Hydrologic and Water Quality Modeling with HSPF: Utilization of Data from a Novel Field Data Collection System and Historical Archives

by

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SUBMITTED TO THE DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING IN PARTIAL FULFILLMENT FOR THE DEGREE OF

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ABSTRACT

Catchment-scale hydrology and water quality studies are empowered by current mobile computing, wireless, and Internet technologies to new levels of technical assessment capability. These technical developments motivate an investigation into the modern uses of hydrologic and water quality models.

The Hydrologic Simulation Program – FORTRAN (HSPF) is applied using data from the Williams River basin, New South Wales, Australia. The Williams River is an agricultural catchment with interesting physical characteristics and various non-point source water quality issues that warrant a modeling investigation to characterize the hydrology of this large and heavily utilized water resource.

Model inputs include 1) a thorough set of Geographic Information System (GIS) files utilized in a closely coupled interface with the HSPF algorithms; 2) time series meteorologic and water quality datasets from historical archives; and 3) supplemental data obtained during a technically enabled field sampling campaign.

These inputs are formatted for import to the HSPF routines, streamflow is simulated, and outputs are analyzed for accuracy.

Thesis Supervisor: E. Eric Adams
Title: Senior Research Engineer and Lecturer

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The inspiration and motivation for the launch of STEFS is attributed to Richard Camilli and Enrique Vivoni. Their charisma and determination started this thing, drove it, and pushed us all through it. Further thanks go to Enrique for his continued support through the research.

The programming difficulties encountered during the model development process were extremely frustrating, and without the expertise of the best, this research would not have come close to being completed. A million thanks go out the finest of the BASINS support team: Dan Sandhaus, Paul Cocca, and Henry Manguerra. These men were instrumental in the assimilation of the Australian datasets.

Further thanks go out to Arun Varghese and Kurt Herman. Arun is responsible for the brilliant idea to pre-process my datasets in STATA. It was a nice surprise and a huge time-saver. Kurt is my HSPF hero. Without his concurrent work on a local watershed, and the knowledge that came of that, I would never have made everything work.

Finally, I would like to thank the STEFS Undergraduates and my team: Neeraj Agarwal, Eric Lau, Kris Kolodziej, Russell Spieler, and Ching-Huei Tsou. Without them I would have thrown my computer out my eighteen-story window and taken up street musicianship a long time ago.

Thanks!

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1 Introduction

1.1 Motivation

As technology advances, water resource engineers have the opportunity to utilize cutting edge tools to fulfill their interests in a more efficient frame of time and effort. The technology and engineering interface enables optimized observation, modeling, and allocation of water resources via streamlined computing architectures. In the absence of computing technologies, water resource management practices are fragmented. Observation is limited by manpower and cost to short-term sampling studies and intermittent monitoring programs, and models are limited by discontinuous data inputs and insufficient processing power.

Application of technological innovations provides some enhancement to these practices. Remote sensing and telemetry enable streamlined observation of parameters and newer, more intelligent computers give modeling programs the speed and flexibility to manage large quantities of dynamic data input. This gives models the ability to simulate over longer time periods with shorter time steps, and the resulting optimization algorithms are progressively founded on facts over statistics.

The union of information technology with water resource engineering was the fundamental motivation in this investigation. A widely used hydrologic and water quality model is applied to a system with limited data inputs. The robust functionality that is achieved by this integration makes use of, or supplements particular information technologies that improve the monitoring and modeling of water resources.

1.2 Background

The foundation for this research is the Environmental Information Technology (ENVIT) student group at the Massachusetts Institute of Technology. ENVIT was initiated in February 2001 by MIT doctoral students, Enrique Vivoni and Richard Camilli; funding was received in June 2001, from the MIT / Microsoft I-Campus Initiative; and the project began in September 2001. Central to the first phase of the project was a two part program involving 1) a seminar designed to introduce environmental engineering undergraduates to the integration of environmental science and computing and 2) a master of engineering project involving water resources and information technology team members pursuing the challenge of bringing computing power to environmental engineering. The diverse team of faculty advisors, graduate students, and undergraduate students all worked towards the design of Software Tools for Environmental Field Study (STEFS), and its field implementation in the Williams River watershed, New South Wales, Australia.

The work has lead to this thesis in which data from the STEFS campaign is utilized in a catchment-scale hydrologic and water quality model. This is an important end use for field sampled data in that it helps to summarize results and characterize the study area. The development of the Hydrologic Simulation Program – FORTRAN in its relevance to the STEFS campaign and the Williams basin will be explored in detail. However, some introduction to the technology that motivates the model study is presented first.

The tools developed by the STEFS team are both novel and useful in their integration. Mobile, hand-held computers contain software applications configured for facilitated data collection and analysis; wireless Local Area Network architecture enables seamless transfer of the collected and processed data between multiple teams; and mobile phone communication allows data transfer to the Internet for wide distribution and review. All of these are achieved while the multiple field teams are conducting the sampling study.

In the hands of a mobile field workforce, these tools allow for considerable savings in collection time and data transcription effort. The software design in the integrated system is both robust and flexible, so scientists can adjust the configuration should the project scope change; the wireless network saves time as field teams have instant access to others' results; and the data streaming to an Internet application allows project managers to have a real-time influence on the project from a remote location.

1.2.1 Organization

Scientific motivation of this development was the study of a river system in New South Wales, Australia. Water quality and hydrology impacts were investigated in relation to land uses within the river basin.

Based on this fundamental goal, undergraduate teams were to 1) design the graphical user interface of the personal device application such that river cross section geometry and associated water quality and quantity parameters could be easily entered while in the field; 2) design Geographic Information Systems (GIS) incorporating Geographic Positioning Systems (GPS) on the personal devices such that maps would be displayed with georeferenced location points while in the field; 3) prepare, configure, and integrate the water quality sensor (Hydrolab™), chemistry analysis kits, and biology testing kits with the rest of the system; and 4) prepare hardware customizations such as a waterproof encasement for the personal devices, a battery pack with the proper connections for all power needs, and a durable river velocity flow meter.

The information technology division of the master of engineering team was to 1) advise the undergraduates on their respective software, hardware, and computing assignments; 2) design hardware integration technology; 3) design software, central database, and application integration technology; and 4) design the wireless local area network (wLAN) technology and architecture. The water resource division of the master of engineering team was to 1) advise the undergraduates on their respective GIS, GPS, and environmental assignments; 2) advise the information technology team on the technological designs and their suitability for the field sampling campaign; 3) locate an interesting and suitable study site; 4) research and gather data from the study area and prepare field deployment strategies and schedules.

See reference [1] for details on the undergraduate student projects. For further details on the information technology specifics, see reference [2].

1.2.2 Research

The preliminary research for the STEFS development was directly in conjunction with the necessary research for this thesis. This entailed gathering as much information about study area, specific goals, and tools needed to fulfill the initial requirements. Many sites were considered, and the Williams River Watershed was selected based on its relatively large set of favorable characteristics over other site considerations. The catchment is 30 kilometers North of Newcastle, NSW, only a two hour drive from Sydney which was the team's point of entry. Furthermore, the proximity to Newcastle gave the study a convenient point of relief and a wealth of resources at the University of Newcastle.

Professor Garry Willgoose of the university's Department of Civil, Surveying, and Environmental Engineering is an alumnus of MIT, a seasoned observer of the Williams Watershed, and a native Australian. His help facilitated preparations and research efforts. GIS coverage maps of the catchment, including watershed boundary, digital land use, soil landscape, vegetation, and canopy density; digital elevation models at 1:25000 and 1:100000 resolution; and river network files were readily available.

The choice was made to project all data into geographic coordinates. Though some degree of spatial accuracy is lost in this projection, point location is facilitated in the geographic coordinate system of decimal degrees (dd). This was convenient for the STEFS campaign as existing monitoring stations are located in dd and the GPS units utilized by STEFS locate sampling sites in dd. Therefore, in the interest of facilitated point theme overlay in the field application GIS, the small amount of spatial error was acceptable. The maps are projected back to Cartesian coordinates for modeling analyses that require precise spatial accuracy.

1.2.3 STEFS

The STEFS database was intended to be robust and flexible so that adaptation to a variety of projects, sites, and sampling tools would be possible. The architecture can be divided into seven general data categories:

- Equipment
- Log in
- Calibration
- Measurement Validation
- GPS Locations
- Manual parameter entry
- Automated parameter entry

The equipment and log in entries are submitted through a desktop configuration application prior to field deployment. These datasets contain information about users, site locations, and equipment that is known as the deployment strategy is planned. This data is transcribed to the personal devices upon field deployment, at which time the user will select the particular records that apply. Similarly, calibration and validation information needs to be entered prior to field deployment to ensure that sensors are taking accurate readings. These tables are filled in using the same desktop application as the equipment and log in tables, and sensor readings will be referenced against these entries during the field study. GPS data, manually entered kit and instrument data, as well as automated instrument input are entered in the field. These tables remain blank until the field sampling begins.

As a compliment to the robust database framework, a two-phase configuration scheme is integrated to provide adaptive software application design. The first schema is a desktop/laptop application that resides on the network server. Its purpose is to pre-configure the database framework during the project planning stages. These forms were constructed with Visual Basic .NET and are dynamically linked to the database query code. The server application is designed to accept project-planning parameters such as project specifications, location information, team member information (users), personal device identification, instrument identification, and measurement kit identification. Once these preparation parameters are entered completely, the configured database is ready to be "pulled" onto the personal devices.

The database "pull" process is initiated by the personal device software application shown in Figure 1. This application is written in Embedded Visual Basic and is comparable to the desktop application. The personal device applications were designed to 1) provide facilitated data visualization and entry during field studies and 2) compliment the configured database design identically. A copy of the configured database is "pulled" into the personal device when a user enters an existing database name at the welcome screen. The tables are copied to the personal device, and a dynamic link is established between the application and the SQL Server CE query code. The database "pull" prepares the device for sampling input. During a field study, information is submitted to the graphical user interface, and the values are copied to the respective record within the proper table in the personal device database.

ENVIT Field Notebook
Version 1.0
Copyright 2001

MIT ENVIT Student Group
STEFS Project

Enter Database Name :

Select Existing Database : williamsriver

Depth: 4
Flow@0.0m: .1
Flow@3.2m: .4

Number of Sections: 10

Q (m3/s): 0.48780

Select a section segment. Enter the depth in meters. Enter the two velocities in ft/s.

Figure 1: Personal Device Software Application

The information is stored here until sampling at the specific location is finished. At this time, the personal device database can be "pushed" back to the server database. The server will accept updates from all of the personal devices within range of the wireless local area network. When a team arrives at a new site, the user will "pull" a new version of the central database onto the personal device and proceed as before.

The wireless local area network (wLAN) is the primary component within the STEFS integration scheme shown in Figure 2. The core of the wLAN is the "push" and "pull" model between the configuration (desktop/laptop) application, the field server database, the personal device database, and the personal device application.

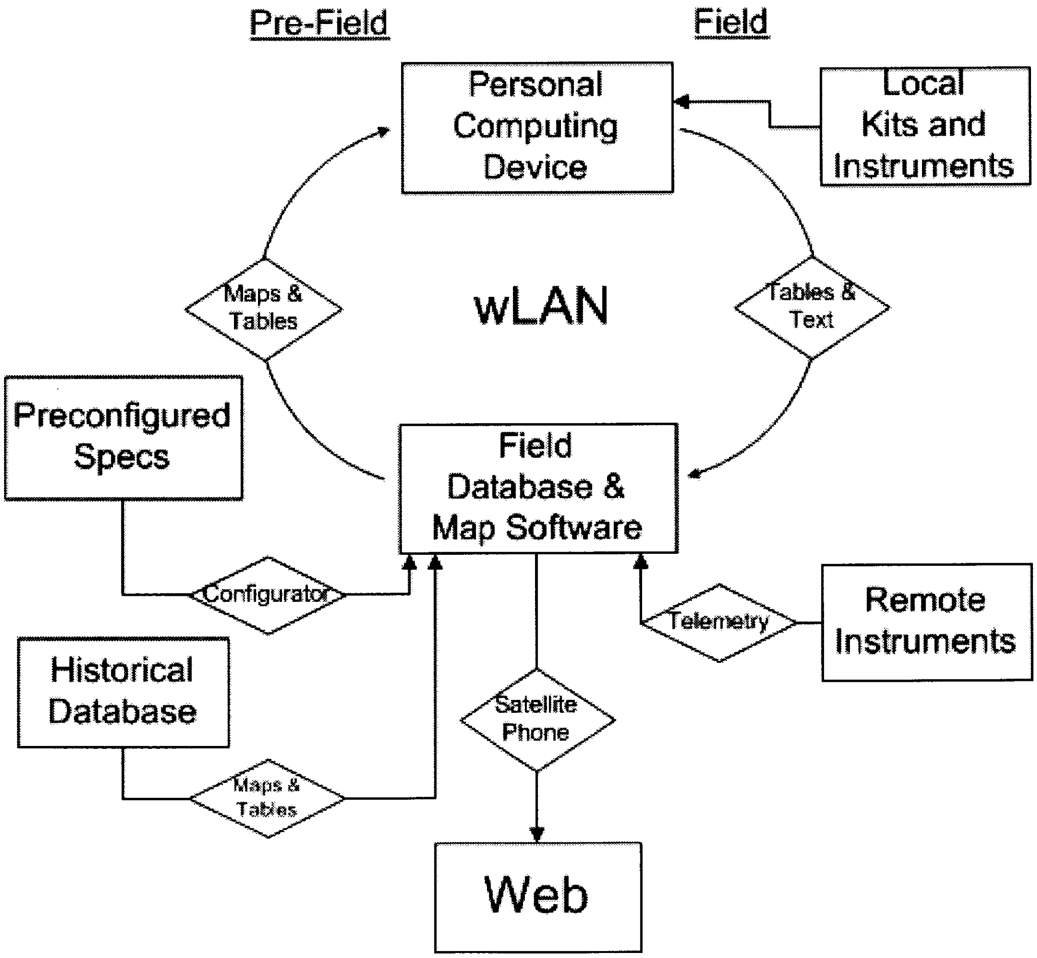


Figure 2: Integration Scheme

In addition to the configuration scheme, historical data is incorporated to the field server prior to field deployment. This incorporation can be as the insertion of tabular data or the processing of shapefiles, coverages, grids and/or tables into maps.

In the field, local kit measurement values and instrument measurement values are manually incorporated to the wLAN through the personal device application. Remotely sensed data can be telemetrically incorporated to the wLAN either directly, if the sensor is within range of the wLAN, or through the Internet. See reference [3] for further details on wireless integration.

The ultimate destination for the data gathered and processed within the wLAN is the Internet. All data can be uploaded at any time from the laptop to a remote Internet server if a satellite phone or other remote connection technology is used. The remote server is located at the home office or campus on a high-speed, continuous connection, where a project manager, professor, or consultant can manipulate data. The data may also be streamed into an Internet application. See references [4] and [5] for further details about Internet applications and mapping services.

The integration of a mobile central database with mobile software applications and the Internet is a powerful tool to utilize in environmental fieldwork. The system enables real-time computer processing of collected field data and instant visualization of the results. With this tool, a field scientist is dynamic.

1.3 Objective

Dynamic research enabled by mobile computing requires an equally dynamic model with which to process the data. A good synergy between the mobile computing network, the software architecture, and a functional watershed model is a powerful step towards real-time modeling of hydrology and water quality parameters. It is possible for a model to interact with STEFS in three ways: 1) Mobile computing provides the flexible framework with which to perform an initial study oriented towards model input collection. 2) Mobile computing can work in conjunction with a functional watershed model running on the home server so that a field team can collect real-time calibration data during a meaningful event (e.g. storm, chemical spill, etc. 3) Finally, a future generation of personal device that contains adequate memory and processing speed may contain an embedded model such that field workers can utilize real-time modeling in the field.

This thesis focuses on the first interaction, and the utilization of a watershed model in the aftermath of a field campaign. It is useful in the study of a remote site to perform a detailed investigation prior to model use because it is inevitable that the necessary knowledge and required datasets that go into a thorough watershed model are not realized through research alone.

This thesis develops the readily available catchment-scale model, Hydrologic Simulation Program – FORTRAN (HSPF) with its windows interface program, the Better Assessment Science Integrating Point and Non-point Sources (BASINS) for use on a foreign study site, the Williams River, New South Wales, Australia. The model is based on United States Environmental Protection Agency databases and is thoroughly tested on domestic watersheds. The integrated package links the algorithms for contaminant propagation and hydrologic response in a watershed with the topographic capabilities and graphical convenience of Geographic Information Systems (GIS). The package is a very useful tool in utilizing modern technologies for water quality assessment if the model inputs are plentiful and properly formatted.

Thus, entrainment of foreign datasets into the BASINS package is a non-trivial investigation that constitutes a significant portion of this study. Model inputs are primarily from historical data archives. Various governmental agencies maintain an inventory of datasets from water quality and quantity monitoring sites throughout the Williams catchment. Much of this expansive data source was available for the uses of this study. The model inputs that are not fulfilled by archives are supplemented by data acquired during the STEFS field deployment in January 2002.

A study area description is illustrated, the subsequent model selection process is described, a methodology for the incorporation of incompatible datasets into the dedicated BASINS framework is presented, simulations are run, and results are discussed.

2 Study Area

2.1 The Williams River Watershed

The area of interest is the Williams River catchment in the lower Hunter Valley Region of New South Wales, Australia. Shown in Figure 3, the watershed spans an approximate 1200 square kilometers, just to the North of Newcastle, and it supplies about 70% of the municipal drinking water for the city of Newcastle. This demand raises concern about water quality and hydrology issues within the basin.

Especially during the summer months of January and February, increased volumes of precipitation can raise the surface water runoff to as much as 80000 megaliters per day (~800 cubic meters per second), and it tends to wash large amounts of nutrients, sediment, and bacteria into the system from the surrounding land. During rain events, there is a high incidence of water quality parameters exceeding health guidelines throughout the river.

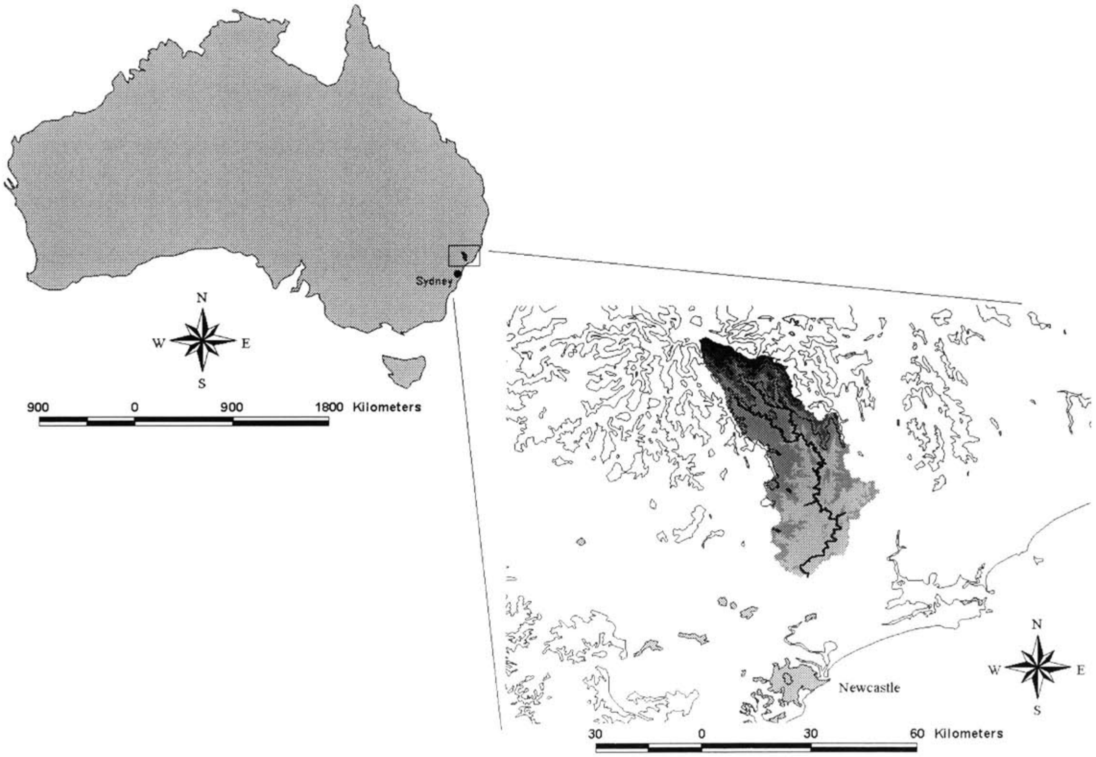


Figure 3: The Williams River Watershed

One possible contribution to these issues is the land use distribution. Of the 1200km^2 area, approximately one-third is forested with eucalyptus and other natural trees. The remaining two-thirds are composed of natural grasses utilized as grazing land for beef cattle. These regions have been mostly cleared of natural trees [6]. Figure 4 displays this land use distribution. There are patches of urban development throughout the catchment, and there are spotted cropping uses along the riverfront.

