

A generic database and spatial interface for the application of hydrological and water resource models

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Abstract

The paper discusses a software package that has been designed to enhance the efficiency of applying a range of hydrological and water resource simulation models. The SPATSIM (SPatial and Time Series Information Modeling) system has been developed in Delphi using MapObjects and incorporates a spatial data interface for access to the different types of information commonly associated with water resource analyses. All of the information is stored within database tables (Paradox by default) with generic structures. The structure and components of the system are briefly described and some example applications provided. The discussion identifies some of the criticisms that have been leveled at the software, the approach of the developers to user support and some possible future developments. The conclusions suggest that the development can be considered successful in that it has substantially improved the efficiency of the Institute for Water Research to undertake one of its core functions of hydrological model development and application.

1. Introduction

Ever since the concepts of geographical information systems (GIS) were introduced there have been many reports of the development of hydrological modeling platforms incorporating data management systems, GIS and models (Mancini and Rosso, 1989; Maidment, 1991; Loucks, 1993; Schumann et al., 2000). The perceived need for complex, spatially distributed models that use parameter estimation approaches based on high resolution spatial data certainly contributed to these developments. The increasing availability of GIS information, high speed computers and software development tools (object orientated, visual programming languages) also contributed significantly to the number of developments. It has now become a relatively straightforward task to develop a hydrological modeling system with data access management and some basic GIS functionality. A review of some of the available products reveals, however, that the development emphasis is frequently very different. Some systems have focused on GIS issues supporting a single model, while others have concerned themselves with the outputs of the model and focused on water resource management decision support systems, using GIS to assist with results interpretation. With respect to data management, some systems appear to retain the input/output approaches of older models and use individual files (text or binary), but manage the file access through project 'dictionaries'. These have the advantage of being able to use older versions of models without altering their structures, but improving the efficiency of setting up and running a model. Ultimately, the design criteria will be based on a combination of what is already available (in terms of an established model, existing data inputs, etc.), what the principle aims of the package are, the perceived user base and the development resources that are available. It is almost impossible to make general comparisons between different modeling platforms, as they all have different advantages and are frequently designed for different purposes.

The system that is described in this contribution has its roots in an earlier system that had no GIS functionality and was mainly a tool for managing the flow of input and output information to several hydrological models (Hughes et al., 1994). Despite its limitations, this system was found to be (at that time) an efficient method for managing modeling projects and adding new models to an existing data management system that included a number of time series data analysis routines that were common to all models. Many of the design principles were therefore retained when it was decided to revise the

system. New principles included the addition of a spatial data interface and the storage of the majority of information in database table structures. The new system is referred to as SPATSIM (SPatial and Time Series Information Modeling).

The development philosophy has been to create a software package for users of hydrological and water resource simulation models that provides tools for managing and manipulating the associated data, setting up and running models, as well as analyzing and interpreting the output. The design originates from the development teams involvement in the development and practical application of water resource assessment tools. It is recognized that the solution to many water resource problems involves the use of several models or data analysis tools that share input or output data. SPATSIM is therefore designed to make such data sharing reasonably efficient. It is also designed to allow new data types, as well as models, to be added without having to modify the package itself. This applies equally to users (given some training) and the development team. SPATSIM does not include many of the spatial data analysis tools that are typically found in GIS software packages (such as DEM/DTM generation and automated catchment delineation). This omission is based on the availability of such tools in already established software packages, the outputs of which can be readily used within SPATSIM. The software development focus has been on the water resource modeling issues.

2. Language and database structure

The software has been developed in Delphi with ESRI MapObjects being used to provide the links to the spatial data. Data access is controlled through the spatial interface using shape files and four data dictionaries. The information (referred to as SPATSIM attributes) associated with the spatial elements (point, line or polygon) of the shape files are stored in Paradox (by default) database tables, with generic formats for eight different data types. It is important to recognize the distinction between the SPATSIM attribute data that are stored within the database tables, separate from the shape files, and the internal attributes of the shape files.

The only restriction on the format of the shape files is that they should contain two internal attributes (or fields within the database table). The first is an 'IDField' that contains unique integer values for each spatial element and the second is a field ('DescField') that contains alphanumeric information that can be used to uniquely identify spatial elements. Both of these attributes are required to be included in the shape file and users need to identify them the first time a shape file is added to a SPATSIM application. Once identified, the 'IDField' cannot be changed, nor its contents altered, while the 'DescField' attribute can be subsequently changed. The fields associated with the four data dictionaries are listed in Table 1. The first data dictionary contains the references to all the shape files that are used, including the fields to be used by SPATSIM for identification purposes. Dictionary 2 contains the references to the SPATSIM attributes and their data types, while dictionary 3 specifies where in the SPATSIM database structure the information associated with these attributes can be found. Finally, dictionary 4 links the records in the spatial data (using the contents of the 'IDField') with the records in the SPATSIM attribute data tables for all the attributes.

Table 1
Structure of four data dictionaries

Data dictionary	Fields				
1	Feature Code (unique integer value for each shape file)	Feature Name (unique name for the feature)	Feature Source (full path and file name of the shape file)	IDField (shape file attribute containing unique integer values)	DescField (shape file attribute containing alphanumeric description data)
2	Feature Code (reference to dictionary 1)	Attribute Name (unique name for the attribute)	Attribute Code (unique code for the attribute)	Datatype (integer value between 0 and 7 defining the type of data)	
3	Attribute Code (reference to dictionary 2)	Table Code (unique code for the table)	Database Alias (which contains the database table)	Table Name (name of the table storing the data for this attribute)	Max. No. Records (current maximum number of records in the table)
4	Attribute Code (reference to attribute)	Spatial Record (reference to shape file record)		Table Record (reference to database table record)	

