ENHANCEMENTS OF THE WATER RESOURCES MANAGEMENT MODEL (WRMM) THROUGH AN IMPROVED COMMUNICATION WITH USERS

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Enhancements of the Water Resources Management Model (WRMM) Through an Improved Communication with Users

BY

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ABSTRACT

There has been extensive development of computer models relevant to water resources engineers in the last two decades. This is a result of the attractive new development tools that have emerged, as well as significant increase in computing power. Older models, which have gained reputation as good and reliable are still used, although they are often accompanied by recently developed additional modules to make their use more appealing and user friendly. This thesis describes three additional program modules developed to ease the use of the Water Resources Management Model (WRMM) of Alberta Environment and Natural Resources, a provincial water management agency in Alberta, Canada. The purpose of the modules is to allow visual editing of input data as well as graphical and statistical analyses of output data. The interface between the modules and the main WRMM program is built around the modelling schematic which is the basis for using the WRMM. The modelling schematics are developed as a set of two or more thematic layers in Geographic Information System (GIS), namely a component layer and the background descriptive layer(s). The component layer contains a simple database used to communicate to the other two modules – the SCFBuilder and the Plotsim programs. The SCFbuilder program was developed as a graphical tool for editing the WRMM input data files, while the Plotsim program helps with graphical and statistical analysis of the WRMM output. Both are written in Visual Basic and they can also be used as stand-alone programs when GIS is not activated. An additional module is written in MapBasic, a native Mapinfo development tool, to provide communication between the GIS component layer and the other modules. The use of these modules is demonstrated in the application of the WRMM model to the Brantas river basin in Indonesia. The advantages of using the new modules include visual component selection in the GIS schematic layer; quick database, graphical and statistical analyses of simulated output conducted on the selected component(s) using the Plotsim module, and user friendly input data graphical editing with format checks provided by the SCFBuilder module.

Key Words: Graphical User Interface (GUI), Geographic Information Systems (GIS), Water Resources Management Model (WRMM), Mapinfo, Visual Basic

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This project has been sponsored by a collaborative research grant from NSERC and Optimal Solutions Ltd. from Calgary, Alberta. The GIS schematics used in the examples comes from Perum Jasa Tirta, a river basin management agency from East Java, Indonesia. The WRMM model is in the public domain and it belongs to Alberta Environment and Natural Resources, a Provincial water management agency in Canada.

The Plotsim and SCFBuilder programs have been used by Alberta Environment and Natural Resources and the by the Eastern Irrigation District in Alberta. Transalta Utilities and SaskWater Corporation are two other agencies that use that WRMM and that have expressed interest in using the programs.

Anonymous Visual Basic internet user group members have been of significant help offering suggestions how to resolve some of the difficulties related to the programming of Plotsim and SCFBuilder.

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1 INTRODUCTION

1.1 Problem Statement

Water resources engineers have come to depend significantly on the use of computer modelling tools for their analyses. There is a large variety of computer programs developed to model different physical processes or management alternatives. They can be classified in various ways, depending on their purpose or internal structure. More information on the classifications and the recent developments can be found in Chapter 2. For various reasons, many models have failed to gain acceptance within the modelling community. One of the possible reasons is lack of a user friendly interface which would allow easy communication with the models. To rectify this issue, the recent model developments have taken two distinct directions:

a) New models are generated using an object oriented approach with built-in graphical user interface to overcome the limitations common to older models. This task has been made easier with the new development tools that have recently become available, such as the Visual Basic and various GIS platforms.
b) Older models that have gained popularity and good reputation are now "re-packaged" by additional developments, added as separate modules in an effort to provide the graphical user interface features. The result is the level of user friendliness similar to those of recently developed models, while the actual built-in numerical algorithms are retained with little or no modifications.

The older models typically involve above 15,000 lines of source code and years of on-going maintenance, hence their performance is trusted. This is why their recent upgrades are no longer focussed on the main solution engine, but rather on the shell that provides the "look and feel", a feature that was unavailable twenty or thirty years ago when those models were initially developed. The users thus get the best of both worlds – the safety and confidence in results based on many years of extensive use by various agencies and individuals, on the one hand, and the new attractive working environment associated with new developments on the other.

One example of an older model with a proven track record is the Water Resources Management Model (WRMM) which belongs to Alberta Environment and Natural Resources, a provincial water management agency in Canada. The model has become a standard water management planning tool for several provinces and states in North America and overseas. The work presented here was aimed at developing new concepts of how this model should be used in conjunction with the additional modules that were created to accompany the main module.

1.2 Research Objectives

The research objectives of this work can be broken down into several sequential steps:

a) evaluate how similar integration has been done previously by conducting literature review;

b) determine what functions the add-on modules should have, given the WRMM model purpose and typical applications;

c) find the best tools to incorporate those functions in the modules; and,

d) implement and test the new interface modules.

The final objective was to create a user friendly environment for the community of WRMM users, since one of the most disinclining features about the WRMM was related to its lack of user friendliness. This is not surprising, since the initial WRMM model mainframe development dates back to the early 1980s. The complex input data file format developed then is still in use now, with text editors as the only tool for modifying the input data files.

1.3 Brief Outline of the Methodology

What is common to all water resources management programs is the *modelling schematic*. The modelling schematic is a sketch of the catchment components which are of importance for representing the issues being investigated in the basin. Most water resources models that deal with surface water related issues require a user-defined modelling schematic with identified reservoirs, river or canal reaches, diversions, confluences and other points of interest. The input data files for those models are based on component types and their connectivity in the schematic. Thus, while the modelling schematic is a human image of relevant basin factors included in the modelling process, the computer program reads this information from an input data file which is not graphical and usually not very user friendly.

Traditionally, users had to manually develop both the modelling schematic (using the available maps) and the corresponding input data files for computer programs, and then check that the two were in agreement.

The emergence of modern sophisticated computer development tools such as Geographic Information Systems (GIS) made it possible to develop modelling schematics as one or more GIS layers and provide tools for various outside models to communicate with the schematic through its database. The advantages of this approach are:

a) several outside applications can be linked to the same GIS layers representing the modelling schematic in an effort to address various issues under investigation;
b) use of graphical user interface (GUI) routines to perform useful statistical or graphical tasks related to the components in the modelling schematic;
c) modelling schematic can be overlayed on top of actual map layers such that they are tied to the real-world spatial coordinates and other existing map layers; and,
d) GIS programs provide the select, zoom-in, grabber and other features and tools

allowing users to extract and analyse various information of interest that is linked to the components included in the modelling schematic.

It was initially believed that GIS development tools could easily handle all required tasks related to input data editing and output data processing. This turned out not to be the case, and the development was broken down into three separate modules – the SCFBuilder, Plotsim and the GIS-interface program. The first two are written in Visual Basic in such a way that they can be used as stand alone programs, or in combination with the GIS interface program. The SCFBuilder program is used for editing the Simulation Control File (SCF), which is the main WRMM input data file. The Plotsim program is used for plotting and statistical analyses of the WRMM output. The GIS interface program provides a link between the GIS thematic layers representing the modelling schematic and the three remaining programs (SCFBuilder, Plotsim, and the WRMM).

The architecture of the interface is easily transferrable to various GIS platforms. This was done to accommodate possible future requests to transfer the developments in this study to other GIS platforms.

1.4 Summary of the Findings

The modules developed in this research have proven useful to the WRMM user community. They offer a more appealing graphical environment, fast processing of output for the most common tasks without the need to rely on spreadsheets, databases or other tools, along with a safer environment for input data modification due to the safety features built into the SCFBuilder. Of additional interest is the ability to link the map layers in GIS to the WRMM modules and allow users to "see" the impact of a change in water allocation policy for a given component quickly, within a few steps.

This research also involved comparisons of various windows software development tools.

It was found that for a complex set of data manipulation requirements the most flexible tool for the intended purposes of this assignment was Visual Basic (VB). Other tools such as Visual C++ would not add much in terms of performance, while they would require a more comprehensive development effort. The SCFBuilder and Plotsim were programmed in such as way as to give users a choice to use them as stand alone applications without any reference to GIS, or in conjunction with GIS. Their link with GIS adds additional level of enhancement.

1.5 Thesis Summary

Chapter 2 gives an introduction to recent developments in tools for water management. A general classification of the available tools follows, with a short review of their strengths and weaknesses, along with a special reference to the earlier and current efforts to introduce modern user friendly interfaces. The role of GIS in coupling water management models is also reviewed in this context. Chapter 3 introduces the main features of the WRMM and other similar basin management models. Chapter 4 introduces the WRMM enhancements and explains their purpose by using the Brantas river basin case study. The Brantas river basin is the second largest basin on the Island of Java in Indonesia, and it is considered the most advanced basin in terms of basin management. The basin management authority (Perum Jasa Tirta, or PJT) is mandated by the government to charge fees for water use. Mapinfo GIS is used by PJT staff who have provided several Mapinfo layers as background information for this study. Chapter 4 relies heavily on the figures available in the three Appendices (A, B and C), which are written as the accompanying technical documentation for the enhancements. Chapter 5 provides general remarks and conclusions, followed by acknowledgments and references.

2 RECENT DEVELOPMENTS IN WATER MANAGEMENT TOOLS

2.1 Introduction

Modern water resources management is faced with difficult issues that future planners and decision makers will have to cope with. In general, they can be classified into two groups as *domain specific* and *technical* (Simonovic, 1999). The domain specific problems are related to population growth, increasing demand for water, limited availability and seasonal scarcities. There are also organizational and administrative issues, since there are many social groups, or stakeholders, who have a vested interest in participating in the decision making process. Water management in the developing countries is often stalled by the unresolved issues of political jurisdiction, chain of command and responsibilities.

The technical issues are related technical tools (computer models) that have become increasingly important in the decision making process. Models can be defined as mathematical representation of real world phenomena, and their use in water resources can be generally referred to as system analysis (Yeh, 1985). In the last two decades there were growing pressures on planners and managers to create modern computer models that could assist the stakeholders in the decision making process. The models should be capable of addressing the growing complexities of the domain specific issues in a way that will be understood and acceptable to the stakeholders.

2.2 Model Classifications

There are many ways to classify computer models used in water resources. Some classifications are listed below.

a) Steady-state vs dynamic models. Steady state models are based on variables that are averaged over a time step. The dynamic nature of the storage change in a river reach over the calculation time step is ignored in steady state models, while the dynamic (or unsteady flow) models take this process into account using various approximations of the flow process which are described by differential equations.

b) Deterministic vs Stochastic models. Deterministic models are those that rely on known input variables, while stochastic models typically use randomized functions to portray some stochastic process. Stochastic models can be divided into explicit (Tejada-Guilber et al., 1993; Loucks et al., 1981) or implicit (Bhaskar and Whitlach 1980; Karamouz et al., 1992), depending on the use of stochastic functions directly in the model or as part of input data development in the first phase, where long input data series developed by stochastic models in the initial phase are then used by deterministic models for further analyses.

c) Surface water vs ground water models. This distinction stems from the different physics of surface and porous media flows. There have been efforts to combine both surface and sub-surface systems into a single model (Sudicky et al., 2000; Loucks, 1996).

d) Water quality vs water quantity models. The main decision variables in water quality models are related to concentration of various dissolved constituents. Water quantity models ignore dissolved substances and focus on the mass balance analyses to address the issue of supply and demand.

e) Simulation vs Optimization models. In simulation, input is transformed into output using a known transformation function which often has a few parameters that need to be calibrated. In optimization, the model is asked to find the best alternative out of many available options using a specified criteria (objective function) and physical or operational constraints. This distinction is discussed in more detail below.

The first emergence of water resources models is associated with *simulation* of natural processes, where input variables are transformed into outputs using the physical equations that describe the transformation process. Examples are transformation of rainfall to runoff or routing of inflows through reservoirs. Many successful models developed in the

FORTRAN language over twenty years ago are still in use today, including the Hydrologic Engineering Center (HEC) family of models (US Army Corps of Engineers, 2000) and their more recent variants such as the **H**ydrologic **E**ngineering **C**entre **R**iver **A**nalysis **S**ystem (HEC-RAS). Models such as the HEC-1 and HEC-5 set the standard for the engineering community and they are still widely used today. Some models, **W**ater **Q**uality for **R**eservoir and **R**iver **S**ystems (WQRRS) developed by the US Army Corps of Engineers have been superceded by more successful releases from other agencies, such as the Enhanced Stream Water Quality Model (QUAL2EU) from the Environmental Protection Agency (2000). Most of the model classifications mentioned above from a) to d) refer to simulation models, which account for the majority of water resources models in use at present. The US Bureau of Reclamation (2000), the US Geological Survey (2000), the US Environmental Protection agency and the US Corps of Engineers are the major United States government agencies that support and distribute a number of computer models in water resources. More than 80 water resources models can be downloaded from the web sites of those four agencies. Alternative sources of computer models in water resources are universities and private corporations.

All of the 80 or so water resources models mentioned above are simulation models. The notable exception is the **P**rescriptive **R**eservoir **M**odel (HEC-PRM) from the US Corps. of Engineers, which has an embedded network optimization solver for each simulated time step. Although optimization models have been present in the literature for the past four decades, their widespread use and popularity is lacking when compared to simulation models. Yeh (1985) cites as possible reasons for this, the general lack of background mathematical knowledge on the part of reservoir operators as well as complexities and lack of proper documentation associated with some of the optimization models. The use of optimization techniques started in the 1950s with linear programming applications based on the Simplex solver introduced by Dantzig (1963). Because constraints and objectives in water resources are non-linear, researchers had to resort to various attempts to linearize the objective functions and constraints, often using separable programming to linearize the objective function and iterative linear approximations of constraints (Loucks et al., 1981).

Dynamic Programming (DP) has been used extensively in the research community to solve optimization problems in water resources (Yeh, 1985). Dynamic programming requires that each decision variable be represented by a discrete set of possible outcomes or states. For example, if storage is the state variable, it is to be discretized into a number of feasible levels. In each time step of the optimizing horizon, one of those levels will be selected as optimal based on the available optimal solution of the previous stage. Dynamic programming is not affected by the shape of the objective functions and constraints. However, the exponential increase in the number of decision variables and the number of states has been a major obstacle for developing applications for large water resources problems. Some efforts to overcome these limitations are the use of incremental DP (Hall et al., 1969), an iterative DP procedure, and discrete differential DP (Heidari et al., 1971).

Non-linear programming (NON-LP) is another optimization tool that can be applied in water resources management. In general, constraints and the objective function can be non-linear, and the gradient of the objective function is usually evaluated in every step of the search process (there are also direct NON-LP search algorithms that do not evaluate gradient). While there is universal Simplex method that can be applied to any linear program, there is no such equivalent for NON-LP problems. Also, the NON-LP search algorithms do not only examine the corners of the feasible region as do the LP algorithms, hence the NON-LP search space is much bigger than that of LP. The main problem with NON-LP algorithms is that none can guarantee convergence to a global optimum. The best known set of non-linear problems that can be solved with NON-LP algorithms such as quadratic, separable or unconstrained programming all have linear constraints. NON-LP algorithms work well with problems where the constraints are non-linear while the objective function is linear and vice versa. Solvers for problems where both constraints and objective function are non-linear are not abundant in the literature. The most popular non-linear solvers are MINOS (Murtagh and Saunders, 1995) and GAMS (Brooke et al., 1996). The GAMS library of solvers has only two modules capable of addressing non-linear constraints and non-linear objective function – CONOPT and MINOS, which is included in GAMS as a module. Both come with a disclaimer that they can only find local optimums, which can often serious degrade the quality of the final solution. Lack of universal algorithm applicable to a wide range of problems, along with the high likelihood of getting stuck in local optimums are the current obstacles in application of NON-LP programs in water resources.

Because of the limitations of DP and NON-LP, the search is currently under way for new solution methodologies that would provide reasonably fast execution times and a high likelihood of converging closer to global optimum. A promising approach is the use of genetic algorithms (Holland, 1975). These are combinatorial algorithms that generate new solutions (individuals) using the best previously found solutions (parents) whose properties (genetic material) are transferred to new solutions using the cross-over and mutation techniques similar to concepts in biology that bear the same names. Simulated annealing (Kirkpatrick et al., 1983) is somewhat similar although the progress is not acheived by the use of genetic operator such as crossover. These algorithms may terminate search with a group of high quality solutions, which is another advantage compared to other search methods. The difficulties are in the lack of universal approach to a group of problems and the need to calibrate the search parameters. The applications in water resources are few, however the expectations are promising as attested in examples provided by Savic and Walters (1996) or Oliviera and Loucks (1997).

2.2.1 Object Oriented Modelling Environments

A number of emerging object oriented tools that were not designed specifically for water resources are being used in water resources studies. These software tools contain many built-in mathematical functions and allow users to define objects (such as reservoirs or other water resources components) and describe what each object can do (by defining mathematical functions associated with them, such as reservoir storage or release) and also define links between different objects. Users are thus encouraged to develop the model by defining its elements and putting them together. Examples of these models are DYNAMO (Lyneis et al., 1994), VENSIM (Ventana, 1995), POWERSIM (Powersim Corp. 1996), STELLA (High Performance Systems, 1992), and MATLAB (Mathworks, 1999). The advantages of these tools are in shortening of time required to develop a model application. This is because the users rely on built-in facilities to interactively create a large part of input data file by simply creating objects and links on the screen using the available program options. These programs are usually windows based, intuitive and supplied with on-line help files. They are easier to learn because they take advantage of user friendly graphical environments for which they were created. The use of the STELLA modelling environment was demonstrated on a real world water resources system in Egypt (Simonovic et al., 1997). The process is easier to understand and therefore more acceptable to stakeholders (Palmer et al., 1993; Simonovic and Fahmy, 1999). There are drawbacks, however. If something does not work, the users may be unable to fix it. For example, if a simple reservoir routing equation does not give the same results as those obtained using other proven models, users cannot easily investigate why, since they are unable to trace the values of the variables internally within the model as they could with a debugger available for most high level compilers. The actual step by step instructions executed within an object member are not visible to the end user.

2.2.2 Object Oriented Models Specific to Water Resources

The object oriented approach is not exclusive to modelling environments such as STELLA or MATLAB. Recent developments in computer science over the past 15 years have shifted strongly in the direction of the object oriented approach, as opposed to procedural programming that represents the earlier preferred practice. Early programming languages such as FORTRAN relied on the use of one of several simple data types (integer, floating point, character, etc.) that could be used as single variables or arrays. Virtually all modern object oriented programming languages provide the capability to create user-defined data types. These are called *classes*. Each class contains data and functions (or "methods") which manipulate the data. While an instance of an earlier built in type integer was called an *integer variable*, an instance of a class is called an *object*. In water resources models objects could represent all elements that comprise the system, e.g. reservoirs, channels, water users, etc. Each object would contain its data (e.g. volume vs elevation curve for a reservoir) and functions (e.g. reservoir storage balancing equation). It is also possible to copy individual objects and modify them. The object oriented models reviewed below include Aquarius (1999) and RiverWare (Zagona et al., 1999). They were developed in Visual C++ and the available classes represent the types of components that are encountered in water resources management. In addition to storing data and manipulating them using the available classes, users can also visualize each object on the screen and define its relationship with other objects.

Water systems are ideal candidates for object oriented modelling, where each system component (e.g. reservoir, demand area, diversion point, river reach) is an object in the programming environment. The Aquarius model supports components describing reservoirs, hydro power plants, agricultural water use, municipal and industrial water use, in-stream recreation water use, reservoir recreation water use and fish habitat protection.

The water allocation problem solved by Aquarius requires a complex nonlinear objective function. The solution technique uses a special case of general nonlinear programming that occurs when the objective function is reduced to a quadratic form and all the constraints are linear. The method approximates the original nonlinear objective function by a quadratic form using the Taylor series expansion and solves the problem using quadratic programming. A succession of these approximations is performed using sequential quadratic programming until the solution of the quadratic problem approaches the optimal solution.

The user interacts with the model through what is known as the network worksheet screen (NWS), which represents the water system of interest using the capability of the object-oriented paradigm for graphical representation. In the NWS, each water system component corresponds to an object, a graphical node or link, of the flow network. These components are represented by icons, which are graphical representations of the objects. By dragging and dropping these icons from the menu, the model creates instances of the objects on the screen. Components can be repositioned anywhere in the NWS or they can be removed. Once nodes (e.g., reservoirs, demand areas) are placed, they are linked by river reaches and conveyance structures. This operation occurs by left-clicking on the outgoing terminal of a node and then on the incoming terminal of the receiving node. This procedure facilitates the creation or alteration of water systems by connecting their system components in the NWS. The creation and alteration of flow networks is further enhanced by copying and inserting an object or whole portions of an existing network onto the same or a new NWS. Copy and paste creates new instances of the object(s) and duplicates their structure.

The present version of the Aquarius model implements only a monthly time step. The model can apply optimization to one or more time steps simultaneously. Setting the optimization horizon equal to the period of analysis produces a full-period optimization. The main weaknesses of the model are the complete lack of any treatment of non-linear flow constraints, which are the main source of non-linearities in water resources networks, along with simulation restrictions to only monthly time steps.

A similar effort undertaken by Zagona et al. (1996) resulted in the development of the Riverware system. This system was also developed in C++ using the object oriented approach. It has three optional running modes, including pure simulation, rule based simulation and optimization based on the goal programming implementation of LP. The system has been used by the Tennessee Valley Authority and the U.S. Bureau of Reclamation. The authors report the use of Riverware with monthly time steps in planning mode and also in operational mode with short term (6 hour) time steps, although no documentation is provided regarding the necessary linearization of channel flow routing functions for such small time steps. Some reference is made to the process of linearization of hydro power related constraints and objectives, with acknowledgment that linearization introduces an approximation error of unknown magnitude in the calculation process.

Similar developments include Waterware (Environmental Software and Services, 1999), Aquator (Oxford Scientific Software, 1999) and Interactive River and Aquifer Simulation (IRAS) from Labadie et al. (1996).

2.3 Other Recent Developments

In addition to the use of object orientation, three additional trends related to water resources model use and development can be identified. They are the shared vision concept, GIS links with watershed management models, and the addition of graphical user interface to existing models / systems.

2.3.1 Shared Vision Concept

In spite of the large number of competing computer models generated for a variety of water management purposes, there is still very little real time use by the operators. As mentioned earlier, the reasons are both technical (models are crude representations of reality) and psychological (operators do not like to use models as a "black box" without fully understanding how they work). Earlier planning studies conducted on a contract basis by consultants also relied on the use of models, but the results were often ignored in the decision making process for the same reasons. To overcome this problem, and to introduce some order in the rapidly growing model development, the American Society of Civil Engineers (ASCE) has initiated a task committee on "the use of shared vision modelling in water resources planning" (Palmer, 2000). Shared vision modelling is a disciplined approach to developing water resources models for conflict resolution that requires active participation of stakeholders (those who are affected by water resources management decisions). These models typically incorporate social, economic and environmental analysis in addition to hydrologic and hydraulic analyses. Because they require active participation of individuals with various backgrounds, they must be easy to understand and modify, in addition to being easy to run.

2.3.2 GIS Links with Water Management Models

Few research fields have generated as much interest as the emerging Geographic Information Systems (GIS), which were created in the early 1960s in Canada (Coppock and Rhind, 1991) to analyze the national land inventory. GIS software now runs on personal computers and allows for the inclusion of almost any kind of information. The only requirement is that the information must be linked to a geographic location. Since GIS was created there have been many developments related to its use. These have lead to the creation of research institutes starting in 1969, satellites being launched in the early 1970s and the creation of many companies working with GIS in the early 1980s such as ESRI (Arcview, 1996) and Mapinfo (1997), and also the beginning of many research projects and their published results. GIS has also moved to the Internet as a means to distribute information to both government and private agencies.

There are many definitions of GIS owing to its versatile nature and open environment for functional development. They range from a view of GIS as a sophisticated technical tooi to a broad aspect of defining GIS as a new science. Wright (1997) provides a detailed discussion and justification for both ends of the spectrum, as well as for those attempting to find a common ground between them. A comprehensive definition of GIS from Hastings (1992) is: "GIS is a system of hardware, software, and data that facilitates the development, enhancement, modelling, and display of multivariate (e.g. multilayered) spatially referenced data. It performs some analytical functions itself, and by its analysis, selective retrieval and display capabilities, helps the user to further analyze and interpret the data".

GIS links with river basin management models have resulted in the emergence of new concepts and terminology, such as the special decision support system (SDSS), representing computer systems where both GIS and decision support systems (DSS) technologies have been merged. A GIS is good at handling spatial representation of water resources systems, but with little built-in predictive and analytical tools for solving complex water resources planning and management problems (Walsh, 1992; Parks 1993). On the other hand, decision support systems are interactive tools based on water resources simulation or optimization capabilities. Densham and Goodchild (1989) formulated the concept of a spatial decision support system as an integration of GIS and DSS. This concept in water resources was later addressed by Walsh (1992). McKinney et al. (1997) illustrates one example of SDSS in water resources management as an aid to decision makers. In this work GAMS solvers were used to conduct linear and non-linear optimization sub-tasks, and their input and output files were linked with ARCVIEW thematic layers.

Compared to a traditional DSS, SDSS are more powerful and flexible since they bring GIS capabilities into their database and interface. The database is improved by gaining a spatial dimension of GIS along with its integrating functions, while the GUI interface of the DSS is significantly enhanced with GIS visual and mapping capabilities, bringing the best of both worlds into a single package (Lam and Swayne, 1991; Cowan et al., 1996). Additional work on integrating the existing DSS graphical user interface with that of the GIS platform may often be required, but it is usually a good investment (Crosbie, 1996). While GIS provides a spatial representation of water resources systems, the DSS provides definition of the water resources problem under investigation and the tools for addressing it, hence the SDSS provides an integration of both (Walsh, 1992). The architecture used to combine both can range anywhere from loose to tight coupling (Nyegres, 1993; Fedra, 1996). A loose coupling refers to tools and procedures for data transfers between the two, while maintaining generally two separate databases (GIS and DSS). A tight coupling requires that the GIS and DSS share the same database. Complete coupling is an integrated (or embedded) system, with all modelling tools and data packaged together in a single operating framework (McKinney et al. 1993; Burgin, 1995). Tight coupling is usually founded on a development of object oriented approach. Several examples of object-oriented SDSS have been published so far (Loucks et al., 1996; Reitsma, 1996; Fedra and Jamieson, 1996).

An example of loose coupling is presented in this study. There are more strengths than weaknesses to this approach at present. Further developments can provide tighter coupling. However, it will be seen that this would involve significant effort while offering relatively little benefit at this point. The purpose of using GIS links to the modelling schematic is demonstrated in the case study presented in Chapter 4.

2.3.3 Addition of Graphical User Interface (GUI) to Popular Models

The community of model users is reluctant to abandon the models that have been used successfully for a long time. The reasons are diverse. For one thing, many bugs have been found and corrected over the years. Combining this with numerous reports of successful model applications resulted in increased confidence within the modelling community. The work of re-writing everything from scratch using an object oriented approach and new compilers with powerful interface capabilities is appealing, but in most cases it is deemed risky and unaffordable. Many programs contain over 20000 lines of old FORTRAN code, which have been patched by various individuals over the years. Re-writing it all from scratch is risky due to possibilities of introducing new errors, and it can also be very expensive. Many agencies have therefore opted for a limited additional development of GUI routines that do not affect the proven quality of the existing models while at the same time they add the user friendly communication interface that has become standard for the more recently developed models. The old programs are called interactively as subroutines from within the new interface modules.

The main emphasis of these developments has been to make the entry of data into the input data file user friendly and error free, and to allow faster processing and visual presentation of the results. Examples are many. HEC-RAS, the extension of the popular HEC-2 program created by the US Corps of Engineers, was initially developed with its own graphical user interface both for editing files and viewing the output (water surface profiles and cross sections). In the most recent version of HEC-RAS these interface programs have been linked to Arcview and Arcinfo GIS systems, adding additional capabilities for mapping the flood line and for interpolation of river cross sections using, for example, the digital elevation model (DEM) database accessible to GIS programs. Other programs where flood line mapping or other spatial information is an essential part of input or output can benefit from linkage to GIS. An example is the popular DAMBRK model for which the US Bureau of Reclamation has helped fund the development of an interface with the ARCINFO GIS platform (Sebhat and Heinzer, 2000). Some private consulting firms have joined the effort to add useful modules to popular public domain programs that would enhance and ease their use. Companies like Boss International (2000) and Heastad Methods (2000) market a number of such enhancements as their versions of the popular models, charging fees effectively for their added value user interface modules, while the embedded old public domain FORTRAN programs are rarely touched.

The developments outlined in this thesis are similar in nature to those described above. They rely on the use of the proven river basin allocation model WRMM which has not been modified, but which has been enhanced through the creation of additional modules aimed at making it easier to understand and use. The attached GIS link has been primarily of benefit for the development and handling of the modelling schematic. While other GIS features could be utilized effectively in the future, it should be noted that the WRMM does not rely on the spatial information as much for delivering a solution as do the rainfall- runoff of river routing models. Consequently, its use of the GIS capabilities is relatively modest.

3 DESCRIPTION OF THE WRMM

The WRMM (Alberta Environment, 1997) is one in a series of river basin models that relies on the use of linear programming network flow algorithms. Several computer models have been developed since the early 1970s based on similar concepts. A comprehensive review of these developments was compiled by Yeh (1985). The models which utilized these concepts are SIMYLD (Evanson and Mosley, 1970), ACRES (Sigvaldason, 1976), MODSIM3 (Labadie et al, 1986), WASP (Kucera and Dimnet, 1988); DWRSIM (Chung et al., 1989), CRAM (Brendecke et al., 1989), and KCOM (Andrews et al, 1992). Non-linear constraints associated with the bounds are handled by using longer computational time steps and by applying successive iterations within a time step if necessary (Ilich, 1993). These models are popular since they can simulate large basins with various types of components over long multi-year historic time periods within minutes on desktop computers.

3.1 Introduction

The WRMM is a computer program used to analyze the impact of various operational policies or structural developments within a river basin. It is the result of a great deal of work by professionals from various disciplines who have contributed to it over the years. The use of WRMM began in 1981 on an IBM mainframe. The model belongs to the Government of Alberta, Canada, and is in the public domain, i.e. it can be obtained free of charge. The WRMM has undergone numerous revisions and improvements since its inception.

The WRMM can be defined as a *steady-state, deterministic water allocation* model. The model variables are channel flows for various river or canal reaches, and reservoir releases. There is no variation of flow along an identified channel section, so inflow at the upper end of the canal section equals outflow at its bottom. The significance of this is that the use of the model as a real time operational tool is only possible with sufficiently large time steps.

As a deterministic model, the WRMM requires a perfect forecast of inflows and demands for a given time step. The use of the WRMM as a planning tool is predicated on the development of estimates of natural flows for various locations in the basin. Naturalization of flows includes development of estimates of flows that would historically occur had there been no man-made diversions and reservoirs.

The WRMM is an allocation model, which means that it has the ability to allocate water according to a specified set of priorities. The allocation algorithm used in the WRMM is called the Out-of-Kilter algorithm (OKA) and it is based on the theory of Linear Programming. The algorithm takes into account the available water in the system (runoff forecast and initial reservoir storage) at the beginning of a simulated time interval, canal capacities and other flow constraints, water demands for all in-stream and off-stream water users, and the allocation priorities among different users to derive the best allocation for a given time step. The model then takes the ending reservoir elevation from the solution for one time step as the starting elevation for the next time step, and proceeds in the same manner for all other time steps in a chosen simulated period.

The main mechanism for establishing allocation priorities in Alberta is based on water licences. Water licences refer to limits to the instantaneous flow rate as well as the annual volume that a user is entitled to divert. However, licences merely provide the upper limit that can be diverted. The actual diversions for a given simulated week in planing simulation runs with the WRMM are demand driven, and they may be less than the licence limit on flow. Water licences are the most important input required to setup the *operating guidelines*, which are usually decided by senior water management committees including representatives from all agencies involved in water use. One of the major strengths of the WRMM is its ability to include various sets of operating guidelines in the input data file and modify them easily.

3.2 Model Background

The WRMM is a general tool capable of modelling any river basin for which sufficient data exist. It is capable of modelling the following components of river basin management:

Component	Description
Reservoir	simulates change in storage based on inflow, outflow, precipitation and evaporation.
Irrigation	simulates an irrigation system consumption for a specified irrigated area, irrigation depth requirement and system efficiency.
Major Withdrawal	simulates water consumption by a user such as a municipality or an industry.
Return flow	used for return flows from Irrigation and Major Withdrawal components. Specified as a fraction of the gross diversion to these components.
Hydropower Plant	simulates power generation based on headwater and tailwater elevations and generating plant characteristics.
Natural Channel	simulates flow in natural stream reaches.
Apportionment Channel	simulates flows at borders between the states and provinces which have a legal agreement on sharing water (an apportionment agreement).
Diversion Channel	simulates conveyance of water between nodes subject to a specified maximum diversion capacity.

In addition, four features may be specified which are not classified strictly as components:

Feature	Description
Inflow at a node	represents runoff between the node and all immediate upstream nodes above it. When there is no "node above", the inflow is the headwater flow.
Minor Withdrawal	Mandatory net consumption by a user. There is no return flow.
Outlet Structure	a mechanism for setting limits on the flow in the channel immediately downstream of a reservoir or diversion structure. It controls the maximum outflow from the reservoir to the downstream channel.
Canal Loss	allows the user to specify water lost during canal operations, e.g. due to seepage, evaporation, evapotranspiration.

The model can simulate large river basins with many reservoirs; diversions for industrial, municipal and irrigation use; in-stream flow requirements; apportionment agreements between bordering states or provinces; hydro power production; evaporation; precipitation; and local runoff.

3.3 Required Input Data

The model deals with complex issues and requires comprehensive data, which must include:

i) hydrologic data (weekly or monthly naturalized flows, evaporation, and precipitation);
ii) physical system data (storage vs elevation curves for reservoirs, outflow vs elevation for control structures, flow limits for channels, etc.)
iii) estimate of all water demands in the system;
iv) operational priority policies; and
v) travel time vs flow relationship for each river reach (only required when time-lagging

routines are used)

The model is normally run using a historical time series of hydrologic data which are matched with estimates of future water demands and structural developments. It is also possible to use a synthetic time series of flows generated using stochastic generation models.

3.4 Conceptual Basis of the Model

As stated earlier, the model determines all reservoir releases and diversion flow rates for a given time interval without any knowledge of the runoff and demand conditions in subsequent time intervals.

A dam operator, in real life, decides how much water to release from the reservoir usually once every few days. His decision is based on the runoff and demand forecasts. The optimization sub-program in the WRMM takes on the role of the dam operator. The forecast of flows and demands throughout the basin is in the input data file for every simulated time step. The WRMM finds an optimal water distribution policy for each time step individually (a calculation time step can be any multiple of one day). The model uses flows and demands which are averaged per time step.

There may be up to 50 iterations within each time step. These are caused by the dependent flow limits imposed by control structures on reservoirs, hydro power plants, return flows for irrigation and industrial consumption, or time lagging. The WRMM deals with the dependent variables by using an iterative process of guessing them first, deriving a solution, and then improving the guess until the final solution is within the bounds permitted by the guess. This process is customized for each type of component based on the nature of the dependent variable associated with a particular component. All bounds are specified as zone boundaries in the input data file.

3.5 The Zoning Penalty Concept

Use of the WRMM is based on understanding the "zoning-penalty" concept. Users must identify one or more significant zones for each modeled component, e.g. storage zones for reservoirs, flow zones for channels, or consumptive use zones for irrigation or industrial water use. Each zone is assigned a penalty which represents its priority of use. The general thrust of the model is to allocate water to the zones with highest penalty first, using the available runoff and then the top storage zones, which normally have the lowest penalties such that they make water available to other components with higher penalties during dry periods. Some zone bounds represent physical constraints (e.g. full-bank flow capacity of a channel), some are operational constraints (e.g. more than 50% deficit of the irrigation target destroys the crop), while some can be arbitrarily set by the user. Both zone sizes and their penalties are set by the user in the input data files. Figure 3.1 shows an example of the zoning concept.

The zones in Figure 3.1are depicted for one point in time. Numbers inside the zones are penalties, and they represent the priorities of allocating water to each zone. The higher the penalty, the higher the priority of allocation. Therefore, during conditions of reduced runoff, the natural channel (river) flow is first allowed to drop to its specified minium flow. Further reduction in runoff is followed by reservoir release from the top zone with the penalty of 10. This is the second lowest penalty in the system and it helps maintain the supply for municipal and irrigation water use at 100%. Once the level in the reservoir drops to the bottom of the second zone, irrigation supply is reduced to 50% of its target, followed by the municipal supply since its penalty of 30 is greater than 20. Further reduction in storage from the second zone with the penalty of 40 is then allowed to maintain the level of supply at 50% as well as to maintain the minimum flow target. Finally, when the bottom of the second reservoir zone is reached, water supply is cutoff completely first to irrigation, then to municipality and finally to the natural channel. Note that a small amount of storage is still kept in the reservoir although all other components have run out of supply. Within the model, each zone is

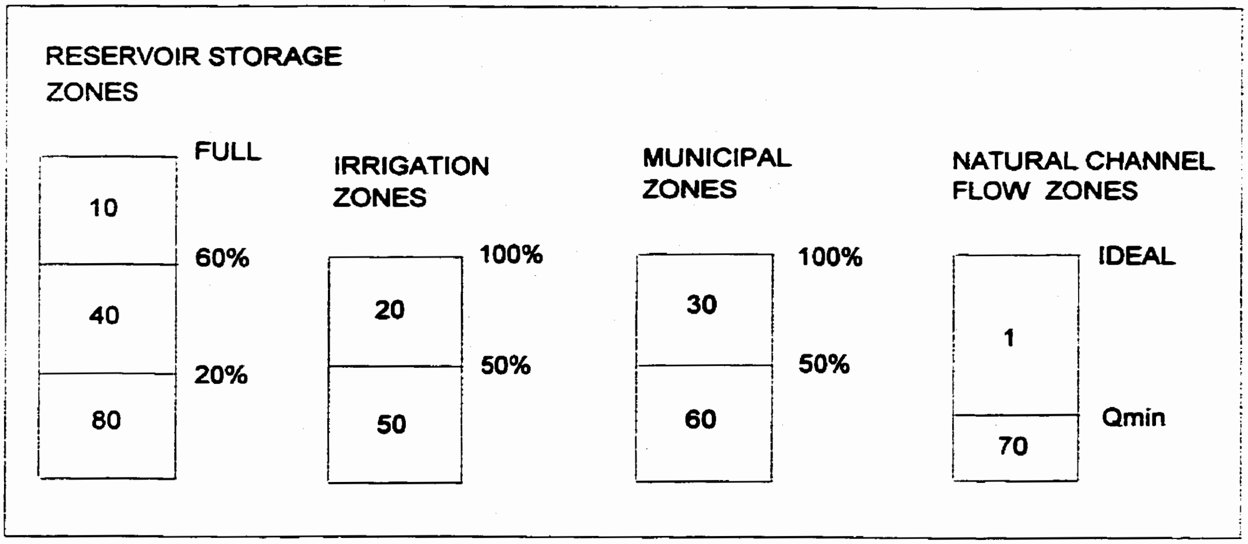

Figure 3.1 Example WRMM operating zones

represented as a flow along an arc with its upper and lower bounds and a cost (zone penalty) incurred per unit of flow. The problem of balancing the available supply (flow in arcs representing runoff and the initial reservoir storage) with water demands throughout the system can be formulated mathematically as the minimum cost network flow problem, i.e.

$$\text{minimize} \sum_{(i,j)\in A} c_{ij} x_{ij} \qquad \forall (i,j) \in A \tag{3.1}$$

Subject to:

$$\sum_{\{(i,j)\in A\}} x_{ij} - \sum_{\{(j,i)\in A\}} x_{ji} = 0 \quad \forall i \in N \tag{3.2}$$

$$0 \le l_{ij} \le x_{ij} \le u_{ij} \qquad \forall (i,j) \in A \tag{3.3}$$

Where (i,j) represents an arc oriented from node i to node j, A is the set of all arcs in the system, N is the set of all nodes, l_{ij}, x_{ij} and u_{ij} the arc lower flow bound, flow and the upper flow bound while c_{ij} is the user defined penalty associated with transferring one unit of flow from node i to node j along arc (i,j). Constraint (3.2) is the mass conservation equation expressed for each node while l_{ij} and u_{ij} are associated with zone bounds. Since c_{ij}, l_{ij} and u_{ij} are constants, expressions (3.1) through (3.3) constitute a linear programming problem.

It should be noted that there is more than one set of penalties that would result in identical water allocation. For example, instead of penalties 10, 20, 30, 40, 50, 60, 70 and 80 in Figure 3.1 user could input 1, 4, 5, 6, 9, 11, 15, 80 and the solution would be the same for a given set of water demand targets and the starting reservoir level.

By far the most significant feature of the zoning concept is the fact that zones can be time dependent. The result of this is that it is possible to shape the reservoir zones into suitable draw-down and refill curves. The best shape of these curves can be found with the WRMM using a trial and error procedure, given that the modelling objectives are clear and a common evaluation criteria is maintained for all trial runs. An example of the variation of reservoir operating zone with time is given in Figure 3.2. The meaning of the above time variation of reservoir zones is as follows: in the ideal situation of abundant supply, keep the reservoir full (horizontal top of zone 1) at all times. For any other point in time, allow a draw-down within one simulated time step from the starting elevation to the bottom of the first zone (below the starting level), taking the prescribed priorities of allocation among other components into account. It can be seen from Figure 3.2 that storage is easily made available when the curve is declining, while storage is hard to get during the snow melt runoff in the spring (days

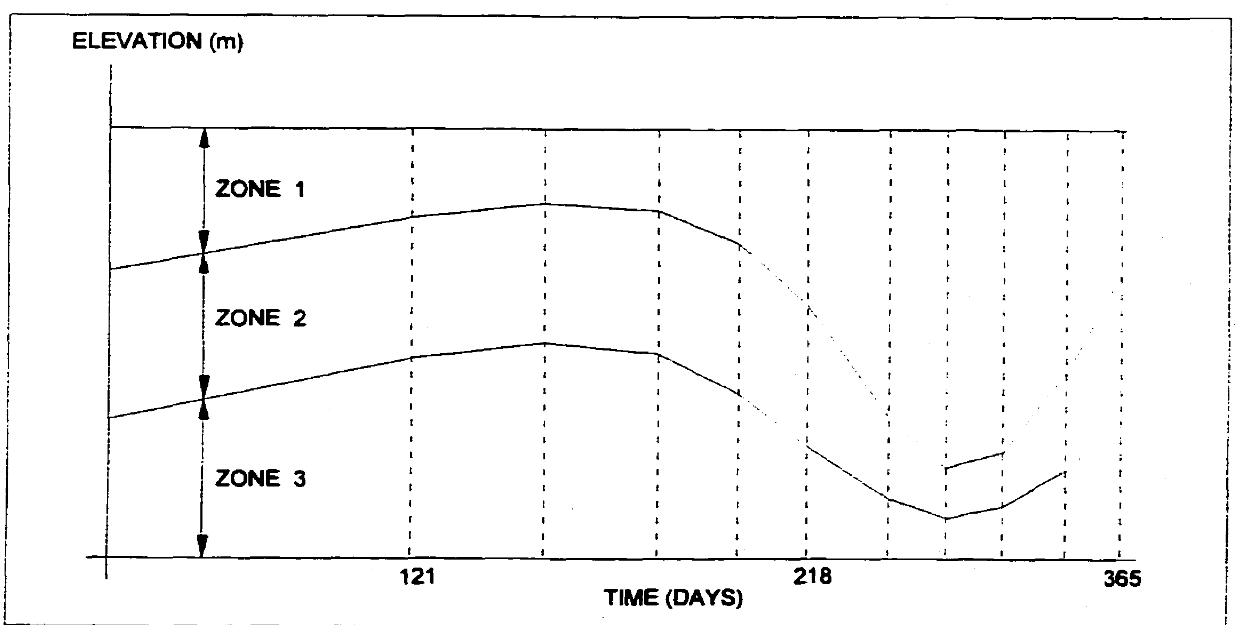

Figure 3.2 Time variation of reservoir operating zones

between 121 and 180). The top of zone 3 is elevated at the end of the snowmelt period, such that it ensures that some storage is always available at the beginning of the dry season. This is because zone 3 has the highest penalty, and no other component in Figure 3.1 can lower its elevation. Typically, evaporation is the only process that could cause the reservoir level to dip below the top of zone 3.

3.6 Time Lagging Routines and Steady State Simulation

Pure steady-state simulation ignores the travel time through the modelled region, since the assumed travel time is well below the length of the calculation time step. For some large river basins this assumption does not hold, so they can only be modelled using larger (e.g. monthly) time steps. To overcome this problem, the time-lagging routines have been incorporated into the WRMM to enable modelling of large river basins with weekly time steps. They allow shifting of the demands such that the reservoir releases are timed with the demands based on the travel time between the reservoir and points of demand. A simplistic exponential relationship between channel flow and travel time is used for every river or canal reach in the modelling schematic. This was considered necessary since it was noted that monthly simulation results have significantly lower reservoir spills than those found in the weekly simulation of the same system. Therefore, simulation with weekly time steps is considered more realistic.

3.7 Identifying Model Components and Creating a Modelling Schematic

The first step in the use of the WRMM is to setup a modelling schematic, which is a collection of all model components included in the study along with their mutual links. There are useful rules that a novice user can follow when setting up schematic for the first time.

The definition of the modelled region is the first step in applying the WRMM. Users should identify the parts of the watershed area to be included in the study and identify the diversion structures, reservoirs, hydrometric stations and water users. This information forms the basis for creating the modelling schematic. The following general guidelines for some types of components could be useful when setting up a schematic.

3.7.1 Rules for Selecting Natural Channels

Long rivers and their tributaries identified within the watershed area must be sub-divided in smaller sections, or *reaches*. The following is a list of desirable points of division into reaches:

a) diversion structures (weirs, intake structures, etc.);
b) natural confluence between the main river and its tributary or between tributaries;
c) reservoirs or other sizeable in-stream storage; and,
d) locations of hydrometric stations.

Historic flow records from existing hydrometric stations are used in the process of naturalizing flows by adding back the water abstractions and removing the effect of storage for every reservoir in the system. The purpose of this exercise is to re-create the estimates of natural (or virgin) flow conditions which would have happened in the absence of any man-made structures (diversions or reservoirs). These flow estimates are required as part of the WRMM input data.

All of the above points in the physical system are represented as nodes in the network. Nodes act as (a) meeting points (or *junctions*) between two or more links, as (b) points where water is supplied to the system (inflows or reservoir nodes); or (c) as points where water is lost from the system (irrigation blocks or industrial water use). Components represented as "links" are all others, i.e. natural channels, diversion canals, apportionment channels and hydro power plants.

3.7.2 Diversion Canals

Diversion canals begin at their respective intake structures and they end either at other structures diverting water into two or more canals or at an irrigation block where water is lost to evapotranspiration. When there is a return flow associated with irrigation or industrial consumptive use, the relationship maintained by the WRMM is in the form of:

$$GD = CU + RT \; ; \qquad \text{and} \qquad GD = f \cdot RT \tag{3.4}$$

where GD is the gross diversion into the canal, CU is the consumptive use (e.g. crop evapotranspiration), RT is the return flow and f is the return flow factor (between 0 and 1) showing the percentage of gross diversion that remains unused. The term RT here refers to the total return flow which may be distributed along up to five return flow channels.

3.7.3 Representation of Runoff

In the WRMM, flow along one river (or canal) reach is constant, which means that flow at the beginning of the canal is the same as the flow at the end. This is generally not the case in reality, especially for river systems, due to minor tributaries and other runoff contributions (or losses) along the reach. To rectify this, the WRMM uses two mechanisms: (a) longer time steps, which minimize the effects of channel storage change; and, (b) inflow nodes at the end of every reach for which the inflow data have been made available. The effect of this is shown in Figure 3.3

A distinction should be made between location 2 and 3, even though they both represent inflows. At location 2 there is a tributary, hence there is a sudden increase in river flows downstream of the confluence. At location 3 there is a hydrometric station and all runoff between location 2 and 3 is added as a single "equivalent" tributary in the WRMM, represented as inflow into node 3, while outflow from node 2 along the channel remains

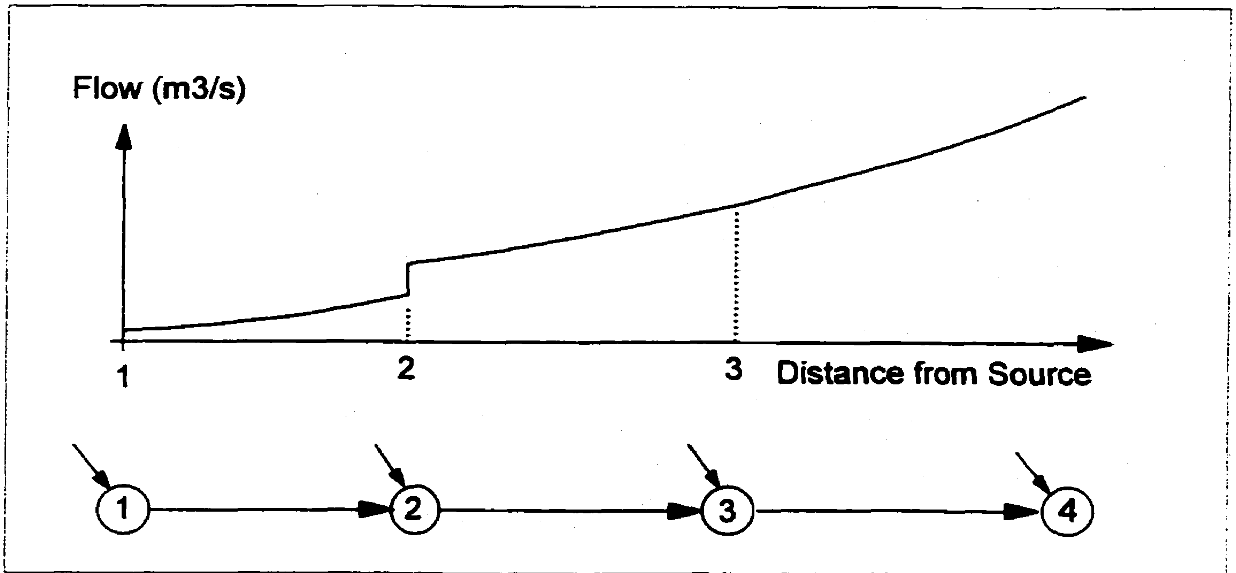

Figure 3.3 Representation of Runoff

constant. It should also be noted that inflows can sometimes have negative values, either as a result of legitimate seepage losses to groundwater or as a result of attenuation processes. To demonstrate the former, consider natural flow hydrographs at nodes 2 and 3 as shown in Figure 3.4 and assume that the travel time between nodes 2 and 3 is two days. Note that the flood at node 2 has taken some time to propagate to node 3 and that this has also resulted in attenuation of the initial hydrograph at node 2, which is now a bit delayed and "flatter". The average weekly flow (from time 0 to time 7 days) is in this case lower at node 3 than at node 2, as depicted by the broken horizontal lines associated with the Qav symbol on both graphs. Since local sub-catchment runoff contribution along the reach 2 - 3 is calculated as natural flow at node 3 minus natural flow at node 2, in this case the result is negative. Consequently, the average flow at node 2 is not available in the same week at node 3. Some of it will come later, in the following week. This is the only way to represent variation of available runoff in the basin using the steady-state flow representation within a river basin.