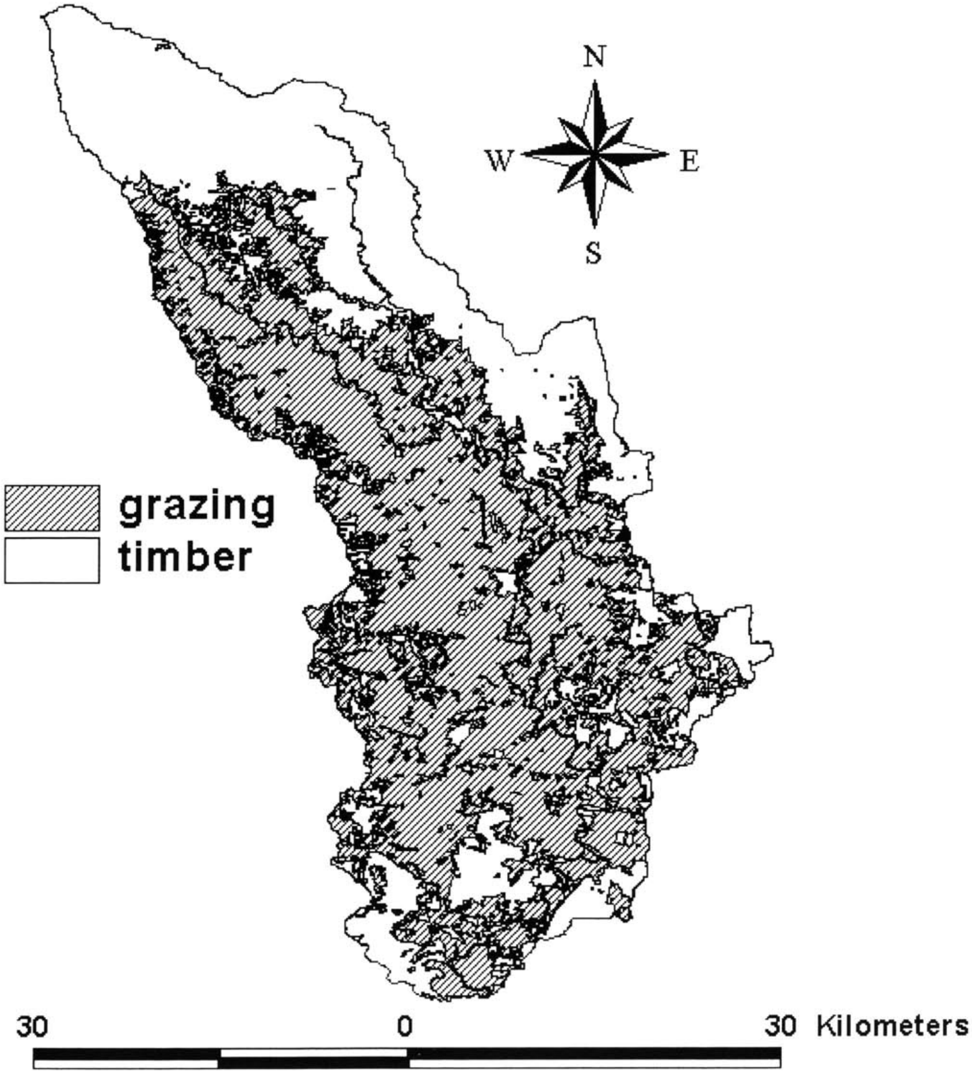


Figure 4: Williams Watershed Land Uses

The University of Newcastle's Department of Civil, Surveying, and Environmental Engineering donated GIS datasets, including land use, vegetation, soils, and stream network. Water Quality and other historical time series datasets were obtained from the Hunter Water Corporation, the New South Wales Department of Land and Water Conservation, and the Australian Bureau of Meteorology. These data enabled a solid grasp of the surface characteristics the model selection was to be based upon.

Subsurface characteristics have to be considered in the selection of a proper model, as well. Groundwater pressure gradients may push water to a surface basin far from the basin of initial infiltration, and the water can be as old as 10000 years by the time it surfaces (C. Harvey, pers.comm., 2001). This raises an appreciable amount of uncertainty in the watershed boundary, but an analysis of subsurface conditions will minimize the uncertainty.

In summary of this analysis, the basin subsurface is characterized by a dual horizon profile. The near-surface layer is shallow and consists of various sandy/silty permeable soils. A clay layer lies beneath the relatively permeable surface layer, and the interface creates an effective lateral subsurface flow. Beneath the clay lies foundation of volcanic and sedimentary rock, impeding the intrusion of deep groundwater to the effect of a system with minimal deep water "slow-flow" contributions [7]. This characteristic validates the watershed delineation as a hydrologic boundary, and focuses modeling interest on surface water processes.

The surface area land uses and their potential non-point source water quality issues inspired the environmental modeling effort in this project.

- Cropping → Nutrient Loading
- Grazing → Sedimentation
- Grazing → Bacteria Loading

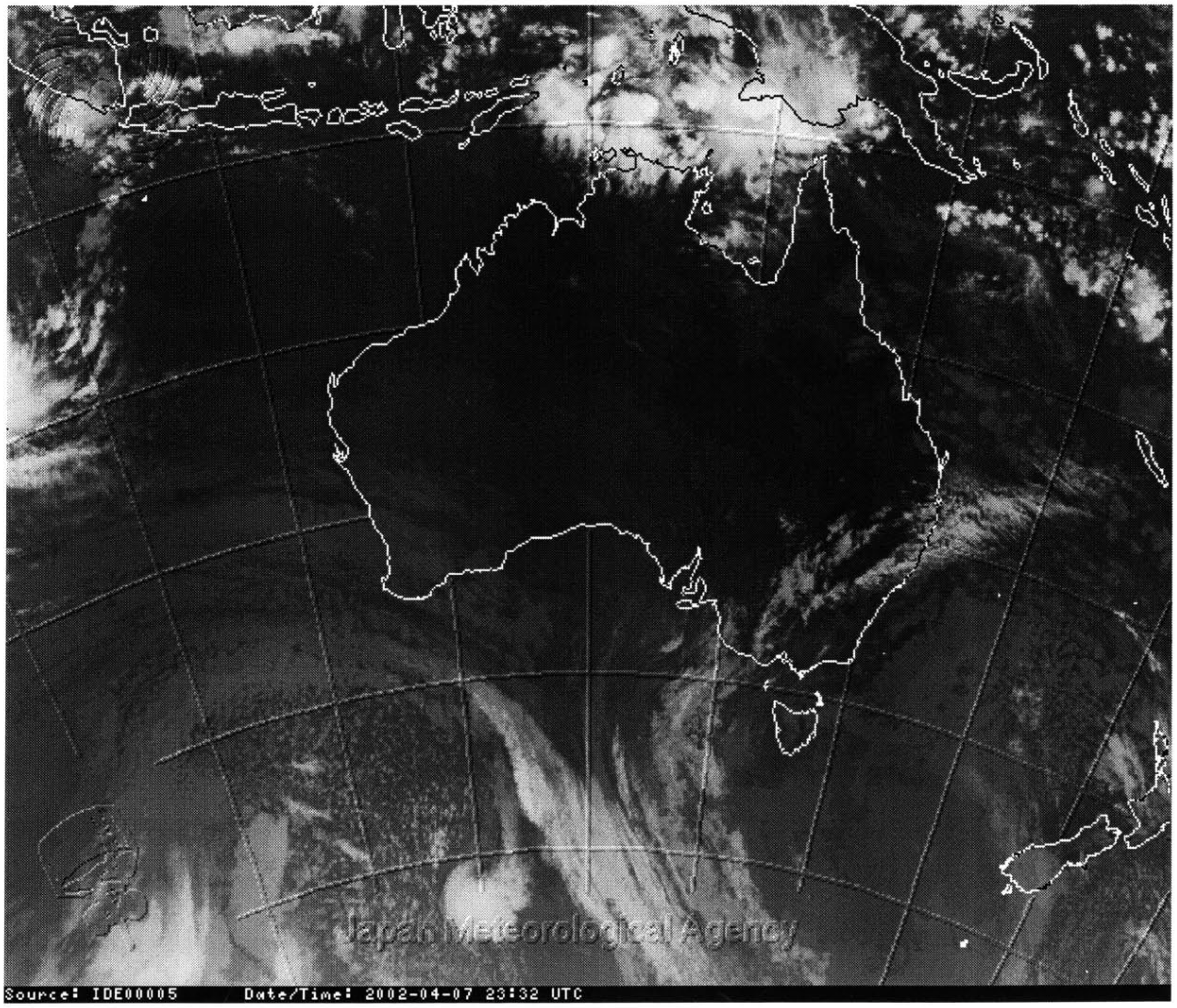
Although the cropping uses are very limited, their proximity to the river demands some attention in regards to nutrient loading that fertilizers and pesticides may introduce. The excess nutrients enrich the growth of particular blue-green algae. Anabaena is a resilient fresh water cyanobacterium that is filamentous (it binds together into single cell chains) and attaches symbiotically to diatoms. The symbiotic relationship is based on Anabaena's ability of nitrogen fixation in which it reduces elemental nitrogen to ammonia as food. The single-celled plants thrive on the increased nitrogen intake, and Anabaena's constructive abilities are enhanced by the symbiotic bond, so when the nutrient load is high, they thrive in mutual resilience. The result is an algal bloom downstream, especially in the relatively still waters of the Seaham Weir pools at the South border of the watershed. The blooms can spread rapidly as the bacteria multiply, and before long, the stream is toxic to other species including humans.

The second concern is in relation to excess erosion caused by grazing uses. Not only do the cattle themselves influence riverbank erosion when they come to the stream, but the relative lack of natural vegetation in grazing regions contributes. Relatively shallow roots of the grasses replace the natural, soil-binding root systems of diverse vegetation. This vegetative monopoly reduces soil cohesion, and excess erosion accompanies heavy storms.

The final concern is bacteria count escalation during the wet season. In addition to Anabaena blooms, the concentrations of various pathogens rise as cattle waste is washed into the river.

These three water quality issues are certainly escalated during the wet season, so a focus on the weather patterns of the summer months between December and March is warranted.

The catchment is located between the 32° and 33° South Latitudes on the border zone of the Sub-tropical High and the mid-latitude Westerlies. Though weather is typically dominated by the synoptic high-pressure system, there is consistent bombardment by low-pressure troughs, "Southerly Busters," that precede Antarctic cold fronts. Furthermore, the Intertropical Convergence Zone is shifted South during the summer. The resulting atmospheric moisture colliding with the "Southerly Busters" cause peak precipitation in the summer months throughout the Newcastle area. A satellite image of the seasonal weather pattern is depicted in Figure 5.

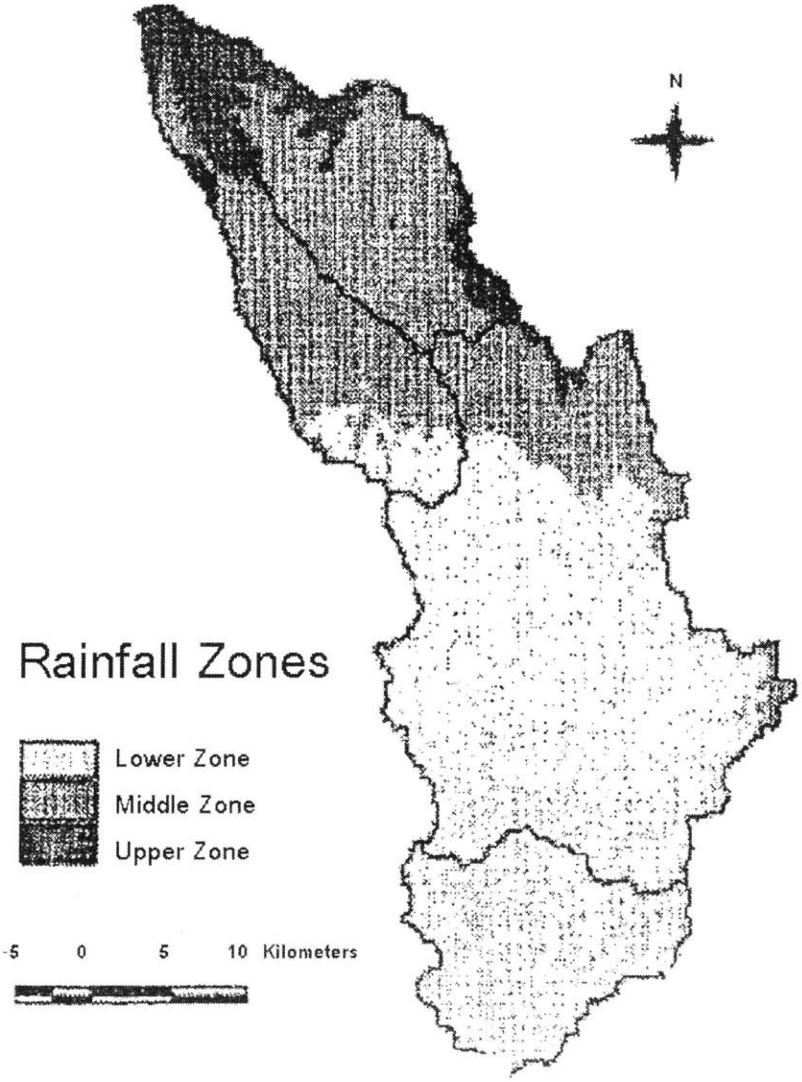


(http://www.bom.gov.au/, 2002)

Figure 5: Satellite Image of Seasonal Weather Pattern

Within the Watershed, there are three precipitation effects as shown in Figure 6:

1) The Upper Zone, to the North, receives high volumes of precipitation due to an orographic effect in the Great Dividing Range peaks at Barrington Tops; 2) the Lower Zone, to the South, receives significant volumes of precipitation due to a coastal effect; and 3) the Middle Zone is characterized by relatively moderate volumes of precipitation, most likely due to a collision of the two dominant effects [7].



Adapted from reference [7]

Figure 6: Williams Watershed Rainfall Zones

These effects cause significantly variable rainfall throughout the basin. However, daily precipitation records are kept from several sites throughout the Williams catchment as shown in Figure 7.

Datasets from two flow monitoring sites complement the precipitation readings with sub-basin outlet flow. One of these sites is at the outlet of the Tillegra region for which the Barrington Guest House precipitation monitoring site corresponds, and the other flow monitoring site is at Glen Martin @ Mill Dam Falls.

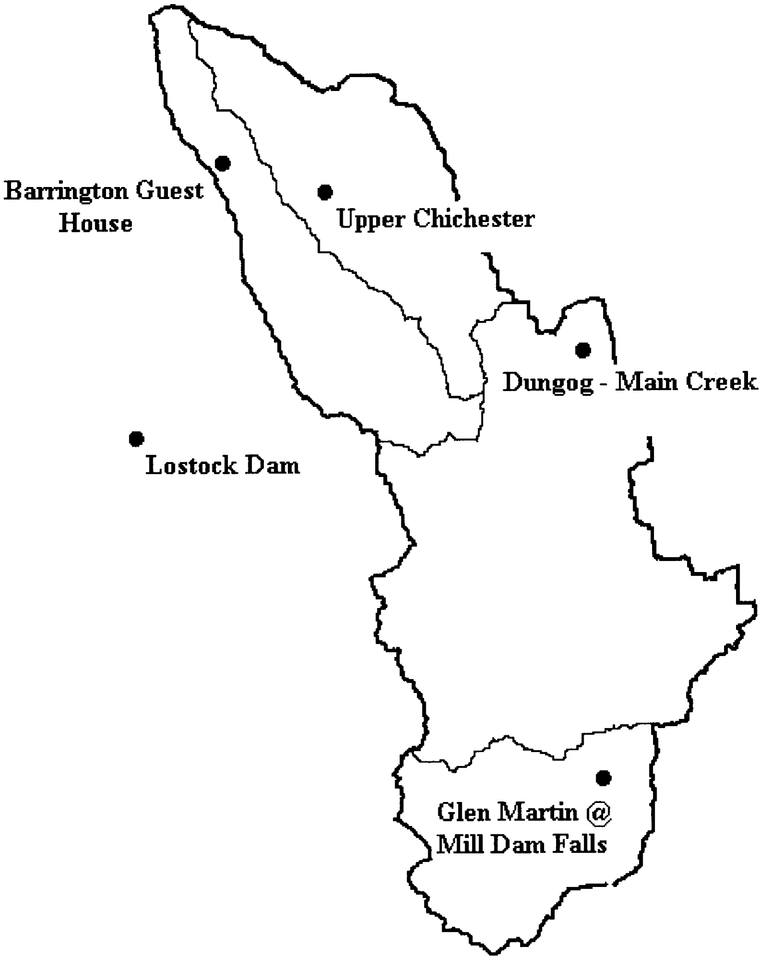


Figure 7: Precipitation Monitoring Sites

2.2 Tillegra

The Tillegra region, located in the Northwest of the watershed, is shown in Figure 8. This region is particularly interesting for three reasons:

- Its stream flow characteristics are affected entirely by precipitation from the Upper Zone that can be accurately represented by the Barrington Guest House monitoring site.
- It is a completely unregulated sub-basin. The Chichester Dam and the Seaham Weir alter natural flow through the Upper Chichester and the middle to lower reaches of the Williams, but the Upper Williams maintains a natural response to timber and grazing land uses.
- Finally, there is significant cattle grazing in the region, and historic bacteria contamination has been seen at the Tillegra monitoring site.

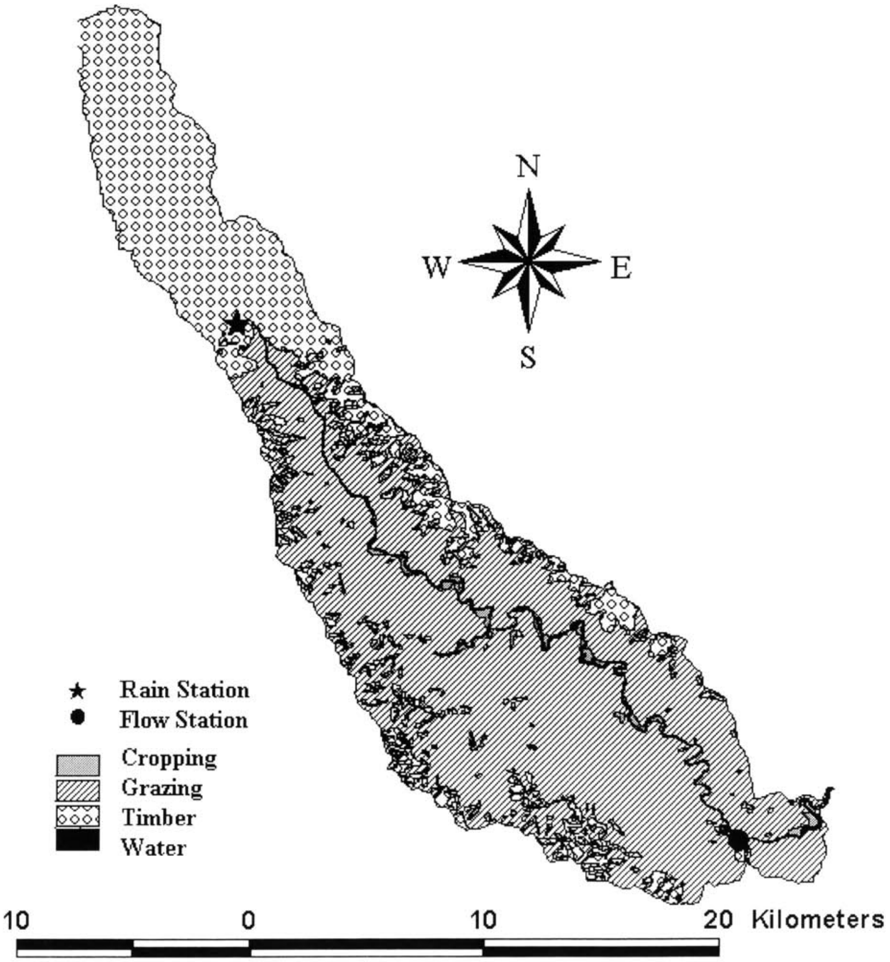


Figure 8: Tillegra

The land use contributions to the sub-basin are as follows:

• Grazing and Grassland	32774 acres
• Timber	16858 acres
• Cropping	480 acres

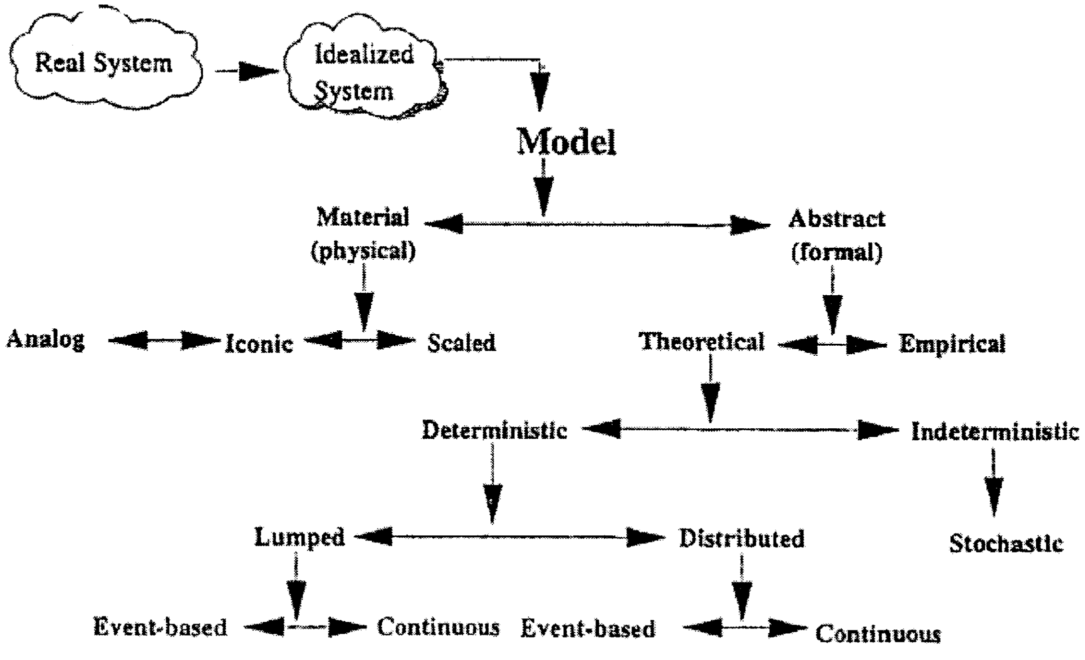
Simplifying the study to this smaller area enables a more detailed analysis of model sensitivity to parameter changes. These focused model scenarios are run with the Barrington Guest House precipitation set, and flow is simulated at the outlet of Tillegra. This flow is compared with historically observed flow at the Tillegra monitoring site. Chapter 5 discusses the comparison between simulated and observed flows in further detail.

3 Model Selection

3.1 Criteria

Based on the knowledge gained about the Williams River Watershed, the first and most critical criterion in model selection is a dedication to surface response simulation. The next decision is what kind of model to use. Figure 9 displays an abstracted depiction of model categorization from which to choose the proper model.

For the purposes of hydrologic and water quality control/management on the watershed-scale, the objective is to account for and simulate a great variety and quantity of inputs, controls, and states over a large area of interest. The principle outputs of interest are a stream flow and a contaminant concentration at a particular time and location of interest. The driving input with which to simulate these outputs is a time-series array of precipitation data.



Adapted from reference [8]

Figure 9: Abstracted Model Categorization

Additional forcing influences on the surface water budget are potential evapotranspiration, wind speed, solar radiation, and other land-atmosphere interaction parameters. Vegetation, land, and soil characteristics govern the surface response to these meteorological influences, so the hydrologic and water quality model must represent these controls, as well.