Table 2 lists the eight possible data types and the fields associated with the generic database table structures. The first three types are straightforward and simply contain a record number (for linking to dictionary 4) and the data. The time series type includes 16 fields which describe the data and specify the variable type and units, the start and end dates and times, the number of records, missing data code, etc. The final field contains the data stored as a binary large object (BLOB). Fixed interval data can be stored using just the variable value, while it is also possible to store variable time interval data using data pairs of decimal days (since 1800) and the variable value. The graphic type is used to store pictures or short video clips, where the 'Type' field is used to interpret the contents of the 'Graphic' field for display purposes. The array type is used to store one- or two-dimensional tables of values (monthly temperatures, population numbers of different age and cultural groups, etc.) and these data are also stored as a BLOB. The format of the array is defined by the 'Format' field which contains a reference to a text file that specifies the number and descriptions of the rows and columns. This approach allows users to add new array types without having to modify the generic database structure. The memo type allows users to store larger quantities of formatted text than the text type and is useful for adding notes and metadata to SPATSIM applications. The final data type ('linked') can be used to cross-refer the information contained within an attribute associated with one feature with a different feature. This data type allows (mainly) time series information to be shared between features without having to store the information more than once.

Table 2
Structure of eight generic database table types used to store SPATSIM attribute data

Data type	Fields						
Text	Record ID	Text (maximum of 80 characters)					
Integer	Record ID	Value					
Real	Record ID	Value					
Time series	Record ID	Time Series Attribute Fields (16 fields defining the data type, units, start and end time, no. of records, etc.)				Data (stored as a BLOB)	
Graphic	Record ID	Title	Xsize	Ysize	Date	Type	Graphic (stored as a BLOB)
Array	Record ID	Title	Date	Rows	Columns	Format	Data (stored as a BLOB)
Memo	Record ID	Title	Date	Memo (text information up to 32k)			
Linked	Record ID	Feature	Attribute	Type	Spatial Record		

The user has reasonable flexibility in the way in which data associated with a specific SPATSIM application are stored. The structure of data dictionary 3 implies that all data associated with a single attribute will be stored in the same database table. However, data for different attributes of the same type can be stored in the same, or different, tables.

3. SPATSIM components

Fig. 1 provides an example of the main SPATSIM screen and includes an enlarged insert of the menu options, which consists of six main menu items and 12 icon buttons. The icon buttons are used for quick access to common tools (zooming and panning, label displaying, spatial element selection and attribute displays). The drop-down menu item groups are summarized in the following sections.

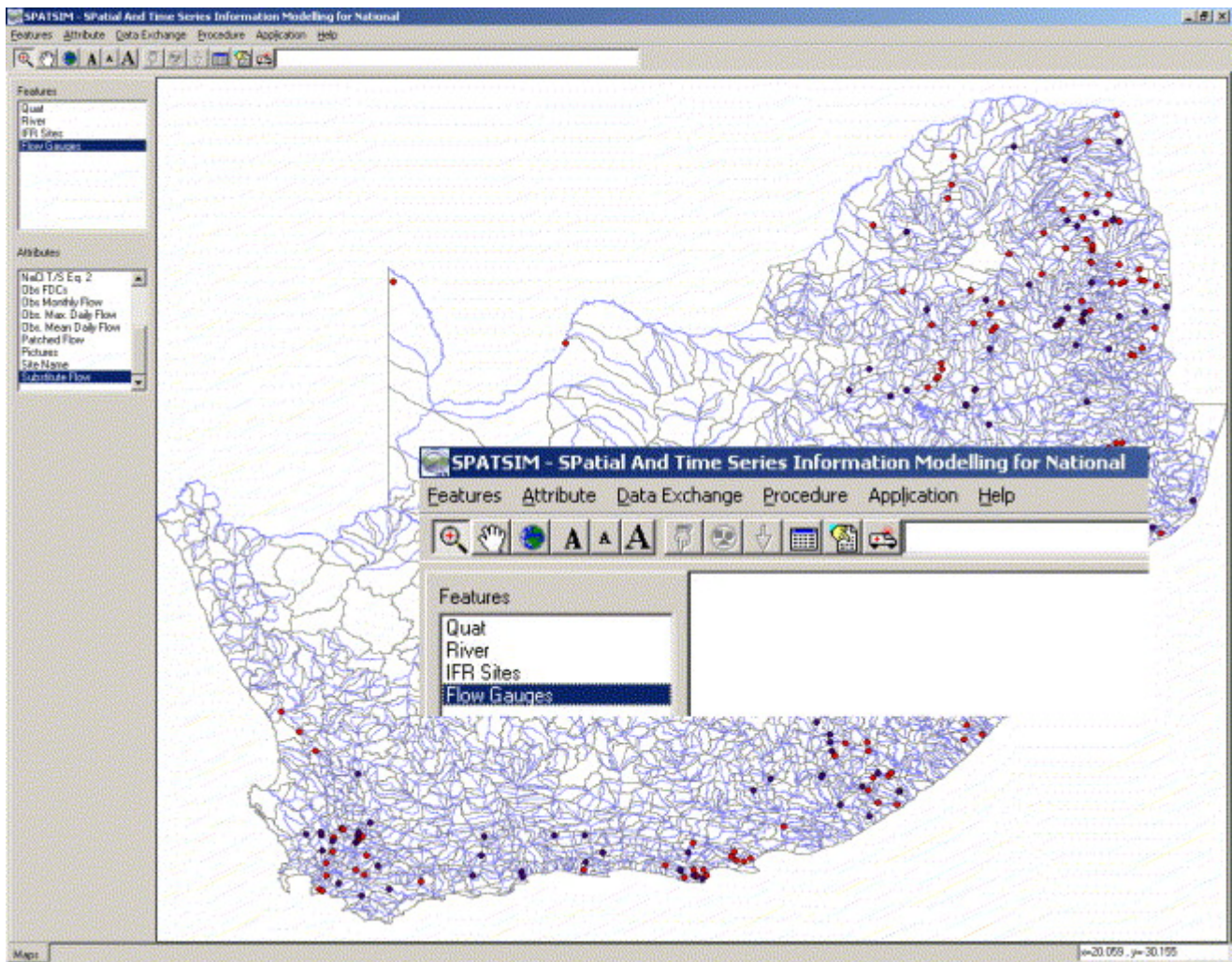


Fig. 1. SPATSIM main screen (with insert showing menu options enlarged).

