Integral System for Nonpoint Source Pollution Modeling in Surface Waters

by

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ABSTRACT

This research describes an integrated system to model nonpoint source pollution in surface waters. Two diffuse pollution models were implemented in a Spatial Decision Support System (SDSS) with common interfaces and Geographic Information System (GIS) capabilities. The system includes pre- and post-processing tools, model control and sensitivity analysis for the models. The construction of the interfaces for the AGNPS (Agricultural Non-Point Source) model and WATFLOOD (a flood forecast hydrological model) and their link with the decision support system RAISON (Regional Analysis by Intelligent Systems On microcomputers) are presented. A water quality component was developed for the WATFLOOD model in order to deal with sediment and nutrient transport. Using data for the Duffins Creek watershed, the AGNPS model is used to assess the results from the water quality component coupled into WATFLOOD. Hourly measured data for two separate events were compared against both models. Sensitivity analysis and decision support tools provide a complete setup and the full integration of the system.

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DEDICATION

With all my love I dedicate this thesis to:

My wife Angeles, my sons Alejandro and Daniel and my daughter Marcela

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CHAPTER 1. Introduction

1.1 General

Water resource management was focused initially on water quantity issues. Solving water quality problems did not constitute a primary objective for regulatory agencies until recent years. Interest in water quality only arose with the increase in water degradation and the decrease in available water supplies of acceptable quality. Until the mid-1970s, the problem of Non-Point Source pollution (NPS) was an unknown phenomenon to the general population (Novotny and Chesters, 1981). Environmental engineering and science were basically oriented toward water conveyance, supply, treatment, and disposal.

In the last two decades, NPS has become a topic for research that resulted in the development of numerous models and modelling techniques. Most models simulate hydrologic, chemical, and physical processes involved in the entrainment and transport of sediment, nutrients, and pesticides. The difficulty in modelling NPS is the problem of identifying sources and quantifying loadings. In contrast to a point source, where a known volume of contaminant is discharged from a single identifiable source, diffuse pollution is an aggregate of small contaminant inputs. Such concentrations are released from many sources spatially distributed through a watershed. Thus, NPS models require a distributed modelling approach. The difficulty is that traditional distributed models are limited in scope by the requirement of within element homogeneity and by the need to manipulate extensive data sets.

This thesis addresses these two issues. First, to deal with heterogeneity, a group response unit (GRU) approach is used in the water quality component coupled to a hydrologic model. Its performance is compared with a well established NPS model based on classical hydrologic response unit methods. Second, to handle the extensive data requirements of both models, an integrated system, constructed with powerful data management capabilities, is developed to help in the setup, data input and result analysis.

Application of the GRU concept is another step in the evolution of NPS models. Early models used the lumped approach, considering an area or field to be homogeneous and calculating a hydrologic response from the unit. For larger areas the watershed was divided into individual elements, each with its own set of model parameters, in an effort to account for the spatial variability. This led to so-called distributed models, in which many sub-basins are used.

As the area of the basin to simulate increases, the size of the grid-cells has to increase in order to maintain a manageable number of elements. Most distributed models use the hydrologic response unit approach (HRU), which assumes homogeneity for each cell, and thus restricting the size of the cell to be modelled. Recently a different approach, based on the GRU concept, described by Kouwen *et al.* (1993), calculates the response for each landcover class within the element making larger cells a practical alternative. This approach is included in the hydrologic model WATFLOOD (Kouwen, 1988). Part of this research is to test the GRU concept by adding a water quality component to WATFLOOD and comparing it against an established HRU model. The AGNPS (Young *et al.*, 1986) is the selected HRU reference model.

The successful use of distributed models, either GRU or HRU based, requires the ability to handle large amounts of data, increasing the effort required to collect and compile the input files. Preparing data input for models and analyzing results are probably the most common problems encountered by model users. "Interactive programs are needed to assist model developers and users in processing data, initiating model simulations, and analyzing model results using a variety of statistical and graphical techniques" (Leavesley *et al.*, 1988).

To this end, a integral system is developed in this research, first, to facilitate the GRU-HRU comparison and second, to provide a general tool for NPS studies. The system involves linking the two NPS models to a decision support system with GIS capabilities in such a way to take full advantage of digital mapping information. This provides data compilation for the models thus helping in the setup and operation of the simulation process. Post-processing features are included to assist with the interpretation of model results. For example, the system therefore includes tools for comparative analysis of different scenarios provided with a measure of the confidence limits of the simulation results.

1.2 Research Plan and Contributions

The principal objective of this research was to produce an integral system for nonpoint source pollution modelling in surface waters. Diffuse pollution models, AGNPS and WATFLOOD with the water quality component, were included in a decision support system with a unique platform, common interfaces, and GIS capabilities. The system accommodates pre- and post-processing tools, decision support tools and sensitivity analysis for the models. This integrated approach can be used in further investigations to explore the effects of modifying model parameters. The specific tasks included:

i) Incorporate a water quality component for sediment and nutrients, into WATFLOOD using the GRU approach.

ii) Integrate the AGNPS model for use as a reference for the nonpoint source models.

iii) Create the integral system through the development of interfaces for the two models to interact with a decision support.

iv) Apply and test the performance of the models at a watershed level.

The coupling and testing of the water quality component based on the GRU approach into WATFLOOD formed the major part of this work. A distributed approach based on the GRU concept for landcover characteristics, led to a simplified method to specify the parameters in each grid cell and improve NPS modelling. As part of the research, a water quality component was developed to simulate the processes governing fate and transport of NPS contaminants. The water quality relationships were based on landcover at a watershed scale, and at the same time, accounted for the physical processes.

The application of the AGNPS model provided the opportunity to compare results from both approaches. The initial testing of the system, including automation of input data from vector maps (soil type, land use, digital elevation), was done in Duffins Creek (a watershed located east of Metro Toronto). Available data files and runs of the AGNPS model helped to test the pre-processing tools.

WATFLOOD had already been tested for hydrologic response and achieved satisfactory results in the proposed areas. The objective was to test the water quality component without further calibration for the runoff component. The transferability of model parameters to other watersheds, especially those in remote areas without enough data for calibration, is a major problem with existing NPS models. If the hypothesis behind this work be true, that is, the parameters are related to landcover and the response for each element is weighted on results and not on the coefficients, model portability will increase substantially, which is a significant achievement in NPS modelling.

The main task of creating the integral system for nonpoint source pollution modelling in surface waters was achieved through the linkage of the two distributed models with a decision support system. This provided easy data compilation for the models, facilitated the setup, the operation of the simulation processes and the interpretation of model results. It included the creation of pre- and post-processing tools to automate data input and analyze output. The system components were created in modular form in order to facilitate future improvements.

In order to test the applicability and performance of the models, simulations on the Duffins Creek watershed were conducted and the results compared between the models and against field sample data. Results were compared for peak flows, sediment yields and nutrient loading. Hourly event sampling was used to evaluate the performance of the WATFLOOD model with the water quality component attached.

Due to the simplifying assumptions in current models, the uncertainties in the values of input parameters, and the difficulty in validation with field data, no model can predict absolute quantities with proven accuracy (Leonard and Knisel, 1989). Providing a measure of the confidence limits in the simulation results and its behavior due to the values of input data is a crucial step in the simulation process. As a preliminary analysis on the sensitivity of the parameters in the model outcome, normalized sensitivity coefficients were used to study the importance of parameter variation in the results. The system tools for comparative analysis of different scenarios include different techniques to analyze the sensitivity associated to the models and scenario comparison capabilities.

CHAPTER 2. Literature Review

2.1 Description of the Problem

Sources of pollution are broadly classified as either point or nonpoint sources (Krenkel, 1980). Point sources of pollution, as discrete identifiable locations, include sewered municipal and industrial effluents and discharges from solid waste disposal sites among others. On the other hand NPS, as the result of intermittent releases of pollutants over large areas, are difficult to identify and measure directly.

Nonpoint source pollution enters the receiving surface waters diffusely at intermittent intervals related mostly to the occurrence of meteorological events. There is correlation between the pollutant loading from a watershed and rainfall volume (Novotny and Chesters, 1981). Infiltration and storage characteristics of the basin, the permeability of soils, and other hydrological parameters also play an important role as driving forces of diffuse contamination.

The extent of NPS is also related to geographic, geological and land cover conditions differing greatly in space. The most important waste constituents from diffuse sources are suspended solids, nutrients, and pesticides. If agricultural chemicals such as pesticides and herbicides are placed on the land and surface overland flow is generated by a storm, a significant amount of these contaminants can be lost into surface waters.

The most severe concentrations for point source pollutants carried in surface waters are during low-flow conditions. In contrast, the highest pollutant loading, and in many cases the highest concentrations from diffuse sources, occur during high-flow and flood conditions. Therefore most of the models used for simulating NPS are linked to models of watershed hydrology.

One important issue in estimating nonpoint pollution load from a watershed is the type and extent of activities occurring on the land. Nonpoint source pollution is usually associated with land use. The relative importance and magnitude of the processes (i.e., hydrologic, physical, and chemical), in determining nonpoint loads, will vary among land use categories and associated activities.

The focus on the majority of nonpoint source estimation procedures and models has been on agricultural issues. The entrainment, transport, and fate of sediment, nutrients, and pesticides are largely controlled by the volume and rate of water movement through and across the soil surface. Precipitation, infiltration and surface runoff are the dominant processes.

2.1.1 Existing Nonpoint Source Models

As stated above, the development of models for NPS is linked to the hydrology of the watershed. There are basically two approaches to model diffuse pollution. The more widely used are lumped-parameter models, while more complex models are based on the distributed-parameter concept.

The lumped models were developed at a field-size scale using homogeneous areas. In order to apply them to larger areas "various characteristics of the watershed are often averaged together, and the final form and magnitude of the parameters are simplified to represent the model unit as a uniform system" (Novotny and Chesters, 1981). The distributed approach involves dividing the watershed into smaller homogenous units and adding up the results. While this is the next logical step, it means that calibration data for each field in the watershed is needed.

A real limitation is that runoff and water quality data are collected at only a few points across the watershed and normally at the outlet. The lumped-parameter approach treats the watershed as a hydrological unit using calibrated values for the involved parameters. This simplification tends to represent the model unit as a uniform system and thus limits its use in larger areas.

On the other hand, distributed models take into account spatial variability by dividing the watershed into smaller units with uniform characteristics. It is evident that distributed-parameter models require larger computer storage for performing comparable modelling tasks. A detailed description of the system parameters must be provided and stored for each element.

A key question in distributed modelling is the selection of the criteria for the discretization of the watershed into grid elements. The main difficulty in subdividing watersheds into areas or cells having uniform response is determining what constitutes a hydrological homogeneous area (Kouwen *et al.*, 1993). One of the main characteristics of NPS is the spatial variability and its relation to land use. Therefore the common factor for grouping and selecting the cell size on most of the distributed models is the type of landcover. It should be recognized though, that land use management may cause different responses.

In the attempt to maintain a manageable number of grid elements as the watershed area increases, the assumption of uniformity is normally violated. The most common approach on hydrologic models is to obtain a response for each grid element by weighting the values of the parameters related to landcover area. This is known as the hydrologic response unit approach. Often this assumption of homogeneity, commonly related to landcover, dictates the grid size used to model the watershed.

At this point, special mention is required for the grouped response unit approach. It is based on calculating the response for each of the landcover classes within the element and then weighting the response by area. Grid cell response will then depend on the landcover fractions within the element.

Different types of landcovers can have a wide range of response characteristics; thus the grid elements are made up of different landcovers, each with its own response characteristics that are assumed to be uniform. It is this approach, grouping responses for different landcover classes, that can produce improvements in nonpoint source modelling. This grouped response unit approach forms the basis for the hydrologic model WATFLOOD (Kouwen, 1988).

Transferability, the capability to calibrate a model in one scenario and apply it in a different area, is also an important attribute of a such a scheme. If the model parameters are associated with landcover classes, they can be transferred to other watersheds that would have the same landcover classes but with a different distribution.

The size of the element is not restricted by the assumption of hydrologic homogeneity, only to a size where travel times within the element are small compared with the overall basin travel time. Thus the location of the responding units is not significant. Only the percent of each land class is necessary to characterize a grouped response unit (Kouwen *et al.*, 1993).

Since the early 1970s, a large number of NPS models have been developed. Reviews of the available runoff-water quality models applicable to diffuse pollution modelling of urban and agricultural watersheds have been prepared by Giorgini and Zingales (1986), Rose *et al.* (1988), and Donigian and Huber (1990) among others.

Table 2.1 contains a summary of the features from some of the reviewed hydrologic and agricultural models. It can be noted that WATFLOOD is included to compare its hydrologic capabilities. Part of this research intends to add a contaminant component to WATFLOOD, based on the grouped response unit approach outlined above.

Following is a brief description of the reviewed models with the intention of determining what is already done, what could be improved, and what is still needed.

Table 2.1. Summary of Models Characteristics

Model	surface runoff	soil water	ground water	single event	continous	lumped	distributed (response)	sediment	nutrients	pesticides	Source
	Tasks, simulation, type and pollutants modeled										
AGNPS[1]	●			●	●		●h	●	●	●	USDA-ARS, Morris Minnesota
ANSWERS[1]	●			●			●h	●	●		University of Georgia, Tifton
ARM	●				●	●		●	●	●	EPA, Athens, Georgia
CREAMS-GLEAMS	●	●	●	●	●	●		●	●	●	ASDA-ARS, Tifton, Georgia
GAMES	●			●			●h	●			University of Guelph, Canada
HSPF[2]	●				●	●s		●	●	●	EPA, Athens, Georgia
SWAT	●				●	●s		●	●		USDA-ARS, Temple, Texas
SWRRB[2]	●				●	●s		●	●	●	USDA-ARS, Temple, Texas
WATFLOOD[1]	●	●	●	●	●		●g				University of Waterloo, Canada

1 - For distributed type response: (h)-hydrologic response unit, (g)-grouped response unit
2 - Watershed spatial domain allowing sub-basin division.

AGNPS - *Agricultural Nonpoint Source Pollution Model* was developed by the US Department of Agriculture (Young *et al.*, 1986). It can simulate sediment, nutrient and pesticide loads from agricultural watersheds for a single storm event or for a continuous simulation. The watershed must be divided into uniform square cells where computations are done, and runoff, sediment, nutrients and chemicals are routed from cell to cell from the watershed boundaries to the outlet. The hydrology is calculated by the Soil Conservation Service (SCS) runoff curve number approach, combined with a unit hydrograph type for uniform rainfall. Soil erosion is based on the Universal Soil Loss Equation (USLE). Simple correlation for extraction of nutrients and pesticides in runoff and sediment forms the water quality component of the model.

ANSWERS - *Areal, Nonpoint Source Watershed Environment Response Simulation* was developed by the Agricultural Engineering Department of Purdue University (Beasley and Huggins, 1985). It is a distributed parameter and event oriented model. The watershed is divided into uniform square elements ranging from 1 to 4 hectares. Within each element the model simulates processes of interception, infiltration, surface storage, surface flow, sediment detachment (USLE) and transport. The output from one element becomes the input to the adjacent one. It is primarily a runoff and sediment model; the nutrient simulation is based on simple correlation between chemical concentrations, sediment yield, and runoff volume.

ARM - *Agricultural Runoff Management Model* is a version of the HSP-F *Hydrologic Simulation Program in Fortran* that was originally developed from the Stanford Watershed Model (Donigian and Davis, 1985). It is a large, lumped model and requires considerable effort when applied to a watershed. It is capable of simulating a hydrologic time series event, including hydrographs and conventional pollutants. The model uses a basin-scale analysis framework that includes fate and transport in one-dimensional stream channels. It integrates the simulation of land runoff processes (SCS) with in-stream hydraulics, sediment detachment (USLE), transport, and nutrients. Besides the complex and large amount of data needed, the model requires extensive calibration and application for large drainage systems is very limited.

CREAMS - *Chemicals, Runoff, and Erosion from Agricultural Management Systems* was developed by the US Department of Agriculture (Knisel, 1980). It is a field scale lumped approach model that uses separate hydrology, erosion, and chemistry submodels, connected by shared files. It can simulate continuous series, using the SCS runoff curve number, when daily rainfall data are available or single events with hourly rainfall data using the Green-Ampt equation. The erosion component of the model considers the basic processes of soil detachment (USLE), transport, and deposition. The basic concepts for nutrient modelling treat their transport as proceeding separately in adsorbed and dissolved phases where soil nitrogen is modified by nitrification-denitrification processes. The GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) module is essentially a vadose zone component for CREAMS.

GAMES - *Guelph model for evaluating effects of Agricultural Management Systems on Erosion and Sedimentation* (Dickinson and Rudra, 1990). Developed to describe and predict soil loss by fluvial erosion and the delivery of suspended solids from agricultural fields. The analyisis of erosion is achieved throught the use of the USLE with modifications to the rainfall erosion index and to the soil erodibility factor for local and seasonal conditions. The SCS curve number method drives the hydrology of the model. The discretization of a watershed into field sized elements is done based on homogeneity of land use, soil type and slope.

SWAT - *Soil-Water Analysis Tool* developed by the USDA-ARS, Temple, Texas, to help water resource managers in assessing water supplies, soil erosion, and water and sediment transfers through watersheds (Arnold *et al.*, 1995). The SWAT model estimates surface runoff volume using the Soil Conservation Service (SCS) curve number procedure. Overland sediment yield is computed using the Modified Universal Soil Loss Equation (MUSLE). Nutrient yield and nutrient cycling use the algorithms developed for the EPIC model (Arnold *et al.*, 1993). SWAT allows for simultaneous computations on each sub-basin and routes the water, sediment and nutrients from the sub-basin outlets to the basin outlet.

SWRRB - *Simulator for Water Resources in Rural Basins* was developed for evaluating basin-scale quality in rural watersheds (Williams *et al.*, 1985). It operates on a daily time step and simulates hydrology, crop growth, sedimentation, flood plain degradation, and nitrogen, phosphorus, and pesticide movement. The lumped approach model was developed by modifying the CREAMS model for applications to larger rural basins. Surface runoff is calculated using the SCS curve number technique and sediment yield is computed using the modified USLE. More information is not available to judge data and calibration requirements.

WATFLOOD - A full description of the hydrologic model can be found elsewhere (Kouwen, 1988 and 1993). Briefly, it is a distributed hydrologic modelling system that uses the grouped response unit concept. It can use spatially distributed meteorological data, for example from radar, for rainfall estimation. The model accounts for the dominant short duration rainfall-runoff processes including interception, surface storage, infiltration, interflow, and overland flow as well as the slower processes of snowmelt and evapotranspiration.

As each element response is based on land class area, the runoff is modeled in an element by adding the contributions from each land cover type and routing the results to the drainage system. It uses the storage routing technique to route the water through the channel system. The system includes a pattern search optimization technique to estimate the model parameters that cannot be previously assigned with standard values.

2.1.2 GIS and Decision Support Systems

Geographical Information Systems (GIS) can be thought as a means of storing and retrieving spatially varied data. In the strictest sense, a GIS is a computer system capable of storing, manipulating, and displaying geographically referenced information. They are ideally suited for studying the processes and impacts of diffuse pollution (Connors and Gardner, 1991).

In a GIS system, information about the spatial characteristics of a geographic area can be stored in a grid system (pixel value or vector-polygon object). Information is stored for each grid element and several layers can be used to account for different types of data (i.e., soil type, elevation, and land use). Manipulations, such as overlaying, can be used to extract additional information.

There have been several efforts using GIS technology in the field of nonpoint source pollution. Stuebe and Johnson (1990) used a GIS system for estimating runoff volumes. DeRoo *et al.* (1989) used a GIS system with ANSWERS to model soil erosion. Rewerts and Engel (1991) and Srinivasan and Engel (1994) used a public domain system GRASS to facilitate the input file creation and output visualization for the ANSWERS and AGNPS models. Bekdash *et al.* (1991) evaluated best management practices in agricultural lands using a linkage of a GIS and the CREAMS model.

One step further, to facilitate watershed management and planning, is to integrate different sources of information and knowledge into what is called spatial decision support systems. Lam *et al.* (1994) described an approach to build an environmental information system using RAISON (Regional Analysis Information System) as the base. It is expected that further development will allow it to become a system that will be part of the many research tools needed for better watershed management and planning.

While there are some similarities to GIS (Lam and Swayne, 1991), the RAISON system differs significantly as it emphasizes decision support and expert systems analysis that are difficult or impossible to achieve with traditional GIS. One of the important RAISON features to be used in this work, is its capability to incorporate modelling tools into the system.

This is done by building interfaces that interact with existing models and that can intercept the input and output to connect to the database in the system. Booty and Wong (1994) linked a water quality model within the RAISON system to simulate river flow, effluent advection and dispersion to study the effects on downstream concentrations in the Athabasca River.

2.1.3 Sensitivity Analysis

Sensitivity analysis can be defined as a procedure to determine the relative change in the results of a model due to changes in parameters values. If a small change in a parameter results in relatively large changes in the result, the model is said to be sensitive to that parameter. This may mean that the parameter has to be determined very accurately or that the model has to be redesigned. The most common approach in runoff models to analyze sensitivity is based on direct parameter sampling and normalized sensitivity coefficients (James, 1992), indicating the percentage change in the result due to individual parameter perturbations.

The two major drawbacks of this technique are: (a) the variations are referred to a base solution, e.g. precipitation input function for runoff models, and (b) different locations in space can have different responses to the same parameter perturbation. This results in a large number of runs required to assess the sensitivity of the model. Even with its limitations, it is a very powerful technique to detect the parameters that affect the results the most and others to which the model is less sensitive. The variations in the response of a model to changes in the parameters are also associated with the uncertainty in the values assigned to such parameters. There is an uncontrollable random component inherent to any parameter estimation. It is important to differentiate between risk and uncertainty analysis.

The distinction is that in a risky situation, the uncontrollable random event comes from a known probability distribution; whereas in an uncertain situation the probability distribution is unknown. Analysis of scenarios explores the effect on alternative strategies of changes in input. This is a "what-if" type of analysis with the "what-ifs" being external to the model parameters. The variation of the response to a parameter can be minimized if the variance (uncertainty) associated with such parameter can be reduced. However, if the sensitivity of the outcome to the parameter is small, reduction of its variance may not result in an improvement.

The basic concepts and numerical approaches for parameter sampling have been largely dominated by stochastic techniques such as Monte Carlo or Latin Hypercube sampling procedures. In the Monte Carlo analysis (Hornberger and Spear, 1980), the full distribution of the model output is accomplished through a very large number of simulations where the parameters are randomly selected according to their probability distributions.

The random sampling technique can assume uniform distributions and independence between parameters, requiring large number of samples to properly define the tails of the distributions. In the Latin hypercube procedure (McWilliams, 1987), the range of variation is partitioned into intervals of equal probability and uses a random selection of parameters within each of the intervals reducing the required number of samples.

A serious drawback of using deterministic models with stochastic sampling techniques is the failure to detect the random variation of the output. Only the uncorrelated variations of the input and system parameters can be adequately simulated. If this input and system parameters are cross-correlated, the sampling procedures must be modified to incorporate the cross-correlation, which is tedious and sometimes impossible. Recently, as a result of improvements in decision theory and artificial intelligence, a set of probabilistic approaches under high uncertainty has emerged (Shafer, 1990). These techniques, known as belief networks, are based on the principle of networking nodes representing conditional and locally updated probabilities.

This allows construction of large and densely coupled (interrelated) networks. Furthermore, without excessive growth in computation, such networks can be constructed to operate interactively and on-line. Varis (1995) suggested a methodology to use a belief network 'below' a deterministic model approach to deal with uncertainty in optimization and parameter estimation. This technique is spreading quickly to many application areas.

2.2 Integration in a Decision Support System

2.2.1 Selection of Models

NPS modelling is strongly affected by land use activities with its performance tied to the ability to model surface runoff and sediment erosion. Distributed models based on the hydrologic response unit consider each grid element to be homogeneous. As described in Section 2.1.1, there are numerous distributed models that simulate the fate and transport of diffuse pollutants at a watershed scale.

The AGNPS model is currently one of the proposed nonpoint source pollution models for use at the National Water Research Institute (NWRI) in Burlington, Ontario, Canada. As part of this research, work was done to link it with the RAISON system.

The AGNPS model was chosen for this study due to its accessibility, its multigrid division capability and the ability to simultaneously simulate water quantity and quality in different parts of the watershed. The AGNPS model is a well established and tested simulation event model (Mostaghimi *et al.*, 1997, Bingner *et al.*, 1989, Finney *et. al.*, 1995). Due to its distributed scheme it is also a good choice for GIS integration and it is used to compare results of the addition of the proposed water quality component into the WATFLOOD model.

From the model review (see Table 2.1), it can be noted that the models with a distributed approach are based on the hydrologic response unit concept. AGNPS falls in this category. A distributed approach for which homogeneity in its elements is not required (ie. based on the group response for different land classes), can be a better choice for modelling NPS. A limitation of most models is that uniform precipitation is assumed during the event.

This is acceptable at field scale, but when the simulated area increases, the spatial variation of the rainfall must be taken into account. The availability of radar precipitation data and recent advances in the remote sensing of land cover characteristics, together with GIS tools to store and manipulate such data and a formulation that takes advantage of this information, could yield to an improvement in NPS modelling.

This research is based on selecting a water quality component to simulate the processes governing fate and transport of agricultural pollutants. This component would be incorporated into the distributed hydrologic model WATFLOOD, which uses the group response unit approach and was designed to account for the spatial variability of runoff.

2.2.2 Water Quality Component

To develop a water quality component that is appropriate at a watershed scale, a compromise must be established between the relationships that describe the processes at the microscale (such as adsorption, volatilization, and rainfall effect on soil erosion), and those that will be appropriate at the mesoscale group response unit approach.

Because most of these processes have being developed at a field scale, it is a concern that when applied to wider areas, the relationships used to simulate such processes, nevertheless correct, are taken out of context and stretched beyond their limits in most of the distributed models. By weighting the parameters and not the response for each land class places the effect of the variability on the averaged parameters.

Furthermore, the role that the distribution of landcover would have in the calibration of the parameters is hard to identify. This is the hypothesis to test in this part of the research. The main task was to identify and adapt the governing processes to calculate the response for each land class and then weight the response by area within the unit. In this way, by using the grouped response unit concept, the values of the parameters describing the response processes can be calibrated based on the landcover alone. This should lead to the possibility of transferring the model to other areas without the need of recalibration.

Soil Erosion.- Even though erosion, sediment transport, and deposition are to a large degree natural processes, sediment *per se* are considered a major pollutant in receiving waters. Soil erosion is the major cause of diffuse pollution and sediment is the most visible pollutant and a primary carrier of organic components, phosphates and metals (Beasley *et al.*, 1984).

Soil erosion depends on particle size, soil texture, and the presence or absence of protective surface cover such as vegetation. Vegetative cover is extremely important since it provides additional resistance to shear stresses caused by falling and running water. Hydrologically the erosion processes are classified as overland and stream or channel erosion. Many factors, such as distance from source to streams, vegetative covers, slope, and roughness characteristics of the land, together with the presence of depositional areas during overland flow, affect the delivery of the sediment to the receiving body of water.

As noted from the reviewed models, most of them use the Universal Soil Loss Equation (USLE), or modifications of it, to estimate the soil loss caused by rainfall and runoff. Despite the empirical nature of the method, it is still the most widely used and validated technique to estimate soil erosion. The sediment component used in this research is based in the Simplified Process (SP) model developed by Hartley (1987). It considers the transport capacity of surface runoff and the soil erosion resulting from both runoff shear stress and rainfall impact. The sediment yield equals the smaller of the sediment transport capacity or the supply rate.

This method was selected due to a stronger physical basis than the USLE and therefore it was judged to be more suited to work coupled to the process oriented WATFLOOD model. Some modifications were required to take into account the GRU approach. The method was verified for unit consistency and modified to use the hydrology from WATFLOOD and incorporated as a subroutine into the system.

Nutrients.- In order to provide better plant production rates, fertilizers rich in nitrogen, phosphorus and potassium are applied on agricultural land. From the water quality point of view and as nonpoint source pollutants, nutrients are transported from the watershed by runoff, erosion and leaching. Soluble forms of nitrogen and phosphorus are transported in the runoff. Insoluble forms and forms adsorbed to the soil are moved by the sediments. Nitrate is the principal nutrient form leached to groundwater by percolation. The concentrations of nutrients and total loads depend on the amount of nutrient available for transport and on the conditions that affect the transport mechanisms.

Weather, soils, topography, and land uses all affect the transport capacity. Information about hydrology, erosion, and availability of nutrients should be considered as input data for any nutrient model. Previous calculations of runoff and erosion should be performed in the watershed in order to predict the nitrogen and phosphorus moving in runoff, with sediment, and by leaching.

Process descriptions have to be consistent with the hypothesis that a distributed approach based on land use response will improve the nonpoint source modelling predictions. As part of this research, simple relations (similar to those used in most of the reviewed models) to account for enrichment, solubility, adsorption and leaching (Frere *et al.*, 1980 and Mills *et al.*, 1985) are used. For example, to estimate the sediment transport of nutrients, the algorithms are based on a proportional factor that equates sediment loading to that of the contaminant. The potency factor is related to the concentration in the soil and the enrichment ratio for the contaminant. Calculations are limited to sediment only from overland erosion.

Pesticides.- Use of pesticides revolutionized agricultural production to the point that most agricultural practices formerly used to control weeds, insects, and disease shifted in favor of chemical control. To estimate the amount of pesticide that can be found in surface waters, properties of the applied chemical, amount applied, and the time of the application relative to the rainfall should be known.

Intensive research has been done on the mechanisms for decay of pesticides to define half life values, solubility, and partition coefficients (Wauchope and Leonard, 1980, Lyman, W.J., 1982, Nash, 1980, and Leonard, 1990). Application rates, efficiencies, and elapsed time between the storm event and application can be estimated from agricultural practices in the area of interest. Fortunately, application rates tend to fall within rather narrow ranges; "single applications of 1-5 kg/ha are typical for most herbicides and multiple applications totaling 10-20 kg/ha for insecticides" (Leonard and Knisel, 1989).

After initial application losses, such as canopy interception, volatilization and degradation, the remaining pesticide reaches the soil. The primary source of pesticide available to enter the runoff is from the surface layer of soil. Washoff applied to foliage is another source that may enter the runoff. Pesticide can dissipate from soil and foliar surfaces by degradation and volatilization.

During rainfall events, pesticides may move below the surface zone in the infiltrating water and across the surface in runoff. Pesticide can be extracted by water flowing over the surface, by dispersion and mixing of the soil material in the flow, and by raindrop impact. Once in the runoff, it can be either in solution or attached to the eroded sediment. Simple relations to describe these processes are used in the majority of the models (Knisel, 1980 and Young *et al.*, 1986) were used in the water quality component.

Some important relations that the model takes into account when dealing with the pesticide component are as follows:

(a) first order decay function to account for degradation based on the half-lives of the chemicals,

(b) Henry's law which describes the relation between vapor and solution phases to account for volatilization,

(c) isotherms for the sorption mechanism that controls the partitioning processes between the particulate and dissolved fractions based on a Freundlich equation and an octanol-water partition coefficient.

2.3 Chapter Summary

In this chapter a literature review has been presented. The problem of nonpoint source pollution was outlined and some of the existing models described in order to select the ones to be integrated in the decision support system. AGNPS and WATFLOOD with a water quality component to be incorporated into it were the selected models. A brief description of the GIS techniques used in the area of diffuse pollution and the decision support system RAISON were also described. The methods and algorithms to use in the water quality component for the WATFLOOD model were reviewed and a selection was done based on the physical processes of the yield sediment model. The nutrient relationships will be the same formulations as in the AGNPS that were adapted after the CREAMS model development.

CHAPTER 3. Description of the Models from the Integration Perspective

3.1 AGNPS Model

This section describes the AGNPS model in a more detailed way and from the perspective of the integration approach. The objective is to identify the variables that will be manipulated through the use of the interface. This means that only some of the equations will be presented and is by no means a full technical document for the model. When appropriate, references will be made to the manual and documentation of the AGNPS model (Young *et al.*, 1994) where the equations are defined.

The objective of the model is to compare the effects of various best management practices that could be incorporated into the management of watersheds. It is a distributed model that simulates agricultural watersheds for a single storm event assuming uniform precipitation patterns.

Watersheds modeled by AGNPS must be divided into homogenous square working areas called cells. Subdivision of main cells into smaller sub-cells, gives flexibility to account for the heterogeneity in the watershed. The hydrology is calculated by the SCS curve number approach and the USLE is used for predicting soil erosion. Erosion is predicted for five different particle sizes namely sand, silt, clay, small aggregates, and large aggregates.

The pollutant transport portion is subdivided into one part handling soluble pollutants and another part for sediment based pollutants. The methods used to predict nitrogen and phosphorus yields from the watershed and individual cells were developed by Frere *et al.* (1980); for pesticides the method described by Wauchope and Leonard (1980) is used. As in most nonpoint source pollution models, the equations are based on the CREAMS model described in Knisel, (1980).

The nitrogen and phosphorus calculations are performed using relationships between chemical concentration, sediment yield and runoff volume. For the pesticide component, a distinction is made between foliar and soil application to account for the different decay rates for each source of the same chemical. Pesticide runoff is partitioned between water and sediment using a linear form of the Freundlich isotherm.

Data needed for the model can be classified into two categories, watershed and cell data. Watershed data include information applying to the entire watershed such as watershed size, number of cells, and if running for a single event, the storm type, duration and intensity. Cell data includes information on the parameters based on soil type, land use, and management practices within the cell. The following sections will expand on the physical processes that the AGNPS model uses and will be described from the perspective of the proposed integration.

3.1.1 Hydrology

The purpose of this section is to identify the hydrology and hydraulic methods that the AGNPS model uses, together with the variables that are involved in the different processes. First, it is necessary to define the options available in the AGNPS model that affect the calculation of the hydrology and hydraulic related values. The options include (a) the choice of peak flow method, (b) the geomorphic calculation option and (c) the hydrograph shape generation option. The choice of peak flow method includes two different techniques for peak flow calculations called the *AGNPS* and the *TR55* options.

The *AGNPS* option uses the peak discharge equation based on the SCS curve number technique and limits the channel shape to triangular. The *TR55* option uses the SCS unit hydrograph generation theory and assumes a rectangular shaped channel (top width and bankfull depth). The *TR55* method is an extension of the basic curve number theory including rainfall amount and distribution through the use of a unit hydrograph.

The choice of peak flow method affects the peak flow calculations and the channel shape data requirements. As concluded in the verification section of the technical documentation of the model, the choice for the peak flow method should be based on the scale of the application. If the model is going to be used for watershed-scale applications, then the choice of the *TR55* option is recommended wherever one of the SCS rainfall distributions is reasonably assumed.

The geomorphology option provides a choice between having the model use the geomorphic calculations for channel dimensions or not. The hydraulic geometry predicted by geomorphic calculations is an approach that estimates the downstream trend of increasing channel widths, depths and lengths within well-defined geomorphic regions as a function of the drainage area.

If the geomorphic options and the *TR55* peak flow method are chosen, the channel widths, depths and lengths are calculated based upon functions of the drainage area. If the *AGNPS* peak flow method is selected, the geomorphic option is limited to the stream length, assuming a triangular shaped channel. This is the recommended option found in the model technical documentation. The non- geomorphic option requires cell-by-cell input of channel length, top widths and bankfull depths.

The options for the hydrograph shape generation, shape coefficient or percentage of total runoff prior to the peak, fix the method for calculating the triangular hydrograph. The composite hydrograph is partitioned into three equally spaced ascending limb increments and whatever number of partitions resulting on the recession limb for the time increment.

The algorithm for the hydrograph generation satisfies conservation of mass principles, using the runoff volume, peak flow and time to peak based on the amount of runoff under the ascending limb of the hydrograph. The pre-peak runoff fraction is the recommended option.

The following section presents the equations of the model to deal with the hydrology. The SCS curve number technique is a simplified method for estimating rainfall excess that does not require computing infiltration and surface storage separately. Both processes are included as one runoff watershed characteristic. The excess rain volume (runoff) depends on the amount of precipitation and the volume of total storage (retention). The runoff is predicted for each cell by the SCS equation:

$$Q=\frac{(P-0.2S)^2}{(P+0.8S)} \tag{3.1}$$

where Q is the runoff volume, P is the total rainfall from the storm and S is the retention factor:

$$S=\frac{1000}{CN}-10 \tag{3.2}$$

where CN is the curve number for the cell. These runoff curve numbers depend on the soil water content (moisture condition) and can be found as tabulated values for different land use descriptions. The CN value for each cell will be calculated, as a function of the landcover assuming an average moisture condition, with the values presented in the Lookup Table B4 in Appendix B.

The antecedent soil moisture condition (AMC) represents the watershed soil moisture content and the runoff curve numbers depend on the AMC as described by the SCS as follows:

AMC I - Dry soils but not to the wilting point.

AMC II - Average moisture condition. General case for annual floods.

AMC III - Nearly saturated if rainfall have occurred in the 5 days prior to the storm.

It is worth to note that the values stored in the database are for the average condition II. If a different soil moisture condition is present, the program internally modifies the curve number values according to the following relationships:

$$CN_I = 4.2*CN_{II} / (10 - 0.058*CN_{II}) \quad ; \quad CN_{III} = 23*CN_{II} / (10 + 0.128*CN_{II})$$

where CN_I is the curve number for moisture condition I, CN_{II} for condition II, and CN_{III} for condition III.

The SCS method uses the convolution of a triangular hydrograph to route excess rainfall; thus the peak time is the only parameter determining the shape of the hydrograph. The area under the unit hydrograph equals the unit volume of the rainfall excess. With the *AGNPS* hydrology option, the overland flow duration is calculated as the ratio between the slope length and the overland velocity. The slope length, L_s, is the length where the overland and rill erosion occurs, defined from the top of the slope to the point where the flow becomes concentrated.

The overland velocity V_r is:

$$V_r = 10^{\frac{1}{2}\log_{10}(S_l) - C_s} \tag{3.3}$$

where S_l is the average land slope for the cell and C_s is the surface condition constant based on the land use of the cell.

The average slope will be calculated automatically from digital elevation data for each cell. This will be explained with more detail in Chapter 4. The C_s value for each cell is calculated as function of the land use with the values presented in the Lookup Table B4 in Appendix B.

If the *TR55* option is selected there is no need to calculate the overland velocity. It is indirectly estimated resulting in the overland flow duration by adding the sheet and shallow concentrated flow times.

The equation to calculate the time of sheet flow, T_s, is:

$$T_s = \frac{0.007(n\,L_s)^{0.8}}{P^{0.5}(S_l\,/\,100)^{0.4}} \qquad (3.4)$$

where n is the overland Manning's roughness coefficient and S_l is the average land slope for the element cell.

The Manning's coefficient for each cell will be calculated as a function of the land use with the values presented in the Lookup Table B4 in Appendix B. On the other hand, the time of concentrated flow is the ratio between the flow length, L_f, and the shallow concentrated flow velocity.

The flow length is calculated differently for primary and non-primary cells. Primary cells are the starting elements at the top of the watershed. Non-primary cells are elements receiving flow from other cells.

$$\textit{Non-primary cells:}\quad L_f = 1.061\,W - L_s \qquad \textit{Primary cells:}\quad L_f = 1.5\frac{W}{2} - L_s \qquad (3.5)$$

where W is the cell width and the constant 1.061 and 1.5 factors are adjustments for the curving of the stream. The input required, considering the cell a square, is the area for a primary cell.

The cell width is then calculated as the square root of the area times a units conversion constant. The area for a basic cell will be calculated and stored when the grid is created. The triangular hydrograph is standard in the SCS version of the AGNPS. The time to peak at the top of the cell is used in calculating the hydrograph for the top of the cell.

Since the method only requires the duration for the storm rainfall flow in the cell, point source flows and volumes are not included in this calculation. The point sources are all considered to be downstream from the top hydrograph.

The time to peak at top of the cell hydrograph, t_{pt}, is calculated using the following equation:

$$t_{pt} = \frac{3600\, K_c\, Q_a\, A_a}{640\, q_a} \qquad (3.6)$$

where the 3600 converts the time peak to seconds, K_c is the shape coefficient for the triangular part of the hydrograph, Q_a is the runoff volume above the cell and is accumulated in the routing portion of AGNPS

Since this is only for the cell flow, it simply uses the runoff volume from all the cells flowing into this cell. A_a is the drainage area above the current cell and q_a is the flow rate above. The flow rate below for all the cells flowing into the current cell is the flow rate from above. If the current cell is a primary cell, the value is zero.

Below the cell hydrograph, equation (3.6) is also used but with the values at the bottom of the cell (Q_b, A_b, q_b). The only difference is that the variables that go into this calculation include the amounts from the current cell together with any point source input into the cell. The peak flow rate q, for the current cell is calculated using the equation (Smith and Williams, 1980):

$$q = 200\, A^{0.7}\, S_c^{\,0.16}\, Q^{0.9A^{0.017}}\, L_w^{\,-0.19} \qquad (3.7)$$

where A is the drainage area for the cell, S_c is the mainstream channel slope, Q is the runoff volume and L_w is the length-width ratio of the watershed. The flow rate of all the point sources above the current cell is then added to get the peak flow rate below the cell, q_b. The channel slope will be calculated with the average overland slope from the digital elevation model data.

Summarizing, the data detected from the equations that will be extracted automatically from digital files are for each cell: the SCS curve number, the surface condition constant, the overland Manning's roughness coefficient, the topology of the grid (receiving cells and flow directions), the average overland slope and the mainstream channel slope.

3.1.2 Sediment Transport

The AGNPS model simulates the soil loss and sediment yield in a two-step process. For the soil erosion calculations it uses a modification of the USLE described by:

$$E_u = EI\,K\,LS\,f_{ss}\,f_{sh}\,C\,P \tag{3.8}$$

where E_u is the upland erosion, EI is the erosion index for the storm, K is the soil erodibility factor, LS is the slope length factor, f_{ss} and f_{sh} are the slope steepness and slope shape factors to account for the effects of steepness and shape of the slope, C is the vegetative cover factor and P is the control practice factor. The soil erodibility factor is a measure of potential erodibility of soil and is a function of soil texture. The K value for each cell will be calculated from digital soil type files with the values presented in the Lookup Table B2 in Appendix B.

The LS factor is a function of the overland runoff length and slope. It is a dimensionless factor that cover soil loss estimates for the effects of the field slope and is calculated with:

$$LS = \left[\frac{L_s}{72.6}\right]^d \tag{3.9}$$

where L_s is the slope length already defined in the hydrology section and d is a slope length exponent based upon the average land slope (0.3 for land slopes <4%, 0.4 for slopes between 4 and 5% and 0.5 for average land slopes >5%).

The average overland slope will be calculated automatically from digital elevation data for each cell. The slope steepness and shape factors are introduced to take into account the effects of steepness and shape of the average overland slope. The steepness factor is calculated internally in the model with a quadratic regression curve as a function of the land slope. The shape factor takes the value of 1 for uniform slope shape, 1.3 for convex shape and 0.88 for concave slope shape (Young *et al.*, 1986).

The vegetative cover factor *C*, estimates the effect of ground cover conditions. It is a factor that accounts for the effect of vegetation and land management on erosion rates resulting from canopy protection, reduction of rainfall energy and protection of soil by plant coverage. The *C* value for each cell will be calculated, as function of the land use, with the values in the Lookup Table B4 in Appendix B.

The erosion control practice factor accounts for the effectiveness of soil conservation practices such as contouring, compacting, establishing sedimentation basins and other control structures. Because of the specificity of the *P* values, assignment requires input for each cell. Initially, in order to examine a worst case scenario, a default value of 1 will be assumed when extracting the data. Several values of P for various agricultural practices can be found in Wishmeier and Smith (1978) and in the AGNPS user's guide (Young *et al.*, 1994).

Once the sediment yield is estimated, it is then compared with the sediment transport capacity of the flow. The eroded sediment is then routed based on a steady-state continuity equation for sediment transport and deposition described by Foster *et al.* (1980). The model defines the sediment transport capacity for each of the five particle size classes: clay, silt, sand, small and large aggregates, and then computes deposition. The flow conditions for sediment transport are based on the calculated velocities at peak flow rates presented in the hydrology section.

Because the scope of the present section is only to describe the model from the integration perspective, no further details on the sediment equations will be included. A more detailed explanation of the process will be described in the water quality component development for the WATFLOOD model.

Finally, the data detected from the sediment equations that will be extracted automatically from digital files are for each cell: the soil erodibility factor and the vegetative cover factor. At the same time the slope shape factor and the erosion control practice factor will be defaulted to constant values as described during the data extraction.

3.1.3 Nutrients

The chemical component of the AGNPS model divides nutrient transport into two parts. The first deals with soluble nutrients that are transported by the runoff. The second part addresses nutrients that are transported by the sediment. This means that soluble and sediment-bound phases are calculated separately from available nutrient concentrations in the top 1 cm of the soil profile. From the point of view of the integration, and because similar equations will be used for the development of the water quality component for the WATFLOOD model, the presentation of the equations that drive the nutrient process is deferred to Section 3.3.2, and only the general process will be described here.

The AGNPS equations for nutrients are based on the rationale of the CREAMS model. The methods used to predict nitrogen and phosphorus yields (Frere *et al.*, 1980) account for the effects of rainfall, fertilization and leaching. Rainfall is the driving force for the system and also contains nutrients. Nitrogen concentration occurring in precipitation varies around the 1 ppm range. This level is not agronomically significant for crops but could be for unfertilized and forested areas.

Other sources of nutrients are fertilizers. Normally nitrogen fertilizers are water soluble and phosphate fertilizers are moderately soluble. Consequently, water from the soil and light rains dissolves the granules from the fertilizer application. Only part of the rainfall leaves the field as runoff. The part of the rain that does not runoff fills the surface layer and leaches soluble nutrients into the soil. In the AGNPS model a leaching rate is calculated through the use of extraction coefficients for soil and runoff, with values assigned as defaults.

The input, for cells where fertilizer has been applied, include the level of fertilization and the availability factors for N and P. These refer to the percentage of fertilizer left in the surface of soil at the time of the storm and their values depends on the tillage practices within the field. Nutrient concentrations contributed by animal feedlots are treated as point sources.

These contributions are estimated within the model and routed along with the contributions from nonpoint sources, as well as the additions from springs, wastewater treatment plant discharges and other point sources. Inputs are accounted for by entering inflow rates and concentrations to the cells where the point sources are located. Sediment from stream bank and gully erosion is also treated as a point source input and is added to the overland sediment.

3.1.4 Pesticides

In this section the processes for pesticide fate and transport will be generally described and the pertinent input data will be outlined. The equations that drive the pesticide processes are presented in detail in the water quality component for WATFLOOD in Section 3.3.3.

In the pesticide component, foliar and soil applied pesticides are described separately so that different decay rates can be used for each source. Pesticide residing on foliage dissipates more rapidly than that from soil. Movement of pesticides from soil surface as a result of infiltrating water is estimated with different mobility parameters. Pesticide in runoff is partitioned between the solution and the sediment phase.

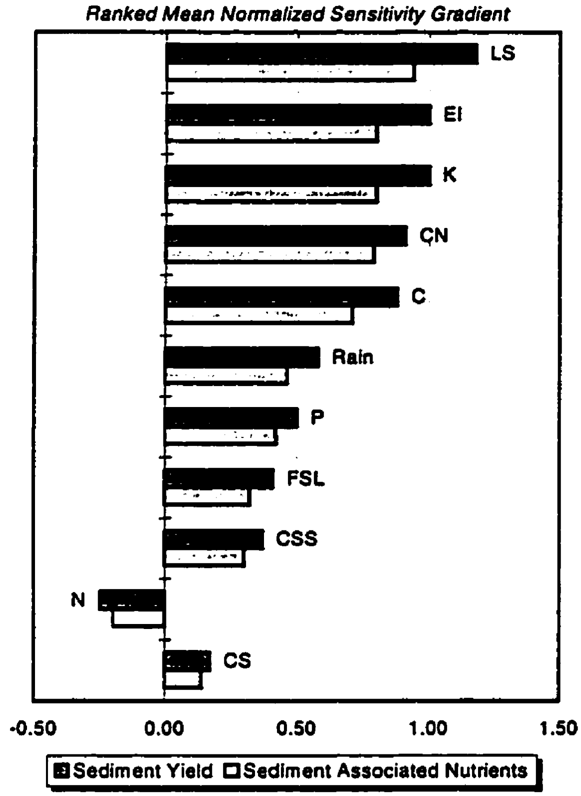
The primary source of pesticide available to enter the runoff stream is idealized as a surface layer of soil with a depth of 1 cm (Leonard and Wauchope, 1980). Washoff of pesticide applied to foliage is another source that may enter the runoff stream. In the AGNPS model, the type of application determines the required data for foliar washoff fraction and percent of canopy cover. For instance, if the pesticide is applied in a pre-plant stage then the canopy cover and subsequent foliar washoff fraction are not required. On the other hand, for a post-emergence application both values will be used in the calculations. Once in the surface, the pesticide dissipates primarily by degradation, infiltration and volatilization processes. Initial concentrations are computed as if they were uniformly incorporated into the top 1 cm depth.

Concentrations of incorporated pesticides are computed based on their incorporation depth and efficiency. A simple exponential dissipation rate is assumed for both soil and foliar residues throughout the model application period. Runoff potential of mobile pesticides is reduced as infiltrating water moves some of the pesticide below the soil surface. A linear adsorption isotherm is used to describe the distribution of pesticide between the solution and soil phases.

Finally the available pesticide is extracted by water flowing over the surface and by dispersion and mixing of the soil material by the flow. At the interface between the soil and the runoff, some mass of soil is effective in supplying pesticide to the runoff volume. Supporting information and parameter values for different kinds of pesticides are provided by the model and accessed through the use of an indexed database. Such a database is presented in Appendix D with the information for the 257 different types of pesticides that the AGNPS model delivers with its documentation and additional files. Summarizing, from the description and equations used in the AGNPS model, the variables and input requirements were defined.

A complete description of all the variables, their structure and naming conventions is presented in the next chapter. Appendix A contains a detailed description of all the variables that the AGNPS model uses. Some of the model parameters and values will be obtained automatically from digital files while others are assigned with default values or data from specific databases (*ie.* pesticides). In order to identify the variables involved in the extraction process and make the definition of the data suitable to be calculated automatically more robust, a preliminary sensitivity analysis was performed for the most common parameters in the model.

A detailed explanation of the method used to perform the sensitivity analysis, including the use of normalized sensitivity gradients to rank the most sensitive parameters to the model outcome, is presented in Chapter 6. The complete set of numbers for this analysis are compiled and presented in Table F1 of Appendix F. The resulting graph is presented in Figure 3.1, showing the ranked normalized sensitivity gradients for different parameters and the effects on the sediment yield and the sediment associated nutrients.



Variables:

LS	land slope
EI	storm energy-intensity
K	soil erodibility factor
CN	SCS curve number
C	cropping or cover factor
Rain	storm rainfall
P	practice factor
FSL	field slope length
CSS	channel side slope
N	Manning's roughness coefficient
CS	channel slope

Figure 3.1 Preliminary sensitivity analysis results for the AGNPS model.

The numbers for the present analysis were obtained from Young *et al.* (1986). It can be noted that the parameters for which the sediment related output is more sensitive to are: the land slope (*LS*), the energy intensity factor (*EI*), the soil erodibility factor (*K*), the SCS curve number (*CN*) and the cropping or cover factor (*C*).

All of these variables were selected to be extracted automatically from digital files and care was taken that they were estimated as accurate as it can be done from the resolution of the digital information. On the other hand, the outcome is much less sensitive to the practice factor (P) and the field slope length (FSL), which were selected to be assigned with default values.

3.2 WATFLOOD Model

A full description of the hydrologic model WATFLOOD can be found elsewhere (Kouwen *et al.*,1993 and Kouwen, 1999). As mentioned before, it is a flood forecasting system with a distributed hydrologic simulation model designed to work under the grouped response unit concept. It can use radar data, if available, for rainfall estimation. The model accounts for the dominant short duration rainfall-runoff processes including interception, evapotranspiration, surface storage, infiltration, interflow, snowmelt, and overland flow.

As each element response is based on land class area, the runoff is calculated in an element by adding the contributions from each land cover type and routing the results to the drainage system. It uses a storage routing technique to route the water through the channel system. The program includes a method (a pattern search optimization algorithm) to estimate the model parameters that cannot be previously assigned with standard values. The added water quality component calculates the transport of sediments, nutrients and pesticides based on the same concept of the grouped response unit.

3.2.1 Hydrology

The following is a brief description of the hydrologic section used in WATFLOOD in order to identify the requirements from the integration perspective. The equations have been extracted from the model documentation (Kouwen, 1997). Rainfall drives the model; interception is calculated with the exponential relationship presented by Linsley *et al.* (1949):

$$V=(S_i+C_pE_at_R)(\overline{1}-e^{-kP}) \tag{3.10}$$

where V is the interception depth [mm], S_i the storage capacity [mm], C_p the ratio of vegetated surface area, E_a the evaporation rate [mm/hr], t_R the duration of the rainfall [hr], k a constant [mm^{-1}] and P the precipitation [mm].

The values for the storage capacity are set for each landuse class. The product of the cover area ratio and the evaporation rate is used as a single parameter. The surface storage is assumed to be reached exponentially (Linsley *et al.* 1949):

$$D_S = S_d\,(1 - e^{-kP_e}) \qquad (3.11)$$

where D_s is the depression storage [mm], S_d is the surface retention value [mm] and P_e is the accumulated rainfall excess [mm]. The surface retention values are assigned depending on the type of landcover (ASCE, 1969). The infiltration process and the concept of surface detention, is represented by the formula (Philip, 1954):

$$\frac{dF}{dt} = K\left[1 + \left(\frac{(m - m_o)(Pot + D_1)}{F}\right)\right] \qquad (3.12)$$

where F is the total depth of infiltrated water [mm], t is time [s], K is the saturated conductivity [mm/s], m is the average moisture content of the soil to the depth of the wetting front, m_o is the initial soil moisture content, Pot is the capillary potential at the wetting front [mm] and D_1 is the depth of water on the soil surface or detention storage [mm].

The values of the saturated conductivity are assigned through the optimization technique for each land class. Interflow is defined as a fraction of the initially infiltrated water or upper zone storage that is exfiltrated to nearby water courses. The simple storage-discharge relation is:

$$Q_{int} = REC * (WAC - RETN) * SLOPE \qquad (3.13)$$

where Q_{int} is the interflow [m^3/s], *REC* is a coefficient representing the depletion fraction and estimated through optimization, *WAC* is water accumulation in the upper zone storage [mm] and *RETN* is the retained storage [mm]. Finally, when the infiltration capacity is exceeded and the depression storage has been satisfied, water is discharged to the drainage system based on uniform flow.

The Manning formula for overland flow as used in the model is:

$$Q_r = \frac{1}{R_3}(D_1 - D_S)^{5/3} S_l^{1/2} A \tag{3.14}$$

where Q_r is the channel inflow [m^3/s], (D_1 - D_S) represents the runoff depth above ponding, R_3 is a combined roughness and channel-length parameter optimized for each land class, S_l is a average overland slope and A is the area of the GRU element [m^2]. The above equations are used separately for each land class in each computational element to calculate the total inflow to the river system.

The total runoff for each element is calculated by adding the surface runoff contributions from the various landcover classes to the base flow. The routing through the channel system is achieved using a storage-routing technique based on the continuity equation:

$$\frac{I_1 - I_2}{2} - \frac{O_1 - O_2}{2} = \frac{S_2 - S_1}{\Delta t} \tag{3.15}$$

where $I_{1,2}$ is the inflow to the reach [m^3/s] and consists of overland flow, interflow, base flow and channel flow from all contributing upstream basin elements, $O_{1,2}$ is the outflow from the reach [m^3/s], $S_{1,2}$ is the storage in the reach [m^3] and Δt is the time step of the routing [s]. The subscripts 1 and 2 indicate the beginning and end of the time step. Again, assuming uniform flow, the outflow is related to the storage through the Manning formula:

$$O = \frac{1}{R_2} A_x^{4/3} S_o^{1/2} \tag{3.16}$$

where O is the outflow [m^3/s], R_2 is the channel roughness parameter, A_x is the channel cross section area, geomorphic or actual if available, which is related to storage by dividing it by the channel length [m^2] and S_o is the channel slope.

Two aspects have been constantly mentioned in the above description, variables related to land cover classes and an optimization technique to assign some of the parameters values. The first deals with the input requirements for the model and the second refers to an automatic pattern search optimization for calibration purposes. Data requirements are divided in two sections: watershed and event data.

For the watershed input some topographical data are required for each cell, such as the stream bed elevation at half way through the element, the drainage direction, the fraction area of the cell within the watershed, the typical surface slope of the element and the number of channels crossing the element. All this data will be extracted automatically using digital elevation model files as explained in the next chapter.

3.2.2 Radar & Remote Sensing Data

WATFLOOD has been designed since its inception to take advantage of weather radar and satellite imagery. The fundamentals and equations used in the model in order to convert the radar reflectivity values into rainfall rates can be found in Kouwen (1988). In general terms consist of different processes to adjust the data for clutter, beam-blocking and attenuation, and compute rainfall rates with values of radar reflectivities using an exponential relationship.

Other processes are used to average the data hourly, calibrate the radar rainfall with raingauge data, fill missing data and distribute the rainfall at specified grid sizes. The scope of the present integration attempt will not deal with any modification or interface conversion of radar images and they are treated only as known input into the model. WATFLOOD is based on the group response unit approach. Runoff is calculated in a grid element by estimating the contributions from each land cover separately. This approach allows for larger element sizes as they are not limited to the hydrologically homogeneous assumption. Tao and Kouwen (1989) presented the advantage of using satellite derived land cover information for data input into WATFLOOD.

The input requirement is to transform land use maps into percentages of coverage for each landcover within the grid element. From the point of view of the integration approach, the source of data for automatically extracting the percentages of different land classes within a grid element is a digital land use map. This map is usually derived from Landsat imagery through the process of classification techniques upon spectral signatures. Once the image has being classified, vector polygons or raster data are created. This work is based on the vectorized information.

It has been found, at least for the personal computer environment and with the RAISON system, that searching techniques on the attributes and positioning on different geo-projections are better handled with the vector polygon data than with the raster values. The number of classes that the model can handle is not a restriction, but it is limited by the classification technique depending on the number of distinct spectral signatures that can be identified in the Landsat image. Provisions will be taken to make this class definition as transparent and robust as possible to include different sources of information. For example, some land classifications include a very detailed differentiation between land use classes, such as different crops types, while others are more general by grouping all crops as agricultural land.

As described in Kouwen *et al.* (1993), it is assumed that, unless there are major irregularities in the soil types, that is, completely heterogeneous soil content in the surface, the topographic and land cover effects far outweigh the effects of variations of soil. As this may be true for the hydrological response, when dealing with soil erosion, transport and deposition, the soil type will play a major role on the sediment component.

The variables that require soil data for the water quality component attached to the hydrologic model are described in Section 3.3. A similar extraction procedure from digital files, to account for the percentage of soil type within the study area, will be included to account for the sediment processes to be attached to WATFLOOD.

3.3 Water Quality Component for WATFLOOD

3.3.1 Sediment

A simple sediment yield model for single storm events (Hartley, 1987) was already coupled with the WATFLOOD model but had not yet been successfully implemented by the time this research was undertaken. A review of this model component revealed some units errors and coding omissions. As part of this research, the hydrology of the Hartley model was replaced by the values calculated with WATFLOOD. A brief description of the sediment component to be coupled with the model follows.

The sediment model is based on calculating the sediment transport capacity and the potential sediment supply, choosing whichever is less and routing it downstream. The sediment transport capacity is calculated with a simple shear stress relationship (Hartley, 1987):

$$c = A\left(\frac{\tau_d}{\tau_c}\right)^B \quad (3.17)$$

where c is a volumetric sediment concentration, τ_d is the dominant flow shear stress on the soil and τ_c is the critical stress based on the shear Shields criteria (Simons and Senturk, 1976), A and B are constants with values of 0.00066 and 1.61 respectively. These values are empirical based on field data and taken directly from the original reference.

The shear stress for the runoff is derived from shear stress relationships on the soil surface and accounts for the part of the total flow shear stress absorbed by ground cover. The integration of the time average flow shear on the soil gives the dominant shear stress and is calculated with:

$$\tau_d = \frac{\beta}{\beta+1}\left(\frac{60}{K_f}\right)\gamma H_L S_o \quad (3.18)$$

where β is a constant discharge parameter with a value of 5/3, γ is the water specific weight, H_L is average runoff depth, S_o is the average overland slope and K_f is an overland flow friction parameter. H_L corresponds to (D_1 - D_S) presented in the hydrology section of WATFLOOD.

The overland friction parameter is a function of the ground cover for each land class and is calculated with:

$$K_f = 60 + 3140\, GC^{1.65} \tag{3.19}$$

where GC is the ground cover factor and an estimate of the landcover density for different land uses. Values for GC can be found in Table B5 on Appendix B and are assigned automatically during the extraction process and stored as a parameter for the different land classes.

The critical shear stress is determined by:

$$\tau_c = (\sigma - 1)\gamma\, \Phi\, D_{50} \tag{3.20}$$

where D_{50} is the median size of the soil particles, σ is the specific weight of the sediment and Φ is the Shields entrainment function depending on the Reynolds number, R^*, defined by:

$$R^* = \frac{\sqrt{\tau_d \gamma}\; D_{50}}{\nu} \tag{3.21}$$

where ν is the kinematic viscosity of water. The Shields relationship for shear stress is based on dimensional analysis and experimental observations. From the Shields diagram, a plot of the entrainment function against the Reynolds number, a linear relationship is obtained for $R^*<3$ from which Φ can be estimated. The equation is (Simons and Senturk, 1976):

$$\Phi = \frac{0.11}{R^*} + 0.021 \log_{10} R^* \tag{3.22}$$

To determine D_{50}, according to Foster *et al.* (1985), it is necessary to establish a distribution for particle size and specific gravity of detached sediment particles. A series of equations related to the primary particle define the size distributions of the matrix soil. The equations for size and numerical values of specific gravity are those suggested by Foster *et al.* (1980) for the CREAMS model. Figure 3.2 shows the size distribution using such equations, for a basic silt loam soil, as an example on how the particle median size is estimated. Table B2 on Appendix B presents the size distributions and specific weights based on the mentioned equations and adopted by Hartley in his sediment model.

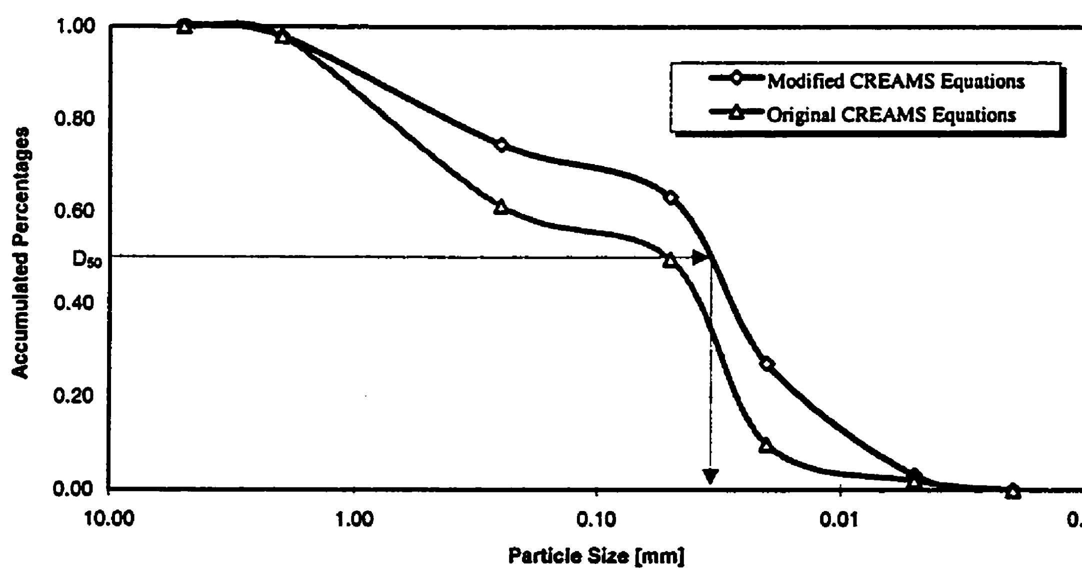


Figure 3.2 Particle size distribution for silt loam (after Foster *et al.*, 1985)

Substituting the shear and critical stresses into equation (3.17) gives an average capacity of the flow to transport sediment for the whole surface over the runoff period. Finally, the sediment transport capacity in terms of mass per unit area is then calculated with:

$$Y_C = 2.65\,\rho\;c\;r_f \tag{3.23}$$

where the 2.65 is the specific weight of the finer particles on the sediment (silt or clay), Y_C is the sediment transport capacity, r_f is the runoff amount provided by the hydrology section of WATFLOOD and ρ is the density of water.

To calculate the potential sediment supply due to rainfall and runoff, an empirical relationship for rainfall energy rate is calculated with:

$$E_{rf} = i(11.9 + 8.7 \log_{10} i) \qquad (3.24)$$

where E_{rf} is the rate of rainfall energy and i the rainfall intensity. In this case, the precipitation value used in WATFLOOD divided by the time increment will be used to convert it to rainfall intensity. The rate of soil detachment by rainfall is then calculated with:

$$G_{rf} = E_{rf}(1 - GC)\,CF\,D \qquad (3.25)$$

where G_{rf} is the rate of soil detachment due to rainfall, CF is a canopy factor based on the percentage of canopy cover of the soil and D is a soil erodibility factor equivalent to the K factor from the USLE. The values for CF are assigned as parameters for the model depending on the landuse extraction and can be found in Table B5 on Appendix B. The values for soil erodibility are converted from the erodibility factor from the USLE, as described in Section 3.1.2, by a conversion factor during the extraction process.

Runoff also detaches and erodes sediment on the overland. The sediment supply due to surface runoff is calculated with:

$$E_{ro} = \left(\frac{60}{K_f}\right)\gamma \frac{Q_L}{2} S_o \qquad (3.26)$$

where E_{ro} is the rate of energy input to the soil by the flow and Q_L is a unit flow discharge passed from the hydrology section of WATFLOOD. The rate of soil detachment by runoff, G_{ro}, is analogous to that of the rainfall and estimated with:

$$G_{ro} = E_{ro}\,D \qquad (3.27)$$

Taking into account both effects, rainfall and runoff detachment, the sediment yield based on the supply rate, Y_S, in terms of mass per unit area is:

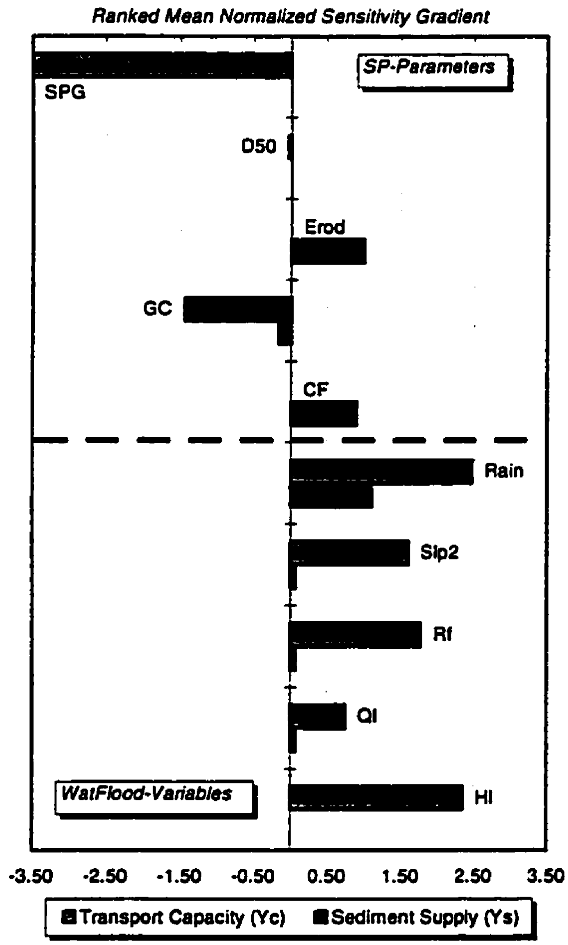
$$Y_S = (G_{rf} + G_{ro})\Delta t \qquad (3.28)$$

The minimum of Y_S and Y_C represents the sediment yield for the time increment for a single element and a specified land class that will be routed downstream based on a continuity equation for the cell.

The source FORTRAN code for the sediment subroutine was revised and some modifications made to correct for the units and omissions. It can be found in Appendix G. The listing is documented to identify variables and units to be used. In order to define how precisely the parameters and values assigned with the automatic extraction procedures must be, a preliminary sensitivity analysis was performed on the sediment model.

Figure 3.3 shows the results of the preliminary sensitivity analysis with the ranked normalized sensitivity gradients for different parameters, sediment model and WATFLOOD, and the effects on the sediment supply and transport capacity. A more detailed explanation of the methodology to perform sensitivity analysis and the use of normalized sensitivity gradients is presented in Chapter 6. The complete set of numbers are in Table F2 of the Appendix F.

The specific weight, once established does not change. It is therefore important to select the best possible value since the sediment transport capacity is highly sensitive to it. The median particle size changes with the soil type, but its impact on the sediment supply and transport is negligible. The sediment capacity is also quite sensitive to canopy and cover factors, so a good first estimation on these values is important. They will be extracted from landuse maps and assigned as parameters that can be optimized by the calibration procedure of the model.



Sediment Model Parameters:

SpG	Specific weight [-]
D_{50}	Median particle size [mm]
Erod	Soil erodibility, D [g/J]
GC	Ground cover [-]
CF	Cover factor [-]

WATFLOOD variables:

Rain	Precipitation intensity [mm/hr]
Slp2	Overland slope [-]
Rf	Runoff amount [mm]
Ql	Unit flow discharge [m^2/hr]
Hl	Runoff depth [mm]

Figure 3.3 Preliminary sensitivity analysis results for the sediment model/WATFLOOD.

3.3.2 Nutrients

The methods selected to simulate the nutrient processes in the water quality component for WATFLOOD are based on those used in AGNPS developed from the earlier CREAMS model. These algorithms are the most widely used and accepted. They were developed for CREAMS by several research teams attempting to create a model that would not require extensive calibration efforts (Frere *et al.*,1980). Young *et al.* (1986) modified the algorithms to use them at a watershed scale and created the AGNPS model. Further details can be found in the technical documentation on nutrient information from the AGNPS and CREAMS models.

The nutrient simulation is divided in two parts that handle the soluble nutrients in the runoff and in the sediments separately. For the soluble part, the general assumption is that the rate of change in concentration of soluble nutrients in the water, in the surface (top 1 cm) of soil, is proportional to the difference between existing concentrations and concentration in rainfall.

Nitrogen

The soluble nitrogen concentration in the runoff is calculated with (Young *et.al.*, 1986):

$$C_{RON} = \frac{(N_{AVS} - N_{AVR})}{F_{POR}}\left[e^{(-N_{DMV}I_{EFF})} - e^{(-N_{DMV}I_{EFF} - N_{RMV}R_{OFF})}\right] + \frac{N_{RNC}\,R_{OFF}}{P_{EFF}} \tag{3.29}$$

where C_{RON} is the soluble nitrogen concentration in runoff [kg/ha], N_{AVS} is the available nitrogen content in the surface [kg/ha], N_{AVR} is the available nitrogen in rainfall [kg/ha], N_{DMV} is the rate for downward movement of nitrogen into the soil, N_{RMV} is the rate for nitrogen movement into the runoff, I_{EFF} is the effective or total infiltration [mm], R_{OFF} is the total runoff [mm], F_{POR} is a porosity factor, N_{RNC} is the nitrogen contribution due to rain [kg/ha], and P_{EFF} is the effective precipitation [mm]. The available nitrogen content in the surface is a result of combining the residual nitrogen in the surface with the amount from the fertilizer application:

$$N_{AVS} = [Sol_N + (N_{FER}\,N_{fa})]\,F_{POR} \tag{3.30}$$

where Sol_N is the soluble nitrogen in the surface centimeter of the soil [kg/ha], N_{FER} is the nitrogen fertilizer application [kg/ha] given as a input data for the model, N_{fa} is the fraction of nitrogen availability for the fertilizer application also given as input data. The soluble nitrogen in the surface top of the soil is estimated by:

$$Sol_N = 0.10\,N_{CPW}\,Por \tag{3.31}$$

where N_{CPW} is the nitrogen concentration in the pore water of the top centimeter of surface soil and is given as a default data value for nitrogen of 5 ppm, Por is the soil porosity.

The porosity and porosity factor are calculated with the bulk density, σ, values for the soil as:

$$Por = 1 - (\sigma / 2.65) \quad ; \quad F_{POR} = 0.00001 / Por \qquad (3.32\text{-}33)$$

The available nitrogen due to rainfall is:

$$N_{AVR} = N_{CRN} \, x \, 10^{-6} \qquad (3.34)$$

where N_{CRN} is the nitrogen concentration in the rainfall [ppm] and is given as input data. The movement rates are evaluated using:

$$N_{DMV} = \frac{N_{LEC}}{10\,Por} \quad ; \quad N_{RMV} = \frac{N_{REC}}{10\,Por} \qquad (3.35)$$

where N_{LEC} is the nitrogen leaching extraction coefficient with a default value of 0.25 and N_{REC} is the nitrogen runoff extraction coefficient with a default value of 0.05, both given as input data for the model. The 10 in the equation is the depth of soil interaction in millimeters, giving to the movement rates units of [mm^{-1}] that will cancel with the [mm] from infiltration and runoff in equation (3.29). In the AGNPS model the infiltration is calculated simply by subtracting the runoff from the amount of rainfall, while the runoff is calculated with the SCS curve number method. For this coupling, these values are taken directly from the hydrology section of WATFLOOD as:

$I_{EFF} = F$	total depth of infiltrated water [mm]
$R_{OFF} = H_L = (D_I\text{-}D_S)$	runoff depth [mm]

The WATFLOOD variables F, H_L and $(D_I\text{-}D_S)$ are defined in Section 3.2.1. For the nitrogen contribution due to rain, N_{RNC}, the following expression is used:

$$N_{RNC} = 0.01 (N_{CRN}) P \qquad (3.36)$$

where P is the storm precipitation [mm] and the 0.01 is a unit conversion factor.

The effective precipitation is related to the precipitation and soil porosity by:

$$P_{EFF} = P - (10\,Por) \tag{3.37}$$

The 10 in the equation is the top 1 cm in millimeters of soil interaction. The precipitation values will be taken directly from the radar files used by WATFLOOD as rainfall in a cell.

Phosphorus

The phosphorus calculations are similar to the nitrogen ones except that the effects of rainfall are omitted. This is due to the fact that very little soluble phosphorus is found in rainfall. The equation used to predict soluble phosphorus in the runoff is:

$$C_{ROP} = \frac{(P_{AVS} - P_{AVR})}{F_{POR}}\left[e^{(-P_{DMV} I_{EFF})} - e^{(-P_{DMV} I_{EFF} - P_{RMV} R_{OFF})}\right] + \frac{P_{AVR}\,P_{RMV}\,R_{OFF}}{F_{POR}} \tag{3.38}$$

where C_{ROP} is the soluble phosphorus concentration in runoff [kg/ha], P_{AVS} is the available phosphorus in the surface due to fertilizer application [kg/ha], P_{AVR} is the available phosphorus due to residual levels in the soil [kg/ha], P_{DMV} and P_{RMV} are the movement rates for leaching and runoff respectively. The rest of the terms are the same as in the nitrogen calculations:

$$P_{AVS} = [\,Sol_P + (P_{FER}\,P_{fa})\,]\,F_{POR} \tag{3.39}$$

where Sol_P is the soluble phosphorus in the surface centimeter of the soil [kg/ha], P_{FER} is the phosphorus fertilizer application [kg/ha] given as a input data for the model, P_{fa} is the fraction of the phosphorus availability for the fertilizer application also given as input data. The soluble phosphorus in the surface top of the soil is estimated by:

$$Sol_P = 0.10\,P_{CPW}\,Por \tag{3.40}$$

where P_{CPW} is the phosphorus concentration in the pore water of the top centimeter of surface soil and is given as a default data value for phosphorus of 2 ppm.

The available phosphorus due to initial soil residuals is solved using the equation:

$$P_{AVR} = Sol_P \, F_{POR} \tag{3.41}$$

The movement rates are evaluated using:

$$P_{DMV} = \frac{P_{LEC}}{10\,Por} \quad ; \quad P_{RMV} = \frac{P_{REC}}{10\,Por} \tag{3.42}$$

where P_{LEC} is the phosphorus leaching extraction coefficient with a default value of 0.25 and P_{REC} is the phosphorus runoff extraction coefficient with a default value of 0.025, both given as input data for the model. The rest of the terms are the same as in the nitrogen calculations.

The nutrient yields associated with the sediment are calculated using total sediment yields from each cell. Such values are obtained with the process described in the sediment section. The nitrogen yield in the sediment is calculated with the following equation:

$$N_{SED} = N_{SCN} \, Y_{SED} \, ER \tag{3.43}$$

where N_{SED} is the overland nitrogen transported by the sediment [kg/ha], N_{SCN} is the soil nitrogen concentration with a value of 0.001 g N/g soil, Y_{SED} is the total sediment yield [kg/ha], and ER is the nutrient enrichment ratio calculated with:

$$ER = a \, Y_{SED}{}^{b} \, T_f \tag{3.44}$$

where a and b are experimental constants with values of 7.4 and -0.20 respectively. T_f is a correction factor for soil texture and has a value of 0.85 for sand, 1.0 for silt, 1.15 for clay and 1.50 for peat. For the phosphorus yield in the sediment, the equation is:

$$P_{SED} = P_{SCN} \, Y_{SED} \, ER \tag{3.45}$$

where P_{SED} is the overland phosphorus transported by the sediment [kg/ha], P_{SCN} is the soil phosphorus concentration with a value of 0.0005 g P/g soil. The source FORTRAN code for the nutrient subroutines can be found in Appendix G.

3.3.3 Pesticides

As before, the methods used to simulate the pesticide processes in the water quality component are the same as the ones used in AGNPS. The pesticide model was developed by Leonard and Wauchope (1980) and adapted by Young *et.al.* (1986). The following information will describe how the soluble, sediment and percolated fractions of the pesticides are calculated. Further details can be found in the technical documentation for the AGNPS model.

Losses due to evaporation, application technique and other factors are taken into account by calculating the effective pesticide amount with:

$$P_{EFF} = P_{APR}\,(A_{EFF} / 100) \qquad (3.46)$$

where P_{EFF} is the effective pesticide amount [kg/ha], P_{ARP} is the pesticide application rate given as input data [kg/ha], and A_{EFF} is the application efficiency as the percent of pesticide that reaches the field and also given as input data. The amount of pesticide that ends up on the foliage of the plant immediately after application is:

$$P_{CAN} = P_{EFF}\,CC + P_{CAN_{res}} \qquad (3.47)$$

where P_{CAN} is the pesticide on the canopy [kg/ha], CC is the canopy cover as the percent of ground area covered by foliage, P_{CANres} is the initial foliar residue before the application. The amount of pesticide in the soil is:

$$P_{SUR} = P_{EFF} - P_{CAN} + P_{SUR_{res}} \qquad (3.48)$$

where P_{SUR} is the amount of pesticide that reaches the surface soil [kg/ha], P_{SURres} is the residual soil residue from previous applications [kg/ha]. To convert to concentrations, it is assumed that the interaction layer is the top centimeter of soil, then:

$$C_{P_{SUR}} = P_{SUR}\,(10 / \sigma) \qquad (3.49)$$

where C_{PSUR} is the pesticide concentration available in the surface soil [ppm] and σ is the specific weight of soil. This last value is extracted from the soil map and assigned for each cell during the data automatic extraction process. To take into account the effect of tillage, the concentration in the soil is affected by the incorporation depth and efficiency factors:

$$C_{P_{SUR\_T}} = C_{P_{SUR}} \left[\frac{In_{EFF} / 100}{In_{DEP} / 0.39} \right] \tag{3.50}$$

where C_{PSUR_T} is the concentration of available pesticide on the ground including the tillage effects [ppm], In_{EFF} is the incorporation efficiency in percent, and In_{DEP} is the incorporation depth [in]. The amount of pesticide remaining on the plant at the time of the rainfall event is:

$$P_{CAN\_F} = P_{CAN}\, e^{-0.693(t_a / F_{RHL})} \tag{3.51}$$

where P_{CAN_F} is the pesticide on plant at the time of the event [kg/ha], t_a is the time between the application and the storm [days], and F_{RHL} is the foliar residue half life of the pesticide [days]. This value is available for data input in the pesticide database. Similarly, the concentration of pesticide remaining in the soil at the time of the storm event is:

$$C_{P_{SUR\_F}} = C_{P_{SUR\_T}}\, e^{-0.693(t_a / S_{RHL})} \tag{3.52}$$

where C_{PSUR_F} is the pesticide concentration in the soil at the time of the event [ppm] and S_{RHL} is the soil residue half life also available in the pesticide database [days]. The potential amount of pesticide on the ground susceptible to enter the runoff, must include the foliar washoff:

$$C_{P_{WSH}} = P_{CAN\_F} \frac{F_{WF}}{100} \frac{10}{\sigma} \tag{3.53}$$

where C_{PWSH} is the amount of pesticide washoff from the rainfall [ppm], F_{WF} is the foliar washoff fraction in percent. This value is also available in the pesticide database. The amount of pesticide on the ground, C_{PGRN} [ppm], is:

$$C_{P_{GRN}} = C_{P_{SUR\_F}} + C_{P_{WSH}} \tag{3.54}$$

To calculate the fraction of pesticide in the runoff, the following equation is used:

$$C_{P_{RFF}} = C_{P_{GRN}} \, e^{\left(-I_{EFF} \frac{0.1}{Por + K_{SW}\,\sigma}\right)} \tag{3.55}$$

where C_{PRFF} is the amount of pesticide for runoff [ppm], I_{EFF} is the total depth of infiltrated water [mm], *Por* is the soil porosity as described in the nutrient section, K_{SW} is the soil-water partition coefficient calculated with:

$$K_{SW} = 0.0058\, K_{OC}\, OM \tag{3.56}$$

where K_{OC} is the organic carbon sorption coefficient available in the pesticide database and *OM* is the soil organic matter percent. The amount of percolated pesticide is:

$$P_{PER} = (C_{P_{GRN}} - C_{P_{RFF}}) \frac{\sigma}{10} \tag{3.57}$$

where P_{PER} is the amount of percolated pesticide [kg/ha]. The percent of percolated pesticide, PP_{PER}, can be estimated as a fraction of the application rate:

$$PP_{PER} = 100 \frac{P_{PER}}{P_{APR}} \tag{3.58}$$

The pesticide soluble concentration in the runoff, C_{PSOL} [ppm], is calculated with:

$$C_{P_{SOL}} = \frac{\beta\, C_{P_{RFF}}}{1 + \beta\, K_{SW}} \tag{3.59}$$

where β is a constant value of 0.5 if the solubility in water of the pesticide (database) is less than 1 ppm, 0.3 if between 1 and 3 ppm, and 0.1 for values greater than 3 ppm.

The amount of soluble pesticide is then calculated with:

$$P_{SOL} = C_{P_{SOL}} \frac{R_{OFF}}{100} \tag{3.60}$$

where P_{SOL} is the soluble pesticide amount [kg/ha], R_{OFF} is the runoff depth [mm]. The percent of soluble pesticide, PP_{SOL}, is then calculated as a fraction of the application rate as:

$$PP_{SOL} = 100\frac{P_{SOL}}{P_{APR}} \tag{3.61}$$

Finally the amount of pesticide attached to the sediment is:

$$P_{SED} = P_{SOL}\, K_{SW}\, ER \tag{3.62}$$

where P_{SED} is the pesticide amount in the sediment [kg/ha] and ER is the enrichment ratio as described in the nutrient section. The percent of pesticide in the sediment, PP_{SED}, is calculated as a fraction of the application rate:

$$PP_{SED} = 100\frac{P_{SED}}{P_{APR}} \tag{3.63}$$

3.3.4 Routing Processes

The routing of sediments, nutrients and pesticides are carried out using a mixing cell model based on the continuity equation. Deposition for sediments and the decay in the case of nutrients and pesticides will be estimated using fractions of the transported mass that can be calibrated with the optimization technique of WATFLOOD. Mixing cell models, like other transport models, are subject to numerical dispersion affected in part by cell size and the assumption of complete mixing. The mixing cell approach is used here as a first approximation for the transport module to create a complete system. If future research is devoted to the water quality component, more elaborate transport models can be easily incorporated into the routing process. In general terms, the process is summarized as:

(i) the amount of mass generated on each cell is calculated for each time step,

(ii) this mass is added from the cells flowing into the current cell to the amount generated within the current cell,

(iii) this amount is decayed (deposition for sediments) as it runs through the channel to get the amount remaining at the cell outlet.

The continuity equation for the sediments can be written as:

$$Sed_{OUT} = Sed_{ABOVE} + Sed_{WITHIN} - Sed_{DEP} \tag{3.64}$$

where the subscripts *OUT* refers to the sediment leaving the element, *ABOVE* stands for the sediment entering the cell from the elements above the current cell and *DEP* to the sediment amount being deposited in the cell. Using the sediment yield obtained from the sediment section and converting to concentration units, the equation takes the form:

$$Y_{SED\_OUT} = 1000\left[(1 - S_{DEP})(Y_{SED\_ABOVE} + Y_{SED\_WITHIN})\right] \tag{3.65}$$

where Y_{SED_OUT} is the sediment leaving the cell [ppm], S_{DEP} is a deposition fraction, Y_{SED_ABOVE} is the sum of all the sediment entering the cell [kg/ha] and Y_{SED_WITHIN} the sediment generated within the element. Similar equations are used for the soluble and sediment attached nutrients:

$$CC_{RON\_OUT} = \frac{100}{R_{OFF}}\left[(1 - N_{DEC})(C_{RON\_ABOVE} + C_{RON\_WITHIN})\right] \tag{3.66}$$

where CC_{RON_OUT} is the soluble nitrogen concentration in runoff leaving the cell [ppm], N_{DEC} is the nitrogen decay fraction and the rest of the terms are as described in the nutrient section.

$$CC_{ROP\_OUT} = \frac{100}{R_{OFF}}\left[(1 - P_{DEC})(C_{ROP\_ABOVE} + C_{ROP\_WITHIN})\right] \tag{3.67}$$

where CC_{ROP_OUT} is the soluble phosphorus concentration leaving the cell [ppm], P_{DEC} is the phosphorus decay fraction and the rest of the terms are as described in the nutrient section. For the sediment attached nutrients, the concentration terms are substituted by the N_{SED} and P_{SED} values and the same equations are used for the routing. Table 3.1 presents a list of the model parameters of the WATFLOOD water quality component summarized by category and showing the values, ranges and sources for each parameter.

Table 3.1 Model Parameters Summary of the WATFLOOD Water Quality Component

Parameter	Symbol	Value or Range	Comments
Physical Constants			
Gravity acceleration	g	9.806 m/s^2	Constant values in ASCII
Kinematic viscosity	ν	1×10^{-6} m^2/s	input data file
Density of water	ρ	1×10^{6} g/m^3	
Experimental Constants			
Stress relationship coefficient	A	0.00066	Constant values in ASCII input data
Stress relationship exponent	B	1.61	Source Hartley, 1987
Landuse Coefficients			
Ground cover factor	GC	0 - 1	
Canopy factor	CF	0 - 1	Function of landuse (lookup table B5)
Soil Type Constants			
Median sediment diameter	d_{50}	0.015 - 0.61 (silt) - (clay)	Function of soil type (lookup table B2)
Particle specific weight	σ	1.84 - 2.45 (clay) - (sand)	Function of soil type (lookup table B2)
Soil Type Coefficients			
Soil erodibility factor	D	0.25 - 2.90 (sand) - (silt)	Function of soil type (lookup table B2)
Process Coefficients			
Nitrogen decay fraction	N_{DEC}	0 - 100%	
Phosphorus decay fraction	P_{DEC}	0 - 100%	Source: AGNPS manual
Sediment deposition fraction	S_{DEP}	0 - 100%	

3.4 Chapter Summary

This chapter described the models from the integration perspective, presenting the equations in order to identify the variables that will be calculated automatically from digital information with an extraction process. Some results of the preliminary sensitivity analysis, performed and described in Chapter 6, are presented in order to help in selecting which variables deserve more attention during the extraction process and which ones can be assigned with default values without impacting the simulation results. Finally the equations that will form the water quality component, for sediment, nutrient and pesticide transport, which will be coupled with the WATFLOOD hydrologic model, are presented together with the basic routing procedures. The algorithms and equations were coded in FORTRAN and the full source listings are included in Appendix G.

CHAPTER 4. Model Interfaces for RAISON

As mentioned in the Introduction, attempts to improve NPS modelling capabilities need to be combined with the application of new technologies to resolve problems associated with ease of model use. This will allow the user to track the decision-making processes through the model to obtain a better understanding of the simulation. An integrated approach is achieved in this research with the linkage of the selected models, AGNPS and WATFLOOD with the water quality component added, within the RAISON decision support system with GIS capabilities.

4.1 RAISON as the GIS and SDSS Platform

Interactive programs were created to assist in processing data, initiating model simulations, and analyzing model results. Exploiting the capabilities of RAISON, graphical interfaces were built to allow interaction with the models by intercepting input and output and to connect them to the database in the system. Work was done to create communication links between the AGNPS model and RAISON. The pre-processing tools provide easy data compiling for the models. Using topography, soil type, and land use maps in vector formats, procedures are designed to automate as much input data as possible. With minor changes, the same tools were applied to create input files for WATFLOOD and for the water quality model developed as part of this research.

Design of a control panel for model operation helps in the setup and operation of the simulation process. Actually this also triggers the model to run by creating a shell that activates the model and controls the mode of operation. Post-processing for output data by means of graphical and statistical tools also assists with the interpretation of model results. Such a generic application is very useful for applying the models to different watersheds in order to validate the hydrologic and water quality components. It is worth mentioning that due to the modularity involved in the development of the subroutines and processes, if better ways of estimating nutrient and pesticide release and transport become available, little of the present work would be lost. The procedures and modules can be adapted to accommodate such improvements.

Finally different techniques, to analyze the sensitivity associated to the models, were evaluated and selected to be included in the system. Typically, the best use for nonpoint source models is for comparative analysis between different scenarios. This involves modifying parameters to account for the desired change in conditions. The capability to undertake rapid "what if" scenarios, in defining and managing future landuse, will be critical in maintaining the ecological function of urbanizing watercourses.

Providing a measure of the confidence limits that can be placed on the simulation results due to the uncertainties in values of input parameters is a crucial step in the simulation process. As a preliminary analysis of the sensitivity of the parameters on the model results, a sensitivity module was created that would allow interactive selection of parameters to perturb. This also involves possible selection of different precipitation input functions since it is known that runoff models are highly sensitive to rainfall intensity and duration. The technique for the sensitivity analysis is based on the normalized sensitivity coefficients, which indicate a percent change in the results for individual perturbations of the parameters. After creating the temporary files with the variation for the selected parameters, the models run in batch mode for all the different input files. Visual outputs of the normalized coefficients help in defining the importance of each parameter variation in the overall result. Comparison of different analysis can be made as a function of input rainfall function and spatial selection.

4.1.1 Description of RAISON

RAISON is a software package developed at Environment Canada's National Water Research Institute. It is a analysis toolkit that integrates database, spreadsheet and graphic interpretive tools with GIS and expert systems capabilities for microcomputers. The system provides an intuitive environment for displaying data and analysis results in the context of local geography. It was originally developed to facilitate access to watershed water quality data and to combine several models to evaluate the water resources at risk due to acid rain. Ongoing development of the system has led to a generic integrated set of tools for data analysis. It has evolved from practical concerns for an affordable working system that can help design environmental information systems and decision support systems (Lam and Swayne, 1996).

RAISON offers a friendly interface to integrate data, text, maps, satellite images, video, models and other knowledge input. The system provides a library of functions to design customized applications. The database component is the core of the system and has to work with other modules such as GIS, expert systems, statistics, models, graphics and analysis tools. RAISON is not a full GIS nor a stand alone database but it provides enough functionality to link them. It accepts files from most commercial GIS and database systems and allows the customization of the software for any specific application. The geographic linking is provided with background maps that are produced from vector files or imported directly into RAISON from a variety of commercial file formats.

Data stored in UTM and Latitude/Longitude coordinates may be used interchangeably. For example, data in UTM coordinates may be displayed on a map defined in Lat/Lon coordinates. Maps may be customized and color coded using external graphic applications that support bitmap or metafile formats. One of the important RAISON features used in this work is its capability to incorporate modelling tools into the system by building interfaces that interact with existing models intercepting input and output to the database in the system.

4.1.2 Layers and Grids

The way in which RAISON handles geo-referenced information for different attributes is through the use of databases. A layer database is a collection of spatial polygons (objects) with an attached attribute. RAISON supports three types of layers: i) spatial layers of points, lines or polygons, ii) grids as a network of squares with associated spatial coordinates, iii) grid layers as data associated with the grid but without spatial information. The last two layer types work in conjunction, linking the object geo-reference with the data attached to it. The grid layer feature in RAISON was designed to be used by models that use a regular grid and collect or process information related to individual grid cells. In this way, data can be associated with the grid easily after it has been created. The grid is usually used to process information before a value for the grid layer is found. This is the case of the present interface for the agricultural model where, for example, the land slope is calculated by intersecting digital elevation model data with the grid and then attached to the grid layer.

For each layer range, legends or characteristics tables can be assigned to draw the layer and graphically identify the different attributes according to the data values. This feature allows spatial display of grid data (model input or results). The communication with RAISON is through dynamic data exchange (DDE) as an established protocol for exchanging data through active links between applications that run under windows. Most of the functions used in the interface are available in the layer dynamic-link library (DLL), which is a library of routines loaded and linked into applications at run time. The LAYER.DLL includes routines for standard application tasks such as initializing database files and structuring tables, creating grid layers, retrieving and changing database values, drawing maps and handling user actions. All the tables that handle the data required by the models follow the RAISON layer data structure:

i) layer summary table holding the information about the tables from layer database,

ii) type table that holds all the information for the spatial objects such as number of vertices and kind of object (point/line/polygon),

iii) position table that holds the coordinates information for each spatial object.

4.2 Integration of the Models

This section describes in detail how the interfacing to the models from the RAISON system is achieved through the use of relational databases. The data requirements and structure of the tables for the database are described for the two models. The variables to be automatically extracted are defined and the extraction process for the different digital sources is presented.

4.2.1 Data Requirements and Structure

As described in Chapter 3, data needed for the AGNPS model are classified in two categories: watershed and cell data. The first includes information applying to the entire watershed such as size, number of cells, storm intensity, etc. Cell data include information on the approximately 20 parameters based on topography, soil type, land use and management practices within the cell. Additional data are required if the cell is selected for fertilizer or pesticide application. It also handles point sources, impoundment data and additional erosion. The input data and output results for the AGNPS model have been organized in Table 4.1.