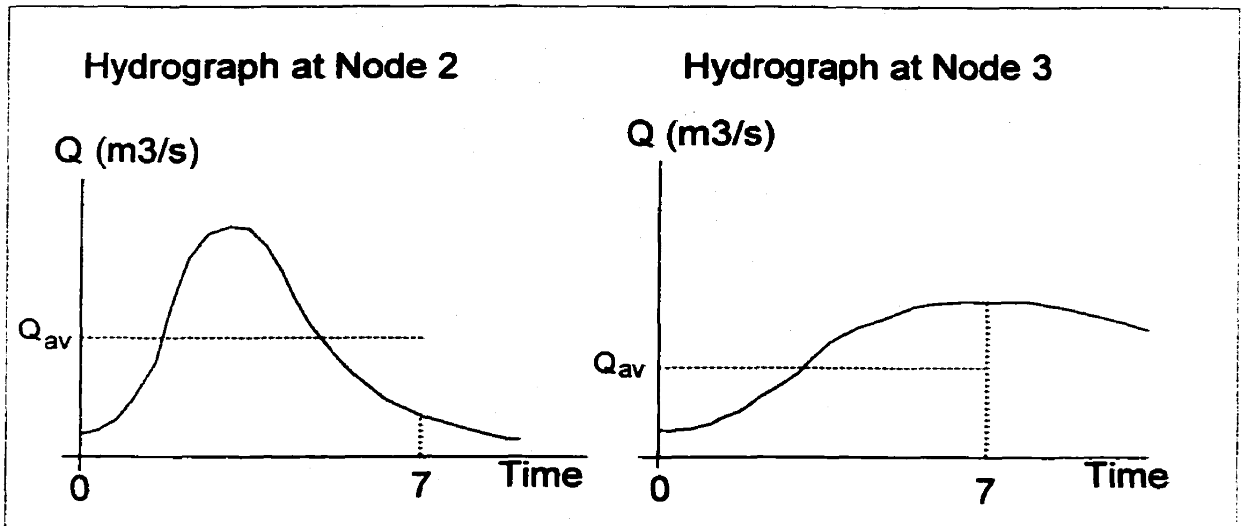

Figure 3.4 Demonstration of Negative Local Inflow

3.8 Input Data

3.8.1 Input / Output Block Diagram

The required input data files are the Simulation Control File (SCF) and the Hydrometeorologic Base Data File (HBDF). For single year runs only the SCF is sufficient. The output data files produced are OUTSIM, OUTID and SCFECHO. There are two output formats, depending on the use of the OUTNODES and OUTLINKS options in the SCF file. When either one of these options is used, the SCFECHO file contains only the SCF input data file and output for the selected components is stored in the OUTSIM and OUTID files. Without either of these options, the entire output is stored in two files: SCFECHO and OUTID, and the OUTSIM file is not used. In this case the SCFECHO file contains a detailed printout for all components with additional symbolic information which is useful for checking the initial model setup. This option is rarely used now and the use of OUTSIM and OUTID has long been a standard.

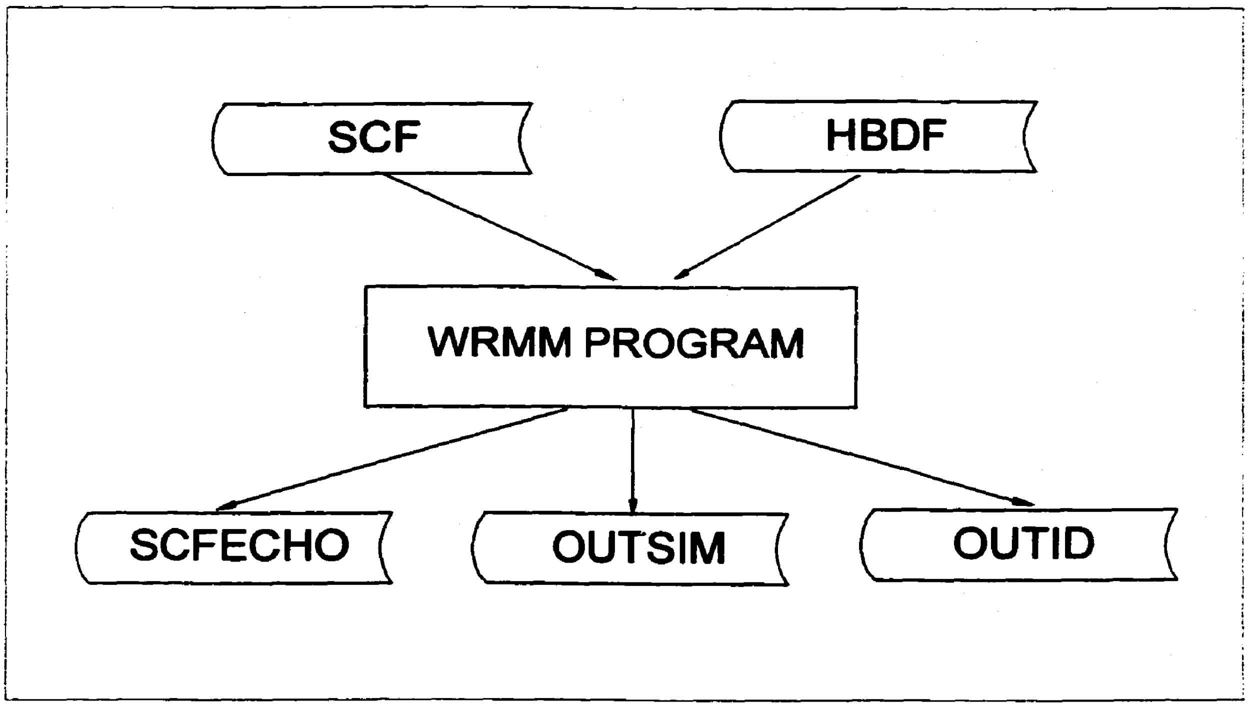

Figure 3.5 The WRMM I/O Block Diagram

3.8.2 Input Data File Formats

The WRMM input and output files are in ASCII format and adhere to several general rules:

a) All integers use five fields, and all floating point numbers use ten fields (nine for digits and one for the decimal point).

b) The name of the input data file is SCF (Simulation Control File) and the model opens it in the current working directory at run time, which means that the user must create the actual input data file as a working file called SCF prior to running the model.

c) For a single year simulation, only the SCF file is required. For multi-year simulations, multi-year data stored in the HBDF file is also required.

d) Prior to running the model the user must create a modelling schematic and assign a number to each modeled component.

e) The SCF file is divided into six sub-sections indicated by a keyword starting with a $ sign. They are the following:

$IDENT	Identification subsection. Contains descriptive information about the simulation run with the name of the basin and the date of the run.
$SIMCON	Simulation control subsection. Contains the starting and ending year, the length of time intervals in days, and optional printout control variables.
$PHYSYS	Physical system subsection. Contains storage volume curves, canal capacities, irrigated areas, connectivity paths for various components and the number of return flow channels for each irrigation or industrial use component.
$PENSYS	Penalty system subsection. Contains the definition of zones sizes in each point in time along with the priorities of allocation.
$WATDEM	Water demand subsection. Contains water demands for all time steps which can be read directly from the SCF or which have a reference name in the SCF that links them to the proper HBDF section.
$WATSUP	Water supply subsection. Contains inflows, the starting reservoir levels, precipitation and evaporation estimates.
$LAGDAT	Channel lag subsection. Contains two empirical parameters (A and B) for each channel that specify the relationship between channel flow and travel time using the expression $T = A / Q^B$ where T is the travel time in days and Q is the average channel flow in m^3/s.
$ENDFILE	Keyword denoting the end of the SCF file.

The SCF is a complex file since it must describe all constraints and the internal relationship of all components in the modelling schematic. It also has to provide accurate links with the hydrologic, meteorologic and water demand data in the HBDF file. Since it is in ASCII format, it can be edited with any text editor. Moving a floating point beyond the specified fields, or leaving accidentally invisible characters in the file such as tabs can cause a lot of frustration. Users are required to familiarize themselves intimately with the SCF file format, which is not an easy job. The most difficult parts of the SCF file are the $PHYSYS and $PENSYS subsections. A systematic 50-page input data file description that covers each line in the file is available in the WRMM manual (Alberta Environment and Natural Resources, 1995). More information on the SCF file is available in Appendix C.

The HBDF file format is easier to master than the SCF. While the SCF is versatile with each line having a unique format, the HBDF looks more like a typical data file. The HBDF is divided into segments that look like a series of matrices in sequential order. There are two types, monthly and weekly HBDF files. One subsection of a weekly HBDF is depicted in Table 3.1.

Table 3.1 A segment of HBDF file

GBE MOU 1928 68 CMS
Belly River at the Mouth
Natural Weekly Mean Flows Calculated (m³/s)
SOURCE: SSRB Weekly Natural Flow Database, Water Sciences Branch, January 1999

Year	WK01	WK02	WK03	WK04	WK05	WK06	WK07	WK08
1928	5.309	25.190	18.550	16.750	13.270	10.240	10.380	8.763
1928	25.390	23.570	19.970	21.510	48.850	76.430	138.000	186.800
1928	271.800	114.700	82.200	56.840	45.950	32.210	22.410	19.390
1928	14.030	30.130	43.870	39.950	22.910	19.460	17.560	16.280
1929	5.062	6.290	7.070	6.603	5.567	5.159	5.009	4.895
1929	12.930	14.060	14.670	25.560	47.570	59.180	95.970	146.600
1929	55.320	58.260	40.270	27.070	20.350	17.100	14.800	11.300
1929	10.970	14.300	11.950	10.370	10.430	8.833	7.646	5.019
1930	6.366	5.207	4.893	4.001	4.087	7.409	9.324	18.650
1930	27.330	40.170	57.060	72.460	103.800	93.810	76.570	110.200
1930	55.430	42.370	39.170	31.730	21.830	17.210	16.430	13.100
1930	12.550	13.390	10.650	9.827	8.238	7.451	5.872	5.854

The first line contains the keyword "GBE MOU" which may be present in the SCF file. If that is the case, the next four title lines will be skipped and the WRMM will read the data for the first year (in the above case 1928) on four lines, each line containing 13 columns such that the total number of values read from four lines is 52. The monthly HBDF file has 12 values on each line for each year.

3.8.3 Output Data File Format

This review centres only on the output data format of the OUTSIM and OUTID files. File OUTSIM contains a time series of regulated flows (i.e. flows allocated by the model) for each component of the modelling schematic specified explicitly in the OUTNODES and OUTLINKS option in the $SIMCON subsection of the SCF. The format of the OUTSIM and OUTID files are identical. A sample containing the first 15 lines of the OUTSIM file is shown in Table 3.2.

Table 3.2 A segment of the OUTSIM file

			7JAN	14JAN	21JAN	28JAN	4FEB	11FEB
RESERV	24	1928	960.75	960.76	960.80	960.84	960.88	960.92
RESERV	200	1928	946.54	946.00	945.47	944.93	944.43	943.95
RESERV	202	1928	874.00	874.01	874.01	874.01	874.02	874.02
IRRIGAT	314	1928	0.000	0.000	0.000	0.000	0.000	0.000
IRRIGAT	315	1928	0.000	0.000	0.000	0.000	0.000	0.000
MAJOR	2	1928	0.000	0.000	0.000	0.000	0.000	0.000
MAJOR	214	1928	0.000	0.000	0.000	0.000	0.000	0.000
APPORT	104	1928	118.228	194.804	257.231	190.147	162.700	150.594
DIVCHL	88	1928	0.000	0.000	0.000	0.000	0.000	0.000
DIVCHL	517	1928	0.000	0.000	0.000	0.000	0.000	0.000
DIVCHL	521	1928	0.000	0.000	0.000	0.000	0.000	0.000
NATCHL	37	1928	81.255	99.238	79.361	69.806	68.572	66.130
NATCHL	38	1928	88.077	111.437	88.185	75.960	74.724	72.533
NATCHL	39	1928	85.406	108.596	92.016	76.425	74.401	72.700
NATCHL	40	1928	81.134	104.075	98.823	77.555	74.175	73.319
NATCHL	41	1928	23.299	28.919	29.911	28.732	28.030	28.130
NATCHL	42	1928	21.396	27.605	29.125	28.161	27.367	27.372
NATCHL	43	1928	18.815	27.455	29.505	28.783	27.725	27.263
RETURN	504	1928	0.000	0.000	0.000	0.000	0.000	0.000
RETURN	505	1928	0.000	0.000	0.000	0.000	0.000	0.000
RETURN	506	1928	0.000	0.000	0.000	0.000	0.000	0.000
RESERV	24	1929	964.60	964.63	964.66	964.69	964.70	964.70

The first line shows the ending date for each time interval. An allocation solution for a time interval is placed in each column. Hence, the solution for the third time interval starting on January 14 and ending on January 21 is in the column with 21JAN as its heading. The first three columns provide the component type (NATCHL is a natural channel reach, RESERV is a reservoir, etc.), followed by the component number in the schematic and by the simulated year. Note that the last line in the above sample is the first line that belongs to year 1929. All other lines below it are repeated in the same order as for the year 1928 except that the individual flow values are different.

3.8.4 Typical Output Analyses

The output data files contain a time series of regulated channel flows, reservoir levels, consumptive water use for irrigation, municipal and industrial water use and generated hydro power. It is also possible to obtain reservoir evaporation losses as an optional output feature.

There are many ways of evaluating the model output. The actual issues that are analysed in the output depend on the intended purpose of a given simulation run. Sensitivity analyses are conducted sometimes to see how a variation of one input parameter (such as evaporation, for example) affects the operation of some of the critical reaches in the system. Evaporation may be increased by 10% in the input data file, and after re-running the model only the most critical river reach may have to be examined and compared with previous simulations. This means that even though the output data file is voluminous, sometimes it is necessary to quickly extract only a small fraction for further analyses.

The WRMM output analysis usually refers to statistical analyses of water supply deficits, or analyses of the magnitude and frequency of failures to meet a given management criteria as for example in the case of failing to provide minimum in-stream flows for a critical river reach. The need for graphical scanning of the output has long been recognized by the community of WRMM users, which has been provided by the Plotsim program developed in this study. The Plotsim program is written in Visual Basic. In addition to time series plots which can be obtained for every type of component found in the OUTSIM and OUTID files, it is also capable of producing probability plots, known as the flow-duration curves for channels or elevation-duration for reservoir, along with several tabular options containing statistical summaries for consumptive use components. The option to use probability plots has additional features related to generating statistical analyses for user defined periods of the year.

To summarize, the purpose of developing additional modules for the WRMM main program is related to simplifying its input data development and output analyses. The simplifications regarding input data are in safer editing and additional error trapping capability, along with a user friendly graphical environment which allows instant plots of input data when applicable. Output analyses are made easier with visual component selection, interactive user defined plots and a number of frequently used statistical summaries. Additional options can be added in the future.

4 BRANTAS BASIN CASE STUDY

4.1 Project Description

Figure A.6 in the Appendix A shows the Brantas river located in East Java, Indonesia, along with its major structures and tributaries. Initially, the river flows in the south-westerly direction and keeps turning to the right as it stretches in the downstream progression such that by the time it reaches the northern coast of the Java sea it has almost completed a full circle.

There are currently six hydro power plants in the system. Of those, only Sutami and Selorejo have balancing storage, the rest are run-off-the-river plants. The major structure in the system is the Sutami reservoir, with storage capacity of 165 million cubic meters and installed power capacity of 105 MW, which is roughly half of the combined capacity of all hydro power plants. The Lahor reservoir acts as additional storage to Sutami with 26 million cubic meters. It has no power generation, however it is connected with Sutami reservoir via a tunnel represented by diversion canal 131 in Figure A.4. In reality, the tunnel flow may have any direction, since it is driven by the elevation at both Lahor and Sutami reservoirs. Consequently, there are two diversion canals with opposite directions to represent tunnel flows, although one of them (the flow from Sutami to Lahor) was excluded from the schematic in Figure A.4 for brevity (it is still included in model runs). The main water intake structures in the system are represented with diversion canals 148, 144, 143, 142 and 141.

The Konto river tributary (channel 88) is non contributing during the dry season, while in the wet season its runoff contribution is already included in the natural flow estimate at Ploso (node 8). Therefore, although it is correctly shown to join the Brantas river at node 7, it is effectively modelled as a separate system which discharges its outflow out of the system (to node zero).

The main current basin management issue is the low flows in the Surabaya river (channel 85) during the dry season. This has caused problems for water supply to the city of Surabaya (diversions 154 and 155), which is the second largest city in Java with a population nearing 5 million including surrounding areas. To augment flows in channel 85 during the dry season the new Wonorejo reservoir (number 34 in Figure A.4) and two diversion canals (114 and 116) along with a pump station with capacity of 7.5 m^3/s (channel 141) are currently being built, in an effort to transfer the available runoff at nodes 14, 34, and 18 to the Surabaya river when needed. There is no such transfer at present. The size of the Wonorejo reservoir, which is currently under construction, and the pump station capacity were determined in earlier studies by consultants from Japan (JICA, 1998). There was no consideration of joint operation of the existing (Lahor and Sutami) reservoirs and the new Wonorejo reservoir within the framework of earlier designs.

4.2 Study Objectives

The goal of this is to develop reservoir operating rules that will best meet the established objectives of Perum Jasa Tirta (PJT), a water management agency in charge of regulating the major water intake structures and reservoirs in the Brantas river basin. The reservoir operating rules to be developed should be based on short term (10-day or less) forecasts of runoff and demands in the entire basin, with emphasis on operation in the dry season, when water supply is critical.

PJT is financed by charging fees for water use in the basin. There are four types of users in the basin: hydro power producers, municipalities, industries, and agriculture. Although the present situation is in the process of change, there is no fee for irrigation water use at present, although irrigation withdrawals account for more than 90% of the consumptive water use. Other water users in the basin are levied commercial rates in Indonesian currency Rupiah (Rp, Can$1 ≈ 5000Rp) which is aimed to encourage water use efficiency and water conservation.

Irrigation, municipal or industrial water use all have upper limits on demand which vary in time and space. There is no such limit explicitly stipulated for hydro power generation, where the goal is to maximize power generation. Maximizing total power generation in the basin over the whole year is a desirable objective since PJT collects a percentage of the generated power as its revenue. This objective is constrained physically by the flow and head capacities of the turbines, and operationally by other priorities that may take precedence. Hence, the management objective for the Brantas basin (and many other similar river basins) can be mathematically expressed as:

$$\max \{\sum P \cdot Rp - \sum Qp \cdot Cp + \sum Qir \cdot Rir + \sum Qin \cdot Rin + \sum Qm \cdot Rm + \sum [(Qrm - Drm) \cdot Crm]\} \tag{4.1}$$

where:

P	power generation at any of the hydro power plants in the basin (Kwh)
Rp	revenue per kwh allocated to PJT as per the existing agreement (Rp)
$\sum P \cdot Rp$	sum of revenues from all hydro power plants in the basin (Rp)
Qp	pumped flow through a pumping station (m^3/s)
Cp	cost of pumping per 1 m^3/s assuming constant head rise (Rp)
$\sum Qp \cdot Cp$	sum of all pumping costs in the basin (Rp)
Qir	water supply for irrigation (m^3/s)
Rir	added value of crop production due to 1 m^3/s of irrigation supply (Rp)
$\sum Qir \cdot Rir$	added value of total crop production from all irrigated areas (Rp)
Qin	water supply for industry (m^3/s)
Rin	revenue from industrial fee per 1 m^3/s of water use (Rp)
$\sum Qin \cdot Rin$	total revenue from all industrial water use in the system (Rp)
Qm	water supply for municipalities (m^3/s)
Rm	revenue from municipal fee per 1 m^3/s of water use (Rp)
$\sum Qm \cdot Rm$	total revenue from all municipal water use in the system (Rp)
Qrm	water supply for riparian needs (river maintenance) (m^3/s)

Drm	river maintenance flow target (m^3/s)
Crm	the cost of damage caused by not meeting the riparian flow requirement by having 1 m^3/s deficit (Rp)
$\sum[(Qrm - Drm) \cdot Crm]$	the total value of loss for not meeting the riparian flow targets (Rp)

The current fees are 51Rp/m^3, 35 Rp/m^3 and 13.61 Rp/KWh for industrial, municipal and hydro power use, respectively.

The legal and operational requirements supercede the economic values attached to them. For example, industrial users pay a higher fee than municipalities. However, municipal supply takes legal precedence over industrial water use, and as such it has to be assigned a higher price indicating higher priority within the model. There are other water management objectives that are political, such as irrigation or the maintenance flow. The fee levied for irrigation water use is still a political issue which brings uncertainty to the value of Cir. If zero is used as the value for Cir (since irrigators are currently not paying), water may not be allocated to irrigation within the model. Hence the value of Cir must be determined using its political importance. Similar remarks are applicable to Crm, which is the equivalent monetary value associated with river maintenance (this implicitly includes water quality as the maintenance flows may be governed by water quality requirements).

Since allocation in one time interval has implications on the management options in the following time intervals, it is desirable to carry out basin-wide optimization of allocation both in space and in time. Hence, the goal of finding optimal allocation must include the time component by summing up the above expression over all time intervals within a year:

$$\max\sum\{\sum P \cdot Rp - \sum Qp \cdot Cp + \sum Qir \cdot Rir + \sum Qin \cdot Rin + \sum Qm \cdot Rm + \sum[(Qrm - Drm)\cdot Crm]\} \quad (4.2)$$

where the first summation is over all time intervals within a year, while the summations inside the curly braces are conducted over all basin components of the same type (e.g. irrigation, industrial, or municipal users). The above equation maximizes annual net revenue for PJT. The following constraints apply to the above maximization problem:

$P \leq Pmax(Q, H)$	Power generation is constrained by the operating characteristics of the turbine and generator, which are functions of flow and average net head over a time interval. The average net head is a function of average reservoir inflow, outflow and the starting elevation for a time interval.
$Qp \leq Qmax(H)$	Maximum pumping rate is constrained by the operating characteristics of the pump.
$Qir \leq Dir$	Irrigation supply should not exceed the ideal demand 'Dir' defined by for each area by the crop requirements and conveyance losses.
$Qin \leq Din$	Industrial supply should not exceed the ideal demand 'Din' (m^3/s).
$Qm \leq Dm$	Municipal supply should not exceed the ideal demand 'Dm' (m^3/s).

Finally, one more term should be added to the objective function. It represents importance of storing excess water in reservoirs. Without this term, the model would be indifferent to spilling surplus flows as opposed to storing them in reservoirs. The pricing vector for storage is the lowest in the system, which means that storage will give in to any other demand. The low pricing vector is still required to make sure that reservoirs re-fill during the wet season. With this term the objective function takes the following form:

$$\max \sum \{ \sum P \cdot Rp - \sum Qp \cdot Cp + \sum Qir \cdot Rir + \sum Qin \cdot Rin + \sum Qm \cdot Rm + \sum [(Qrm - Drm) \cdot Crm] + \sum [(Qr - Dr) \cdot Cr] \} \tag{4.3}$$

where:

Qr	ending reservoir storage in the units of flow for a time interval (m^3/s)

Dr	target flow into reservoir required to keep it full at the end of a time step (m^3/s)
Cr	the value of storage (i.e. the cost of 1 m^3/s of deficit in storage)
$\sum[(Qr - Dr) \cdot Cr]$	the value of total cost for deficit in storage for all reservoirs

Since the cost of storage deficit is the lowest in the system, it does not alter the solution (water allocation) for other components. However, it is required by the model to avoid unnecessary spills and ensure re-fills during high flow seasons. Input data series of 23 years (1977 - 1999) comprising the estimates of 10-day natural flows and water requirements for selected locations in the basin were available from earlier studies.

4.3 Methodology

The only non-linear term in the objective (4.3) function is related to power generation. The non-linear constraints are associated with the tunnel flows and the upper limit on the flow through the Sutami hydro power plant. The WRMM model uses linear programming to find the best basin allocation for each time step. There are several difficulties related to its use in this study:

(a) The WRMM is unable to solve the above mathematical program without the explicit target for hydro power production for each time interval. Exceeding the power target is not a desirable outcome and it incurs a penalty in the model. Yet the goal is to maximize power.

(b) The WRMM is unable to handle flow in the tunnel between the Lahor and Sutami dams. The flows will satisfy the mass balance, but their values will not conform to the hydraulic head determined by reservoir elevation at both Sutami and Lahor.

(c) The WRMM is unable to optimize operation for more than one time step simultaneously, hence the development of reservoir operating zones using the WRMM will have to rely on an iterative approach to find the rules which seem to give the best overall performance.

Therefore, the use of the WRMM in the Brantas basin is only justifiable as a planning tool which gives approximate solutions. To conform to the issues outlined in a), b) and c) above the following approximations were introduced:

a) The hydro power component was setup to generate power as a by-product of reservoir releases made for other purposes. Hence, its pricing vector was set to zero.

b) Flows in the tunnel connecting the Lahor and Sutami reservoirs were set to a maximum of 15 m^3/s. They are driven by the operating levels of the Sutami and Lahor reservoirs up to a point, since their storage is subdivided into five zones with penalties that ensure the elevation difference between the two is never larger than the thickness of one zone.

c) The best operating rules were determined using a trial-and-error approach, requiring the users to manually adjust the zone shapes after each trial run and quickly evaluate the output from a subsequent simulation run for all 23 years of record.

Two scenarios are analyzed in this study. They differ in the level of municipal and industrial demand, as well as in the maintenance flow target in the Surabaya river. They are referred to as Scenario 2001, referring to year 2001 when the Wonorejo system is supposed to become operational, and Scenario 2010 which depicts the anticipated situation in the basin in ten years time. The differences in the expected water requirements and operational priorities between Scenario 2001 and Scenario 2010 are:

- total municipal water requirement is increased by 149% in year 2010 as compared to year 2001;
- total industrial water demand is increased by 60% from Scenario 2001 to 2010;
- the maintenance flow target in the Surabaya river (channel 85) is increased from 20 m^3/s in Scenario 2001 to 27 m^3/s in Scenario 2010.

These differences are based on the previous forecast of increases in water requirements conducted by Binnie & Partners Ltd. (1979), while flow targets in item c) have been suggested by PJT staff.

Both scenarios utilize the following allocation priorities among various water users (listed in order from highest to lowest):

1) municipal supply
2) maintenance flow in the Surabaya River
3) irrigation
4) industrial supply
5) storage conservation
6) hydro power generation
7) pump (channel 141 in the schematic)

According to the above priority policy, water is released from storage for municipal supply, maintenance flow, irrigation and industrial water use. It is not released specifically for power generation. Rather, power generation is a by-product of storage releases made for other water use. Reservoir operating rules can be summarized in the following:

a) if the reservoir is full and the downstream runoff is greater than or equal to water demand for all downstream users, then the reservoir should remain full by setting its outflow equal to inflow;
b) if the reservoir is not full and the downstream runoff is greater than or equal to water demand for all downstream users, then the reservoir should be re-filled first with the incoming inflow and any excess inflow should be spilled;
c) when the downstream runoff is less than water demand for any downstream user, the deficit is supplied from each reservoir according to the rules defined by the reservoir operating zones.

The zones describe joint operation for all reservoirs and encourage slower reduction of storage at each reservoir, i.e. they define a deficit sharing policy among all three reservoirs (Lahor, Sutami and Wonorejo). The objective function (4.3) is adjusted to accommodate the limitations of linear programming which are inherent to the WRMM. The objective function is then formulated as:

$$\max\{-\sum Qsp \cdot Csp - \sum Qp \cdot Cp + \sum Qir \cdot Rir + \sum Qin \cdot Rin \\ + \sum Qm \cdot Rm + \sum[(Qrm - Drm) \cdot Crm] + \sum[(Qr - Dr) \cdot Cr] \} \quad (4.4)$$

Note that the summation over all time intervals in (4.3) is removed in (4.4) since the WRMM solves only one time step at a time. The first term in (4.3) is related to power generation. This has been replaced in (4.4) with a large penalty 'Csp' applied to spills 'Qsp', where spills refer to any flows bypassing the turbines. The above expression defines water allocation objective function in its linear form, since all terms in the expression are linear functions of flow. One more transformation of the above objective function is required because the WRMM solves the minimum cost flow problem. Therefore the problem must be specified as minimization of the objective function, while the above expression is maximization of the net benefit function. Since this is equivalent to minimizing the sum of all deficits in supply, with the corresponding costs carried over from the above expression but with the opposite sign, the expression can be re-written as:

$$\min\{\sum Qsp \cdot Csp + \sum Qp \cdot Cp + \sum(Dir - Qir) \cdot Rir + \sum(Din - Qin) \cdot Rin + \\ \sum(Dm - Qm) \cdot Rm + \sum[(Drm - Qrm) \cdot Crm] + \sum[(Dr - Qr) \cdot Cr] \} \quad (4.5)$$

The above is the objective function used by the WRMM to allocate water in the Brantas basin in each simulated 10-day time interval. Hydro power generation has been replaced with an objective to minimize spills that by-pass turbines in the wet season, while maximizing power generation in the dry season is achieved by keeping reservoir levels as high as possible by making the minimum required releases (those that are required after the runoff originating downstream of the reservoir has been fully utilized).

The penalties (cost factors) in the above objective function are ranked from top to bottom as follows: Csp, Rm, Crm, Cp, Rir, Rin, and Cr. In other words, the operators pay the highest price for unit of flow that was spilled (Csp), followed by the deficits in municipal supply (Rm) and the deficit in maintenance flows (Crm). The use of the pump (Cp) is allocated lower cost than having either municipal or maintenance flow deficits, such that pump operation can only be justified for those two components. Irrigation (Rir) has a higher penalty factor than industry (Rin), and finally storage conservation has the lowest penalty (Cr) of all components. Any seven numbers ranked sequentially from the highest to the lowest can be input as values for the parameters Csp, Rm, Crm, Cp, Rir, Rin, and Cr resulting in the same water allocation by the WRMM. Therefore, the absolute values of the penalties used are not essential for the WRMM, since there are many combinations of penalties that will give the same allocation. What is important is the relative difference (rank) between the penalties. The chosen penalties are 1000, 500, 90, 75, 51 and 6 for Csp, Rm, Crm, Cp, Rir, Rin, and Cr, respectively.

4.4 The use of GIS_interface, SCFBuilder and Plotsim

Since there are iterative WRMM runs involved in this study, the new tools – the SCFBuilder and the Plotsim programs – can be a useful aid in the required analyses, as described below. Each sub-section that follows demonstrates a distinct feature of the new tools.

4.4.1 Developing the Modelling Schematic

The existing GIS map layers provide sufficient information about the location of all major diversion structures and reservoirs in the system, along with a layer of reservoirs and the layer containing the main Brantas river and its major tributaries. These layers were used as background information to build the three additional layers entitled *schematics*, *numbers* and *background*, shown in Figures A.2, A.3 and A.4, respectively.

Figure A.5 shows the database for an object in the schematic layer. The first field (ID) must be filled in by the user for each object in this layer. The other two are optional and they can remain blank. Once the schematic layer has been created, the other two layers (background and numbers) can be added. Their purpose is to provide additional information of interest. For example, the numbers layer contains the node and channel numbers for each component in the schematic layer, while the background layer may contain other descriptive information.

4.4.2 Creating the SCF file

The program SCFBuilder is designed primarily to modify an existing SCF file. When the WRMM program is distributed to new users, it comes with a sample SCF and HBDF file. This SCF file can be modified with the SCFBuilder program to fit different river basins by deleting the existing components and by inserting new components into it.

The first step is to open an existing SCF file. Typically, users would start by modifying the IDENT and SIMCON subsections of the SCF file by selecting the appropriate options as shown in the pull-down menu inFigure C.3 and using the built in text editor. If users are not sure about the format of any of the lines, they could switch to the Help / SCF File Format selection from the main menu as shown in Figure C.1 and then choose to view the explanation for the appropriate line in a given subsection.

The second step is to list all available components as shown in Figure C.13 and delete those that are not found in the schematic created in the previous step. Component deletion is a simple process which consists of (a) component selection from the menu in Figure C.13 and (b) deletion of the selected component from the pull-down menu, as shown in Figure C.30. Component deletion automatically removes all references to a given component in the SCF file. If there are components in the SCF and in the schematic which match in terms of the type and the SCF number, users can edit them using one of the menus shown in Figures C.15, C.21, C.23, C.25, or C.27 depending on the type of component.

The third step is to insert the components found in the schematics but unavailable in the SCF file. After inserting the new component by giving them component numbers and placing them in desired penalty groups, as demonstrated in Figures C.30 through C.32, users must select each new component for further editing as in Figure C.33 and enter the correct information (tail and head node number, zone bounds, etc.) as required by the prompts in Figures C.15, C.21, C.23, C.25, or C.27 depending on the type of component.

Once all the SCF file modifications have been completed, the file format checks are done automatically when the user attempts to save the file, as shown in Figure C.40. Additional information on the SCF file format and possible errors can be obtained using the statistics option (Figure C.39) which is invoked from the components selection of the main menu (Figure C.30). Connectivity checking can also be done to ensure that all links have the proper tail node and head node, as depicted in Figure 4.1. Note that the node numbered 0 (the system outflow node) has two physical locations in the schematic in Figure A.4, while Figure 4.1 must have a unique node 0, to which four link type components discharge flows (components 95, 64, 88 and 86). A comparison of Figure 4.1 and Figure A.4 reveals two errors: (a) return flow channel 234 in Figure A.4 is numbered 243 in Figure 4.1; and, (b) reservoir 35 in Figure A.4 is numbered 33 in Figure 4.1. These discrepancies should be removed before proceeding to detailed modelling.

4.4.3 Modifying the SCF File in Subsequent WRMM Runs

This section explains how the reservoir operating rules were optimized by the trial and error process. This process was started by running the basin simulation with the WRMM using only one operating zone and a fixed full supply level (FSL) of 272.5 m for reservoir Sutami. The Plotsim program was then used to observe the achieved reservoir levels in the WRMM

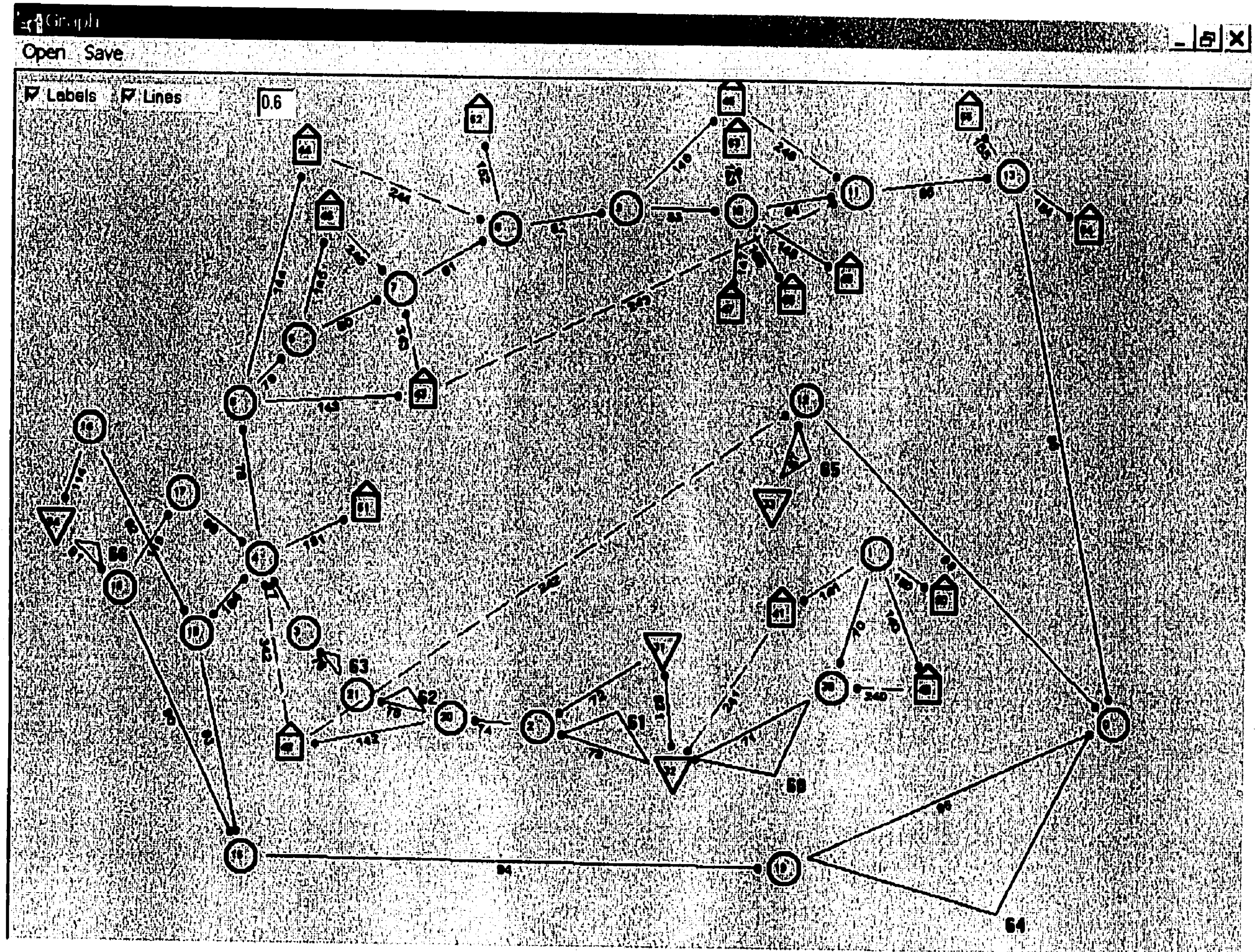

Figure 4.1 Connectivity check for the Brantas basin schematic

output data files and draw conclusions regarding the shape of the Sutami reservoir operating zones. In this trial-and-error process, the ability to view the zone shapes and change them graphically is valuable. The primary objective is to minimize the number of failures to deliver the maintenance flow target in the Surabaya river (channel 85) and to meet all municipal water requirements (demands numbered 50, 54 and 56). It is the failure to meet those objectives in each 23 year simulation run with the WRMM that drives the direction of reshaping the zones by the user from one simulation run to another. To start the process of creating the initial zone shapes, a run was generated with only two zones, one at 272.5 m and the other one at 259 m (Sutami elevation should not drop below 259 m since that is the minimum operating level for hydro power plant). The WRMM was run using the *Run WRMM* option shown in Figure A.7 and then the simulated Sutami reservoir levels were viewed using the Plotsim program. Selecting the exceedence format the critical periods were picked to be the end of time intervals 20, 22, 24, 26, 28, 30, 32 and 34. For each of those periodsthe Sutami reservoir levels were plotted (each plot has 23 points since there are 23 simulated years). The plot for the end of time interval 32 (November 20) is shown in Figure 4.2. Users can then read the elevations for various probabilities of exceedence, for example for 90%, 70%, 50% and 30%. The process can be repeated for other time intervals, to give the elevations in Table 4.1 below, which were input graphically into SCFBuilder as illustrated in Figures C.16 through C.19 using the mouse, to give Figure 4.3.

Table 4.1 Summary of simulated Sutami reservoir levels

Interval	Julian Day	Percentile			
		90%	70%	50%	30%
20	201	265	271.5	272	272.5
22	222	263.5	270.8	271.4	272.5
24	243	259.7	268.5	269.8	272
26	263	259	263	268.5	271.4
28	283	259	259.5	267.5	271.7
30	304	259	262	270.5	272.5
32	324	259	262	272	272.5
34	344	264	272	272.5	272.5

There were several iterative steps from this phase until the final shape of the zones shown in Figure C.14 are reached. Each time the zones were changed, the WRMM was re-run and the output files were read into the Plotsim program using the *Reopen* option under the *File* selection from the main Plotsim program menu as shown in Figure B.2. Flows in channel 85 were then plotted in exceedence format as shown in Figure B.17 to see if there were any failures to meet the prescribed maintenance flow target. The deficit table option (Figure B.26) was used to confirm whether there were any deficits for the three municipal demand components (major withdrawals 50, 54 and 56 in the modelling schematic). At this point the entire process becomes dependent on the experience and judgment of the modeler. The goal is to minimize deficits to the municipal supply and to channel 85, which has a flow target (20 m^3/s in Scenario 2001 and 27 m^3/s in Scenario 2010).

The SCFBuilder, Plotsim and GIS_interface modules allow repeated WRMM runs with easy editing of the reservoir zones while simultaneously viewing their shape. This is an advantage over the earlier use of text editors since the shape of the zones was not visible.

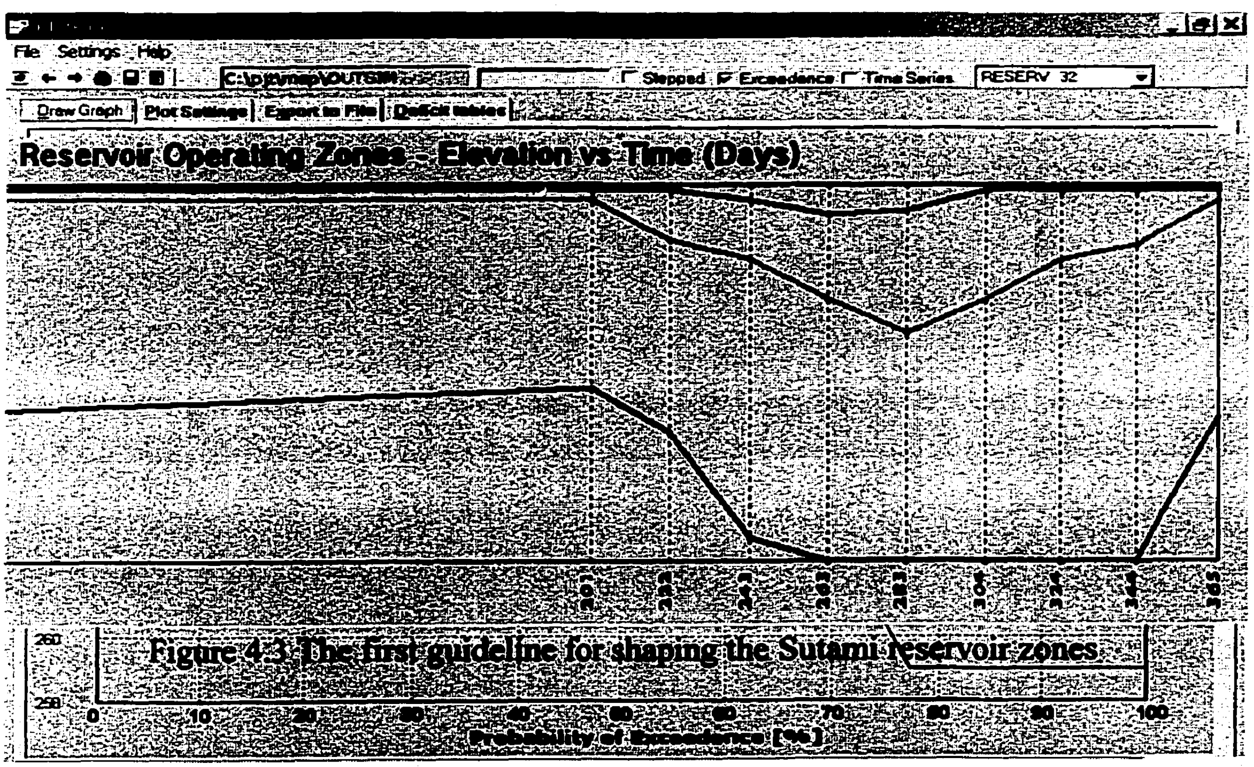

Figure 4.2 Simulated Sutami reservoir of levels for November 20

4.4.4 Transforming the Schematic to the Year 2000 Conditions

The Wonorejo reservoir (34) is currently under construction. Diversion canals 104, 116 and the pump (141) are still not operational at present. If the users want to create a modelling schematic which represents the current conditions, they would have to delete all components associated with nodes 14, 15, 16, 17, 18, 29 and 34. To do this, users would select all those components in the GIS schematic layer (which is easy using the group selection within a specified window) and transfer the group selection into the SCFBuilder, as displayed in Figure 4.4 (similar to Figure C.43 but without any additional explanation in this case). Deleting all these components is now a matter of a single mouse click.

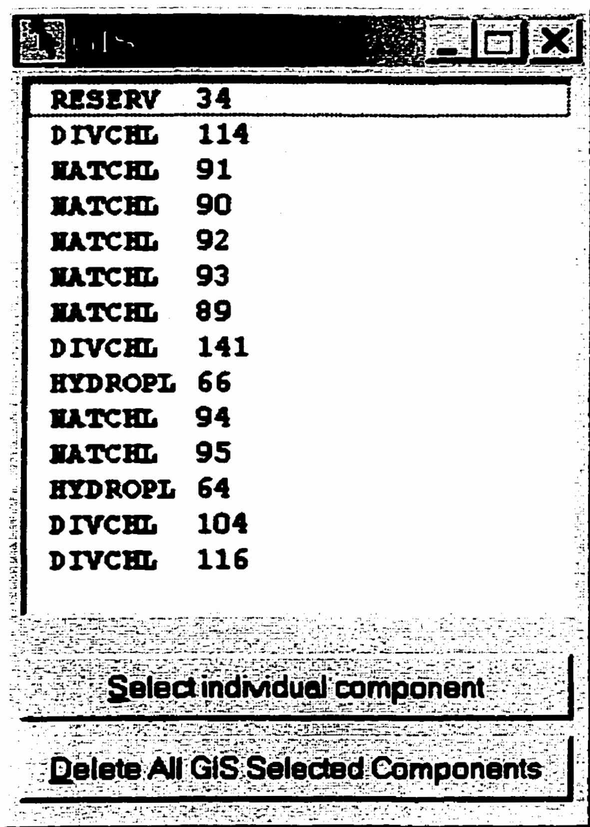

Figure 4.4 Group component selection

Classical use of the WRMM with text editors would require finding references to each component in all corresponding subsections and deleting them one by one, with the appropriate updates of the remaining number of components in the corresponding penalty groups to which the given component used to belong. Each of the components shown in Figure 4.4 has references in two or three subsections within the SCF file. All references are automatically deleted when a component is deleted. This represents a significant reduction of effort afforded by the SCFBuilder in conjunctive use with the GIS_interface program.

4.4.5 Viewing the WRMM flow solution within the Schematic

Users sometimes need to check the solution of an individual time step in detail. This could be caused by an unexpected value of allocation to a component, or it may be driven by a desire to simply check if the allocated flows conform to the intended priority policy. Figures A.8 and A.9 show the selection of the time step to be analysed and the zoomed-in image of one part of the schematic such that the flow solutions for the selected time step can be viewed. The standard GIS features can be used to change fonts and size of the numbers, as well as the type of highlighting to make them more visible. A printout of the entire flow solution for a given time step can be made as a standard GIS printout. Without the GIS interface program, this option must be executed manually, by drawing the part of the schematic under investigation and by finding the flow values for each component in order to write it into the schematic drawing. This check was frequent among the WRMM users, and it was also time consuming, with many possibilities for making an accidental error.

4.5 Final Choice of Operating Zones

Figures 4.5 and 4.6 show the operating zones that have been created on the Sutami and Wonorejo reservoirs using a trial and error approach such that the overall performance of the model is optimized as a result of the shape of the zones, as demonstrated in Section 4.4.5. The operating zones at Lahor reservoir are the same as for Sutami but they are raised by 0.2 meters as dictated by their design specifications. The expected flow is always from Lahor to Sutami, except in a rare event when reservoirs are being re-filled such that the rate of elevation increase at Sutami is higher than at Lahor. The zones can be identified from top to bottom as zone 1 through zone 5. When local runoff downstream of Sutami is not sufficient to meet the water requirements at any of the diversion points, releases are made from all three reservoirs in the following order (starting from the assumptions that the initial storage is full):

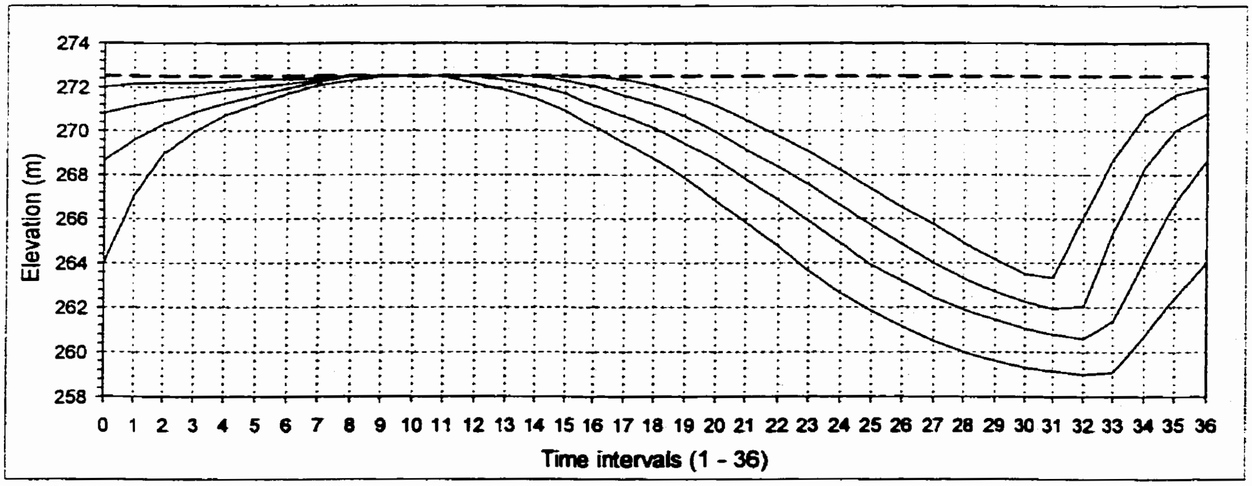

Figure 4.5 Sutami reservoir operating zones

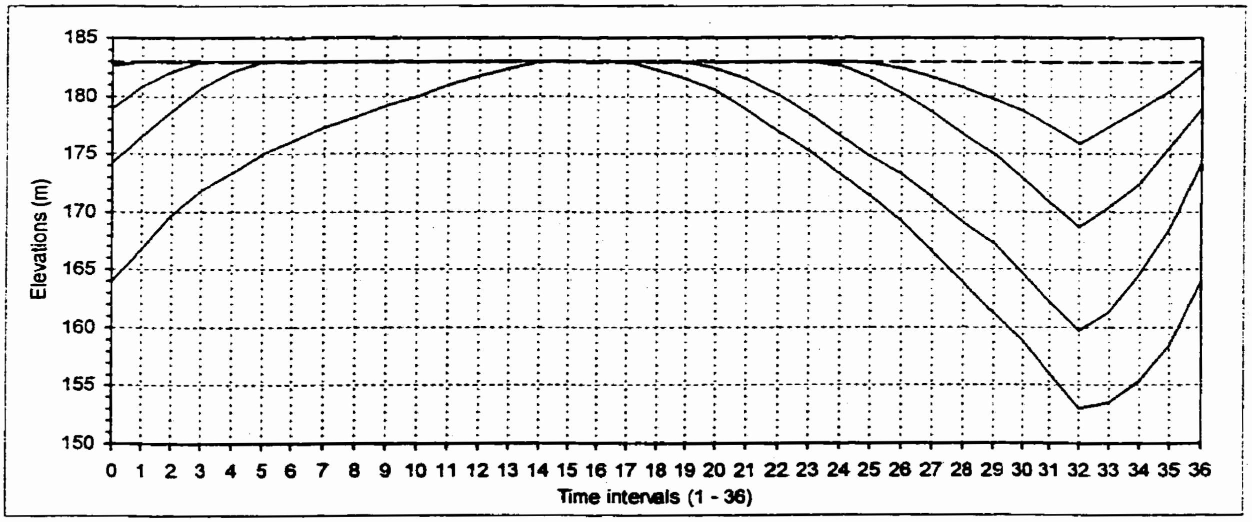

Figure 4.6 Wonorejo reservoir operating zones

- release is made from the first zone of the Sutami reservoir until the elevation of Sutami has reached the bottom of zone 1 (hydro power is generated as a result of this release);

- before using the storage in the first zone of the Wonorejo reservoir, water is released from Lahor into Sutami using the connection tunnel until the elevation in Lahor reaches the bottom of its first zone;
- when both Sutami and Lahor are at the bottom of their first zone, the releases are made from the first zone of the Wonorejo reservoir.