3.1. Features

This group includes facilities to add features (shape file point, line or polygon coverages) to the display that have either been previously stored in the database or are to be added to a specific application. They can also be removed from the view or from the database entirely. If the latter option is chosen all database entries for that feature are also removed. There are options to change colors, display or edit the DescField information in a shape file, output the displayed map and add, move or delete spatial elements within point features. It is also possible to create a new polygon feature made up of rectangular grids with a size and extent defined by the user.

3.2. Attributes

The attribute menu includes all the options associated with managing the attribute data connected to the spatial elements of a feature. Several of these allow users to add, delete or rename attributes, show on the map which spatial elements have attribute data associated with them and export attribute data to a text file. There is also a facility to create a text file that contains the template for a new array type. This prompts the user to specify the number and titles of the rows and columns of the array type to be created.

There are a range of facilities available for importing attribute data of different types from various sources, including other database tables and text files. Some of these are based on importing data for a single spatial element, while others allow large blocks of data to be imported for many spatial elements. The standard approach is to precede each block of information in a text file with the contents of the 'DescField' entry in the shape file. This allows SPATSIM to identify the spatial element that 'owns' the data and either create the correct entry in dictionary 4, or if the data already exist, identify the database table and record number where the new data should be stored. There are a wide range of standard file formats that can be directly accessed for importing time series data. A typical application of the time series import routines involves ensuring that all the raw data files are in the same format and are named using the 'DescField' contents of the shape file. This approach allows a large number of raw data files to be accessed and the information imported in a single operation. A facility also exists for transferring data from an internal shape file attribute to a SPATSIM attribute of a compatible type (single numbers or short text).

There are two menu options that make use of the SPATSIM attribute data in some form of spatial analysis. The first is a facility to intersect two polygon features and generate new information for one of them on the basis of the area-weighted average value of an attribute associated with the other. This option can be useful in setting up the parameter values of a hydrological model associated with a sub-basin boundary polygon feature from index values of (for example) physical land surface characteristics, such as soils or vegetation, from another polygon feature. The user can specify a transformation matrix that is used to convert the index values to a parameter value. The resulting weighted average can be stored in a single real number attribute, or in one specified cell of an array type attribute. The second option is a generalized rendering facility designed to use single integers or real numbers, or one cell of an array attribute as the basis for classifying polygons and coloring the displayed map.

3.3. Data exchange

The data exchange options are designed to facilitate the movement of attribute data between users of similar SPATSIM applications. The tools allow one user to generate copies of parts of the database tables and another user to import these into specified attributes forming part of their own application.

3.4. Procedures

These are internal data processing methods (compared to the external model applications discussed in the next section). They have been added directly to the main SPATSIM code as they represent frequently used approaches in the field of water resource analysis. Some of them are very specific to South Africa and rely on access to national database information, while others are more generic. There is a procedure to summarize a data time series and generate additional attribute information in the form of a mean annual value (real data), seasonal distribution (one-dimensional array data) and values representing a table of values with different percentages of exceedance frequency for each calendar month (two-dimensional array data). A frequently required data analysis method in rainfall-runoff modeling applications is the generation of sub-basin average rainfall time series from observed rainfall data recorded at gauging stations. The 'point to area' procedures allow a user to specify an area of interest on a polygon (sub-basin) feature, select a point feature and associated rainfall time series attribute, specify maximum search radius and gauge numbers and then apply an inverse distance

squared weighting procedure to interpolate areal rainfall from the point data. If more complex spatial interpolation methods are required (such as geostatistical methods) it is assumed that the point rainfall data will be exported, additional software is used to process the data and the results are imported into a SPATSIM polygon feature as spatially averaged rainfall data. This is consistent with the design philosophy of not reproducing procedures within SPATSIM that are readily available within other, well established, software packages.

The drought index option covers a range of procedures that are designed to generate time series of drought indices from rainfall data (Fig. 2) and to create summary tables of index values for specified years and months (Smakhtin and Hughes, 2004). These facilities were developed through a partnership between the Rhodes IWR and the International Water Management Institute (IWMI) in Sri Lanka. There are also a few relatively trivial procedures such as a tool for displaying pdf files on the basis of a text type attribute specifying the path and file name (useful for storing references to large reports) and a method for transforming time series data using one of two possible non-linear equations ($Y=Ax^B+C$ or $Y=Ax^2+Bx+C$, where X and Y are the un-transformed and transformed variables, while A , B and C are user supplied parameters. Two sets of parameters can be applied for above and below a user specified threshold of X). This can be used for several purposes, one of which would be the conversion of stage data to discharges using a two-element rating curve. If more complex transformations are required, the data would have to be exported, transformed and then re-imported to SPATSIM.

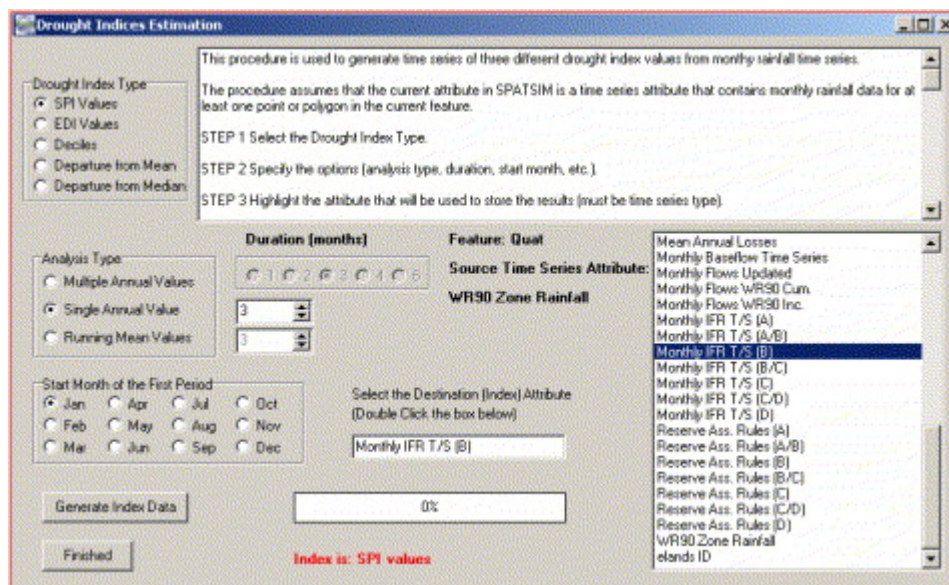


Fig. 2. Drought index generation procedure form showing various available options.