If Geographic Information Systems (GIS) data sets are available for the watershed of interest, many of the surface control characteristics can be modeled graphically. However, most of the characteristics and all of the interaction processes require theoretical abstraction and mathematical representation. Therefore, the proper surface hydrologic and water quality model will be a deterministic representation of the interactive processes based on known time-series and spatial inputs from monitored or sampled datasets.

The Williams River System has the convenient land use layout described in the previous section that allows surface control factors to be "lumped" into two principal units of homogeneity. Furthermore, the motivation of this study is in the interest of watershed management including water resources and land use planning; therefore, a continuous simulation capability is desirable. An event-based model is the other option within the deterministic framework, and it is useful in observing detailed impacts at specific locations during specific events, but this would have to be a supplement within a continuous watershed management strategy. Also specific to the Williams study is the readily and thoroughly available GIS data sets provided by the University of Newcastle. Therefore, a continuous and lumped computer simulation of surface water hydrologic and water quality processes integrated with GIS is ideal.

A thorough evaluation of various water models was conducted by Camp Dresser & McKee Inc. [9]. Tables 1 and 2 display summaries of that model study and were the primary aid in choosing the Hydrologic Simulation Program – FORTRAN to model the Williams River watershed.

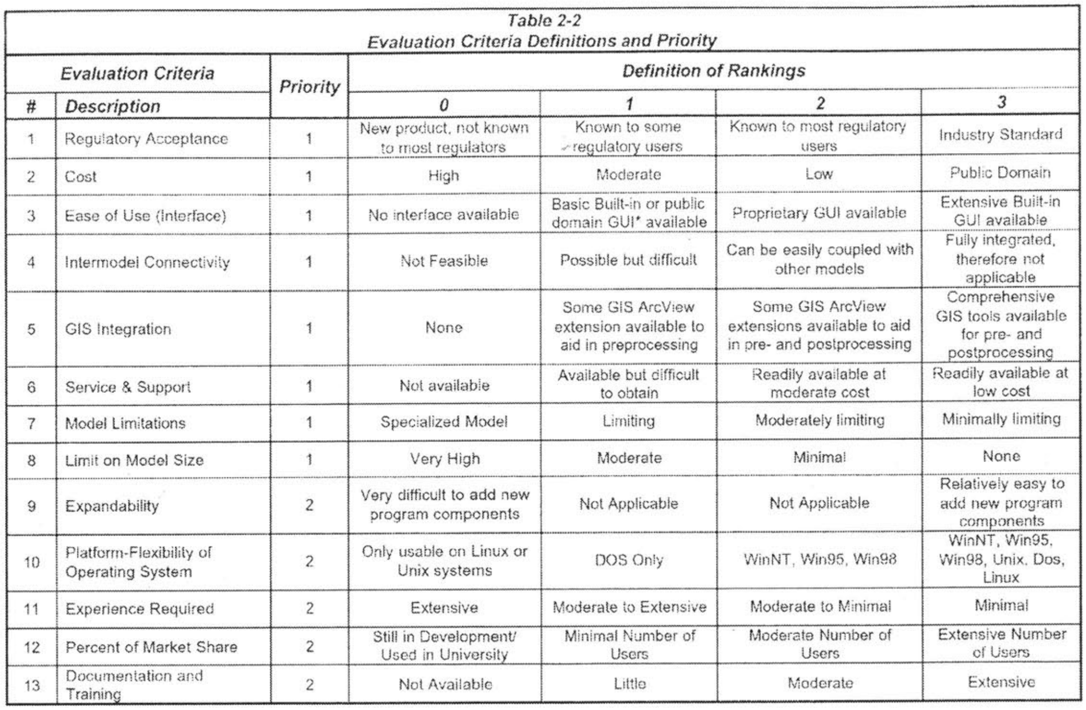


Table 2-2

Evaluation Criteria Definitions and Priority

Evaluation Criteria		*Priority*	*Definition of Rankings*			
#	*Description*		*0*	*1*	*2*	*3*
1	Regulatory Acceptance	1	New product, not known to most regulators	Known to some regulatory users	Known to most regulatory users	Industry Standard
2	Cost	1	High	Moderate	Low	Public Domain
3	Ease of Use (Interface)	1	No interface available	Basic Built-in or public domain GUI* available	Proprietary GUI available	Extensive Built-in GUI available
4	Intermodel Connectivity	1	Not Feasible	Possible but difficult	Can be easily coupled with other models	Fully integrated, therefore not applicable
5	GIS Integration	1	None	Some GIS ArcView extension available to aid in preprocessing	Some GIS ArcView extensions available to aid in pre- and postprocessing	Comprehensive GIS tools available for pre- and postprocessing
6	Service & Support	1	Not available	Available but difficult to obtain	Readily available at moderate cost	Readily available at low cost
7	Model Limitations	1	Specialized Model	Limiting	Moderately limiting	Minimally limiting
8	Limit on Model Size	1	Very High	Moderate	Minimal	None
9	Expandability	2	Very difficult to add new program components	Not Applicable	Not Applicable	Relatively easy to add new program components
10	Platform-Flexibility of Operating System	2	Only usable on Linux or Unix systems	DOS Only	WinNT, Win95, Win98	WinNT, Win95, Win98, Unix, Dos, Linux
11	Experience Required	2	Extensive	Moderate to Extensive	Moderate to Minimal	Minimal
12	Percent of Market Share	2	Still in Development/ Used in University	Minimal Number of Users	Moderate Number of Users	Extensive Number of Users
13	Documentation and Training	2	Not Available	Little	Moderate	Extensive

Adapted from reference [9]

Table 1: Model Evaluation Criteria and Rankings

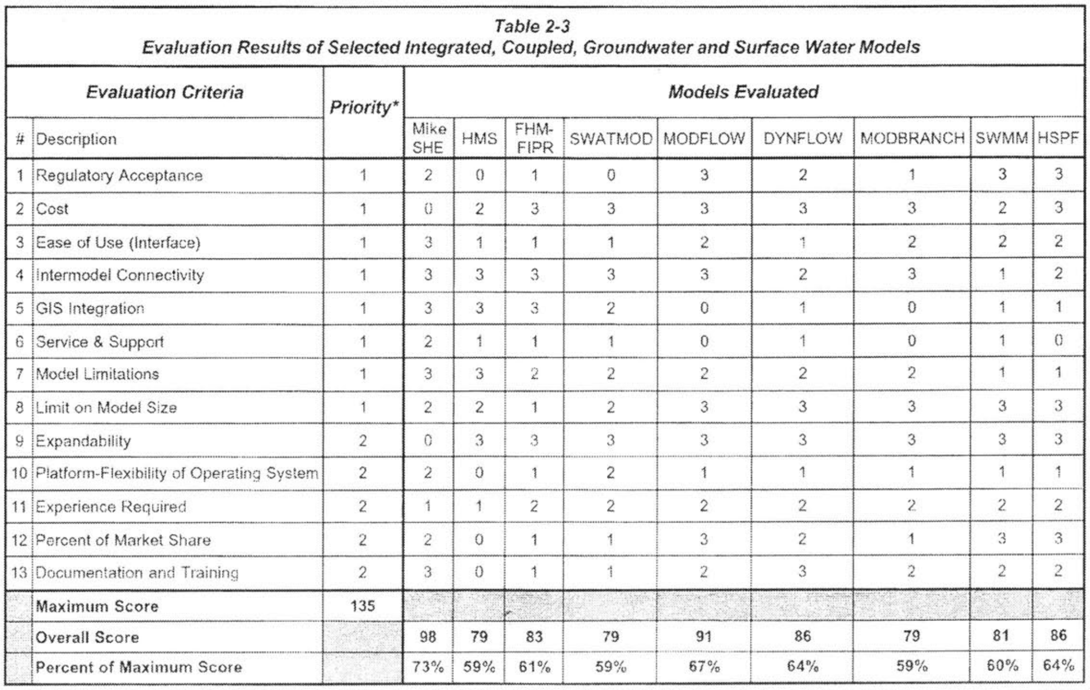


Table 2-3

Evaluation Results of Selected Integrated, Coupled, Groundwater and Surface Water Models

Evaluation Criteria		*Priority**	*Models Evaluated*								
#	Description		Mike SHE	HMS	FHM-FIPR	SWATMOD	MODFLOW	DYNFLOW	MODBRANCH	SWMM	HSPF
1	Regulatory Acceptance	1	2	0	1	0	3	2	1	3	3
2	Cost	1	0	2	3	3	3	3	3	2	3
3	Ease of Use (Interface)	1	3	1	1	1	2	1	2	2	2
4	Intermodel Connectivity	1	3	3	3	3	3	2	3	1	2
5	GIS Integration	1	3	3	3	2	0	1	0	1	1
6	Service & Support	1	2	1	1	1	0	1	0	1	0
7	Model Limitations	1	3	3	2	2	2	2	2	1	1
8	Limit on Model Size	1	2	2	1	2	3	3	3	3	3
9	Expandability	2	0	3	3	3	3	3	3	3	3
10	Platform-Flexibility of Operating System	2	2	0	1	2	1	1	1	1	1
11	Experience Required	2	1	1	2	2	2	2	2	2	2
12	Percent of Market Share	2	2	0	1	1	3	2	1	3	3
13	Documentation and Training	2	3	0	1	1	2	3	2	2	2
	Maximum Score	**135**									
	Overall Score		**98**	**79**	**83**	**79**	**91**	**86**	**79**	**81**	**86**
	Percent of Maximum Score		**73%**	**59%**	**61%**	**59%**	**67%**	**64%**	**59%**	**60%**	**64%**

Adapted from reference [9]

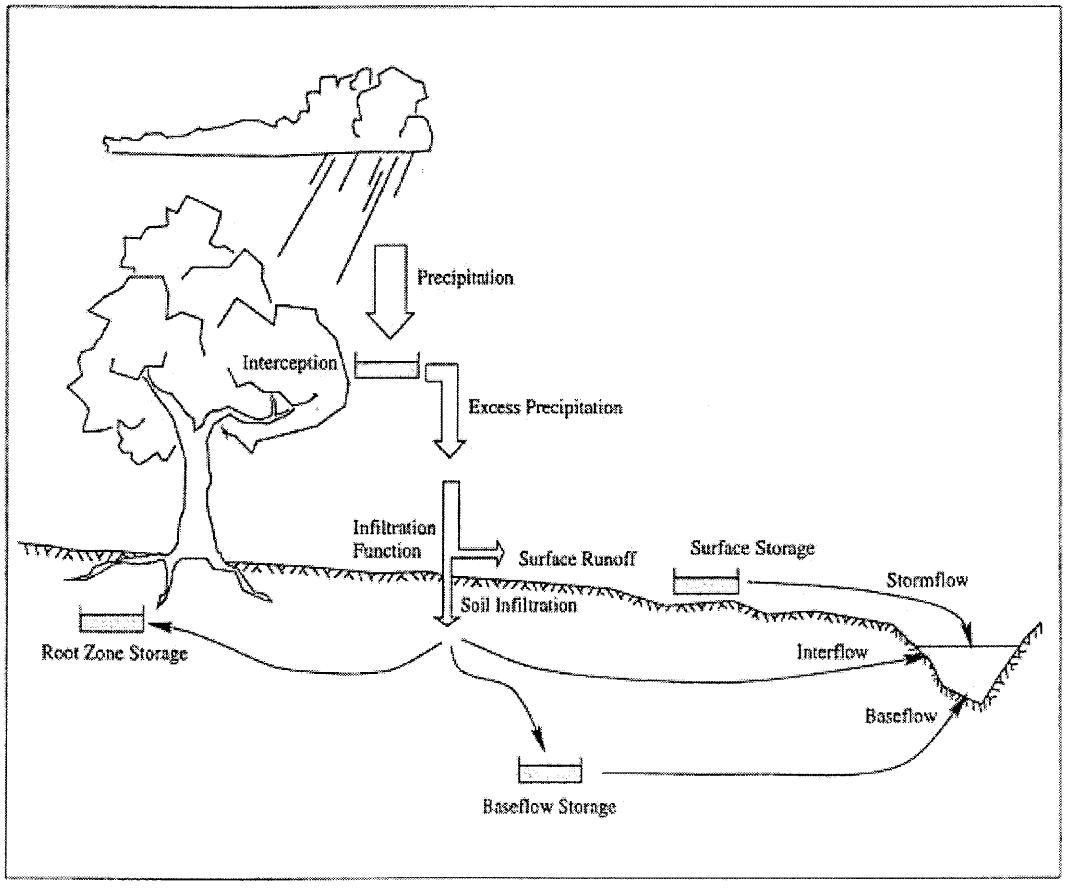
Table 2: Model Evaluation Results

3.2 HSPF

The Hydrologic Simulation Program – FORTRAN (HSPF) was selected based on the following three factors:

- Focus on Surface Water processes
- Cost
- Interface

The first factor is accounted for in the HSPF allocation of surface components of the water budget as shown in Figure 10. The Williams subsurface profile negates the effects of "baseflow," so the system is modeled by the interaction of vegetative interception processes, surface runoff and storage parameters, land surface infiltration, and "interflow."



Adapted from reference [10]

Figure 10: Hydrologic Cycle in a River System

The second criterion was an issue due to the expenses of software development and hardware configuration during the STEFS campaign. It was not cost efficient to spend money on an advanced model with HSPF publicly available.

The final criterion in the model selection process was the GIS interface. HSPF has a convenient user interface that connects water quality algorithms with GIS. The Better Assessment Science Integrating Point and Non-point Sources (BASINS) provides a relatively seamless link between the HSPF algorithms and the Environmental Systems Research Institute GIS software, Arcview. This was suitable for the project due to the availability of thorough GIS data sets.

3.3 BASINS

The United States Environmental Protection Agency developed the Better Assessment Science Integrating Point and Non-point Sources (BASINS) as a watershed management tool that integrates GIS, national watershed and meteorologic databases, and a variety of environmental assessment and modeling tools into one graphically interfaced suite.

The system has been utilized in many arenas throughout the United States:

- identifying impaired surface waters from point and non-point pollution;
- wet weather combined sewer overflows (CSO);
- storm water management issues;
- drinking water source protection;
- urban/rural land use evaluations;
- habitat management practices.

These uses are enabled by a range of data management, visualization, and modeling tools:

- nationally derived environmental and GIS databases (the 48 continuous states and the District of Columbia);
- assessment tools for evaluating water quality and point source loadings on large or small scales;
- data import and management utilities for local water quality observation data;
- two watershed delineation tools;
- utilities for classifying elevation, land use, soils, and water quality data;
- in-stream water quality model (QUAL2E);
- simplified GIS-based non-point source annual loading model (PLOAD);
- two watershed loading and transport models (HSPF and SWAT);
- postprocessor of model data and scenario generator to visualize, analyze, and compare results from HSPF and SWAT (GenScn);

(Adapted from http://www.epa.gov/ost/basins)

Through the ArcView interface, shown in Figure 11, the user can better visualize the watershed and its issues. Beginning with the basic ArcView watershed files: land use, digital elevation model, soils, and watershed boundary, the user can process the map characteristics and associated attributes into the properly discretized sub-basin parameters that the embedded models require. The simulation models run in the same Windows environment using data input files generated by BASINS processing.

WinHSPF is one of these Windows enabled codes. The original FORTRAN routines have been linked to the BASINS objects with some Visual Basic commands, and the object-oriented, graphical package facilitates use and understanding of a watershed model. However, for every unit of convenience that the integrated system provides, a unit of flexibility is lost, and custom applications are difficult to enable.

Thus the decision to use BASINS for a foreign watershed is not straightforward. The system functionality is based largely upon the large data requirement that is satisfied by the EPA databases. These data sets are plentiful, properly formatted, and well tested to supply a steady stream of inputs for a United States based study. Chapter 4 describes a method for integrating a set of foreign data with the BASINS and winHSPF framework. Relative discontinuities and incompatible formatting are inevitable problems, but they can be supplemented by a technically oriented field campaign utilizing STEFS.

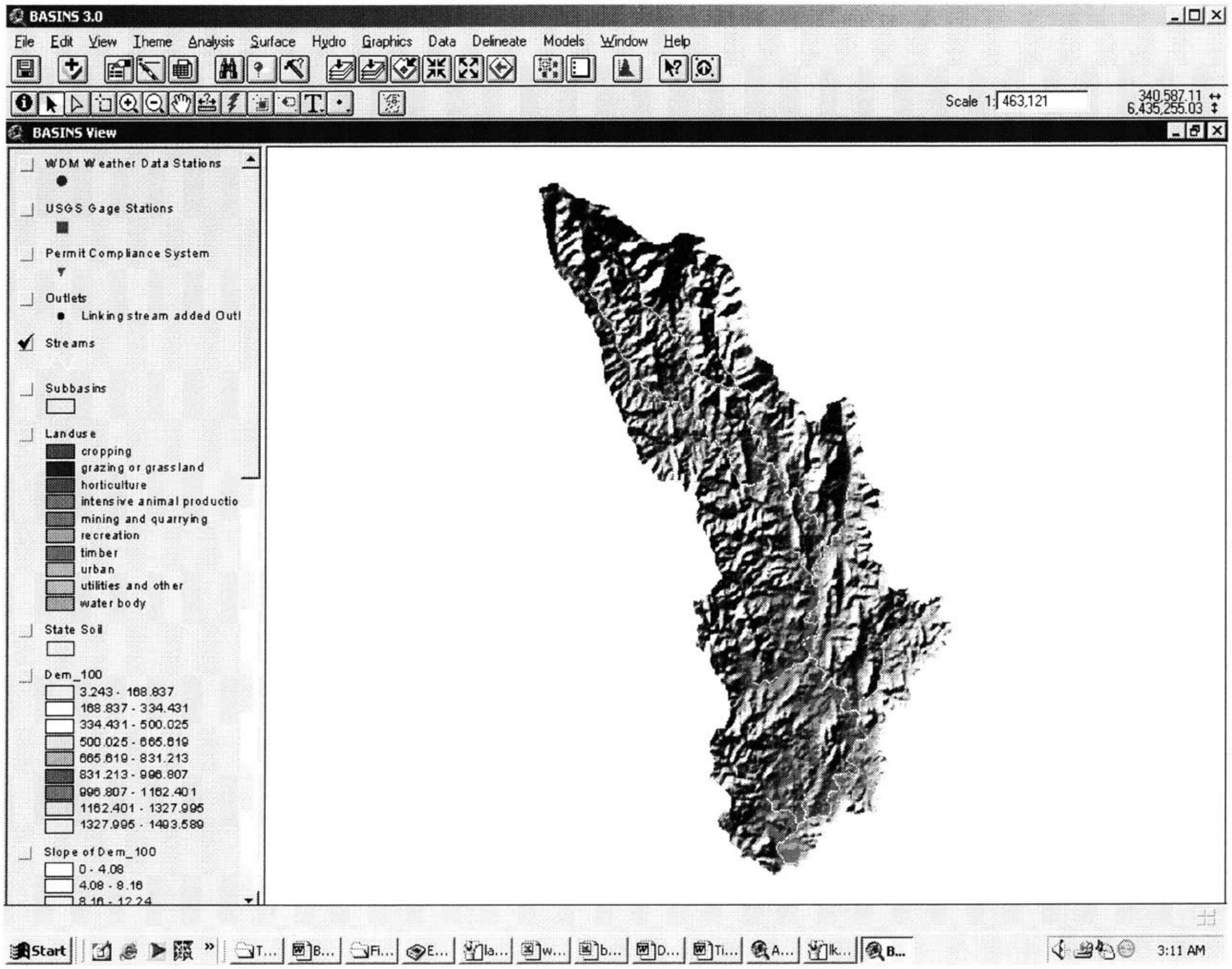


Figure 11: BASINS Graphical User Interface

4 Data Processing

A great challenge in working on a foreign study area and its associated data sets is the inevitable incompatibility of units and file formats. Ideally, an experienced modeler will be aware of the input needs with regards to these variables, and STEFS can be configured to account for the conversions.

Also problematic for a data intensive program such as HSPF are discontinuous input files. The routines are not written to navigate through blank fields in the input stream. These discontinuities are common, and in some cases, entire files may be absent. This chapter describes a process for importing external GIS data into BASINS, constructing the proper forcing files from foreign meteorology series, extrapolating missing data, and translating it all into the proper formats for HSPF to use.

4.1 Sampled Data

The necessary HSPF input files were, for the most part, available from transcription of historic archives, yet channel survey data was not available. HSPF assigns detailed channel geometry parameters to all reaches throughout the river system. The *.rch files consist of a cross section profile including:

- Length (ft)
- Mean depth (ft)
- Mean width (ft)
- Channel depth (ft)
- Longitudinal Slope
- Maximum depth (ft)
- Manning's roughness coefficient
- Side slope of upper flood plain
- Side slope of lower flood plain
- Zero slope flood plain width left (ft)
- Side slope of channel left
- Side slope of channel right
- Flood side slope change of depth (ft)

Historical sets of these data were not available from the local authorities. This problem was not foreseen, or plans would have been made to include a detailed cross section survey within the STEFS deployment schedule.

Fortunately, width and depth measurements were taken as part of the field sampling campaign. These measurements will be the foundation of the cross-sectional geometry analysis based on an assumption of channel geometry continuity: in an unregulated system, if soil characteristics are relatively homogeneous, slope is relatively constant, surface roughness characteristics are relatively uniform, and channel depth is relatively constant, channel width is proportional to flow as seen in Manning's equation:

$$V = \frac{Q}{(B*h)} = \frac{1.49*R_h^{2/3}*S^{1/2}}{n}; \quad \therefore Q \propto B$$

V = Velocity
Q = Flow
B = Width
h = Depth
R_h = Hydraulic radius (Cross sectional area / Wetted perimeter)
S = Channel slope
n = Manning's roughness coefficient

Table 3 displays channel width measurements taken throughout the watershed during the STEFS field campaign. Using the measurements and the continuity assumption, width can be extrapolated throughout the watershed by utilizing ArcView. ArcView processes a flow accumulation grid for each cell in a digital elevation model by calculating the upstream topography characteristics and counting the number of grid cells that contribute to flow at the calculation cell.

	Width (ft)		Width (ft)
Upper Tillegra	6.56	Lower Chichester	56.09
Middle Tillegra	12.14	Upper Williams	57.4
Lower Tillegra	30.18	Middle Williams	68.88
Upper Chichester	36.74	Lower Williams	127.92

Table 3: Channel Width Measurements

Since the Williams digital elevation model is comprised of 100m grid cells, the flow accumulation number represents the upstream area of flow contribution in hectares (1 hectare (ha) = 10000m^2).

