AER	Alpha	Development constraints
ECONA_AER	Alpha	Agricultural constraints
SOCIA_AER	Alpha	Social opportunities
A_CONS	Numeric	Total # of ecological opportunities
A_DEVE	Numeric	Total # of development constraints
A_AGRI	Numeric	Total # of agricultural constraints
ECOLO_LGR	Alpha	Ecological opportunities land atlas: geology and reason
ECOND_LGR	Alpha	Development constraints
ECONA_LGR	Alpha	Agricultural constraints
SOCIA_LGR	Alpha	Social opportunities
ECOLO_LSR	Alpha	Ecological opportunities land atlas: soil and reason
ECOND_LSR	Alpha	Development constraints
ECONA_LSR	Alpha	Agricultural constraints
SOCIA_LSR	Alpha	Social opportunities
ECOLO_LGMR	Alpha	Ecological opportunities land atlas: topography and reason
ECOND_LGMR	Alpha	Development constraints
ECONA_LGMR	Alpha	Agricultural constraints
SOCIA_LGMR	Alpha	Social opportunities
L_CONS	Numeric	Total # of ecological opportunities
L_DEVE	Numeric	Total # of development constraints
L_AGRI	Numeric	Total # of agricultural constraints
ECOLO_WCR	Alpha	Ecological opportunities water atlas: catchment and reason
ECOND_WCR	Alpha	Development constraints
ECONA_WCR	Alpha	Agricultural constraints
SOCIA_WCR	Alpha	Social opportunities
ECOLO_WRR	Alpha	Ecological opportunities water atlas: river and reason
ECOND_WRR	Alpha	Development constraints
ECONA_WRR	Alpha	Agricultural constraints
SOCIA_WRR	Alpha	Social opportunities

ITEM NAME	ITEM TYPE	ITEM DESCRIPTION
ECOLO_WDR	Alpha	Ecological opportunities water atlas: dams and reason
ECOND_WDR	Alpha	Development constraints
ECONA_WDR	Alpha	Agricultural constraints
SOCIA_WDR	Alpha	Social opportunities
ECOLO_WSYR	Alpha	Ecological opportunities water atlas: sediment yield and reason
ECOND_WSYR	Alpha	Development constraints
ECONA_WSYR	Alpha	Agricultural constraints
SOCIA_WSYR	Alpha	Social opportunities
W_CONS	Numeric	Total # of ecological opportunities
W_DEVE	Numeric	Total # of development constraints
W_AGRI	Numeric	Total # of agricultural constraints
ECOLO_LFPD	Alpha	Ecological opportunities land-use atlas: vegetation and reason
ECOND_LFPD	Alpha	Development constraints
ECONA_LFPD	Alpha	Agricultural constraints
SOCIA_LFPD	Alpha	Social opportunities
LF_CONS	Numeric	Total # of ecological opportunities
LF_DEVE	Numeric	Total # of development constraints
LF_AGRI	Numeric	Total # of agricultural constraints
ECOLO_LUR	Alpha	Ecological opportunities land-use atlas: towns and reason
ECOND_LUR	Alpha	Development constraints
ECONA_LUR	Alpha	Agricultural constraints
SOCIA_LUR	Alpha	Social opportunities
LU_CONS	Numeric	Total # of ecological opportunities for land-use
LU_DEVE	Numeric	Total # of development constraints
LU_AGRI	Numeric	Total # of agricultural constraints
CONSERV	Numeric	Total # of ecolo + socia opportunities
DEVELOP	Numeric	Total # of econd constraints
AGRICUL	Numeric	Total # of econa constraints
ECOLOGIC	Numeric	Total # of ecolo opportunities
ECONOMIC	Numeric	Total # of econd constraints
SOCIAL	Numeric	Total # of socia opportunities