Some of the models that are expected to be included within SPATSIM in the near future have their parameters associated with 'nodes' of different types (runoff, channel, reservoir, irrigation, etc.) within a linked network. The 'network build' procedure allows users to create a new network based on the centroids of polygons selected from the main map and to add additional nodes and define the links (Fig. 3). The procedure creates new point (the nodes) and line (the links) shape files which can be included in a SPATSIM application and have attributes added, which are then populated with data in preparation for use with a model.

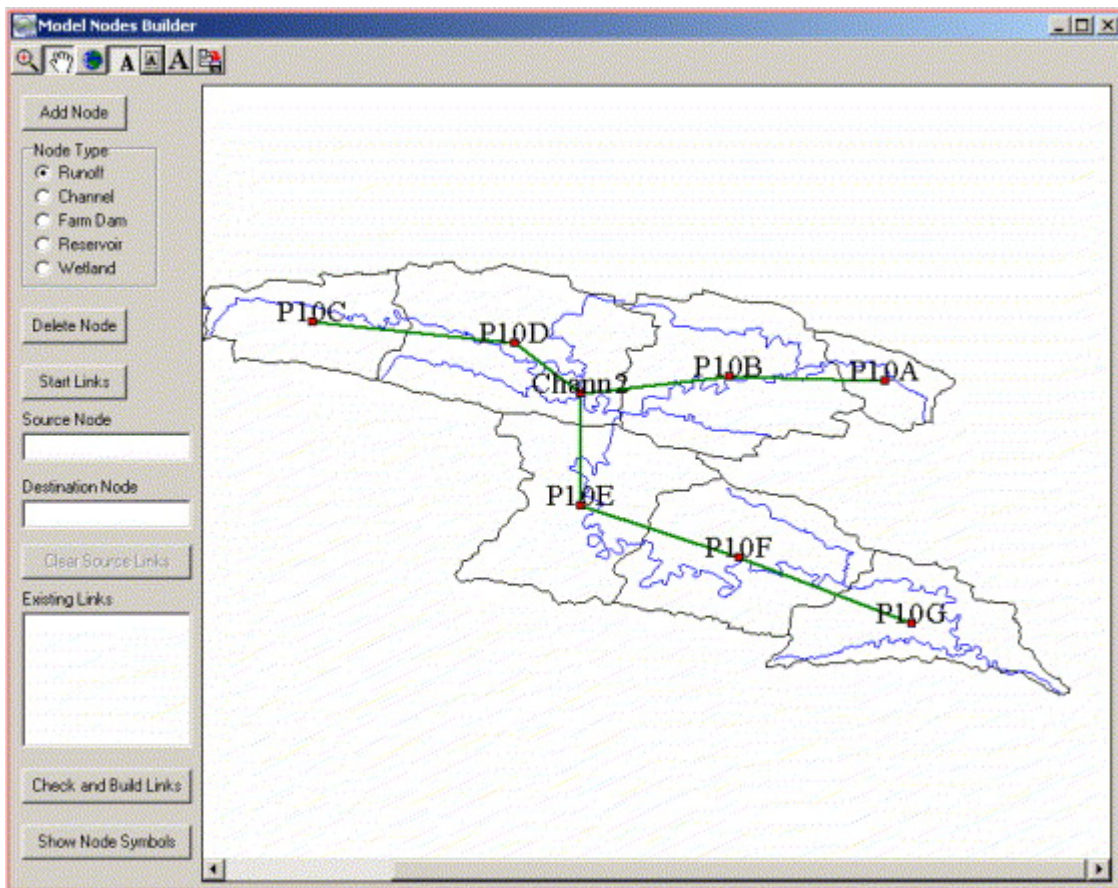


Fig. 3. Procedure for constructing networks of model nodes.

3.5. Applications

These options provide links to external model or data analysis programs that are not part of the main SPATSIM code, but are developed separately and have links to the data stored within the main database. They can either be setup (i.e. by specifying the spatial elements to be used and the attribute data to be associated with their input or output requirements) from within SPATSIM, or they can be run directly after being setup.

The first application is a generic time series data display and analysis tool (TSOFT, Hughes et al., 2000) that was developed prior to SPATSIM. Time series data stored within a SPATSIM database are referenced in a 'profile' which is then used within TSOFT to access the data directly from the database. The 'profile' can also include other sources of time series data (binary files, for example). TSOFT allows multiple time series to be displayed and includes a number of standard analysis methods (seasonal distributions, flow duration curves, run or spell analysis, baseflow separation, scatterplots and pair-wise analysis of two time series). It includes a full range of tools for zooming and panning, integrating data over longer time periods (plotting daily data as monthly totals, for example), etc. It is used quite extensively for detailed visual and numerical comparisons of observed and simulated data generated during manual calibrations of rainfall–runoff models.

The remaining applications are all linked to SPATSIM using a generic approach, based on storing references to the information required to run the model in a database table (see Table 3). Each external application developed for inclusion with SPATSIM has a text file associated with it that defines the types of input and output data and whether they are required or optional. The procedure for setting up an application is to identify the spatial element(s) to be used with the application (using the appropriate selection icon button), select the application from a list provided and go through the process of matching available attributes with the application requirements (Fig. 4). The approach is to highlight an attribute in the list on the main SPATSIM screen and then double-click on an entry in the

requirement table. There are checks to ensure that all the required data inputs are completed and that the selected attributes are of the correct type. Saving the requirements creates a record in a model application database table and populates the fields with the relevant cross-references to the SPATSIM database. If an application is run 'directly', the table of saved applications is displayed, a specific record selected and the application loaded for running.

