DEVELOPMENT OF A WATER QUALITY AND QUANTITY MODELLING SYSTEM WHICH WILL PROVIDE A COMMON CURRENCY FOR COMMUNICATION BETWEEN RESEARCHERS IN THE KRUGER NATIONAL PARK RIVERS RESEARCH PROGRAMME

by

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EXECUTIVE SUMMARY

1. AIMS

The Kruger National Park and the associated private reserves together constitute one of the world's most extensive and valued nature conservation areas. As centers of tourism they are vital for socio-economic development at the local, provincial and national level. It is both in the national and southern African regional interest to secure the future of these systems so that they can continue to provide living examples of the natural ecosystems for the benefit and enjoyment of mankind and for moral and ethical reasons. Appropriate research is fundamental to secure such a future.

The project described in this report forms part of the Training, Information and Technology Transfer Sub-programme of the Kruger National Park Rivers Research Programme (KNPRRP). Before describing the aims of the project reported in thus document a brief overview of the origins, aims, supporters and current status of the KNPRRP will be presented in order to place it in perspective.

The following extract from Breen, et al (1994) provides that outline:
"The Kruger National Park Rivers Research Programme is a cooperative undertaking by resource-use managers, funding agencies and researches. It addresses the water quality and the water quantity requirements of the natural environments of rivers, particularly those flowing through the Kruger National Park.
The programme, conceived at a workshop convened by the Department of Water Affairs in March 1987, was initiated in December 1988, jointly by the government departments of Water Affairs, the foundation for Research Development, the National Parks Board, the Water Research Commission and various research institutions and provincial nature conservation authorities."

Breen at al (1994) present a detailed description of the second phase of the programme (1994-1996). The programme, as described by Breen et al (1994), builds on the understanding and expertise developed in the first phase and its purpose is to communicate pertinent information on the programme and its cooperative, inter-disciplinary approach, structure and management. The programme is directed at contributing to the conservation of the natural environment of rivers through developing skills and methodologies required to predict the response of the systems to natural and anthropogenic factors affecting water supply (quantity & quality); skills and methodologies required to establish the social acceptability of predicted changes; and through directed research, to develop the understanding of the ecological functioning of these systems required to improve the quality of the prediction and advice to resource-use managers, researchers and stakeholders.

The work of the KNPRRP is conducted within four sub-programmes:

1. Information Systems Development and Management : - the purpose of this sub-programme is to provide an information management system which enables the efficient capture, storage, retrieval and dissemination of information to serve the needs of researchers, decision-makers and stakeholders.

2. Decision support System Development and Management :- the purpose of this sub-programme is to provide methodologies for integrating information and expert opinion into structured decision support systems directed at achieving the best possible answers at the time and informing researchers of the information needs required to improve answers in the future.

3. Research development and Management :- the purpose of this sub-programme is to provide, in the efficient and cost-effective manner, the information and expert opinion required to improve the quality and usefulness of the responses to enquiries from researches, resource managers and stakeholders.

4. Training, Information and Technology Transfer :- the purpose of this sub-programme is to ensure that the information and technology developed within the programme are transferred effectively to the appropriate users including researches, managers and stakeholders.

This project was initiated within the framework of the Training, Information and Technology Transfer (TITT) Sub-Programme of the Kruger National Park Rivers Research Programme (KNPRRP) as described by Breen, Quinn and Deacon (1994). The project commenced in July 1994 and had a duration of 1 year.

The aims of the project were threefold :

1. To develop, for the Sabie River, the framework of a modelling system which incorporates *inter alia* ARC/INFO, HSPF and the Watershed Data Management System (WDMS), into a flexible, versatile and professional tool.

   (It was stressed in the project aims, as recorded in the contract, that the objective was NOT to produce top quality simulations by the HSPF model. Such simulations would require data sets and knowledge of the systems and their physical interactions which are as yet far from complete and are also beyond the skills of the contractees in this project).

2. To demonstrate that the product of the above development can serve as a catalyst to elicit more meaningful interaction, communication and ultimately integration than is presently the case amongst researchers in the KNPRRP.

3. To empower the teams of researchers who are seeking to integrate their work on the KNPRRP to embark on an informed search for a better modelling system at some future time when they have learned to communicate well at the detailed scientific levels required by a programme of this nature.

This last point emphasised that the HSPF (or any other) modelling system, which is incorporated at this stage, is in no way being proposed as the final and only solution to the simulation modelling challenge in the KNPRRP. It was simply a pragmatic first step, which was able to commence immediately. Furthermore the kinds of data which have been gathered and processed for the HSPF model are the same as those which would be required for most other systems of similar capability. None of this effort has therefore been wasted, if, in the future the HSPF system is replaced. The project aimed to interface the GIS and time series graphics to the HSPF system in a generic fashion to further ensure the longevity and relevance of the work.

2. BACKGROUND

Due to the complex and largely undefined conceptual nature of the Training and Information and Technology Transfer (TITT) sub-programme in which this project is set, it is necessary to divide the background to this project into a conceptual component and a technical component.

An understanding of the conceptual and philosophical environment in which the technology operates is vital to the appreciation of the role that the technology (produced in this project) can play in the TITT sub-programme and hence in the KNPRRP as a whole.

2.1 Conceptual background

The KNPRRP Description by Breen, Quinn and Deacon (1994) provided for 4 Sub-programmes:-

I) Information Systems Development & Management (ISDM)
ii) Decision Support Systems Development & Management (DSSDM)
iii) Research Development and Management (RDM)
iv) Training and Information and Technology Transfer (TITT)

For the first 3 named above, a fairly detailed conceptual description was developed by Breen et al (1994). However, for the TITT sub-programme only an outline was provide and it was stated that the TITT sub-programme's first action would be to develop a conceptual framework for its task.

The major aspects of the external environment which shaped the conceptual framework for this project are captured succinctly in the following extracts from a paper by Breen, Biggs, Dent, Görgens, O'Keeffe & Rogers (1995).

"....resolution of conflict lies at the heart of effective river basin management."

"River basin management is practised in a dynamic biophysical and social environment. An appropriate decision today on allocation and use of the resource can be inappropriate under changed circumstances. Adaptive management is required to continually optimise allocation and to promote sustainable use of resources under changing circumstances."

" If research is to contribute usefully to river basin management for sustainable development it should develop understanding, information and technologies which promote adaptive management. Its purpose should be to promote the process by which decisions are made rather than to promote a particular decision." Pg 2

Breen, Biggs, Dent, Görgens, O'Keeffe & Rogers (1995)

In the light of the above, several issues were evident to the TITT sub-programme management, from the outset, viz.

* That the TITT sub-programme would have to work very closely with the DSSDM sub-programme throughout Phase II of the KNPRRP.
* That the process of developing a *modus operandi* for the TITT sub-programme would have to be adaptive.
* That most of the training, information, communication and technology transfer work required of the sub-programme would have to be channelled through modelling systems, developed with or within the other KNPRRP sub-programmes.
* That the process of developing these modelling systems would have to be an adaptive and co-operative venture with all the KNPRRP sub-programmes but especially the DSSDM sub-programme.
* Operational prototyping as described by Davis (1992) would be necessary.
* That the issue of time series and hence time series management was of paramount importance, especially also to the states, frames and rules based modelling paradigms of Starfield *et al* (1993).
* The importance of time series management is further emphasised if one considers that;

  - change implies **time**

  - cause/effect implies **time**

- probability (risk) implies **time**

- rate of change implies **time**

- **time** scale range from instantaneous ie velocity to centuries for some processes

- the future implies **time**

- the past implies **time**

- frequency of occurrence implies **time**

- duration implies **time**

- regeneration implies **time**

- decay implies **time**

- feedback implies **time**

- scenarios (or alternative futures) implies **time**

- patterns of supply implies **time**

- regime disturbance factors based on indexes of variability imply **time**

- competition, invasion, success have **time** components

* The wide area computer networks would have to be used extensively as a medium of communication and software systems would have to optimise the features of WAN's and local processing.
* GIS would play a central role in the development.
* Time and budget restraint was of the essence, both in the KNPRRP and in this project of 1 year only. It was therefore essential to use existing software wherever possible and particularly where such software was linked to a currently practising group of scientists.
* Related to the above point was also the firm belief that the dynamic process human of interaction both in the development and subsequent use of the systems was of cardinal importance. This is entirely in line with the philosophical approaches so clearly stated above by Breen et al (1995).
* The processes of stimulating co-operation in this project were guided by the view that the KNPRRP must stimulate a large degree of enthusiastic and voluntary "buy-in" to the programme if it is to progress and survive as a programme in the current economic climate.

A final conceptual point of departure for the sub-programme is the firm belief that **good outward communication is founded on good internal communication**. The modelling and graphical presentation systems which are the subject of this report are designed to address both the internal and external communication and to provide a common currency for communication on major aspects of the KNPRRP programme.

2.2 Technical background

The philosophy of using models was strong and pervasive in the KNPRRP's primary guiding document by Breen, Quinn and Deacon (1994)

Having combined the KNPRRP description by Breen et al (1994) with the conceptual background outlined above it became clear that the criteria for the technical approach had to include a backbone modelling system to provide continuity and cohesion for the time series involved in abiotic simulation portion of the programme. The chosen system had to meet the following criteria :

- sound time series management system
- simulate at daily time step and preferably smaller time steps if required **(this is not to imply that all the ecosystem processes need to be simulated at daily time steps, it is simply the smallest pragmatic time step and all larger time steps can be achieved by aggregation from this base)**
- simulate water quantity and quality at a range of spatial scales
- the models included in the hydrological (abiotic) simulation system should be based on physical processes as far as possible and specifically able to simulate , inter alia, forestry, irrigation, dryland agriculture
- modelling software should be currently available, since there was no time for new development of models
- utilities to support that backbone models are important
- that the system does model the core hydrology, hydraulics, erosion and sedimentation and water quality at an acceptable level for initial purposes, despite the fact that the individual model processes may not be "the best in the world" with respect to isolated aspects of the system
- that the system of models covers both land and instream processes
- that the networking of a complex web of time series flows and fluxes is accommodated

* that in the abovementioned areas, the chosen system has an international record of success and continuing endeavour in providing a common currency for communication in complex integrated catchment management systems
* the systems should be documented , stable , affordable , changeable , credible and supported at reasonable cost.

The Hydrological Simulation Program Fortran (HSPF) and the ACRU agro-hydrological modelling system were selected, since they met the above criteria. The DSSDM sub-programme agreed to fund the hydrological simulation with the ACRU model. The bona fide's and the attributes of the ACRU model are well known to South Africans and therefore will not be repeated in this Executive Summary. The HSPF system which was developed for the United States Environmental Protection Agency (EPA) :

* was written in a consulting environment,
* is widely used by consultants in the USA and elsewhere (extensive bibliography which lists these uses is available if required),
* is currently available in the public domain, in version 10,
* is readily linked to other models through the Watershed Data Management System (WDM), which was developed and is supported by the US Geological Survey (USGS), with the support of the US Soil Conservation Service (SCS), the US Department of Agriculture (USDA) and the Environmental Protection Agency (EPA),
* is being used as a "backbone" to installed modelling systems in Chesapeake Bay (USA), Sydney Bay (Australia) and in many other areas of the USA, in particular.

HSPF is undergoing continual development in the USA through support from the USGS, the EPA and consultants.

It was decided at the conception stage of this project to use the considerable client/server multi-tasking capability which is available to users of the wide are networks of UNINET and the INTERNET. This would enable the project to deliver, users of the product, the ability to optimise their co-ordination, control and response potential, for the best integration of effort. Integration, after all, is the key to success in the KNPRRP.

A final point with regard to the technical background concerns the adoption and use of the time series manipulation and display capability of the software developed by Ninham Shand Inc. This move was specified in the project proposal and was in accordance with the philosophy of co-operating with existing groups to reduce both costs and time on a project of this nature.

3. METHODOLOGY

The project commenced with a 3 day workshop on HSPF. The workshop which was led by Professor R. Johanson, the senior author of HSPF, focused specifically on the aspects of HSPF which were relevant to the KNPRRP. The workshop was attended by 34 scientists and engineers.

Immediately following the workshop extensive effort was expended on the GIS and climatic data sets (at the daily level from 1930-1994). These are now included in the modelling system and the accompanying WDMGUIDE software system which is used to view the GIS and model simulated information. The WDMGUIDE, which is based on the Arcview2 system is one of the main products of this project.

The Sabie catchment was divided into 57 sub-catchments, so that the HSPF and ACRU models could run the simulation system in a distributed fashion. The project personnel then linked the output from the hydrological simulations from the ACRU model with the stream channel simulation routines of the HSPF model via the WDM. In the reaches of the Sabie within the KNP, the sub-catchment boundaries were chosen to enable the hydrological simulations to provide information at the 31 locations at which the University of the Witwatersrand's, Centre for Water in the Environment (CWE) researchers had been studying morphometry, sedimentation and riverine vegetation in detail.

At the same time as the above work was taking place Ninham Shand Inc in the persons of Mr K. de Smidt and Mr A. Greyling were preparing a subset of the Ninham Shand suite of time series analysis and plotting programmes to present the output from the HSPF and ACRU simulations. This software now operates on a PC simultaneously with, but independently of the WDMGUIDE.

When operated in a multi-tasking windows environment this offers the user substantial flexibility and functionality.

The DOS based interactive digital version of the DATA CATALOGUE developed by the KNPRRP's ISDM sub-programme is also running on the same computer. The net result is that the user of the system developed and integrated during the course of this project has all the abovementioned capabilities and the ability to run simultaneous sessions at one or more remote UNIX based sites on the Internet. The user is thus now able to switch between these systems, literally at the flick of a "mouse" button. Several photographic images have also been included in the software. At present these are for purposes of illustrating a concept , however, many more images could be inserted to enhance considerably the communication power of the system.

It is unusual to include illustrations in an executive summary, however, in this case Figure 1 below is considered essential to convey the focal point of the methodology described above.

