Appropriate positioning of modelling as a decision support tool for surface water resources planning in South Africa

by

Renias Admore Dube

Submitted in partial fulfilment of the requirements for the degree of Philosophae Doctor in the Faculty of Natural and Agricultural Sciences

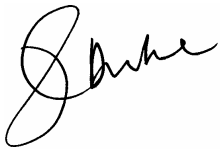
University of Pretoria

Pretoria

March 2006

DECLARATION

I declare that the thesis, which I hereby submit for the degree of Philosophae Doctor at the University of Pretoria is a result of my own work and has not been submitted previously by me for a degree at another university.



R A Dube

APPROPRIATE POSITIONING OF MODELLING AS A DECISION SUPPORT TOOL FOR SURFACE WATER RESOURCES PLANNING IN SOUTH AFRICA

BY

RENIAS ADMORE DUBE

Promoters: Prof. T. E. CLOETE

Dr. P. J. ASHTON

Department: MICROBIOLOGY AND PLANT PATHOLOGY

Degree: Ph.D

Summary

The availability of adequate information is one of the basic requirements of sound water resources development. Simple water resource development options that required less detailed studies have already been developed, such that development proposals today require more detailed and comprehensive studies. Among other factors, these studies generate information on the hydrological risk of implementing water resources projects. The modelling tools used to generate water resources information are usually complicated by the many variables involved, which are inter-linked and usually unpredictable. The National Water Act (Republic of South Africa, 1998) emphasises the need for integrated water resources management, social equity, and ecological sustainability, which have added new dimensions to water resources planning. Water catchment simulation models that account for all the dimensions of water resources planning and bring more information than ever before to the decision-maker have become the preferred tools.

Whilst earlier water resources planning tools are still in common use, this study found that these earlier tools lagged behind developments in important aspects such as national legislation, water stakeholders' working environment, and rapid changes in computer software and hardware. The appropriateness of water resources modelling tools in South Africa was investigated in the light of a changing water environment as well as the need to address specific factors that are unique to South Africa. The water resources factors investigated included hydro-climatic, water institutional frameworks and stakeholder needs, available expertise and technological aspects of the available water management and planning tools. On the basis of the outcome of the investigation of South Africa's unique water environment, recommendations and guidance were developed with the aim of developing a preferred local water resources modelling approach.

This study investigated and recommended the use of water resources system models which are based on up to date modelling and Information Technology (IT) developments, such as HYDRO25, for multi-criteria planning of integrated water resources. In this study, the development of object oriented programming (OOP) models with visual interfaces that fit in the popular Windows operating environment was distinguished as a key aspect of water resources modelling. This modelling route was selected because it generates tools that are more user-friendly, have visual clues that relate closely with the physical system, including easy GIS integration, can handle the higher computer memory volume demands of longer time series data, and could handle a greater number of parameters as well as the increasingly more complex management scenarios. In the OOP approach, modelling tools are easily integrated with the input processing and output analysis objects that are developed separately before integration into the main model framework. All the separate software objects can easily be utilised in other models when the need arises. The HYDRO25 model uses modular objects and a visual-based programming language that easily accommodates integration with other software objects based on the component object model system. This has made further upgrading and redevelopment of the model easy to handle.

In this study, the HYDRO25 model was developed and used in the Doring River catchment as a case study which was aimed at providing first-hand information about model

development and application in South Africa. In the HYDRO25 model, computer code was used systematically to handle the catchment hydrology, geographical information, climatic factors, water use, catchment development proposals, the requirement of water legislation, and other factors to provide information that is useful for decision-making.

In the Doring River case study, proposed irrigation developments in the Koue Bokkeveld and Aspoort area of the Western Cape were assessed using the HYDRO25 model to determine the most viable development options from a hydrological perspective. The study showed that the full irrigation potential of the catchment cannot be utilised with the available surface water resources in the catchment. The model simulation results showed that a maximum of 700 hectares can be irrigated in the Koue Bokkeveld area without creating additional water storage. Analysis of the Aspoort irrigation scheme showed that the irrigation area should be limited to 1000 hectares, with the proposed 178 million m^3 Aspoort Dam being developed to support irrigation water demand and, to a small extent, to contribute to other water uses in the catchment, such as ecological flows and domestic uses.

Opsomming

Die beskikbaarheid van voldoende inligting is een van die basiese vereistes vir doeltreffende waterbronontwikkeling. Eenvoudige alternatiewe vir die ontwikkeling van waterbronne, waar minder uitvoerige ondersoeke benodig word, is reeds ontwikkel, en wel tot so ‘n mate, dat ontwikkelingsvoorstelle deesdae meer indringende en omvattende navorsing vereis. Hierdie ondersoeke genereer onder meer inligting oor die hidrologiese risiko wat gepaard gaan met die implementering van waterbronprojekte. Die modelleringshulpmiddels wat gebruik word om inligting oor waterbronne te verkry word gewoonlik gekompliseer deur die betrokkenheid van talle veranderlikes wat met mekaar verband hou en gewoonlik onvoorspelbaar is. Die onlangse Waterwet (Republiek van Suid-Afrika, 1998) beklemtoon die behoefte aan geïntegreerde waterbronbestuur, billikheid en ekologiese volhoubaarheid - aspekte wat nuwe dimensies verleen het aan waterbronbeplanning. Simulasiemodelle vir wateropvanggebiede wat al die verskillende dimensies van waterbronbeplanning in ag neem en wat meer inligting as ooit tevore tot die beskikking van besluitnemers stel, het die hulpmiddels geword wat voorkeur geniet.