Table 3
Fields within application-run database table

Field	Description of contents
Description	User supplied description of the application
Date	Date of setup
EXE	Executable file associated with the model
Data directory	Default directory to be used for any non-SPATSIM output data
Feature	Feature code
No. of spatial elements	Number of spatial elements included in the model scheme
No. of attributes	Number of attributes for input or output data
^a Attribute list	List of attribute codes to be used for input or output
^a Spatial input list	List of spatial record numbers for accessing data through dictionary 4
^a Spatial link list	Series of codes to identify the order in which spatial elements will be modeled
^a Spatial output list	List of spatial record numbers for which output data are generated
Start date	Start date for time series modeling
End date	End date for time series modeling

^aThese fields are lists of codes stored as a binary large object.

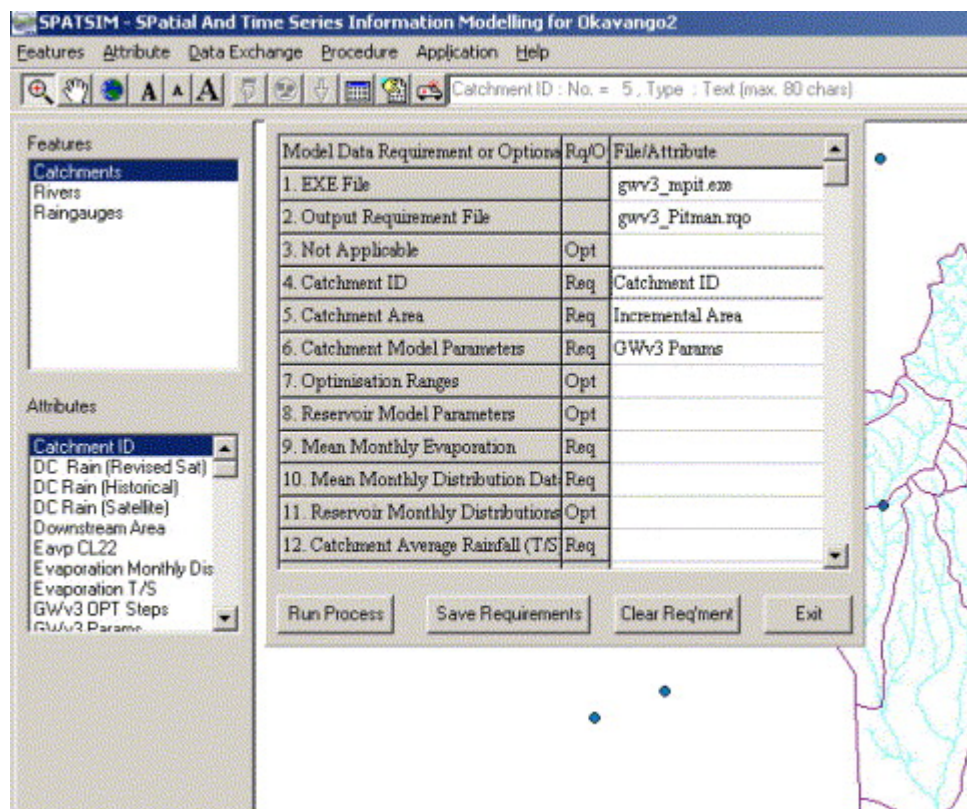


Fig. 4. Process of selecting attributes to match application input and output data.

Within the various applications, standard procedures have been designed for exchanging (reading and writing) different data types between the application and SPATSIM. These simply access the SPATSIM database tables (through the data dictionaries) and populate the local variables of the application. This approach makes it a relatively straightforward task for any model developer to add a new application to SPATSIM without having to modify the main code. All that is required are some simple guidelines for data exchange which are available from the SPATSIM development team at Rhodes University.

A wide range of applications have already been incorporated, including several general hydrological data analysis methods, rainfall–runoff models and a number of applications that have been designed to support the determination of environmental flow requirements in a South African context.

3.6. Help facilities

Help facilities have been developed using HTML files for several reasons. These are relatively easy to create and manage and they can be linked to a web page so that updates to the help system can be made available to the users as soon as possible. It is also straightforward for the users to edit or add to the help files themselves, without the need for any specialist software.

The help information can be divided up into four main groups. The first group explains the structure of SPATSIM, as well as some general information regarding the use of the package and has been included mainly for background purposes. The second contains specific explanations of how to use the software to perform certain functions. This includes explanations of the use of the various menu options and icon buttons. The third includes explanations of the use of the software for a range of typical applications. These may take the form of ‘road maps’ explaining the processes to follow in data preparation, model set-up and results interpretation. They may also explain the inner workings of the models. Where new modeling developments have been incorporated into the SPATSIM system, they are frequently explained in detail within the help system.

4. An example application

To provide further insight into the use of SPATSIM, the steps and procedures involved in an environmental flow determination in the context of South Africa are described below. These determinations typically follow an inter-disciplinary approach involving hydrologists, hydraulic specialists, geomorphologists, as well as several biological specialists. The aim is for all the specialists to gather relevant information and to integrate their knowledge in a way that allows the ecological impacts of changes to the flow regime of the river to be determined. This information is then made available to water resource managers who would make use of it, together with information on the requirements of various users, to make water allocation and operating rule decisions.

The following sub-sections briefly summarize the steps that could be followed in the application of SPATSIM to this type of problem.