Figure 12 displays a plot of measured channel widths versus flow accumulation for the corresponding sites throughout the watershed. Assuming 1) an average depth for each location, 2) an average theoretical slope for each location based on calculations from the ArcView digital elevation model, and 3) uniform channel roughness, the ordinate is directly proportional to the abscissa, and a linear trend can be fit to the plotted points. This enables the modeler to extrapolate channel width at any point in the watershed.

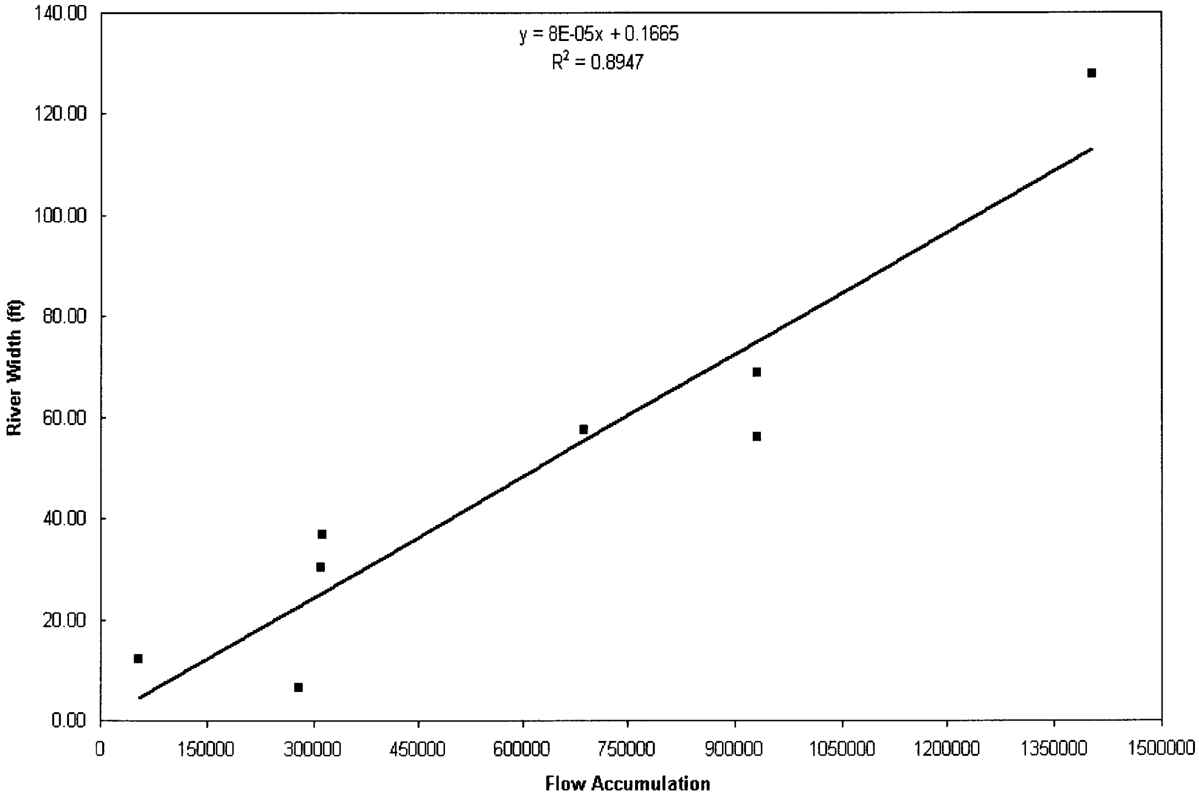


Figure 12: Channel Width Extrapolation

A closer look is taken at the Tillegra region in preparation for data input to the model. Table 4 displays utilized measurements and corresponding calculation results. Channel width, average channel depth, and river velocity were measured in the field; cross sectional area was calculated as $B*h$; average slope was calculated from the digital elevation model in ArcView; and Manning's roughness coefficient was calculated with Manning's equation.

	Width (ft)	Avg.Depth (ft)	X-Sectional Area (ft^2)	Avg.Slope	Velocity (ft/s)	Manning's n
Upper Tillegra	6.56	0.52	3.41	0.0027	1.5	0.03
Middle Tillegra	12.21	0.328	4.00	0.0022	0.4	0.08
Lower Tillegra	30.36	0.51	15.48	0.0021	0.5	0.09

Table 4: Tillegra Region Channel Survey Parameters

Slope variations can be observed in the shaded digital elevation model of Figure 11. The peaks of the Northern region are as high as 1500m (4920 ft), and the plains of the Southern region are near sea level. Thus local-scale topography is fairly variable; however, within a river channel, average values of longitudinal slope are assumed to maintain relative constancy. The upper Tillegra channel was analyzed as descending approximately 93 meters over an effective reach length of 34672 meters, the middle Tillegra channel drops 25 meters over a reach length of 11375 meters, and the lower Tillegra channel drops 47 meters over a length of 22450 meters. These approximations were used to calculate longitudinal slope for the respective stream reach, and in conjunction with field measurements, calculate Manning's roughness coefficient.

Typical values of Manning's roughness coefficient vary from 0.05 for an extremely rough natural channel (ie. heavy vegetation), to 0.012 for a smooth concrete channel [11]. Therefore, the value obtained for the upper reach of the Tillegra sub-basin is accurate in depicting a rough natural channel. The unacceptable values obtained for the middle and lower Tillegra will be replaced with a Manning's n of 0.03 in the model. The inaccuracy of these calculations could be due to a number of errors.

The STEFS campaign was not devoted to channel survey, so there were not enough measurements taken to statistically verify accuracy. Moreover, each measurement was taken hastily due to the accelerated schedule of the STEFS deployment. If model accuracy depends on these measurements, the STEFS data is not sufficient. However, these measurements are accurate enough to be useful in testing HSPF sensitivity to customized inputs. Channel width and average depth will be incorporated as measured. Longitudinal slope will be input as calculated, and Manning's coefficient will be entered at the assumed value of 0.03. Chapter 6 will assess the value of these inputs in comparison to default values.

4.2 GIS Data

As stated in Chapter 3, one of the criteria in choosing HSPF was the interface to GIS layer inputs via EPA developed BASINS. The interface is very nice in its compatibility with GIS, but as with HSPF, it was designed to receive a large amount of very specific inputs. The "Project Builder" function of BASINS searches the EPA databases or a BASINS CDROM, either of which contains all 33 files that the BASINS functions expect. For the case of a foreign model, all 33 files may not be available, and even if they are, the file names, paths, and formats are likely to differ from the order that BASINS expects. The following chapter describes the process for entraining a foreign dataset with a minimum number of inputs into the stream of BASINS routines.

First, it is necessary to project all GIS data into a Cartesian coordinate system. Slope and other calculations that relate vertical and horizontal scales will not function properly in a Geographic coordinate system. The Williams GIS data was prepared as follows:

- Projection: TRANSVERSE
- Datum: AUA
- Units: METERS
- Spheroid: AUSTRALIANNATIONAL
- Parameters:
  - scale factor at central meridian: 0.99960000
  - longitude of central meridian: 153 0 0.00
  - latitude of origin: 0 0 0.000
  - false easting (meters): 500000.00000
  - false northing (meters): 10000000.0000

Three terms are used that should be clarified here: "Working project" refers to the model being developed for a foreign watershed; "sample project" refers to a relevant and functional BASINS project for a domestic watershed; and "dataset folder" refers to a folder under the directory \BASINS\data into which all GIS inputs relevant to the working project must be copied.

The data preparation process involves: 1) Create a dataset folder; 2) identify key sets in the working project and name them identically to similar sets in a sample project; 3) construct a projection identification file and copy it to the dataset folder; 4) modify the raw project building file so that it searches for its required sets within the dataset folder.

As mentioned, a folder must be created under the directory of \BASINS\data. It should be named identically to the meteorologic input file (*.wdm), the project file (*.apr), and the output file (*.out). The Williams dataset folder and all associated files were named "willx.*" with the x corresponding to trial number. Renaming each trial is necessary as BASINS maintains a log of all routines, and the log is involved in many subsequent processes. If a file name is reused, errors will generate.

The next step is to name the key datasets so BASINS will recognize them for their function. The first file of primary importance is the watershed boundary. BASINS names this shapefile cat.shp, so the Williams watershed boundary coverage was renamed, converted to a shapefile, and copied to the dataset folder. This is done for the meteorologic station shapefile, named wdm.shp, and the monitoring station shapefile, named gage.shp. Also added to the dataset folder, under no name restrictions, are the digital elevation model, land use shapefile, and river network shapefile. These three themes are "burned" into the "BASINS View" regardless of name and independent from the "Project Builder" function. These 6 files are all the modeler needs to construct an HSPF project.

In order for all routines to run properly, a consistent projection must run through all input files. BASINS requires a tag file within the dataset folder to define the projection of the "BASINS View." A sample prj.odb file as formatted for the Transverse Mercator projection is shown on the following page.

```
/3.2
(ODB.1
	FirstRootClassName:	"Trnmerc"
	Roots:	2
	Version:	32
)

(Trnmerc.2
	InternalName:	"Transverse Mercator"
	Description:	"Custom Transverse Mercator"
	Ellipsoid:	3
	Lambda0:	2.67035375555050
	k0:	0.99960000000000
	FalseEasting:	500000.00000000000000
	FalseNorthing:	10000000.00000000000000
)

(Elpsoid.3
	Radius:	6378160.00000000000000
	Eccentricity:	0.00669454200000
	Type: 2
	Units:	0x07
)
```

There are two choices for adding the proper prj.odb to the dataset folder: 1) Copy the file from a sample project with an identical projection; 2) if such a sample project does not exist, build the file with the makeprojdb.ave script:

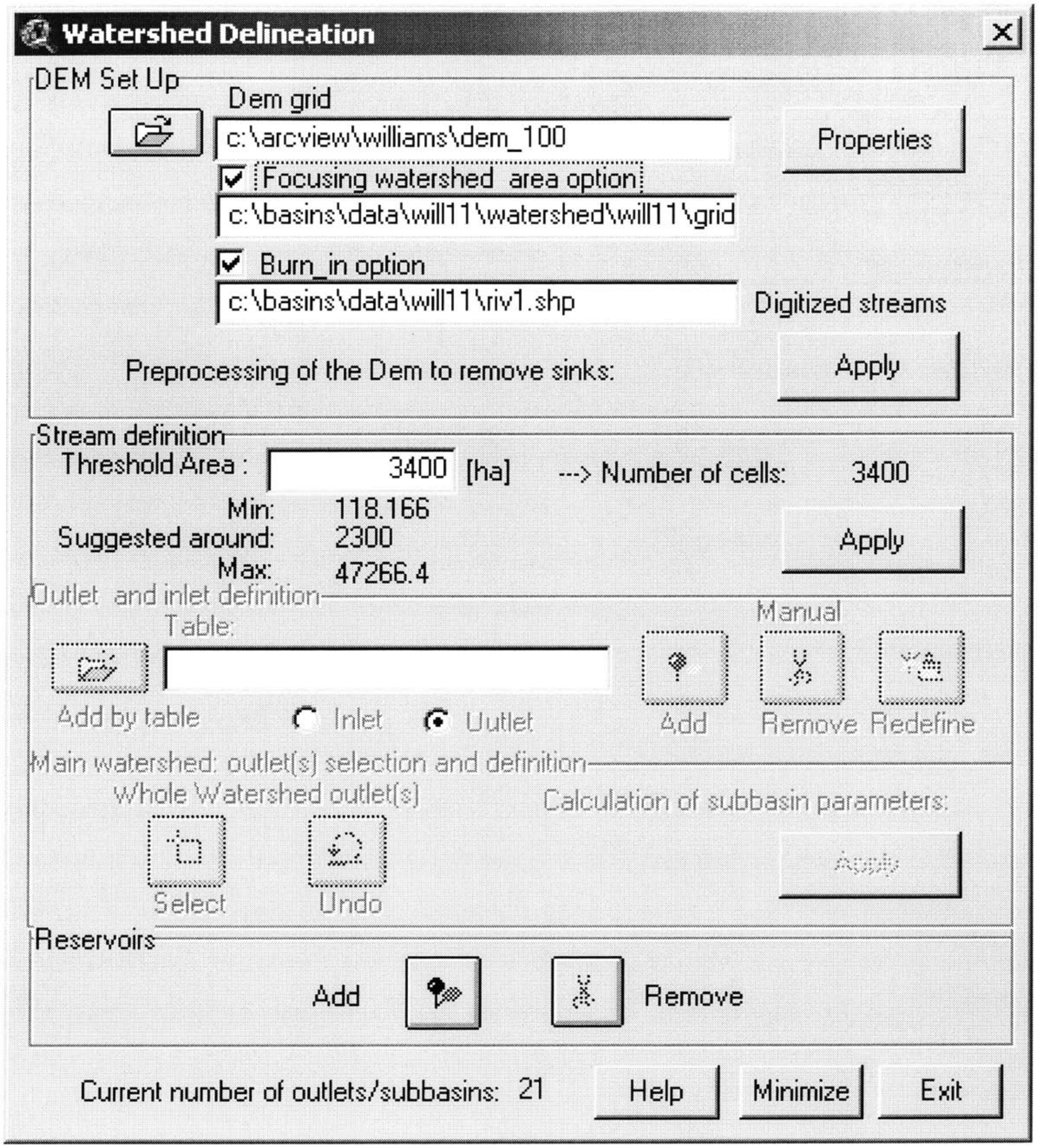
```
aView = av.FindDoc("BASINS View")
theprj = ProjectionDialog.Show (aView, #UNITS_LINEAR_METERS)

prjODB =
ODB.Make(("C:\BASINS\data\<datasetfolder>\prj.odb").asFileName)
prjODB.Add(theprj)
prjodb.Commit

' prjODBFn  = (usrDataPath +"\prj.odb").asFileName
```

This script reads the themes in the “BASINS View”, in which the working project should reside by default, and it builds the prj.odb file based on the projection of those themes.

Once the file formats and locations are in order, the "Project Builder" must be altered to initiate from the dataset folder. To do this, the "Build.dat" file should be copied, renamed as <dataset>.apr, and opened with a text editor. All occurrences of the word "tutorial" should be replaced with "dataset." If all files and formats are in order, this edited project builder should initiate BASINS with the working project. The three name-specific files will appear in the "BASINS View" as initial themes: Cataloging Unit Boundaries, WDM Weather Data Stations, and USGS Gage Stations.

At this point, the core BASINS routines may be run. The automatic delineation tool is used to prepare the relevant GIS data for input to HSPF. This BASINS tool requires the Spatial Analyst (at least version 1.1) and Dialog Designer (at least version 3.1) extensions to ArcView [12], both of which are readily available. These extensions, a DEM, a watershed boundary polygon, and a digitized stream network are all that are required to prepare an automatic delineation. Figure 13 displays the dialog box that appears upon selection.

- The DEM source is easily browsed to within the dataset folder
- The watershed boundary designation is capable of importing a pre-defined watershed boundary shapefile or constructing a boundary manually. The Williams dataset includes an accurate watershed boundary theme, so this option is chosen and the Cataloging Unit Boundaries theme is browsed to.
- The Stream Network "Burn-in" option is utilized since a digitized stream network has been created.
- The Threshold to Control Drainage Density was experimented with so as to produce a river network that matched the original digitized network.
- One outlet was manually input at the Southern tip at the intersection of the watershed boundary and the stream network.
- The delineation is performed



Dem grid: c:\arcview\williams\dem_100

☑ Focusing watershed area option: c:\basins\data\will11\watershed\will11\grid

☑ Burn_in option: c:\basins\data\will11\riv1.shp

Threshold Area : 3400 [ha] ---> Number of cells: 3400

Min: 118.166

Suggested around: 2300

Max: 47266.4

○ Inlet ● Outlet

Current number of outlets/subbasins: 21

Figure 13: Automatic Watershed Delineation Function

The result of these trials is displayed in Figure 14. The 3400 ha threshold area constrains streams to cells for which 3400 upstream grid cells contribute to flow. This constraint produces a virtually identical digital stream network with 21 sub-basins. A smaller threshold assignment yields a more detailed stream network with more sub-basins, whereas a larger threshold assignment yields a less detailed stream network with fewer sub-basins. This tool processes for several minutes and produces four new themes to the BASINS project: Sub-basins, Streams, Outlets, and an optional Reservoirs theme if the user chooses to designate existing reservoirs at this point.

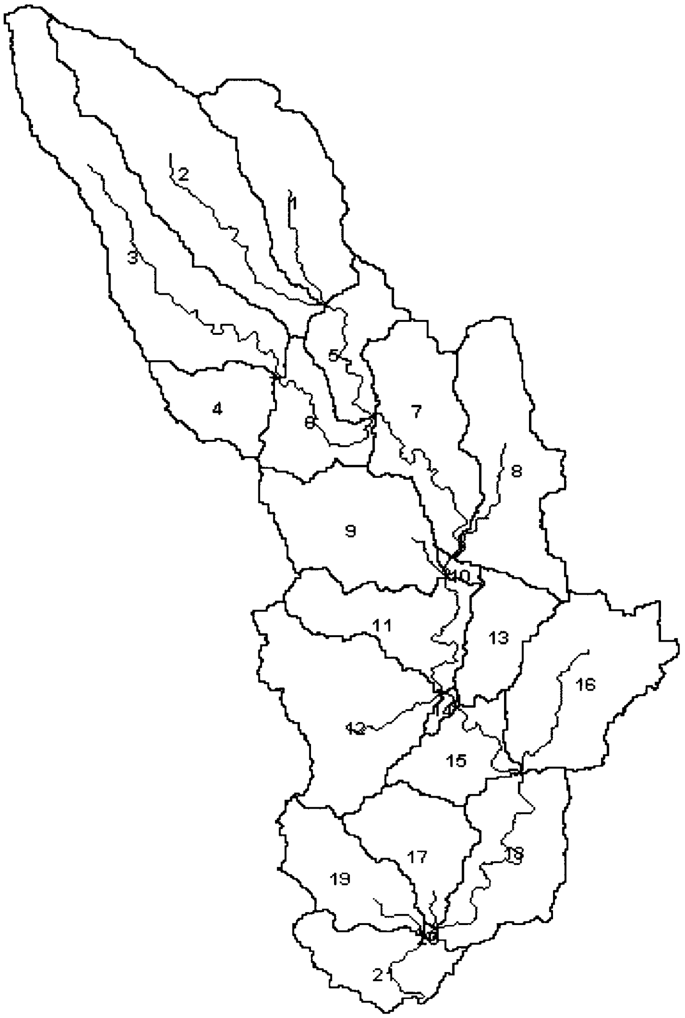


Figure 14: Williams Watershed Sub-basin Delineation

4.3 Time Series Data

Before the Hydrologic Simulation Program – FORTRAN will run, time series data inputs must be pre-processed and imported into the properly formatted *.wdm file for HSPF to force into the BASINS preparations. The required hourly meteorologic data inputs are:

- Precipitation
- Evaporation
- Air Temperature
- Wind Speed
- Solar Radiation
- Potential Evapotranspiration
- Dew Point Temperature
- Cloud Cover
- Maximum Temperature
- Minimum Temperature

The user will also want time series inputs of observed flow with which to compare stream flow outputs. Some unit conversion is necessary to obtain the HSPF standards from Australian standards:

Parameter	*To Convert from Australian Standard:*	*Multiply By:*	*To get HSPF Standard:*
Precipitation/Evaporation	Millimeters	0.039	Inches
Temperature	Centigrade	9/5 + 32	Fahrenheit
Wind Velocity	Kilometers per hour	0.621	Miles per hour
Solar Radiation	Megajoules per square meter	23.9	Langleys
River Flow	Megaliters per day	0.409	Cubic feet per sec.

Table 5: Unit Conversion Chart

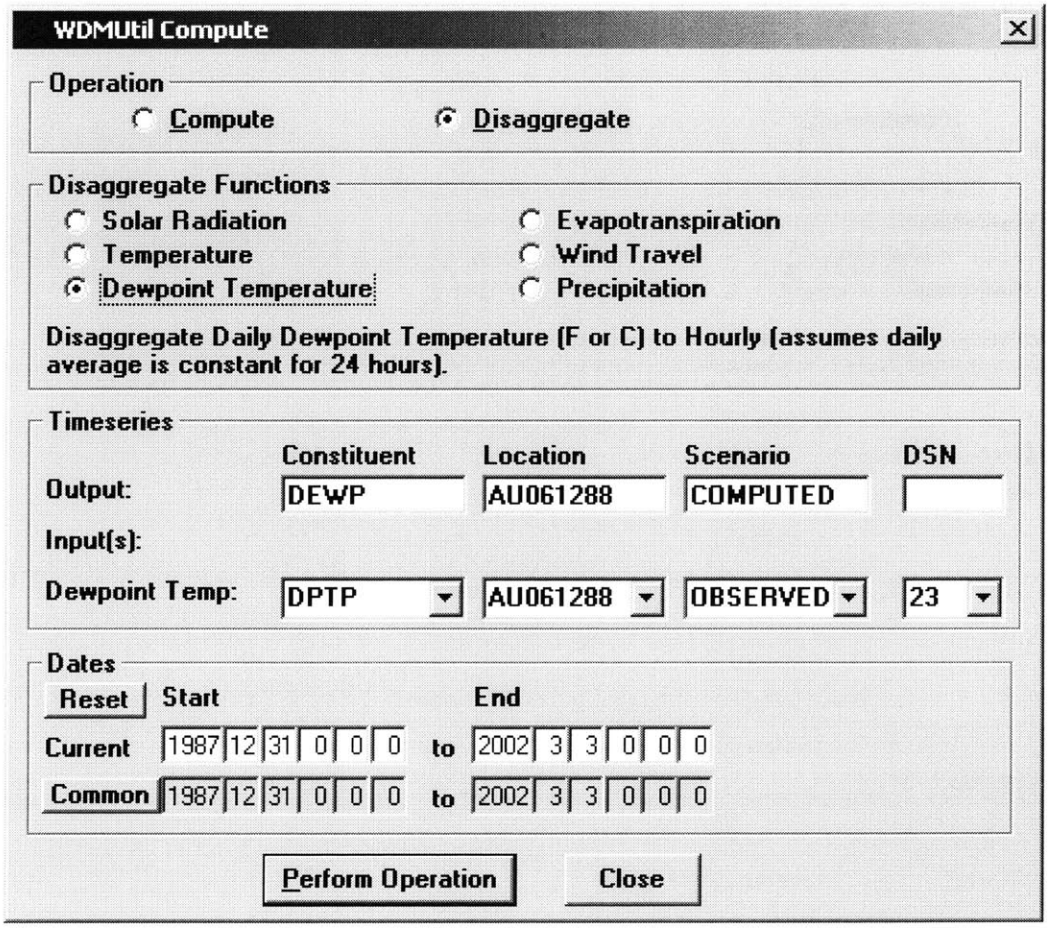
Another obstacle in importing foreign data to the BASINS routines is the unavoidable existence of blank entries. An efficient program for filling blank entries and performing other statistical operations is STATA, a statistical analysis package that is readily available on the UNIX system at MIT. STATA is also available in more current, user-friendly Windows versions. This program has a straightforward command for filling blank entries throughout a field regardless of size. It also has commands for renaming field headers and performing field type conversions. This proved useful as most of the values in the original dataset were saved as strings, while the *.wdm file requires a numeric entry.