The same rules as the ones described above are applied for all other zones (2, 3, and 4). Releases are not supposed to be made from the bottom zone (5), which means that reservoir operators should not allow the reservoir levels to drop into zone 5. If this does happen, it should be quickly corrected by getting the level back above the top of zone 5. The zones represent a sharing policy which is not discrete but is rather continuous. The operators should therefore release water gradually from all reservoirs such that their zones remain at the same level in all reservoirs. For example, all reservoirs should be within zone 2 before one of them (in this case Sutami) falls into zone 3, with all others following suit as soon as the Sutami reservoir has reached the bottom of zone 3. This would become a more continuous process if more than five zones were used in this study, however the WRMM limitation for reservoir zones at present is set to a maximum of five.

The operating zones provide rules that are easy to follow. They determine a desired configuration of elevations at all three reservoirs at any point in time. To apply these rules in real time operation the management must have the forecast of runoff (local inflows for all inflow nodes in the attached schematics) and water requirements for water users in the basin for one time step ahead. This is not unrealistic in a dry season, which is critical in terms of the available supply.

4.6 Summary of Results

The ability to plot more than one OUTSIM file simultaneously is an important feature of

Plotsim that is fully exploited in these analyses. The following are the functions that users would normally have to perform manually to get the plot of WRMM results for one or more selected components:

a) extract the lines from OUTSIM (or OUTID) files containing only the selected component(s) and save them in a temporary file;

b) change the format of the temporary file such that values related to each component are stored in a single array (or row);

c) calculate the values of the X axis using the appropriate formula depending on the type of graph (time series or exceedence); and,

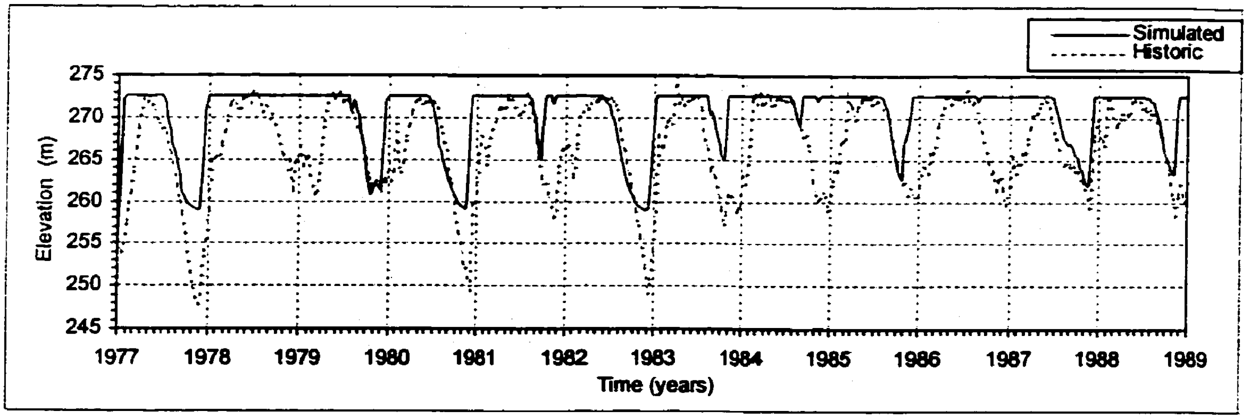

Figure 4.7 Historic and simulated levels of the Sutami reservoir (1977-1989)

d) attach the graph title and the labels for the X and Y axes.

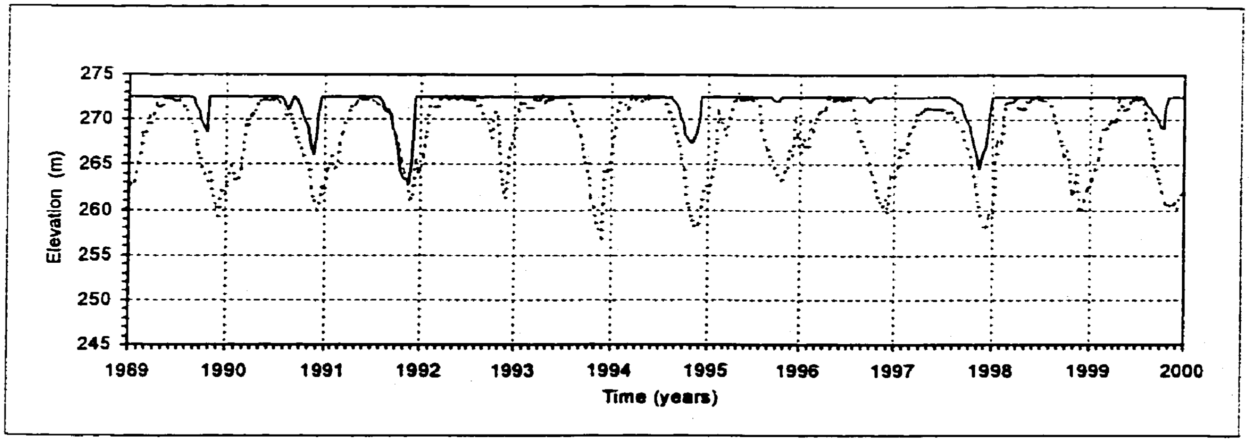

Figure 4.7 (continued) Historic and simulated levels of the Sutami reservoir (1989-2000)

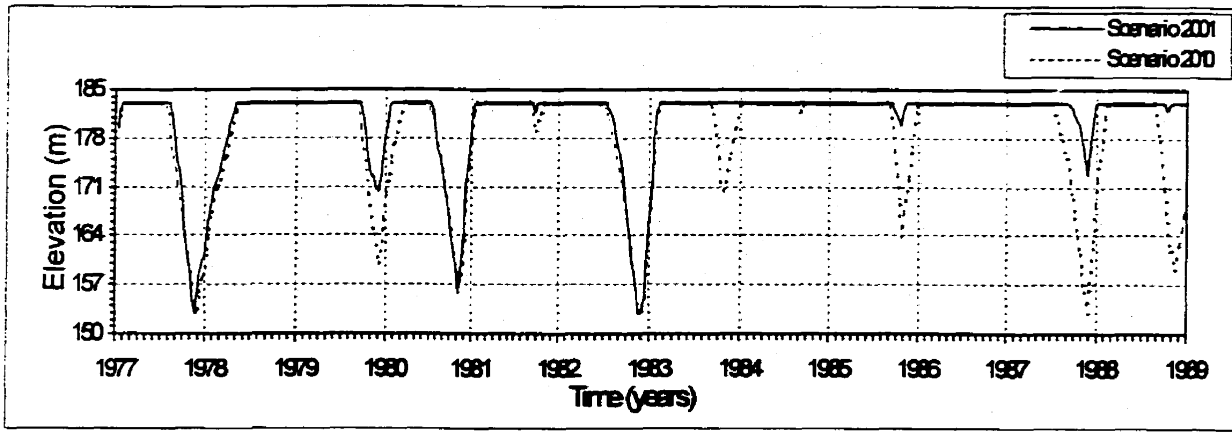

Figure 4.8 Simulated elevations of the Wonorejo reservoir (1977-1989)

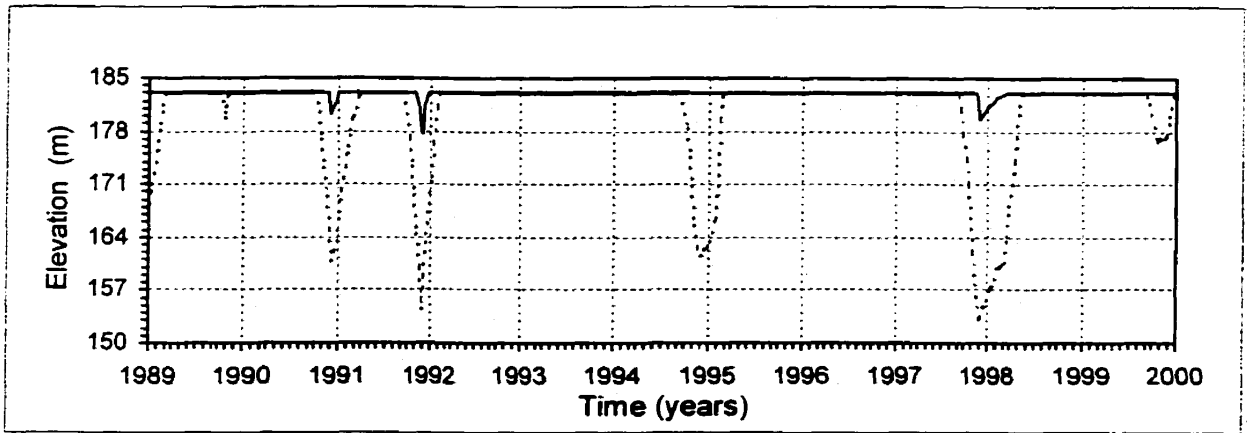

Figure 4.8 (cont...d) Simulated elevations of the Wonorejo reservoir (1989-1999)

All of the above tasks are automatically completed by the Plotsim program if used for viewing only. When a decision is made to provide final quality printing of a given graph, the Plotsim still completes the tasks listed as a), b) and c) by exporting the plot data to an ASCII file as shown in Figures B.23 and B.25. The plot data file can easily be imported and plots can be regenerated with a spreadsheet without any additional manipulation. All that must be done using the spreadsheet is the completion of task d). Figures 4.7 and 4.8 were created using the plot export capabilities of the Plotsim program. The historic levels show how the system was operated in the last 23 years using rules of thumb. The historic reservoir levels are typically lower than simulated, indicating that there is variability from year to year, and according to the simulation results shown in Figure 4.7. Storage in the Sutami reservoir is hardly needed in some years such as 1986, 1989, 1992-1996, and 1998. Higher reservoir levels have a positive impact on the hydro production at Sutami hydro power plant. Another interesting graph created using the Plotsim plot export option is the plot of the new Wonorejo reservoir for both Scenario 2001 and 2010, depicted in Figure 4.8.

The higher reservoir withdrawals in Scenario 2010 are due to the higher water demands for maintenance flow, municipal and industrial water use. A significant finding is that the pump station (channel 141) has never been turned on by the model even in Scenario 2010. This can be verified by plotting the flows in Channel 141 which are equal to zero for all time intervals. Therefore, the suggested reservoir operating policy as outlined by zoning policy in Figures 4.5 and 4.6 has eliminated the need for pumping. Unfortunately, the decision to build the pump station was made in 1992 and the construction was completed in April 2000 based on a design conducted by a team of Japanese consultants in 1992. This design did not involve studying joint operation of the reservoirs in the Brantas basin.

One of the most frequently used features of the Plotsim program is the annual deficit tables option displayed in Figure B.28. Users wishing to generate this table manually would have to perform a sequence of tasks for each consumptive use component, starting from retrieval of the component from both the OUTSIM and OUTID files for all simulated years and followed by the calculation of annual deficits according to expression B.4. This table is automatically created within the Plotsim program. It can be exported to an ASCII file and imported into a spreadsheet or word processor for final formatting, as shown, for example in Table 4.2. The stated allocation policy can be evaluated by studying the values in Table 4.2. For example, municipal supply has the highest priority so it should have the lowest deficits, which can be verified by checking the deficits for components 50, 54 and 56. Irrigation supply is given higher priority than industrial, so the irrigation deficits are lower on average than industrial. Of all industrial components, the lowest deficits are for component 55 because it is located at the downstream end of channel 85. Because channel 85 represents the high maintenance flow requirement (20 m^3/s in Scenario 2001 and 27 m^3/s

in Scenario 2010) there is always sufficient water for industrial use at component 55 since it is located at the downstream end of channel 85. In other words, the industrial use in the city of Surabaya is helped by the high priority put on the maintenance flows in the Surabaya river (channel 85), although the maintenance flow is primarily driven by the need to maintain minimum water quality for municipal supply. Other industrial use components cannot benefit from their location in the same manner.

Table 4.2 Annual deficit for consumptive use components (transferred from Plotsim deficit tables option)

	ANNUAL DEFICITS FOR CONSUMPTIVE USE COMPONENTS (%)															
	IRRIGATION COMPONENT NUMBERS									MUN.	INDUSTRIAL COMPONENTS				MUNICIPAL	
YEAR	40	41	42	43	44	45	46	47	48	50	51	52	53	55	54	56
1977	2.78	3.85	0	0	0	0	0	0	3.62	0	19.89	27.86	24.87	0	0	0
1978	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0.03	0	0.42	0.93	3.73	0	0	0
1980	0	0	0	0	0	0	0	0	6.41	0	43.83	52.52	32.77	0	0	0
1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	2.61	0	0.86	1.84	12.46	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	0.12	0.17	0	0	0	0	0	0	0.55	0	2.83	3.61	3.21	0	0	0
Maximum	2.78	3.85	0	0	0	0	0	0	6.41	0	43.83	52.52	32.77	0	0	0

4.7 Summary of WRMM Enhancements in the Brantas River Basin

The following list summarizes the WRMM enhancements that have been achieved in the application to the Brantas river basin compared to the earlier way of using the WRMM which relied exclusively on the use of text editors:

- A modelling schematic has been developed using the drawing tools available in GIS in combination with GIS features such as copy, paste and snap to create a Map-based schematic as an additional layer on top of the existing GIS layers.
- Working with GIS based schematics is easier since the users can utilize GIS based functions such as (a) single or group selection; (b) zoom-in and zoom-out; (c) moving the schematic on the screen using the grabber feature; and, (d) viewing the schematic in combination with other GIS layers as required.
- Editing of the SCF file with the SCFBuilder program provides a number of safety features which check the new input for typical errors and issue warnings prior to saving the changes to the disk. Also, the saving of changes in the $PENSYS and $PHYSYS subsections of the SCF file is guaranteed to follow the proper format since the program ensures writing the modified values in proper locations within the SCF file.
- Visual editing of components using the SCFBuilder offers a more rewarding working environment with faster detection of anomalies such as irregular slopes in reservoir capacity curves or elevation vs. outflow curves. Checking connectivity can also save hours of effort to detect accidental mistake in the linkage of nodes and channels.
- The Plotsim program offers quick component selection and analysing its performance using graphical and tabular formats, along with fast conversion to final quality plots by other commercial plotting tools, which can be done for selected graphs using the file export capabilities built into the Plotsim program.
- Ability to import and view the network flow solution for any simulated time step graphically in the schematic GIS layer as numbers attached to each channel representing the simulated flows.

5 CONCLUSIONS AND RECOMMENDATIONS

This thesis dealt with the development of a user friendly communication environment that links the Water Resources Management Model (WRMM) with three additional modules. The flexibility of the approach is emphasized in the following: (a) the two modules (Plotsim and SCFBuilder) are written as stand alone applications that can operate with or without the GIS link; and, (b) the loose coupling of system components allows easy transfer of the GIS link to other GIS platforms if required. The advantage of using the program modules are in that they provide a safer (error free) environment for saving the changes as well as a user-friendly graphical environment for running the model and for conducting output analyses.

Several possible improvements would make these developments more attractive. At this moment, the historic recorded and naturalized flow database is only used by the WRMM as input data in the simulations. It would be advantageous to be able to include handling of this file by the GIS schematics (perhaps as an additional layer of hydrometric stations) and in particular by the Plotsim program. This would allow users to compare plots of historic recorded (or naturalized) flows with the future regulated flows that can be anticipated as a result of increased water use and alternative allocation policies or reservoir operating rules. Alberta Environment is in the process of deciding which database format to chose for the HBDF file, which is currently in ASCII format. Future capabilities added to the Plotsim program may include reading the HBDF database and providing concurrent plots from simulated output as well as historic values from the database for the same river crossings. Additional statistical analyses could also be added to the Plotsim program to include more than just the consumptive use components which are subjected to statistical analyses at present. Also, options for generating additional statistical parameters in the analyses could be included. Finally, it would be a valuable addition to have a capability for each link in the GIS schematic layer to find its closest upstream and downstream node and input the information in the SCFBuilder (this currently has to be done manually).

There are several conclusions regarding the results of the WRMM application to the Brantas river basin:

- Design of new structures should be done by conducting operational studies of the entire system in an effort to find the best operating policy for all structures in the system. Failing that, the planners are at risk of over designing capacities of the proposed structures, or sometimes building a structure that was not necessary, as in the case of the pumping station in the Wonorejo subsystem.
- Design of the required live storage at Wonorejo system should have been done based on an operational study of the entire basin. This would show that the proposed live storage is not needed in the first 10 years of operation. Even in Scenario 2010 the proposed live storage seems to be over designed about 50% of the time.
- The model results are based on the assumed availability of short term forecast during the low flow season. While this goal is within the reach technologically, the forecasts are still not available due to problems with low flow measurements and the lack of a calibrated flow forecasting tool for day to day use in the Brantas basin. Significant improvements in the basin operation are possible once the proper monitoring and reasonably reliable forecasting is in place.
- Reservoir releases should be based on the net demand downstream of the reservoirs. This would result in much higher average elevations of Sutami reservoir, which would have positive overall impacts on reliability of supply as well as on hydro power generation. Reservoir releases are currently based on the rule of thumb.
- Assuming that the proposed reservoir operating rules were followed during the last 18 years and a one-week perfect forecast was available during the dry season, the management would be able to increase power production on average by 6% while maintaining about three times higher flows at the Surabaya river and meeting all other consumptive use demands in the basin at the year 2001 level. This could be achieved without the pump station and by using only a fraction of live storage available at Wonorejo reservoir.

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APPENDIX A

DESCRIPTION OF THE GIS_INTERFACE.MBX PROGRAM

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A PROGRAM GIS_INTERFACE.MBX

A.1 Introduction

GIS_interface.mbx is a MapBasic program which transfers information related to component(s) selection to the SCFBuilder and Plotsim programs. It is also capable of reading the OUTSIM and OUTID files to allow the user to view a complete water distribution for any simulated time step in the schematic layer. Program GIS_interface.mbx also allows the users to call the wrmm.exe without leaving the Mapinfo environment. The Mapinfo GIS must be installed prior to running GIS_interface.mbx.

The program modules are shown in Figure A.1 using rectangular boxes with their *.exe name extension, while the input and output data files are shown in rounded boxes. The link from

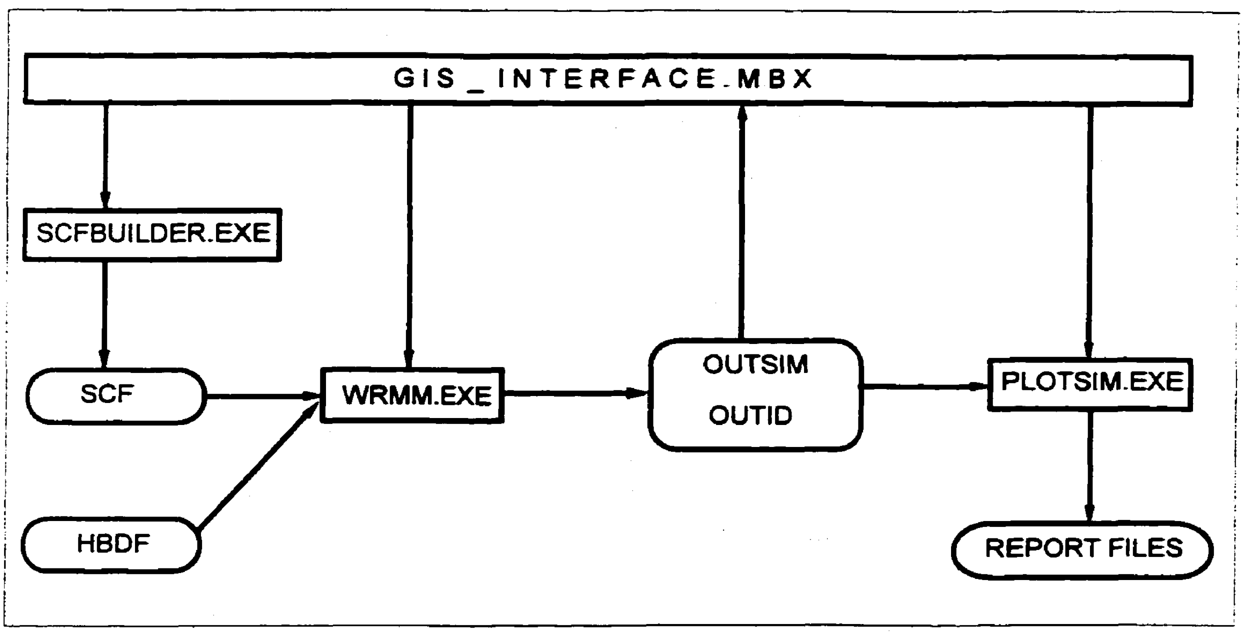


Figure A.1 Block diagram of GIS / WRMM interface

GIS_Interface to SCFBuilder indicates that a component selection made in the GIS schematic layer can be transferred to the SCFBuilder. The same is the case for the Plotsim program. The link between the SCFBuilder and the SCF file reflects the fact that the SCFBuilder can modify the contents of the SCF file prior to running the WRMM program. The WRMM program needs two files to run (SCF and HBDF), as displayed by the links from the SCF and HBDF files to the WRMM. Also, the WRMM can be executed as a call to an outside program from within the GIS_Interface program. The WRMM creates two output data files, OUTSIM and OUTID. These two files can be read by the PLOTSIM program as well as by the GIS_Interface program itself. If read by the PLOTSIM program, solutions for all simulated time intervals for a selected component can be plotted in time series or probability formats. The link between the OUTSIM or the OUTID file and the GIS_Interface program reflects the fact that it is possible to retrieve a solution for one chosen time interval for all components and import it into the schematic layer for graphical viewing.

A.2 Description of the Mapinfo Schematic Layers

A schematic layer such as the one described below can be easily created with any GIS software. One of the requirements of this project was integration flexibility that may be needed in the future with other GIS platforms, since various agencies use different GIS tools. The GIS_Interface.mbx program is therefore short and it is the only part of this interface that would have to be re-written using the native development tools or macro capabilities of other GIS platforms if transfer from Mapinfo to another GIS tool is required.

Figure A.2 shows a sample Mapinfo representation of the WRMM schematic of the Brantas River Basin in East Java, Indonesia. This representation consists of three layers: (a) *schematic* (Figure A.2), (b) *background*, shown together with *schematic* in Figure A.3 and the (c) *number* layer, shown together with the other two layers in Figure A.4. The only layer that actively communicates with other programs according to the block diagram in Figure A.1 is the schematic layer. The other two layers provide additional graphical information that can be useful to the user, however their contents do not affect the interface. Other layers showing additional geographical information can also be viewed simultaneously, without affecting the functionality of the interface process.

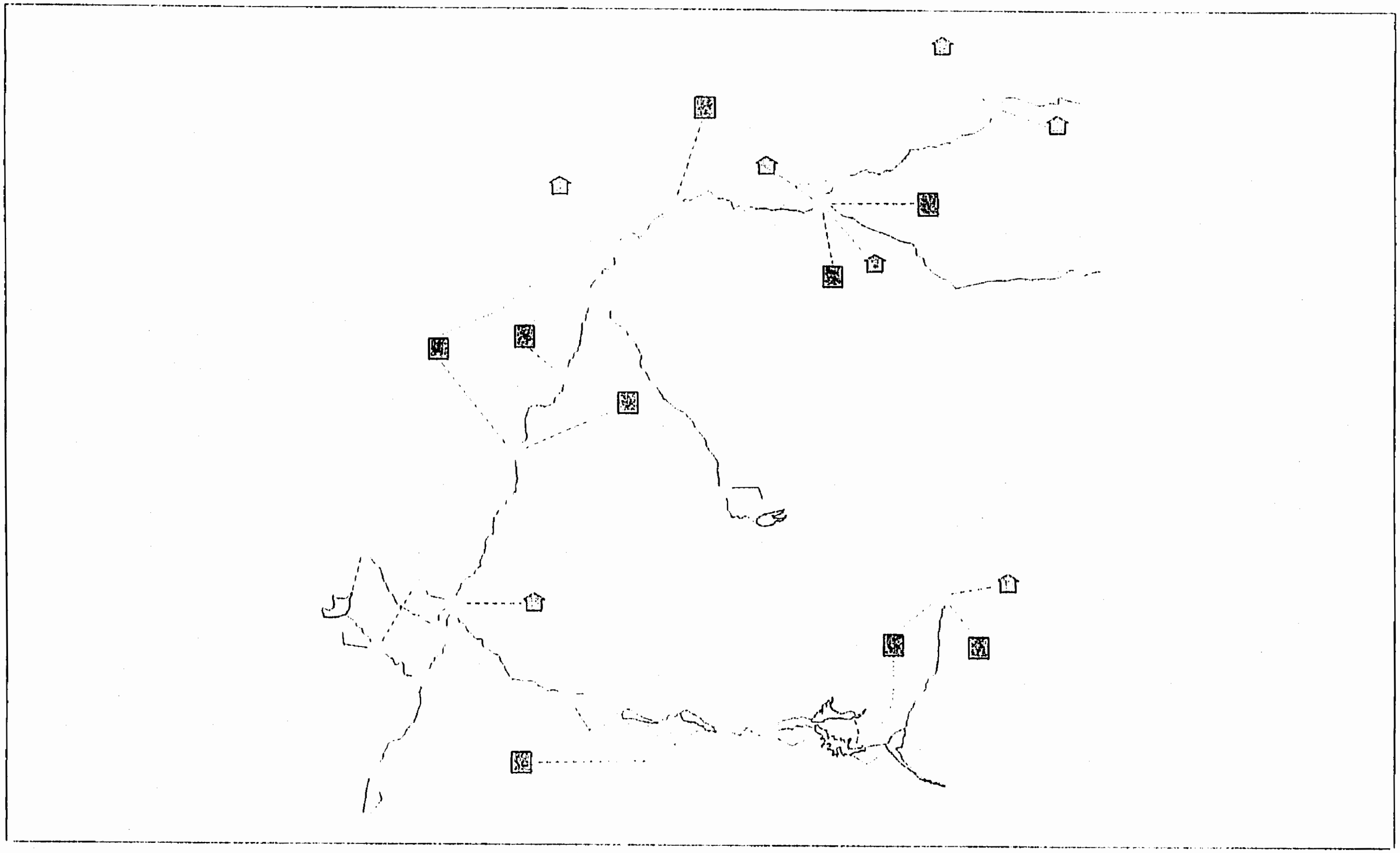


Figure A.2 Schematic layer

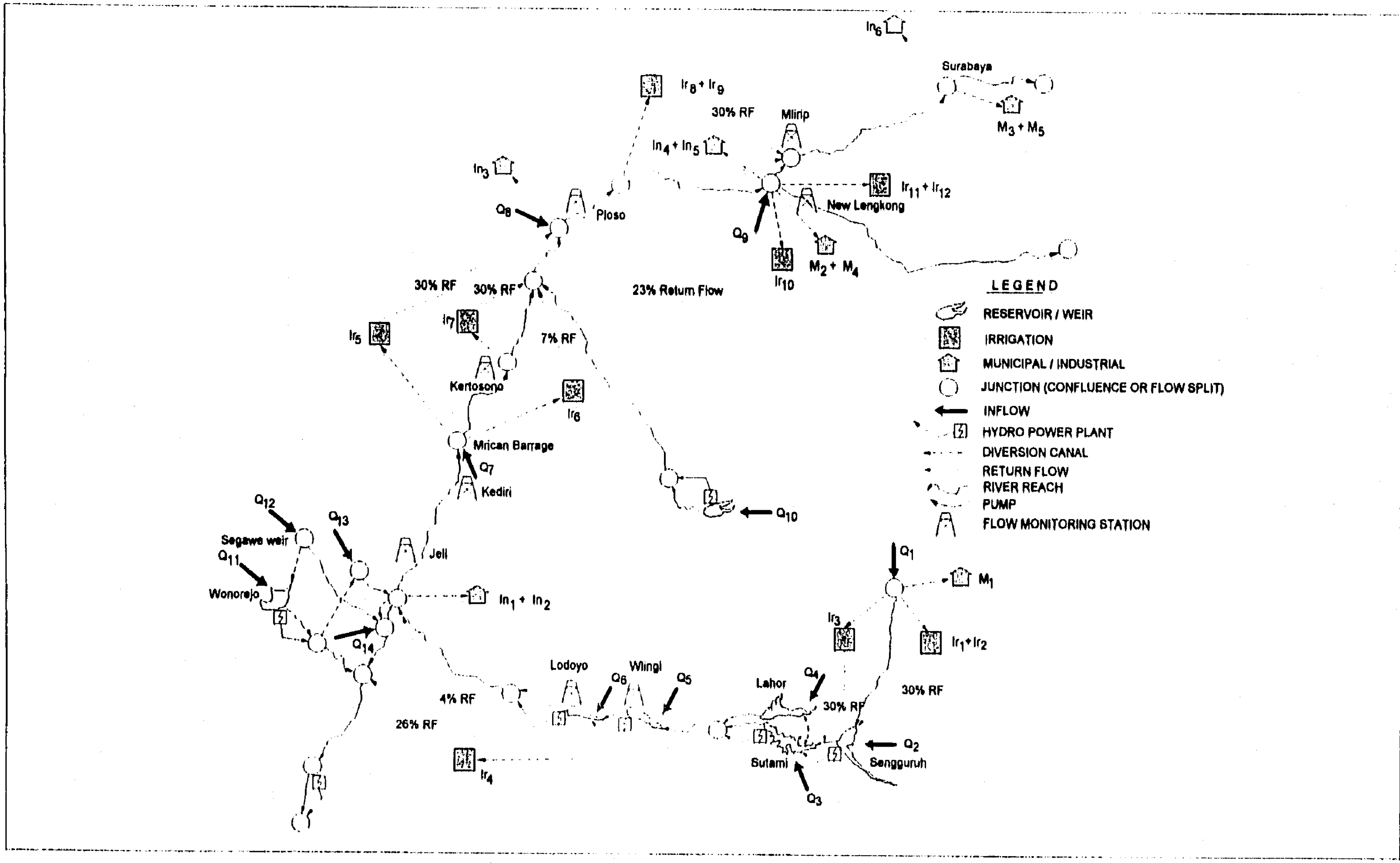


Figure A.3 Background and Schematic layer

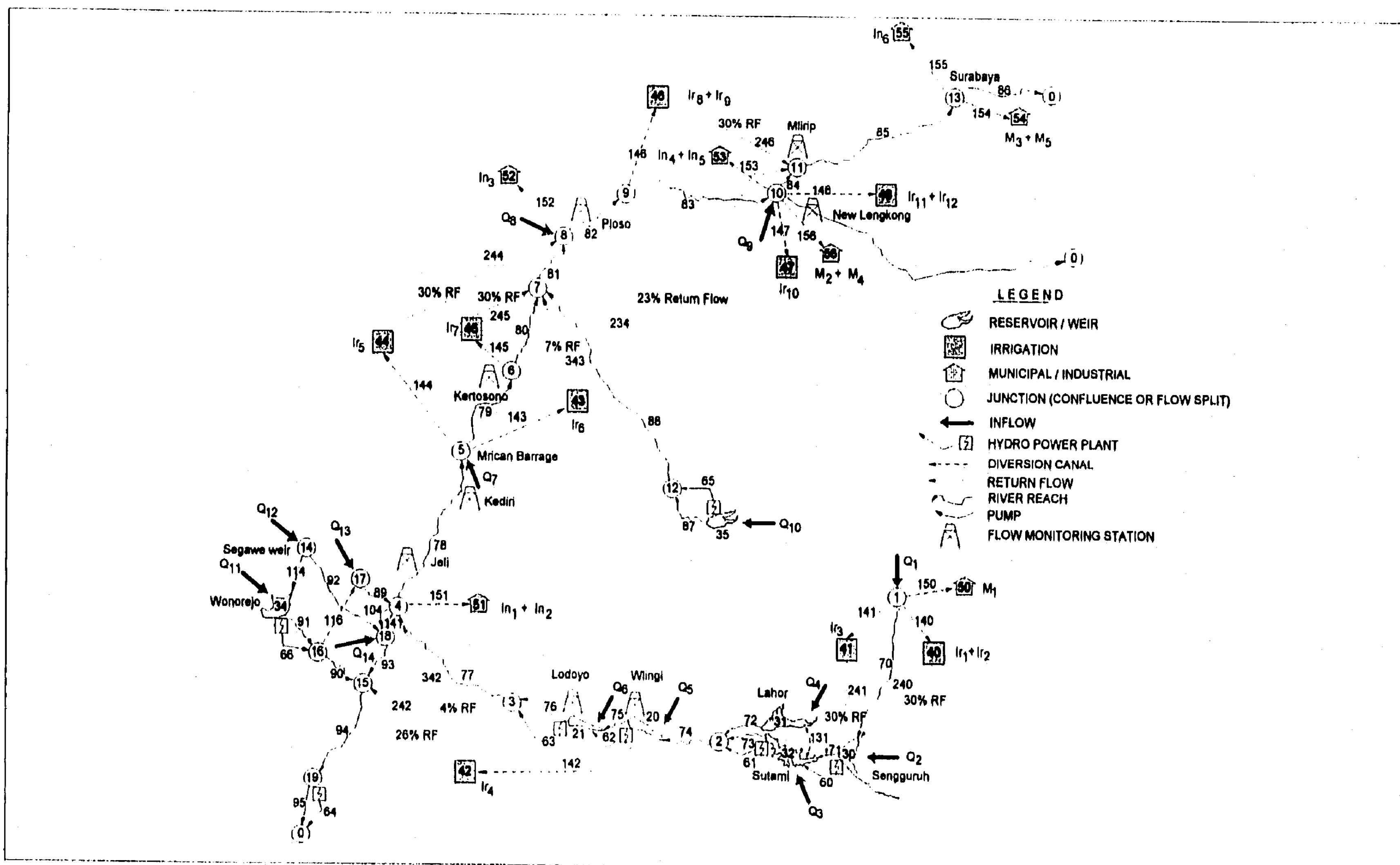


Figure A.4 Numbers, Background and Schematic layers combined

The "info" button in Mapinfo allows the user to view all variables in the Mapinfo internal database associated with a given object (component) in the schematic layer. By pressing the info button first, and then selecting any component in the Brantas schematic layer, a table

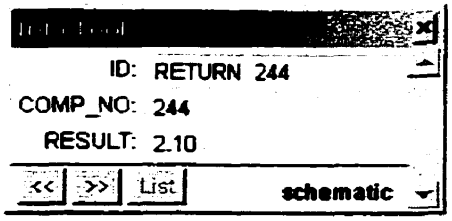


Figure A.5 GIS layer database

depicted in Figure A.5 appears. The table in Figure A.5 shows the return flow channel number 244 as the selected component, with three variables associated with each object in the layer:

a) Character variable ID containing 12 characters with component type and component number exactly as they appear in the OUTSIM and OUTID files at the beginning of any line that contains simulated output of the return flow channel numbered 244.

b) Variable COMP_NO is of type integer and it contains only the component number. This variable is in the database as a way of quick check to make sure that all component numbers in the first field (ID) have been entered properly, since it can be displayed as a label attached to an object in the Schematic layer.

c) Variable RESULT is of type real. It contains the WRMM solution for a selected time interval. Only one time interval can be selected for simultaneous viewing through the whole schematic. This is done interactively and it can be done for any time interval that was simulated successfully.

The variable ID is used in transferring information related to component selection from GIS_Interface to SCFBuilder and Plotsim. The variable RESULT is used to transfer required information from OUTSIM (or OUTID) to the GIS_Interface program. Every component in the GIS schematic will have the three variables listed above associated with it.

A.3 Development of the Schematic GIS Layers

A modelling project usually starts by identifying on the map the locations of interest in the river basin. These include reservoirs, irrigated areas, major municipal and industrial users, major diversion structures from the streams and the points of return flows for irrigation and industrial components. Those locations identify components in the modelling schematic which are generally called *nodes*. They break the modelling schematic into smaller sub-systems.

Once the nodes have been identified using other available GIS layers instead of the traditional maps, they can be connected using the GIS drawing tools. Users can simply apply straight lines between the two adjacent nodes, or they can use the "snap" feature available in most GIS programs to create new objects in a given layer by copying the shape of other objects in other layers displayed simultaneously with the schematic layer. Figure A.2 shows the use of straight lines to depict irrigation canals and return flow channels. All natural streams in Figure A.2 are copied from the Mapinfo layer of natural streams in the basin. This layer can be viewed in combination with the rest of the schematic as shown in Figure A.6. Other layers showing the layout of irrigation canals and the spread of irrigated areas can also be viewed together with the schematic layer. However, bringing too much information on the screen makes it difficult to use the schematic layer as an interactive aid in the process of using the WRMM program. This is the reason for the idea of breaking the available information into thematic layers and using only one or two at a time.

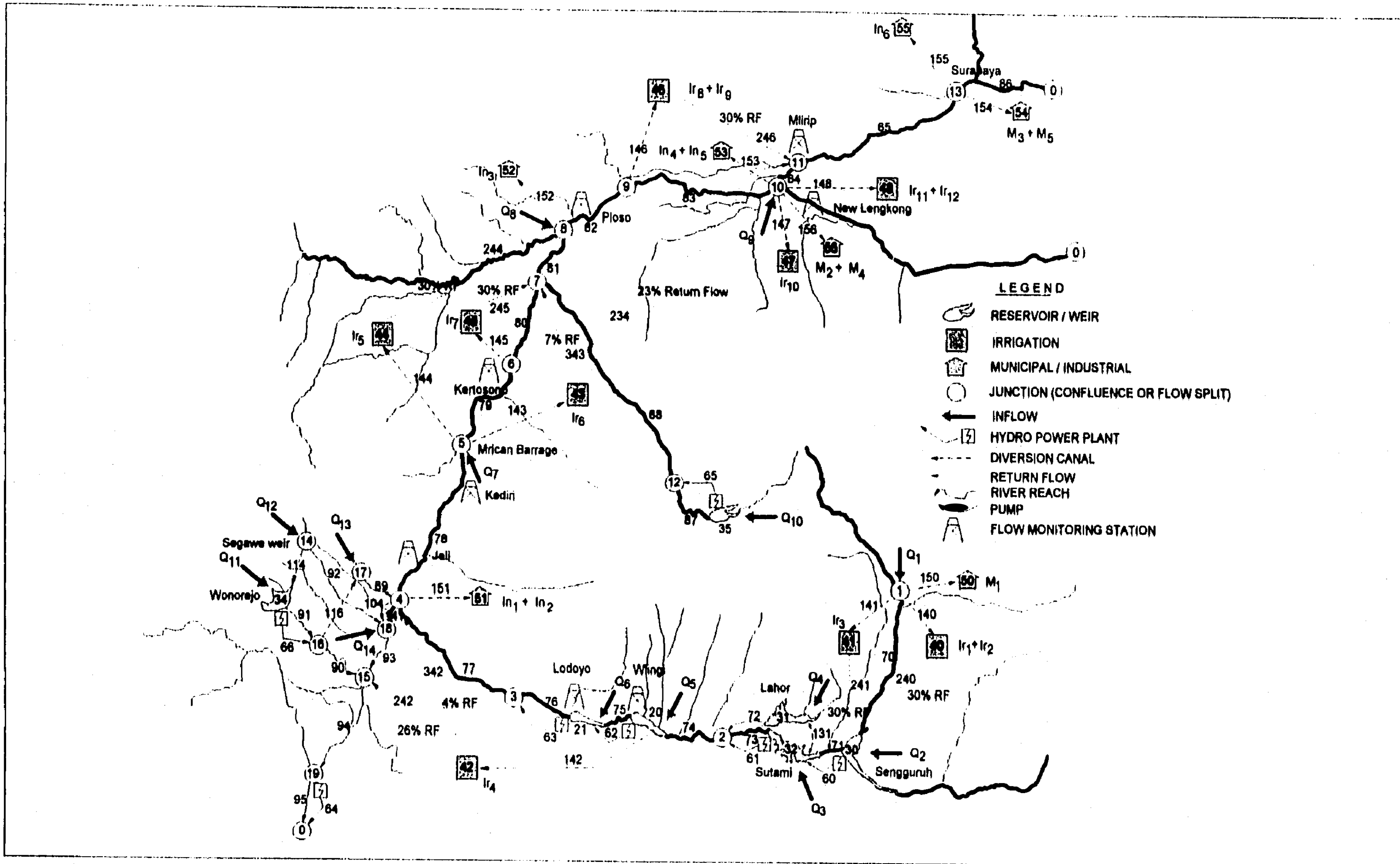


Figure A.6 Schematic, Number, Background and Rivers layers combined

A.4 Program GIS_Interface.mbx

The GIS_Interface.mbx file is an executable module produced from the GIS_interface.mb file, which contains source code in MapBasic, a development tool native to Mapinfo GIS software. Mapbasic is very similar to Visual Basic in terms of its syntax. The GIS_interface program requires that the following be installed on the computer prior to running the interface program:

a) The Mapinfo 5.0 GIS program should be installed using the default settings;
b) SCFBuilder.exe should be installed in the directory c:\Program Files\SCFBuilder;
c) Plotsim.exe should be installed in the directory c:\Program Files\Plotsim; and,
d) WRMM.EXE should be installed in the directory c:\Program Files\wrmm.

The GIS_interface program can be started from any directory on the hard disk. It can be started by double clicking with a mouse or by using the run option available on the start button menu. The GIS_interface.mbx program initially does two things: (i) it starts the Mapinfo GIS program and allows the user to open the files containing the schematic layer and other layers that the user may wish to view simultaneously; and, (ii) it modifies the main menu bar within Mapinfo to include the "WRMM Simulation" option as shown in Figure A.7.

It is good practice to have the GIS_interface.mbx started from a working directory which also contains the SCF and HBDF files. This is because the option "Run WRMM" calls the wrmm.exe program which looks for the SCF and HBDF files in the working directory, and that by default is the last directory that the user was in prior to running the GIS_interface.mbx program. The WRMM uses scratch file names SCF and HBDF to which the actual project files must be copied prior to running the model. There was no choice in modifying this since the WRMM program owners at Alberta Environment have insisted on using the WRMM model with scratch files named SCF and HBDF.

The Mapinfo GIS platform offers several component selection choices. Components can be selected individually or in groups. Individual selection is of more interest in this application, however a group selection can also be transferred to the SCFBuilder if massive deletion of one part of the schematic or one type of component is required. Group selection is almost entirely used for that purpose at present.

After starting the GIS_interface program, users can minimize the Mapinfo screen and start individually both the SCFBuilder and the Plotsim program by double clicking their program icons. The first step with the SCFBuilder is to read the appropriate SCF file that corresponds to the given schematic, while with the Plotsim program th user must first read the OUTSIM and OUTID files for a simulation run corresponding to the given schematic. At this point it is easy to switch between any of the three interactive programs by clicking on the Windows bar at the bottom of the screen, which automatically activates one application (for example the SCFBuilder) while at the same time it minimizes the other two (Plotsim and Mapinfo). To communicate component selection between the three programs, users must first select a component in the schematic layer using the standard Mapinfo selection tool and then confirm the selection on the "WRMM Simulation" option of the modified top menu bar. For example, to select the natural channel reach 82 between junction nodes 8 and 9 that can be seen in Figure A.7, the user must first activate the single component select option with a single pointing arrow in Mapinfo by clicking on the first button in the last menu bar from the top (this option was chosen as indicated by the image of the button appearing slightly sunken compared to the others). Next the user must click on the component in the schematic layer that is to be selected. The component will appear "marked" by red shading, which is a standard feature of Mapinfo used to distinguish selected components from the rest. Finally, the user needs to click on the "WRMM Simulation" option and then click on the "Confirm Single Component Selection" option in the drop down menu. This will result in the ID

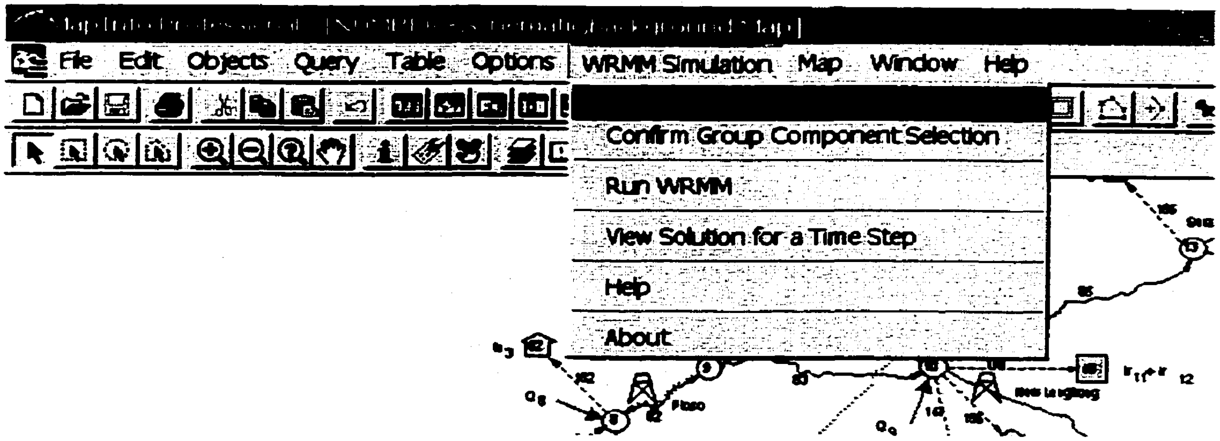


Figure A.7 Modified Mapinfo top menu bar

variable related to this component being saved in C:\GIS.TMP – a temporary file on the disk which is read by both the SCFBuilder and Plotsim programs, and which is written to by the GIS_interface.mbx program. This is the simplest way of transferring component selection between the programs, and it is also GIS platform independent, which means that it could easily be programmed into other GIS programs. The next step is to maximize the window for either SCFBuilder or Plotsim (depending on whether the user wants to edit the input data file or view the simulated output) and retrieve the component selection by a single click on the "GIS selection" button which is available in both the SCFBuilder and in the Plotsim program. This and other options within SCFBuilder and Plotsim are discussed in Appendix B and Appendix C.

The option "Run WRMM" calls the program wrmm.exe which re-writes the OUTSIM and OUTID files. Once these files are updated, they must be read into the Plotsim program again. Plotsim displays time series and statistical information related to a selected component. However, users may sometimes want to look at one individual time step solution for all components. This is done to check water distribution for the whole system for a critical time interval, giving the users an opportunity to verify whether the model solution indeed follows the prescribed set of priorities. The "View Solution for a Time Step" option is designed to handle this task. This option provides the user with two prompts – one

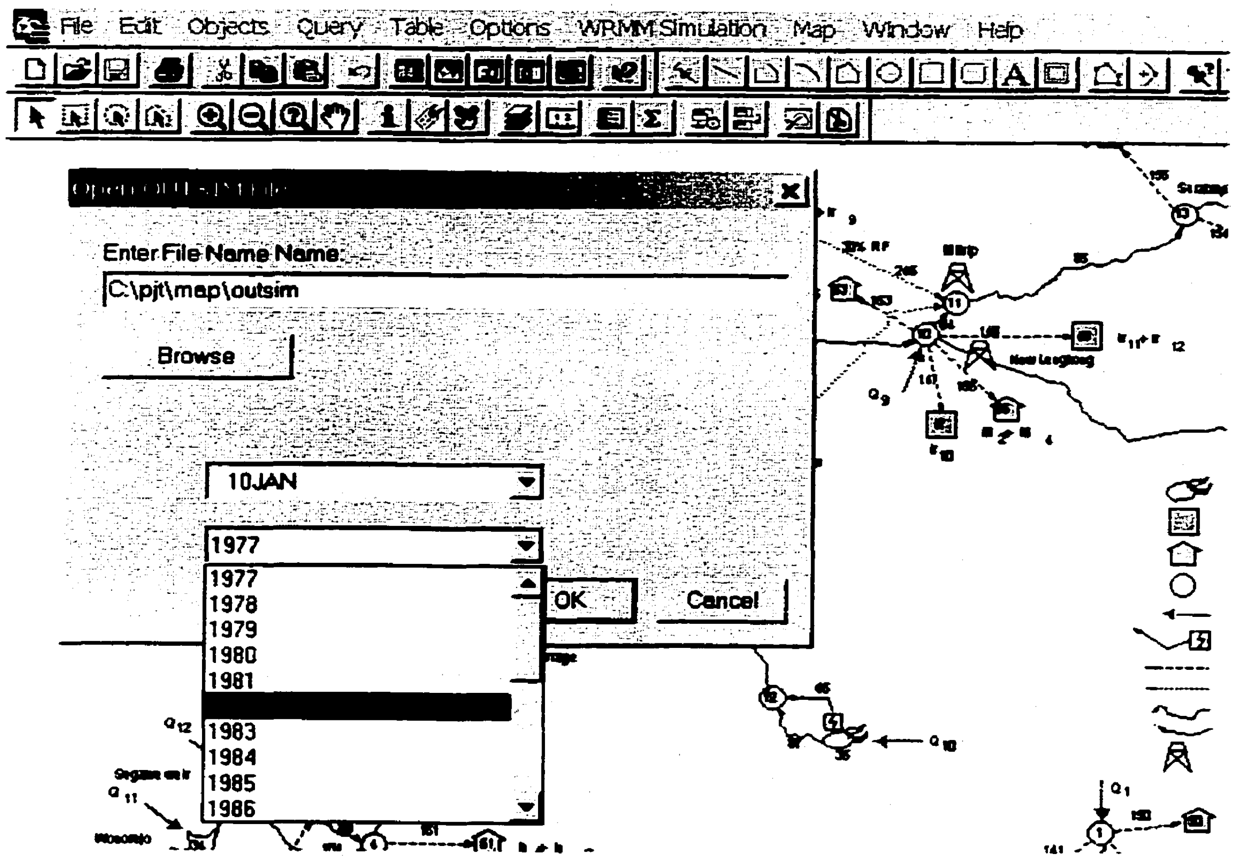


Figure A.8 Interactive menu for viewing the solution for one time step

for the full path of the OUTSIM data file which is usually viewed with this option, and the other with two combination boxes prompting the user to select the year and the time interval that should be displayed, as depicted in Figure A.8 where selection was made for the year 1982. Similar selection can be conducted for a time interval 10JAN (in the example 10-day time intervals were used and the first time interval ended on January 10, as indicated by the contents of the first combo box. Any time interval found in the OUTSIM file can be selected from this menu. When the user clicks the OK button, the GIS_interface program reads the solution for the selected time step in the OUTSIM file and places the values in the appropriate RESULT variables associated with each component in the schematic. To see the results displayed on the schematic clearly, the users may need to zoom in on the desired part of the schematic first, switch off viewing of the "numbers" layer which contains the component numbers and select the proper font size for variable RESULT in the schematic layer. Selecting the font size and zooming in on the part of the schematic of interest are GIS functions usually that are available in most GIS programs. Figure A.9 shows an example of the view for one time step solution of the upper part of the Brantas basin schematic.