Table 4.1a. AGNPS Model Input

Table Name	*No.*	*Variables*
Watershed Data	A1	14
General Cell	A2	20
Soil	A3	9
Fertilizer	A4	4
Pesticide	A5	17
NonFeedlot	A6	5
Feedlot	A7	58
Add Erosion	A8	6
Impoundment	A9	3
Channel	A10	21
Totals		157

Table 4.1b. AGNPS Model Output

Table Name	*No.*	*Variables*
Watershed Summary	A11	17
Sediment Analysis	A12	42
Hydrology	A13	7
Sediments	A14	30
Nutrients	A15	14
Pesticide	A16	13
Landuse Summary	A17	8*
Sources and Deposition	A18	44
Totals		175

*Depends on number of classes

Similarly, WATFLOOD requires general watershed information and cell data. Table 4.2 shows the structure for the data input. Appendix A has details on the variables assigned to each table, sample values, units and descriptions.

Table 4.2. WATFLOOD Model Input

Table Name	*No.*	*Variables*
Watershed Data	A19	24
General Cell	A20	13
Soil	A21	15
Fertilizer	A22	4
Pesticide	A23	17
Totals		73

In terms of GIS data, some of the variables in both models are related to topography, soil type or land use. The automatic extraction of map data uses a Digital Elevation Model (DEM) file and Map files with soil type and landcover layers. Tables 4.3 and 4.4 present a summary of the variables dependency for both models.

Table 4.3 AGNPS Variables as Function of DEM and MAP

Variable	*DEM*[1]	*LU*[2]	*S*[3]
Receiving Cell Number	●		
Receiving Cell Subdivision	●		
Flow Direction	●		
SCS Curve Number		●	●
Land Slope	●		
Overland Manning's		●	
K - Factor			●
C - Factor		●	
P - Factor (1 all cases)		●	
Surface Condition Constant		●	
COD Factor		●	
Soil Texture ID			●

[1]Digital Elevation Model; [2]Landcover layer: [3]Soil type layer

Table 4.4 WATFLOOD Variables as Function of DEM and MAP

Variable	*DEM*[1]	*LU*[2]	*S*[3]
River Elevation	●		
Drainage Area	●		
Drainage Direction	●		
River Classification	●		
Contour Density	●		
Channel Density	●		
Routing Reach Number	●		
Land Classes[4] (6, 10, etc.)		●	
Soil Textures[5] (12 types)			●

[1]Digital Elevation Model; [2]Landcover layer: [3]Soil type layer: [4]Percentage of area for each land cover; [5]Percentage of area for each soil texture.

4.2.2 DEM and MAP files

A Digital Elevation Model (DEM) is a digital representation of the continuous variation of relief over space. A DEM consists of a sampled array of elevations for ground positions that are normally spaced at regular intervals. The 30 arc-second DEM file used in this project are based on GTOPO30 arc-second DEM data for the entire world. These data are publically available from the U.S. Geological Survey's EROS Data Center.

Prior to the DEM utilization, a conditioning processes must be made to the file, for example using the Easy/Pace PCI software. This includes drainage watershed conditioning (DWCON), a program that is a conditioning phase that prepares the data prior to drainage and watershed analysis. This conditioning involves a cleanup of the elevation data and generation of flow direction and flow accumulation values. The results of the conditioning phase are:

1. *A Depressionless DEM*: Depressions present a significant problem in flow prediction models for two reasons; they are often data errors introduced during the DEM interpolation process and depressions confuse flow direction models and must be filled before flow can continue.

2. *A Flow Direction Channel*: Water at any given pixel location will flow into one of its eight adjacent neighboring pixels. This value indicates the neighboring direction of flow for each DEM element. The direction is calculated so it follows a continuous downhill path.

3. *A Flow Accumulation Channel:* This value represents the number of DEM elements whose water flows into its location. Examination of this channel by level thresholding can provide much information (ie. the drainage river system in the watershed).

After the conditioning phase, the resulting values can be exported as ASCII text files and then combined in a comma separated value (CSV) file to be imported into the RAISON map system. Each attribute will be imported as a field in the point layer database that will later be used to extract the information related to topography.

In relation to the Map files, the source of information can be a digitized map with attributes that are the soil type for each of the polygons in the soil layer. For the landuse layer, a supervised classification process can be made to a remote sensing image. The results, either from the digitization or polygon classification should be exported to ArcInfo Shape files that can be imported by RAISON and stored as spatial layers in the database. When importing polygons into the RAISON database layer, an optimization process to reduce the numbers of points that describe each polygon has been implemented. Figure 4.1 shows an example of the digital data using RAISON to display it.

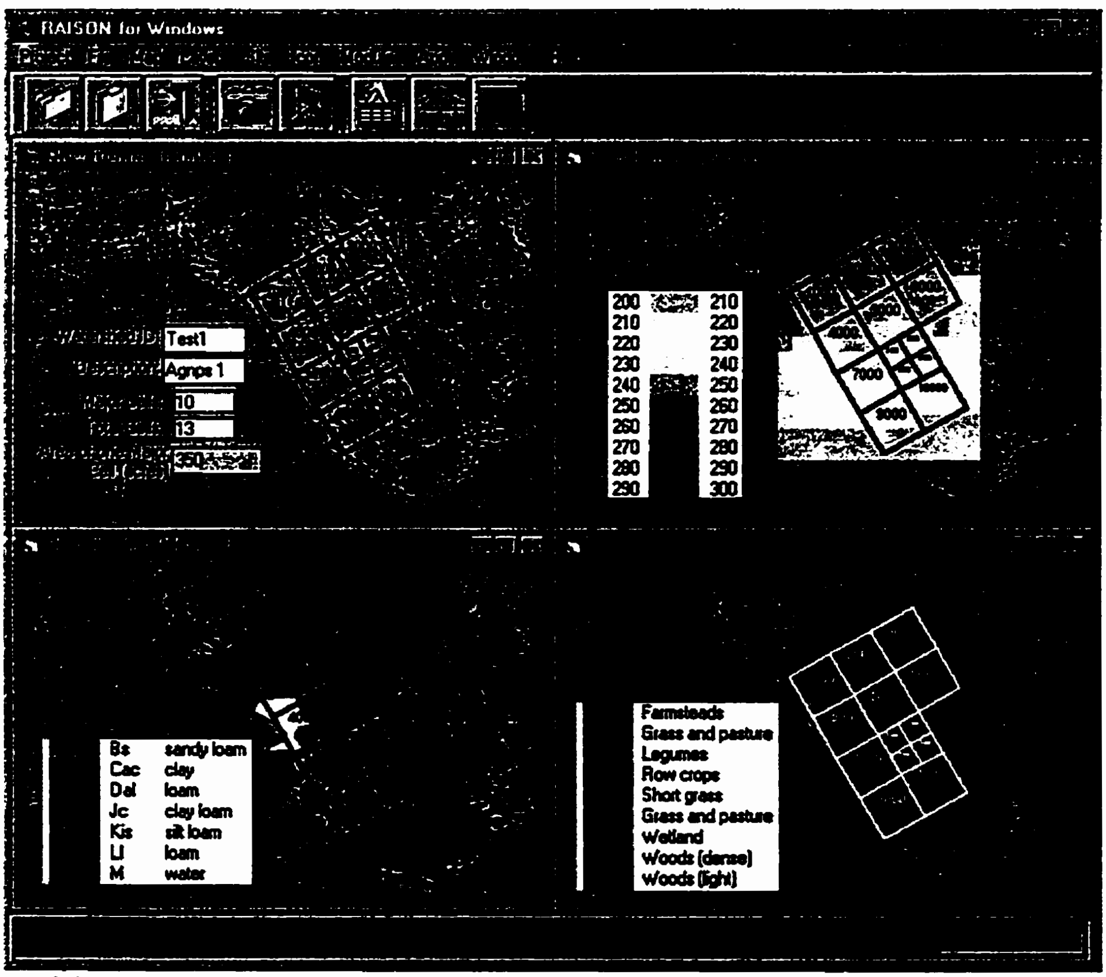


Figure 4.1 Input sources displayed in RAISON. From top left in clockwise direction: a) AGNPS test file with the grid aspect, b) DEM file (elevations) for study area., c) landcover layer and d) soil texture layer.

This reduction is based on angle variation from a sequence of vectorized points. This is done by comparing the direction in two adjacent points with the direction that results from the first point and the next one in the sequence. If the change in direction is significant (compared with a preset tolerance) then the point is maintained; if the change is not significant it can be removed. In some cases the optimization of points to be included can result in a reduction of almost 50% of the original dataset.

4.2.3 Extraction of DEM and Map Data

The major asset of the GIS approach is to automatically extract the required information to calculate the model data. Depending on the topography of the watershed and the configuration of the grid, some variables are topographically related. Others are functions of the soil type and landcover. The process of extracting data from map sources has been divided into two major sections: i) topography related data using the DEM file, ii) soil type and landcover data using the Map file.

Prior to the extraction process and in order to speed up the display and calculations, some optimization is achieved and auxiliary files are created that contain only the polygons that fall inside a container box of the grid or the cell. The first step is to search for the four corners of a box (minimum and maximum latitudes/longitudes) that contains the grid. For each polygon, the corresponding corners of a bounding box that accommodate the polygon are read from the type table of the layer database. Comparing the vertices with the ones from the box will result in deciding whether or not to copy the polygon in the temporal file.

Following the same idea, in order to speed up the calculations a bounding box created at run time is used to select the DEM or polygon points that fall inside each cell. To give an idea of this optimization and the final performance of the extraction process, the elapsed time, based on a Pentium 90Mhz, for different stages of the development is presented in Table 4.5.

Table 4.5 Optimization of Extraction Times. a) First stage, no optimization made. b) Reducing files and creating auxiliary files. c) Narrowing to bound box at run time.

a) Full DEM & MAP files for all the elements on the grid

Grid Size	DEM Ext		MAP Ext (h:m:s)	Total Ext (h:m:s)
3x3(9)	0:12:00	*Soil*	0:09:20	
		Landuse	0:28:30	0:49:50
7x7(49)	1:29:15	*Soil*	0:52:55	
		Landuse	2:32:50	4:55:00
12x12(144)	4:19:12	*Soil*	2:35:31	
		Landuse	7:29:18	14:24:01

b) Reduced DEM & MAP files for all the elements on the grid

Grid Size	DEM Red	DEM Ext	Total DEM		MAP Red	MAP Ext	Total MAP	Total Ext
3x3(9)	0:00:50	0:01:55	0:02:45	*Soil*	0:00:10	0:02:15	0:02:25	
				Landuse	0:00:25	0:05:35	0:06:00	0:11:10
7x7(49)	0:01:35	0:10:24	0:11:59	*Soil*	0:00:21	0:06:25	0:06:46	
				Landuse	0:00:50	0:15:50	0:16:40	0:35:25
12x12(144)	0:03:51	1:14:11	1:18:02	*Soil*	0:00:45	0:29:20	0:30:05	
				Landuse	0:01:31	1:10:15	1:11:46	2:59:53

c) Full DEM & MAP bounded for each cell on the grid (reduction optional for display)

Grid Size	DEM Ext	Total DEM		MAP Ext	Total MAP	Total Ext
3x3(9)	0:01:02	0:01:02	*Soil*	0:01:35	0:01:35	
			Landuse	0:01:42	0:01:42	0:04:19
7x7(49)	0:03:35	0:03:35	*Soil*	0:03:45	0:03:45	
			Landuse	0:04:20	0:04:20	0:11:40
12x12(144)	0:10:55	0:10:55	*Soil*	0:10:05	0:10:05	
			Landuse	0:11:21	0:11:21	0:32:21

For the DEM extraction, the calculations are performed in two steps. For the flow direction the DEM elements that intersect the borders of each cell in the grid are identified. Using the flow accumulation values of the DEM, the element with the highest drainage value that intersects one of the four borders of the grid cell is used to calculate the flow direction. If the selected DEM element falls within the current cell, the angle for the flow direction is calculated between the center of the cell to the center of the DEM element. If the DEM element falls in the receiving cell, then the angle for the flow direction is calculated between the center of the current cell to the center of the receiving one. Figure 4.2 shows an example of the intersection of the DEM file elements with the grid cells. The second step is to calculate the land slope within each grid cell. This is done by first calculating the maximum slope between each DEM element and its immediate neighbors and then averaging the results for the grid to define the internal overland slope. Figure 4.3 shows an example of the slope calculations.

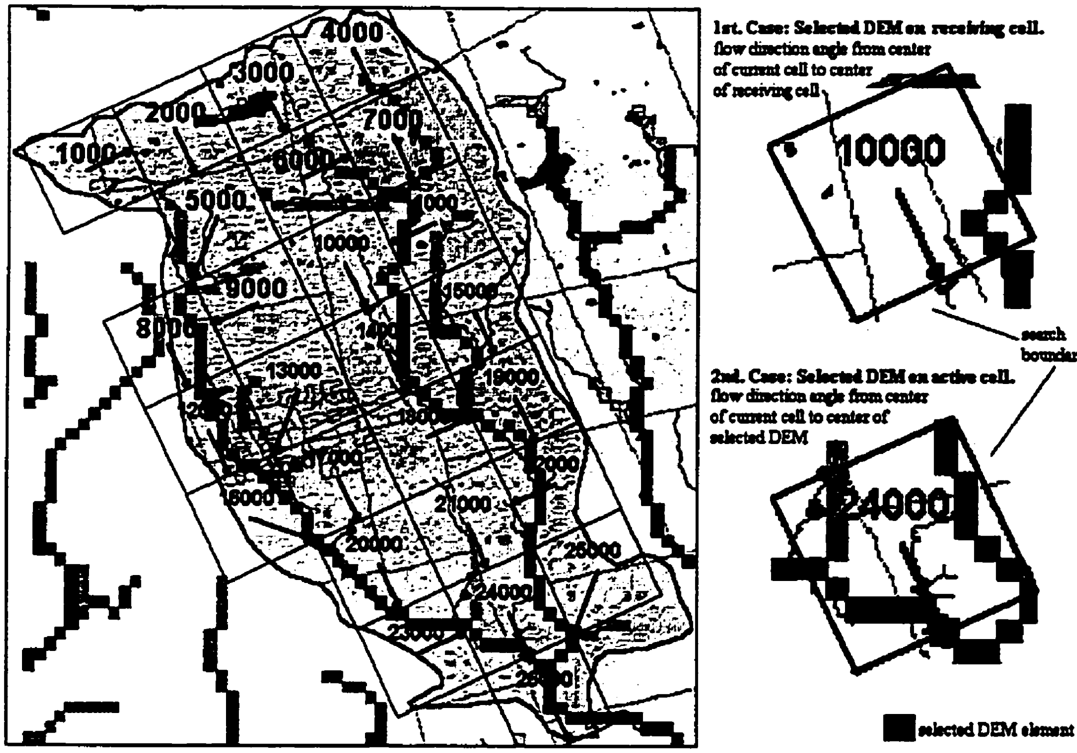
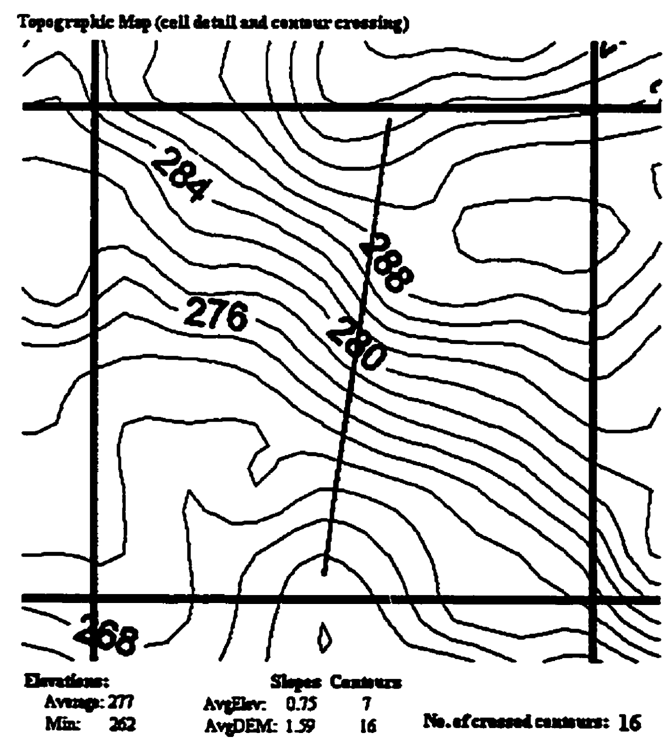


Figure 4.2 - DEM extraction example for grid flow direction



DEM elevations

282	287	289	291	296	296	294	294	293	292
280	281	285	288	290	290	290	289	289	288
279	279	282	283	286	289	290	290	290	289
279	275	278	276	281	287	289	288	289	286
273	272	272	273	277	281	282	283	285	283
272	270	270	270	272	275	277	279	282	282
271	270	268	270	268	269	271	274	278	280
270	270	268	266	264	266	269	270	273	280
268	269	268	265	262	264	268	269	269	274
264	266	266	264	262	262	260	264	263	266

DEM element slope

0.80	2.33	2.67	2.00	2.67	2.00	1.67	1.67	1.67	1.33
0.33	0.67	2.00	2.00	2.33	1.33	0.33	0.00	0.33	1.33
1.33	1.33	2.33	1.67	2.67	2.67	1.00	0.67	1.33	2.33
2.33	1.00	2.00	[illegible]	2.67	3.33	2.67	2.00	2.00	2.33
1.00	0.67	0.67	1.00	2.33	3.00	2.33	2.00	2.00	1.33
0.67	0.67	0.67	0.67	1.33	2.33	2.67	2.67	2.67	1.33
0.33	0.67	0.67	2.00	1.33	1.67	1.67	1.67	2.67	2.33
1.00	0.67	1.00	1.33	0.67	1.33	1.67	0.67	1.33	3.67
1.67	1.67	1.33	1.00	0.00	1.33	2.67	3.00	2.00	3.67
1.67	2.00	1.67	1.33	2.00	3.00	2.33	3.67	2.67	3.67

Figure 4.3 - DEM extraction example for grid overland slope

The contour density value for WATFLOOD deserves special mention. In this case, extracted from a topographic map, the number of contours crossing a straight line perpendicular to the flow direction are the input data for the model. Though this is the recommended value, internal slope may provide a different way to calculate it. Using the same procedure to calculate the slope as described above, and assuming a certain value for the contour interval, the number of contours was estimated from internal slope.

The same data were also estimated by performing a Kriging interpolation to get the contours using the DEM elevations and counting the number of times a line perpendicular to the flow direction crosses a contour object. Figure 4.4 presents the results comparison for estimated contours and map derived values. At the same time calculations were done to test the values for the channel slope by averaging DEM elevation values. As can be noted, the channel slope values, calculated with the average elevations, correlates quite well with but underestimates the measured contours.

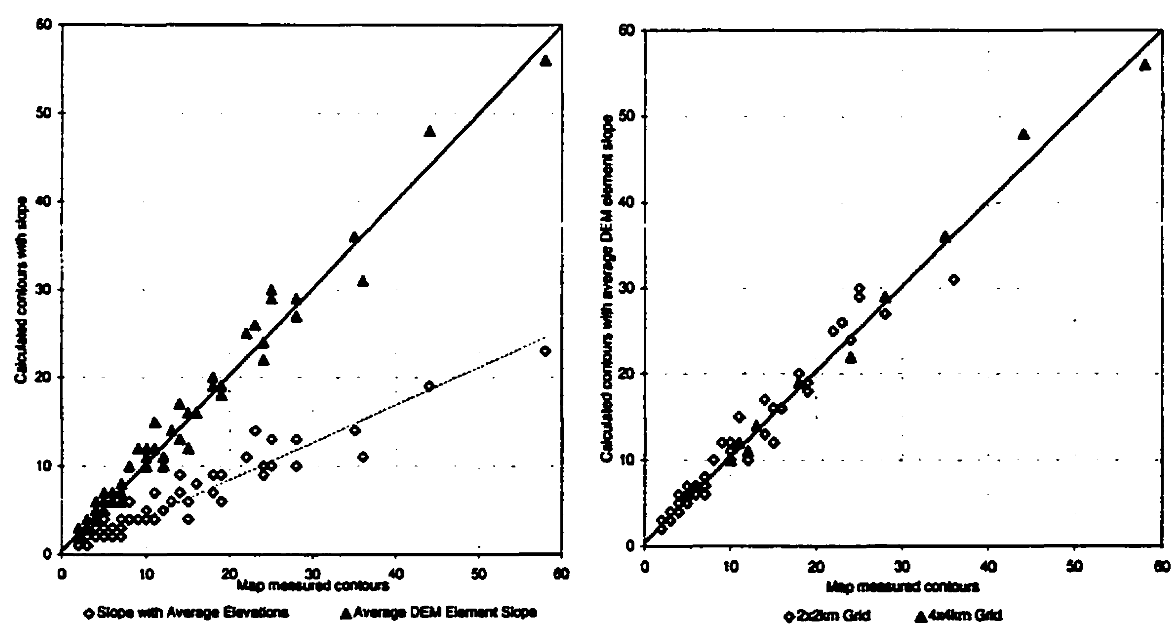


Figure 4.4 Number of contours. Comparison with contouring and slope calculations.

In fact, the process using the DEM elements directly to calculate the slope may be accurate enough. With this procedure, determining the number of contours is less time consuming and leads to a consistent way of calculating the internal slope required by WATFLOOD. It is worth mentioning that the scale ratio between the size of the DEM elements and the grid cell size was maintained approximately constant in a 1:100 relation for all the tests.

For the variables that depend on soil type and landuse information, a different process is used to perform the calculations for the selected grid according to an active lookup table (LUT) for soil type and landuse characteristics. These include the relational indexes that link the code map with the data values and are summarized in Appendix B. For the AGNPS extraction, the process will start browsing the layer file looking for the intersection with every cell in the grid file, calculating the area for each attribute (ie. soil type) and its percentage with respect to the total area of the cell. With this percentage, it retrieves the values for the selected field in the LUT and calculates the weighted value for the cell. The general expression used in the extraction process to weight the parameters is:

$$Weighted\ Parameter = \sum_{i=1}^{n} \frac{A_i}{A_T} Parameter_i \qquad (4.1)$$

where A_i/A_T is the percentage of area for the i soil type or landcover, and $Parameter_i$ is the value from the lookup table for the soil type or landcover attribute. An exception is the value for soil texture that is assigned directly from the dominant class within the cell. As an example of the extraction process where polygon information is converted into model grid input data, Table 4.6 presents the detailed process for a variable dependent on the soil type field. It shows the calculations for two arbitrary cells in order to estimate the K factor for the USLE method. The map code is the original field variable in the soil layer map file. Using this code and reading the values from the LUT, the soil class and the K factor are retrieved from the database file. Weighting the values according to the percentage of each soil type within the cell (Equation 4.1) and accumulating these values, gives the representative parameter value for the cell as accurately as it can be done.

Table 4.6 Example Calculations for the K-factor Using Soil Map Information.

Cell Number	Soil Type (fraction)	Map Code	Soil Class in the Lookup Table (LUT)	K factor in LUT	Weighted K factor	Accumulated K factor
1000	0.1411	B.L.	Bottom Land : water-alluvial	0	0.000	0.000
1000	0.0274	Pec	Peel : clay loam	0.29	0.008	0.008
1000	0.1074	Ml	Milliken : loam	0.31	0.033	0.041
1000	0.0294	Wol	Woburn : loam	0.31	0.009	0.050
1000	0.2248	Ml	Milliken : loam	0.31	0.070	0.120
1000	0.1816	Kis	King : silt loam	0.37	0.067	0.187
1000	0.1287	Ml	Milliken : loam	0.31	0.040	0.227
1000	0.0422	Cac	Cashel : clay	0.20	0.008	0.236
1000	0.0664	Kis	King : silt loam	0.37	0.025	0.260
1000	0.0243	Wol	Woburn : loam	0.31	0.008	**0.268**
2000	0.1644	B.L.	Bottom Land : water-alluvial	0	0.000	0.000
2000	0.1322	Pec	Peel : clay loam	0.29	0.038	0.038
2000	0.2760	Pec	Peel : clay loam	0.29	0.080	0.118
2000	0.0009	Pec	Peel : clay loam	0.29	0.000	0.119
2000	0.1218	Brsl	Brighton : sandy loam	0.14	0.017	0.136
2000	0.1402	Ml	Milliken : loam	0.31	0.043	0.179
2000	0.1676	Brsl	Brighton : sandy loam	0.14	0.023	**0.203**

For the WATFLOOD model, the areal extraction is exactly the same as described, but after obtaining the percentages of soil type and land use, no further calculations are required. The only additional process is to group the soil and land classes according to the classification groups defined in the lookup tables. With these procedures in place, all the cell data are automatically extracted and stored in the grid layer.

As previously mentioned, the AGNPS model can accommodate specific cell data, for example, if the cell is selected for fertilizer or pesticide application. Also there is the possibility to attach point sources (ie. feedlots and non-feedlots), impoundment data and additional erosion. All these additional data are captured through the use of input forms.

4.3 Interfaces for RAISON

4.3.1 Conceptual Design

The main objective of this work is to include diffuse pollution models in a Spatial Decision Support System (SDSS) with common interfaces and Geographic Information System (GIS) capabilities. An integrated approach is developed involving the linkage of the AGNPS and WATFLOOD models with RAISON to form the SDSS to deal with NPS modelling. Figure 4.5 shows a schematic representation of the linkage between the models and RAISON through the use of interfaces.

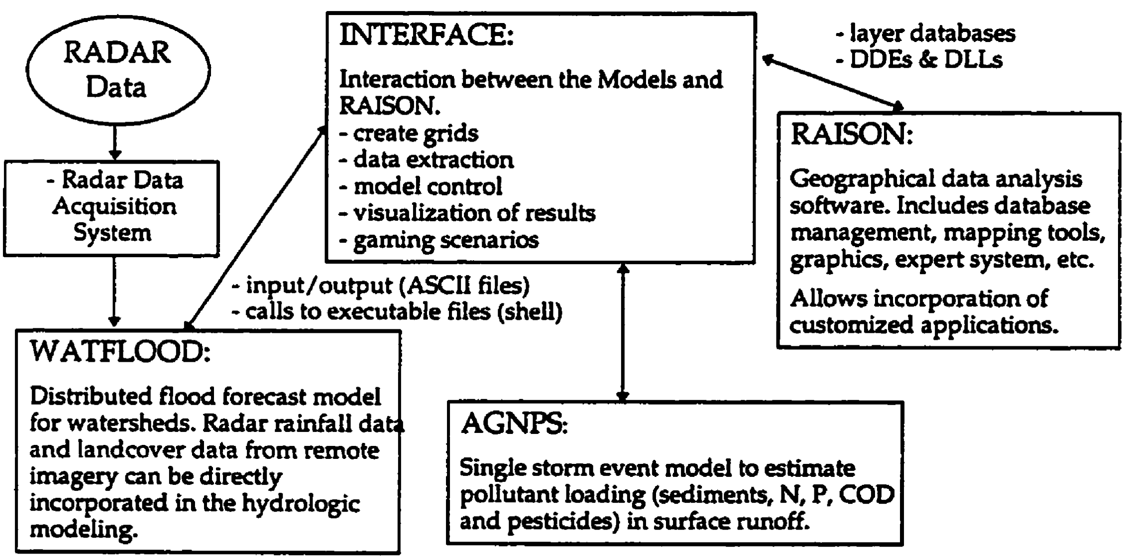


Figure 4.5 Schematic representation of the linkage between the models and RAISON.

In order to create such interfaces, interactive programs were written to assist in processing data, initiating model simulations and analyzing model results. Building up graphical interfaces by exploiting the capabilities of RAISON, allows interaction with the models by intercepting input/output data and connecting them to the database. The design of the interface consists of a main window that controls the access to the different available toolbars. The toolbars group different tasks or procedures to be performed in order to create/edit the grid, collect/edit the required data, run the model and display results.

Table 4.7 shows the conceptual design of the interfaces. Communication links between the interfaces and RAISON were established by using the DLL for the layer functions. The interaction between the interfaces and the models is done through interchange of data via ASCII files and calls to executable files. The pre-processing tools provide easy data compiling for the models. Using topography, soil type and land use maps in vector formats, procedures were developed to automate as much data input as possible as described previously. Design of a control panel for model operation helps in the setup and simulation. This also triggers the model to run by creating a shell that activates the model. Post-processing for output data by means of graphical tools assists with the interpretation of model results.

Table 4.7 Conceptual Design of the Interfaces.

Toolbar	Tool/Procedure	Description
Make/Edit Grid	Initialize Database	Initialize the database file and create the basic file structure.
	Create Grid	Create a basic grid and save to an existing database file.
	Create Tables	Create the required tables and structure for the models.
	Edit Grid	Edit the grid by adding, deleting, and/or subdividing cells.
Collect/Edit Data	Initial Data	Capture the initial watershed data.
	Collect Data	Extract data as function of topography, soil type, and landuse.
	Edit Flow Direction	Edit the flow directions and receiving cells.
	Cell Editor	View and edit the general cell data.
Run Model	Write ASCII File	Utility to convert the database to an ASCII file for the model.
	Run Model	Run the model for the selected file(s).
Display Input/Output	Create/Edit Ranges	Create and edit ranges for the selected variable.
	Display I/O	Using the layer view, display the available input/output.
	Tabular Results	Using the tabular view, display the output (model results).
	Trace Contributions	Account for various sources in any given cell.
Analysis/Scenarios	Duplicate Grid	Duplicate grid and copy data under a new grid name.
	Modify Landuse	Change percentage of landcover and recalculate parameters.
	Summarize Runs	Display summary of the different runs in a database.
	Sensitivity Analysis	Perform sensitivity analysis and ranking.

4.3.2 Description of the Interface

The main windows for the AGNPS and WATFLOOD interfaces, that control the access to the different sections of the interfaces are showed in Figure 4.6. Each button accesses a different toolbar. The same toolbars can be selected from the tools menu. The bar beneath the buttons is the status bar that gives a short description of what each tool will activate.

When a main button is selected, the specific toolbar is displayed and the different options for the active procedure are enabled. The sequence of the procedures and tools are arranged to encourage a proper order in the creation of a specific scenario. Following is a very brief explanation for the toolbars. More detailed description of the different sections of the interface is presented in Appendix C, where all the options are explained and the windows mentioned in the next section are shown with more detail and full explanations.

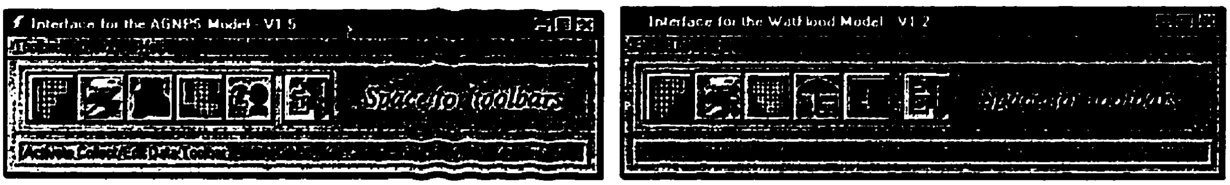
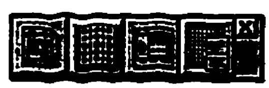


Figure 4.6 Main interface windows for AGNPS (left) and WATFLOOD (right).

In both interfaces, the different buttons will activate the *Make/Edit Grid* toolbar, the *Collect/Edit Data* tools, the *Run Model (AGNPS or WATFLOOD)* toolbar, the *Display Input/Output* tools and the *Analysis Scenarios* toolbar. When any of the procedures is selected, the available options for each tool are displayed in a form of a graphical toolbar together with the respective popup options menu. This toolbars where developed as navigational aids through the interface but their main objective is to access the different modules of the program.

The Make/Edit toolbar:

 *(AGNPS)*  *(WATFLOOD)*

[Initialize Database] - Initialize the database file. It will open a *File Dialog Box* asking for the name of the file to create. After inputting the name, the program will proceed to create the basic file structure for the database.

[Create Grid] - Create a basic grid and add it to an existing database. It will open the *Grid Maker* window to create a basic grid and save it in an existing database file.

[Create Tables] - Create the required tables and database structure for the models. It will open the *Create Tables* window and allows to generate the structure to hold the data for the model.

[Edit Grid] - Modify the basic grid by adding, deleting and/or sub-dividing cells in AGNPS or selecting and deselecting cells for WATFLOOD. It will open the *Grid Editor* window and allow modifications to the basic grid.

The Collect/Edit Data toolbar:

 *(AGNPS and WATFLOOD)*

[Initial Data] - Capture the initial watershed data. It will open the Initial *Watershed Data* window that allows required data input.

[Collect Data] - Collect cell data from Soil and Landcover Maps. It will open the *Collect Data* window that allows calculation of the data as a function of topography, soil type, and landcover maps. It will also facilitate the display of the DEM file and the soil and landcover maps.

[Flow Direction] - Edit the flow directions and receiving cells. It will open the *Flow Direction Editor* that will help the user in the selection of the flow directions and receiving cells.

[Cells Editor] - View and edit the general cell data in summary form. It will open the *Cell Editor* in order to facilitate the view and editing of the different grid parameters.

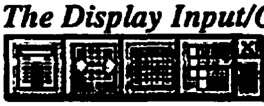
The Run Model toolbar:

 *(AGNPS)*  *(WATFLOOD)*

[Write ASCII File] - Access the export utility to convert the data stored in a database file to an ASCII file that the model can understand. It will open the *Export ASCII* window to export into a specified ASCII file.

[Run Model] - Run the models for the selected file(s). It will open the *Run Model* window to select the file and grid to use for running the model.

The Display Input/Output toolbar:

 *(AGNPS)*  *(WATFLOOD)*

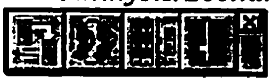
[Edit Ranges] - Create or edit the table for the ranges to be used when displaying the input data or output results. It will open the *Create/Edit Ranges* window to create or edit the ranges.

[Graphic Display I/O] - Spatially display the input data or the model results. It will open the *Graphic Display* window that allows the user to spatially display the input data or the model results in the database file for the selected grid.

[Tabular Results] - (Only for AGNPS) View the model results in tabular form. It will open the *Tabular Display* window that allows the user to view the model results in a spreadsheet tabular form.

[Trace Contribution] - (Only for AGNPS) Activates the source accounting options. It will open the *Trace Contribution* window that allows the user to see the various sources of pollution in any given cell..

The Analysis/Scenarios toolbar:



(AGNPS)

[Duplicate Grid] - Duplicate grids in the database file. It will open the *Duplicate Grid* window that allows the user to replicate a specific grid with a new grid name.

[Modify Landuse] - Modify land coverage percentages. It will open the *Landuse Editor* that allows the user to change the amounts of land coverage for the different land classes.

[Summarize Runs] - (Only for AGNPS) Display the summary of the different runs. It will open the *Summary Runs* window to view a summary of the differents runs.

[Sensitivity Analysis] - Perform the sensitivity analysis. It will open the *Sensitivity Analysis* tool that will allow the user to select the variables to perturbe, perform the sensitivity and display the results.

4.3.3 Online Help File

The AGNPS and WATFLOOD interfaces have been developed in an object oriented environment using a graphical user interface. The main interface windows contain a status bar to provide a quick and easy way of identifying the different sections. As the mouse pointer is moved over the various buttons, information about the object appears in the status bar. Additionally, an *Online Help File* has been created as a reference to get more information about the variables from the model.

In fact the online help files are a very comprehensive and fully functional Windows help system developed around the AGNPS and WATFLOOD Interfaces. In order to access them, from the *Help* menu in the main window, choose *Contents* to bring up the help contents page. Figure 4.7 shows the table of contents from the AGNPS and WATFLOOD interface help files.

The hypertext help files were created with the help compiler for windows using a rich text format (RFT) source document. Help topics include:

AGNPS and WATFLOOD Interface: Includes the main interface description, providing hyperlinks to the different sections (toolbars).

Toolbars: Presents all of the details on the toolbars and links to the different windows are provided by clicking in the respective buttons.

Input/Output Description: Outlines the data requirements for the models and the results obtained from running it. Describes the dependency of the variables on the different map files and provides information on the database structure and detailed information on the variables.

Creating Model Grids: Explains the methodology for starting the database file and creating/editing the required grids.

Collecting and Editing Data: Explains the methodology to input the initial watershed data and how to automatically collect data from the maps and its subsequent editing.

Running the Model: Provides the available running procedures for the models.

Displaying Data/Results: Describes the visualization tools for spatially displaying the input data and/or the model results.

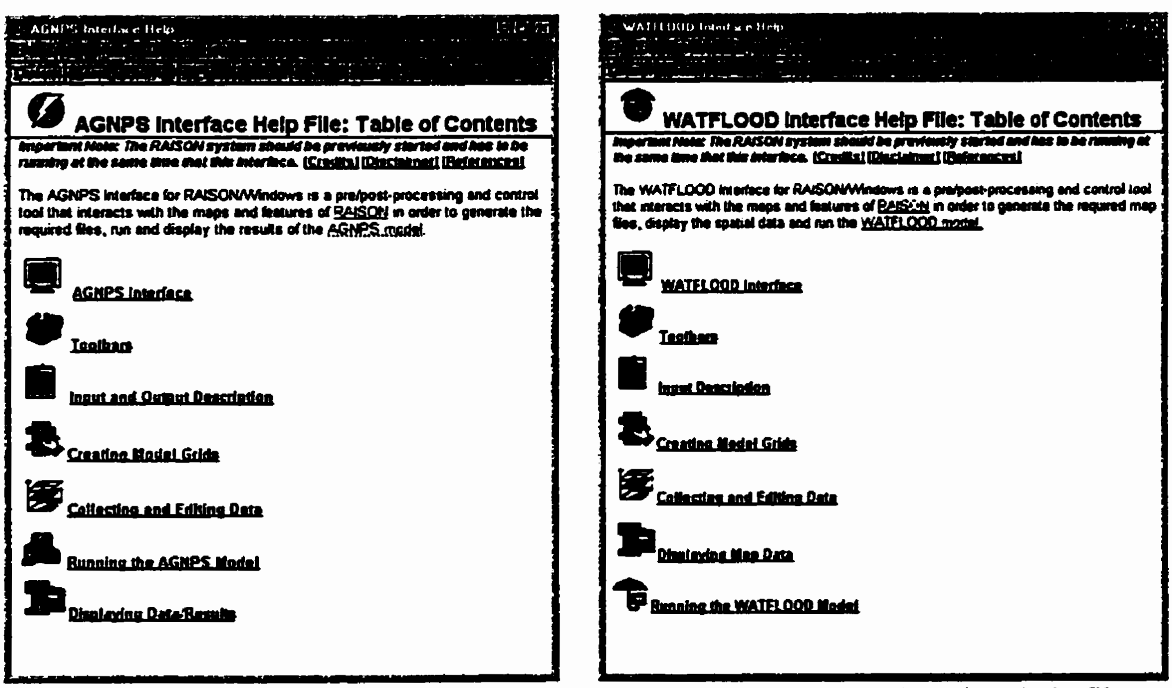


Figure 4.7 Table of contents from the AGNPS and WATFLOOD interface help files.

Almost all of the information contained in the help file was created in order to explain the different components of the interface. The input and output descriptions was elaborated using the text information delivered with the documentation of the models. Several levels of help are available at any moment while running the interface by pressing the F1 function key. For example, when the user is in the *Flow Direction Editor* window and the F1 key is pressed, the help file is opened exactly in that section. Most of the help images are clickable, providing links that allow further topics to be accessed.

As an example of the flow direction editor, Figure 4.8 shows the help file with the *Flow Direction Editor* topic opened in the screen. If the user clicks on the *Grid* or *Flow* buttons, the respective window topic will open with the description displayed. The same applies to the description of the variables. When a window with variables is open, the user can click on most of the variables names and get additional information about the desired parameter. The help system is structured in such a way that is intended as a brief tutorial that will describe how to do a NPS simulation using the AGNPS or WATFLOOD interface for RAISON.

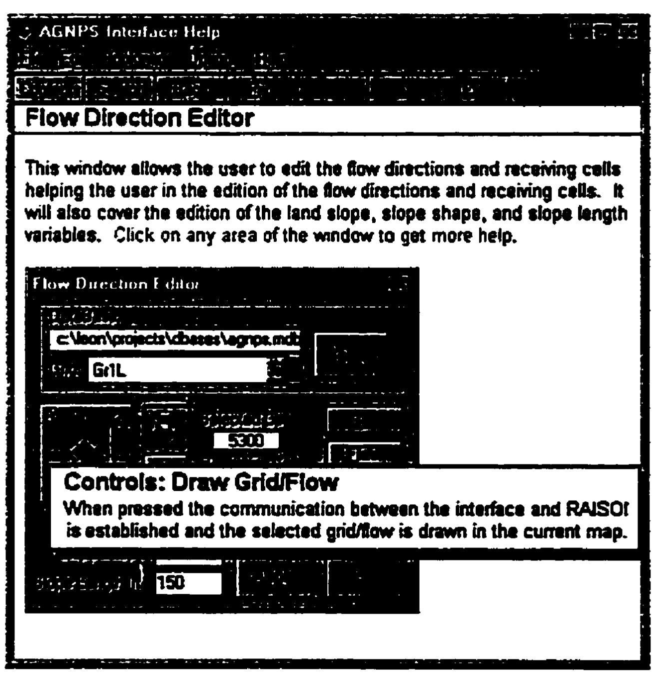


Figure 4.8 Flow direction editor help with further controls explanation.

4.4 Example: Use of the Interface

This section describes how to do a NPS simulation using the AGNPS Interface for RAISON. In the example, it is assumed that RAISON is already started with the project of interest (background map - snapshot) displayed. Also the DEM and MAP files are assumed to be previously imported into the RAISON layer database structure. For the following example, the snapshot and map files are from the Duffins Creek area. All of the datasets (except for the maps) used in the example have been generated for demonstration purposes only. They are mock datasets and do not represent any real simulation on the Duffins Creek watershed. Real data and simulations are presented in the application section.

4.4.1 Creating Grids

All the data required for the model are stored in a database file that can contain several grids. So the first step is to prepare a file and create the grids for the model. This is done from the *Make/Edit Grid* toolbar. Selecting the *Initialize Database* button a *File Dialog Box* will open asking for the name of the database file to create. The program will then proceed to create a basic file for the database. If the file name already exists, an option exists to overwrite the file.

After creating the database file, the next step is to generate the grid. This task is performed through the *Create Grid* option that allows a basic grid to be generated and saved in an existing database file. Allow interaction with RAISON by clicking with the mouse in the map where the upper left corner of the grid will be positioned. At this point, the grid properties (number of rows, columns, width of the cell, color and orientation) are introduced.

When the appearance of the basic grid is satisfactory, it can be stored in the database file. Once the grid is saved, the next step is to build the structure of the database. This is achieved with the *Create Tables* procedure. If the program detects that the tables were already created, no action can be taken other than exit. Otherwise a message will appear in order to perform the creation of the tables following the structure described above.

Finally, the form of the grid can be edited by adding/deleting or subdividing cells. Figure 4.9 shows an example of how a grid is created and edited to match the topology of the watershed to be simulated. The main interface window is displayed, together with the *Create Grid* and *Edit Grid* tools that help with the its creation and edition by adding, deleting and subdividing cells.

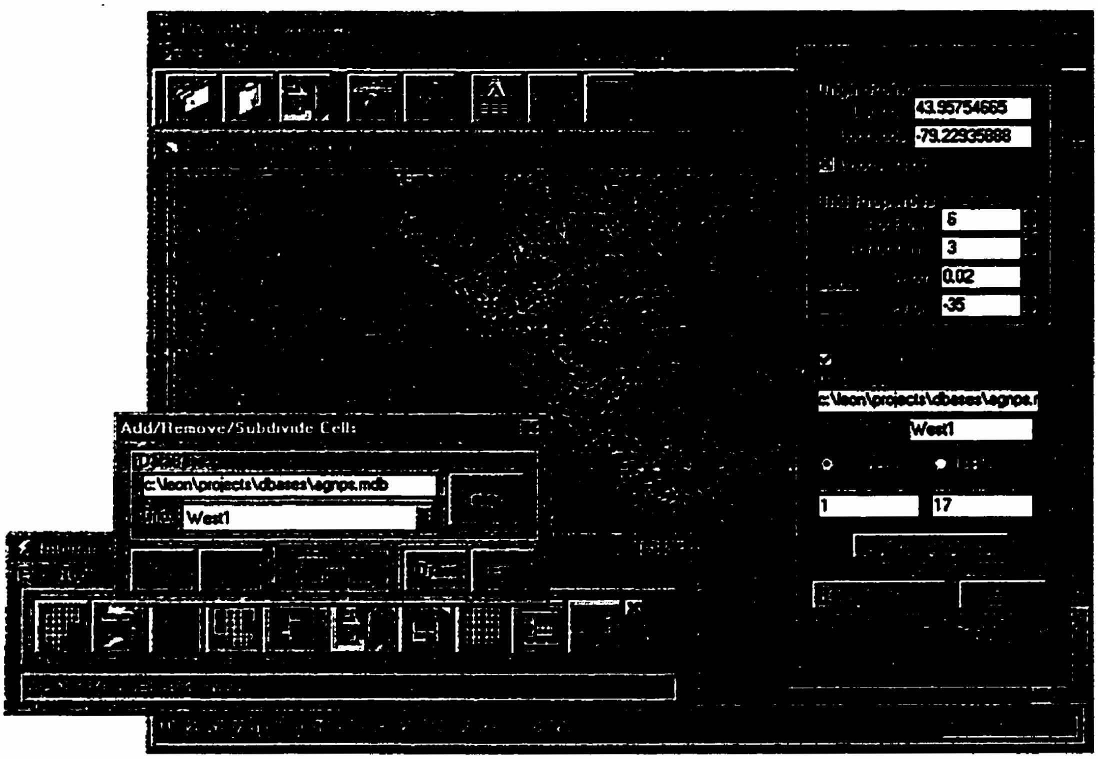


Figure 4.9 Example of the creation and editing of a grid for the AGNPS model.

4.4.2 Collecting Data

After the grid is generated and the required database structure is created in order to hold the data for the model, the next step is to start capturing the required data. As explained in the data requirements and structure section, the two categories of data, watershed and cell related, have to be captured for the selected grid, reviewed and, if needed, edited. The initial watershed data are captured directly into an input form that will verify if the data are valid and save them to the database. This is done through the *Initial Watershed Data* window.

The major asset of the GIS approach is the automatic extraction of the cell related data for the variables that depend on topography, soil type and landuse information. The extraction of the data from map files is achieved with the *Collect Data* procedure. This will perform the calculations described in the section about extraction of DEM and Map data. Figure 4.10 is an example of data extraction and display of the DEM file for the drainage characteristic (flow accumulation). It shows the original DEM file, the grid and the calculated flow directions.

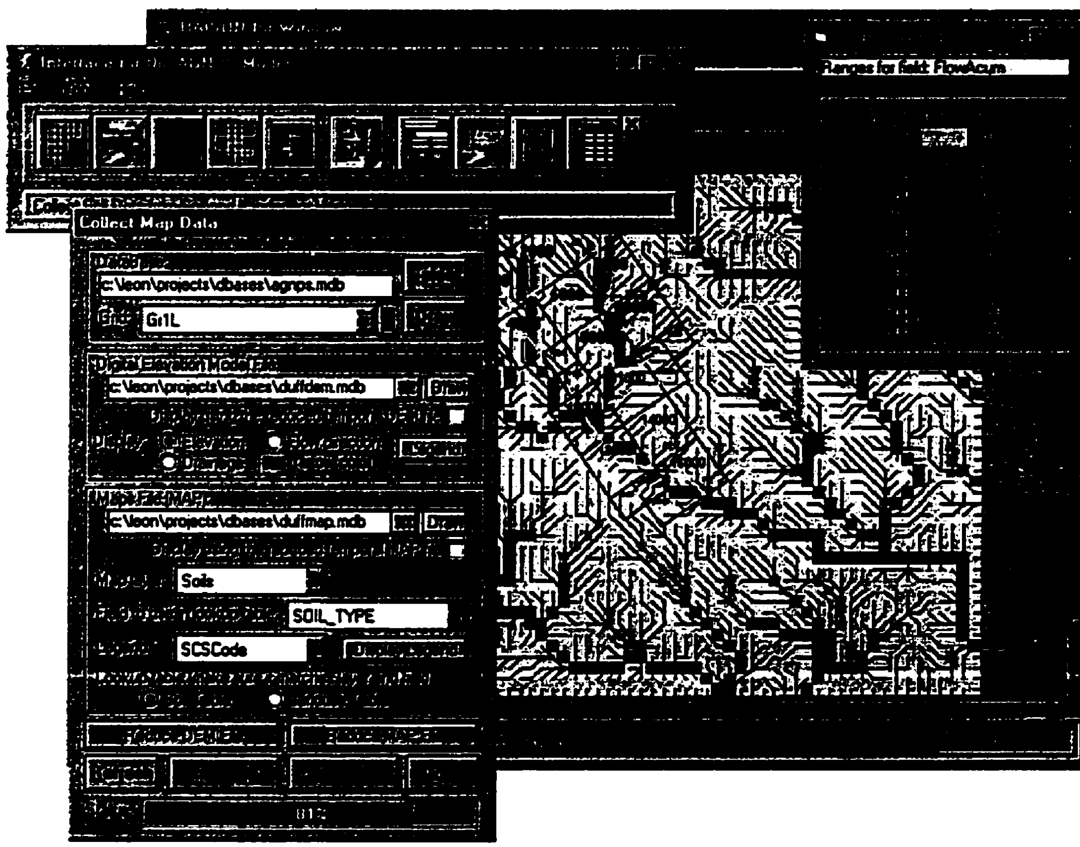


Figure 4.10 Example of DEM extraction and display of original DEM and flow direction.

To collect the information from the Map file, the process has to be made in two steps, first for the **soil layer** and the soil lookup table. Then the process should be repeated for the **landuse layer** and the landcover lookup table. When the extraction is completed, the resulting values can be reviewed and edited with the *Edit Flow Directions* or the *Cell Data Editor*. The *Flow Direction Editor* helps in editing and displaying flow directions and receiving cells.

To view and edit the general and additional cell data, the *Cell Editor* can be accessed. This editor will bring the cell data into a spreadsheet view where any value can be modified and automatically updated in the database. It is also possible to edit the additional cell related information, such as data for point sources, fertilizer and pesticide application. Figure 4.11 is an example of the cell editor tool with the results from the map data extraction. It can be noted that, in the background map, the soil type layer and its legend are displayed together with the arrows for the estimated flow direction for each cell.

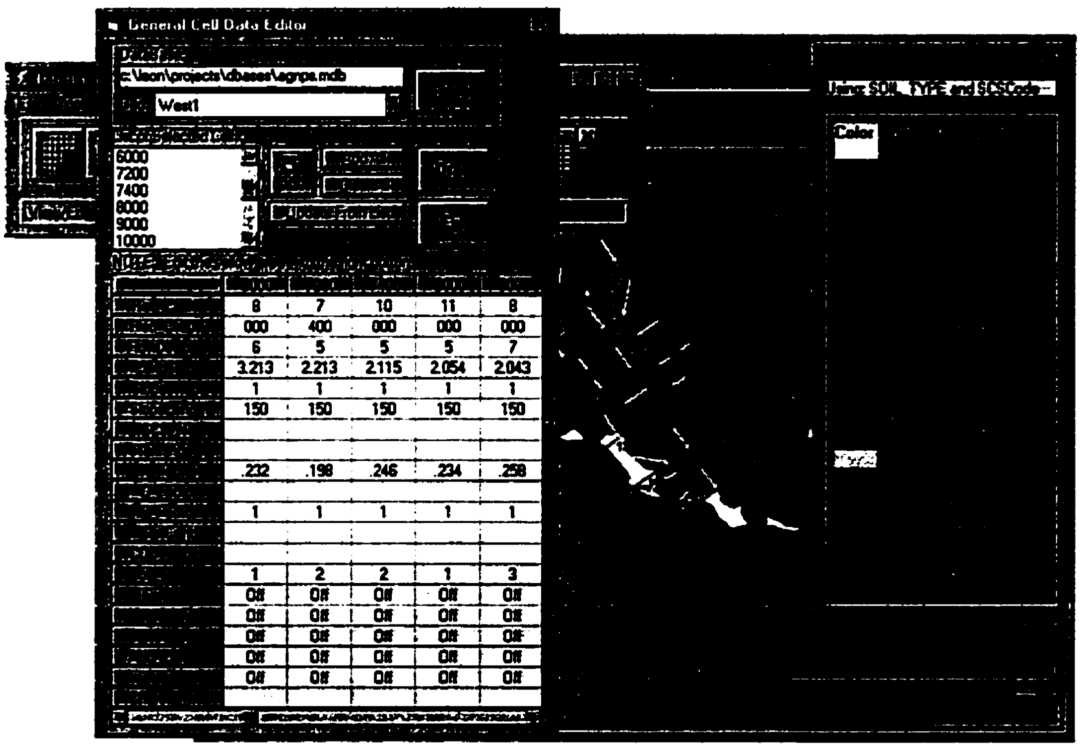


Figure 4.11 Example of the cell editor and display of the soil texture layer.

4.4.3 Running the Model

Once the data have been captured and/or automatically collected from the maps with the described procedures and stored in the database file, the next step is to run the model and visualize the results. In order to run the AGNPS model, the data stored in the database has to be exported to an ASCII file in the format that the model can understand.

This export and the running of the model can be done through the *Run AGNPS* toolbar. In this toolbar there are three procedures that write the ASCII file, run the model or activate a DOS shell that the AGNPS model provides to control the model. The recommended process to run the model from the interface is actually to select the *Run AGNPS Model* procedure.

This creates a temporal ASCII file, runs the model and extracts the results from the output file, storing them in the unique database file in the system. Witte *et al.* (1995) found that for large watersheds, the model should be run from outside the spreadsheet (DOS shell) program, so this is the approach used in this work to actually run the model.

The *Write ASCII File* option can be used to create an ASCII file for revision purposes. This will access the export utility to convert the data stored in a database file to an ASCII file that the model can understand. It will launch the *Export ASCII* procedure to export the data into a specified ASCII file. Note that this exported file is only for review purposes and will not be run within the interface.

An additional provision to access the DOS version of the model is available through the *AGNPS-DOS Shell* option. This will activate the AGNPS DOS Shell in a separate window and is left only for the user to take advantage of the check utility to verify the input data.

4.4.4 Displaying Data/Results

AGNPS, once run, gives detailed output, in fact a very large amount of data for analysis in even a small watershed. Graphical displays of the results have proven to be a more effective and efficient way of interpreting them than browsing through pages of numerical output. Visual tools have been created to display the spatial data in order to help with the analysis, interpretation and decision making processes. When the results are finally extracted from the output file and stored in the database, the *Display Input/ Output* toolbar can be selected to display the input data and/or the results from the simulation.

As an example of the graphical tools available, Figure 4.12 presents the spatial display of the *K* factor (input data) and the sediment erosion (model result). This feature uses part of the internal grid layer drawing commands of RAISON, showing the power of the system once all the information is stored as a database compatible with it.

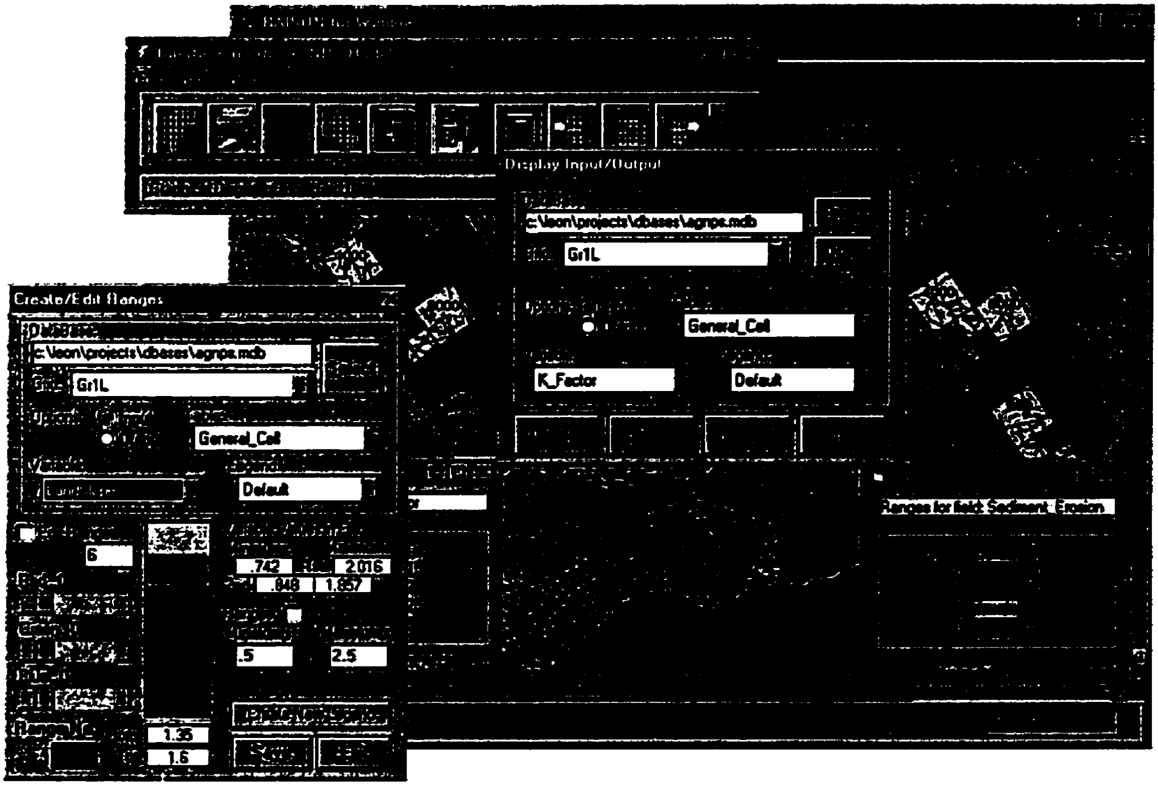


Figure 4.12 Example of graphical input/output display.

4.4.5 Modifying Scenarios

The AGNPS model can be used to simulate different scenarios (ie. best management practices) and its effects on runoff and pollutants loading. To provide support in the decision making process, the tools to duplicate a grid, modify the landcover percentages and recalculate the model parameters can be used to create the different scenarios. Once a basic set of data is extracted from the maps, the resulting gridded values can be copied and modified using the *Analysis/Scenario* options.

As an example of some of the available options, figure 4.13 presents two different runs on the Stouffville Creek watershed. A 500m cell size grid with 97 elements was generated to cover the area of interest. The precipitation was set to 2 inches and the energy intensity value to 15. The first scenario uses the land use coverage from a satellite image classification for 1983. The second one assumes that the top 30% of the watershed remained unchanged and the remaining 70% is developed as urban area with 25% of impervious area (streets, roofs, etc) with the rest having grass ground cover.

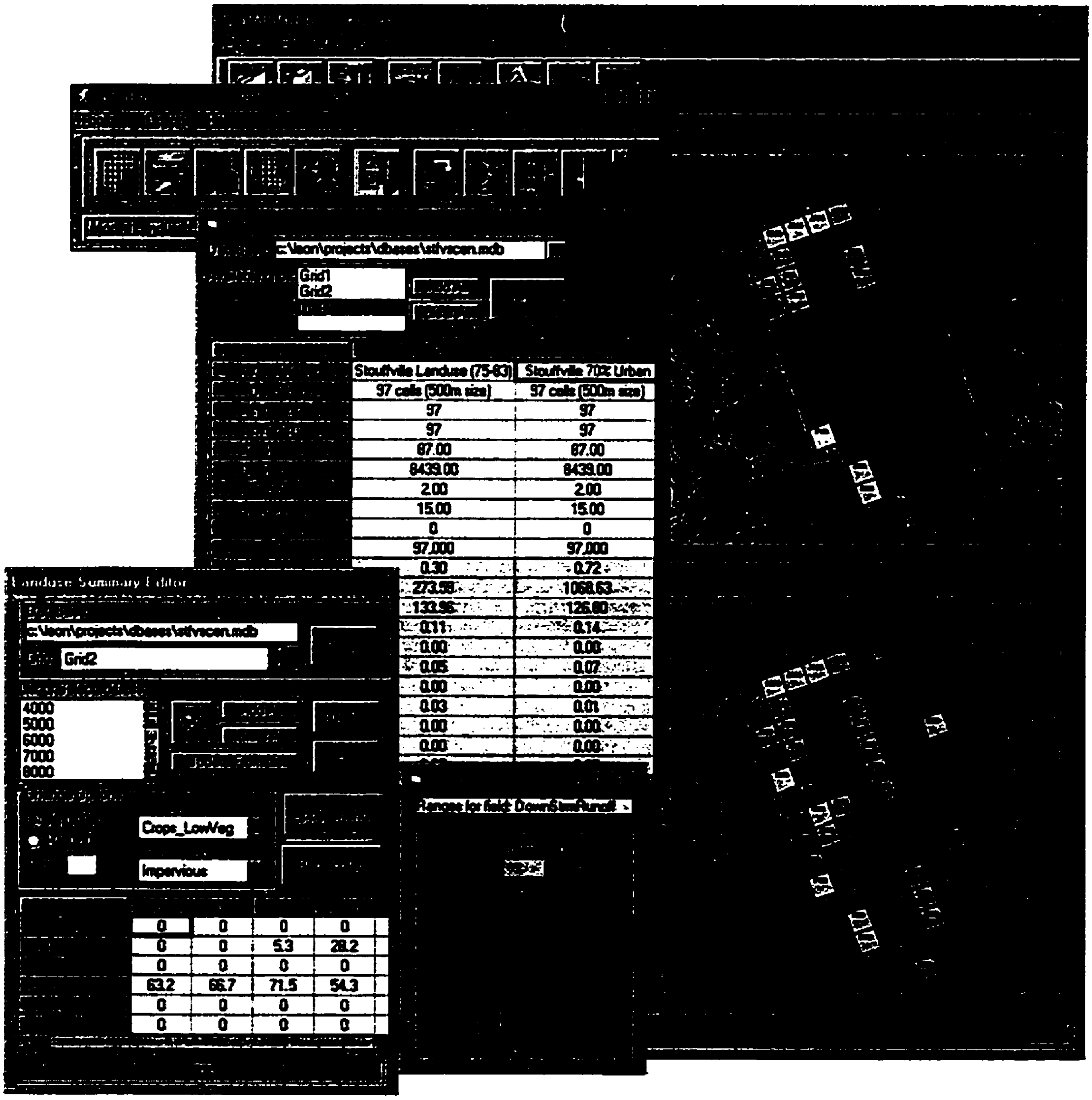


Figure 4.13 Example of different scenarios, modification and graphical output display.

4.5 Chapter Summary

This chapter presented the integral approach to include NSP models in a Spatial Decision Support System (SDSS) with a unique platform, common interfaces and Geographic Information System (GIS) capabilities. This consists of pre- and post-processing tools, model control panels gaming scenarios and sensitivity analysis for the parameters in the models. The construction of the interfaces, for the Agricultural Nonpoint Source (AGNPS) model and WATFLOOD, and their link with the decision support system RAISON (Regional Analysis by Ingelligent Systems On microcomputers) is described. First, a brief description of RAISON as the GIS and SDSS platform is presented. Some characteristics are outlined and the available tools used in this work for interfacing it with the models are mentioned. Finally, a detailed description about the AGNPS and WATFLOOD interfaces is presented. The conceptual designs are outlined and the interfaces presented in full detail, with highlights and explanations for all the commands and controls involved. The online help files are also briefly described, together with a brief example on how to use the interfaces.

CHAPTER 5. Data Acquisition and Application

Traditionally, input data are described as a set of parameter values in a format to be read by the model. During the development of this work, a major emphasis was placed on developing the automatic extraction of input data from digital sources. It is this that creates the distinction from the traditional input data methods. The required data are then in the form of digital information files which will be processed to extract the required input values for the models.

5.1 DEM and Map Files

RAISON works with relational databases and the different layers in these databases represent various sources of digital information such as DEM, soil and landuse. In order to incorporate different data sources into the database management system of RAISON, several import facilities were developed.

In general terms, three sources of information, DEM, soil and landuse data, are required to take full advantage of the automatic extraction of input data. A detailed description of the source data files and the import process are described in the following examples for the Duffins Creek watershed, east of Metropolitan Toronto, in southern Ontario.

5.1.1 Digital Elevation Model Data

The DEM data as described in the previous chapter consist of elevation data for each element, flow direction and flow accumulation. Normally the basic information of a DEM includes the elevation of each element for the full extent of the study area. Some commercial applications include a conditioning process to create depressionless data and to calculate flow directions and flow accumulation values (Jenson *et al*, 1988). The three sets of values are required to create the DEM layer database. Two different options are included on the import facility: using the three datasets as individual ASCII files or using just one comma separated value (CSV) file which includes the three fields. An intermediate process will create the CSV file to be used by the general import program.

The DEM data for the Duffins Creek area was obtained from the United States Geological Survey (USGS) internet site (*http://edcwww.cr.usgs.gov/landaac/gtopo30/gtopo30.html*). The required topographic map files at every 30 second interval for the North America region were already available in CD-ROM at the University of Waterloo. In order to increase the resolution of the DEM, before importing, the data were resampled at every 15 seconds and a conditioning process was performed to create a depressionless DEM, together with the flow directions and flow accumulations data channels. The process was performed with the EasyPace/PCI program as described previously.

The extents and characteristics of the final file are presented in Table 5.1, together with the header and first lines of the CSV file created to be imported into RAISON. Once imported the DEM layer for Duffins Creek consists of 3,360 elements with the three attributes for elevation, flow direction and flow accumulation attached to each record. Figures 5.1 and 5.2 show the DEM elevation data and flow accumulation values respectively. They are displayed using RAISON with a scanned background map from the Duffins Creek from a 1:250,000 scale map of Toronto and surroundings. The background scanned map was then converted to a BMP (bitmap image file) and georeferenced within RAISON.

Table 5.1 DEM File for Duffins Creek, Description of ASCII and CSV Files for Import

Duffins Creek extent:

	Latitude	Longitude
Left top corner:	N44° 00' 00" ;	W79° 16' 00"
Right bottom:	N43° 48' 00" ;	W79° 02' 00"

The ASCII files have 56 columns and 60 rows in one vector, each pixel is 0°0'15" in both directions.

Duffins ASCII files:

- DuffElev.txt - elevations:
265, 260, 257, 248, 242, 233,...
- DuffDir.txt - flow direction*:
1, 128, 128, 128, 2, 4,...

*The flow direction is encoded to correspond to the orientation of one of the eight cells that surround the cell (x) as follows (PCI convention):

64	128	1
32	x	2
16	8	4

- DuffFlow.txt - flow accumulation:
0, 2, 0, 1, 1, 31,...

Duffins CSV file:

First line:
Title,Spacing (decimal), # of elements
DEM, 0.0041666, 3360
Lat, Lon, Elevation, Direction**, FlowAcum
44,79.26667,265,2,0
44,79.2708366,260,1,2
44,79.2750032,257,1,0
44,79.2791698,248,1,1
44,79.2833364,242,3,1
44,79.287503,233,4,31
. . .
. . .
. . .
. . .

**The import procedure converts the directions to values for the convention adopted in the interfaces:

8	1	2
7	x	3
6	5	4

5.1.2 Soil Type and Landcover Files

The map data includes the soil type and landcover information. Both data sources consist of a number of polygons with attached attributes. In the case of soil type the attribute of interest, in order to perform the data extraction, is the soil texture classification. For the landuse layer, the field to use in the extraction is the landcover attribute of the polygon. There are several ways of generating such files. They can be created with a simple digitization of map hard copies or with a more complex process by using automatic image classification techniques.

By means of a standard shape file format, a general import facility was created in order to bring the polygons from the shape file into polygon layers in the RAISON system. The soil data for Duffins Creek were digitized from soil maps by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) and made available through the NWRI. This set of data consists of 165 polygons with a total of 6,207 vertices. The files were provided in standard shape format.

Using the shape import utility, the polygon layer import was performed to create the database layer soil. The map code and the soil type are related through the lookup table (see Appendix B) to find the adequate parameter values based on the soil classification convention from the SCS. For the landuse data, two sources of information were used: Landuse maps from OMAFRA for the 1975-83 period and three classified satellite images (1975, 1985 and 1992) obtained from the Metro Toronto Regional Conservation Authority (MTRCA). The OMAFRA file consists of digitized landuse map with extensive classification, imported directly as a layer for a total of 720 polygons and 21,723 vertices.

The MTRCA landcover data derives from landsat imagery. Remote sensing data for 1975 was obtained with a multi-spectral scanner with a resolution of 80m. For 1985 and 1992 the data were captured using a thematic mapper with a 30m resolution (personal communication with MTRCA personnel, 1997). An unsupervised classification technique of spectral signatures was used to classify the images together with airphoto archives and field recognition to validate classified areas. The classification process was achieved with the image analysis package PCI/EasyPace. The classified files (PIX) were saved as ArcInfo grids and converted to ArcInfo polygonal coverage and finally exported to shape files (SHP).

The interfaces for the models and RAISON are 16 bit applications. This poses a particular problem in the layer operations on the database with a limit of 4,000 points per polygon to handle and pass huge arrays. If necessary the source files have to be preprocessed by breaking up and smoothing the polygons. In the case of the MTRCA files, a 2km grid intersection process and 15m interval smoothing were performed with the ArcInfo grid generator. Finally the shape files were imported into RAISON layers by a generic shape import utility. Three final files, one for each year, were created. The 1975 file consists of 1,983 polygons with a total of 33,687 vertices, the 1985 file has 1,391 polygons with 24,718 vertices and the 1992 file contains 1,327 polygons with 24,484 vertices. Figures 5.3 and 5.4 present the soil type layer and the landuse layer (1992 coverage) respectively. They are also displayed in RAISON using the same scanned background map from the Duffins area.

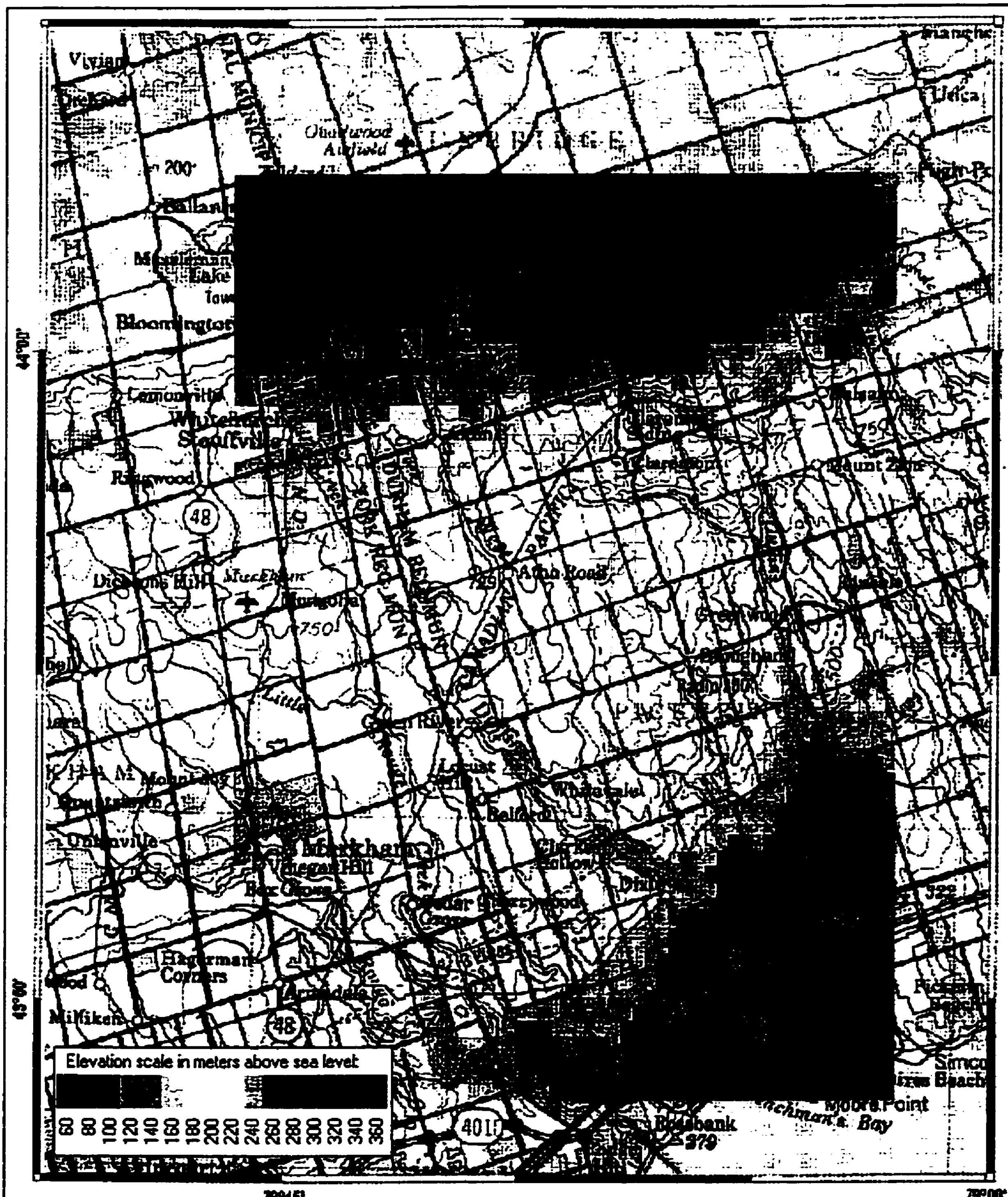


Figure 5.1 DEM file - elevations for the Duffins Creek area.

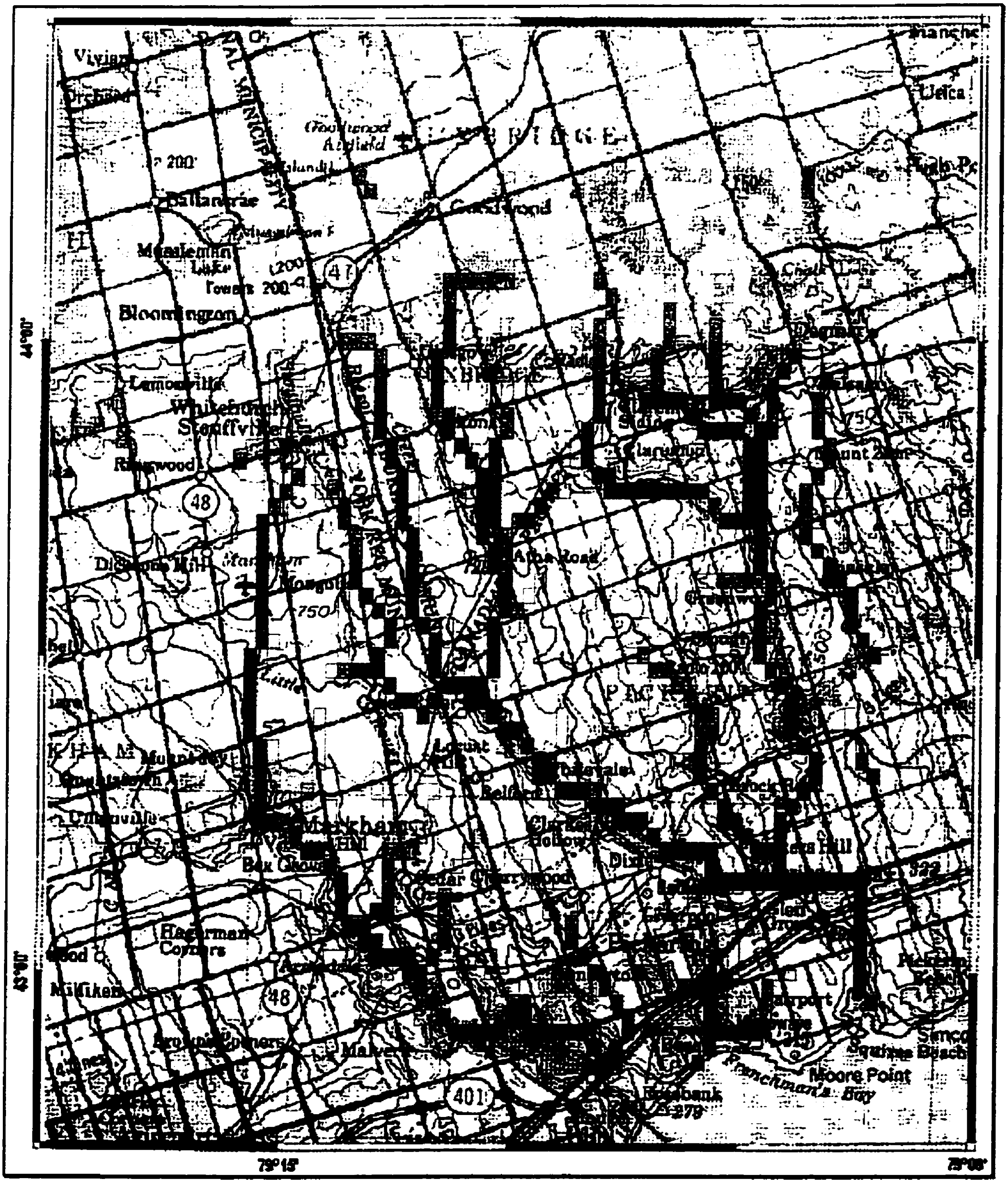


Figure 5.2 DEM file - flow accumulation for the Duffins Creek area.

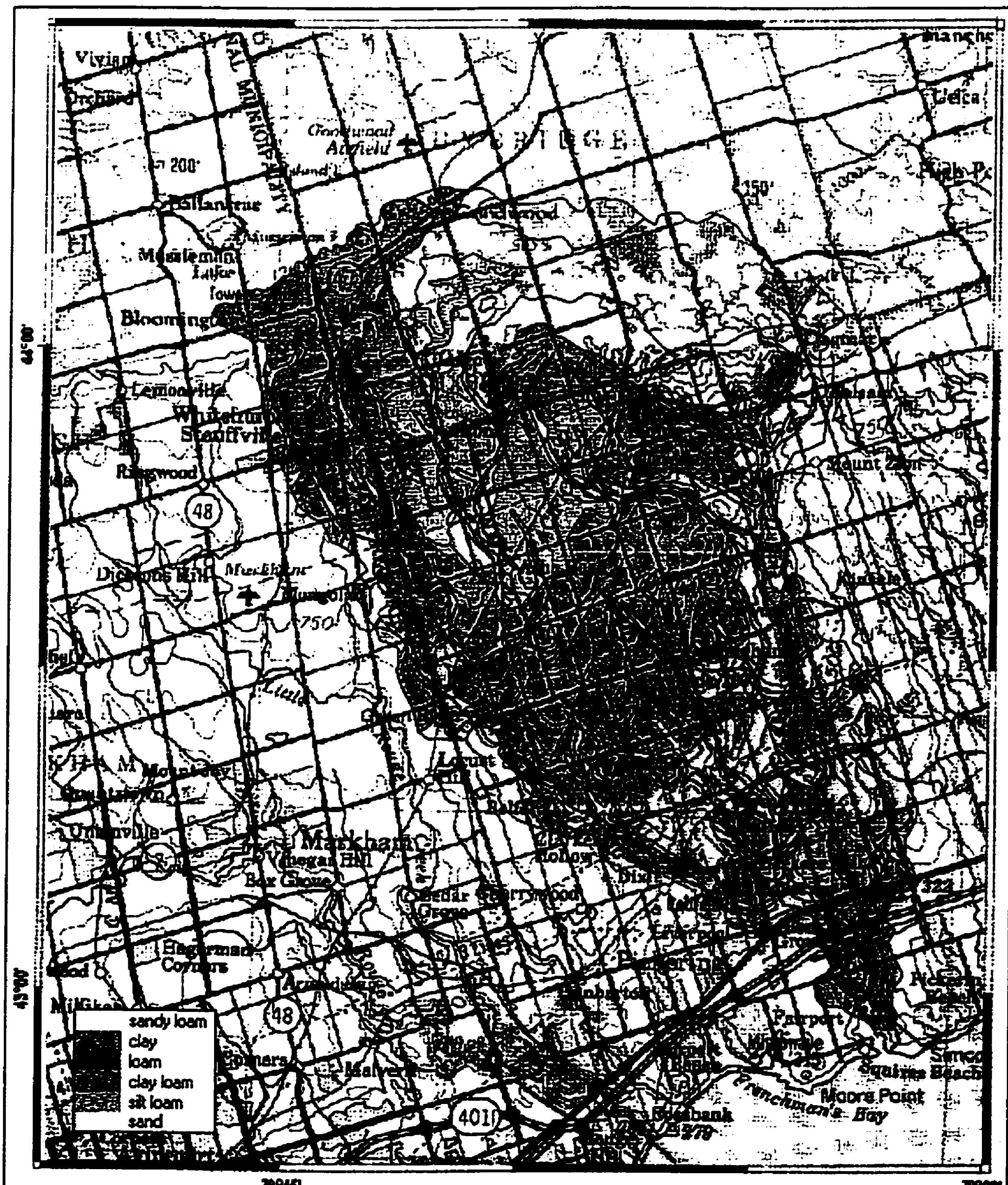


Figure 5.3 Map layer file - soil textures for the Duffins Creek area.

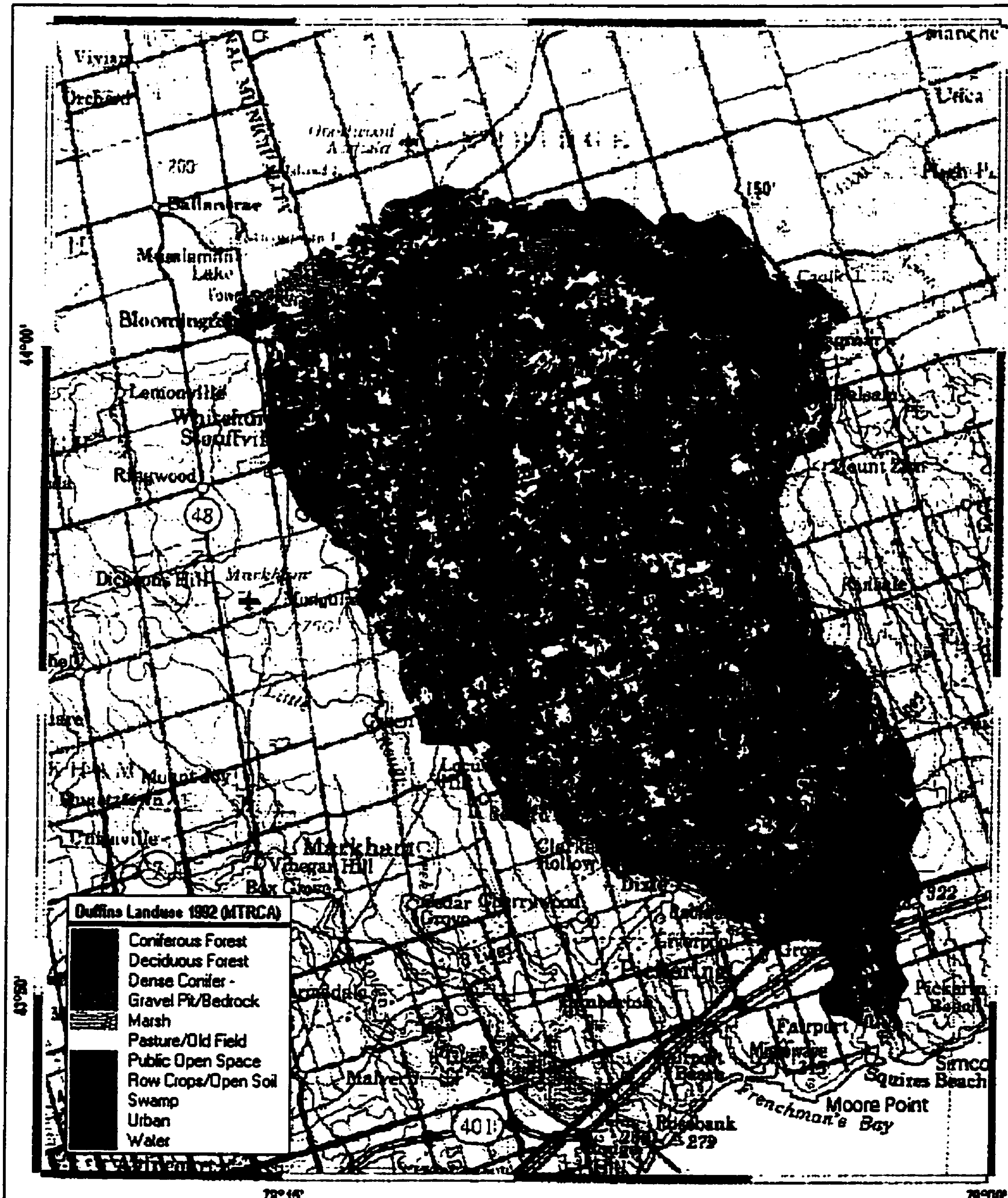


Figure 5.4 Map layer file - landuse for the Duffins Creek area.

5.1.3 Utilities to Incorporate Source Data in RAISON

To import the described digital information into RAISON database layers, three program utilities where created. The first one imports the shape file into a database layer. The second tool facilitates the DEM import. The third one provides a set of tools to edit and modify the lookup table that allows the link between the imported files and the extraction process requirements. Figure 5.5 shows the tools and how they are accessed through a control window.

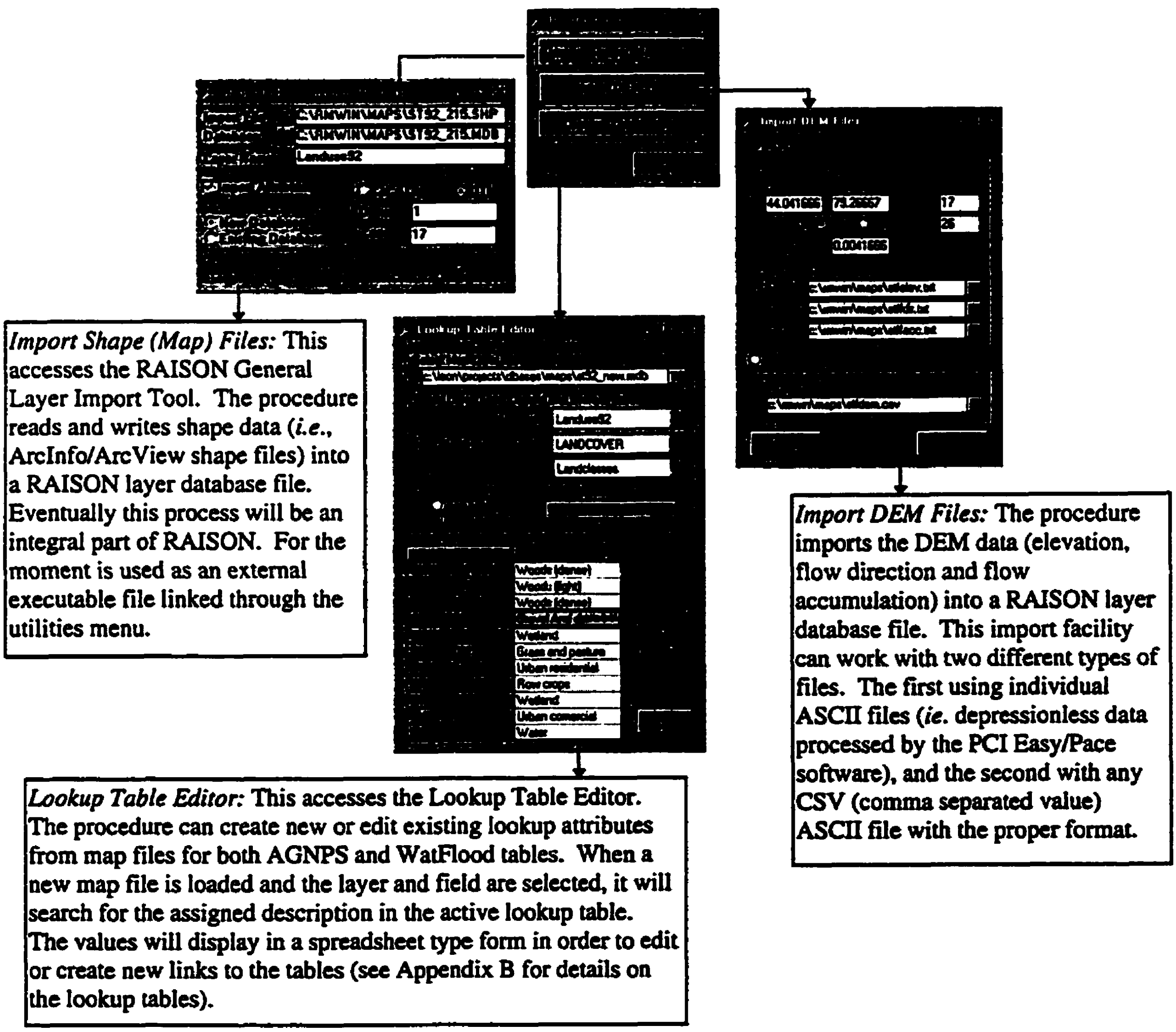


Figure 5.5 Utilities to import and link digital source data into the RAISON interfaces.

Using the utilities, all the source files were imported to be used with the interfaces. Table 5.2 summarizes the digital data processed and resulting files for the Duffins Creek and Stouffville areas. Additional radar, streamflow and water quality data were also collected for this research. This data will be described later on the application section of this chapter.

Table 5.2 Summary of Digital Information Acquisition

Source File	Utility	Target File	Size	Characteristics
Duffins Shape Files:				Used directly to draw RAISON maps and
-rivers, roads, etc.	None	None	Variable	snapshots (no import required).
Watershed Files:				Watershed files contain just 1 polygon and
- DuffShed.shp	ImportShape	DuffShd.mdb	160 Kb	are used for automatic selection of grid
- StfShed.shp		StoufShd.mdb	128 Kb	elements within the borders of the basin.
DEM Files:				CSV files from ASCII-PCI elevation, flow
- DuffDEM.csv		DuffDEM.mdb	2.4 Mb	accumulation and flow direction files:
- StffDEM.csv	ImportDEM	StfDEM.mdb	448 Kb	- Duffins: 3,360 elements (56x60 @ 15")
- StffDEM5.csv		StfDEM5.mdb	3.3 Mb	- Stouffville: 442 elements (17x26 @ 15")
				and 4,536 elements (63x72 @ 5")
MAP Files:				OMAFRA files (DuffMAP):
- DuffMaps.shp	ImportShape	DuffMAP.mdb	2.1 Mb	-Soil layer: 165 polygons (10,094 points)
				-Landuse: 720 polygons (17,836 points)
- Stouffville	Reduce Duff	StfMAP.mdb	544 Kb	-Soil layer: 25 polygons (1,868 points)
				-Landuse: 150 polygons (3,843 points)
Remote Sensing				
Landuse Maps:				MTRCA files (2km grid/15m weed) for
Duffins Creek				both Duffins and Stouffville areas:
- Duff75.shp		Df75_215.mdb	18.3 Mb	1975 - 15,725 polygons (229,703 points)
- Duff85.shp	ImportShape	Df85_215.mdb	11.8 Mb	1985 - 8,926 polygons (148,988 points)
- Duff92.shp		Df92_215.mdb	12.5 Mb	1992 - 9,357 polygons (158,285 points)
Stouffville Creek				
- Stf75.shp		St75_215.mdb	2.75 Mb	1975 - 1,983 polygons (33,687 points)
- Stf85.shp	ImportShape	St85_215.mdb	2.10 Mb	1985 - 1,391 polygons (24,718 points)
- Stf92.shp		St92_215.mdb	1.99 Mb	1992 - 1,150 polygons (19,020 points)

At this point, only the digital mapping information is described together with the tools used to import them into a format that can be used by the decision support system. As can be seen, there are more than 58 megabytes of digital data to represent all the different sources of data for the Duffins region. A lesson learned in this process is to keep files organized at a regional basis and only for the extent of the study area in order to keep manageable file sizes.

Once all the information is in the same platform, several shortcuts can be made to speed up the display of the maps. Taking advantage of the RAISON features, different snapshots can be created using the original source information (*ie.* previous examples for the DEM, soil and landuse maps around Duffins Creek). Though these maps are quite detailed, they can be too cluttered to use for displaying grids and results. Additional screens were created with less map information in order to facilitate the use of the interface and the display of results. Figure 5.6 shows, as an example, one of such RAISON snapshots for the Duffins Creek area. It displays the river system, the main roads and the two watersheds, Duffins and Reesor Creek, where the modelling was performed.

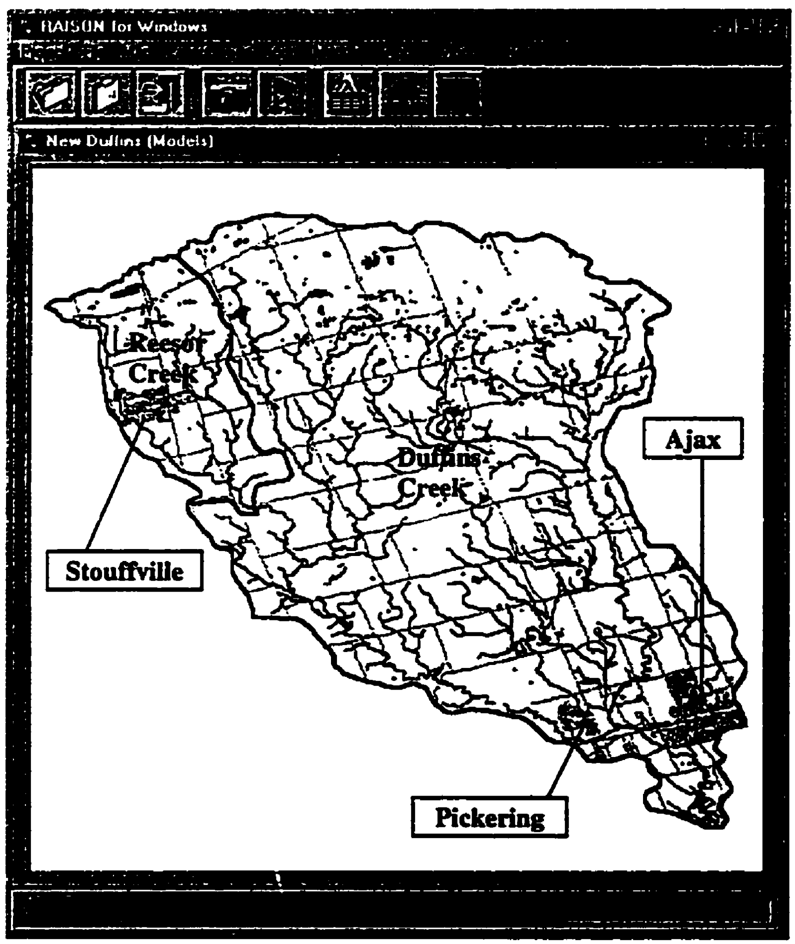


Figure 5.6 Snapshot of Duffins Creek (rivers , roads and watersheds)

5.2 Duffins Creek Application

The Duffin's Creek Project is a collaborative research project between Environment Canada and the Ontario Ministry of Environment and Energy. The main objective of this project is to provide planning groups with improved scientific procedures to assist them in achieving their program targets (Bowen *et al.*, 1995). Use of the AGNPS model was one of the components of the project. The linkage with a decision support system was then proposed and a further technology transfer, described later in this Chapter, was aimed at providing the required tools to achieve such objective.

