The Ability of Catchment Basins to Supply the Water Demands of Rural and Urban Areas

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GISLAB, University of Pretoria

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WATER RESEARCH COMMISSION

THE ABILITY OF CATCHMENT BASINS TO SUPPLY THE WATER DEMANDS OF RURAL AND URBAN AREAS

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EXECUTIVE SUMMARY

The project duration was one year with the following goals and objectives:

Goals

* To determine an environmental database as a base platform from which to work from.

* To establish a national water resource database based on WR90 and the National Groundwater maps

* To establish a national people database based on 1991 and the current 1993 census data

* To determine the impact of population densities on these resources

* To determine the ability of catchments to be able to supply the water demands of various communities

Objectives

* Using existing national data from the ENPAT, an environmental base will be developed. This will contain features such as geology and vegetation.

* Obtain WR90 data and manipulate this data to conform to national atlas projections and scale. This data will be analyzed and manipulated in the GIS (Geographic Information System).

* Using 1991 and updated 1993 census data, a National People database will be established and manipulated to give population figures per magisterial district, census district and catchment basin.

* Obtain and install the National maps database on GIS. This data must be manipulated to establish groundwater potentials on a national scale.

* Manipulate census data to indicate population densities.

* Relate groundwater, surface water and population to determine areas of constraint and areas of opportunity with regards to water demand.

* Establish the availability of water per population distribution as well as the water demand per population distribution.

* Identify critical areas with regard to the above scenarios.

Database description

The SGPATLAS GIS is based on the micro computer (PC) version of ARC/INFO™ release 3.4D from Environmental System Research Institute (ESRI), Redlands California, USA. All data has been compiled as viewable maps in a software package known as ARCVIEW.

ARC/VIEW™ operates in the Microsoft Windows™ operating system and a working knowledge of both will be a prerequisite to successful utilization of SGPATLAS.

The GIS database consists of a series of ARC/INFO coverages residing in a dedicating sub-directory called SGPATLAS. One overall unioned coverage exists, called SGPATLAS. A detailed description of item or field names in the attribute (non-geographic) data file is included in this document as Appendix A. A list of all coverage names and abbreviations are included in Appendix B.

No data was specifically captured for this study. Existing data sets were combined and manipulated for use on a national scale. Although some original data was captured to accuracy of 1:50000, it is recommended that the SGPATLAS be used as national data at a scale of 1:1000 000.

All geographic data is represented in the Albers Projection System with central meridian 24 degrees East, units expressed in meters with zero offsets in Y and X co-ordinates. 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 are swopped and their numerical signs reversed. This is not a serious limitation and is not expected to pose any problems to users.

Without the use of the ARC/INFO GIS System this study would not have been possible. The large existing datasets could never have been dissected and recompiled into the current format without the use of the GIS. To enable the user access to this complex database, a conversion was completed allowing all coverages to be viewed and queried through PC version of ARC/VIEW™. This package is now freely available on the internet.

By providing all the data for groundwater, surface water, the landscape and the people on a unioned digital format of uniform projection and scale, it is hoped that the users of this database will compile their own queries and resolve some of the water management problems we are currently experiencing.

The entire database is stored in compressed format on 1.44Mb 3.5" floppy disks.

ACKNOWLEDGMENTS

This project was made possible by:

1) The Water Research Commission funding, a special thanks to Mr. H. Maaren

2) The Department of Water Affairs and Forestry for the supply of data from studies such as the National Groundwater Report and WR90.

3) The GisLAB at the University of Pretoria for use of equipment and technical backup skills, a special thanks to Mr. J. Van Rensburg.

4) A special thanks to Mr. Tony Reynders for his interaction and assistance.

INTRODUCTION

The water resources of South Africa are currently being placed under severe pressure from all sectors. The current costs and the frequently occurring stringent restrictions on water are an indication to the public of the severity of the problem researches have been predicting for years. Not only do the present climatic conditions add to the problem, but the political distribution of people in the past has become an area of major concern. Catchment basins are faced not only with the immediate water demands for local developments within these catchments, but also from increasing population densities and the need from other catchments for water via pumping schemes.