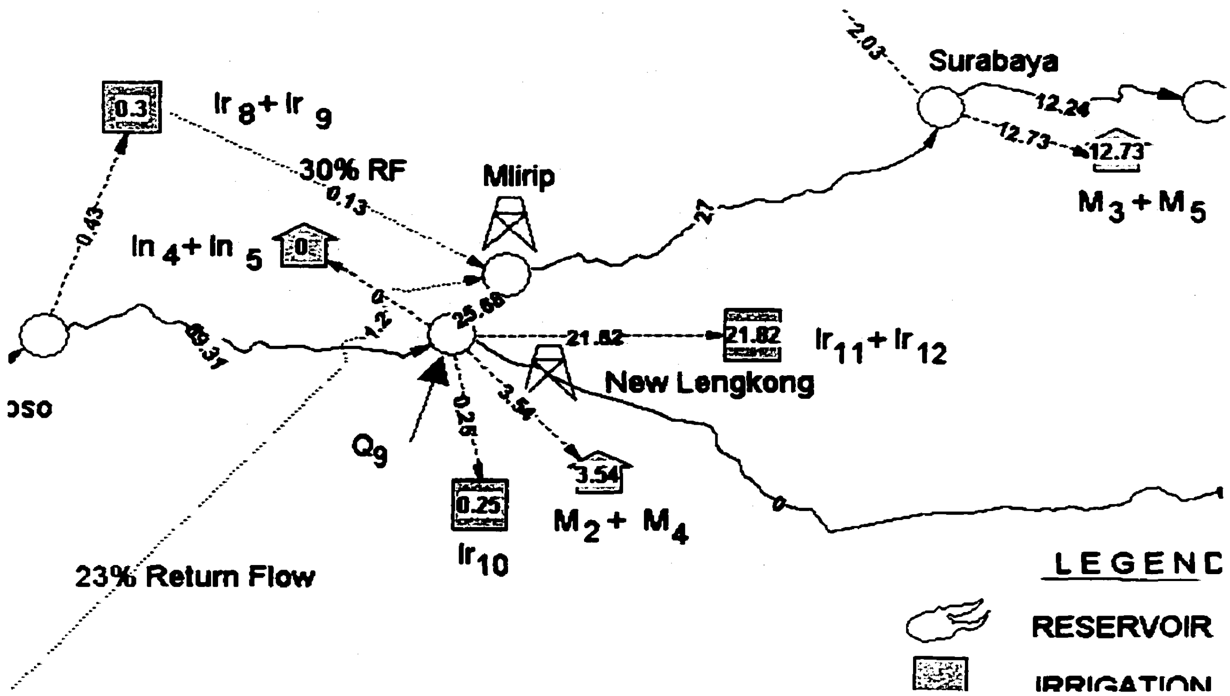


Figure A.9 Sample view of one time step solution

The box highlight feature is used to make the solution more visible. The numbers associated with each component now represent flows. For example, flow in channel 85 between the Mlirip gate and Surabaya is 27 m^3/s. This consists of the diversion at the Mlirip gate of 25.68 m^3/s and the two return flows of 1.2 m^3/s and 0.13 m^3/s. The sum of all three constituents is 27.01 m^3/s, while it should be 27 m^3/s. The round off error is due to the OUTSIM file containing three decimal places of accuracy while the GIS_interface display is setup to handle only two decimal places to increase legibility. Users can check the node balance and follow the flow changes within a given time interval from one river reach to the next. For example, the flow diversion of 0.43 m^3/s is split into consumptive use of 0.3 m^3/s and the return flow of 0.13 m^3/s. This balances (0.13+.3=0.43) and also meets the required criteria that the return flow be equal to 30% of the gross diversion (0.13/0.43 = 0.302). Again users should beware of small inaccuracies due to round off errors. The only component which participates in the nodal balance but which is not clearly visible with its own contribution in Figure A.9 is inflow. For example, inflow Q_9 in Figure A.9 can be calculated as the only unknown by balancing out all other inflows and outflows for node 9 (69.31-0.25-3.54-21.82-25.8=18.02). Inflow is not specifically listed in the OUTSIM file since it is part of the input data, while the OUTSIM file contains the simulated output. Therefore, users can look at the HBDF file for any time interval to determine the actual inflow values. The other way to do this using the OUTSIM file is to introduce a single reach tributary component for any inflow node and move the inflow to the upstream node of the tributary. The entire inflow for a time step would then become visible as the channel flow in a given tributary. This allows the users to check mass balance for every node in the schematic, but the downside is an increase in the number of components in the schematic.

APPENDIX B

DESCRIPTION OF THE PLOTSIM PROGRAM

TABLE OF CONTENTS

LIST OF FIGURES

B DESCRIPTION OF THE PLOTSIM PROGRAM

B.1 Introduction

The Plotsim program was designed to provide user friendly graphical presentation and analyses of the WRMM output. As mentioned earlier, the WRMM produces two output files with identical formats:

a) OUTSIM file, which contains the simulated output; and,

b) OUTID file, which contains the target values for each component.

Both files are usually large due to the typically large number of simulated years and modeled components, with the number of columns equal to the number of simulated time intervals (e.g. 52 for weekly simulations), plus the first three columns which identify the component type, number and the simulated year, respectively. The number of rows in the OUTSIM and OUTID is equal to the number of components times the number of simulated years plus one. For large river basins with many components these two files can be of up to 10 Mega Bytes each, which can slow down their reading and processing. When this happens, the WRMM users can resort to an option to print only selected components from the modelling schematics into the OUTSIM and OUTID files. This is achieved using the OUTNODES and OUTLINKS options in the $SIMCON subsection of the SCF file. The PLOTSIM program was programmed to handle a maximum of 500 components, which is also the limit in the WRMM. It is considered that schematics with more than 500 components are difficult to analyze and therefore should be broken into smaller sub-systems.

The Plotsim program reads the OUTSIM and OUTID files, and allows the user to interactively select any of the components found in the OUTSIM and OUTID files and view them using the time series and probability plots and their respective plotting options. It also provides optional tabular summaries of absolute and relative deficits for consumptive use components.

The Plotsim program was designed to work either as a stand-alone program, where users can select which component they wish to analyze using a combo box that lists all components found in the OUTSIM and OUTID files, or alternatively the selection can be made within a Mapinfo GIS layer and transferred to the Plotsim program.

The use of the Plotsim starts by calling the program which can be done by double clicking on the program icon. This is followed by opening the OUTSIM and OUTID files that are to be input, and then by selecting components to view or analyze. The program has several useful features for quick analyses of the WRMM output:

a) It is possible to open up to 4 data files. That allows users to compare more than one scenario simultaneously, which can be very valuable when the WRMM is run in an effort to conduct sensitivity analyses on a certain parameter.

b) If only one file is open (i.e. one OUTSIM file), the model allows a simultaneous plot of up to four different components. The scale is automatically adjusted to handle the range defined by a combination of chosen components.

c) Time series plots have several options, including the number of years per screen, variable starting year, and histogram (stepped) vs hydrograph (continuous) type plots.

d) Exceedance (or probability) plots follow the concept of plotting position probability using one of the more popular (Weibul) probability plotting position formulas. Users can select which period should be included in the probability plot. The period can include any number of consecutive time intervals which start and end within the same year. This makes it easier to analyze the WRMM output only during dry months such as, for example, August and September.

e) The model allows typical statistical analyses of the consumptive use components. Three statistics are calculated: absolute and relative deficit for each time interval for a given component, along with average and maximum deficits for each time interval within the entire simulated period, and the annual deficit for all consumptive use components for all years.

f) For final report quality printing of a chosen graph, users can use the "export to file" feature to save the data which were used to plot the selected graph. The saved file is in ASCII format and it can be easily input into any spreadsheet or other high quality plotting software package.

The above features are reviewed in more detail in the following.

B.2 Description of the Plotsim Main Menu

The main top bar menu of the Plotsim program consists of three options: File, Settings and Help. The second menu bar located below the top bar has six command buttons, followed by a text description "Program Plotsim version 1.2", the progress bar, and three check boxes labeled *Stepped, Exceedance and Time Series* (default), respectively, as depicted in Figure B.1. The final option in the second menu bar is a combination box that will contain a list of

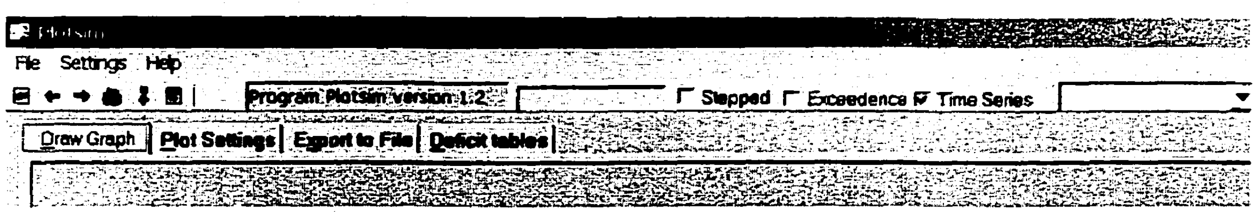


Figure B.1 The Plotsim program visual layout

all components found in the OUTSIM and OUTID files once the first file of those two files is opened. There are four tab forms below the second menu bar, giving users an option to *Draw Graph*, change the *Plots Settings*, *Export to File* the data for a given plot in ASCII format, or use the *Deficits Tables* option to view the statistical summary of deficits per component for each simulated time interval, or for all components at once on an annual basis.

B.2.1 The File Selection Pull Down Menu

The first selection (File) on the top menu has four options: Open, Reopen, Close and Exit, as depicted in Figure B.2. Options *Open* and *Close* handle a single file, while the option *Exit* stops the program execution. Option *Reopen* reopens the last files that were previously open

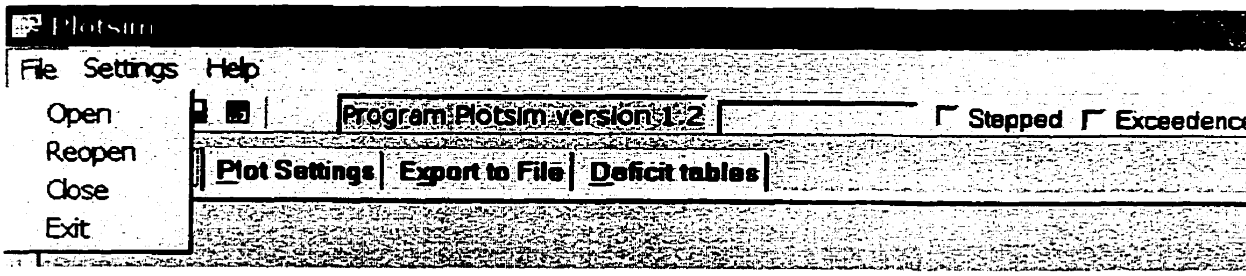


Figure B.2 File selection options

(this is needed if the files were changed by a subsequent WRMM run). Figure B.3 shows the standard windows file open dialog box that appears after the *Open* option has been selected. This dialog box allows the user to select any OUTSIM or OUTID file by changing directories or typing the full path in the File name text box. The exact look of this box is determined by the version of Windows operating system installed on the PC where the Plotsim is run. Figure B.3 shows the standard Windows 95 version, which differs significantly from the latest Windows 2000 layout.

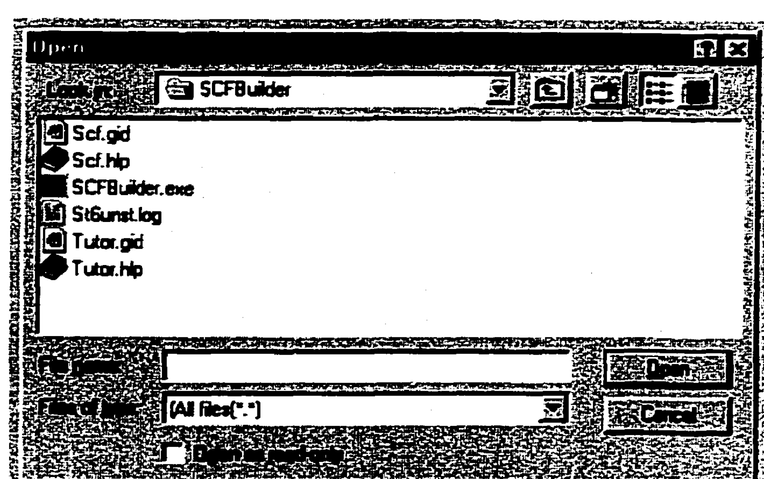


Figure B.3 File open dialog box

B.2.2 The Settings Selection Pull Down Menu

This menu provides options to select which *Component* to plot, select the *Graph Type*, change the *Line* properties, *Background* color or the *Grid* lines of the graph, as depicted in Figure B.4.

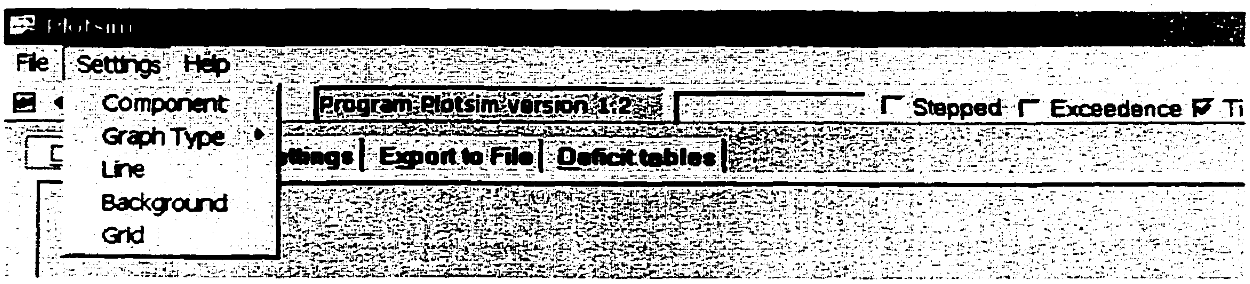


Figure B.4 Options available in the Settings selection

The only option with additional sub-options in the above menu is the *Graph Type*, which allows further choice of Time Series or Exceedance (probability) plots, as discussed later in this Appendix.

After the user opens a file and clicks on the *Component* option available in the *Settings* menu, the *Select Component* dialog box will appear as shown in Figure B.5. This box shows the list of components based on those found in the selected OUTSIM or OUTID file. The user should click on a desired component with the mouse and confirm this selection by clicking the OK button. The components listed in the dialog box are sorted in alphabetical order which takes into account the component type and the component number, both of which are found in the first two columns of the OUTSIM file. The dialog box will automatically allow users to page down through the list of components if the number of components exceeds the size of the box. An optional way of making a component selection is by clicking on the Plot Settings tab, which is also discussed later in this Appendix. Once the component is selected it is automatically plotted in time series format using the first three years per screen with the starting year found in the OUTSIM file used as the first

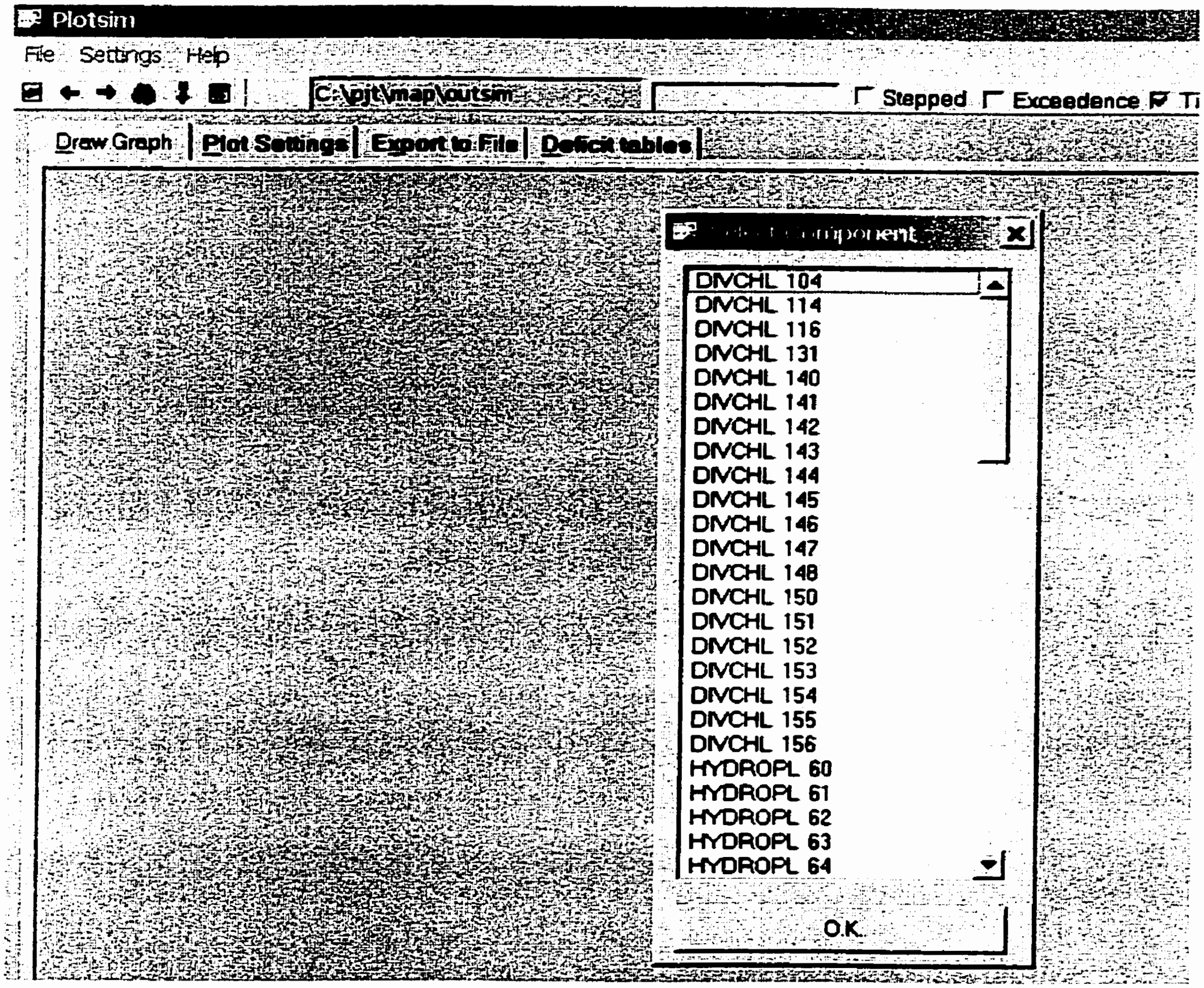


Figure B.5 Component selection dialog box

The *Graph Type* option provides a choice of two types of plots: *Time Series* or *Exceedance*,

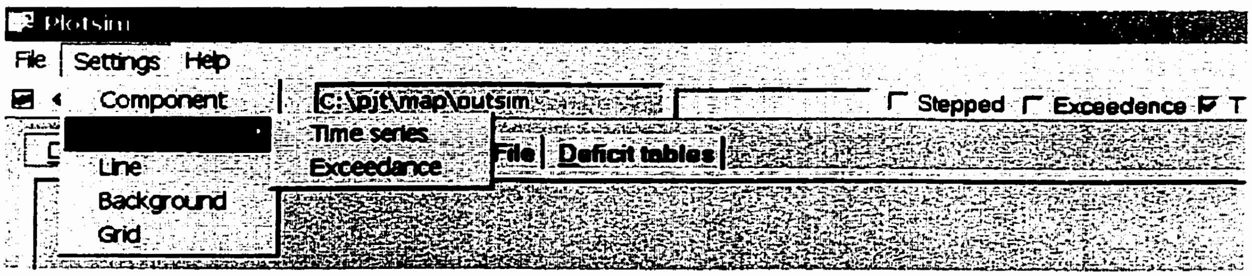


Figure B.6 Graph type options

as shown in Figure B.6. Users can select the type of graph from the settings menu as shown in Figure B.6, or alternatively by clicking the empty box on one of the three available options (*Stepped, Exceedance* or *Time Series*) on the second menu bar at the top of the program. The *Stepped* option should be used for Time Series plots for all components other than reservoirs. This is because the model outputs average flows and hydro power production over a simulated time interval, which is correctly portrayed by the stepped option. However, for reservoirs the WRMM model outputs elevation at the end of the simulated time step, so the stepped option is not suitable. Both the *Stepped* and the *Time Series* option are effectively time series plots. The difference is only in the format, as will be displayed in the following.

The dialog box in Figure B.7 appears after the user selects the Time Series option from the *Settings* menu. It allows the user to pick the starting year and the number of years to be plotted per screen. The starting year can be any year found in the OUTSIM file, while the number of years per screen can range from one to the maximum number of years found in the OUTSIM file, taking the starting year into account. Naturally, the higher the number of years per screen, the lower the quality of the plot.

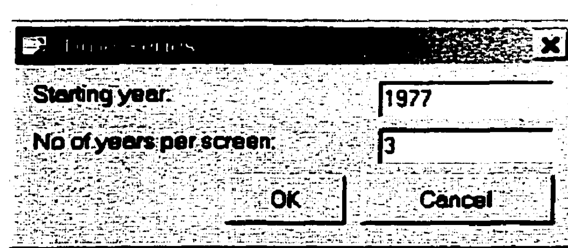


Figure B.7 Time series plot options

Time Series plots provide simulated output for a given component as a function of time. The WRMM simulations are carried out for many years to enable the model to cope with the variation of wet and dry years. The output analysis includes statistical summaries of how many times the model failed to deliver a specified water requirement to a given component as well as the analysis of the magnitude of failure.

Exceedance plots are probability plots based on the Weibul plotting position formula:

$$P = \frac{m}{n+1} \tag{B.1}$$

where P is the plotting position probability, m is the rank of a sorted list of simulated values for a given period and n is the total number of simulated values in the chosen period. Plotsim displays probability P on the x axis as a percentage, and the cumulative frequency values on the y axis. These plots are known in water resources engineering as flow-duration curves (FDC), or elevation-duration curves for reservoirs.

When an exceedance plot is selected, the program prompts users to define a critical time period that should be examined for a given component as shown in Figure B.8.

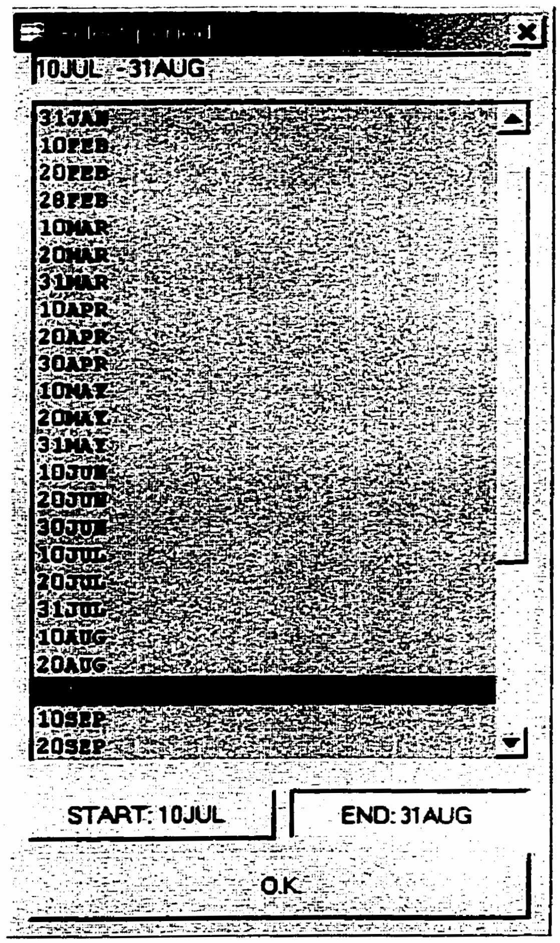


Figure B.8 Period selection

To define a critical period the user should select the start period by selecting a date in the available list and clicking on the START button and the end period by selecting another date in the available list and clicking the END button. This prompt always appears if the exceedance plot is selected as a graph type. For example, a critical period for an irrigation component can be from June 30 to August 31. This period typically includes several sequentially linked time intervals. The choice of selected time intervals shown in Figure B.8 is from July 10 to August 31. In this example the simulation time intervals are ten days. The list shows the ending date for a simulated time interval, hence selecting July 10 automatically includes the 10-day period from July 1 to July 10 inclusive. Therefore, the Plotsim program picks only those solutions for each year which fall into the critical period (i.e. July 1 to August 31 in this example). A subset of the WRMM output data related to a selected component is thus created. This data subset is sorted out and plotted in frequency-duration format using the above plotting position formula. This task is often required in output data analyses. It has traditionally been performed using data manipulation with spreadsheets, which was more time consuming requireing several intermediate steps.

The *Line Settings* option allows the user to change the line color, line thickness and line style (solid, broken or dashed) for any type of plot. Figure B.9 shows a dialog box which appears when this option is selected and allows users to enter the desired changes.

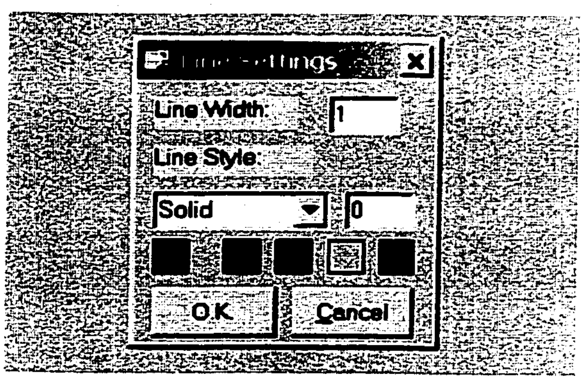


Figure B.9 Line settings options

There is an alternative way of specifying the line settings options, by using the global setup options from the command button in the second top menu bar. This option is described in the next section. The difference between the two options is that the above option does not change the settings permanently, while the global setup options command button offers a choice to users to save all setup changes permanently in the plot.ini file which contains the settings after the Plotsim program has exited. The plot.ini file is read by Plotsim each time the program is run.

Figure B.10 shows the grid line settings dialog box which appears after this option has been selected form the Settings selection on the top menu bar.

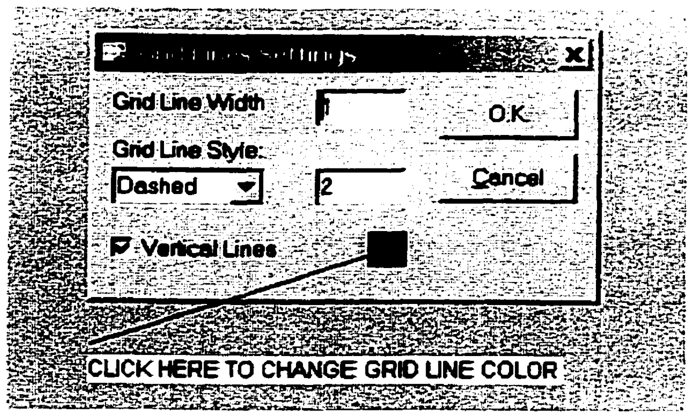


Figure B.10 Grid line options

This option is used to set the grid lines width and style. The user can also select vertical lines to include in the graph by clicking the empty box to the left of the vertical line option. Clicking O.K. exits the grid lines settings and clicking Cancel exits without making changes if no change to the grid lines setting is desired.

The *Background* option allows users to change both the background and foreground colors of the graph by using the color options window that appears every time the user clicks on the color boxes next to the O.K. button. The leftmost box of the *Background Settings* dialog box in Figure B.11 is used to set the background color of the graph while the box next to it is used to set the foreground text color. The user can add a new color into the custom color collection by selecting the color on the right side of color window and clicking the Add to Custom Colors button. Figure B.11 shows an example of background and foreground color setting.

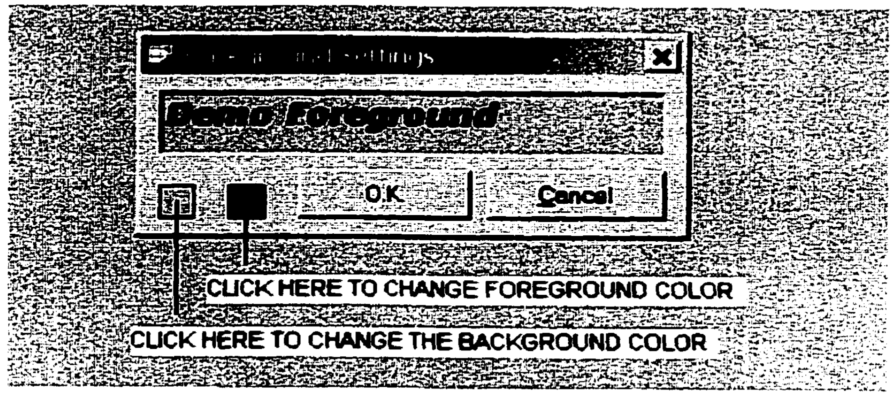


Figure B.11 Background settings option

Following a selection of either the foreground or the background color box, a new box appears with a wide selection of available colors, along with a possibility to use user-defined custom colors if activated, as shown in Figure B.12.

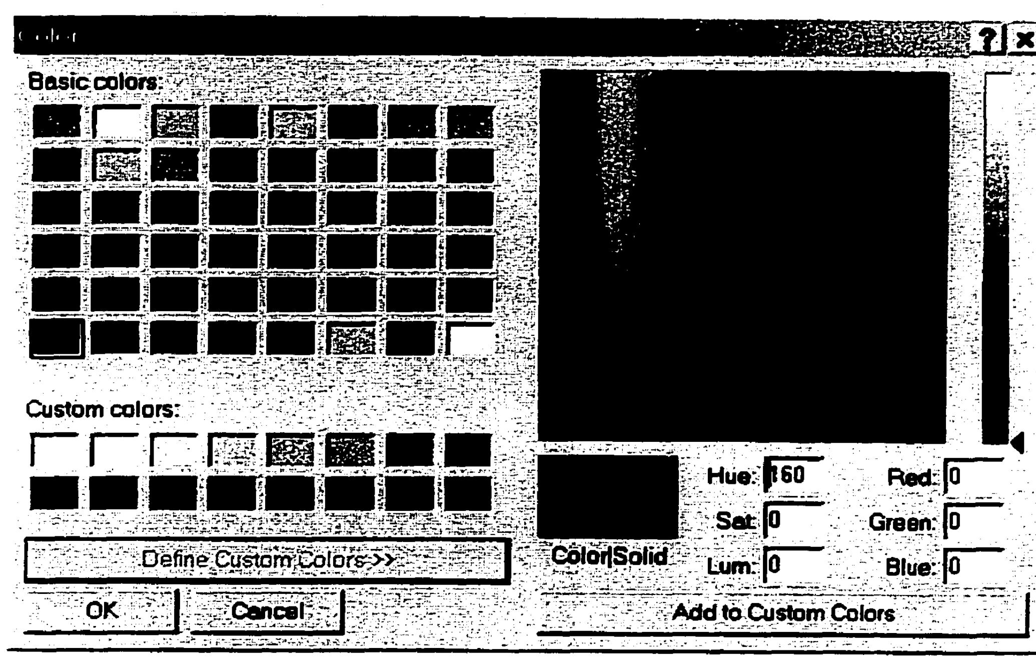


Figure B.12 Background and foreground color options

B.2.3 The Help Selection Pull Down Menu

The top bar of the main menu also offers the *Help* selection, which invokes a windows help file written in VB Helpwriter 3.2. This help file contains basic information on how to run the Plotsim program for a novice user. Figure B.13 shows the front page of the Plotsim help file.

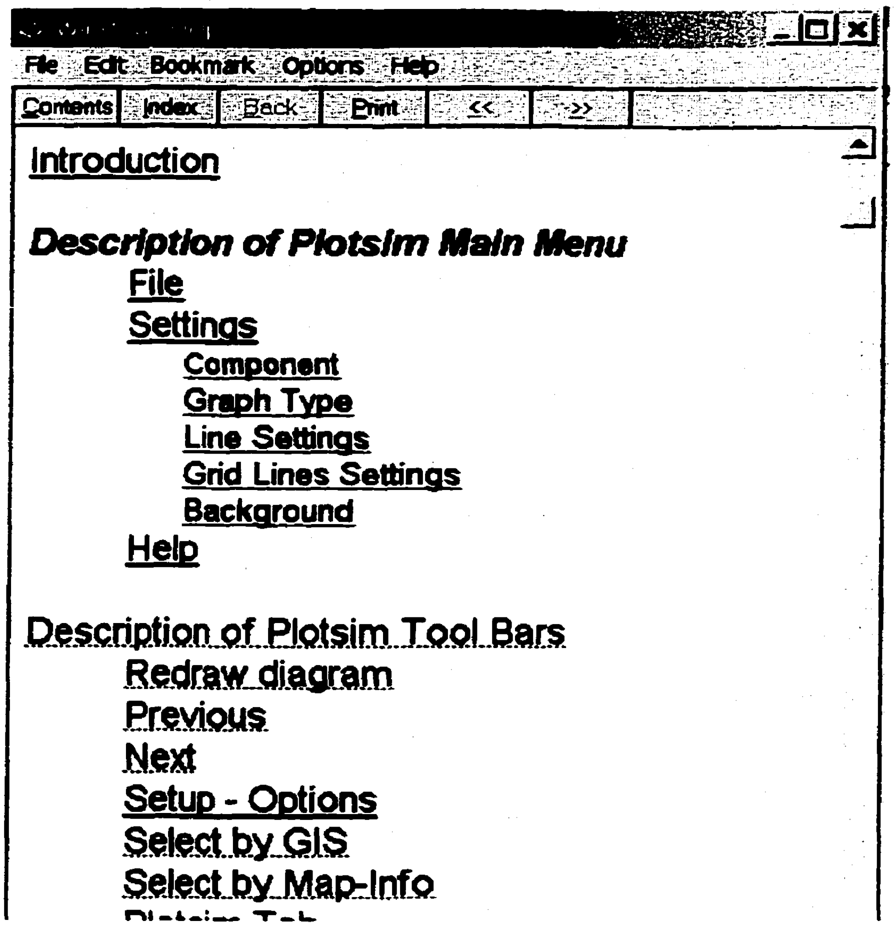


Figure B.13 Plotsim Help File

The Plotsim help file contains information in this Chapter.

B.3 Description of Plotsim Tool Bars

The Plotsim tool bar located in the second row of the top bar menu provides a number of shortcuts to the most frequently used commands within the Plotsim program. The purpose of each command button shown in Figure B.14 is briefly outlined below.

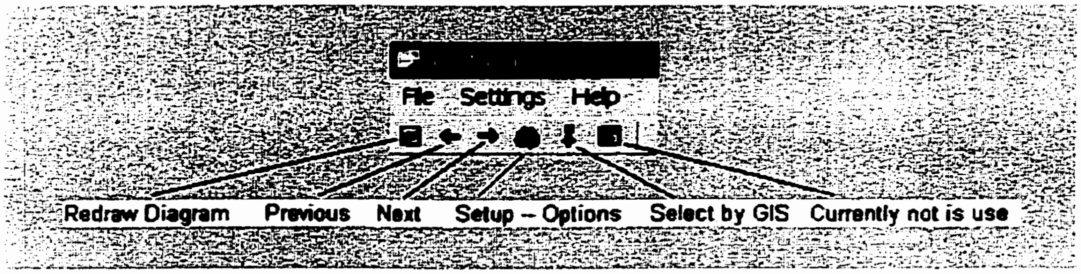


Figure B.14 Plotsim tool bar commands

The *Redraw Diagram* button is used to re-draw the plot after any change in the settings. The *Previous* and the *Next* buttons are used only with Time Series plots to allow users to page time series plots back and forward in time by the number of years displayed on the screen. Once the final year is reached, the program sounds a warning if further attempts are made to scroll beyond the last year.

The *Setup Options* button provides a facility for global change of all program settings as shown in Figure B.15 with an ability to save the settings permanently in the plot.ini file.

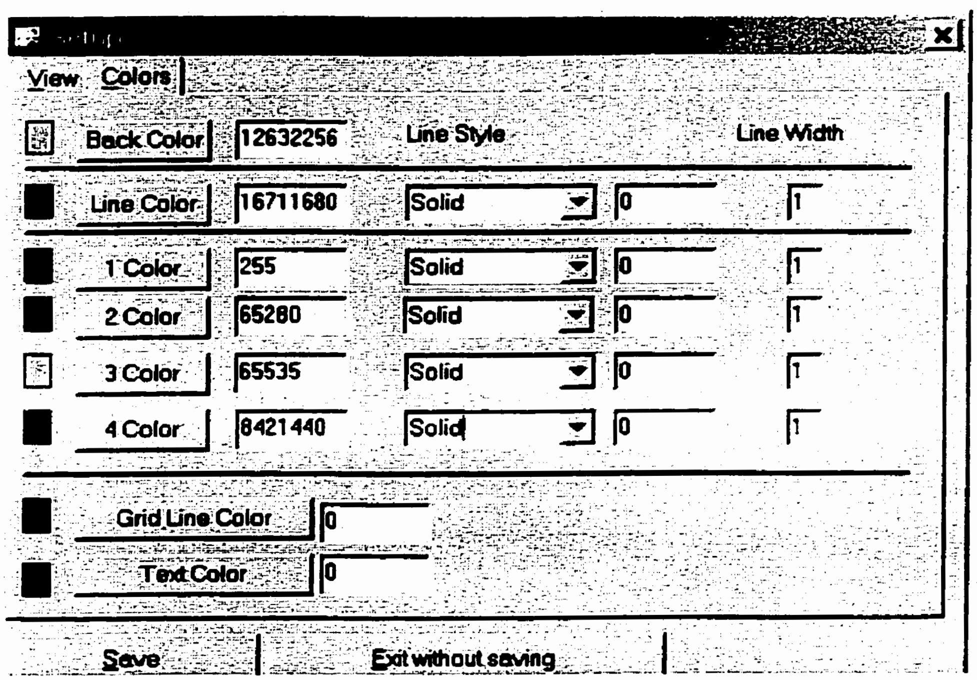


Figure B.15 Global setup options

The *Select by GIS* command button allows users to select the component from a schematic drawn in a GIS layer. By selecting the component in GIS, the program reads the component identifier from the GIS database and selects it automatically just as if the selection was made manually within the Plotsim program. This process is demonstrated in the next section.

The final command button was left for a new option that may be added in the future.

B.4 Description of Plotsim Tabs

This program has four tabs that are explained in the following:

B.4.1 The Draw Graph Tab

This tab is used to view a graph that can be in Excedence or Time Series format. Time Series graphs can also be viewed as Stepped functions. Its function is the same as that of the redraw tool bar. Examples of the three types of graphs that can be produced are shown in Figures B.16, B.17 and B.18. Figure B.16 is a time series graph which shows the default 3-year plot for natural channel 85. The y axis scale is determined based on the minimum and maximum values found in the OUTSIM file for a selected component.

Figure B.17 shows the same graph using the stepped (histogram) format. This format more adequately portrays the OUTSIM and OUTID values for all components except reservoirs, since the WRMM produces channel flows and hydro power generation as average values per time step. Users should click on the check box next to the *Stepped* label to convert a linear time series plot into a stepped format.

Similarly, clicking on the check box associated with the *Exceedance* keyword will convert the entire plot to a probability format, as shown in Figure B.18 with the default period initially covering the entire calendar year from January 1 to December 31. This period can be changed by clicking on the *Settings* pull down from the main menu, followed by the *Graph Type* and then *Exceedance* to obtain the dialog box displayed in Figure B.8.

B.4.2 The Plot Settings Tab

This tab provides shortcuts to some of the options already available in the main menu, and it also provides some additional options that are unique. It is displayed in Figure B.19. Like the main menu, it allows users to select which component is to be plotted and for what period if the exceedance option is chosen. This is done in a more straight forward fashion by clicking on the starting and the ending time interval in the list box on the left side of the form. The current selection of the starting and the ending time intervals is displayed at the top of the time intervals list box. Users can also manually select which years they wish to plot by checking the boxes at the beginning of each year in the list box that displays a subset of the OUTSIM file showing only the lines referring to the chosen component. If selected in this manner, the years do not have to be in chronological order.

The Plot Settings tab allows the introduction of additional WRMM output files. This can be an OUTID file associated with the same simulation run that generated the OUTSIM file initially read by the program, but it can also include other OUTSIM files from alternative scenario simulations. Up to four files can be read into the Plotsim program. They should all have the same components and years, to represent simulation outputs for the same system but different operating scenarios. This capability allows visual comparisons of the impact that changes in operating priorities would have on selected components. Figure B.20 shows the July-September exceedance plot for withdrawal 48 in terms of its ideal demand (obtained from the OUTID.01 file), Scenario 2001 in the OUTSIM.01 and OUTSIM.10 files (referring to the level of development and water demands in years 2001 and 2010, respectively). For 80 percent probability (one in five dry year) the ideal demand is around 24 m^3/s, the 2001 Scenario supplies 23 m^3/s while in year 2010 the available supply drops to about 20 m^3/s due to higher priority of other components such as the riparian flow and municipal supply.

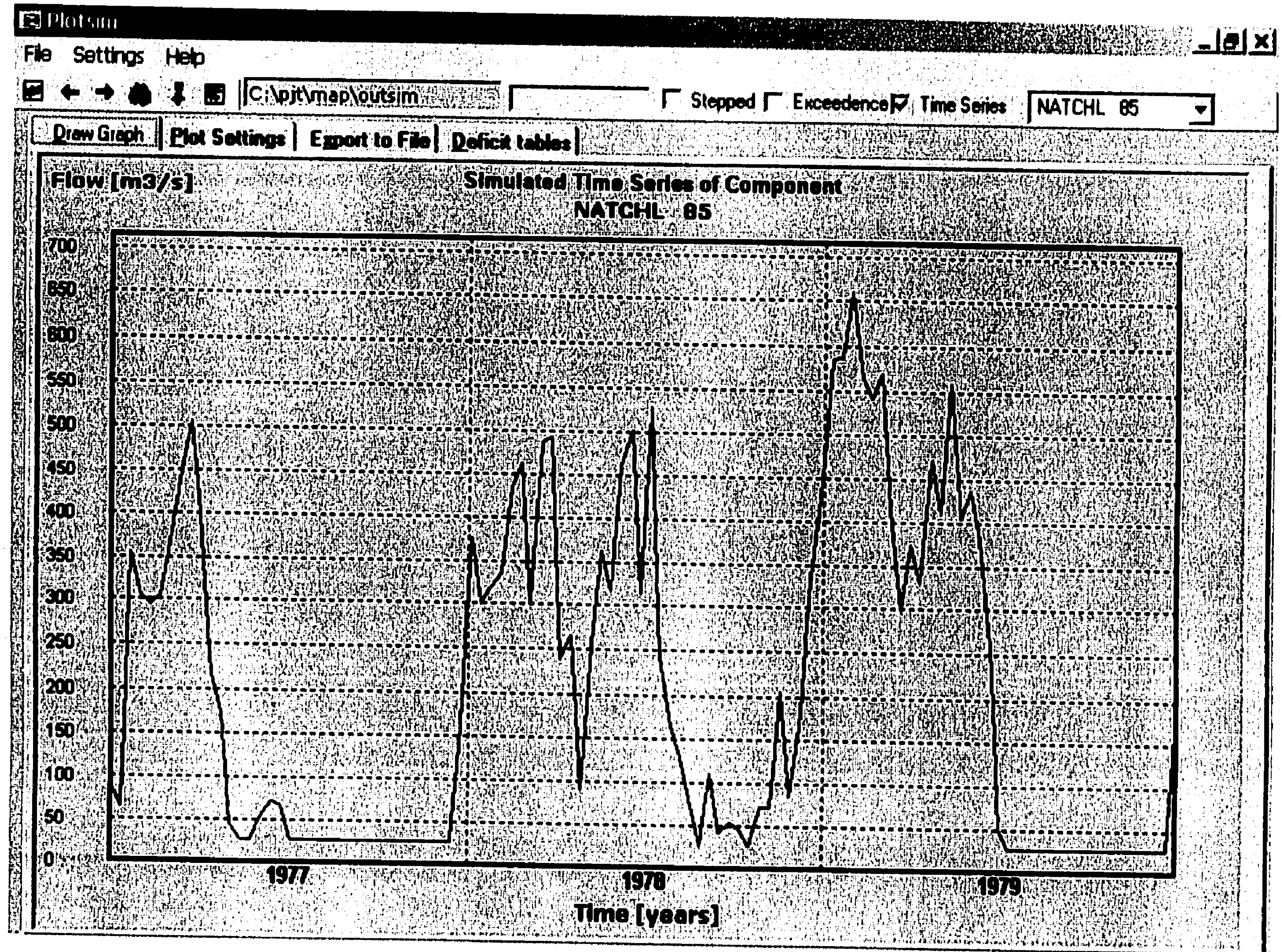


Figure B.16 Continuous time series plot

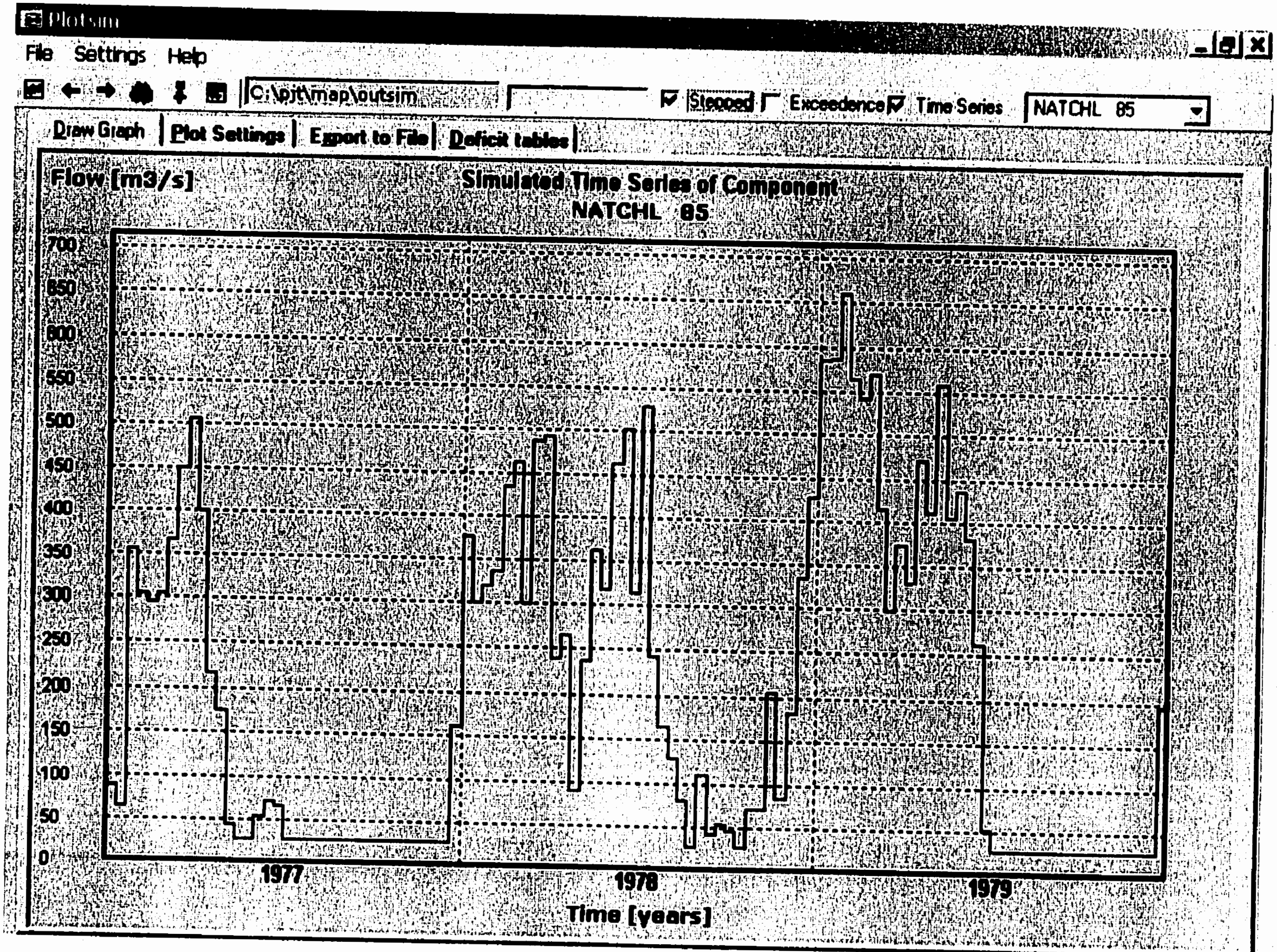


Figure B.17 Stepped time series plot

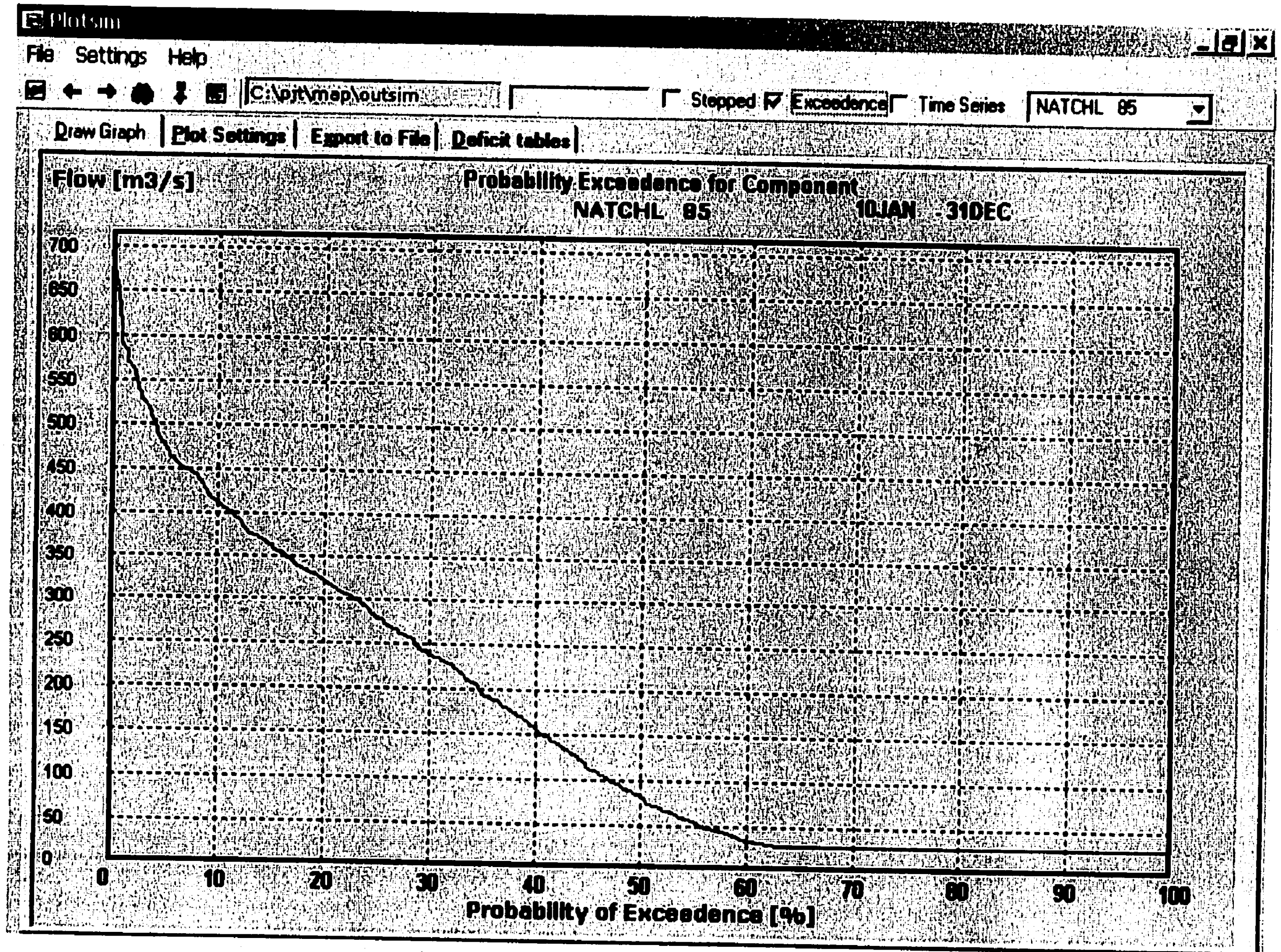


Figure B.18 Exceedance plot for channel 85

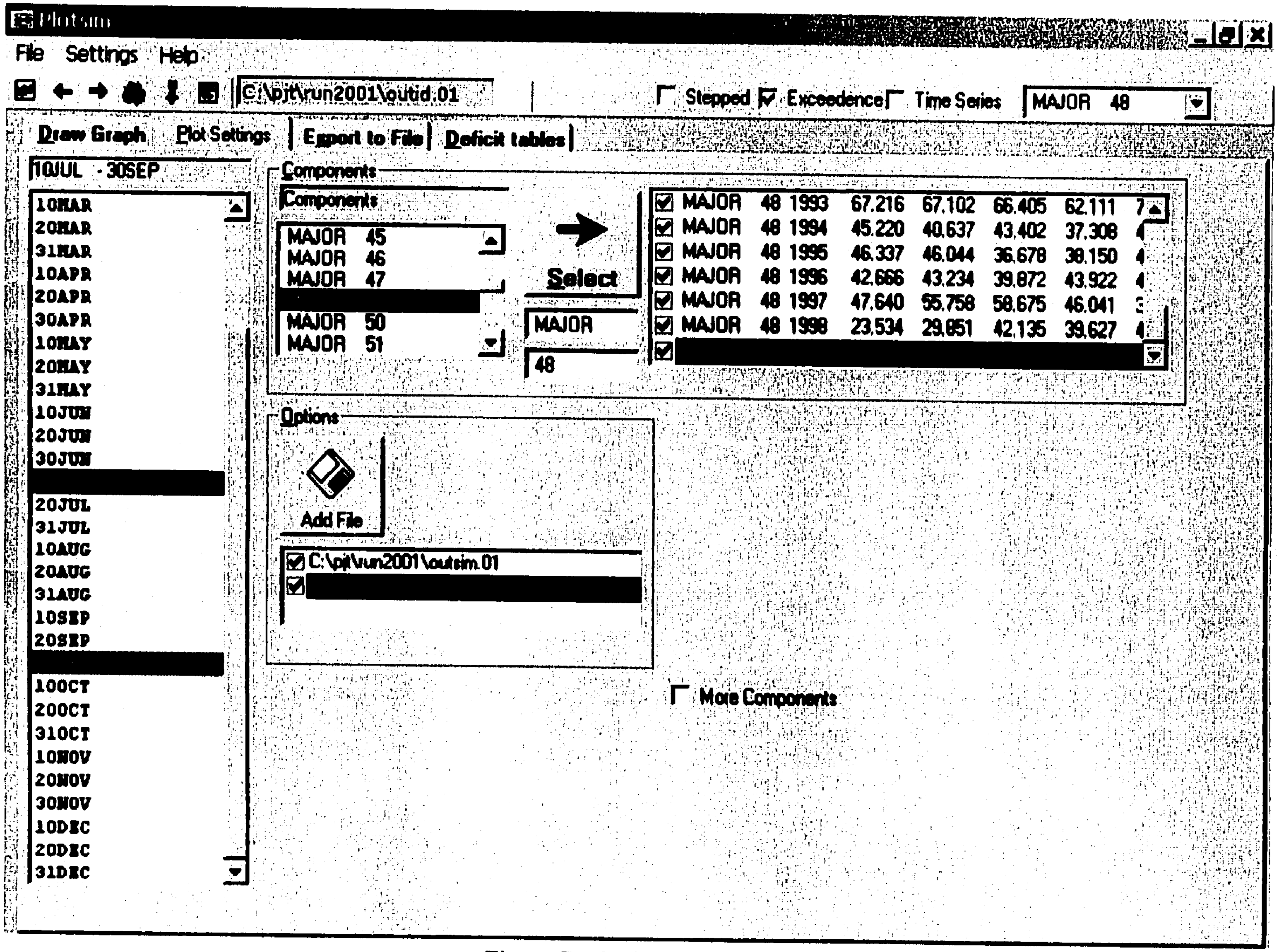


Figure B.19 Plot Settings tab

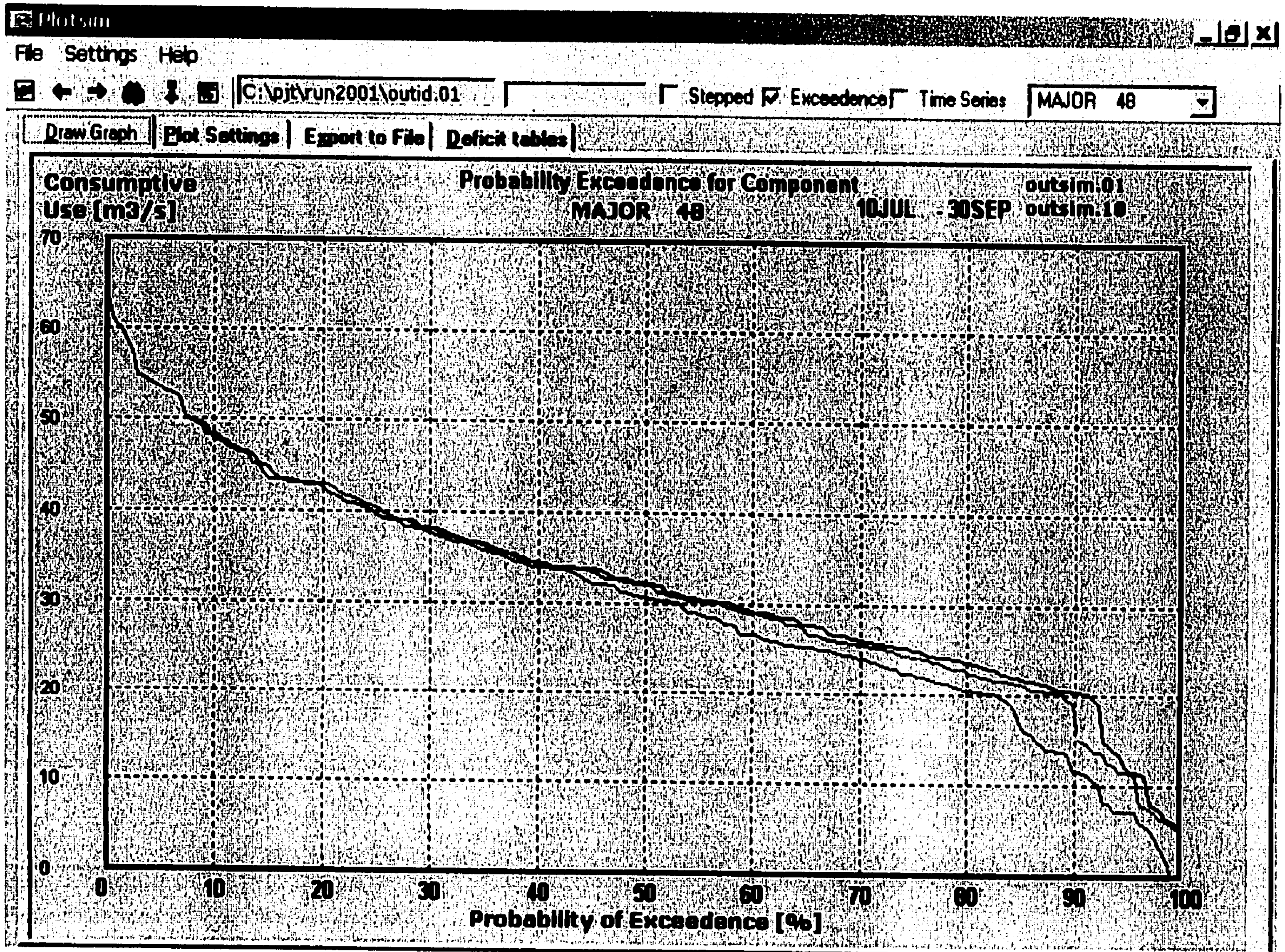


Figure B.20 Exceedance plot for component 48 from three files

Note the check box labeled "More Components" on the Plot Settings tab form in Figure B.19. When only one input data file is open, it is possible to plot up to four components on the same plot. For example, users can view up to four selected river reaches starting from the most upstream to the most downstream and view the time series or probability plots for all four of them concurrently. Figure B.21 shows the Plot Settings tab after four components from a single OUTSIM file have been selected for plotting. Notice that the *Add File* command button has disappeared. When users select an option to add more components to a plot, those can be added only from a single file that was opened first when the program was started. Hence the suppression of the *Add File* command button. There is no use for having an option to plot several components from different simulation runs simultaneously.