This application focuses on Duffin's Creek, a 293 km^2 watershed draining into Lake Ontario at Ajax, 10 km east of Metropolitan Toronto. The headwaters originate in the northern regions of the watershed in the Oak Ridges Moraine where sub-surface drainage predominates (Bowen *et al.*, 1995). The landuse in the basin is mainly non-intensive agricultural with growing urban areas in the lower parts of the watershed at Pickering and Ajax. Towards the western area is Stouffville, with a flood control reservoir and a water treatment plant that discharges into the Duffins Creek west river system.

Duffins Creek was chosen for three reasons: i) the Federal and Ontario governments are major owners of the land, expropriated in the 1970s to build an international airport, ii) the watershed has a comprehensive environmental database to work with and iii) project plans proposed the need for non-point source pollution modelling in the watershed. As additional advantages, it is located near the Atmospheric Environment Service (AES) King City Weather Radar Research Station so hourly radar data and temperature measurements are available for the area. It also has a comprehensive record of streamflows at several flow gauges. As part of the project for his Master degree, Cranmer (1998), compiled the required radar and streamflow data and helped with the setup of WATFLOOD for the Duffins Creek watershed. Warm weather data, from April-November 1995, were used for this application. Due to the lack of operating rain gauges during the study period, radar data were the only source for rainfall.

The high spatial and temporal resolution of rainfall is taken into account when using radar data to estimate precipitation. Event models, such as AGNPS, require total rainfall amounts. To get the total precipitation for specific events, the compiled radar files (MET) were processed to hourly values of rainfall. This was achieved through the use of a mask which consists of the percentage of area for each cell within the watershed. The filtering process through the mask produces the required hourly rainfall values for each cell. The total amount for the watershed is then calculated as an average of the cell values. Table 5.3 shows a sample of the radar file were the mask of the watershed is highlighted in bold style.

Table 5.3 Sample of a Radar (MET) File with Hourly Precipitation Values (mm)

HOUR= 256 1 Radar

3.5	3.5	3.0	2.5	3.0	3.5	2.0	2.0	2.0	2.0	1.5	2.0
4.0	3.0	2.5	3.0	3.5	2.0	2.0	2.0	2.0	1.5	2.0	1.5
3.0	3.5	3.5	4.0	3.0	3.0	2.0	2.0	2.5	2.0	2.0	1.0
3.5	3.0	3.5	3.0	2.5	2.0	2.0	2.0	2.0	1.5	1.5	2.0
4.0	3.5	3.5	2.0	2.0	2.5	2.5	1.5	2.0	2.0	1.5	2.0
3.5	3.0	2.0	2.0	2.0	2.5	3.5	2.0	2.5	2.5	2.0	1.5
2.5	2.5	2.5	1.5	2.5	2.5	2.5	2.5	2.5	2.0	2.0	2.0
3.0	2.0	2.0	2.0	1.5	3.5	3.0	4.0	2.5	3.5	3.0	1.5
3.0	2.5	2.5	2.0	2.0	2.5	3.0	4.0	4.0	3.5	3.5	2.0
3.0	3.0	2.5	2.0	2.0	2.0	3.0	3.0	3.5	3.5	2.5	2.0
3.0	3.5	3.0	2.5	2.0	3.0	2.5	4.5	3.0	2.5	2.5	2.0
3.5	3.0	3.0	2.0	2.5	3.0	3.5	3.5	2.5	2.5	2.5	2.0
3.0	4.0	3.0	2.0	2.5	3.0	2.0	2.0	2.5	2.5	2.5	1.5
3.5	3.0	3.0	2.5	3.0	3.0	2.5	2.5	2.5	2.0	2.0	1.5
3.0	2.0	2.5	2.5	2.0	2.0	2.0	2.0	3.0	2.0	1.5	1.5

Average value = **2.63**

HOUR= 257 1 Radar

2.0	2.0	2.0	2.0	2.0	1.5	2.0	2.0	1.5	2.5	2.5	2.5
2.0	2.5	1.5	2.0	2.0	1.5	2.0	2.0	2.5	2.0	2.0	3.0
2.0	2.0	2.0	1.5	2.0	2.0	2.0	2.0	2.5	1.5	1.5	2.5
2.0	2.5	1.5	2.0	1.5	1.5	1.5	2.0	2.0	3.0	1.5	2.0
2.0	3.0	2.0	2.0	1.5	2.0	2.5	2.0	2.0	2.5	2.5	3.0
2.0	2.5	2.0	2.0	2.0	2.0	2.5	2.0	2.5	2.5	2.0	2.5
1.5	2.0	3.0	1.5	2.0	2.5	2.0	2.0	2.5	2.0	2.5	2.0
2.0	2.0	2.0	2.5	3.0	2.5	3.0	2.5	2.0	2.0	2.0	2.0
2.0	2.0	2.0	2.5	2.5	3.0	3.0	2.0	2.0	2.5	2.5	2.0
2.0	2.5	2.5	2.5	2.0	2.5	2.5	2.5	2.0	2.5	1.5	2.0
2.5	2.0	2.0	3.0	2.5	2.0	3.0	2.5	2.5	2.0	2.0	2.0
2.5	3.0	2.5	2.5	3.5	3.0	2.5	3.0	1.5	2.5	2.5	2.0
3.0	3.0	2.5	3.0	2.5	2.5	2.5	3.0	2.0	2.0	2.5	2.5
2.5	3.0	2.5	2.5	2.5	2.5	3.0	3.5	2.0	2.5	2.5	2.5
3.5	2.5	3.0	2.0	2.0	3.5	2.5	3.0	2.0	3.0	2.5	3.0

Average value = **2.76**

HOUR= 258 1 Radar

2.0	2.0	2.5	4.0	4.0	4.0	3.0	3.0	3.5	3.0	3.5	3.5
2.5	2.0	2.5	3.5	3.5	3.5	3.5	3.0	3.0	3.5	3.5	3.5
1.5	1.5	2.5	4.0	3.0	3.5	3.5	3.5	3.5	3.5	4.0	4.5
2.0	2.0	2.5	3.0	3.0	3.5	3.0	3.0	3.0	3.5	4.0	3.5
1.5	2.5	2.5	2.5	3.0	3.0	3.5	3.5	3.0	3.5	3.5	3.0
1.5	2.0	2.0	2.5	2.5	3.0	3.5	3.0	2.5	3.5	3.0	3.0
1.5	2.0	2.0	2.0	3.0	2.5	4.0	3.0	3.0	3.0	3.5	3.0
2.0	2.0	2.0	2.0	3.0	3.0	3.5	3.0	3.0	4.0	2.5	3.5
2.0	1.5	2.0	2.5	3.0	2.5	4.0	3.0	3.0	2.5	3.0	3.0
1.5	1.5	2.5	2.5	2.5	3.0	4.0	4.0	2.5	2.5	2.5	3.0
2.0	2.5	2.5	2.5	2.0	3.0	3.0	2.5	3.0	2.0	2.5	2.5
1.5	2.0	2.0	2.5	2.0	2.0	4.0	3.0	2.0	3.5	3.0	2.5
2.5	2.5	2.0	2.0	2.0	2.5	3.0	2.0	2.5	2.5	2.5	2.5
2.0	2.0	2.0	2.0	3.0	2.0	2.5	3.0	3.5	2.5	2.5	3.0
2.0	2.0	2.0	2.5	2.5	2.5	2.0	3.0	2.0	2.5	2.0	2.5

Average value = **3.01**

HOUR= 259 1 Radar

1.5	1.5	2.0	2.0	2.0	2.5	2.5	2.0	2.5	3.0	2.5	3.0
1.5	1.5	2.0	2.0	3.0	2.0	2.5	2.0	2.0	3.0	2.5	2.0
2.0	2.0	1.5	2.0	1.5	1.5	2.0	2.0	1.5	2.5	2.5	3.0
1.5	2.0	2.0	2.0	2.0	1.5	2.0	2.0	2.5	2.0	2.0	2.5
1.5	2.0	2.0	2.0	1.5	2.0	1.5	1.5	2.0	3.0	2.0	2.5
1.5	2.0	2.5	2.0	1.0	2.0	2.0	1.5	2.0	2.5	2.5	2.5
1.5	1.5	1.5	1.5	2.0	1.5	2.0	2.0	2.5	3.0	3.0	2.0
2.0	1.5	1.5	1.5	2.0	1.5	1.5	1.5	2.0	2.0	2.5	3.0
2.0	1.5	2.0	2.0	2.0	1.5	2.0	1.5	2.0	2.0	2.0	3.0
2.0	1.5	1.5	2.0	2.0	2.0	2.5	2.0	1.5	2.5	2.5	2.5
1.5	2.0	2.0	2.0	2.5	2.0	2.5	2.5	2.5	2.5	3.0	3.5
2.5	1.5	3.0	3.0	3.5	2.0	2.5	3.5	3.0	3.5	3.5	3.0
2.0	2.0	2.5	2.5	2.5	3.5	3.0	3.5	3.5	3.0	3.0	4.0
2.5	2.0	1.5	2.5	4.0	4.0	3.0	4.5	3.5	3.0	3.5	4.0
2.5	3.0	3.0	3.0	2.5	3.0	2.5	4.0	4.5	4.0	3.5	3.0

Average value = **2.26**

Processing all the compiled radar files (MET) with an average of 744 hours per month, hourly precipitation amounts were calculated for April-November 1995. Figure 5.7 shows the rainfall values extracted from radar data for Duffins Creek. For the AGNPS initial watershed data, the storm precipitation and duration for the individual events were extracted from these records. Appendix E contains the detailed hourly rainfall graphs for each of the individual events.

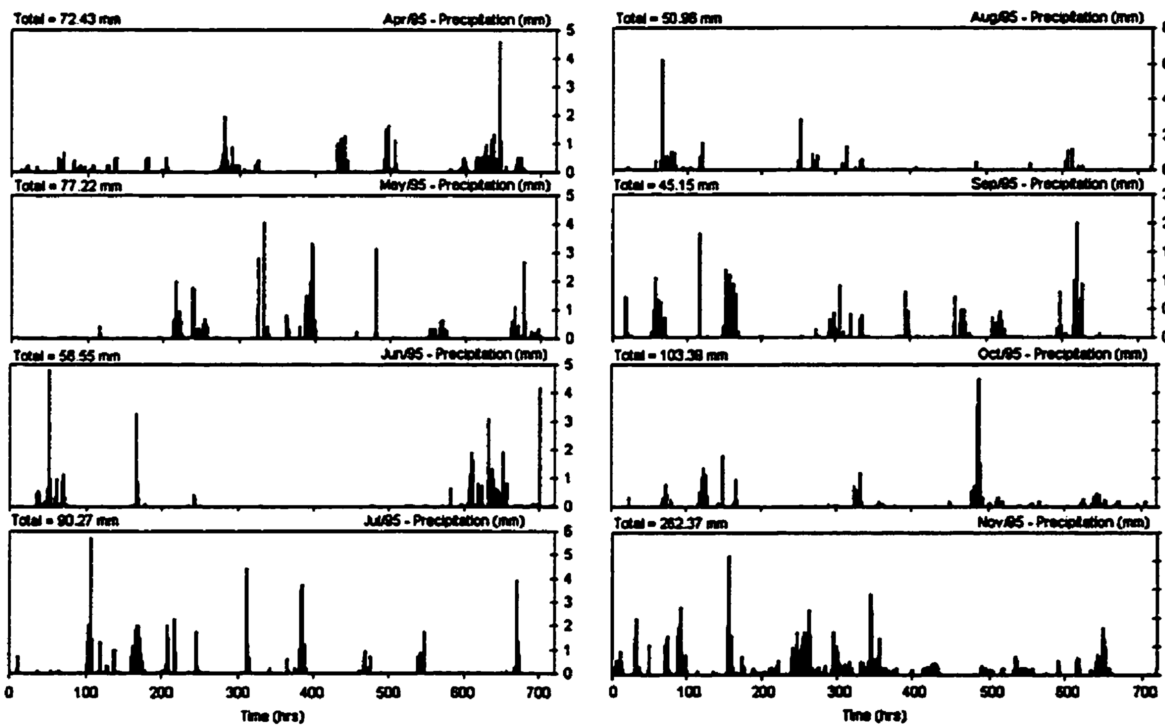


Figure 5.7 Hourly precipitation in Duffins Creek (extracted from RADAR data)

Hourly streamflow data were provided by the Monitoring and Systems Branch of Environment Canada for the three stream gauge stations in current operation. Table 5.4 shows the gauge summary information for the three stations.

Table 5.4 Active Streamflow Gauges in Duffins Creek

Station Number	Location	Latitude (dd°mm'ss" N)	Longitude (-dd°mm'ss" W)	Drainage Area (km^2)
02HC039	Reesor Creek above Green River	43°56'07"	-79°12'03"	38.3
02HC019	Duffins Creek above Pickering	43°53'30"	-79°03'33"	93.5
02HC049	Duffins Creek at Ajax	43°50'57"	-79°03'25"	251.0

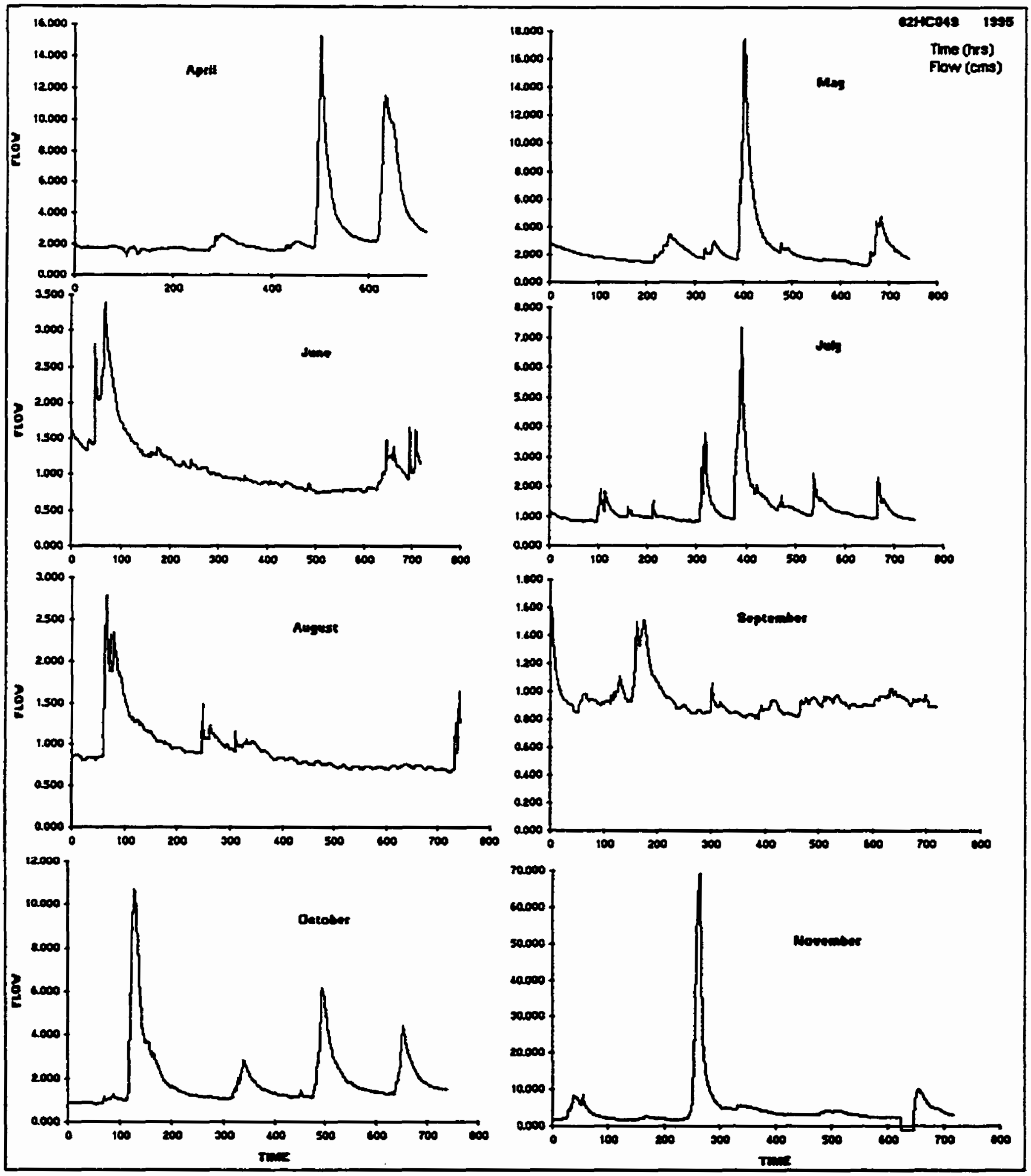


Figure 5.8 Streamflows April-November, 1995 in Duffins Creek at Ajax (02HC049)

5.2.1 Hydrology with the AGNPS and WATFLOOD Models

The objective of this application is to calibrate and validate the hydrology results of the models for the study period. Eight events where selected to test the models (Table 5.5), one for each of the available months of data. The periods for each event were selected from the precipitation values extracted from the radar data and the measured runoff flows.

Care was taken when selecting the events to avoid the effects of over estimation of rainfall due to the "bright band" condition, a radar phenomenon which causes a false over-estimate of rainfall (Garland, 1986). This was also supported when the WATFLOOD model was run for the entire period (Cranmer, 1998), optimizing the rainfall radar scale, where the results show a response from the model to spurious precipitation values that measured flows did not reflect.

With the rainfall data, the 5-day antecedent rain was calculated and the events from April, May and November are considered to have nearly saturated soil conditions (type III) according to the SCS classification for Antecedent Moisture Condition (AMC). For the rest of the events the condition was estimated to have an average moisture content (AMC II).

Two different grid sizes were created in order to run AGNPS for Duffins Creek. The first grid is a 1km cell size with 205 cells of 351 acres (1.37km^2) of area for each cell. The 1km size is the width of each cell and a perfect square in lat/long coordinates was selected in order to create the grid. This means that the actual size of a cell for a 1km grid is 1x1.37km. In the same context, the second grid is a 2km cell size (2x2.85km) with 57 cells of 1,406 acres (5.69km^2) of area for each cell.

It is worth mentioning that the AGNPS manual suggests single cell resolutions between 2.5 to 40 acres, with more detailed sizes of 10 acres (200x200m) recommended for watersheds <2,000 acres (8 km2) and 40 acres (400x400m) for watersheds >2,000 acres. Even though, AGNPS has being used successfully with cell sizes up to 250 acres (1,000x1,000m).

The sizes used in this application were selected to exceed these recommendations to test the assumption that more accurate results can be obtained by reducing the cell size. On the other hand, enlarging the cell size reduces time and labor, but the savings must be balanced against the loss of accuracy resulting from treating larger areas as homogeneous units.

The data extraction for both grids was accomplished using the DuffDEM file for the elevation, slopes and flow directions. The DuffMAP file was used to extract the soil dependent data and the Df92_215 file for the most recent available landcover data (1992). Figure 5.9 presents the 2km grid showing the extracted flow directions and highlighting the streamflow gauges where the comparison between calculated and measured flows was made.

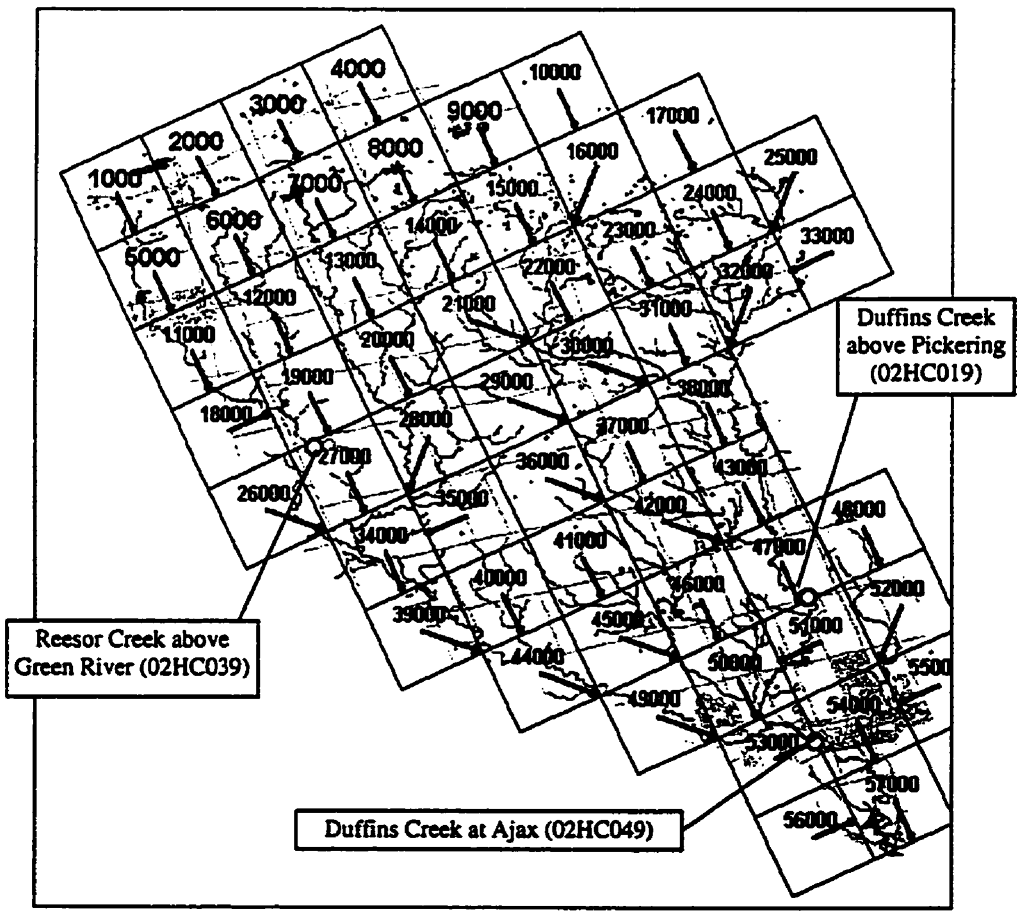


Figure 5.9 AGNPS 2km grid showing flow directions and streamflow gauge stations.

Once the 16 simulations were done, eight for each grid size (the results for these simulations are presented in Appendix E), the peak flows were recorded for the outlets of Stouffville and Duffins to be compared with the Reesor Creek and Ajax gauging stations respectively. Table 5.5 presents the results comparing the two grids and figure 5.10 shows the graph for measured and calculated peak flows for all the gauge locations.

Table 5.5 AGNPS Results (1 and 2 km grids*)

Event	Rainfall (mm)	Duration (hrs)	Peak Meas (m^3/s)	Calc 1x1km (m^3/s)	Calc 2x2km (m^3/s)	Gauge Station
25-29 Apr/95	16.5	18	11.50	10.24	10.77	Duffins Creek at Ajax
(AMC-III)			1.72	3.76	3.44	Reesor Creek above Green River
16-20 May/95	20.0	15	17.50	18.32	19.79	Duffins Creek at Ajax
(AMC-III)			4.14	6.64	6.50	Reesor Creek above Green River
1-6 Jun/95	10.7	20	3.40	2.40	2.30	Duffins Creek at Ajax
(AMC-II)			1.00	0.70	0.39	Reesor Creek above Green River
13-18 Jul/95	24.4	10	7.34	6.20	6.14	Duffins Creek at Ajax
(AMC-II)			2.70	1.77	0.98	Reesor Creek above Green River
2-6 Aug/95	18.1	20	2.79	2.42	2.37	Duffins Creek at Ajax
(AMC-II)			1.01	0.43	0.85	Reesor Creek above Green River
2-10 Sep/95	14.2	15	1.51	1.06	1.06	Duffins Creek at Ajax
(AMC-II)			0.40	0.38	0.28	Reesor Creek above Green River
4-16 Oct/95	26.9	13	10.70	8.61	8.65	Duffins Creek at Ajax
(AMC-II)			2.06	2.71	1.84	Reesor Creek above Green River
8-12 Nov/95	29.7	14	69.40	49.98	55.36	Duffins Creek at Ajax
(AMC-III)			6.29	7.03	7.84	Reesor Creek above Green River

*A 1km grid in lat/lon is 1x1.37km (1.37km^2=340acres) and a 2km grid in lat/lon is 2x2.85km (5.69km^2=1,406acres)

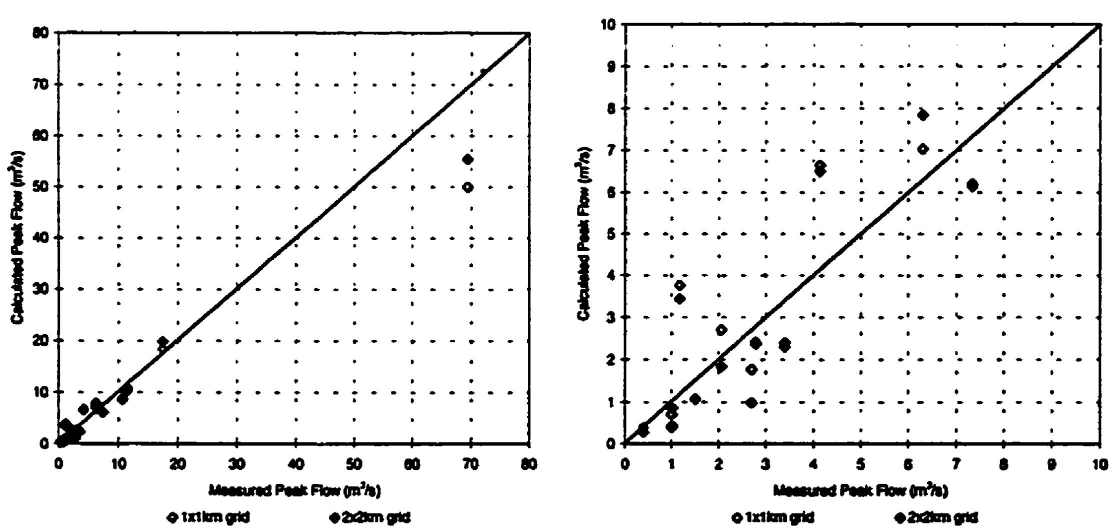


Figure 5.10 AGNPS results, measured and calculated peak flows for all gauge stations.

In a very similar approach, two grids were created for the WATFLOOD model, one with a 2x2 km cell size (in this case the option for perfect squares in UTM coordinates was selected) and a second one with a 4x4 km size. The files used for the data extraction were the same as for the AGNPS application. Figure 5.11 shows the 2x2 km grid with flow directions and the location of the streamflow gauges.

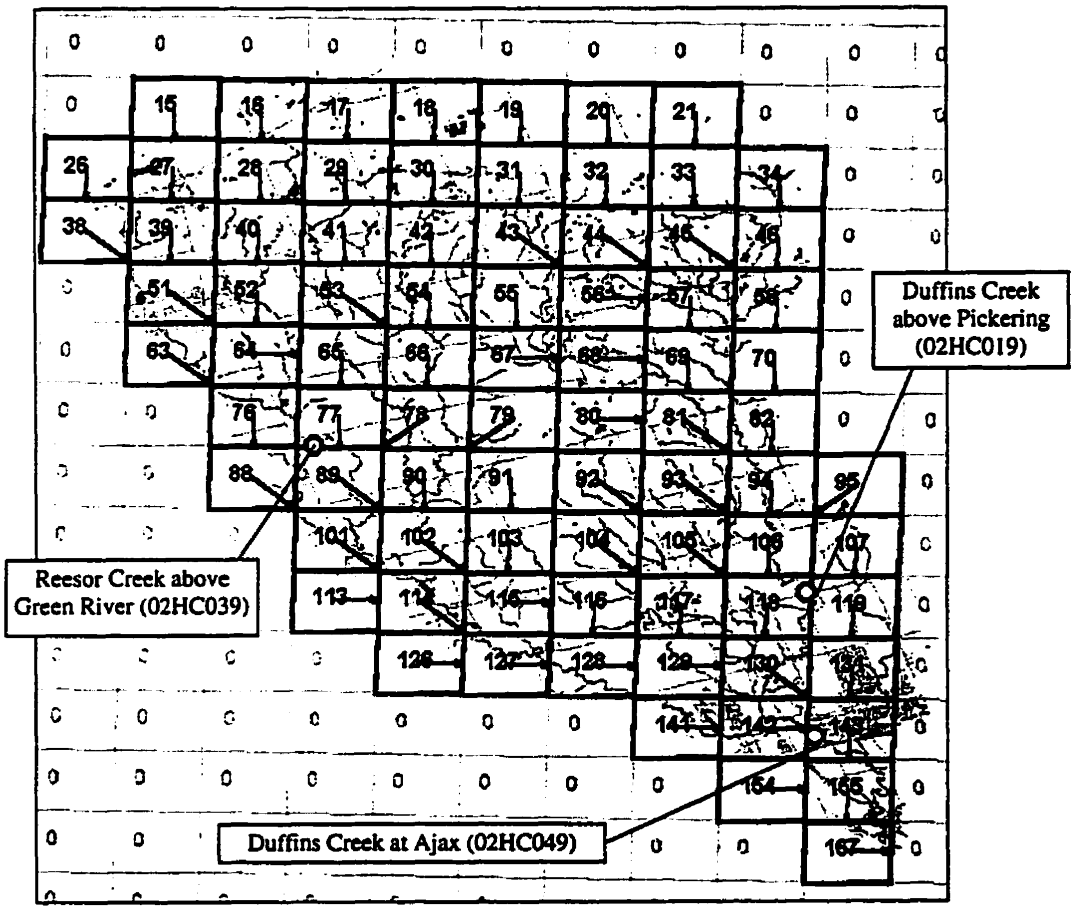


Figure 5.11 WATFLOOD 2km grid showing flow directions and streamflow gauge stations.

After the simulations, the output files where processed to get the calculated peak values at the required cells. Table 5.6 presents the WATFLOOD results and compares them with the measured flows for the two grids at the three different gauging stations. Figure 5.12 shows graphically the measured and calculated peak flows. As can be seen there is no important difference between the values calculated with the 2x2 or the 4x4 grids.

Table 5.6 WATFLOOD Results (2x2 and 4x4 km grids)

Event	Rainfall (mm)	Duration (hrs)	Radar Scale	Peak Meas (m^3/s)	Calc 2x2km (m^3/s)	Calc 4x4km (m^3/s)	Gauge Station
25-29	16.5	18	0.5	11.50	17.15	16.16	At Ajax
Apr/95				4.93	8.01	6.51	Above Pickering
				1.72	1.50	2.33	Reesor Creek
16-20	20.0	15	0.6	17.50	21.80	17.64	At Ajax
May/95				10.20	9.44	6.29	Above Pickering
				4.14	4.16	4.50	Reesor Creek
1-6	10.7	20	0.8	3.40	3.17	2.22	At Ajax
Jun/95				1.38	1.44	0.83	Above Pickering
				1.00	0.51	0.61	Reesor Creek
13-18	24.4	10	0.5	7.34	10.42	7.16	At Ajax
Jul/95				3.99	4.92	3.42	Above Pickering
				2.70	2.02	2.53	Reesor Creek
2-6	18.1	20	0.5	2.79	4.85	3.9	At Ajax
Aug/95				1.76	2.09	1.95	Above Pickering
				1.01	0.78	1.13	Reesor Creek
2-10	14.2	15	0.5	1.51	2.68	1.85	At Ajax
Sep/95				0.78	0.98	0.58	Above Pickering
				0.40	0.72	0.25	Reesor Creek
4-16	26.9	13	0.7	10.70	13.78	13.10	At Ajax
Oct/95				8.04	6.03	5.68	Above Pickering
				2.06	1.79	2.79	Reesor Creek
8-12	29.7	14	1.0	69.40	73.39	55.02	At Ajax
Nov/95				31.20	29.16	22.01	Above Pickering
				6.29	13.30	13.89	Reesor Creek*

*The measured flow is probably indicating the effect of the Stouffville reservoir upstream of the water treatment plant.

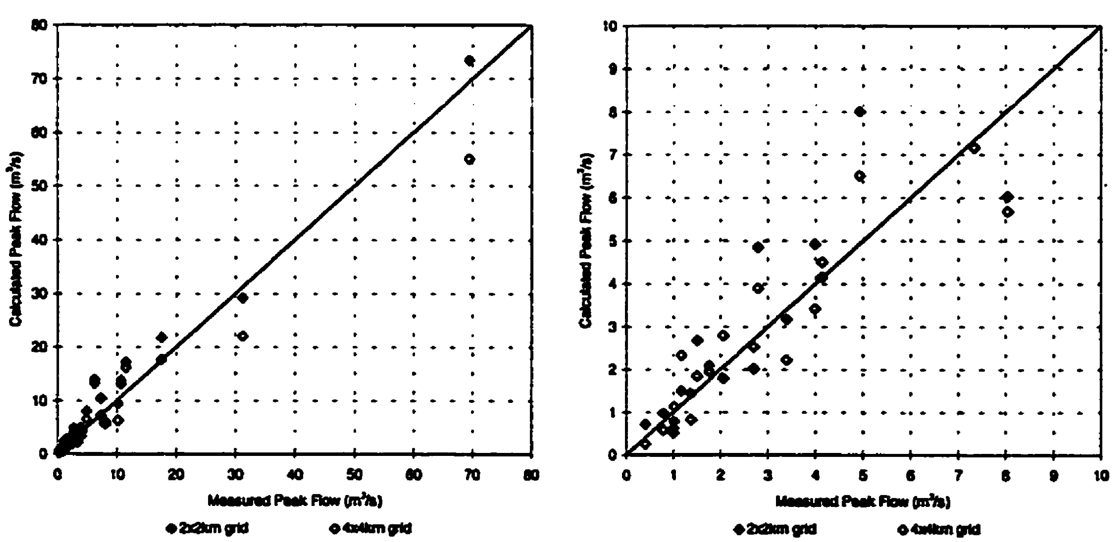


Figure 5.12 WATFLOOD results, measured and calculated peak flows for all gauge stations.

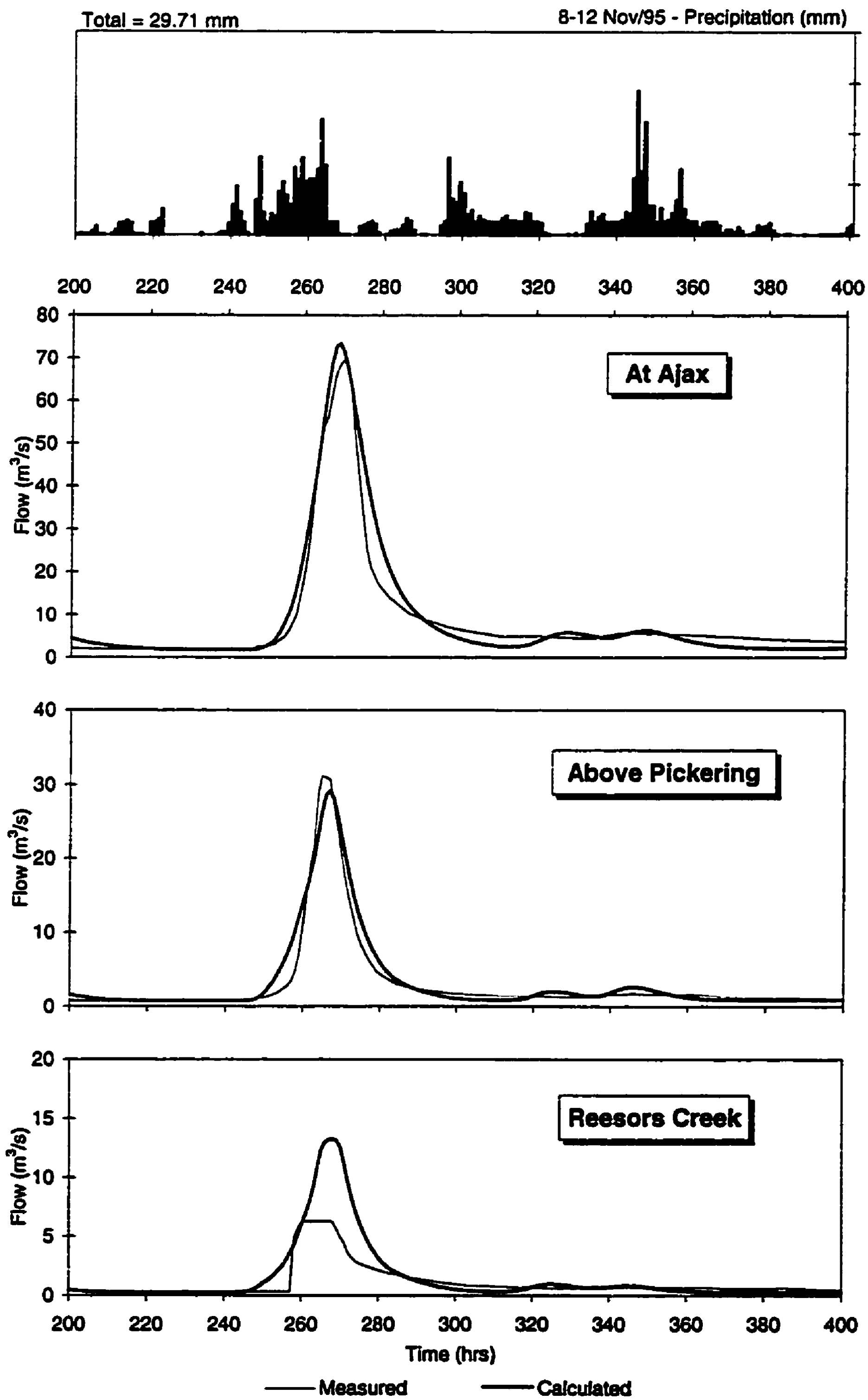


Figure 5.13 WATFLOOD results for November 8-12, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 1.0)

While the results from the WATFLOOD simulations compare hydrographs for the complete event, peak flows were extracted from the output. Figure 5.13 shows one of these comparisons between measured and calculated flows for the event of November 8-12, 1995 (for all the hydrographs see Appendix E). Table 5.7 presents a summary of the results and compares the AGNPS and WATFLOOD peak flows using the 2x2 km grid from both models. Figure 5.14 shows graphically the comparison for the two models together with the measured peak flows.

Table 5.7 Hydrology Comparison Between AGNPS and WATFLOOD Results

Event	Rainfall (mm)	Duration (hrs)	Peak Meas (m^3/s)	WatFl 2x2km (m^3/s)	AGNPS 2x2km (m^3/s)	Gauge Station
25-29 Apr/95	16.5	18	11.50	17.15	10.77	Duffins Creek at Ajax
			1.72	1.50	3.44	Reesor Creek above Green River
16-20 May/95	20.0	15	17.50	21.80	19.79	Duffins Creek at Ajax
			4.14	4.16	6.50	Reesor Creek above Green River
1-6 Jun/95	10.7	20	3.40	3.17	2.30	Duffins Creek at Ajax
			1.00	0.51	0.39	Reesor Creek above Green River
13-18 Jul/95	24.4	10	7.34	10.42	6.14	Duffins Creek at Ajax
			2.70	2.02	0.98	Reesor Creek above Green River
2-6 Aug/95	18.1	20	2.79	4.85	2.37	Duffins Creek at Ajax
			1.01	0.78	0.85	Reesor Creek above Green River
2-10 Sep/95	14.2	15	1.51	2.68	1.06	Duffins Creek at Ajax
			0.40	0.72	0.28	Reesor Creek above Green River
4-16 Oct/95	26.9	13	10.70	13.78	8.65	Duffins Creek at Ajax
			2.06	1.79	1.84	Reesor Creek above Green River
8-12 Nov/95	29.7	14	69.40	73.39	55.36	Duffins Creek at Ajax
			6.29	13.30	7.84	Reesor Creek above Green River

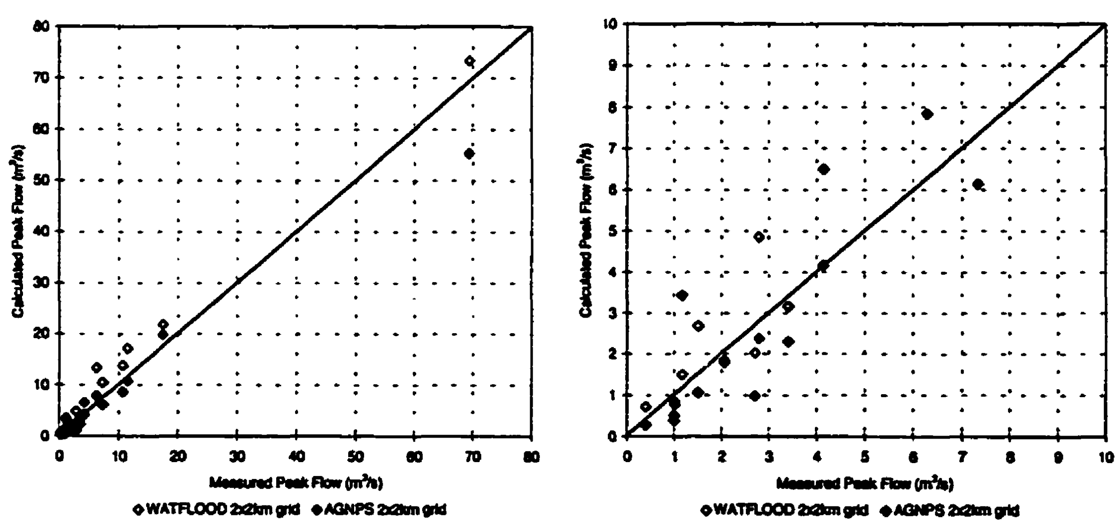


Figure 5.14 WATFLOOD and AGNPS results, peak flows for all gauge stations.

5.2.2 Sediment and Nutrient Transport

The objective of this section is to test how the sediment and nutrient transport components coupled to the WATFLOOD model perform. The results will be compared with the output from the AGNPS model. Using the same events as in the hydrology section, several runs were conducted using both models to test the results from the sediment and nutrient transport. The sediment tests were performed on all grids while the 2x2 km grids were selected to test the fertilizer component. The fertilizer amounts were assigned as a function of the percentage of agricultural land. This was done in order to achieve similar levels of nutrients applied to the surface for the two grids. The spatial distribution of agricultural land where the fertilizer is applied for the AGNPS and WATFLOOD grids are shown in Figures 5.15 and 5.16.

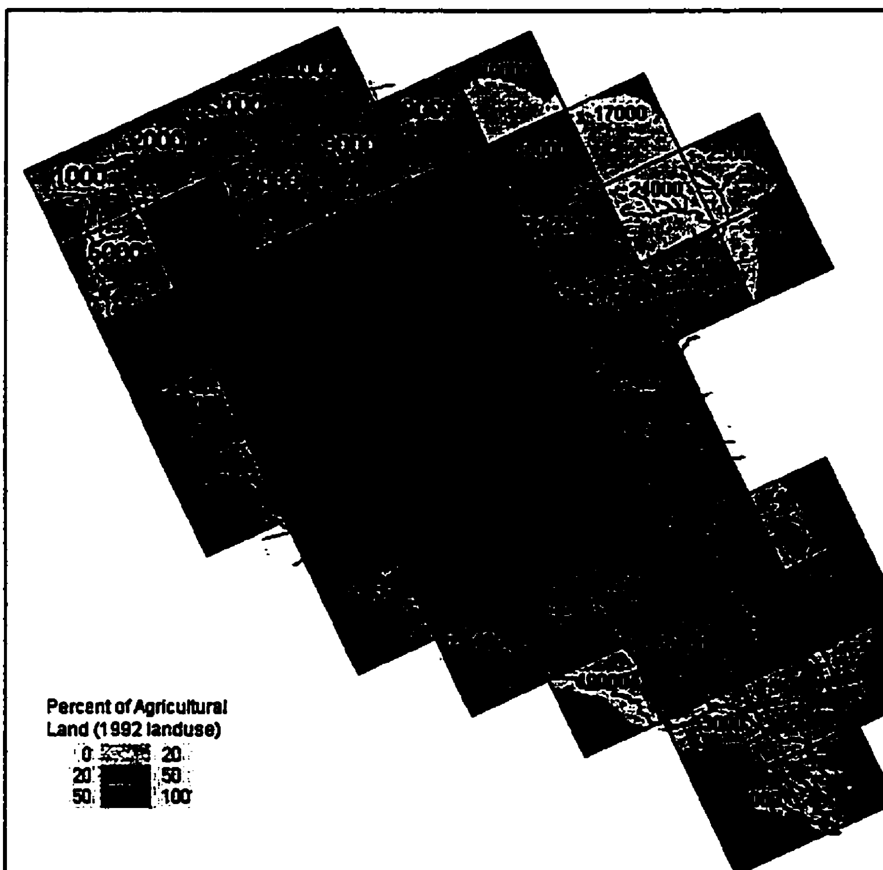


Figure 5.15 Agricultural land distribution in the AGNPS 2x2km grid.

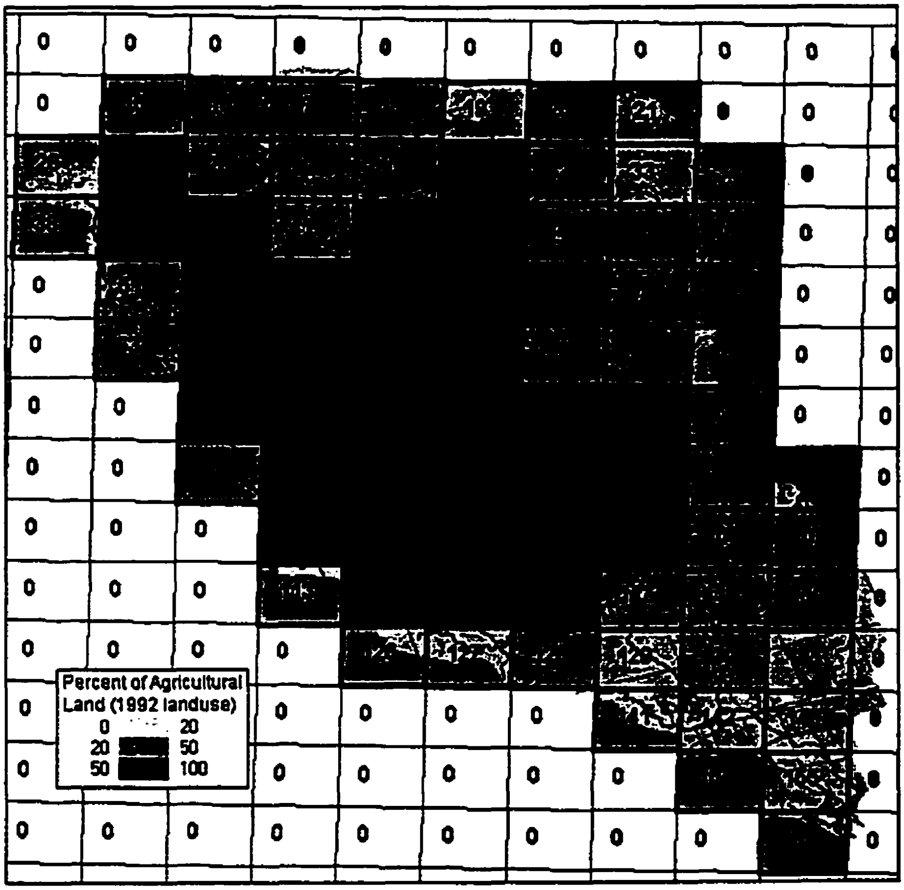


Figure 5.16 Agricultural land distribution in the WATFLOOD 2x2km grid.

With this distribution, the criteria to indicate the level of fertilization on the field were selected as follows: Cells with 0 to 20% of agricultural land have a low fertilization level, 50 lb/acre of nitrogen and 20 lb/acre of phosphorus. Cells representing between 20 and 50% of agricultural land, 100 lb/acre of N and 40 lb/acre of P were applied. Finally for cells with percentages of agricultural land above 50%, a high level of fertilization was assigned, 200 lb/acre of N and 80 lb/acre of P. For all cells with fertilizer application, the availability factors for both nitrogen and phosphorus was 50%. This factor is the percentage of fertilizer left in the top half inch of the soil at the time of the storm. It is a function of the tillage practices and the worst case, having a factor of 100%, would be when none of the fertilizer had been incorporated into the soil and all is available for dilution in the runoff.

Duplicates of the grids were created and modified to include the fertilizer inputs. The rest of the parameters were kept unchanged so flow calculations remain the same and comparisons would reflect only the effect of fertilizer application. To compare with the AGNPS total loads for the event, the WATFLOOD results (Figures 5.17 and 5.18) were post-processed to calculate the loads for sediment, nitrogen and phosphorus. This was done by calculating the area under the curve for the total mass graphs. Table 5.8 compares results at the basin outlet.

Table 5.8 Water Quality Results. Models Comparison at Duffins Creek Outlet

Event/Model Result	Peak Flow (m3/s)	Sediment yield (ton)	Nitrogen load (Kg)	Phosphorus load (Kg)
Event: 25-29 Apr/95	Meas=11.50			
AGNPS (1x1)	10.24	143.13	na	na
(2x2)	10.77	137.93	140.04	16.48
WATFLOOD (2x2)	17.15	171.92	133.62	13.93
(4x4)	16.16	165.64	na	na
Event: 16-20 May/95	Meas=17.50			
AGNPS (1x1)	18.32	232.43	na	na
(2x2)	19.79	230.98	215.01	29.66
WATFLOOD (2x2)	21.80	225.47	214.09	29.77
(4x4)	17.64	182.14	na	na
Event: 1-6 Jun/95	Meas=3.40			
AGNPS (1x1)	2.40	43.34	na	na
(2x2)	2.30	37.88	37.89	2.47
WATFLOOD (2x2)	3.17	46.64	22.80	1.20
(4x4)	2.22	34.66	na	na
Event: 13-18 Jul/95	Meas=7.34			
AGNPS (1x1)	6.20	141.14	na	na
(2x2)	6.14	130.19	71.67	4.94
WATFLOOD (2x2)	10.42	154.53	85.66	4.27
(4x4)	7.16	123.21	na	na
Event: 2-6 Aug/95	Meas=2.79			
AGNPS (1x1)	2.42	44.28	na	na
(2x2)	2.37	37.13	28.01	1.65
WATFLOOD (2x2)	4.85	61.08	33.14	1.69
(4x4)	3.90	49.88	na	na
Event: 2-10 Sep/95	Meas=1.51			
AGNPS (1x1)	1.06	22.99	na	na
(2x2)	1.06	20.58	31.30	0.82
WATFLOOD (2x2)	2.68	25.88	25.68	1.28
(4x4)	1.85	20.61	na	na
Event: 4-16 Oct/95	Meas=10.70			
AGNPS (1x1)	8.61	193.52	na	na
(2x2)	8.65	186.91	88.97	6.59
WATFLOOD (2x2)	13.78	260.85	83.28	8.38
(4x4)	13.10	242.35	na	na
Event: 8-12 Nov/95	Meas=69.40			
AGNPS (1x1)	49.98	536.07	na	na
(2x2)	55.36	549.23	415.18	59.31
WATFLOOD (2x2)	73.39	676.26	547.58	49.47
(4x4)	55.02	538.56	na	na

Note: For the AGNPS 1x1 km and the WATFLOOD 4x4 km grids no fertilizer runs were made (na on table)

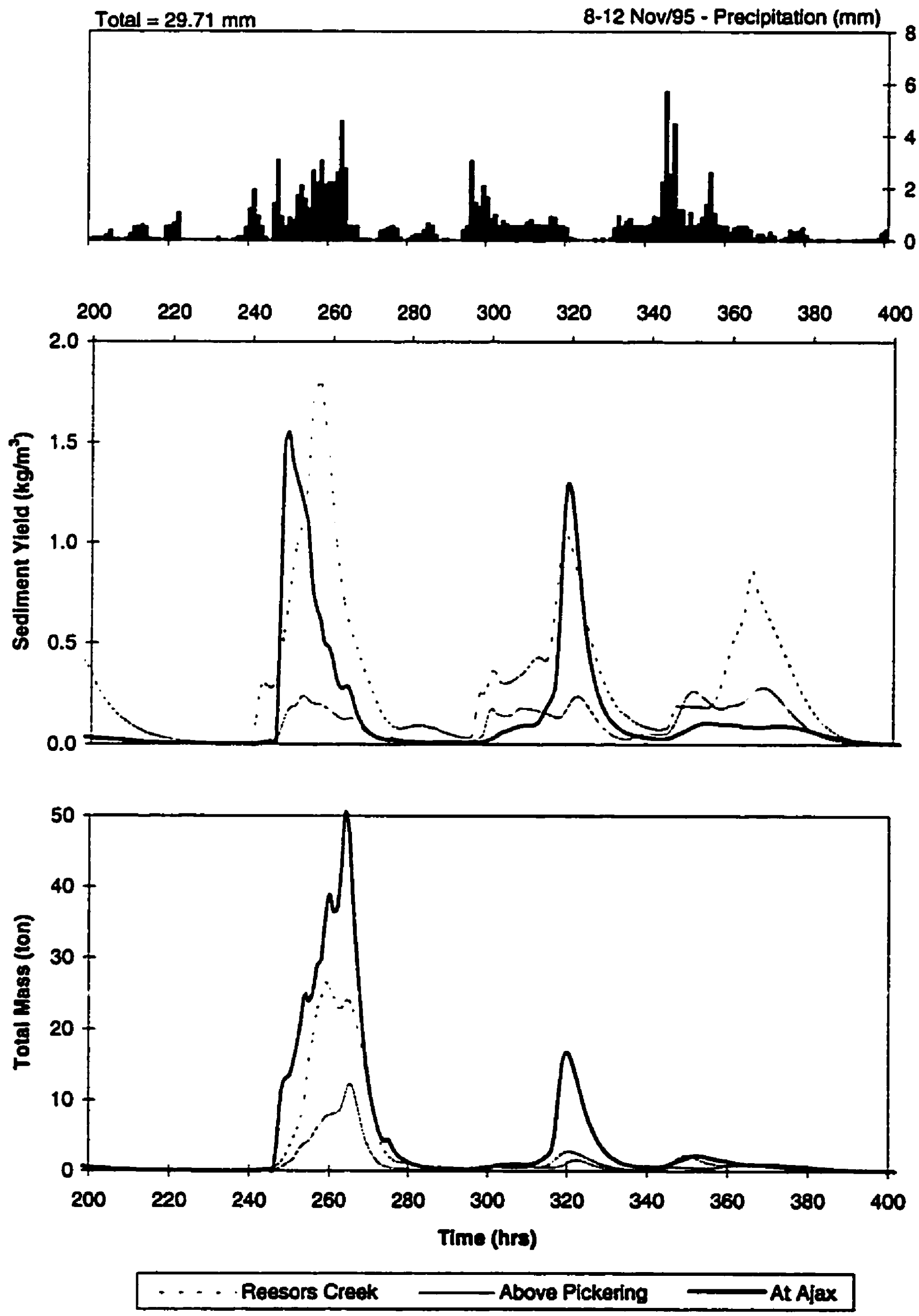


Figure 5.17 WATFLOOD/Sediment results for November 8-12, 1995 (2x2 km Grid - Sediment Yield and Total Mass - Deposition Factor 20%)

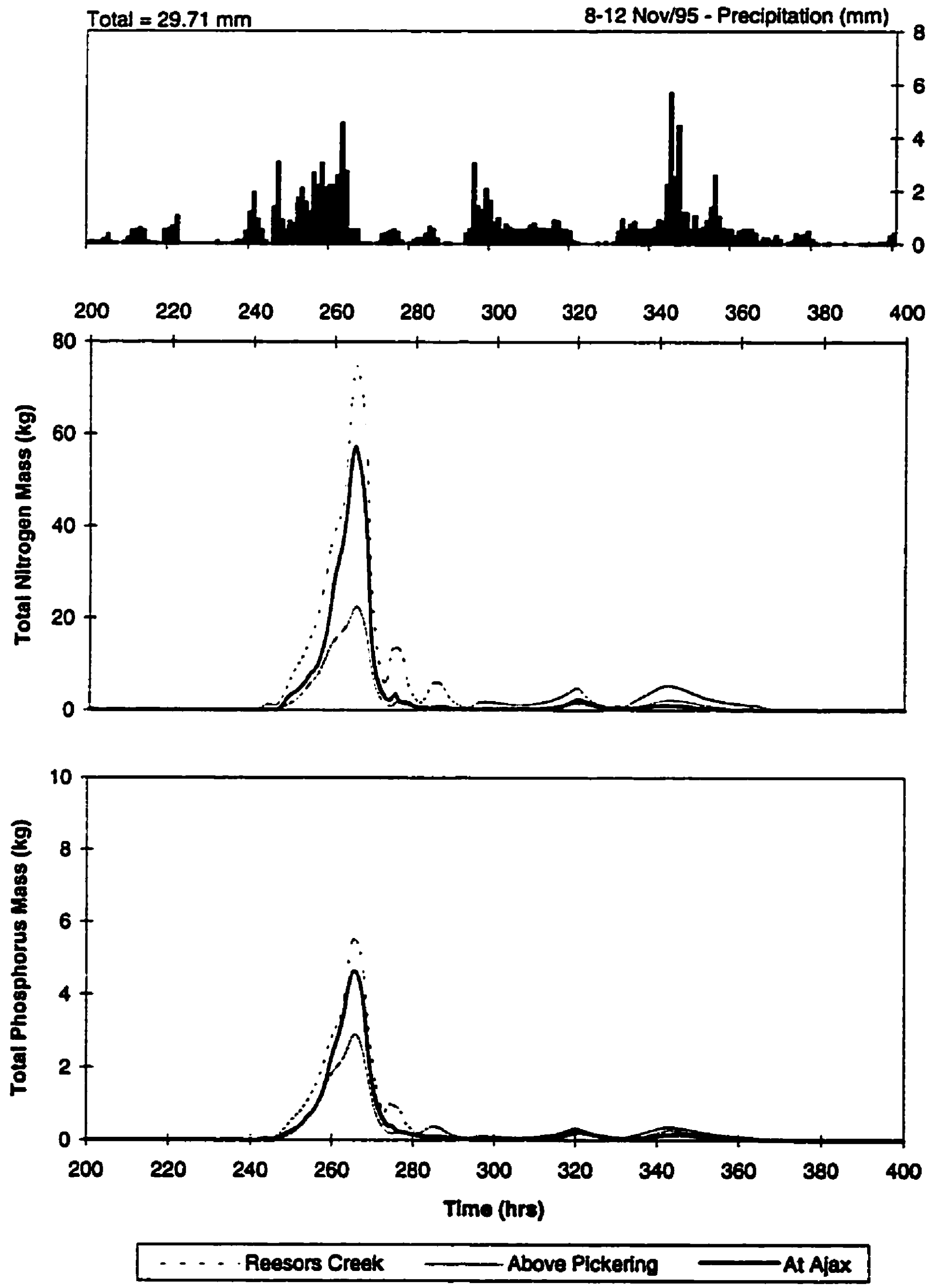


Figure 5.18 WATFLOOD/Nutrient results for November 8-12, 1995 (2x2 km Grid - Nitrogen and Phosphorus Total Mass - Decay 60-40%)

As with the hydrology results, the water quality component provides time series output for sediment and nutrients. Figures 5.17 and 5.18 are examples of results, showing the sediment yield and nitrogen load respectively for the November 1995 event. All of the sediment and nutrient figures for the simulations can be found in Appendix E. Figure 5.19 compares the sediment yields and nutrient loads results from both models for all the tested events.

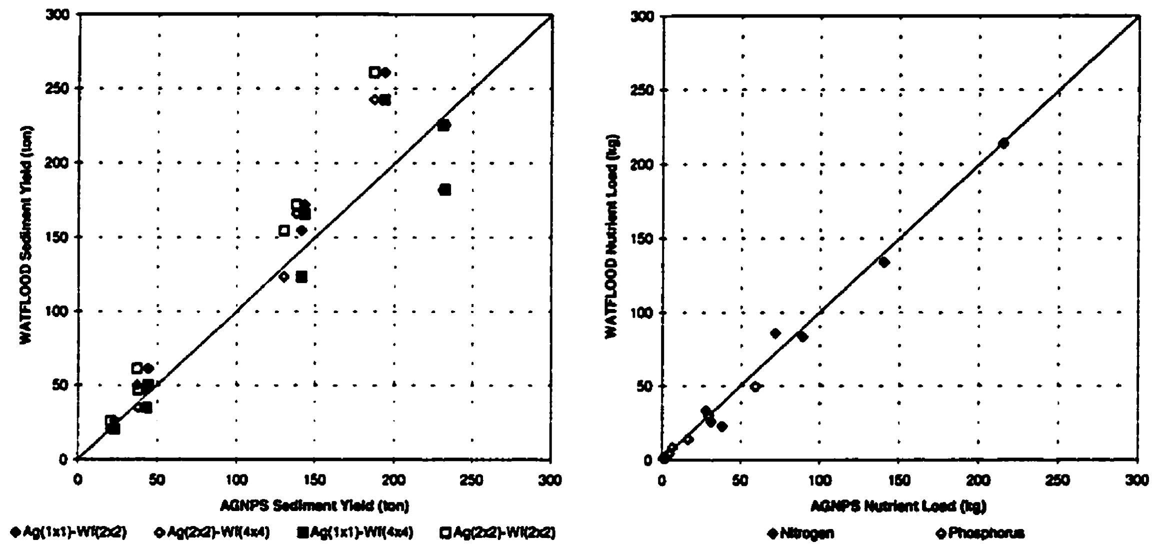


Figure 5.19 WATFLOOD and AGNPS results comparison for sediment yields and nutrients

The following section shows the work done to test the validity of the models against measured data. A sampling campaign was undertaken during 1996-1998 by the MOE together with the NWRI and, though oriented to the calibration-validation process for the AGNPS model, some hourly events were sampled to compare the time series capabilities of the water quality component coupled to the WATFLOOD model. The events sampled during June, 1997 and March, 1998 were selected to perform the validation tests. Radar files were extracted from the University of Waterloo archives for the two months. Again the first tests were performed on the hydrology section and as expected the results correlate quite well with the measured values at the outlet of Reesor Creek, where the hourly event sampling was conducted. Figure 5.20 shows the comparison for the calculated and measured flows together with the hourly rainfall values extracted from radar data.

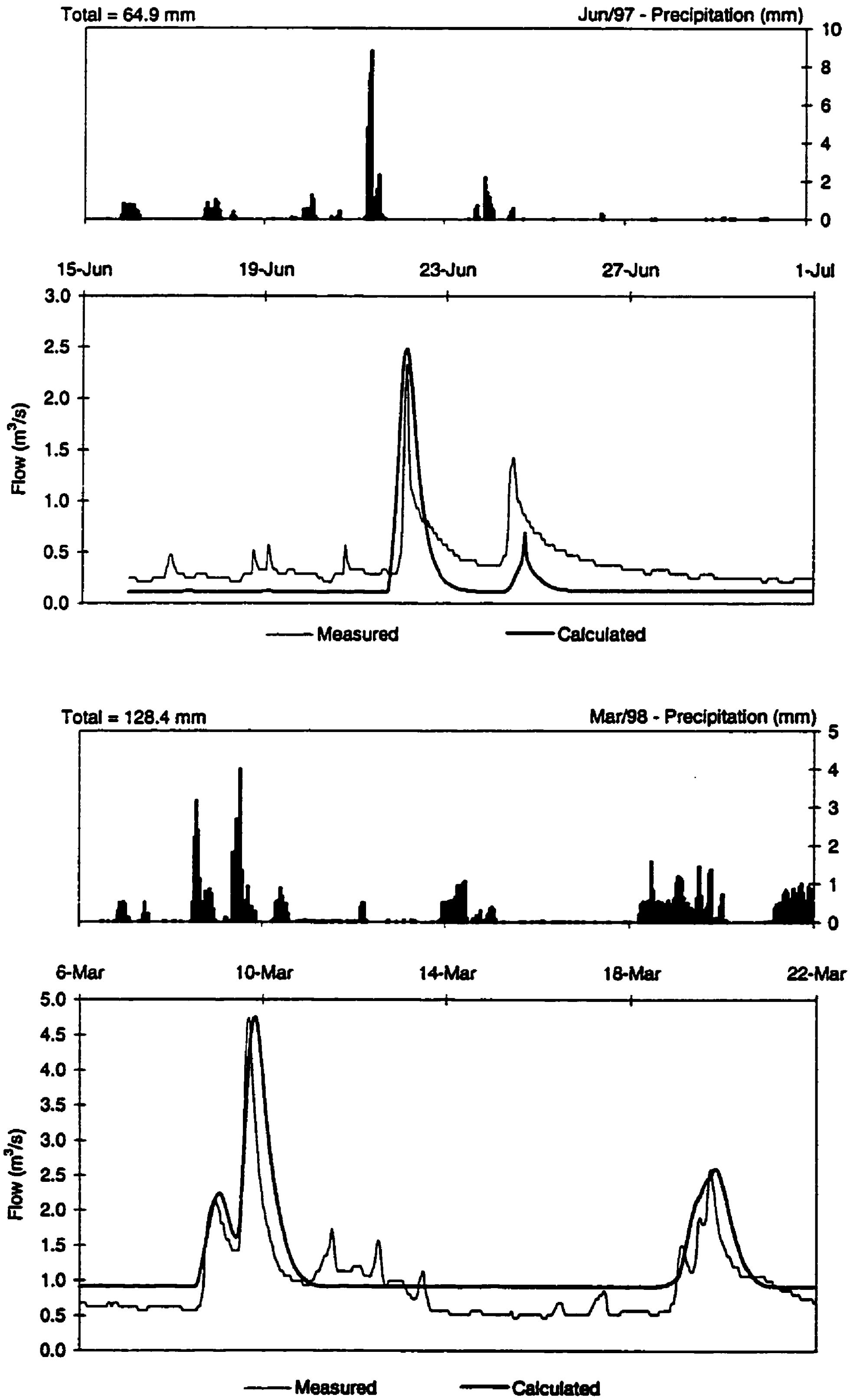


Figure 5.20 WATFLOOD flow results for the sampled events (Jun/97 and Mar/98)

For the sediment and nutrient validation, the output was post-processed to extract the results for the specific dates of the events (June 22, 1997 and March 8-10, 1998). Figures 5.21 and 5.22 present the sediment (total suspended solids) and nutrient (total nitrogen concentration) comparisons between calculated and measured values for the two events.

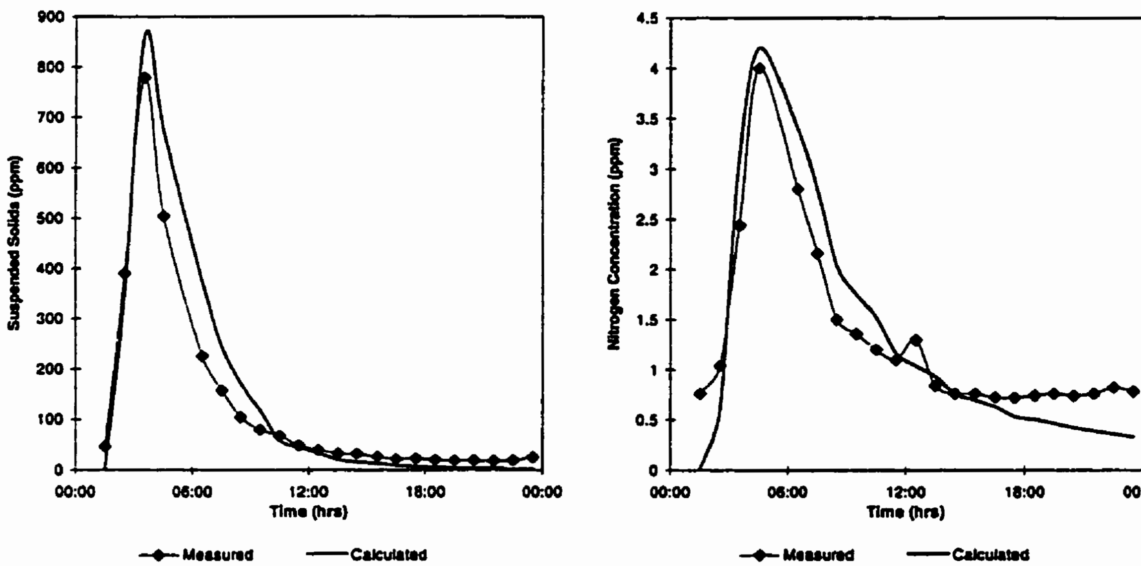


Figure 5.21 WATFLOOD sediment and nutrient comparison for the June 22, 1997 event

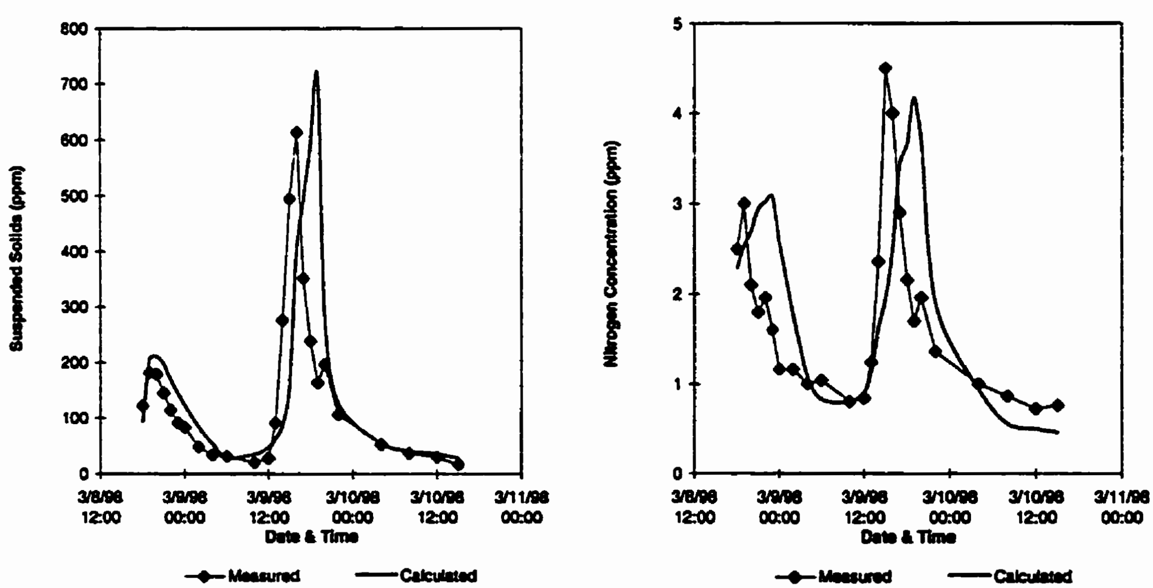


Figure 5.22 WATFLOOD sediment and nutrient comparison for the March 8-10, 1998 event

Finally, to compare the results between models for the hourly sampled events, the required input data for the AGNPS model was prepared from the radar files and the two runs made for the events. For the June 1997 event the precipitation was 26.6mm in 8hr with AMC-II and for March 1998 the rainfall was 22.5mm in 15hr and AMC-III. The total sediment yield and nutrient loads were recorded at the Reesors Creek outlet for the AGNPS model. For WATFLOOD the time series at the outlet were used to calculate the yield and loads. Table 5.9 shows the comparison between model results and measured values for peak flow, sediment yields and nutrient loads at the Reesors Creek outlet.

Table 5.9 Comparison of Model Results for the Hourly Sampled Events

	Jun 1997			Mar 1998		
Parameter/Event	**Meas**	**AGNPS**	**WATF**	**Meas**	**AGNPS**	**WATF**
Peak Flow (m3/s)	2.06	1.84	2.48	4.72	4.45	4.75
Sediment Yield (ton)	18.52	24.06	21.21	33.70	37.76	38.70
Nitrogen Load (Kg)	147.15	157.81	156.75	448.77	491.28	514.68
Phosphorus Load (Kg)	3.59	3.89	3.15	84.11	93.27	86.33

5.2.3 Discussion of Results

As can be seen from the simulations, the model predictions match the measured values for peak flow very well using both models. The different grid sizes for the AGNPS model did not have a major impact on the results. In the case of WATFLOOD the computed hydrographs for the selected events matched the observed hydrographs extremely well. It is worth noticing that a larger grid size (4x4 km) tends to be more accurate in the prediction of peak flows. This is consistent with the concept behind the model and its ability to simulate larger areas. Normally WATFLOOD uses a 10x10 km grid size for larger basins providing that the cell drainage areas are described appropriately. Larger elements can be used but the resolution for the resulting hydrographs may be compromised. On the other side, smaller elements are possible as long as they contain at least a first order current within the cell. Another practical limitation is the data resolution itself. A recommended minimum should be at least four times the size of a single DEM element, so that the flow direction and slope data extraction will be accurate.

Most of the WATFLOOD calculated hydrographs compare well with the measured values. In some cases the effect of the "bright band" condition, overestimated rainfall values from radar data, is evident as the model predicts runoff not present on the measured records. It is worth mentioning that, for low intensity rainfall, the computed results tend to present a lag off for the peak flows on the hydrographs and larger values than the ones recorded at the gauging stations. This is probably caused by the interflow-infiltration component in the model causing it to overestimate the surface runoff.

For both AGNPS and WATFLOOD comparisons, the trend or regression between measured and calculated peak flows has a correlation value R^2 quite high, in the range of 0.91-0.98. It is important to mention, as stated before, that no specific calibration was performed on the simulations. WATFLOOD was originally calibrated on the Grand River watershed and has been used successfully in neighboring basins with similar physiography by transferring the calibrated parameters based on particular land covers (Kouwen *et al.*, 1993).

The parameter files for the Duffins Creek were created using the Grand River watershed files without further calibration. The input data for the model was produced from the extraction process developed in this research project. The results from the simulations suggest that the approach was adequate and provides further evidence of the benefit of the GRU method.

On the other hand, AGNPS is a robust and well tested model. It has being used in different circumstances to calculate sediment and nutrient loadings due to nonpoint source pollution in watersheds (Koelliker and Humbert, 1989, Binger *et al.*, 1989, Young *et al.*, 1989, Finney *et al.*, 1995, Mostaghimi *et al.*, 1997). In almost all the cases it was found that the predicted sediment and nutrient yields agreed reasonably well with the measured data. It is important to remember that AGNPS was conceived on the basis of the CREAMS model, which was developed with the intention of minimizing the calibration efforts. For the AGNPS application the coefficients used in the model were the recommended default values. Adjusting of such values is possible if the results were poor, but in this case to do so was not necessary.

Furthermore, Mostaghimi *et al.*, (1997) found that, based on several simulations, the AGNPS was a suitable model for their watershed conditions. At the same time, they also noted that the input data preparation for the model was very time consuming and pointed out the difficulties for determining the accuracy of the input values. The interface created in the present research, drastically reduces such time consuming task and provides good input data based on the digital information of the watershed. Results of this research support the fact that, as long as the input parameters are well established, the model performs accurately. If point sources are present, the model has the capability to include them as direct inputs into the river system; or the grid sizes can be reduced by subdivision, for example, to simulate buffer areas near a stream.

With respect to the hourly sampled event tests, the results are encouraging. The good match between observed and calculated values for both sediment and nutrient yields give further proof that the approach followed in this research can eventually improve the modelling of non-point source pollution. Again no major calibration was performed except for the fine tuning of the decay factors for nutrients and the deposition coefficient for sediments. The values used in the two models were exactly the same to allow comparison of results without any bias. The sediment deposition was in the 25-35% range for the two events and the decay factors were maintained around a 50% value. This is consistent with the findings of Rode and Frede (1997) in their calibration efforts of the AGNPS model.

5.3 AGNPS Applications in Other Watersheds

The part of this research dealing with the integration of the AGNPS model in a decision support system was conducted in a cooperative research program under the umbrella of the 1994 Canada-Ontario Agreement (COA). The overall objective of these research projects is to provide Ontario planning centres with better procedures, models and tools to aid in the design and implementation of watershed management programs (Bowen *et al.*, 1995). The planning centres involved in the project include the South Nation Conservation Authority, Lake Simcoe Conservation Authority and the Metro-Toronto and Region Conservation Authority.

As part of COA, the National Water Research Institute (NWRI) of Environment Canada and the Science and Technology Branch of the Ministry of the Environment and Energy (MOEE) have been working in collaboration with conservation authorities and other groups to research, develop and transfer new technologies and planning tools to assist the planning centres in achieving their program objectives. Because nonpoint source pollution is a major component that must be considered when carrying out watershed environmental studies, this AGNPS Interface project and its link with RAISON were central parts of this project

5.3.1 Technology Transfer

The goal for the regional conservation authorities was to assess the use of the AGNPS model as a tool to evaluate the effectiveness of management strategies for water quality, sediments and nutrients, in southern Ontario watersheds. In a two phase technology transfer program, in October, 1997 and January, 1998, staff from the MOEE and Conservation Authorities attended training sessions on RAISON and the AGNPS Interface. Participants included personnel from the Grand River Conservation Authority, the Credit Valley Conservation Authority, the South Nation Conservation Authority, the Lake Simcoe Region Conservation Authority, the Metro-Toronto Region Conservation Authority and the Ministry of the Environment and Energy.

The author was the principal instructor at these sessions and his research procedures and model interfaces were the main topics. Deliverables included: i) installation of the executable files of the AGNPS Interface, ii) a seminar on AGNPS dealing with model description, input requirements, capabilities, etc., iii) a tutorial on how to create a project in RAISON, iv) training on the use of the AGNPS interface, and v) a description of the utilities needed to incorporate digital data into RAISON. What follows is a discussion and presentation of a particular application of this research in the Lake Simcoe Region after the two training sessions were conducted. This is done with the intention of showing how the interface work developed in this research is starting to be used by planning centres in their own environmental studies.

5.3.2 Lake Simcoe Application

After the technology transfer sessions, personnel from the Lake Simcoe Region Conservation Authority (LSRCA) applied the RAISON-AGNPS Interface in two watersheds draining to Lake Simcoe, Maskingonge and Uxbridge. The following information presents partial results with respect to the use of the interface on the applications (Peat, 1998). Note that the setup of the scenarios and conclusions from this study are the sole responsibility of the LSRCA.

The study on the Maskinonge watershed had the objective to outline a remedial strategy to reduce water quality degradation in the Maskinonge river and its 60 km^2 watershed. The main cause of pollution in the river system since the mid 1980's is nutrient availability, which has produced excessive growth of algae and aquatic plants, most noticeably duckweed. Nitrogen in the form of nitrates has been linked to this excessive growth Phosphorus has been recognized as the key nutrient driving pollution problems with Lake Simcoe. In order to evaluate different alternatives for remediation, several Best Management Practices (BMPs) were tested by means of modelling different scenarios with the AGNPS model.

Preliminary work provided by the author for the LSRCA included the extraction and conditioning of the DEM data as well as the setup of the soil and landuse maps. The DEM data was obtained, as previously, from the United States Geological Survey (USGS) internet site (*http://edcwww.cr.usgs.gov/landaac/gtopo30/gtopo30.html*). The topographic map files at every 30 second interval where resampled at 10 second interval to increase the DEM detail for the study area. The conditioning process was performed and files were imported into RAISON database files. Figure 5.23 shows the DEM data for the two selected watersheds. Use of the integrated system AGNPS-Interface-RAISON developed in this research project was the critical step in this part of the study. Original OMAFRA landuse data were updated using a vegetation coverage from the Ministry of Natural Resources. Together with digital soil survey maps, the database layers for the model data extraction were created. The discretization of the watershed was achieved by dividing it into 87 uniform square cells. Figure 5.24 shows the soil and landcover layers on the Maskinonge watershed and the 750x750 m model grid.

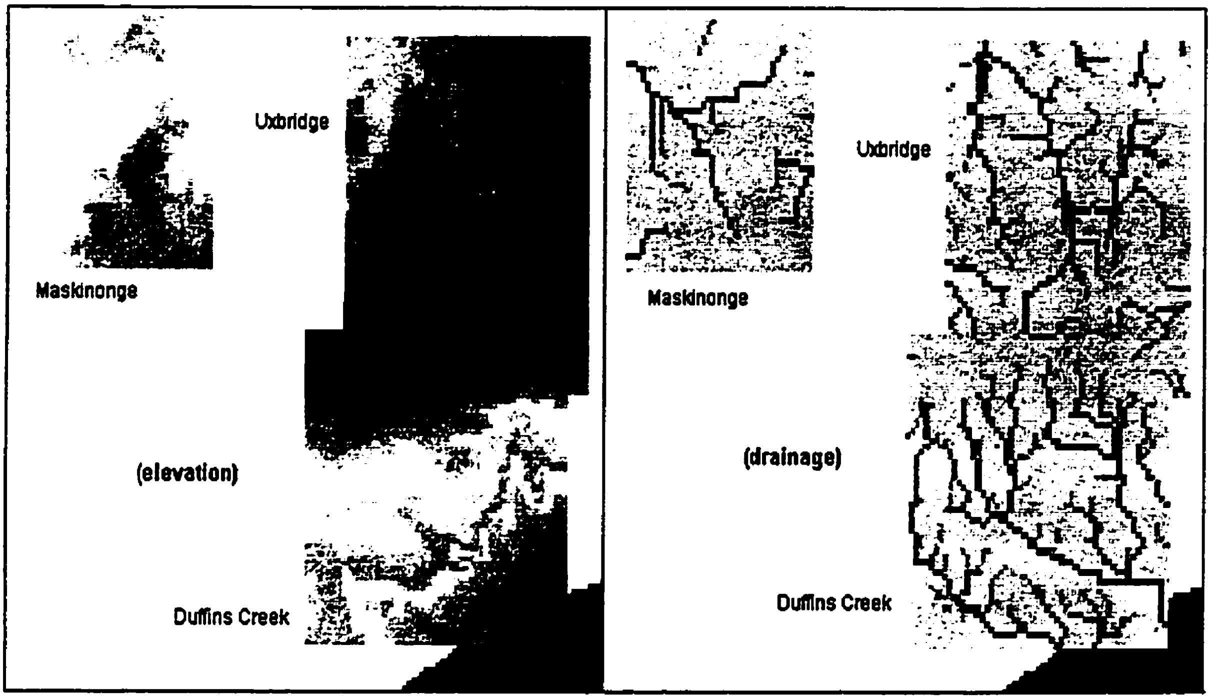


Figure 5.23 DEM files for Southern Ontario showing Lake Simcoe extracted watersheds.

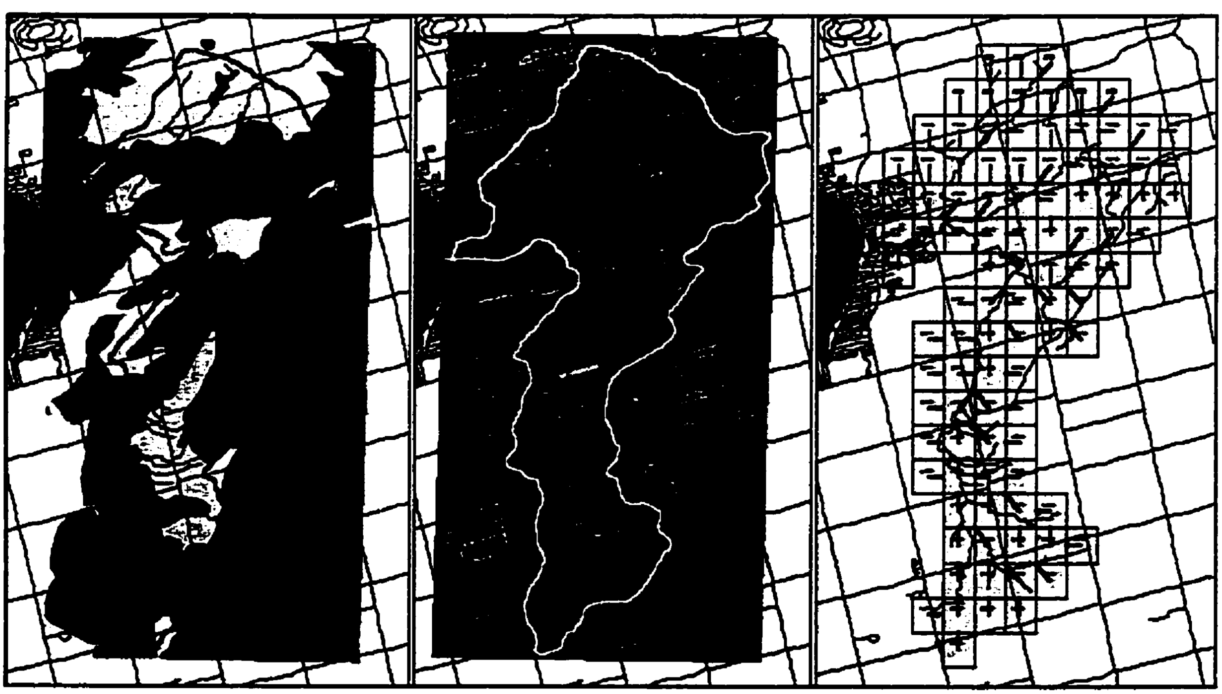


Figure 5.24 Maps on the Maskinonge watershed (soils, landuse) and model grid

A number of future growth scenarios within the Maskinonge river watershed were evaluated using the AGNPS model. The modelling efforts focused only on the nitrogen and phosphorus loading. The idea of using the AGNPS model was to simulate what changes in water quality might occur for different BMPs and potential landuse scenarios. The testing scenarios were:

A) Existing conditions. Describes the present-day conditions of the Maskinonge River watershed. These include present land use as well as current farming practices

B) Existing conditions implementing rural BMPs. Looks at the implementation of various remedial BMPs. These include an increase of forest cover to approximately 25% in all catchments, a 25% decrease in fertilizer application rate, an increase in conservation tillage and the elimination of cattle access to streams.

C) Future growth (Official Plan Designation). Looks at future urban growth, with no implementation of rural BMPs. This will predict how the watershed will react to an increase in urban area with a status quo with respect to remedial measures and landuse practices.

D) Existing conditions and increase in forest cover of 25%. Looks at existing conditions with an increase in forest cover to 25% in all catchments.

E) Existing conditions and reduction of fertilizer application by 25%. Looks at existing conditions with a 25% reduction in fertilizer application on agricultural land.

All the simulations were done for a single two inch rain storm and the results are reported at the outlet of the watershed. Table 5.10 shows a summary of the modelling results, including the nutrient loading for the various scenarios and compares the present day conditions of the first scenario (A) to the different possible alternatives investigated. It is worth mentioning that no field data were used to validate these results and the following discussion will be based only on their relative differences to assess the impact of the proposed scenario.

Table 5.10 Summary of Model Results Based on Different Scenarios.

Model Result	Scenario "A"	Scenario "B"	Scenario "C"	Scenario "D"	Scenario "E"
Runoff (in)	0.37	0.29	0.42	0.29	0.37
Sediment yield (ton)	308.66	185.33	306.58	255.55	308.66
Phosphorus load* (Kg)	74.25	38.80	84.29	53.35	55.69
Phosphorus Conc (ppm)	0.12	0.08	0.12	0.11	0.09
Nitrogen load* (Kg)	433.15	242.50	470.61	310.39	352.70
Nitrogen Conc (ppm)	0.7	0.5	0.76	0.64	0.57

Scenario "B" involves the implementation of a full range of BMPs to address rural mostly non-point sources such as runoff from livestock and cropland erosion. The total phosphorus load under this scenario was estimated to be 38.80 kg, while the total nitrogen loading was 242.5 kg. This means that the implementation of BMPs could potentially reduce phosphorus loading by almost 48% and nitrogen loading by 44% as compared to the existing conditions of scenario A.

Scenario "C" represents the worst case scenario based on future urban growth within the watershed and no implementation of BMPs. Phosphorus loading to the Maskinonge river is estimated at 84.3 kg, that is an increase of 13.5% above current conditions. Nitrogen loading increased to 470.61 kg, up by 8.6%.

Scenario "D" illustrates the changes which occurs if a landuse change increases forest cover in all catchments to approximately 25%. Phosphorus loading decreased by 28% to 53.35 kg. The nitrogen loading also decreased by 28% to 310.4 kg. Most of this load reduction was due to a decrease in total runoff during the rain event.

Scenario "E" illustrates what changes would occur if the fertilizer application rates were reduced by 25%. The total phosphorus loading decreased more than 25% to 55.69 kg, while the nitrogen decreased by 18.6% to 352.7 kg. The amount of total runoff water from this scenario remained the same as the base case scenario and therefore all of the load reduction was due to a decrease in the concentration of phosphorus and nitrogen in the runoff.

It is apparent from these results that the various scenarios have a large impact on nitrogen and phosphorus loadings. The increase in these loadings with respect to the increment of algae and duckweed growth should be further investigated. The loading increase of 13.5% in phosphorus and 8.6% in nitrogen for the worst case scenario may not have much of an impact above the current conditions.

On the other hand the application of BMPs do make a large difference in the nutrients loading, so it is a good recomendation to state that future development in the watershed should occur accompanied by the implementation of some of the BMPs. Although only some of the BMPs may actually be implemented, these modelling results have shown that there would be overall gains in water quality in doing so.

Furthermore, some actions such as reduced fertilizer application rates and increased forest cover would be highly beneficial to water quality improvement. With the previous example, the author's intention was to demonstrate the usefullness of the work being developed in the present research. As mentioned before, the main conclusions of the Maskingonge study were taken from the draft report of the project.

The model application appears to have performed well. According to LSRCA personnel (Peat, 1998), the AGNPS Interface was a critical tool that they used extensively in the study allowing them a stable and reliable integration of the geographical data and the running of the AGNPS model. It provided them also with an easy and straightforward way to create alternative scenarios to simulate.

5.4 Chapter Summary

This chapter presented the data acquisition from the integration perspective. It describes in detail the different digital files (DEM, soil and landuse) required, showing the information gathered for the Duffins Creek application. Additional utilities were developed to incorporate such files into a layer database, which includes the import of shape and DEM files as well as capabilities to edit the lookup table. Once the information was in the proper format, the integrated models, AGNPS and WATFLOOD, were applied to the same storm events. Several tests were conducted to test the validity of the models. The hydrology results were compared together with the outlet values for sediment and nutrient transport. Since the AGNPS Interface section of this research forms a part of a collaboration agreement with the NWRI and MOEE, the technology transfer to the Conservation Authorities was described and a partial example of the application in the Maskinonge watershed from the Lake Simcoe Region Conservation Authority was presented.

CHAPTER 6. Sensitivity Analysis and Decision Support

A sensitivity analysis is an essential process to understand how a model responds to parameter changes and, in particular, to identify the impact that the various parameters and processes have on the computed response. It is usually performed for single events and individual parameters. Of major importance is finding those parameters which have the largest impact and those which can be neglected from further analysis. The objective of this section is to explain the methods used in the sensitivity analysis and describe how they were implemented as a tool in the integrated system.

6.1 Sensitivity Analysis Methods

The sensitivity analysis is performed by changing the value of one parameter (perturbation) while keeping the remaining ones unchanged and running the model to analyze the variation in the response compared to the results of a base case. Normally, the parameter is not changed arbitrarily, but over a reasonable range. The results of the sensitivity analysis may be different for different base cases. To illustrate this, an excerpt taken from James (1992) mentions two cases where sensitivity analysis provides different results: "The sensitivity analysis produces different results for each application and for different weather conditions. An obvious example, snowmelt in the summer months, the response is insensitive to the snow parameters. A less obvious case is that of the infiltration parameters for light or heavy rainfall rates...."

"...For both cases they are not at all sensitive because: a) light rain only runs off impervious areas; the pervious areas contribute no runoff to the outflow, and b) in long-duration heavy rain, all the pervious areas have reached their final, low constant infiltration rates, and changing the initial infiltration capacity, or the infiltration capacity decay constant, does not affect the calculation; the whole area acts as though it is more or less impervious. So the infiltration parameters are sensitive only for intermediate rainfalls rates".

Understanding the sensitivity changes provides a better comprehension of the model and the results become more defensible and credible. Most of the discussion of sensitivity analysis is based on the assumption that the computed responses are smoothly varying (linear response). A common application involves changing the parameter values on both directions (increase and decrease a small percentage) of the base case and tracing the resulting response gradient. The normalized sensitivity coefficients and its ranking using average gradients are the methods chosen to perform the sensitivity analysis in the present work.

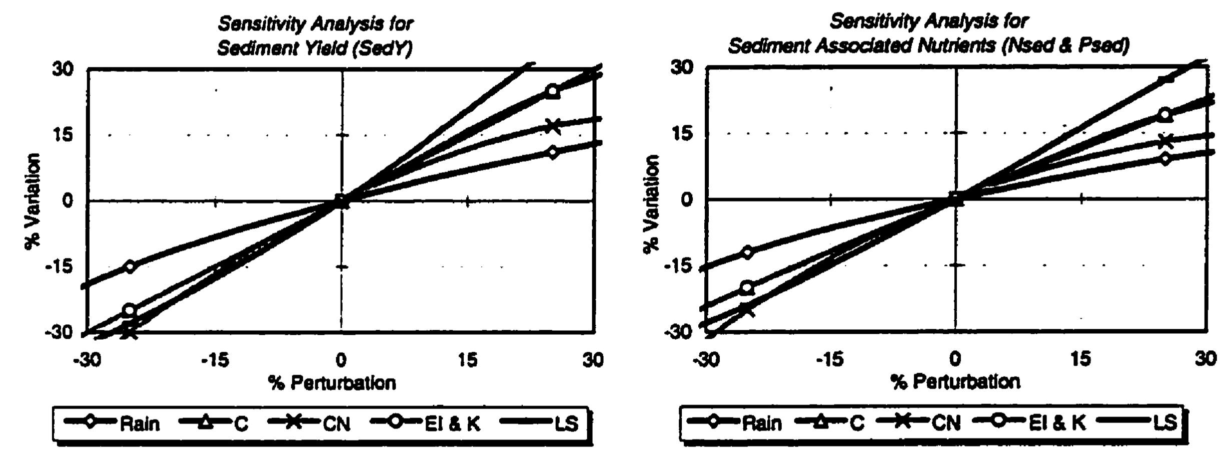
6.1.1 Normalized Sensitivity Gradients

The normalized sensitivity gradients indicates the percentage change in the result for a certain percentage change in a parameter, defined as (Sykes, 1994):

$$Sn_i = \left(\frac{d\varphi}{d\alpha_i}\right)\frac{\alpha_i}{\varphi_i} \tag{6.1}$$

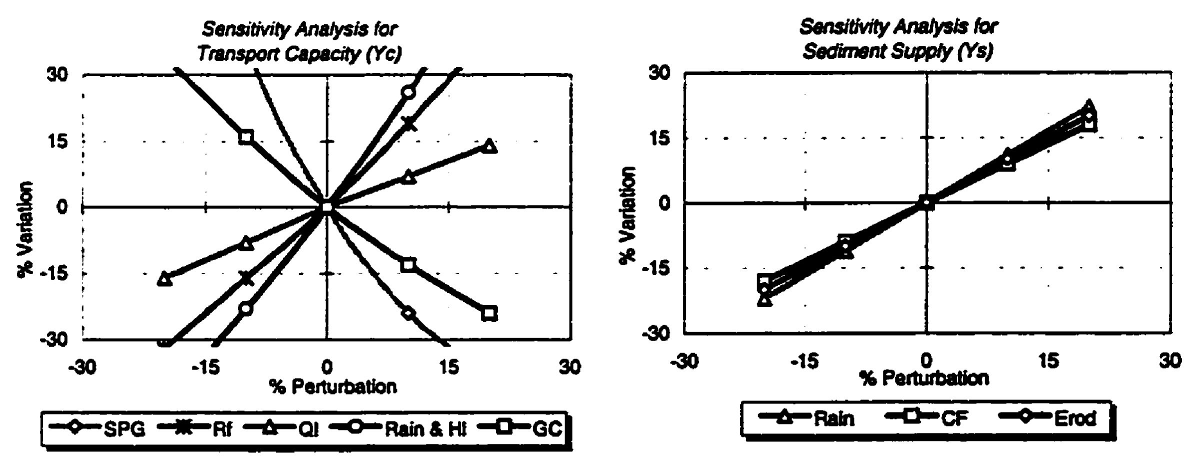
where Sn_i is the normalized sensitivity coefficient related to the base case (dimensionless), $d\varphi$ is the change in the result φ, and $d\alpha$ is the perturbation of the parameter α_i. If these coefficients are calculated for low and expected parameter values together with high and expected parameter values, a local derivative can be assessed for each case. This gives the slope or gradient for that specific range of percentage change. The greater the slope the greater the response to the parameter change.