4.1. Data preparation and collection

This step involves the establishment of the various spatial coverages that are required, including polygons of sub-basin boundaries, line coverages of the channel network, point coverages of hydrological gauging stations, channel cross-section sites, water abstraction points, photographic survey points and others. Most of these would be created using propriety GIS software, although the point coverages can be largely created within SPATSIM itself. Once the spatial data coverages have been included in the SPATSIM database as features, it is necessary to establish the required attributes. This is essentially a database design issue that relies on a clear understanding of what information is available (or will be generated) and in what format, as well as how it will be used throughout the investigation. It is always a good idea to document this design, which could be added to the help files that are distributed with the specific SPATSIM application. The information associated with these investigations is wide ranging and covers many different types of data, all of which can be readily stored within the defined attribute types of SPATSIM. Examples include:

- Hydrological time series data (observed or simulated by one or more models).
- Numeric tabular data related to the parameters of the various models that will be used, water use, biological and social information, channel cross-section survey and hydraulic data, etc.

- Text type information including short descriptions of sample sites, investigation procedures followed during the study, etc.
- Longer text type information in the form of previous scientific or management reports that can be converted to pdf format and referenced through a text attribute.
- Photographic or other graphical information, including short video (mpeg) clips of study site locations.

A large proportion of the data used is typically already available, has to be accessed from other sources and imported into SPATSIM. While some specialist import routines have been added to SPATSIM for the purpose of linking directly to existing South African databases, in other cases data can be prepared in a spreadsheet, saved as text files and then imported.

4.2. Data modeling

The next step is the generation of the additional data required by each discipline involved in the investigation. From a hydrological (Hughes, 2001) and hydraulic perspective, most of the required models have already been incorporated into SPATSIM. The hydrological studies typically involve establishing a rainfall–runoff model to simulate the natural and present day flow regime for points of interest within the basin. SPATSIM includes both daily (Hughes and Sami, 1994) and monthly time-step (Hughes, 2004) models for this purpose, as well as all the supporting tools for input data preparation, results analysis and visualization.

The approach for hydraulic information is to survey sample channel cross-sections, measure discharge for a range of flow conditions and synthesize the rating curve based on estimations of roughness characteristics (Birkhead and James, 1998). In cooperation with the University of the Witwatersrand, Centre for Water in the Environment and Dr Andrew Birkhead of Streamflow Solutions, a SPATSIM application has been established to facilitate this process and to display the results (Fig. 5). The model can be used to establish synthetic rating curve points based on estimates of roughness coefficients, fitting rating curves, displaying frequency distributions of hydraulic properties (depth, velocity, etc.) within the cross-section, displaying water surfaces at selected flows and displaying time series of hydraulic variables under different flow regimes. The objective of the model is to provide as much of the information that the other specialists (biologists and geomorphologists) require to be able to interpret flow regime changes in terms of changes in physical habitat availability.

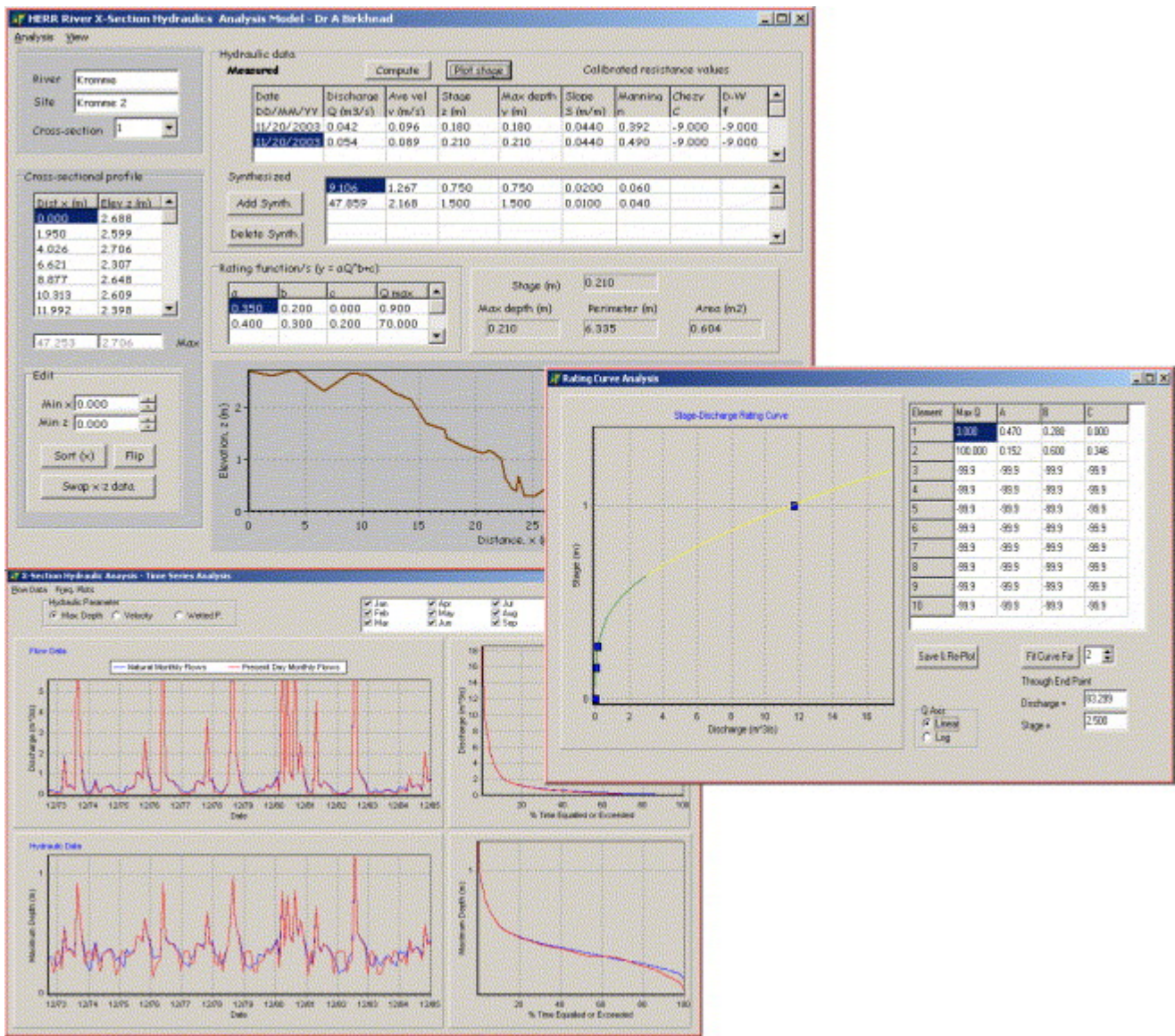


Fig. 5. Hydraulic data analysis model.