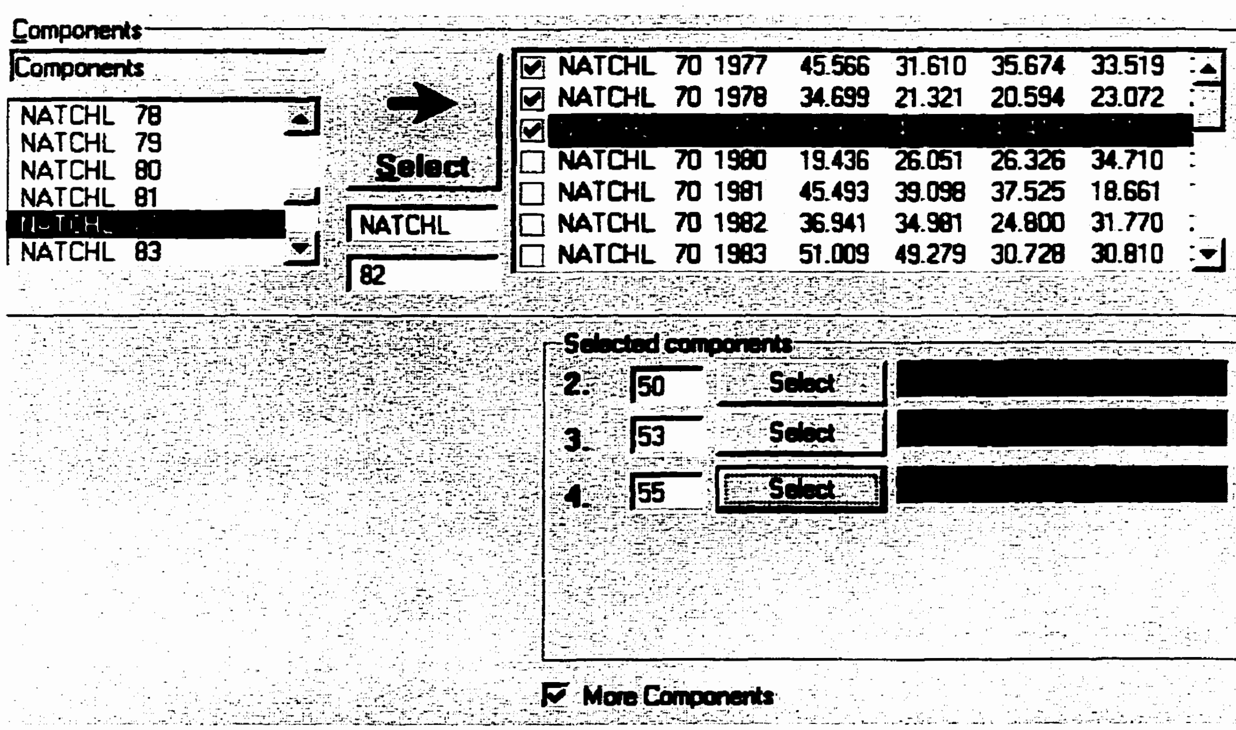


Figure B.21 Option to plot more than one component from a single file

The exceedance plot in Figure B.20 shows a plot of the same component (withdrawal 48) from three different files. The plots are labeled using the originating file names. This is different from plotting several components originating from a single file. In that case the component name and number are automatically used as labels, as depicted in Figure B.22.

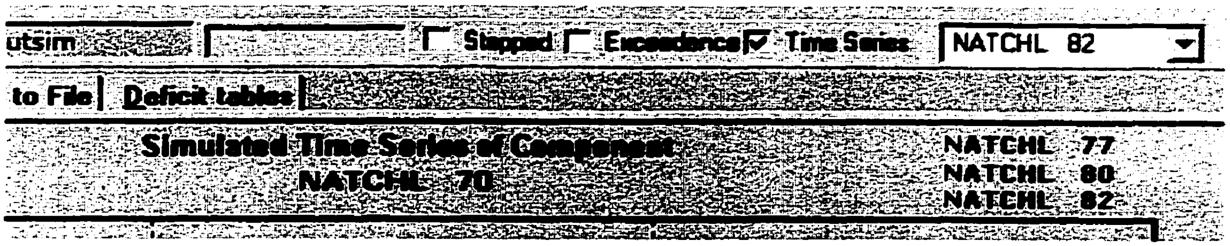


Figure B.22 Line labels for components from the same file

In Figure B.22 the initial component selected for plotting was natural channel 70. The three components that were added using the option to add more components are natural channels 77, 80 and 82.

With either option (opening more than one file or plotting more than one component from the same file) the maximum number of lines per plot is four. The decision to allow a maximum of four lines per graph was due to clarity. In the process of making that decision several WRMM users were asked to comment on the maximum number of lines displayed simultaneously that they considered was reasonable for simultaneous viewing.

As stated earlier, the *Plot Settings* tab can act as a shortcut to most of the functions that are available from the main menu. For example, selecting a component can be done by clicking on a component in the component list and confirming the selection using the *Select* command button. After the component is selected from the available list and the *Select* command is executed, the second list box containing only the lines of the OUTSIM file with the selected component will be filled. Checking the box at the beginning of each line gives users an option to select the number of years per screen which can be done by clicking the empty box beside each item.

The *Start and End Period* list in the Plot Settings tab appears only when the exceedance type of graph is selected. The list contains the ending dates for each simulated time interval. The user should click two lines in this list, once as the start period and another as the end period. However, the user may select more than two lines. When this is done, the selected period(s) between the uppermost and lowermost selection are ignored and the valid start and end period can be seen on the text box on top of the list. It is suggested to select only one starting and one ending time for defining the critical period.

B.4.3 The Export to File Tab

The Plotsim program was not programmed to send any plots to the printer. There are numerous advanced printing options for a variety of printer drivers available in commercial software packages such as Lotus or Excel. Rather than try to compete with those, it was decided to take advantage of them. The role of the Plotsim program is primarily as a pre-screening and output analysis tool. It allows users to select the critical components and critical periods and summarize the findings using the most standard plotting options. Once the appropriate graph has been identified by using the Plotsim program, users can save the data that are required to generate the graph in an ASCII file using the *Export to File* tab. When this tab is activated, the screen shown in Figure B.23 appears.

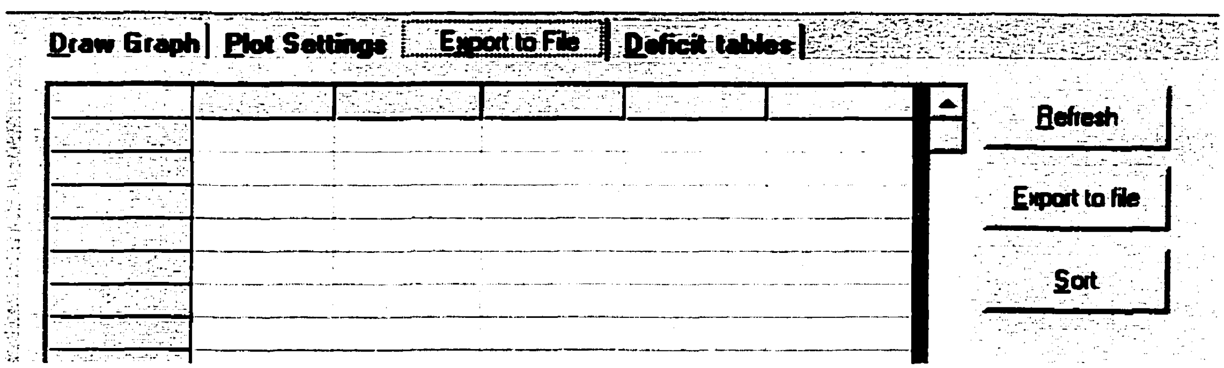
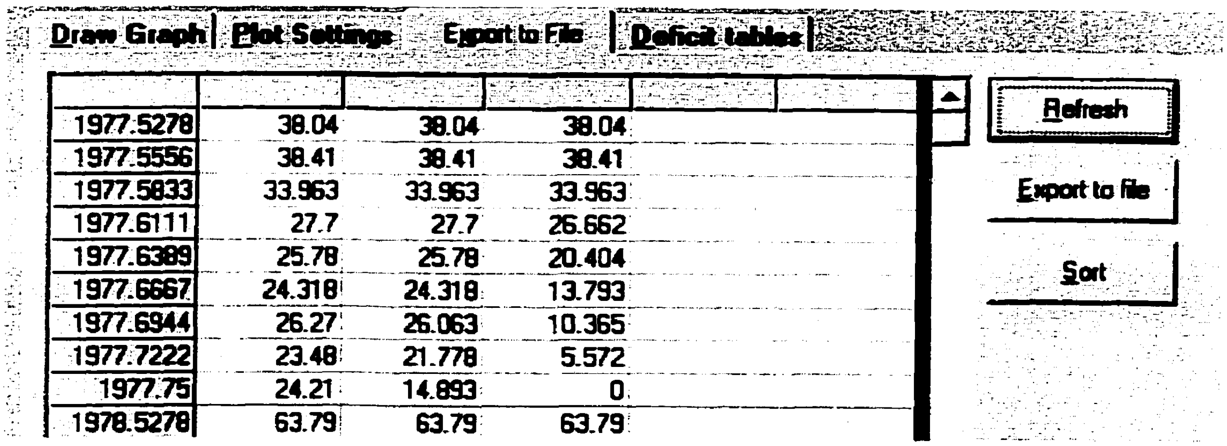


Figure B.23 Export to File tab form

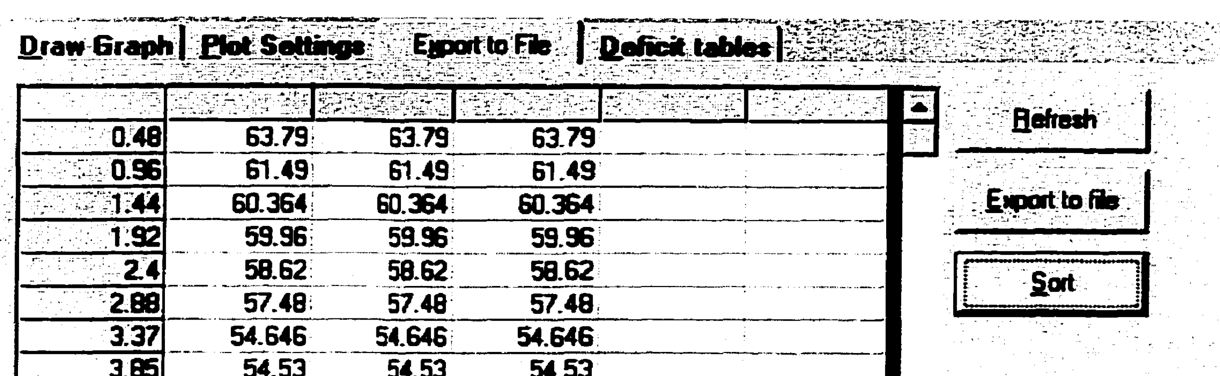
After clicking on the *Refresh* command button, the data that formed the last viewed plot will be transferred in a column format, starting with the x coordinate in the first column, followed by the y coordinates for up to four lines included in the plot. The example in Figure B.24 involves data transfer related to plot shown in Figure B.20. The initial transfer is the raw time series data. Note that the plot in Figure B.20 includes only the July 10 to September 30 period, hence the starting x coordinate is 1977.5278 which corresponds to year 1977 plus 19 time intervals divided by 36 (annual total) which is 0.5278. Similarly, the ending time coordinate is September 30, or 27 time intervals out of 36, hence the x coordinate 1977.75.



1977.5278	38.04	38.04	38.04
1977.5556	38.41	38.41	38.41
1977.5833	33.963	33.963	33.963
1977.6111	27.7	27.7	26.662
1977.6389	25.78	25.78	20.404
1977.6667	24.318	24.318	13.793
1977.6944	26.27	26.063	10.365
1977.7222	23.48	21.778	5.572
1977.75	24.21	14.893	0
1978.5278	63.79	63.79	63.79

Figure B.24 Initial data fill following the *Refresh* command

The following years will also have coordinates between July 10 and September 30. The first line of year 1978 is displayed in Figure B.24. Users wishing to plot only data for July 10 to September 30 for each year in time series format can click on the *Export to File* command button, which will prompt them for a file name and save the table displayed in Figure B.24 in ASCII format. However, Figure B.20 shows a probability plot. To display the data that were used for generating this plot, users need to activate the *Sort* command. The result of this action is shown in Figure B.25.



0.48	63.79	63.79	63.79
0.96	61.49	61.49	61.49
1.44	60.364	60.364	60.364
1.92	59.96	59.96	59.96
2.4	58.62	58.62	58.62
2.88	57.48	57.48	57.48
3.37	54.646	54.646	54.646
3.85	54.53	54.53	54.53

Figure B.25 Result of executing the sort command

The data in Figure B.25 can be saved in any file under any user specified name. The actual window that appears when activating the *Export to File* command button will vary depending on the version of Windows installed. Figure B.25 shows the screen that appears under the Windows 2000 operating system.

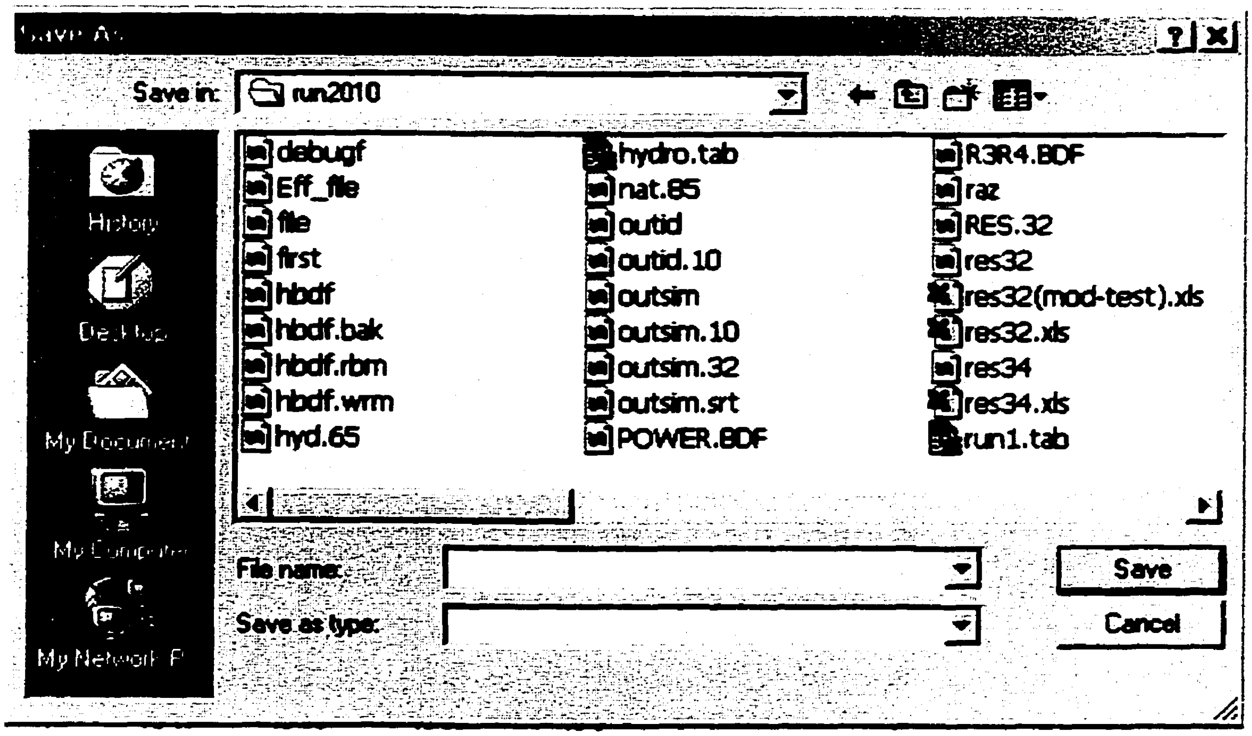


Figure B.26 Save file window activated by *Export to File* command

B.4.4 The Deficit Tables Tab

The last tab is the *Deficit Tables* tab. This tab provides a tabular form that offers the three most common types of statistical analyses provided in the WRMM output. Of particular interest is the analyses of supply to consumptive use components, hence the term *deficit tables*.

The user can get the deficit values in this table provided that two files are open; one containing the simulated, and another containing the ideal target values. Otherwise, the deficit calculation cannot be obtained because there can be no comparison between the simulated and the ideal target values. Therefore, the user should ensure that the ideal target values (OUTID) are added before generating this table. If that is not the case and the use of this tab is activated, Plotsim will display a message box on the screen requesting that one more file be opened.

There are three kinds of tables that the user can generate in this tab:

a) absolute deficit for the selected component;
b) relative deficit for the selected component; and,
c) annual deficit for all consumptive use components.

Each table can be obtained by clicking the *Refresh* button after selecting the available option for the type of table. These tables can also be saved on the disk by clicking the *Save* button.

B.4.4.1 Absolute deficit for the Selected Component

This table is used for analyzing the deficit of each consumptive use component in the system. The value in this table is absolute which means that the user can view the difference between the ideal target of water demand and the available water supply in the system for the particular or selected component in the units assumed in the OUTSIM and OUTID files, i.e. units of application (mm) for irrigation and units of flow (m^3/s) for industrial and municipal water use. The absolute deficit *Da* is obtained by the following:

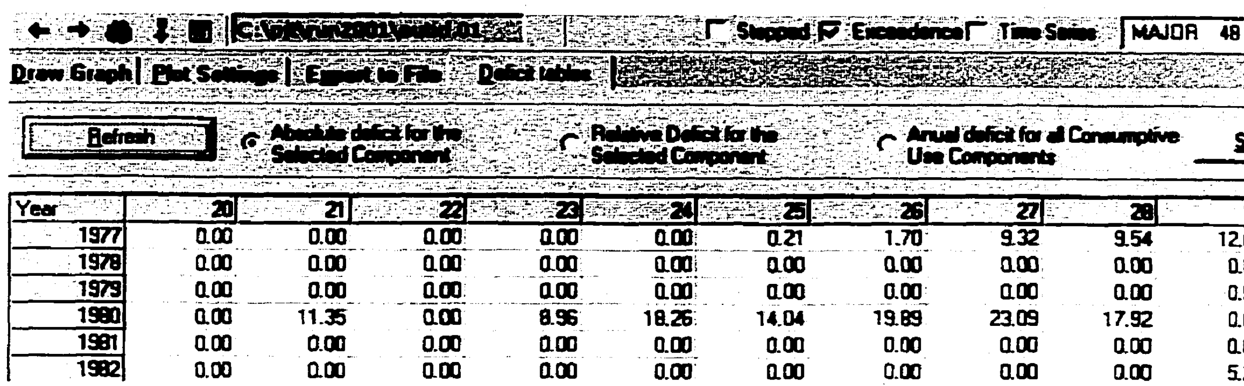
$$Da = Idl - Sim \qquad \text{(B.2)}$$

where :

Idl the ideal target for the selected component (mm or m^3/s)

Sim the simulated allocation for the selected component (mm or m^3/s)

Figure B.26 shows a portion of the deficit table for component 48 in m^3/s. The first six years



Year	20	21	22	23	24	25	26	27	28	2
1977	0.00	0.00	0.00	0.00	0.00	0.21	1.70	9.32	9.54	12.6
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.5
1980	0.00	11.35	0.00	8.96	18.26	14.04	19.89	23.09	17.92	0.0
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.2

Figure B.26 Absolute deficit table

are shown along with time intervals 20 through 28, (i.e. day 200 to 280) which represents a dry period prone to deficits in supply. Users can page this table up and down, as well as left and right. Each row contains a solution for one year, while each column contains a solution for one time interval. In this example there are 36 time intervals. There are two additional rows added after the final year in the table: the row containing averages and the row containing maximum deficit found for a time interval. These two rows (average and maximum) appear in all three tabular options (absolute, relative and annual deficit).

B.4.4.2 Relative Deficit for the Selected Component

This table is used for analyzing the deficit of each component and each time interval in the system relative to the demand. The relative deficit (Dr) expressed as a percentage is obtained by the following formula:

$$Dr = \left(\frac{Idl_n - Sim_n}{Idl_n} \right) * 100 \qquad \text{(B.3)}$$

where :

Idl_n the ideal target for a selected component n

Sim_n the simulated allocation for a selected component n

An example of a relative deficit table is depicted in Figure B.27 (note that this time the last two rows are displayed. The average deficits may be small due to many years with no deficits as seen by a large number of zeros in the deficit table. In this time series, the critical years seem to be 1980 and 1982, since many of the maximum deficits for individual time intervals are found within those two years. Other years or time intervals in the table can be viewed by paging the table up and down, or left and right. The FlexGrid control available in Visual Basic automatically provides the scroll down and scroll left bars if the size of the grid area containing the data is larger than the space available on the screen, which is the case in this example, although not visible in Figure B.27 since that would require a choice of displaying deficits in the last 6 weeks of the year that fall in the wet season, when all deficits are zero.

To switch from the absolute deficit table in Figure B.26 to the relative deficit table in Figure B.27 users must click on the bullet next to the desired table on top of the form and click on the Refresh command after that.

B.4.4.3 Annual Deficit for all Consumptive Use Components

This table is used to view the annual deficit for all consumptive use components in the study region so that users could analyze the deficit in water supply annually and adjust the water allocation policies. The following formula is used to obtain the annual deficit (*Dan*) for one component:

$$Dan = \left(\frac{\left(\sum_{1}^{T} Idl_{CU} - \sum_{1}^{T} Sim_{CU} \right)}{\sum_{1}^{T} Idl_{CU}} \right) * 100 \qquad (B.4)$$

where :

Idl_{cu} the ideal target for a consumptive use component (mm or m^3/s)

Sim_{cu} the simulated supply to a consumptive use component (mm or m^3/s)

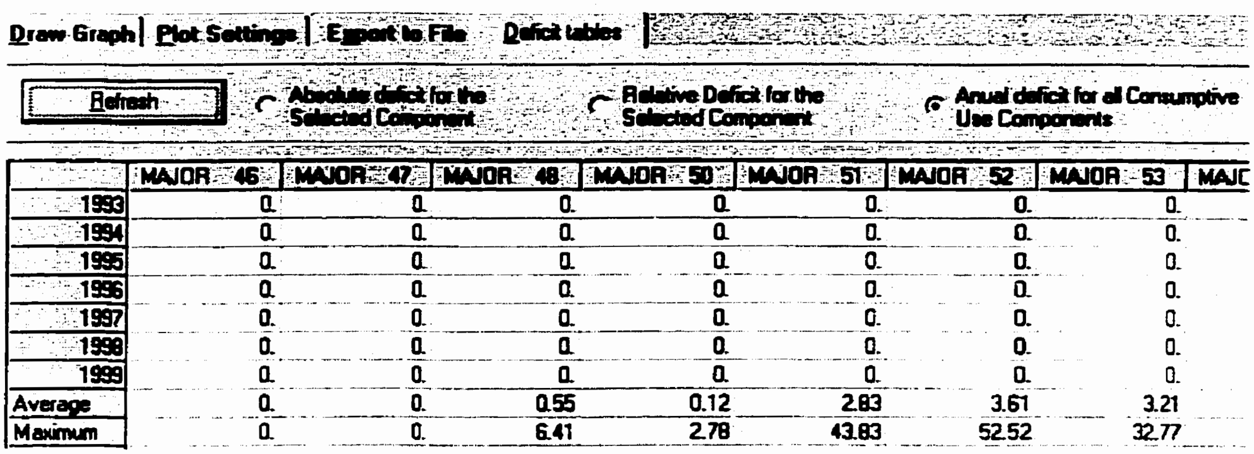
T number of simulated time intervals in a year

Refresh | Absolute deficit for the Selected Component | Relative Deficit for the Selected Component | Anual deficit for all Consumptive Use Components

Year	25	26	27	28	29	30	31	32	33
1980	50.90	74.28	80.90	66.95	0.00	0.00	4.30	0.00	0.00
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.00	0.00	22.46	34.74	58.96	31.31	55.94
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	2.18	3.54	5.3	4.7	3.07	1.99	3.24	1.39	0.78
Max	50.9	74.28	80.9	66.95	65.14	34.74	71.04	31.31	55.94

Figure B.27 Relative deficit table

This table also has each row dedicated to a year, however the columns contain component numbers. The Plotsim program automatically includes all consumptive use components (irrigations and major withdrawals) into an annual deficit table, shown in Figure B.28.



	MAJOR 46	MAJOR 47	MAJOR 48	MAJOR 50	MAJOR 51	MAJOR 52	MAJOR 53	MAJC
1993	0.	0.	0.	0.	0.	0.	0.	
1994	0.	0.	0.	0.	0.	0.	0.	
1995	0.	0.	0.	0.	0.	0.	0.	
1996	0.	0.	0.	0.	0.	0.	0.	
1997	0.	0.	0.	0.	0.	0.	0.	
1998	0.	0.	0.	0.	0.	0.	0.	
1999	0.	0.	0.	0.	0.	0.	0.	
Average	0.	0.	0.55	0.12	2.83	3.61	3.21	
Maximum	0.	0.	6.41	2.78	43.83	52.52	32.77	

Figure B.28 Annual deficit table

APPENDIX C

DESCRIPTION OF THE SCFBUILDER PROGRAM

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C PROGRAM SCFBUILDER

C.1 Introduction

The Simulation Control File (SCF) is the most complex WRMM input data file. As mentioned earlier in Section 3.8.2, the SCF file is divided into six thematic subsections. Of those, the physical system ($PHYSYS) and the penalty system ($PENSYS) subsections are the most complex and by far the largest.

Traditionally, the SCF has been modified using various text editors. This used to cause frustration to new users who were not used to the SCF format, due to accidentally entering illegal characters such as tabs, or moving digits (or the decimal point) by one or more fields to the right or the left, all of which could cause the WRMM to crash with often vague error messages. As documented later in this chapter, the SCF format is unique for each SCF subsection and for each component. Mastering the SCF format is usually the first obstacle in developing expertise in the use of the WRMM.

The other difficulty related to the use of a plain text editor for modifying the SCF is that when editing pairs of points representing a curve (i.e. volume vs elevation or outflow vs elevation) the user is unaware of the actual shape of the curve. Moving the decimal point to the right by one field may give ten times more volume to the reservoir, thus seriously affecting simulation results that would certainly look different than in earlier trial runs. These kinds of errors may be difficult for the inexperienced users to detect. Being able to look at the shape of each curve, or the shape of operating zones while editing their values is a useful feature.

The SCFBuilder program was developed with a philosophy of providing a hybrid of the old text editing with the new graphical editing capabilities available in Visual Basic 6. For some SCF sub-files the old text editing is more than sufficient and it was retained as such within

SCFBuilder. However, for the $PHYSYS and $PENSYS subsections users are given a choice of either text editing or graphical editing.

In addition to graphical editing of the two SCF subsections, the SCFBuilder also provides other useful features:

a) checking the SCF file consistency using the *Statistics* option allows users to detect errors early and correct them;

b) the use of the *Connectivity* option allows users to check the connectivity of components visually for any SCF file that has been read into SCFBuilder;

c) saving an SCF file that has been edited graphically with the SCFBuilder ensures that all lines of the $PHYSYS and $PENSYS subsections are saved in correct format, since SCFBuilder was programmed to save the edited values in proper fields; and;

d) SCFBuilder can be run in parallel to the GIS_interface.mbx program which allows users to select components from the schematic layer visually.

As in the case of the Plotsim program, SCFBuilder can also be used on its own. The GIS link is only one of the program options. The component selection to be edited by the SCFBuilder is done in the same way for both SCFBuilder and the Plotsim program, as described in Appendix A, Section 5.

This Appendix starts by describing the SCF format first. This is followed by description of the SCFBuilder main menu and all of its options in secondary menus. It is felt that understanding the SCF format especially as it pertains to the $PHYSYS and $PENSYS subsections provides a good basis for appreciating the functionality of SCFBuilder.

C.2 Brief Description of the SCF Format

In the WRMM manual the SCF format is covered in detail for each line in the file. The input data file description is a document in itself, of about 60 pages. The purpose is not to copy that document here, but rather to explain the overall concept and to point out the complexity of representing the diverse data needed for running the WRMM. However, a detailed SCF format description has been provided as a separate help file as part of this project, and it can be accessed via the Help pulldown in the main menu, as shown in Figure C.1, obtained by starting SCFBuilder and clicking once on the Help selection.

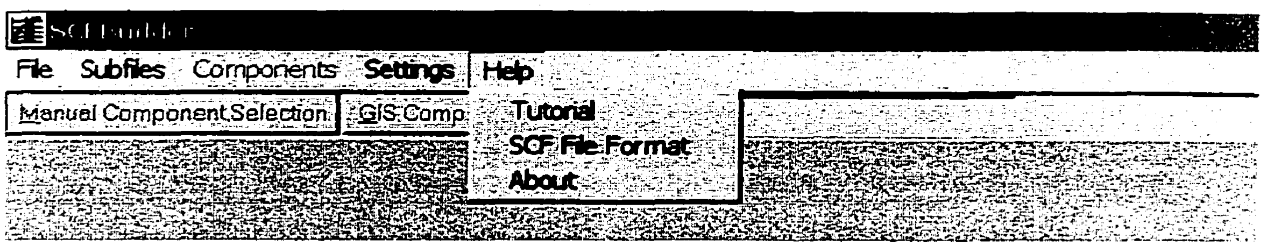

Figure C.1 The SCFBuilder main menu with the *Help* options

The help file was written using the VB Helpwriter software. There are two help files (*Tutorial* and the *SCF File Format*) and one message box appears when the *About* option is selected to provide some basic information, such as the program origin and version. Both help files are discussed in more detail later in this Appendix.

In a way similar to the Plotsim program, the File selection pull down menu allows the user to select which SCF file to open. It has three options, as shown in Figure C.2.

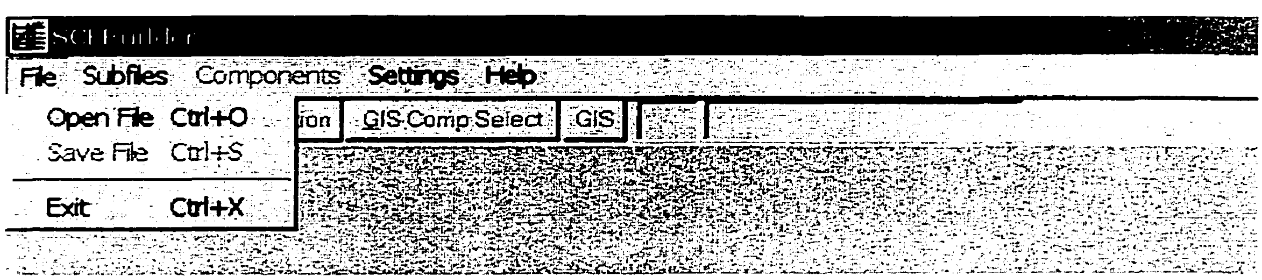

Figure C.2 File selection and its options

Once the *Open File* option has been selected, users are prompted to select which file to open using the standard Windows dialogue box (shown earlier in Figure B.3).

The selection *Subfiles* pull-down allows the user to edit any part of the SCF file using a simple editor built into SCFBuilder. Although the $PHYSYS and $PENSYS subsections can also be edited this way, that practice should be avoided and they should be edited using the graphical editing capabilities of SCFBuilder which are explained later in this Appendix. Figure C.3 shows the options available when the *Subsections* selection is activated in the main menu.

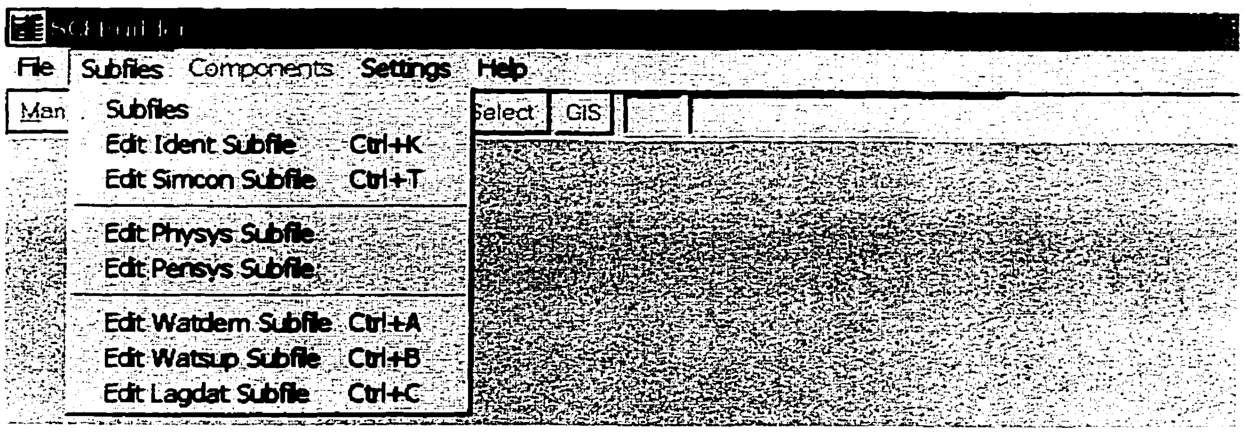

Figure C.3 Options available under the *Subsections* selection

There are two ways to approach each SCF subsection -- by using the *Subfile* option available from the above menu, or by selecting any of the individual subsections from the above menu using the *Edit [name] Subfile* option. Both approaches take the user into a text editing mode, where each subsection is placed on an individual tab form. This was done for two reasons:

a) The subsections $IDENT, $SIMCON and to a large extent $WATDEM and $WATSUP cannot benefit from graphical editing, since there are no curves or other time dependent functions included in their data; and,

b) many WRMM users have been using text editors to modify the SCF for a long time so they would be likely resort to the use of their old text editors if a similar option is not provided in SCFBuilder.

The text editor capability included in SCFBuilder cannot compete with commercial text editors. The main strength of the program is its graphical editing, which is restricted to two subsections ($PHYSYS and $PENSYS).

C.2.1 The $IDENT Subsection

When users click on the Subfile pulldown, the screen provides a form depicted in Figure C.4.

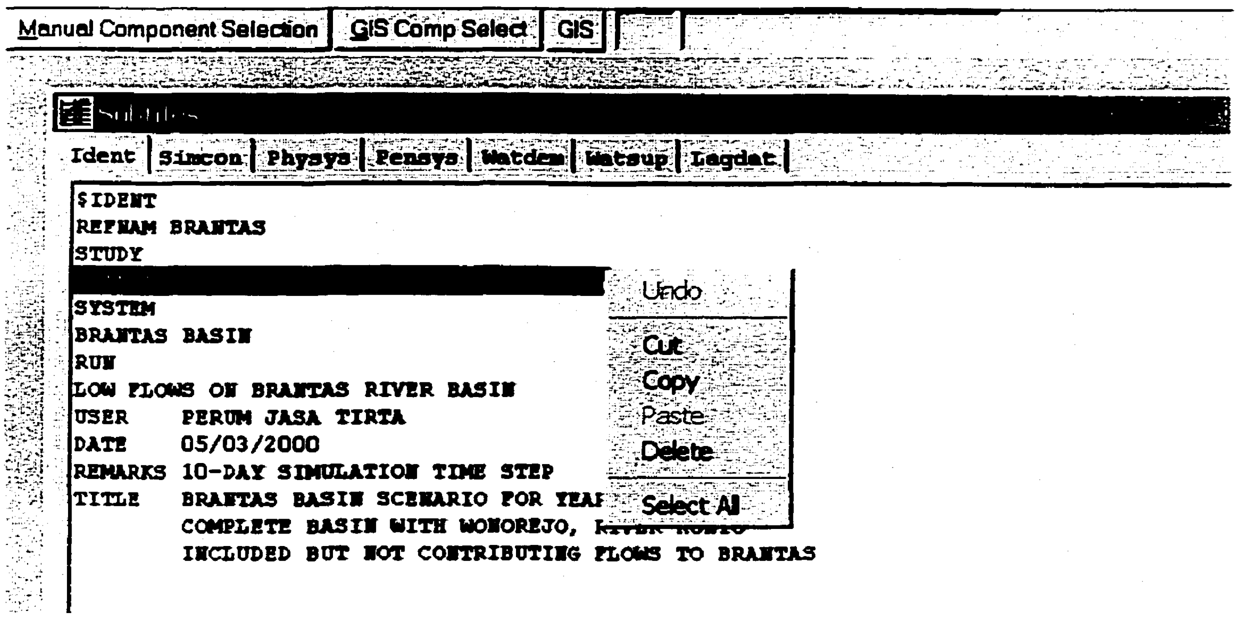

Figure C.4 The layout of the *Subsections* option

One line has been highlighted in Figure C.4 using the standard click and drag of the mouse pointer over the characters (one or more lines can be selected this way). Following the selection, a right mouse button click provides the pop-up menu shown in Figure C.4 with choices to *Cut* or *Copy* to the clipboard, or to *Delete* the selected line. Also, keyboard cursor keys can be used to position the cursor to any location, and insert or delete keys located on the keyboard will work as with any other text editor. The bottom bar of the Subsections tab form has a numeral on each 10^{th} field to allow users to determine in which column the cursor is located at any given time. Figure C.4 provides the all 14 lines of $IDENT subfile. The help file named the *SCF File Format* provides descriptions for each underlined character in the file. Figure C.5 shows its layout and Figure C.6 shows what happens if a user clicks on the first underlined word ($IDENT) in the help file. Each underlined word invokes a

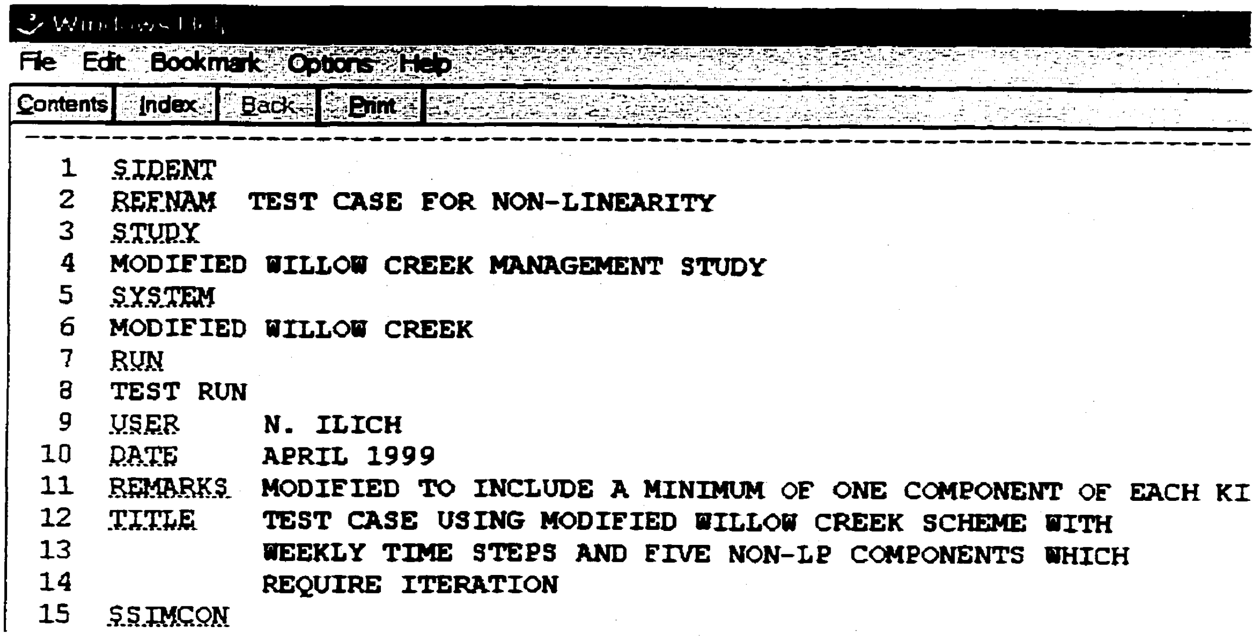

Figure C.5 SCF Format help file

paragraph explaining its purpose and format. A plot of a small SCF with components from Alberta is used as a sample and is included at the end of the help file, giving users an on-line SCF format documentation. Note that each line in the help file is numbered. This was done to ease the explanation contained within the help file. The $IDENT subsection always has 14 lines, and the underlined words in it must be present in the file exactly as shown. The rest of the information provided in it is ignored by the WRMM, it is only of interest to the user. Clicking on any underlined word in the help file (i.e. the hyper word) provides additional information, as shown in Figure C.6 where the $IDENT word has been clicked.

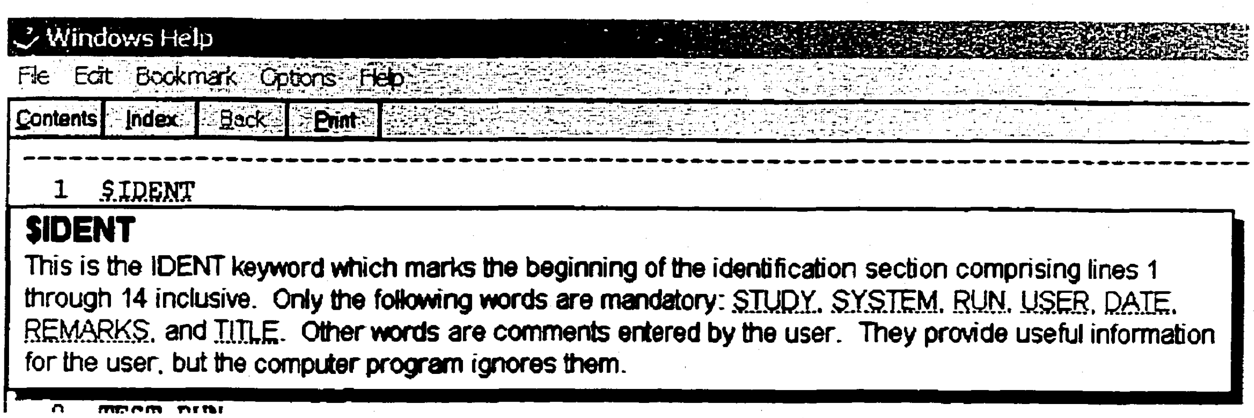

Figure C.6 Help file documentation on $IDENT keyword

C.2.2 The $SIMCON Subsection

Similar to $IDENT subsection, the Simulation Control ($SIMCON) subsection is also short. It contains some basic information about the number of time intervals, their length in days, the starting year for simulation and the number of simulated years. It also contains the OUTNODES and OUTLINKS keywords with a list of components of type "node" and "link" which are selected to appear in the OUTSIM and OUTID files following a WRMM run. Figure C.7 shows the contents of the $SIMCON subsection included in the sample SCF which was used as a sample to build the help file. The mandatory cards are INTRVLS, CYCLES and START. Other lines are optional. Lines APPTPER and ADJINT are only needed if there is at least one apportionment agreement included in the schematic. Lines OUTNODES and OUTLINKS are not mandatory but they are frequently used. If they are not specified the WRMM creates a voluminous output which includes all components in the schematic. Line OUTEVAP specifies an output option to print reservoir net evaporation. Clicking on any underlined word provides an explanation of its format and purpose.