As mentioned in Chapter 3, a preliminary sensitivity analysis was performed using the above concepts, for both AGNPS and the water quality component added to WATFLOOD. Complete set of results and calculations can be found in Tables F1 and F2 of Appendix F. To illustrate the results obtained, the gradient graphics are presented in Figures 6.1 and 6.2 for the analysis performed for AGNPS and for the sediment transport component of WATFLOOD respectively.



Variable description: LS-land slope, EI-storm energy-intensity, K-soil erodibility factor, CN-SCS curve number, C-cropping or cover factor, Rain-storm rainfall, P-practice factor, FSL-field slope length, CSS-channel side slope, N-Manning's roughness coefficient, CS-channel slope

Figure 6.1 Sensitivity analysis for sediment yield and sediment nutrients in AGNPS



Variable description: *Sediment Model:* SpG-specific weight, D_{50}-median particle size, Erod-soil erodibility, GC-ground cover, CF-cover factor, *WATFLOOD:* Rain-precipitation intensity, Slp2-overland slope, Rf-runoff amount, Ql-unit flow discharge, Hl-runoff depth

Figure 6.2 Sensitivity analysis for transport capacity and sediment supply in WATFLOOD

In the figures, the parameter perturbations are in the horizontal axis while the changes in the output are in the vertical axis. Figure 6.1 shows, for the AGNPS model, the normalized sensitivity gradients for the sediment yield and for the nutrients associated to the sediments and Figure 6.2 shows, for the sediment component for WATFLOOD, the normalized sensitivity gradients for the transport capacity and sediment supply.

6.1.2 Ranked Mean Normalized Gradients

Once the normalized gradients are calculated, a mean gradient provides a good ranking method to detect which parameters influence the output variable of interest. The mean normalized gradients close to zero indicate little sensitivity on the outcome of those parameters. For values greater than 0.5 but less than 1 a moderate variation can be defined. Finally, for values above 1, the output value is highly sensitive to the perturbation of the related parameters.

In general terms, the mean normalized gradient can be calculated through the use of the sensitivity coefficients or the percentages of variation for the output variables and parameter perturbations. The equation used in the calculation of the normalized gradients is:

$$Sm_i = \frac{1}{2}\left[\frac{Vl_i}{Pl_i} + \frac{Vh_i}{Ph_i}\right] \tag{6.2}$$

where Sm_i is the mean normalized gradient; Vl_i , Vh_i are the low and high variations for the output variable, and Pl_i , Ph_i are the low and high parameter perturbations. A numerical example follows to clarify the use of the above equations. Assuming that the base case value of an output variable is 0.17 and that a parameter i is perturbed $\pm 20\%$ to get a low output value of 0.08 and a high output value of 0.28, then the low and high variations are:

$Vl_i = (0.08/0.17) - 1 = -0.53 = -53\%$ and $Vh_i = (0.28/0.17) - 1 = +0.65 = +65\%$

The mean normalized gradient is:

$$Sm_i = \frac{1}{2}\left[\frac{-53}{-20} + \frac{65}{20}\right] = 2.94$$

meaning that, for a gradient of almost 3, an increase of 10% in parameter *i* produces an increment in the output value close to 30% higher. If the sign of the gradient is negative, then an increase in the parameter corresponds to a decrement in the output value.

Using the mean normalized gradients with the above equations, the graphs for the ranked mean normalized gradients in the preliminary sensitivity analysis for AGNPS and the water quality components of WATFLOOD were prepared and presented in Chapter 3. Table 6.1 presents a summary of the mean normalized gradients for the preliminary sensitivity analysis performed on both models.

Table 6.1 Summary of the Mean Normalized Gradients for Preliminary Sensitivity Analysis

	AGNPS Model			WATFLOOD Model	
Variable	**Sediment Yield**	**Nitrogen in Sediment**	**Variable**	**Transport Capacity**	**Sediment Yield**
LS	1.18	0.94	SPG	-3.50	0
EI	1.00	0.80	D50	-0.04	0
K	1.00	0.80	Erod	0	1.00
CN	0.91	0.79	GC	-1.45	-0.17
C	0.88	0.71	CF	0	0.90
Rain	0.58	0.46	Rain	2.48	1.10
P	0.50	0.42	Slp2	1.60	0.07
FSL	0.41	0.32	Rf	1.78	0.07
CSS	0.37	0.30	Ql	0.75	0.07
N	-0.25	-0.20	Hl	2.35	0
CS	0.17	0.14			

Variable description: LS-land slope, EI-storm energy-intensity, K-soil erodibility factor, CN-SCS curve number, C-cropping or cover factor, Rain-storm rainfall, P-practice factor, FSL-field slope length, CSS-channel side slope, N-Manning's roughness coefficient, CS-channel slope, SpG-specific weight, D_{50}-median particle size, Erod-soil erodibility, GC-ground cover, CF-cover factor, Rain-precipitation intensity, Slp2-overland slope, Rf-runoff amount, Ql-unit flow discharge, Hl-runoff depth

The analysis suggests that, for the AGNPS model, the variables most significantly affecting the sediment yield and the nutrient loadings associated with the sediments are the land slope, the storm energy intensity, the soil erodibility, the cover factor and the curve numbers. As stated in Chapter 3, the input data were extracted directly from digital information as accurately as possible. Although close estimates are desirable for all input parameters, greater justification can be made for rough estimation of the ones that least affect the major outputs of the model.

6.2 Implementation in the AGNPS Interface

As mentioned, the results of the sensitivity analysis may be different for each base case and the same change in parameters can affect other output variables in different ways. It was therefore considered desirable to provide the user with a set of tools so that the sensitivity analysis could be performed in a case by case basis. The AGNPS interface was selected to implement such tools. Because WATFLOOD has a parameter optimization method internally in its code, the following implementation was only developed for the AGNPS model.

6.2.1 Structure and Procedures

A brief description of the interface tools for the sensitivity analysis was presented in Chapter 4 and in Appendix C. A more detailed description is presented here. The selection of the output variables and input parameters to perturb was the first stage in the design of the sensitivity tools. This defines the number of runs and available results from the sensitivity analysis. The output variables are based on the resulting values at the outlet cell of the watershed. Among the input parameters, some are related to general watershed data while others are cell based values, either for general cell parameters, soil, fertilizer or channel data. This means that when perturbing the parameters, some of the variations have to be performed on a cell by cell basis.

A total of 8 output variables where selected together with 32 input parameters, implying that for a full analysis, a total of 64 runs are required for each base case. Table 6.2 shows the grouping and parameters for which a specific database table is created through the use of the interface to store the resulting values of the analysis. As a measure of both, the magnitude of the task involved and the usefulness of the implementation, the example that follows in this chapter involves the 64 runs. Each run will be made by modifying a total of 4 general input variables and 28 cell data values for every cell in the 57 elements in the grid. This activity that can require many hours with the manual edition of the AGNPS editor, is performed in minutes with the tools provided with the interface.

Table 6.2 Output Variables and Input Data Parameters by Group

Output Variables	*Initial Data*	*General Cell Data*
Total Runoff Volume Peak Runoff Rate Total Sediment Yield Nitrogen in Sediment Nitrogen in Runoff Soluble Nitrogen Concentration Phosphorus in Sediment Phosphorus in Runoff Soluble Phosphorus Concentration COD in Runoff COD Concentration	Precipitation Nitrogen in Rain Energy Intensity Factor K Coefficient/Percent Runoff	SCS Curve Number Land Slope Slope Length Overland Mannings_n K_Factor C_Factor P_Factor Surface Condition Constant COD_Factor
Soil Related Data	***Fertilizer Related Data***	***Channel Related Data***
Soil Nitrogen Soil Phosphorus Pore Water Nitrogen Pore Water Phosphorus Nitrogen Runoff Extraction Phosphorus Runoff Extraction Nitrogen Leakage Extraction Phosphorus Leakage Extraction Percent of Soil Organic Matter	Applied Nitrogen Applied Phosphorus Nitrogen Availability Factor Phosphorus Availability Factor	Channel Slope Channel Side Slope Channel Manning n Decay Percent for Nitrogen Decay Percent for Phosphorus Decay Percent for COD

The tools to implement the sensitivity analysis are divided in 3 sections: preparing input for the analysis, running the model in batch mode and intercepting the outputs to graphically display the sensitivity results. These procedures were attached as toolbars in the interface under the scenarios and sensitivity analysis section. Details of the interface windows are presented in the Appendix C. The input preparation for the sensitivity analysis will open the input data window and allows the selection of the parameter(s) to modify and the percentage of variation. The parameter selection can be made by group or individually. Also the variation can be set for each parameter for all selected parameters. Once selected and perturbed, these settings are saved in order to track the values to be modified during the export process of ASCII data.

The procedure to run the sensitivity analysis is programmed to export the required ASCII files with the modifications described in the input preparation. This means that for each parameter selected to be perturbed, two files must be created with a low and high value for that parameter. In the case of grid cell data, the program will modify the values for all the cells. Once all the data files are created, the process continues by running the model in batch mode and intercepting the relevant values for the output variables. The intercepted output is stored in memory arrays to be used later in the sensitivity coefficients and gradients calculations.

To calculate the sensitivity coefficients, the base case output is read from the grid database and using the equations presented in this chapter, the variations and gradients are calculated. These results are then stored in the grid database in the sensitivity table. This was done so that, once the analysis has been done, the results can be processed and visualized at any later time without running it again. The graphical display of the sensitivity analysis results is achieved by means of two types of displays. The first consists of the normalized sensitivity gradients that show the slope of the variations between the selected output variable and the selected parameters (see Figures 6.1 and 6.2 as examples of this display). The second type allows the display of the ranked normalized gradients. Both graphic windows have capabilities to display a legend, file and grid description together with the options for selecting/deselecting the parameters to be used in the graph.

Several windows can be open simultaneously to allow comparison of results between different sensitivity runs and even for results in different files. Some zoom capabilities are included in the display either by dragging a zoom box in the case of the normalized gradients or by a mouse click in the case of the ranked means. The numeric values are stored in the database file and can easily be extracted into a spreadsheet for further analysis. In what follows, examples of the use of the sensitivity analysis tools with numerical results display and graphical output will be presented.

6.2.2 Examples Using the Sensitivity Analysis Implementation

In order to test the sensitivity analysis module, several examples where performed by using the tools and procedures described above. The major test was to perform a full analysis by using the 2x2 km grid presented in Chapter 5. All of the 32 possible input parameters where selected to be perturbed by 10% for both low and high variations. After conducting the 64 model runs involved in the process by automatic batch mode, the numerical results where extracted from the database and tables were created accordingly. All the resulting tables are presented in Tables F3 to F13 in Appendix F. A summary of the normalized sensitivity gradients was created from these results and is shown in Table 6.3; a zero value means no response.

These results are compatible with the preliminary sensitivity analysis and show which of the parameters are more likely to produce important variations in the output variables. For the hydrology, represented by the total runoff volume and peak rate output variables, the values of precipitation and curve number are the most sensitive to the outcome. For sediment yield and the nitrogen associated with the sediments, the parameters that produce the largest variations in the output are the land slope, the rainfall intensity energy, the soil erodibility, the cover factor and the curve numbers. In order to verify that the sensitivity analysis is case dependent, a second test was performed using the 1x1 km grid. This increased by four the number of cells in the grid as a test of how sensitive is the model to cell size when compared with the 2x2 km grid. The main parameter changed in this test was the precipitation.

Table 6.3 Summary of the Normalized Sensitivity Gradients for the 2x2 km AGNPS Grid

Parameter	TRV	PRR	TSY	NS	NR	SNC	PS	PR	SPC	CODr	CODc
Initial Data											
Precipitation	3.16	2.90	0.93	0.50	0	-1.00	1.00	0	-5.00	2.19	-0.80
Nitrog_Rain	0	0	0	0	0	0.67	0	0	0	0	0
EI_Rfactor	0	0	0.74	0.50	0	0	1.00	0	0	0	0
KCoeff_PerRunoff	0	0	-1.31	-1.50	0	0	-2.00	0	0	0	0
General Cell Data											
SCS_No	8.16	7.92	2.53	2.00	5.00	0.33	2.00	0	5.00	7.19	-1.26
LandSlope	0	0	0.54	0.50	0	0	0	0	0	0	0
SlopeLength	0	0	0.22	0.50	0	0	0	0	0	0	0
Mannings_n	0	0	0	0	0	0	0	0	0	0	0
K_Factor	0	0	0.73	0.50	0	0	1.00	0	0	0	0
C_Factor	0	0	0.74	0.50	0	0	1.00	0	0	0	0
P_Factor	0	0	0.37	0	0	0	0	0	0	0	0
SurfCond	0	0	0	0	0	0	0	0	0	0	0
COD_Factor	0	0	0	0	0	0	0	0	0	0.94	0.99
Soil Related Data											
Soil_Nitro	0	0	0	1.00	0	0	0	0	0	0	0
Soil_Phos	0	0	0	0	0	0	1.00	0	0	0	0
PoreW_Nitro	0	0	0	0	0	0	0	0	0	0	0
PoreW_Phos	0	0	0	0	0	0	0	0	5.00	0	0
ExtR_Nitro	0	0	0	0	0	0.33	0	0	0	0	0
ExtR_Phos	0	0	0	0	0	0	0	0	5.00	0	0
ExtL_Nitro	0	0	0	0	0	-0.67	0	0	0	0	0
ExtL_Phos	0	0	0	0	0	0	0	0	-5.00	0	0
Per_OMS	0	0	0	0	0	0	0	0	0	0	0
Fertilizer Related Data											
Applied_Nitro	0	0	0	0	0	0.33	0	0	0	0	0
Applied_Phos	0	0	0	0	0	0	0	0	5.00	0	0
AvFac_Nitro	0	0	0	0	0	0.33	0	0	0	0	0
AvFac_Phos	0	0	0	0	0	0	0	0	5.00	0	0
Channel Related Data											
Chan_Slope	0	0.16	0.06	0	0	0	0	0	0	0	0
Chan_SideSlope	0	0	0.02	0	0	0	0	0	0	0	0
Chan_ManningN	0	0	-0.43	-0.50	0	0	0	0	0	0	0
Decay_Nitro	0	0	0	0	-5.00	-3.33	0	0	0	0	0
Decay_Phos	0	0	0	0	0	0	0	0	-5.00	0	0
Decay_COD	0	0	0	0	0	0	0	0	0	-2.50	-2.41

Variable description: TRV-Total Runoff Volume,PRF-Peak Runoff Rate, TSY-Total Sediment Yield, NS-Nitrogen in Sediment, NR-Nitrogen in Runoff, SNC-Soluble Nitrogen Concentration, PS-Phosphorus in Sediment, PR-Phosphorus in Runoff, SPC-Soluble Phosphorus Concentration, CODr-COD in Runoff, CODc-COD Concentration. For input data refer to the variables described in Table 6.2

In the 2x2 km grid the event was labeled as a long duration with medium intensity rainfall. For the 1x1 km grid, two different runs were performed. The first one with the same long duration/ medium intensity values for precipitation and the second one with a short duration/high intensity rainfall. Care was taken to ensure that the total volume of precipitation was the same for all cases. As can be seen, the grid size was not a dominant factor. The sensitivity values for the 1x1 and 2x2 km grids were almost the same for the long duration medium intensity event. This can be seen in the summary of the results for the effect of base case presented in Table 6.4.

Table 6.4 Normalized Sensitivity Gradients for the AGNPS Model. Effect of Grid Size, Storm Intensity and Duration.(1x1 km Grid)

	Long Duration/Medium Intensity			**Short Duration/High Intensity**		
Parameter	**TRV**	**TSY**	**NS**	**TRV**	**TSY**	**NS**
Precipitation	3.00	1.17	0.50	2.59	0.60	0.38
EI_factor	0	0.69	0.50	0	0.94	0.64
SCS_No	8.00	2.63	2.00	6.72	1.51	0.90
Land Slope	0	0.52	0.50	0	0.70	0.51
K_factor	0	0.70	0.50	0	0.94	0.77
C_factor	0	0.70	0.50	0	0.95	0.64

Variable description: TRV-Total Runoff Volume, TSY-Total Sediment Yield, NS-Nitrogen in Sediment

On the other hand, the effect of the precipitation compared with the short duration high intensity event is more important. For the total sediment yield, for example, the precipitation has a less impact for a short duration high intensity event while the energy, erodibility and cover factor are more important. Figure 6.3 shows a comparison of the mean sensitivity gradients for the total sediment yield displayed with the tools from the interface. With these tools in place, performing the sensitivity analysis is quite simple and straight forward, allowing the user to identify for each case the parameters that would mostly impact his results and making the modeling task more credible and its results more defensible.

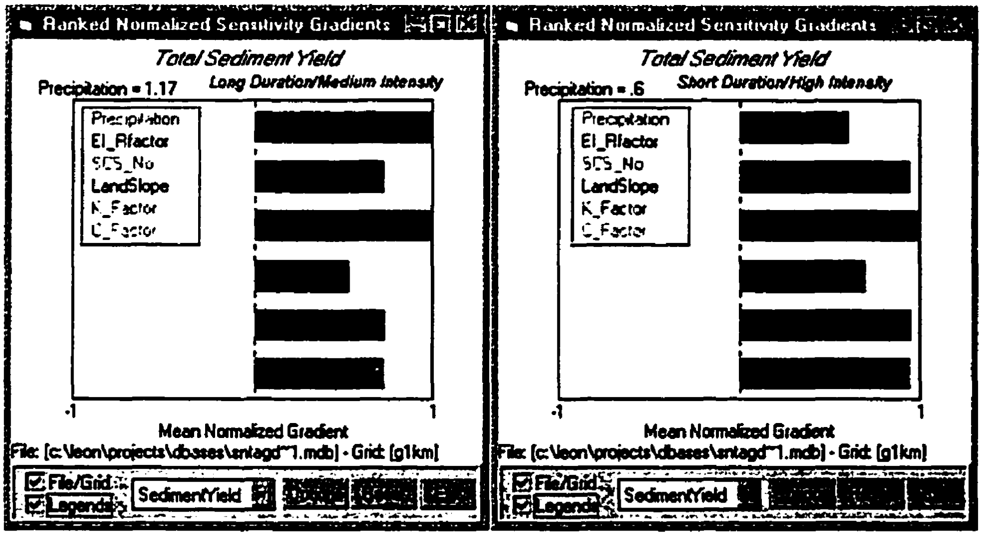


Figure 6.3 Ranked normalized sensitivity gradients for sediment yield and different events

6.3 Gaming Scenarios for Decision Support

This section was included to present additional tools that were developed during this research and designed to assist in the decision support area of non-point source modeling. It is fair to state that, from a management point of view, it is not enough just running a model to get some loading results. It will be a more useful tool if certain manipulating capabilities oriented to the decision making process are included. Some of the additional procedures were developed as a result of requests from pilot testing of the interface by MOE personnel and from the Lake Simcoe application.

Some descriptions of the tools for modifying scenarios with examples of the results that can be achieved were presented briefly in Chapters 4. A more complete discussion is presented here. The interface provides the means to easily set up, automatically extract data and simulate storm events on a given watershed, thus providing a major improvement in the modeling effort. It is also true that additional tools can provide a more useful system to help in the decision making process. In order to facilitate the decision support section, two aspects were taken into account, ease of use in modifying input data and availability of the most common features to create and analyze results for new scenarios.

Taking advantage of the system design and the use of relational databases, it was possible to implement the required options by storing in the same database, several grids for different scenarios in order to facilitate management and comparison. The first tool was designed for duplicating grids. Duplication was needed to avoid extracting the data from digital information over and over for the same landscape unless strictly required (i.e. landuse imagery for different years). The option is given during the duplication process to copy the existing data into the newly created grid. This is useful when creating different scenarios for the same landscape (ie. test BMPs, fertilizer reductions, etc.). A new set of tables for each duplicated grid is generated and stored in the same database. This allows further comparison of scenarios while keeping the integrity of the original data. If during the process, the user decides to copy the data for the grid that is being duplicated, then an indexed copy of the stored data in all the tables is triggered and the new grid is created as an exact duplicate of the selected grid. From this point, the new grid can be modified by changing any of the data.

Another tool was devised to support the decision making process to deal with landuse management issues. It accommodates changes in the landcover percentages. Several tools are available to select fields and amounts to change from one landuse to another. Once this change is complete, the model parameter values affected by the landuse change are recalculated. The program then reads the new landuse percentages and, using the same lookup table as in the extraction process, it calculates the new parameters and stores them in the general cell table of the new grid. This can be done for all the elements of the grid or only for those cells selected by the user through direct map clicking. This kind of flexibility has being found to be the most valuable aspect of the integration. It will give freedom of choice while maintaining the integrity and validity of the data. The newly created and modified grid can be viewed as a new scenario and while, it is still attached to the same file, the results can be compared quite easily. A spreadsheet type display was created to perform such comparisons by showing side to side summaries of results for as many grids as the database file contains. The detailed windows for the described procedures are presented in section C5 of Appendix C.

In order to show the flexibility of the integration, an application was created for Reesor Creek in the Stouffville area (AgStScen.mdb). A 1x1 km grid for the Reesor Creek watershed with 29 elements was created. This grid was considered as the base case with a long duration-medium intensity (1.5" of rain in 10 hr.) storm assigned for the event. The DEM, soil and landuse layers were used to extract the information from the digital maps. Figure 6.4 shows the grid for the simulation together with the flows direction.

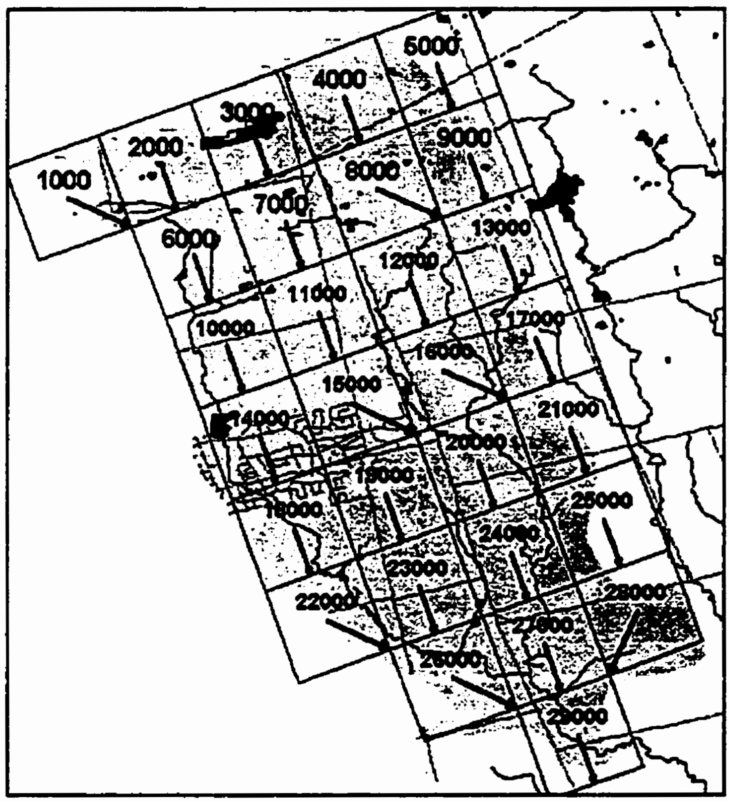


Figure 6.4 Grid at Reesor Creek with flow direction from DEM extraction

After the model is run and the results displayed for the base case, the next step is to show the gaming scenarios tools. The grid was duplicated three times, one for a sensitivity analysis comparison of the impact on the storm duration and intensity. The other two grid duplications were designed to demonstrate the effect on nutrients loads due to fertilizer application and reforestation practices.

For the first duplicate, the storm event was assigned a short duration-high intensity rainfall (2" of rain in 30 min). The second duplicate was subjected to a fertilizer application on areas with values above 25% of agricultural land according to the distribution described in chapter 5. The last duplicate, to simulate the effect of reforestation, was created from the fertilized grid to maintain the same rate of application but with the areas and model parameters automatically modified to change 20% of crop areas to forest.

The model was run for the three different scenarios and the comparisons made through the use of the spreadsheet view. Table 6.5 is a copy of the display showing the ease with which the user can compare results from different simulations. The sensitivity effect was already shown in the present chapter. The real time requirement for this example, including the extraction of data from digital maps, was less than an hour.

Table 6.5 Scenarios Summary Comparison for the AGNPS Model

Variable/Case	Units	Base	Base	Fertilizer	Reforest
Description		LDMI	SDHI	LDMI	LDMI
# Base Cells		29	29	29	29
# Total Cells		29	29	29	29
Area base cell	acre	351	351	351	351
Drainage area	acre	10179	10179	10179	10179
Precipitation	in	1.5	2	1.5	1.5
Energy intensity		16.6	112.55	16.6	16.6
Nitrogen in rain	ppm	1	1	1	1
Outlet Cell		29,000	29,000	29,000	29,000
Runoff Volume	in	0.17	0.37	0.17	0.07
Peak Rate	cfs	350.48	765.63	350.48	152.16
Sediment Yield	ton	207.21	1489.49	207.21	129.77
Nitrogen-Sediment	lb/acre	0.15	0.7	0.15	0.11
Nitrogen-Runoff	lb/acre	0	0.01	0.07	0.01
Phosphorus-Sediment	lb/acre	0.07	0.35	0.07	0.05
Phosphorus-Runoff	lb/acre	0	0	0.01	0
COD-Runoff	lb/acre	0.33	0.72	0.33	0.04
Nitrogen Conc	ppm	0.1	0.1	1.77	0.59
Phosphorus Conc	ppm	0	0	0.34	0.11
COD Conc	ppm	8.64	8.46	8.64	2.29

Variable description: LDMI=Long Duration/Medium Intensity, SDHI=Short Duration/High Intensity

6.4 Chapter Summary

This chapter deals with the sensitivity analysis methods and tools which were developed as a part of this research for inclusion in the interfaces. It shows the different equations used to calculate the normalized sensitivity gradients and its mean ranking. The implementation of the procedures is described and several examples on the use of the sensitivity analysis are presented. It also includes a more detailed description of the tools that where created to support the decision making process when dealing with nonpoint source pollution modeling. It describes the available options to create different scenarios and with a full example shows the ease of use and feasibility as a fully integrated decision support system.

CHAPTER 7. Summary, Conclusions and Recommendations for Future Work

Summary

The main result achieved in this research is the creation of an integral system to model NPS pollution in surface waters. This work has demonstrated the feasibility of applying advanced technologies in order to integrate models in a uniform platform with GIS capabilities. The work developed in this research produced an integrated support system that helps in the modelling tasks and in the decision making process of NPS studies.

One of the major contributions to NPS modelling was adding a water quality component to WATFLOOD based on the GRU approach. The spatial variability of the physical processes occurring in the watershed is an essential characteristic to take into account. As part of the research, a water quality component was developed to simulate the processes governing the fate and transport of NPS pollutants. The distributed approach based on the GRU concept was extended to the algorithms selected to simulate the sediment and nutrient processes.

A simple sediment yield model for single storm events (Hartley, 1987) was successfully linked to the WATFLOOD model. The contaminant relationships coupled with the hydrologic model were taken from the CREAMS and AGNPS models. The methods selected for the water quality component in WATFLOOD were developed by Frere *et al.* (1980) and adapted by Young *et al.* (1986) in AGNPS. The relationships were modified to perform based on landcover to follow the GRU concept at a watershed scale.

The AGNPS and WATFLOOD models were included in a decision support system through the development of interfaces into RAISON, a decision support system with GIS capabilities. This integrated approach was then tested in different applications and validated against measured data. The development of the interfaces includes the creation of pre- and post-processing tools, the former to allow the interactive process of setting up model grids and automate data input and the latter to analyze the output. The integration effort was conducted with the idea that better modelling capabilities need to be combined with the application of new technologies, such as the use of GIS capabilities, to resolve problems associated with ease of model use. The sensitivity analysis and the decision support tools provide additional means to identify the importance of the variables and to track the simulation process for different scenarios.

One of the major assets of this work was the automatic data extraction from digital maps. Two basic procedures were created to achieve the extraction of data. One deals with the DEM files to extract topographic related data such as flow direction and slope. The other uses landcover and soil type maps with polygon attributes to extract the relevant data for each model according to land cover and soil information. The procedures to extract polygon information from digital maps developed in this research are unique achievements in the field of input data acquisition. They differ from traditional GIS applications where raster or pixel values of attributes are used to create average parameter values for the grid. In this case, a more general procedure was developed and optimized. It actually uses polygon values to calculate the input data through the use of lookup tables. This allows the use of almost any type of map file as long as it is converted to the standard shape format and the linkage to the lookup table is provided.

Even for this data intensive task, the procedure was developed for completion in reasonable times for a desktop computer. As technology on PC evolves to provide even faster machines, this issue will become less important. But, in the meantime, it is essential to have procedures that can be run in minutes rather than in days. A complete setup for the Duffins Creek application can be achieved, using the developed system in a Pentium II-233Mhz desktop, in less than an hour.

The application of the AGNPS model provided the opportunity to compare results from both approaches. Initial testing of the system, including automation of input data from vector maps (soil type, land use, and digital elevation) was done using data from Duffins Creek. On the other hand WATFLOOD has already been tested for hydrologic responses and achieved satisfactory results in the proposed areas. The objective was to test the water quality component performance without further calibration for the runoff prediction. The results from the WATFLOOD and the water quality component developed in this research, support the hypothesis behind this work, that is, if the parameters are related to landcover and the response for each element is weighted on results and not on the coefficients, the model will perform quite accurately and will represent a major improvement in NPS modelling.

Conclusions

The conclusions and contributions from this research are presented in the following categories:

a) Model Development

- Blending of a water quality component into WATFLOOD in the context of the GRU is a key contribution of this research.
- A physical based sediment yield model was successfully used as the soil erosion component for the water quality component of WATFLOOD.
- The algorithms to simulate the nutrient processes were based on the CREAMS and AGNPS models and modified to take into account the GRU approach.
- These procedures were coded as subroutines in WATFLOOD giving the flexibility to modify them if further research is aimed towards improving the algorithms.

b) Data Management

- An integral system was constructed with the development of interfaces for the AGNPS and WATFLOOD models.
- Pre- and post-processing tools were created to help in the setup of the model, automate data input and analyze the results of the simulations.

- Specific procedures were created to automatically extract model data from digital information sources, such as DEM, soil and landuse maps.
- Sensitivity analysis utilities were included in the system to provide the user with the means to identify the importance of the variables involved in a simulation.
- Decision support tools were developed to allow the creation and testing of different gaming scenarios to support the decision making process on NPS studies such as in BMPs evaluations.

c) Model Application

- Application of the system was done at the Duffins Creek watershed. The integral system was successfully used to setup both models and automatically extract the data for the study area.
- The performace of the models were tested with hydrology data and the comparisons for the calculated and measured peak flows were accurate for both models.
- The comparison between models provided close matches for sediment and nutrients results.
- Hourly sampled events were used to test the performance of the model. The results from the tests were excellent. Nearly perfect matches between calculated and measured values for sediment and nutrients were achieved for the hourly sampled events.

Recomendations for Future Work

Some improvements in the AGNPS interface can still be made. To get better results from the DEM extraction process in the borders of the watershed being simulated, tools to include flow direction auto-check and to highlight cells with flow direction problems for easier on screen identification can be implemented. To facilitate the fertilizer input data, it would be of help to develop a process to assist in the fertilizer propagation in the cells. A first approach based on landuse could be attempted. Fertilizer rates and availability can be linked to landuse through lookup tables in order to populate the cells with the fertilizer data.

Current development of AGNPS98 from the USDA features modifications to the hydrology component to increase the capabilities for continuous modelling. The new version actually in beta testing mode is consistent with older versions for data import. For this work to be compatible with the new version of AGNPS, straightforward extension of the interface to accommodate the changes in the new version can be easily achieved. At the same time, as RAISON moves to a 32 bit object oriented application, it would be useful to modify and recompile the interface and extraction code to take advantage of the new 32 bit capability. This will eliminate the 4,000 points per polygon limit to handle and pass very large arrays.

With respect to the WATFLOOD model, and because the code development is an ongoing process, the water quality component has to be incorporated into the latest version of the model code. This should pose no problem; thanks to the modular approach all the subroutines will merge effortlessly into the most recent code. In fact, if further research is aimed towards improving the methods for sediment or nutrients calculations or routing this can be easily incorporated into the model. For the interface, additional integration can be achieved by linking the WATFLOOD utilities with RAISON directly. For example the streamflow data can be captured directly from RAISON databases by clipboard copy or code. Radar visualization is another area that can take advantage of the system capabilities and can be pursued in future work as well as the output display for sediment and nutrient concentrations.

Further work on validating the model capabilities to simulate sediment and nutrient transport has to be done. It is recognized that additional field sampling has to be done. The Duffins Creek application produced excellent results but more than one field trial is needed to confirm this conclusions. This field testing should accommodate a wide range of field conditions, climate, topography, landuse, etc. The transferability of model parameters to other watersheds, especially those in remote areas without enough data for calibration, is a major problem with current NPS models.

REFERENCES

American Society of Civil Engineers, (1969). Design and construction of sanitary and storm sewers, *Manual and Reports of Engineering Practice*, No. 37, New York.

Arnold, J.G., and Sammons, N.B., (1988). Decision Support System for Selecting Inputs to a Basin Scale Model, *Water Resources Bulletin*, Vol. 24, No. 4, pp. 749-759.

Arnold J.G., P.M. Allen, And G. Bernhardt (1993). A Comprehensive Surface-Groundwater Flow Model. *Journal of Hydrology*, pp. 142:47-69.

Arnold, J.G., R. Srinivasan, R.S. Muttiah and R.H. Griggs, (1995). *Watershed Modeling and GIS with SWAT and GRASS. SWAT User's Manual.* Blackland Research Center, Texas Agricultural Experiment Station, Temple, Texas.

Beasley, D.B., and Huggins, L.F., (1985). *ANSWERS: Areal Nonpoint Source Watershed Environment Response Simulation-User Manual*, Agricultural Engineering Department., Purdue University, USA

Beasley, R.P., Gregory, J.M, and McCarty T.R., (1984). *Erosion and Sediment Pollution Control*, Iowa State University Press, 2nd Ed., p. 355.

Bekdash, F., Shirmohammadi, A., Magett, W., and Lifft, T., (1991). Best Management Practices (BMP) Evaluation Using GIS-CREAMS Linkage. *ASAE Paper 91-7516*, St. Joseph, MI.

Bingner, R.L., Murphree, C., and Mutchelr, C. (1989). Comparison of Sediment Yield Models on Watersheds in Mississippi. *Transactions of ASAE*, No. 32, pp. 529-544.

Booty, W.G., and Wong, W.S., (1994). Water Quality Modelling Within the RAISON Expert System, *Jr. of Biological Systems*, Vol. 2, No. 4, pp. 453-466.

Bowen,.G., Kay D., Lam D.C., and Booty, W.G.. (1995). *Environmental Databases Duffin's Creek Watershed. Duffin's Creek*, Project Technical Report 95-2, MOEE.

Connors, K., and Gardner, T.W. (1991). Watershed Configuration and GIS Parametrization for SPUR Model Hydrologic Simulation, *Water Resources Bull.*, N27(1), pp 7-18.

Cranmer, A.J. (1998) Modelling the Non-linearities of Hydrologic Response to Storm Intensities using WATFLOOD, Masters Project, Civil Eng. Dept. University of Waterloo.

DeRoo, A., Hazelhoff, L., and Burrough, P., (1989). Soil Erosion Modeling Using ANSWERS and Geographical Information Systems, *Earth Surf. Proc. Land.*, Vol 14, pp. 517-532.

Dickinson, W.T., and Rudra, R.P. (1990) *GAMES - The Guelph model for evaluating effects of Agricultural Management Systems on Erosion and Sedimentation*, User's Manual, V3.01, Tech. Rep. 126-86, School of Engineering, University of Guelph, On., Canada.

Donigian, A.S., and Davis, H.H., (1985). *User Manual for Agricultural Runoff Management (ARM) Model*, EPA 600/3-78-080, U.S. Environmental Protection Agency, Athens, GA.

Donigian, A.S., and Huber, W.C., (1990). *Modeling Nonpoint Source Water Quality in Urban and Non-urban Areas*, EPA 68-03-3513, Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Finney, V.L., Banasik, K., Needham, S. & Young, R.A. (1993). Comparison of DR-USLE, SEGMO and AGNPS with Actual Events in the Moyer Watershed, *Proc. Int. Symposium at Warsaw Agricultural University - SGGW*, Ed. Banaski & Zbikowski, pp. 195-200.

Finney, V.L., Cocke, M.A., Moorhead, S.T., Klug, J. (1995). Nutrient Analysis of the Malibu Watershed Using the AGNPS Model. *Animal Waste and the Land-Water Interface*, Ed. Kenneth Steele, Lewis Publishers, pp. 305-312.

Foster, G.R., Lane, L.J., Nowlin, J.D., Laflen, J.M., and Yountg, R.A., (1980). A Model to Estimate Sediment Yield from Field-Sized Areas: Development of the Model. In: *Knisel, W.G. (ed.) 1980. CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems*, USDA, Cons. Research Report No. 26, pp. 36-63.

Foster, G.R., Young, R.A., and Neibling, W.H., (1985). Sediment Composition for Nonpoint Source Pollution Analysis, *Transactions of the ASAE*, No 28(1), pp. 133-139.

Frere, M.H., Ross, J.D., and Lane, L.J. (1980). The Nutrient Submodel. In: *Knisel, W.G. (ed.) 1980. CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems*, USDA, Cons. Research Report No. 26, pp. 65-86

Garland, A.G. (1986) "Resolution Considerations in Using Radar Rainfall Data for Hydrologic Modeling", Master's Thesis, University of Waterloo, Waterloo

Giorgini, A., and Zingales, F., (1986). *Agricultural Nonpoint Source Pollution: Model Selection and Application*, Elsevier, Amsterdam.

Hartley, D.M., (1987). Simplified Process Model for Water and Sediment Yeld from Single Storms, *Transactions of the ASAE*, Vol. 30, No. 3, pp. 718-723.

Hornberger, G.M., and Spear, R., (1980). Eutrophication in Peel Inlet. Problem-defining behavior and a mathematical model, *Water Res.*, Vol.14, pp. 29-42.

James, W., (1992). *Workbook for Stormwater Management Modelling*, Computational Hydraulics Inc., 1st ed., Guelph, Ont.

Jenson, S.K., and Dominguez, J.O, (1988). Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis, *Photogrammetry Engineering and Remote Sensing*, vol. 54, No. 11, pp. 1593-1600.

Knisel, W.G., (1980). *CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems*, Conservation Research Report No. 26, U.S. Department of Agriculture, Washington, D.C.

Koelliker, J.K. and Humbert, C.E. (1989). Application of AGNPS Model for Water Quality Planning, *ASAE Paper No. 89-2042*, American Society of Agricultural Engineers, USA.

Kouwen, N., (1988). WATFLOOD: A Micro-Computer Based Flood Forecasting System Based on Real-Time Weather Radar, *Canadian Water Resources Jr.*, Vol. 13(1), pp. 62-77.

Kouwen, N., (1999). *WATFLOOD / SPL8 Flood Forecasting System*, Documentation and User Manual, Department of Civil Engineering, University of Waterloo. First Edition-March 1986, Last revision - March 1999.

Kouwen, N., Soulis, E., Pietroniro, A., Donald, J., and Harrington, R., (1993). Grouped Response Units for Distributed Hydrologic Modeling, *J. Water Resources, Planning and Management*, Vol. 119, No. 3, pp. 289-305.

Lake Simcoe Region Conservation Authority, (1998) *Maskinonge River Remedial Strategy*, LSRCA Document, Final Draft prepared for the Town of Georgina, October 1998.

Lam, D.C., Mayfield, C.I., Swayne, D.A. and Hopkins, K., (1994) A Protytype Information System for Watershed Management and Planning, *Jr. Biol. Sys.*, Vol. 2, No. 4, pp. 499-517.

Lam, D.C. and Swayne, D.A., (1991). Integrating Database, Spreadsheet, Graphics, GIS, Statistics, Simulation Models and Expert Systems: Experiences with the RAISON System on Microcomputers, *NATO ASI Series*, Vol. G26, Decision Support Systems, pp 429-459.

Leavesley, G.H., Beasley, D.B., Pionke, H.B., and Leonard, R.A., (1988) Modeling of Agricultural Nonpoint Source Surface Runoff and Sediment Yield - A Review from the Modeler's Perspective, *Proceedings International Symposium on Water Quality Modeling of Agricultural Nonpoint Sources*, Part 1, Utah Univ., pp. 171-189.

Leonard, R.A., (1990). Chapter 3. Herbicides in Surface Waters, In: *Grover, R. (ed.), Environmental Chemistry of Herbicides*, Vol.I, CRC Press, Florida.

Leonard, R.A, and Knisel, W.G., (1989). Can Pesticide Transport Models be Validated with Field Data - Now and in the Future, *Jr. Environ. Health Sci.*, Part B, pp.

Leonard, R.A., and Wauchope, R., (1980). The Pesticide Submodel. In *CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems*, US Dep. of Agriculture, Con. Res. Report No. 26, pp.88-112.

Linsley, R.k., Kohler, M.A., Paulhus, L., (1949). *Applied Hydrology*, McGraw Hill, New York.

Lyman, J., (1982). Octanol/Water Partitioning Coefficients, *Handbook of Chemical Property Estimation Methods*, W.J. Lyman *et al.*, eds., McGraw-Hill, New York, pp. 2.1-2.52.

McWilliams, T.P., (1987). Sensitivity Analysis of Geologic Computer Models: A Formal Procedure Based on Latin Hypercube Sampling, *Math. Geology*, Vol.19(2), pp. 81-90.

Mostaghimi, S., Park, S.W., Cooke, R.A., and Wang, S.Y. (1997). Assessment of Management Alternatives on a Small Agricultural Watershed, *Wat. Res.* Vol. 31, No 8, pp. 1867-1878.

Nash, R.G., (1980). Dissipation of Pesticides from Soils. In: *Knisel, W.G. (ed.) 1980. CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems*, USDA, Conservation Research Report No. 26, pp. 560-594.

Novotny, V., and Chesters, G., (1981). *Handbook of Nonpoint Pollution: Sources and Management*, Van Nostrand Reinhold, New York.

Oliver, G., Burt, J. and Solomon, R., (1988). The Use of Surface Runoff Models for Water Quality Decisions - A users perspective, *Proc. Int. Symp. on Water Quality Modeling of Agricultural Nonpoint Sources*, Part 1, Utah Univ., pp.197-204.

Peat, G., (1998). LSRCA, Personal communication, October 1998.

Philip, J.R., (1957). The Theory of Infiltration: 1 The Infiltration Equation and its Solution, *Soil Sci.*, 83(5), pp. 245-357.

Rewerts, C.C., and B.A. Engel, (1991). ANSWERS on GRASS: Integrating Watershed Simulation with a GIS, *ASAE Paper* No. 91-2621, St. Joseph, Michigan.

Rode M. and H.G. Frede, (1997). Modification of AGNPS for Agricultural Land and Climate Conditions in Central Germany, *Jr. Environ Qual.* Vol 26 Jan-Feb, pp. 165-712.

Rose, C.W., Dickinson, W.T., Ghadiri, H., Jorgenson, S., (1988). Agricultural Nonpoint-Source Runoff and Sediment Yield Water Quality (NPSWQ) Models: Modeler's Perspective, *Proc. Int. Symposium on Water Qulity Modeling of Agricultural Non-Point Sources*, U.S. Department of Agriculture, Utah State University, pp. 145-169.

Rudra, R.P., Whiteley, H.R., Dickinson, W.T. & Tan, C.S. (1998) The Importance of Rain Events Without Runoff in Modeling Erosion at Various Spatial Scales, *Canadian Water Resources Journal*, Vol. 23, No. 3, pp. 273-286.

Schafer, G., (1990), Decision Making. In: Shafer, G. & Pearl, J. (Eds.): *Readings in Uncertain Reasoning*, Morgan-Daufmann, San Mateo, Ca., pp. 61-67

Simons, D.B., and Senturk, F. (1976), *Sediment Transport Technology*, Water Resources Publications, Fort Collins, Colorado, USA.

Smith R.E. and Williams R.J. (1980). Simulation of the surface runoff hydrology. In *CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems*, US Dep. of Agriculture, Con. Res. Report No. 26, pp.13-35.

Srinivasan, R., and Engel, B.A., (1994). A Spatial Decision Support System for Assessing Agricultural Nonpoint Source Pollution, *Water Resour. Bull.*, No.30(3), pp 441-452

Stuebe, M., and Johnson, D.M. (1990). Runoff volume estimation using GIS techniques, *Water Resour. Bull.*, No. 26(4), pp 611-620.

Sykes, J.K., (1994) Case Studies in Groundwater Management, *Civ.E. 676 Course Notes*, University of Waterloo.

Tao, T., and Kouwen, N. (1989). Remote Sensing and Fully Distributed Modeling for Flood Forecasting, *Jr. Water Res. Planning and Management*, V-115, No. 6, ASCE, pp. 809-823.

Varis, O., (1995). A Belief Network Approach to Optimization and Parameter Estimation in Resource and Environmental Management Models, *Work Paper WP-95-11, IIASA*, Laxenburg, Austria, 16p.

Wauchope, R.D., and Leonard, R.A., (1980). Pesticide concentrations in agricultural runoff: availabel data and an approximation formula, In: *Knisel, W.G. (ed.) 1980. CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems*, US Dep. of Agriculture, Con. Res. Report No. 26, pp. 544-559.

Williams, J.R., Nicks, A.D., and Arnold, J.G., (1985). Simulator for Water Resources in Rural Basins, *Jr.of Hydraulic Eng. ASCE*, Vol. 111(6), pp. 970-986.

Wishmeier, W.H. and Smith D.D., (1978). Predicting Rainfall Erosion Losses. U.S. Dep. of Agriculture, Agriculture Handbook No. 537, 58pp.

Witte, J., Theurer, F.D., and Baker, K.D. (1995). AGNPS Version 5.0 Verification: Software, Technical Document File downloaded from *ftp.mrsars.usda.gov*, USDA-ARS, Morris, MN.

Young R., Onstad, C., Bosch, D., Anderson, W., (1986). *Agricultural Nonpoint Source Pollution Model: A Watershed Analysis Tool*, Model Documentation, Agricultural Research Service, U.S. Department of Agriculture, Morris, MN.

Young, R., Onstad, C., Bosch, D., and Anderson, W., (1989). AGNPS: A Nonpoint Source Pollution Model for Agricultural Watersheds. *Jr. Soil Wat. Conserv.* 44(2), pp. 168-173.

Young R., Onstad, C., Bosch, D., and Anderson, W., (1994). *Agricultural Nonpoint Source Pollution Model: Version 4.03*, User's Guide, Agricultural Research Service, U.S. Department of Agriculture.

APPENDIX A. Table Structure for AGNPS and WATFLOOD Interfaces

Appendix A describes the structure of the tables in the database together with the variable description, sample values and units for every parameter. The appendix is divided into three sections: AGNPS Input Tables, AGNPS Output Tables and WATFLOOD Input Tables.

Section A.1. AGNPS Input Tables (Reference - Table 4.1a):

Table A1 - Initial Watershed Data[One Record/Grid]

Variable	*Sample*	*Unit*	*Variable Description*
Watershed_ID	Title		Watershed Identification
Description	Subtitle		Description
AreaCell	200.00	acres	Area of each cell
NoMajorCells	2		Number of Base Cells (Limit 1000)
NoTotalCells	5		Number of Total Cells (Limit 64,000=3 levels)
Precipitation	1.00	inches	Total Precipitation
Nitrog_Rain	0.80	ppm	Nitrogen Concentration in Rainfall
EI_Rfactor 'or'	4.81		Energy-Intensity Value
Duration	0.0	hrs	Storm Duration
StormType	000		Storm Type (I, IA, II, III options)
PeakFlow_Tog	AGNPS		Peak Flow Calculations (SCS-TR55/AGNPS)
Geomorphic_Tog	Yes		Geomorphic Calculations (Yes/No)
HydrShape_Tog	K Coef		Hydrograph Shape Factor (K Coef/% Runoff)
KCoeff_PerRunoff	484.00		Value of K Coef or % Runoff

Table A2 - General Cell Data[Grid]

Variable	*Sample*	*Unit*	*Variable Description*
Rec_CellNo	2		Receiving Cell Number
Rec_CellDiv	100		Receiving Cell Subdivision
FlowDirection	5		Flow Direction
SCS_No	54		SCS Curve Number

Table A2 - General Cell Data^{Grid} (Cont.)

Variable	*Sample*	*Unit*	*Variable Description*
LandSlope	3.5	%	Land Slope
SlopeShape	1		Slope Shape
SlopeLength	150	ft	Slope Length
Mannings_n	0.030		Overland Manning's
K_factor	0.60		K - Factor
C_factor	0.3000		C - Factor
P_factor	1.00		P - Factor
SurfCond	0.21		Surface Condition Constant
COD_factor	65	mg/l	COD Factor
Soil_Texture	2		Soil Texture ID
Fert_Ind	On/Off		Fertilizer Indicator
Pest_Ind	On/Off		Pesticide Indicator
Point_Ind	On/Off		Point Source Indicator
Add_Erosion	On/Off		Additional Erosion Indicator
Impound_Ind	On/Off		Impoundment Indicator
Channel_Ind	7		Channel Indicator

Table A3 - Soil^{Grid}

Variable	*Sample*	*Unit*	*Variable Description*
Soil_Nitro	0.0010	lbN/lbsoil	Nitrogen concentration in soil
Soil_Phos	0.0005	lbN/lbsoil	Phosphorus concentration in soil
PoreW_Nitro	5.00	ppm	Nitrogen concentration in pore water
PoreW_Phos	2.00	ppm	Phosphorus Concentration in pore water
ExtR_Nitro	0.05		Nitrogen extraction coefficient for runoff
ExtR_Phos	0.025		Phosphorus extraction coefficient for runoff
ExtL_Nitro	0.25		Nitrogen extraction coefficient for leaching
ExtL_Phos	0.25		Phosphorus extraction coefficient for leaching
Per_OMS	20	%	Percent of organic matter in soil

Table A4 - Fertilizer^{Grid}

Variable	*Sample*	*Unit*	*Variable Description*
Applied_Nitro	200	lb/acre	Nitrogen applied
Applied_Phos	80	lb/acre	Phosphorus applied
AvFac_Nitro	45	%	Availability factor for nitrogen
AvFac_Phos	55	%	Availability factor for phosphorus

Table A5 - Pesticide^{Grid}

Variable	*Sample*	*Unit*	*Variable Description*
Com_Name	ATRAZINE		Common Pesticide Name (DB)
Trad_Name	ATRATOL		Trade Name (DB)
Type_App	Preplant		Type of application (option value)
App_Time	5.0	days	Time since application
App_Rate	2.00	lb/acre	Application rate
App_Effic	75	%	Application efficiency (default=75)
Per_CanCov	20	%	Percent canopy cover (default=20)
SoilRes_Init	0.10	lb/acre	Initial soil residue

Table A5 - Pesticide^{Grid} (Cont.)

Variable	*Sample*	*Unit*	*Variable Description*
SoilRes_Half	60.0	days	Soil residue half life (DB)
Inc_Depth	1.00	in	Incorporation depth (default=1.0
Inc_Effic	75	%	Incorporation efficiency
Solub_Wat	33.000	ppm	Solubility in water (DB)
OrgCar_Koc	100.000		Organic carbon sorption Koc (DB)
FolRes_Init	0.00	lb/acre	Initial foliar residue
FolWash_Thres	0.10	in	Foliar washoff threshold (default=0.10)
FolWash_Frac	45	%	Foliar washoff fraction (DB)
FolRes_Half	5.0	days	Foliar residue half life (DB)

(DB) - Available from Pesticide Data Base

Table A6 - NonFeedlot$^{Non\text{-}Grid}$

Variable	*Sample*	*Unit*	*Variable Description*
Flow_Rate	2.000	cfs	Non-feedlot flow rate
Total_Nitro	2.10	ppm	Non-feedlot nitrogen concentration
Total_Phos	2.20	ppm	Non-feedlot phosphorus concentration
Total_COD	2.30	ppm	Non-feedlot COD concentration
EnterCell	Top		Entrance at Cell

Table A7 - Feedlot$^{Non\text{-}Grid}$

Variable	*Sample*	*Unit*	*Variable Description*
Feed_Area	15.00	acre	Feedlot area
Feed_CN	45.00		Curve number for feedlot
Roof_Area	2.00	acre	Roofed area
Feed_Nitro	300	ppm	Nitrogen concentrations for feedlot runoff
Feed_Phos	85	ppm	Phosphorus concentrations for feedlot runoff
Feed_COD	4500	ppm	COD concentrations for feedlot runoff
Ind_Buffer	AGNPS		Buffer indicator
RedOF_Nitro	12.0	%	Nitrogen reduction in overland flow
RedOF_Phos	13.0	%	Phosphorus reduction in overland flow
RedOF_COD	14.0	%	COD reduction in overland flow
RedGW_Nitro	24.0	%	Nitrogen reduction in grass waterways
RedGW_Phos	23.0	%	Phosphorus reduction in grass waterways
RedGW_COD	22.0	%	COD reduction in grass waterways
Sub_Area2(1)	3.00	acre	Tributary area 2 in feedlot (six subareas)
Sub_Area2(2)	1.00	acre	Tributary area 2 in feedlot
...	...	...	...
Sub_Area2(5)	2.00	acre	Tributary area 2 in feedlot
Sub_Area2(6)	2.00	acre	Tributary area 2 in feedlot
CN_Area2(1)	35.00		Curve number for area 2 (six subareas)
CN_Area2(2)	45.00		Curve number for area 2
...	...	...	...
CN_Area2(5)	15.00		Curve number for area 2
CN_Area2(6)	10.00		Curve number for area 2
Sub_Area3(1)	1.00	acre	Adjacent area 3 in feedlot (six subareas)
Sub_Area3(2)	1.00	acre	Adjacent area 3 in feedlot

Table A7 - Feedlot$^{Non-Grid}$ (Cont.)

Variable	*Sample*	*Unit*	*Variable Description*
Sub_Area3(5)	0.00	acre	Adjacent area 3 in feedlot
Sub_Area3(6)	0.00	acre	Adjacent area 3 in feedlot
CN_Area3(1)	13.00		Curve number for area 3 (six subareas)
CN_Area3(2)	14.00		Curve number for area 3
...	...	...	...
CN_Area3(5)	0.00		Curve number for area 3
CN_Area3(6)	0.00		Curve number for area 3
Buff_Slope(1)	4.00	%	Slope of buffer area
Buff_Slope(2)	2.00	%	Slope of buffer area
Buff_Slope(3)	3.00	%	Slope of buffer area
Buff_SurfC(1)	0.25		Surface condition in buffer area
Buff_SurfC(2)	0.24		Surface condition in buffer area
Buff_SurfC(3)	0.22		Surface condition in buffer area
Buff_FLeng(1)	100	ft	Length of buffer strip
Buff_FLeng(2)	120	ft	Length of buffer strip
Buff_FLeng(3)	140	ft	Length of buffer strip
Anim_No(1)	100		Number of animals
Anim_No(2)	1000		Number of animals
Anim_No(3)	9999		Number of animals
Anim_COD(1)	0.17		COD ratio produced by each type of animal*
Anim_COD(2)	0.18		COD ratio produced by each type of animal*
Anim_COD(3)	0.01		COD ratio produced by each type of animal*
Anim_Phos(1)	0.07		Phosphorus ratio produced by animal type*
Anim_Phos(2)	0.06		Phosphorus ratio produced by animal type*
Anim_Phos(3)	0.01		Phosphorus ratio produced by animal type*
Anim_Nitro(1)	0.26		Nitrogen ratio produced by animal type*
Anim_Nitro(2)	0.13		Nitrogen ratio produced by animal type*
Anim_Nitro(3)	0.03		Nitrogen ratio produced by animal type*

**A 1,000 pound slaughter steer is used as a standard in representing the amount of each pollutant produced on a regular basis. Thus, the amount of pollutant produced by a beef animal is represented by a value of one, with the amount produced by all other animals being relative to that.*

Table A8 - Additional Erosion$^{Non-Grid}$

Variable	*Sample*	*Unit*	*Variable Description*
Eros_Type	Gully		Type of additional erosion (option)
Eros_Amount	2	tons	Amount of additional erosion
Eros_SoilType	1		Soil texture (default = from cell soil texture)
SoilBack_Nitro	0.2000	lb/lb soil	Nitrogen background concentration in soil
SoilBack_Phos	0.2500	lb/lb soil	Phosphorus background concentration in soil
Desc_ErosType	other...		Description by user for 'other' option

Table A9 - Impoundment$^{Non-Grid}$

Variable	*Sample*	*Unit*	*Variable Description*
Imp_Area	1.5	acre	Drainage area
Diam_Pipe	1	in	Diameter of pipe outlet
Inf_Rate	0.70	in/hr	Infiltration rate (default)

Table A10 - Channel Information^{Grid}

Variable	*Sample*	*Unit*	*Variable Description*
Chan_Width	12.00	ft	Channel Width (NonGeomorphic)
Chan_WidthCoef	3.4250		Default =3.4250 -always value
Chan_WidthExp	0.3151		Default =0.3151 -always value
Chan_Depth	2.80	ft	Channel Depth (NonGeomorphic)
Chan_DepthCoef	0.4537		Default =0.4537 -always value
Chan_DepthExp	0.2192		Default =0.2192 -always value
Chan_Length	135.00	ft	Channel Length (NonGeomorphic)
Chan_LengthCoef	153.000		Default =153.000 -always value
Chan_LengthExp	0.6000		Default =0.6000 -always value
Chan_Slope	1.80	%	Default =1/2 LandSlope -always value
Chan_SideSlope	10.00	%	Default =10 -always value
Chan_ManningN	0.040		Default =0.040 -always value
UseDecay	Yes		Use AGNPS Decay values (yes/no)
Decay_Nitro	50	%	Nitrogen decay percent
Decay_Phos	50	%	Phosphorus decay percent
Decay_COD	50	%	COD decay percent
Allow_Clay	x		Allow scouring of Clay
Allow_Silt	x		Allow scouring of Silt
Allow_SAgg	x		Allow scouring of Small Aggregates
Allow_LAgg	x		Allow scouring of Large Aggregates
Allow_Sand	x		Allow scouring of Sand

Section A.2. AGNPS Output Tables (Reference - Table 4.1b):

Table A11 - Watershed Summary$^{One\ Record/Grid}$

Variable	*Sample*	*Unit*	*Variable Description*
Watershed_ID	Title		Watershed Identification
DrainArea_Ttl	660.00	acres	Drainage Area of the Watershed
AreaBaseCell	40.00	acres	Area of each Base Cell
Precipitation	4.40	inches	Characteristic Storm Precipitation
EIValue	56.00		Storm Energy-Intensity Value
OutletCell	16,400		Watershed Outlet Cell
RunoffVolume	2.00	inches	Runoff Volume
PeakRate	552.00	cfs	Peak Runoff Rate
SedimentYield	174.68	tons	Total Sediment Yield
NitroSed	0.91	lbs/acre	Total Nitrogen in sediment
NitroRun	0.01	lbs/acre	Total Soluble Nitrogen in Runoff
NitroConcRun	0.02	ppm	Soluble Nitrogen Concentration in Runoff
PhosSed	0.46	lbs/acre	Total Phosphorus in sediment
PhosRun	0.00	lbs/acre	Total Soluble Phosphorus in Runoff
PhosConcRun	0.00	ppm	Soluble Phosphorus Concentration in Runoff
CODRun	0.25	lbs/acre	Total Soluble COD in Runoff
CODConcRun	0.56	ppm	Soluble COD Concentration in Runoff

Table A12 - Sediment Analysis[One Record/Grid]

Variable	*Sample*	*Unit*	*Variable Description*
ClayAreaEUpland	0.07	ton/acre	Upland Area Weighted Clay Erosion
ClayDeliverRatio	97	%	Clay Delivery Ratio
ClayEnrichRatio	5		Clay Enrichment Ratio
ClayMeanConc	392.12	ppm	Clay Mean Concentration
ClayAreaYield	0.09	ton/acre	Area Weighted Clay Yield
ClayYield	58.50	tons	Total Clay Yield
SiltAreaEUpland	0.09	ton/acre	Upland Area Weighted Silt Erosion
SiltDeliverRatio	54	%	Silt Delivery Ratio
SiltEnrichRatio	3		Silt Enrichment Ratio
SiltMeanConc	231.49	ppm	Silt Mean Concentration
SiltAreaYield	0.05	ton/acre	Area Weighted Silt Yield
SiltYield	35.54	tons	Total Silt Yield
SAggAreaEUpland	0.58	ton/acre	Upland Area Weighted Small Agg. Erosion
SAggDeliverRatio	15	%	Small Agg. Delivery Ratio
SAggEnrichRatio	1		Small Agg. Enrichment Ratio
SAggMeanConc	381.12	ppm	Small Agg. Mean Concentration
SAggAreaYield	0.09	ton/acre	Area Weighted Small Agg. Yield
SAggYield	56.86	tons	Total Small Agg. Yield
LAggAreaEUpland	0.35	ton/acre	Upland Area Weighted Large Agg. Erosion
LAggDeliverRatio	8	%	Large Agg. Delivery Ratio
LAggEnrichRatio	0		Large Agg. Enrichment Ratio
LAggMeanConc	127.43	ppm	Large Agg. Mean Concentration
LAggAreaYield	0.03	ton/acre	Area Weighted Large Agg. Yield
LAggYield	19.01	tons	Total Large Agg. Yield
SandAreaEUpland	0.07	ton/acre	Upland Area Weighted Sand Erosion
SandDeliverRatio	11	%	Sand Delivery Ratio
SandEnrichRatio	1		Sand Enrichment Ratio
SandMeanConc	38.62	ppm	Sand Mean Concentration
SandAreaYield	0.01	ton/acre	Area Weighted Sand Yield
SandYield	5.76	tons	Total Sand Yield
TotalAreaEUpland	1.17	ton/acre	Upland Area Weighted Total Erosion
TotalDeliverRatio	23	%	Total Delivery Ratio
TotalEnrichRatio	1		Total Enrichment Ratio
TotalMeanConc	1170.76	ppm	Total Mean Concentration
TotalAreaYield	0.26	ton/acre	Area Weighted Total Yield
TotalYield	174.68	tons	Total Sediment Yield

Table A13 - Hydrology[Grid]

Variable	*Sample*	*Unit*	*Variable Description*
DrainArea	80.00	acres	Drainage Area
OverlandRunoff	1.90	in	Overland Runoff
UpStrmRunoff	1.90	in	Upstream Runoff
UpStrmPeakF	97.38	cfs	Peak Flow Upstream
DownStrmRunoff	1.90	in	Downstream Runoff
DownStrmPeakF	133.22	cfs	Peak Flow Downstream
GenAbRunoff	50.0	%	Runoff Generated Above

Table A14 - Sediments^{Grid}

Variable	*Sample*	*Unit*	*Variable Description*
ClayCellErosion	0.05	ton/acre	Clay Cell Erosion
ClayGenAbove	1.56	tons	Clay Generated Above Cell
ClayGenWithin	1.93	tons	Clay Generated Within Cell
ClayCellYield	3.30	tons	Clay Cell Yield
ClayDeposition	5	%	Clay Cell Deposition
SiltCellErosion	0.08	ton/acre	Silt Cell Erosion
SiltGenAbove	1.94	tons	Silt Generated Above Cell
SiltGenWithin	3.09	tons	Silt Generated Within Cell
SiltCellYield	1.49	tons	Silt Cell Yield
SiltDeposition	70	%	Silt Cell Deposition
SAggCellErosion	0.48	ton/acre	Small Agg. Cell Erosion
SAggGenAbove	5.04	tons	Small Agg. Generated Above Cell
SAggGenWithin	19.29	tons	Small Agg. Generated Within Cell
SAggCellYield	1.03	tons	Small Agg. Cell Yield
SAggDeposition	96	%	Small Agg. Cell Deposition
LAggCellErosion	0.30	ton/acre	Large Agg. Cell Erosion
LAggGenAbove	0.10	tons	Large Agg. Generated Above Cell
LAggGenWithin	11.96	tons	Large Agg. Generated Within Cell
LAggCellYield	1.48	tons	Large Agg. Cell Yield
LAggDeposition	88	%	Large Agg. Cell Deposition
SandCellErosion	0.06	ton/acre	Sand Cell Erosion
SandGenAbove	0.03	tons	Sand Generated Above Cell
SandGenWithin	2.32	tons	Sand Generated Within Cell
SandCellYield	0.45	tons	Sand Cell Yield
SandDeposition	81	%	Sand Cell Deposition
TotalCellErosion	0.96	ton/acre	Total Cell Erosion
TotalGenAbove	8.67	tons	Total Generated Above Cell
TotalGenWithin	38.59	tons	Total Generated Within Cell
TotalCellYield	7.75	tons	Total Cell Yield
TotalDeposition	85	%	Total Cell Deposition

Table A15 - Nutrients^{Grid}

Variable	*Sample*	*Unit*	*Variable Description*
NitroSedWCell	3.07	lbs/acre	Nitrogen in Sediment Within Cell
NitroSedOCell	0.39	lbs/acre	Nitrogen in Sediment Cell Outlet
NitroWatWCell	2.92	lbs/acre	Nitrogen in Water Within Cell
NitroWatOCell	0.46	lbs/acre	Nitrogen in Water Cell Outlet
NitroConc	1.06	ppm	Nitrogen Concentration in Water
PhosSedWCell	1.54	lbs/acre	Phosphorus in Sediment Within Cell
PhosSedOCell	0.20	lbs/acre	Phosphorus in Sediment Cell Outlet
PhosWatWCell	0.59	lbs/acre	Phosphorus in Water Within Cell
PhosWatOCell	0.09	lbs/acre	Phosphorus in Water Cell Outlet
PhosConc	0.22	ppm	Phosphorus Concentration in Water
CODWatWCell	36.93	lbs/acre	COD in Water Within Cell
CODWatOCell	5.69	lbs/acre	COD in Water Cell Outlet
CODConc	13.25	ppm	COD Concentration in Water

Table A16 - Pesticide^{Grid}

Variable	*Sample*	*Unit*	*Variable Description*
DrainArea	80.00	acres	Drainage Area
PestMassWatWCell	0.02	lbs/acre	Pesticide Mass in Water Within Cell
PestConcWatWCell	0.04	ppm	Pesticide Concentration in Water Within Cell
PestPtgApWatWCell	0.75	%	Pesticide % of Application in Water Within Cell
PestMassWatOCell	0.01	lbs/acre	Pesticide Mass in Water at Cell Outlet
PestConcWatOCell	0.01	ppm	Pesticide Concentration in Water at Cell Outlet
PestMassSedWCell	0.00	lbs/acre	Pesticide Mass in Sediment Within Cell
PestConcSedWCell	0.95	ppm	Pesticide Concentration in Sediment Within Cell
PestPtgApSedWCell	0.02	%	Pesticide % of Application in Sediment Within Cell
PestMassSedOCell	0.00	lbs/acre	Pesticide Mass in Sediment at Cell Outlet
PestConcSedOCell	0.00	ppm	Pesticide Concentration in Sediment at Cell Outlet
PestMassPercWCell	0.05	lbs/acre	Pesticide Percolation Mass Within Cell
PestPtgApPercWCell	2.00	%	Pesticide Percolation % of Application Within Cell

Table A17 - Landuse Summary^{Grid}

Variable	*Sample*	*Unit*	*Variable Description*
BareGround	26	%	*LU - Class(1) = Bare ground
Forests	10	%	*LU - Class(2) = Forests
Crops	53	%	*LU - Class(3) = Fields with crops or low vegetation
Wetlands	10	%	*LU - Class(4) = Wetlands
Water	1	%	*LU - Class(5) = Water (nclass + 1)
Impervious	0	%	*LU - Class(6) = Impervious (nclass + 2)

*The number of variables depend on the classification scheme selected when creating the database structure.

Table A18 - Source_Deposition^{Grid}

Variable	*Sample*	*Unit*	*Variable Description*
clay_sheet	5159.86	lbs	Sheet clay source
clay_gully	0.00	lbs	Gully clay source
silt_sheet	8255.77	lbs	Sheet silt source
silt_gully	0.00	lbs	Gully silt source
sagg_sheet	51598.55	lbs	Sheet small aggregates source
sagg_gully	0.00	lbs	Gully small aggregates source
lagg_sheet	31991.10	lbs	Sheet large aggregates source
lagg_gully	0.00	lbs	Gully large aggregates source
sand_sheet	6191.83	lbs	Sheet sand source
sand_gully	0.00	lbs	Gully sand source
sed_n_overland	246.68	lbs	Sediment attached nitrogen in overland flow
sed_n_gully	0.00	lbs	Sediment attached nitrogen in gully erosion
sed_n_impound	246.68	lbs	Sediment attached nitrogen in impoundments
sed_p_overland	0.00	lbs	Sediment attached phosphorus in overland flow
sed_p_gully	1973.42	lbs	Sediment attached phosphorus in gully erosion
sed_p_impound	0.00	lbs	Sediment attached phosphorus in impoundments
sol_n_overland	2466.77	lbs	Soluble nitrogen in overland flow
sol_n_fertilizer	0.00	lbs	Soluble nitrogen due to fertilizer application
sol_n_feedlots	7400.32	lbs	Soluble nitrogen due to feedlots
sol_p_overland	857.98	lbs	Soluble phosphorus in overland flow

Table A18 - Source_Deposition^{Grid} (Cont)

Variable	*Sample*	*Unit*	*Variable Description*
sol_p_fertilizer	0.00	lbs	Soluble phosphorus due to fertilizer application
sol_p_feedlots	464.66	lbs	Soluble phosphorus due to feedlots
sol_cod_overland	0.00	lbs	Soluble COD in overland flow
sol_cod_feedlots	476.69	lbs	Soluble COD due to feedlots
runoff_volume	145.13	in-acre	Runoff volume
clay_bed	0.00	lbs	Bed and banks clay
clay_deposition	561.03	lbs	Deposition of clay
silt_bed	0.00	lbs	Bed and banks silt
silt_deposition	7347.65	lbs	Deposition of silt
sagg_bed	0.00	lbs	Bed and banks small aggregates
sagg_deposition	51317.55	lbs	Deposition of small aggregates
lagg_bed	0.00	lbs	Bed and banks large aggregates
lagg_deposition	31586.30	lbs	Deposition of large aggregates
sand_bed	0.00	lbs	Bed and banks sand
sand_deposition	6069.15	lbs	Deposition of sand
sed_n_deposition	246.68	lbs	Sediment attached deposition for nitrogen
sed_p_deposition	0.00	lbs	Sediment attached deposition for phosphorus
sol_n_decay	246.68	lbs	Water soluble decay of nitrogen
sol_p_decay	0.00	lbs	Water soluble decay of phosphorus
sol_cod_decay	1973.42	lbs	Water soluble decay of COD
sol_n_nonfeedlots	0.00	lbs	Water soluble nitrogen yield due to nonfeedlots
sol_p_nonfeedlots	2466.77	lbs	Water soluble phosphorus yield due to nonfeedlots
sol_cod_nonfeedlots	0.00	lbs	Water soluble COD yield due to nonfeedlots
sol_n_impoundments	0.00	lbs	Water soluble nitrogen yield due to impoundments
sol_p_impoundments	0.00	lbs	Water soluble phosphorus yield due to impoundments

*This variables are read from the binary files when AGNPS is executed with the accounting option selected.

Section A.3. WATFLOOD Input Tables (Reference - Table 4.2):

Table A19- Initial Watershed Data[One Record/Grid]

Variable	*Sample*	*Unit*	*Variable Description*
Watershed Data			
Watershed_ID	Title		Watershed identification
IYMin	4790	km	Northing coordinate (From Coordinates Table)
IYMax	4900	km	Northing coordinate (From Coordinates Table)
JXMin	500	km	Easting coordinate (From Coordinates Table)
JXMax	580	km	Easting coordinate (From Coordinates Table)
GridSize	10000	m	Converted to m from GridSize in km (Coordinates)
Storms	3		LS - Maximum number of storm events *Not used
PrecStat	1		KS - Number of precipitation stations *Not used
StreamStat	9		JS - Number of streamflow stations *Not used
MaxLenRec	123	hrs	IH - Lenght of streamflow record *Not used
Local	0		LOCAL - Number of reservoirs *Used by developers
ContInterv	10	m	CINTVL - Contour interval
Impervious	0	%	IMPR - % of urban area that is impervious
PermClasses	5		NTYPE - Number of classes
Conversion	1		ELVCONV - Toggle (1=S.I. ; 0.305=Imperial)
Water Quality Data			
Nitrog_Rain	0.80	ppm	Nitrogen Concentration in Rainfall
Decay_Nitro	50	%	Nitrogen decay percent
Decay_Phos	50	%	Phosphorus decay percent
Soil_Nitro	0.0010	g N/g soil	Nitrogen concentration in soil
Soil_Phos	0.0005	g N/g soil	Phosphorus concentration in soil
PoreW_Nitro	5.00	ppm	Nitrogen concentration in pore water
PoreW_Phos	2.00	ppm	Phosphorus Concentration in pore water
ExtR_Nitro	0.05		Nitrogen extraction coefficient for runoff
ExtR_Phos	0.025		Phosphorus extraction coefficient for runoff

Table A20 - General Cell Data[Grid]

Variable	*Sample*	*Unit*	*Variable Description*
RiverElev	781	m	ELV- Channel invert elevation
DrainArea	100	%	FRAC - Element drainage area
FlowDirection	5		S - Drainage direction
RiverType	1		IBN - River classification (1 to 5)
Contours	4		IROUGH - Contour density (No. of contours)
Channels	1		ICHNL - Channel density (No. of channels)
ExtRouting	0		IREACH - Routing reach number (External routing)
BareGround	26	%	*LU - Class(1) = Bare ground
Forests	10	%	*LU - Class(2) = Forests
Crops	53	%	*LU - Class(3) = Fields with crops or low vegetation
Wetlands	10	%	*LU - Class(4) = Wetlands
Water	1	%	*LU - Class(5) = Water (nclass + 1)
Impervious	0	%	*LU - Class(6) = Impervious (nclass + 2)

*The number of variables depend on the classification scheme selected when creating the database structure.

Table A21 - Soil^{Grid}

Variable	*Sample*	*Unit*	*Variable Description*
sand	0.0996	%	Soil type percentage (texture)
loamy sand	0.8120	%	Soil type percentage (texture)
sandy loam	0.7288	%	Soil type percentage (texture)
loam	0.1157	%	Soil type percentage (texture)
silt loam	0.4407	%	Soil type percentage (texture)
silt	0.8084	%	Soil type percentage (texture)
sandy clay loam	0.0996	%	Soil type percentage (texture)
clay loam	0.1470	%	Soil type percentage (texture)
silty clay loam	0.3228	%	Soil type percentage (texture)
sandy clay	0.8084	%	Soil type percentage (texture)
silty clay	0.1157	%	Soil type percentage (texture)
clay	0.7288	%	Soil type percentage (texture)
SizeD50	0.035	mm	d50 - Particle median diameter
SpecWght	2.01	-	Particle specific weight
Erodibility	1.553	g/J	D - Soil erodibility factor

Table A22 - Fertilizer^{Grid}

Variable	*Sample*	*Unit*	*Variable Description*
Applied_Nitro	200	lb/acre	Nitrogen applied
Applied_Phos	80	lb/acre	Phosphorus applied
AvFac_Nitro	45	%	Availability factor for nitrogen
AvFac_Phos	55	%	Availability factor for phosphorus

Table A23 - Pesticide$^{One\ Record/Grid}$

Variable	*Sample*	*Unit*	*Variable Description*
Com_Name	ATRAZINE		Common Pesticide Name (DB)
Trad_Name	ATRATOL		Trade Name (DB)
Type_App	Preplant		Type of application (option value)
App_Time	5.0	days	Time since application
App_Rate	2.00	lb/acre	Application rate
App_Effic	75	%	Application efficiency (default=75)
Per_CanCov	20	%	Percent canopy cover (default=20)
SoilRes_Init	0.10	lb/acre	Initial soil residue
SoilRes_Half	60.0	days	Soil residue half life (DB)
Inc_Depth	1.00	in	Incorporation depth (default=1.0
Inc_Effic	75	%	Incorporation efficiency
Solub_Wat	33.000	ppm	Solubility in water (DB)
OrgCar_Koc	100.000		Organic carbon sorption Koc (DB)
FolRes_Init	0.00	lb/acre	Initial foliar residue
FolWash_Thres	0.10	in	Foliar washoff threshold (default=0.10)
FolWash_Frac	45	%	Foliar washoff fraction (DB)
FolRes_Half	5.0	days	Foliar residue half life (DB)

(DB) - Available from Pesticide Data Base

APPENDIX B. Lookup Tables for AGNPS and WATFLOOD Interfaces

Section B.1 Soil Lookup Table (Map Codes and Data)

Table B1. Soil Type Map Codes*

Map	*Name*	*Lookup: SCS*
B.L.	BOTTOM LAND	sand
Bl	BONDHEAD	loam
Brsl	BRIGHTON	sandy loam
Brsl-st	BRIGHTON	sandy loam
Brsl/g	BRIGHTON	sandy loam
Bs	BONDHEAD	sandy loam
Cac	CASHEL	clay
Dal	DARLINGTON	loam
Jc	JEDDO	clay loam
Kis	KING	silt loam
Ll	LYONS	loam
M	MUCK	sand
Ma	MARSH	sand
Ml	MILLIKEN	loam
Moc	MONOGHAN	clay loam
Pec	PEEL	clay loam
Ps	PONTYPOOL	sand
Psl	PONTYPOOL	sandy loam
Scl	SMITHFIELD	clay loam
Shc	SCHOMBERG	clay loam
Tsl	TECUMSETH	sandy loam
Tsl-st	TECUMSETH	sandy loam
Wol	WOBURN	loam
Wos	WOBURN	sandy loam

**Examples from arbitrary soil type layer.*

Table B2. Soil Type Data Table

SCS Code	*Soil Class*	*HSC*	*SText*	*K*	D_{50}	*SpG*
s	sand	A	1	0.01	0.110	2.455
ls	loamy sand	A	1	0.05	0.130	2.293
sl	sandy loam	B	1	0.14	0.105	2.111
l	loam	B	2	0.31	0.075	2.009
sil	silt loam	C	2	0.37	0.035	2.099
si	silt	C	2	0.42	0.015	1.920
scl	sandy clay loam	B	1	0.22	0.330	1.949
cl	clay loam	C	3	0.29	0.310	1.857
sicl	silty clay loam	C	2	0.31	0.038	1.977
sc	sandy clay	B	1	0.15	0.550	1.849
sic	silty clay	C	3	0.24	0.100	1.920
c	clay	D	3	0.20	0.610	1.840

HSC-Soil Group: SText-Soil Texture: K-K factor: D_{50} *-Median Particle Size: SpG - Specific Weight*

Section B.2 Landuse Lookup Table (Map Codes and Data)

Table B3. Landuse Map Codes*

Map Description	*MCode*	*Lcode - Description*	
Water	W	NUWa	Water
Agricultural land idle <10yrs	A1	NUHw	Heavy weeds
Agricultural land idle >10yrs	A2	NUWol	Woods (light)
Built up (Urban)	B	UrRe	Urban residential
Corn or beans system	C	NURc	Row crops
Extraction, sand & gravel pits	E1	UrGd	Gravel and dirt
Extraction, topsoil removal	E2	UrTs	Topsoil removal
Grazing systems	G	NUMe	Meadow
Hay system	H	NUFa	Farmsteads
Pasture system	HG	NUGr	Grass and pasture
Field Vegetables	KF	NULe	Legumes
Market Gardens	KM	NUFa	Farmsteads
Mixed System	M	NULe	Legumes
Grain System	MG	NUSg	Small grains
Orchard	OR	NUFr	Fruits
Continuous row crops	P	NURc	Row crops
Recreation	R	UrGr	Short grass
Sod Farms	T	NUGr	Grass and pasture
Swamp, marsh - wetland	X	NUWe	Wetland
Woodland	Z	NUWod	Woods (dense)
Pastured Woodland	ZP	NUWol	Woods (light)
Reforestation	ZR	UrDt	Dense turf

**Examples from arbitrary landuse layer.*

Table B4. Landuse Data Table

Land Code	*LandUse*	*Man n*	*SrfCond*	*Curve Numbers (SGroups)* A	B	C	D	*COD_Fac*	*C_Fac*
	Urban zones								
UrRe	Urban residential	0.011	0.00	90	90	90	90	10	0
UrCo	Urban comercial	0.012	0.00	95	95	95	95	10	0
UrSp	Street pavement	0.013	0.00	98	98	98	98	10	0
UrAs	Asphalt	0.014	0.00	100	100	100	100	10	0
UrGd	Gravel and dirt	0.025	0.01	75	83	88	90	10	0.1
UrTs	Topsoil removal	0.030	0.05	70	80	85	87	10	0.02
UrLt	Light turf	0.200	0.15	47	67	81	88	30	0.04
UrDt	Dense turf	0.350	0.30	25	59	75	83	50	0.08
UrFo	Forest litter	0.400	0.60	36	60	73	79	65	0.01
UrGr	Short grass	0.032	0.15	68	79	86	89	30	0.05
UrHg	High grass	0.040	0.25	49	69	79	84	50	0.07
	Rural zones								
NUHw	Heavy weeds	0.060	0.50	39	61	74	80	65	0.09
NUFf	Fallow field	0.100	0.22	77	86	91	94	115	0.1
NULe	Legumes	0.200	0.30	58	72	81	85	60	0.3
NUFr	Fruits	0.300	0.40	40	62	76	81	40	0.2
NUMe	Meadow	0.400	0.50	30	58	71	78	20	0.1
NUFa	Farmsteads	0.080	0.01	59	74	82	86	80	0.25
NUGr	Grass and pasture	0.040	0.22	49	69	79	84	60	0.05
NUSg	Small grains	0.250	0.29	65	75	83	87	80	0.35
NURc	Row crops	0.100	0.15	67	78	85	89	170	0.5
NUWol	Woods (light)	0.400	0.25	36	60	73	79	45	0.01
NUWod	Woods (dense)	0.800	0.35	25	55	70	77	65	0.001
NUWa	Water	0.990	0.00	100	100	100	100	0	0
NUWe	Wetland	0.990	0.00	85	85	85	85	25	0

SGroups-Soil Group: Man n-Manning's n ; COD_Fac-COD Factor ; C_Fac-Cover Factor; SrfCond-Surface Condition

Table B5. Land Classes Schemes

ClassNo	*ClassType*	*Typical Land Code*	*GC*	*CF*
Class 6	Impervious	UrRe	0.1	0.9
	Bareground	UrGd	0.1	0.9
	Forests	NUWod	0.8	0.4
	Crops_LowVeg	NUSg	0.5	0.6
	Wetlands	NUWe	0.6	0.5
	Water	NUWa	0	0
Class 10	Impervious	UrRe	0.1	0.9
	Bareground_Light	NUFf	0.1	0.9
	Bareground_Dark	UrTs	0.2	0.85
	Forests_Light	NUWol	0.8	0.35
	Forests_Dense	NUWod	0.9	0.3
	Grass	NUGr	0.5	0.6
	Crops_Low	NUSg	0.6	0.5
	Crops_High	NURc	0.7	0.4
	Wetlands	NUWe	0.6	0.5
	Water	NUWa	0	0

GC-Ground Cover Density ; CF-Canopy Cover Factor (Source Wischmeier and Smith, 1978)

APPENDIX C. Details of the AGNPS and WATFLOOD Interfaces

The following is a detailed description of the AGNPS and WATFLOOD interfaces. It is presented according to the sequence of the toolbars in the main interface windows. The outline of the different toolbars corresponds to the Section *4.3.2 Description of the Interface*:

C1. Make/Edit Grid toolbar
- *Initialize Database*
- *Create Grid*
- *Create Tables*
- *Edit Grid*

C2. Collect/Edit Data toolbar
- *Initial Data*
- *Collect Data*
- *Flow Direction*
- *Cells Editor*
- *Additional Cell Data (*Soil Texture, Fertilizer, Pesticide, Point Source, Additional Erosion, Impoundment and Channel*)*

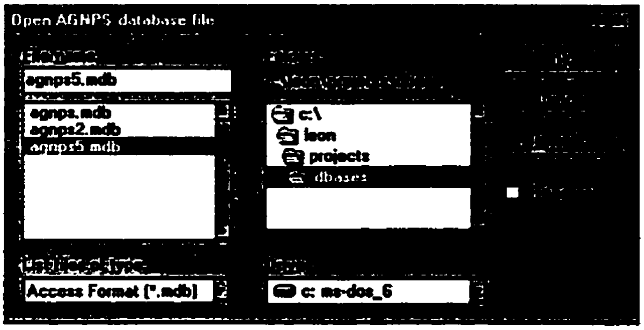
C3. Run Model toolbar
- *Write ASCII File*
- *Run Model*

C4. Display Input/Output toolbar
- *Edit Ranges*
- *Graphic Display I/O*
- *Tabular Results*
- *Trace Contribution*

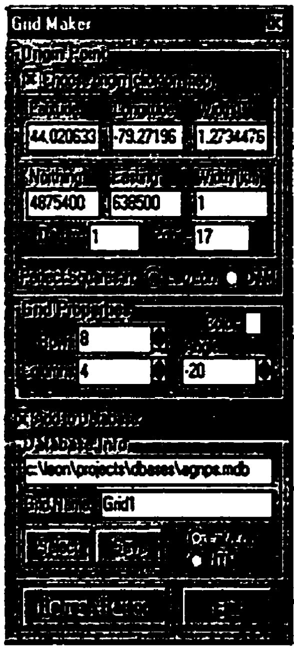
C5. Analysis/Scenarios toolbar
- *Duplicate Grid*
- *Modify Landuse*
- *Summarize Runs*
- *Sensitivity Analysis*

C1. Make/Edit Grid Toolbar

Initialize Database: Will open the *File Dialog Box* that allows the user to select the drive, path and filename of the database to be used in the current window.



Create Grid: Will open the *Grid Maker* window and allows the user to create a basic grid for the watershed to be modeled, and save it to the selected database.



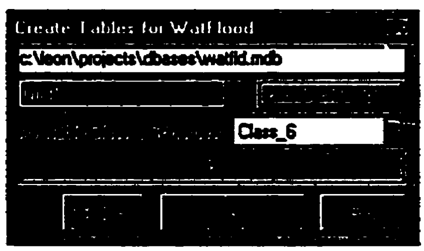
Mark the Choose origin box in order to click with the mouse directly on the current map for the top left corner of the basic grid. The UTM section displays the values in UTM coordinates. Adjustments can be made in the coordinates and grid size. Select the display option for perfect squares.

Input number of rows and columns that will form the basic grid, the angle (rotation of the grid with respect to the map) and the color for the grid.

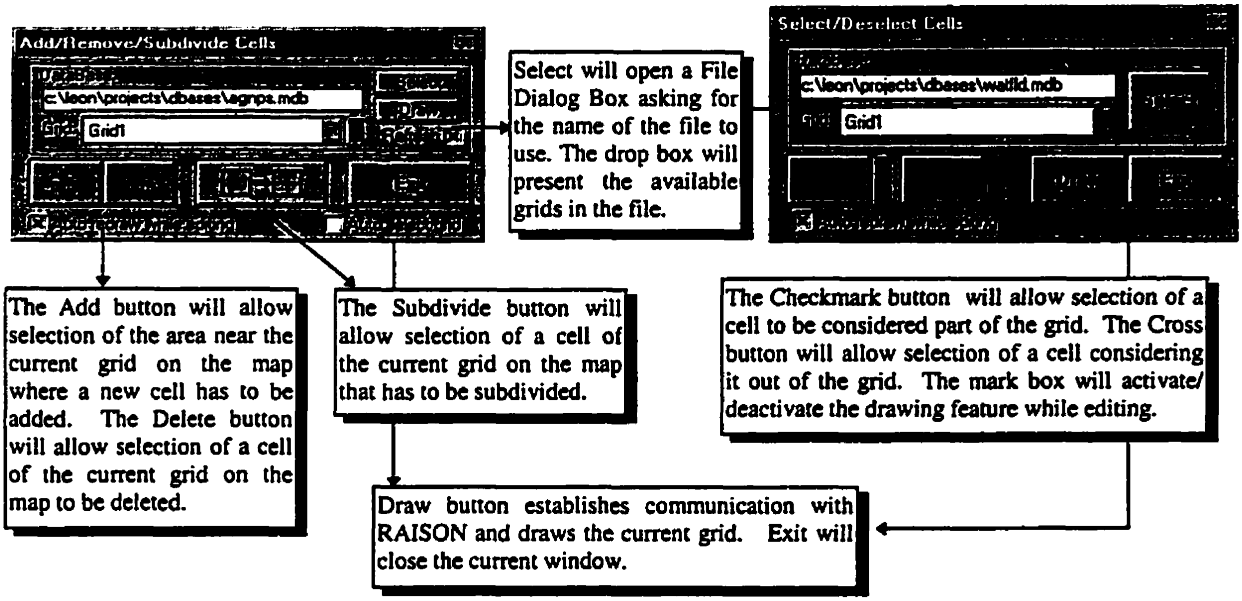
Click in the Add to Database check box and a File Dialog Box will open allowing the user to select the database file for which the grid should be attached. The user must supply the grid name and the projection. The Save button stores the values in the database file.

The Refresh button erases the contents of the map and redraws the map. Exit will close the current window.

Create Tables: Open the *Create Tables* window that allows the user to create the database structure to hold the grid data and results. One database file can hold different grids (ie. for various scenarios). If the tables are already created, no action can be taken other than exit. Otherwise a message will prompt to Create Tables for that grid; a status bar shows the percentage achieved.

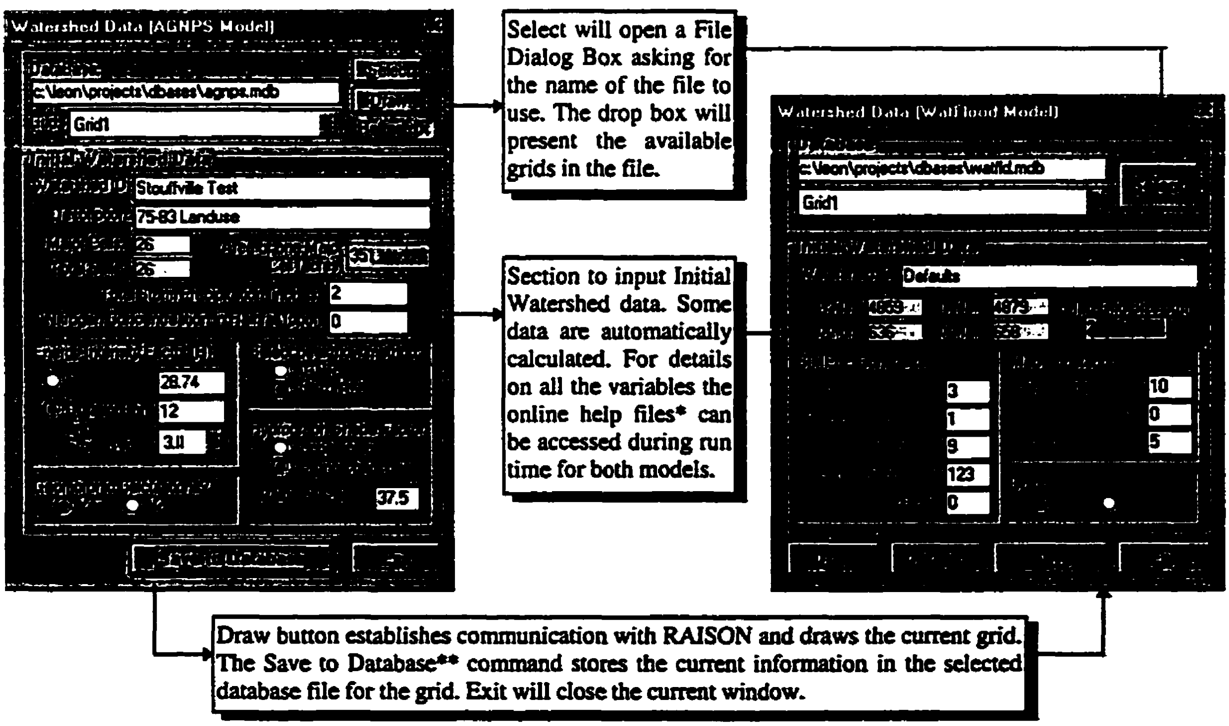


Edit Grid: Will open the *Grid Editor* window and allow the user to modify the basic grid. For the AGNPS model by adding, deleting and subdividing cells (up to three sublevels) and for WATFLOOD by selecting or deselecting cells.