4.3. Estimating environmental flows

The process of estimating environmental flows in South Africa usually involves one of two approaches (O’Keeffe et al., 2002; King et al., 2003) both of which culminate in a workshop of specialists where all the available information is integrated and flows required for defined levels of ecological protection established through expert judgment. Both methods require that the available information be readily accessible and understandable to all the different disciplines and that the effects of various flow recommendations can be quickly assessed during the workshop. These assessments might involve the impacts on biotic habitat of flow regime changes (using the hydraulic model), or the potential impact of reserving flows for environmental purposes on other users (water resource and rainfall–runoff models). SPATSIM provides a wide range of data display and analysis facilities (see Fig. 6, for example) to satisfy the requirements of the various specialists, all accessible from a common platform and spatial interface. This promotes common understanding amongst the group of specialists and encourages a truly inter-disciplinary approach to the study.

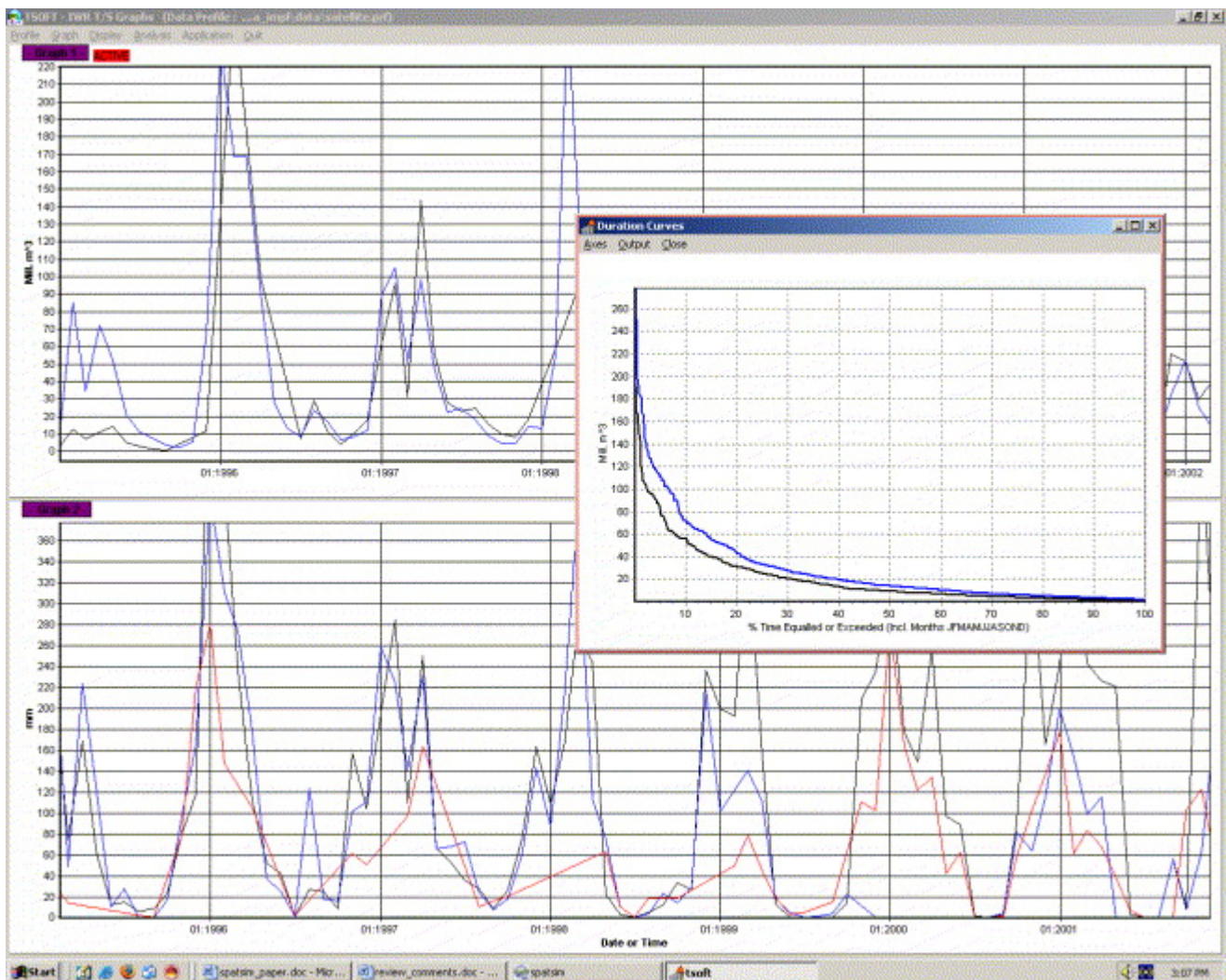


Fig. 6. Example of time series display and analysis facility. Top graph shows comparison between observed and simulated flows, whereas lower graph shows rainfall records from three gauges. Insert illustrates flow duration curves compiled from data used to generate top graphs.

4.4. Scenario analyses

One of the critical components of any environmental flow determination is to integrate the outputs from the specialist workshop with the water requirements of other users (domestic, industrial, agricultural, etc.) so that water resource managers have all the necessary information upon which to make informed planning or management decisions (Louw et al., 2000). The ideal approach to such integration is to use a system yield model (Basson et al., 1994) which allows the environmental flows to be incorporated as a system demand together with the other water users and then to run the model under various management scenarios. No such model currently exists within SPATSIM, although data generated within SPATSIM are routinely exchanged with existing models of this type. A planned future development is to add a water resource systems model to SPATSIM so that scenarios can be generated using the same platform.