The ecological and environmental condition of catchments becomes of major importance as the bulk of our water supply relies on surface runoff. These two conflicting components (environment and people) must therefore be addressed to ensure management and planning of our national water resources.

During the past 40 years political decisions have had the largest influence on the distribution of people on a national scale. These decisions have resulted in large concentrations of people in areas that have little or no relation to the ability of these areas to support such densities.

It is the aim of this study to research these matters and determine the status of the current situation regarding water resources on a national scale. This can lead to proposed management and planning of our most important natural resource, water.

Current information that has been incorporated is the WR90 report on Surface Water Resources of S.A. 1990, completed by the Water Research Commission (WRC). The National Groundwater map of South Africa (Vegter, 1995)[1] has also been incorporated. The 1993 census data from the Development Bank was consulted for updated population distributions and finally the data collected for the Department of Environmental Affairs and Tourism for the ENPAT (Environmental Potential Atlas) has been included as part of the research material.

In order to ascertain the ability of catchments to supply the water demands of rural and urban communities it will be necessary to study population data, surface water data, groundwater data. and the environmental conditions of the catchments. All activities within the catchments will effect the ability of water supply. Such activities will include land cover, land use, development, etc.

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[1] Vegter, JR (1995) An explanation of a set of National Groundwater maps. Water Research Commission Report No TT74/95

GOALS AND OBJECTIVES

1. GOALS

* To determine an environmental database as a base platform from which to work from.

* To establish a national water resource database based on WR90 and the National Groundwater maps

* To establish a national people database based on 1991 and the current 1993 census data

* To determine the impact of population densities on these resources

* To determine the ability of catchments to be able to supply the water demands of various communities

2. OBJECTIVES

* Using existing national data from the ENPAT, an environmental base will be developed. This will contain features such as geology and vegetation.

* Obtain WR90 data and manipulate this data to conform to national atlas projections and scale. This data will be analyzed and manipulated in the GIS (Geographic Information System).

* Using 1991 and updated 1993 census data, a National People database will be established and manipulated to give population figures per magisterial district, census district and catchment basin.

* Obtain and install the National maps on GIS. This data must be manipulated to establish groundwater potentials on a national scale.

* Manipulate census data to indicate population densities.

* Relate groundwater, surface water and population to determine areas of constraint and areas of opportunity with regards to water demand.

* Establish the availability of water per population distribution as well as the water demand per population distribution.

* Identify critical areas with regard to the above scenarios.

SECTION 1

NATIONAL ENVIRONMENTAL DATABASE

As a point of departure for this project it was decided to compile a National Environmental database. Most of this information exists in the ENPAT NATIONAL (Environmental Potential Atlas) completed for the Department of Environmental Affairs and Tourism.

The data deemed necessary was extracted from the ENPAT and simplified to fit the purpose of this study. Data extracted include the regional boundaries of the new Provinces, main roads on a national scale, geology and vegetation types on a national scale.

Once this base has been established, new data can be incorporated and overlaid for comparison and scenario generation purposes. The base data also then sets the standard for scale, format and projection.

Interesting scenarios can now be viewed through ARCVIEW. The effect geology has on the groundwater potentials is just one example.

As a result of water being this project's prime objective, it is suggested that for detailed environmental data the Department of Environmental Affairs and Tourism be consulted for a copy of the ENPAT NATIONAL database.

SECTION 2

NATIONAL WATER RESOURCE DATABASE

2.1 WR90 STUDY

The first step in establishing a National Water Resource database was to obtain as much of the existing data as possible, and then to find a way of combining this data in one standard database.

The National Surface Water study entitled WR90, by the WRC was the first of the existing databases analyzed.

It was decided that the study be compiled according to quaternary catchments on a national scale. The quaternary catchment boundaries were obtained from the WR90 database, as well as the surface stream flow figures calculated for each sub-catchment.