C2. Collect/Edit Data Toolbar

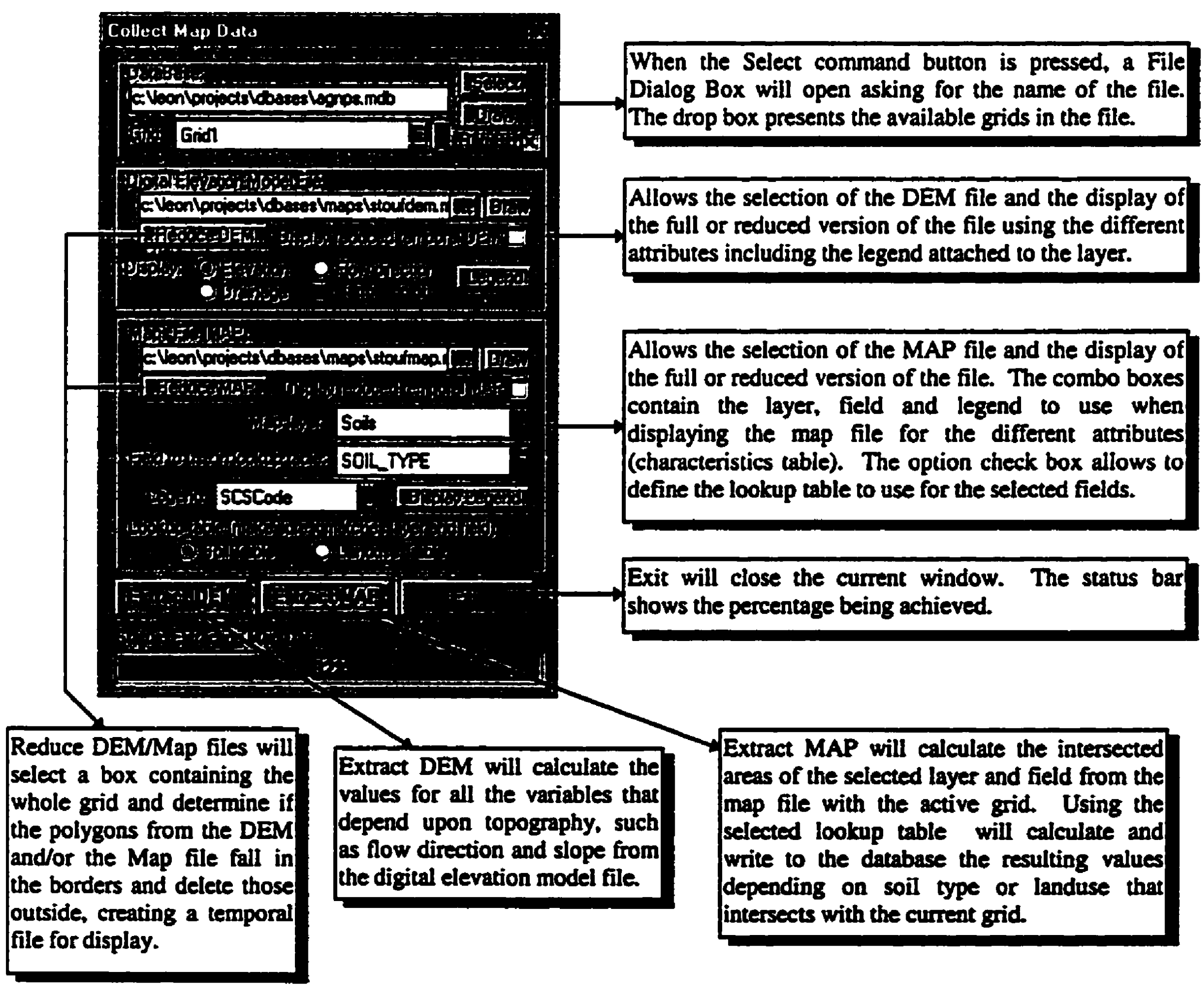
Initial Data: Will open the *Initial Watershed Data* window that allows the user to capture the required initial data for the watershed to be modeled and save them to the selected database.



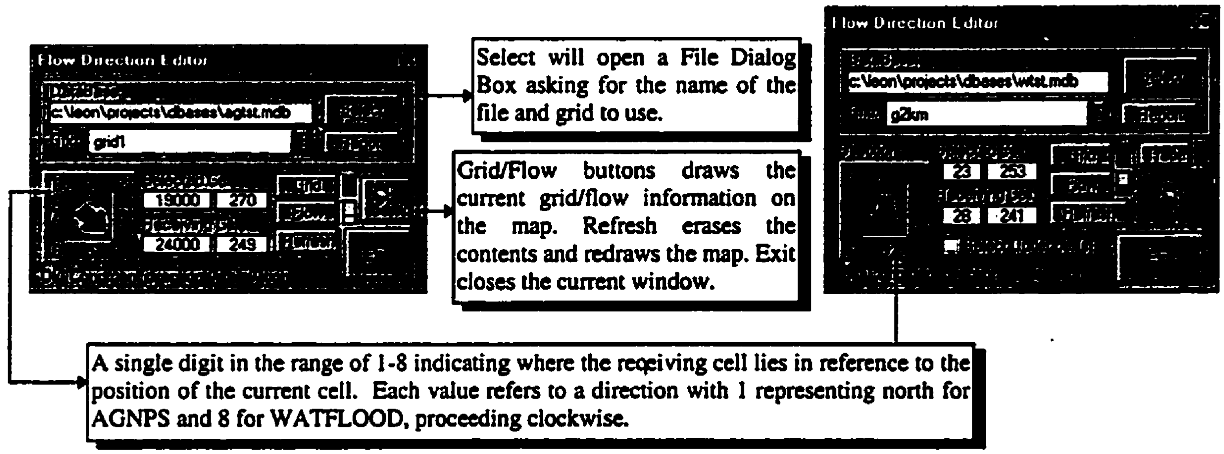
*The help files consists of clickable images that explain the process being described in this chapter. Additionally, the description for all the variables (see Appendix I for details) is included in such a way that the user can identify them with a short explanation. The AGNPS and WATFLOOED help files were produced with information taken from the original manuals (AGNPS-Young *et. al.* 1994, WATFLOOD- Kouwen, 1995).

**When saving to the database, a verification process takes place to see if all the data are valid (ie. positive values) and if no errors are encountered, will then allow them to be saved in the database. If invalid data are found, an error message will appear and the focus will be set to the variable that needs to be re-entered.

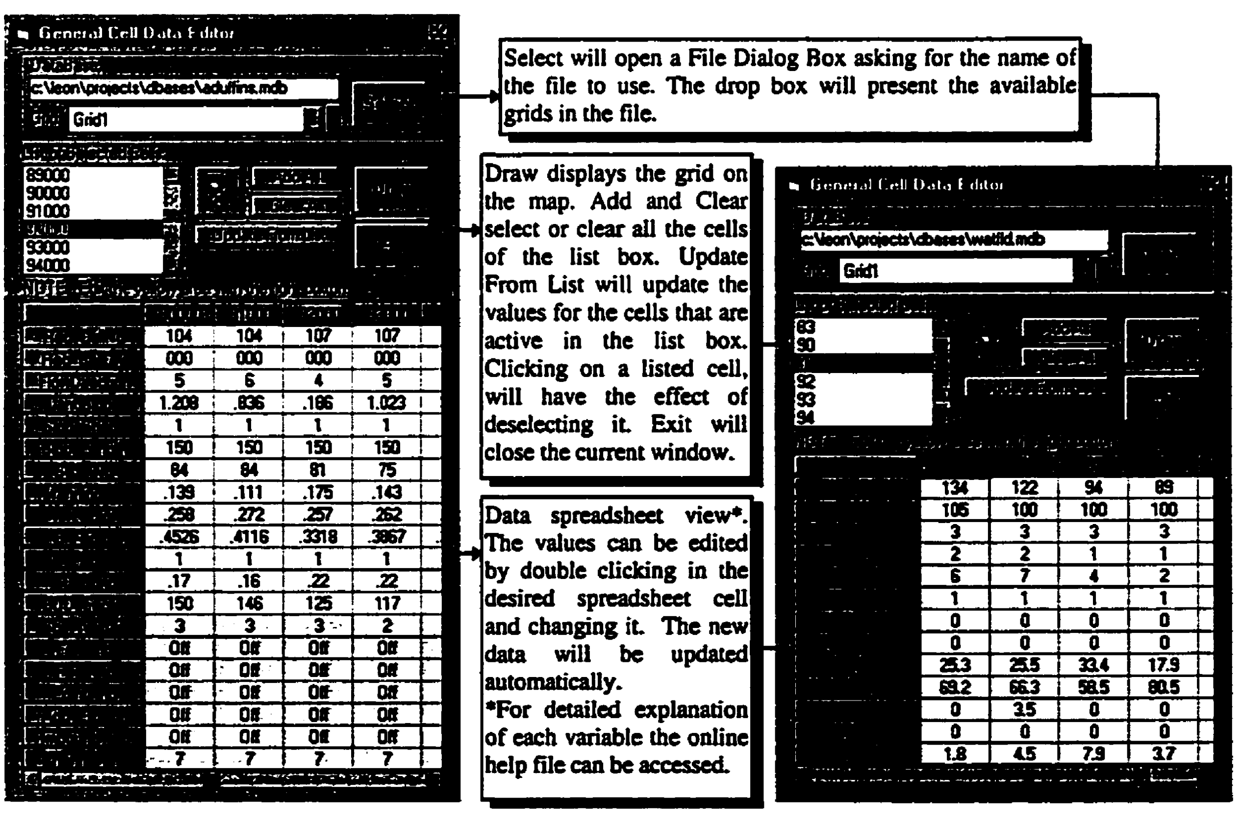
Collect Data: Will open the *Collect Data* window that allows the user to extract the data from maps relative to topography, soil type and landcover. It facilitates the display of the DEM file, and the soil and land use layers from the Map file. The process will calculate the variables that are dependent upon topography, soil and landcover for the selected grid and according to lookup tables as described in the previous chapter.



Flow Direction: Will open the *Flow Direction Editor* window helping the user in the editing of the flow directions and receiving cells *(AGNPS left, WATFLOOD right).*



Cell Editor: Will open the *General Cell Data Editor* that allows the user to edit the cell data for the watershed to be modeled and save them to the selected database. The user can change the values in the spreadsheet view *(AGNPS left, WATFLOOD right).*

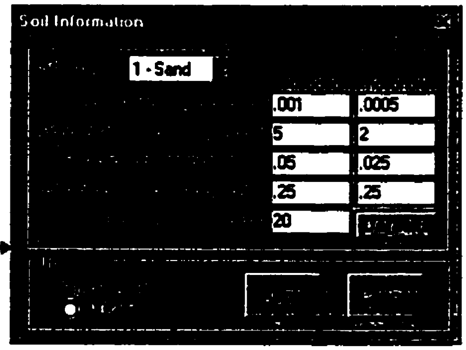


Additional Cell Data

The following variables for the AGNPS model are additional cell related data. When edited, additional windows will pop-up to input/edit the variables related to the additional data:

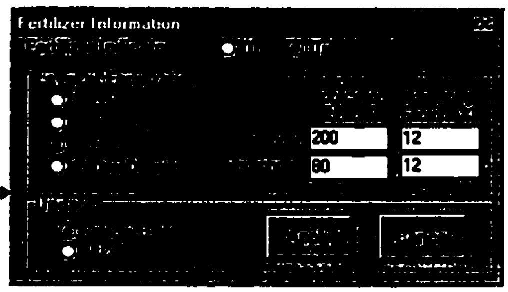
Soil Texture: The major soil texture classification for the cell from the texture triangle. The *Soil Information* window will pop-up to input/edit the values related to this variable. Initially the values will be defaulted from the *Collect Data* procedure.

The Apply command saves the current information in the selected database file for the grid and the selected cells. Cancel will quit saving and close the current window. For a detailed explanation of each variable the user can access the online help file.

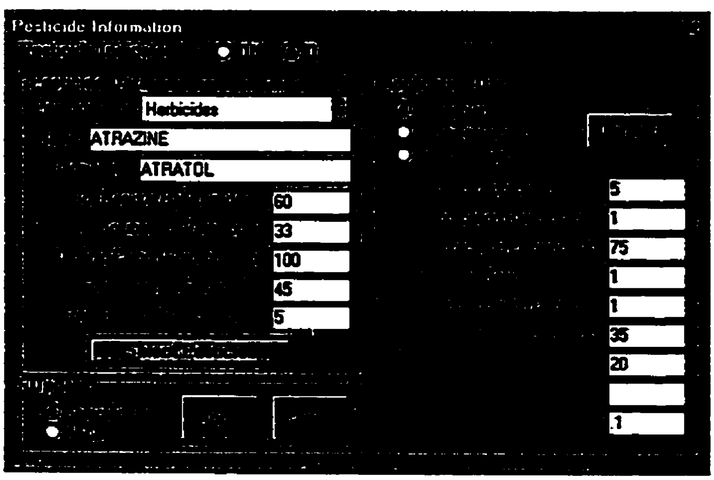


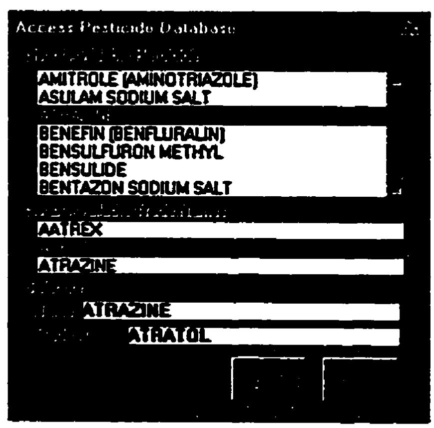
Fertilizer Indicator: A toggle value defines the application of fertilization within the cell. *Off* indicates no fertilization while *On* indicates fertilization being applied. When editing the cell, the *Fertilizer Data* window will appear allowing the data entry.

The Apply command saves the current information in the selected database file for the grid and the selected cells. Cancel will quit saving and close the current window. For a detailed explanation of each variable the user can access the online help file.

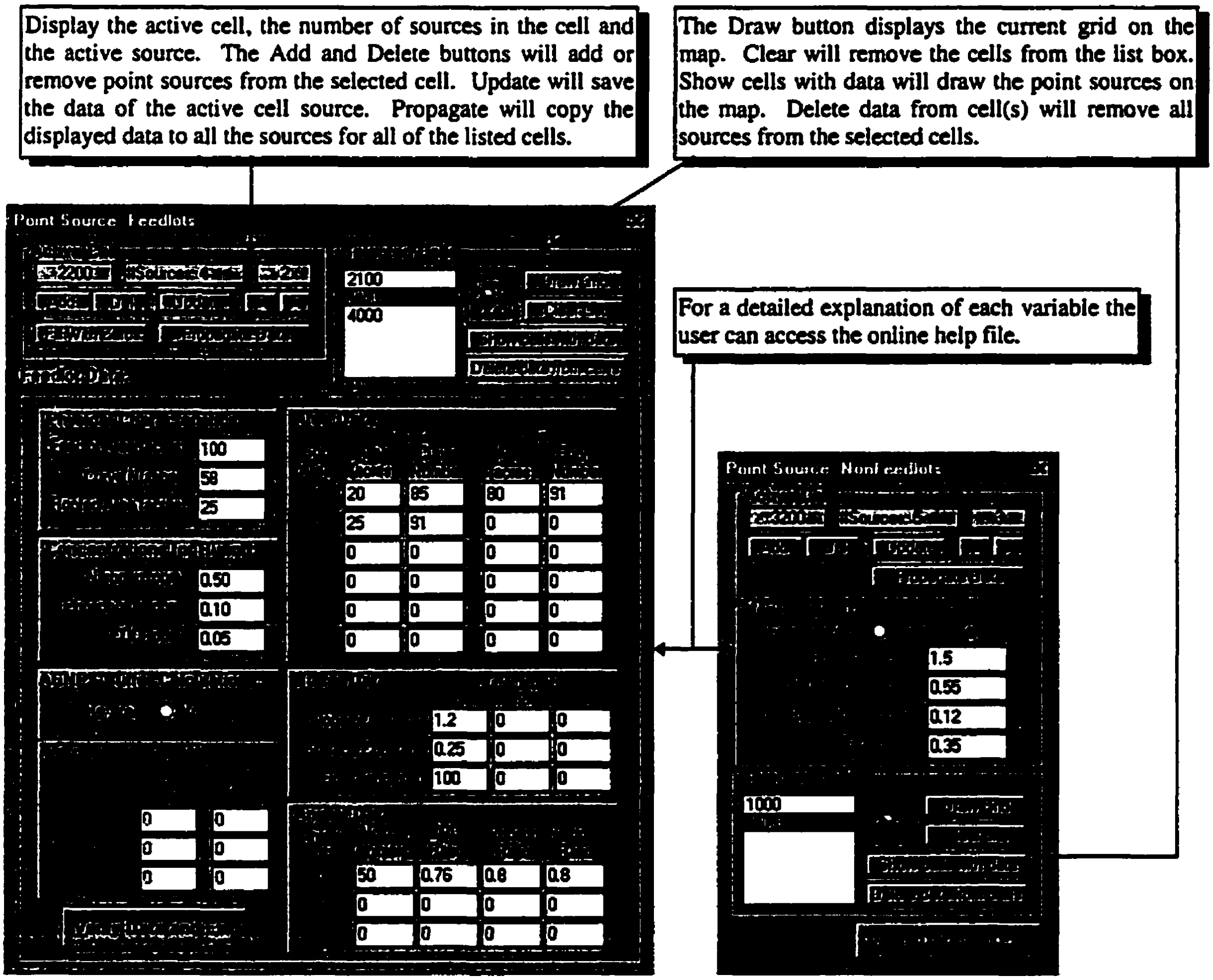


Pesticide Indicator: A toggle value indicating the presence of pesticide application within the cell. *Off* indicates that no pesticide is applied. When editing the cell, the *Pesticide Data* window will appear allowing the selection of the type of pesticide applied within the cell, time of application and other specific pesticide information. The pesticide data can be selected and retreived from the pesticide database (PESTIC.MDB) which was converted to Access format from the file provided with AGNPS.

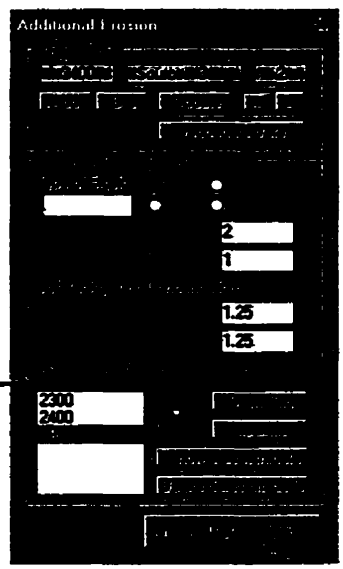




Point Source Indicator: An integer value indicating the presence of point sources (Non-Feedlots and/or Feedlots) within the cell. *Off* indicates no point sources. When editing the cell, the *Point Sources* window will open allowing the selection of Feedlots or Non-Feedlots within the cell. The input window will then pop-up depending on this selection.

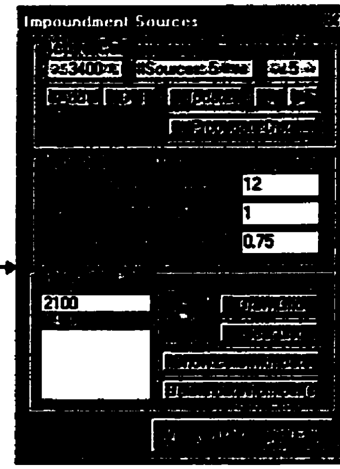


Additional Erosion: An integer value indicating the presence of some type of additional erosion within the cell (Gully, Construction, River Bank, or other). *Off* indicates that no additional erosion is present within the cell. When editing the cell, the *Additional Erosion* window will appear allowing specific information entry for each source within the cell.



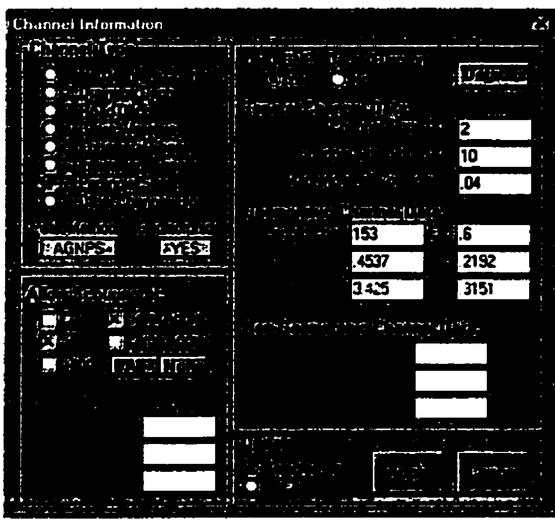
Display the active cell, the number of sources in the cell and the active source. The Add and Delete buttons will add or remove point sources from the selected cell. Update will save the data of the active cell source. Propagate will copy the displayed data to all the sources for all of the listed cells. For a detailed explanation of each variable the user can access the online help file.

Impoundment Indicator: An integer value indicating the presence of impoundment(s) within the cell. *Off* indicates that no impoundments exist within the cell. When editing the cell, the *Impoundment* window will appear allowing specific information for impoundments to be entered.



Display the active cell, the number of sources in the cell and the active source. The Add and Delete buttons will add or remove point sources from the selected cell. Update will save the data of the active cell source. Propagate will copy the displayed data to all the sources for all of the listed cells. For a detailed explanation of each variable the user can access the online help file.

Channel Indicator: An integer value indicating the type of channel. A value of 0 indicates a cell that is mainly water and a digit (1-8) for channel type. The *Channel* window will appear allowing selection of channel data. For more detail on the variables the user can access the online help file.

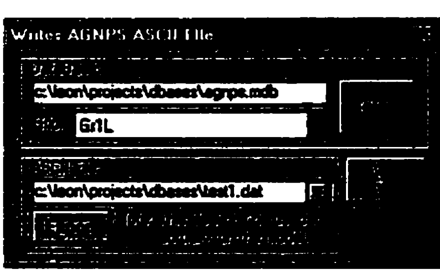


For a detailed explanation of each variable the user can access the online help file.

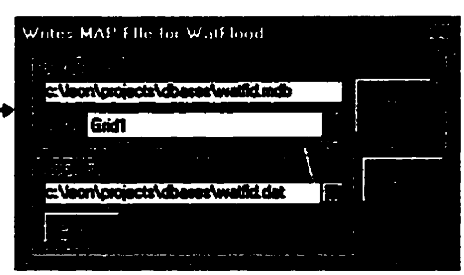
The Apply command saves the current information in the selected database file for the grid and the selected cells. Cancel will quit saving and close the current window.

C3. Run Model Toolbar

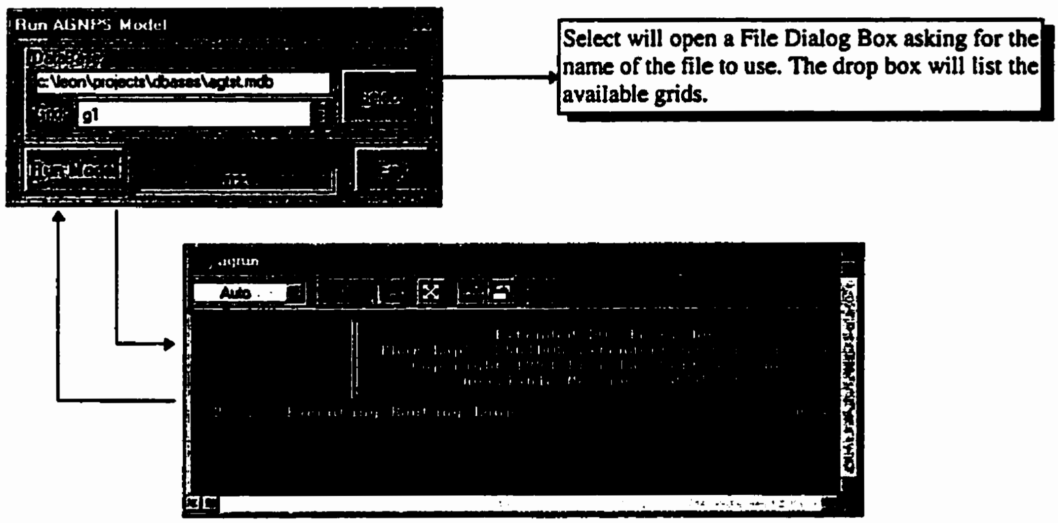
Write ASCII File: Will open the *Export ASCII* window to allow the user to select the grid file to export into a specified ASCII file that the models can understand. In the case of AGNPS this is done for review purposes only and will not be used to run the model within the interface.



Select will open a File Dialog Box asking for the name of the file to use. The drop box will list the available grids. Export will write the database in an ASCII formated file.

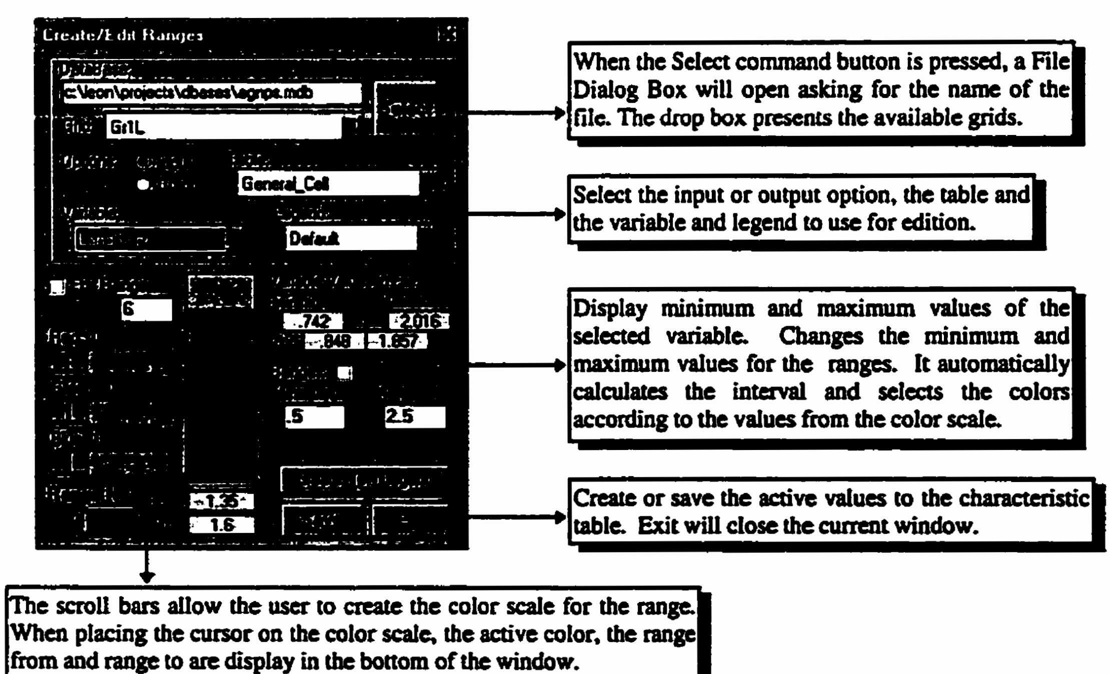


Run Model: This section will allow the user to run the models for the selected file and grid. In the case of WATFLOOD it will activate the program WATFLOOD for Windows. For AGNPS, with the *Run Model* button the file will be exported to ASCII format, a separate DOS window will show the running status and when the model finishes running, it will import the results into the database file. An additional access to the DOS shell for AGNPS is provided by pressing the *Shell* button.

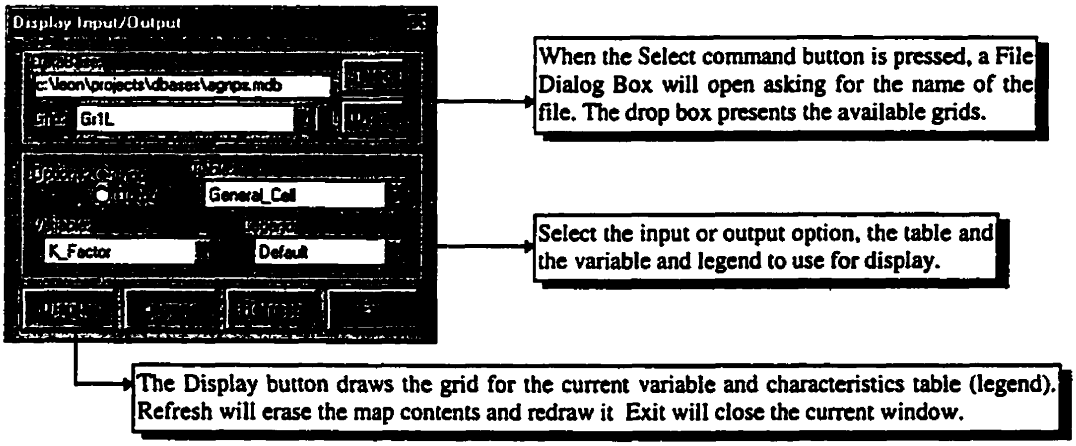


C4. Display Input/Output Toolbar

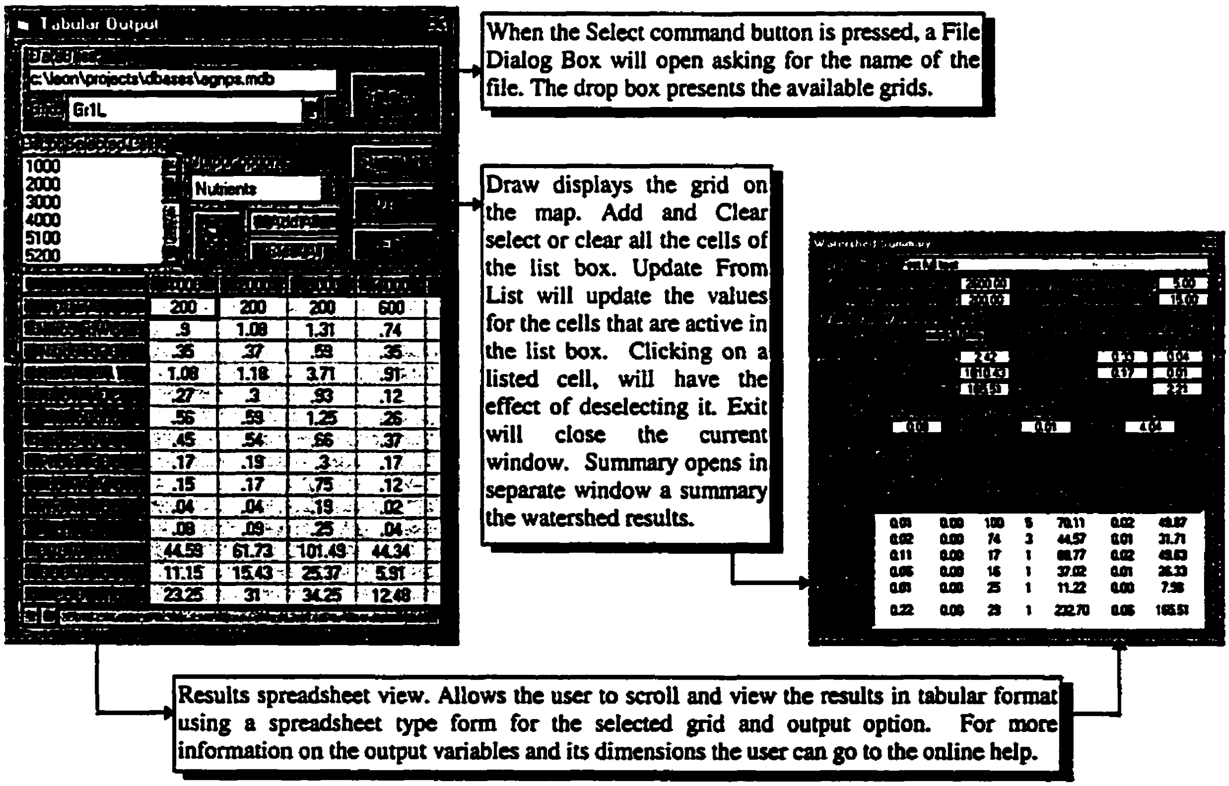
Edit Ranges: Will open the *Create/Edit Ranges* window to allow the user to create or edit the table for the ranges to be used when displaying the input data or output results.



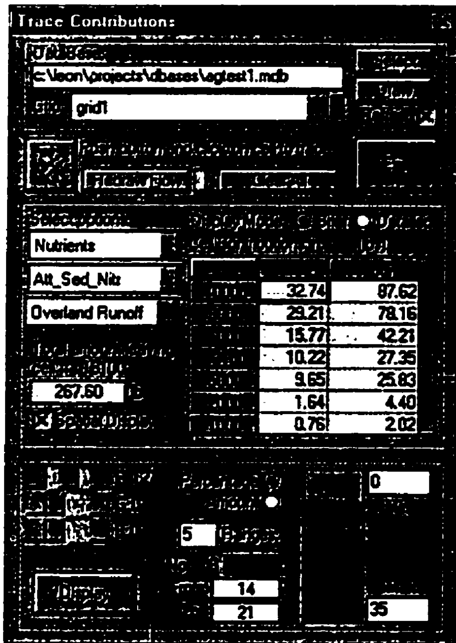
Graphic Display I/O: This will open the *Display of Input/Output* window to allow the user to spatially display the input data or the model results stored in the database file for the selected grid, table and variable.



Tabular Results: Only created for the AGNPS Interface, it will open the *Tabular Display* window to allow the user to view the model results in tabular form and view a summary of the run.



Trace Contribution - Only created for the AGNPS interface, it will open the *Trace Contribution* window that allows the user to see the various sources of pollution in any given cell..



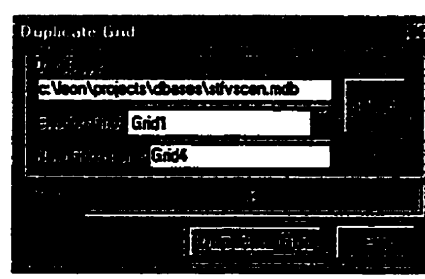
When the Select command button is pressed, a File Dialog Box will open asking for the name of the file. The drop box presents the available grids.

Clicking on a cell, will select it in order to trace the flow route and source contributions up to that point. The Draw Flow button draws the route on the map. Clear will reset the map and form. Exit will close the current window.

Selects the option on the combo boxes of flow routing or type of pollution to monitor upstream of the selected cell. In the spreadsheet view a summary of contributions for each cell is presented, allowing the user to identify where the flow or pollution is comming from. The Brief option will present and sort only the contributing cells (%>0), while the Detailed option will present the values for all the cells in the trace path and display them in the routed order.

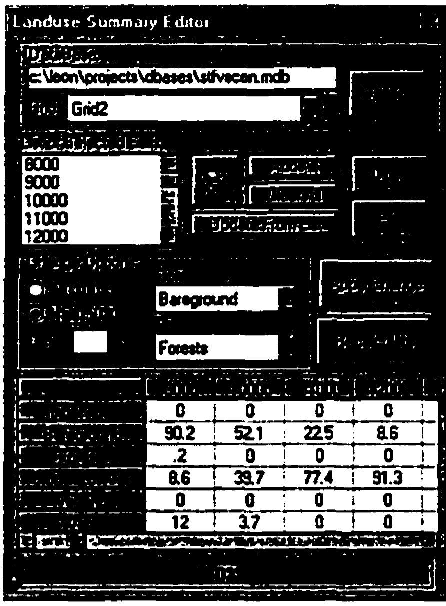
In the display options, changes to the minimum and maximum values for the ranges are allowed. It automatically calculates the interval and selects the colors according to the values from the color scale. The scroll bars allow the user to create the color scale for the range. Percentage or amount values can be spatially displayed. When placing the cursor on the color scale, the active color, the range from and range to are display in the bottom of the window. The Display button will spatially draw the cell values using the grid and map currently active.

C5. Analysis/Scenarios Toolbar



Duplicate Grid: This will open the *Duplicate Grid* window that allows the user to duplicate a specific existing grid with a new grid name. Use the Input box to assign the new grid name for the data to be duplicated. If it already exists the program will prompt a message not allowing to use an existing name. When the duplication of the grid is completed, the user will be asked if the related data should be also copied into the newly created grid. This will allow the user to end up with a full copy of the previous grid or just a mask of the grid where the data extraction process have to be performed again (*ie.* for a different landuse map).

Modify Landuse: This will allow to modify the land coverage percentages. It opens the *Landuse Editor* that allows to change the amounts of land coverage for the different land classes in the selected cells.

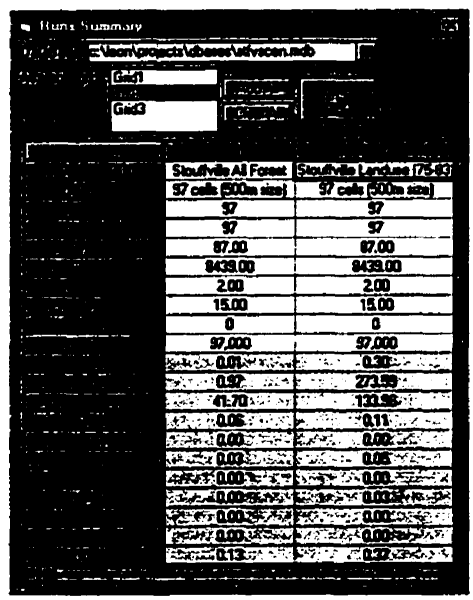


When the Select command button is pressed, a File Dialog Box will open asking for the name of the file. The drop box presents the available grids.

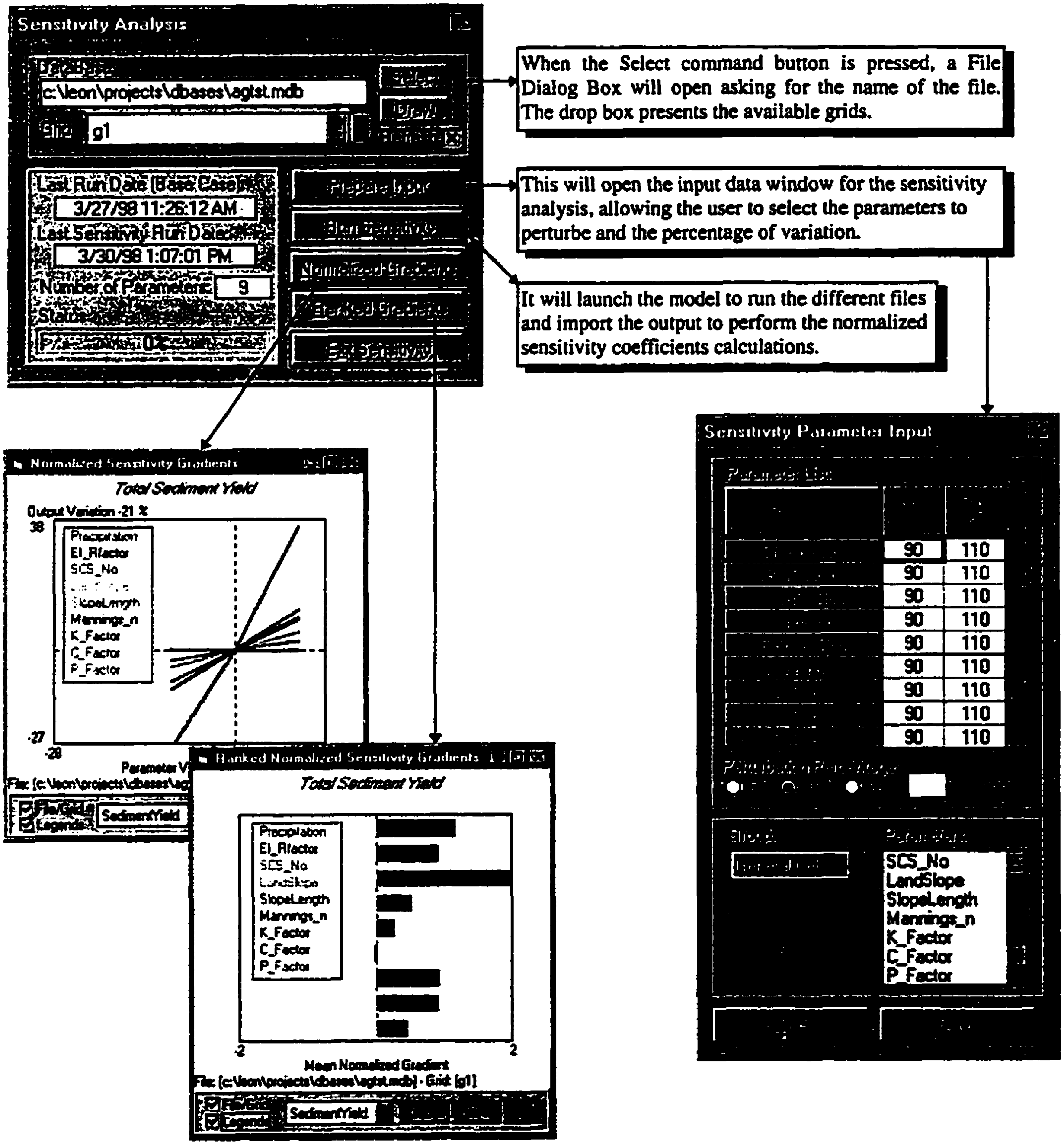
Draw displays the grid on the map. Add and Clear select or clear all the cells of the list box. Update From List will update the values for the cells that are active in the list box. Clicking on a listed cell, will have the effect of deselecting it. Exit closes the current window.

Selects the percentage to be used to change coverage from one land class to another. The From and To fields allows the selection of the land classes to change. The spreadsheet view allows to display the percentages of the different land classes in the selected cells. The Recalculate button estimates the parameter values that depend on landuse to reflect the changes on the land classes for the selected cells.

Summarize Runs: Only created for the AGNPS Interface, it display the summary of the different runs. It will open the *Runs Summary* window to view a summary of the differents runs stored in the database. The spreadsheet is sizable and it is partitioned in two sections, the first one for the general watershed data and the second one for the summary results of the run. The user can select to display all the runs stored in the file or just the desired ones by clicking in the list of the available grids.



Sensitivity Analysis: Perform the sensitivity analysis. It will open the *Sensitivity Analysis* window that allows the user to perform the sensitivity analysis for any given grid and initial (base case) data. Through the buttons, the input for the analysis, the actual batch running of the model and the display of results (normalized gradients and ranking) can be achieved.



APPENDIX D. Pesticide Database

The following shows the information contained in the Pesticide Database used to extract the parameter values for 257 different types of pesticides for both, the AGNPS model and the WATFLOOD/Water Quality Component.

The indexing in the database is done through the type field and it refers to:

H	- Herbicides
I	- Insecticides
F	- Fungicides
N	- Nematicides
P	- Plant Growth Regulators
D	- Desiccants or Defoliants
O	- Others

The columns or fields on the database file stand for the different parameter values according to:

Com_Name	Common pesticide name
SoilRes_H	Soil residue half-life (days)
Solub_W	Solubility in water (ppm)
OrgCar_K	Organic carbon sorption (K_{oc} - octanol partition coefficient)
FolW	Foliar washoff fraction (%)
FolR	Foliar residue half-live (days)

The source of information for the database is the AGNPS documentation and additional files that are distributed with the model. The conversion to the access file used by the interfaces was accomplished by direct import of the ASCII structure and DBIV files.

Table D1. Pesticide Database

Type	Com Name	SoilResH	SolubW	OrgCarbK	FolWash	FolResH
N	1,3DICHLOROPROPENE (1)	10	100	100	0	0
N	1,3DICHLOROPROPENE (2)	24	500000	80	0	0
N	1,3DICHLOROPROPENE (3)	10	22	32	0	0
P	1NAPHTHALENEACETAMID	10	89	20	0	0
H	2,4,5-T	12	5	85	45	9
H	2,4,5T AMINE SALTS	24	500000	80	45	10
H	2,4-D AMINE	10	100	100	0	0
H	2,4D ACID	10	890	20	45	5
H	2,4D ESTERS OR OILSOL.	10	100	100	0	0
H	2,4DB BUTOXYETHYL	7	8	500	45	9
H	2,4DB DIMETHYLAMINE	10	709000	20	0	0
P	3CPA SODIUM SALT	10	200000	20	95	3
I	ACEPHATE	3	818000	2	70	2
H	ACIFLUORFEN SODIUM	14	250000	113	95	5
H	ALACHLOR	15	240	170	40	3
I	ALDICARB	40	6000	40	0	0
O	ALDICARB SULFOXIDE	40	6000	30	0	0
I	ALDOXYCARB (ALDICARB	20	10000	10	0	0
O	ALDRIN	28	0.1	160	5	2
H	AMETRYN	60	185	300	65	5
O	AMINOCARB	6	915	100	90	4
I	AMITRAZ	2	1	1000	45	1
H	AMITROLE	14	360000	100	95	5
P	ANCYMIDOL	120	650	120	50	30
F	ANILAZINE	1	8	3000	50	0
D	ARSENIC ACID	10000	17000	100000	95	10000
H	ASULAM SODIUM SALT	7	550000	40	95	3
H	ATRAZINE	60	33	100	45	5
I	AZINPHOSMETHYL	10	29	1000	65	2
O	BEC	600	0.1	55000	5	3
I	BENDIOCARB	5	40	570	85	3
H	BENEFIN (BENFLURALIN)	40	0.1	9000	20	10
F	BENOMYL	240	2	1900	25	6
H	BENSULFURON METHYL	5	120	310	0	0
H	BENSULIDE	120	5.6	1000	40	30
H	BENTAZON SODIUM SALT	20	2300000	34	60	2
O	BIFENOX	7	0.398	10000	40	3
I	BIFENTHRIN	26	0.1	240000	40	7
H	BROMACIL ACID	60	700	32	75	20
H	BROMOXYNIL BUTYRATE	7	0.08	10000	0	0
H	BUTYLATE	13	44	400	30	1
F	CAPTAN (1)	2.5	5.1	200	65	9
F	CAPTAN (2)	10	4	198	65	9
I	CARBARYL	10	120	300	55	7
I	CARBOFURAN	50	351	22	0	0
O	CARBOPHENOTHION	15	0.6	12500	65	6
F	CARBOXIN	7	195	260	0	0
H	CHLORAMBEN SALTS	14	900000	15	95	7
O	CHLORDANE	100	0.1	100000	5	2
I	CHLORDIMEFORM	60	500000	100000	90	1
H	CHLORIMURON ETHYL	40	1200	110	90	15
O	CHLOROBENZILATE	20	13	2000	5	10
F	CHLORONEB	130	8	1650	50	30
F	CHLOROPICRIN	1	2270	62	0	0
F	CHLOROTHALONIL	30	0.6	1380	50	10
O	CHLOROXURON	60	2.5	3000	40	15
H	CHLORPROPHAM (CIPC)	30	89	400	90	8
I	CHLORPYRIFOS	30	0.4	6070	65	3

Type	Com.Name	SoilRes.H	Solub.W	OrgCar.K	FolWash	FolRes.H
H	CHLORSULFURON	160	7000	40	75	30
H	CLOMAZONE	24	1100	300	80	3
H	CLOPYRALID AMINE SALT	30	300000	6	95	2
H	CYANAZINE	14	170	190	60	5
H	CYCLOATE	30	95	430	50	2
I	CYFLUTHRIN	30	0.002	100000	40	5
I	CYPERMETHRIN	30	0.004	100000	0	0
I	CYROMAZINE	150	136000	200	0	0
O	DALAPON	30	1000	4	95	37
H	DALAPON SODIUM SALT	30	900000	1	95	37
N	DBCP	180	1000	70	0	0
F	DCNA (DICLORAN)	10	7	1000	50	4
H	DCPA	100	0.5	5000	30	10
O	DDT	120	0.1	240000	5	4
H	DESMEDIPHAM	30	8	1500	70	5
I	DIAZINON	40	60	1000	90	4
H	DICAMBA SALT	14	400000	2	65	9
H	DICHLOBENIL	60	21.2	400	45	5
H	DICLOFOPMETHYL	37	0.8	16000	45	8
I	DICOFOL	60	1	180000	5	4
I	DICROTOPHOS	28	1000000	75	70	20
O	DIELDRIN	1400	0.1	50000	5	5
H	DIETHATYLETHYL	21	105	1400	40	10
H	DIFENZOQUAT	100	817000	54500	95	30
I	DIFLUBENZURON	10	0.08	10000	5	27
P	DIMETHIPIN	10	3000	10	80	3
I	DIMETHOATE	7	39800	20	95	3
O	DINITRO	23	50	490	0	0
I	DINOCAP	20	4	550	30	8
H	DINOSEB PHENOL	20	50	500	60	3
H	DIPHENAMID	30	260	210	80	5
H	DIPROPETRYN	30	16	900	40	5
H	DIQUAT DIBROMIDE SALT	1000	718000	1000000	95	30
I	DISULFOTON	30	25	600	50	3
H	DIURON	90	42	480	45	30
F	DNOC SODIUM SALT	20	100000	20	95	8
F	DODINE ACETATE	20	700	100000	50	10
I	ENDOSULFAN	50	0.32	12400	5	3
H	ENDOTHALL (ENDOTHAL)	7	100000	20	90	7
O	EPN	5	0.5	13000	60	5
H	EPTC	6	344	200	75	3
I	ESFENVALERATE	35	0.002	5300	40	8
H	ETHALFLURALIN	60	0.3	4000	40	4
P	ETHEPHON	10	1239000	100000	95	5
I	ETHION	150	1.1	10000	65	7
H	ETHOFUMESATE	30	50	340	65	10
I	ETHOPROP (ETHOPROPHOS)	25	750	70	0	0
F	ETRIDIAZOLE	20	50	1000	60	3
H	FENAC (CHLORFENAC) SALT	180	500000	20	95	30
I	FENAMIPHOS	50	400	100	0	0
O	FENAMIPHOS SULFOXIDE	42	400	40	0	0
F	FENARIMOL	360	14	600	40	30
I	FENBUTATIN OXIDE	90	0.013	2300	20	30
O	FENITRITHION	8	30	2000	90	3
H	FENOXAPROPETHYL	9	0.8	9490	20	5
I	FENOXYCARB	1	6	1000	0	0
O	FENSULFOTHION	24	1500	10000	90	3
O	FENTHION	34	4.2	1500	65	2
I	FENVALERATE	35	0.002	5300	25	10
F	FERBAM	17	120	300	90	3

Type	Com.Name	SoilRes.Hl	Solub.W	OrgCarb.K	FolWash.	FolRes.Hl
H	FLUAZIFOPPBUTYL	15	2	5700	40	4
I	FLUCYTHRINATE	21	0.06	100000	40	5
P	FLUMETRALIN	20	0.1	10000	40	7
H	FLUOMETURON	85	110	100	50	30
H	FLURIDONE	21	10	1000	0	0
I	FLUVALINATE	30	0.005	1000000	40	7
H	FOMESAFEN SODIUM SALT	100	700000	60	95	30
I	FONOFOS	40	16.9	870	60	2
I	FORMETANATE	100	500000	1000000	95	30
H	FOSAMINE AMMONIUM	8	1790000	150	95	4
F	FOSETYLALUMINUM	0.1	120000	20	95	0
H	GLUFOSINATEAMMONIUM	7	1370000	100	95	4
H	GLYPHOSATE	47	900000	24000	60	2
H	HEXAZINONE	90	3300	54	90	30
I	HEXYTHIAZOX	30	0.5	6200	40	5
I	HYDRAMETHYLNON	10	0.006	730000	0	0
H	IMAZAMETHABENZMETHY	35	1370	66	65	18
H	IMAZAPYR ACID	90	11000	100	90	30
H	IMAZAQUIN AMMONIUM	60	160000	20	95	20
O	IMAZETHAPYR (AC 263, 499)	90	200000	10	0	0
F	IPRODIONE	14	13.9	700	40	5
I	ISAZOFOS	34	69	100	65	5
I	ISOFENPHOS	150	24	600	65	30
H	ISOPROPALIN	100	0.1	10000	0	0
H	LACTOFEN	3	0.1	100000	20	2
O	LAMBDACYHALOTHRIN	30	0.005	180000	40	5
I	LINDANE	400	7	1100	5	2
H	LINURON	60	75	400	60	15
I	MALATHION (1)	1	130	1800	90	3
I	MALATHION (2)	25	145	1800	90	3
P	MALEIC HYDRAZIDE	30	400000	20	95	10
F	MANCOZEB	70	6	2000	25	10
H	MCPA DIMETHYLAMINE	25	866000	20	95	7
H	MCPA ESTER	25	5	1000	50	8
H	MCPB SODIUM SALT	14	200000	20	95	7
H	MECOPROP (MCPP) AMINE	21	660000	20	95	10
P	MEPIQUAT CHLORIDE SALT	1000	1000000	1000000	95	30
F	METALAXYL	70	8400	50	70	30
O	METALDEHYDE	10	230	240	0	0
F	METHAM (METAM) SODIUM	7	963000	10	0	0
I	METHAMIDOPHOS	6	1000000	5	95	4
H	METHANEARSONIC ACID	1000	1400000	100000	95	30
H	METHAZOLE	14	1.5	3000	40	5
I	METHIDATHION	7	220	400	90	3
I	METHIOCARB	30	24	300	70	10
I	METHOMYL	30	58000	72	55	0
I	METHOXYCHLOR	120	0.1	80000	5	6
O	METHYL BROMIDE	55	13400	22	0	0
I	METHYL PARATHION (1)	5	60	14000	65	3
I	METHYL PARATHION (2)	5	60	5100	65	3
F	METIRAM	20	0.1	500000	40	7
H	METOLACHLOR	90	530	200	60	5
H	METRIBUZIN	40	1220	60	80	5
H	METSULFURONMETHYL	120	9500	35	80	30
I	MEVINPHOS	3	600000	44	95	0
H	MOLINATE	21	970	190	0	0
I	MONOCROTOPHOS	30	1000000	1	95	2
P	NAA ETHYL ESTER	10	105	300	40	5
P	NAA SODIUM SALT	10	419000	20	0	0
I	NALED	1	2000	180	90	0

Type	Com_Name	SoilRes_HL	Solub_W	OrgCar_K	FolWash	FolRes_HL
H	NAPROPAMIDE	70	74	400	60	15
O	NAPTALAM	12	200	30	0	0
H	NAPTALAM SODIUM SALT	14	231000	20	95	7
O	NITRAPYRIN	10	40	570	0	0
H	NORFLURAZON	90	28	600	50	15
H	ORYZALIN	20	2.5	600	40	5
H	OXADIAZON	60	0.7	3200	50	20
I	OXAMYL	4	282000	25	95	4
F	OXYCARBOXIN	20	1000	95	70	10
I	OXYDEMETONMETHYL	10	1000000	10	95	3
H	OXYFLUORFEN	35	0.1	100000	40	8
I	OXYTHIOQUINOX	30	1	2300	50	10
O	PARAQUAT	99	500000	10000000	40	3
H	PARAQUAT DICHLORIDE	1000	620000	1000000	60	30
I	PARATHION (ETHYL	14	24	5000	70	4
F	PCNB	21	0.44	5000	40	4
H	PEBULATE	14	100	430	70	4
H	PENDIMETHALIN	90	0.275	5000	40	30
I	PERMETHRIN	30	0.006	100000	30	8
H	PETROLEUM OIL	10	100	1000	50	2
H	PHENMEDIPHAM	30	4.7	2400	70	5
O	PHENTHOATE	40	200	250	65	2
I	PHORATE	60	22	1000	60	2
I	PHOSALONE	21	3	1800	65	8
I	PHOSMET	19	20	820	90	3
I	PHOSPHAMIDON	17	1000000	7	95	5
H	PICLORAM SALT	90	200000	16	60	8
F	PIPERALIN	30	20	5000	60	10
I	PIRIMIPHOSMETHYL	10	9	1000	0	0
F	PROCHLORAZ	120	34	500	50	30
I	PROFENOFOS	8	28	2000	90	3
O	PROFLURALIN	140	0.1	2	35	1
H	PROMETON	500	720	150	75	30
H	PROMETRYN	60	33	400	50	10
H	PRONAMIDE	60	15	200	30	20
H	PROPACHLOR	6.3	613	80	40	3
F	PROPAMOCARB	30	1000000	1000000	95	15
H	PROPANIL	1	200	149	70	1
I	PROPARGITE (1)	56	0.5	4000	20	5
I	PROPARGITE (2)	135	8.6	154	20	5
H	PROPAZINE	10	250	200	45	5
H	PROPHAM (IPC)	110	110	1000	50	2
F	PROPICONAZOLE	110	110	1000	70	30
I	PROPOXUR	30	1800	30	0	0
H	PYRAZON (CHLORIDAZON)	21	400	120	85	5
H	QUIZALOFOP ETHYL	60	0.31	510	20	15
H	SETHOXYDIM	5	4390	100	70	3
H	SIDURON	90	18	420	70	30
O	SILVEX	20	2.5	2600	40	5
H	SIMAZINE	60	6.2	130	40	5
H	SULFOMETURON METHYL	20	70	78	65	10
I	SULPROFOS	140	0.31	12000	55	0
H	TEBUTHIURON	360	2500	80	90	30
I	TEMEPHOS	30	0.001	100000	65	5
H	TERBACIL	120	710	55	70	30
I	TERBUFOS	5	5	500	60	2
H	TERBUTRYN	42	22	2000	50	5
F	THIABENDAZOLE	403	50	2500	60	30
D	THIDIAZURON	10	20	110	40	3
O	THIFENSULFURONMETHYL	12	2400	45	80	3

Type	Com Name	SoilRes H	Solub W	OrgCar K	FolWash	FolRes Ha
H	THIOBENCARB	21	28	900	70	7
I	THIODICARB	7	19.1	350	70	4
F	THIOPHANATEMETHYL	10	3.5	1830	40	5
F	THIRAM	15	30	670	50	8
I	TOXAPHENE (1)	500	0.4	400000	5	2
I	TOXAPHENE (2)	9	3	100000	5	2
I	TRALOMETHRIN	27	0.001	100000	40	1
F	TRIADIMEFON	26	71.5	300	30	8
H	TRIALLATE	82	4	2400	40	15
D	TRIBUFOS	30	2.3	5000	25	7
I	TRICHLORFON	10	120000	10	95	3
H	TRICLOPYR AMINE SALT	46	2100000	20	95	15
H	TRICLOPYR ESTER	46	23	780	70	15
H	TRIDIPHANE	28	1.8	5600	40	8
H	TRIFLURALIN	60	0.3	8000	40	3
F	TRIFORINE	21	30	540	80	5
I	TRIMETHACARB	20	58	400	0	0
F	TRIPHENYLTIN HYDROXIDE	75	1	23000	40	18
H	VERNOLATE	12	108	260	80	2

APPENDIX E. Model Results. Tables and Graphs

This section includes the complete set of results for the AGNPS and WATFLOOD modeling in the Duffins Creek watershed. The study period is for the warm weather months from April to November of 1995. Eight events were selected avoiding the "bright band' condition that can overestimate the precipitation values. The complete set of results from the AGNPS modeling and the runs of WATFLOOD are presented in the following pages.

April	- event 25-29 Apr/95
May	- event 16-20 May/95
June	- event 1-6 Jun/95
July	- event 13-18 Jul/95
August	- event 2-6 Aug/95
September	- event 2-10 Sep/95
October	- event 4-16 Oct/95
November	- event 8-12 Nov/95

Table E1. AGNPS Results for the 2x2 km Grid

Hyd-Sed-Nut:EVENT		25-29 Apr/95	16-20 May/95	1-6Jun/95	13-18 Jul/95
	AMC	III	III	III	II
AGNPS Results	Units	g2km	g2km	g2km	g2km
Watershed ID		Duffins (2x2km)	Duffins (2x2km)	Duffins (2x2km)	Duffins (2x2km)
Description		1992 Landuse	1992 Landuse	1992 Landuse	1992 Landuse
# Base Cells		57	57	57	57
# Total Cells		57	57	57	57
Area base cell	acre	1406	1406	1406	1406
Drainage area	acre	80142	80142	80142	80142
Precipitation	in	0.65	0.79	0.42	0.96
Energy intensity		2.13	3.5	0.79	6.33
Nitrogen in rain	ppm	1	1	1	1
Outlet Cell		57,000	57,000	57,000	57,000
Runoff Volume	in	0.05	0.09	0.01	0.03
Peak Rate	cfs	380.33	698.7	81.32	216.65
Sediment Yield	ton	137.93	230.98	37.88	130.19
Nitrogen-Sediment	lb/acre	0.02	0.04	0.01	0.02
Nitrogen-Runoff	lb/acre	0	0.01	0	0
Phosphorus-Sediment	lb/acre	0.01	0.02	0	0.01
Phosphorus-Runoff	lb/acre	0	0	0	0
COD-Runoff	lb/acre	0.05	0.07	0.01	0.04
Nitrogen Conc	ppm	0.34	0.29	0.46	0.29
Phosphorus Conc	ppm	0.04	0.04	0.03	0.02
COD Conc	ppm	4.24	3.59	6.45	6.52
Conversions					
Rainfall	mm	16.5	20.1	10.7	24.4
Duration	hrs	18	15	20	10
Peak Flow	m3/s	10.77	19.79	2.30	6.14
Sediment Yield	ton	137.93	230.98	37.88	130.19
Nitrogen load	kg	140.04	215.01	37.89	71.67
Phosphorus load	kg	16.48	29.66	2.47	4.94
Stouffville Outlet	Cell	19000	19000	19000	19000
DrainArea	acre	11248	11248	11248	11248
OverlandRunoff	in	0.03	0.07	0	0
UpStrmRunoff	in	0.05	0.1	0.01	0.01
UpStrmPeakF	cfs	155.02	287.75	18.89	47.06
DownStrmRunoff	in	0.05	0.1	0.01	0.01
DownStrmPeakF	*cfs*	*121.57*	*229.63*	*13.68*	*34.66*
GenAbRunoff	%	91.6	90.6	98.1	97.8
Conversions					
Peak Flow	m3/s	3.44	6.50	0.39	0.98

Table E1. AGNPS Results for the 2x2 km Grid (Cont.)

Hyd-Sed-Nut:EVENT		2-6 Aug/95	2-10 Sep/95	4-16 Oct/95	8-12 Nov/95
	AMC	II	II	II	III
AGNPS Results	Units	g2km	g2km	g2km	g2km
Watershed ID		Duffins (2x2km)	Duffins (2x2km)	Duffins (2x2km)	Duffins (2x2km)
Description		1992 Landuse	1992 Landuse	1992 Landuse	1992 Landuse
# Base Cells		57	57	57	57
# Total Cells		57	57	57	57
Area base cell	acre	1406	1406	1406	1406
Drainage area	acre	80142	80142	80142	80142
Precipitation	in	0.72	0.56	1.06	1.17
Energy intensity		2.54	1.66	7.03	8.45
Nitrogen in rain	ppm	1	1	1	1
Outlet Cell		57,000	57,000	57,000	57,000
Runoff Volume	in	0.01	0.01	0.04	0.24
Peak Rate	cfs	83.8	37.42	305.29	1954.69
Sediment Yield	ton	37.13	20.58	186.91	549.23
Nitrogen-Sediment	lb/acre	0.01	0	0.03	0.07
Nitrogen-Runoff	lb/acre	0	0	0	0.01
Phosphorus-Sediment	lb/acre	0	0	0.02	0.04
Phosphorus-Runoff	lb/acre	0	0	0	0
COD-Runoff	lb/acre	0.02	0.01	0.05	0.16
Nitrogen Conc	ppm	0.34	0.38	0.27	0.21
Phosphorus Conc	ppm	0.02	0.01	0.02	0.03
COD Conc	ppm	7.52	7.67	5.98	2.83
Conversions					
Rainfall	mm	18.3	14.2	26.9	29.7
Duration	hrs	20	15	13	14
Peak Flow	m3/s	2.37	1.06	8.65	55.36
Sediment Yield	ton	37.13	20.58	186.91	549.23
Nitrogen load	kg	28.01	31.30	88.97	415.18
Phosphorus load	kg	1.65	0.82	6.59	59.31
Stouffville Outlet	Cell	19000	19000	19000	19000
DrainArea	acre	11248	11248	11248	11248
OverlandRunoff	in	0	0	0.01	0.23
UpStrmRunoff	in	0	0	0.03	0.28
UpStrmPeakF	cfs	39.98	19.98	85.97	353.15
DownStrmRunoff	in	0	0	0.03	0.27
DownStrmPeakF	*cfs*	*29.94*	*9.92*	*64.84*	*276.79*
GenAbRunoff	%	100	0	95.5	89.4
Conversions					
Peak Flow	m3/s	0.85	0.28	1.84	7.84

Table E2. AGNPS Results for the 1x1 km Grid

Hyd-Sed only:EVENT		25-29 Apr/95	16-20 May/95	1-6Jun/95	13-18 Jul/95
	AMC	III	III	III	II
AGNPS Results	Units	g1km	g1km	g1km	g1km
Watershed ID		Duffins (1x1km)	Duffins (1x1km)	Duffins (1x1km)	Duffins (1x1km)
Description		1992 Landuse	1992 Landuse	1992 Landuse	1992 Landuse
# Base Cells		205	205	205	205
# Total Cells		205	205	205	205
Area base cell	acre	351	351	351	351
Drainage area	acre	71955	71955	71955	71955
Precipitation	in	0.65	0.79	0.42	0.96
Energy intensity		2.13	3.5	0.79	6.33
Nitrogen in rain	ppm	1	1	1	1
Outlet Cell		205,000	205,000	205,000	205,000
Runoff Volume	in	0.05	0.09	0.01	0.03
Peak Rate	cfs	361.37	646.63	84.59	218.91
Sediment Yield	ton	143.13	232.43	43.34	141.14
Nitrogen-Sediment	lb/acre	0.02	0.04	0.01	0.02
Nitrogen-Runoff	lb/acre	0	0.01	0	0
Phosphorus-Sediment	lb/acre	0.01	0.02	0	0.01
Phosphorus-Runoff	lb/acre	0	0	0	0
COD-Runoff	lb/acre	0.03	0.04	0.01	0.03
Nitrogen Conc	ppm	0.11	0.62	1.25	0.17
Phosphorus Conc	ppm	0	0.11	0.21	0.01
COD Conc	ppm	2.56	2.11	4.03	4.06
Conversions					
Rainfall	mm	16.5	20.1	10.7	24.4
Duration	hrs	18	15	20	10
Peak Flow	m3/s	10.24	18.32	2.40	6.20
Sediment Yield	ton	143.13	232.43	43.34	141.14
Stouffville Outlet	Cell	83000	83000	83000	83000
DrainArea	acre	10179	10179	10179	10179
OverlandRunoff	in	0.01	0.04	0	0
UpStrmRunoff	in	0.06	0.11	0.01	0.03
UpStrmPeakF	cfs	200.8	347.56	39.98	98.65
DownStrmRunoff	in	0.06	0.11	0.01	0.03
DownStrmPeakF	*cfs*	*132.77*	*234.52*	*24.79*	*62.6*
GenAbRunoff	%	99.3	98.8	100	100
Conversions					
Peak Flow	m3/s	3.76	6.64	0.70	1.77

Table E2. AGNPS Results for the 1x1 km Grid (Cont.)

Hyd-Sed only:EVENT		2-6 Aug/95	2-10 Sep/95	4-16 Oct/95	8-12 Nov/95
	AMC	II	II	II	III
AGNPS Results	Units	g1km	g1km	g1km	g1km
Watershed ID		Duffins (1x1km)	Duffins (1x1km)	Duffins (1x1km)	Duffins (1x1km)
Description		1992 Landuse	1992 Landuse	1992 Landuse	1992 Landuse
# Base Cells		205	205	205	205
# Total Cells		205	205	205	205
Area base cell	acre	351	351	351	351
Drainage area	acre	71955	71955	71955	71955
Precipitation	in	0.72	0.56	1.06	1.17
Energy intensity		2.54	1.66	7.03	8.45
Nitrogen in rain	ppm	1	1	1	1
Outlet Cell		205,000	205,000	205,000	205,000
Runoff Volume	in	0.01	0.01	0.04	0.25
Peak Rate	cfs	85.39	37.33	303.81	1764.47
Sediment Yield	ton	44.28	22.99	193.52	536.07
Nitrogen-Sediment	lb/acre	0.01	0	0.03	0.07
Nitrogen-Runoff	lb/acre	0	0	0	0
Phosphorus-Sediment	lb/acre	0	0	0.02	0.04
Phosphorus-Runoff	lb/acre	0	0	0	0
COD-Runoff	lb/acre	0.01	0.01	0.03	0.09
Nitrogen Conc	ppm	0.24	0.32	0.15	0.05
Phosphorus Conc	ppm	0.01	0.01	0.01	0
COD Conc	ppm	4.96	5.31	3.69	1.56
Conversions					
Rainfall	mm	18.3	14.2	26.9	29.7
Duration	hrs	20	15	13	14
Peak Flow	m3/s	2.42	1.06	8.61	49.98
Sediment Yield	ton	44.28	22.99	193.52	536.07
Stouffville Outlet	Cell	83000	83000	83000	83000
DrainArea	acre	10179	10179	10179	10179
OverlandRunoff	in	0	0	0	0.16
UpStrmRunoff	in	0.01	0	0.05	0.3
UpStrmPeakF	cfs	25.44	15.61	148.67	511.98
DownStrmRunoff	in	0.01	0	0.04	0.3
DownStrmPeakF	*cfs*	*15.28*	*13.26*	*95.78*	*248.19*
GenAbRunoff	%	100	100	100	98.1
Conversions					
Peak Flow	m3/s	0.43	0.38	2.71	7.03

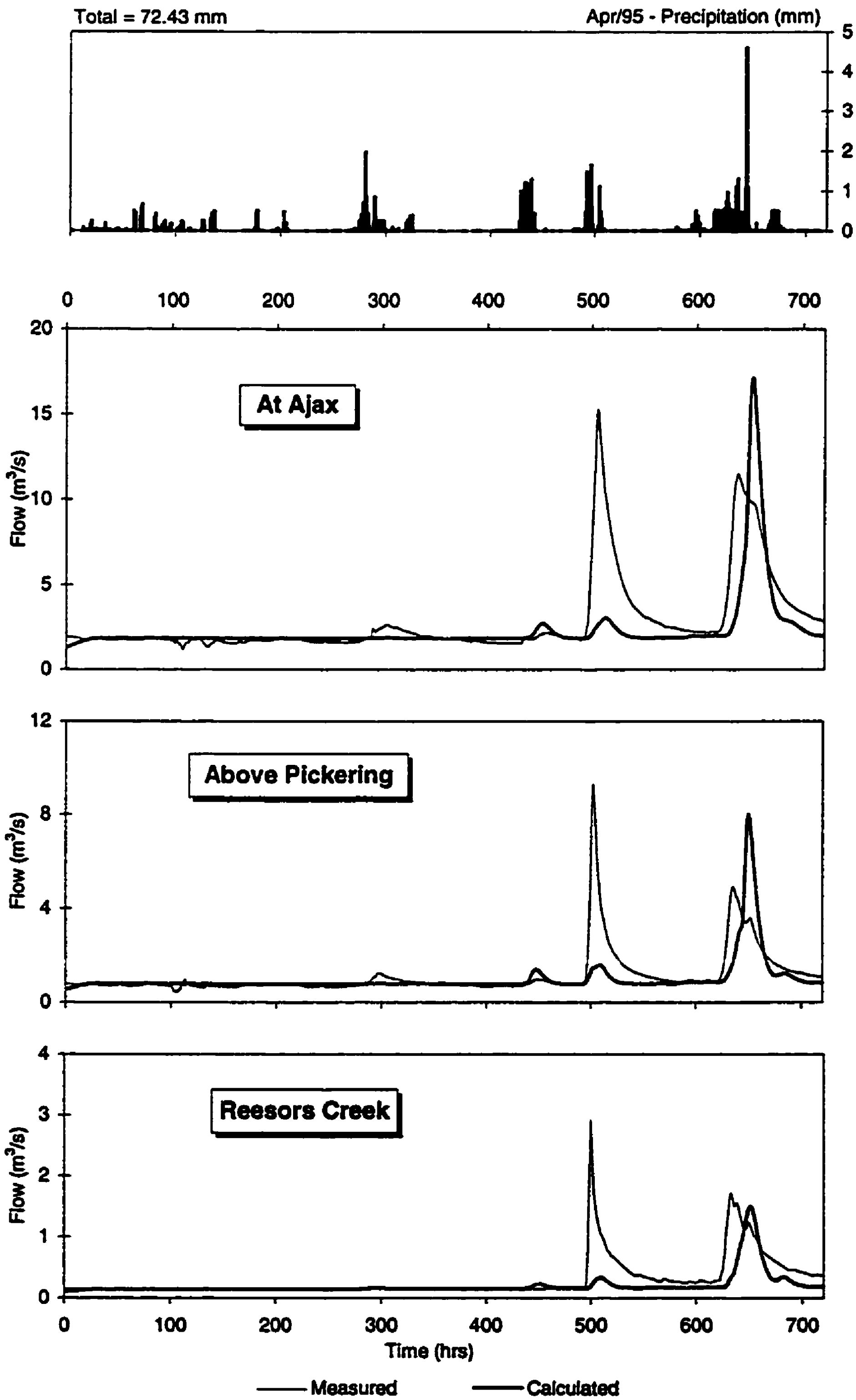


Figure E.1 WATFLOOD results for April, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.5)

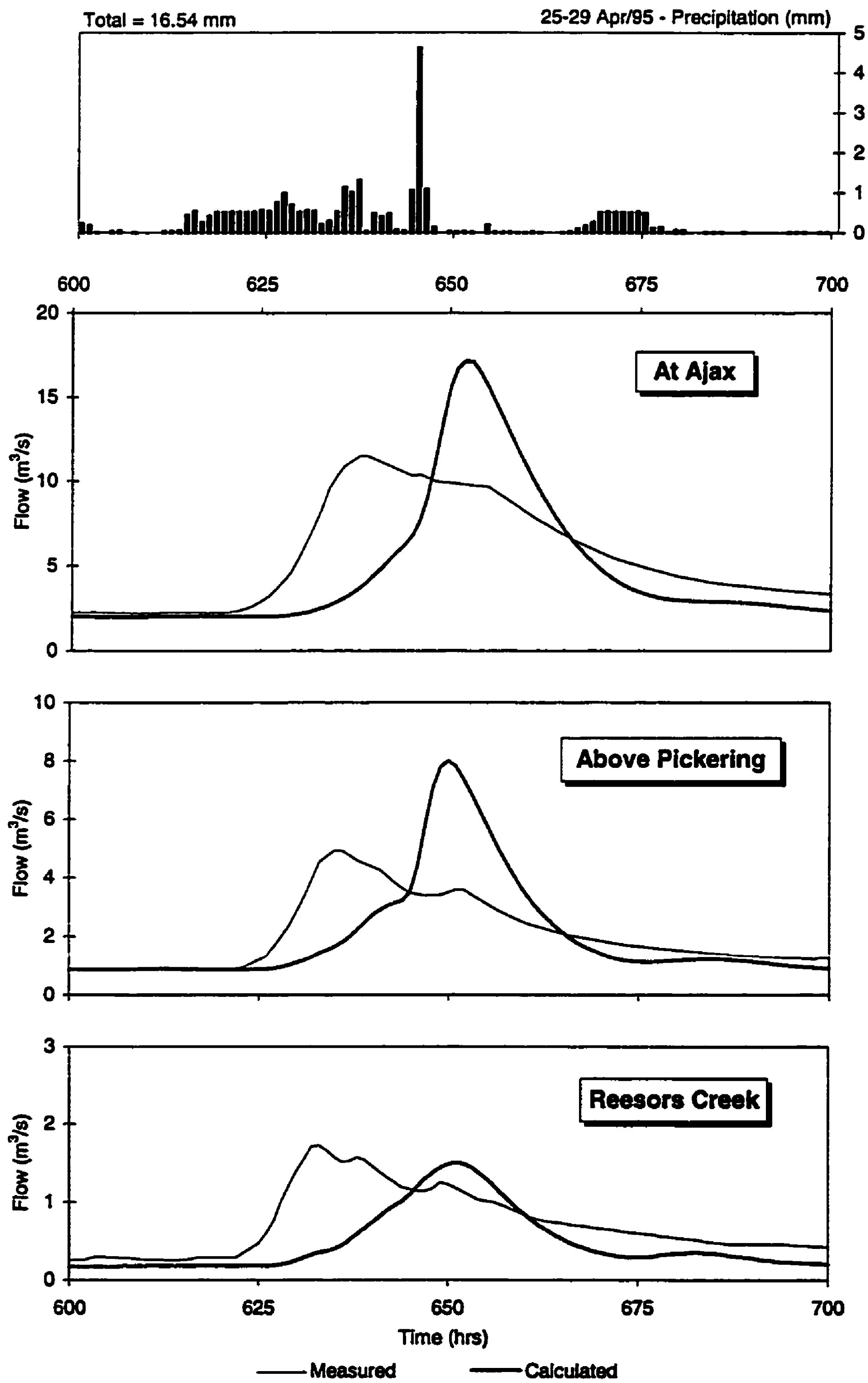


Figure E.2 WATFLOOD results for April 25-19, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.5)

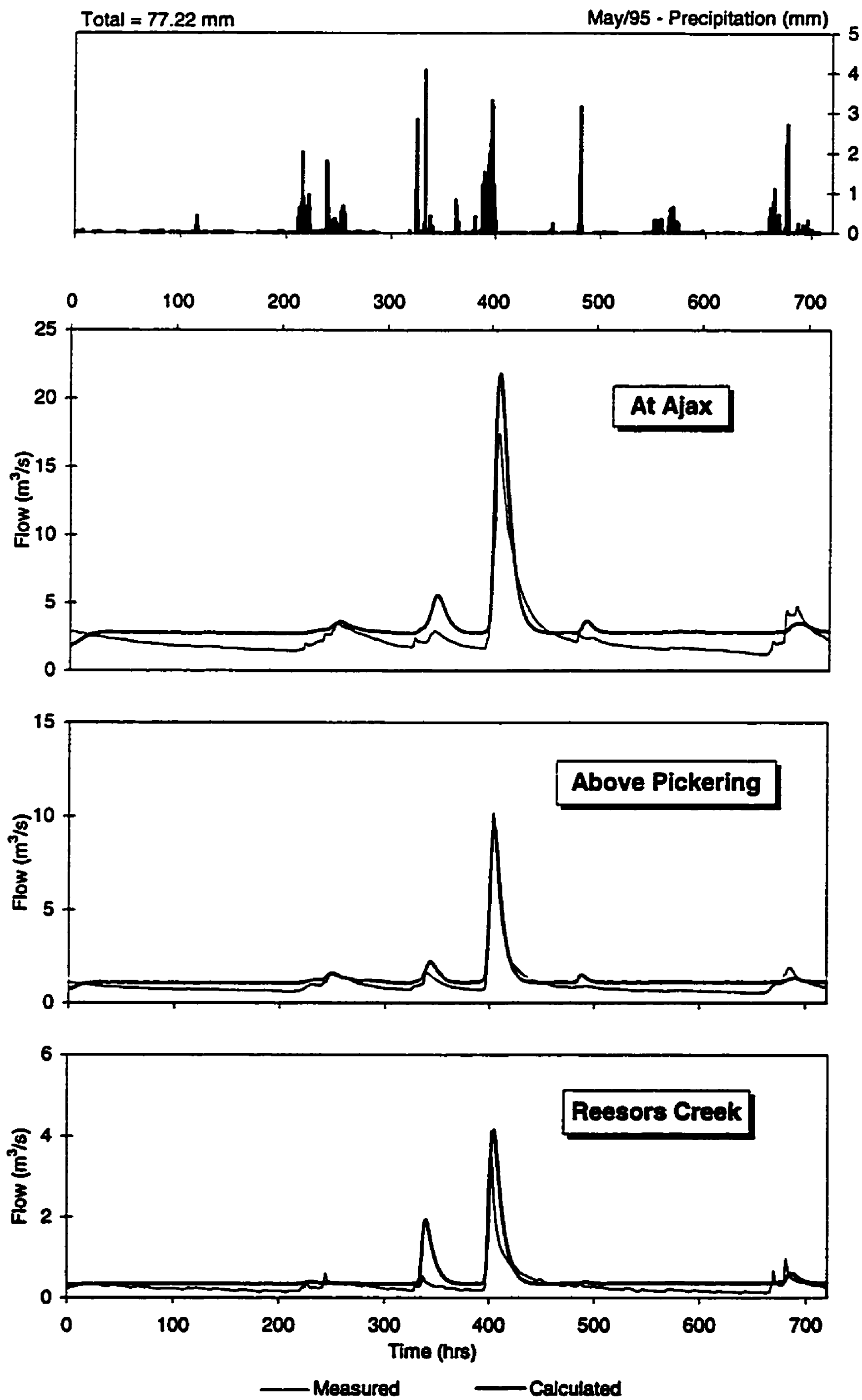


Figure E.3 WATFLOOD results for May, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.6)

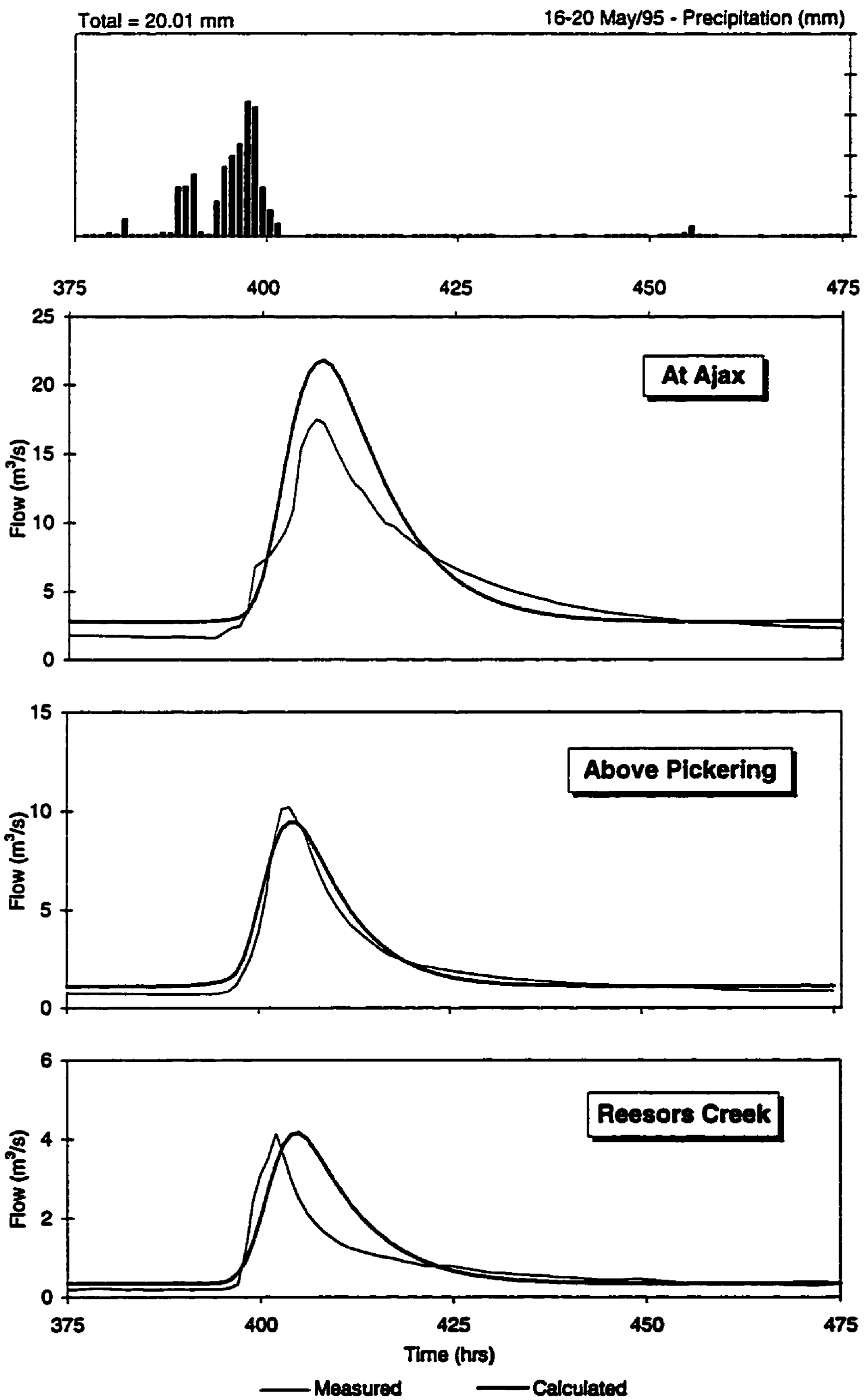


Figure E.4 WATFLOOD results for May 16-20, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.6)

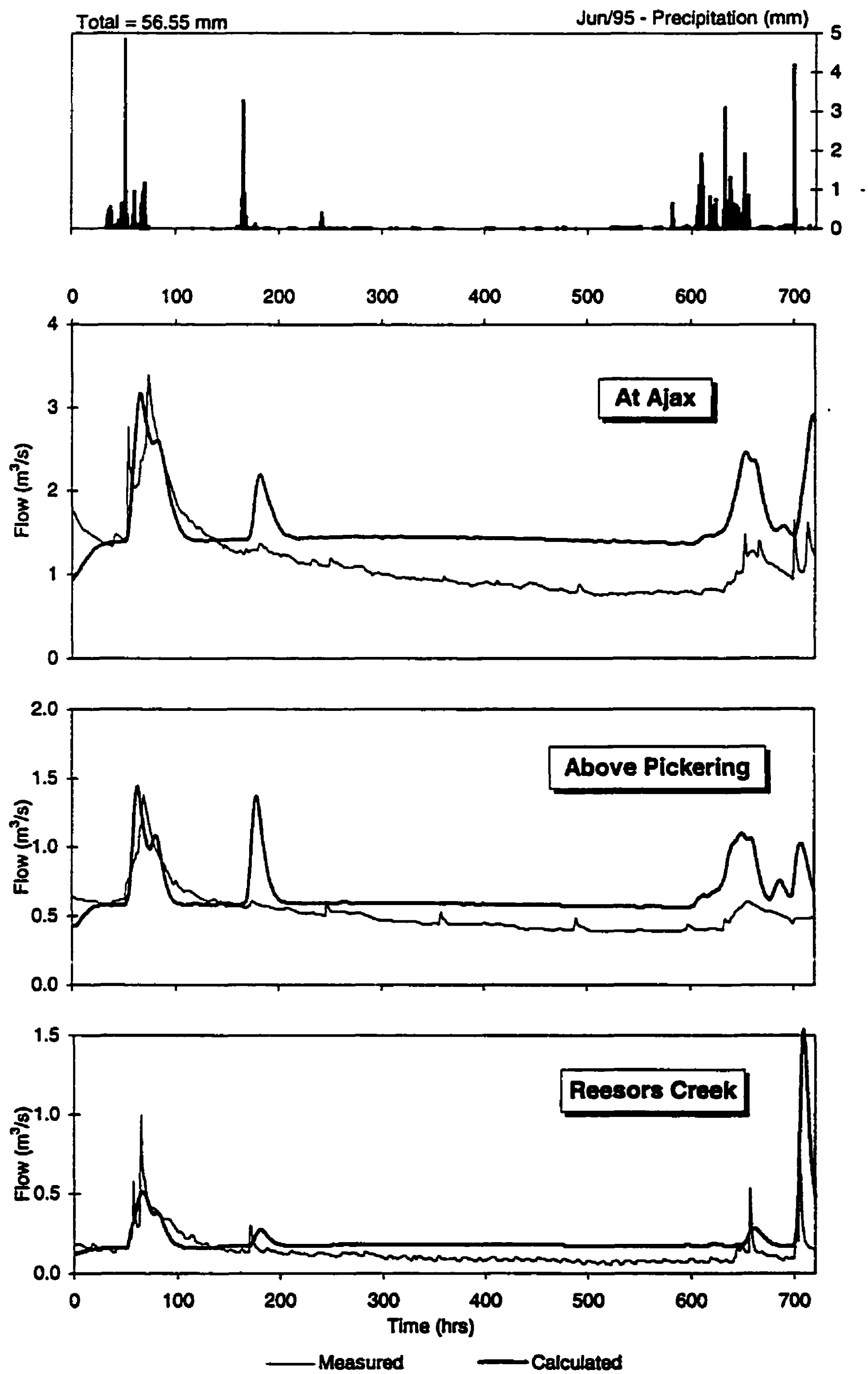


Figure E.5 WATFLOOD results for June, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.8)

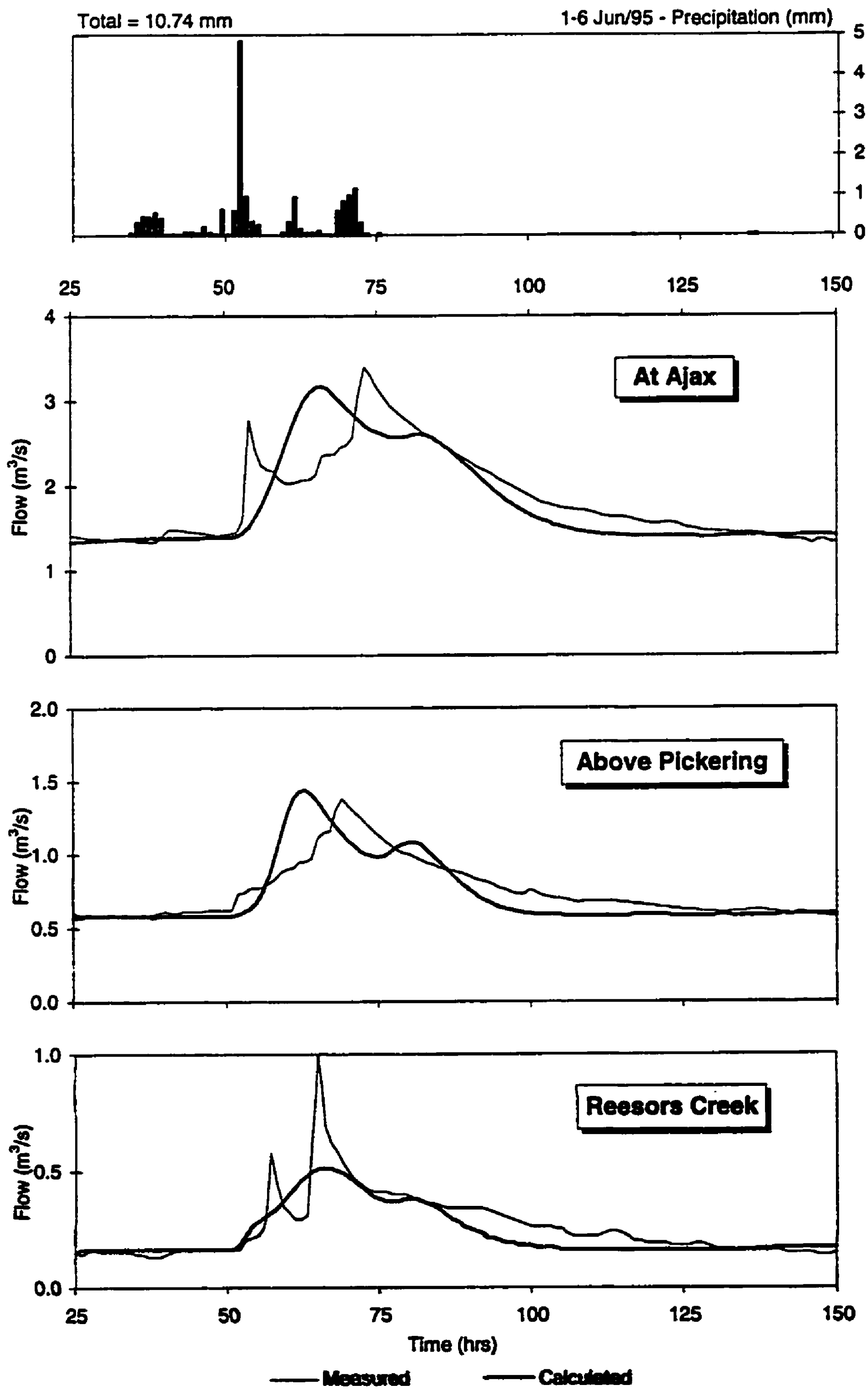


Figure E.6 WATFLOOD results for June 1-6, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.8)

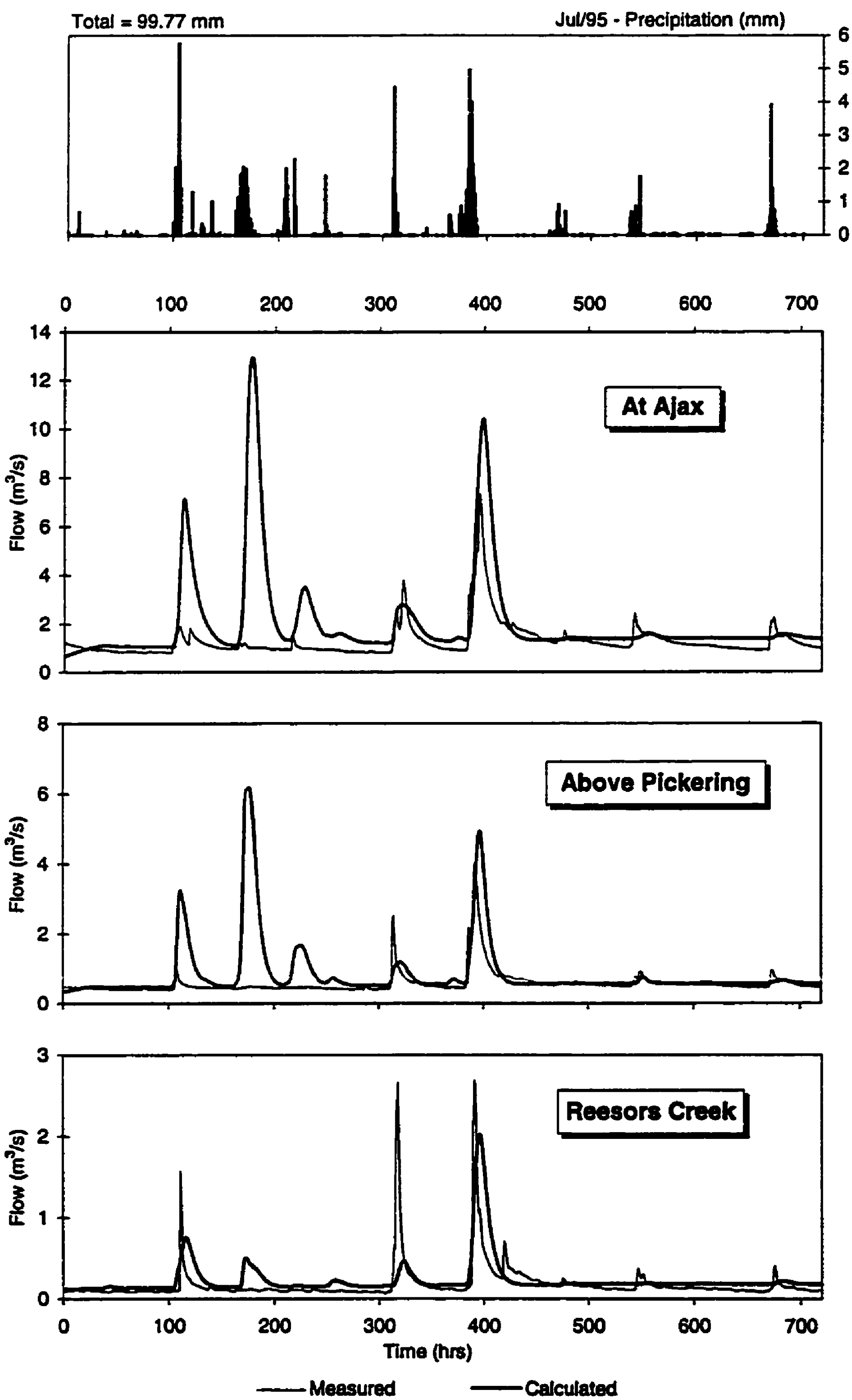


Figure E.7 WATFLOOD results for July, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.5)