The command series for this conversion process is as follows:

```
insheet using filename  % loads the file into STATA
summ  % displays file contents and properties in coherent tabular format.  With columns:
          variable, # observations, mean, std. dev., min, max
desc variable  % displays field storage type
destring variable, replace  %  converts a string to a numeric storage type and
                               displays number of missing values
replace variable=0 if variable==.  % enters a 0 in all formerly blank entries
outsheet using new filename  % sends finished array out to specified folder
```

Now the time series files are prepared for import to WDMUtil. WDMUtil is a utility included in the BASINS package that facilitates time series data manipulation and formatting for use by HSPF. A major problem with the working dataset was the absence of hourly time series. Only daily sets were available for purchase. Fortunately, the WDMUtil contains a disaggregation function with which to generate hourly data from a daily input. The computation/disaggregation dialog box is shown in Figure 15.

All required meteorology sets could be computed or disaggregated from daily sets at the Lostock Dam site to the West of the watershed. Though this was the only station with detailed parameter archives, most meteorologic parameters are safely assumed constant across the watershed.



Operation

○ Compute ● Disaggregate

Disaggregate Functions

○ Solar Radiation ○ Evapotranspiration
○ Temperature ○ Wind Travel
● Dewpoint Temperature ○ Precipitation

Disaggregate Daily Dewpoint Temperature (F or C) to Hourly (assumes daily average is constant for 24 hours).

Timeseries

	Constituent	Location	Scenario	DSN
Output:	DEWP	AU061288	COMPUTED	
Input(s):				
Dewpoint Temp:	DPTP	AU061288	OBSERVED	23

Dates

	Start							End					
Current	1987	12	31	0	0	0	to	2002	3	3	0	0	0
Common	1987	12	31	0	0	0	to	2002	3	3	0	0	0

Figure 15: Computation and Disaggregation Functions in WDMUtil

4.4 Initial Results

The first HSPF run was made using the complete set of GIS data processed in BASINS, and the complete set of meteorologic inputs calculated from the Lostock Dam monitoring site. Flow was simulated throughout the watershed based exclusively on precipitation at Lostock Dam. The hydrograph for flow at Tillegra in this base case run is shown in Figure 16.

Simulated flow at Tillegra is compared to historically observed flow at Tillegra. Vegetative interception, surface infiltration, groundwater storage allocation, and channel geometry parameters were all kept at default values for this base case scenario.

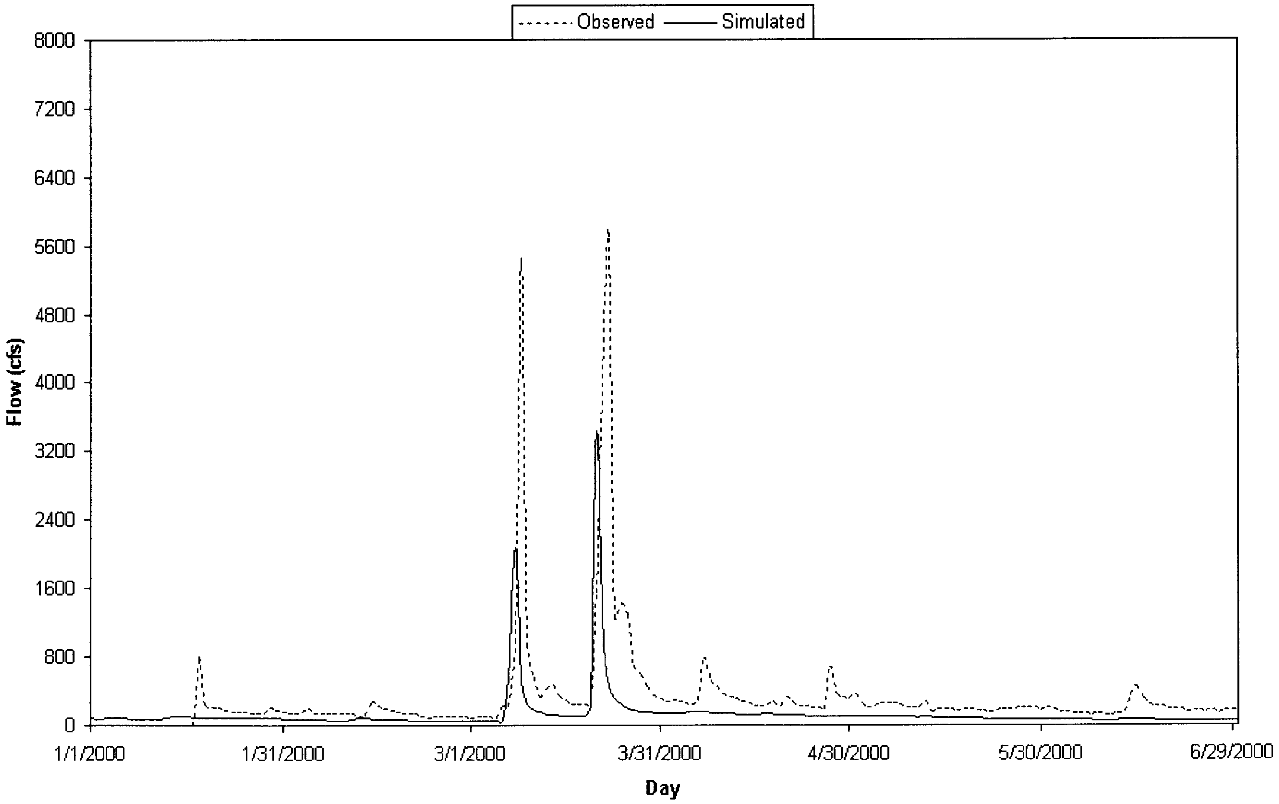


Figure 16: Base Case Hydrograph - Tillegra, 2000

5 Model Calibration - Hydrology

In contrast to the base case scenario, which used Lostock Dam precipitation, the hydrology calibration will focus on the Tillegra region in response to precipitation as measured at the Barrington Guest House monitoring station (refer to Figure 7). An initial run with this precipitation set resulted in the hydrograph of Figure 17.

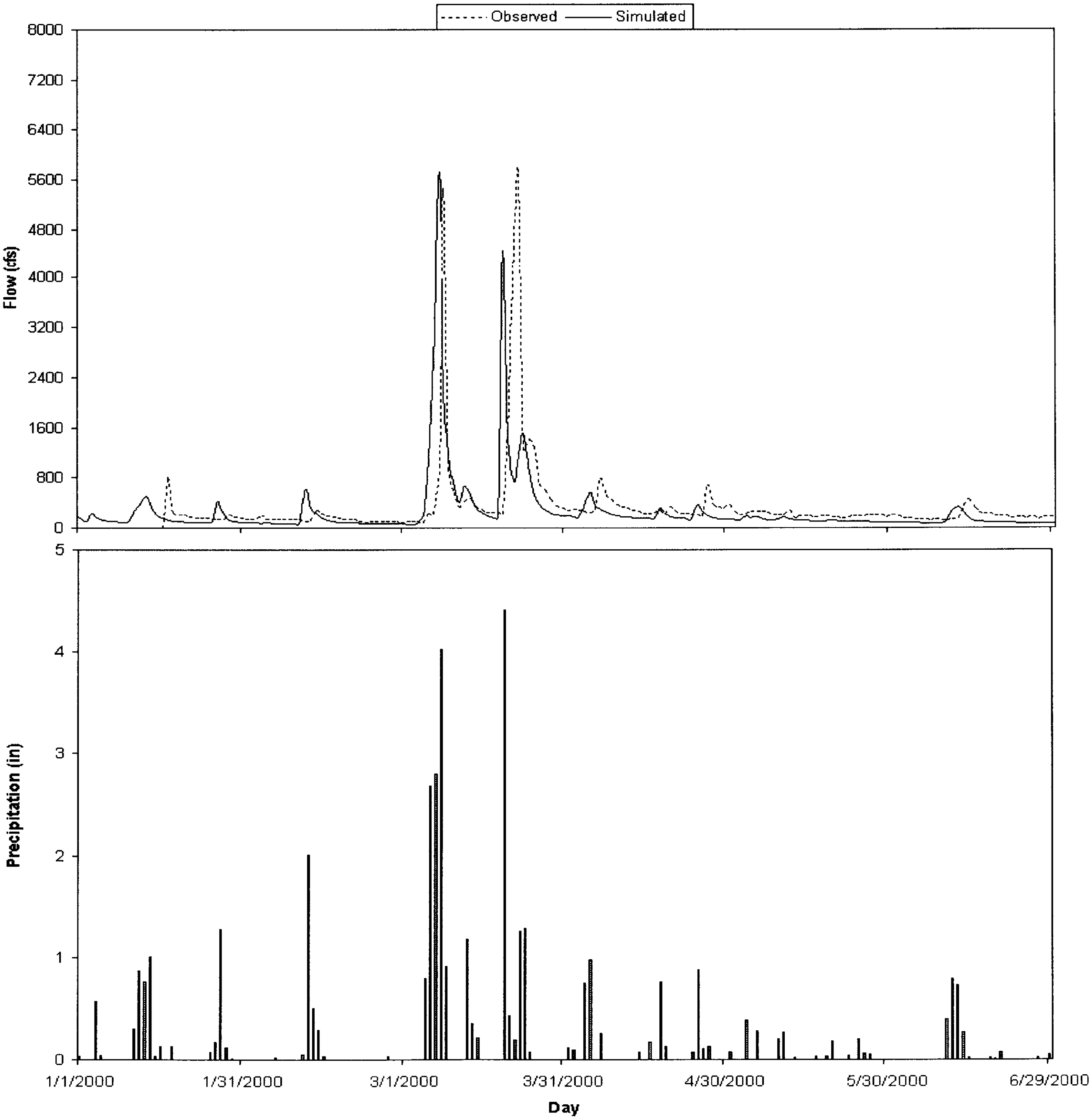


Figure 17: Tillegra Region Hydrograph, 2000

Barrington Guest House Precipitation Response Compared w/ Observed Flow @ Tillegra

The result appears to be far more accurate than the base case scenario. This is expected due to the closer proximity between the Barrington Guest House site and the Tillegra site. Nevertheless, further calibration is needed. The recession rate of the simulation curve is faster than the observed curve, baseflow in the simulation curve is slightly lower than the baseflow in the observed curve, and peaks are slightly off.

The following parameters were chosen from reference [13] as the most important factors in storage allocation:

- INFILT - Index to infiltration capacity
  - The model is very sensitive to this parameter. It allocates flow between surface and subsurface
- DEEPFR - Ratio of loss to deep storage
  - Important to adjust this parameter since the Williams River is mostly shallow
- UZSN - The upper zone nominal moisture storage
  - This parameter is sensitive to changes in land use and slope
- INTFW - Interflow inflow parameter
  - Important to adjust in complement of DEEPFR
- LZETP - Index to lower zone evapotranspiration
  - This parameter is sensitive to vegetation and land use variation

In the first calibration run, adjustments to the base case default values were made as shown in Table 6.

Parameter	Value	Default
LZSN	3	6
INFILT	0.01	0.16
DEEPFR	0	0.1
UZSN	1	1.128
INTFW	2	0.75
LZETP(grassland)	0.4	0.1
LZETP(timber)	0.6	0.1

Table 6: Calibration #1 Parameter Adjustment

Lower zone storage was reduced, infiltration capacity was minimized, deep storage was eliminated, and upper zone storage was decreased in an effort to increase surface flow and examine the model sensitivity. The interflow inflow default value seems very low for a system based largely on interflow processes, so this value was increased to the typical maximum value. In addition, evapotranspiration indices were raised to typical values for grassland and timber. Figure 18 displays the output for these adjustments and the dramatic results of such a reduction in groundwater influence.

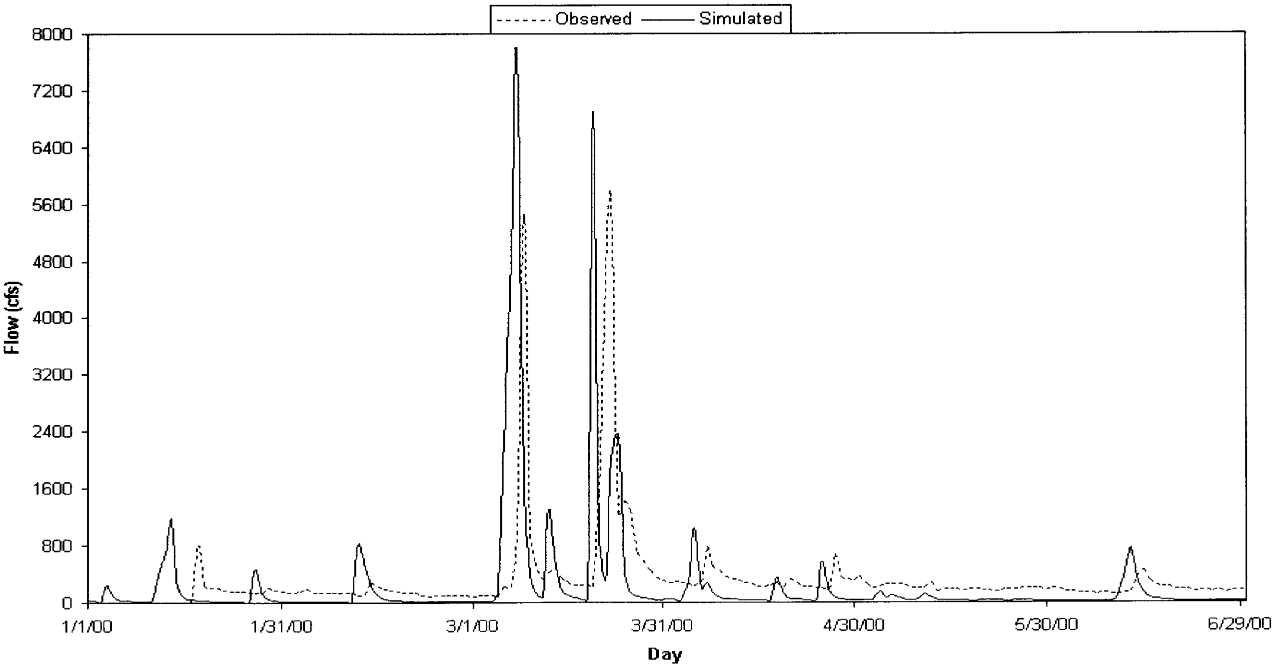


Figure 18: Minimal Groundwater Storage and Flow

The next run was meant to simulate a realistic set of parameters with a slight adjustment in infiltration and lower zone storage in an attempt to achieve a slower curve recession. Table 7 displays these changes.

Parameter	Value	Default
LZSN	6	6
INFILT	0.16	0.16
DEEPFR	0	0.1
UZSN	1	1.128
INTFW	2	0.75
LZETP(grassland)	0.4	0.1
LZETP(timber)	0.6	0.1

Table 7: Calibration #2 Parameter Adjustment

The interflow domination over baseflow is maintained in the INTFW and DEEPFR settings, but lower zone storage and infiltration capacity are returned to the default values. Upper zone storage and lower zone evapotranspiration are logical values and are not changed. These settings produce a well-matched hydrograph, shown in Figure 19, and they are acceptable as representative water storage and allocation settings.

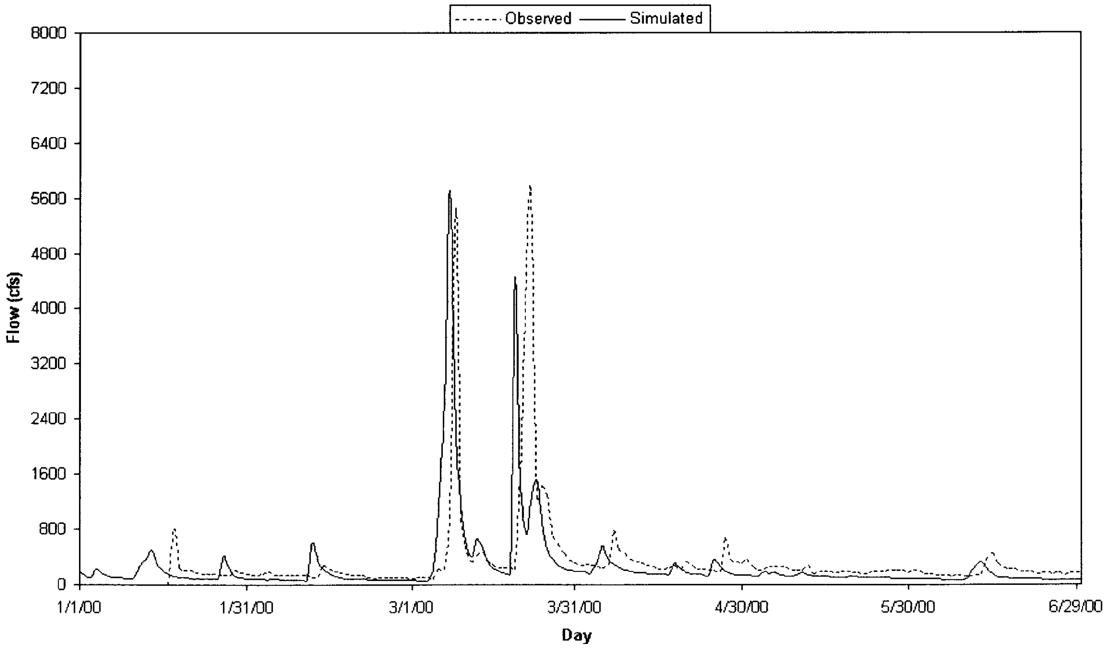


Figure 19: Storage and Flow Allocation Calibration

A third calibration was done to examine the model's sensitivity to the incorporation of field sampled channel geometry. Mean width, mean depth, longitudinal slope, and Manning's roughness coefficient are incorporated to the HSPF reach file as displayed in Table 3. As described in Chapter 4, the Manning's roughness coefficients for the middle and lower Tillegra reaches are assumed to be 0.03 since the calculated values were outliers. The other values are inserted as shown in Table 3, and the resulting hydrograph is displayed in Figure 20. The difference is very subtle, but compared to Figure 19, peaks are smoothed over and recession rates are slightly reduced.

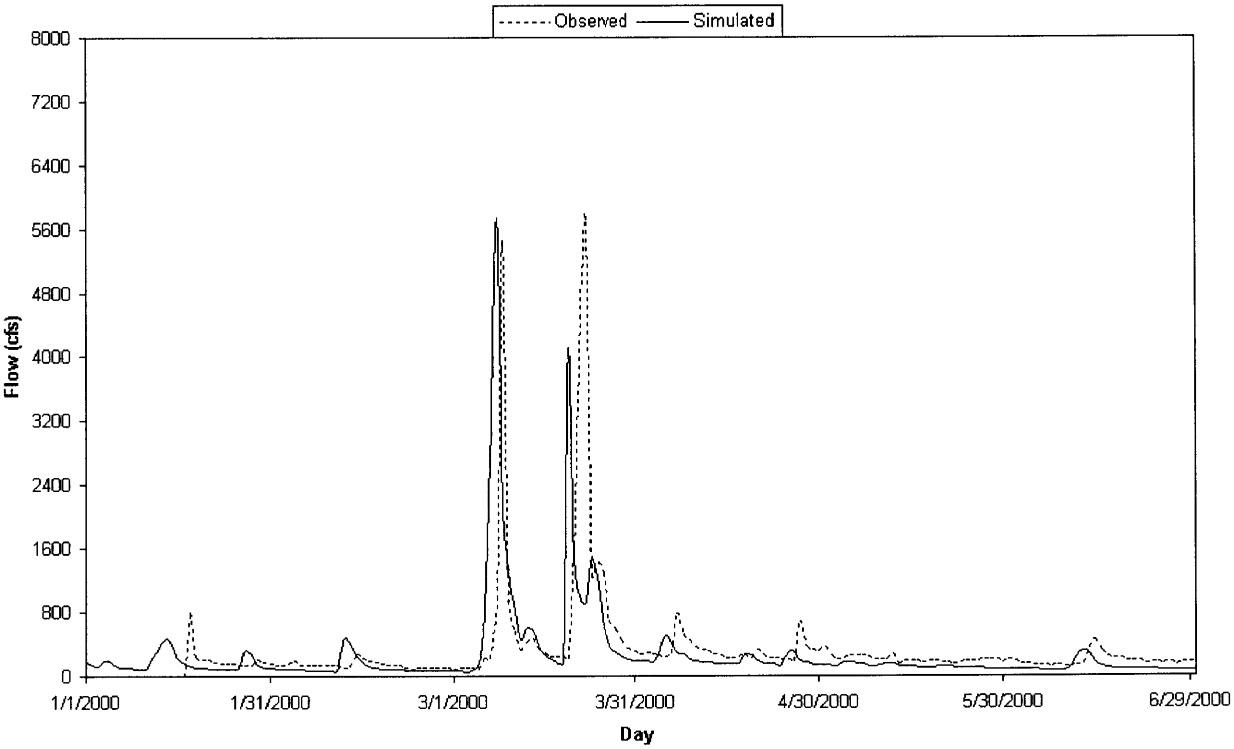


Figure 20: Channel Geometry Calibration

6 Accuracy Analysis

Hydrology calibrations appear to be fairly accurate in regards to peak flow, recession rate, and baseflow; however, there is a consistent discrepancy between the observed and simulated phases. Many calibration efforts attempted to slow the hydrologic response enough to account for this lag, but these attempts altered the peak flow, recession rate, and baseflow far more than they influenced the phase change. The lag averages approximately 3 days throughout the datasets, and without snow pack influences, there is not a parametric explanation.