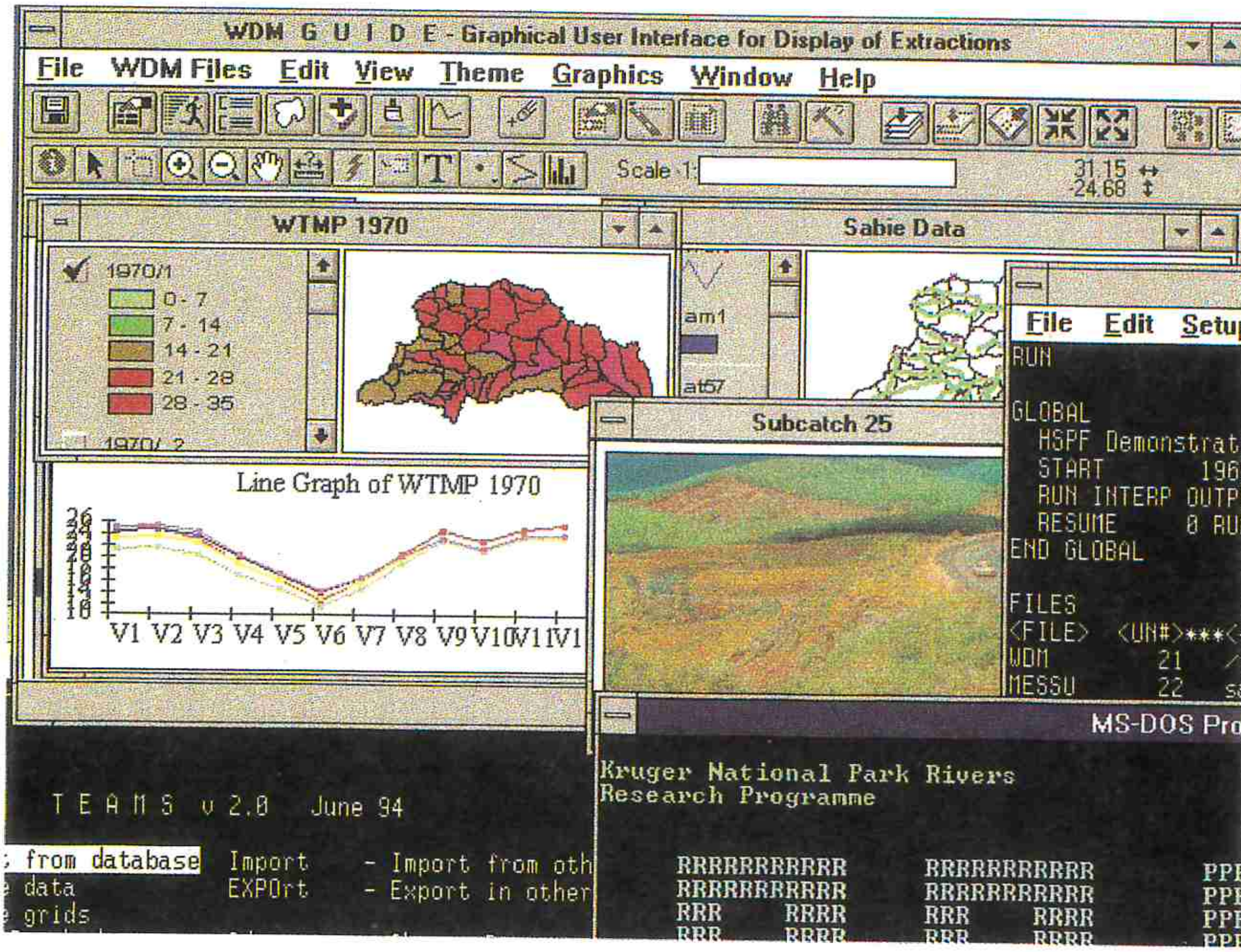

Figure 1

4 PROJECT ACHIEVEMENTS

In terms of Aim 1 :

The framework of a modelling system which incorporates *inter alia* ARC/INFO, the ACRU agro-hydrological modelling system, HSPF for instream processes and flow routing and the Watershed Data Management System (WDMS), into a flexible, versatile and professional tool, has been developed for the Sabie River,

> ***It must be stressed again that the objective, as stated in the contract, was NOT to prove the quality of simulation by the models. That would require data sets and knowledge of the systems and their physical interactions which are as yet far from complete and are also beyond the skills of the contractees in this project. The aim was to provide a***

framework and a platform which was capable of rapid and cost effective refinement in the future.

In terms of Aim 2 :

It has been demonstrated that the product of the above development can serve as a catalyst to elicit more meaningful interaction, communication and ultimately integration than is presently the case amongst researchers in the KNPRRP.

In terms of Aim 3 :

The project has empowered the teams of researchers who are seeking to integrate their work on the KNPRRP to embark on an informed search for a better modelling system at some future time. Researchers are, through this project, learning to communicate at the detailed scientific levels required by a programme of this nature.

The TITT sub-programme is now in a position to offer, geographically scattered groups, the ability to simultaneously view, manipulate and analyse the same information. Such information can be text, numerical or graphical. Further tools have been developed to view the time dependent data in temporal and spatial context. Such facilities will substantially enhance the TEMPO and SYNERGY which can be applied to the situation. The technology developed in this project is capable of achieving this in a most cost effective manner. Furthermore, through this project the TITT sub-programme has acted as a catalyst to secure a growing commitment from a range of scientists to work together on these developments in such a way that the established expertise base of each group is NOT THREATENED. A key objective in all cases has been to find the most cost effective and non intrusive way to interface the work of each group.

The project has also served as the focal point and interface for developing links between the KNPRRP and many institutions, both nationally and internationally.

5 FUTURE OF THE SYSTEM AND RECOMMENDATIONS FOR FUTURE RESEARCH

The personnel on this project have worked closely with the DSSDM sub-programme and the intention is to incorporate the system, developed thus far, into the decision support system. The system needs to be further operationalised by incorporating the numerous abstractions from the Sabie and its tributaries and also the dams and their operating rules. The water quality simulations will also have to be improved with the incorporation of more comprehensive landuse and point discharge information. It is recommended that the KNPRRP seek the assistance of the DWA&F in this regard.

The DSSDM sub-programme intends to use the products of this project to assist with the prototyping exercises required to formulate the abiotic/biotic link in the DSS system. It is believed that this work will commence shortly.

As far as custodianship of the products of this project are concerned, it is intended (for the present) that they should be housed, inter alia, at the Computing Centre for Water Research (CCWR). It is further recommended that copies of the WDMGUIDE software portion of the project should be distributed to the research centres at which the key role players in the KNPRRP are working viz. Freshwater Research Unit at UCT, Centre for Water in the Environment, Wits, the Institute for Water Research, Rhodes, the Institute for Water Quality Studies, DWA&F and the National Parks Board at Skukuza. The proposed budget for the TITT sub-programme for 1996 has made provision for this. The technology is already available at Stellenbosch University where it has been used in the close collaboration between the DSSDM and TITT sub-programmes over the past 6 months.

The TITT sub-programme intends to offer training courses on this software in 1996 and provision is made on the 1996 budget for the CCWR personnel to travel to these centres to carry out that training. Such training will be carefully co-ordinated with the DSS and other sub-programme managers.

6 CONCLUSION

Integrated catchment management cannot be founded on disintegrated science. The basis of sound integration is good communication and the basis of that communication is a sound knowledge of the subject matter to be conveyed and a recognition that the process of communication is as important as the content of that communication.

This project has succeeded in providing a structured and operational form of communication between the research groups within the KNPRRP, both at the conceptual and technical level. As such, it is the view of the authors', that this project has contributed significantly to the TITT sub-programme objectives and to those of the KNPRRP as a whole.

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Chapter 1

AIMS

The Kruger National Park and the associated private reserves together constitute one of the world's most extensive and valued nature conservation areas. As centers of tourism they are vital for socio-economic development at the local, provincial and national level. It is both in the national and southern African regional interest to secure the future of these systems so that they can continue to provide living examples of the natural ecosystems for the benefit and enjoyment of mankind and for moral and ethical reasons. Appropriate research is fundamental to secure such a future.

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"The Kruger National Park Rivers Research Programme is a cooperative undertaking by resource-use managers, funding agencies and researches. It addresses the water quality and the water quantity requirements of the natural environments of rivers, particularly those flowing through the Kruger National Park.
The programme, conceived at a workshop convened by the Department of Water Affairs in March 1987, was initiated in December 1988, jointly by the government departments of Water Affairs, the foundation for Research Development, the National Parks Board, the Water Research Commission and various research institutions and provincial nature conservation authorities."

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2. To demonstrate that the product of the above development can serve as a catalyst to elicit more meaningful interaction, communication and ultimately integration than is presently the case amongst researchers in the KNPRRP.

3. To empower the teams of researchers who are seeking to integrate their work on the KNPRRP to embark on an informed search for a better modelling system at some future time when they have learned to communicate well at the detailed scientific levels required by a programme of this nature.

This last point emphasised that the HSPF (or any other) modelling system, which is incorporated at this prototyping stage, is in no way being proposed as the final and only solution to the simulation modelling challenge in the KNPRRP. It was simply a pragmatic first step, which was able to commence immediately. Furthermore the kinds of data which have been gathered and processed for the HSPF model are the same as those which would be required for most other systems of similar capability. None of this effort has therefore been wasted, if, in the future, the HSPF system is replaced.

The project aimed to interface the GIS and time series graphics to the HSPF system in a generic fashion to further ensure the longevity and relevance of the work. This prototyping approach which the project aimed to follow is well established and researched in the field of software systems engineering. A discussion on this approach is presented in Section 4.1 of this report.

Chapter 2

BACKGROUND

Due to the complex and largely undefined conceptual nature of the Training and Information and Technology Transfer (TITT) sub-programme in which this project is set, it is necessary to divide the background to this project into a conceptual component and a technical component. An understanding of the conceptual and philosophical environment in which the technology operates is vital to the appreciation of the role that the technology (produced in this project) can play in the TITT sub-programme and hence in the KNPRRP as a whole.

2.1 Conceptual background

The KNPRRP Description by Breen, Quinn and Deacon (1994) provided for 4 Sub-programmes:-

i) Information Systems Development & Management (ISDM)
ii) Decision Support Systems Development & Management (DSSDM)
iii) Research Development and Management (RDM)
iv) Training and Information and Technology Transfer (TITT)

For the first 3 named above, a fairly detailed conceptual description was developed by Breen et al (1994). However, for the TITT sub-programme only an outline was provided and it was stated that the TITT sub-programme's first action should be to develop a conceptual framework for its task.

The major aspects of the external environment which shaped the conceptual framework for this project are captured succinctly in the following extracts from a paper by Breen, Biggs, Dent, Görgens, O'Keeffe & Rogers (1995).

"....resolution of conflict lies at the heart of effective river basin management."

"River basin management is practised in a dynamic biophysical and social environment. An appropriate decision today on allocation and use of the resource can be inappropriate under

changed circumstances. Adaptive management is required to continually optimise allocation and to promote sustainable use of resources under changing circumstances."

" If research is to contribute usefully to river basin management for sustainable development it should develop understanding, information and technologies which promote adaptive management. Its purpose should be to promote the process by which decisions are made rather than to promote a particular decision."

In the light of the above, several issues were evident to the TITT sub-programme management, from the outset, viz.

* That the TITT sub-programme would have to work very closely with the DSSDM sub-programme throughout Phase II of the KNPRRP.
* That the process of developing a *modus operandi* for the TITT sub-programme would have to be adaptive.
* That most of the training, information, communication and technology transfer work required of the sub-programme would have to be channelled through modelling systems, developed with or within the other KNPRRP sub-programmes.
* That the process of developing these modelling systems would have to be an adaptive and co-operative venture with all the KNPRRP sub-programmes but especially the DSSDM sub-programme.
* Operational prototyping as described by Davis (1992), and discussed in Section 4.1 of this report, would be necessary.
* That the issue of time series and hence time series management was of paramount importance, especially also to the states, frames and rules based modelling paradigms of Starfield *et al* (1993).
* The importance of time series management is further emphasised if one considers that;
  - change implies **time**
  - cause/effect implies **time**
  - probability (risk) implies **time**

- rate of change implies **time**

- **time** scale range from instantaneous i.e. velocity to centuries for some processes

- the future implies **time**

- the past implies **time**

- frequency of occurrence implies **time**

- duration implies **time**

- regeneration implies **time**

- decay implies **time**

- feedback implies **time**

- scenarios (or alternative futures) implies **time**

- patterns of supply implies **time**

- regime disturbance factors based on indexes of variability imply **time**

- competition, invasion, success have **time** components

* The wide area computer networks would have to be used extensively as a medium of communication and software systems would have to optimise the features of WAN's and remote and local processing.
* Geographic Information Systems (GIS) would play a central role in the development.
* Time and budget restraint was of the essence, both in the KNPRRP and in this project of 1 year only. It was therefore essential to use existing software wherever possible and particularly where such software was linked to a currently practising group of scientists.
* Related to the above point was also the firm belief that the dynamic process of human interaction both in the development and subsequent use of the systems was of cardinal importance. This is entirely in line with the philosophical approaches so clearly stated above by Breen et al (1995) and encapsulated in the prototyping concepts discussed in Section 4.1.
* The processes of stimulating co-operation in this project were guided by the view that the KNPRRP must stimulate a large degree of enthusiastic and voluntary "buy-in" to the programme if it is to progress and survive as a programme in the current economic climate.

A final conceptual point of departure for the sub-programme is the firm belief that **good outward communication (to sponsors and stakeholders) is founded on good internal communication (amongst researchers)**. The modelling and graphical presentation systems which are the subject of this report are designed to address both the internal and external communication and to provide a common currency for communication on major aspects of the KNPRRP programme.

2.2 Technical background

The philosophy of using models was strong and pervasive in the KNPRRP's primary guiding document by Breen, Quinn and Deacon (1994)

Having combined the KNPRRP description by Breen et al (1994) with the conceptual background outlined above it became clear that the criteria for the technical approach had to include backbone modelling systems to provide continuity and cohesion for the time series involved in abiotic simulation portion of the programme. The chosen system had to meet the following criteria :

* sound time series management system
* simulate at daily time step and preferably smaller time steps if required **(this is not to imply that all the ecosystem processes need to be simulated at daily time steps, it is simply the smallest pragmatic time step and all larger (or smaller) time steps can be achieved by aggregation (or disaggregation) from this base)**
* simulate water quantity and quality at a range of spatial scales
* the models included in the hydrological (abiotic) simulation system should be based on physical processes as far as possible and specifically able to simulate , inter alia, forestry, irrigation, dryland agriculture
* modelling software should be currently available, since there was no time for new development of models
* the availability of utilities to support the backbone models are important
* that the system does model the core hydrology, hydraulics, erosion and sedimentation and water quality at an acceptable level for initial purposes, despite the fact that the individual model processes may not be "the best in the world" with respect to individual sections of the system
* that the system of models covers both land and instream processes
* that the networking of a complex web of time series flows and fluxes is accommodated

* that in the abovementioned areas, the chosen systems have an international record of success and continuing endeavour in providing a common currency for communication in complex integrated catchment management systems
* the systems should be documented , stable , affordable , changeable , credible and supported at reasonable cost.

The Hydrological Simulation Program Fortran (HSPF) and the ACRU agro-hydrological modelling system were selected, since they met the above criteria. The DSSDM sub-programme agreed to fund the hydrological simulation with the ACRU model. The bona fide's and the attributes of the ACRU model (Schulze, 1995) are well known to South Africans and therefore will not be repeated in this report. The HSPF system which was developed for the United States Environmental Protection Agency (EPA) :

* was written in a consulting environment,
* is widely used by consultants in the USA and elsewhere (extensive bibliography which lists these uses is available if required),
* is currently available in the public domain, in Version 10, (Bicknell et al. 1993)
* is readily linked to other models through the Watershed Data Management System (WDM), which was developed specifically to manage dynamic time series both within and outside of the modelling systems. The WDM is maintained by the US Geological Survey (USGS), with the support of the US Soil Conservation Service (SCS), the US Department of Agriculture (USDA) and the Environmental Protection Agency (EPA),
* is being used as a "backbone" to installed modelling systems in Chesapeake Bay (USA), Sydney Bay (Australia) and in many other areas of the USA, in particular.(de Vos, 1995)

HSPF is undergoing continual development in the USA through support from the USGS, the EPA and consultants.

It was decided at the conception stage of this project to use the considerable client/server multi-tasking capability which is available to users of the wide area networks of UNINET and the INTERNET. This would enable the project to deliver, users of the product, the ability to optimise their co-ordination, control and response potential, for the best integration of effort. Integration, after all, is the key to success in the KNPRRP.

A final point with regard to the technical background concerns the adoption and use of the time series manipulation and display capability of a software package developed by Ninham Shand Inc specifically for this purpose. This move was specified in the project proposal and was in accordance with the philosophy of co-operating with existing groups to reduce both costs and time on a project of this nature.