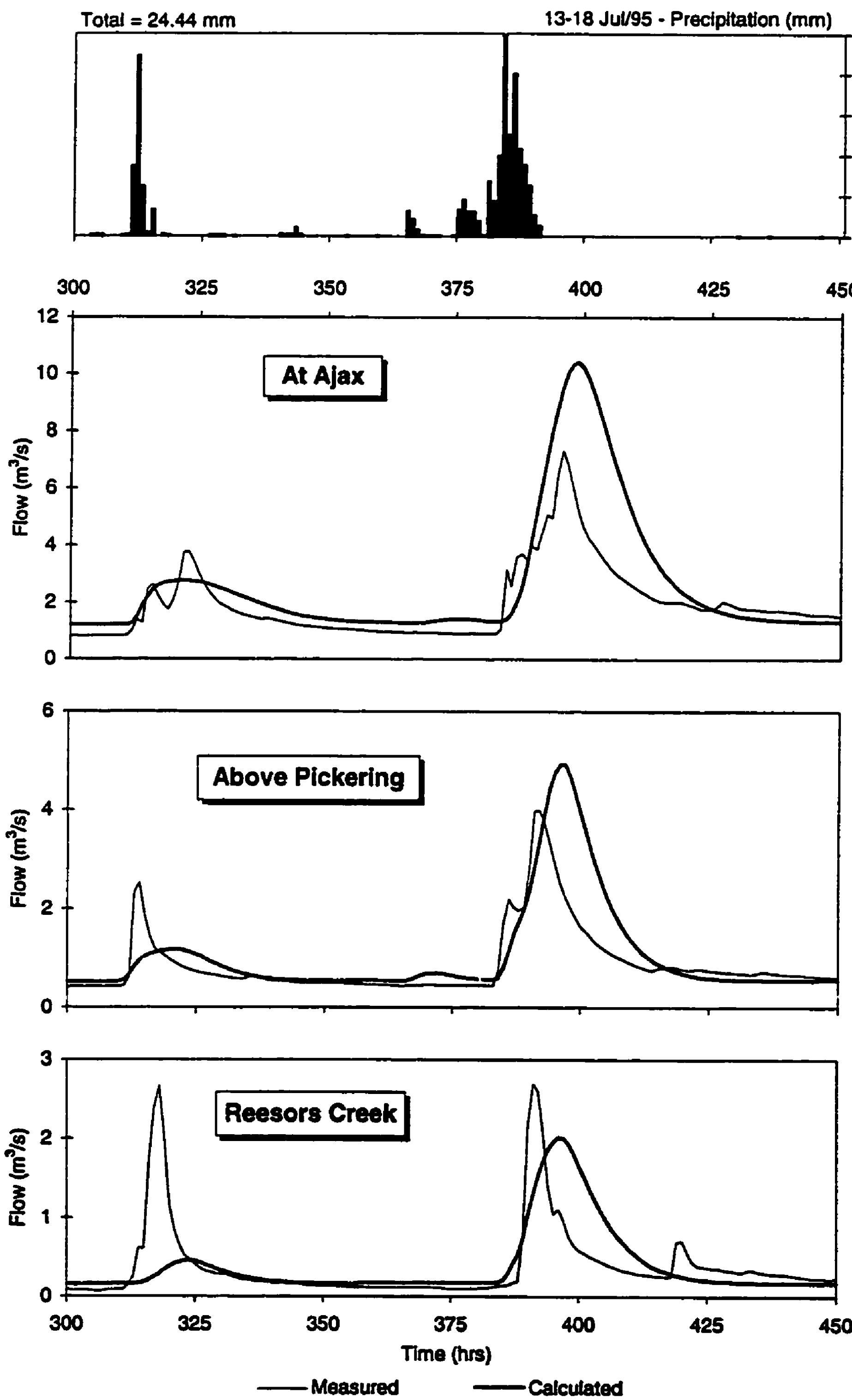


Figure E.8 WATFLOOD results for July 13-18, 1995 (2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.5)

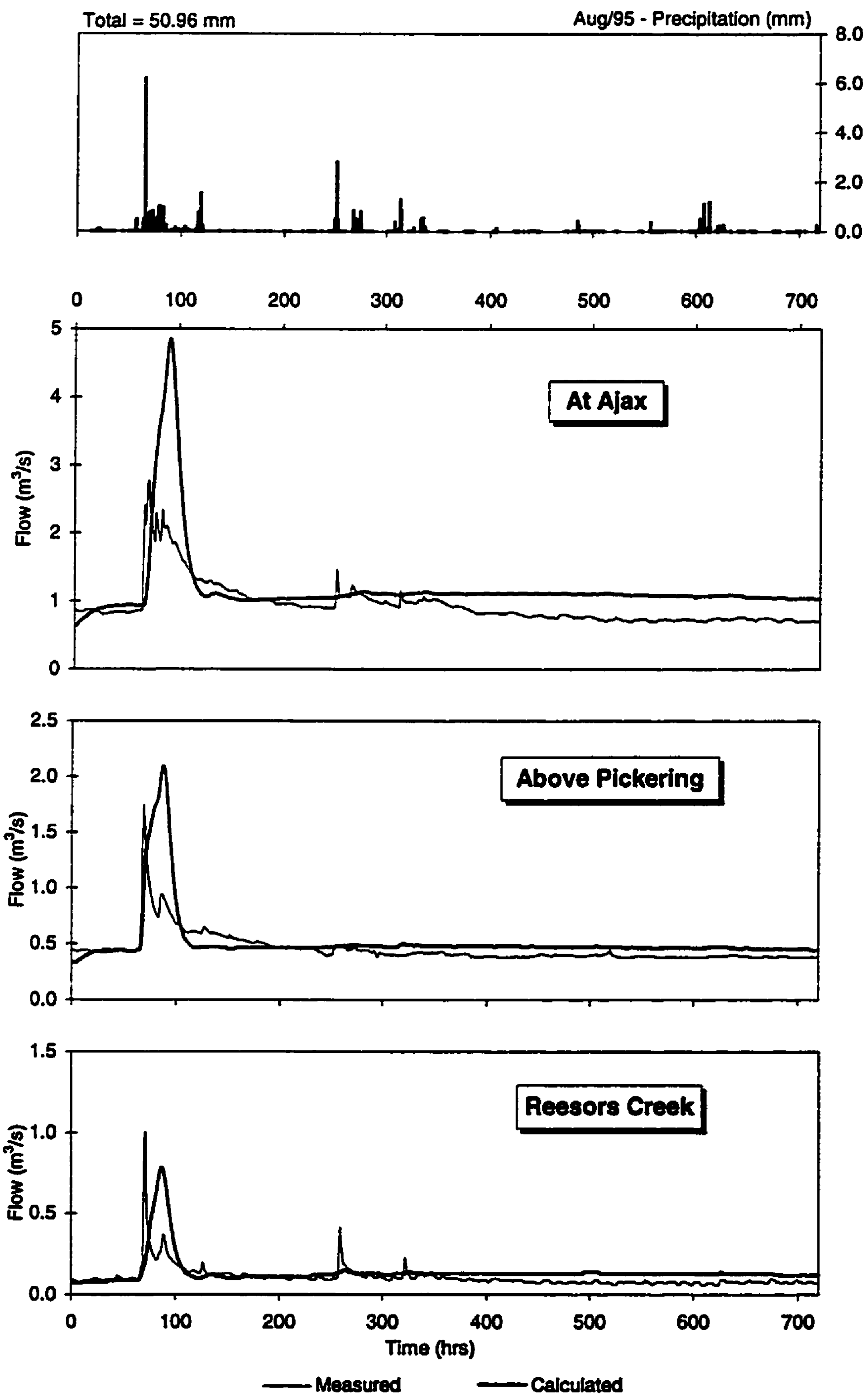


Figure E.9 WATFLOOD results for August, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.5)

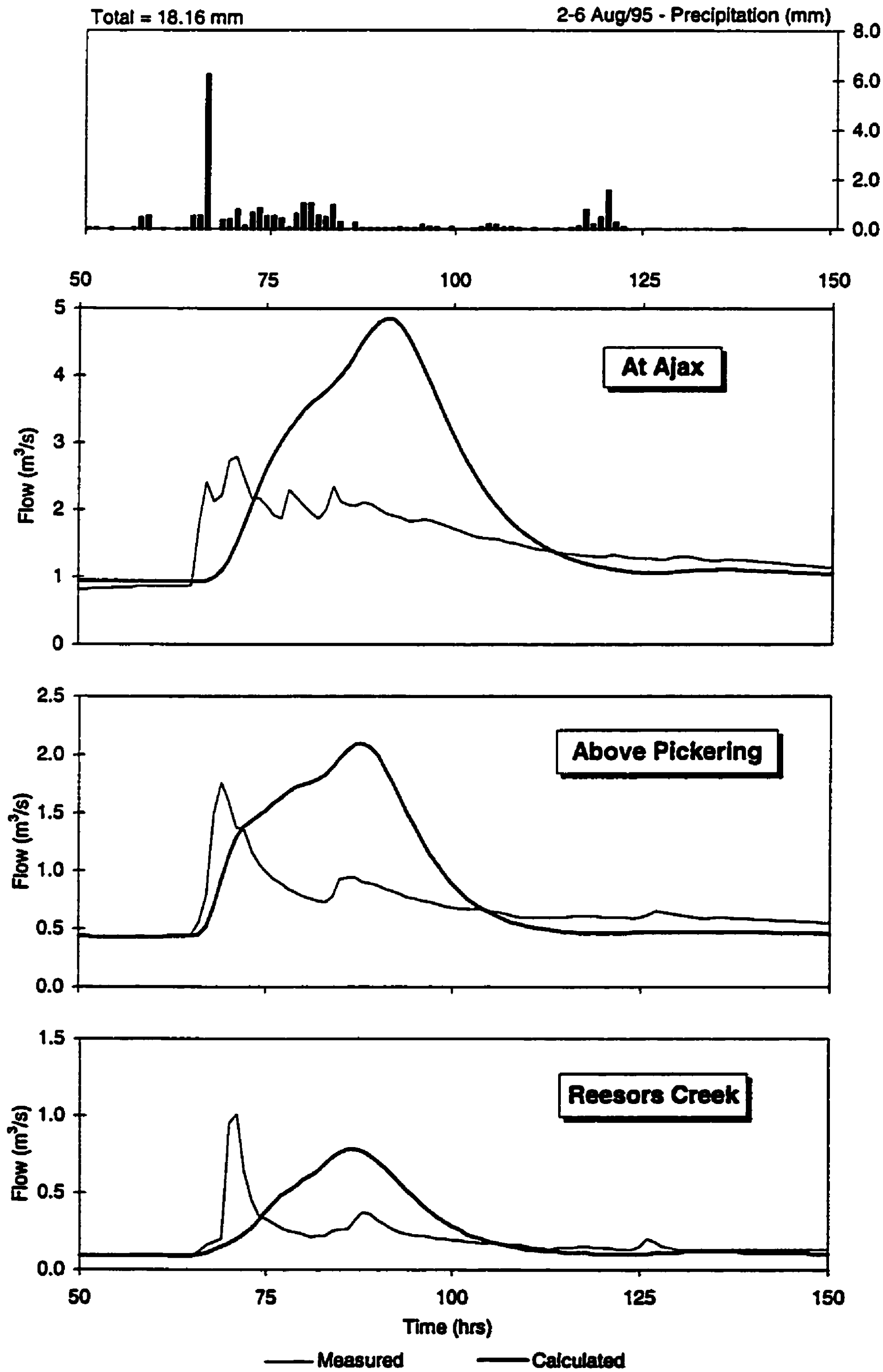


Figure E.10 WATFLOOD results for August 2-6, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.5)

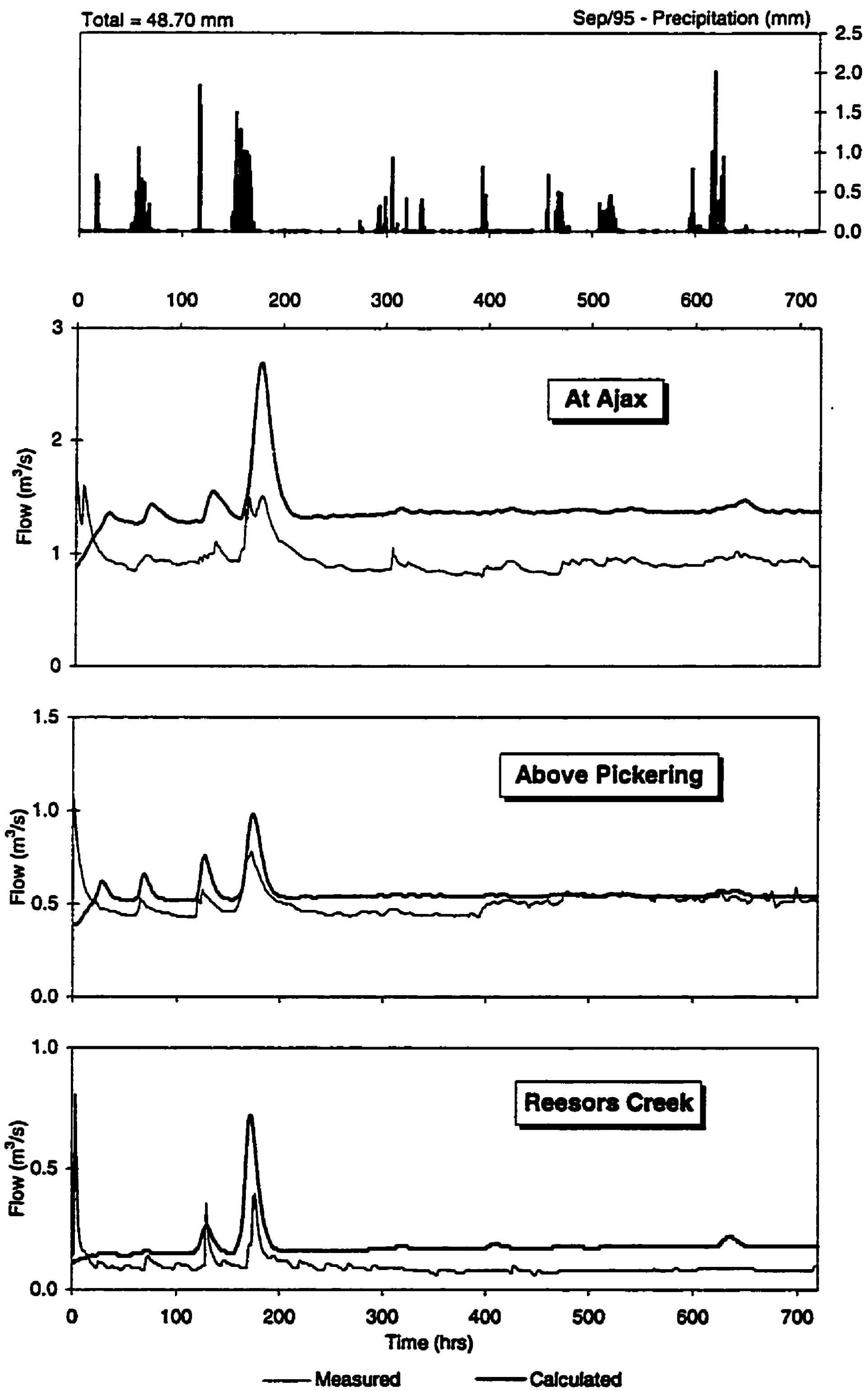


Figure E.11 WATFLOOD results for September, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.5)

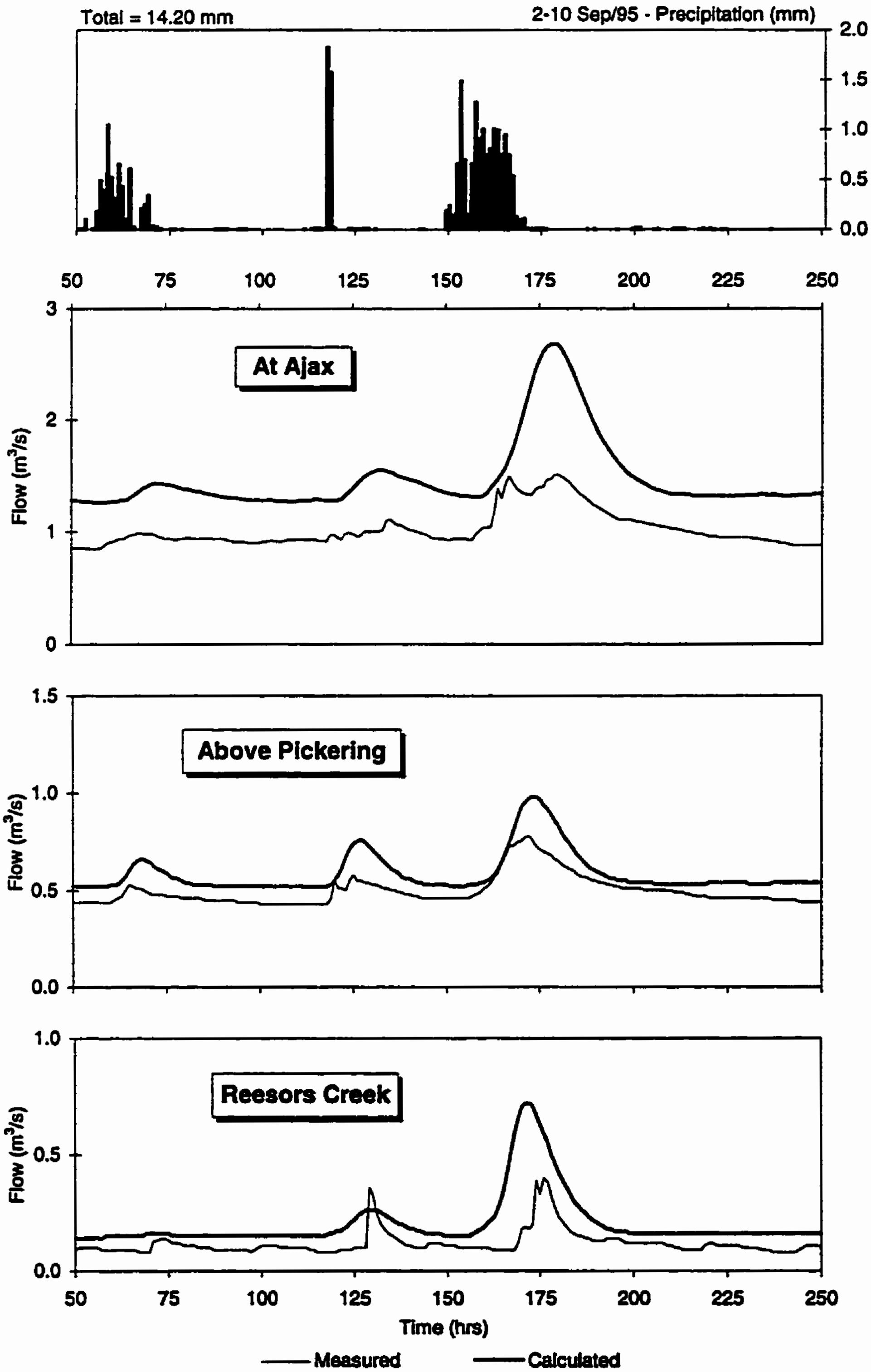


Figure E.12 WATFLOOD results for September 2-10, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.5)

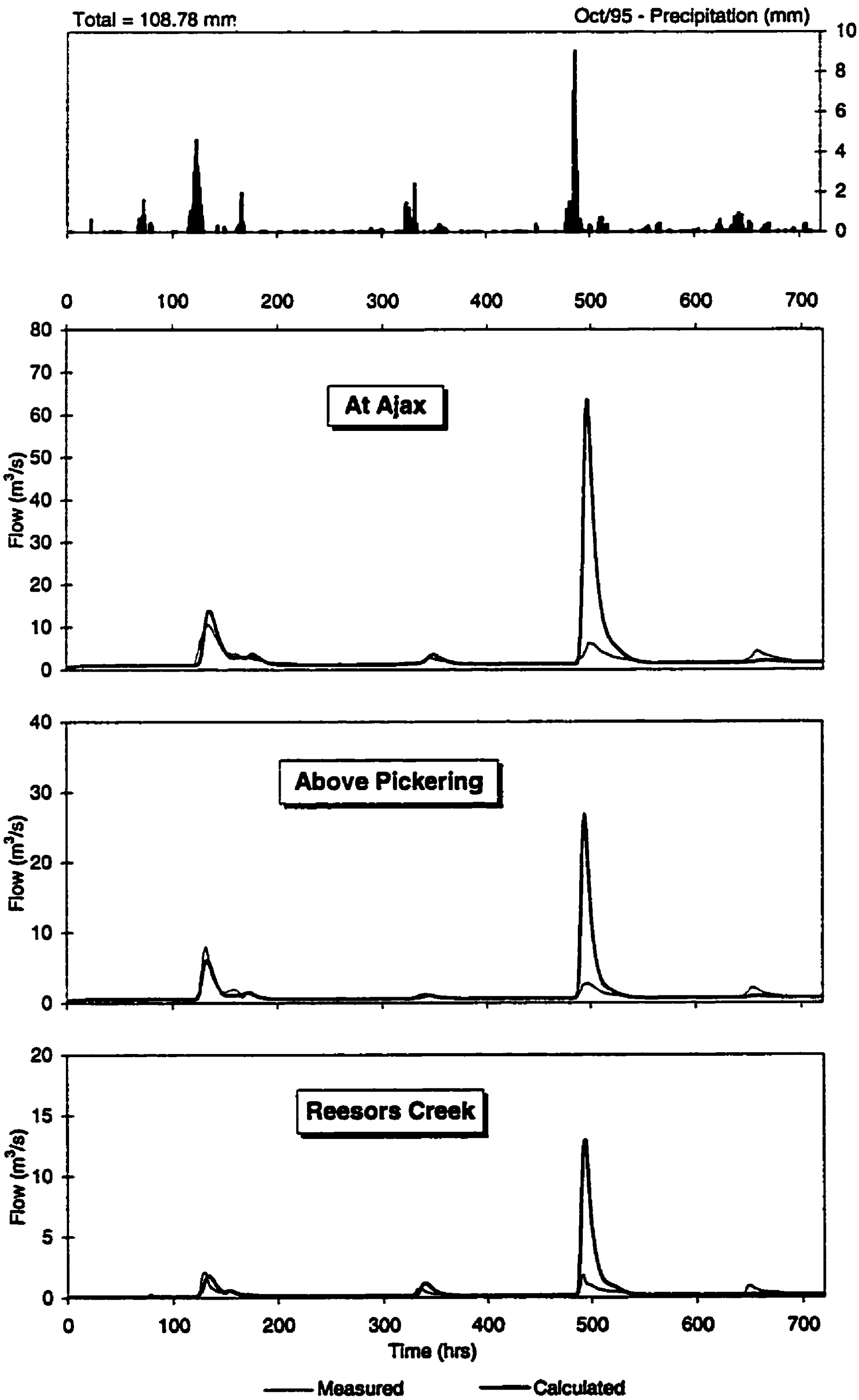


Figure E.13 WATFLOOD results for October, 1995 (2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.7)

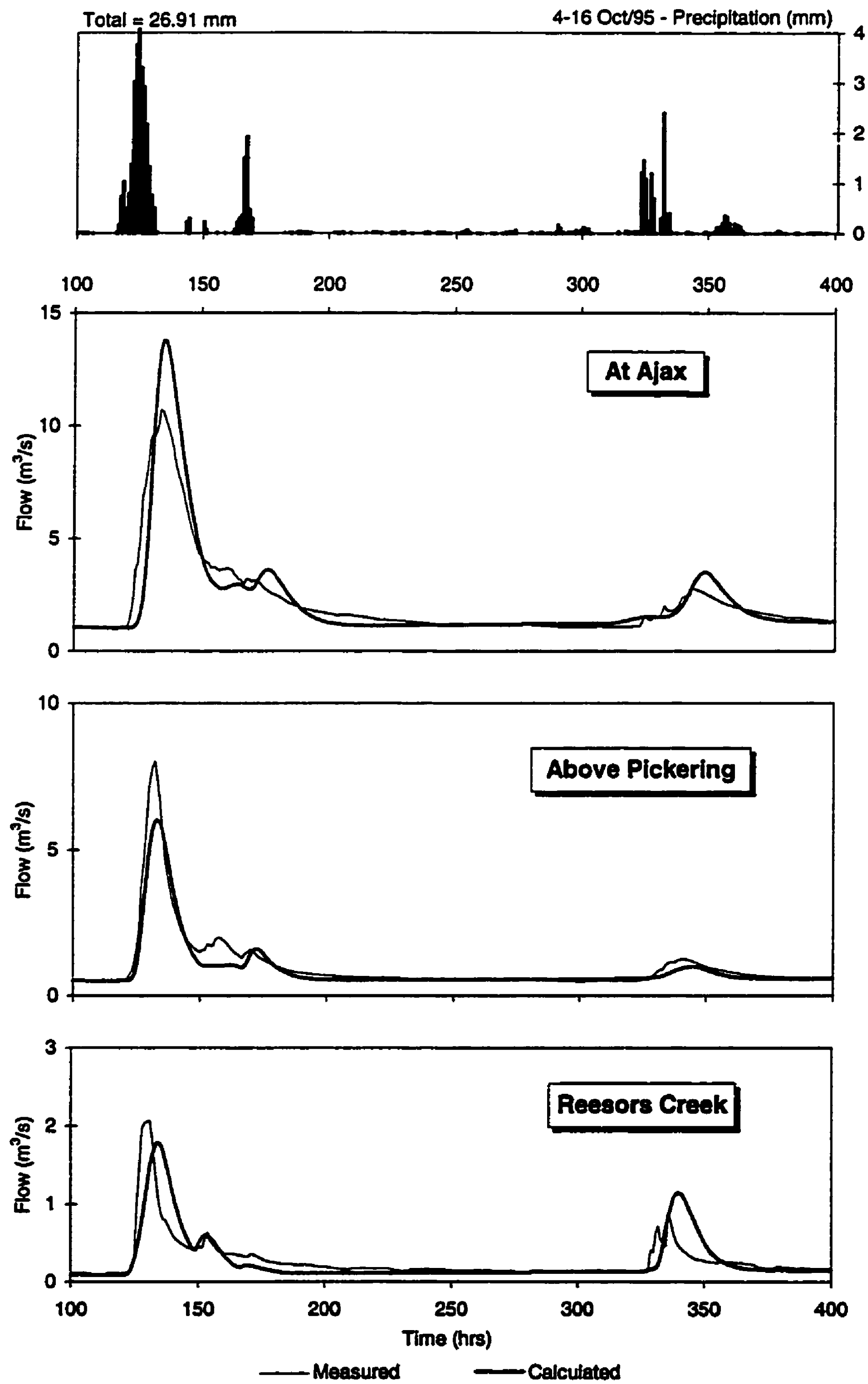


Figure E.14 WATFLOOD results for October 4-16, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 0.7)

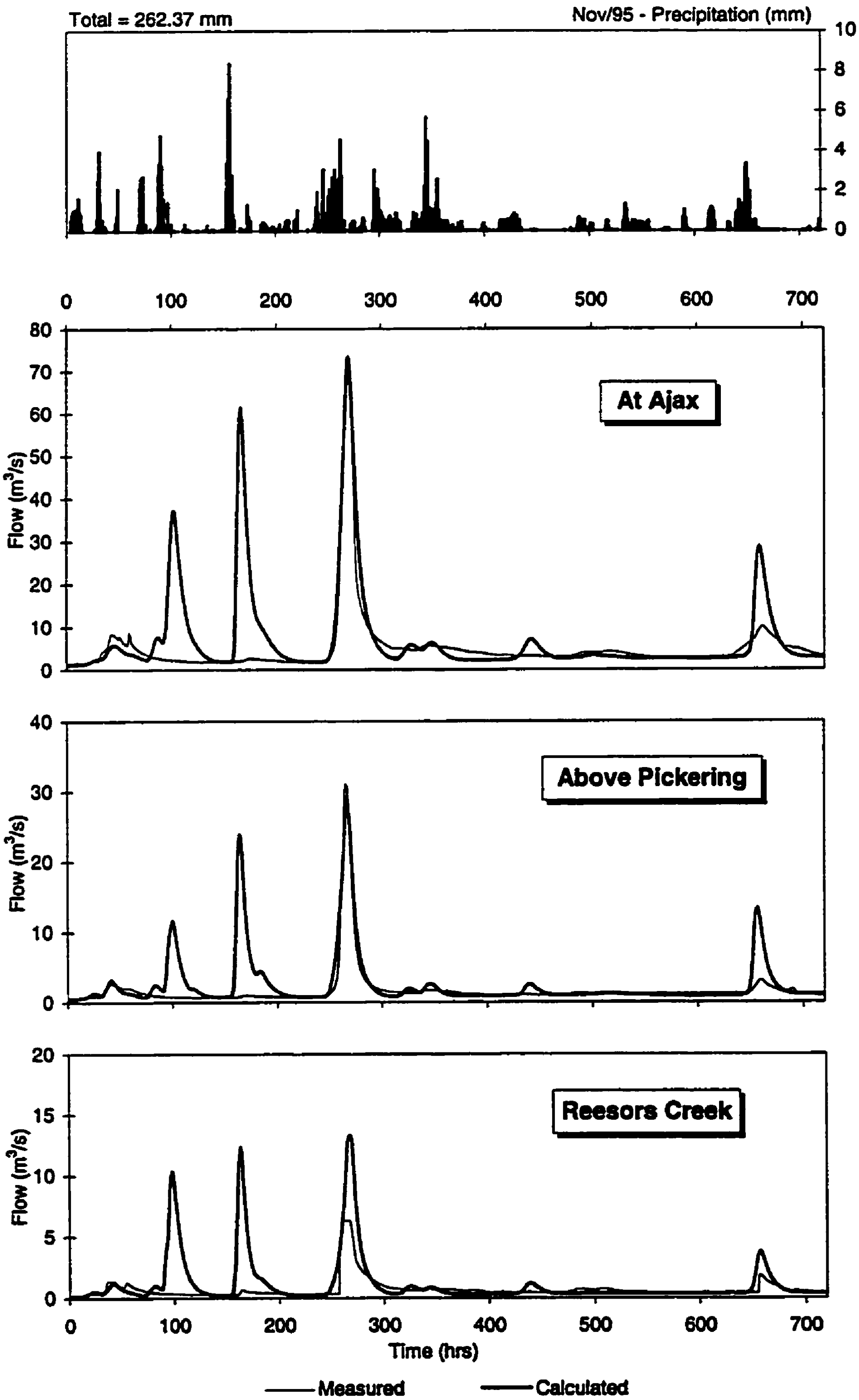


Figure E.15 WATFLOOD results for November, 1995 (2x2 Grid - Uncalibrated Radar Data - Radar Scale 1.0)

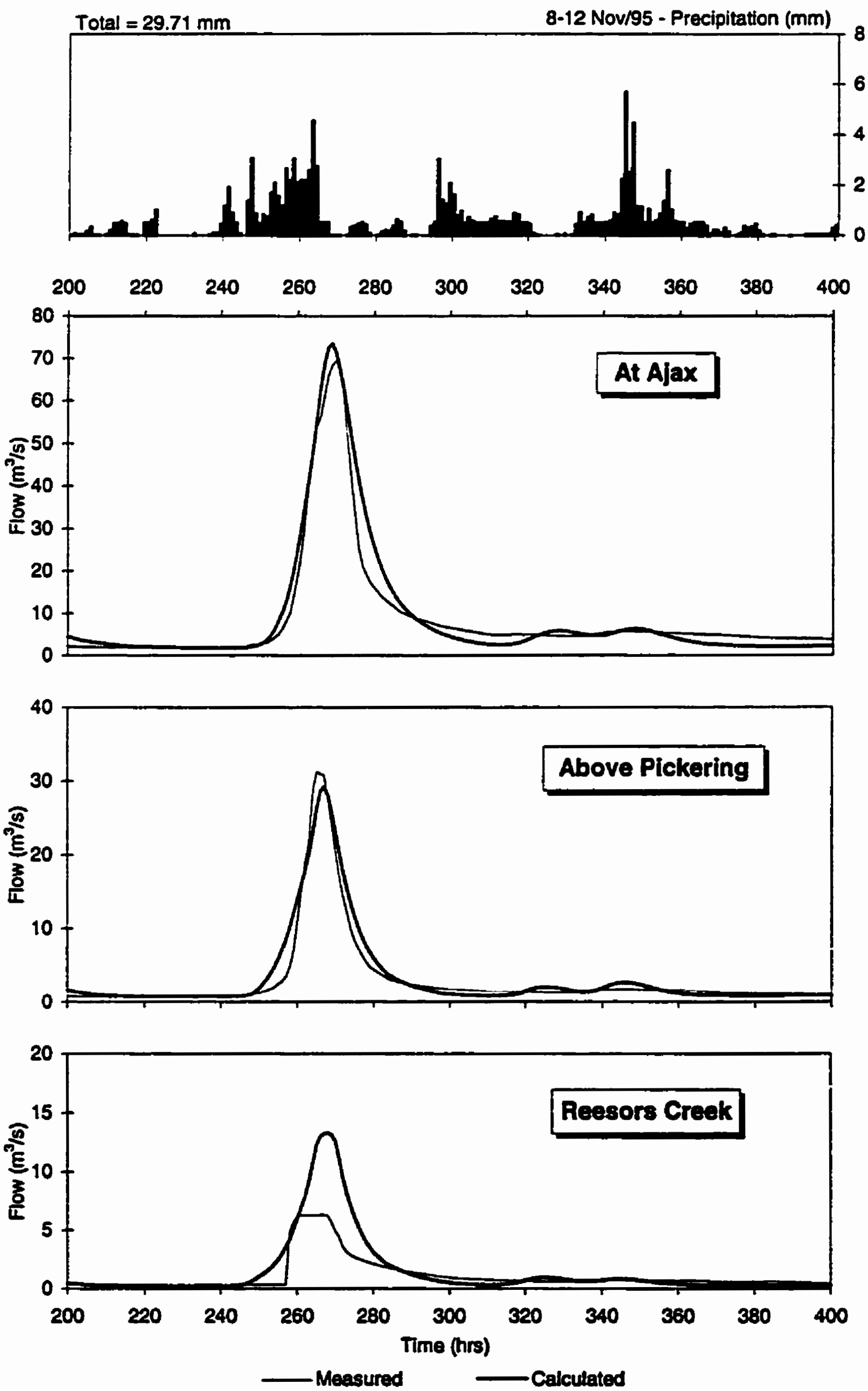


Figure E.16 WATFLOOD results for November 8-12, 1995
(2x2 Grid - Uncalibrated Radar Data - Radar Scale 1.0)

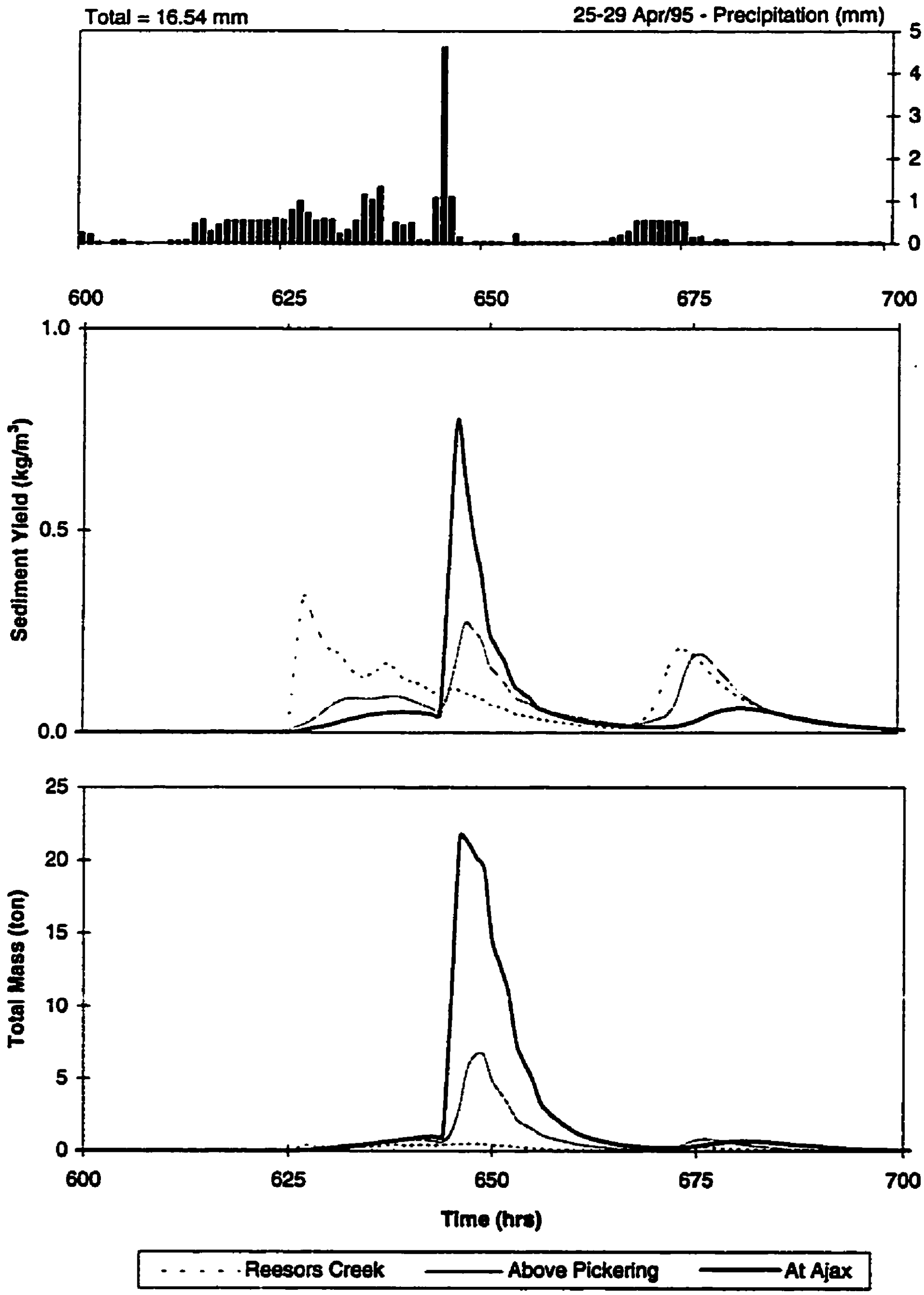


Figure E.17 WATFLOOD/Sediment results for April 25-29, 1995
(2x2 km Grid - Sediment Yield and Total Mass - Deposition Factor 15%)

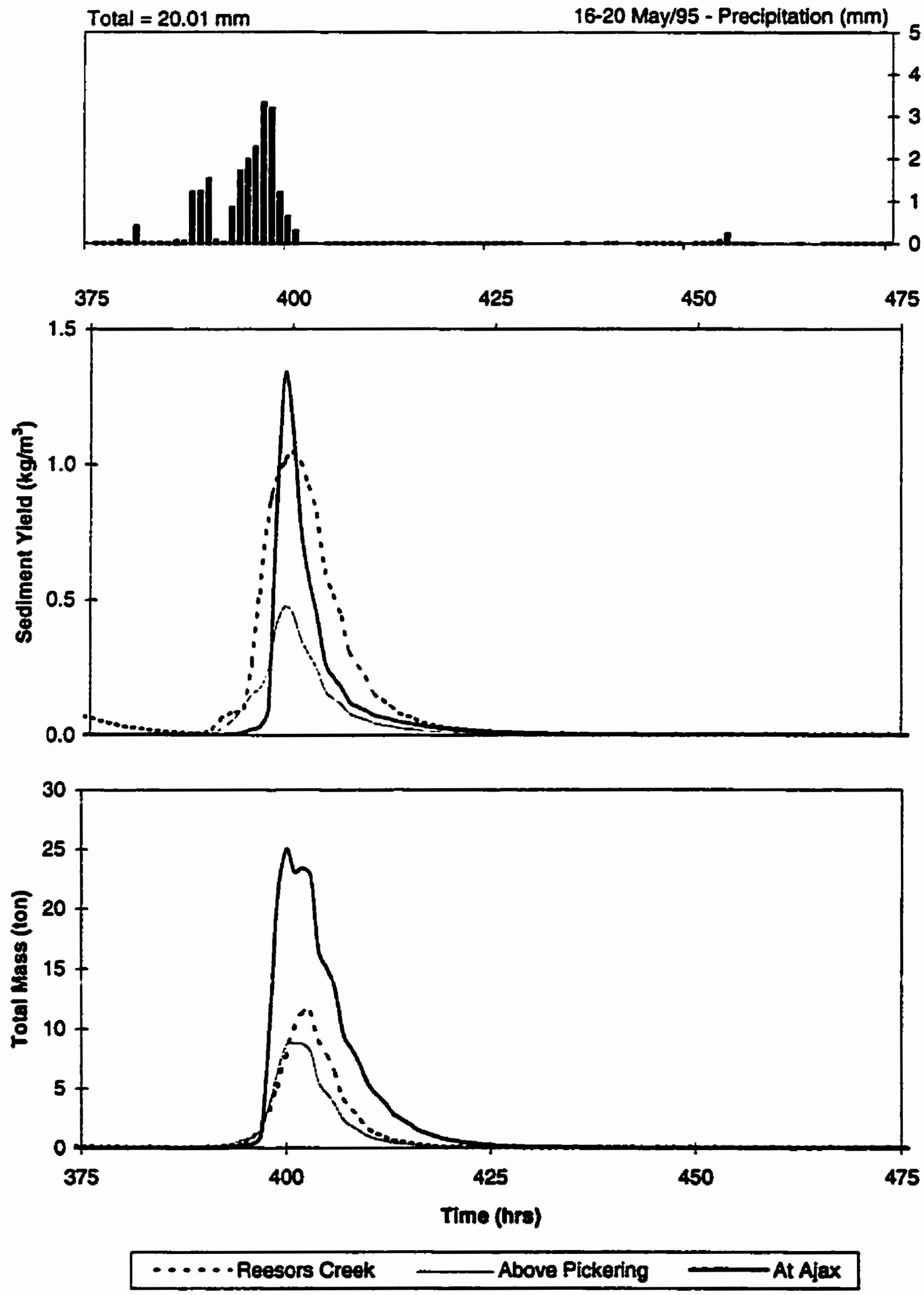


Figure E.18 WATFLOOD/Sediment results for May 16-20, 1995
(2x2 km Grid - Sediment Yield and Total Mass - Deposition Factor 15%)

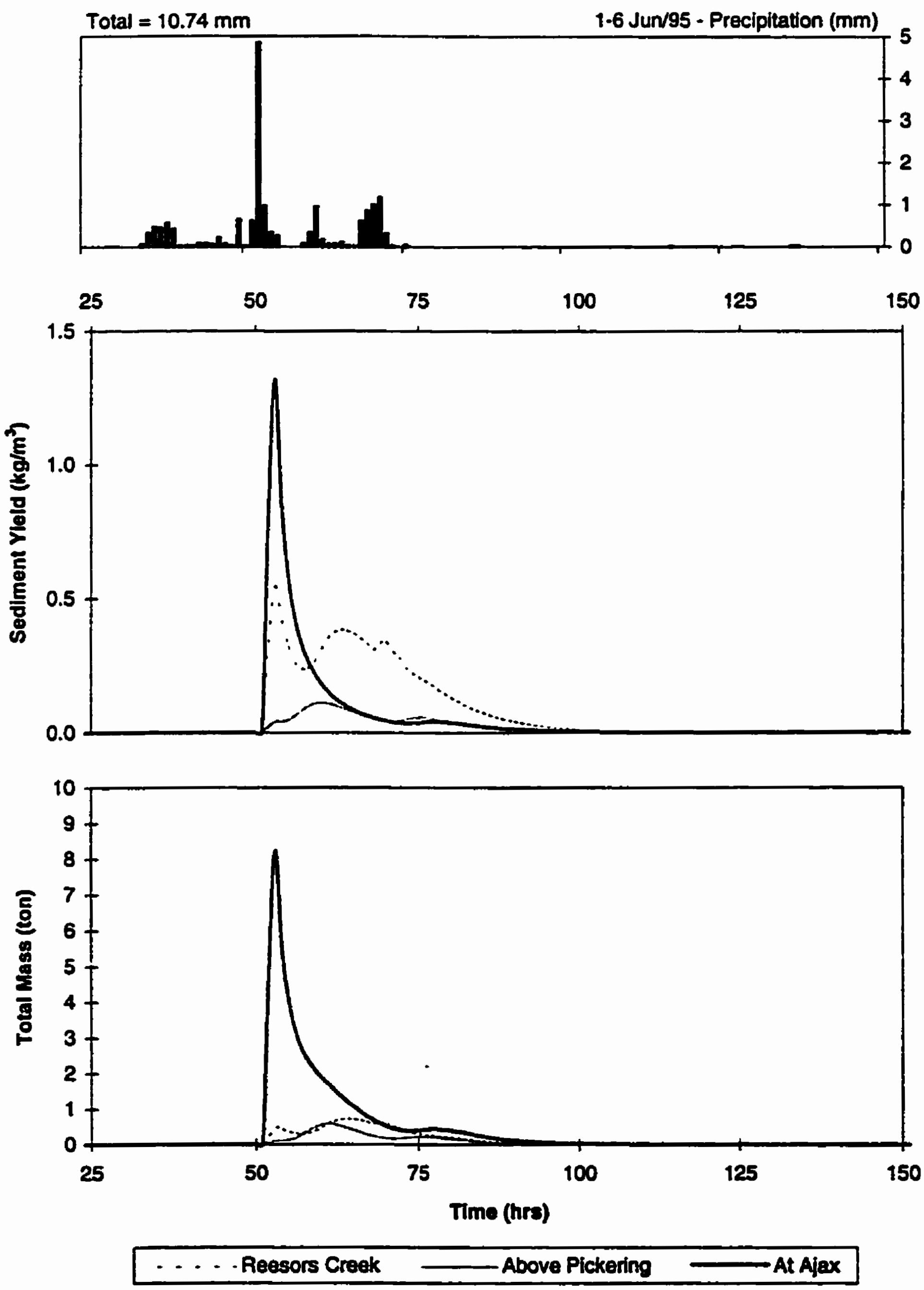


Figure E.19 WATFLOOD/Sediment results for June 1-6, 1995
(2x2 km Grid - Sediment Yield and Total Mass - Deposition Factor 15%)

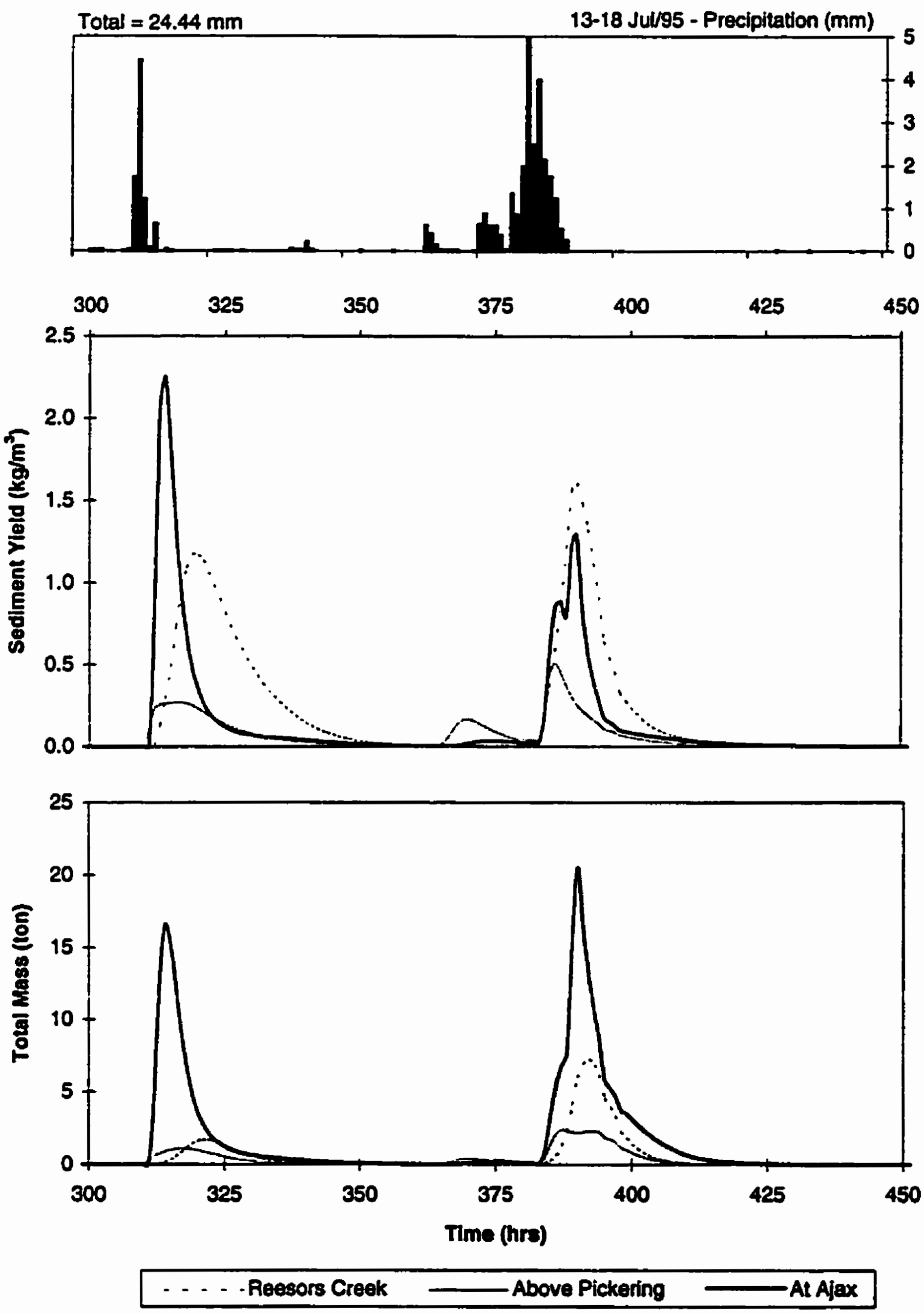


Figure E.20 WATFLOOD/Sediment results for July 13-18, 1995
(2x2 km Grid - Sediment Yield and Total Mass - Deposition Factor 20%)

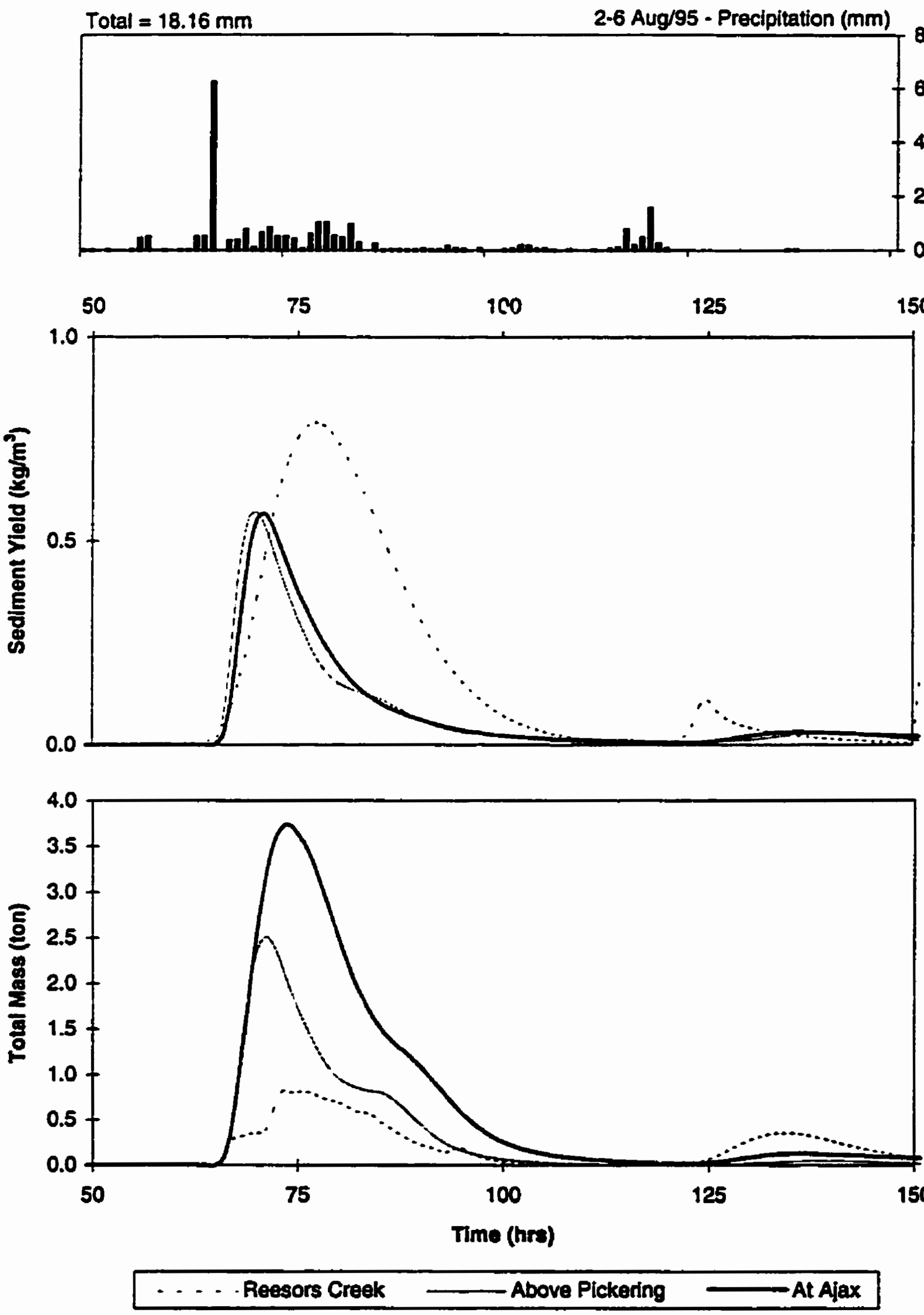


Figure E.21 WATFLOOD/Sediment results for August 2-6, 1995
(2x2 km Grid - Sediment Yield and Total Mass - Deposition Factor 15%)

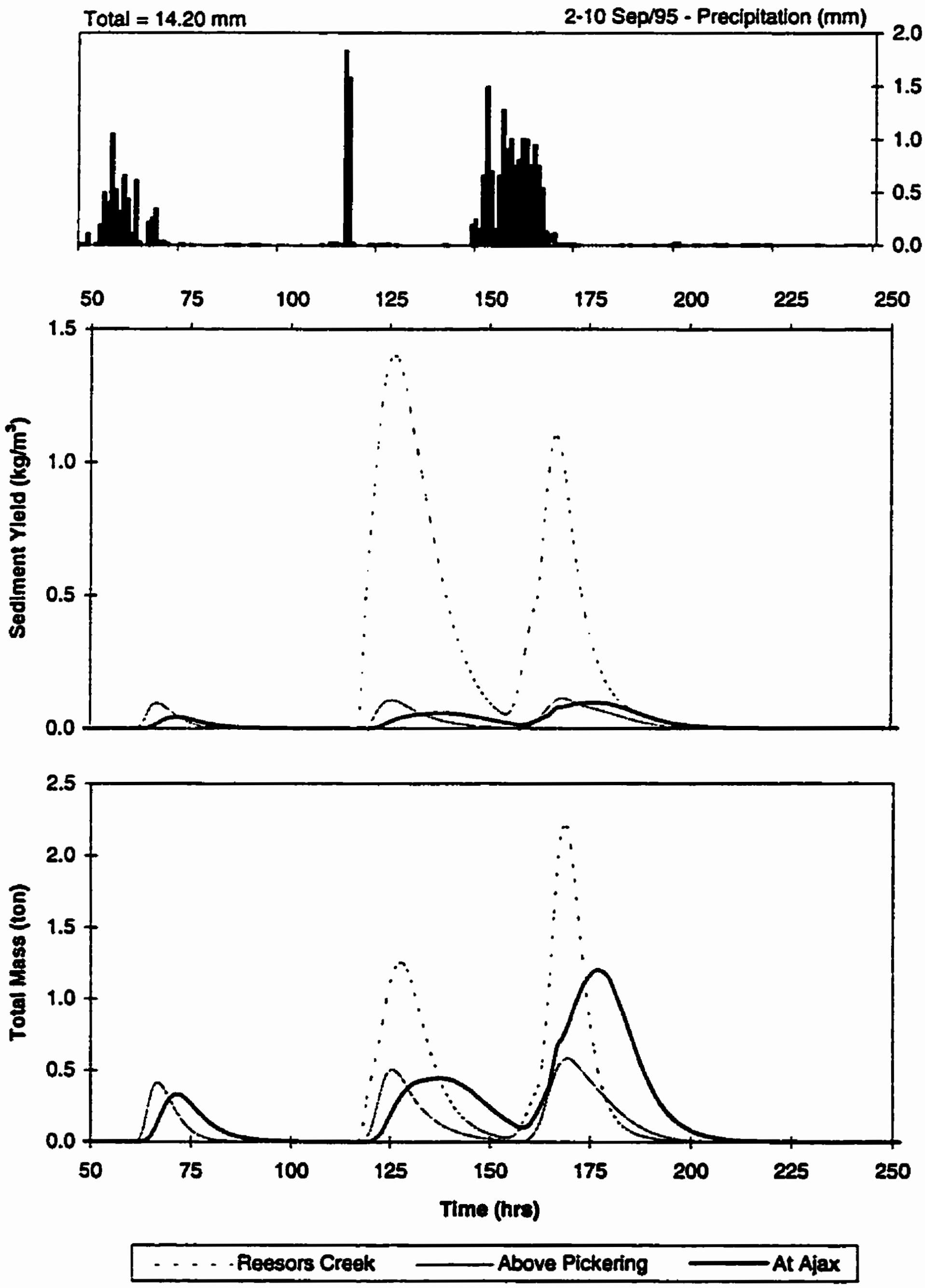


Figure E.22 WATFLOOD/Sediment results for September 2-10 1995 (2x2 km Grid - Sediment Yield and Total Mass - Deposition Factor 15%)

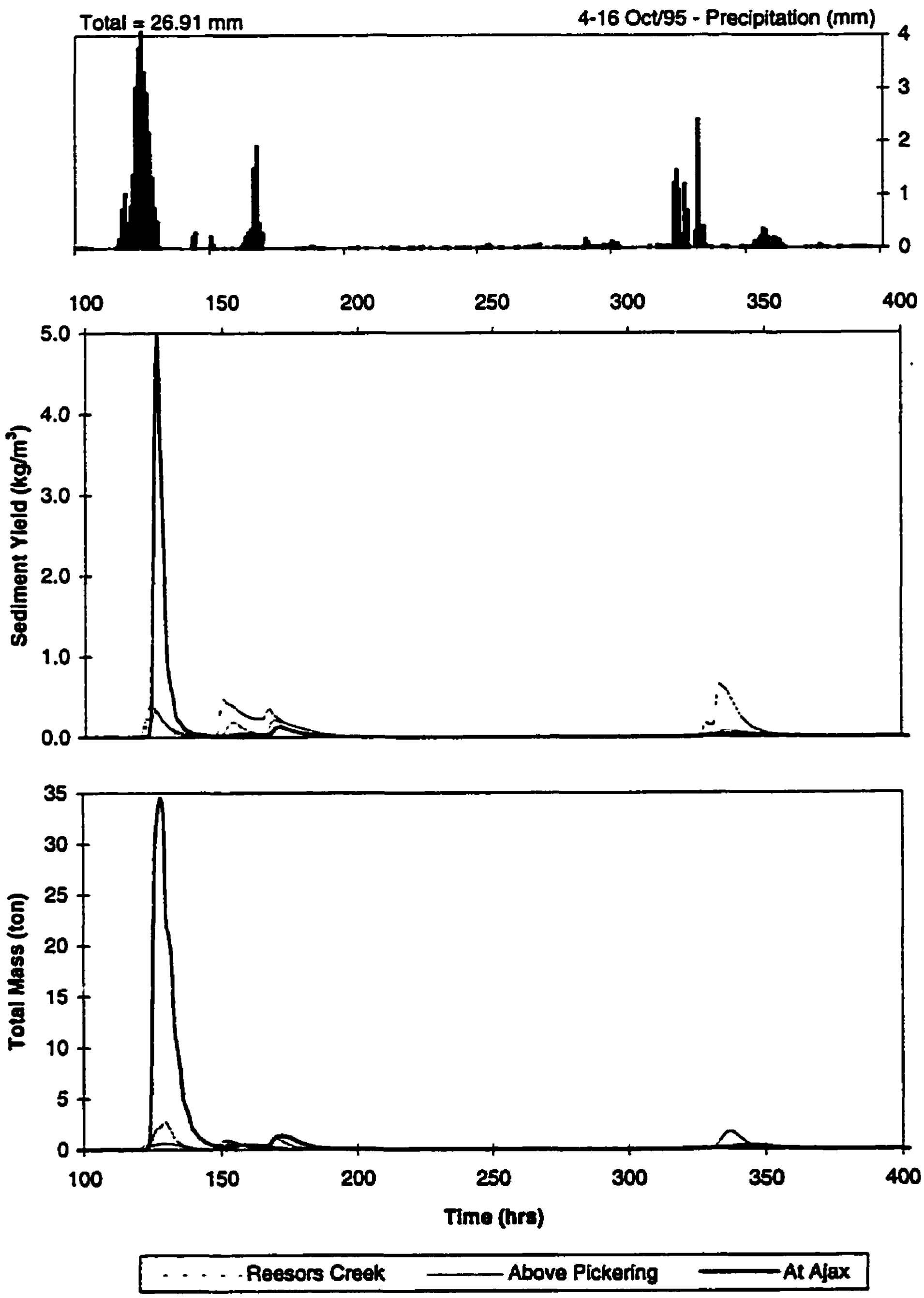


Figure E.23 WATFLOOD/Sediment results for October 4-16, 1995
(2x2 km Grid - Sediment Yield and Total Mass - Deposition Factor 20%)

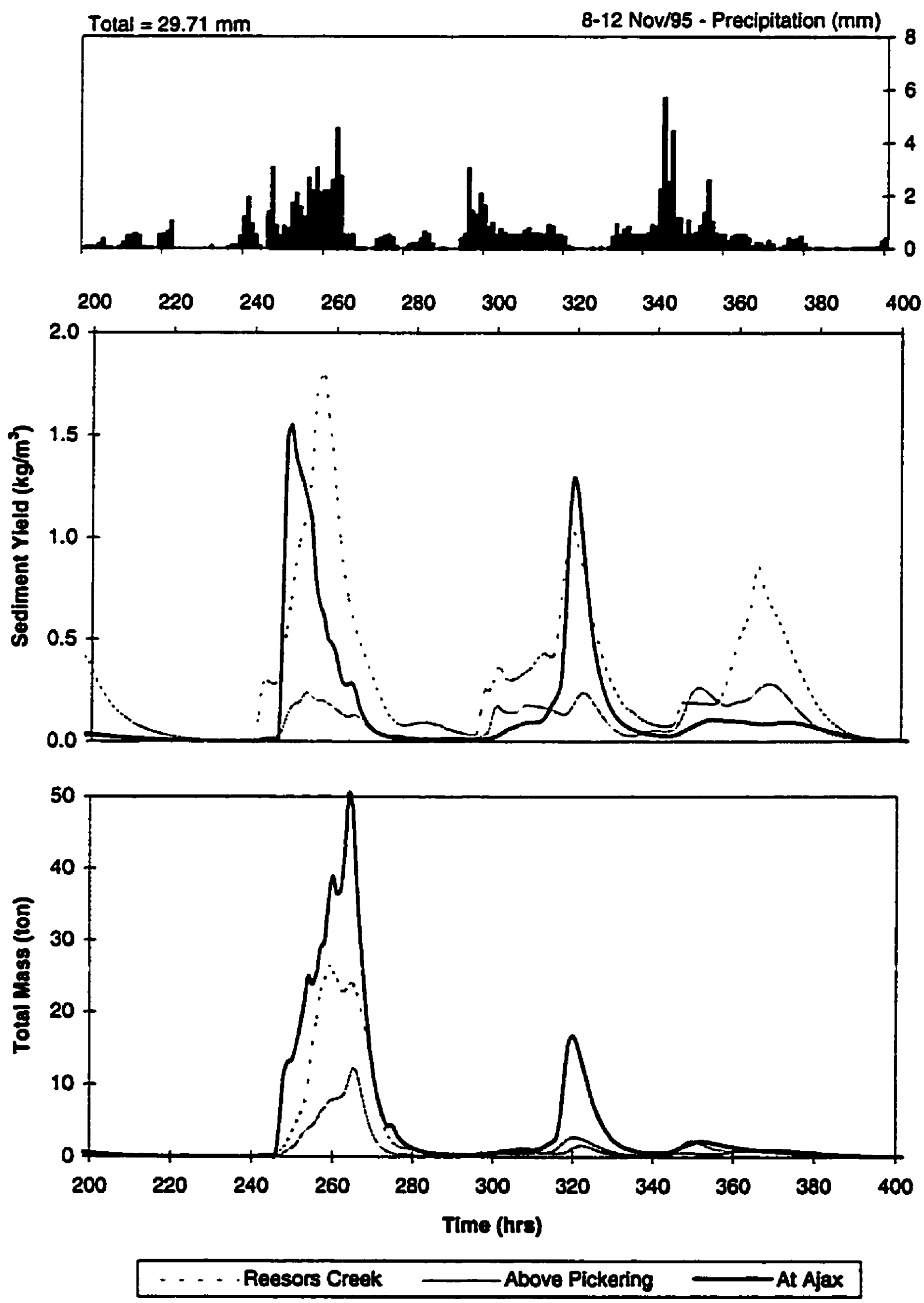


Figure E.24 WATFLOOD/Sediment results for November 8-12, 1995 (2x2 km Grid - Sediment Yield and Total Mass - Deposition Factor 20%)

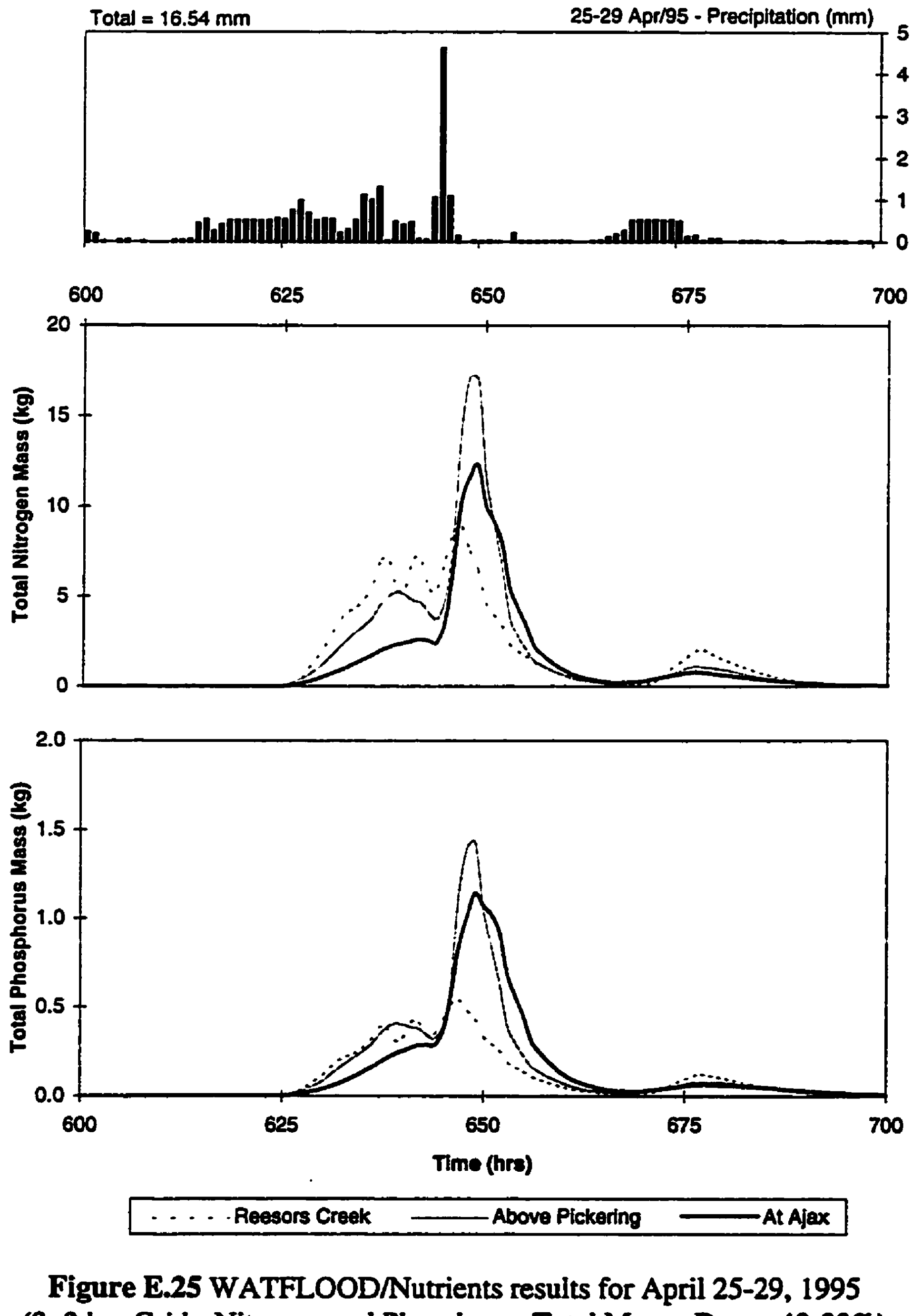


Figure E.25 WATFLOOD/Nutrients results for April 25-29, 1995
(2x2 km Grid - Nitrogen and Phosphorus Total Mass - Decay 40-30%)

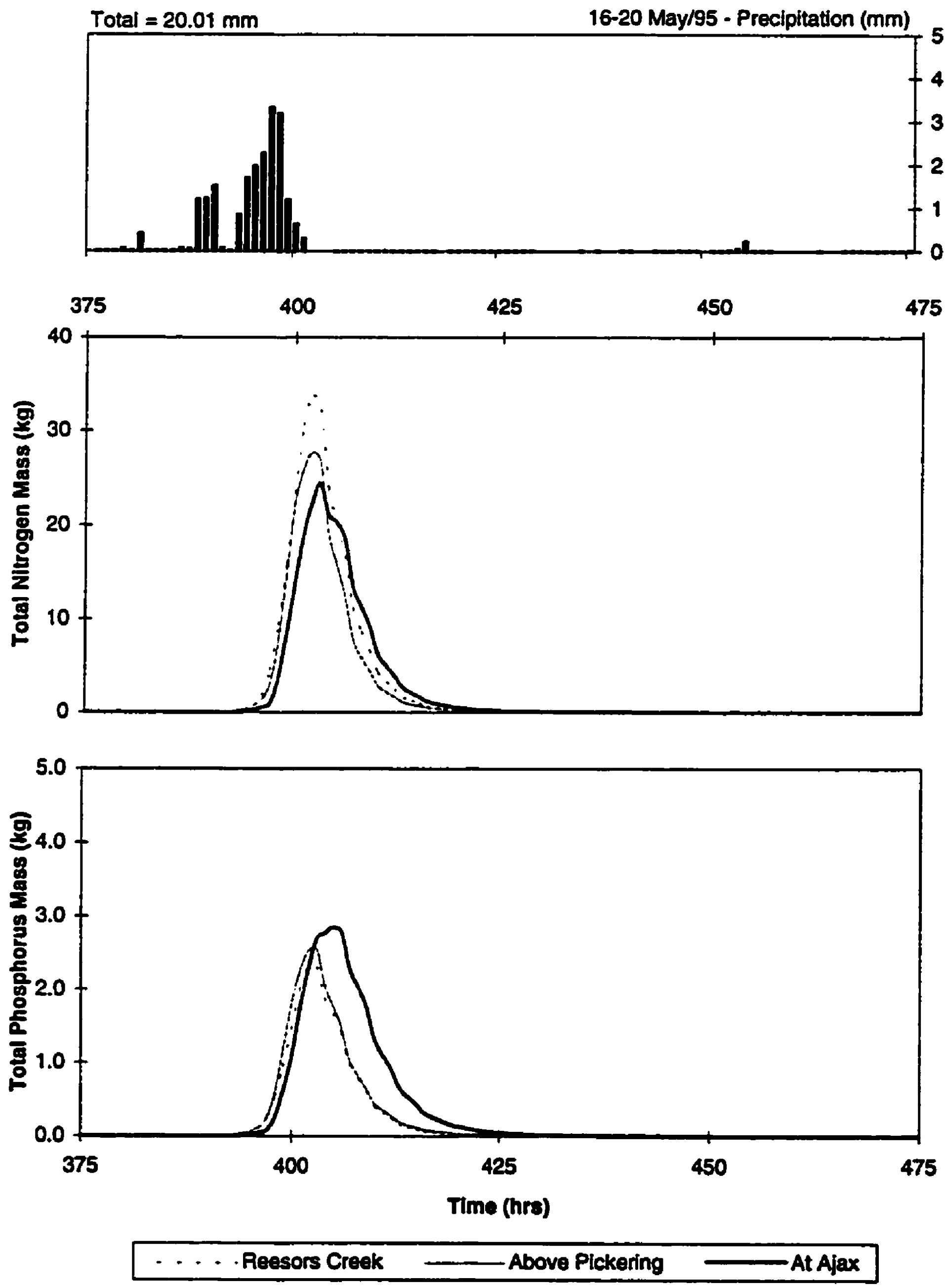


Figure E.26 WATFLOOD/Nutrients results for May 16-20, 1995
(2x2 km Grid - Nitrogen and Phosphorus Total Mass - Decay 30-20%)

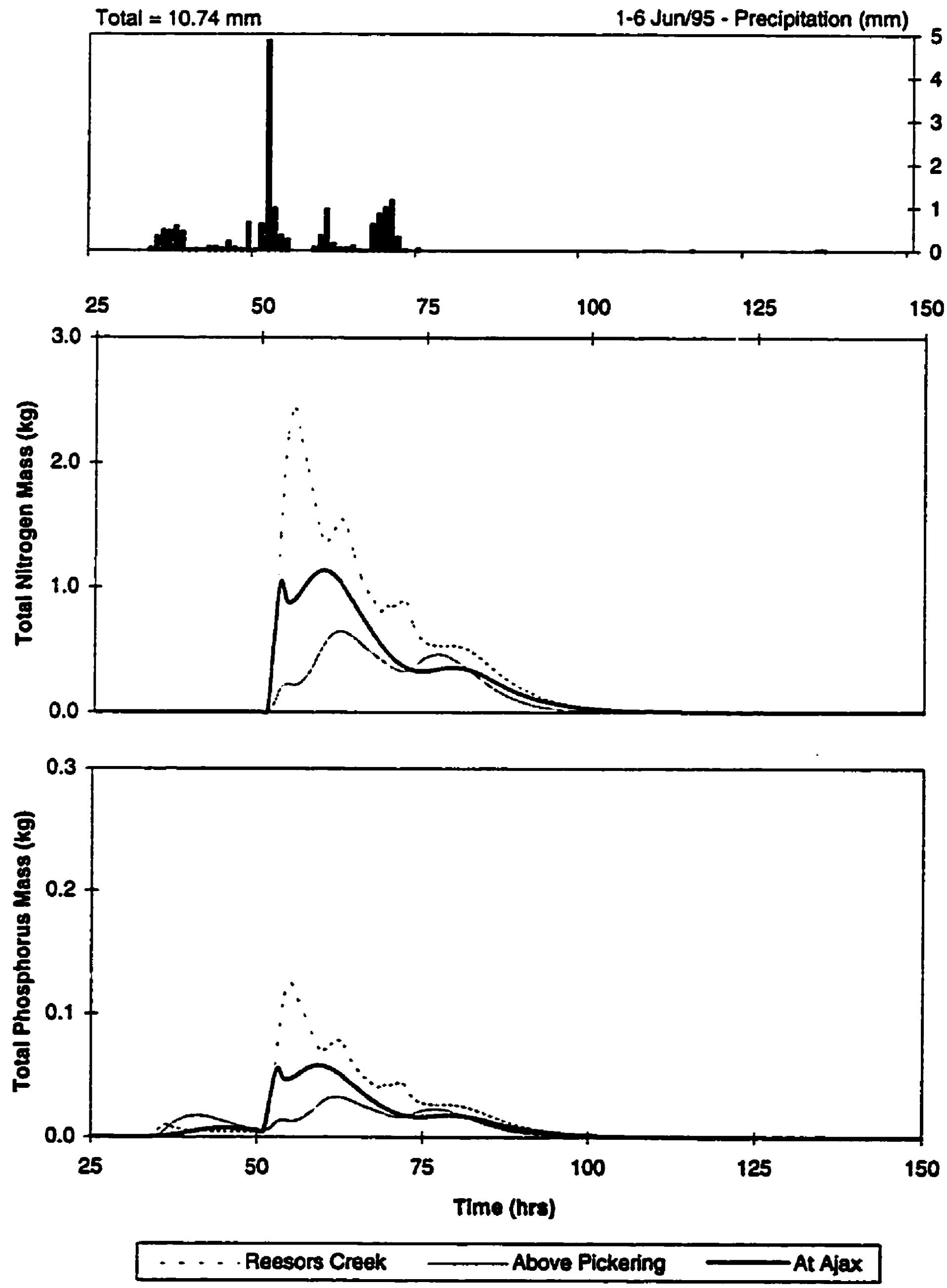


Figure E.27 WATFLOOD/Nutrients results for June 1-6, 1995
(2x2 km Grid - Nitrogen and Phosphorus Total Mass - Decay 30-30%)

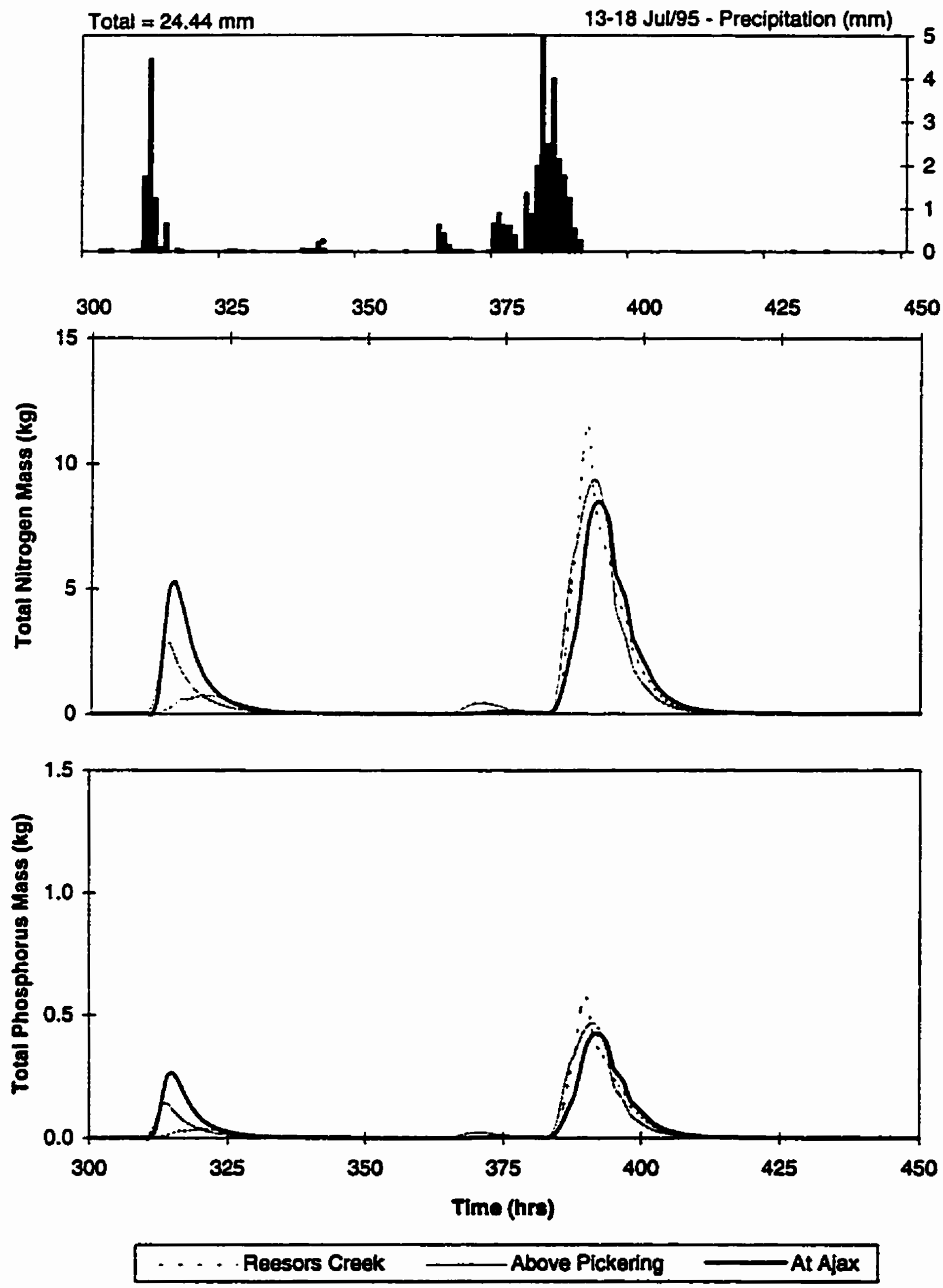


Figure E.28 WATFLOOD/Nutrients results for July 13-18, 1995
(2x2 km Grid - Nitrogen and Phosphorus Total Mass - Decay 35-35%)

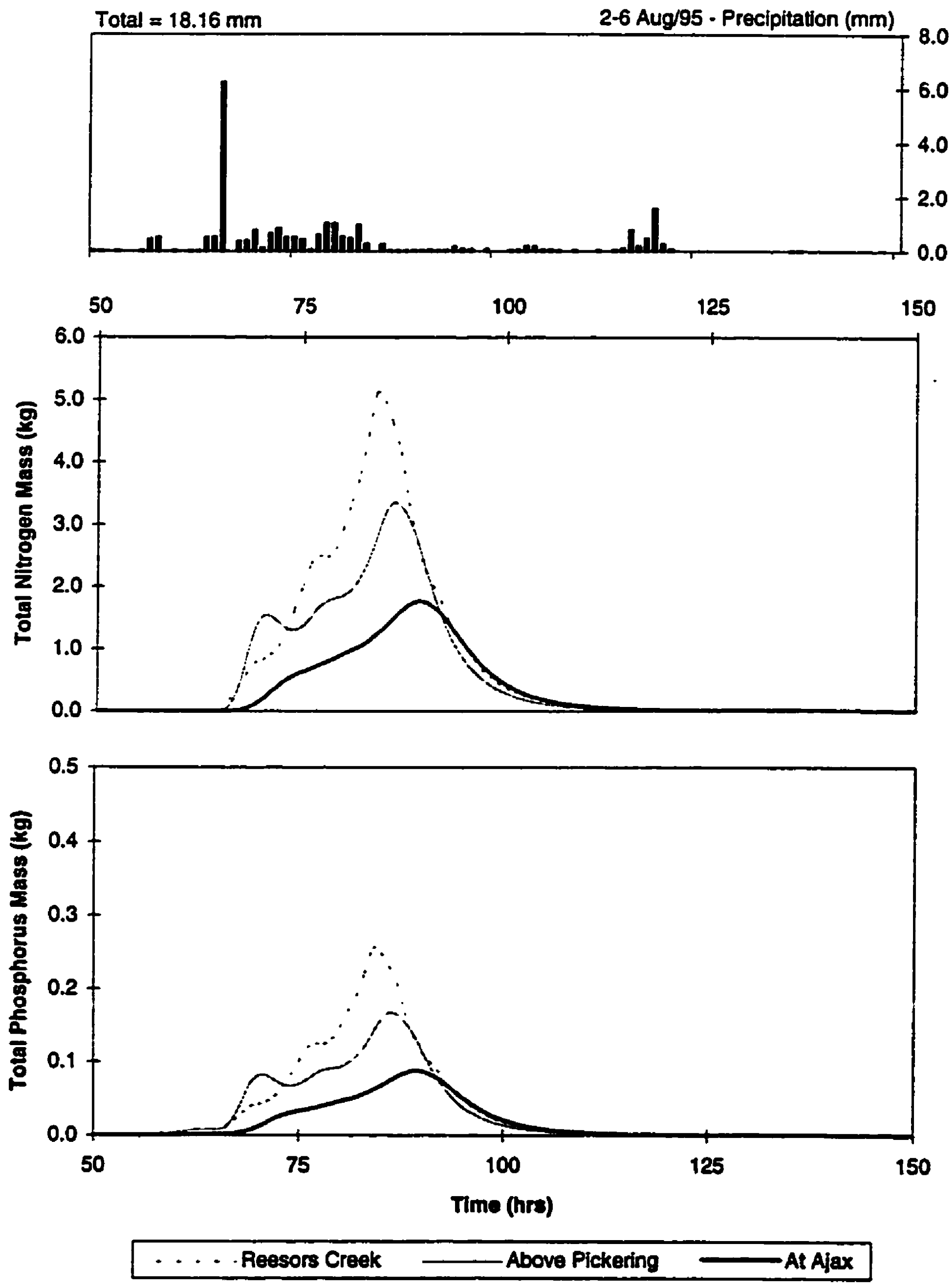


Figure E.29 WATFLOOD/Nutrients results for August 2-6, 1995 (2x2 km Grid - Nitrogen and Phosphorus Total Mass - Decay 35-35%)

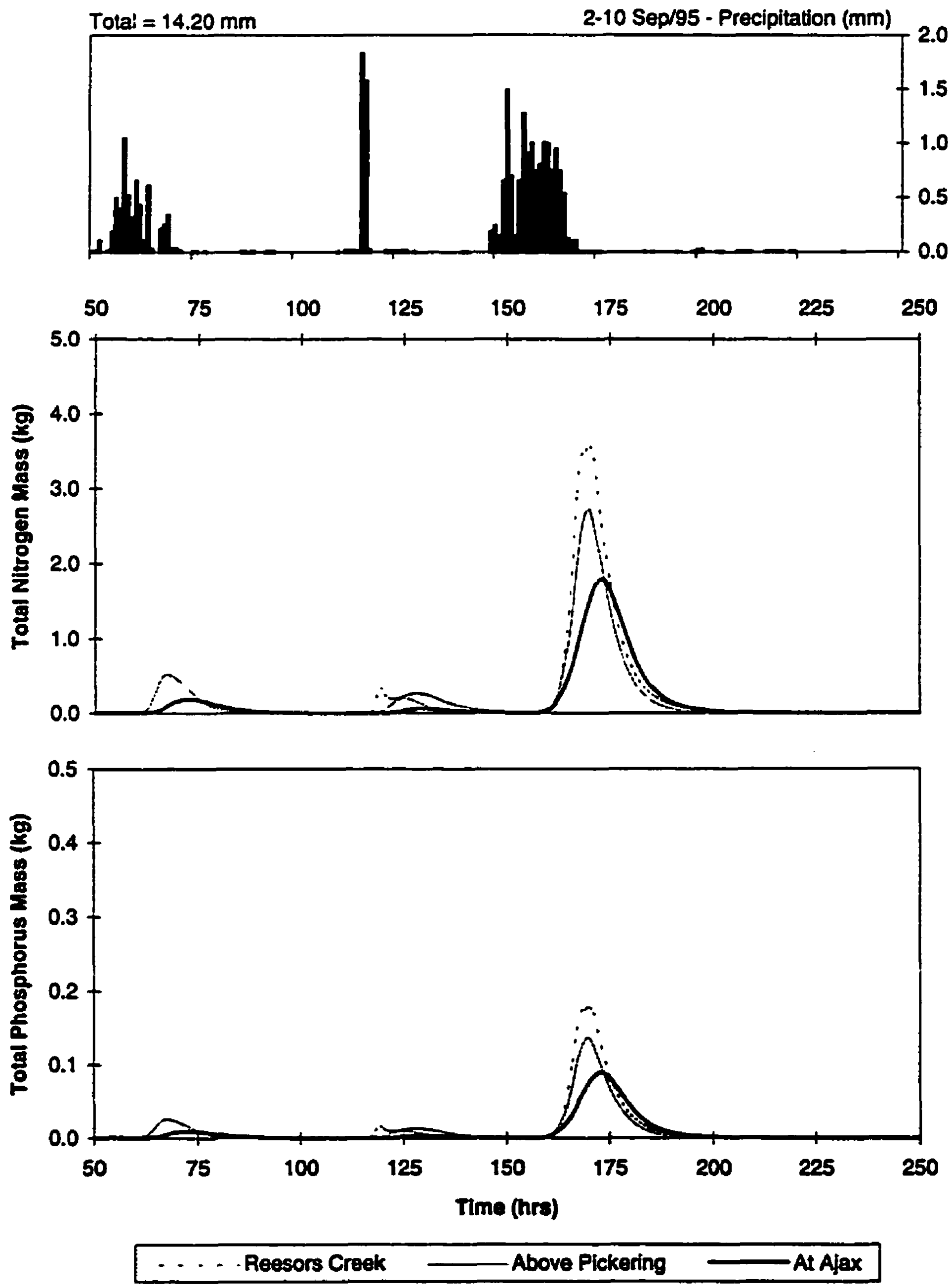


Figure E.30 WATFLOOD/Nutrients results for September 2-10, 1995 (2x2 km Grid - Nitrogen and Phosphorus Total Mass - Decay 30-30%)

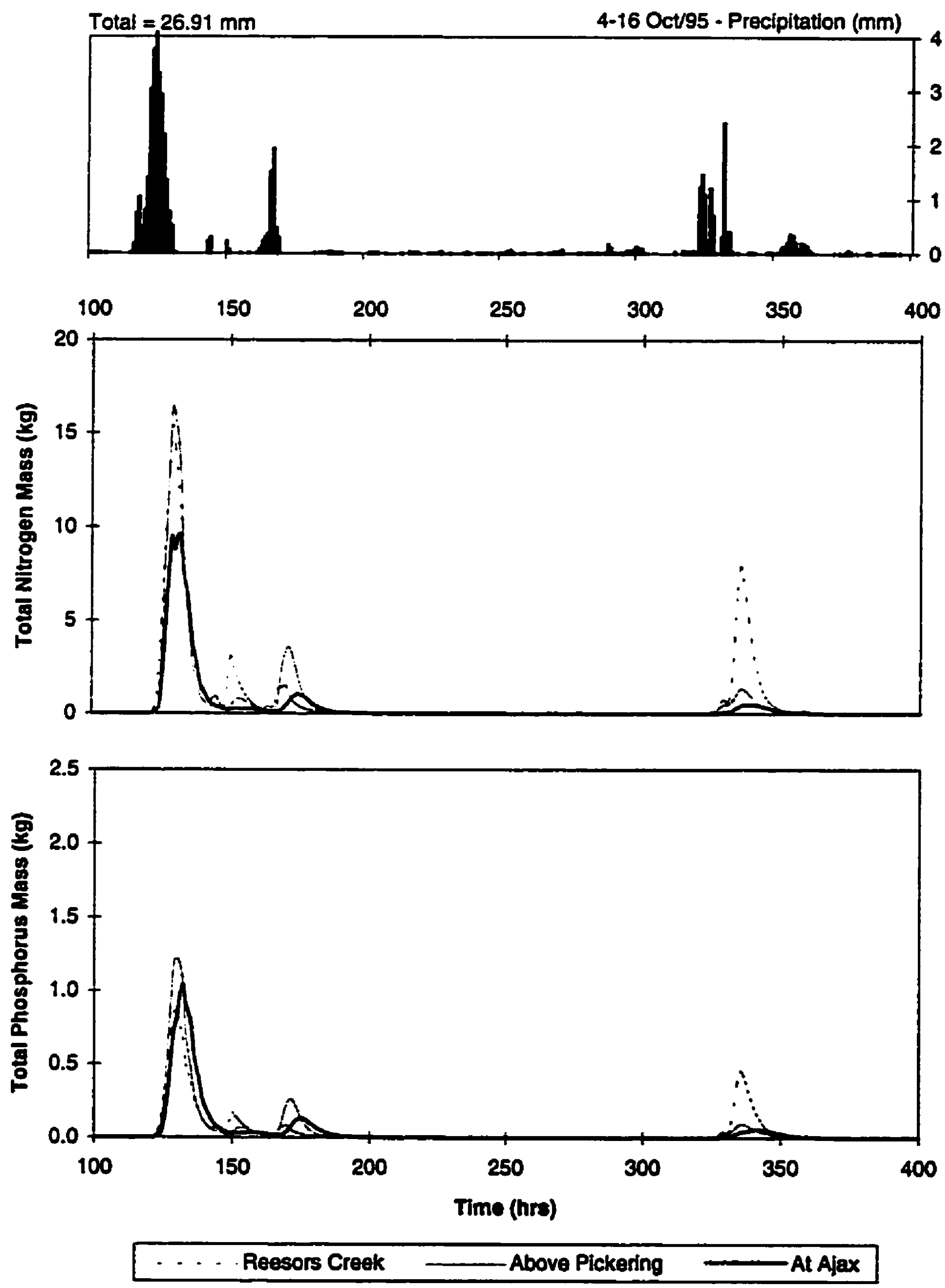


Figure E.31 WATFLOOD/Nutrients results for October 4-16, 1995
(2x2 km Grid - Nitrogen and Phosphorus Total Mass - Decay 40-30%)