Geographic separation between the Barrington Guest House precipitation-monitoring site and the Tillegra flow-monitoring site would justify a 3-day inconsistency, but Figure 16 shows that Barrington Guest House is approximately 25 kilometers from Tillegra. The discrepancy is most likely not a geographic lag.

Therefore, it is postulated that the phase lag is a compilation of human error. The error may be due to the tedious data import procedure and some transcription errors during the copying and processing of input files.

The lag may also be due to sampling error. For example, the Bureau of Meteorology time series data are recorded for "today" as the value "in the 24 hrs before 9am." This terminology is vague, and it does not clearly define which day the rainfall corresponds to. If contrastingly unique standards are observed in the Department of Land and Water Conservation flow record archiving, it is possible that the flow observations vary on the order of days from the precipitation readings.

This error creates difficulty in assessing the accuracy of the model outputs; however, an attempt was made to manually align the phase and calculate some statistics for the data sets. Statistics were calculated at a –1-day shift, a +1-day shift, a +2-day shift, and the dataset as modeled, but results were chaotic. A 3-day shift produced a sudden convergence of correlations between the two sets implying that the apparent phase shift in Figures 16-20 is truly 3 days throughout the dataset.

$\frac{(Q_{obs} - Q_{\text{model}})}{Q_{obs}}$ was calculated for the first half of the year 2000 (January through June, as shown in Figures 16-20).

An accuracy comparison between the run including STEFS channel geometry inputs and the run using default geometry inputs is shown in Table 8.

STEFS Channel Geometry Inputs	Default Channel Geometry Inputs
0.214	0.216

Table 8: Statistical Comparison, $\frac{(Q_{obs} - Q_{\text{model}})}{Q_{obs}}$

In calculating $\frac{(Q_{obs} - Q_{\text{model}})}{Q_{obs}}$, a near-zero result is indicative of a close correlation between observed and simulated flow series. Both runs result in a good correlation, and the inclusion of STEFS sampled channel geometry inputs slightly improves accuracy.

To validate these statistics, the Nash-Sutcliffe equation was employed.

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (Q_i - Q_i^{'})^2}{\sum_{i=1}^{n} (Q_i - \overline{Q})^2}$$

Q_i = Observed flow
$Q_i^{'}$ = Simulated flow
$\overline{Q}$ = Observed flow average over the time period
n = Number of records within simulation period

In this case, a result that approaches 1 implies good correlation. Table 9 displays the Nash-Sutcliffe results.

STEFS Channel Geometry Inputs	Default Channel Geometry Inputs
0.591	0.582

Table 9: Nash-Sutcliffe Correlations

Modelers of watersheds with large groundwater contributions typically hope to obtain a higher Nash-Sutcliffe correlation than shown in Table 9. Most systems contain a higher percentage of baseflow, which provides a buffer to the hydrologic response and is typically easier to correlate than the more variable "peaks" and "valleys" of a dry system.

Figures 16-20 display the nature of such a dry region with minimal baseflow. The Williams River system responds to rainfall very violently as depicted by the sharp rise and fall of the hydrographs. Consequently, there is a sharp gradient in flow response and differences between observed and simulated values can be significant at any given time.

In view of the high variance, a value of 0.6 is reasonable for the Williams River response. Nonetheless, some follow-up work should be done to assess the accuracy of the data source, the data import process should be reworked to optimize efficiency, and some further calibration should be done.

7 Future Work

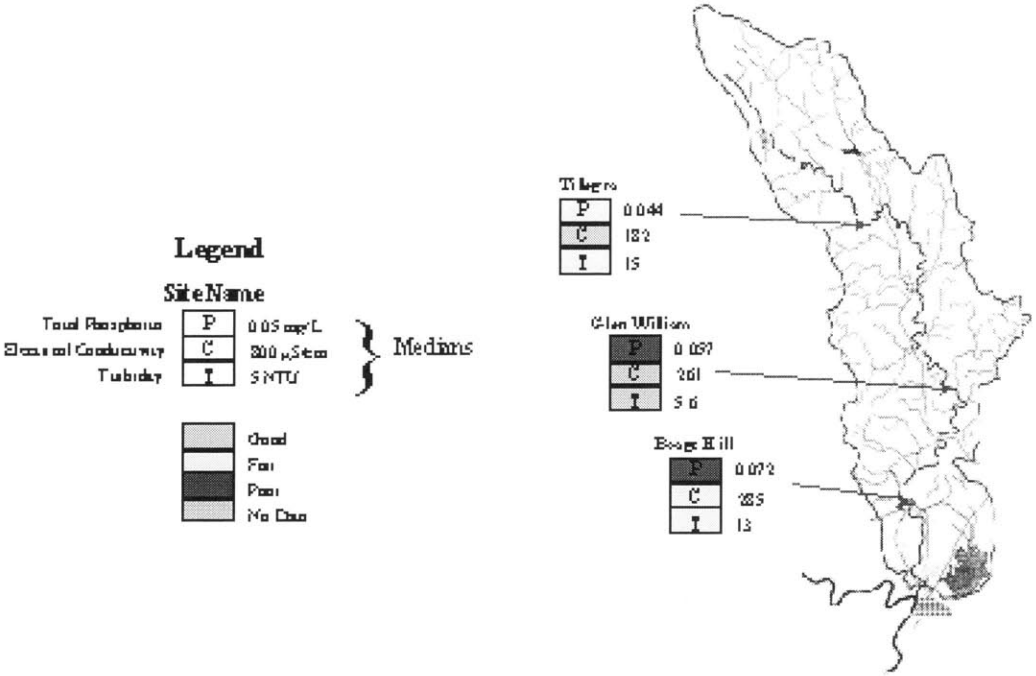
Modeling of the Williams River watershed proved to be a very time-intensive process with a steep learning curve and many obstacles in foreign dataset entrainment. Within the time scale of the Master of Engineering program, STEFS development and application of a hydrologic model were completed, but there is more work to be done.

7.1 Water Quality Modeling

Continuation of this work will incorporate water quality parameters; both field sampled and historically observed, into the non-point source modeling capabilities of BASINS and winHSPF in order to characterize the agricultural contributions to contamination of the Williams watershed. Many results from the sampling campaign have been compiled, and with a running hydrology simulation, water quality parameters can be modeled.

The Hunter Water Corporation maintains a thorough water quality-monitoring program at three sites within the basin. Tillegra is a station on the North Williams reach just upstream from the confluence with the Chichester River; Glen William is located in the Southern portion of the main reach of the lower Williams; and Boag's Hill is a station that monitors water quality at the Seaham Weir extraction site. The Seaham Weir is one of two locations in the watershed where water is withdrawn from the system.

The other site is the Chichester Dam, just north of the confluence of the Chichester and North Williams rivers. Water from these two extraction points is piped to the Grahamstown Reservoir, located southeast of the Williams watershed, which is the primary storage area for Newcastle municipal water. The parameters of most interest to quality control of this reservoir are phosphorous concentration, turbidity, and total coliform count. These are indicators of the three main issues: nutrient loading, sedimentation, and bacterial contamination. Figure 21 displays a graphical representation of the 2000/2001-concentration distribution of the three problem parameters.



Courtesy of the Hunter Water Corporation, 2001

Figure 21: Concentration Distribution of Water Quality Control Parameters

In addition to the historical archives available from these three sites, ENVIT sampling results will be compared to the Hunter Water Corporation inventory. ENVIT samples are plotted against maximum, minimum, and mean values of all historical data from the month of January in Figures 22 and 23.

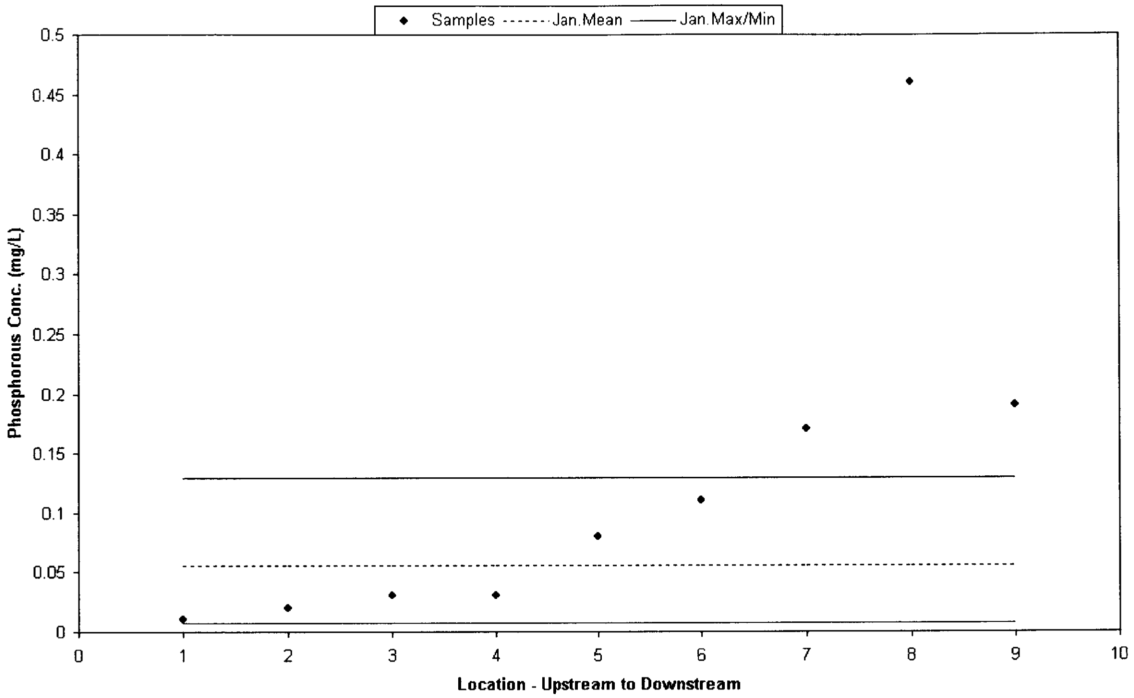


Figure 22: STEFS Phosphorous Samples
Compared with Historical January Statistics

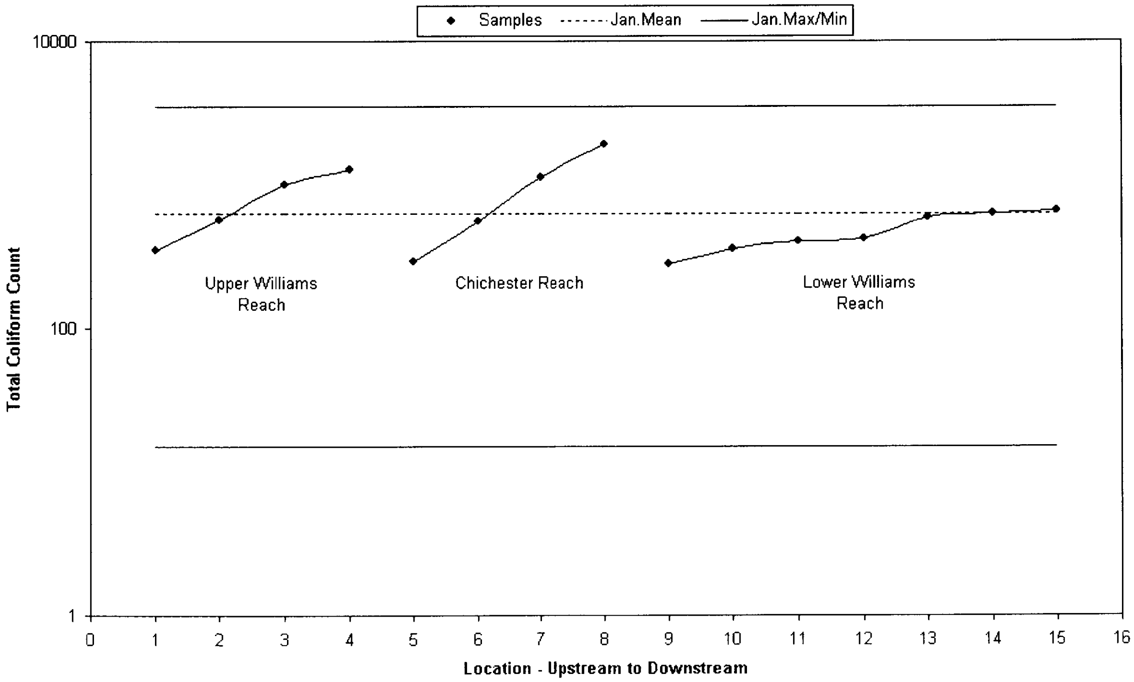


Figure 23: STEFS Biology Samples
Compared with Historical January Statistics

A review of the 2000/2001 phosphorous summary (Figure 21) indicates a rise in phosphorous loads near the outlet of the watershed. A similar review of biology impacts shows Coliform contamination tending towards higher counts in the middle to upper reaches of the watershed. STEFS samples agree with both of these trends (Figures 22 and 23), so water quality modeling will target an investigation of these impacts.

7.2 Better Watershed Management Practices

There is increasing awareness of the contributions that non-point source pollution can have on watershed health. A hydrologic and water quality model can provide a valuable tool for improving watershed management planning. The model enables a visualization and simulation capability that not only predicts impacts during current events, but also can be utilized in the prediction of future impacts.

In order to do this, some future work will be done to forecast future rain events. Precipitation patterns follow a statistically predictable trend. The dry period intervals are typically modeled with a random Poisson distribution, and the amount of rainfall on a given "wet" time slice can be modeled with a random exponential distribution. Numeric programs such as MATLAB have the capability to randomly generate a series of values with a Poisson distribution and an exponential distribution. If the Poisson parameter, λ (mean interval between number generations) and the exponential parameter, μ (mean value of generated number) are designated such that the modeled series fits the observed series, these sets of numbers can be calibrated with the existing series of precipitation values for the Williams basin rainfall monitoring sites. With this forecasted precipitation series, future runoff simulations can be conducted.

Thus, planning scenarios can be introduced to the GIS interface, and future impacts can be predicted. For example, if the current impacts of a certain plot of grazing land are seen to be significant, a scenario in which riverfront grazing areas are restricted from cattle entry may be introduced. The results can be forecast, and an assessment of the water quality improvement can be made.

Another example is in future development impacts. If it is desired to build a new dam, farm, etc., the land use scenario can be modeled for it's loadings and hydrology/water quality impacts assessed.

7.3 Mobile Computing/Model Integration

Mobile computing will enable watershed authorities to better understand the management area by 1) deploying many field workers over a short period of time and 2) integrating a watershed model with the mobile application.

Due to temporal conditions tending to rapidly fluctuate relative to the spatial scale of watersheds, a large pulse deployment is an efficient method of capturing large amounts of data within the time span of a storm, chemical spill, or other meaningful event. This spatially intense, time specific data set will, if properly displayed in a map, provide a clear understanding of event-based propagation of pollutants.

Furthermore, the system can feed, qualify, or even apply a model of the watershed's stream network and hydrologic behavior. STEFS is an example of basic integration with a watershed model. In this case, a model was not yet prepared prior to the fieldwork, so the ability to feed, qualify, or apply was not ready. It should be noted that even if ENVIT did have a model prepared for this end, the computing power of the personal devices used in STEFS is not nearly enough to apply a comprehensive, watershed-scale model. However, the database of the PDAs can be linked to a model running on the home server, and the server can issue displays of model results. The desktop server is always likely to be a few steps ahead of the personal device, so it is important to maintain the necessity of the wireless network.

7.4 STEFS Improvements

It has been briefly mentioned that STEFS can be custom configured for a particular study. Here are two improvements that can be made on the software to optimize model preparation through STEFS deployment:

- Digital photograph storage: The database can be configured to store georeferenced photographs from the field. A picture can be taken at each relevant location in a field study and automatically logged to storage in a database entry that is time-stamped and associated with the coordinates of the site. This is useful if the modeler believes in qualitative input to a numeric model.
- Automated unit conversion: the inherent difficulty of data import processes has been discussed. STEFS can appease this problem by automating a duplicate field of data for each relevant database table. This duplicate entry would have the proper unit conversion calculation associated between the original field and the converted field. This will save large amounts of time in the data processing phase of a modeling study.

8 Conclusions

The streamlined data flow provided by STEFS is useful in many arenas that necessitate immediate understanding of where, how, and by whom the project is progressing. It has particularly interesting possibilities as a supplemental model input tool at study sites for which local historic data sets do not complete the model input needs

The extensive channel geometry inputs were the test of relevance between the STEFS prototype and a watershed model. These inputs are one of the model controls that are independent of time, so a short STEFS deployment is a feasible collection tool. Conversely, flow inputs gathered by STEFS are irrelevant to a good hydrology model as these inputs must be consistent over a large time slice. A STEFS deployment is not practical for a long-term sampling campaign.

The calibration of flow simulations for the Tillegra region of the basin was improved by the STEFS channel geometry inputs; however, their importance was not as great as expected. The error reduction was minimal, suggesting that the outputs achieved in this thesis would have been similar without the contribution of STEFS.

Often a model is used as a precursor to a field study. Field deployments are expensive, so it is desirable to insure the need for the study by running detailed model simulations of the problem of interest. In the case of STEFS, a field study is used in the opposite manner. It is an initial step towards a good model, and in the case of a remote location with sparse availability of recorded datasets, this strategy is sound. If improvements described in the previous section are implemented, and if time is taken to meet with all local authorities in hopes of acquiring as many archived datasets as possible, the pre-model field study is advisable.

Compared to the data preparation processes, the calibration effort of the Williams River watershed was fairly simple and straightforward. This demonstrates that HSPF is very useful for a basin with similar characteristics as the Williams watershed.

9 References

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Appendix I - Sampling Data

	Day 1		**Day 2**									
	Test		**Location 2**			**Location 3**			**Location 4**			**Location 5**
	Sub-section 1	Sub 2	Sub-section 1	Sub 2	Sub 3	Sub-section 1	Sub 2	Sub 3	Sub-section 1	Sub 2	Sub 3	Sub-section 1
Hydrolab												
Temp	31.33		26.14	26.4	24.42	27.37	27.39	27.43	26.75	26.96	26.69	21.43
Depth	0			0.2	0.80	0.7	0.16	0.25	0.12	0.09	0.05	0.1
pH	7.17		7.05	7.05	6.99	7.08	7.09	7.09	6.94	6.96	6.99	7.4
D.O.	10.17		5.74	6.11	5.46	7.1	7.12	6.75	6.72	6.88	7.04	3.2
Sp.Cond	0		233.6	233.5	236.20	158.9	158.5	159.2	155.8	155.9	157.4	1668
Turb	7											4.5
ORP	298		493	495	477.00	489	485	487	483	480	479	299
IBV	7.5		7.5	7.5	7.50	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Chlor												4.8
River Width	12		21			35			17.5			3.7
Depth (m)	0.425	0.029	0.39	1.25	1.23	1.036	0.28	0.79	0.255	0.295	0.1	0.1
Width of sub	6	6	7	7	7.00							
20% velocity	0	0	0	0	0.00	0	0.3	0	0	0.4	0	0
80% velocity	0	0	0	0	0.00	0	0.3	0	0	0	0	0
GPS												
Long.	151.8		151.764			151.717			151.716			151.6459
Lat.	32.52		32.397			32.302			32.302			32.2789
Biology		Blue	Red	Total	Error				Blue	Red	Total	Error
Location 2	7 m (1)	2	630	632			Location 3	6m (1)	0	200	200	
	7m (2)	5	400	405	0.37			6m (2)	20	680	700	0.71
	14m (1)	40	550	590				12m (1)	0	292	292	
	14 m (2)	5	654	659	0.16			12m (2)	2	560	562	0.48
								18m (1)	0	10	10	
Location 4	6m (1)	0	1412	1412								
	6m (2)	0	564	564	0.60							
	12m (1)	0	270	270			Location 5	2m (1)	0	350	350	
	12m (2)	6	1582	1588	0.83			2m (2)	3	560	563	0.38

	Day 1			Day 2								
	Test			**Location 8**			**Location 9**			**Location 10**		
	Sub-section 1 (left)	Sub 2	Sub 3	Sub-section 1	Sub 2	Sub 3	Sub-section 1	Sub 2	Sub 3	Sub-section 1	Sub 2	Sub 3
Hydrolab												
Temp	26.6			25.98	25.96	25.52	26.42	26.37		28.37		
Depth	0.3			0.1	0.3	0.3						
pH	7.21			7.03	7.08	7.03	6.99	6.95		8.08		
D.O.	6.69			6.58	6.4	6.6	8.31	8.57		8.32		
Sp.Cond	390			232	231	232	85.3	85.2		259.2		
Turb												
ORP												
IBV												
Chlor												
River Width	39			17.1			11.2			9.2		
Depth (ft)	0.84	1.08	1.1	0.9	4.2	6.5	0.3936	0.4264	0.7052			
Width of sub	13	13	13	5.7	5.7	5.7						
20% velocity (ft/s)	0	0.2	0	0	0	0.1	0.8	1.5	0.6	0.5		
80% velocity (ft/s)	0.1	0	0	0	0	0.5	0.1	1.5	0.4			
GPS												
Long.	151.79			151.7632			151.6938			151.6874		
Lat.	32.52			32.3964			32.2376			32.3192		
Chemistry												
Phosphorus	0.19		0.2	0.17	0.11	0.46	0.03	0.01	0.02		0.08	0.03
Nitrate	0.02			0.03		0.03	0.03		0.04		0.02	0.03
Ammonia	0.01			0.03	0.05	0.04	0.05	0.04	0.01		0.01	0
Biology	Blue	Red	Total									
Location 10	0	548	548									