Chapter 3

METHODOLOGY

3.1 Workshop on HSPF

The project commenced with a 3 day workshop on HSPF. The workshop which was led by Professor R. Johanson, the senior author of HSPF, focused specifically on the aspects of HSPF which were relevant to the KNPRRP. The workshop was attended by 34 scientists and engineers. The list of workshop participants appears in Appendix B.

The primary objective of the workshop was to learn about the capabilities of the HSPF modelling system and thereafter to discuss its suitability as a vehicle to carry the water quality modelling requirements of the KNPRRP (at this stage). Particular emphasis was given to HSPF's structures, its ability to manage time series in conjunction with the Watershed Data Management system (WDM), and its potential to facilitate the process of inter-disciplinary communication on the programme.

The focus of the lectures and discussions was on the instream channel processes and to some extent the reservoir water quality processes. Professor Johanson also discussed HSPF's current use in large multi-disciplinary and ongoing projects in the USA, where it is being used to resolve conflicts before they develop into litigations and to simultaneously guide research.

Version 1 of HSPF was written in 1981, when Hydrocomp which was commissioned by the Environmental Protection Agency (EPA) to write a comprehensive hydrological program included both water quantity and quality simulation. The authors of HSPF focused particularly on designing a modular system in which the processes, and the time series management within the model were separated. The Hydrological Simulation Program Fortran (HSPF) consists of a suite of computer routines that can simulate the hydrologic and associated water quality processes on and under the land surface and in streams and well mixed impoundments.

Stating one's own perceptions regarding the focal point of consensus at the workshop on the complex issues of modelling the catchments and rivers of the KNP in a multi-disciplinary and multi-organisational research programme such as the KNPRRP is a risky business. However, we believe that if we are going to progress in our communications in the KNPRRP programme then we have to take such risks and speak our minds openly, but with care and consideration. Having thus prefaced our remarks let us outline our impressions of the workshop.

* It was fully and openly recognised that the HSPF model does not necessarily encompass the most sophisticated process models on each and every aspect of the many facets to the KNPRRP's challenges.
* However, at the same time it was also recognised that in terms of its flexibility and suitability as a "back bone" system as well as its general allround capability, the HSPF modelling system does contain the essentials needed for a useful start to the KNPRRP modelling efforts, a start on which substantial progress has now been made.
* Participants generally expressed a feeling of hope that through reference to this model they will be able to develop a common currency for communication on the abiotic aspect of the programme and particularly on time series management and linkage issues.
* It was acknowledged that the range of temporal and spatial scales available to modellers in HSPF was of particular importance.
* It was felt the HSPF modelling system could become a medium for extending the communication beyond the researchers in the programme to include resource managers in the catchments outside the park. In fact this is precisely how it is being used elsewhere in the world.
* It was recognised that through its powerful and flexible time dependent data handling capabilities that the HSPF modelling system was not a threat to the inclusion of other models into the suite required by the DSS. On the contrary it was recognised that HSPF will in fact facilitate their inclusion. As indeed has been the case with respect to the ACRU modelling system.

* It was believed that the HSPF system certainly required a graphical user interface (GUI) to post process and display the simulated output. The WDMGUIDE discussed in Section4.2 fulfils this need.

3.2 Geographic Information System coverages

Geographic information system (GIS) coverages are fundamental requirements of any water resources analysis in which land use is so critical to the generation of runoff as well as the use and abuse of water. This project has been no exception and a number of coverages have been obtained from elsewhere or produced by the project. Several examples are given below along with a list of the coverages which appear in in Appendix C

The majority of the coverages utilised were obtained from a previous WRC project on the Sabie river catchment (Van Riet, et al (1994)). The following GIS data coverages have been used and are included in the project results:

Climatic

* rainfall, temperature, altitude

Land

* geomorphology
* topography

Land use

* nature reserves and national parks
* irrigation farming
* potential irrigation areas

Water

* rivers
* dams
* river catchments

Infrastructure

* roads
* power lines

* towns
* rainfall gauging stations
* evaporation and temperature gauging stations

Socio-economic

* population density

Where appropriate these GIS data are included as input to the modelling system.

The system also includes a number of scanned photographic images. It is our view that these images will be extremely useful in building bridges of conceptual understanding between members of the research groups and also in enhancing understanding in the highly heterogeneuos stakeholder environment in which this product must operate in the future. The images included at this stage are purely for the purposes of illustrating a concept and thus stimulating more contributions from researchers.

One of the focal points of this project, namely the software which has been written in Arcview2.1 and AVENUE and has been given the acronym " WDMGUIDE", is used to view the GIS and model simulated information as well as the images. The WDMGUIDE is discussed in Chapter 4.

3.3 Climatic and other input time series information

Extensive effort was expended on the climatic data sets (at the daily level from 1930-1994). The Sabie catchment was divided into 57 sub-catchments, so that the HSPF and ACRU models could run the simulation system in a distributed fashion. Within or near to each of these 57 sub-catchments a long term daily rainfall station was selected. The gaps in the daily rainfall record at these stations were infilled using techniques which relied primarily on nearby rainfall station measurements. Daily temperature and evaporation stations were identified in some sub-catchments but in most sub-catchments the project had to rely on the generation of synthetic temperature and evaporation based on the techniques developed by Schafer, Dent and Schulze (1991) and temperature and evaporation surfaces being developed by Schulze and Maharaj (1994). Several long term, daily "driver" stations were used to ensure that these synthetic daily temperature and evaporation estimates were realistically synchronised with the actual temperature and evaporation sequences. These time dependent data sets along with observed streamflow and water quality from the DWA&F were extracted, produced or collated by this project and later passed on to the Department of Agricultural Engineering, University of Natal, for use in the ACRU model which produced the hydrological simulations of runoff and sediment from rural landuse in the catchments.

3.4 Specialised analysis and display of time series

At the same time as the above work was taking place Ninham Shand Inc. in the persons of Mr K. de Smidt and Mr A. Greyling were contracted to prepare a subset of the Ninham Shand suite of time series analysis and plotting program (1995) to present the output from the HSPF and ACRU simulations. This software, which has been given the acronym "WDMPLOT", operates under DOS and hence on a multi-tasking operating system such as OS/2 or Windows 95 is able to run simultaneously with, but independently of the WDMGUIDE. An example, showing one of the output options of WDMPLOT is shown in Figure 3.1 below.

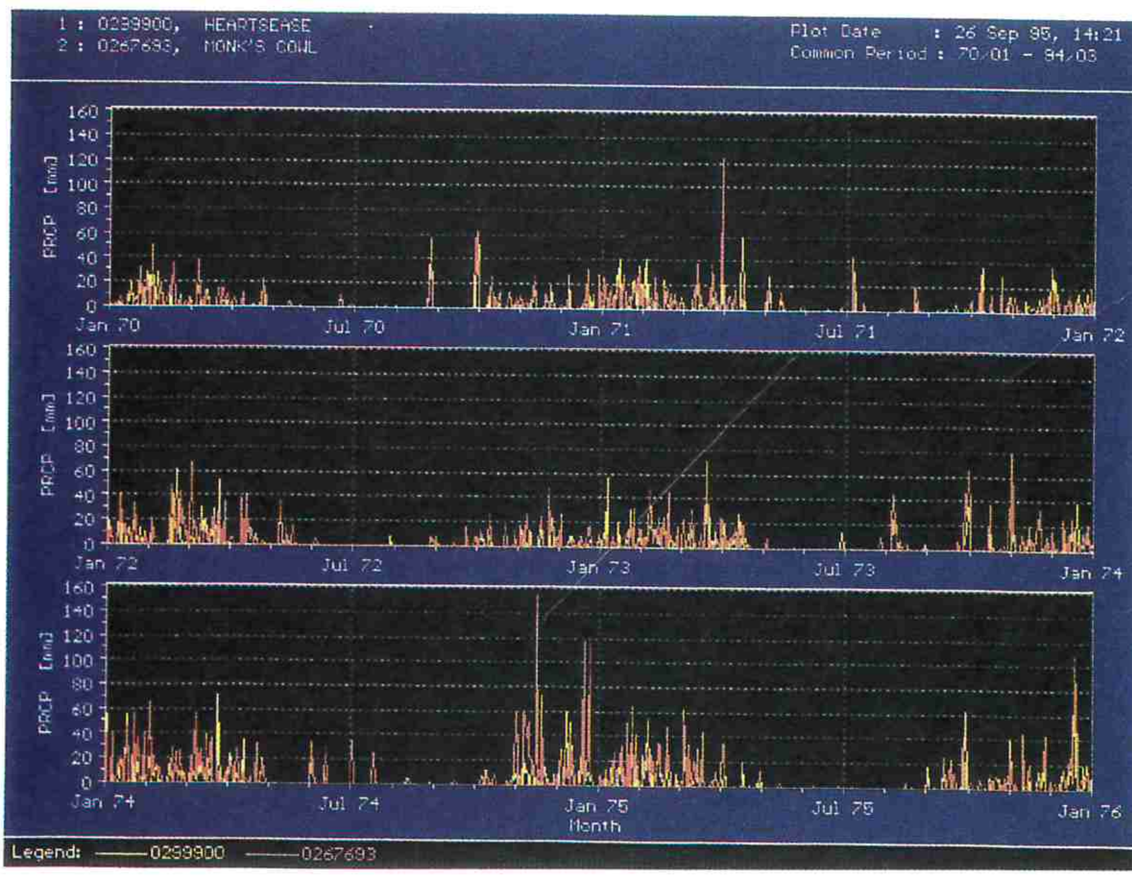

Figure 3.1 One of the output options from the WDMPLOT software

The Time Series Extraction And Manipulation System (TEAMS), which was developed inter alia by Horn (1995), is able to run simultaneously in a telnet session on the same PC.

3.5 Distributed computing platform

In a research programme such as the KNPRRP it is important to strike a balance between local and remote computing. The software system which was developed in this project sought to achieve such a balance. The geographic separation of the various participants, each of whom brings critical expertise to the KNPRRP, means that the wide area networks (WAN's) ie UNINET and the INTERNET must be used. At the same time fast response for local line graphics and GIS display is essential. The advent of multi-tasking operating systems, such as OS/2 and Windows 95 on PC's has enabled this project to strike the required balance. The enormous benefit of this development is best illustrated by referring to the screen picture in Figure 3.2 below. At the time of generating this screen image the PC in question was simultaneously connected to;

- 4 telnet sessions at remote sites on the UNINET and INTERNET systems,
- the WDMGUIDE,
- the information extraction system developed by Biggs *et al* (1995) as part of the KNPRRP's ISDM sub-programme,
- the WDMPLOT system.

In the abovementioned setup the ACRU model, TEAMS and HSPF were each running in separate sessions on the remote host. The user controls movement between these various programmes and sessions simply by the movement of the PC's mouse controller.

Using the systems developed in this project it is now possible to have the numerous research groups (and ultimately sponsors and stakeholders) involved in the KNPRRP, each with their own PC connected to the INTERNET and all viewing the same data sets and or model(s) output simultaneously. Communication with each other can then take place either via the "talk" facility on UNIX or by telephone.

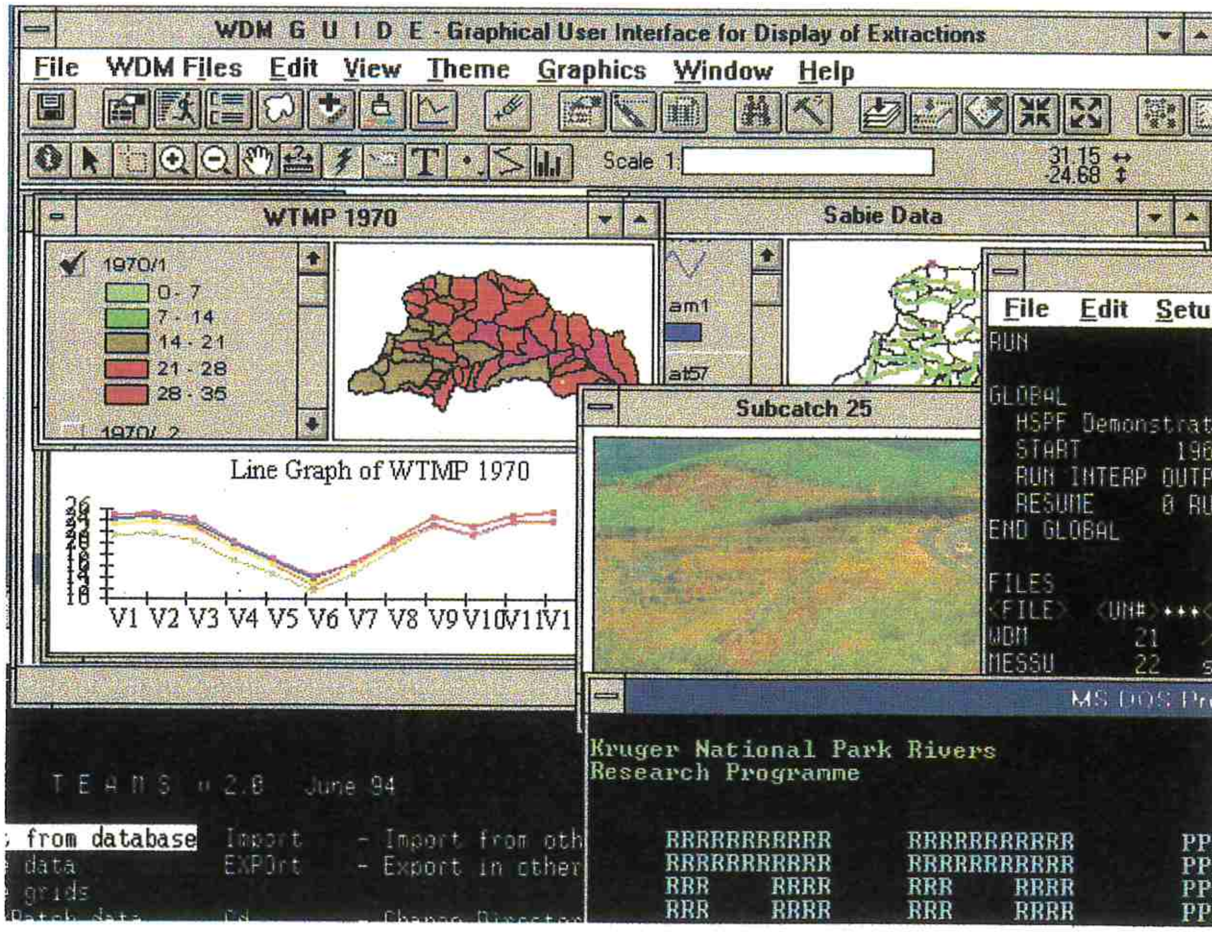

Figure 3.2 Example of multi-tasking, wide area network connectivity on users PC.

3.6 Simulation modelling

In Sections 2.1 , 2.2 and 3.1 of this report and in the KNPRRP Description by Breen, Quinn and Deacon (1994) the importance of hydrological simulation modelling was emphasised. Such modelling is necessary to generate time series of simulated water quality and quantities for the river systems of the KNP. In Sections 2.2 and 3.1, some of the reasons for selecting the HSPF modelling system were outlined and more information on the HSPF modelling system is given in Appendix A.