5. Other applications

One of the applications for which SPATSIM was originally designed is regional water resource assessments (Hughes et al., 2002). The software is ideally suited for managing the different types of hydrometeorological, basin physical property, land use and water use data that are commonly associated with such studies. To date SPATSIM has been used to store the majority of the South African national water resource database (Midgley et al., 1994) that was previously available in a large number of text files and printed maps. It has also been used for regional assessments in other parts of southern Africa including the Okavango (Andersson et al., 2003) and Kafue (Mwelwa, 2005) basins.

Within the field of rainfall–runoff modeling in southern Africa, there has been a strong tradition of using conceptual type models and manual calibration (rather than simpler models and automatic calibration). To be able to efficiently calibrate a model manually across a number of sub-basins it is essential to have access to software that allows the distributed model parameter values to be managed effectively. This involves being able to modify them between model runs, as well as being able to visualize their spatial distribution.

Manual model calibration relies heavily on both statistical measures of correspondence between observed and simulated data, as well as visual comparisons of both the two time series and summary information, such as seasonal distributions and flow duration curves. The time series display and analysis routines that are included in SPATSIM are designed specifically for this purpose (Fig. 6, for example).

6. Discussion and conclusions

SPATSIM has been applied for research development purposes, post-graduate study programmes and consultancy projects by both the developers as well as several other groups. It has been used mostly in the southern Africa region and mainly for environmental flow determinations. Perhaps the main reason for the latter is that there are several alternative water resource assessment packages (including hydrological and water resource yield models) available, while most of the models, used in the region that are specific to environmental flow determinations (Hughes, 2001) are only found within SPATSIM. It has also been used for drought assessments within south west Asia, largely through the involvement of IWMI in the promotion of drought analysis methods (Smakhtin and Hughes, 2004).

The database structure has been found to be more than satisfactory for the storage and access of the type of information typically associated with water resource studies. While data storage space is not a major issue these days, it is nevertheless interesting to compare the storage requirements of SPATSIM for time series data with other common approaches. SPATSIM requires 8.5 MB to store the 70 years of naturalized monthly flow data associated with the 1946 so-called quaternary catchments in the South African national database. The equivalent space required for text files storing the flows as $m^3 \times 10^6$ with three decimal places is over 16 MB, while converting these to excel files uses nearly 39 MB. First time users, unfamiliar with the use of database tables and the storage of time series data in binary format are often unsettled by the fact that they cannot 'see' their data. However, once familiar with the various SPATSIM options for displaying and editing the data, experience suggests that this problem normally disappears.

There are many areas where the software can be criticized and some of these relate to the efficiency with which certain operations are achieved. Unfortunately, many of these are difficult to address without compromising the 'generic' nature of the package. Designing the software to satisfy the requirements of many users and several different modeling tools, results in a loss of efficiency to a user who only applies a single model. A more important criticism is that where applications require the use of several models, these are applied in series, which effectively precludes the simulation of feedback loops and time-dependent interactions. This issue has been identified by the HarmonIT research project (Blind and Gregersen, 2004 and www.harmonit.org) which is aimed at developing an Open Modeling Interface and Environment (OpenMI) designed to simplify the linking of hydrology related models. The essence of OpenMI is to allow models to run in parallel, sharing information as required. While there are no immediate plans to implement such an approach within SPATSIM (largely due to available resources), this is clearly the direction in which most modeling frameworks should move. There are no perceived difficulties with implementing such an approach within SPATSIM beyond the obvious one of the availability of resources to implement the necessary changes to the models linked to the main package.

The relatively few spatial data analysis features in SPATSIM has also attracted criticism. However, it has already been emphasized that it was never the intention to reproduce the capabilities of existing GIS packages, which are developing in sophistication and power all the time. The focus within SPATSIM is on data management and efficient access to a range of modeling tools, while at the same time ensuring that outputs from other software can be used effectively.

6.1. Support

SPATSIM has reached a relatively stable level of development, but new features and applications are occasionally added, either in response to user requests or improvements identified by the developers. To ensure that registered users are kept up-to-date, revisions are posted to the IWR web page (www.ru.ac.za/institutes/iwr—the link to hydrological models and software). These can be downloaded and installed on a system that has an existing SPATSIM version. This approach ensures that all users have access to improvements as soon as they are finalized.

Within the Southern Africa Development Community, the need for building capacity in water resource assessment methods has been frequently recognized (SADC, 2001). SPATSIM has the potential to address some of these human resource development requirements, in that it already contains some of the methods in common use within the region and could provide a common platform for their application. One of the major problems in the past has been the lack of continued technical support for modeling technology that has been introduced into the region. It is possible that by adopting a single modeling platform there is the potential for greater shared experience and less need for outside technical support once an initial intensive training programme has been completed.

6.2. Major future developments

Any major developments that are identified and suggested by users are normally treated as cooperative projects between the IWR and the user group that identifies the needs. This may involve the addition of a new model, or a set of internal data analysis procedures. An example is the cooperation between the IWR and IWMI that led to the addition of the drought analysis procedures (Smakhtin and Hughes, 2004). Progress is currently being made on adding a water resource system yield model (partnership with a consulting engineering company), an additional daily model (partnership with another University through a Water Research Commission funded project) and the establishment of SPATSIM as the platform for the update of the national water resources database (WR2005—partnership with a consortium of consultants and funded by the Water Research Commission).

6.3. Conclusions

In general terms the current version of SPATSIM has met the original design objectives, in that it provides:

- an efficient and secure approach to managing information associated with various water resource analysis projects;
- a platform for setting up and running several hydrological and water resource models that are in frequent use within the southern Africa region;
- a platform for the development of new models and data analysis tools, within which many of the supporting procedures are already available.

The software has certainly improved the productivity of the Institute for Water Research in terms of research and development, as well as the practical application of many of the research products. A measure of its success is the fact that it has been selected as the platform for future model developments by other organizations after relatively rigorous review processes of alternatives.

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