Location	1	1	14	14	14	15	15	15	15	16	16	16
Day	1	1	2	2	2	2	2	2	2	2	2	2
Subsection	1	2	1	2	3	1	2	3	4	1	2	3
Hydrolab Depth (m)	0.10	0.20	-9999	0.60	0.20	0.10	0.10	0.30	-9999	0.08	-9999	-9999
Temp	26.57	26.57	-9999	25.50	26.17	25.39	24.70	24.48	-9999	26.08	-9999	-9999
pH	7.17	7.17	-9999	6.93	6.98	6.81	6.78	6.75	-9999	7.30	-9999	-9999
D.O.	7.74	7.80	-9999	6.57	6.85	8.23	8.16	7.75	-9999	8.78	-9999	-9999
Sp.Cond	380.60	341.00	-9999	227.20	28.00	99.10	98.90	98.80	-9999	229.30	-9999	-9999
Turb	-9999	30.40	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
ORP	318.00	319.00	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
IBV	7.20	7.20	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
Chlor	-9999	3.50	-9999	4.00	2.90	0.90	0.70	0.80	-9999	4.30	-9999	-9999
River Width	6.00	-9999	11.80	-9999	-9999	9.00	-9999	-9999	-9999	2.00	-9999	-9999
Flow Meter Depth (m)	0.22	0.25	0.44	1.00	0.44	0.18	0.32	0.48	-9999	0.16	-9999	-9999
Discharge	1.12	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
Width of sub	3.00	3.00	4.00	4.00	4.00	3.00	3.00	3.00	-9999	2.00	-9999	-9999
20% velocity (ft/s)	0	0	0	0	0	0	0.50	0	-9999	1.80	-9999	-9999
80% velocity (ft/s)	0	0.10	0	0.30	0	0	0.30	0	-9999	1.30	-9999	-9999
Long.	151.47	151.47	151.47	151.47	151.47	151.46	151.46	151.46	-9999	151.67	-9999	-9999
Lat.	32.56	32.56	32.56	32.56	32.56	32.24	32.24	32.24	-9999	32.29	-9999	-9999
Sample Depth (m)	-9999	-9999	0	6.00	10.00	0	1.50	4.50	7.50	0	1.00	2.00
Blue	-9999	-9999	0	0	0	1.00	0	0	0	0	45.00	17.00
Red	-9999	-9999	0	380.00	546.00	1.00	360.00	280.00	420.00	0	1220.00	980.00
Total	-9999	-9999	0	380.00	546.00	2.00	360.00	280.00	420.00	0	1265.00	997.00
Error					0.30				0.33			0.21

Location	21	21	22	22	23	23	24	24	25	25	26	26	27	27	28	28	29	29	30	30
Depth	3	6	3	6.1	3	5.9	3.1	6	3.2	4.7	3	6.1	3.1	6.2	3.1	4.1	2.9	6.1	3.1	6.2
Temp	24.49	20.28	24.55	18.6	24.54	20.01	24.67	20.11	24.4	23.31	24.56	20.04	24.61	21.5	24.99	24.13	24.96	20.61	25.08	21.19
Conductivity	326.6	318.7	328.5	325.4	328.8	320.6	329.4	314.9	327.3	321.5	329	314.3	329.9	304.5	329.7	325.5	326.3	319.9	329.5	327.1
Turbidity	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
DO	1.64	0.16	5.14	0.12	5.26	0.46	5.65	0.09	4.2	0.2	5.62	0.17	7.17	2	7.15	3.24	6.79	0.51	6.88	0.41
Chloro	5.1	4.6	6.2	6.7	7.5	5.1	7.1	4.4	61	6.9	6.4	4.3	6.8	4.3	7.2	5.5	6.7	4.2	5.8	4.4
pH	6.72	6.5	6.96	6.6	6.99	6.1	7.07	6.36	6.97	6.64	7.1	6.64	7.18	6.66	7.26	6.94	7.27	6.68	7.27	6.68
ORP	263	70	228	63	202	90	200	91	213	151	236	94	190	110	207	218	244	98	205	97
IBV	7.2	7.2	7.2	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.6	7.6
Scchi Disk	-9999	-9999	1	-9999	1.1	-9999	1.1	-9999	1	-9999	1	-9999	1	-9999	1.25	-9999	1.1	-9999	1	-9999
Nitrate (mg/L)	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.1	-9999	-9999	-9999	0.08	-9999	-9999	-9999	0.08	-9999	-9999	-9999
Ammonia (mg/L)	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0.02	-9999	-9999	-9999	-0.07	-9999	-9999	-9999	0	-9999	-9999	-9999
Phosphorus (mg/L)	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	[redacted]	-9999	-9999	-9999	-9999	-9999	-9999	-9999	[redacted]	-9999	-9999	-9999
Blue (E. Coli)	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	0	-9999	4	-9999	0	-9999	-9999	-9999	-9999	-9999	-9999	-9999
Red	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	1130	-9999	175	-9999	1695	-9999	-9999	-9999	-9999	-9999	-9999	-9999
Total Coliform	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	1130	-9999	179	-9999	1695	-9999	-9999	-9999	-9999	-9999	-9999	-9999
Location	31	31	32	32	33	33	34	34	35	35	36	36	37	37	38	38	39	39	40	40
Depth	3	5.3	3	4.8	3	6.1	3.1	4.2	3	6	3.3	6.4	2.6	4	3	6.2	2.8	6.2	3.1	5.4
Temp	25.47	21.87	25.74	23.65	25.29	21.05	25.16	24.04	25.65	21.25	25.04	20.82	25.5	24.51	26.26	21.58	26.44	21.71	24.36	22.98
Conductivity	325.4	332.4	328.1	330.2	327.2	328.9	328.5	379.9	331.5	334	329	332	338.4	377.3	336.1	333.9	338.8	352	374.1	461.3
Turbidity	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
DO	7.85	2.27	8.2	1.43	0.74	0.03	5.21	0.26	7.81	0.09	5.77	0.61	6.52	2.42	8.75	0.97	8.21	2.07	7.12	0.34
Chloro	6.1	4.4	7.3	5	5.1	4	5.5	7.1	5.5	4.2	5.9	4	6.1	6.6	6.6	4.1	8.1	4.9	5.9	8.8
pH	6.9	6.73	7.36	6.79	7.07	6.63	7	6.68	7.2	6.65	7.1	6.68	7.11	6.81	7.33	6.7	7.41	6.76	7.11	6.69
ORP	318	139	269	162	217	91	215	171	223	100	208	101	216	217	221	104	203	98	216	146
IBV	7.63	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
Scchi Disk	0.8	-9999	1	-9999	1	-9999	0.9	-9999	1	-9999	0.75	-9999	0.8	-9999	0.8	-9999	0.75	-9999	1	-9999
Nitrate (mg/L)	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
Ammonia (mg/L)	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
Phosphorus (mg/L)	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
Blue (E. Coli)	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
Red	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
Total Coliform	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999

Appendix II - HSPF User Control Input File

```
GLOBAL
  UCI Created by WinHSPF for will11c
  START       1987/12/31 00:00  END    2002/03/02 24:00
  RUN INTERP OUTPT LEVELS    1    0
  RESUME     0 RUN     1                          UNITS    1
END GLOBAL

FILES
<FILE>  <UN#>***<----FILE NAME-----------------------------------------
-------->
MESSU      24   will11c.ech
           91   will11c.out
WDM1       25   ..\outwill11c.wdm
WDM2       26   ..\..\data\met_data\will11c.wdm
END FILES

OPN SEQUENCE
    INGRP              INDELT 01:00
      PERLND     101
      PERLND     102
      PERLND     103
      PERLND     104
      PERLND     105
      PERLND     106
      PERLND     107
      PERLND     108
      PERLND     109
      PERLND     110
      IMPLND     101
      IMPLND     102
      IMPLND     103
      IMPLND     104
      IMPLND     105
      IMPLND     106
      IMPLND     107
```

```
      IMPLND     108
      IMPLND     109
      RCHRES       1
      RCHRES       2
      RCHRES       3
      RCHRES       5
      RCHRES       4
      RCHRES       6
      RCHRES       7
      RCHRES       8
      RCHRES       9
      RCHRES      10
      RCHRES      11
      RCHRES      13
      RCHRES      12
      RCHRES      16
      RCHRES      14
      RCHRES      15
      RCHRES      17
      RCHRES      19
      RCHRES      18
      RCHRES      20
      RCHRES      21
      COPY         1
    END INGRP
END OPN SEQUENCE

PERLND
  ACTIVITY
*** <PLS >               Active Sections
***
*** x -  x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
***
  101  110    0    0    1    0    0    0    0    0    0    0    0    0
  END ACTIVITY

  PRINT-INFO
```

```
*** < PLS>                      Print-flags
PIVL  PYR
*** x   - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
  101  110    4    4    4    4    4    4    4    4    4    4    4    4
1    9
  END PRINT-INFO

  GEN-INFO
***              Name                     Unit-systems   Printer
*** <PLS >                                    t-series Engl Metr
*** x -   x                                    in   out
  101     grazing or grassland                  1    1    0    0
  102     water body                            1    1    0    0
  103     timber                                1    1    0    0
  104     cropping                              1    1    0    0
  105     urban                                 1    1    0    0
  106     mining and quarrying                  1    1    0    0
  107     utilities and other                   1    1    0    0
  108     recreation                            1    1    0    0
  109     horticulture                          1    1    0    0
  110     intensive animal pro                  1    1    0    0
  END GEN-INFO

  PWAT-PARM1
*** <PLS >                  Flags
*** x -   x CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC  HWT IRRG
  101  110    0    1    1    1    0    0    0    0    1    1    0    0
  END PWAT-PARM1

  PWAT-PARM2
*** < PLS>    FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY
AGWRC
*** x   - x               (in)   (in/hr)      (ft)             (1/in)
(1/day)
  101  103        1.        6.      0.16      300.     0.265        0.
0.98
  104  105        1.        6.      0.16      300.    0.2323        0.
0.98
```

```
  106              1.        6.      0.16      300.    0.1711        0.
0.98
  107              1.        6.      0.16      300.    0.1356        0.
0.98
  108              1.        6.      0.16      300.     0.122        0.
0.98
  109              1.        6.      0.16      300.     0.086        0.
0.98
  110              1.        6.      0.16      300.    0.1014        0.
0.98
  END PWAT-PARM2

  PWAT-PARM3
*** < PLS>    PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP
AGWETP
*** x  - x   (deg F)   (deg F)
  101            40.       35.        2.        2.        0.      0.02
0.
  102            40.       35.        2.        2.       0.1      0.02
0.
  103            40.       35.        2.        2.        0.      0.02
0.
  104  110       40.       35.        2.        2.       0.1      0.02
0.
  END PWAT-PARM3

  PWAT-PARM4
*** <PLS >     CEPSC      UZSN      NSUR     INTFW       IRC     LZETP
*** x -  x      (in)      (in)                       (1/day)
  101            0.1        1.       0.2        2.       0.5       0.4
  102            0.1     1.128       0.2      0.75       0.5       0.1
  103            0.1        1.       0.2        2.       0.5       0.6
  104  110       0.1     1.128       0.2      0.75       0.5       0.1
  END PWAT-PARM4

  PWAT-PARM5
*** <PLS >       FZG      FZGL
*** x -  x
```

```
  101  110        1.       0.1
  END PWAT-PARM5

  PWAT-PARM6
*** <PLS >     MELEV      BELV    GWDATM       PCW       PGW      UPGW
*** x -  x      (ft)      (ft)      (ft)
  101  110        0.        1.        1.      0.01      0.01      0.01
  END PWAT-PARM6

  PWAT-PARM7
*** < PLS>    STABNO      SRRC     SREXP     IFWSC     DELTA    UELFAC
LELFAC
*** x  - x               (/hr)                (in)      (in)
  101  110        0.       0.1        1.        1.     0.001        4.
2.5
  END PWAT-PARM7

  PWAT-STATE1
*** < PLS>  PWATER state variables (in)
*** x  - x      CEPS      SURS       UZS      IFWS       LZS      AGWS
GWVS
  101  110      0.01      0.01       0.3      0.01       1.5      0.01
0.01
  END PWAT-STATE1

  MON-INTERCEP
*** <PLS >  Interception storage capacity at start of each month (in)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101  110  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
  END MON-INTERCEP

  MON-LZETPARM
*** <PLS >  Lower zone evapotransp   parm at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101  110  0.2  0.2  0.3  0.3  0.4  0.4  0.4  0.4  0.4  0.3  0.2  0.2
  END MON-LZETPARM

END PERLND
```

```
IMPLND
  ACTIVITY
*** <ILS >               Active Sections
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL
  101  109    0    0    1    0    0    0
  END ACTIVITY

  PRINT-INFO
*** <ILS > ******** Print-flags ******** PIVL  PYR
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
  101  109    4    4    4    4    4    4    1    9
  END PRINT-INFO

  GEN-INFO
***              Name             Unit-systems   Printer
*** <ILS >                            t-series Engl Metr
*** x -  x                            in  out
  101     grazing or grassland         1    1    0    0
  102     timber                       1    1    0    0
  103     cropping                     1    1    0    0
  104     urban                        1    1    0    0
  105     mining and quarrying         1    1    0    0
  106     utilities and other          1    1    0    0
  107     recreation                   1    1    0    0
  108     horticulture                 1    1    0    0
  109     intensive animal pro         1    1    0    0
  END GEN-INFO

  IWAT-PARM1
*** <ILS >        Flags
*** x -  x CSNO RTOP  VRS  VNN RTLI
  101  109    0    0    0    0    0
  END IWAT-PARM1

  IWAT-PARM2
*** <ILS >       LSUR      SLSUR       NSUR      RETSC
*** x -  x       (ft)                             (ft)
```

```
  101  102    6873.1     0.265        0.1      0.065
  103  104    9733.1    0.2323        0.1      0.065
  105        12864.7    0.1711        0.1      0.065
  106         6370.2    0.1356        0.1      0.065
  107         6118.2     0.122        0.1      0.065
  108         7004.3     0.086        0.1      0.065
  109          6602.    0.1014        0.1      0.065
  END IWAT-PARM2

  IWAT-PARM3
*** <ILS >    PETMAX    PETMIN
*** x -  x   (deg F)   (deg F)
  101  109       40.       35.
  END IWAT-PARM3

  IWAT-STATE1
*** <ILS >  IWATER state variables (inches)
*** x -  x      RETS      SURS
  101  109      0.01      0.01
  END IWAT-STATE1

END IMPLND

RCHRES
  ACTIVITY
*** RCHRES  Active sections
*** x -  x HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG
    1   21    1    0    0    0    0    0    0    0    0    0
  END ACTIVITY

  PRINT-INFO
*** RCHRES  Printout level flags
*** x -  x HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR
    1   21    4    4    4    4    4    4    4    4    4    4    1    9
  END PRINT-INFO

  GEN-INFO
***             Name        Nexits   Unit Systems   Printer
```

```
*** RCHRES                               t-series  Engl Metr LKFG
*** x -  x                                 in  out
    1   21                        1         1    1   91     0     0
  END GEN-INFO

  HYDR-PARM1
***          Flags for HYDR section
***RC HRES  VC A1 A2 A3  ODFVFG for each *** ODGTFG for each     FUNCT
for each
*** x  - x  FG FG FG FG  possible   exit *** possible   exit
possible   exit
    1   21   0  0  0  0    4  0  0  0  0       0  0  0  0  0       1  1
1  1  1
  END HYDR-PARM1

  HYDR-PARM2
*** RCHRES FTBW FTBU        LEN      DELTH      STCOR         KS       DB50
*** x -  x              (miles)       (ft)       (ft)                  (in)
    1         0.   1.      5.97        278        3.2        0.5       0.01
    2         0.   2.     11.18        369        3.2        0.5       0.01
    3         0.   3.     16.06        748        3.2        0.5       0.01
    4         0.   4.      0.37         20        3.2        0.5       0.01
    5         0.   5.      7.32        296        3.2        0.5       0.01
    6         0.   6.      7.86        159        3.2        0.5       0.01
    7         0.   7.     10.65        111        3.2        0.5       0.01
    8         0.   8.       6.4        179        3.2        0.5       0.01
    9         0.   9.      2.52         60        3.2        0.5       0.01
   10         0.  10.      1.16          7        3.2        0.5       0.01
   11         0.  11.      7.95         44        3.2        0.5       0.01
   12         0.  12.      4.77         99        3.2        0.5       0.01
   13         0.  13.      0.58         22        3.2        0.5       0.01
   14         0.  14.      1.09          9        3.2        0.5       0.01
   15         0.  15.      5.98         35        3.2        0.5       0.01
   16         0.  16.      7.27        136        3.2        0.5       0.01
   17         0.  17.      1.95         15        3.2        0.5       0.01
   18         0.  18.      12.4         26        3.2        0.5       0.01
   19         0.  19.      3.19         36        3.2        0.5       0.01
   20         0.  20.      0.63          0        3.2        0.5       0.01
```

```
   21          0.  21.       4.53         7        3.2        0.5      0.01
  END HYDR-PARM2

  MON-CONVF
*** RCHRES  Monthly f(VOL) adjustment factors
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
    1   21 0.97 0.89 0.89 0.91 0.93 0.93 0.94 0.95 0.95 0.98 0.98 0.97
  END MON-CONVF

  HYDR-INIT
***          Initial conditions for HYDR section
***RC HRES        VOL  CAT Initial value  of COLIND     initial  value
of OUTDGT
*** x  - x     ac-ft      for each possible   exit  for each possible
exit,ft3
    1   21       0.01       4.2  4.5  4.5  4.5  4.2       2.1  1.2  0.5
1.2  1.8
  END HYDR-INIT

END RCHRES

FTABLES

  FTABLE      1
 rows cols                               ***
    8    4
     depth      area    volume  outflow1 ***
        0.     37.88        0.        0.
      0.24     38.23      9.21     13.76
      2.42     41.38     95.94    635.25
      3.03     46.64    121.25    920.79
      3.78    127.22    216.65   1182.28
      4.54     129.4    313.71   2163.91
     77.91    341.65  17595.58 894912.38
    151.29    553.89  50450.953719293.25
  END FTABLE  1

  FTABLE      2
```

```
rows cols                              ***
   8    4
    depth       area     volume  outflow1 ***
       0.      93.73         0.        0.
     0.29      94.52      27.27     20.64
      2.9     101.59     282.97    952.68
     3.62     113.37     357.27   1380.81
     4.53     311.64     637.23   1765.37
     5.43     316.55     921.64   3228.17
    93.26     792.76  49637.811293315.13
    181.1    1268.97 140180.72 5283201.5
  END FTABLE  2

  FTABLE      3
rows cols                              ***
   8    4
    depth       area     volume  outflow1 ***
       0.     141.49         0.        0.
      0.3     142.65      42.51      27.2
     2.99     153.14     440.81   1256.02
     3.74     170.62     556.46   1820.46
     4.68     469.61     992.19   2325.76
     5.61     476.89    1434.73   4252.25
    96.32    1183.25   76726.51694314.25
   187.02    1889.61 216088.72 6899989.5
  END FTABLE  3

  FTABLE      5
rows cols                              ***
   8    4
    depth       area     volume  outflow1 ***
       0.       1.43         0.        0.
     0.18       1.45       0.26      5.43
     1.77       1.59       2.68    250.75
     2.21       1.83       3.39    363.53
     2.76       4.91       6.08    470.71
     3.32       5.01       8.82    863.13
    56.93      14.56     533.51 379495.59
```

```
   110.54     24.11   1570.191625683.13
 END FTABLE  5

 FTABLE      4
rows cols                               ***
   8    4
     depth      area    volume  outflow1 ***
        0.     92.55        0.        0.
      0.38     93.22     35.16     53.88
      3.78     99.27    362.99   2488.43
      4.73    109.34    457.71   3606.54
      5.91    303.67     814.4   4584.84
       7.1    307.87   1176.04   8373.78
    121.82    714.97  59849.463213772.75
    236.55   1122.08 165228.45 12800817.
 END FTABLE  4

 FTABLE      6
rows cols                               ***
   8    4
     depth      area    volume  outflow1 ***
        0.    141.49        0.        0.
       0.3    142.65     42.51      13.6
      2.99    153.14    440.81    628.01
      3.74    170.62    556.46    910.23
      4.68    469.61    992.19   1162.88
      5.61    476.89   1434.73   2126.12
     96.32   1183.25   76726.5 847157.13
    187.02   1889.61 216088.723449994.75
 END FTABLE  6

 FTABLE      7
rows cols                               ***
   8    4
     depth      area    volume  outflow1 ***
        0.    217.22        0.        0.
      0.52    218.55    112.64     74.08
      5.17    230.56    1157.5    3423.3
```

```
     6.46    250.58   1457.65    4961.4
     8.08    703.36   2587.27   6271.17
     9.69     711.7   3730.36  11440.02
   166.41   1520.77  178660.2  4201604.
   323.12   2329.84 480382.16 16264023.
 END FTABLE  7

 FTABLE       8
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.      26.1        0.        0.
     0.55     26.26      14.4     67.53
      5.5     27.65    147.87    3120.7
     6.88     29.98    186.17   4522.87
      8.6     84.32    330.29   5710.94
    10.32     85.29    476.09  10415.79
   177.08    179.36  22542.843794875.75
   343.85    273.43  60297.47 14608426.
 END FTABLE  8

 FTABLE       9
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.     15.64        0.        0.
     0.24     15.79      3.75      9.42
     2.38      17.1     39.05    434.77
     2.98     19.29     49.35    630.21
     3.73     52.58      88.2    809.46
     4.47     53.49    127.72   1481.67
    76.76    141.84   7188.04  614414.5
   149.05    230.19  20635.31 2557136.5
 END FTABLE  9

 FTABLE      10
rows cols                               ***
   8    4
```

```
     depth      area    volume  outflow1 ***
        0.     42.45        0.        0.
      0.25     42.84     10.62     11.68
      2.49     46.32    110.53    539.24
      3.11     52.11    139.66    781.61
      3.89    142.33    249.48   1002.86
      4.67    144.74    361.18   1835.25
     80.15    378.92  20125.02 755051.69
    155.64    613.09  57564.98  3129414.
  END FTABLE 10

  FTABLE     11
 rows cols                               ***
    8    4
     depth      area    volume  outflow1 ***
        0.    200.93        0.        0.
      0.59    202.08    119.86     84.26
      5.95     212.4   1229.23    3894.5
      7.43    229.59   1547.19   5644.38
      9.29    647.22   2743.54   7118.03
     11.15    654.38   3953.19  12978.71
    191.45   1349.23  184575.5 4682757.5
    371.75   2044.08 490477.09 17902428.
  END FTABLE 11

  FTABLE     13
 rows cols                               ***
    8    4
     depth      area    volume  outflow1 ***
        0.     29.67        0.        0.
      0.63     29.83     18.62    120.17
      6.26     31.32     190.8   5554.71
      7.82     33.79    240.11   8050.57
      9.78     95.39    425.64   10144.5
     11.73     96.42    613.17   18494.1
    201.41    196.31  28374.68  6631831.
    391.08     296.2   75082.1 25241894.
  END FTABLE 13
```

```
 FTABLE     12
rows cols                               ***
   8    4
     depth      area    volume  outflow1 ***
        0.      2.26        0.        0.
      0.18      2.28       0.4      4.54
      1.77       2.5       4.2    209.29
      2.21      2.88      5.32    303.43
      2.76      7.73      9.54    392.92
      3.31      7.89     13.85    720.49
     56.83     22.92    838.33 316895.91
    110.35     37.96   2467.681357753.75
 END FTABLE 12

 FTABLE     16
rows cols                               ***
   8    4
     depth      area    volume  outflow1 ***
        0.     34.54        0.        0.
      0.26     34.85      9.14     12.06
      2.64     37.59     95.05    556.88
      3.29     42.16    120.07    807.17
      4.12    115.44    214.36   1034.24
      4.94    117.34    310.22   1892.12
     84.83    302.11    17065. 770632.81
    164.72    486.88  48580.73 3176743.5
 END FTABLE 16

 FTABLE     14
rows cols                               ***
   8    4
     depth      area    volume  outflow1 ***
        0.     50.01        0.        0.
      0.25     50.46      12.8     10.28
      2.55      54.5    133.17    474.49
      3.19     61.24    168.25    687.76
      3.98    167.43    300.48    881.96
```

```
       4.78    170.24    434.94   1613.79
      82.03    442.64  24108.38 661198.38
     159.29    715.04  68825.66  2734389.
   END FTABLE 14

   FTABLE     15
  rows cols                               ***
     8    4
      depth      area    volume  outflow1 ***
         0.    171.81        0.        0.
       0.65    172.75    111.38    113.62
       6.47    181.19   1141.12   5252.11
       8.08    195.26   1435.88   7612.04
       10.1    551.78   2544.77    9587.1
      12.12    557.64    3665.5  17476.12
      208.1   1126.23 168664.56  6242639.
     404.08   1694.81 445092.47 23693576.
   END FTABLE 15

   FTABLE     17
  rows cols                               ***
     8    4
      depth      area    volume  outflow1 ***
         0.      8.78        0.        0.
       0.19      8.87      1.71       2.7
       1.94       9.7     17.89    124.75
       2.42     11.08     22.64    180.85
       3.03      29.9     40.57    233.58
       3.63     30.48     58.83    428.06
      62.32     86.11   3480.09 184779.11
     121.01    141.74  10166.29 784686.19
   END FTABLE 17

   FTABLE     19
  rows cols                               ***
     8    4
      depth      area    volume  outflow1 ***
         0.     20.31        0.        0.
```

```
      0.7     20.42     14.27     50.29
     7.01     21.37    146.06    2324.9
     8.76     22.97    183.74   3369.58
    10.95     65.05    325.46   4238.78
    13.14     65.72    468.65   7724.88
   225.55    130.14  21270.292733906.25
   437.96    194.57  55756.68 10304995.
 END FTABLE 19

 FTABLE     18
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.     15.09        0.        0.
      0.2     15.24      3.04       3.7
       2.     16.63     31.74    170.63
      2.5     18.95     40.16    247.36
     3.13     51.26     71.92    319.18
     3.75     52.22    104.28    584.81
    64.42    146.03   6118.17 250764.17
   125.09    239.83  17823.191061456.75
 END FTABLE 18

 FTABLE     20
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.    392.61        0.        0.
     0.69    394.68     271.3     83.65
     6.89    413.33   2777.24   3867.16
     8.61    444.41   3493.86   5604.82
    10.77   1258.12   6189.58   7052.32
    12.92   1271.07    8913.2    12853.
   221.83   2527.34 405680.41  4557436.
   430.75   3783.621064897.63 17202928.
 END FTABLE 20

 FTABLE     21
```

```
 rows cols                               ***
    8    4
     depth      area    volume  outflow1 ***
        0.    154.33        0.        0.
      0.72    155.12    111.89      81.6
      7.23    162.27   1144.74   3772.78
      9.04    174.19    1439.9   5468.07
      11.3    493.77   2550.11   6875.41
     13.56    498.73   3671.54  12528.75
    232.76    980.21 165764.75  4418489.
    451.96   1461.69 433399.31 16610448.
  END FTABLE 21
END FTABLES

COPY
  TIMESERIES
  Copy-opn***
*** x -  x  NPT  NMN
    1         0    7
  END TIMESERIES

END COPY

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-
Member-> ***
<Name>   x <Name> x tem strg<-factor->strg <Name>   x   x        <Name>
x x ***
*** Met Seg AU061136
WDM2    11 PREC     ENGLZERO          SAME PERLND 101 110 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME PERLND 101 110 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME PERLND 101 110 EXTNL  DTMPG
WDM2    14 WIND     ENGL              SAME PERLND 101 110 EXTNL  WINMOV
WDM2    15 SOLR     ENGL              SAME PERLND 101 110 EXTNL  SOLRAD
WDM2    16 PEVT     ENGL              SAME PERLND 101 110 EXTNL  PETINP
*** Met Seg AU061136
WDM2    11 PREC     ENGLZERO          SAME IMPLND 101 109 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME IMPLND 101 109 EXTNL  GATMP
```

```
WDM2    17 DEWP     ENGL              SAME IMPLND 101 109 EXTNL  DTMPG
WDM2    14 WIND     ENGL              SAME IMPLND 101 109 EXTNL  WINMOV
WDM2    15 SOLR     ENGL              SAME IMPLND 101 109 EXTNL  SOLRAD
WDM2    16 PEVT     ENGL              SAME IMPLND 101 109 EXTNL  PETINP
*** Met Seg AU061136
WDM2    11 PREC     ENGLZERO          SAME RCHRES   1  21 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME RCHRES   1  21 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME RCHRES   1  21 EXTNL  DEWTMP
WDM2    14 WIND     ENGL              SAME RCHRES   1  21 EXTNL  WIND
WDM2    15 SOLR     ENGL              SAME RCHRES   1  21 EXTNL  SOLRAD
WDM2    18 CLOU     ENGL              SAME RCHRES   1  21 EXTNL  CLOUD
WDM2    12 EVAP     ENGL              SAME RCHRES   1  21 EXTNL  POTEV
END EXT SOURCES

SCHEMATIC
<-Volume->                 <--Area-->     <-Volume->  <ML#> ***
<sb>
<Name>   x                 <-factor->     <Name>   x        ***
x x
PERLND 101                         22     RCHRES   1      2
IMPLND 101                          3     RCHRES   1      1
PERLND 102                        217     RCHRES   1      2
PERLND 103                      15157     RCHRES   1      2
IMPLND 102                       3327     RCHRES   1      1
PERLND 104                         35     RCHRES   2      2
IMPLND 103                          6     RCHRES   2      1
PERLND 101                       5193     RCHRES   2      2
IMPLND 101                        642     RCHRES   2      1
PERLND 102                        410     RCHRES   2      2
PERLND 103                      19132     RCHRES   2      2
IMPLND 102                       4200     RCHRES   2      1
PERLND 105                          4     RCHRES   2      2
IMPLND 104                          4     RCHRES   2      1
PERLND 104                        251     RCHRES   3      2
IMPLND 103                         44     RCHRES   3      1
PERLND 101                      14624     RCHRES   3      2
IMPLND 101                       1807     RCHRES   3      1
PERLND 106                          4     RCHRES   3      2
```