At this point we believe that it is pertinent to repeat that it was not a project objective to produce top quality simulations by the HSPF model. Such simulations would require data sets and knowledge of the systems and their physical interactions which are as yet far from complete and are also beyond the skills of the contractees in this project. The aim of the modelling was simply to demonstrate that the product of the above development can serve as a catalyst to foster more meaningful interaction, communication and ultimately integration amongst researchers, sponsors and stakeholders in the KNPRRP. This approach is in keeping with the strategic methodology of adaptive, participative prototyping which is discussed in Section 4.1.

Furthermore the aims of the project also state that it is intended that this approach be used to empower the teams of researchers who are seeking to integrate their work on the KNPRRP to embark on an informed search for a better modelling system at some future time when they have learned to communicate well at the detailed scientific levels required by a programme of this nature.

This last point emphasised that the HSPF and ACRU modelling systems are certainly not being proposed as the final and only solution to the simulation modelling challenges in the KNPRRP. The decision to use these modelling systems was simply a pragmatic first step, which enabled work to commence immediately. Furthermore the kinds of data which have been gathered and processed for the HSPF and ACRU models are the same as those which would be required for most other systems of similar capability. None of these efforts by the TITT sub-programme (HSPF) and DSSDM sub-programme (ACRU) will have been wasted, if, in the future the HSPF or ACRU systems is replaced. The project interfaced the GIS and time series graphics display of output to the both these systems in a generic fashion to further ensure the longevity and relevance of the work.

The ACRU/HSPF linkage is performed via the WDM. This linkage transfers the time series of water and sediment flows from the land segments (where the simulation is performed using the ACRU model) to the stream channel where HSPF takes over the modelling. In the reaches of the Sabie within the KNP, the sub-catchment boundaries were chosen to enable the hydrological simulations to provide information at the 31 locations at which the University of the Witwatersrand's, Centre for Water in the Environment (CWE) researchers had been studying morphometry, sedimentation and riverine vegetation in detail.

The modelling system outlined above is working and is producing "reasonable" natural flows. However, before such a system can be used operationally i.e. outside a prototyping exercise, it will be necessary to gather more realistic estimates of input for many of the water quality simulations and also for the water abstractions, dam operating rules and discharge characteristics of structures. It will also be necessary to glean more information into historical landuse patterns. In this regard it is recommended that the Department of Water Affairs and Forestry (DWA&F) and Agriculture be approached to become involved and that, at all times, the philosophy of best available data not requiring excessive cost be followed. In a number of cases it may be necessary to resort to expert opinion for input estimates. This last statement may raise eyebrows. However, such input estimates are not uncommon in many fields of modelling and are certainly preferable to **output** estimates.

We make no apology for the fact that the simulation of water quality and quantity has not been achieved to suitable operational levels. This was anticipated at the conception of the project and was thus stated clearly in the project aims as recorded in the contract, and explained in Sections 1 and 3.6 of this report. The recommendation from the TITT sub-programme is for the KNPRRP to now approach the DWA&F and our other suitable institutions to take over the simulation modelling in HSPF and in ACRU with the aim of producing operationally acceptable flow sequences of water quality and quantity using the modelling systems and the considerable data infrastructure which has already been established by this project.

Chapter 4

DEVELOPMENT OF THE WDMGUIDE SYSTEM

The graphical user interface which is based inter alia on Arcview2.1 and AVENUE is one of the primary products of the project. WDMGUIDE as it has been called is the software system which embodies many of the achievements of this project. It has been accepted as a key element in the prototype of the DSS system which is being crafted by the DSSDM sub-programme.

The main features of the WDMGUIDE are perhaps best illustrated through a series of screen prints accompanied by short descriptions. These will follow in the next few pages. However, before presenting these features it is necessary to discuss the subject of prototyping since the intention is for the WDMGUIDE to serve as the first prototype in a process of software development which is designed to assist the DSSDM sub-programme.

4.1 Prototyping

The prototyping strategy was built into the design of this project at conception. This is implied in Aim 3 as stated in Chapter 1.

Aim 3. *To empower the teams of researchers who are seeking to integrate their work on the KNPRRP to embark on an informed search for a better modelling system at some future time when they have learned to communicate well at the detailed scientific levels required by a programme of this nature.*

The world renowned systems software engineer and architect F.P. Brooks states;
"The management question, is not whether to build a pilot system and throw it away. You will do that. The only question is whether to plan in advance to build the throwaway, or to promise to deliver the throwaway to the customer".

Brooks (1982)

On the question of dealing with the often considerable uncertainty in computer applications and its control through the engineering of software Lehman (1989) states that software must **evolve**.

According to Tate (1990), the primary reason for prototyping is, , to buy knowledge and thus reduce uncertainty and increase the likelihood of success of a software project. Tate (1990) goes on to state that the knowledge one is seeking may relate to clarification of requirements, feasibility, user acceptance, marketability, systems behaviour or critical performance factors. Prototyping may be considered as a possible means of reducing any project risk that arises from incomplete knowledge of what is required or how to achieve it. Although the KNPRRP Description by Breen, Quinn and Deacon (1994) is considered by us to be an excellent document, it is evident that in the execution of their sub-programmes, both the TITT and DSSDM sub-programmes are required to deal with areas of considerable uncertainty. This is particularly so as we move into the integration process. The experiences of large systems software architects and engineers and their strong encouragement to prototype, should be heeded by the KNPRRP.

According to Boehm (1987), finding and fixing a software problem after delivery is 100 times more expensive than finding and fixing it during the requirements and early design phases

Dearnley & Mayhew (1983), state that it is essential that better methods are found, both of obtaining from the user and understanding the "real" systems requirements. This is often referred to as the communication problem. As Dearnley & Mayhew (1983) add, it is increasingly difficult for the systems analyst and the user to understand one another. This experience is shared within the KNPRRP as well, and it is partially the function of the TITT sub-programme to overcome this, inter alia through this prototyping project.

The conventional approach to systems design is one in which the user is passive and the analyst active. The only part the user plays is when s/he is interviewed by the analyst during the fact-finding investigation. Dearnley and Mayhew (1983) state that it is their experience that; " To protect themselves from recrimination many analysts would pressurise the user into signing documents agreeing to the design, when the user does not fully understand the consequences. This does little to help create better-fit systems and often generates mistrust." Certainly something that we would wish to avoid in the KNPRRP.

In contrast the participative approach allows the user more control over the project direction. It was the desire to assist the participative approach which motivated this project. Benefits of this participative approach are;

* greater commitment on the part of the user to the new system
* greater understanding on the part of the user of any changes necessary to make it work
* better understanding of the new system
* most important, is better access to the user's knowledge and understanding of the problem

Dearnley & Mayhew (1983) maintain that one of useful techniques to assist with the particpative approach is prototyping, which has a number of advantages over other, more formal approaches. Prototyping ;

* is an exceptionally efficient method of fact finding,
* is excellent when systems requirements are difficult to establish,
* is good when dealing with inexperienced users,
* is effective when the situation and the environment are changing or uncertain,
* enables the user and the analyst to converse in more real terms,
* facilitates substantial saving of time,
* allows user to check that s/he has explained exactly what was required,
* allows the analyst the opportunity to check his/her understanding of the problem,
* foster the generation of "team spirit" feeling between user and analyst,
* encourages a continuos communication between user and analyst,
* is an excellent learning tool Brittan (1980),
* has succeeded where conventional approaches to systems design (not involving prototyping) have proved inadequate in the more complex areas,
* is suited to on-line development, *(given the high travel costs in SA we must make more use of the INTERNET in this regard)*
* are used as part of a mutual learning process for both user and analyst, thus diminishing the possibilities of communications problems
* encourage loopbacks which are used in order to gain as much information as possible

In the light of the above it is not surprising that the TITT sub-programme of the KNPRRP should have initiated a project such as the one being reported in this document.

Realistically there must be **disadvantages** in any course of action and prototyping has a few. One of the disadvantages is that people tend to latch onto a relatively crude prototype and use it as ammunition against the system. Another is that if the prototype has been amended with ease and speed , there is a chance that the inexperienced user might think this is normal and that the production system can change at the same speed. For this reason the inexperienced user may not appreciate the importance of designing a complete, correct system. It is up to the analyst to avoid this situation.

It is often the case that diagrams are worth many words. The diagrams below are included to illustrate several important points concerning protoyping and its operation in practice.

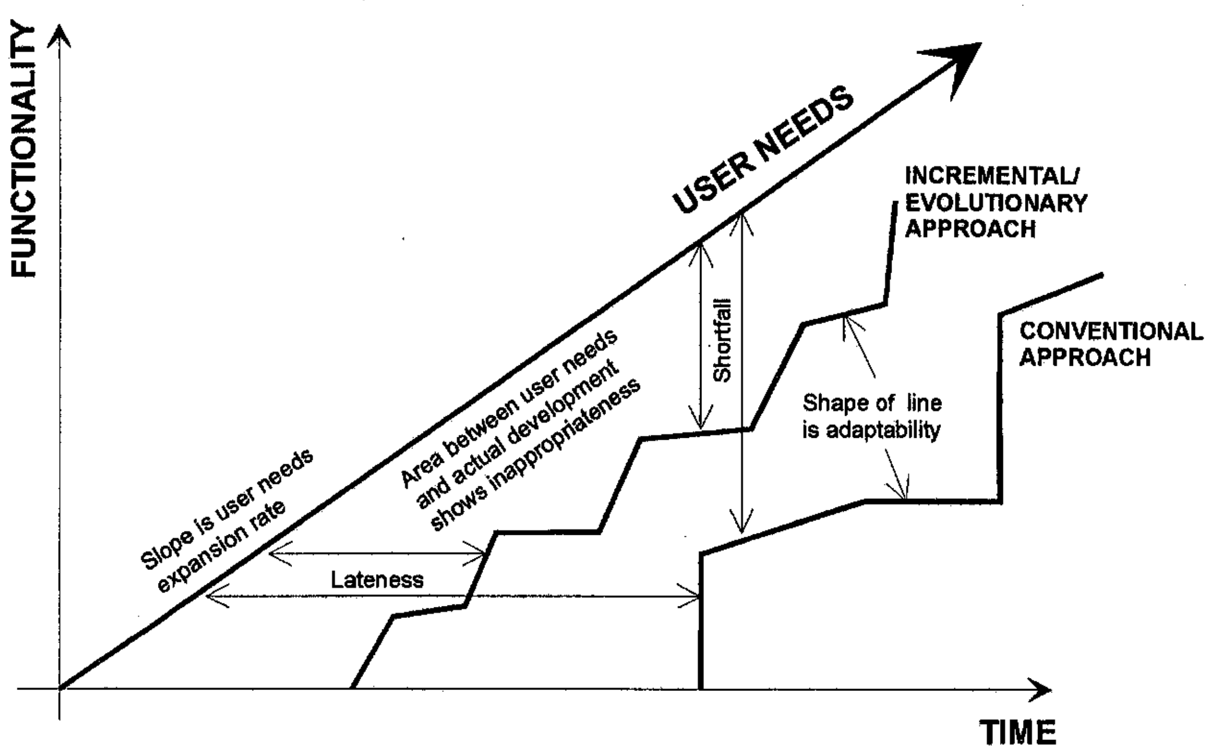

Figure 4.1 Diagram comparing evolutionary/incremental and conventional prototyping approaches (after Davis *et al* 1988)

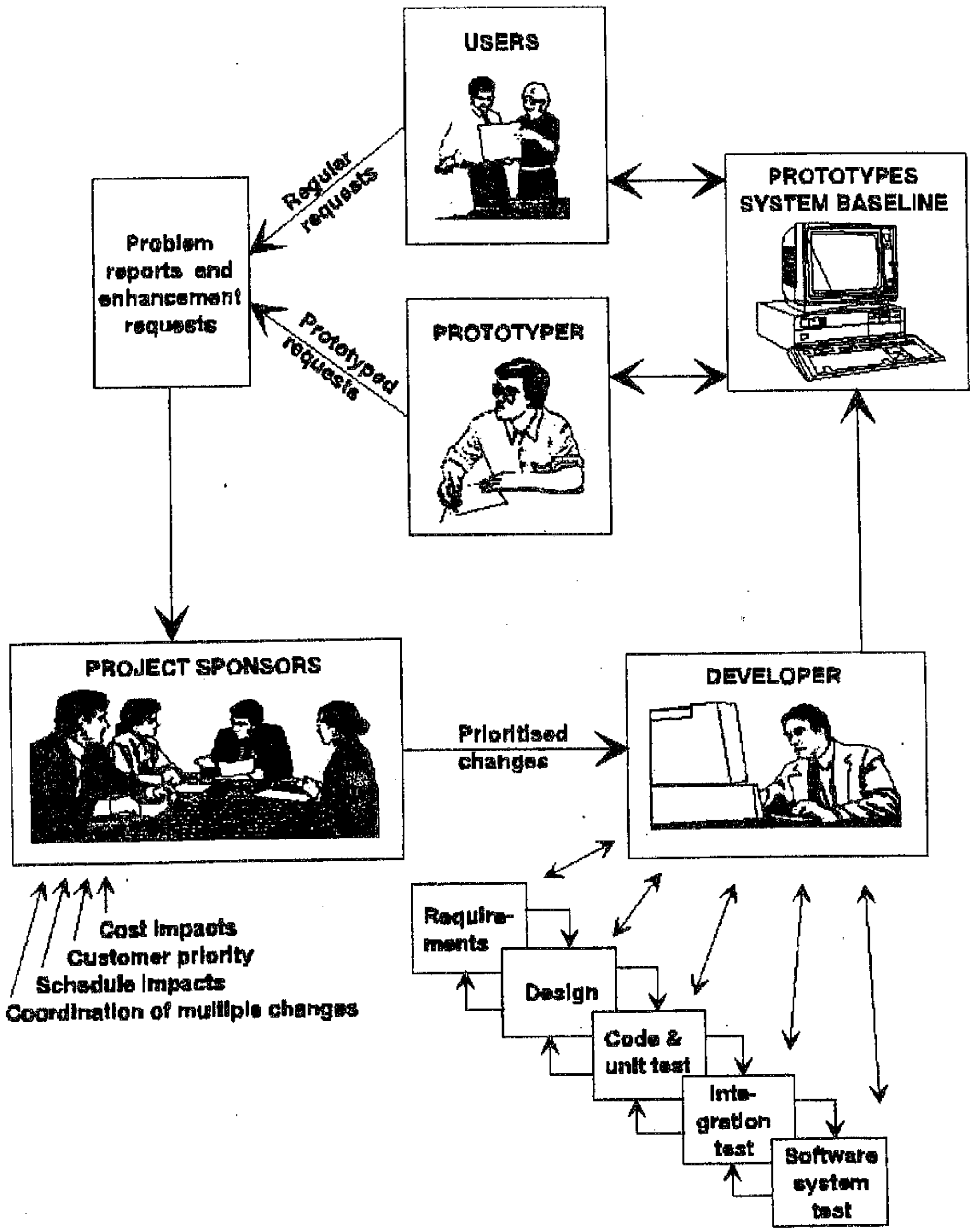

Figure 4.2 Configuration management for operational prototyping (after Davis 1992)

Rapidity in prototyping is most commonly achieved by using standard components (Tate, 1990). It is for this reason that one of the key strategies of this project has been to employ "standard" software wherever possible. The only new portion of the system has been the interfacing and some code written in AVENUE. The ACRU, HSPF, Arcview2.1, the WDM, and much of the CCWR's software could all be considered "standard". It certainly did not have to be written from scratch for this project. The emphasis fell heavily on interfacing. The development of the Ninham Shand software WDMPLOT was also largely an interfacing exercise, performed off a base of software which was "standard" to its developers. A good prototype is one which has the right balance of simplicity and reality at an acceptable price

4.2 WDMGUIDE features

The WDMGUIDE software runs on a PC under Windows or on a UNIX workstation. As mentioned above the basic interface comprises the wide array of standard features of Arcview2.1. During the course of this project the AVENUE programming language has been invoked to allow the intelligent, user friendly, mouse and menu driven interaction with time series, image and Arc/Info data sets which reside either locally and remotely i.e. elsewhere on a LAN or on UNINET or INTERNET.