Some time was spent ensuring the data conformed to the scale and projection of ENPAT data, which is used now as the standard format. (Albers projection, 18 and 32 standard parallels, and 24° East central meridian)

The database contains information such as catchment numbers, mean annual precipitation, mean annual stream flow.

2.2 NATIONAL GROUNDWATER

A recent study of the WRC produced a set of National groundwater maps in GIS ARC/INFO format. This data was compiled by J.R. Vegter and contains various aspects associated with groundwater.

The data includes saturated interstices, effective rainfall, depth to water level, groundwater quality, hydrochemical type, base flow, exploitability and accessibility.

Again this data was loaded onto the GIS ARC INFO System and manipulated to conform to a standard scale and projection. The unioned coverage was dismantled and the result is two unique coverages indicating groundwater exploitability and groundwater accessibility.

The exploitability is illustrated as a percentage of the probability of a successful borehole yielding greater than 2 litres per second, graded from less than 10% to greater than 50%.

The accessibility is illustrated as a percentage of the probability of drilling a successful borehole, graded from less than 40% to greater than 60%.

SECTION 3

NATIONAL PEOPLE DATABASE

The 1991 census data was updated according to the 1993 census data obtained from the Development Bank. These figures were manipulated through the GIS to produce a database showing the following facts:

* Population numbers per census districts
* Population numbers per magisterial districts
* Population distribution
* Population densities (people/km^2)
* Population per catchment

The database shows population figures for both the 1991 and updated 1993 census data. A population density of people per km^2 was produced. Also shown is the name of the census district and the dominant language of this district. A typical example would be:

* census district = Messina
* language district = Venda
* pop 1991 = 22959
* pop 1993 = 24620
* pop density = 4.58 p/km^2

SECTION 4

IMPACT OF PEOPLE ON WATER RESOURCES

Through the use of the GIS, the people database and the WR90 database can now be manipulated to be on the same scale and projection. An overlay or union of this data produces a new coverage with the combined data. This can now be re-calculated, reselected and manipulated to produce a comparative study of how people's distributions effect the water resources. The scenario can be taken a step further by the incorporation of the groundwater database.

The following effects were obtained: (Produce own views using SGPATLAS)

Water per population:

Through a series of re-selections and calculations in the GIS, it is possible to ascertain how many people occur in each catchment. The amount of surface water per catchment is obtained from the WR90 study and a simple calculation of water over people gives us the availability of water per person.

Population per catchment:

Once the national census data has been converted to the amount of people per km^2 (expressed as density per km^2) the areas of catchments are calculated and the amount of people per catchment obtained. As can be seen through ARCVIEW, the distribution of people can easily be overlaid with the distribution of surface water.

Water per province:

Once the amount of water is calculated for each catchment, the amount of catchment areas are calculated per province. This allows a calculation of how much water is available per province. A further item was added in which this amount is expressed as a percentage of the national mean annual streamflow available per Province.

Once views are compiled of each of these coverages, it becomes clear that a very real conflict exists between the amount of water available and the actual water demand.

This study shows the facts of what amount of water is found where, and the number of people found where. The following section proposes a few models to obtain critical zones and other areas of potential, **but it is left to the user to compile final calculations and in depth studies of how to overcome these problems.**

SECTION 5

THE ABILITY OF CATCHMENTS TO SUPPLY THE NATIONAL WATER DEMANDS OF COMMUNITIES.

In the attempt to ascertain the ability of catchments to supply the demands for water, a few scenarios were compiled. The first of these is to go beyond the physical boundaries of the catchments and look at the groundwater potentials of the area. This is illustrated by two coverages and two ARCVIEW views called exploitability (exp) and accessibility (acc). Both of these datasets are expressed as a percentage of the exploitability (probability of a successful borehole yielding more than 2 litres per second) and as a percentage of the accessibility (probability of drilling a successful borehole) respectively. As can be seen from the views, the general distribution of high groundwater potentials occurs in most areas of low surface water availability. The groundwater potentials must therefore be considered for the supply of water in areas of great demand. A further two views were created which show groundwater potential areas (>50% exp. and >60% acc) as well as groundwater crisis areas (<20%exp and <40% acc). All of the above datasets will give the user an indication of the ability of groundwater within catchments to supply the water demands.