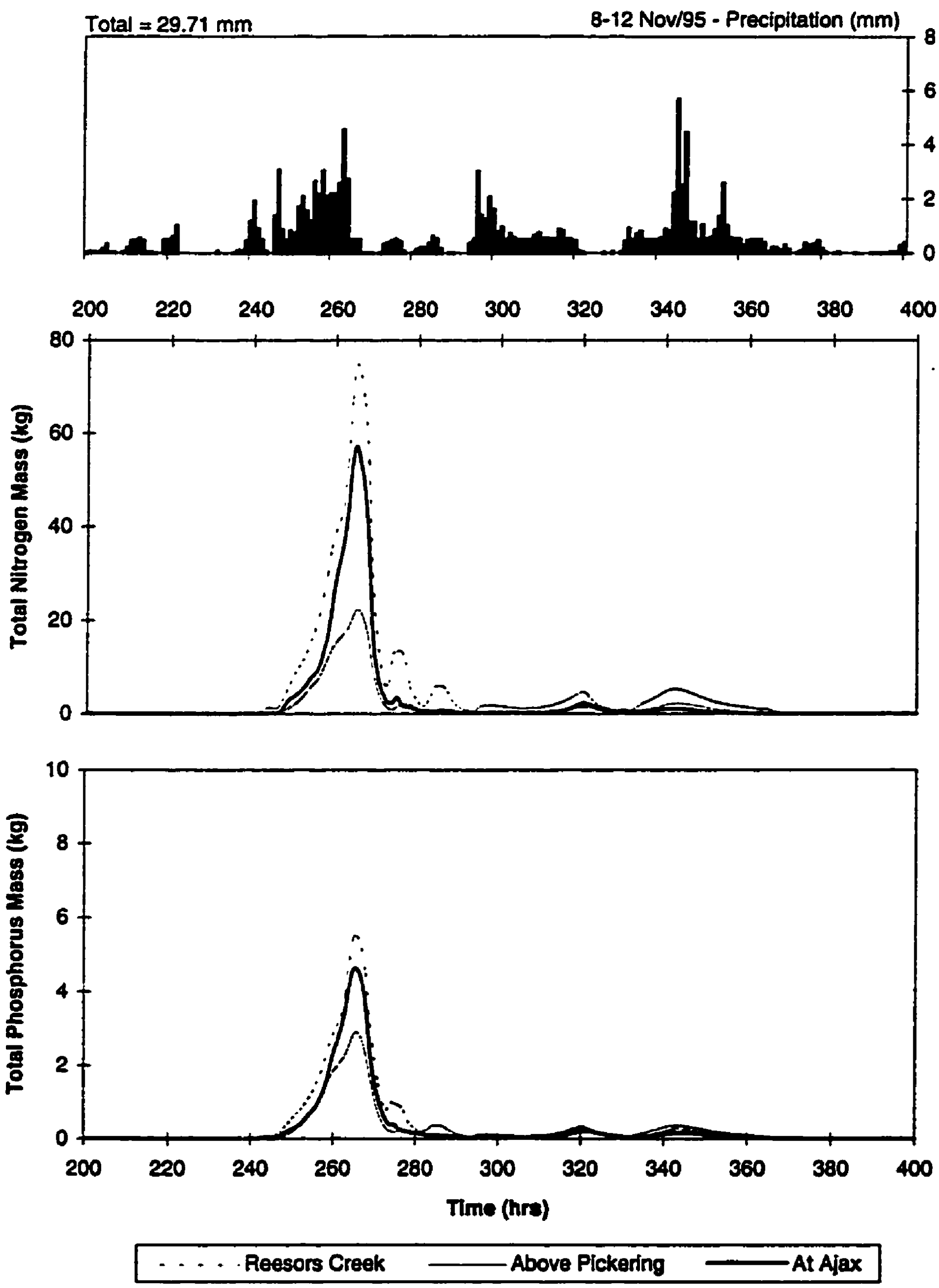


Figure E.32 WATFLOOD/Nutrients results for November 8-12, 1995 (2x2 km Grid - Nitrogen and Phosphorus Total Mass - Decay 60-40%)

APPENDIX F. Sensitivity Analysis Calculations

This section includes the complete results from the sensitivity analysis calculations performed during the present research. Two preliminary analysis performed on the AGNPS and water quality component for WATFLOOD, and the full sensitivity analysis for the AGNPS model. The tables are:

Preliminary Sensitivity for the AGNPS Model

Preliminary Sensitivity for SP-Model (Water Quality Component)

Sensitivity Analysis for the AGNPS Model:

Total Runoff Volume
Peak Runoff Rate
Total Sediment Yield
Nitrogen in Sediment
Nitrogen in Runoff
Soluble Nitrogen Concentration
Phosphorus in Sediment
Phosphorus in Runoff
Soluble Phosphorus Concentration
COD in Runoff
COD Concentration

Table F1. Preliminary Sensitivity for the AGNPS Model

% Variation on Sediment Yield:											
ParVar	**Rain**	**EI**	**CN**	**LS**	**FSL**	**CS**	**CSS**	**N**	**K**	**C**	**P**
-50	-38	-50	-71	-49	-24	-11	-23	16	-50	-50	-50
-25	-15	-25	-30	-28	-11	-5	-10	7	-25	-25	-25
0	0	0	0	0	0	0	0	0	0	0	0
25	11	25	17	35	9	3	8	-5	25	25	0
50	20	50	20	69	17	6	14	-9	50	38	0
	Normalized Sensitivity Non-Linear Gradients										
	0.92	1.00	1.64	0.84	0.52	0.24	0.52	-0.36	1.00	1.00	1.00
	0.60	1.00	1.20	1.12	0.44	0.20	0.40	-0.28	1.00	1.00	1.00
	0.44	1.00	0.68	1.40	0.36	0.12	0.32	-0.20	1.00	1.00	0.00
	0.36	1.00	0.12	1.36	0.32	0.12	0.24	-0.16	1.00	0.52	0.00
AGrad	**0.58**	**1.00**	**0.91**	**1.18**	**0.41**	**0.17**	**0.37**	**-0.25**	**1.00**	**0.88**	**0.50**
	Ranked Sensitivity Gradients										
	LS	**EI**	**K**	**CN**	**C**	**Rain**	**P**	**FSL**	**CSS**	**N**	**CS**
	1.18	**1.00**	**1.00**	**0.91**	**0.88**	**0.58**	**0.50**	**0.41**	**0.37**	**-0.25**	**0.17**
% Variation on Sediment Associated Nutrients (N & P):											
ParVar	**Rain**	**EI**	**CN**	**LS**	**FSL**	**CS**	**CSS**	**N**	**K**	**C**	**P**
-50	-31	-42	-63	-42	-19	-9	-19	13	-42	-42	-42
-25	-12	-20	-25	-24	-9	-4	-8	5	-20	-20	-20
0	0	0	0	0	0	0	0	0	0	0	0
25	9	19	13	27	7	3	6	-4	19	19	0
50	15	38	16	52	13	5	11	-7	38	29	0
	Normalized Sensitivity Non-Linear Gradients										
	0.76	0.88	1.52	0.72	0.40	0.20	0.44	-0.32	0.88	0.88	0.88
	0.48	0.80	1.00	0.96	0.36	0.16	0.32	-0.20	0.80	0.80	0.80
	0.36	0.76	0.52	1.08	0.28	0.12	0.24	-0.16	0.76	0.76	0.00
	0.24	0.76	0.12	1.00	0.24	0.08	0.20	-0.12	0.76	0.40	0.00
AGrad	**0.46**	**0.80**	**0.79**	**0.94**	**0.32**	**0.14**	**0.30**	**-0.20**	**0.80**	**0.71**	**0.42**
	Ranked Sensitivity Gradients										
	LS	**EI**	**K**	**CN**	**C**	**Rain**	**P**	**FSL**	**CSS**	**N**	**CS**
	0.94	**0.8**	**0.8**	**0.79**	**0.71**	**0.46**	**0.42**	**0.32**	**0.3**	**-0.2**	**0.14**

Variable description: LS-land slope, EI-storm energy-intensity, K-soil erodibility factor, CN-SCS curve number, C-cropping or cover factor, Rain-storm rainfall, P-practice factor, FSL-field slope length, CSS-channel side slope, N-Manning's roughness coefficient, CS-channel slope

Table F2. Preliminary Sensitivity for SP-Model (Water Quality Component)

% Variation of Transport Capacity (Yc):

	Soil & Landuse Parameters					*Watflood Variables*				
ParVar	**SPG**	**D50**	**Erod**	**GC**	**CF**	**Rain**	**Slp2**	**Rf**	**Ql**	**Hl**
-20	102	0.6	0	34	0	-44	-30	-32	-16	-43
-10	37	0.3	0	16	0	-23	-15	-16	-8	-24
0	0	0	0	0	0	0	0	0	0	0
10	-24	-0.4	0	-13	0	26	16	19	7	22
20	-38	-0.8	0	-24	0	55	34	39	14	51
	Normalized Sensitivity Non-Linear Gradients									
	-6.50	-0.03	0.00	-1.80	0.00	2.10	1.50	1.60	0.80	1.90
	-3.70	-0.03	0.00	-1.60	0.00	2.30	1.50	1.60	0.80	2.40
	-2.40	-0.04	0.00	-1.30	0.00	2.60	1.60	1.90	0.70	2.20
	-1.40	-0.04	0.00	-1.10	0.00	2.90	1.80	2.00	0.70	2.90
AGrad	**-3.50**	**-0.04**	**0.00**	**-1.45**	**0.00**	**2.48**	**1.60**	**1.78**	**0.75**	**2.35**
	Ranked Sensitivity Gradients									
	SPG	**D50**	**Erod**	**GC**	**CF**	**Rain**	**Slp2**	**Rf**	**Ql**	**Hl**
	-3.50	**-0.04**	**0.00**	**-1.45**	**0.00**	**2.48**	**1.60**	**1.78**	**0.75**	**2.35**

% Variation of Sediment Supply (Ys):

	Soil & Landuse Parameters					*Watflood Variables*				
ParVar	**SPG**	**D50**	**Erod**	**GC**	**CF**	**Rain**	**Slp2**	**Rf**	**Ql**	**Hl**
-20	0	0	-20	3.5	-18	-22	-1.5	-1.5	-1.5	0
-10	0	0	-10	1.6	-9	-11	-0.7	-0.7	-0.9	0
0	0	0	0	0	0	0	0	0	0	0
10	0	0	10	-1.6	9	11	0.7	0.7	0.5	0
20	0	0	20	-3.3	18	22	1.4	1.4	1.2	0
	Normalized Sensitivity Non-Linear Gradients									
	0.00	0.00	1.00	-0.19	0.90	1.10	0.08	0.08	0.06	0.00
	0.00	0.00	1.00	-0.16	0.90	1.10	0.07	0.07	0.09	0.00
	0.00	0.00	1.00	-0.16	0.90	1.10	0.07	0.07	0.05	0.00
	0.00	0.00	1.00	-0.17	0.90	1.10	0.07	0.07	0.07	0.00
AGrad	**0.00**	**0.00**	**1.00**	**-0.17**	**0.90**	**1.10**	**0.07**	**0.07**	**0.07**	**0.00**
	Ranked Sensitivity Gradients									
	SPG	**D50**	**Erod**	**GC**	**CF**	**Rain**	**Slp2**	**Rf**	**Ql**	**Hl**
	0.00	**0.00**	**1.00**	**-0.17**	**0.90**	**1.10**	**0.07**	**0.07**	**0.07**	**0.00**

Variable description: *SP-Model:* SpG-specific weight, D_{50}-median particle size, Erod-soil erodibility, GC-ground cover, CF-cover factor, *WATFLOOD:* Rain-precipitation intensity, Slp2-overland slope, Rf-runoff amount, Ql-unit flow discharge, Hl-runoff depth

Table F3. Sensitivity Analysis for the AGNPS Model (Total Runoff Volume)

OUTPUT = Total Runoff Volume		**0.19**					
OutletCell = 57,000		**Parameter Value**		**Output Value**		**Sensitivity**	
Parameter	**Base**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Initial Data							
Precipitation	1.75	1.58	1.93	0.14	0.26	-26.3	36.8
Nitrog_Rain	1.00	0.90	1.10	0.19	0.19	0	0
EI_Rfactor	17.52	15.77	19.27	0.19	0.19	0	0
KCoeff_PerRunoff	37.50	33.75	41.25	0.19	0.19	0	0
General Cell Data (min-max)							
SCS_No	39-92	35-82	42-100	0.08	0.39	-57.9	105.3
LandSlope	0-5.4	0-4.8	0-5.9	0.19	0.19	0	0
SlopeLength	150	135	165	0.19	0.19	0	0
Mannings_n	0.051-0.513	0.05-0.46	0.06-0.56	0.19	0.19	0	0
K_Factor	0.15-0.37	0.14-0.34	0.17-0.41	0.19	0.19	0	0
C_Factor	0.035-0.373	0.03-0.34	0.04-0.41	0.19	0.19	0	0
P_Factor	1	0.9	1	0.19	0.19	0	0
SurfCond	0.03-0.29	0.03-0.26	0.03-0.32	0.19	0.19	0	0
COD_Factor	24-138	21-124	26-151	0.19	0.19	0	0
Soil Related Data							
Soil_Nitro	0.001	0.0009	0.0011	0.19	0.19	0	0
Soil_Phos	0.0005	0.0005	0.0006	0.19	0.19	0	0
PoreW_Nitro	5	4.50	5.50	0.19	0.19	0	0
PoreW_Phos	2	1.80	2.20	0.19	0.19	0	0
ExtR_Nitro	0.05	0.045	0.055	0.19	0.19	0	0
ExtR_Phos	0.025	0.023	0.028	0.19	0.19	0	0
ExtL_Nitro	0.25	0.23	0.28	0.19	0.19	0	0
ExtL_Phos	0.25	0.23	0.28	0.19	0.19	0	0
Per_OMS	20	18	22	0.19	0.19	0	0
Fertilizer Related Data							
Applied_Nitro	50-200	45-180	55-220	0.19	0.19	0	0
Applied_Phos	20-80	18-72	22-88	0.19	0.19	0	0
AvFac_Nitro	50	45	55	0.19	0.19	0	0
AvFac_Phos	50	45	55	0.19	0.19	0	0
Channel Related Data							
Chan_Slope	0-2.7	0-2.8	0-2.9	0.19	0.19	0	0
Chan_SideSlope	0-0.27	0-0.28	0-0.29	0.19	0.19	0	0
Chan_ManningN	0.4	0.36	0.44	0.19	0.19	0	0
Decay_Nitro	50	45	55	0.19	0.19	0	0
Decay_Phos	50	45	55	0.19	0.19	0	0
Decay_COD	50	45	55	0.19	0.19	0	0

Variable description: ***For the full variable description and units, refer to Appendix A.***

Table F4. Sensitivity Analysis for the AGNPS Model (Peak Runoff Rate)

OUTPUT = Peak Runoff Rate		**1560.52**					
OutletCell = 57,000		**Parameter Value**		**Output Value**		**Sensitivity**	
Parameter	**Base**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Initial Data							
Precipitation	1.75	1.58	1.93	1150.10	2056.77	-26.3	31.8
Nitrog_Rain	1.00	0.90	1.10	1560.52	1560.52	0	0
EI_Rfactor	17.52	15.77	19.27	1560.52	1560.52	0	0
KCoeff_PerRunoff	37.50	33.75	41.25	1560.52	1560.52	0	0
General Cell Data (min-max)							
SCS_No	39-92	35-82	42-100	627.33	3099.19	-59.8	98.6
LandSlope	0-5.4	0-4.8	0-5.9	1560.52	1560.52	0	0
SlopeLength	150	135	165	1560.52	1560.52	0	0
Mannings_n	0.051-0.513	0.05-0.46	0.06-0.56	1560.52	1560.52	0	0
K_Factor	0.15-0.37	0.14-0.34	0.17-0.41	1560.52	1560.52	0	0
C_Factor	0.035-0.373	0.03-0.34	0.04-0.41	1560.52	1560.52	0	0
P_Factor	1	0.9	1	1560.52	1560.52	0	0
SurfCond	0.03-0.29	0.03-0.26	0.03-0.32	1560.52	1560.52	0	0
COD_Factor	24-138	21-124	26-151	1560.52	1560.52	0	0
Soil Related Data							
Soil_Nitro	0.001	0.0009	0.0011	1560.52	1560.52	0	0
Soil_Phos	0.0005	0.0005	0.0006	1560.52	1560.52	0	0
PoreW_Nitro	5	4.50	5.50	1560.52	1560.52	0	0
PoreW_Phos	2	1.80	2.20	1560.52	1560.52	0	0
ExtR_Nitro	0.05	0.045	0.055	1560.52	1560.52	0	0
ExtR_Phos	0.025	0.023	0.028	1560.52	1560.52	0	0
ExtL_Nitro	0.25	0.23	0.28	1560.52	1560.52	0	0
ExtL_Phos	0.25	0.23	0.28	1560.52	1560.52	0	0
Per_OMS	20	18	22	1560.52	1560.52	0	0
Fertilizer Related Data							
Applied_Nitro	50-200	45-180	55-220	1560.52	1560.52	0	0
Applied_Phos	20-80	18-72	22-88	1560.52	1560.52	0	0
AvFac_Nitro	50	45	55	1560.52	1560.52	0	0
AvFac_Phos	50	45	55	1560.52	1560.52	0	0
Channel Related Data							
Chan_Slope	0-2.7	0-2.8	0-2.9	1535.55	1583.93	-1.6	1.5
Chan_SideSlope	0-0.27	0-0.28	0-0.29	1560.52	1560.52	0	0
Chan_ManningN	0.4	0.36	0.44	1560.52	1560.52	0	0
Decay_Nitro	50	45	55	1560.52	1560.52	0	0
Decay_Phos	50	45	55	1560.52	1560.52	0	0
Decay_COD	50	45	55	1560.52	1560.52	0	0

Variable description: *For the full variable description and units, refer to Appendix A.*

Table F5. Sensitivity Analysis for the AGNPS Model (Total Sediment Yield)

OUTPUT = Total Sediment Yield **785.28**

OutletCell = 57,000		**Parameter Value**		**Output Value**		**Sensitivity**	
Parameter	**Base**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Initial Data							
Precipitation	1.75	1.58	1.93	711.46	857.53	-9.4	9.2
Nitrog_Rain	1.00	0.90	1.10	785.28	785.28	0	0
EI_Rfactor	17.52	15.77	19.27	727.17	843.39	-7.4	7.4
KCoeff_PerRunoff	37.50	33.75	41.25	839.46	634.51	6.9	-19.2
General Cell Data (min-max)							
SCS_No	39-92	35-82	42-100	579.54	976.89	-26.2	24.4
LandSlope	0-5.4	0-4.8	0-5.9	744.45	829.26	-5.2	5.6
SlopeLength	150	135	165	767.22	802.56	-2.3	2.2
Mannings_n	0.051-0.513	0.05-0.46	0.06-0.56	785.28	785.28	0	0
K_Factor	0.15-0.37	0.14-0.34	0.17-0.41	728.74	844.18	-7.2	7.5
C_Factor	0.035-0.373	0.03-0.34	0.04-0.41	727.17	843.39	-7.4	7.4
P_Factor	1	0.9	1	727.17	785.28	-7.4	0
SurfCond	0.03-0.29	0.03-0.26	0.03-0.32	785.28	785.28	0	0
COD_Factor	24-138	21-124	26-151	785.28	785.28	0	0
Soil Related Data							
Soil_Nitro	0.001	0.0009	0.0011	785.28	785.28	0	0
Soil_Phos	0.0005	0.0005	0.0006	785.28	785.28	0	0
PoreW_Nitro	5	4.50	5.50	785.28	785.28	0	0
PoreW_Phos	2	1.80	2.20	785.28	785.28	0	0
ExtR_Nitro	0.05	0.045	0.055	785.28	785.28	0	0
ExtR_Phos	0.025	0.023	0.028	785.28	785.28	0	0
ExtL_Nitro	0.25	0.23	0.28	785.28	785.28	0	0
ExtL_Phos	0.25	0.23	0.28	785.28	785.28	0	0
Per_OMS	20	18	22	785.28	785.28	0	0
Fertilizer Related Data							
Applied_Nitro	50-200	45-180	55-220	785.28	785.28	0	0
Applied_Phos	20-80	18-72	22-88	785.28	785.28	0	0
AvFac_Nitro	50	45	55	785.28	785.28	0	0
AvFac_Phos	50	45	55	785.28	785.28	0	0
Channel Related Data							
Chan_Slope	0-2.7	0-2.8	0-2.9	780.57	789.21	-0.6	0.5
Chan_SideSlope	0-0.27	0-0.28	0-0.29	783.71	786.85	-0.2	0.2
Chan_ManningN	0.4	0.36	0.44	822.97	754.65	4.8	-3.9
Decay_Nitro	50	45	55	785.28	785.28	0	0
Decay_Phos	50	45	55	785.28	785.28	0	0
Decay_COD	50	45	55	785.28	785.28	0	0

Variable description: *For the full variable description and units, refer to Appendix A.*

Table F6. Sensitivity Analysis for the AGNPS Model (Nitrogen in Sediment)

OUTPUT = Nitrogen Amount in Sediment				**0.1**			
OutletCell = 57,000		**Parameter Value**		**Output Value**		**Sensitivity**	
Parameter	**Base**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Initial Data							
Precipitation	1.75	1.58	1.93	0.10	0.11	0	10
Nitrog_Rain	1.00	0.90	1.10	0.10	0.10	0	0
EI_Rfactor	17.52	15.77	19.27	0.10	0.11	0	10
KCoeff_PerRunoff	37.50	33.75	41.25	0.11	0.08	10	-20
General Cell Data (min-max)							
SCS_No	39-92	35-82	42-100	0.08	0.12	-20	20
LandSlope	0-5.4	0-4.8	0-5.9	0.10	0.11	0	10
SlopeLength	150	135	165	0.10	0.11	0	10
Mannings_n	0.051-0.513	0.05-0.46	0.06-0.56	0.10	0.10	0	0
K_Factor	0.15-0.37	0.14-0.34	0.17-0.41	0.10	0.11	0	10
C_Factor	0.035-0.373	0.03-0.34	0.04-0.41	0.10	0.11	0	10
P_Factor	1	0.9	1.0	0.10	0.10	0	0
SurfCond	0.03-0.29	0.03-0.26	0.03-0.32	0.10	0.10	0	0
COD_Factor	24-138	21-124	26-151	0.10	0.10	0	0
Soil Related Data							
Soil_Nitro	0.001	0.0009	0.0011	0.09	0.11	-10	10
Soil_Phos	0.0005	0.0005	0.0006	0.10	0.10	0	0
PoreW_Nitro	5	4.50	5.50	0.10	0.10	0	0
PoreW_Phos	2	1.80	2.20	0.10	0.10	0	0
ExtR_Nitro	0.05	0.045	0.055	0.10	0.10	0	0
ExtR_Phos	0.025	0.023	0.028	0.10	0.10	0	0
ExtL_Nitro	0.25	0.23	0.28	0.10	0.10	0	0
ExtL_Phos	0.25	0.23	0.28	0.10	0.10	0	0
Per_OMS	20	18	22	0.10	0.10	0	0
Fertilizer Related Data							
Applied_Nitro	50-200	45-180	55-220	0.10	0.10	0	0
Applied_Phos	20-80	18-72	22-88	0.10	0.10	0	0
AvFac_Nitro	50	45	55	0.10	0.10	0	0
AvFac_Phos	50	45	55	0.10	0.10	0	0
Channel Related Data							
Chan_Slope	0-2.7	0-2.8	0-2.9	0.10	0.10	0	0
Chan_SideSlope	0-0.27	0-0.28	0-0.29	0.10	0.10	0	0
Chan_ManningN	0.4	0.36	0.44	0.11	0.10	10	0
Decay_Nitro	50	45	55	0.10	0.10	0	0
Decay_Phos	50	45	55	0.10	0.10	0	0
Decay_COD	50	45	55	0.10	0.10	0	0

Variable description: *For the full variable description and units, refer to Appendix A.*

Table F7. Sensitivity Analysis for the AGNPS Model (Nitrogen in Runoff)

OUTPUT = Nitrogen Amount in Runoff				**0.01**			
OutletCell = 57,000		**Parameter Value**		**Output Value**		**Sensitivity**	
Parameter	**Base**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Initial Data							
Precipitation	1.75	1.58	1.93	0.01	0.01	0	0
Nitrog_Rain	1.00	0.90	1.10	0.01	0.01	0	0
EI_Rfactor	17.52	15.77	19.27	0.01	0.01	0	0
KCoeff_PerRunoff	37.50	33.75	41.25	0.01	0.01	0	0
General Cell Data (min-max)							
SCS_No	39-92	35-82	42-100	0.01	0.01	0	0
LandSlope	0-5.4	0-4.8	0-5.9	0.01	0.01	0	0
SlopeLength	150	135	165	0.01	0.01	0	0
Mannings_n	0.051-0.513	0.05-0.46	0.06-0.56	0.01	0.01	0	0
K_Factor	0.15-0.37	0.14-0.34	0.17-0.41	0.01	0.01	0	0
C_Factor	0.035-0.373	0.03-0.34	0.04-0.41	0.01	0.01	0	0
P_Factor	1	0.9	1.0	0.01	0.01	0	0
SurfCond	0.03-0.29	0.03-0.26	0.03-0.32	0.01	0.01	0	0
COD_Factor	24-138	21-124	26-151	0.01	0.01	0	0
Soil Related Data							
Soil_Nitro	0.001	0.0009	0.0011	0.01	0.01	0	0
Soil_Phos	0.0005	0.0005	0.0006	0.01	0.01	0	0
PoreW_Nitro	5	4.50	5.50	0.01	0.01	0	0
PoreW_Phos	2	1.80	2.20	0.01	0.01	0	0
ExtR_Nitro	0.05	0.045	0.055	0.01	0.01	0	0
ExtR_Phos	0.025	0.023	0.028	0.01	0.01	0	0
ExtL_Nitro	0.25	0.23	0.28	0.01	0.01	0	0
ExtL_Phos	0.25	0.23	0.28	0.01	0.01	0	0
Per_OMS	20	18	22	0.01	0.01	0	0
Fertilizer Related Data							
Applied_Nitro	50-200	45-180	55-220	0.01	0.01	0	0
Applied_Phos	20-80	18-72	22-88	0.01	0.01	0	0
AvFac_Nitro	50	45	55	0.01	0.01	0	0
AvFac_Phos	50	45	55	0.01	0.01	0	0
Channel Related Data							
Chan_Slope	0-2.7	0-2.8	0-2.9	0.01	0.01	0	0
Chan_SideSlope	0-0.27	0-0.28	0-0.29	0.01	0.01	0	0
Chan_ManningN	0.4	0.36	0.44	0.01	0.01	0	0
Decay_Nitro	50	45	55	0.01	0.01	0	0
Decay_Phos	50	45	55	0.01	0.01	0	0
Decay_COD	50	45	55	0.01	0.01	0	0

Variable description: *For the full variable description and units, refer to Appendix A.*

Table F8. Sensitivity Analysis for the AGNPS Model (Soluble Nitrogen Concentration)

OUTPUT = Soluble Nitrogen Concentration				0.15			
OutletCell = 57,000		Parameter Value		Output Value		Sensitivity	
Parameter	Base	Low	High	Low	High	Low	High
Initial Data							
Precipitation	1.75	1.58	1.93	0.17	0.14	13.3	-6.7
Nitrog_Rain	1.00	0.90	1.10	0.14	0.16	-6.7	6.7
EI_Rfactor	17.52	15.77	19.27	0.15	0.15	0	0
KCoeff_PerRunoff	37.50	33.75	41.25	0.15	0.15	0	0
General Cell Data (min-max)							
SCS_No	39-92	35-82	42-100	0.16	0.17	6.7	13.3
LandSlope	0-5.4	0-4.8	0-5.9	0.15	0.15	0	0
SlopeLength	150	135	165	0.15	0.15	0	0
Mannings_n	0.051-0.513	0.05-0.46	0.06-0.56	0.15	0.15	0	0
K_Factor	0.15-0.37	0.14-0.34	0.17-0.41	0.15	0.15	0	0
C_Factor	0.035-0.373	0.03-0.34	0.04-0.41	0.15	0.15	0	0
P_Factor	1	0.9	1.0	0.15	0.15	0	0
SurfCond	0.03-0.29	0.03-0.26	0.03-0.32	0.15	0.15	0	0
COD_Factor	24-138	21-124	26-151	0.15	0.15	0	0
Soil Related Data							
Soil_Nitro	0.001	0.0009	0.0011	0.15	0.15	0	0
Soil_Phos	0.0005	0.0005	0.0006	0.15	0.15	0	0
PoreW_Nitro	5	4.50	5.50	0.15	0.15	0	0
PoreW_Phos	2	1.80	2.20	0.15	0.15	0	0
ExtR_Nitro	0.05	0.045	0.055	0.15	0.16	0	6.7
ExtR_Phos	0.025	0.023	0.028	0.15	0.15	0	0
ExtL_Nitro	0.25	0.23	0.28	0.16	0.14	6.7	-6.7
ExtL_Phos	0.25	0.23	0.28	0.15	0.15	0	0
Per_OMS	20	18	22	0.15	0.15	0	0
Fertilizer Related Data							
Applied_Nitro	50-200	45-180	55-220	0.15	0.16	0	6.7
Applied_Phos	20-80	18-72	22-88	0.15	0.15	0	0
AvFac_Nitro	50	45	55	0.15	0.16	0	6.7
AvFac_Phos	50	45	55	0.15	0.15	0	0
Channel Related Data							
Chan_Slope	0-2.7	0-2.8	0-2.9	0.15	0.15	0	0
Chan_SideSlope	0-0.27	0-0.28	0-0.29	0.15	0.15	0	0
Chan_ManningN	0.4	0.36	0.44	0.15	0.15	0	0
Decay_Nitro	50	45	55	0.21	0.11	40	-26.7
Decay_Phos	50	45	55	0.15	0.15	0	0
Decay_COD	50	45	55	0.15	0.15	0	0

Variable description: *For the full variable description and units, refer to Appendix A.*

Table F9. Sensitivity Analysis for the AGNPS Model (Phosphorus in Sediment)

OUTPUT = Phosphorus in Sediment				**0.05**			
OutletCell = 57,000		**Parameter Value**		**Output Value**		**Sensitivity**	
Parameter	**Base**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Initial Data							
Precipitation	1.75	1.58	1.93	0.05	0.06	0	20
Nitrog_Rain	1.00	0.90	1.10	0.05	0.05	0	0
EI_Rfactor	17.52	15.77	19.27	0.05	0.06	0	20
KCoeff_PerRunoff	37.50	33.75	41.25	0.06	0.04	20	-20
General Cell Data (min-max)							
SCS_No	39-92	35-82	42-100	0.04	0.06	-20	20
LandSlope	0-5.4	0-4.8	0-5.9	0.05	0.05	0	0
SlopeLength	150	135	165	0.05	0.05	0	0
Mannings_n	0.051-0.513	0.05-0.46	0.06-0.56	0.05	0.05	0	0
K_Factor	0.15-0.37	0.14-0.34	0.17-0.41	0.05	0.06	0	20
C_Factor	0.035-0.373	0.03-0.34	0.04-0.41	0.05	0.06	0	20
P_Factor	1	0.9	1.0	0.05	0.05	0	0
SurfCond	0.03-0.29	0.03-0.26	0.03-0.32	0.05	0.05	0	0
COD_Factor	24-138	21-124	26-151	0.05	0.05	0	0
Soil Related Data							
Soil_Nitro	0.001	0.0009	0.0011	0.05	0.05	0	0
Soil_Phos	0.0005	0.0005	0.0006	0.05	0.06	0	20
PoreW_Nitro	5	4.50	5.50	0.05	0.05	0	0
PoreW_Phos	2	1.80	2.20	0.05	0.05	0	0
ExtR_Nitro	0.05	0.045	0.055	0.05	0.05	0	0
ExtR_Phos	0.025	0.023	0.028	0.05	0.05	0	0
ExtL_Nitro	0.25	0.23	0.28	0.05	0.05	0	0
ExtL_Phos	0.25	0.23	0.28	0.05	0.05	0	0
Per_OMS	20	18	22	0.05	0.05	0	0
Fertilizer Related Data							
Applied_Nitro	50-200	45-180	55-220	0.05	0.05	0	0
Applied_Phos	20-80	18-72	22-88	0.05	0.05	0	0
AvFac_Nitro	50	45	55	0.05	0.05	0	0
AvFac_Phos	50	45	55	0.05	0.05	0	0
Channel Related Data							
Chan_Slope	0-2.7	0-2.8	0-2.9	0.05	0.05	0	0
Chan_SideSlope	0-0.27	0-0.28	0-0.29	0.05	0.05	0	0
Chan_ManningN	0.4	0.36	0.44	0.05	0.05	0	0
Decay_Nitro	50	45	55	0.05	0.05	0	0
Decay_Phos	50	45	55	0.05	0.05	0	0
Decay_COD	50	45	55	0.05	0.05	0	0

Variable description: *For the full variable description and units, refer to Appendix A.*

Table F10. Sensitivity Analysis for the AGNPS Model (Phosphorus in Runoff)

OUTPUT = Phosphorus in Runoff				0			
OutletCell = 57,000		**Parameter Value**		**Output Value**		**Sensitivity**	
Parameter	**Base**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Initial Data							
Precipitation	1.75	1.58	1.93	0.00	0.00	0	0
Nitrog_Rain	1.00	0.90	1.10	0.00	0.00	0	0
EI_Rfactor	17.52	15.77	19.27	0.00	0.00	0	0
KCoeff_PerRunoff	37.50	33.75	41.25	0.00	0.00	0	0
General Cell Data (min-max)							
SCS_No	39-92	35-82	42-100	0.00	0.00	0	0
LandSlope	0-5.4	0-4.8	0-5.9	0.00	0.00	0	0
SlopeLength	150	135	165	0.00	0.00	0	0
Mannings_n	0.051-0.513	0.05-0.46	0.06-0.56	0.00	0.00	0	0
K_Factor	0.15-0.37	0.14-0.34	0.17-0.41	0.00	0.00	0	0
C_Factor	0.035-0.373	0.03-0.34	0.04-0.41	0.00	0.00	0	0
P_Factor	1	0.9	1.0	0.00	0.00	0	0
SurfCond	0.03-0.29	0.03-0.26	0.03-0.32	0.00	0.00	0	0
COD_Factor	24-138	21-124	26-151	0.00	0.00	0	0
Soil Related Data							
Soil_Nitro	0.001	0.0009	0.0011	0.00	0.00	0	0
Soil_Phos	0.0005	0.0005	0.0006	0.00	0.00	0	0
PoreW_Nitro	5	4.50	5.50	0.00	0.00	0	0
PoreW_Phos	2	1.80	2.20	0.00	0.00	0	0
ExtR_Nitro	0.05	0.045	0.055	0.00	0.00	0	0
ExtR_Phos	0.025	0.023	0.028	0.00	0.00	0	0
ExtL_Nitro	0.25	0.23	0.28	0.00	0.00	0	0
ExtL_Phos	0.25	0.23	0.28	0.00	0.00	0	0
Per_OMS	20	18	22	0.00	0.00	0	0
Fertilizer Related Data							
Applied_Nitro	50-200	45-180	55-220	0.00	0.00	0	0
Applied_Phos	20-80	18-72	22-88	0.00	0.00	0	0
AvFac_Nitro	50	45	55	0.00	0.00	0	0
AvFac_Phos	50	45	55	0.00	0.00	0	0
Channel Related Data							
Chan_Slope	0-2.7	0-2.8	0-2.9	0.00	0.00	0	0
Chan_SideSlope	0-0.27	0-0.28	0-0.29	0.00	0.00	0	0
Chan_ManningN	0.4	0.36	0.44	0.00	0.00	0	0
Decay_Nitro	50	45	55	0.00	0.00	0	0
Decay_Phos	50	45	55	0.00	0.00	0	0
Decay_COD	50	45	55	0.00	0.00	0	0

Variable description: *For the full variable description and units, refer to Appendix A.*

Table F11. Sensitivity Analysis for the AGNPS Model (Soluble Phosphorus Concentration)

OUTPUT = Soluble Phosphorus Concentration				**0.01**			
OutletCell = 57,000		**Parameter Value**		**Output Value**		**Sensitivity**	
Parameter	**Base**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Initial Data							
Precipitation	1.75	1.58	1.93	0.02	0.01	100	0
Nitrog_Rain	1.00	0.90	1.10	0.01	0.01	0	0
EI_Rfactor	17.52	15.77	19.27	0.01	0.01	0	0
KCoeff_PerRunoff	37.50	33.75	41.25	0.01	0.01	0	0
General Cell Data (min-max)							
SCS_No	39-92	35-82	42-100	0.01	0.02	0	100
LandSlope	0-5.4	0-4.8	0-5.9	0.01	0.01	0	0
SlopeLength	150	135	165	0.01	0.01	0	0
Mannings_n	0.051-0.513	0.05-0.46	0.06-0.56	0.01	0.01	0	0
K_Factor	0.15-0.37	0.14-0.34	0.17-0.41	0.01	0.01	0	0
C_Factor	0.035-0.373	0.03-0.34	0.04-0.41	0.01	0.01	0	0
P_Factor	1	0.9	1.0	0.01	0.01	0	0
SurfCond	0.03-0.29	0.03-0.26	0.03-0.32	0.01	0.01	0	0
COD_Factor	24-138	21-124	26-151	0.01	0.01	0	0
Soil Related Data							
Soil_Nitro	0.001	0.0009	0.0011	0.01	0.01	0	0
Soil_Phos	0.0005	0.0005	0.0006	0.01	0.01	0	0
PoreW_Nitro	5	4.50	5.50	0.01	0.01	0	0
PoreW_Phos	2	1.80	2.20	0.01	0.02	0	100
ExtR_Nitro	0.05	0.045	0.055	0.01	0.01	0	0
ExtR_Phos	0.025	0.023	0.028	0.01	0.02	0	100
ExtL_Nitro	0.25	0.23	0.28	0.01	0.01	0	0
ExtL_Phos	0.25	0.23	0.28	0.02	0.01	100	0
Per_OMS	20	18	22	0.01	0.01	0	0
Fertilizer Related Data							
Applied_Nitro	50-200	45-180	55-220	0.01	0.01	0	0
Applied_Phos	20-80	18-72	22-88	0.01	0.02	0	100
AvFac_Nitro	50	45	55	0.01	0.01	0	0
AvFac_Phos	50	45	55	0.01	0.02	0	100
Channel Related Data							
Chan_Slope	0-2.7	0-2.8	0-2.9	0.01	0.01	0	0
Chan_SideSlope	0-0.27	0-0.28	0-0.29	0.01	0.01	0	0
Chan_ManningN	0.4	0.36	0.44	0.01	0.01	0	0
Decay_Nitro	50	45	55	0.01	0.01	0	0
Decay_Phos	50	45	55	0.02	0.01	100	0
Decay_COD	50	45	55	0.01	0.01	0	0

Variable description: *For the full variable description and units, refer to Appendix A.*

Table F12. Sensitivity Analysis for the AGNPS Model (COD in Runoff)

OUTPUT = COD in Runoff				**0.16**			
OutletCell = 57,000		**Parameter Value**		**Output Value**		**Sensitivity**	
Parameter	**Base**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Initial Data							
Precipitation	1.75	1.58	1.93	0.13	0.20	-18.7	25
Nitrog_Rain	1.00	0.90	1.10	0.16	0.16	0	0
EI_Rfactor	17.52	15.77	19.27	0.16	0.16	0	0
KCoeff_PerRunoff	37.50	33.75	41.25	0.16	0.16	0	0
General Cell Data (min-max)							
SCS_No	39-92	35-82	42-100	0.08	0.31	-50	93.8
LandSlope	0-5.4	0-4.8	0-5.9	0.16	0.16	0	0
SlopeLength	150	135	165	0.16	0.16	0	0
Mannings_n	0.051-0.513	0.05-0.46	0.06-0.56	0.16	0.16	0	0
K_Factor	0.15-0.37	0.14-0.34	0.17-0.41	0.16	0.16	0	0
C_Factor	0.035-0.373	0.03-0.34	0.04-0.41	0.16	0.16	0	0
P_Factor	1	0.9	1.0	0.16	0.16	0	0
SurfCond	0.03-0.29	0.03-0.26	0.03-0.32	0.16	0.16	0	0
COD_Factor	24-138	21-124	26-151	0.15	0.18	-6.2	12.5
Soil Related Data							
Soil_Nitro	0.001	0.0009	0.0011	0.16	0.16	0	0
Soil_Phos	0.0005	0.0005	0.0006	0.16	0.16	0	0
PoreW_Nitro	5	4.50	5.50	0.16	0.16	0	0
PoreW_Phos	2	1.80	2.20	0.16	0.16	0	0
ExtR_Nitro	0.05	0.045	0.055	0.16	0.16	0	0
ExtR_Phos	0.025	0.023	0.028	0.16	0.16	0	0
ExtL_Nitro	0.25	0.23	0.28	0.16	0.16	0	0
ExtL_Phos	0.25	0.23	0.28	0.16	0.16	0	0
Per_OMS	20	18	22	0.16	0.16	0	0
Fertilizer Related Data							
Applied_Nitro	50-200	45-180	55-220	0.16	0.16	0	0
Applied_Phos	20-80	18-72	22-88	0.16	0.16	0	0
AvFac_Nitro	50	45	55	0.16	0.16	0	0
AvFac_Phos	50	45	55	0.16	0.16	0	0
Channel Related Data							
Chan_Slope	0-2.7	0-2.8	0-2.9	0.16	0.16	0	0
Chan_SideSlope	0-0.27	0-0.28	0-0.29	0.16	0.16	0	0
Chan_ManningN	0.4	0.36	0.44	0.16	0.16	0	0
Decay_Nitro	50	45	55	0.16	0.16	0	0
Decay_Phos	50	45	55	0.16	0.16	0	0
Decay_COD	50	45	55	0.21	0.13	31.3	-18.7

Variable description: *For the full variable description and units, refer to Appendix A.*

Table F13. Sensitivity Analysis for the AGNPS Model (COD Concentration)

OUTPUT = COD Concentration				3.74			
OutletCell = 57,000		**Parameter Value**		**Output Value**		**Sensitivity**	
Parameter	**Base**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Initial Data							
Precipitation	1.75	1.58	1.93	4.07	3.47	8.8	-7.2
Nitrog_Rain	1.00	0.90	1.10	3.74	3.74	0	0
EI_Rfactor	17.52	15.77	19.27	3.74	3.74	0	0
KCoeff_PerRunoff	37.50	33.75	41.25	3.74	3.74	0	0
General Cell Data (min-max)							
SCS_No	39-92	35-82	42-100	4.42	3.48	18.2	-7
LandSlope	0-5.4	0-4.8	0-5.9	3.74	3.74	0	0
SlopeLength	150	135	165	3.74	3.74	0	0
Mannings_n	0.051-0.513	0.05-0.46	0.06-0.56	3.74	3.74	0	0
K_Factor	0.15-0.37	0.14-0.34	0.17-0.41	3.74	3.74	0	0
C_Factor	0.035-0.373	0.03-0.34	0.04-0.41	3.74	3.74	0	0
P_Factor	1	0.9	1.0	3.74	3.74	0	0
SurfCond	0.03-0.29	0.03-0.26	0.03-0.32	3.74	3.74	0	0
COD_Factor	24-138	21-124	26-151	3.37	4.11	-9.9	9.9
Soil Related Data							
Soil_Nitro	0.001	0.0009	0.0011	3.74	3.74	0	0
Soil_Phos	0.0005	0.0005	0.0006	3.74	3.74	0	0
PoreW_Nitro	5	4.50	5.50	3.74	3.74	0	0
PoreW_Phos	2	1.80	2.20	3.74	3.74	0	0
ExtR_Nitro	0.05	0.045	0.055	3.74	3.74	0	0
ExtR_Phos	0.025	0.023	0.028	3.74	3.74	0	0
ExtL_Nitro	0.25	0.23	0.28	3.74	3.74	0	0
ExtL_Phos	0.25	0.23	0.28	3.74	3.74	0	0
Per_OMS	20	18	22	3.74	3.74	0	0
Fertilizer Related Data							
Applied_Nitro	50-200	45-180	55-220	3.74	3.74	0	0
Applied_Phos	20-80	18-72	22-88	3.74	3.74	0	0
AvFac_Nitro	50	45	55	3.74	3.74	0	0
AvFac_Phos	50	45	55	3.74	3.74	0	0
Channel Related Data							
Chan_Slope	0-2.7	0-2.8	0-2.9	3.74	3.74	0	0
Chan_SideSlope	0-0.27	0-0.28	0-0.29	3.74	3.74	0	0
Chan_ManningN	0.4	0.36	0.44	3.74	3.74	0	0
Decay_Nitro	50	45	55	3.74	3.74	0	0
Decay_Phos	50	45	55	3.74	3.74	0	0
Decay_COD	50	45	55	4.74	2.94	26.7	-21.4

Variable description: *For the full variable description and units, refer to Appendix A.*

APPENDIX G. Visual Basic Pseudocode and Fortran Subroutines

This section presents the Visual Basic pseudocode for both interfaces and the FORTRAN code for the water quality component developed for WATFLOOD. The full source code will take several hundreds of pages to be printed and defies any rational attempt to be included as a hardcopy printout. So what is presented here is a pseudocode that contains the subroutines and functions with a brief description of the process involved. For the main procedures, the full code is included. The source code in full extent resides in ASCII text files for each interface.

Table G1. Visual Basic File Structure of the Interfaces (●AGNPS / ■WATFLOOD)

Main Forms:		LANDATA.FRM	●■	AGNPSGR.BAS	●
INTERAGN.FRM	●	RESUME.FRM	●	+ WATFLDGR.BAS	■
+ INTERWAT.FRM	■	SENSANAL.FRM	●	DATACTL.BAS	●■
GRIDMAKE.FRM	●■	SENSINPU.FRM	●	DRAWFLOW.BAS	●■
AGNPSCDB.FRM	●	SENSNORM.FRM	●	LAYERDB.BAS	●■
+ WATFCDB.FRM	■	SENSRANK.FRM	●	LAYERDLL.BAS	●■
CONTROL.FRM	●■	**Additonal Forms:**		GLOBAL.BAS	●■
INITIAL.FRM	●■	SOIL.FRM	●	MAIN.BAS	●■
COLLECT.FRM	●■	FERTILIZ.FRM	●■	DEMLIB-A.BAS	●
FLOWDIR.FRM	●■	PESTDB.FRM	●■	+ DEMLIB-W.BAS	■
DATA.FRM	●■	PESTICID.FRM	●■	**Declarations & VBX:**	
EXPORTAS.FRM	●■	POINTSOU.FRM	●	WIN30API.BAS	●■
EDRANGES.FRM	●■	FEEDLOT.FRM	●	GLOBDEC.BAS	●■
DISPLEG.FRM	●■	NONFEED.FRM	●	MSOLE2.VBX	●■
DISPRANG.FRM	●■	IMPOUND.FRM	●	MSOUTLIN.VBX	●■
DISPGIO.FRM	●■	ADDEROS.FRM	●	CMDIALOG.VBX	●■
OUTPUT.FRM	●	CHANNEL.FRM	●	THREED.VBX	●■
SUMMARY.FRM	●	**Common Files:**		SPIN.VBX	●■
TRACE.FRM	●	AGNPSLIB.BAS	●	RMWIN4.VBX	●■
DUPGRID.FRM	●■	+ WATFLIB.BAS	■	ANIBUTTON.VBX	●■

VISUAL BASIC PSEUDOCODE

(Subroutines and functions with brief description)

Program Name: InterAGN
Module: INTERAGN.FRM

Sub CheckSerialNumber ()
' Verify serial number from distribution disk
' GetINIInfo : pHex : PutIniInfo

Sub cmdAnalScen_Click ()
' Activates the Analysis and Scenarios toolbar

Sub cmdASCII_Click ()
' Activates the Export ASCII file Procedure
' optMode(0):: ExportASCII.Show

Sub cmdCollect_Click ()
' Activates the Collect Data Toolbar

Sub cmdCollDat_Click ()
' Activates the Collect Data: Collect.Show

Sub cmdCreaDB_Click ()
' Activates the Create Structure:
' CreaDBAGNPS.Show

Sub cmdDispInput_Click ()
' Activates the Graphical Display Procedure
' DisplayGIO.Show

Sub cmdDupGrid_Click ()
' Activates the Duplicate Grid: DupGrid.Show

Sub cmdEditGrid_Click ()
' Activates the Grid Editor: EditGrid.Show

Sub cmdEditRanges_Click ()
' Activates the Range Editor: EditRanges.Show

Sub cmdEditSum_Click ()
' Activates the Cell Editor: DataForm.Show

Sub cmdExit_Click ()
' Exit the AGNPS Interface: Unload Me

Sub cmdFlowDir_Click ()
' Activates Flow Direction Editor: FlowDir.Show

Sub cmdMake_Click ()
' Activates the Grid Maker Toolbar

Sub cmdMakeGrid_Click ()
' Activates the Grid Maker: GridMaker.Show

Sub cmdModata_Click ()
' Activates the Landcover Editor: Landata.Show

Sub cmdResTable_Click ()
' Activates the Output Display: OutputForm.Show

Sub cmdResults_Click ()
' Activates the Graphic Display Toolbar

Sub cmdResume_Click ()
' Activates the Output Summary Form:
' ResumeRes.Show

Sub cmdRun_Click ()
' Activates the Run AGNPS Procedure
' optMode(1) : ExportASCII.Show

Sub cmdRunAGNPS_Click ()
' Activates the Run AGNPS Toolbar

Sub cmdSaveGrid_Click ()
' Creates an empty Database file

Sub cmdSensit_Click ()
' Activate the Sensitivity Analysis Form
' Sensitivity.Show

Sub cmdShell_Click ()
' Activates the AGNPS Shell

Sub cmdWatDat_Click ()
' Activates the Initial Data Form: InitialData.Show

Sub Form_Load ()
' Initializes Program by calling:
' CheckSerialNumber : ReadINIFile

Function GetINIInfo$ (section$, parm$)
' Gets a Field From intaglic.INI

Function makecheck% (a$)
' Calculate checksum for a string

Sub mnuAnalScen_Click ()
' Access through menu: cmdAnalScen_Click

Sub mnuAnalScenar_Click (Index As Integer)
' Access through menu:
'   Case 1: cmdDupGrid_Click
'   Case 2: cmdModata_Click
'   Case 3: cmdSensit_Click

Sub mnuCollect_Click ()
' Access through menu: cmdCollect_Click

Sub mnuCollectEdit_Click (Index As Integer)
' Access through menu:
'   Case 1: cmdWatDat_Click
'   Case 2: cmdCollDat_Click
'   Case 3: cmdFlowDir_Click
'   Case 4: cmdEditSum_Click

Sub mnuDispInpOut_Click (Index As Integer)
' Access through menu:
' Case 1: cmdEditRanges_Click
' Case 2: cmdDispInput_Click
' Case 3: cmdResTable_Click

Sub mnuMake_Click ()
' Access through menu: cmdMake_Click

Sub mnuMakeEdit_Click (Index As Integer)
' Access through menu
' Case 1: cmdSaveGrid_Click
' Case 2: cmdMakeGrid_Click
' Case 3: cmdCreaDB_Click
' Case 4: cmdEditGrid_Click

Sub mnuResults_Click ()
' Access through menu: cmdResults_Click

Sub mnuRunAGNPS_Click ()
' Access through menu: cmdRunAGNPS_Click

Sub mnuRunModel_Click (Index As Integer)
' Access through menu
' Case 1: cmdASCII_Click
' Case 2: cmdRun_Click
' Case 3: cmdShell_Click

Function phex$ (i%, w%)
' Convert i to a fixed width hex string

Sub putIniInfo (sect$, parm$, Val As Variant)
' These writes to the intaglic.INI

Program Name: InterAGN
Module: GRIDMAKE.FRM

Sub addbtn_Click ()
' Calculates and rotate the grid points and
' Adds the grid to the active database by calling:
' CheckGridName
' CreateLL_GridRectTable for Lat/Long grids
' CreateUTM_GridRectTable for UTM grids

Sub addcheck_Click (Value As Integer)
' If checked allows grid to be saved in the selected
' database. It will also allow to change active file by:
' cmdLoadDB

Sub Check3D1_Click (Value As Integer)
'Sends Command to interact with RAISON
' SendCommand "[EV_MPCHLL]ON" -checked
' SendCommand "[EV_MPCHLL]OFF" -unchecked

Function CheckGridName (grNm As String)
' This function check to see if the gridname exists
' in the layer database. Returns true if name exists.

Sub cmdLoadDB_Click ()
' Opens a Database File and assigns it as default
' Uses Dialog Box Action 1

Sub colour_Click ()
' Sets Color by using Dialog Box Action 3

Sub Command3D1_Click ()
' Draws the Grid
' DrawGrid or DrawUTMGrid

Sub Command3D2_Click ()
' Closes current form
' Unload Me

Sub DrawGrid () and Sub DrawUTMGrid ()
' Sends Command to interact with RAISON
' a = "[PR_REDRAW]"
' Calculates and rotate the grid points and
' Draws the grid polygon and text
' a = "[MP_LLPOLY]" + parameters"
' a = a + "[MP_LLRTEXT]" + parameters"

Sub Eas_Change ()
' Updates UTM values from eastern change by:
' UpdateFromUTM

Sub FillUTMValues ()
' Fill UTM values from grid position by:
' ConvertGeotoUTM

Sub Form_Activate ()
'Sends Command to interact with RAISON

Sub Form_Load ()
' Initializes form and test for RAISON link:

Sub grdSize_Change ()
' Updates UTM values from grid size change by:
' UpdateFromUTM

Sub Nor_Change ()
' Updates UTM values from northern change by:
' UpdateFromUTM

Sub SendCommand (ddecommand$)
'Sends Command to RAISON
' form.object.LinkExecute ddecommand$

Sub Spin1_Spin Up/Down () and Spin2
' Increase/Decrease number of rows and columns

Sub Text2_LinkNotify ()
' Notify for RAISON link: and gets zone and datum
when clicking in map: FillUTMValues

Sub UpdateFromUTM ()
' Update from lat/lon to UTM: ConvertUTMtoGeo

Program Name: InterAGN
Module: AGNPSCDB.FRM

Sub cmdLoadDB_Click ()
' Opens a Database File and assigns it as default
' Uses Dialog Box Action 1

Sub Command3D1_Click ()
' Creates tables for the AGNPS structure by:
'   CreateAGNPSTables & WriteClassesScheme

Sub Command3D2_Click ()
' Closes current form: Unload Me

Sub FillinClasses ()
' Selects lookup table for grouping landuse and
' Gets available classes schemes to fill combo box
'   GetLookupDBName

Sub Form_Load ()
' Initializes form: FillinClasses

Sub GetLookupDBName ()
' Get lookup table file. Uses Dialog Box Action 1

Sub gridname_Click ()
' Selects and opens gridname from combo box and
' Verifies if tables exist if not prompts to create

Sub WriteClassesScheme ()
' Creates table for selected classes scheme

Program Name: InterAGN
Module: CONTROL.FRM

Sub AreaThres_Change ()
' Sets the area for automatic cell selection

Sub chkAutoSelect_Click (Value As Integer)
' Access the autoselection options

Sub cmdAutoSelect_Click ()
' Verify error layer & name shed: VerifyMatch
' Calculate grid intersection: FillPolyData
' Write to General Cell and Mark/Unmark Cell:
'   MarkUnmarkAreas
' Delete from summary: RemoveSummaryData

Sub cmdDrawMaps_Click ()
' Draw selected layer
'   SendCommand "[PR_CURWIN]"
'   a = "[LY_DRAW]" + parameters"

Sub cmdLoadDB_Click ()
' Opens a Database File and assigns it as default
' Uses Dialog Box Action 1

Sub cmdLoadMaps_Click ()
' Open available layer file. Uses Dialog Box Action 1
'   FindGridTblLayers

Sub Command3D1_Click ()
' Refresh RAISON map
'   SendCommand "[PR_REDRAW]"
'   a = "[LY_DRAWGRID]" + parameters"

Sub Command3D2_Click ()
' Closes current form: Unload Me

Function FillinGrids (dbname$) As Integer
' Fills the gridname combo box with available grids

Sub Form_Load ()
' Initializes form and test for RAISON link:

Sub GridAddCell_Click (Value As Integer)
' Send command to add cell

Sub GridDeleteCell_Click (Value As Integer)
' Send command to remove cell

Sub gridname_Click ()
' Selects gridname from combo box and
' Verifies if tables exist if not prompts to create

Sub GridSubCell_Click (Value As Integer)
' Send command to subdivide cell

Sub lblGridColor_Click ()
' Sets Color by using Dialog Box Action 3

Sub lblWshdColor_Click ()
' Sets Color by using Dialog Box Action 3

Sub MarkUnmarkAreas (dbGridName, GrdName)
' Based on summary results keep or remove cell

Sub OpenDBFile ()
' Opens Database File and Sets Default Name

Sub RemoveSummaryData (db$, gridname$)
' Query Database and remove all records

Sub SendCommand (ddecommand$)
'Sends Command to RAISON

Sub Text2_LinkNotify ()
' Notify for RAISON link:
'   If EditGrid.DeleteCell : AGNPS_DeleteGridCell
'   If EditGrid.SubCel : AGNPS_SubdivideCell
'   If EditGrid.AddCell : AGNPS_AddGridRectCell

Sub VerifyMatch (Resp)
'Verify that selected layer correspond to Watershed

Program Name: InterAGN
Module: INITIAL.FRM

Sub CalculateCellArea (db, grdn As String)
' Calculates cell area based on origin grid values

Sub CalculateEI ()
' Calculate EI value as function of Precipitation and
' Storm Type.....function is:
'   EI = c(dur^n)(prec^m)

Sub cmdExit_Click ()
' Closes current form: Unload Me

Sub cmdLoadDB_Click ()
' Opens a Database File and assigns it as default
' Uses Dialog Box Action 1

Sub cmdRain_Click ()
' Provides guide values for duration and intensity

Sub cmdSaveDB_Click ()
' Verify data and save input in DB: VerifyInput

Sub Command3D1_Click ()
' Refresh RAISON map
'   SendCommand "[PR_REDRAW]"
'   a = "[LY_DRAWGRID]" + parameters"

Sub EnabledSelection ()
' Enables selection or automatic calculation of EI

Function FillinGrids (dbname$) As Integer
' Fills gridname combo box with available grids
'   FindGrids

Sub Form_Load ()
' Initializes form and test for RAISON link:

Sub gridname_Click ()
' Selects gridname, reads from database &
' Calculates Cell Area and number of cells in grid:
'   Call CalculateCellArea

Sub InitializeForm ()
' Initialize form and reset values with defaults

Sub optEIVal_Click (Index%, Value%)
' Checks for selections and calculates EI values:
'   EnabledSelection
'   If optEIVal(1) : CalculateEI

Sub optHydCal_Click (Index%, Value%)
' Checks for hydrology options and defaults

Sub RainIntensity_Click ()
' Select Case for Rain Intensity Box

Sub SendCommand (ddecommand$)
'Sends Command to RAISON

Sub Text2_LinkNotify ()
' Notify for RAISON link:

Sub txtDuration_Change ()
' Duration Input - Send to calculate EI by
'   CalculateEI

Sub txtPrecipitation_Change ()
' Precipitation Input - Send to calculate EI by
'   If optEIVal(1) : CalculateEI

Sub txtStormType_Click ()
' Storm type selection - Send to calculate EI by
'   If optEIVal(1) : CalculateEI

Sub VerifyInput ()
' Validate Input Data (Return RetryInput%)

Program Name: InterAGN
Module: COLLECT.FRM

Sub cmdCollect_Click ()
' Main procedure to collect data from maps
' Calculate grid intersection: Call FillPolyData
' Write to General Cell depending on lookup table
'   Call WriteSoilDependent
' Delete grid summary table & compact database
'   Call RemoveSummaryData
'   CompactDatabase

Sub cmdDispLegend_Click ()
' Display legend form...:   DispLegend.Show

Sub cmdDraw_Click ()
' Draw selected Grid
'   SendCommand "[PR_REDRAW]"
'   a = "[LY_DRAWGRID]" + "parameters"

Sub cmdDrawElev_Click ()
' Draw selected layer (elevation or flow
'   SendCommand "[PR_CURWIN]"
'   a = "[LY_DRAW]" + parameters"

Sub cmdDrawMaps_Click ()
' Draw selected layer
'   SendCommand "[PR_CURWIN]"
'   a = "[LY_DRAW]" + parameters"

Sub cmdExit_Click ()
' Closes current form: Unload Me

Sub cmdFlowDir_Click ()
' Calculates data from DEM file
'   Call DoAGNPSFillData

Sub cmdLegendDEM_Click ()
' Set variables to display general numeric ranges

Sub cmdLoadDB_Click ()
' Open a Database File. Uses Dialog Box Action 1

Sub cmdLoadElev_Click ()
' Open a DEM File. Use Dialog Box Action 1

Sub cmdLoadMaps_Click ()
' Opens a Map File and allow selection of layer
' Uses Dialog Box Action 1

Sub cmdReduceDem_Click ()
' Add polygons in grid BOX to a new temporal
' database for DEM layers (DEM & PtDem):
'   Call GetBoxCheckUTM
'   e = NarrowRegionLayer
'   Call CopyLayerCharacteristics

Sub cmdReduceMap_Click ()
' Add polygons in grid BOX to a new temporal
' database for MAP layers (Soil & Landuse):
'   Call GetBoxCheckUTM

Sub comboFieldLook_Click ()
' Fills combo box for available fields

Sub comboLayerName_Click ()
' Fills combo box for available layers

Sub CopyLayerCharacteristics ()
' Copy the characteristics table for the database
'   e = CopyLayersChar

Sub DrawFlow (dbnameE As String)
' Draw flow directions: DrawFlowArrow

Sub DrawFlowArrow()
' Calculate position point for arrow
' Send command to draw line in RAISON
'   a = "[LY_DRAWARROW]" + "parameters"

Function FillInGrids (dbname$) As Integer
' Fills gridname combo box with available grids

Sub FillInGridSummary()
' Fill Lookup value in Grid Summary

Sub Form_Load ()
' Initializes form and test for RAISON link:

Sub GetBoxCheckUTM()
' Select the Minimum x,y and Maximum x,y for the
' active grid = BOX and check for UTM

Sub GetLandDependantValues ()
' Get land values from lookup using map code

Sub GetLanduseSummaryValues ()
' Get land summary from table using map code

Sub GetLookupDBName ()
' Locate Lookup Database (lookup.mdb)

Sub GetPercentageCounters (ActiveFile)
' Resets & gets percent counter from record table

Sub GetSoilDependantValues ()
'Get soil type from lookup table using map code

Sub gridname_Click ()
' Select gridname, reads from database

Sub lblColor_Click ()
' Sets Color by using Dialog Box Action 3

Sub lblGridColor_Click ()
' Sets Color by using Dialog Box Action 3

Sub OpenDBFile ()
' Opens Database File and Sets Default Name

Sub optDisplay_Click()
' Sets display options for DEM file

Sub optLookTable_Click ()
' Select lookup table to use for model data...

Sub RemoveSummaryData (db$, gridname$)
' Query Database and remove all records

Sub SendCommand (ddecommand$)
' Sends Command to RAISON
'   form.object.LinkExecute ddecommand$

Sub Text2_LinkNotify ()
' Notify for RAISON link:

Sub VerifyLookupMatch (Resp)
' Verifies that soil process is to be done first
' Check that layer match the active lookup table

Sub WaterValues ()
' Assign defaults for water to general cell table &
' Assign defaults for water to channel table

Sub WriteLandDependent ()
' Write landuse values on General Cell Data
' Reads percentage on summary table
'   Call GetLandDependantValues
' Compares with limits and writes in cell table

Sub WriteLanduseSummary ()
' Gets classes types...
' Extract values from summary table...
' Write the values in the Landuse Summary table

Sub WriteSoilDependent ()
' Write soil dependent values on General Cell Data:
Call GetSoilDependantValues
' Compare with limits & writes in cell and soil table

Program Name: InterAGN
Module: FLOWDIR.FRM

Sub CheckStatus ()
' Check elevation status according to direction

Sub cmdCheck_Click ()
' Produce text report of elevation status in all cells
' Deletes old text reports and open editor to view

Sub cmdLoadDB_Click ()
' Open a Database File. Use Dialog Box Action 1

Sub Command3D1_Click ()
' Refresh RAISON map
' SendCommand "[PR_REDRAW]"
' a = "[LY_DRAWGRID]" + parameters"

Sub Command3D2_Click ()
' Closes current form: Unload Me

Sub Command3D3_Click ()
' Draws flow direction: Call DrawFlow

Sub DrawFlow (dbnameE As String)
' Draw flow directions: DrawFlowArrow

Sub DrawFlowArrow()
' Calculate position point for arrow
' Send command to draw line in RAISON
' a = "[LY_DRAWARROW]" + "parameters"

Function FillInGrids (dbname$) As Integer
' Fills gridname combo box with available grids

Sub Form_Load ()
' Initializes form and test for RAISON link:

Sub gridname_Click ()
' Selects gridname, reads from database &
' For river elevation update...Verifies if field exists

Sub lblcolorold_Click ()
' Sets Color by using Dialog Box Action 3

Sub lblDir_Click (Index As Integer)
' Click in direction, change picture & assign the
' Flow Direction, Receiving Cell & Elevation

Sub lblElevFrom_DblClick ()
' Modify the elevation value for the selected cell &
' Save the elevation and recheck the status

Sub lblColor_Click ()
' Sets Color by using Dialog Box Action 3

Sub OpenDBFile ()
' Opens Database File and Sets Default Name

Sub ReadCellValues ()
' Reads flow direction, receiving cell & elevation
' for the selected cell and check status

Sub SelectCell_Click (Value As Integer)
' Clicks on map and select cell and grid number
' SendCommand "[EV_MPCHLL]ON"
' Returns selected grid number

Sub SendCommand (ddecommand$)
' Sends Command to RAISON
' form.object.LinkExecute ddecommand$
' And changes color of selected cell
' ddestr = "[LY_DROBJUSERDEF]" + "params"

Program Name: InterAGN
Module: DATA.FRM

Sub AGNPSSpread_Change (Col#, Row#)
' Edits spreadsheet & changes database table
' Function ChangeGridValue

Sub AGNPSSpread_Click (Col#, Row#)
' Avoids editing water cells

Sub AGNPSSpread_RightClick()
' Edit yellow range. Launch additional forms

Sub CellList_Click ()
' Select cell number from list & goto cell on spread

Sub cmdAddSpecific_Click ()
' Select cells according to specific criteria
' If optSpecify(0) "Soil_Texture"
' If optSpecify(1) "Fert_Ind"
' If optSpecify(2) "Pest_Ind"
' If optSpecify(3) "Point_Ind"
' If optSpecify(4) "Add_Erosion"
' If optSpecify(5) "Impound_Ind"
' For selected options add cell to list & to spread
' Finally read grid values from database
' CellList.AddItem (selGridNumber)
' SpreadAddCell
' ReadGridValues

Sub cmdCancel_Click ()
' Cancels search by criteria

Sub cmdLoadDB_Click ()
' Opens a Database File and assigns it as default
' Uses Dialog Box Action 1

Sub cmdUpdate_Click ()
' Initialize Spreadsheet and updates from list by:
' selGridNumber
' SpreadAddCell
' ReadGridValues

Sub Command3D1_Click ()
' Refresh RAISON map
' SendCommand "[PR_REDRAW]"
' a = "[LY_DRAWGRID]" + parameters"

Sub Command3D2_Click ()
' Closes current form: Unload Me

Sub Command3D3_Click ()
' Select All of the cells in the grid
' CellList.AddItem (selGridNumber)
' SpreadAddCell
' ReadGridValues

Sub Command3D4_Click ()
' Initialize Spreadsheet: CellList.Clear : InitSpread()

Sub Command3D5_Click ()
' Initialize spreadsheet list and combo boxes
' CellList.Clear : InitSpread() : Add Items

Function FillinGrids (dbname$) As Integer
' Fills gridname combo box with available grids

Sub Form_Load ()
' Initializes form and test for RAISON link:

Sub gridname_Click ()
' Selects gridname, reads from database &
' Initializes the spreadsheet

Function InitSpread () As Integer
' Initializes the spreadsheet variables names

Sub lblGridColor_Click ()
' Sets Color by using Dialog Box Action 3

Sub OpenDBFile ()
' Opens Database File and Sets Default Name

Sub ReadGridValues ()
' Reads grid values from database
' Uses spreadsheet names as table fields

Sub SelectCell_Click (Value As Integer)
' Clicks on map and select cell and grid number
' SendCommand "[EV_MPCHLL]ON"
' Returns selected grid number

Sub SpreadAddCell ()
' Adds Column to Spread from ListCell and
' Prevents block of aditional info cells to be edited

Sub Text2_LinkNotify ()
' Notify for RAISON link:
' If selected : Removes cell from list & spread
' Else add cell to list & to spreadsheet

Program Name: InterAGN
Module: EXPORTAS.FRM

Sub CheckMode ()
' Checks mode for export data or run the model

Sub cmdExit_Click ()
' Closes current form: Unload Me

Sub cmdExport_Click ()
' Open file for output & writes formated data
' WriteInitialData & WriteCellData

Sub cmdFile_Click ()
' Select ASCII export file. Use Dialog Box Action 2

Sub cmdLoadDB_Click ()
' Open a Database File. Uses Dialog Box Action 1

Sub cmdRun_Click ()
' If run mode: activates the model executable file
' First exports data in model format
' WriteInitialData & WriteCellData
' Then run the model by activating shell command
' When terminated import the model ouput: Import

Function FillinGrids (dbname$) As Integer
' Fills gridname combo box with available grids

Sub Form_Load ()
' Initializes form and test for RAISON link:

Sub gridname_Click ()
' Selects gridname, reads from database &
' For runing date...Verifies if field exists

Sub Import ()
' Opens temporal model output file to read and
' Write into the current database
' Watershed Summary..WriteWatershedSummary
' Sediment Analysis...WriteSedimentAnalysis
' Hydrology & Sediments...WriteHydroSediments
' Nutrients...WriteNutrients
' Pesticide...RWPesticide
' If Source_Deposition table does'nt exists, create
' Call ImportBinary_SRC_DEP

Sub ImportBinary_SRC_DEP ()
' Reads binary .SRC..Cell Potential Contributions
' Reads and writes the SRC file
' Reads binary .DEP file...Deposition Cell Values
' Reads and writes the DEP file

Sub OpenDBFile ()
' Opens Database File and Sets Default Name

Sub RWAddErosValues (selGridNumber)
' Read Add_Erosion from Add_Erosion Table
' Do numeric format...and Writes to ASCII file

Sub RWChanValues (selGridNumber)
' Read Channel values from Channel Table
' Do numeric format...and Writes to ASCII file

Sub RWFeedlotValues (selGridNumber)
' Read Feedlot values from Feedlot Table
' Do numeric format...and Writes to ASCII file

Sub RWFertValues (selGridNumber)
' Read Fertilizer values from Fertilizer Table
' Do numeric format...and Writes to ASCII file

Sub RWGenCellValues (selGridNumber)
' Read Grid values from General Table
' Do numeric format...and Writes to ASCII file
' Soil_Texture : RWSoilValues (selGridNumber)
' Fert_Ind : RWFertValues (selGridNumber)
' Pest_Ind : RWPestValues (selGridNumber)
' NonFeed : RWNonFeedValues (selGridNumber)
' Feedlot : RWFeedlotValues (selGridNumber)
' Add_Eros : RWAddErosValues (selGridNumber)
' Imp_Ind : RWImpoundValues (selGridNumber)
' RWChanValues (selGridNumber)

Sub RWHydroValues (selGridNumber)
' Import hydrology output and store in database

Sub RWImpoundValues (selGridNumber)
' Read Impoundment values from Impoundment
' Do numeric format...and Writes to ASCII file

Sub RWNonFeedValues (selGridNumber)
' Read Non-Feedlot values fom NonFeedlot Table
' Do numeric format...and Writes to ASCII file

Sub RWNutrients (selGridNumber)
' Import nutrients output and store in database

Sub RWPesticide ()
' Read pesticide for the cells & write in PesticideR

Sub RWPestValues (selGridNumber)
' Read Pesticide values from Pesticide Table
' Do numeric format...and Writes to ASCII file

Sub RWSedimValues (selGridNumber)
' Import sediment output and store in database

Sub RWSoilValues (selGridNumber)
' Read Soil values from Soil Table...
' Do numeric format...and Writes to ASCII file...

Sub WriteCellData ()
' Send to Read/Write values with selGridNumber
' RWGenCellValues (selGridNumber)

Sub WriteHydroSediments ()
' Read/write hydrology and soil loss for all cells:
' RWHydroValues (selGridNumber)
' RWSedimValues (selGridNumber)

Sub WriteInitialData ()
' Read from Database...for Initial Watershed Data
' Do numeric format...and Writes to ASCII file

Sub WriteNutrients ()
' Import by reading nutrients
' Read NUTRIENTS and write in Nutrients table

Sub WriteSedimentAnalysis ()
' Import by reading sediments
' Read SEDIMENT and write in Sediment Analysis

Sub WriteWatershedSummary ()
' Import initial and summary results
' Read INITIAL and write in Watershed Summary
' Updates running time. If required, create field.

Program Name: InterAGN
Module: EDRANGES.FRM

Sub blue_Change ()
' Changes blue color value

Sub CalcRanges ()
' Calculate Ranges based on increment

Sub chkExtremes_Click (Value As Integer)
' Allow spliting ranges in the extremes values

Sub chkRanges_Click (Value As Integer)
' Allow edition of ranges

Sub cmdColorScale_Click ()
' Process the color ramp with current color values

Sub cmdCreateNew_Click ()
' Create new legend for selected field.
' Save current ranges information to new table

Sub cmdDefRang_Click ()
' Uses default ranges & colors to display legends

Sub cmdExit_Click ()
' Closes current form: Unload Me

Sub cmdLoadDB_Click ()
' Opens a Database File and assigns it as default
' Uses Dialog Box Action 1

Sub cmdSave_Click ()
' Deletes all of the current characteristics...
' Then Add Characteristics for selected values

Sub comboFieldLook_Click ()
' Selects field to use

Sub comboLegend_Click ()
' Sort the range list : SortRange
' Selects legend to use

Sub DeleteCharAllMultIndex ()
' Delete all from characteristic table

Function FillInGrids (dbname$) As Integer
' Fill gridname combo box with available grids

Sub Form_Load ()
' Initializes form and test for RAISON link:

Sub green_Change ()
' Changes green color value

Sub gridname_Click ()
' Select gridname & Initialize form

Sub InitializeForm ()
' Reset form by erasing labels and setting controls

Sub optLayer_Click (Index%, Value As Integer)
' Selects layer to use:
' Input options:
"General_Cell" "Soil" "Fertilizer" "Pesticide"
' Output options:
"Hydrology" "Sediments" "Nutrients" "PesticideR"

Sub Picture2_MouseMove ()
' Displays color for active range

Sub ReadCellValues ()
' Reads cell values from database
' Search maximum, minimum and extreme values

Sub red_Change ()
' Changes red color value

Sub SortRange ()
' Sort range to get RngTo and RngFrom values

Sub txtNoRanges_Change ()
' Changes the number of ranges to use

Sub txtRngMax_Change ()
' Changes the maximum value

Sub txtRngMin_Change ()
' Changes the minimum value

Program Name: InterAGN
Module: DISPLEG.FRM

Sub ColorBox_Click (Index As Integer)
' Sets Color by using Dialog Box Action 3

Sub Form_Load ()
' Display legend form...

Sub GetLandCover (MCode, LookText)
' Gets landuse from lookup table using map code

Sub GetSoilTexture (MCode, LookText)
'Gets soil type from lookup table using map code

Program Name: InterAGN
Module: DISPRANG.FRM

Sub Form_Load ()
' Display range form...
' Sort the range list : SortRange

Sub SortRange ()
' Sort range to get RngTo and RngFrom values

Program Name: InterAGN
Module: DISPGIO.FRM

Sub cmdDraw_Click ()
' Draw selected Grid
'   SendCommand "[PR_REDRAW]"
'   a = "[LY_DRAWGRID]" + "parameters"

Sub cmdDrawLayer_Click ()
' Draw selected layer
'   SendCommand "[PR_CURWIN]"
'   a = "[LY_DRAW]" + parameters"

Sub cmdExit_Click ()
' Closes current form: Unload Me

Sub cmdLegend_Click ()
' Set variables to display numeric ranges
'   DisplayRanges.Show

Sub cmdLoadDB_Click ()
' Opens a Database File and assigns it as default
' Uses Dialog Box Action 1

Sub cmdRedraw_Click ()
' Refresh map : SendCommand "[PR_REDRAW]"

Sub comboFieldLook_Click ()
' Selects field to use

Sub comboTable_Click ()
' Selects table to use

Function FillinGrids (dbname$) As Integer
' Fills gridname combo box with available grids

Sub Form_Load ()
' Initializes form and test for RAISON link:

Sub gridname_Click ()
' Select gridname, reads from database

Sub lblGridColor_Click ()
' Sets Color by using Dialog Box Action 3

Sub OpenDBFile ()
' Opens Database File and Sets Default Name

Sub optLayer_Click (Index%, Value As Integer)
' Selects layer to use Input/Output tables

Sub SendCommand (ddecommand$)
' Sends Command to RAISON

Sub Text2_LinkNotify ()
' Notify for RAISON link:

Program Name: InterAGN
Module: OUTPUT.FRM

Sub CellList_Click ()
' Select cell number and go to cell on spread

Sub cmdLoadDB_Click ()
' Opens a Database File and assigns it as default
' Uses Dialog Box Action 1

Sub comboTable_Click ()
' Initialize Spreadsheet and selects table to use

Sub Command3D1_Click ()
' Draw selected Grid
' SendCommand "[PR_REDRAW]"
' a = "[LY_DRAWGRID]" + "parameters"

Sub Command3D2_Click ()
' Closes current form: Unload Me

Sub Command3D3_Click ()
' Select All of the cells in the grid
' CellList.AddItem (CStr(selGridNumber))
' SpreadAddCell
' ReadGridValues

Sub Command3D4_Click ()
' Initialize Spreadsheet and clears all

Sub Command3D5_Click ()
' Display summary table : Summary.Show

Function FillinGrids (dbname$) As Integer
' Fill gridname combo box with available grids

Sub Form_Load ()
' Initializes form and test for RAISON link:

Sub gridname_Click ()
' Select gridname, reads from database &
' Initialize Spreadsheet

Function InitSpread () As Integer
' Reset spreadsheet depending on table name:
' Hydrology : Sediments : Nutrients : Pesticides

Sub lblGridColor_Click ()
' Sets Color by using Dialog Box Action 3

Sub OpenDBFile ()
' Opens Database File and Sets Default Name

Sub ReadGridValues ()
' Reads grid values from database
' Uses spreadsheet names as table fields

Sub SelectCell_Click (Value As Integer)
' Clicks on map and select cell and grid number
' SendCommand "[EV_MPCHLL]ON"

Sub SpreadAddCell ()
' Adds Column to Spread from ListCell and
' Prevents block of aditional info cells to be edited

Sub Text2_LinkNotify ()
' Notify for RAISON link:
' If selected, remove cell from list and spreadsheet
' Else add cell to list and to spreadsheet
' CellList.Addtem : SpreadAddCell : ReadGridValues

Program Name: InterAGN
Module: SUMMARY.FRM

Sub Form_Load ()
' Initialize form and read summary data and output:
' Read from the Watershed Summary Table...
' Read from the Sediment Analysis Table...
' Fills all text labels with variable values...

Program Name: InterAGN
Module: TRACE.FRM

Sub blue_Change ()
' Changes blue color value

Sub CalculateContributions ()
' Select options and read data
' If Hydrology then Amount is' returned directly :
' DefineSourceOptions
' Calculate Sediment Yields. Returns cell_yield,
' cell_gen, cell_flowin. Then Calculate Delivery
' Ratios and percentage of contribution
' Receives Amount returned and display results

Sub CalculateDeliveryRatios ()
' Calculate Cell Delivery Ratios: Cell_Yield, Cell_GenIn, Cell_FlwIn
' Aggregate Downstream Delivery Ratio for draining cells (recursive)
' Calculate Downstream Delivery Ratio & Amounts

Sub CalculateSedimentYields ()
' Calculate Yields and Flowing in values
' Accumulate amounts in for receiving cells (rec)
' Copy Results to Generic Variables

Sub CalculateSedNutrientYields ()
' Calculate Yields and Flowing in values
' Accumulate amounts in for receiving cells (rec)

Sub CalculateSolNutrientYields ()
' Calculate Yields and Flowing in values
' Accumulate amounts in for receiving cells (rec)

Sub chkSpaDisp_Click (Value As Integer)
' Access spatial display options

Sub cmdCalculate_Click ()
' Sends to : CalculateContributions

Sub cmdLoadDB_Click ()
' Open a Database File. Use Dialog Box Action 1

Sub cmdColorScale_Click ()
' Process the color ramp with current color values

Sub Combo1_Click ()
' Controls combo selection for options

Sub Combo2_Click ()
' Selects source and initialize spread :
' InitBrfResultSpread

Sub comboTable_Click ()
' Selects table to use

Sub Command3D1_Click ()
' Draw selected Grid
' SendCommand "[PR_REDRAW]"
' a = "[LY_DRAWGRID]" + "parameters"

Sub Command3D2_Click ()
' Closes current form: Unload Me

Sub Command3D3_Click ()
' Draw traced flow : Call DrawFlow

Sub Command3D4_Click ()
' Initialize Spreadsheet : InitAccountSpread
' Redraw Grid
' SendCommand "[PR_REDRAW]"
' a = "[LY_DRAWGRID]" + "parameters"

Sub Command3D5_Click ()
' Select cells on spreadsheet that fall inside range
' Change color of selected cells...
' ddestr = "[LY_DRGRIDCELLUSERDEF]"

Sub DefineSourceOptions ()
' Define source options for contributions:
' Hydrology : pass values from Spread to Amount()
' Depending on combo options:
' Read data from spreadsheet.
' Redimension variables...
' Select rows for input spreadsheet data...

Sub DrawFlow (dbnameE As String)
' Draw flow directions for the grid
' DrawFlowArrow

Sub DrawFlowArrow()
' Calculate position point for arrow
' Send command to draw line in RAISON
' a = "[LY_DRAWARROW]" + "parameters"

Function FillinGrids (dbname$) As Integer
' Fills gridname combo box with available grids

Sub FixBrfResultSpread ()
' Set floating for sort and prevent block to be edited

Sub Form_Load ()
' Initializes form and test for RAISON link:
' Initialize Spreadsheets : InitSpread : Call InitAccountSpread

Sub green_Change ()
' Changes green color value

Sub gridname_Click ()
' Selects gridname, reads from database &
' Initialize Spreadsheet

Sub InitAccountSpread ()
' Initializes account spreadsheet & format cells

Sub InitBrfResultSpread ()
' Initializes results spreadsheet and format cells

Sub InitCombos ()
' Resets combos contents and initialize spread InitBrfResultSpread

Function InitSpread () As Integer
' Reset spreadsheet depending on table name:
' Hydrology : Sediments : Nutrients

Sub lblColor_Click ()
' Sets Color by using Dialog Box Action 3

Sub OpenDBFile ()
' Opens Database File and Sets Default Name

Sub ReadGridValues ()
' Reads grid values from database

Sub red_Change ()
' Changes red color value

Sub SelectCell_Click (Value As Integer)
' Clicks on map and select cell and grid number
'   SendCommand "[EV_MPCHLL]ON"

Sub SendCommand (ddecommand$)
' Sends Command to RAISON

Sub SpreadAddCell ()
' Adds Column to Spread from ListCell

Sub Text2_LinkNotify ()
' Notify for RAISON link:
' Change color of selected cell...
'   ddestr = "[LY_DRGRIDCELLUSERDEF]"

Sub TraceContributions ()
' Create snapshot of receiving cell by query
' From cells on query result:
'   SpreadAddCell : ReadGridValues
'   Call DrawFlow(

Sub txtNoRanges_Change ()
' Changes number of ranges on spatial display

Sub txtRngMax_Change ()
' Changes the maximum value

Sub txtRngMin_Change ()
' Changes the minimum value

Program Name: InterAGN
Module: DUPGRID.FRM

Sub cmdDuplicate_Click ()
' Checks if grid already exists...
' If not exists then duplicate grid...CreateCopyGrid
' When done copy grid input data...CopyGridData

Sub cmdExit_Click ()
' Closes current form: Unload Me

Sub cmdLoadDB_Click ()
' Opens a Database File and assigns it as default

Sub CopyGridData (db, grid, NewGrd)
' Assign table names:
' For all the grid and nongrid tables...copy data

Function FillinGrids (dbname$) As Integer
' Fills gridname combo box with available grids

Sub Form_Load ()
' Initializes form

Sub gridname_Click ()
' Selects and opens gridname

Sub NewGrdName_Change ()
' Checks for valid grid name & enable duplication

Sub OpenDBFile ()
' Opens Database File and Sets Default Name

Program Name: InterAGN
Module: LANDATA.FRM

Sub CellList_Click ()
' Select cell number and go to cell on spread

Sub ChangeBackColor ()
' Changes back color of rows in spreadsheet

Sub cmbFrom_Click ()
' Selects landclass to change % from

Sub cmbTo_Click ()
' Selects landclass to change % to

Sub cmdApply_Click ()
' Proceed to change % of landcover "from-to"
' ChangeBack - Calculate changes - ResetBack

Sub cmdLoadDB_Click ()
' Opens a Database File and assigns it as default
' Uses Dialog Box Action 1

Sub cmdRecalc_Click ()
' Calculate land values based on class grouping
'   Call GetTypicalValues
' Calculate for active cells with typical values
' Write values in database for the active cells
'   Call WriteLandParameters

Sub cmdUpdate_Click ()
' Initialize Spreadsheet and from cells in list:
'   SpreadAddCell
'   ReadGridValues

Sub Command3D1_Click ()
' Draw selected Grid
' SendCommand "[PR_REDRAW]"
' a = "[LY_DRAWGRID]" + "parameters"

Sub Command3D2_Click ()
' Closes current form: Unload Me

Sub Command3D3_Click ()
' Select All of the cells in the grid

Sub Command3D4_Click ()
' Initialize Spreadsheet

Function FillinGrids (dbname$) As Integer
' Fills gridname combo box with available grids

Sub Form_Load ()
' Initializes form

Sub GetTypicalValues ()
' Reads Classes Scheme from Initial Data...
' Gets classes types...

Sub gridname_Click ()
' Selects and opens gridname : Initialize Spreadsheet

Function InitSpread () As Integer
' Reads Classes Scheme from Initial Data...
' Gets classes types...
' Add classes types according to lookup and selection...

Sub lblGridColor_Click ()
' Sets Color by using Dialog Box Action 3

Sub OpenDBFile ()
' Opens Database File and Sets Default Name

Sub optChange_Click (Index%, Value%)
' Changes percentage by option or text input

Sub ReadGridValues ()
' Reads grid values from database
' Use spreadsheet column names as field names

Sub ResetBackColor ()
' Reset FROM & TO cells colors to spread back

Sub SelectCell_Click (Value As Integer)
' Clicks on map and select cell and grid number
' SendCommand "[EV_MPCHLL]ON"
' Returns selected grid number

Sub SendCommand (ddecommand$)
' Sends Command to RAISON

Sub SpreadAddCell ()
' Adds Column to Spread from ListCell

Sub SummarySpread_Change (Col#, Row#)
' Change value on spread & save on database

Sub Text2_LinkNotify ()
' Notify for RAISON link:
' Change color of selected cell...
' ddestr = "[LY_DRGRIDCELLUSERDEF]"

Sub WriteLandParameters ()
' Open database and tables.....
' With the values calculated from the typical data:
' Write the values in the General Cell table for the selected grid...

Program Name: InterAGN
Module: RESUME.FRM

Sub cmdAddAll_Click ()
' Initialize Spreadsheet : InitSpread

Sub cmdClearAll_Click ()
' Initialize Spreadsheet : InitSpread

Sub cmdExit_Click ()
' Closes current form: Unload Me

Sub cmdLoadDB_Click ()
' Opens a Database File and assigns it as default

Function FillinGrids (dbname$) As Integer
' Fill gridname combo box with available grids

Sub Form_Load ()
' Initializes form and spreadsheet
' Clears combo & fill with grids on file: FillinGrids

Sub gridname_Click ()
' Select gridname : Initialize Spreadsheet

Function InitSpread () As Integer
' Reset spreadsheet depending on table name:
' Column names on spreadsheet as fields names

Sub OpenDBFile ()
' Opens Database File and Sets Default Name

Sub ReadResults (gridn)
' Read from the Watershed Summary Table...

Sub SpreadAddCell ()
' Adds Column to Spread from ListCell
' Prevents block to be edited (data) and (results)
' Resets position

Program Name: InterAGN
Module: SENSANAL.FRM

Sub CalculateVarGrad()
' Calculate mean normalized sensitivity gradient

Sub cmdDraw_Click ()
' Draw selected Grid
' SendCommand "[PR_REDRAW]"
' a = "[LY_DRAWGRID]" + "parameters"

Sub cmdExit_Click ()
' Closes current form: Unload Me

Sub cmdLoadDB_Click ()
' Opens a Database File and assigns it as default

Sub cmdNormGrad_Click ()
' VerifySensTbl - If table does not exist; create it
' Open Prepare Sensitivity Input Window
' SensInput.Show 1 (modal 1)

Sub cmdRankGrad_Click ()
' Open Ranki window : NewSensRankGrad.Show

Sub cmdRunSens_Click ()
' Exports ASCII data and prepares BAT file...
' Run DOS batch file...
' Import output for batch file: ImportOutput
' Calculate variation and write in table...
'   WriteDateSensRun

Sub ExportData ()
' Open file for output & write data in model format
' For perturbed variables read parameters &
' percentages from sensitivity table:
' WriteInitialData & WriteCellData
' Prepare BAT file

Function FillinGrids (dbname$) As Integer
' Fills gridname combo box with available grids

Sub Form_Load ()
' Initializes form and test for RAISON link:

Sub gridname_Click ()
' Selects and opens gridname : InitializeForm
' Read from Watershed Summary Table and Sensitivity Table...

Sub ImportOutput ()
' Read base case output data from watershed summary table....
' Read parameters and percentages from summary table..until EOF
' Calculate variation and gradients...write to sensitivity table

Sub InitializeForm ()
' Resets label values

Sub lblGridColor_Click ()
' Sets Color by using Dialog Box Action 3

Sub OpenDBFile ()
' Opens Database File and Sets Default Name

Sub RWAddErosValues (f1, f2, Par, Low, High)
' Reads Add_Erosion from Add_Erosion Table
' Does the Numeric Format for file...
' No sensitivity parameters for Additional Erosion
' Writes ASCII files...1 for Low / 2 for High

Sub RWChanValues (f1, f2, Par, Low, High)
' Reads Channel Values From Channel Table...
' Does the Numeric Format for file...
' Calculate Low and High for Channel Data
' Writes ASCII files...1 for Low / 2 for High

Sub RWFeedlotValues (f1, f2, Par, Low, High)
' Reads Feedlot Values From Feedlot Table
' Does the Numeric Format for file
' No sensitivity parameters for Feedlots
' Writes ASCII files...1 for Low / 2 for High

Sub RWFertValues(f1, f2, Par, Low, High)
' Reads Fertilizer Values From Fertilizer Table...
' Does the Numeric Format for file...
' Calculate Low and High for Soil Data
' Writes ASCII files...1 for Low / 2 for High

Sub RWGenCellValues (f1, f2, Par, Low, High)
' Reads Grid Values From General Table...
' Does the Numeric Format for file...
' Calculate Low and High for Cell Data
' Writes ASCII files...1 for Low / 2 for High
' Soil_Texture : RWSoilValues (selGridNumber)
' Fert_Ind : RWFartValues (selGridNumber)
' Pest_Ind : RWPestValues (selGridNumber)
' NonFeed : RWNonFeedValues (selGridNumber)
' Feedlot : RWFeedlotValues (selGridNumber)
' Add_Eros : RWAddErosValues (selGridNumber)
' Impnd_Ind : RWImpoundValues (selGridNumber)
' RWChanValues (selGridNumber)

Sub RWImpoundValues (f1, f2, Par, Low, High)
' Reads Impoundment Values From Impoundment
' Does the Numeric Format for file...
' No sensitivity parameters for Impoundments...
' Writes ASCII files...1 for Low / 2 for High

Sub RWNonFeedValues (f1, f2, Par, Low, High)
' Read Non-Feedlot values from NonFeedlot
' Does the Numeric Format for file...
' No sensitivity parameters for Non-feedlots...
' Writes ASCII files...1 for Low / 2 for High

Sub RWPestValues(f1, f2, Par, Low, High)
' Reads Pesticide Values From Pesticide Table...
' Does the Numeric Format for file...
' No sensitivity parameters for pesticide...
' Writes ASCII files...1 for Low / 2 for High

Sub RWSoilValues (f1, f2, Par, Low, High)
' Reads Soil Values From Soil Table...
' Does the Numeric Format for file...
' Calculate Low and High for Soil Data
' Writes ASCII files...1 for Low / 2 for High

Sub SendCommand (ddecommand$)
' Sends Command to RAISON

Sub Text2_LinkNotify ()
' Notify for RAISON link:
' Change color of selected cell...
'   ddestr = "[LY_DRGRIDCELLUSERDEF]"
'   SendCommand ddestr

Sub VerifyFieldExist ()
' For LastSensRunDate update...Verifies if exists
' If field does not exist, then create it

Sub VerifySensTbl ()
' Check if Sensitivity table exists, if not create it...
'   CreateAGNPSSens(dbname, gridname)

Sub WriteCellData (f1, f2, Par, Low, High)
' Send to Read/Write cell data..Call RWGenCellValues

Sub WriteInitialData (f1, f2, Par, Low, High)
' Read from Database...for Initial Watershed Data
' Does the Numeric Format for file...
' Calculate Low and High for Initial Data
' Writes ASCII files...1 for Low / 2 for High

Program Name: InterAGN
Module: SENSINPU.FRM

Sub cmbGroup_Click ()
' Select variables according to data group:
' Initial Data, General Cell, Soil, Fertilizer and Channel

Sub cmdAdd_Click ()
' If an item is selected, add it to spreadsheet
'   Call SpreadAddParam

Sub cmdAddAll_Click ()
' Add all listed parameters to spreadsheet
• Call SpreadAddParam

Sub cmdCancel_Click ()
' Closes current form: Unload Me

Sub cmdClear_Click ()
' Initialize Spreadsheet: InitParamSpread

Sub cmdDel_Click ()
' If an item is selected, delete it from spreadsheet
' Use delete action from spreadsheet...

Sub cmdDelAll_Click ()
' Delete all listed parameters from spreadsheet
' Use delete action from spreadsheet...

Sub cmdGlobal_Click ()
' Assign % of variation to all listed variables...

Sub cmdSave_Click ()
' Verify that all LowPct and HighPct have values...
' Save to Database and Exit...
'   Call RemovSensitivityData
'   Call WriteSensitivityData

Sub Form_Load ()
' Initialize combo Group: InitComboGroup
' Initialize Spreadsheet: InitParamSpread
' Read Sensitivity Table: ReadSensTable

Sub InitComboGroup ()
' Initialize combo Group

Sub InitParamSpread ()
' Initialize Spreadsheet

Sub optPct_Click (Index%, Value As Integer)
' Assign perturbation percentage by case or input

Sub ParamList_DblClick ()
' Add/Remove Parameter to spreadsheet
'   Call SearchExists(Index, Add)
'   If Add : Call SpreadAddParam
'   Else use delete action from spreadsheet...