Hoewel vroeëre hulpmiddels vir waterbronbeplanning nog steeds algemeen gebruik word, het die studie getoon dat hierdie ouer hulpmiddels agter geraak het wat betref die ontwikkeling op gebiede soos nasionale wetgewing, waterbelanghebbendes se werksomgewing asook die snelle verandering in rekenaarsagteware en hardeware. Die geskiktheid van modelleringshulpmiddels vir waterbronne in Suid-Afrika is ondersoek in die lig van ‘n veranderende wateromgewing asook die behoefte om verskeie faktore wat uniek aan Suid-Afrika is, aan te spreek. Die waterbronfaktore wat ondersoek is, sluit onder andere in hidro-klimatologiese, waterinstitusionele raamwerke en die behoeftes van belanghebbendes, beskikbare kundigheid en die tegnologiese aspekte van die beskikbare waterbestuur- en beplanningshulpmiddels. Op grond van die uitslae van die ondersoek na Suid-Afrika se unieke wateromgewing, is aanbevelings en riglyne ontwikkel met die doel om ‘n voorkeurscenario vir plaaslike waterbronmodellering daar te stel.

Hierdie studie ondersoek en beveel die gebruik aan van modelle vir waterbronstelsels wat gegrond is op die jongste modellering- en IT ontwikkelings, soos HYDRO25 vir die multi-kriteriabeplanning van geïntegreerde waterbronne. In hierdie studie word die ontwikkeling van objekgeoriënteerde programmeringsmodelle met visuele koppelvlakke wat by die gewilde Windows bedryfsomgewing inskakel, onderskei as ‘n kernaspek van waterbronmodellering. Hierdie modelleringsaanslag is geïdentifiseer om hulpmiddels daar te stel wat meer gebruikersvriendelik is, wat visuele leidrade verskaf na aan die werklike stelsel, insluitende GIS integrasie, wat die groter vereiste vir rekenaargeheuevolume van langer tydreekse se data kan hanteer en wat ‘n groter aantal parameters kan behartig, asook die toenemend meer ingewikkelde scenarios. Met die benadering van objekgeoriënteerde programmeringsmodelle word die modeleringshulpmiddels maklik geïntegreer met die sagteware vir die insetteprosessering en die uitsetanalise wat as afsonderlike objekte ontwikkel word alvorens hulle saam met die hoofmodelraamwerk geïntegreer word. Die HYDRO25 model maak gebruik van modulêre objekte en ‘n visueel-gebaseerde programmeringstaal wat die integrasie met ander sagtewareobjekte, gebaseer op die komponent-objekmodelsisteem, maklik kan behartig. Dit het die verdere opgradering en herontwikkeling van die model makliker gemaak.

In hierdie studie is die HYDRO25 model ontwikkel en in die Doringrivieropvanggebied as ontledingstegniek gebruik. Dit was daarop gemik om eerstehandse inligting oor modelontwikkeling en die toepassing daarvan in Suid-Afrika te verskaf. In die HYDRO25 model is rekenaarkode gebruik om waterbronveranderlikes in ‘n opvanggebied sistematies te hanteer, insluitende die hidrologie, geografiese inligting, klimaatsfaktore, watergebruik, ontwikkelingsvoorstelle vir die opvanggebied en waterwetgewing ten einde inligting beskikbaar te stel wat nuttig is vir besluitneming.

In die Doringriviergevallestudie is die voorgestelde besproeiingsontwikkeling in die Koue Bokkeveld en die Aspoortgebied van die Weskaap beoordeel met behulp van die HYDRO25 model ten einde die mees lewensvatbare ontwikkelingsopsies vanuit ‘n hidrologiese perspektief te bepaal. Die studie het getoon dat die volle besproeiingspotensiaal van die opvanggebied nie verwesenlik sal kan word met die beskikbare oppervlaktewaterbronne

binne die opvanggebied nie. Die resultate van die modelsimulasies het aangetoon dat ‘n maksimum van 700 hektaar in die Koue Bokkeveldgebied besproei sal kan word sonder die daarstelling van bykomende wateropgaarfasiliteite. ‘n Ontleding van die Aspoortbesproeiingskema het aangetoon dat die besproeiingsgebied tot 1 000 hektaar beperk moet word, terwyl die voorgestelde 178 miljoen m^3 Aspoortdam ontwikkel word om in die vraag na besproeiingswater te voorsien, en, in ‘n mindere mate, om ‘n bydrae te lewer tot ander watergebruike in die opvanggebied, soos ekologiese vloeie en huishoudelike gebruik.