At present the system has the following features, some of which will be illustrated in the ensuing pages.

* graphical query of selected variables at any point in the stream network and for any of the simulated time periods (Figure 4.3)
* ability to query and plot any number of variables at the same time (Figure 4.4)
* query a single river reach, downstream trace of river reaches, upstream trace of river reaches OR all the river reaches in the whole system (Figure 4.5)
* query sub-catchments for a list of available images and display these (Figure 4.6)
* query the textual information at selected river reaches (Figure 4.7)
* display the whole range of GIS coverages which are listed in Section 3.2 and which appear in graphical form in Appendix C.
* step through and display, through colour coding on the river network, a monthly time series of any preselected variable (Figure 4.8)

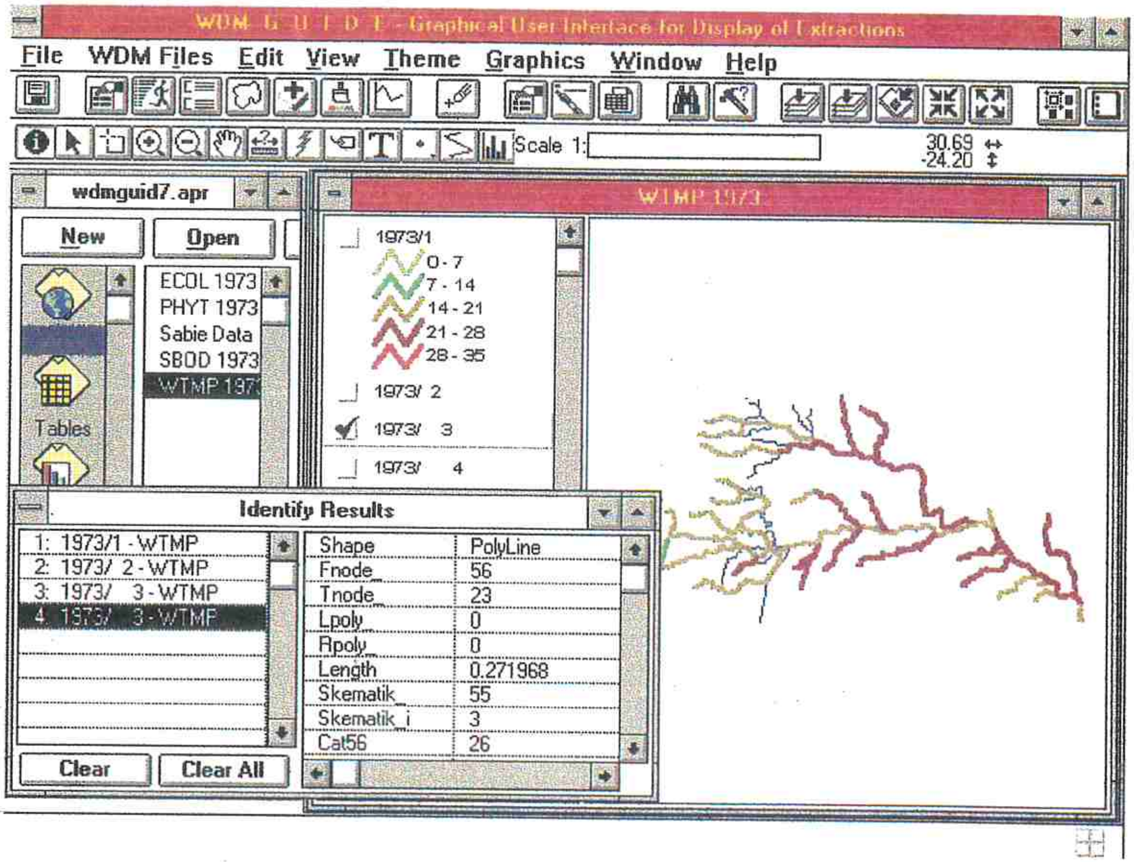

Figure 4.3 Graphical query of selected variables at any point in the stream network and for any of the simulated time periods

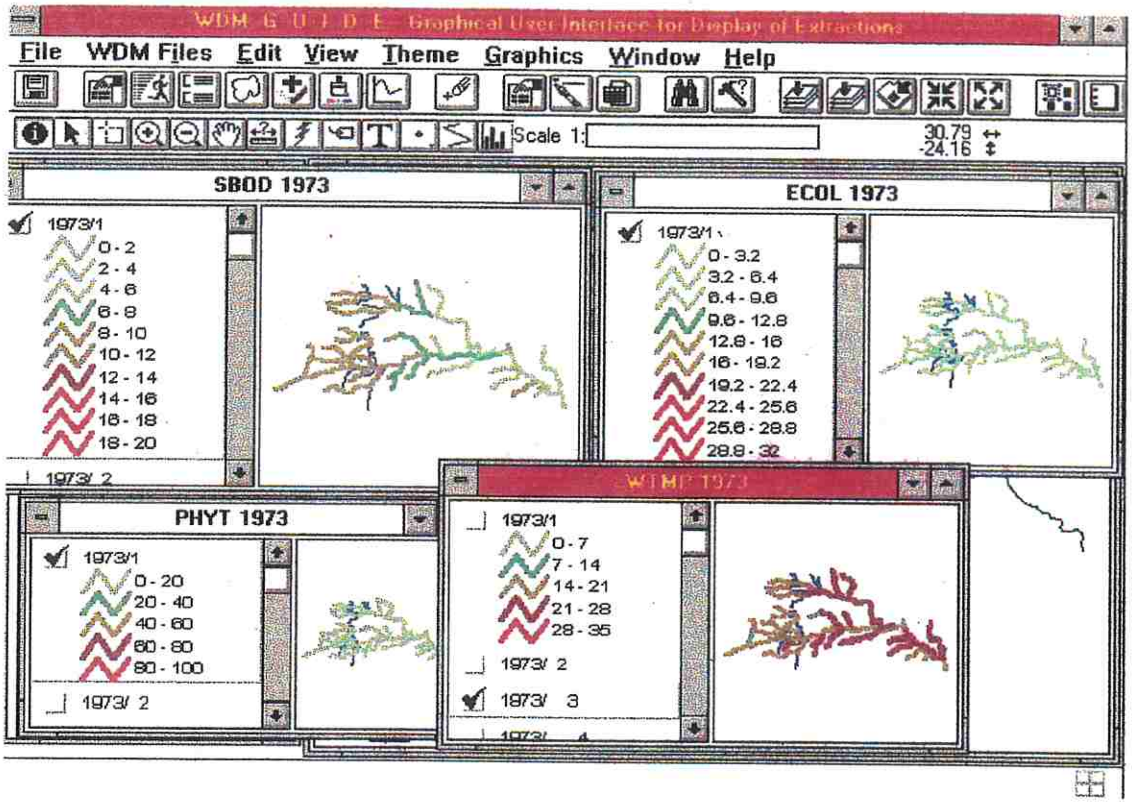

Figure 4.4 Query and plot any number of pre-selected variables at the same time

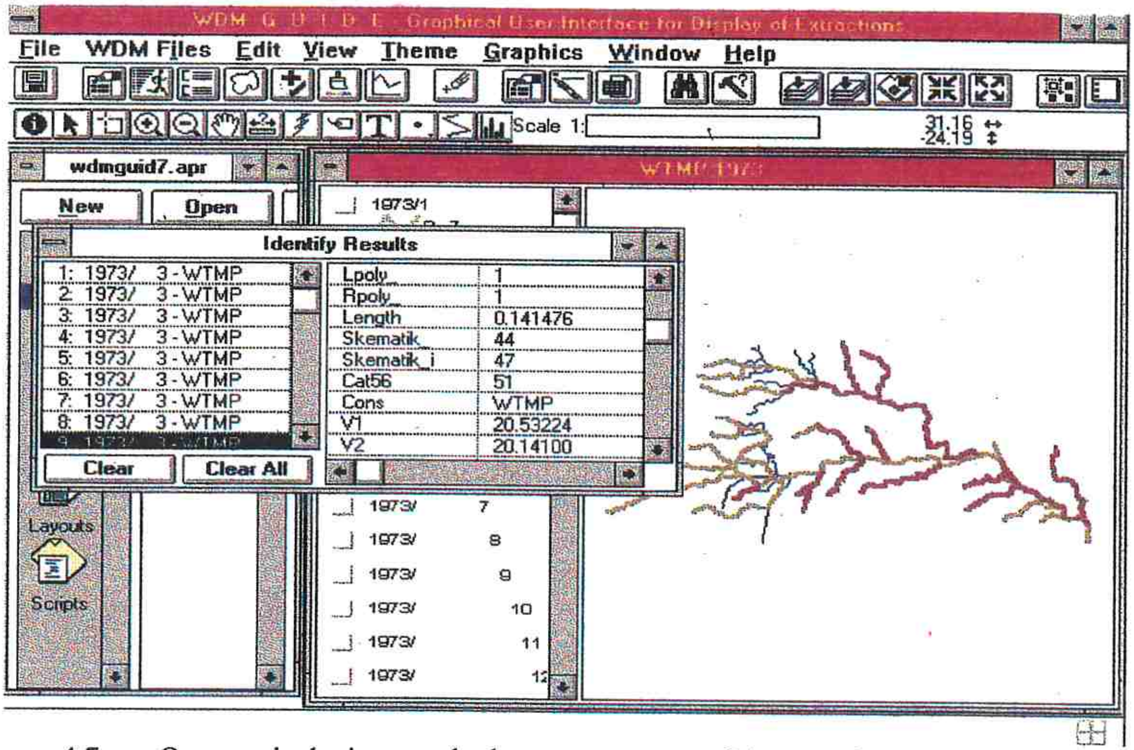

Figure 4.5 Query a single river reach, downstream trace of river reaches, upstream trace of river reaches OR all the river reaches in the whole system

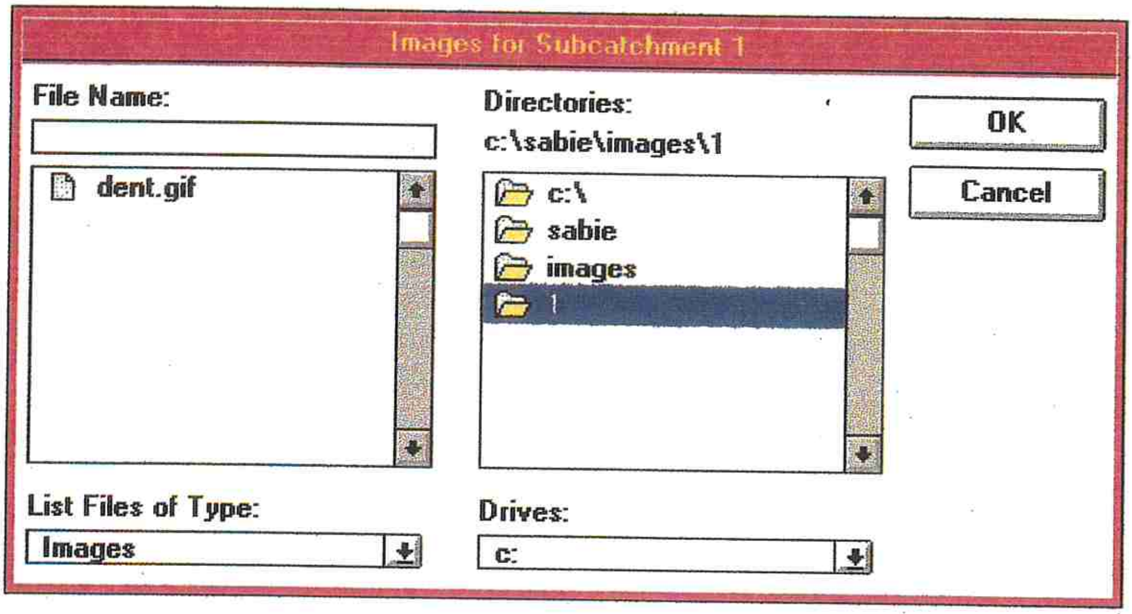

Figure 4.6 Query sub-catchments for a list of available images and display these

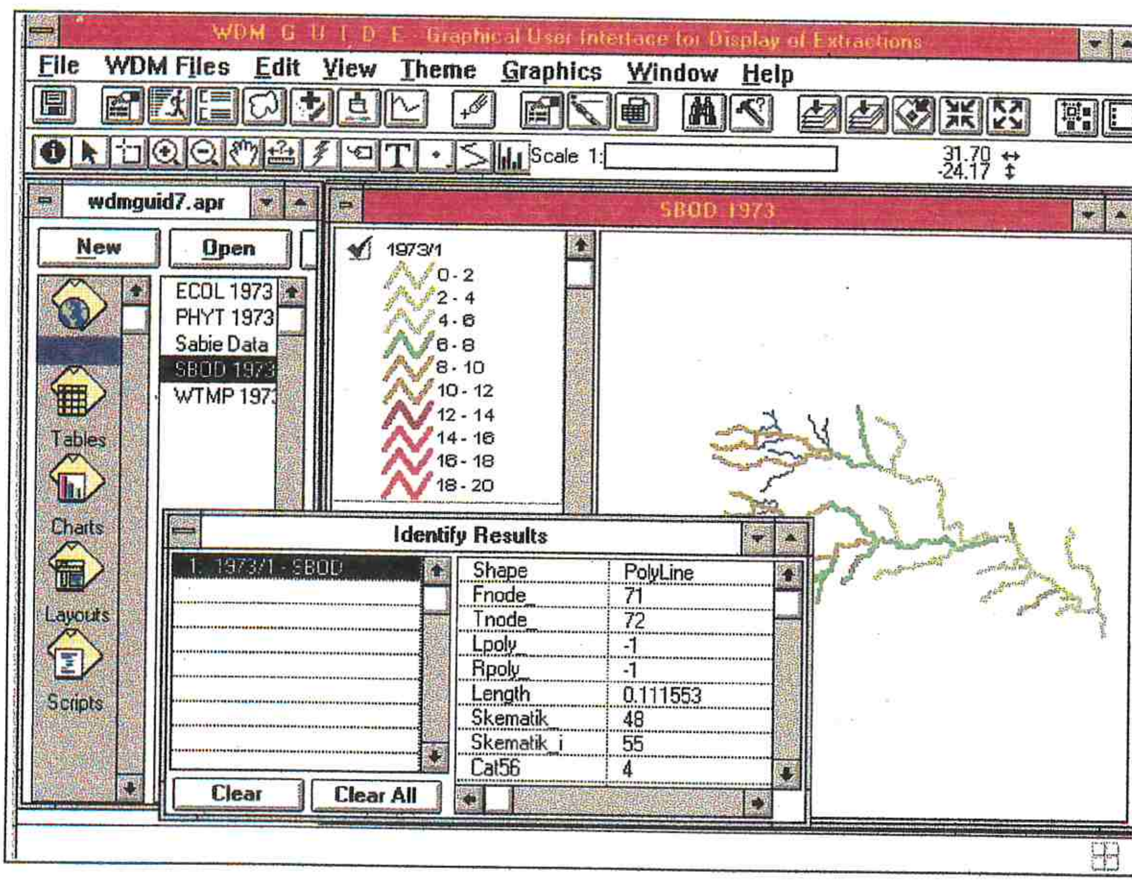

Figure 4.7 Query the textual information at selected river reaches.