Windows Help

File Edit Bookmark Options Help

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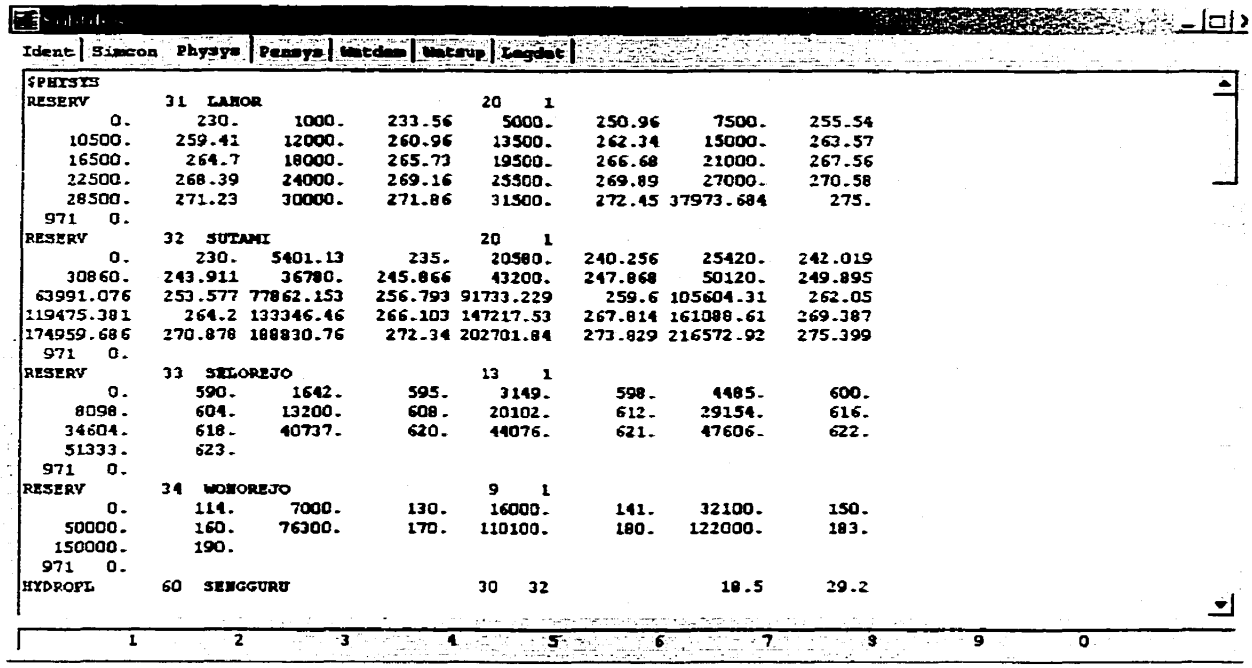
```
$SIMCON
INTRVLS          52    52
    7     7     7     7     7     7     7     7     7     7     7     7     7
    7     7     7     7     7     7     7     7     7     7     7     7     7
    7     7     7     7     7     7     7     7     7     7     7     7     7
    7     7     7     8
CYCLES            3
APPTPER           1
   52
ADJINT            1
   52
START             1  1912
OUTNODES          4
  212   201   353   500
OUTLINKS         13
  601    66    67    68    69   101   113   114   115   213   313   400   401
OUTEVAP
```

Figure C.7 Sample $SIMCON subfile

C.2.3 The $PHYSYS Subsection

The length of this section depends on the size of the modelling schematic. The larger the schematic, the larger the physical system subsection. All physical information of interest to the simulation is located in this subsection, including the network connectivity, reservoir storage and canal flow capacities, evaporation and precipitation stations for each reservoir and their weight factors, etc.. Figure C.8 shows the layout of the *Edit Physys* subsection form available as an option in the Subfile pulldown selection from the main menu.



```
Ident | Simcon  Physys | Pensys | Watdem | Watsup | Legdat |
$PHYSYS
RESERV       31  LAHOR                         20     1
        0.       230.      1000.     233.56      5000.     250.96      7500.     255.54
    10500.     259.41     12000.     260.96     13500.     262.34     15000.     263.57
    16500.      264.7     18000.     265.73     19500.     266.68     21000.     267.56
    22500.     268.39     24000.     269.16     25500.     269.89     27000.     270.58
    28500.     271.23     30000.     271.86     31500.     272.45  37973.684      275.
  971    0.
RESERV       32  SUTAMI                        20     1
        0.       230.   5401.13       235.     20580.    240.256     25420.    242.019
    30860.    243.911    36780.    245.866     43200.    247.868     50120.    249.895
 63991.076    253.577  77862.153    256.793  91733.229      259.6  105604.31    262.05
119475.381      264.2  133346.46    266.103  147217.53    267.814  161088.61   269.387
174959.686    270.878  188830.76     272.34  202701.84    273.829  216572.92   275.399
  971    0.
RESERV       33  SELOREJO                      13     1
        0.       590.      1642.       595.      3149.       598.      4485.      600.
     8098.       604.     13200.       608.     20102.       612.     29154.      616.
    34604.       618.     40737.       620.     44076.       621.     47606.      622.
    51333.       623.
  971    0.
RESERV       34  WONOREJO                       9     1
        0.       114.      7000.       130.     16000.       141.     32100.      150.
    50000.       160.     76300.       170.    110100.       180.    122000.      183.
   150000.       190.
  971    0.
HYDROPL      60  SENGGURU                      30    32                  18.5      29.2
           1          2          3          4          5          6          7          8          9          0
```

Figure C.8 Sample $PHYSYS subfile

Users are not encouraged to edit the $PHYSYS subsection using the text editing capabilities of SCFBuilder. It is easier and safer to use the graphical editing capabilities. Also, this rids the user of the need to learn the actual format which is different for each type of component. The graphical interface editor ensures that edited information is saved in the proper format, the users don't need to know anything about that format. However, the format information is still provided in the help file for those who wish to master it. Figure C.9 shows a typical help file response to a line in the $PHYSYS subsection.

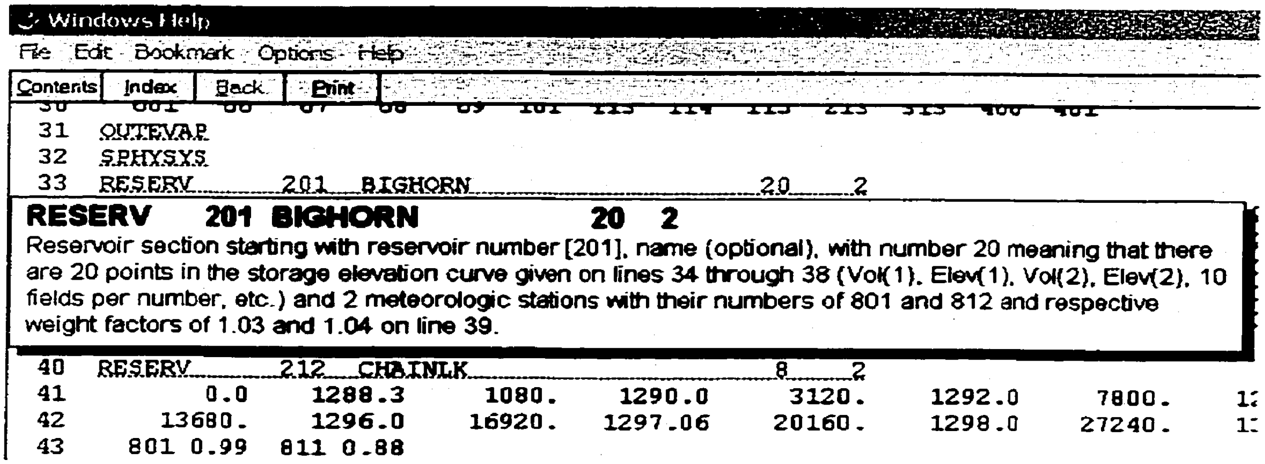


Figure C.9 $PHYSYS section within the help file

In the above example the storage capacity curves are given as pairs of points containing the volume and elevation coordinates. The storage capacity curve is expected to have a certain shape, while this is not obvious by looking at the points alone. The graphical editing capability of SCFBuilder shows the capacity curve both in tabular form and as a plot. Any time a tabular value is changed, the plot is automatically updated and users can visually check its shape.

C.2.4 The $PENSYS Subsection

This subsection contains the information required to plot Figure 3.1 and Figure 3.2 for all components in a given schematic. Zone sizes can vary with time for reservoirs, irrigation blocks and natural channels. Other components do not vary zone sizes in the $PENSYS subsection, but the variation is still provided by a different level of ideal demand for each time interval provided in the $WATDEM subsection.

The concept of group policy has been introduced to reduce the size of the $PENSYS subfile and also to ease its maintenance and updates. Using this concept a group of components of the same type and similar priority is placed into a group. Their penalties are still not identical, they differ by a small amount of 0.1 according to their rank in the group. The first component in the group has the lowest penalty, while the last one has the highest and all others in between are spread linearly between them. In this way the zone sizes and penalties are specified only for a group, and a list of components belonging to a group is given.

Figure C.10 shows the part of the $PENSYS subsection which describes the zone shapes as depicted in Figure 3.2. In this case there are 36 points in time when the zones are specified.

```
Ident | Simcon | Physys | Pensys | Watdem | Watsup | Lagdat |
$PENSYS
RESERV    1     SUTAMI               3    0    5
          5.         6.        7.        8.       800.
   32   SUTAMI       36
    1      272.5       272.      270.82     268.63      264.
   10      272.5     272.14      271.16      269.6    267.03
   20      272.5     272.19      271.42     270.28    268.94
   31      272.5     272.22      271.62     270.87    269.97
   41      272.5     272.27      271.83     271.23    270.72
   51      272.5     272.35        272.     271.62     271.2
   59      272.5     272.37      272.16     271.96    271.68
   69      272.5     272.42      272.32     272.27     272.1
   79      272.5      272.5       272.5      272.5     272.3
   90      272.5      272.5       272.5      272.5     272.5
  100      272.5      272.5       272.5      272.5     272.5
  110      272.5      272.5       272.5      272.5     272.5
  120      272.5      272.5       272.5      272.5    272.14
  130      272.5      272.5       272.5     272.29    271.83
  140      272.5      272.5       272.5     272.05    271.44
  151      272.5      272.5      272.29     271.68    270.92
  161      272.5      272.5      272.04     271.17    270.21
  171      272.5     272.35      271.62     270.66    269.43
  181      272.5     272.04      271.18     270.09     268.7
  191      272.5     271.67      270.64     269.42    267.85
  201      272.5     271.13      269.94     268.68    266.81
  212      272.5     270.48      269.17     267.82    265.85
  222      272.5     269.76      268.34     266.87    264.77

         1        2        3        4        5        6        7        8
```

Figure C.10 Reservoir zones in the $PENSYS subsection

The first column lists cumulative days in the year as the time coordinate while the next five columns list the zone elevation for a given point in time. The graphical editor that will be introduced later in this Appendix allows users to view the plot of all zones in time and to reshape them using the click and drag mouse action.

C.2.5 The $WATDEM Subsection

All water requirements are listed in this subsection. This includes irrigation, municipal and industrial, hydro power and ideal target flows for natural channels if they vary from year to year. Usually, water requirements vary from one time interval to another. However, sometimes they are cyclical, meaning that although there is seasonal variation, there is little or no variation from one year to another (e.g. municipal demand). An important distinction is made between such water demands and those that may vary significantly from year to year (e.g. irrigation). The actual water requirements for each simulated time step can be entered in the $WATDEM subsection only if they remain the same from year to year. For demands that vary annually, users must provide the HBDF reference name in the $WATDEM subsection instead of the numeric values. The WRMM then locates the multi year time series of demands in the HBDF file under the same reference name provided in the $WATDEM subsection. Because most demands do vary from year to year, the $WATDEM subsection may not be very large since each component that has the HBDF reference name occupies only one line. Figure C.11 shows the $WATDEM subsection in the SCF help file.

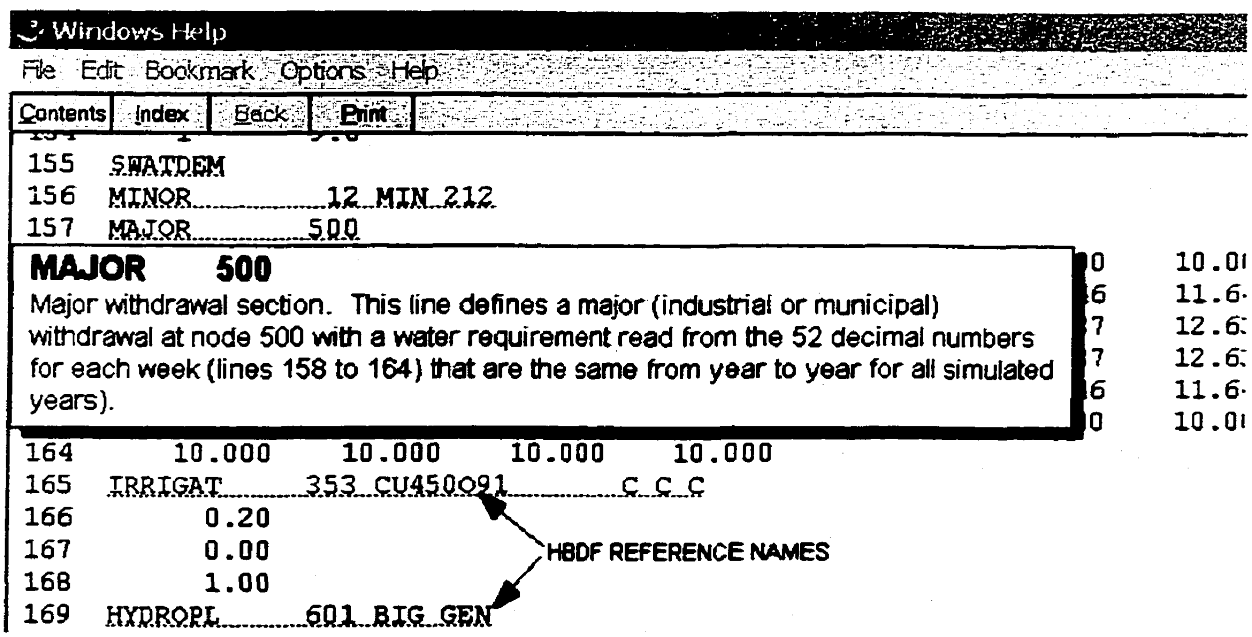


Figure C.11 Sample $WATDEM subfile

C.2.6 The $WATSUP Subsection

The water supply ($WATSUP) subsection provides all information related to the available water supply. This includes the available runoff, along with the initial reservoir storage at the beginning of the simulated period. Evaporation and precipitation on reservoirs is also specified in this subsection. Like the $WATDEM subsection, the $WATSUP subsection can have many HBDF reference name links. Figure C.12 shows the $WATSUP section of the help file with a detailed explanation obtained by clicking on line 175.

C.3 Graphical Editing

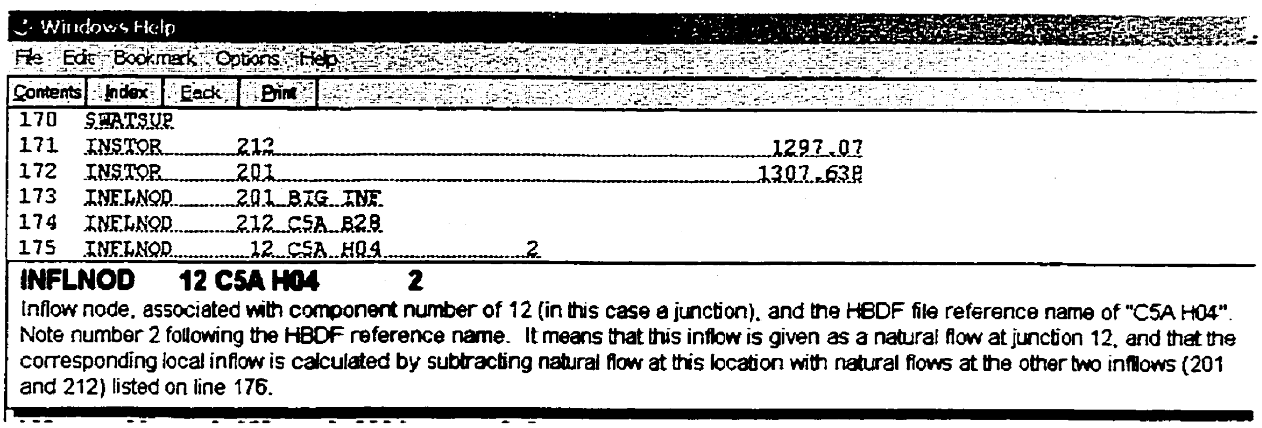


Figure C.12 Sample $WATSUP subsection

To apply graphical editing on an existing component in the SCF, users must first select the component within SCFBuilder. There are two ways of selecting an existing component – manually and by GIS. The manual selection button and the selection window with a list of components found in the SCF are shown in Figure C.13 with the selection pointed at the component RESERV (reservoir) 32. When the list of components is longer than the size of the list box provided in the dialogue window, the program automatically provides the scroll bar shown in Figure C.13. For large SCF files the command search buttons related to

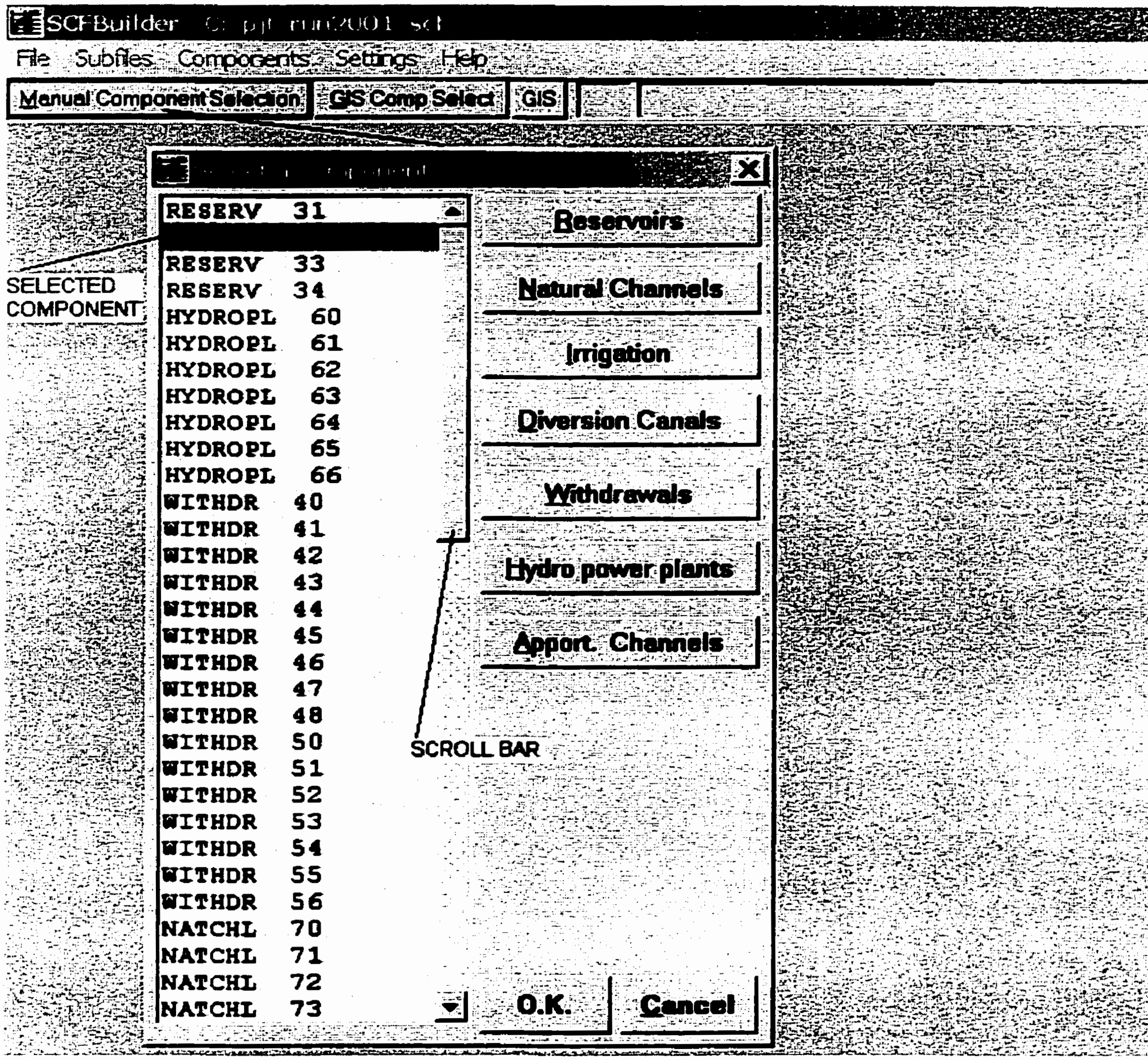


Figure C.13 Manual component selection window

different types of components are shown in the right hand part of the dialogue window. For example, a click on the *Diversion Canals* command button will scroll the list down so that the last diversion canal is displayed as the last component visible in the list in Figure C.13. In addition to using these command buttons, the regular scroll bar feature can also be used to position the list of components as desired. Finally, a single component that will be edited is selected. SCFBuilder is an event driven program and changes are made individually to one component at a time as they are selected.

C.3.1 Graphical Editing of Reservoir Components

Reservoir components are the most complex of all components in the SCF. Reservoirs have a storage capacity curve, a number of operating zones below and above the ideal elevation along with a time variation of each zone, and up to six meteorologic stations associated with the calculation of net evaporation for each time interval. This information is displayed on a single screen, as shown in Figure C.14 (for component reservoir 32 in the example). Clarification of details shown in Figure C.14 are listed below starting from the text boxes on the top menu bar after the 'GIS Comp. Selection' and the 'GIS' command buttons. The number 32 in the text box next to the 'GIS' command button is the component number of the reservoir being edited, while its name found in the SCF is SUTAMI. The check box labelled *Grid* is explained later in this section. The number 20 refers to the number of points in the storage vs elevation curve (the up/down control associated with this box allows users to change the number of points included in this curve). This control does not allow the number of points to exceed 20 or be less than 2, which are the minimum and maximum currently used in the WRMM, thus safeguarding users from entering a number out of range. Finally, the number 1 in the following text box (to the right) is the group policy number to which this reservoir belongs and the word SUTAMI is the name of the group policy (any name could have been used, or if no name option is desired the field could be left blank).

The rest of the screen is divided into two parts. The top part has three forms, entitled *Met Stations*, *Penalty Zones*, and *Volume - Elevation*. The *Met Stations* form starts with a *No:* box identifying the total number of meteorologic (evaporation and precipitation stations) used in calculation of net evaporation for the reservoir. The number of stations used in Figure C.14 is 1, and the station number currently used for reservoir 32 is 971 with a weight factor of zero (which means that this analysis is conducted without taking evaporation into account). Any non-zero weight factor can be used if the data at station 971 are to be taken into account. Typical values of weight factors are close to 1.0 in most instances. Users can change the number of meteorologic stations that are used to calculate net evaporation for the

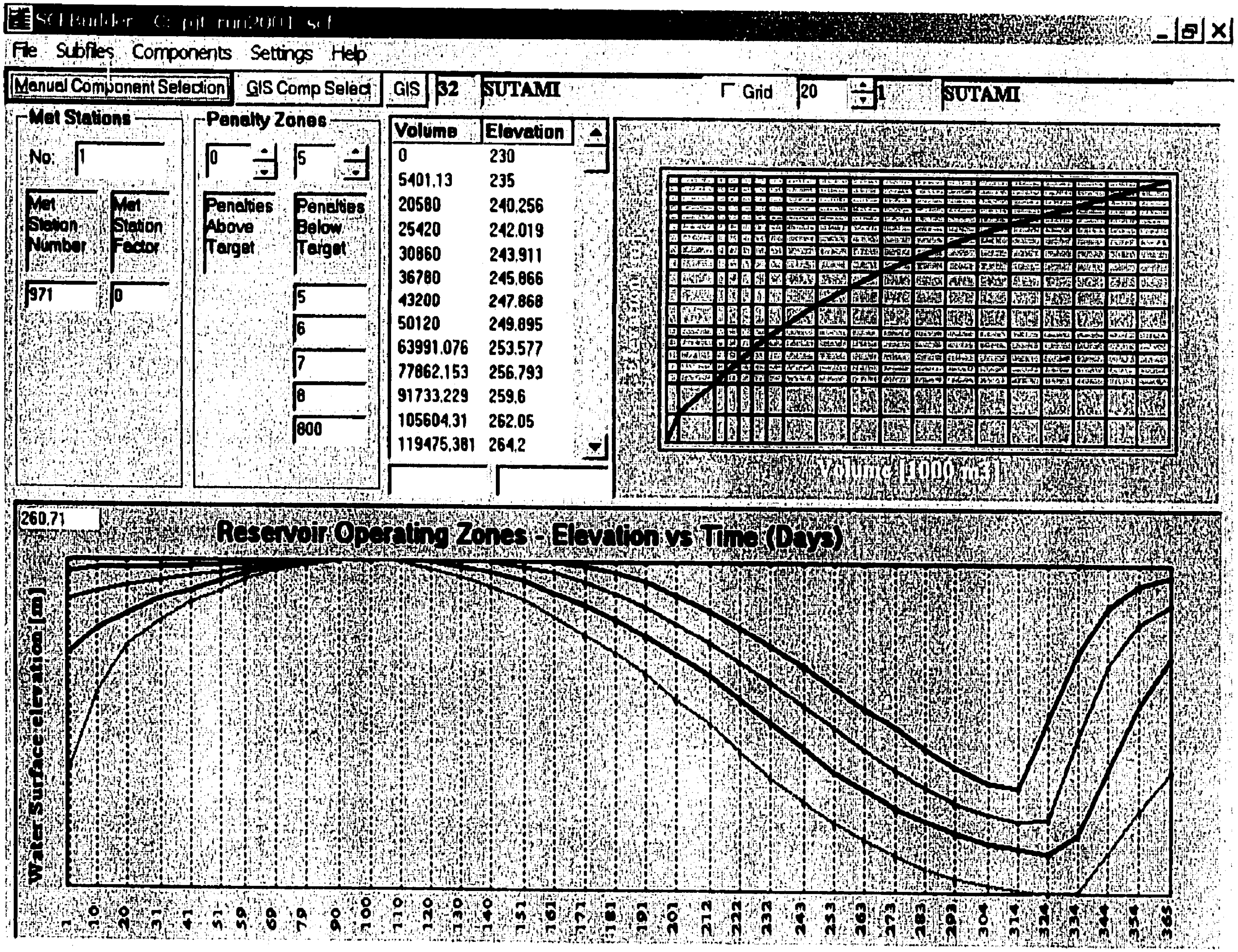


Figure C.14 Graphic editor for reservoir component selected reservoir. This number can be changed to any value between 1 and 6 inclusive, which is immediately followed by a display of additional empty boxes prompting the user for new meteorologic station numbers and their corresponding weight factors, as seen in Figure C.15. Users trying to enter a number higher than 6 or less than 1 into the *No:* box will will be prevented from doing so. This is yet another safeguard from entering data that are out of range. If the user forgets to enter a value in any of the newly added boxes, SCFBuilder will issue a warning prior to saving the SCF file with the new changes.

The next form is entitled *Penalty Zones*. The number of zones found in this SCF is zero above the ideal and five below the ideal. There can be a maximum of 2 zones above the ideal and 5 zones below the ideal. SCFBuilder prevents the user from entering any number higher than 2 for the zones above or higher than 5 for the zones below the ideal. Once the number of the zones has been changed the new added zones are inserted half way between the existing ones, while any removed zones are deleted from the graph and the database immediately. Figure C.15 shows two new zones added above the ideal zone, thus increasing the total number of zones in the graph to seven instead of five as in Figure C.14. Users are prompted to enter penalty values for the new zones. If the penalties are left blank they are considered zeros, which is not desirable since zones with zero penalties have no purpose. Also, the values have to be increasing in the direction of departure from the ideal. Hence for the zones above the ideal the first zone should have lower penalty than the second. Similarly, the zones below the ideal have increasing penalties with the increased distance from the ideal, as seen in Figure C.14 where the penalties are 5, 6, 7, 8 and 800 for zones 1, 2, 3, 4, and 5, respectively.

The *Volume vs. Elevation* table and graph are the last item in the top half of the reservoir edit form. The advantage of seeing the plot of the data is demonstrated in the case of the second point in the series with an elevation equal to 235 m showing a small anomaly in the curve that points to an error in data estimate. There are two ways to correct this, either by double clicking the coordinate 235 in the table and replacing its value with a different one in the dialogue box that appears, or by filling the new value in the blank box at the bottom of the table and clicking on the tabular value that should be replaced. Figure C.15 shows that the value of 235 was corrected to 233.5 with a visible improvement in the shape of the volume vs elevation curve.

The bottom half of the screen is devoted to a plot of zone elevations versus time, where time is in days from 0 to 365. Each zone is represented with a unique colour which can be user defined in the *Settings* option of the top menu bar. The number of zones, as well as the number of points in time when the zones are specified are both user defined.

One of the most important uses of the WRMM is to assist in the effort to determine the best shape of the reservoir operating zones. This is done by a trial and error process, where various zone shapes are specified in the SCF file and the corresponding long term simulation results are evaluated for each trial. The process of converging to the best zone shapes is therefore interactive. The plot describing the reservoir operating zones in Figure C.14 is important to the WRMM operation. As such, it has to be provided with the right features within the SCFBuilder program, as described below.

The horizontal axis in the plot of reservoir zones represents time in days, while the vertical axis represents water surface elevation in metres. There are no numerical labels on the vertical axis, however the white text box at the top of it shows dynamically the value of the vertical coordinate of the mouse pointer location as it is moved within the area of the plot.

The lines representing the operating zones are straight between the two adjacent break points, which are located where the broken vertical grid lines intersect the zone lines. The time step used in this example is 10 or 11 days (except for the last third of February when it is 8 days), so the intervals look approximately the same, but that does not have to be the case. The right mouse button is used to add additional vertical break, while in combination with the SHIFT keyboard button it is used to delete the existing vertical breaks. The break points can

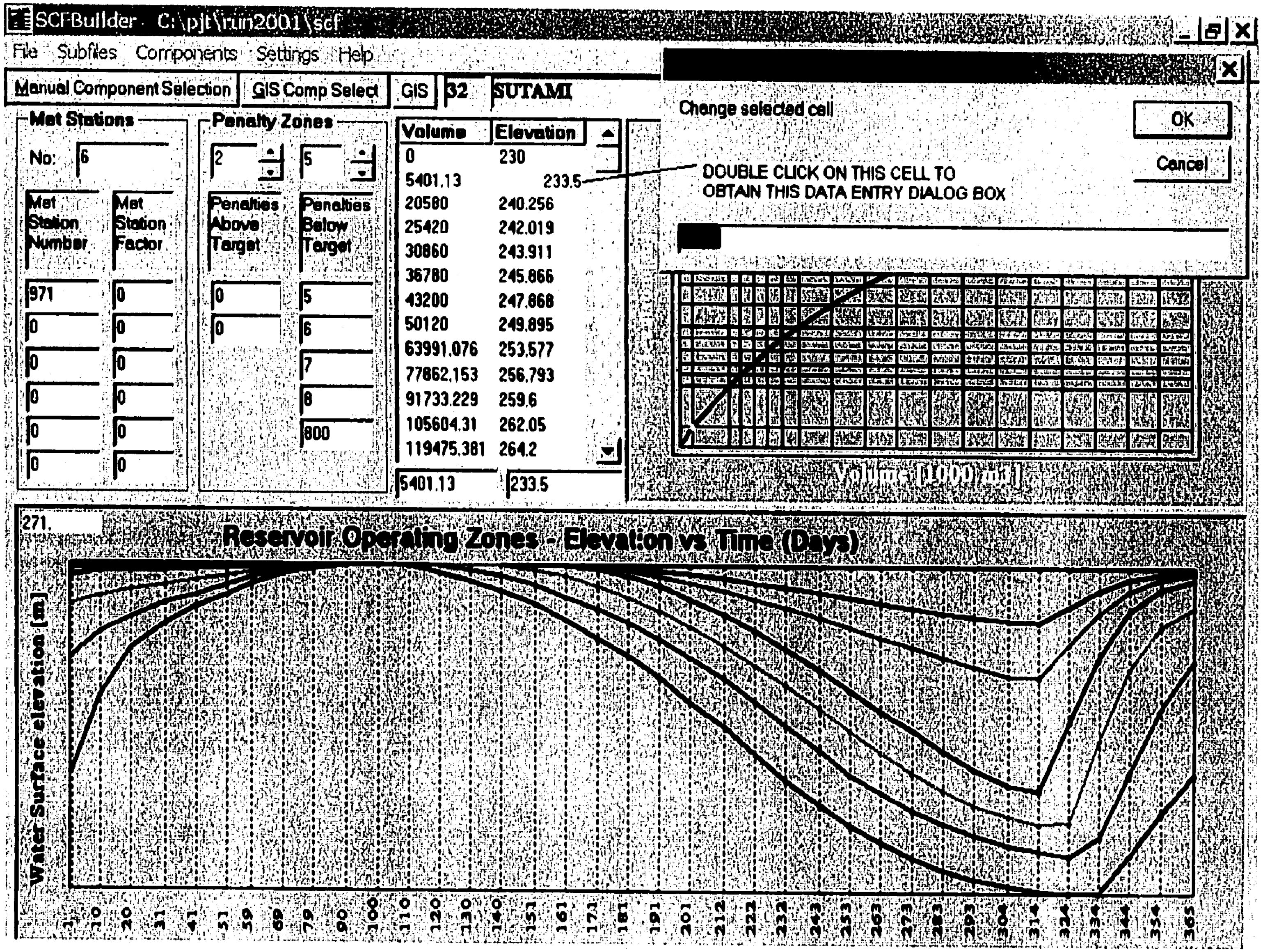


Figure C.15 Modified options in graphic editor for reservoir component be inserted for any day between 1 and 365. When the left mouse button is selected by a click and hold, SCFBuilder selects the closest point to the mouse pointer out of all available breakpoints. The selected point is marked and the user can drag that point up or down along the vertical break line. To demonstrate this process, editing of several zone lines starting from the basic horizontal shape is depicted in the following figures.

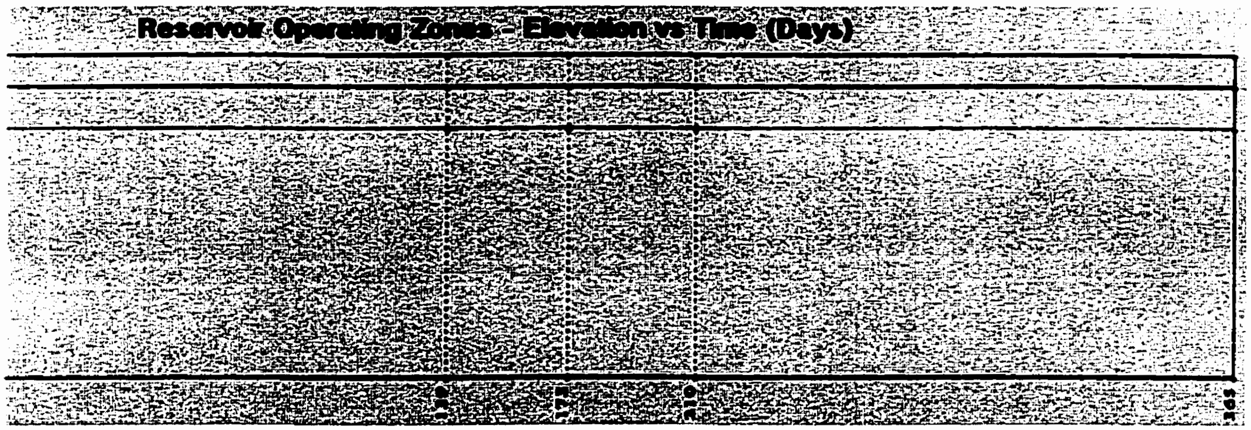


Figure C.16 Horizontal zones

Figure C.16 shows the initial horizontal zones to which three points in time had been added by clicking the right mouse button for days 139, 173 and 210. Each of the vertical break lines can be deleted using the SHIFT-right mouse button combination. Figure C.17 shows how one of the points was selected using click and drag and moved to another location.

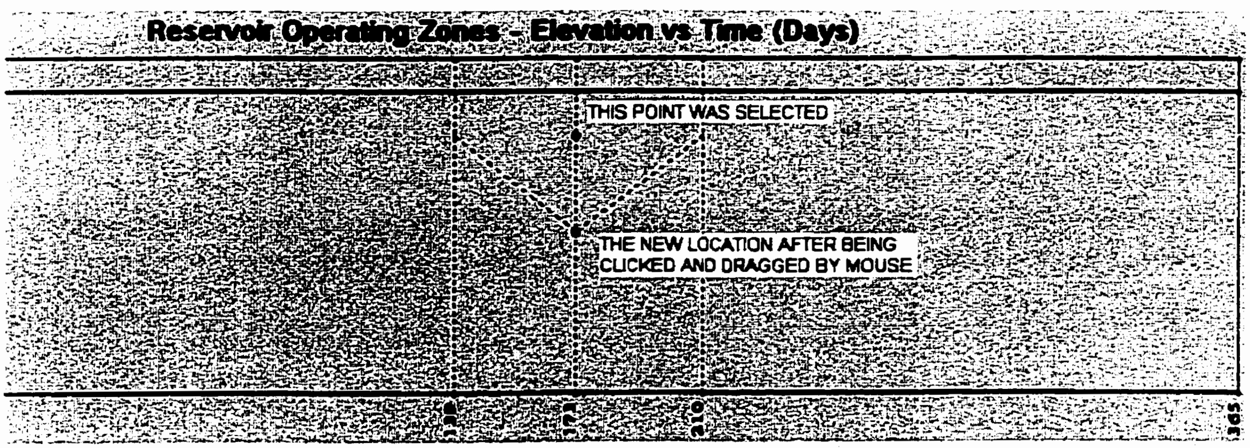


Figure C.17 Demonstration of graphical line editing

The above graph shows a change caused by modifying a single point. Figure C.18 shows the same plot of zones vs time after additional five points have been modified in the same manner. The last time coordinate (day 365) is linked to the first (day 1) such that only day 364 needs to be changed to affect both points on the graph. This is a requirement of the WRMM. Using this technique users can quickly re-shape the zones and re-run the WRMM.

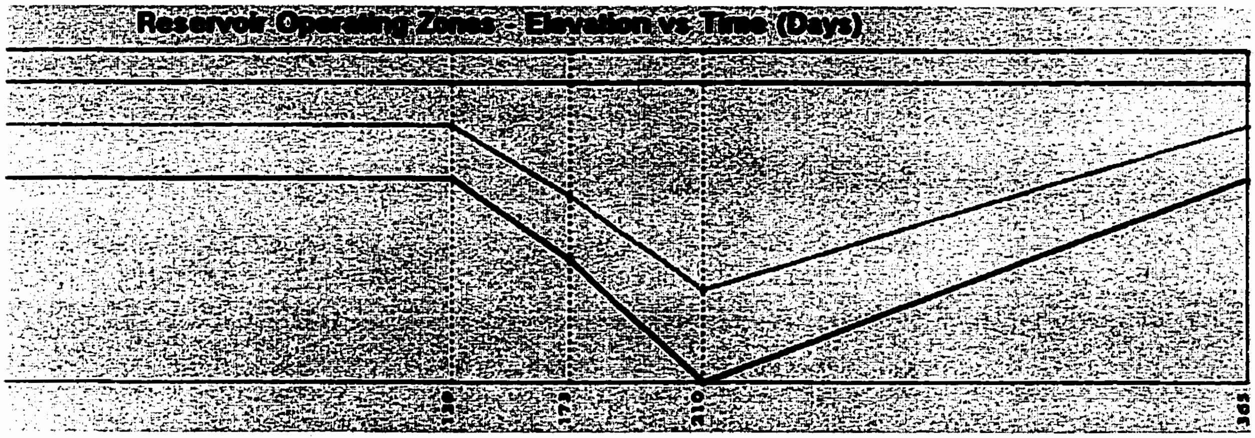
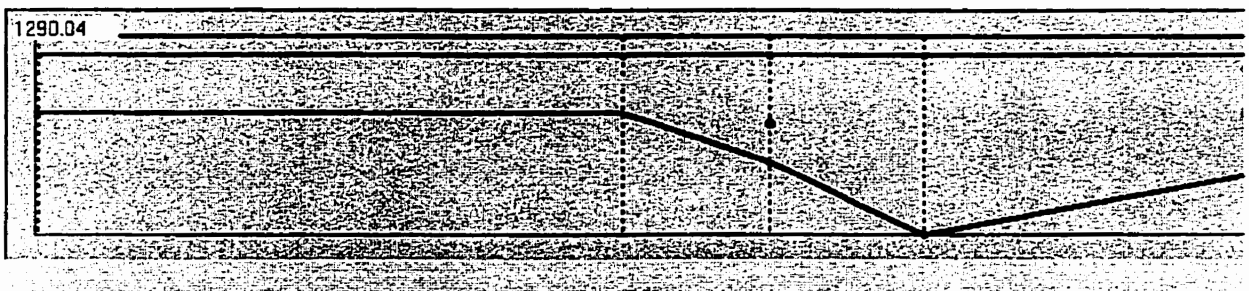


Figure C.18 Sample shaping of the zones

Sometimes it is necessary to introduce the exact value of zone elevation for a specified point in time. This is difficult to do using click and drag. The *Grid* check box on the top menu is used to handle this requirement. Once the grid option is chosen, the screen is split in half between the plot and the tabular values which are displayed as shown in Figure C.19.



	1	139	173	210	365
1	1300	1300	1300	1300	1300
2	1298.91	1298.91	1298.91	1298.91	1298.91
3	1297.47	1297.47	1295.13	1292.02	1297.47
4	1295.7	1295.74	1293.01	1288.97	1295.7

Figure C.19 The grid option shows plotted values in tabular form

Note that the plotted points in time (day 1, 139, 173, 210 and 365) are the same as on the graph in Figure C.18, but they are now displayed as the header in the grid table. Each column of numbers in the table shows the coordinates of the four lines on the plot, starting from top to bottom. The selected point in the plot automatically results in the change of the color of the selected line, while the actual point on the line that represents the selected number in the table is marked with a red square indicator. This is useful for making sure that the right point has been selected. To enter the exact value, users must double click on the selected point to get a data entry dialogue box like that shown in Figure C.20. Any value can

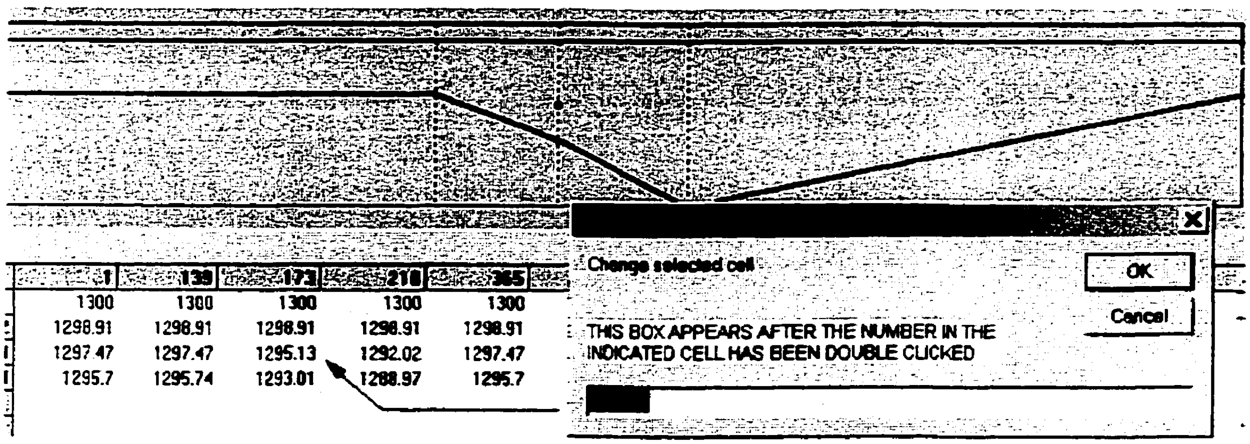


Figure C.20 Dialogue box for entering the exact values

be entered in the dialogue box. After confirming the entered value with the OK button, the new value will be input in the grid table and the plot will be adjusted accordingly.

It is also possible to paste the contents of the entire grid table that had previously been copied to the clipboard for use by another program (e.g. spreadsheet). Although it is envisaged that this option will not be used very often, it does save time required to re-type the numerical values already available in another program. To achieve copy and paste of values from another program (such as Excel or other any spreadsheet) go to the *Settings* selection on the main menu and select the *Copy* option from it. This allows the entry into the grid table of a matrix of numbers already available in some other format.

C.3.2 Graphical Editing of Natural Channel Components

A natural channel is a component of type link, along with diversion canals, return flows, apportionment channels and hydro power plants. All of them require the head and tail node number which are the numbers of the node type components which are connected to the given link component.

In general, each component type requires different information. The graphical editing screens have been designed to allow entry of all information required for the $PHYSYS and $PENSYS subsections. Figure C.21 shows the natural channel graphical editing screen.

Natural (and Diversion) channel components may have a control structure associated with them. The meaning of a control structure refers to a function that determines the upper flow bound. There are two types of control structures, depending on whether the channel flow is limited by a reservoir elevation or by a flow over weir. Figure C.21 shows a case when an upstream node, 212, is a reservoir (which can be verified by editing the control structures from the *Components* selection in the main menu). The curve depicted in the upper right corner of Figure C.21 shows the maximum channel flow as a function of reservoir elevation. This is because the flow in this channel originates from gravitational reservoir releases. This curve can be edited same as the storage capacity curve as was explained in Section C.3.1.

The options in the upper left corner are all self explanatory except for the Y scale check box which merits further attention. A first look at the graph reveals two vertical break points for days 91 and 305, however they seem unnecessary since there appear to be no changes in zones, only two horizontal lines are visible, one almost overlapping the x axis and the other one coinciding with the top of the frame with a flow value of 2000 m^3/s. Once the Y scale check box is selected, users can reduce or enlarge the Y scale on the plot by clicking on the up or down arrow next to the check box. Each click doubles the scale in the indicated direction (i.e. 200% for enlargement or 50% for reduction compared to the initial scale.

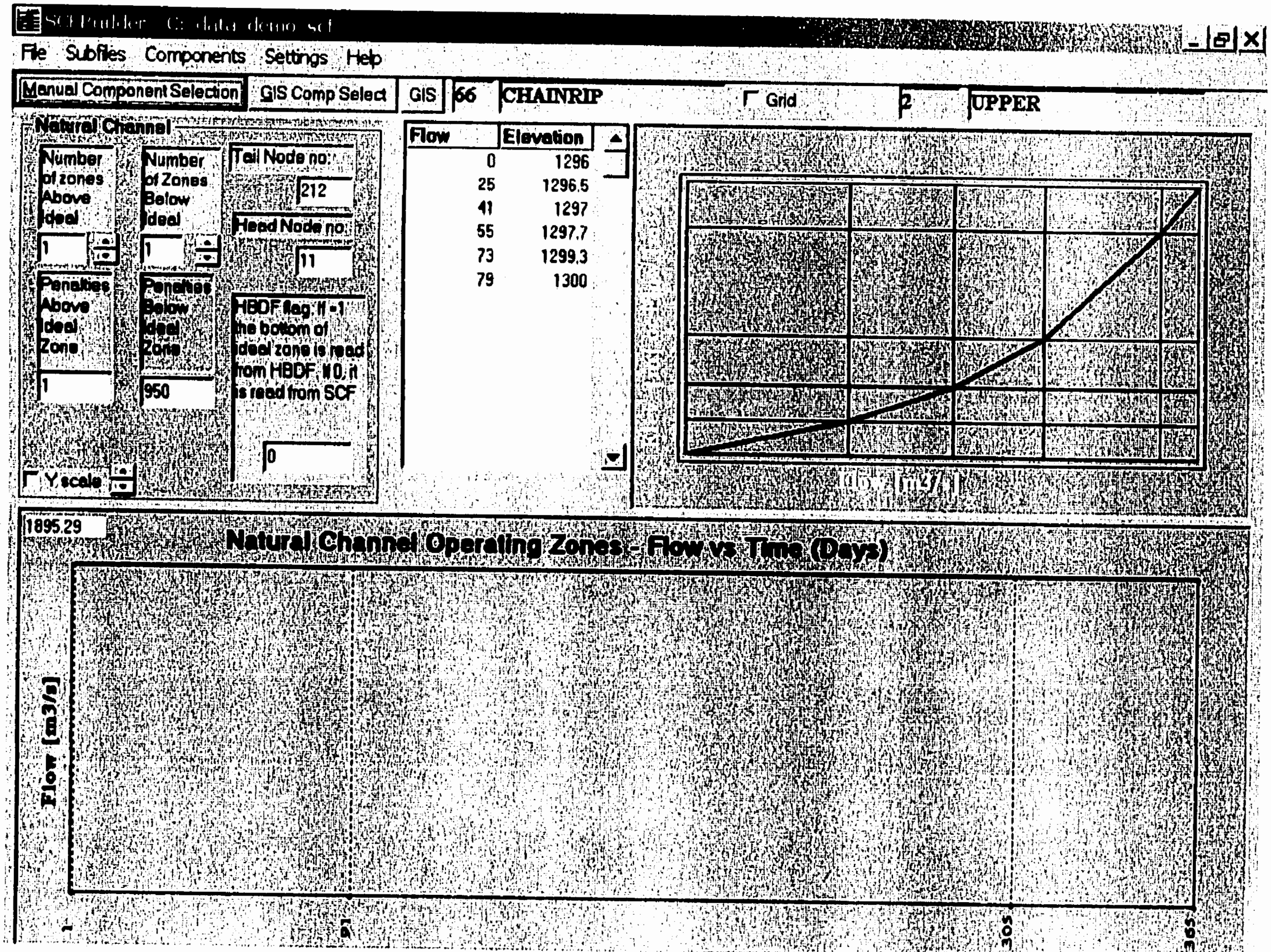


Figure C.21 Natural channel graphical editing screen

Pressing the downward arrow next to the checked box changes the above graph as shown in Figure C.22. The breaks in the zone values are now clearly visible. Note that for all

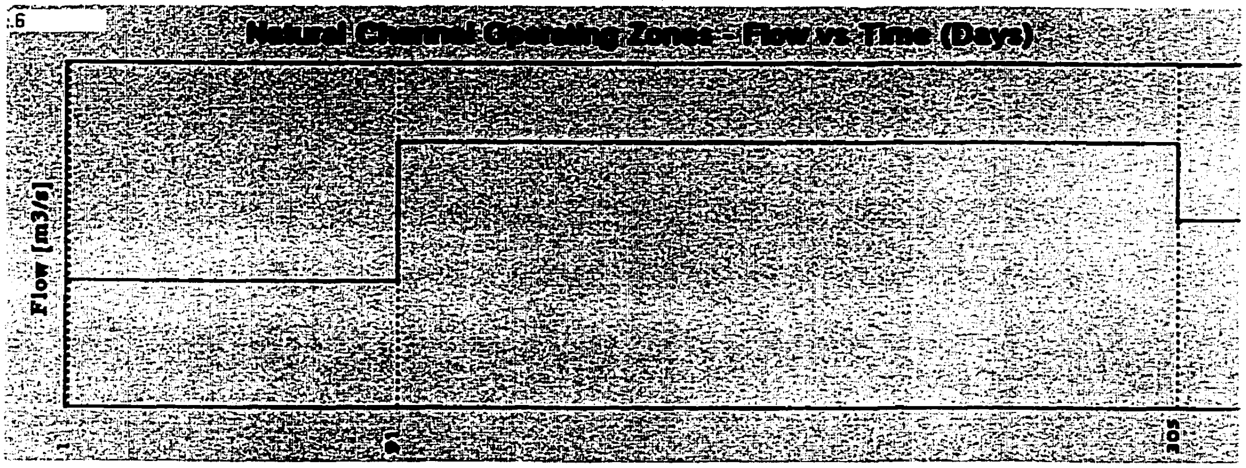


Figure C.22 Y-scale change for natural channels

components other than reservoir the zones are presented in the form of a histogram. Once a flow target is provided for day 91, it remains unchanged until the next flow target is provided for day 305. The bottom zone has a minimum flow requirement of 0.283 m^3/s for days 1 to 91, which is increased to 0.6 m^3/s for days 91 to 305. It now becomes obvious why this zone was not visible in the initial scale. With the bottom of zero and top of the frame set to 2000 m^3/s both values (0.283 and 0.6) were too small to view. This explains why the Y scale change is necessary. This is not as much of an issue for other components, but the natural channel components often have small minimum flow zones while the maximum flow zone must be able to accommodate any historic floods for a given reach.