Sub Params_Change (Col#, Row As Long)
' Change percentage value and check if it's valid

Sub PertPerc_Change ()
' Change percentage value on input box

Sub PertPerc_Click ()
' Reset optPct values to none...

Sub ReadSensTable ()
' Read Sensitivity Table...
'   Call SpreadAddParam

Sub RemovSensitivityData (db$, gridname$)
' Query database and remove data from table

Sub SearchExists (Index%, Add%)
' Search if already has being added to spread

Sub SpreadAddParam (Par, Low, High)
'Adds Column to Spread from ListCell

Sub WriteSensitivityData (db$, gridname$)
' Write sensitivity input in database sensitivity table

Program Name: InterAGN
Module: SENSNORM.FRM

Sub Check1_MouseMove
' Display database and grid being passed

Sub Check2_Click ()
' Display legend options (load and make visible)

Sub cmbVarsOut_Click ()
' Select output variables according to field names
'   ReadOutputValues
'   DrawGraphic

Sub cmdAll_Click ()
' Mark all available parameters

Sub cmdClose_Click ()
' Close legend options and -   DrawGraphic

Sub cmdExit_Click ()
' Closes current form: Unload Me

Sub cmdNone_Click ()
' Unmark all available parameters

Sub DrawGraphic ()
' Draw the Normalized Gradients

Sub Form_DragDrop (Src , X, Y)
' Drag rectangle to zoom on selected area

Sub Form_Resize ()
' Resizes form, controls and set new positions

Sub InitGraph ()
' Reset Graph Settings

Sub lblBackCol_Click ()
' Sets Color by using Dialog Box Action 3

Sub Picture1_MouseDown
' Reset zoom to original setting with right button
' Prepare for dragging
'   Picture1.DrawMode = 10   NOT_XOR_PEN

Sub Picture1_MouseMove
' Start dragging a rectangle

Sub Picture1_MouseUp
' End drag   Picture1.DrawMode = 13   COPY_PEN

Sub ReadOutputValues ()
' Read LOW and HIGH values for the output

Sub ReadSensitivityTable ()
' Read Sensitivity Table...Assign random colors

Sub Scroll_Change ()
' Move options up/down according to scroll control

Program Name: InterAGN
Module: SENSRANK.FRM

Sub Check1_MouseMove
' Display database and grid being passed

Sub Check2_Click ()
' Display legend options (load and make visible)

Sub cmbVarsOut_Click ()
' Select output variables according to field names
'   ReadOutputValues
'   DrawGraphic

Sub cmdAll_Click ()
' Mark all available parameters

Sub cmdClose_Click ()
' Close legend options and -   DrawGraphic

Sub cmdExit_Click ()
' Closes current form :   Unload Me

Sub cmdNone_Click ()
' Unmark all available parameters

Sub cmdOptions_Click ()
' Make options visible

Sub Command1_Click ()
' Draw rank graphic :   DrawGraphic

Sub DrawGraphic ()
' Draw the Mean Normalized Gradients

Sub Form_Resize ()
' Resize form, controls and calculate new positions

Sub InitGraph ()
' Reset Graph Settings

Sub lblBackCol_Click ()
' Sets Color by using Dialog Box Action 3

Sub Picture1_MouseDown
' Zoom out-left(1) in-right(2)
' When done redraw :   DrawGraphic

Sub ReadOutputValues ()
' Read GRAD values for the output variable...

Sub ReadSensitivityTable ()
' Read Sensitivity Table...Assign random colors

Sub Scroll_Change ()
' Move legend up and down according to scroll

Program Name: InterAGN
Module: SOIL.FRM

Sub cmdApply_Click ()
' Verify data input except for water selection
' Write values on database for selected or all cells

Sub cmdCancel_Click ()
' Closes current form: Unload Me

Sub cmdDefaults_Click ()
' Reset to default values

Sub DispWaterValues ()
' Spreedsheet Display of Water Values for all...

Sub Form_Load ()
' Initialize form and read data : ReadCellData

Sub ReadCellData ()
' Read soil related data...

Sub SoilType_Click ()
' Change the soil type for the selected cells

Sub VerifyInput ()
' Validate Input Data (Return RetryInput%)

Sub WaterValues
' Change Channel_Ind, Fert_Ind, Pest_Ind, LandSlope to 0...
' Change SCS_No to 100, Manning's n to 0.99, SlopeLength to 0...
' Change K_factor, C_factor, P_factor, SurfCond, COD_factor to 0...
' Assign defaults for water to channel table...

Program Name: InterAGN
Module: FERTILIZ.FRM

Sub cmdApply_Click ()
' Verify data input except for OFF
' Write values on database for selected or all cells

Sub cmdCancel_Click ()
' Closes current form: Unload Me

Sub optFertInd_Click (Index, Value As Integer)
' Null values for fertilization if off selected...

Sub optLevel_Click (Index, Value As Integer)
' Default values for fertilization rates...

Sub ReadCellData ()
' Read fertilizer related data...

Sub VerifyInput ()
' Validation of Input Data (Return RetryInput%)

Program Name: InterAGN
Module: PESTDB.FRM

Sub cmdAccept_Click ()
' Loads pesticide data for selected pesticide type

Sub cmdCancel_Click ()
' Closes current form: Unload Me

Sub Form_Load ()
' Access pesticide database for list of Available Pesticides

Sub GetPestDBName ()
' Locate Pesticide Database (pestic.mdb)
CMDialog1.Filename = "*.mdb"

Sub List1_Click ()
' Read from database ("Pesticide Names")

Sub List2_Click ()
' Read from database ("Pesticide Tradename")

Program Name: InterAGN
Module: PESTICID.FRM

Sub cmdApply_Click ()
' Verify data input except for OFF
' Write values on database for selected or all cells

Sub cmdCancel_Click ()
' Closes current form : Unload Me

Sub cmdDefaults_Click ()
' Select Pesticide Type and access the pesticide DB
' PestDB.Show

Sub cmdDefltPest_Click ()
'Reset to default values

Sub Form_Load ()
' Initializes form and fill combo with pesticide type

Sub optPestInd_Click (Index%, Value As Integer)
' Null values for pesticides if off selected...

Sub optTimeAp_Click (Index, Value)
' Enable/disable options. Depends: application time

Sub ReadCellData ()
' Read pesticide related data...

Sub VerifyInput ()
' Validate Input Data (Return RetryInput%)
' Check by groups depending on time of application

Program Name: InterAGN
Module: FEEDLOT.FRM

Sub AddPntScr_Click (Value As Integer)
' Add point source and send command
' SendCommand "[EV_MPCHLL]ON"

Sub CellList_Click ()
' Select cell from listbox & make it the active one

Sub ClearValues ()
' Clear values from data form

Sub cmdAccept_Click ()
' Verify data input & write values for selected cells

Sub cmdAdd_Click ()
' Can't fill in any data until "apply" or create the data points: GetValues : CellList_Click

Sub cmdClear_Click ()
' Clear cell list

Sub cmdDel_Click ()
' Delete Layer Object

Sub cmdDeleteData_Click ()
' Delete data in cell(s)

Sub cmdDraw_Click ()
' Draw Grid - SendCommand "[PR_REDRAW]"
' a = "[LY_DRAWGRID]" + "parameters"

Sub cmdFillZ_Click ()
' Fill with zeros the rest of the data...

Sub cmdPropag_Click ()
' Verify data input and proceed with changes...
' Change all source values with the displayed data...

Sub cmdShowCells_Click ()
' Send command to display point sources
' ddestr = "[LY_DRAWUSERDEF]" + "parameters"

Sub cmdUpdate_Click ()
' Verify data input and write form values to database

Sub Form_Load ()
' Define variables before the form will work.. Identify
' DDE share established by source application

Sub GetValues ()
' Get Layer Object Values

Sub optBuffer_Click (Index, Value As Integer)
' Enable/disable options for buffer area selection

Sub SendCommand (ddecommand$)
' Sends Command to RAISON

Sub Text2_LinkNotify ()
' Notify RAISON & change color of selected cell
' Remove cell from list/map or add cell to list/map

Sub VerifyInput ()
' Validate Input Data (Return RetryInput as Integer)

Program Name: InterAGN
Module: NONFEED.FRM

Sub AddPntScr_Click (Value As Integer)
' Add point source and send command
' SendCommand "[EV_MPCHLL]ON"

Sub CellList_Click ()
' Select cell from listbox and make it the active one

Sub ClearValues ()
' Clear values from data form

Sub cmdAccept_Click ()
' Verify data input & write values for selected cells

Sub cmdAdd_Click ()
' Can't fill in any data until "apply" or create the data points: GetValues : CellList_Click

Sub cmdClear_Click ()
' Clear cell list

Sub cmdDel_Click ()
' Delete Layer Object

Sub cmdDeleteData_Click ()
' Delete data in cell(s)

Sub cmdDraw_Click ()
' Draw Grid: SendCommand "[PR_REDRAW]"

Sub cmdPropag_Click ()
' Verify data input and proceed with changes...

Sub cmdShowCells_Click ()
' Send command to display point sources
' ddestr = "[LY_DRAWUSERDEF]"

Sub cmdUpdate_Click ()
' Verify data input & write form values to database

Sub Form_Load ()
' Define variables before the form will work. Identify
' DDE share established by source application

Sub GetValues ()
' Get Layer Object Values

Sub optEnter_Click (Index, Value As Integer)
' Selects if source enters at top or bottom of cell

Sub SendCommand (ddecommand$)
' Sends Command to RAISON

Sub Text2_LinkNotify ()
' Notify RAISON & changes color of selected cell
' Remove cell from list/map or add cell to list/map

Sub VerifyInput ()
' Validate Input Data (Return RetryInput as Integer)

Program Name: InterAGN
Module: IMPOUND.FRM

Sub AddPntScr_Click (Value As Integer)
' Add point source and send command
' SendCommand "[EV_MPCHLL]ON"

Sub CellList_Click ()
' Select a cell from the listbox and make it the active one...

Sub ClearValues ()
' Clear values from data form

Sub cmdAccept_Click ()
' Verify data input & write values for selected cells

Sub cmdAdd_Click ()
' Can't fill data until "apply" or create the data points.
' GetValues : CellList_Click

Sub cmdClear_Click ()
' Clear cell list

Sub cmdDel_Click ()
' Delete Layer Object

Sub cmdDeleteData_Click ()
' Delete data in cell(s)

Sub cmdDraw_Click ()
' Draw selected Grid
' SendCommand "[PR_REDRAW]"

Sub cmdPropag_Click ()
' Verify data input and proceed with changes...

Sub cmdShowCells_Click ()
' Send command to display point sources
' ddestr = "[LY_DRAWUSERDEF]"
' SendCommand ddestr

Sub cmdUpdate_Click ()
' Verify data input & write form values to database

Sub Form_Load ()
' Define variables before the form will work. Identify
' DDE share established by the source application

Sub GetValues ()
' Get Layer Object Values

Sub Text2_LinkNotify ()
' Notify RAISON & changes color of selected cell
' Remove cell from list/map or add cell to list/map

Sub VerifyInput ()
' Validate Input Data (Return RetryInput%)

Program Name: InterAGN
Module: ADDEROS.FRM

Sub AddPntScr_Click (Value As Integer)
' Add point source and send command
' SendCommand "[EV_MPCHLL]ON"

Sub CellList_Click ()
' Select cell from listbox and make it the active one

Sub ClearValues ()
' Clear values from data form

Sub cmdAccept_Click ()
' Verify data input & write values for selected cells

Sub cmdClear_Click ()
' Clear cell list

Sub cmdDel_Click ()
' Delete Layer Object

Sub cmdDeleteData_Click ()
' Delete data in cell(s)

Sub cmdDraw_Click ()
' Draw selected Grid
' SendCommand "[PR_REDRAW]"

Sub cmdPropag_Click ()
' Verify data input and proceed with changes...

Sub cmdShowCells_Click ()
' Send command to display point sources
' ddestr = "[LY_DRAWUSERDEF]"
' SendCommand ddestr

Sub cmdUpdate_Click ()
' Verify data input and write form values to database

Sub Form_Load ()
' Define variables before the form will work. Identify
' DDE share established by the source application

Sub GetValues ()
' Get Layer Object Values

Sub optErosType_Click (Index%, Value%)
' Select type of additional erosion

Sub Text2_LinkNotify ()
' Notify RAISON & changes color of selected cell
' Remove cell from list/map or add cell to list/map

Sub VerifyInput ()
' Validation of Input Data (Return RetryInput%)

Program Name: InterAGN
Module: CHANNEL.FRM

Sub cmdApply_Click ()
' Verify data input
' Write values on database for selected or all cells

Sub cmdCancel_Click ()
' Closes current form : Unload Me

Sub cmdDeflt_Click ()
' Reset to default values

Sub Command3D1_Click ()
' Mark for all particles sizes

Sub Command3D2_Click ()
' Unmark for all particles sizes

Sub Form_Load ()
' Skip if input data is Null or Reads from Initial Watershed Data
' Assigning Labels and Enable/Disable form fields
' AGNPS independent of geomorphic or not, or
' Geomorphic or not independentl of peak method, or
' SCS-TR55 and Geomorphic, and
' SCS-TR55 and Non-Geomorphic
' Finally : ReadCellData

Sub optChanType_Click (Index%, Value%)
' Select channel type

Sub optUseDecay_Click (Index%, Value%)
' Enable options if default decay is selected

Sub ReadCellData ()
' Read channel related data...

Sub VerifyInput ()
' Validation of Input Data (Return RetryInput%)
' General Channel and Use Decay or not...or
' Geomorphic or not independently of peak method...or
' SCS-TR55 and Geomorphic....or
' SCS-TR55 and Non-Geomorphic.
' Check by groups depending on selected options

Program Name: InterAGN
Module: AGNPSLIB.BAS

Function AddPointSource (dbname$, layerName$, gridName$, centre%, GridNumber&, X#, y#) As Long
' Passes back the objectid of the pointsource
' x is lon, y is lat. If centre is true then the point is centred in the

Function AGNPS_CellCnt% (db As Database, gridName$, total&, level1count&)
' Counts the number of cells in a grid

Function CreateAGNPSAddEros (db, grid) As Int
' Creates the Additional Erosion table

Function CreateAGNPSChannel (db, gridID%, gridname) As Integer
' Creates the Channel Information table

Function CreateAGNPSdb (dbname$) As Integer
' Creates the layer database

Function CreateAGNPSFdlt (dbname$, gridName) As Integer
' Creates the Feedlot table

Function CreateAGNPSFert (db, gridid, gridname) As Int
' Creates the Fertilizer table

Function CreateAGNPSGen (db, gridid, gridname) As Int
' Creates the General Cell Data table

Function CreateAGNPSHydro (db, gridid, gridname) As Int
' Creates the Hydrology table

Function CreateAGNPSImpound (db, gridName)
' Creates the Impoundment table

Function CreateAGNPSInit (db, gridName)
' Creates the Intial Watershed table

Function CreateAGNPSNonFdlt (db, gridName)
' Creates the Non-feedlot table

Function CreateAGNPSNutri (db, grdid, gname)
' Creates the Nutrients table

Function CreateAGNPSPest (db, grdid, gname)
' Creates the Pesticide table

Function CreateAGNPSPestic (db, grdid, gname)
' Creates the Pesticide Results table

Function CreateAGNPSSedim (db, gid, gname)
' Creates the Sediment Results table

Function CreateAGNPSSedimAnal (db gName)
' Creates sediment analysis table (model results)

Function CreateAGNPSSens (db, gridName)
' Creates the sensitivity table (% of variation)

Function CreateAGNPSSoil (db, gid, gname)
' Creates the Soil table

Function CreateAGNPSSrcDep (db, gid, gname)
' Creates the Source_Deposition table

Function CreateAGNPSTables (Form, db, gridid, gridName) as Integer
' Controls the creation of AGNPS Tables:
' CreateAGNPSInit(dbname, gridName)
' CreateAGNPSGen(dbname, gridid, gridName)
' CreateAGNPSSoil(dbname, gridid, gridName)
' CreateAGNPSFert(dbname, gridid, gridName)
' CreateAGNPSPest(dbname, gridid, gridName)
' CreateAGNPSNonFdlt(dbname, gridName)
' CreateAGNPSFdlt(dbname, gridName)
' CreateAGNPSAddEros(dbname, gridName)
' CreateAGNPSImpound(dbname, gridName)
' CreateLanduseSum(dbname, gridid, gridName)
' CreateAGNPSChannel(dbnm, gridid, gridName)
' CreateAGNPSWatSum(dbname, gridName)
' CreateAGNPSSedimAnal(dbname, gridName)
' CreateAGNPSHydro(dbname, gridid, gridName)
' CreateAGNPSSedim(dbname, gridid, gridName)
' CreateAGNPSNutri(dbname, gridid, gridName)
' CreateAGNPSPestic(dbname, gridid, gridName)
' CreateAGNPSSrcDep(dbnm, gridid, gridName)

Function CreateAGNPSWatSum (db, gridName)
' Creates the watershed summary table

Function CreateLanduseSum% (Form, db, gridid, gridName)
' Creates the Landuse summary table

Function ExtractNextParameter (CmdString As String, Value As Variant, param As String)
' Extracts next parameter up to separator char '|' a '\|' is interperated
' as a double | in the parameter a '[' signals the end of the command
' and will not move beyond that point.
' use '\[' to pass a '[' as a parameter

Function FindGridPointData% (db As Database, gridLayerID%, gridObjectID&, tableID%, objectIDArray&())
' Get the grid object and put it into a VB array
' Open up the type table and scan for points

Function GetCentrePnt (db, gridid%, GridNumber&, X#, y#, utmflag%, grzone&, grdatum&) As Integer
' Finds centre points of grid element

Sub ReadINIFile ()
' Read file for name of executable and database

Sub WriteINIFile ()
' Write file for name of executable and database

Program Name: InterAGN
Module: AGNPSGR.BAS

Function AGNPS_AddGridRectCell (db As Database, gridID As Integer, lat As Double, lon As Double, NewGridNumber As Long, lsutm%)
' Adds a rectangular grid cell to the existing grid. Assumes that the
' grid number starts at 1 and every grid after is incremented by 1.
' Returns: the new grid cell number added or LAYER_ERROR
' Grid cells can not be negative numbers

Function AGNPS_CheckValidGridCellNumber (db As Database, gridID As Integer, ByVal gridNumber As Long)
' Check whether or not the specified cell exists.
' Returns SUCCESS if it exists.

Function AGNPS_DeleteGridCell (db As Database, gridID As Integer, gridNumber As Long) As Integer
' Delete grid cell from all related grid tables
' Returns SUCCESS or LAYER_ERROR.

Function AGNPS_FitGridCellNumber (db As Database, gridID, NewGridNumber As Long)
' Adds one to all grid cell numbers greater than or
' equal the newGridNumber. In this way it keeps
' all the grid cell numbers unique.

Function AGNPS_NextGridNumber (gridID As Long, cellNumber As Long) As Long
' Returns: the next unique grid number.

Function AGNPS_RemoveGridCellNumber (db As Database, gridID, gridNumber As Long)
' Removes grid cell number from the grid table &
' renumbers the grid cells greater than it.

Function AGNPS_SubdivideCell (db As Database, gridID, gridNumber As Long)
' Subdivides a grid cell into four separate cells.

Program Name: InterAGN
Module: DRAWFLOW.BAS

Sub Intrsct2Lines (m1#, b1#, m2#, b2#, x#, y#)
' Intersect two lines

Sub LineFromPoints (x1#, y1#, x2#, y2#, slope#, yIntercept#)
' Calculate line when points are known

Sub midPointOf2Points (strtX, strtY, endX, endY, midX, midY)
' Calculate mid point in line given 2 points

Sub MidPointOfRect (plyg() As Layer, x#, y#)
' Calculate mid point of a rectanble polygon by:
' Intesrsec2Lines
' LineFromPoints
' midPointOf2Points

Program Name: InterAGN
Module: LAYERDB.BAS

Function AddCharacteristic (db, layid, varFld$, multIndex$, FrmValIndex$, ToValIndex$)r
' Adds Characteristics to the characteristic table specified by layerID.

Function AddCollectionObject (db As Database, collectionID As Integer, layerid As Integer, objectID As Long, drawingorder As Long)
' Adds a collection object to the database.
' A collection is layerID, objectID & drawingOrder.
' The drawingOrder is a priority, so one can set a preference to the order of drawing.
' Returns: SUCCESS if the object was added

Function AddDependencyObject (db, lyrid, obID, DepLyrID%, DependencyObjectID&)
' Adds a dependency object: The layerID and objectID act as a parent to the DependencyLayerID and the DependencyObjectID which acts like a child. Returns: SUCCESS if the object was added, failure if it already exists.

Function AddGridObject (db, gid, gridNumber, numvert%, LAYERPOINT As Integer)
' Adds a grid object to the database. A grid object for example is a grid cell. Object can be a rectangular or polygonal object. Returns: ObjectId

Function AddLayertoLayerSummary (db, tName, gid, lyrtype, application$, appInter As Integer, Caption As String, boolTable As Integer)
' Adds the layer information of a layer to the LayerSummary table. Returns: layer id of new layer

Function AddLL_GridRectCell (db As Database, gridid As Integer, Lat As Double, lon As Double, newGridNumber As Long)
' Adds a rectangular grid cell to the existing grid. Assumes that the Grid is numbered starting at 1
' and every grid there after is incremented by 1.
' Grid cells can not be negative numbers Returns: the new grid cell number or LAYER_ERROR

Function AddLL_GridRectToLayerSummary (db, tabName$, application$, appInter, Caption$, gridLat, gridLon, rows, cols, angle, GridWidth)
' Adds rectangular grid information to the layer summary table. Also updates the grid rect table.
' Returns: layer id of newly added grid layer.

Function AddObject (db, layerid, varFld$, varvalue As Variant, objectType%, numvert&, LAYERPOINT As Integer, Caption As String)
' Adds an object to a given layer. This can be point, line or polygon. Will update only one value field of Layer table. Returns: object id of new object.

Function AddObjectMultData (db As Database, layerid%, varFld() As String, varvalue() As Variant, objectType%, numvert&, LYRPOINT As Integer, Caption As String) As Long
' Adds an object that has multiple values associated with it to a given layer. This object can be a point,. line or polygon. Returns: objectId of new object.

Function AddObjectNoData (db As Database, layerid%, objectType%, numvert&, LAYERPOINT As Integer, Caption As String)
' Adds an object to a given layer. This can be point, line or polygon. No value fields of the Layer table will be updated. Returns: object id

Function AddPolyHoleObjectNoData (db, lyrid, numvert&, LAYERPOINT, Caption, LevelArray() As Long, VertArray() As Long, numpolys#)
' Adds an object to layer. This can only be a polygon with holes. No value fields of the Layer table will be updated. Returns: object id

Function AddUTM_GridRectCell (db As Database, gridid%, gridinX#, gridinY As Double, newGridNumber As Long) As Long
' Adds a rectangular grid cell to the existing grid. Assumes that the Grid is numbered starting at 1
' and every grid there after is incremented by 1.
' Returns: the new grid cell number added.

Function AddUTM_GridRecttoLayerSummary (db, tableName$, application$, appinter%, GridWidth#, layertype As Integer)
' Adds rectangular grid information to the layer summary table. Also updates the grid rect table.
' Returns: layer id of newly added grid layer.

Function ChangeCharacteristic (db, layerid%, varFld$, multindex$, FromValueIndex$, fillpattern%, pointsz%)
' Change characteristics in characteristics table.
' Returns: SUCCESS if SUCCESS.

Function ChangeCharacteristicRngs (db As Database, layerid%, varFld$, multindex$, FromValueIndex$, ToValueIndex$) As Integer
' Change the characteristics ranges in the characteristics table.
' Returns: SUCCESS if SUCCESS.

Function ChangeCollectionDrawingOrder (db As Database, collectionID As Integer, layerid As Integer, objectID As Long, draworder#)
' Allows the user to change/add the drawingOrder of a given collection object.
' Returns: SUCCESS if the object existed

Function ChangeGridMultValue (db, layerid As Integer, gridNumber As Long, varFld() As String, VarData() As Variant) As Integer
' Searches the specified grid layer and changes multiple values. If the function finds the object it changes it Returns: SUCCESS if value existed

Function ChangeGridValue (db As Database, layerid As Integer, gridNumber As Long, varFld As String, VarData As Variant)
' Searches the specified grid layer and changes value to given value. If the function finds a value it changes it, otherwise it adds a new record to the database. Field name defaults to "Value" if none is given. Returns: SUCCESS if the value existed in the database.

Function ChangeGridValueGivenGridObjectID (db As Database, layerid As Integer, gridObjID As Long, varFld As String, VarData As Variant)
' Searches the specified grid layer and changes value to given value. If the function finds a value it changes it, otherwise it adds a new record to the database. Field name defaults to "Value" if none is given. Returns: SUCCESS if the value existed in the database.

Function ChangeLayerGridbyName (db As Database, layer$, gridid%) As Integer
' Changes layer that a grid is associated with.

Function ChangeMultValue (db As Database, layerid As Integer, objectID As Long, varFld() As String, VarData() As Variant) As Integer
' Changes multiple values for a given object.
' Returns: SUCCESS if the values were changed, failure if there was no match.

Function ChangeValue (db As Database, layerid As Integer, objectID As Long, varFld As String, VarData As Variant) As Integer
' Changes the value of one field of an object.
' Returns: SUCCESS if the value was changed and failure if there was no match.

Function CheckValidGridCellNumber (db As Database, gridid As Integer, ByVal gridNumber As Long) As Integer
'Check whether or not the specified grid cell exists.Returns SUCCESS if it exists.

Function CreateCollectionTable (dbname$, collection As String, collcomment As String)
' This procedure creates a collection table given the open database and the collection name.
' The database is passed to this procedure closed. Rturns: layerID of the newly added layer.

Function CreateLayerDatabase (dbname As String) As Integer
' Creates a basic layer database.

Function CreateLayerTable (db, newVarTab$, isgridtable As Integer, isUTM As Integer, zone appinter%, Caption$, boolTable%)
' Adds a new layer table.

Function CreateLL_GridRectLayer (dbname As String, gridName$, application$, appinter%, gridCols%, GridWidth#, GridAngle#) As Integer
' Creates a rectangular grid layer and and puts it in the database. Numbers grids start at 1 and increments each grid by 1 there after. This is only used to create Lat Lon layer tables.
' Returns: layer id of newly added physical grid.

Function CreateLL_GridRectTable (dbname As String, newgridtable As String, app$, appinter%, angle#, GridWidth#) As Integer
' Adds a new rectangular grid table to database.

Function CreateLL_LayerTable (db As String, newVarTable As String, isgridtable As Integer)
' Adds a new layer table.
' This is only used to create Lat Lon layer tables.

Function CreateNewFieldVariable (dbname As String, tbl As String, fld() As Field) As Integer
' Adds a field(s) to a layer table. This can be any layer table; grid or not grid.

Function CreateNewIndx (dbname$, tblname$, indx() As Index) As Integer
'This is a generic function tocreate new indexes

Function CreateParentTable% (db, layID)
' This creates a table to keep track of the parents of objects. This is only used when the created table is the results of polygonal boolean operations.

Function CreateTheDatabase (dbname$)
' Simply creates a new empty database.

Function CreateTheTable (dbname As String, tblname, fld() As Field, indx() As Index)
' Adds a table to the database given the table, fields and indexes. Assumes table does not exist.

Function CreateUTM_GridRectLayer (dbname As String, gridName$, application$, appinter, integer, datum As Integer)
' Creates a rectangular grid layer and and puts it in the database. Number grids start at 1 and increments each grid by 1 there after.
' Returns: layer id of newly added physical grid.

Function CreateUTM_LayerTable (db As String, newVarTable As String, isgridtable As Integer, Caption$, boolTable%) As Integer
' Adds a new layer table.
' This is only used to create UTM layer tables.

Function DeleteCharacteristic (db As Database, layerid%, varFld$, multIndex$, FromValueIndex$, ToValueIndex$)
' Delete the characteristics from the characteristic table. Returns: SUCCESS if SUCCESS.

Function DeleteCollectionObject (db As Database, collectionID As Integer, layerid As Integer, objectID As Long) As Integer
' Deletes a collection object from the collection table. Returns: SUCCESS if the object was deleted, failure if did not exist.

Function DeleteCollectionTable% (db As Database, collection$)
'This function deletes a collection table.

Function DeleteDependencyObject (db As Database, layerid%, objectID&, DependLayerID%, DependObjectID&)
' Deletes a dependency object from the dependencies table. Returns: SUCCESS if the object was deleted, failure if did not exist.

Function DeleteGridCell (db As Database, gridid As Integer, gridNumber As Long)
' Deletes a Grid Cell from the database.
' The following tables are affected : Position, Type, GridSummary, associated Grid Table and all Layer Tables associated with this grid.
' Returns: SUCCESS if SUCCESS.

Function DeleteGridLayerObject (db , layerid As Integer, gridNumber As Long)
' Deletes a Grid layer from the database.
' layerid is id of layer that holds data not the gridid

Function DeleteLayerbyName (db, layer$)
'Deletes an entire layer from a layerdatabase
'This operation can not be undone.

Function DeleteLayerObject (db As Database, layerid As Integer, objectID As Long)
' Deletes an Object from a database along with all the existing data associated with that object.
' Given - the open database, layerid.
' Returns: SUCCESS if SUCCESS.

Function DoesFieldExist (tbl As Table, fld As String) As Integer
'This function checks to see if a field exists in a given table.

Function DoesParentExist (db As Database, layerid As Integer) As Integer
'This tests if a parents table exists for a given layer.

Function DoesTableExist (db As Database, tblname As String) As Integer
' This tests if a given table exists in the database.

Function FindCollections (db As Database, colltbl() As String) As Integer
' Fills array with names of all the collection tables.
' Returns: number of collection tables in the DB

Function FindGridIDGivenLayerID (db As Database, layerid As Integer) As Integer
' Given the layerid
' Returns: the gridId as an integer, if not found returns FAILURE

Function FindGridNumberGivenGridObjectID (db As Database, gridid As Integer, gridObID)
' Returns: the grid number given the grid objectID.

Function FindGridNumberGivenObjectID (db As Database, layerid As Integer, objectID As Long)
'Given the layerid, objectid.
'Returns : the gridnumber as an integer.

Function FindGridObjectIDGivenGridNumber (db As Database, gridid As Integer, gridNum)
' Given the gridID and the grid number.
' Returns: the gridObjectID of the object.

Function FindGridObjectIDGivenObjectID (db As Database, layerid As Integer, objectID As Long)
'Given the open databasae, layerid and ObjectID.
'Returns the GridObjecID.

Function FindGrids (db, gridTbl() As String)
'Given the database. Returns : all the Grids that exist in the file

Function FindGridTblLayers (db As Database, ByVal gridid As Long, GridLayerTbls)
' Fills the string array GridLayerTbls with the names of all the grid layers associated with a particuluar grid. Returns: the number of layers in the array.

Function FindGridTblTypeLayers (db As Database, gridid As Integer, GridLayerTbls() As String, GridLayerType() As Integer) As Integer
' Given the gridID, fills in the names of the tables associated with it, and the array of the type of tables they are. A specialized version of GridTblLayers. Returns: the number of layers.

Function FindLayersAndTypesNonGrid (db As Database, layers() As String, layertypes)
' Given the database, the layers() array is filled with the names of the non-grid layer (layers not associated with a grid) and also the layerstype() array is filled with the tables type.
' Note: doesn't return collection tables!
' Returns: the number of layers.

Function FindObjectIDGivenGridObjectID (db As Database, layerid As Integer, gridObjectID)
'Given the open databasae, layerid and ObjectID.
'Returns the ObjectID.

Function FitGridCellNumber (db As Database, gridid As Integer, newGridNumber As Long)
' Adds one to all grid cell numbers greater than or
' equal to the newGridNumber. In this way it keeps all the grid cell numbers unique.

Function GenerateRangeList (db As Database, tblname As String, varname$, multname$, RngFrom() As String, RngTo() As String)
'This function creates a list of ranges for a given thematic map. The tblname is the name of the layer, varname is the name of the data field and multname is the thematic map or characteristic. Two arrays RngFrom and Rngto are returned.

Function GenerateTableList (db As Database, tblname() As String) As Integer
'This function created a list of tables given a DB. An array of tablename, tblname(), is returned.

Function GenerateVarList (db As Database, tblname As String, vars() As String) As Integer
'This function creates a list of data fields for a given layer anem. Tblname is the name of the layer, nd vars() is the array of field names.

Function GenerateVarMultList (db As Database, tblname As String, varname$, mults() As String)
'This function creates a list of thematic maps or characteristics for a given layer (tblname) and data field (varname). An array called mults() is returned.

Function GetApplication (db As Database, LayerName As String, appInter As Integer)
' Given the layer name, gives the application and the appInter. Returns: the application name.

Function GetGridLayerObject (db, layerid As Integer, objectID As Long, gridid As Integer, gridObjectID As Long, varFld As String, varvalue As Variant, valflag As Integer)
' Given the objectid and the layerid. Default value field is "Value". Returns : gridobjid, gridid & value

Fn GetGridMultValueByLayerIDAndGridN (db, layerid As Integer, gridNumber As Long, varFld() As String, varvalue() As Variant)
' Given the gridnumber and the layerid and array of Value fields and an array of values are returned as a variants. Returns : FAILURE if fails

Fn GetGridMultValueByLayerNameAndGridN (db, LayerN$, gridObjectID As Long, varFld() As String, varvalue() As Variant)
' Given the gridobjectid and the layerid and array of Value fields and an array of values are etumed as a variants. This function is faster than GetGridMultValueByLayerIdAndGridObjID.

Function GetGridObjectLabel (db As Database, gridid As Integer, gridObjectID As Long, gridvalue As Variant) As Integer
' Retrieves the grid object label (i.e. Grid number)
' Returns: SUCCESS if the function was success

Fn GetGridValueByLayerIDAndGridNumber (db, layerid, gridNumber, varFld, varvalue)
' Given the gridnumber, the layerid and the name of the value field the value is returned as a variant. The default is "Value". Returns : the value of the grid cell from the correct database, as a variant

Fn GetGridValueByLayerNameAndGridObjID (db As Database, LayerName As String, gridObjID As Long, varFld As String, varval)
' Given the gridobjectid, the layername and the name of the value field the value is returned as a variant. The default "Value". This function is faster than GetGridValueByLayerIdAndGridObjID.
' Returns : the value of the grid cell from the DB

Function GetLayerObjectFirstPnt (db, layerid As Integer, objectID As Long, pnt)
'This function returns first point of a given object.

Function GetLayerObject (db, lyrid, objID, PnAr, NumVer, objType, LvlArray, VerArr(), numpol)
' Given the open layer database, the layerid and the object this function will return the points, object type of the given object. Returns: If the object does not exists a value of -1 is returned.

Function GetLayerObjectChar (db, layerid, vrfld, multindex, varvalue, fillpattern, pointsz%)
' Retrieves the layer object characteristics based on Value field selected and a value The condition is greater than or equal to the value passed in. This function will work for both polygonal layers and grid layers since the structure of the Characteristic table is the same. Returns: SUCCESS

Function GetLayerObjectMultValue (db, layerid As Integer, objectID As Long, varFld(), varval)
' Retrieves the layer object values. Returns as many of the object's values as requested. Returns: SUCCESS if the function was success

Function GetLayerObjectValue (db, layerid As Integer, objID, varFld As String, varval)
' Retrieves the layer object value. Only one value is returned, if the field is not specified then then default is 'Value'. Returns: SUCCESS

Function GetObjectType (db, layerid, objectID&, objectType, numvert, Caption, numpolys)
' Returns the all data in the type table associated with an object. Return the objecttype or ERROR

Function GetParents (db As Database, layerid%, objectID&, PLayerID() As Integer, PObjID)
'This function returns a given objects parents. Objects can at most have two parents.
'PLayerID and PObjID are the arrays returned.

Function GetUTMData (db As Database, layerid As Integer, zone As Long, datum As Long)
' Retrieves the layer's or grid's UTM data
' Returns: SUCCESS if the function was success

Function GridCell (db As Database, gridTbl As String, X As Double, y As Double) As Long
' Given the (x,y) point - Returns: the grid cell number that the point is inside.

Function gridObjectID (db As Database, gridTbl As String, X As Double, y As Double)
' Given the (x,y) point - Returns: the grid object ID that the point is inside.

Function GridStatus (db As Database, layerid%)
'This returns the grid status of a given layer:
' GRIDTABLE - a grid
' GRIDLAYER - a layer associated with a grid
' LAYERTABLE - a layer is not associated with grid

Function HALL2VBDblArrS (pntArr, nvert, sArr)
' Converts huge array to visual basic double array

Function LayerName (db, ByVal layerid)
' Given the layerid - Returns name of the layer.

Function LayerTableID (db, tbl As String)
' Given the layer name - Returns: the layer id

Function NextGridNumber (db, gridid)
' Returns: the next unique grid number.

Function NextUniqueID (db, layerid As Integer)
' Given the layer - Returns: the next available id.

Function RemoveGridCellNumber (db As Database, gridid As Integer, gridNumber)
' Removes grid cell number from the grid table, and renumbers the grid cells greater than it.

Function RotatePoint (oX As Double, oY As Double, X As Double, y As Double, angle)
' Given the origin point (oX, oY), and the point to be rotated (x, y), this rotates the point an angle about the origin. The result is back into the point (x, y).

Function StringToVar (sampleVar, convString$)
' Ttake variant as string and convert to data type.

Function SubdivideCell (db, gridid, gridNumber)
' Subdivides a grid cell into four separate cells.

Function VB2CFileNameString$ (fileName$)
' Convert VB to C file name string for external use

Function VBArrToHugeArr (X() As lyrPntType, y)
' Convert VB to huge array to pass between dlls

Program Name: InterAGN
Module: MAIN.BAS

Function ConvertGeotoUTM (originLat#, originLon#, datum&, zone&, Gn#, Ge#)
' This converts the geographic lat/lon to UTM

Function ConvertUTMtoGeo (Gn#, Ge#, datum&, zone&, originLat#, originLon#)
' This converts the geographic UTM to lat/lon

Function CopyLayersChar (db As Database, thelayername$, newdb, newlayername$)
' This copies the characteristics table from one layer

Function CreateCopyGrid (db As Database, layername$, newlayername$) As Integer
' Create structure and copy old to new grid

Function CreateCopyLayer (db, layername$, newdb, newdbname$, newlayername$, flds)
' Creates a copy of a layer into a new one.

Sub FillPolyData (dbGridName$, gridName$, dbTableName$, tableName$, Forma$)
' Main procedure for extracting layer values
' Resets percent counter...

Function NarrowRegionLayer (dbname$, newdatabase%, minx#, miny#, maxx#, maxy#)
' Narrows the region of interest to a bounded box

Program Name: InterAGN
Module: DEMLIB-A.BAS

Sub DoAGNPSFillData (GridDb, GridlayerID%, DEMdb As Database, DEMLayerID%)
'Get records for percent counting...
'   Call DoAGNPSFillFlowDirection()
'   Call DoAGNPSFillSlope()
'   Call DoAGNPSReceivingCell

Sub DoAGNPSFillFlowDirection (GridDb, GrdlyrID, DEMdb, DEMLayerID%, gAng#)
' Find delta from DEM file:
'   Call FindDeltaFromDem()
'   FlowDir = FindGridFlowDirection()

Sub DoAGNPSFillSlope (GridDb, GridlayerID, DEMdb, DEMLayerID%, zone&, datum&)
' For river elevation update...Verifies if field exists
' Find the length of the grid
' Find our bounding rectangle
' Create snapshot of elements in bound rectangle
'   Slope = FindGridSlope()
' Write River Elevation using variable: elevation

Sub DoAGNPSReceivingCell (db As Database, GridlayerID%)
' Calculate receiving cell using flow direction value
'   Call GetFlowArrow()
'   Call PointForRecievingCell(x1, y1, x2, y2, tx, ty)

Function FindAngle# (x1#, y1#, x2#, y2#)
' This finds an angle where the +x axis is zero
' and the angle rotates counter-clockwise

Function FindBoundingRectangle# (vbArr#(), nVert&, minx#, miny#, maxx#, maxy#)
' Finds bounding rectangle por a given polygon

Sub FindDeltaFromDem (DEMdb, DeltaValue#)
' Finds the delta value from the DEM file

Function FindDEMsInGrid (Db, StrlayerID, StrobjectID, DEMdb, DEMLayerID, DEMs() As DEMType As Snapshot, vbSObjArr(), snVert)
' Finds DEM elements inside a grid cell

Function FindGridFlowDirection (db, GridId, gridObjectID&, DEMdb, DEMID, gAng, delta)
' Delta is the degree distance that the point must be within the line. Finds flow direction by assigning dominant direction of DEM

Function FindGridSlope# (db, GridlayerID, gridObjectID, DEMdb, DEMID, length, elevat#, demTbl As Snapshot, vbObjArr(), nVert)
' Length is the length of the grid cell
' Find Highest DEM elevation
' Find Lowest DEM elevation
' Calculates and returns slope value

Sub GetDEMValues (db As Database, DEMs)
' Get Elevation value from DEM layer

Sub GetFlowArrow (db As Database, pt As Table, layerID As Integer, objectID As Long, FlowDir As Integer, x1#, y1#, x2#, y2#, plyg() As layerPointType)
' Get flow direction according to DEM direction

Sub PointForRecievingCell (x1#, y1#, x2#, y2#, X#, y#) As Integer
' Calculate point for receiving cell.

FORTRAN Code for the Water Quality Component

READWQD SUBROUTINE

```
c*******************************************************************
    SUBROUTINE readwqd
C*******************************************************************
C
C THIS SUBROUTINE READS IN THE WATER QUALITY DATA FILE
C LFLV - Oct/98

    include 'area1.for'
    include 'area2.for'
    include 'area3.for'
    include 'area111.for'

C Open and read *.wqd file (*=file name, .wqd=water quality data)
    open(unit=70 ,file='basin/duff.wqd' ,status='old',err=99000)

C SEDIMENT DATA...
    read(70,*)
    read(70,*)gamma,ro,viskin,grav,A,B
    read(70,*)(GC(i),i=1,ntype+1)
    read(70,*)(CF(i),i=1,ntype+1)

C    Particle size - d50
    read(70,*)
    do 10 i=imax,1,-1
      read(70,*)(diam(i,j),j=1,jmax)
  10 continue

C    Specific weight - spg
    read(70,*)
    do 20 i=imax,1,-1
      read(70,*)(spew(i,j),j=1,jmax)
  20 continue

C    Erodibility - Erod
    read(70,*)
    do 30 i=imax,1,-1
      read(70,*)(erodi(i,j),j=1,jmax)
  30 continue

C    Put into vector format
    do 50 n=1,naa
      i=yy(n)
      j=xx(n)
      D50(n)=diam(i,j)
      spg(n)=spew(i,j)
      Erod(n)=erodi(i,j)
  50 continue

C NUTRIENT DATA...
    read(70,*)
    read(70,*)Ncm,Ndec,Pdec
    read(70,*)Nscn,Ncpw,Nrec,Nlec
    read(70,*)Pscn,Pcpw,Prec,Plec
```

```
C    Fertilizer Application
     read(70,*)
     read(70,*)NoFer
     do 60 l=1,NoFer
       read(70,*)i,j,mNfer(i,j),mPfer(i,j),mNfa(i,j),mPfa(i,j)
  60 continue

C    Put into vector format
     do 70 n=1,naa
       i=yy(n)
       j=xx(n)
       Nfer(n)=mNfer(i,j)
       Pfer(n)=mPfer(i,j)
       Nfa(n)=mNfa(i,j)
       Pfa(n)=mPfa(i,j)
  70 continue

     return

C    Water Quality Data file not found:
99000 write(*,*)' Error opening or reading WQD file - File not found'
     pause 'Abnormal ending in SPL #1 - hit any key to continue'
     stop

     END
```

FORTRAN Code for the Water Quality Component (Cont.)

SEDIMENT SUBROUTINE

```
C*  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
   SUBROUTINE SED(JAN,AL)
C ******************************************************************
C Modified: May/97 - Luis Leon
C      THIS SUBROUTINE CALCULATES THE SEDIMENT CONCENTRATION
C      FOR EACH ELEMENT OF THE WATERSHED,Y(N,II)
    include 'AREA1.FOR'
    include 'AREA3.FOR'
    include 'AREA4.FOR'
    include 'AREA6.FOR'
    include 'AREAsed.FOR'
    common/area111/gamma,ro,viskin,grav,A,B,D50(99),spg(99)
   *Erod(99),Erf(99),Y(99,5),Kf(5),GC(5),CF(5)
C ****** EQUATIONS REFERENCES AND UNITS FROM:
C     HARTLEY, D.M. 1987. "SIMPLIFIED PROCESS MODEL FOR WATER
C        SEDIMENT YIELD FROM SINGLE STORMS. PART I - MODEL
C        FORMULATION" IN TRANSACTIONS OF THE ASAE 30(3):710-717.
C    NAA = NUMBER OF "N" ELEMENTS
C    NTYPE = TOTAL NUMBER OF "II" LAND CLASSES
C    gamma = SPECIFIC WEIGHT OF WATER [kg/m2/s2]
C    ro = DENSITY OF THE FLUID [kg/m3]
C    viskin = KINEMATIVE VISCOSITY [m2/s]
C    grav = STANDARD ACCELERATION [m/s2]
C    A,B = EMPIRICAL CONSTANTS USED IN TRANSPORT CAPACITY FORMULA
C    Kf(II) = OVERLAND FLOW RESISTANCE [-]
C    GC(II) = GROUND COVER IN PERCENT
C    CF(II) = COVER FACTOR IN PERCENT - DETERMINED BY FIG. 5.(HARTLEY)
C    Erod(N) = SOIL ERODIBILITY D [g/J]
C    D50(N) = AVERAGE D50 OF THE DETACHED SEDIMENT [mm] (LOOKUP TABLE)
C    spg(N) = SPECIFIC GRAVITY OF DETACHED SEDIMENT [-] (LOOKUP TABLE)
C    REY = SHIELD'S CRITERION REYNOLD'S NUMBER [-]
C    phi = SHIELD'S PARMETER [-]
C    slope(N) = SQRT OF CHANNEL SLOPE
C    sl1(N) = SQRT OF OVERLAND SLOPE
C    al = LENGTH OF ELEMENT [m]
C    frac(N) = FRACTION OF ELEMENT WITHIN THE BASIN
C    aclass(N,II) = FRACTION OF CLASS II IN N
C    D1 = DEPTH OF WATER [mm]
C    DS = depression storage [mm]
C    HSED(N,II) = d1-ds, RUNOFF DEPTH [mm]
C    QL(N,II) = OVERLAND FLOW [m2/hr]
C    FLOW_SHEAR = FLOW SHEAR STRESS [Units of gamma * mm]
C    CRIT_SHEAR = CRITICAL SHEAR [Units of gamma * mm]
C    C_val = VOLUMETRIC SEDIMENT CONCENTRATION [-]
C    Y_crit = SEDIMENT TRANSPORT CAPACITY [kg/m2]
C    Coef_Cover = COEFFICIENT GROUP FOR EQ.44
C    Erf = RATE OF RAINFALL ENERGY [J/m2/hr]
C    Ero = RATE OF RUNOFF ENERGY [J/m2/hr]
C    Grf = RAINFALL SOIL DETACHMENT [Kg/m2/hr]
C    Gro = RUNOFF SOIL DETACHMENT [Kg/m2/hr]
C    Y_pot = POTENTIAL SEDIMENT SUPPLY/YIELD [kg/m2]
C    Y(N,II) = MININUM OF Y_pot AND Y_crit [kg/m2]
C    Yrot(N) = TOTAL YIELD FROM ALL CLASSES FOR ROUTING [Kg/m3]
```

```
C ****** Initialize Values ********************
      if(jan.eq.1)then
      close (unit=41)
        open(unit=41,file='basin\sed.par',status='unknown',err=9998)
        read(41,4100,err=9999)(GC(i),i=1,NTYPE)
        read(41,4100,err=9999)(CF(i),i=1,NTYPE)
        read(41,4100,err=9999)gamma,ro,viskin,grav,A,B
C *Note: Temporal - Assume constants for now and change to (N) later
        read(41,4100,err=9999)d50t,spgt,erodt
        close(unit=41)
        DO 40 II = 1,NTYPE
C                Equation 16 (for each landclass)
          Kf(II) = 60.0 + 3140.*GC(II)**1.65
 40     CONTINUE
      endif
C ****** Initialize Sediment Yields *************
      DO 50 N = 1,NAA
C *Note: Temporal assignment of constants values - read later
        D50(N) = d50t
        spg(N) = spgt
        Erod(N) = erodt
        Yrot(N) = 0.0
        do 50 II = 1,NTYPE
          Y(N,II) =0.0
  50  CONTINUE
C ****** Calculate Rainfall Energy *************
      DO 60 N = 1,NAA
      I=YY(N)
       J=XX(N)
        IF (P(I,J).LE.0.0) THEN
          Erf(N) = 0.0
        ELSE
C           Eq43 [J/m2/hr] (for time step = 1hr, P=rain intensity
C               If not then divide P by time step)
          Erf(N)=P(I,J)*(11.9+8.7*LOG10(P(I,J)))
        ENDIF
  60  CONTINUE
C ****** FOR EACH ELEMENT ***********************
      DO 120 N = 1,NAA
       IF(slope(N).GT.0.0) THEN
        I=YY(N)
        J=XX(N)
        I3=IBN(N)
        IF(NTYPE.LE.0)THEN
C          if ntype =0 then program runs in the lumped mode
          II1=IBN(N)
          II2=IBN(N)
        ELSE
C          parameters grouped by land cover/use
          II1=1
          II2=NTYPE
        ENDIF
C ****** FOR EACH LAND CLASS TYPE ***************
      DO 110 II=1,NTYPE
C *Note: Probable change of QS [m3/s] to QL [m2/hr]
        IF ((QS(N,II).GT.0.0).and.(HSED(N,II).gt.0.0)) THEN
```

```
C * * * * Calculate the Sediment Tranport Capacity
C         Eq27 [gamma * mm] gamma cancels in Eq21 : 5/8 is beta/beta+1
          FLOW_SHEAR = (5*60/8*Kf(II)) * HSED(N,II) * sl1(N)
C         Eq29 [-] including grav because shear has no gamma
          REY = ((FLOW_SHEAR*grav/1000)**0.5) * D50(N)/viskin
C         From equation of Shields Diagram
          phi = (0.11/REY) + 0.021*LOG10(REY)
C         Eq20 [gamma * mm] gamma cancels in Eq21
          CRIT_SHEAR = (spg(N)-1) * phi * D50(N)
C         Eq21 [-] for volumetric concentration
          C_val = A * (FLOW_SHEAR/CRIT_SHEAR)**B
C         Eq42 [kg/m2] to compare with potential yield
          Y_crit = 2.65 * ro * C_val * rf(N,II)/1000

C * * * * Calculate the Sediment Supply
C         Eq44 [kg/m2/hr] divide by 1000 to convert g to kg
          Coef_Cover = (1-GC(II)) * CF(II)
          Grf = (Erf(N) * Coef_Cover * Erod(N)) / 1000
C         Eq45 [J/m2/hr] Warning! the constant 60 has units
          Ero = (60/Kf(II)) * gamma * (QL(N,II)/2) * sl1(N)
C         Eq46 [kg/m2/hr] divide by 1000 to convert g to kg
          Gro = (Ero * Erod(N)) / 1000
C         Eq47 [kg/m2] Only if time step is 1 hr
          Y_pot = (Grf + Gro)

C * * * * Calculate the Sediment Yield
C         Compare capacity with supply and choose minimum
          Y(N,II) = MIN(Y_crit,Y_pot)
C         Class weighted and converted to [kg/m3] * (A/Qt)
          Y(N,II) = Y(N,II) * frac(N) * aclass(N,II) *
     *    (al*al/(QS(N,II)*3600))
C         Add for all classes to sediment supply per cell
          Yrot(N) = Yrot(N) + Y(N,II)
      ENDIF
110     CONTINUE
      ENDIF
120   CONTINUE

C             * * * END OF MAIN LOOP * * *
C  Yrot(N)=TOTAL SEDIMENT INFLOW FROM ELEMENT (N) should be in [kg/m3]
C         AND IS ROUTED INTO THE DOWNSTREAM ELEMENT.

4100  format(5f10.6)
4101  format(5f12.6)
      return
9998  write(*,6227)'basin\sed.par'
6227  format(' sed: error on unit=41 fln=basin\sed.par',a30/
     *' probable cause: file not found')
      stop
9999  write(*,6229)'basin\sed.par'
6229  format(' sed: read error on unit=41 fln=basin\sed.par',a30/
     *' probable cause: format error, no data, or end of file')
      stop
      END
```

FORTRAN Code for the Water Quality Component (Cont.)

NUTRIENTS SUBROUTINE

```
C************************************
   SUBROUTINE NUT(JAN,AL)
C *******************************************************************
C Created Jul/98 - Luis Leon
C        THIS SUBROUTINE CALCULATES THE NUTRIENT CONCENTRATIONS
C        FOR EACH ELEMENT OF THE WATERSHED: Cron(N,II), Crop(N,II)
    include 'AREA1.FOR'
    include 'AREA3.FOR'
    include 'AREA4.FOR'
    include 'AREA6.FOR'
    include 'AREAsed.FOR'
    common/area111/Ncm,Ndec,Pcec,Nscn,Ncpw,Nrec,Nlec,Pscn,Pcpw,Prec,Plec
    *NoFer,Nfer(99),Nfa(99),Pfer(99),Pfa(99),Cron(99,5),Crop(99,5)
C ***** EQUATIONS, REFERENCES AND UNITS FROM THE CREAMS MODEL:
C     Frere et.al. (1980) The Nutrient Submodel. In: Knisel, W.G.
C          CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion
C          from Agricultural Management Systems, USDA, Rep No. 26
C     Young e.al. (1986) Agricultural Nonpoint source Pollution Model:
C          A Watershed Analysis Tool, Model Documentation, USDA.
C [General]
C     NAA = Number of "N" elements
C     NTYPE = Total number of "II" land classes
C     Ieff = Effective Infiltration for the Storm [mm] - WatFlood Value F(N,II)??
C     Roff = Total Runoff for the Storm [mm] - WatFlood Value HSED(N,II) = (D1-DS)
C     Fpor = Porosity Factor [-]
C     Peff = Effective Precipitation [mm]
C     Por =  Soil Porosity [-]
C     spg(N) =  Soil Specific Weight [-]
C     P(I,J) = Storm Precipitation for the time step [mm] - WatFlood Value
C     ER = Nuetrient Enrichment Ratio
C     Ysed = Total Sediment Yield [kg/ha]
C     NoFer = Number of Cells with Fertilizer Application
C [Nitrogen]
C     Cron(N,II) = Soluble Nitrogen Concentration in the Runoff [kg/ha]
C     Cron_rot(N) = Nitrogen Concentration all Classes for Routing [kg/ha]
C     Navs = Available Nitrogen in the Surface [kg/ha]
C     Navr = Available Nitrogen due to Rainfall [kg/ha]
C     Ndmv = Rate for Downward Movement of Nitrogen into the Soil [1/mm]
C     Nrmv = Rate for Nitrogen Movement into the Runoff [1/mm]
C     Nrnc = Nitrogen Contribution due to Rain [kg/ha]
C     Soln = Soluble Nitrogen in the Surface CM of the Soil [kg/ha]
C     Nfer(N) = Nitrogen Fertilizer Application [kg/ha] - Input Data
C     Nfa(N)  = Fraction of Nitrogen Availability [%/100] - Input Data
C     Ncpw = Nitrogen Concentration in Pore Water [ppm] - Input Data
C     Ncm = Nitrogen Concentration in Rainfall [ppm] - Input Data
C     Nlec = Nitrogen Leaching Extraction Coefficient - Input Data
C     Nrec = Nitrogen Runoff Extraction Coefficient - Input Data
C     Ndec = Nitrogen Decay Fraction [%]
C     Nsed = Overland Nitrogen Transported by Sediment [kg/ha]
C     Nscn = Soil Nitrogen Concentration [g N/g soil] - Input Data
C [Phosphorus]
C     Crop(N,II) = Soluble Phosphorus Concentration in the Runoff [kg/ha]
C     Crop_rot(N) = Phosphorus Concentration all Classes for Routing [kg/ha]
C     Pavs = Available Phosphorus in the Surface [kg/ha]
```

```
C     Pavr = Available Phosphorus due to Residual in Soil [kg/ha]
C     Pdmv = Rate for Downward Movement of Phosphorus into the Soil [1/mm]
C     Prmv = Rate for Phosphorus Movement into the Runoff [1/mm]
C     Solp = Soluble Phosphorus in the Surface CM of the Soil [kg/ha]
C     Pfer(N) = Phosphorus Fertilizer Application [kg/ha] - Input Data
C     Pfa(N)  = Fraction of Phosphorus Availability [%/100] - Input Data
C     Pcpw = Phosphorus Concentration in Pore Water [ppm] - Input Data
C     Plec = Phosphorus Leaching Extraction Coefficient - Input Data
C     Prec = Phosphorus Runoff Extraction Coefficient - Input Data
C     Pdec = Phosphorus Decay Fraction [%]
C     Psed = Overland Phosphorus Transported by Sediment [kg/ha]
C     Pscn = Soil Phosphorus Concentration [g P/g soil] - Input Data

C ****** Initialize Values *******************
      DO 10 N = 1,NAA
       Cron_rot(N) = 0.0
       Crop_rot(N) = 0.0
       do 10 II = 1,NTYPE
          Cron(N,II) = 0.0
          Crop(N,II) = 0.0
   10 CONTINUE
C ****** Calculate Constants First **************
C     Calculate the Available Nitrogen due to Rainfall
      Navr = Ncm * 0.000001
C ****** FOR EACH ELEMENT **********************
      DO 20 N = 1,NAA
      I=YY(N)
      J=XX(N)
        IF (P(I,J).GT.0.0) THEN
C * * * *     Calculate Soil Porosity and Porosity Factor:
            Por = 1 - (spg(N)/2.65)
            Fpor = 0.00001/Por
C * * * *     Calculate Nutrients Movement Rates:
            Ndmv = Nlec / (10*Por)
            Nrmv = Nrec / (10*Por)
            Pdmv = Plec / (10*Por)
            Prmv = Prec / (10*Por)
C * * * *     Calculate Soluble Nutrients in Top cm of Soil:
            Soln = 0.10 * Ncpw * Por
            Solp = 0.10 * Pcpw * Por
C * * * *     Calculate Available Phosphorus due to Soil Residual:
            Pavr = Solp * Fpor
C * * * *     Calculate Nitrogen Contribution due to Rainfall:
            Nrnc = Ncm * P(I,J)
C * * * *     Calculate the Effective Precipitation in the top cm:
            Peff = P(I,J) - (10 * Por)
C * * * *     Calculate the Available Nutrients in the Surface:
            Nfa = Nfa / 100
            Navs = (Soln + (Nfer(N) * Nfa(N))) * Fpor
            Pfa = Pfa / 100
            Pavs = (Solp + (Pfer(N) * Pfa(N))) * Fpor
C ****** FOR EACH LAND CLASS TYPE ***************
      DO 30 II=1,NTYPE
        IF ((HSED(N,II).gt.0.0)) THEN
C * * * *     Calculate the Nitrogen Concentration in Runoff
            NTerm1 = (Navs - Navr) / Fpor
            NTermexp1 = exp(-Ndmv * F(N,II))
            NTermexp2 = exp(-Ndmv * F(N,II) - Nrmv * HSED(N,II))
```

```
          NTerm2 = NTermexp1 - NTermexp2
          NTerm3 = Nmc * HSED(N,II) / Peff
          Cron(N,II) = (NTerm1 * NTerm2) + NTerm3
C ****     Calculate the Phosphorus Concentration in Runoff
          PTerm1 = (Pavs - Pavr) / Fpor
          PTermexp1 = exp(-Pdmv * F(N,II))
          PTermexp2 = exp(-Pdmv * F(N,II) - Prmv * HSED(N,II))
          PTerm2 = PTermexp1 - PTermexp2
          PTerm3 = Pavr * Prmv * HSED(N,II) / Fpor
          Crop(N,II) = (PTerm1 * PTerm2) + PTerm3
C ****     Class weighted by fractions of landclass
          Cron(N,II) = Cron(N,II) * frac(N) * aclass(N,II)
          Crop(N,II) = Crop(N,II) * frac(N) * aclass(N,II)
C ****     Add for all classes to nutrient concentration per cell
          Cron_rot(N) = Cron_rot(N) + Cron(N,II)
          Crop_rot(N) = Crop_rot(N) + Crop(N,II)

      ENDIF
30   CONTINUE
      ENDIF
20   CONTINUE

C          *** END OF MAIN LOOP ***
C  Cron_rot(N) and Crop_rot(N)=TOTAL NUTRIENTS INFLOW FROM ELEMENT (N)
C         AND ARE ROUTED INTO THE DOWNSTREAM ELEMENT.

4100  format(5f10.6)
4101  format(5f12.6)
     return

9998  write(*,6227)'basin\sed.par'
6227  format(' sed: error on unit=41 fln=basin\sed.par',a30/
    *' probable cause: file not found')
     stop

9999  write(*,6229)'basin\sed.par'
6229  format(' sed: read error on unit=41 fln=basin\sed.par',a30/
    *' probable cause: format error, no data, or end of file')
     stop

    END
```

APPENDIX H. ASCII Input Files for AGNPS and WATFLOOD

This section includes the full ASCII input files for the 2x2km grid in Duffins Creek for both AGNPS and WATFLOOD models. These files were exported from the database of the grids for each project and are presented here as an example of the interaction between the interfaces and the models. Both files are for the same area in Duffins Creek as presented in Chapter 5 under the hydrology comparison. The data files where used as the base for rainfall modifications in order to calculate the hydrographs and peak flows compared in the mentioned section.

The files are:

For AGNPS:

File: SNTAgDf92b.mdb	*Grid: 2x2 km*	*ASCII: SNT_Ag2x2.dat*

For WATFLOOD:

File: SNTWDfbasU.mdb	*Grid: 2x2 km*	*ASCII: SNT_Wf2x2.map*
File: SNTWDfbasU.mdb	*Grid: 2x2 km*	*ASCII: SNT_Wf2x2wqd*

ASCII file for AGNPS

File: SNTAgDf92b.mdb *Grid: 2x2 km* *ASCII: SNT_Ag2x2.dat*

```
AGNPS SCS-TR55 format 5.00
     0       0       0       0       0       0       0       0
Duffins (2x2km)
1992 Landuse
   1406.00      57      57       1       1       0   37.50
        II    2.13    18.0    0.65    1.00
     1   000       5     000       5   85.00     2.9       1
        150   0.208    0.37  0.1213    1.00    0.17      67
          2       1       0       0       0       0       7
Soil:  0.0010  0.0005    5.00    2.00
       0.050   0.025   0.250   0.250      20
Fert:     50      20      50      50
Channel:  0.00  3.4250  0.3151    0.00  0.4537  0.2192
          0.00 153.000  0.6000    1.45   10.00
         0.040       0      50      50      50
             1       1       1       1       1
     2     000       6     000       5   86.00     2.8       1
           150   0.202    0.36  0.1750    1.00    0.16      78
             2       1       0       0       0       0       7
Soil:   0.0010  0.0005    5.00    2.00
         0.050   0.025   0.250   0.250      20
Fert:       50      20      50      50
Channel:  0.00  3.4250  0.3151    0.00  0.4537  0.2192
          0.00 153.000  0.6000    1.41   10.00
         0.040       0      50      50      50
             1       1       1       1       1
     3     000       7     000       5   81.00     1.8       1
           150   0.341    0.32  0.1232    1.00    0.24      81
             2       1       0       0       0       0       7
Soil:   0.0010  0.0005    5.00    2.00
         0.050   0.025   0.250   0.250      20
Fert:       50      20      50      50
Channel:  0.00  3.4250  0.3151    0.00  0.4537  0.2192
          0.00 153.000  0.6000    0.88   10.00
         0.040       0      50      50      50
             1       1       1       1       1
     4     000       8     000       5   82.00     1.2       1
           150   0.281    0.26  0.1461    1.00    0.22      84
             1       1       0       0       0       0       7
Soil:   0.0010  0.0005    5.00    2.00
         0.050   0.025   0.250   0.250      20
Fert:       50      20      50      50
Channel:  0.00  3.4250  0.3151    0.00  0.4537  0.2192
          0.00 153.000  0.6000    0.61   10.00
         0.040       0      50      50      50
             1       1       1       1       1
     5     000      11     000       5   86.00     2.1       1
           150   0.200    0.33  0.1491    1.00    0.17      75
             2       1       0       0       0       0       7
Soil:   0.0010  0.0005    5.00    2.00
         0.050   0.025   0.250   0.250      20
Fert:       50      20      50      50
Channel:  0.00  3.4250  0.3151    0.00  0.4537  0.2192
          0.00 153.000  0.6000    1.07   10.00
         0.040       0      50      50      50
             1       1       1       1       1
     6     000      12     000       5   83.00     1.5       1
           150   0.259    0.34  0.2108    1.00    0.21     100
             2       3       0       0       0       0       7
Soil:   0.0010  0.0005    5.00    2.00
         0.050   0.025   0.250   0.250      20
Fert:      200      80      50      50
Channel:  0.00  3.4250  0.3151    0.00  0.4537  0.2192
          0.00 153.000  0.6000    0.73   10.00
         0.040       0      50      50      50
             1       1       1       1       1
     7     000      13     000       5   78.00     1.5       1
           150   0.486    0.23  0.0676    1.00    0.28      71
             1       1       0       0       0       0       7
Soil:   0.0010  0.0005    5.00    2.00
         0.050   0.025   0.250   0.250      20
Fert:       50      20      50      50
```

```
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    0.77   10.00
            0.040       0      50      50      50
                1       1       1       1       1
        8     000      14     000       5   81.00     2.5        1
              150   0.355    0.21  0.1640    1.00    0.25       94
                1       1       0       0       0       0        7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:          50      20      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    1.25   10.00
            0.040       0      50      50      50
                1       1       1       1       1
        9     000      15     000       5   82.00     1.4        1
              150   0.388    0.19  0.0986    1.00    0.21       68
                1       1       0       0       0       0        7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:          50      20      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    0.68   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       10     000      16     000       5   59.00     2.0        1
              150   0.426    0.16  0.0932    1.00    0.25       72
                1       0       0       0       0       0        7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    0.98   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       11     000      18     000       5   89.00     1.5        1
              150   0.132    0.34  0.2517    1.00    0.14       99
                2       3       0       0       0       0        7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:         200      80      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    0.75   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       12     000      19     000       5   86.00     1.4        1
              150   0.148    0.30  0.2717    1.00    0.18      113
                2       3       0       0       0       0        7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:         200      80      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    0.68   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       13     000      20     000       5   89.00     2.0        1
              150   0.267    0.24  0.2574    1.00    0.21      113
                3       3       0       0       0       0        7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:         200      80      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    0.98   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       14     000      21     000       5   81.00     2.9        1
              150   0.269    0.32  0.1441    1.00    0.23       85
                2       3       0       0       0       0        7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:         200      80      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    1.45   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       15     000      22     000       5   81.00     2.1        1
              150   0.290    0.30  0.0961    1.00    0.24       73
                1       3       0       0       0       0        7
```

```
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:         200      80      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    1.04   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       16     000      22     000       6   79.00     2.1       1
              150   0.396    0.27  0.0812    1.00    0.25      69
                1       1       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:          50      20      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    1.07   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       17     000      24     000       5   76.00     2.5       1
              150   0.513    0.27  0.0481    1.00    0.29      67
                1       0       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    1.23   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       18     000      19     000       3   84.00     1.4       1
              150   0.214    0.31  0.2438    1.00    0.19     106
                1       1       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:          50      20      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    0.68   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       19     000      27     000       5   84.00     1.2       1
              150   0.205    0.31  0.2318    1.00    0.20     105
                2       3       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:         200      80      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    0.61   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       20     000      28     000       5   89.00     1.2       1
              150   0.278    0.23  0.2010    1.00    0.22      99
                3       3       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:         200      80      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    0.61   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       21     000      30     000       4   89.00     1.4       1
              150   0.221    0.25  0.2035    1.00    0.21      99
                3       3       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:         200      80      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    0.68   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       22     000      30     000       5   83.00     2.1       1
              150   0.256    0.33  0.1767    1.00    0.22      92
                2       3       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:         200      80      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    1.07   10.00
            0.040       0      50      50      50
                1       1       1       1       1
```

23	000	31	000	5	78.00	4.5	1
	150	0.428	0.27	0.0616	1.00	0.27	68
	1	1	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Fert:	50	20	50	50			
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	2.25	10.00		
	0.040	0	50	50	50		
	1	1	1	1	1		
24	000	32	000	5	77.00	5.4	1
	150	0.469	0.25	0.0493	1.00	0.28	65
	1	0	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	2.70	10.00		
	0.040	0	50	50	50		
	1	1	1	1	1		
25	000	32	000	6	78.00	4.6	1
	150	0.435	0.23	0.0906	1.00	0.28	77
	1	0	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	2.29	10.00		
	0.040	0	50	50	50		
	1	1	1	1	1		
26	000	34	000	4	86.00	1.2	1
	150	0.169	0.32	0.3184	1.00	0.18	126
	2	1	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Fert:	50	20	50	50			
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	0.61	10.00		
	0.040	0	50	50	50		
	1	1	1	1	1		
27	000	34	000	5	86.00	1.7	1
	150	0.163	0.33	0.3405	1.00	0.18	131
	2	3	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Fert:	200	80	50	50			
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	0.84	10.00		
	0.040	0	50	50	50		
	1	1	1	1	1		
28	000	34	000	6	85.00	1.4	1
	150	0.199	0.27	0.3148	1.00	0.19	126
	3	3	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Fert:	200	80	50	50			
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	0.68	10.00		
	0.040	0	50	50	50		
	1	1	1	1	1		
29	000	37	000	4	86.00	1.0	1
	150	0.146	0.33	0.3727	1.00	0.17	138
	2	3	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Fert:	200	80	50	50			
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	0.52	10.00'		
	0.040	0	50	50	50		
	1	1	1	1	1		
30	000	38	000	4	83.00	1.9	1
	150	0.271	0.34	0.2015	1.00	0.21	97
	2	3	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Fert:	200	80	50	50			
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	0.93	10.00		

	0.040	0	50	50	50		
	1	1	1	1	1		
31	000	38	000	5	81.00	3.2	1
	150	0.316	0.29	0.1823	1.00	0.24	96
	2	1	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Fert:	50	20	50	50			
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	1.59	10.00		
	0.040	0	50	50	50		
	1	1	1	1	1		
32	000	38	000	6	80.00	2.1	1
	150	0.373	0.21	0.1231	1.00	0.26	83
	1	1	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Fert:	50	20	50	50			
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	1.04	10.00		
	0.040	0	50	50	50		
	1	1	1	1	1		
33	000	32	000	7	84.00	4.0	1
	150	0.206	0.25	0.2525	1.00	0.20	111
	1	0	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	2.02	10.00		
	0.040	0	50	50	50		
	1	1	1	1	1		
34	000	39	000	5	83.00	1.0	1
	150	0.250	0.28	0.2028	1.00	0.22	98
	2	3	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Fert:	200	80	50	50			
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	0.50	10.00		
	0.040	0	50	50	50		
	1	1	1	1	1		
35	000	34	000	7	84.00	1.6	1
	150	0.188	0.35	0.2860	1.00	0.19	117
	2	3	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Fert:	200	80	50	50			
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	0.79	10.00		
	0.040	0	50	50	50		
	1	1	1	1	1		
36	000	42	000	4	83.00	1.9	1
	150	0.226	0.37	0.1709	1.00	0.21	88
	2	3	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Fert:	200	80	50	50			
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	0.95	10.00		
	0.040	0	50	50	50		
	1	1	1	1	1		
37	000	42	000	5	84.00	3.2	1
	150	0.204	0.36	0.2198	1.00	0.20	101
	2	3	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		
Fert:	200	80	50	50			
Channel:	0.00	3.4250	0.3151	0.00	0.4537	0.2192	
	0.00	153.000	0.6000	1.61	10.00		
	0.040	0	50	50	50		
	1	1	1	1	1		
38	000	43	000	5	81.00	2.7	1
	150	0.357	0.26	0.1121	1.00	0.24	77
	1	1	0	0	0	0	7
Soil:	0.0010	0.0005	5.00	2.00			
	0.050	0.025	0.250	0.250	20		

```
Fert:          50      20      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    1.34   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       39     000      44     000       4   84.00     1.4       1
              150   0.210    0.29  0.3073    1.00    0.20     124
                1       1       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:          50      20      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    0.68   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       40     000      44     000       5   84.00     2.3       1
              150   0.204    0.34  0.2611    1.00    0.20     112
                2       3       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:         200      80      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    1.13   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       41     000      45     000       5   83.00     2.3       1
              150   0.233    0.35  0.1802    1.00    0.21      89
                2       3       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:         200      80      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    1.16   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       42     000      47     000       4   84.00     2.5       1
              150   0.210    0.29  0.2820    1.00    0.20     117
                2       3       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:         200      80      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    1.27   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       43     000      47     000       5   80.00     1.8       1
              150   0.379    0.26  0.1409    1.00    0.26      88
                1       1       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:          50      20      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    0.91   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       44     000      49     000       4   80.00     2.4       1
              150   0.364    0.28  0.1430    1.00    0.25      87
                1       1       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:          50      20      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    1.20   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       45     000      50     000       4   80.00     3.3       1
              150   0.369    0.28  0.0863    1.00    0.25      70
                1       1       0       0       0       0       7
Soil:      0.0010  0.0005    5.00    2.00
            0.050   0.025   0.250   0.250      20
Fert:          50      20      50      50
Channel:     0.00  3.4250  0.3151    0.00  0.4537  0.2192
             0.00 153.000  0.6000    1.63   10.00
            0.040       0      50      50      50
                1       1       1       1       1
       46     000      50     000       5   78.00     1.8       1
```

```
              150    0.439     0.26  0.0615     1.00     0.27      67
                1        1        0       0        0        0       7
Soil:      0.0010   0.0005     5.00    2.00
            0.050    0.025    0.250   0.250       20
Fert:          50       20       50      50
Channel:     0.00   3.4250   0.3151    0.00   0.4537   0.2192
             0.00  153.000   0.6000    0.88    10.00
            0.040        0       50      50       50
                1        1        1       1        1
       47     000       51      000       5    77.00      2.6       1
              150    0.470     0.23  0.0793     1.00     0.28      75
                1        1        0       0        0        0       7
Soil:      0.0010   0.0005     5.00    2.00
            0.050    0.025    0.250   0.250       20
Fert:          50       20       50      50
Channel:     0.00   3.4250   0.3151    0.00   0.4537   0.2192
             0.00  153.000   0.6000    1.29    10.00
            0.040        0       50      50       50
                1        1        1       1        1
       48     000       52      000       5    80.00      2.3       1
              150    0.408     0.27  0.1241     1.00     0.25      82
                1        0        0       0        0        0       7
Soil:      0.0010   0.0005     5.00    2.00
            0.050    0.025    0.250   0.250       20
Channel:     0.00   3.4250   0.3151    0.00   0.4537   0.2192
             0.00  153.000   0.6000    1.13    10.00
            0.040        0       50      50       50
                1        1        1       1        1
       49     000       53      000       4    82.00      2.1       1
              150    0.382     0.25  0.0351     1.00     0.21      45
                1        0        0       0        0        0       7
Soil:      0.0010   0.0005     5.00    2.00
            0.050    0.025    0.250   0.250       20
Channel:     0.00   3.4250   0.3151    0.00   0.4537   0.2192
             0.00  153.000   0.6000    1.06    10.00
            0.040        0       50      50       50
                1        1        1       1        1
       50     000       53      000       5    84.00      1.6       1
              150    0.268     0.27  0.1010     1.00     0.20      67
                1        1        0       0        0        0       7
Soil:      0.0010   0.0005     5.00    2.00
            0.050    0.025    0.250   0.250       20
Fert:          50       20       50      50
Channel:     0.00   3.4250   0.3151    0.00   0.4537   0.2192
             0.00  153.000   0.6000    0.82    10.00
            0.040        0       50      50       50
                1        1        1       1        1
       51     000       50      000       7    88.00      0.5       1
              150    0.191     0.28  0.1336     1.00     0.15      68
                1        1        0       0        0        0       7
Soil:      0.0010   0.0005     5.00    2.00
            0.050    0.025    0.250   0.250       20
Fert:          50       20       50      50
Channel:     0.00   3.4250   0.3151    0.00   0.4537   0.2192
             0.00  153.000   0.6000    0.25    10.00
            0.040        0       50      50       50
                1        1        1       1        1
       52     000       54      000       6    88.00      0.7       1
              150    0.175     0.27  0.2043     1.00     0.15      87
                1        1        0       0        0        0       7
Soil:      0.0010   0.0005     5.00    2.00
            0.050    0.025    0.250   0.250       20
Fert:          50       20       50      50
Channel:     0.00   3.4250   0.3151    0.00   0.4537   0.2192
             0.00  153.000   0.6000    0.36    10.00
            0.040        0       50      50       50
                1        1        1       1        1
       53     000       54      000       3    91.00      0.9       1
              150    0.165     0.27  0.0663     1.00     0.10      41
                1        0        0       0        0        0       7
Soil:      0.0010   0.0005     5.00    2.00
            0.050    0.025    0.250   0.250       20
Channel:     0.00   3.4250   0.3151    0.00   0.4537   0.2192
             0.00  153.000   0.6000    0.43    10.00
            0.040        0       50      50       50
                1        1        1       1        1
```

```
      54      000      57     000        5   96.00     1.2       1
              150   0.051    0.29   0.0444    1.00    0.03      24
                3       0       0        0       0       0       7
Soil:      0.0010  0.0005    5.00     2.00
            0.050   0.025   0.250    0.250      20
Channel:     0.00  3.4250  0.3151     0.00  0.4537  0.2192
             0.00 153.000  0.6000     0.59   10.00
            0.040       0      50       50      50
                1       1       1        1       1
      55      000      54     000        7   93.00     0.0       1
              150   0.087    0.28   0.0980    1.00    0.08      46
                1       0       0        0       0       0       7
Soil:      0.0010  0.0005    5.00     2.00
            0.050   0.025   0.250    0.250      20
Channel:     0.00  3.4250  0.3151     0.00  0.4537  0.2192
             0.00 153.000  0.6000     0.00   10.00
            0.040       0      50       50      50
                1       1       1        1       1
      56      000      57     000        3   95.00     0.6       1
              150   0.111    0.30   0.0861    1.00    0.06      40
                3       0       0        0       0       0       7
Soil:      0.0010  0.0005    5.00     2.00
            0.050   0.025   0.250    0.250      20
Channel:     0.00  3.4250  0.3151     0.00  0.4537  0.2192
             0.00 153.000  0.6000     0.32   10.00
            0.040       0      50       50      50
                1       1       1        1       1
      57      000      58     000        5   90.00     0.7       1
              150   0.275    0.27   0.0877    1.00    0.10      50
                3       0       0        0       0       0       7
Soil:      0.0010  0.0005    5.00     2.00
            0.050   0.025   0.250    0.250      20
Channel:     0.00  3.4250  0.3151     0.00  0.4537  0.2192
             0.00 153.000  0.6000     0.36   10.00
            0.040       0      50       50      50
                1       1       1        1       1
```

ASCII file for WATFLOOD

File: SNTWDfbasU.mdb *Grid: 2x2 km* *ASCII: SNT_Wf2x2.map*

```
WATFLOOD MAP FILE:
    3     1     9   123     0
      2000  10.0     0     5   1.0
  4850 4878   636   658
 elevations
   0   0   0   0   0   0   0   0   0   0   0   0
   0   0 341 325 317 308 320 343 331   0   0   0
   0 320 300 297 295 302 313 317 292 268   0   0
   0 283 281 288 282 274 276 239 209 208   0   0
   0   0 263 266 245 243 242 239 189 188   0   0
   0   0 250 240 230 226 233 207 161 161   0   0
   0   0   0 229 223 217 230 217 153 145   0   0
   0   0   0 205 199 201 218 190 136 132 126   0
   0   0   0   0 183 182 202 173 139 109 115   0
   0   0   0   0 189 170 167 140 122  98 104   0
   0   0   0   0   0 169 146 116 104  89  96   0
   0   0   0   0   0   0   0   0  88  87  81   0
   0   0   0   0   0   0   0   0   0  74  73   0
   0   0   0   0   0   0   0   0   0   0  72  70
   0   0   0   0   0   0   0   0   0   0   0   0
 element areas
   0   0   0   0   0   0   0   0   0   0   0   0
   0   0  22  33  68 100  99  31  73   0   0   0
   0  42  99 100 100 100 100 100 100  99   0   0
   0  19 100 100 100 100 100 100 100  86   0   0
   0   0  99 100 100 100 100 100 100  72   0   0
   0   0  62 100 100 100 100 100 100  23   0   0
   0   0   0  76 100 100 100 100 100  57   0   0
   0   0   0  42 100 100 100 100 100  90  13   0
   0   0   0   0  94 100 100 100 100 100  83   0
   0   0   0   0  21  85 100 100 100 100 100   0
   0   0   0   0   0  26  70  99 100 100 100   0
   0   0   0   0   0   0   0   0  52 100 100   0
   0   0   0   0   0   0   0   0   0  34  99   0
   0   0   0   0   0   0   0   0   0   0  28   0
   0   0   0   0   0   0   0   0   0   0   0   0
drainage directions
0 0 0 0 0 0 0 0 0 0 0 0
0 0 4 4 4 4 4 4 4 0 0 0
0 4 4 4 4 4 4 4 4 4 0 0
0 3 4 4 4 4 3 3 3 4 0 0
0 0 3 4 3 4 4 2 4 4 0 0
0 0 3 2 4 4 2 2 4 4 0 0
0 0 0 4 4 5 5 2 3 4 0 0
0 0 0 3 3 4 4 3 3 4 5 0
0 0 0 0 3 3 4 3 3 4 4 0
0 0 0 0 2 3 2 4 4 4 4 0
0 0 0 0 0 2 2 2 2 3 4 0
0 0 0 0 0 0 0 0 2 2 4 0
0 0 0 0 0 0 0 0 0 2 4 0
0 0 0 0 0 0 0 0 0 0 2 0
0 0 0 0 0 0 0 0 0 0 0 0
basin number
0 0 0 0 0 0 0 0 0 0 0 0
0 0 1 1 1 1 1 1 1 0 0 0
0 1 1 1 1 1 1 1 1 1 0 0
0 1 1 1 1 1 1 1 1 1 0 0
0 0 1 1 1 1 1 1 1 1 0 0
0 0 1 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 1 0
0 0 0 0 1 1 1 1 1 1 1 0
0 0 0 0 1 1 1 1 1 1 1 0
0 0 0 0 0 1 1 1 1 1 1 0
0 0 0 0 0 0 0 0 0 1 1 1 0
0 0 0 0 0 0 0 0 0 0 1 1 0
0 0 0 0 0 0 0 0 0 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0
contour density
0 0 0 0 0 0 0 0 0 0 0 0
0 0 2 2 3 4 4 2 5 0 0 0
0 3 6 4 2 2 2 4 5 7 0 0
```

```
0 2 2 1 1 4 4 7 9 9 0 0
0 0 1 1 3 3 2 3 5 3 0 0
0 0 1 3 2 2 2 4 5 4 0 0
0 0 0 1 1 2 2 4 6 3 0 0
0 0 0 2 2 2 2 5 6 4 3 0
0 0 0 0 2 3 1 4 3 4 3 0
0 0 0 0 1 3 3 6 2 2 1 0
0 0 0 0 0 2 3 5 3 2 1 0
0 0 0 0 0 0 0 0 3 1 1 0
0 0 0 0 0 0 0 0 0 1 1 0
0 0 0 0 0 0 0 0 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0
number of channels
0 0 0 0 0 0 0 0 0 0 0 0
0 0 1 1 1 1 1 1 1 0 0 0
0 1 1 1 1 1 1 1 1 1 0 0
0 1 1 1 1 1 1 1 1 1 0 0
0 0 1 1 1 1 1 1 1 1 0 0
0 0 1 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 0 0
0 0 0 1 1 1 1 1 1 1 1 0
0 0 0 0 1 1 1 1 1 1 1 0
0 0 0 0 1 1 1 1 1 1 1 0
0 0 0 0 0 1 1 1 1 1 1 0
0 0 0 0 0 0 0 0 1 1 1 0
0 0 0 0 0 0 0 0 0 1 1 0
0 0 0 0 0 0 0 0 0 0 1 0
0 0 0 0 0 0 0 0 0 0 0 0
routing reach number
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0
Impervious
   0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    5    0    0    0    0    0    0    0
   0    5    4    0    0    0    0    0    0    0    0    0
   0    2   15    0    0    0    0    0    0    0    0    0
   0    0   40    8    0    0    6    2    1    0    0    0
   0    0   10    8    0    0    1    4    1    0    0    0
   0    0    0    3    0    0    0    0    9    0    0    0
   0    0    0    0    3    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    1    0
   0    0    0    0    0    0    0    0    2    2   20    0
   0    0    0    0    0    0    3    0    7   18   83    0
   0    0    0    0    0    0    0    0   16   60   89    0
   0    0    0    0    0    0    0    0    0    1   37    0
   0    0    0    0    0    0    0    0    0    0    5    0
   0    0    0    0    0    0    0    0    0    0    0    0
Bareground
   0    0    0    0    0    0    0    0    0    0    0    0
   0    0    3    0    0   11    4    0    0    0    0    0
   0    5   26    0    0    0    3    0    3    0    0    0
   0    0    4    0    0    2    0    0    2    0    0    0
   0    0    1    0    0    0    0    0    1    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    1    0    6    5    0    0    0
   0    0    0    0    0    0    0    0    1    0    1    0
   0    0    0    0    0    0    0    6   18    0    0    0
   0    0    0    0    0    0    0    0    1    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0
```

```
Forests
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   4  32  54  33  76  50  49   0   0   0
 0  12   9  67  47  59  40  79  93  62   0   0
 0   7  32  35  58  48  45  90  47  61   0   0
 0   0  27  16  38  44  31  41  60  25   0   0
 0   0  12  19  24  35  26  53  59  15   0   0
 0   0   0  23  31  21   9  30  42  27   0   0
 0   0   0  15  17  28  41  23  24  53   5   0
 0   0   0   0  33  22  19  46  39  87  50   0
 0   0   0   0   1  34  34  34  78  75  33   0
 0   0   0   0   0   1  35  66  63  41   4   0
 0   0   0   0   0   0   0   0  29  23   6   0
 0   0   0   0   0   0   0   0   0   0  17   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
Crops_LowVeg
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   5  38  43  46  18  20  12   0   0   0
 0  16  51  29  22  40  60  24   8  23   0   0
 0  11  52  70  47  51  56  23  35  31   0   0
 0   0  34  81  67  60  65  60  40  47   0   0
 0   0  42  73  80  68  76  45  41  11   0   0
 0   0   0  56  70  81  94  72  50  30   0   0
 0   0   0  28  84  74  62  82  79  44   9   0
 0   0   0   0  63  85  84  51  60  23  29   0
 0   0   0   0  15  52  69  68  22  27  43   0
 0   0   0   0   0  13  16  29  15  43  14   0
 0   0   0   0   0   0   0   0   2  14  10   0
 0   0   0   0   0   0   0   0   0   1  14   0
 0   0   0   0   0   0   0   0   0   0   4   0
 0   0   0   0   0   0   0   0   0   0   0   0
Wetlands
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   2   0   9   0   0   0   0   0   0
 0   1   6   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   1   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   1   0   0
 0   0   0   0   0   0   0   0   0   1   0   0
 0   0   0   0   0   0   0   0   1   0   0   0
 0   0   0   0   0   0   0   0   1   0   0   0
 0   0   0   0   0   0   0   0   0   0   5   0
 0   0   0   0   0   0   0   0   0   0  10   0
 0   0   0   0   0   0   0   0   0   0   0   0
Water
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   1   2   1   0   0   0   0
 0   0   0   3   1   1   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   1   0   2   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
 0   0   0   0   0   0   0   0   0   0   0   0
```

ASCII file for WATFLOOD

File: SNTWDfbasU.mdb *Grid: 2x2 km* *ASCII: SNT_Wf2x2.wqd*

```
SEDIMENT DATA
 9806 1000 .000001  9.8066  .00066 1.61
 0.10 0.10 0.80 0.50 0.60 0.00
 0.90 0.90 0.40 0.60 0.50 0.00
 particle size d50 [mm]
      0      0      0      0      0      0      0      0      0      0      0      0
      0      0  0.079  0.078  0.100  0.107  0.107  0.105  0.105      0      0      0
      0  0.088  0.093  0.152  0.290  0.156  0.104  0.104  0.105  0.105      0      0
      0  0.083  0.108  0.108  0.187  0.090  0.084  0.103  0.105  0.106      0      0
      0      0  0.098  0.137  0.278  0.236  0.206  0.078  0.093  0.105      0      0
      0      0  0.083  0.103  0.248  0.265  0.209  0.081  0.094  0.105      0      0
      0      0      0  0.127  0.102  0.216  0.124  0.084  0.103  0.188      0      0
      0      0      0  0.132  0.099  0.083  0.075  0.078  0.087  0.107  0.104      0
      0      0      0      0  0.152  0.085  0.076  0.078  0.093  0.105  0.104      0
      0      0      0      0  0.181  0.092  0.079  0.082  0.102  0.103  0.117      0
      0      0      0      0      0  0.098  0.092  0.095  0.098  0.142  0.232      0
      0      0      0      0      0      0      0      0  0.096  0.115  0.222      0
      0      0      0      0      0      0      0      0      0  0.104  0.301      0
      0      0      0      0      0      0      0      0      0      0  0.358      0
      0      0      0      0      0      0      0      0      0      0      0      0
 specific weight [-]
    0    0    0    0    0    0    0    0    0    0    0    0
    0    0 2.02 2.02 2.15 2.27 2.31 2.12 2.11    0    0    0
    0 2.00 2.01 2.02 2.14 2.08 2.11 2.11 2.11 2.16    0    0
    0 2.09 2.01 2.00 2.05 2.04 2.04 2.11 2.13 2.18    0    0
    0    0 2.04 2.01 1.93 1.99 1.99 2.04 2.18 2.16    0    0
    0    0 2.07 2.07 1.99 1.92 2.00 2.06 2.14 2.17    0    0
    0    0    0 2.09 2.05 2.02 1.98 2.02 2.08 2.05    0    0
    0    0    0 2.04 2.05 2.09 2.02 2.05 2.10 2.11 2.11    0
    0    0    0    0 2.04 2.06 2.02 2.05 2.11 2.17 2.11    0
    0    0    0    0 2.00 2.10 2.07 2.08 2.14 2.18 2.09    0
    0    0    0    0    0 2.10 2.13 2.11 2.13 2.09 1.93    0
    0    0    0    0    0    0    0    0 2.12 2.09 1.96    0
    0    0    0    0    0    0    0    0    0 2.10 1.90    0
    0    0    0    0    0    0    0    0    0    0 1.85    0
    0    0    0    0    0    0    0    0    0    0    0    0
 erodibility [g/J]
    0    0    0    0    0    0    0    0    0    0    0    0
    0    0 1.81 1.82 1.25 0.81 0.70 1.30 1.35    0    0    0
    0 1.87 1.81 1.57 0.71 1.27 1.34 1.35 1.32 1.18    0    0
    0 1.56 1.76 1.78 1.24 1.68 1.72 1.33 1.27 1.10    0    0
    0    0 1.66 1.61 1.26 1.26 1.38 1.76 1.20 1.18    0    0
    0    0 1.62 1.55 1.18 1.34 1.34 1.68 1.31 1.15    0    0
    0    0    0 1.44 1.60 1.23 1.77 1.81 1.50 1.31    0    0
    0    0    0 1.78 1.64 1.56 1.85 1.71 1.49 1.37 1.35    0
    0    0    0    0 1.43 1.66 1.84 1.73 1.43 1.15 1.35    0
    0    0    0    0 1.39 1.46 1.66 1.60 1.25 1.12 1.34    0
    0    0    0    0    0 1.42 1.36 1.41 1.32 1.28 1.45    0
    0    0    0    0    0    0    0    0 1.37 1.37 1.40    0
    0    0    0    0    0    0    0    0    0 1.35 1.40    0
    0    0    0    0    0    0    0    0    0    0 1.29    0
    0    0    0    0    0    0    0    0    0    0    0    0
NUTRIENT DATA
 1.00   50   50
0.0010   5    0.050  0.25
0.0005   2    0.025  0.25
FERTILIZER
 63
   14  4     50      20      50      50
   14  5     50      20      50      50
   14  6     50      20      50      50
   14  8     50      20      50      50
   13  3    200      80      50      50
   13  4     50      20      50      50
   13  5     50      20      50      50
   13  6     50      20      50      50
   13  7    200      80      50      50
   13  8     50      20      50      50
   13  10    50      20      50      50
   12  3    200      80      50      50
   12  4    200      80      50      50
   12  5     50      20      50      50
```

```
  12  6    200   80   50   50
  12  7    200   80   50   50
  12  8     50   20   50   50
  12  9     50   20   50   50
  12  10    50   20   50   50
  11  3     50   20   50   50
  11  4    200   80   50   50
  11  5    200   80   50   50
  11  6    200   80   50   50
  11  7    200   80   50   50
  11  8    200   80   50   50
  11  9     50   20   50   50
  11  10    50   20   50   50
  10  3     50   20   50   50
  10  4    200   80   50   50
  10  5    200   80   50   50
  10  6    200   80   50   50
  10  7    200   80   50   50
  10  8     50   20   50   50
  10  9     50   20   50   50
  9   4    200   80   50   50
  9   5    200   80   50   50
  9   6    200   80   50   50
  9   7    200   80   50   50
  9   8    200   80   50   50
  9   9    200   80   50   50
  9   10    50   20   50   50
  8   4     50   20   50   50
  8   5    200   80   50   50
  8   6    200   80   50   50
  8   7    200   80   50   50
  8   8    200   80   50   50
  8   9    200   80   50   50
  8   10    50   20   50   50
  7   5    200   80   50   50
  7   6    200   80   50   50
  7   7    200   80   50   50
  7   8    200   80   50   50
  7   9    200   80   50   50
  7   10    50   20   50   50
  7   11    50   20   50   50
  6   6    200   80   50   50
  6   7    200   80   50   50
  6   8    200   80   50   50
  6   9     50   20   50   50
  6   10    50   20   50   50
  6   11    50   20   50   50
  5   8     50   20   50   50
  5   10    50   20   50   50
PESTICIDE
 0
```