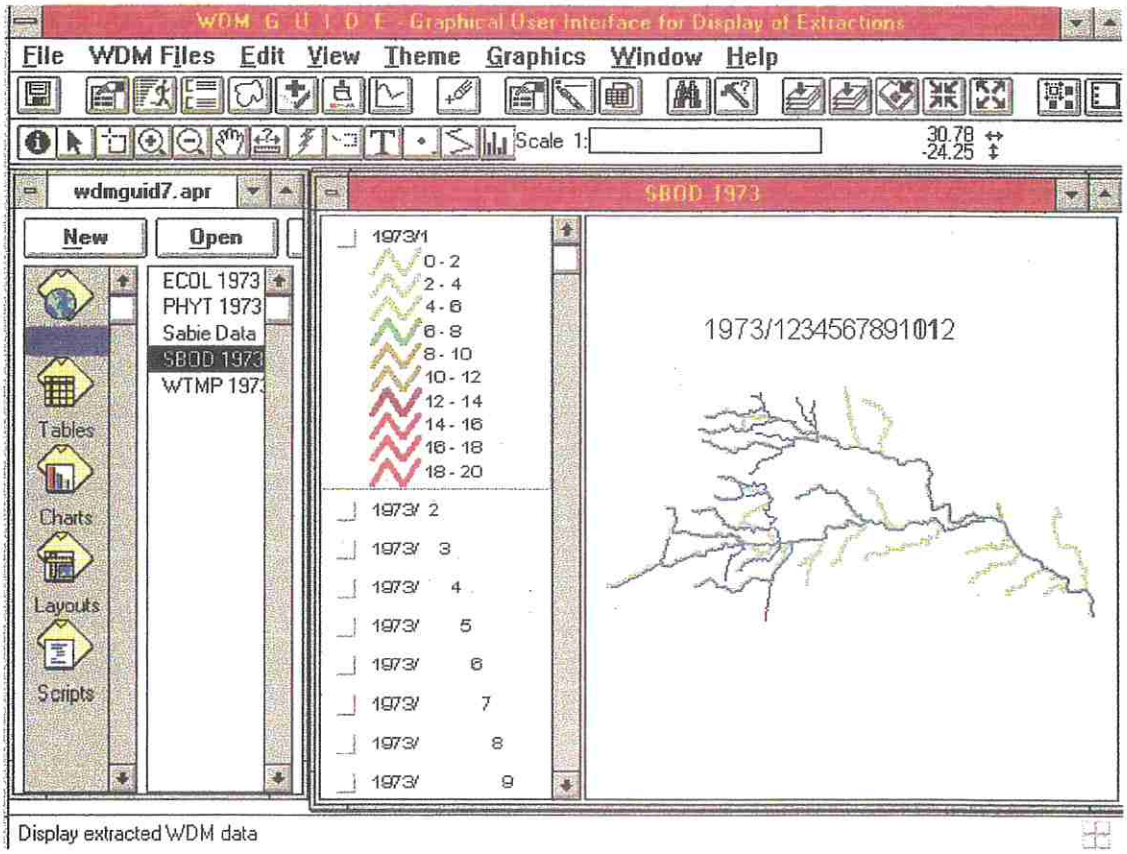

Figure 4.8 Step through and display, through colour coding on the river network, a monthly time series of any preselected variable

One of the features of this system is its ability to combine images, line graphs and text information in a manner which offers exciting potential for conveying unfamiliar and difficult concepts to a variety of audiences.

Two features to be included in the WDMGUIDE soon, are firstly, pictures and cross sectional diagrams at each of the morphological study sites within the Sabie system (Heritage and van Niekerk, 1995). The second feature is to include a geographic location table (where applicable) in the Data Catalogue which has been produced in the ISDM sub-programme Biggs *et al* 1995). Already the DBASE files from the catalogue have been imported into Arcview2.1 and may be queried by Arcview's menu driven query system. The addition of geographic co-ordinates will enable query sites to be located on the maps and queries to be initiated using the mouse.

The WDMGUIDE succeeds in achieving "integration" between the various sub-system described in this report through a mixture of interfaces and bridges and by using the power of multi-tasking windows systems combined with the user's mind to bridge time and space.

To conclude this section it must be stressed at the outset that what has been achieved so far is simply a first step in prototyping which enables researcher, sponsors and stakeholders to view and interact with the available technology and thereby stimulate ideas and needs for future developments. The real value of the system will only be realised if these needs are now articulated and transformed into actions for the next generation of this prototype as it is absorbed into the DSS. Early indications are that the WDMGUIDE is having the anticipated effect and is indeed stimulating more clearly defined needs and innovative ideas.

Chapter 5

INSTITUTIONAL LINKAGES

Modelling system and WDMGUIDE which was developed in this project is not an end in itself. The acid test of its usefulness is the extent to which it assists the objectives of the TITT sub-programme of the KNPRRP. Underlying all the detailed objectives in the TITT sub-programme is the need to effectively link the minds of scientists working at various institutions , countrywide, and whose intellect and expertise is required by a programme such as the KNPRRP. The KNPRRP cannot be seen in isolation from the rest of the research and development work in this line in southern Africa. This is made clear in the statement of the goals in the KNPRRP Second Phase: Programme Description ;

* *TO DEVELOP, TEST AND REFINE METHODS FOR PREDICTING THE RESPONSES OF THE NATURAL ENVIRONMENTS OF RIVERS FLOWING THROUGH THE KRUGER NATIONAL PARK AND IN SOUTHERN AFRICA TO CHANGING WATER QUALITY AND PATTERNS OF SUPPLY.*

Pg 22 Breen, Quinn & Deacon (1994)

In the light of the above, the TITT sub-programme felt that it was important to link the progress made on the WDMGUIDE with other major initiatives being taken by water authorities and research institutions elsewhere in the country. The joint Water Research Commission / University of Natal/ Mgeni Water, installed modelling system for the Mgeni is the first of such initiatives which has adopted the WDMGUIDE and related technology. The WDMGUIDE was exhibited at the 1995 South African National Hydrological Symposium where it generated much interest and several research institutions and consulting firms acquired copies of the software.

Throughout this project we have kept in contact with the Institute for Water Quality Studies in the DWA&F from whom a number of the initial ideas were gleaned. Through the stimulus of this project the CCWR and the IWQS have developed sound contacts between scientists and the interflow of ideas and exchange of programs and information is encouraging to witness. It is our belief that these relationships, which are building trust and faith, are going to be vital for the success of integrated catchment management in the future.

The long list of acknowledgements which appears in the front of this project report is an indication of the degree of interaction which has occurred with various institutions during this project. We believe that systems such as those developed in this project are going to prove their considerable worth as the INTERNET takes off in southern Africa and close regional co-operation on water issues requires effective interaction at the functional model level over the wide are networks.

Further afield on the international front, the decision to use the HSPF modelling system and the WDM, opened up a large number of contacts in the USA primarily. This is evident from the report by de Vos (1995). The KNPRRP and particularly the role that the HSPF and ACRU modelling systems and the WDMGUIDE are playing was the subject of much discussion on the study visit described by de Vos (1995). The KNPRRP is therefore also gaining international exposure through the successful work of this project.

Chapter 6

CONCLUSION

6.1 General

Integrated catchment management cannot be founded on dis-integrated science. The basis of sound integration is good communication and the basis of that communication is a sound knowledge of the subject matter to be conveyed and a recognition that the process of communication is as important as the content of that communication.

This project has succeeded in providing a structured and operational form of communication between the research groups within the KNPRRP, both at the conceptual and technical level. As such, it is the view of the authors', that this project has contributed significantly to the TITT sub-programme objectives and to those of the KNPRRP as a whole.

This project has served to illustrate the practical advantages of the prototyping approach to systems development in complex and uncertain environments. According to Dearnley and Mayhew (1983), prototyping is one of the best approaches to systems development since it encourages and facilitates early user involvement that is both active and meaningful. Such involvement is vital for the KNPRRP's decision support system if it is to possess the utility required and embody the users and stakeholders trust.

This concluding chapter will now end with sections on the perceived achievements of this project and some recommendations for future research and for the systems developed in this project.

6.2 Specific achievements in terms of project aims

In terms of Aim 1 :

The framework of a modelling system which incorporates *inter alia* ARC/INFO, the ACRU agro-hydrological modelling system, HSPF for instream processes and flow routing and the Watershed

Data Management System (WDMS), into a flexible, versatile and professional tool, has been developed for the Sabie River.

It must be stressed again that the objective, as stated in the contract, was NOT to prove the quality of simulation by the models. That would require data sets and knowledge of the systems and their physical interactions which are as yet far from complete and are also beyond the skills of the contractees in this project. The aim was to provide a framework and a platform which was capable of rapid and cost effective refinement in the future.

In terms of Aim 2 :

It has been demonstrated that the product of the above development can serve as a catalyst to elicit more meaningful interaction, communication and ultimately integration than is presently the case amongst researchers in the KNPRRP.

In terms of Aim 3 :

The project is beginning to empower the teams of researchers who are seeking to integrate their work on the KNPRRP to embark on an informed search for a better modelling system at some future time. Researchers are, through this project, learning to communicate at the detailed scientific levels required by a programme of this nature.

The TITT sub-programme is now in a position to offer geographically scattered groups, the ability to simultaneously view, manipulate and analyse the same information. Such information can be text, numerical or graphical. Further tools have been developed to view the time dependent data in temporal and spatial context. Such facilities will substantially enhance the tempo and synergy which can be applied to the situation. The technology developed in this project is capable of achieving this in a most cost effective manner. Furthermore, through this project the TITT sub-programme has acted as a catalyst to secure a growing commitment from a range of scientists to work together on these developments in such a way that the established expertise base of each group is not threatened. A key objective in all cases has been to find the most cost effective and non-intrusive way to interface the work of each group.

The project has also served as the focal point and interface for developing links between the KNPRRP and many institutions, both nationally and internationally.

6.3 Recommendations for future research and for custodianship of the system

The personnel on this project have worked closely with the DSSDM sub-programme. The intention is now incorporate the WDMGUIDE into the decision support system. The system needs to be further operationalised by incorporating the numerous abstractions from the Sabie and its tributaries and also the dams and their operating rules. The water quality simulations will also have to be improved with the incorporation of more comprehensive landuse and point discharge information. It is recommended that the KNPRRP seek the assistance of the DWA&F in this regard.

The DSSDM sub-programme intends to use the products of this project to assist with the prototyping exercises required to formulate the abiotic/biotic links in the DSS. It is believed that this work will commence shortly. Much of this new work may include the rules, frames and states paradigms for dynamic ecosystem modelling as articulated by Starfield et al (1993). The WDM and the WDMGUIDE provide an excellent base from which to proceed with this form of modelling which has a great need for time series management, analysis and display.

As far as the custodianship of the products of this project are concerned, it is intended (for the present) that they should be housed, inter alia, at the Computing Centre for Water Research (CCWR). It is further recommended that copies of the WDMGUIDE software portion of the project should be distributed to the research centres at which the key role players in the KNPRRP are working viz. Freshwater Research Unit at UCT, Centre for Water in the Environment, University of the Witwatersrand, the Institute for Water Research, Rhodes University, the Institute for Water Quality Studies, DWA&F and the National Parks Board at Skukuza. The proposed budget for the TITT sub-programme for 1996 has made provision for this. The technology is already available at Stellenbosch University where it has been used in the close collaboration between the DSSDM and TITT sub-programmes over the past 6 months.

The TITT sub-programme intends to offer training courses on this software in 1996 and provision is made on the 1996 budget for travel to the abovementioned centres to carry out that training. Such training will be carefully co-ordinated with the DSS and other sub-programme managers.

Chapter 7

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APPENDIXES

APPENDIX A

INSTITUTIONAL STRENGTHS AND TECHNICAL FEATURES OF THE HSPF MODELLING SYSTEM

Institutional Strengths

* HSPF was developed by Hydrocomp in the USA under contract to the EPA. First published in 1980, it has been in the public domain for 14 years. It is continually updated and refined by a consulting consortium in the USA under contract to the EPA. Version 10 has just been published.
* Locally the CCWR has committed itself to running HSPF as a pragmatic first step in the long process of forging better communication between scientists from different disciplines.
* HSPF is well suited to use to guide field data collection (please see the article "Data led modelling to modelling led data")
* Internationally perhaps the most well known application of the HSPF modelling system is in the Chesapeake Bay Programme, where the management goal is to reduce the nutrient loading into Chesapeake Bay by 40 per cent.

  This is a detailed, ongoing, multi-disciplinary, multi-organisational programme being carried out on large and complex catchments.

Technical Features

* executable on UNIX, DOS and other platforms
  - professionally documented
  - computer code has been professionally written and adheres strictly to standards and structured programming techniques
  - user documentation is comprehensive
  - default settings supplied (where reasonable)
  - errors and warnings are comprehensive and informative
  - units are BOTH Imperial and Metric
* time series data base

- system is based on the Watershed Data Management (WDM) system which is used by the USDA, USGS, US-SCS and the EPA and is maintained by the USGS
- the CCWR has built a Timeseries Extraction and Manipulation system (TEAMAN) onto the WDM to give added functionality

* spatial resolution
  - from field scale to large catchments
  - user defined networks of interlinking sub-catchments of arbitrary complexity
  - river reaches of several metres up to many kilometres
* time steps
  - 19 time steps available in range from 1 minute up to 1 day
  - dynamic, automatic aggregation and disaggregation of time steps

* hydrology and water quality of pervious and impervious land segments and river reaches as well as well mixed reservoirs
* hydraulic behaviour of river flow
* soil loss and sediment transport
* advection of fully entrained constituents

Conservative Constituents

Such as:

* - total dissolved solids (TDS)
  - chlorides

Water Temperature Simulation

* using heat exchange

Inorganic Sediments

* sand, silt and clay

Generalized Quality Constituents

Constituents may be present in sediment-associated or dissolved state

- Advection of dissolved and sediment-associated material
- Decay processes

  # hydrolysis

  # oxidation by free radical oxygen

photolysis

volatilization

biodegradation

generalized first-order decay

- Production of one generalized quality constituent as a result of decay of another generalized quality constituent by any of the listed decay processes except volatilization. This capability is included to allow for situations in which the decay products of a chemical are of primary interest to the user.
- Advection of adsorbed suspended material
- Deposition and scour of adsorbed material
- Decay of suspended and bed material
- Adsorption/desorption between dissolved and sediment-associated phases
- Used for constituents such as pesticides

CONSTITUENTS IN BIOCHEMICAL TRANSFORMATIONS

- DO and BOD

The following are considered:

longitudinal advection of DO & BOD

sinking of BOD material

benthal oxygen demand

benthal release of BOD material

reaeration

oxygen depletion due to decay of BOD materials

Optionally, the following processes can also be simulated, together with their effect on DO and BOD.