Users will note that the selection by mouse clicking picks the closest break point on the closest line to the mouse pointer, and automatically selects the entire horizontal segment that starts at the selected point. This is a bit different from reservoirs where only the point is selected and dragged down. Here the dragging brings the entire segment of the horizontal line up or down. These difference are due to the different nature of specifying operating zones. For reservoirs, only the points are selected, the target elevation for the end of each time interval is obtained by reading the elevation of each zone for a point in time corresponding to the end of that time interval. For all other components, the zone bounds are read at the beginning and at the end of a given time interval, and their weighted average is calculated if there are one or more break points within a given time interval.

The point selection algorithm is similar to those used in other programs, although there are minor differences. Usually, mouse point-and-click selection in commercial programs (GIS included) relies on a search for an object within a specified radius drawn around the centre which coincides with the mouse pointer. If no objects are found, nothing is selected. In the case of SCFBuilder the entire plotting area is included in the search for the point closest to the mouse pointer at the time the mouse is clicked. Assuming that all the available break points in a given SCFbuilder plot have coordinates labelled as x_i and y_i, the selected point is found by inspecting all points and finding the one with the minimum distance from the mouse pointer (with given coordinates x_m and y_m), where the distance is calculated using the standard geometric expression:

$$d = \sqrt{(x_m - x_i)^2 + (y_m - y_i)^2} \quad \text{(C.1)}$$

There are a finite number of points on the SCFBuilder zone plotting area, so the selection does not have to be confined to a small area as in other commercial packages.

C.3.3 Graphical Editing of Diversion Canal Components

Diversion canals are unique in that they can have only one zone with its penalty always set to zero. Users can specify a variable upper bound for the only zone, which could represent an opening or a closing policy for the canal. Therefore, insertion of break points is available to diversion canal components, although they are not displayed in Figure C.23 which shows the graphical editing screen for diversion canal component number 145. 'Tool tips' have been used extensively in this program. This feature of Visual Basic allows programmers to insert short valuable information that appears during the program use every time the mouse

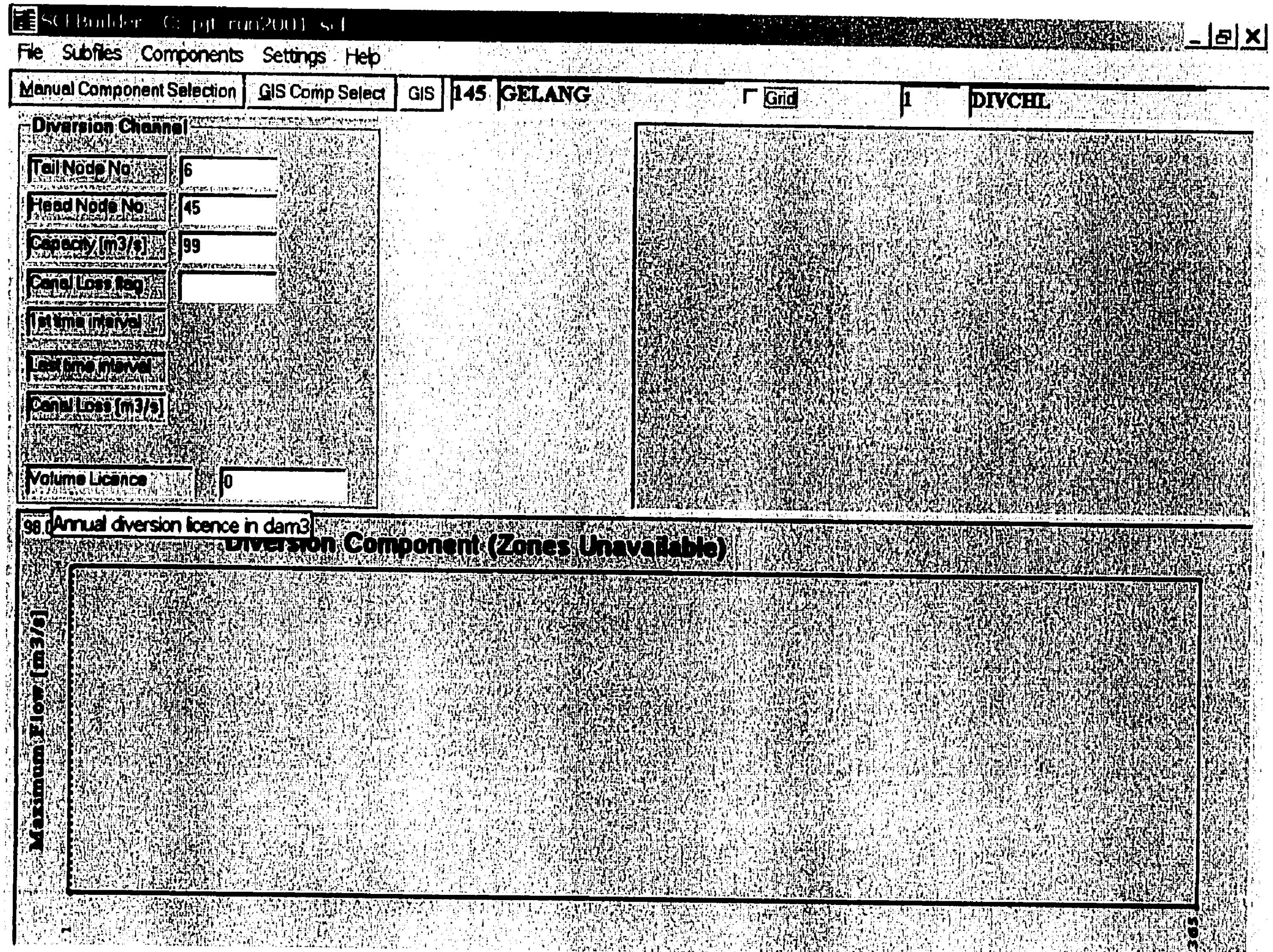


Figure C.23 Graphical editing screen for diversion canal components pointer is moved over the text box or a command button. One example of using the tool box feature is in Figure C.23. The text "annual diversion licence in dam^3" that appears on the left side of the plot is displayed when the mouse pointer is above the *Volume Licence* text box, and its purpose is to give an explanation of what that licence represents. In this case it is the maximum annual volume that can be diverted at this point in decametres cubed (1 dam^3 = 1000 m^3).

The other data item that is unique is the canal loss flag. The tool tip instructs the user to either enter the "CL" characters or to leave it blank if the canal loss is considered zero. Entering the CL flag activates the next three input fields, shown in Figure C.24.

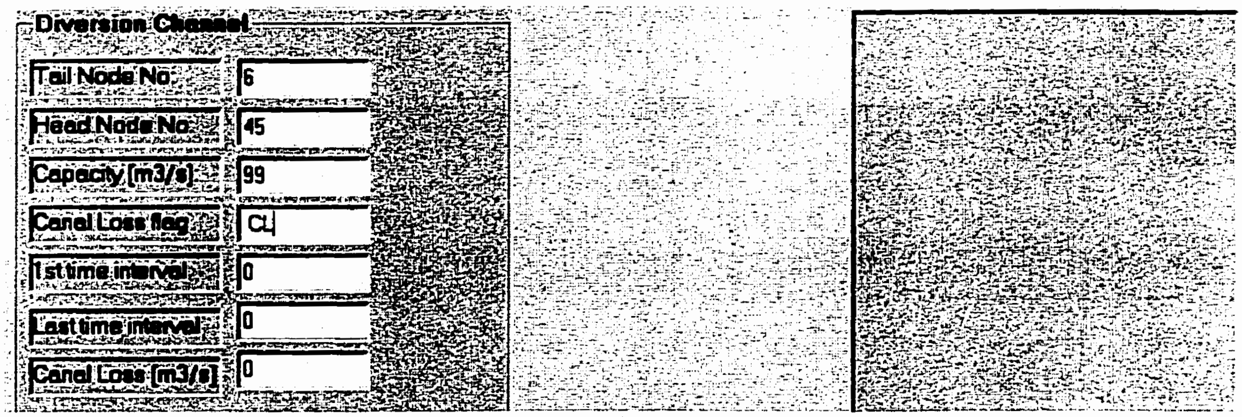


Figure C.24 Activation of canal loss (CL) flag

Note that the remaining right hand side of the graph in Figures C.23 and C.24 are empty. This is because diversion canal 145 is not associated with a control structure mechanism. Control structure is optional, it can be attached but it is not mandatory. When natural or diversion channel components have no control structure, their upper flow limits are read from the highest zone in the $PENSYS subsection, which, in the case of the diversion canal, must be less than or equal to the physical flow capacity of the canal.

C.3.4 Graphical Editing of Hydro Power Components

Hydro power components have many options that fit one screen, as shown in Figure C.25.

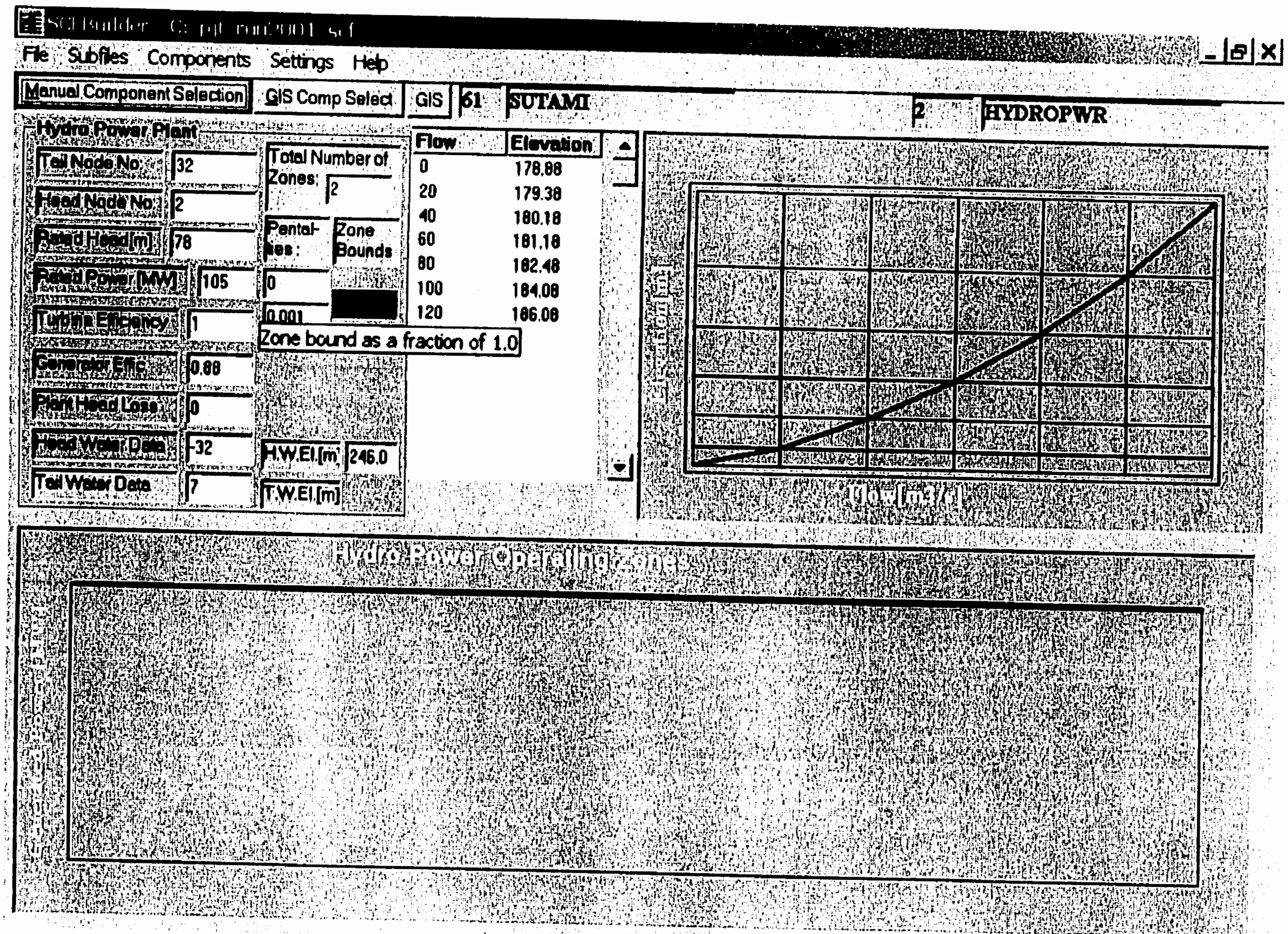


Figure C.25 Graphical editing screen for hydro power components

The tool tip message "zone bound as a fraction of 1" is associated with the value of 1.0 assigned in the box below the "Zone Bounds" text in Figure C.25. Other text boxes are also accompanied by tool tips to simplify their use. In the case of the hydro power component, the zone bounds are specified as a fraction of 1, where 1 refers to 100% of ideal demand found in the $WATDEM subsection, which typically varies for each time interval. A similar concept is used for irrigation, major withdrawals and the apportionment channel component. Each hydro power component includes one mandatory zone above the ideal, for which bounds are set automatically by the model at run time, so no user input is required. However, users must input the penalty for producing power above the target. That is why there are two penalty boxes and only one zone box in Figure C.25.

A graph showing the tail water elevation vs. flow is included in the right upper corner of Figure C.25. This graph includes the stage vs. flow curve at a river section immediately downstream of the turbines. In this case the stage–flow curve was modified to include the hydraulic losses through the plant, which increase exponentially with flow. Hence the curve has lost its familiar shape common to stage–flow curves. There are two more ways of specifying tail water elevation for a hydro power plant : (a) by using a fixed value; or, (b) by using the elevations of the reservoir located downstream of the hydro power plant. If either of these two options is used, the graph in the upper right corner disappears since it is only needed when the stage–flow option is used.

C.3.5 Graphical Editing for Irrigation Components

Figure C.27 shows the graphical editing screen for an irrigation component. A maximum of four deficit zones can be used for this component, as indicated by the four lines in the plot showing zones vs. time. The lines do not have to be horizontal, they can be edited the same way as for the natural channel or diversion canal. However, this is not usual practice, since the time variation of the demand is already given in the $WATDEM subsection. A feature in this screen is related to the introduction of return flow channels. These are associated only

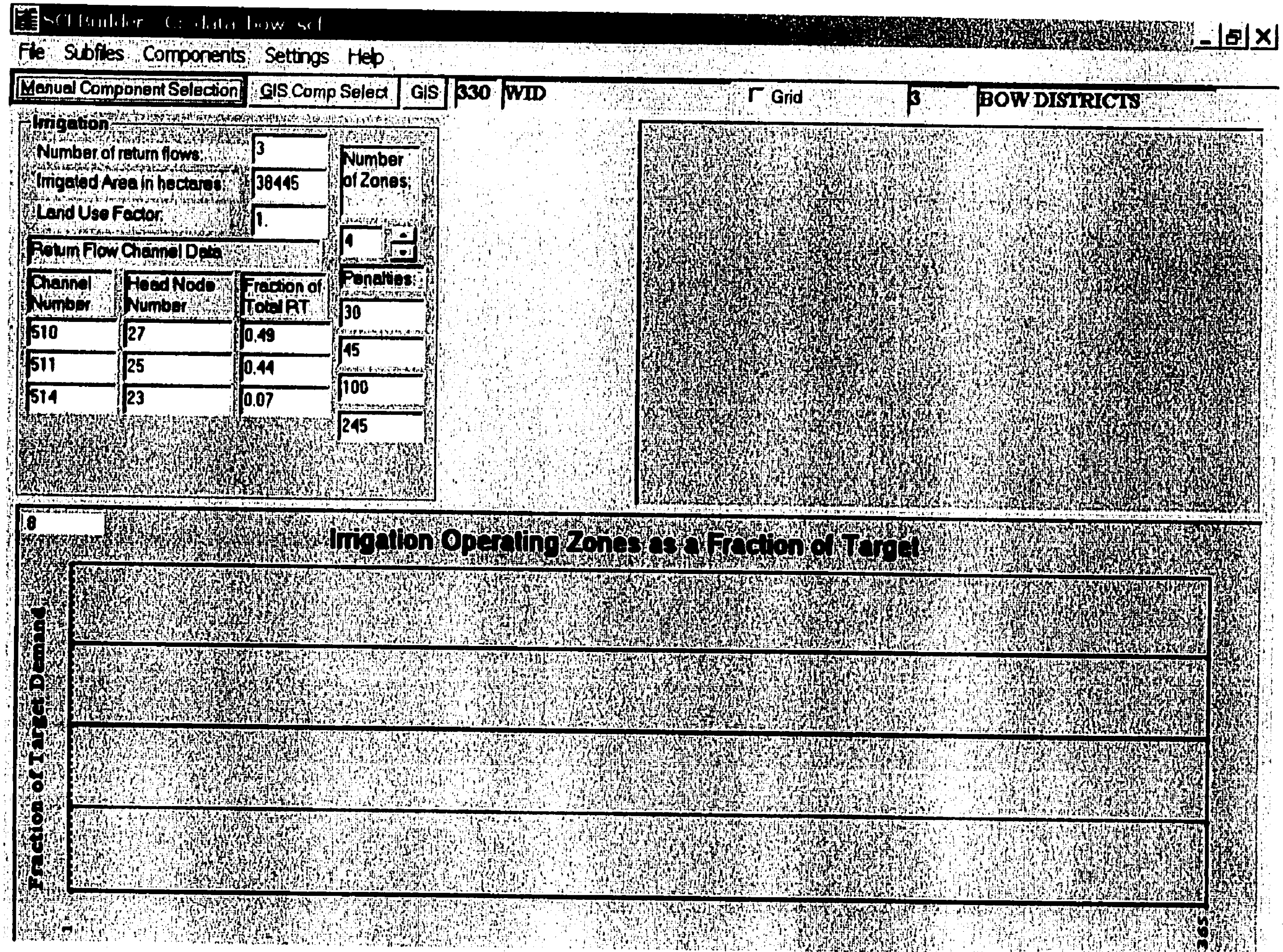


Figure C.26 Graphical editing screen for an irrigation component with irrigation or major withdrawal components. The irrigation component in Figure C.26 has three return flow channels. Their component numbers in the schematic are 510, 511 and 514, and they return flows to nodes 27, 25 and 23, respectively. The sum of all return flow fractions must be equal to 1, i.e. 0.49+0.44+0.07=1, where 1 represents the total return flow from this irrigation component. The total return flow is a percentage of gross diversion into the irrigation block. The actual value of the percentage is found in the $WATDEM subsection. Other items in Figure C.26 are self explanatory. Note that the irrigation water use zones are given as fractions of 1, where 1 represents 100% of the water requirement for a given time interval. Irrigation demands in mm are provided for each time interval in the $WATDEM subsection if they do not change from year to year, or in the HBDF file if they vary from year to year.

C.3.6 Graphical Editing for Major Withdrawal Components

Figure C.27 shows the graphical editing screen for a major withdrawal component. In this case there are two return flow channels and only one water use zone. A penalty of 100 is applied to every 1 m^3/s of deficit in supply. The top of the water use zone is designated with 1.0, which represents 100% of the ideal water demand found in the $WATDEM supply, either as a series of numbers if water requirements do not change from year to year or as a link to the proper section of the HBDF file otherwise. Water requirements for each time interval are given in units of flow (m^3/s). The maximum number of return flow channels for any major withdrawal (or irrigation) component is five. Figure C.28 shows what happens when users increase the number of return flow channels from two to five. Three more sets of empty text boxes are created for users to type in the return flow channel number, the downstream node number of the point of return, and the fraction of the total return flow.

Note that there is nothing listed under the "Lower Bound of each zone as a fraction of 1.0" text box. The reason for this is the use of only one zone, which must have a lower bound equal to zero to allow a complete deficit of 100% for the case when there is no supply at all.

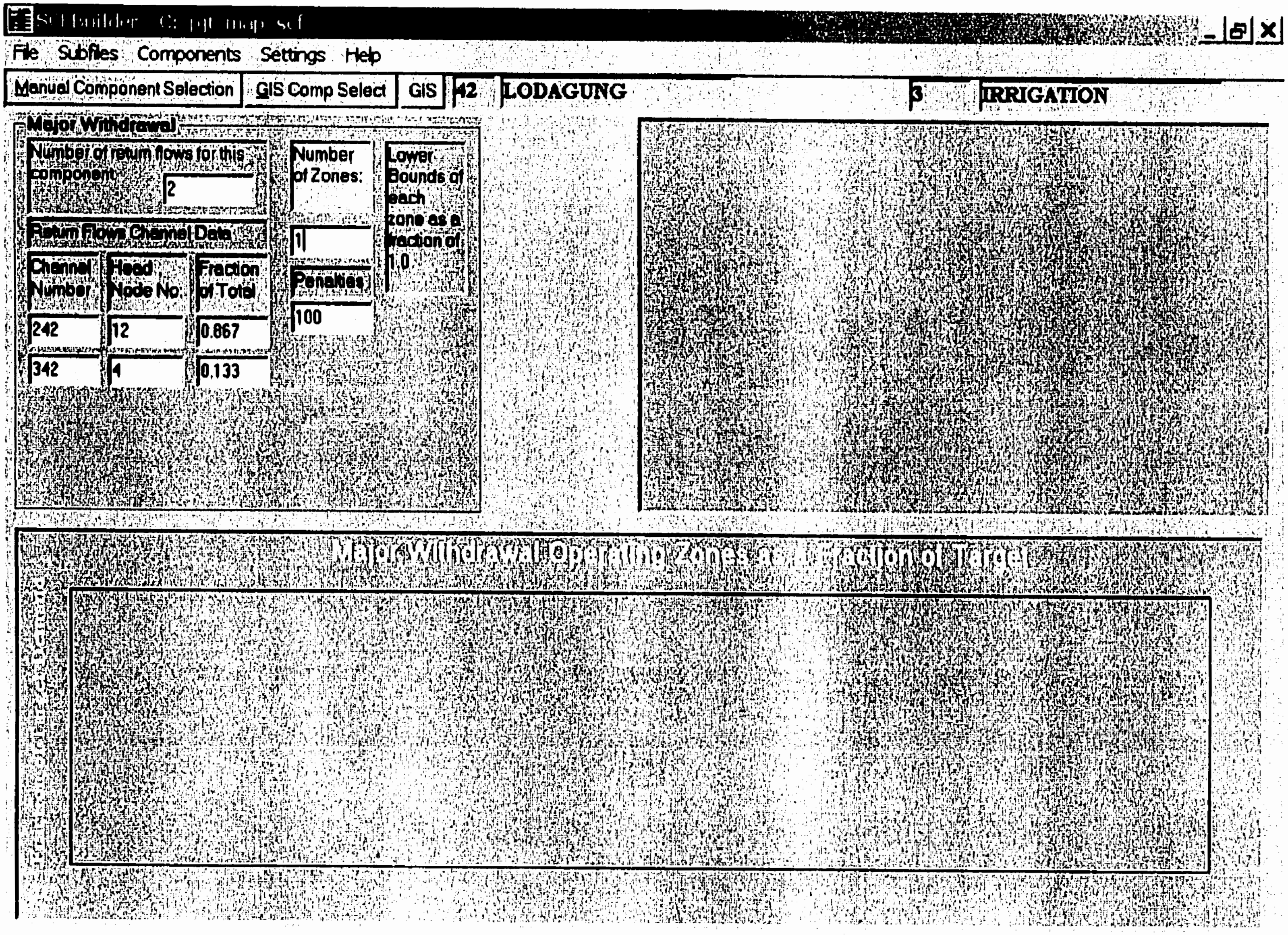


Figure C.27 Graphical editing screen for a major withdrawal component

Figure C.28 shows what happens if users type in the number 3 in the input box below the label "Number of Zones". Two more input boxes are opened for two additional penalties (one zone already has a penalty of 100) and two more boxes are opened below the "Lower Bounds of each zone as a fraction of 1.0" text label. The lower bounds should contain values between 0.0 and 1.0, for example 0.8 and 0.6 would create three zones in the following intervals: 100% - 80% of demand for the top zone, 80% to 60% demand for the second zone and 60% to 0% for the bottom zone. The penalties for 1 m^3/s of deficit have to be specified in an increasing order starting from the top zone with the lowest penalty to bottom zone with the highest penalty. If that is not the case SCFBuilder issues a warning message when the user tries to save the file.

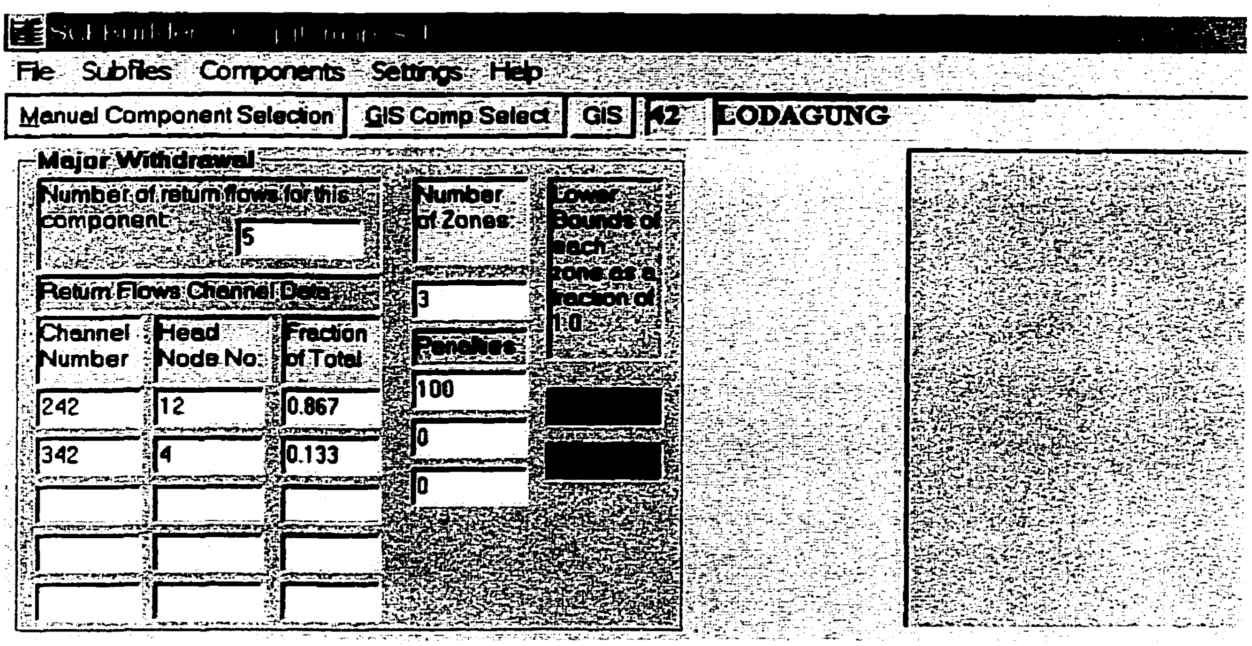


Figure C.28 Modifications of the major withdrawal entries

C.3.7 Graphical Editing for Apportionment Channel Components

Figure C.29 shows the graphical editing screen for an apportionment channel component. As in the case of other link components, the tail and the head node number must be specified. The tail node number represents a component of type node located at the upstream end of the

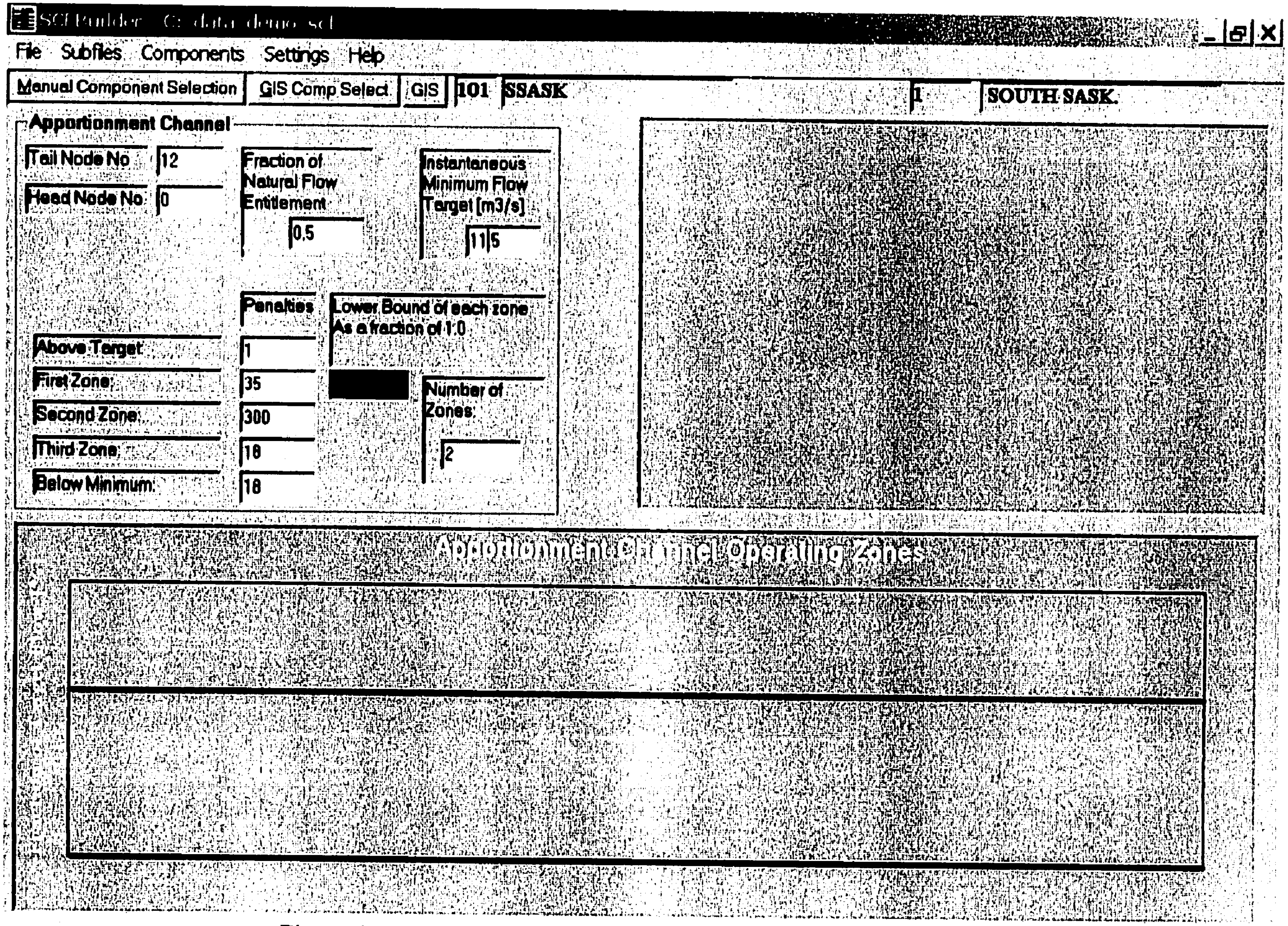


Figure C.29 Graphical editing screen for an apportionment component the apportionment channel, while the head node number represents the number of a component of type node located at its downstream end. The apportionment channel is used for modelling apportionment agreements between bordering political districts (e.g. states or provinces). These agreements usually consist of a combination of two requirements: (a) the minimum instantaneous stream flow that has to be maintained at all times; and, (b) a fixed percentage of natural flow originating from the upstream political district that has to be passed to the downstream political district. In the example in Figure C.29 the percentage of natural flow that has to be passed to the downstream province is 50% (given as the fraction 0.5) and the minimum instantaneous flow is set to 11.5 m^3/s. The cursor is also visible in Figure C.29 on the location of the decimal point of 11.5 since that was the last value modified prior to copying the screen into this document.

C.4 Inserting and Deleting Components

Selecting the *Components* pulldown in the main menu (shown in Figure C.30) allows users to insert or delete components and reorder the position of any component within its policy

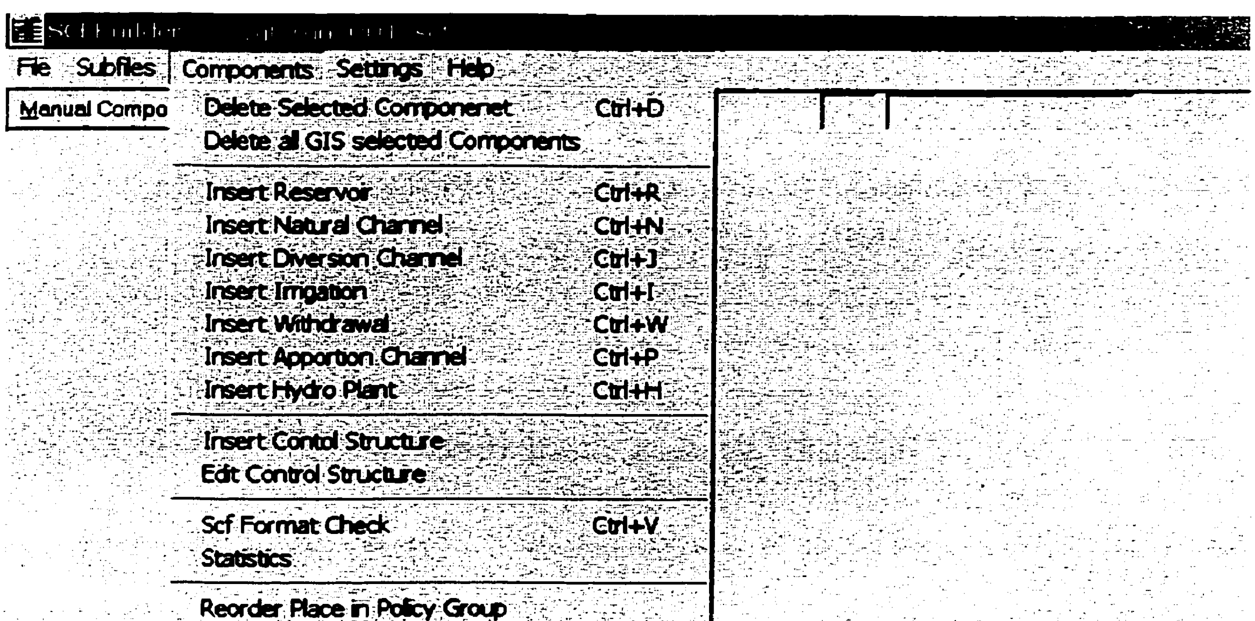


Figure C.30 Components selection in the main menu group. Once a component has been selected using the manual or GIS selection, clicking on "Delete Selected Component" in the pulldown menu will delete all references to that component in the SCF. This is very useful since components are referenced in several subsections of the SCF. SCFBuilder finds all such references and adjusts the SCF so that it can be run following the removal of a selected component. To verify that the component has been removed, users can click on the manual selection button again and view the component selection list. The components that have been deleted during the current session will not be found in the list.

There are seven choices related to *Insert [component type] Component*, one for each component type except for return flows, since they are included as part of inserting irrigation or major withdrawal components. All component types follow the same procedure, so it is enough to demonstrate only one of them. The basic approach is to first ask the user (a) the component number; (b) component name; and, (c) which operating policy group the new component should belong to (at this point users can also create a new policy group for each new component if necessary). After that, SCFBuilder puts the new component in the selection list and allows the user to select and enter the remaining information though editing screens (as discussed in Section C.3). Inserting a new reservoir is demonstrated in Figure C.31 which shows the first dialogue window that appears following the selection of *Insert*

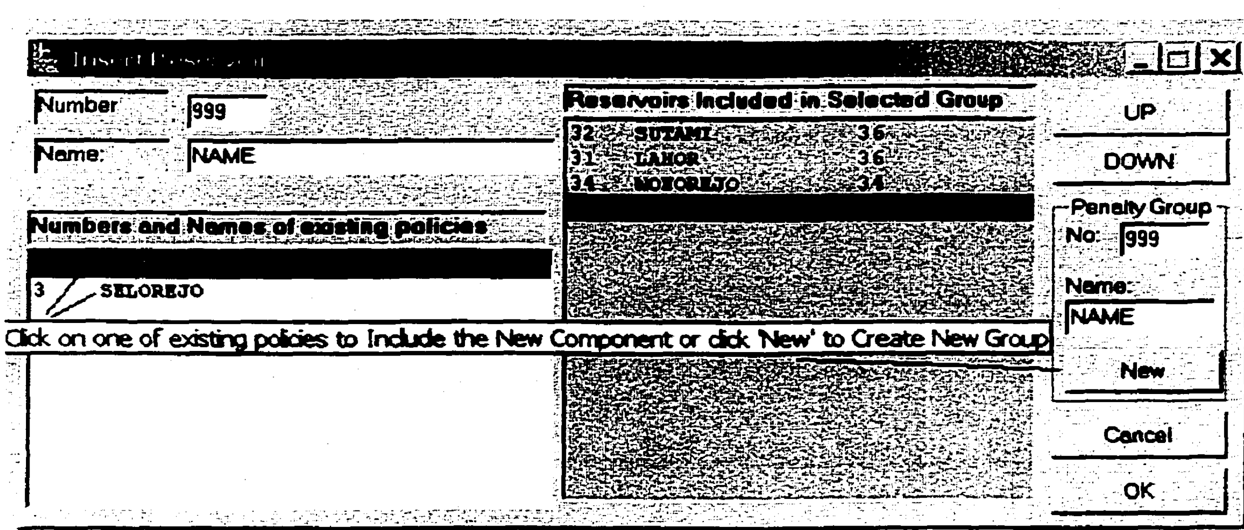


Figure C.31 Insert reservoir dialogue window

Reservoir. Suppose the user wants to introduce a new reservoir into the system with component number 36 and component name SITE36, and wants to put it in a group policy on its own. The steps are as follows:

a) enter number 36 in the text box labelled "Number" in the dialogue window depicted in Figure C.31;

b) enter the name "SITE36" in the text box labelled "Name"; and,

c) enter the group policy name and number in the appropriate text boxes on the right hand form labelled "Penalty Group".

As soon as option c) is executed, the new policy group is displayed in the list of available policy groups. The number 2 is entered as the new policy number (the existing policies are numbered 1 and 3) and the new policy group is labelled "GROUP2". After items a), b) and c) above have been completed SCFBuilder will display the window depicted in Figure C.32.

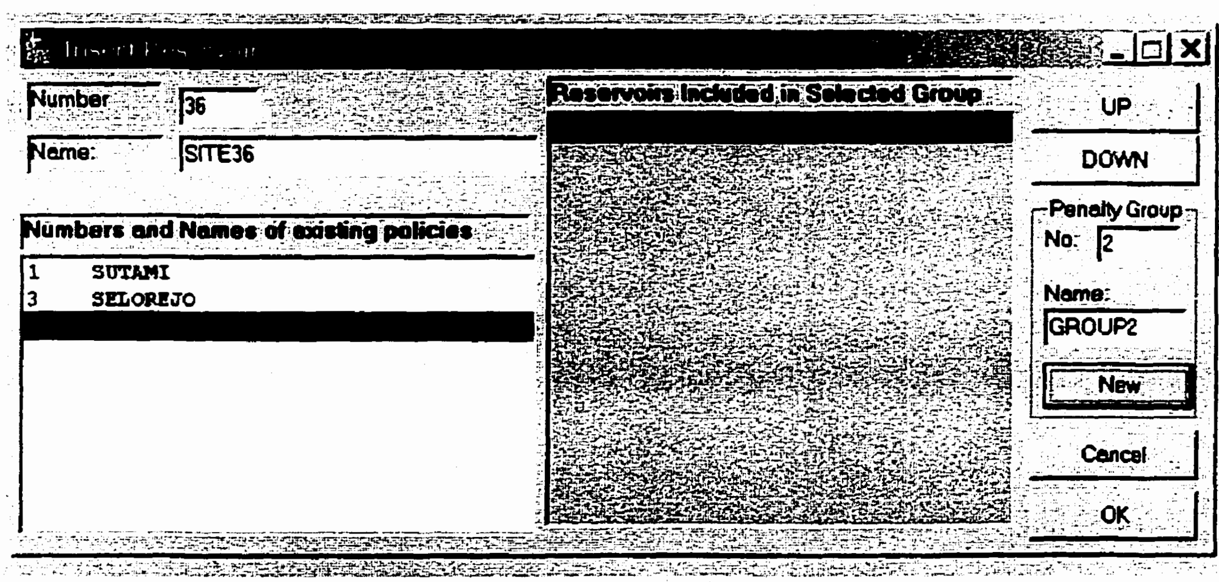


Figure C.32 Insertion of a new reservoir in the system

Reservoir SITE36 is now ready to be added to the system by clicking the OK button. There is only one reservoir included in this policy group, and that is the new reservoir 36. Number 3 is the default for the number of points in time when zone bounds are given. Buttons UP and DOWN will be explained later in the subsection entitled "Reordering Components". Clicking OK gets the user back to the regular SCFBuilder screen. The next step is to click on manual selection and select the new reservoir 36 which will be found at the bottom of the list, as shown in Figure C.33.

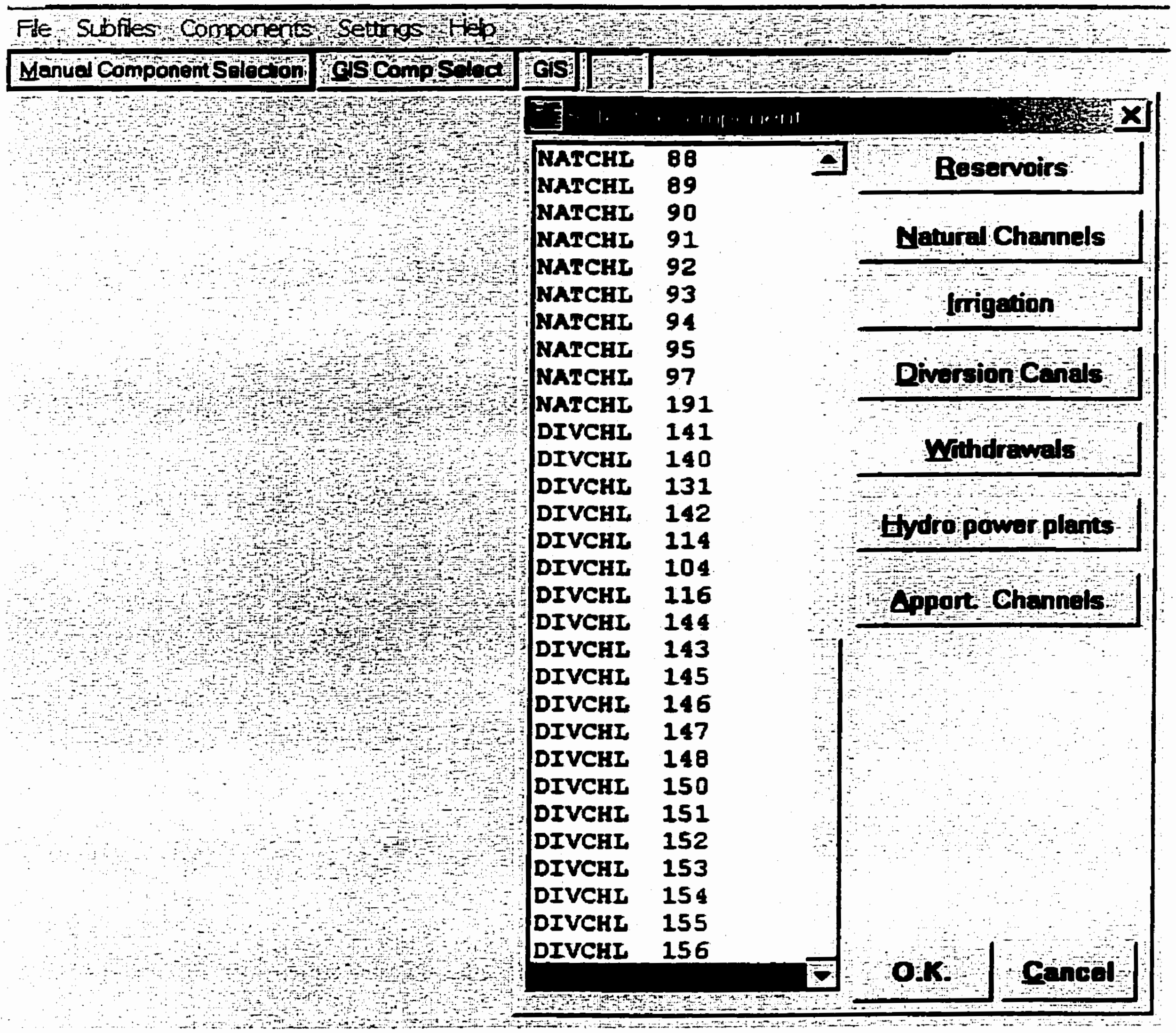


Figure C.33 New component inserted into the component list

After selecting the new component users will be given the standard graphical editing screen with the selected reservoir number 36 and name SITE36 as explained in Section C.3. All other variables (capacity curve and zones) are defaulted to a standard set defined by SCFBuilder, however SCFBuilder allows users to modify them by entering new data as explained in Section C.3. After the file is saved, the new component will be listed in alphabetical order when the component selection list is again displayed for selection.

Entering the reservoir alone with a brand new component number is insufficient modification. The new reservoir must be connected using one or more components of type link. In other words, reservoir number 36 has to be the upstream node of at least one channel in the schematics. If that is not the case a new channel has to be added to link the reservoir to other components. When an existing junction node is converted into a reservoir (which is often done in planning studies), either the number previously used for the junction should be retained and used for the reservoir, or the new reservoir number should be replaced as the head and tail node number for all associated link components.

C.5 Editing Control Structures

As mentioned earlier, control structure is a mechanism (or a function) which defines the maximum flow limit on either a natural channel or a diversion canal component. Control structures are optional. Users must have the capability to add or delete control structures without changing anything else about the component. This is different from the return flow channels which disappear automatically if their respective irrigation (or major withdrawal component) is removed. To remove a control structure while leaving the respective natural channel or diversion canal intact, a separate window dialogue screen is required. There are two choices related to control structures, as seen in Figure C.30 – one is to edit an existing control structure (this also includes an option to delete it) and the other is to insert a new control structure.

The option to edit control structures invokes the dialogue window depicted in Figure C.34 which provides a list of all control structures found in the SCF. The selected control structure is the one highlighted in the list. It can either be deleted using the delete command button in the bottom of the selection list, or its caracteristics can be edited using the other

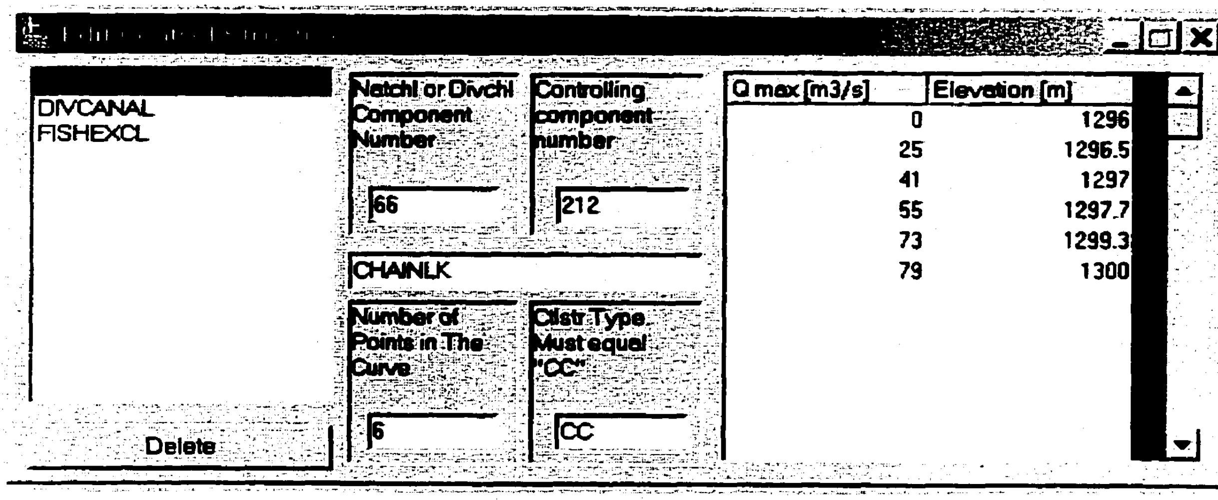


Figure C.34 Edit control structure dialogue window

text boxes in Figure C.34. The usual practice by WRMM users is to always use a curve given with up to 10 pairs of points to represent the control structure function. That option is designated with the "CC" character flag that has become standard over the years, and it is left as the only option within SCFBuilder. There is no loss of generality here, since any type of outlet structure flow function can be represented in this way. Users should note that it is also possible to edit the control structure directly in the main natural channel or diversion canal graphical editing screen, however there is no option to delete a control structure. The editing screen in Figure C.34 also allows users to move the same kind of outflow function from one canal to the other by simply changing the component numbers (66 and 212 in Figure C.34) in the corresponding boxes. What is missing in Figure C.34 is the ability to insert a new control structure, which is an option available in the *Components* pull down menu. When activated, it gives the user several prompts. The first prompt requires the number of the natural or diversion channel component to be entered, displayed in Figure

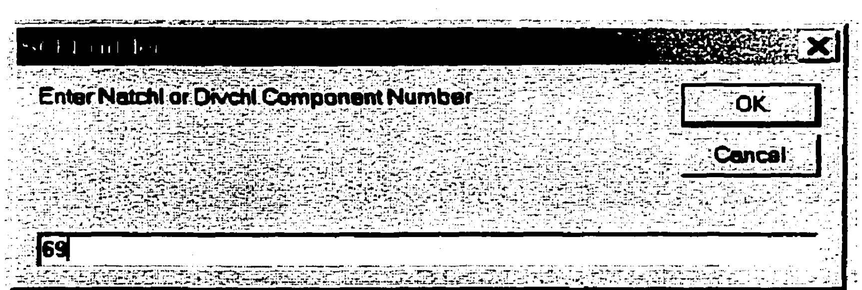


Figure C.35 Inserting new control structure – step I

C.35. This is a component that has not had a control structure before (in the example it is channel 69). The next prompt requires the user to enter the number of the component which regulates the maximum flow in the channel for which the control structure is added (i.e. channel 69 above), as shown in Figure C.36.

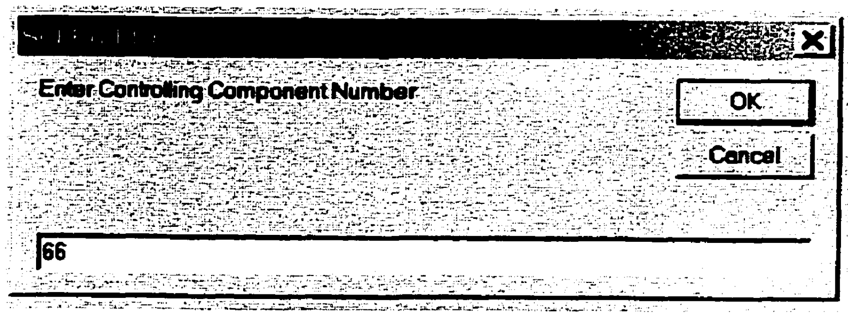


Figure C.36 Inserting new control structure – step II

After confirming the selection by pressing the OK button, the user can go back to the *Edit Control Structure* option. The dialogue window that appears is shown in Figure C.37.