The next step was to look at the surface water of catchments and their contribution to the water demand. It was decided that work will be done from a quaternary catchment level. From existing datasets the mean annual streamflow was obtained for each quaternary catchment. As seen in the previous section, the population densities were compared to this and several scenarios established.

From this data it is possible to obtain crisis zones both of where the density of people and their water demands exceed the surface water availability. This has been illustrated by the POPCRIS (population crisis) and the SWCRIS (surface water crisis) views. The population crisis is an indication of more than 180 000 people per region and the surface water crisis shows the quaternary catchments that have less than 20 million m^3 p.a. There is not enough water to sustain the demand of so many people.

As a final scenario a total crisis map was produced (Totcris). This is an example of what the user can do through manipulations in ARCVIEW of the existing data. A re-selection was compiled through the properties of ARCVIEW of the total SGPATLAS coverage. In this case the values reselected were the following:

acc percen	<40% (groundwater accessibility)
exp percen	<20% (groundwater exploitability)
mar4Q	<20% (mean annual runoff/quart catch)
pop93	>180 000 (population from 1993 census)

The resultant view can be seen in ARCVIEW as a total crisis. This will show all areas that have excessive population densities with very low water availability figures. This scenario can be refined by the user to get specific queries based on the existing data format.

SECTION 6

CONCLUSION

6.1 EXISTING DATABASES

The project duration for this specific project was one year. Together with the status of a pilot study, it was useful to include as much existing data as possible. The fact that existing data and completed projects are usefully incorporated to enable other projects such as this one, contributed to successful research and use of dormant data. Data verification and updating is ensured. Planning and management of our natural resources is encouraged and can now commence from a sound factual base.

6.2 DATABASE DESCRIPTION

6.2.1 GIS Data Format

The SGPATLAS GIS is based on the micro computer (PC) version of ARC/INFO™ release 3.4D from Environmental System Research Institute (ESRI), Redlands California, USA. All data has been compiled as viewable maps in a software package known as ARCVIEW.

ARC/VIEW™ operates in the Microsoft Windows™ operating system and a working knowledge of both will be a prerequisite to successful utilization of SGPATLAS.

6.2.2 GIS Data Structure

The GIS database consists of a series of ARC/INFO coverages residing in a dedicating sub-directory called SGPATLAS. One overall unioned coverage exists, called SGPATLAS. A detailed description of item or field names in the attribute (non-geographic) data file is included in this document as Appendix A. A list of all coverage names and abbreviations are included in Appendix B.

6.2.3 Geographic mapping parameters

Scale

No data was specifically captured for this study. Existing data sets were combined and manipulated for use on a national scale. Although some original data was captured to accuracy of 1:50000, it is recommended that the SGPATLAS be used as national data at a scale of 1:1000 000.

Survey system and map projection
All geographic data is represented in the Albers Projection System with central meridian 24 degrees East, units expressed in meters with zero offsets in Y and X co-ordinates. 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 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 the SGPATLAS is an 80386-based micro computer with a minimum of 8Mb random-access memory (RAM), a mathematical co-processor, 1.44 Mb3.5" 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 SGPATLAS be based on an 80486 DX micro computer with 16 Mb RAM due to the size of the database and its resultant demands on the system.

Software
Software required for viewing SGPATLAS would be PC ARCVIEW™ based on the Microsoft Windows™ operating system.

6.2.5 Copyright

The Water Research Commission (WRC) will effect distribution of the SGPATLAS to users at very low cost. Copyright vests with the Water Research Commission and no part of the SGPATLAS 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 WRC. Baseline data used for the production of the SGPATLAS must be acquired from their original sources if needed. The Water Research Commission can be contacted for more information in this regard.