NITROGEN

- ammonia
- nitrite
- nitrate
- total organic nitrogen

- dead refractory organic nitrogen

In simulating nitrogen & phosphorus balances the following are considered:

longitudinal advection of NO3, NO2, NH3 and PO4

benthal release of inorganic nitrogen and PO4

ammonia vaporization

nitrification

denitrification

ammonification due to degradation of BOD materials

release from the benthos

release through degradation of BOD materials

PHOSPHORUS

- total organic phosphorus
- ortho-phosphorus
- dead refractory organic phosphorus

PLANKTON

photosynthetic and respiratory activity by plankton and/or benthic/algae

grazing and respiration by zooplankton

death of plankton

nonrefractory organic excretion by zooplankton (effect on BOD)

nutrient uptake by phytoplankton and/or benthic algae

respiration and inorganic excretion by zooplankton

CARBON

- total organic carbon
- dead refractory organic carbon

CARBON DIOXIDE and TOTAL INORGANIC CARBON (TIC)

HSPF assumes that changes in the TIC concentration occur only as changes in CO2 concentration.

Sources:

carbon dioxide invasion (input) from the atmosphere

zooplankton respiration

carbon dioxide released by BOD decay

respiration and death of algae

benthal release of carbon dioxide

Sinks:

carbon dioxide release to the atmosphere

net growth of algae

pH

ALKALINITY

TIME SERIES OF TOXIC QUALITY CONSTITUENTS CAN BE PROCESSED TO PRODUCE A LETHALITY ANALYSIS

APPENDIX B

HSPF WORKSHOP PARTICIPANTS

Workshop held at the Department of Landscape Architecture, University of Pretoria, from 4 - 6 July 1994 .

Dr A. Bath, Ninham Shand Inc.

Dr H. Biggs, National Parks Board

Prof C. Breen, INR, University of Natal

Dr L. Broadhurst, Centre for Water in the Environment, University of the Witwatersrand

Ms C. Brown, Institute for Freshwater Studies, University of Cape Town

Mr C. Bruwer, Environmental Div., Dept. Water Affairs & Forestry

Mr K. de Smidt, Ninham Shand Inc.

Mr R. de Vos, CCWR, University of Natal

Dr A. Deacon, National Parks Board

Dr M. Dent, CCWR, University of Natal

Ms S. Freitag, Dept. of Zoology, University of Pretoria

Mr B. Gardner, Watertek, CSIR

Prof. A. Görgens, Dept. Civil Engineering, University of Stellenbosch

Mr M. Horn, CCWR, University of Natal

Mr P. Huizinga, EMATEK, CSIR

Mr G. Jewitt, Dept. Civil Engineering, University of Stellenbosch

Prof. R. Johanson, School of Engineering, University of the Pacific, California, USA.

Dr C. Kleynhans, Institute for Water Quality Studies, Dept. of Water Affairs and Forestry

Dr A. Kuhn, Institute for Water Quality Studies, Dept. of Water Affairs and Forestry

Dr S. Lorentz, Dept. Agricultural Engineering, University of Natal

Mr H. Maaren, Water Research Commission

Dr B. Marjanovic, Centre for Water in the Environment

Mr D. McPherson, Dept. Water Affairs & Forestry

Mr R. Nundlall, CCWR, University of Natal

Dr J. O'Keeffe, Institute for Water Research, Rhodes University

Dr C. Palmer, Institute for Water Research, Rhodes University

Dr G. Pegram, Ninham Shand Inc.

Ms M. Pillay, Umgeni Water

Prof. K. Rogers, Centre for Water in the Environment

Mr W. Rowlston, Strategic Planning, Dept. Water Affairs & Forestry

Ms J. Slinger, EMATEK, CSIR

Mr A. van Niekerk, Centre for Water in the Environment

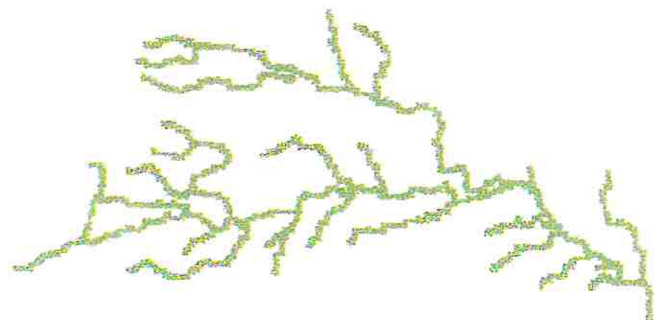
Mr J. van Rensburg, GISLAB, University of Pretoria

Dr F. Venter, National Parks Board

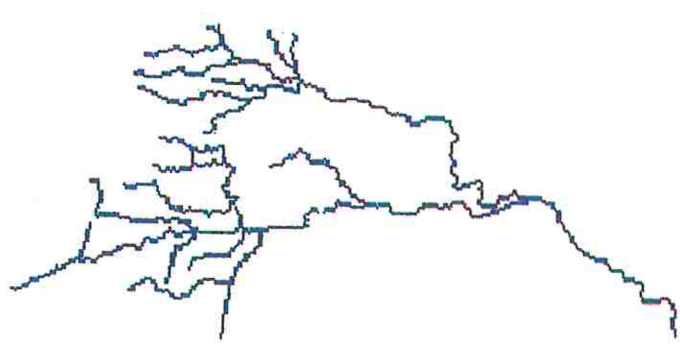
Note: The people whose names appear in bold print were speakers on the programme

APPENDIX C

GIS Coverages for the Sabie /Sand River system

GIS Data Coverage Description	
Coverage name	Skematik
Description	Main rivers (1 each in sub-catchment) of Sabie river catchment
Scale of capture	1:250 000
Geographic data type	Lines
Geographic display	

Relevant Data Fields		
Field name	Type	Description
Cat56	Numeric	River sub-catchment number

GIS Data Coverage Description	
Coverage name	Rivers
Description	Main rivers (1 each in sub-catchment) of Sabie river catchment
Scale of capture	1:250 000
Geographic data type	Lines
Geographic display	

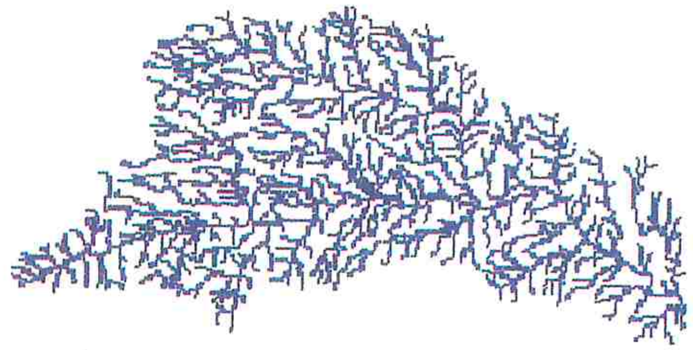
Relevant Data Fields		
Field name	Type	Description
Rivers-id	Numeric	Value not significant

GIS Data Coverage Description	
Coverage name	Dam1
Description	Existing and proposed dams in Sabie river catchment
Scale of capture	1:50 000
Geographic data type	Polygons
Geographic display	

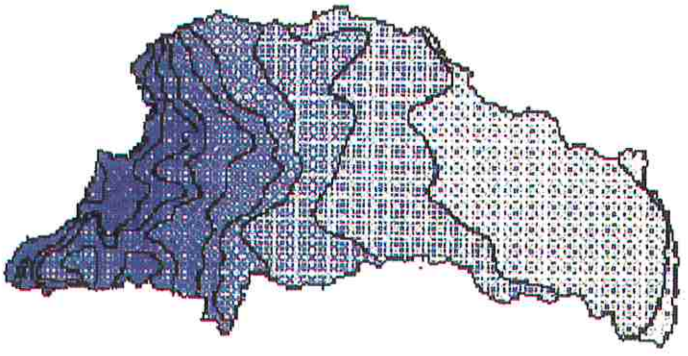
Relevant Data Fields		
Field name	Type	Description
Dam_name	Character	Name of dam
Status	Character	Indicating existing (E) or proposed (P)

GIS Data Coverage Description	
Coverage name	Cat57
Description	Sub-catchment boundaries within the Sabie river catchment
Scale of capture	1:250 000
Geographic data type	Polygons
Geographic display	

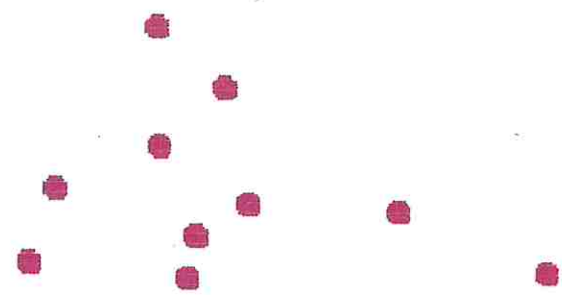
Relevant Data Fields		
Field name	Type	Description
Cat57-id	Numeric	Sub-catchment number
Area_km2	Numeric	Area measured in square kilometres

GIS Data Coverage Description	
Coverage name	Tribs
Description	All tributaries in the Sabie river catchment
Scale of capture	1:250 000
Geographic data type	Lines
Geographic display	

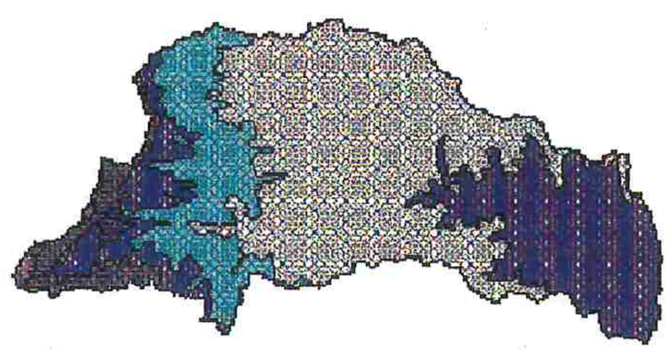
Relevant Data Fields		
Field name	Type	Description
Tribs-id	Numeric	Value not significant

GIS Data Coverage Description	
Coverage name	Mappt
Description	Mean annual precipitation for Sabie river catchment
Scale of capture	Converted from CCWR 1 minute grid data
Geographic data type	Polygons
Geographic display	

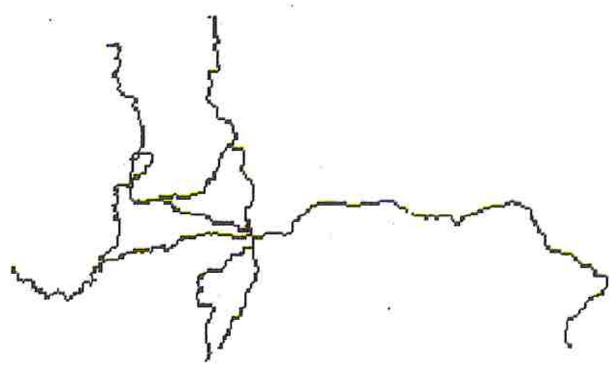
Relevant Data Fields		
Field name	Type	Description
Isohyet	Numeric	Value of mean annual precipitation

GIS Data Coverage Description	
Coverage name	Towns
Description	Major towns in the Sabie river catchment
Scale of capture	1:250 000
Geographic data type	Points
Geographic display	

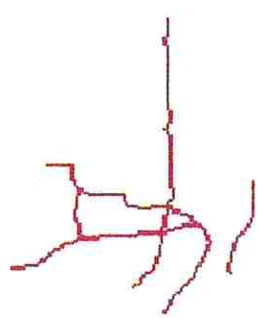
Relevant Data Fields		
Field name	Type	Description
Town_name	Character	Town name

GIS Data Coverage Description	
Coverage name	Topog
Description	Topography
Scale of capture	1:250 000
Geographic data type	Polygons
Geographic display	

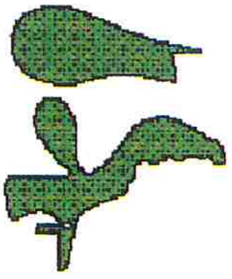
Relevant Data Fields		
Field name	Type	Description
Topo-masl	Character	Mean elevation above sea level

GIS Data Coverage Description	
Coverage name	Roads
Description	Main roads in the Sabie river catchment
Scale of capture	1:250 000
Geographic data type	Lines
Geographic display	

Relevant Data Fields		
Field name	Type	Description
Roads-id	Numeric	Value not significant

GIS Data Coverage Description	
Coverage name	Pwerln
Description	Main ESKOM transmission lines within Sabie river catchment
Scale of capture	1:250 000
Geographic data type	Lines
Geographic display	

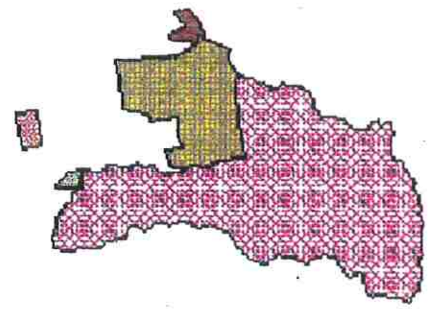
Relevant Data Fields		
Field name	Type	Description
Pwerln-id	Numeric	Value not significant

GIS Data Coverage Description	
Coverage name	Potirrig
Description	Areas of potential irrigation
Scale of capture	Unknown
Geographic data type	Polygons
Geographic display	

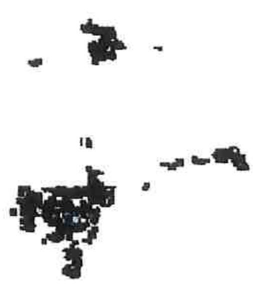
Relevant Data Fields		
Field name	Type	Description
Potirrig_i	Numeric	Value of 1 indicates areas of potential irrigation

GIS Data Coverage Description	
Coverage name	Popden
Description	Areas with population density indicated within Sabie river catchment
Scale of capture	Unknown
Geographic data type	Polygons
Geographic display	

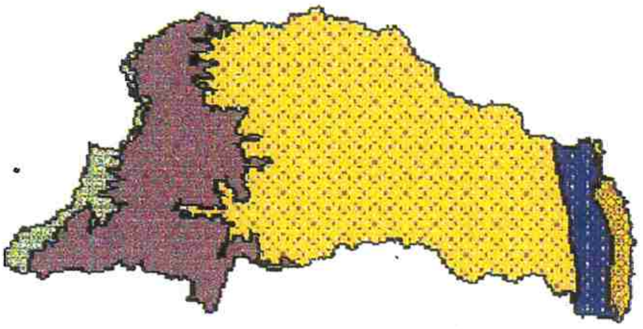
Relevant Data Fields		
Field name	Type	Description
Popdensity	Numeric	Population density

GIS Data Coverage Description	
Coverage name	Natres
Description	Nature reserves and national parks within Sabie river catchment
Scale of capture	1:250 000
Geographic data type	Polygons
Geographic display	

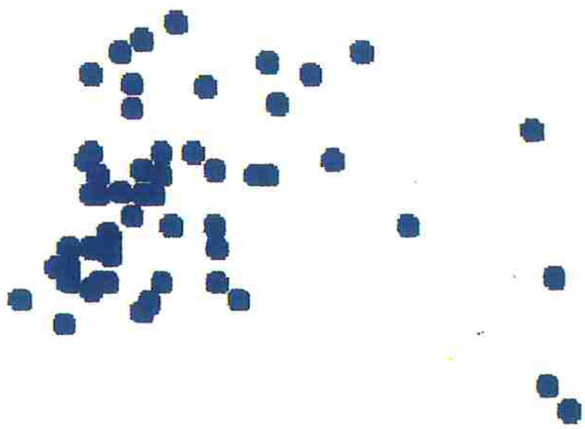
Relevant Data Fields		
Field name	Type	Description
Reserve	Character	Name of nature reserve or national park