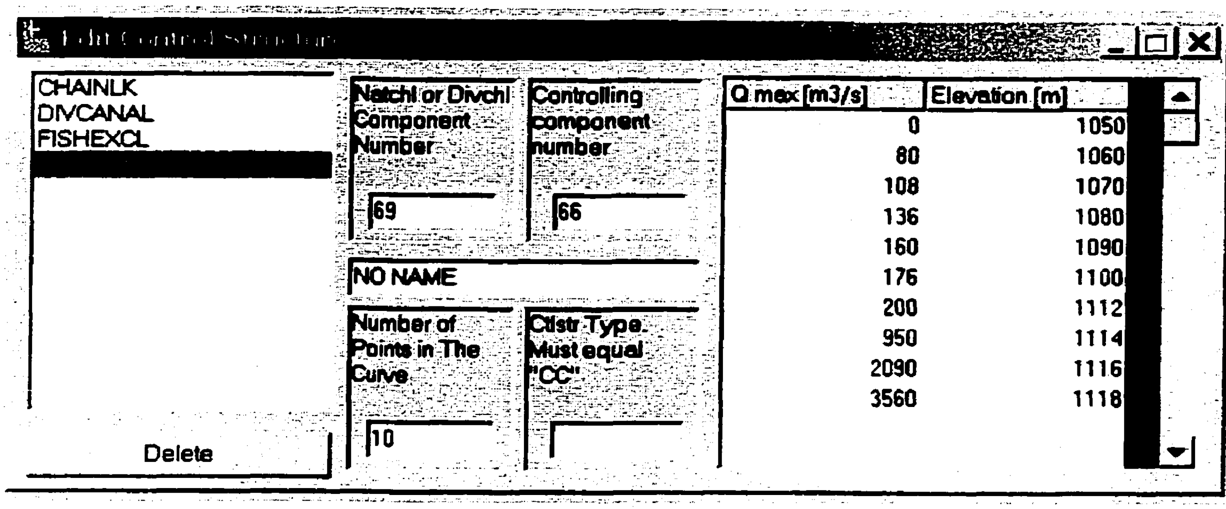


Figure C.37 Insert control structure – step III

The new "NO NAME" control structure is selected and the component numbers entered in the two previous dialogue boxes (69 and 66) are already available. A default flow vs. elevation curve with 10 points is also displayed. At this stage the users should enter a meaningful name to replace the "NO NAME" characters as well as modify the shape of the curve by entering appropriate values.

C.6 Re-ordering Components within a Policy Group

Penalties are given in the SCF file only for a group. Internally within the WRMM, however, each component within the group is assigned a unique value so as to differ by a very small amount from other components in the same policy group. The lowest penalty within the group is given to the first listed component of the group within the $PENSYS subsection. Subsequent components all have their penalties automatically increased so that the minimum difference between the two adjacent components is 0.01. This approach is to prevent having more than one solution with equal optimality which may happen in subsequent WRMM simulation runs when several components have identical penalties. Figure C.38 shows the dialogue window which allows the user to move the currently selected component within its group using the UP or DOWN command buttons.

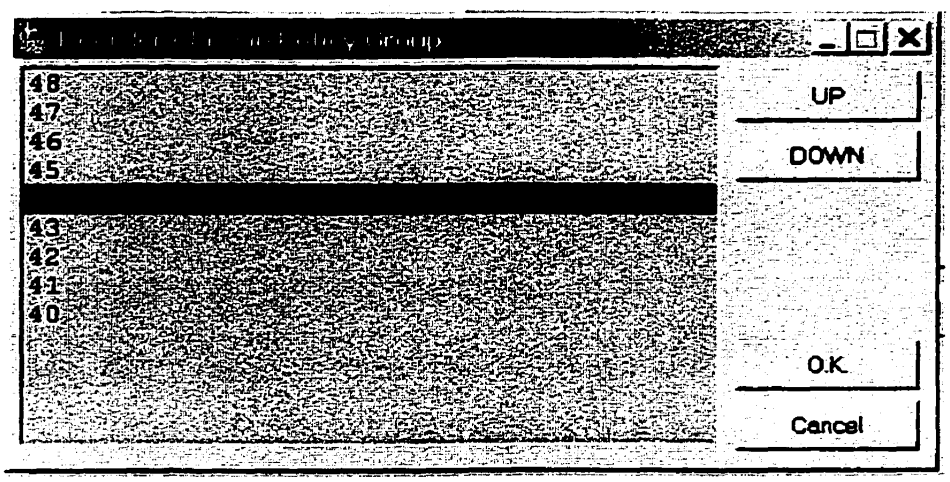


Figure C.38 Re-setting position within the same penalty group

C.7 The Statistics Option

One way to quickly scan the properties of the SCF and check for certain types of errors is by selecting the *Statistics* option from the *Components* selection in the main menu. SCFBuilder

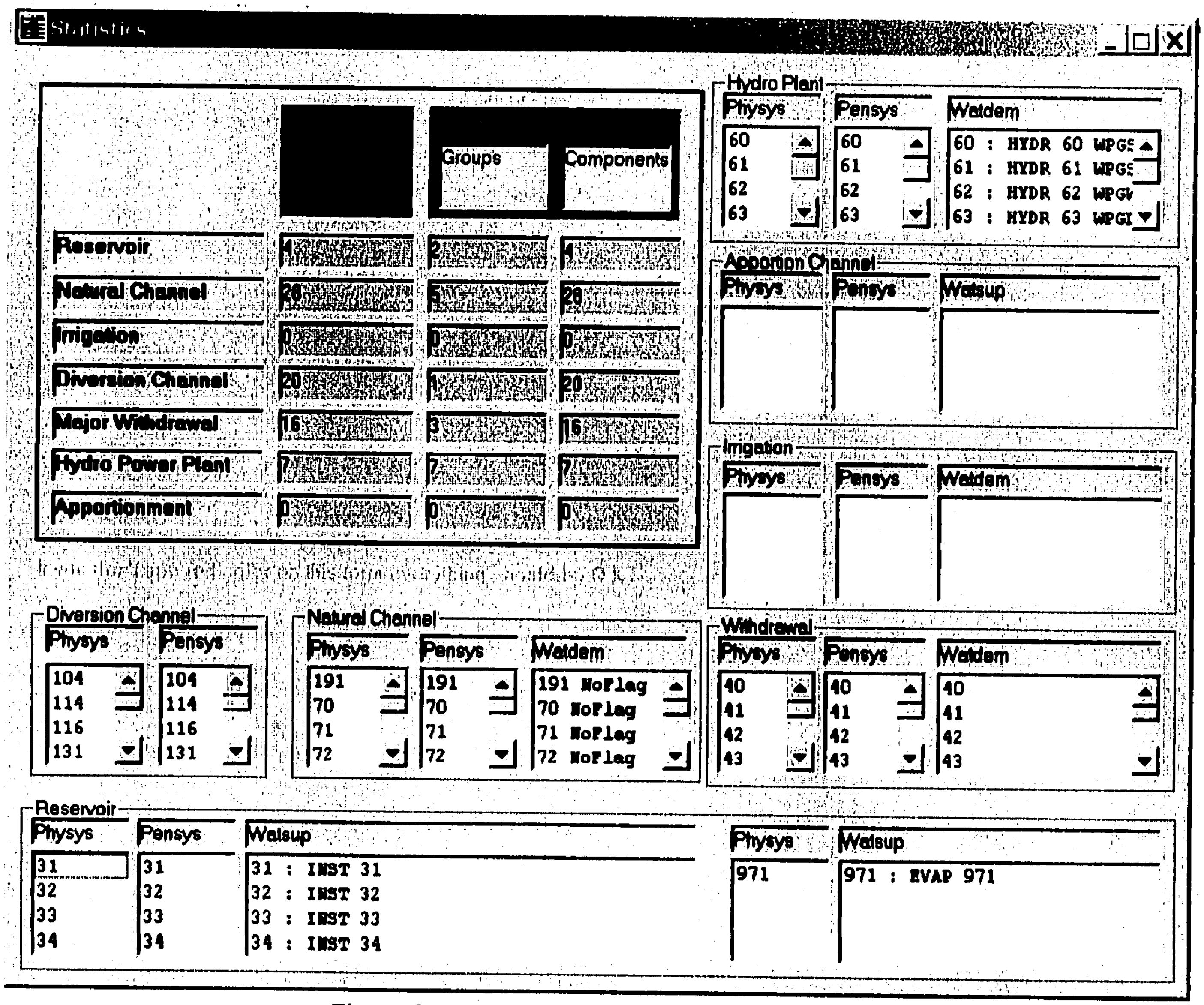


Figure C.39 The SCF statistics dialogue window responds by displaying the window shown in Figure C.39. The upper left corner of the window shows how many components of each kind were found in the $PHYSYS and in the $PENSYS subsections with a breakdown of operating policy groups and the total component numbers. For example, for hydro power plants there are seven components and seven policy groups, which means that each group has only one component. On the other hand there are four reservoirs placed in two policy groups. The number of components of each type found in the $PHYSYS and the $PENSYS subsections must be the same. The sample SCF used to produce Figure C.39 does not have any apportionment channels or irrigation components, so their corresponding list boxes are empty. Other components are listed in a sorted order. If an error is found such as for example one component present in $PHYSYS and $PENSYS but missing in $WATDEM, then the $WATDEM list box is painted red. Users can detect which component is missing by paging down through the lists of all three subfiles until the mismatch is located (all three lists are sorted alphabetically).

There are only four reservoirs in the SCF used to generate Figure C.39. Since all four of them can fit the available space on the screen, no scroll bar is produced at the right hand end of the list box. However, all other components (diversion, natural channel, hydro power plants and major withdrawals) are automatically equipped with a scroll bar to allow users to see each component found in the SCF. The appearance of the scroll bar only when necessary is a standard Visual Basic feature.

C.8 SCF Format Checking

Missing a component in one of the subsections is a logical error. Apart from logical errors, there are also format errors which are caused by misplacing the number when entering the data into the SCF. SCFBuilder is primarily designed to edit existing SCF files. An important step in this process is the ability to check the SCF file format. This can be done at any point using SCFBuilder by selecting the *SCF Format Check* option, but it is always done automatically prior to saving the changes made to the SCF within SCFBuilder. This check generates a ASCII log file which is displayed on the screen. Some of the messages are simply warnings of potential problems, such as a meteorological station factor of zero. This could have been a mistake, but it could also have been set intentionally by the user in an effort to remove the effect of net evaporation in a given scenario. Figure C.40 shows a typical log window displayed when the SCF format check is performed. Another caution is the use of penalties equal to zero. In the sample scenario represented by the SCF used to generated the screen in Figure C.40 hydro power is only produced as a by product of reservoir releases for irrigation and other purposes, hence its zero penalty.

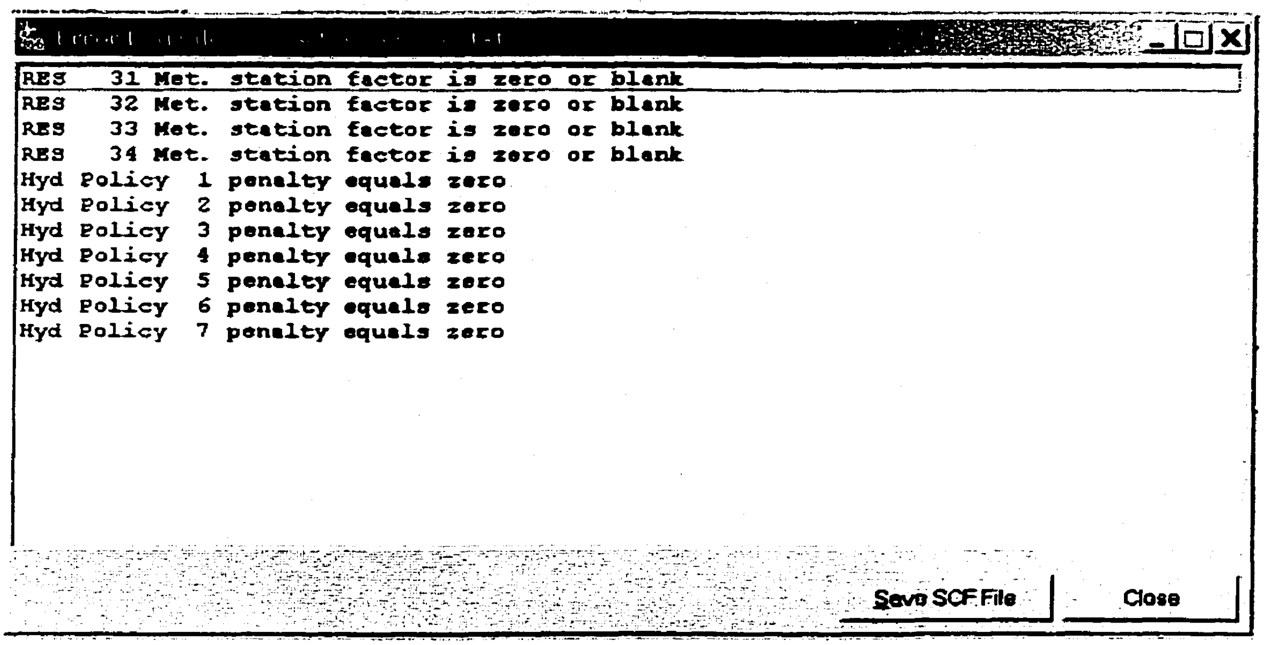


Figure C.40 SCF format check window

C.9 Color Settings

SCFBuilder allows users to set their own choice of colors for foreground lines and background areas by selecting the *Colors* option from the *Settings* selection on the main menu bar. Figure C.41 shows the form that is provided for changing the colors after this option is selected.

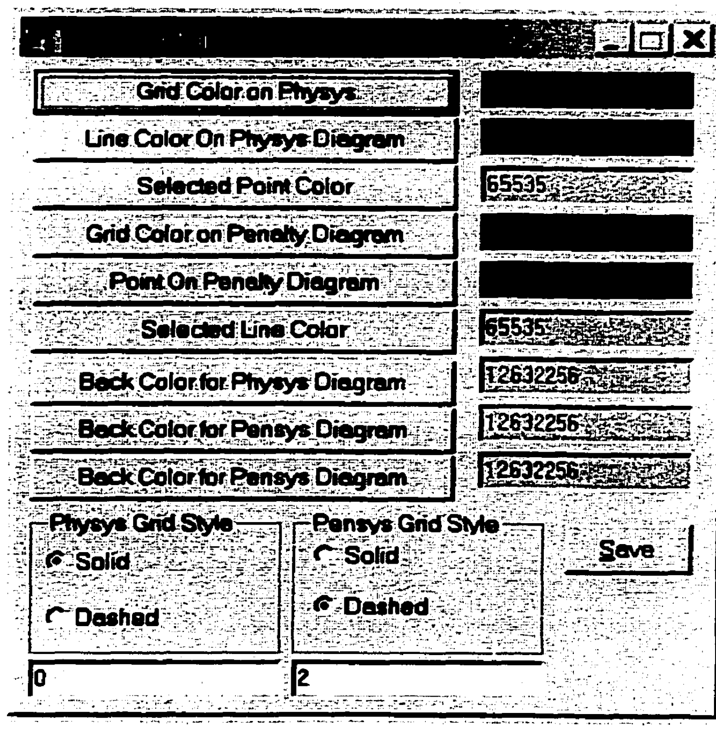


Figure C.41 Color setup window

C.10 SCFBuilder Help File

The on-line manual that explains how to use SCFBuilder can be accessed from the *Tutorial* option from the *Help* selection on the main menu bar. It was written in VB Helpwriter 3.2 and contains the same information as Chapter 6 of this document converted to the windows help file format. Figure C.42 shows the first half of the main tutorial help window.


Introduction to WRMM
Opening SCF file with SCFBuilder
Select a component
- Reservoir
- Natural Channel
- Major Withdrawal
- Irrigation Component
- Hydro Power
- Apportionment Component
- Diversion Channel

Sections
Components
- Insert or delete a component
- Reorder a component within a group
- Statistics
- SCF format check

GIS Link

Figure C.42 Tutorial help file front page

C.11 Group Component Selection from GIS

The third command button located to the right of the *GIS Component Selection* button on the main menu bar is labelled *GIS*. This button is used only if more than one component has been selected simultaneously within the GIS schematics layer. The usual purpose of using this option is group deletion of components, however it can be used for other purposes when alternative selection of one of the several chosen components are of interest.

Users need to first select several components at once using one of the available options within Mapifno (e.g. query select for components of the same type, use of selection window, or individual multiple selection using the SHIFT key pressed down while selection is carried out manually with mouse clicks). The next step is to *Confirm Group Component Selection* in the appropriate menu as shown in Figure A.8. Following this users should press the GIS button in the SCFBuilder to obtain a window like that shown in Figure C.43.

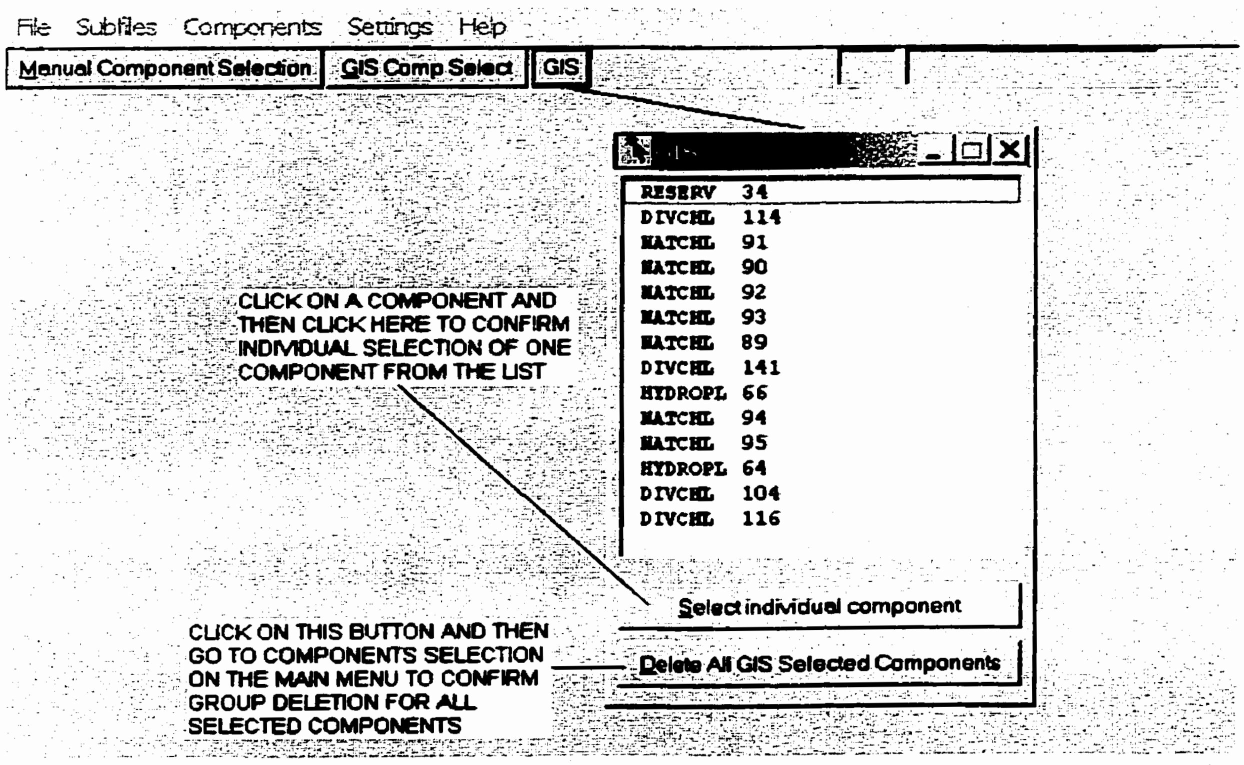


Figure C.43 Group component selection window

C.12 Pasting Data from the Windows Clipboard

Entering exact values for a volume vs elevation curve, flow vs elevation curve for control structures or for the exact values of zone bounds for each point in time can be done using a widows dialogue box as shown in Figure C.20. This option is suitable for changing individual point values, but if many values need to be changed (e.g. an entire curve needs to be replaced) the task of changing points one by one becomes too cumbersome. The outflow elevation and storage elevation curves are usually created with spreadsheets, so it would be advantageous to be able to copy the spreadsheet data into the Windows clipboard and then paste it into SCFBuilder. This can be accomplished for a selected component using the *Paste* option from the *Settings* selection of the main menu shown in Figure C.44.

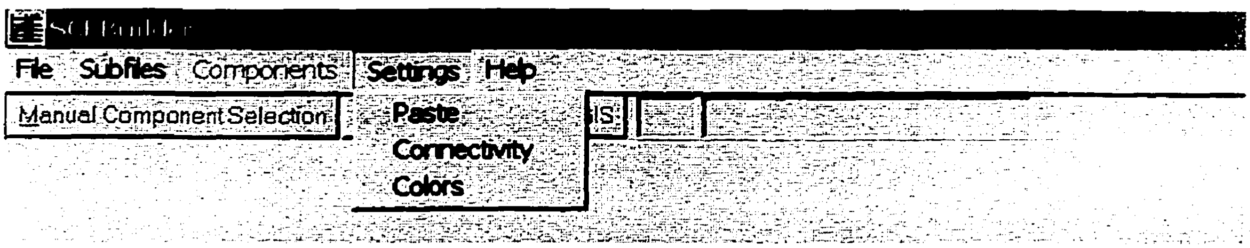


Figure C.44 Paste option from the Settings selection

Before using the Paste option, users have to ensure that a component has been selected for editing in SCFBuilder and that the data to be transferred from the spreadsheet has already been copied to the clipboard. For example, assume that natural channel 66 has been selected. Its current control structure curve is shown in Figure C.45. In this example the sample SCF file used to build the SCF Help file is used instead of the Brantas basin SCF, since no control structures have been modelled in the Brantas basin. The process is completed in a few steps. First the user must click on the *Settings* selection and then the *Paste* option in the main menu. The screen presents a new form shown in Figure C.46. Click on the top white area of the form and press the right mouse button to get the selection menu where *Paste* is shown as the only active option (as in Figure C.46). After pressing the paste option the data copied to clipboard appears in the upper part of the form as displayed in Figure C.47. The next step is to read the data into Visual Basic FlexGrid control below by pressing the *Read* command

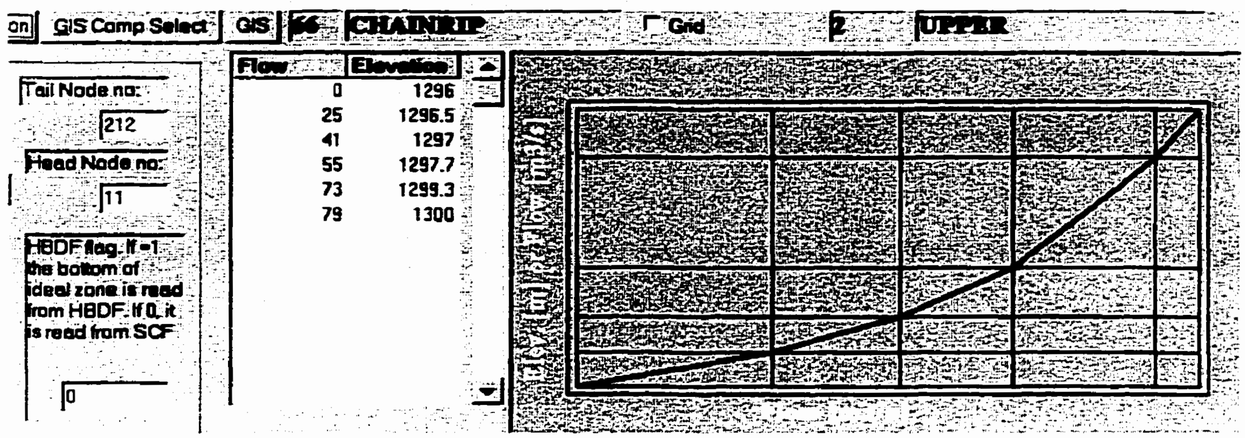


Figure C.45 Current control structure for channel 66

button. Optionally, users can use the *Invert* function to transpose the matrix of data that is being imported into the bottom FlexGrid table.

The final choice before the command button is to paste the control structure curve or to paste the penalty zone curves. Pasting will be conducted only for the selected component. Figure C.48 shows the screen after pressing the *Read* command button, while Figure C.49 shows the screen after pressing the *Paste to Control Structure Curve* button. The new values (flow limits) for each controlling reservoir level are shown in Figure C.49.

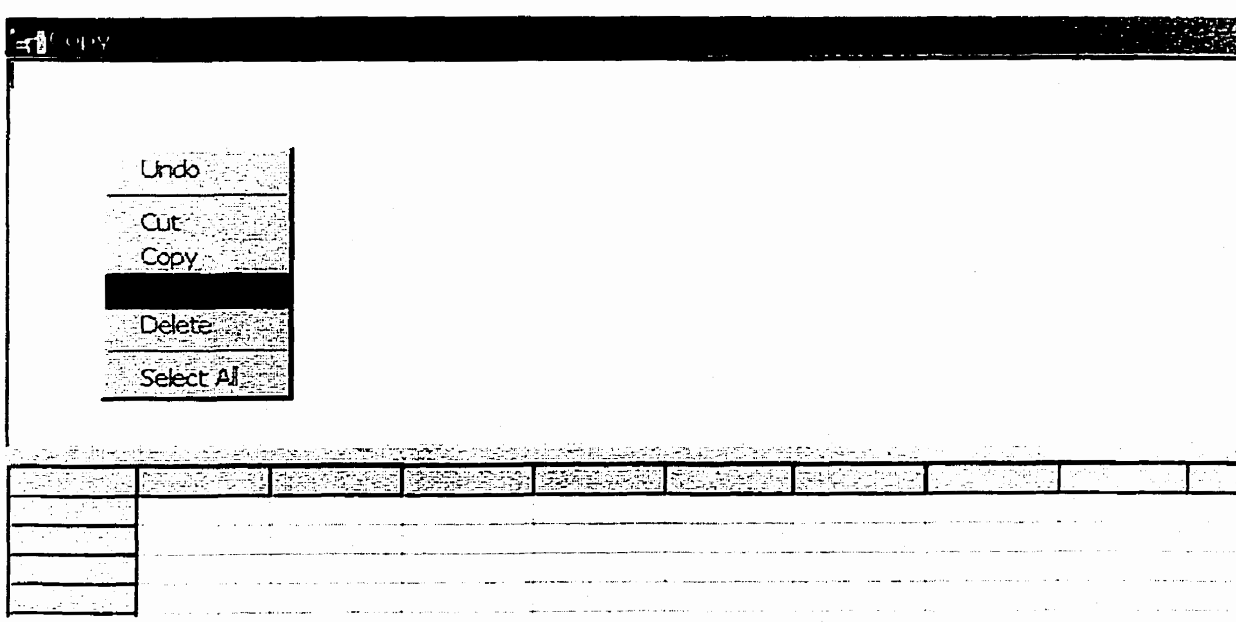


Figure C.46 The first step of the Paste command

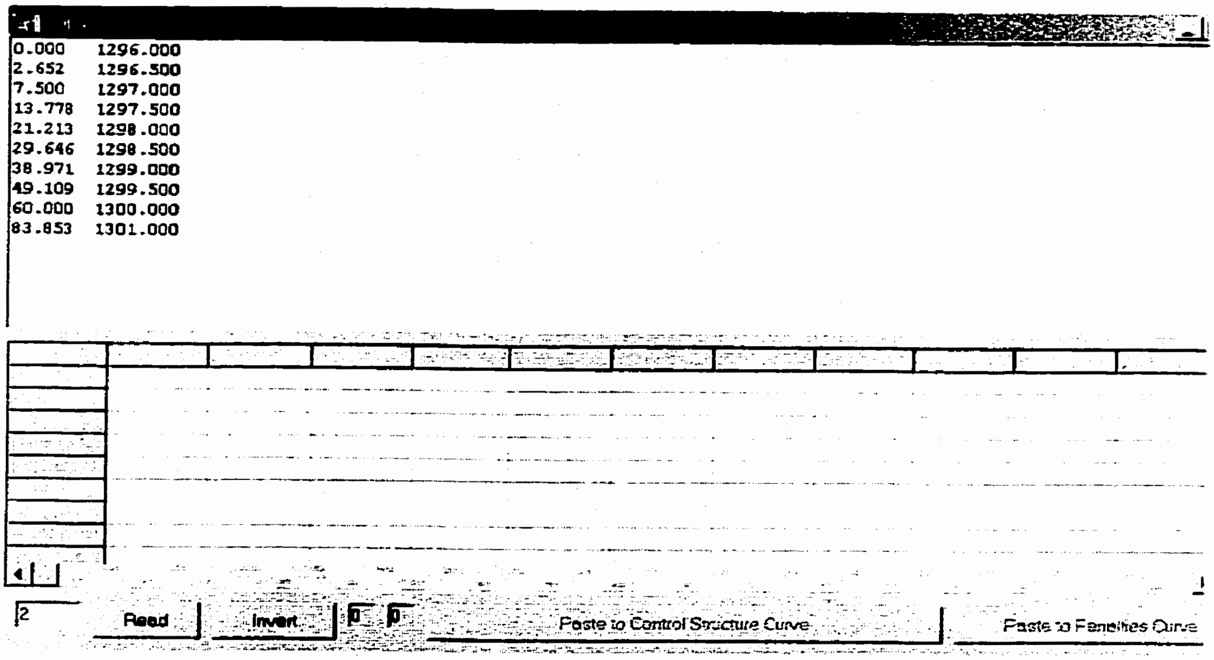


Figure C.47 Starting phase of the Paste process

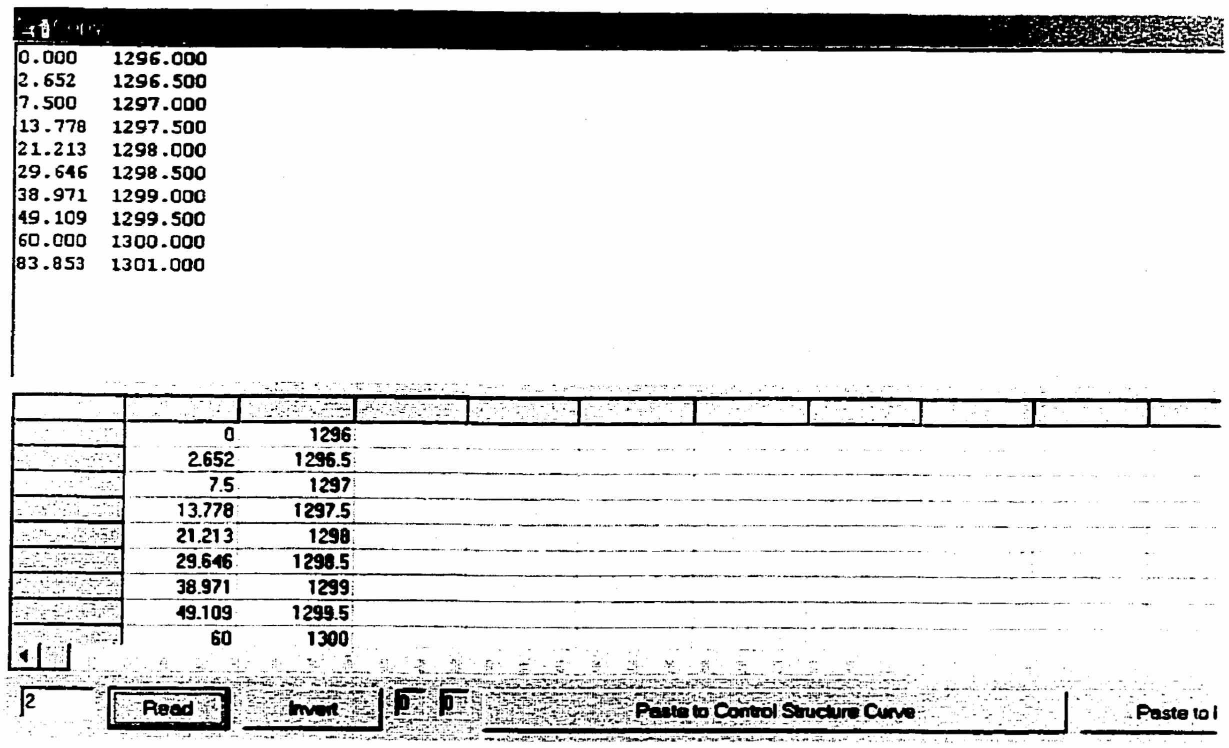


Figure C.48 The final step in Paste option

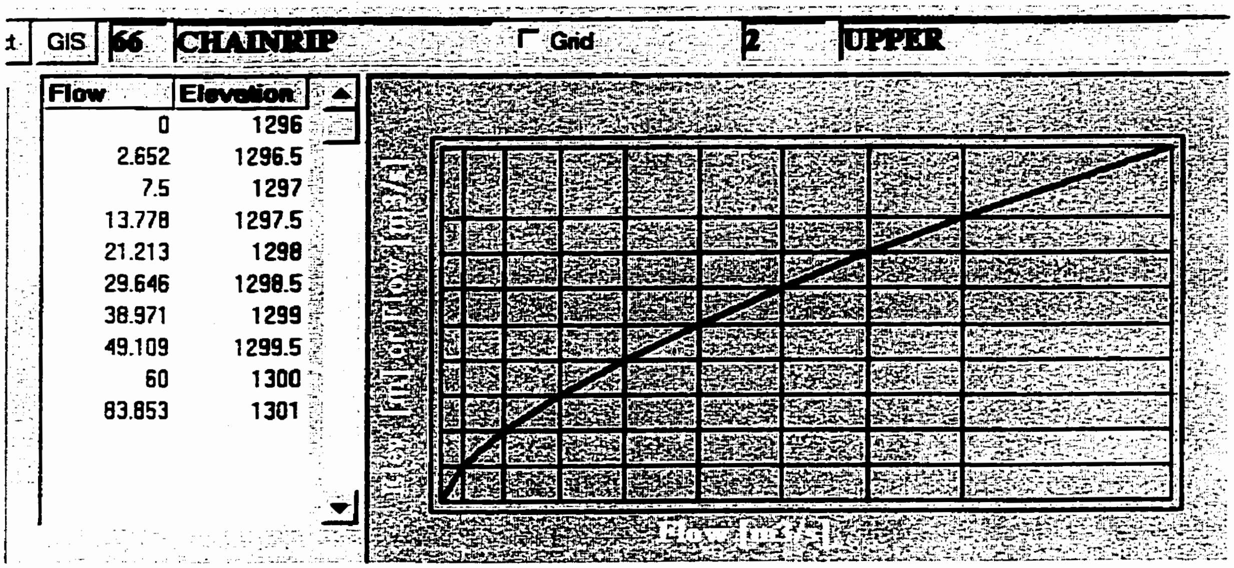


Figure C.49 Completed Paste process

C.13 Checking Connectivity

Logical errors in the input data file are possible and they cannot be detected using format checks. Probably the most typical logical error is associated with connectivity (i.e. wrong tail or head node number entered for a link may alter the internal network representation to the WRMM, while the user is completely unaware of it). Changing the origin or the terminal node for a link is a legitimate action which computer cannot distinguish from an accidental

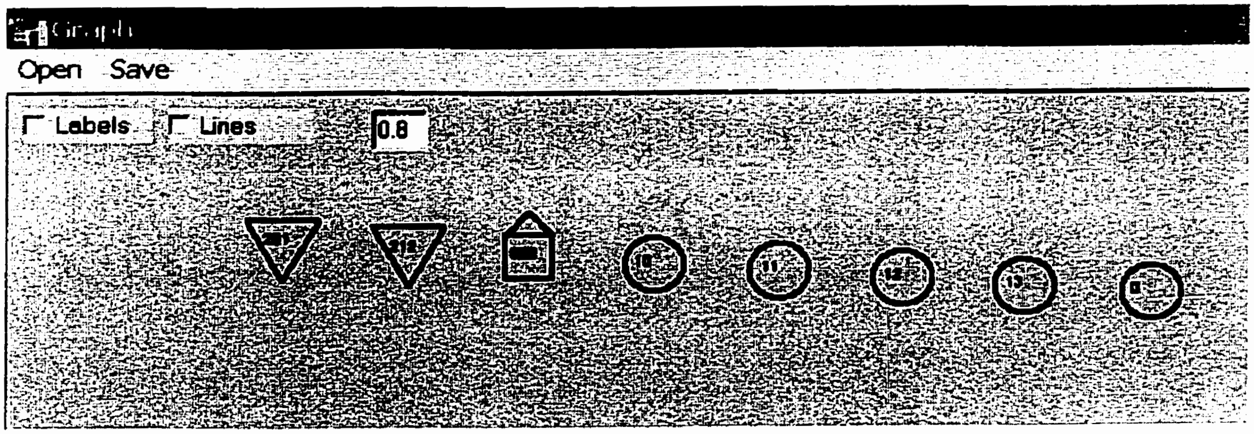


Figure C.50 Initial plot of components of type node error. The *Connectivity* option available from the Settings selection in the main menu (see Figure C.44) allows the user to check how SCFBuilder interprets the link to node relationships based on the data available in the SCF. This option assumes that the user knows how to distribute the nodes properly. SCFBuilder then draws the link components such that they originate and terminate at the corresponding tail and head nodes found in the SCF. This makes it easy to compare the intended linkage available in the modelling schematic with that the linkage understood by SCFBuilder. To use this option, open an SCF file and click on the *Settings / Connectivity* option. The model responds by drawing a screen like that shown in Figure C.50 which contains all the components of type node with their numbers. Click and drag are used to arrange the nodes according to their locations in the modelling schematic. The text box with the number 0.8 in it determines the diameter of each symbol representing a node. The numbers inside the figures are component numbers. Triangles are used for reservoirs, squares for irrigation blocks (there are none in the SCF used in this example), the square with a triangle on top of it represents major withdrawals and the circles represent simple junctions. After reducing the size of the symbols by 25% by specifying their diameter as 0.6 instead of 0.8, and after rearranging the location of nodes

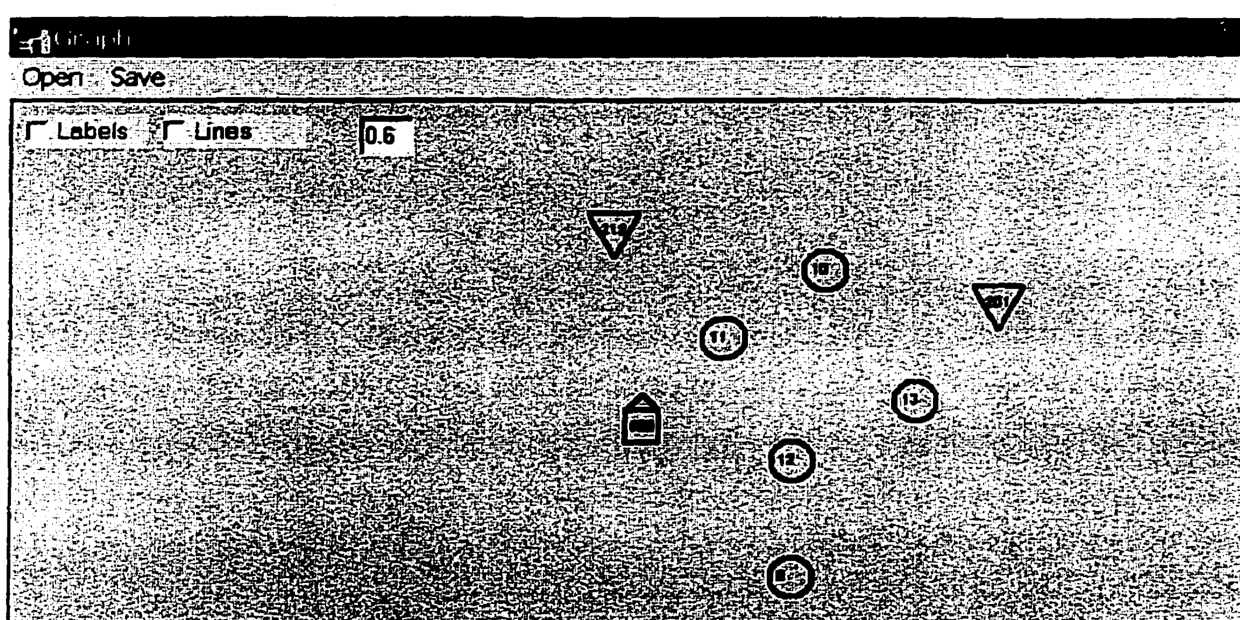


Figure C.51 Rearranging of node size and positions to roughly correspond to those found in Figure A.2, the new screen is shown in Figure C.51. Once the nodes have been re-arranged according to their locations in the modelling schematics using click and drag, users can click on the check box entitled "lines" to get the

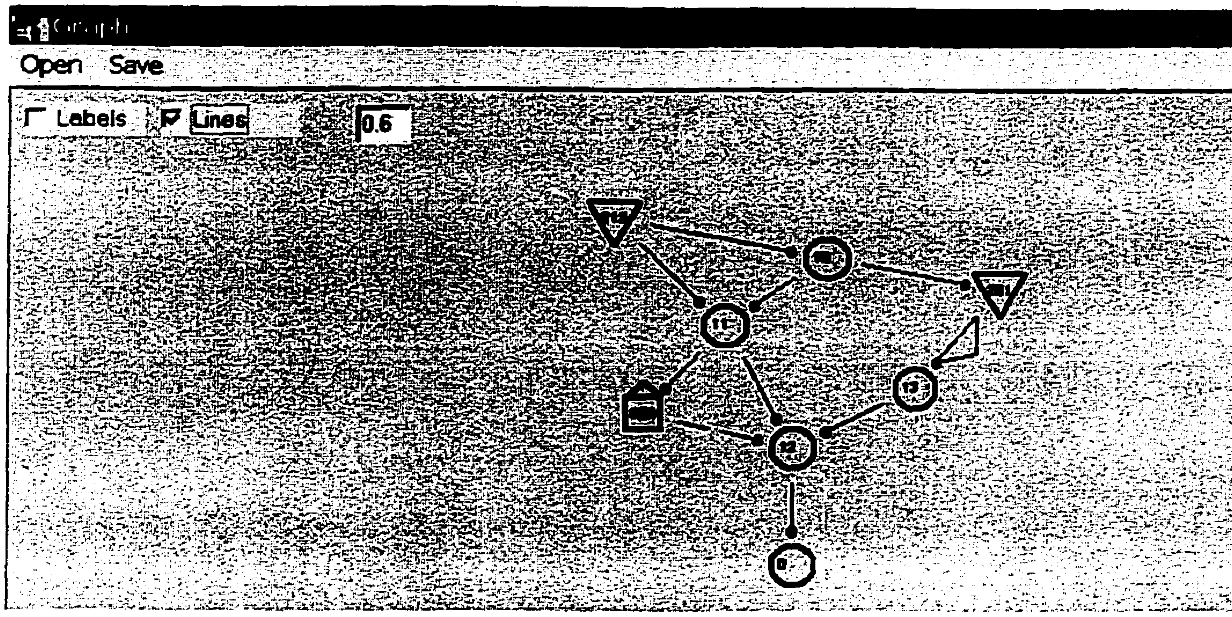


Figure C.52 Display of components of type line

output shown in Figure C.52 which shows the connectivity contained in the SCF.

The small circles at the end of each line are placed at the end (tail node) of each line to indicate the direction of flow. The line color indicates the component type (red for natural channel, pink for diversion, black for apportionment and green for return flow channel). Hydro power plants are depicted with a broken blue line (between reservoir 201 and junction 13 in Figure C.52). Clicking on check box entitled "labels" adds the component numbers to components of type line (as shown in Figure C.53). Once created, the drawing can be saved in a separate file so that users can avoid re-drawing the node positions using click and drag every time they wish to use this option, but can instead open the existing drawing previously saved in a file. The drawing in Figure C.53 should be equivalent to the schematics in terms of connectivity and flow orientation of each line. If that is not the case, the differences between the two schematics (the intended and the one provided by

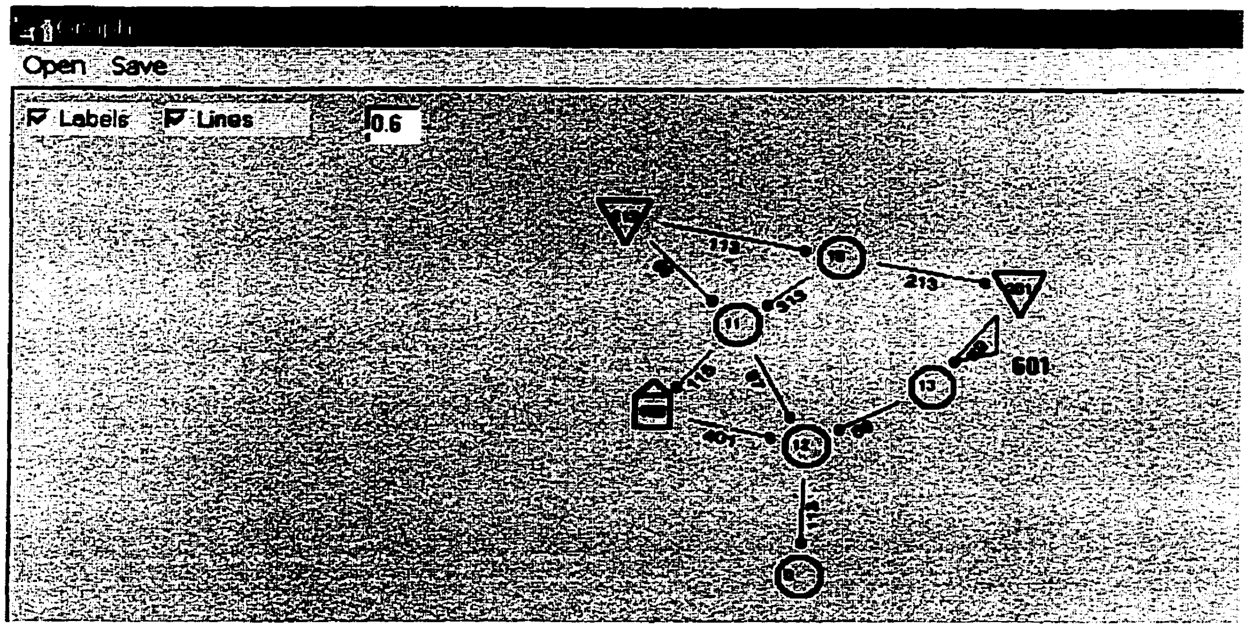


Figure C.53 Final result of the connectivity option

SCFBuilder in Figure C.53) indicate a logical error that should be fixed.

C.14 Copying Data from SCFBuilder to the Clipboard

It is also possible to transfer data from SCFBuilder to the Windows clipboard and save the data as an ASCII file or import it into other programs. To do this, users must click and drag the left mouse button over the FlexGrid data (e.g. volume vs. elevation curve, flow vs. elevation curve for control structure or grid data representing the operating zones for a component). The selection is identified by a change in background colour as shown in Figure C.54 below where volume vs. elevation data has been selected. The next step is to click on the right mouse button. The familiar form (as in Figure C.46) appears, automatically filled with the above volume vs. elevation curve data as in Figure C.55. One more selection with click and drag on the data in this form followed by the right mouse button click provides Windows pull down copy/paste option as in Figure C.46. From here, users can copy the data into clipboard to transfer the values to other programs, or they can select a different component within SCFBuilder and paste the curve into it using the *Settings* selection from

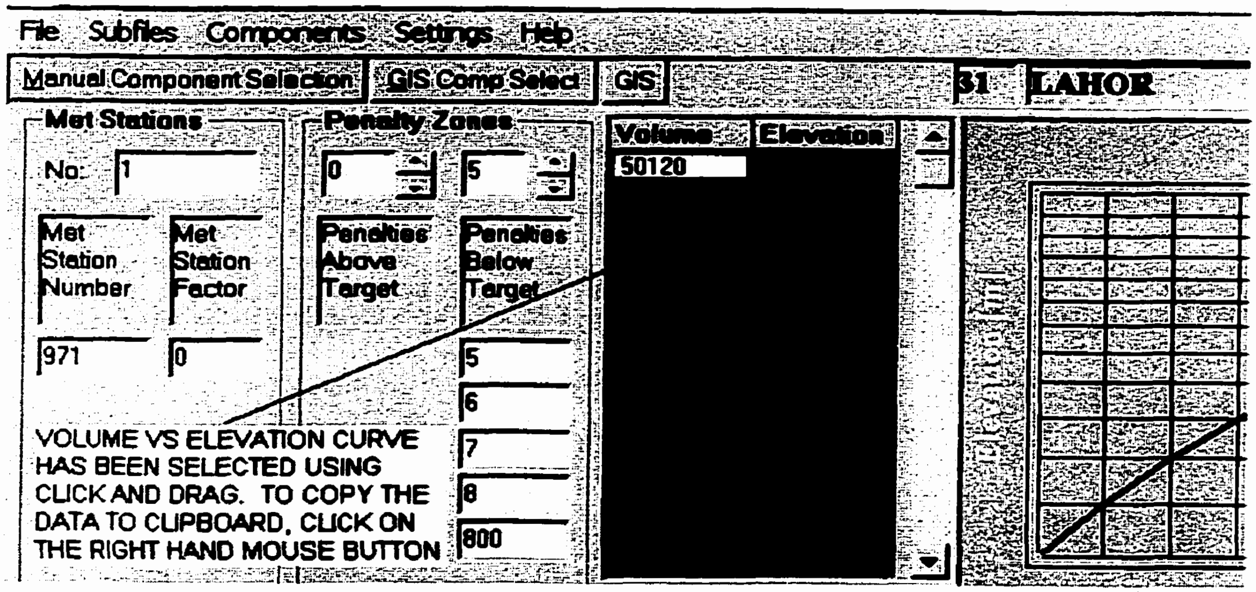


Figure C.54 Copying SCFBuilder data into the Windows clipboard

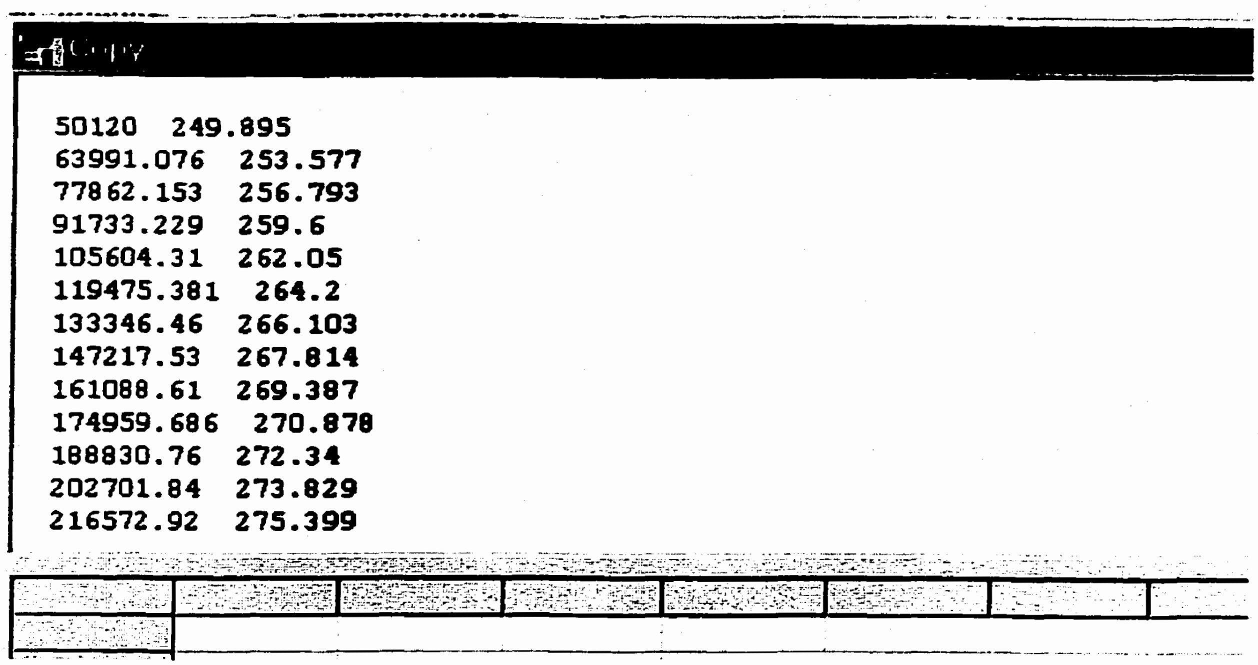


Figure C.55 Copying volume vs elevation curve into the clipboard

the main menu followed by the *Paste* option.