Acknowledgements

I would like to acknowledge the contributions of various people and organisations during the course of the study:

- The Department of Water Affairs and Forestry, the South African Weather Services, the Centre for Computing and Water Research and the University of KwaZulu-Natal for their contributions towards the data used in this study.
- The Water Research Commission, BKS (Pty) Ltd and Ninham Shand (Pty) Ltd for providing useful reference material and information on matters that were useful to this study.
- Mr P. Mathews, Mr M. Marè, Mr C. Langout. Dr J. Ndiritu, Dr W.V. Pitman, Dr K. Pietersen and Dr G. Green for their constructive suggestions and advice at different stages of the study.

I would like to express my sincere gratitude to the following people:

- Prof. P.J. Ashton for his outstanding and consistent support and review of the thesis.

- Prof. T. E. Cloete, for his constant support, constructive guidance and encouragement during the course of the study.

- Colleagues, friends and extended family for their advice, assistance and interest.

- Lastly, and certainly not least, my wife, Beatrice, daughter Chelsea and son Allen for their love and consistent moral support.

TABLE OF CONTENTS

Section 2: Recommendations and Guidance on Water Resources Modelling

LIST OF TABLES

LIST OF BOXES

LIST OF FIGURES

LIST OF ACRONYMS

ACRU	Agricultural Catchments Research Units
API	Application Programming Interface
ARC	Agricultural Research Council
ARSP	Acres Reservoir Simulation Programme
BASINS	Better Assessment Science Integrating Point and Non-Point Sources
BOD	Biochemical Oxygen Demand
CCWR	Computing Centre for Water Research
CMSs	Catchment Management Strategies
CSIR	Council for Scientific and Industrial Research
DEAT	Department of Environmental Affairs and Tourism
DEMs	Digital Elevation Models
DHI	Danish Hydraulic Institute
DO	Dissolved Oxygen
DSC	Dead Storage Capacity
DST	Department of Science and Technology
DTMs	Digital Terrain Models
DWAF	Department of Water affairs and Forestry
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute
EU	European Union
FME	Feature Manipulation Engines
FSC	Full Supply Capacity
GDP	Gross Domestic Product
GIS	Geographical Information Systems
HBV	Hydrologiska Byråns Vattenbalansavdelning (Hydrological Bureau Waterbalance-section)
HIV/AIDs	Human Immunodeficiency Virus / Acquired Immune Deficiency Syndrome
HRU	Hydrological Research Unit
HTML	Hyper Text Mark-up Language
HYCOS	Hydrological Cycle Observing Systems
ICOLD	International Commission on Large Dams
IFR	In-Stream Flow Requirements
IMWI	International Water Management Institute
IT	Information Technology
IUCN	International Union for the Conservation of Nature
IWRM	Integrated Water Resources Management
KBV	Koue Bokkeveld
LAS	Large Aperture Scintillometer
LHWP	Lesotho Highlands Water Project
MAP	Mean Annual Precipitation
MAR	Mean Annual Runnoff
MBB	Model Building Blocks
MDGs	Millennium Development Goals
MCP/PMT	Multi-Criteria Performance /Productivity Measurement Technique

MS	Microsoft
NEPAD	New Partnership for Africa's Development
NGA	National Groundwater Archive
NGDB	National Groundwater Database
NIS	National Information Systems
NSIF	National Spatial Information Framework
NWA	National Water Act
NWRS	National Water Resource Strategy
OLE	Object Linking and Embedding
OO	Object Oriented
OOP	Object Oriented Programming
ORDP	Orange River Development Project
ORRS	Orange River Replanning Study
POSC	Petrotechnical Open Software Corporation
PROMETHENE	Preference Ranking Organisation METHod for ENrichment Evaluation
PWV	Pretoria-Witwatersrand-Vereeniging
QUALDB	National Water Quality Database
RADAR	Radio Detection and Ranging
RDMs	Resource Directed Measures
RMSE	Root Mean Square Error
RQOs	Resource Quality Objectives
RRR	Rainfall-Runoff Relationship
SADC	Southern African Development Community
SASA	South African Sugar Association
SAWS	South African Weather Service
SBEEH	School of Bioresources Engineering and Environmental Hydrology
SCS	Soil Conservation Services
SDSS	Spatial Decision Support Systems
SFRAs	Stream Flow Reduction Activities
SIDA	Swedish International Development Agency
SOTER	Soil and Terrain
TIN	Triangular Irregular Network
TWP	Thukela Water Project
USGS	United States Geological Survey
VRS	Vaal River System
WfW	Working for Water
WMA	Water Management Area
WMO	World Meteorological Organization
WRC	Water Research Commission
WRM	Water Resources Management
WRPM	Water Resources Planning Model
WRS	Water Resources System
WRYM	Water Resources Yield Model
WSAM	Water Situation Assessment Model
XML	e**X**tensible **M**ark-up **L**anguage