GIS Data Coverage Description	
Coverage name	Irrig
Description	Areas currently under irrigation in the Sabie river catchment
Scale of capture	Unknown
Geographic data type	Polygons
Geographic display	

Relevant Data Fields		
Field name	Type	Description
Irrig_id	Numeric	Value of 1 indicates areas of irrigation

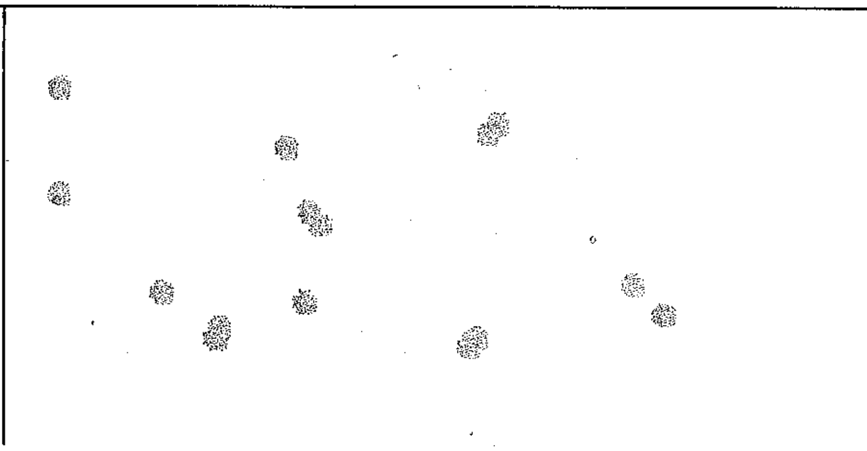
GIS Data Coverage Description	
Coverage name	Geology
Description	Geomorphology of the Sabie river catchment
Scale of capture	1:250 000
Geographic data type	Polygons
Geographic display	

Relevant Data Fields		
Field name	Type	Description
Geomorphol	Character	Description of geomorphology

GIS Data Coverage Description	
Coverage name	Rainstn
Description	Rainfall gauging stations within Sabie river catchment
Scale of capture	Points generated from latitude / longitude values
Geographic data type	Points
Geographic display	

Relevant Data Fields		
Field name	Type	Description
Wb_no	Character	Station code
Station	Character	Station name and description
Altitude	Numeric	Elevation above sea level
St_year	Numeric	Starting data year
Last_year	Numeric	Last year with data
Datayears	Numeric	Number of data years
Map	Numeric	Mean annual precipitation

GIS Data Coverage Description

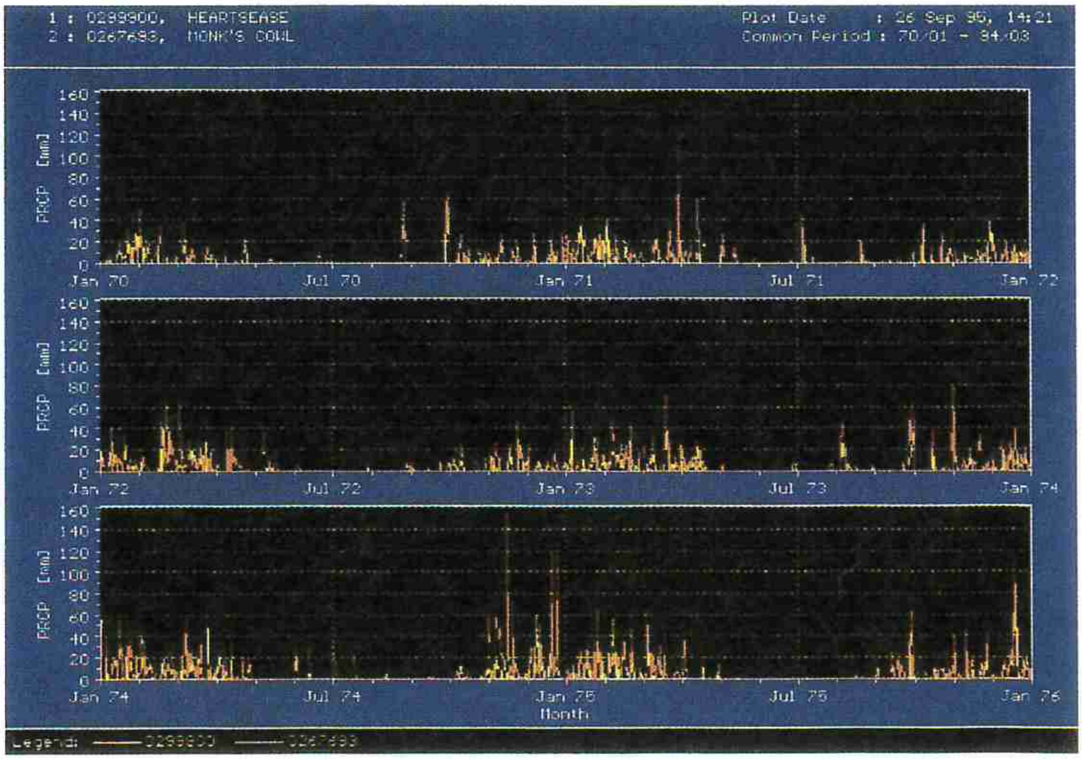
Coverage name	Evapstn
Description	Evaporation measuring stations
Scale of capture	Points generated from latitude / longitude values
Geographic data type	Points
Geographic display	

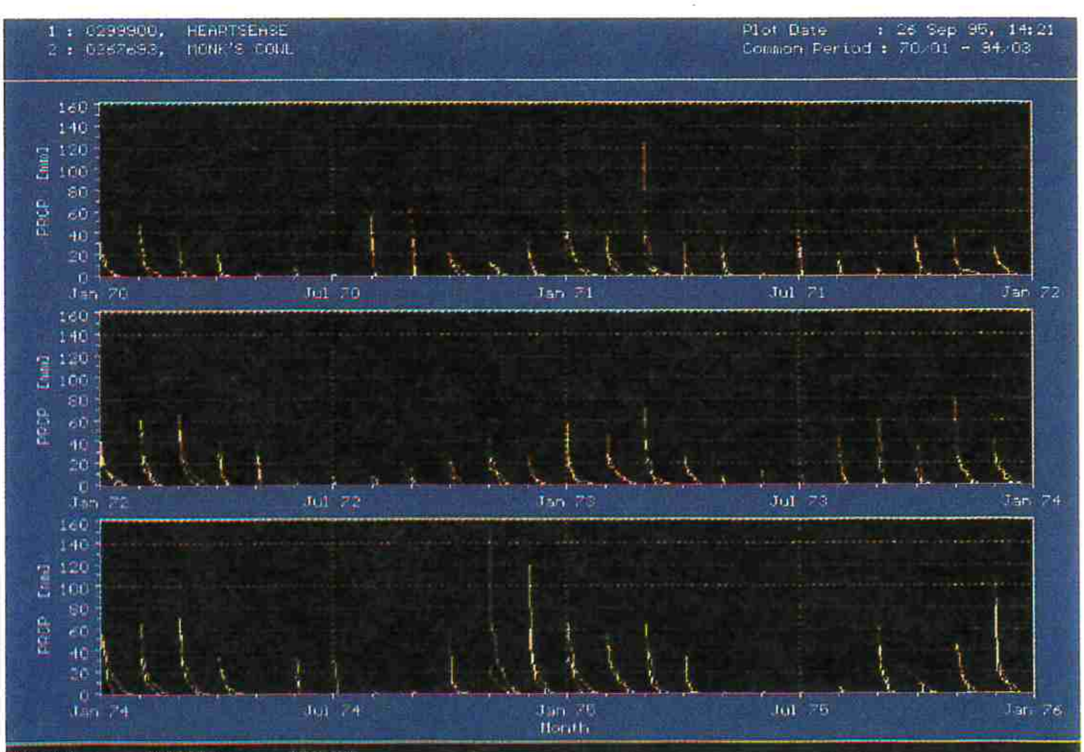
Relevant Data Fields

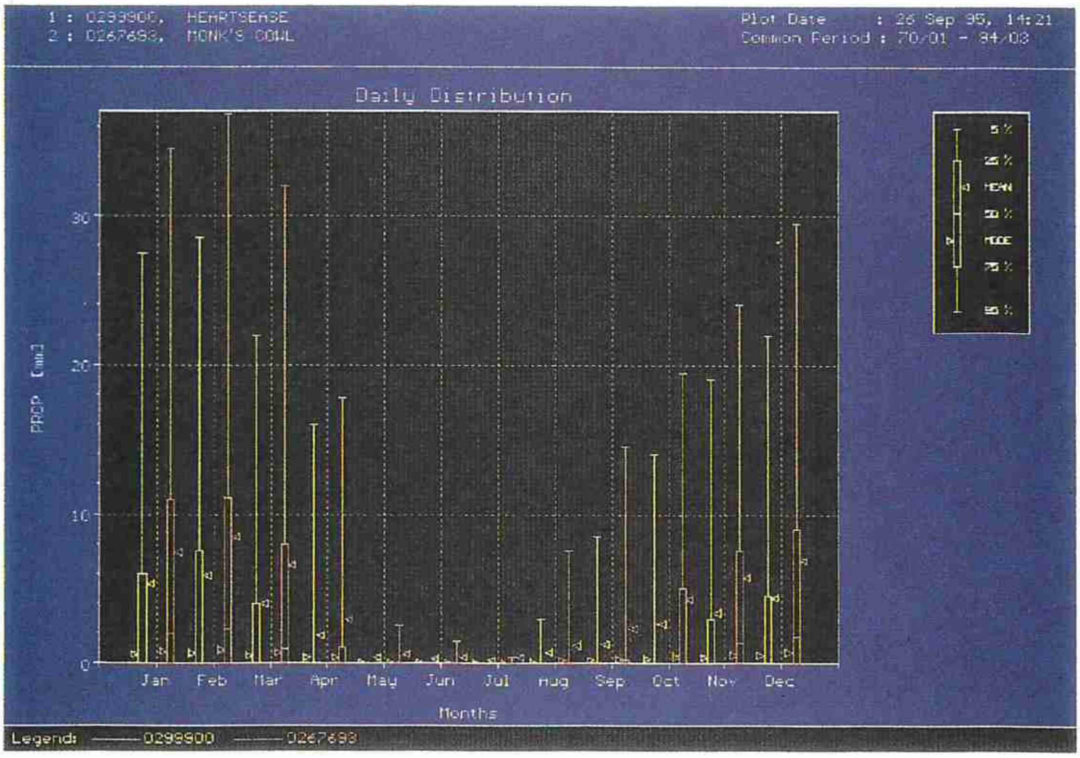
Field name	Type	Description
Wb_no	Character	Station code
Station	Character	Station name and description
Altitude	Numeric	Elevation above sea level
Temp_st_ye	Numeric	Starting temperature data year
Temp_last	Numeric	Last year with temperature data
Temp_datay	Numeric	Number of temperature data years
Evap_st_ye	Numeric	Starting evaporation data year
Evap_last	Numeric	Last year with evaporation data
Evap_datay	Numeric	Number of evaporation data years

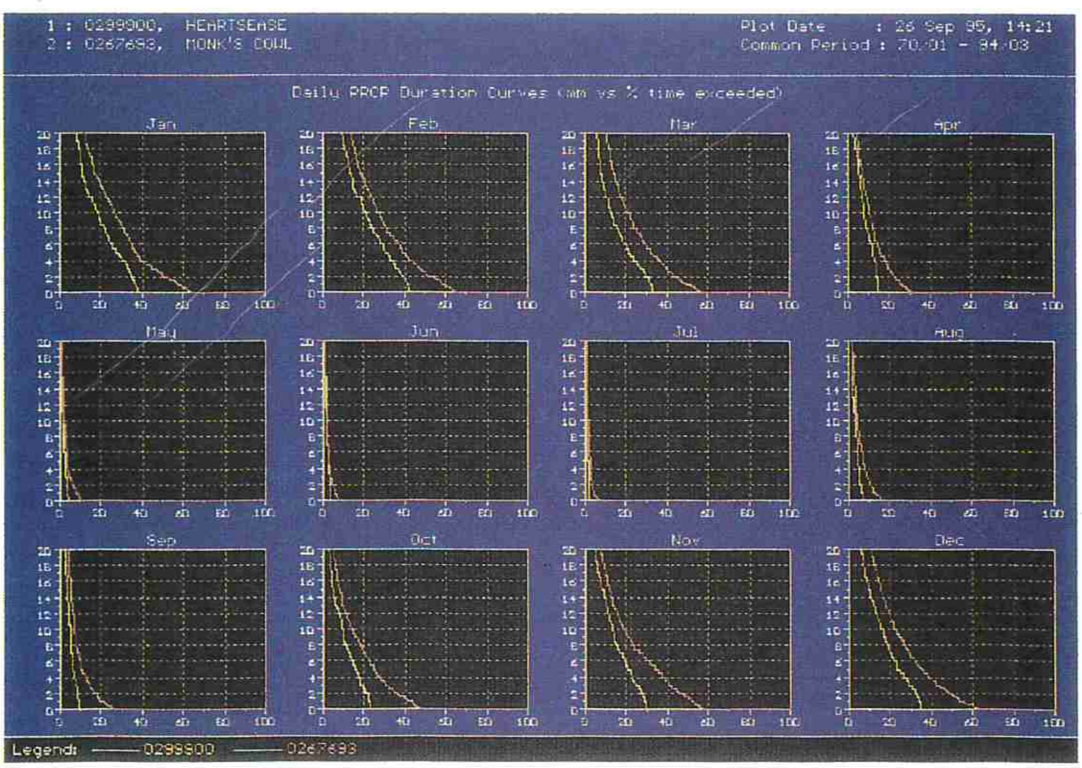
APPENDIX D

Examples of various WDMPLOT output screens






1 : 0299900, HEARTSEASE
2 : 0267683, MONK'S COWL
Plot Date : 26 Sep 95, 14:21
Common Period : 70/01 - 84/03
Daily Distribution
PRCP [mm]
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Months
5 %
25 %
MEAN
50 %
MODE
75 %
95 %
Legend: 0299900 0267683


1 : 0299900, HEARTSEASE
2 : 0267683, MONK'S COWL
Plot Date : 26 Sep 95, 14:21
Common Period : 70/01 - 84/03
Daily PRCP Duration Curves (mm vs % time exceeded)
Jan Feb Mar Apr
May Jun Jul Aug
Sep Oct Nov Dec
Legend: 0299900 0267683

APPENDIX E

List of acronyms and their meanings

CWE	Centre for Water in the Environment, University of the Witwatersrand
DSS	Decision Support System
DSSDM	Decision Support Systems Development and Management
DWA&F	Department of Water Affairs and Forestry
EPA	United States Environmental Protection Agency
GIS	Geographic Information System
HSPF	Hydrological Simulation Program Fortran
ISDM	Information Systems Development and Management
IWQS	Institute for Water Quality Studies, Roodeplaat
KNP	Kruger National Park
KNPRRP	Kruger National Park Rivers Research Programme
RDM	Research Development and Management
SCS	United States Soil Conservation Service
TEAMAN	Timeseries Extraction and Manipulation system
TITT	Training and Information and Technology Transfer
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WAN	Wide Area Network
WDMS	Watershed Data Management System