IMPLND	105	3	RCHRES	3	1
PERLND	102	357	RCHRES	3	2
PERLND	103	12261	RCHRES	3	2
IMPLND	102	2691	RCHRES	3	1
PERLND	105	10	RCHRES	3	2
IMPLND	104	10	RCHRES	3	1
PERLND	104	471	RCHRES	5	2
IMPLND	103	83	RCHRES	5	1
PERLND	101	3525	RCHRES	5	2
IMPLND	101	436	RCHRES	5	1
PERLND	102	214	RCHRES	5	2
PERLND	103	3612	RCHRES	5	2
IMPLND	102	793	RCHRES	5	1
PERLND	105	9	RCHRES	5	2
IMPLND	104	9	RCHRES	5	1
RCHRES	1		RCHRES	5	3
RCHRES	2		RCHRES	5	3
PERLND	104	25	RCHRES	4	2
IMPLND	103	4	RCHRES	4	1
PERLND	101	6642	RCHRES	4	2
IMPLND	101	821	RCHRES	4	1
PERLND	102	7	RCHRES	4	2
PERLND	103	898	RCHRES	4	2
IMPLND	102	197	RCHRES	4	1
PERLND	104	133	RCHRES	6	2
IMPLND	103	23	RCHRES	6	1
PERLND	101	7903	RCHRES	6	2
IMPLND	101	977	RCHRES	6	1
PERLND	106		RCHRES	6	2
IMPLND	105		RCHRES	6	1
PERLND	102	157	RCHRES	6	2
PERLND	103	665	RCHRES	6	2
IMPLND	102	146	RCHRES	6	1
PERLND	105	3	RCHRES	6	2
IMPLND	104	3	RCHRES	6	1
RCHRES	3		RCHRES	6	3
RCHRES	4		RCHRES	6	3
PERLND	104	374	RCHRES	7	2

IMPLND	103	66	RCHRES	7	1
PERLND	101	8278	RCHRES	7	2
IMPLND	101	1023	RCHRES	7	1
PERLND	102	249	RCHRES	7	2
PERLND	103	6076	RCHRES	7	2
IMPLND	102	1334	RCHRES	7	1
PERLND	105	14	RCHRES	7	2
IMPLND	104	14	RCHRES	7	1
RCHRES	5		RCHRES	7	3
RCHRES	6		RCHRES	7	3
PERLND	101	7313	RCHRES	8	2
IMPLND	101	904	RCHRES	8	1
PERLND	106	2	RCHRES	8	2
IMPLND	105	2	RCHRES	8	1
PERLND	102	60	RCHRES	8	2
PERLND	103	9526	RCHRES	8	2
IMPLND	102	2091	RCHRES	8	1
PERLND	107	26	RCHRES	8	2
IMPLND	106	26	RCHRES	8	1
PERLND	101	14065	RCHRES	9	2
IMPLND	101	1738	RCHRES	9	1
PERLND	106	2	RCHRES	9	2
IMPLND	105		RCHRES	9	1
PERLND	102	5	RCHRES	9	2
PERLND	103	1624	RCHRES	9	2
IMPLND	102	356	RCHRES	9	1
PERLND	105	187	RCHRES	9	2
IMPLND	104	187	RCHRES	9	1
PERLND	108	21	RCHRES	9	2
IMPLND	107	5	RCHRES	9	1
PERLND	107	3	RCHRES	9	2
IMPLND	106	3	RCHRES	9	1
PERLND	101	687	RCHRES	10	2
IMPLND	101	85	RCHRES	10	1
PERLND	102	38	RCHRES	10	2
PERLND	103	37	RCHRES	10	2
IMPLND	102	8	RCHRES	10	1
PERLND	105	9	RCHRES	10	2

IMPLND 104	9	RCHRES 10	1
PERLND 107	8	RCHRES 10	2
IMPLND 106	8	RCHRES 10	1
RCHRES 7		RCHRES 10	3
RCHRES 8		RCHRES 10	3
PERLND 104	13	RCHRES 11	2
IMPLND 103	2	RCHRES 11	1
PERLND 109	14	RCHRES 11	2
IMPLND 108	2	RCHRES 11	1
PERLND 101	10497	RCHRES 11	2
IMPLND 101	1297	RCHRES 11	1
PERLND 106	4	RCHRES 11	2
IMPLND 105	3	RCHRES 11	1
PERLND 102	329	RCHRES 11	2
PERLND 103	860	RCHRES 11	2
IMPLND 102	189	RCHRES 11	1
PERLND 105	59	RCHRES 11	2
IMPLND 104	59	RCHRES 11	1
PERLND 108	66	RCHRES 11	2
IMPLND 107	16	RCHRES 11	1
PERLND 107	38	RCHRES 11	2
IMPLND 106	38	RCHRES 11	1
RCHRES 9		RCHRES 11	3
RCHRES 10		RCHRES 11	3
PERLND 101	6184	RCHRES 13	2
IMPLND 101	764	RCHRES 13	1
PERLND 102	13	RCHRES 13	2
PERLND 103	1362	RCHRES 13	2
IMPLND 102	299	RCHRES 13	1
PERLND 104	363	RCHRES 12	2
IMPLND 103	64	RCHRES 12	1
PERLND 101	16791	RCHRES 12	2
IMPLND 101	2075	RCHRES 12	1
PERLND 110	24	RCHRES 12	2
IMPLND 109	6	RCHRES 12	1
PERLND 106		RCHRES 12	2
PERLND 102	27	RCHRES 12	2
PERLND 103	3293	RCHRES 12	2

IMPLND 102	723	RCHRES	12	1
PERLND 105	14	RCHRES	12	2
IMPLND 104	14	RCHRES	12	1
PERLND 101	10409	RCHRES	16	2
IMPLND 101	1287	RCHRES	16	1
PERLND 106		RCHRES	16	2
IMPLND 105		RCHRES	16	1
PERLND 102	71	RCHRES	16	2
PERLND 103	7655	RCHRES	16	2
IMPLND 102	1680	RCHRES	16	1
PERLND 107	3	RCHRES	16	2
IMPLND 106	3	RCHRES	16	1
PERLND 104	25	RCHRES	14	2
IMPLND 103	4	RCHRES	14	1
PERLND 101	640	RCHRES	14	2
IMPLND 101	79	RCHRES	14	1
PERLND 102	36	RCHRES	14	2
PERLND 103	14	RCHRES	14	2
IMPLND 102	3	RCHRES	14	1
RCHRES 11		RCHRES	14	3
RCHRES 12		RCHRES	14	3
PERLND 104	92	RCHRES	15	2
IMPLND 103	16	RCHRES	15	1
PERLND 101	6725	RCHRES	15	2
IMPLND 101	831	RCHRES	15	1
PERLND 106	5	RCHRES	15	2
IMPLND 105	4	RCHRES	15	1
PERLND 102	172	RCHRES	15	2
PERLND 103	697	RCHRES	15	2
IMPLND 102	153	RCHRES	15	1
RCHRES 13		RCHRES	15	3
RCHRES 14		RCHRES	15	3
PERLND 104	12	RCHRES	17	2
IMPLND 103	2	RCHRES	17	1
PERLND 101	5935	RCHRES	17	2
IMPLND 101	734	RCHRES	17	1
PERLND 106	4	RCHRES	17	2
IMPLND 105	2	RCHRES	17	1

```
PERLND 102                          31      RCHRES   17          2
PERLND 103                        3189      RCHRES   17          2
IMPLND 102                         700      RCHRES   17          1
PERLND 105                         102      RCHRES   17          2
IMPLND 104                         102      RCHRES   17          1
PERLND 107                           3      RCHRES   17          2
IMPLND 106                           3      RCHRES   17          1
PERLND 104                          44      RCHRES   19          2
IMPLND 103                           8      RCHRES   19          1
PERLND 109                           7      RCHRES   19          2
IMPLND 108                                  RCHRES   19          1
PERLND 101                        5527      RCHRES   19          2
IMPLND 101                         683      RCHRES   19          1
PERLND 102                          43      RCHRES   19          2
PERLND 103                        4448      RCHRES   19          2
IMPLND 102                         976      RCHRES   19          1
PERLND 105                           6      RCHRES   19          2
IMPLND 104                           6      RCHRES   19          1
PERLND 104                         508      RCHRES   18          2
IMPLND 103                          90      RCHRES   18          1
PERLND 109                           6      RCHRES   18          2
IMPLND 108                                  RCHRES   18          1
PERLND 101                        8922      RCHRES   18          2
IMPLND 101                        1103      RCHRES   18          1
PERLND 110                          23      RCHRES   18          2
IMPLND 109                           6      RCHRES   18          1
PERLND 106                          13      RCHRES   18          2
IMPLND 105                           9      RCHRES   18          1
PERLND 102                         436      RCHRES   18          2
PERLND 103                        4025      RCHRES   18          2
IMPLND 102                         884      RCHRES   18          1
PERLND 105                         195      RCHRES   18          2
IMPLND 104                         195      RCHRES   18          1
PERLND 108                          20      RCHRES   18          2
IMPLND 107                           5      RCHRES   18          1
PERLND 107                          41      RCHRES   18          2
IMPLND 106                          41      RCHRES   18          1
RCHRES  16                                  RCHRES   18          3
```

```
RCHRES  15                                 RCHRES   18      3
PERLND 104                          29     RCHRES   20      2
IMPLND 103                           5     RCHRES   20      1
PERLND 101                          78     RCHRES   20      2
IMPLND 101                          10     RCHRES   20      1
PERLND 102                          48     RCHRES   20      2
PERLND 103                                 RCHRES   20      2
RCHRES  17                                 RCHRES   20      3
RCHRES  18                                 RCHRES   20      3
PERLND 104                          17     RCHRES   21      2
IMPLND 103                           3     RCHRES   21      1
PERLND 101                        4443     RCHRES   21      2
IMPLND 101                         549     RCHRES   21      1
PERLND 110                                 RCHRES   21      2
PERLND 106                           2     RCHRES   21      2
IMPLND 105                                 RCHRES   21      1
PERLND 102                         278     RCHRES   21      2
PERLND 103                        3603     RCHRES   21      2
IMPLND 102                         791     RCHRES   21      1
PERLND 105                         175     RCHRES   21      2
IMPLND 104                         175     RCHRES   21      1
PERLND 108                         129     RCHRES   21      2
IMPLND 107                          32     RCHRES   21      1
PERLND 107                                 RCHRES   21      2
IMPLND 106                                 RCHRES   21      1
RCHRES  19                                 RCHRES   21      3
RCHRES  20                                 RCHRES   21      3
PERLND 104                         409     COPY      1     90
IMPLND 103                          71     COPY      1     91
PERLND 101                       29169     COPY      1     90
IMPLND 101                        3605     COPY      1     91
PERLND 106                           5     COPY      1     90
IMPLND 105                           4     COPY      1     91
PERLND 102                         521     COPY      1     90
PERLND 103                       13824     COPY      1     90
IMPLND 102                        3034     COPY      1     91
PERLND 105                          13     COPY      1     90
IMPLND 104                          13     COPY      1     91
```

```
END SCHEMATIC

EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys
Aggr Amd ***
<Name>   x        <Name> x x<-factor->strg <Name>   x <Name>qf  tem
strg strg***
RCHRES   6 ROFLOW ROVOL  1 1 2.3684e-4     WDM   1001 SIMQ   1 ENGL
AGGR REPL
RCHRES   6 HYDR   RO     1 1           AVER WDM1  1017 FLOW   1 ENGL
AGGR REPL
RCHRES  21 HYDR   RO     1 1           AVER WDM1   101 FLOW   1 ENGL
AGGR REPL
COPY     1 OUTPUT MEAN   1 1 1.9736e-5     WDM   1002 SURO   1 ENGL
AGGR REPL
COPY     1 OUTPUT MEAN   2 1 1.9736e-5     WDM   1003 IFWO   1 ENGL
AGGR REPL
COPY     1 OUTPUT MEAN   3 1 1.9736e-5     WDM   1004 AGWO   1 ENGL
AGGR REPL
COPY     1 OUTPUT MEAN   4 1 1.9736e-5     WDM   1005 PETX   1 ENGL
AGGR REPL
COPY     1 OUTPUT MEAN   5 1 1.9736e-5     WDM   1006 SAET   1 ENGL
AGGR REPL
COPY     1 OUTPUT MEAN   6 1 1.9736e-5AVER WDM   1007 UZSX   1 ENGL
AGGR REPL
COPY     1 OUTPUT MEAN   7 1 1.9736e-5AVER WDM   1008 LZSX   1 ENGL
AGGR REPL
END EXT TARGETS

MASS-LINK

  MASS-LINK        2
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-
Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name>
x x  ***
PERLND     PWATER PERO       0.0833333     RCHRES         INFLOW IVOL
```

```
PERLND     PWTGAS PODOXM                    RCHRES          INFLOW OXIF
1
PERLND     PWTGAS POCO2M                    RCHRES          INFLOW OXIF
2
PERLND     PWTGAS POHT                      RCHRES          INFLOW IHEAT
1
PERLND     PQUAL  POQUAL 1                  RCHRES          INFLOW IDQAL
1
PERLND     PEST   POPST  1                  RCHRES          INFLOW IDQAL
1
PERLND     PEST   SOSDPS 1                  RCHRES          INFLOW ISQAL
1 1
PERLND     PEST   SOSDPS 1                  RCHRES          INFLOW ISQAL
2 1
PERLND     PEST   SOSDPS 1                  RCHRES          INFLOW ISQAL
3 1
PERLND     SEDMNT SOSED  1                  RCHRES          INFLOW ISED
1
PERLND     SEDMNT SOSED  1                  RCHRES          INFLOW ISED
2
PERLND     SEDMNT SOSED  1                  RCHRES          INFLOW ISED
3
  END MASS-LINK    2

  MASS-LINK        1
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-
Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name>
x x  ***
IMPLND     IWATER SURO       0.0833333     RCHRES          INFLOW IVOL
IMPLND     IWTGAS SODOXM                   RCHRES          INFLOW OXIF
1
IMPLND     IWTGAS SOCO2M                   RCHRES          INFLOW OXIF
2
IMPLND     IWTGAS SOHT                     RCHRES          INFLOW IHEAT
1
IMPLND     IQUAL  SOQUAL 1                 RCHRES          INFLOW IDQAL
1
```

```
IMPLND     SOLIDS SOSLD  1                 RCHRES         INFLOW ISED
1
IMPLND     SOLIDS SOSLD  1                 RCHRES         INFLOW ISED
2
IMPLND     SOLIDS SOSLD  1                 RCHRES         INFLOW ISED
3
  END MASS-LINK    1

  MASS-LINK        3
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-
Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name>
x x  ***
RCHRES     ROFLOW                          RCHRES         INFLOW
  END MASS-LINK    3

  MASS-LINK       90
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-
Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name>
x x  ***
PERLND     PWATER SURO                     COPY           INPUT  MEAN
1
PERLND     PWATER IFWO                     COPY           INPUT  MEAN
2
PERLND     PWATER AGWO                     COPY           INPUT  MEAN
3
PERLND     PWATER PET                      COPY           INPUT  MEAN
4
PERLND     PWATER TAET                     COPY           INPUT  MEAN
5
PERLND     PWATER UZS                      COPY           INPUT  MEAN
6
PERLND     PWATER LZS                      COPY           INPUT  MEAN
7
  END MASS-LINK   90

  MASS-LINK       91
```

```
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-
Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name>
x x  ***
IMPLND     IWATER SURO                     COPY           INPUT  MEAN
1
IMPLND     IWATER PET                      COPY           INPUT  MEAN
4
IMPLND     IWATER IMPEV                    COPY           INPUT  MEAN
5
  END MASS-LINK   91
END MASS-LINK

END RUN
```