6.3 DATABASE INSTALLATION

6.3.1 Data backup

Before attempting to install the SGPATLAS 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.

6.3.2 Installation procedure

Installing the SGPATLAS database on hard disk is simple. The entire database is stored in compressed format on 1.44Mb 3.5" floppy disks through the PKZIP™ compress utility from PKWARETM. The steps to install SGPATLAS are as follows:

- 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 SGPATLAS.ZIP C:\ <Enter>
- You will be prompted to insert the last disk into the floppy drive. This step is required by the compress utility. Insert disk into the floppy drive and press <Enter>.
- You will now be prompted to insert disk 1 into the floppy drive again and press any key to begin decompressing the database to the correct part on the destination hard disk. A sub-directory called SGPATLAS will be created along with the relevant ARC/INFO™ data coverages as well as a preset ARC/VIEW™ file.
- Insert disks sequentially as prompted until complete.
- The database installation is now complete and can be viewed and queried through ARC/VIEW™.

6.4 FINAL CONCLUSION:

The first major obstacle was the use of existing databases in various formats and projections. After consultation with the Department of Environmental Affairs regarding the National Data Atlas(Enpat National), it was decided that all data would be converted to Albers 24, with a 18, 32 standard parallel and O x and y offsets. Because of the various problems experienced during this study as a result of various scales and projections of the existing data, it is seriously recommended that researchers consider this as a standard for future data exchange that will be used on a national scale.

Without the use of the ARC/INFO GIS System this study would not have been possible. The large existing datasets could never have been dissected and recompiled into the current format without the use of the GIS. To enable the user access to this complex database, a conversion was completed allowing all coverages to be viewed and queried through PC version of ARC/VIEW™. This package is now freely available on the internet.

By providing all the data for groundwater, surface water, the landscape and the people on a unioned digital format of uniform projection and scale, it is hoped that the users of this database will compile their own queries and resolve the water management crisis we are currently in.

APPENDIX A

DESCRIPTIVE DATA FILES FROM THE SGPATLAS

APPENDIX A

ATTRIBUTE DATA FILE NAMES

ITEM NAME	ITEM TYPE	DESCRIPTION
Area	numeric	Area of land facet in m2
Perimeter	numeric	perimeter of landfacet in m
sgpatlas	numeric	internal system polygon
sgpatlas-id	numeric	user polygon ID
exp-percen	alpha	exploitability % of groundwater
acc-percen	alpha	accessibility % of groundwater
catnum	numeric	primary catchment number
quart-id	alpha	quarternary ID
catid	numeric	catchment ID
cmap	numeric	mean annual precipitation
mar	numeric	mean annual runoff
mar4Q	numeric	mar quaternary catchment
mar3Q	numeric	mar tertiary catch
mar2Q	numeric	mar secondary catch
primary	alpha	prim catchment name
mar1Q	numeric	mar primary catch
cens-distr	alpha	census district name
lang-desc	alpha	dominant language description
pop91	numeric	1991 census data
pop93	numeric	1993 census data
pop-densit	numeric	population density
water-pop	numeric	water available per person
pop-catch	numeric	people per catchment
wat-prov	numeric	water available per province
perc-wat	numeric	% water in each catchment
geology	alpha	geology of the region
vegetation	alpha	vegetation of the region

APPENDIX B

LIST OF PROVIDED DATA COVERAGES AND VIEWS

APPENDIX B

COVERAGES AND VIEWS PROVIDED IN SGPATLAS

Coverages:

* exp (groundwater exploitability)
* acc (groundwater accessibility)
* mar (mean annual runoff)
* sgpatlas (unioned dataset)
* pop (1993 population data)
* gwpot (groundwater potential)
* swpot (surface water potential)
* popcris (population crisis)
* swcris (surface water crisis)
* gwcris (groundwater crisis)
* totcris (total crisis)

Views:

* sgpatlas.av (view file containing all of the above mentioned coverages that can be viewed through ARCVIEW)